NAVAL SHORE ELECTRONICS CRITERIA

LINE-OF-SIGHT MICROWAVE AND TROPOSPHERIC SCATTER COMMUNICATION SYSTEMS

DEPARTMENT OF THE NAVY
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FOREWORD

This handbook is published for use by the operating forces, systems commands, and field activities as a guide to the systems design and installation of line-of-sight and tropospheric scatter communications systems in the 1 gigahertz-to-10 gigahertz frequency range.

The intent of the document is to provide under one cover, with the exception of terrain and meteorological data of particular sites, sufficient information and one calculation method to perform the electronic systems design for a LOS or troposcatter system. Unique installation requirements have been included together with a listing of applicable standard installation criteria.

Personnel concerned with system design of LOS and tropo facility designs and installations may refer to this handbook for the following:

- Acquiring data for site selection
- Predicting transmission path performance
- Providing criteria for the selection of electronic hardware
- Providing information about unique installation problems
- Providing an index of necessary standard installation criteria.

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CHAPTER 1

MICROWAVE COMMUNICATIONS SYSTEMS

1.1 SYSTEM CHARACTERISTICS

Communications systems in the 1 GHz to 10 GHz portion of the radio frequency spectrum utilize the property that propagation approaches an optical straight-line path. Propagation takes place in the lower atmosphere (troposphere) and is affected by meteorological factors such as pressure, temperature, water vapor, turbulence, and stratification. Communications in this media are generally either line-of-sight or tropospheric scatter.

1.1.1 Line-of-Sight System

A line-of-sight (LOS) microwave system consists of one or more point-to-point hops. Each hop is designed so that it can be integrated into a worldwide communications network. LOS system characteristics are:

o Propagation. Free space as affected by the troposphere.

o Communications Capacity/Bandwidth. Up to 600 - 4 kHz voice channels; wideband, can accept TV.

o Range. Usually 50 to 150 km (31 to 95 statute miles). This depends upon antenna height, earth curvature and intervening terrain.

o RF Power. Usually less than 10 watts.

o Antennas. Both transmitting and receiving antennas are horn driven paraboloids providing high gain and narrow beam widths. In some applications plane reflectors are used in combination with the paraboloids.

o Reliability. Designed for operational availability in excess of 99 percent of the time, including effects of poor propagation.

o Countermeasures. Due to directivity of antennas the system is difficult to jam. Should not be susceptible to nuclear disturbances of the ionosphere.

o Site Size. Requires minimum amount of space. Site size is usually governed by the antenna tower guy wire requirements.

o Relative Costs. Construction operation, and maintenance costs as shown in figures 1-1, 1-2, 1-3, and 1-4 of an LOS system are relatively low. Costs include the "Location Factor" commonly used in worldwide construction estimating.

o Application. Due to the bandwidth capability and siting requirements, LOS is well adapted to: moderate distance point to point multichannel communications (with repeaters); transmission of closed circuit TV; transmission of radar information from outlying locations; communications relay between locations in congested areas and "Antenna Farms".

1.1.2 Tropospheric Scatter System

A tropospheric scatter microwave system consists of one or more point-to-point hops (or sections). Each hop is designed so that it can be integrated into the world wide communications network of the Defense Communications System (DCS). Tropospheric scatter links have these characteristics:

o Propagation. Free space as affected by the troposphere

o Communications capacity/bandwidth. Up to 600 - 4 kHz voice channels; wideband, can accept TV.

o Range. Up to 800 km (500 statute miles)

o RF Power. High, up to 75 kilowatts depending upon bandwidth, quality, and range.

o Coverage. Point-to-point only.

o Antennas. Both transmitting and receiving antennas are horn driven paraboloids providing high gain and narrow beam widths. Antenna "dishes" may be as large as 50 to 60 feet in diameter.

o Reliability. Designed for operational availability in excess of 99 percent of the time including periods of poor propagation.

o Countermeasures. Extremely difficult to jam due to high directivity. Should not be susceptible to nuclear disturbances of the ionosphere.

o Site Size. Moderate. The area in front of transmitting antenna must be kept clear due to electromagnetic radiation hazards. The size of this area is dependent upon the beamwidth and RF power.

o Relative Costs. Moderate to high. Start up and operating costs generally higher than for HF communication systems. The greater number of stations required for tropospheric scatter systems is offset by the higher information rate.

o Application. This mode of propagation meets the communications requirements between HF within its minimum skywave one hop distance in the order of 400 miles and the one hop line-of-site of about 30 miles. It is especially useful where

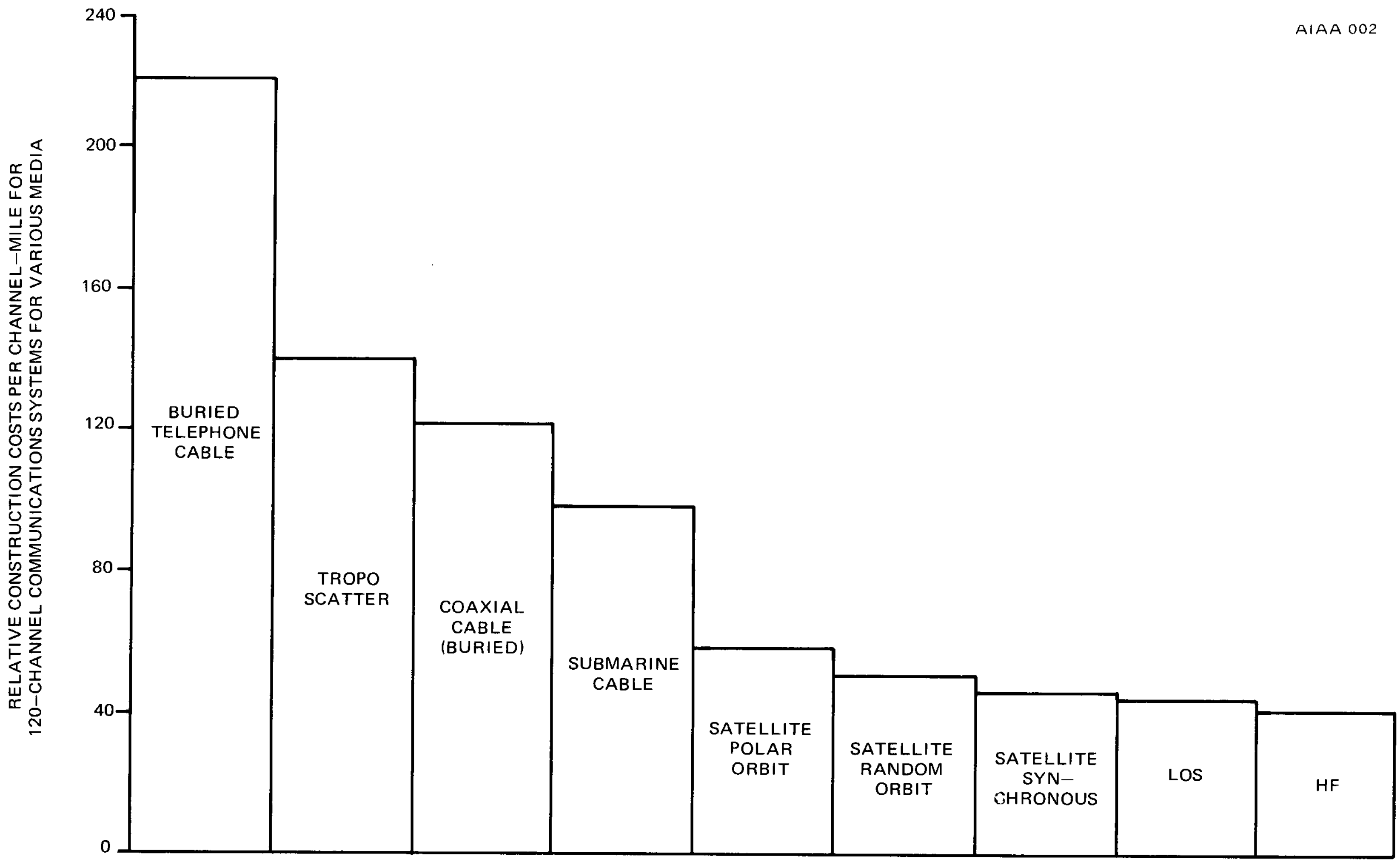


Figure 1-1. Relative Costs of Constructing Various Communication Systems

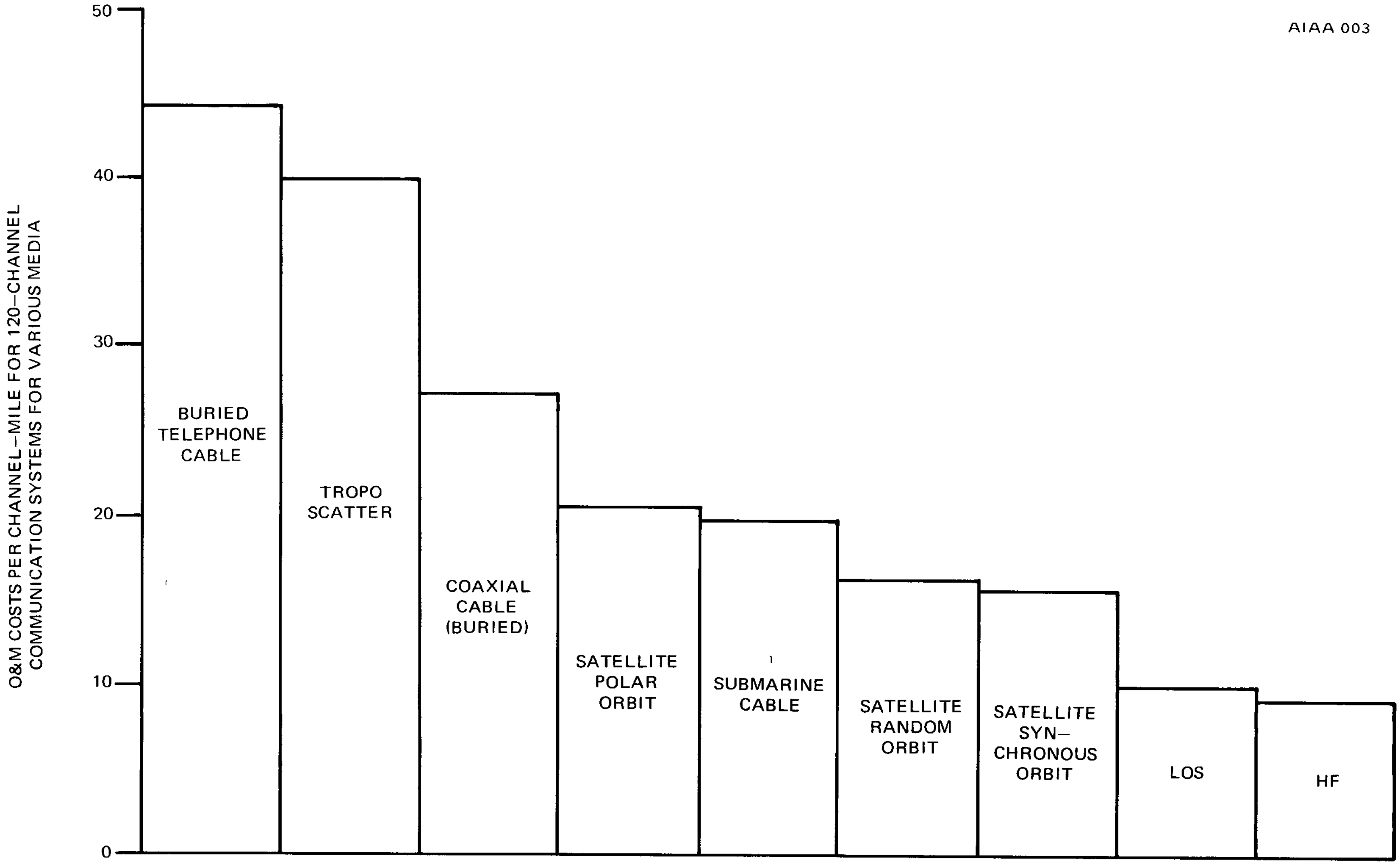


Figure 1-2. Relative Costs of O&M for Various Communication Systems

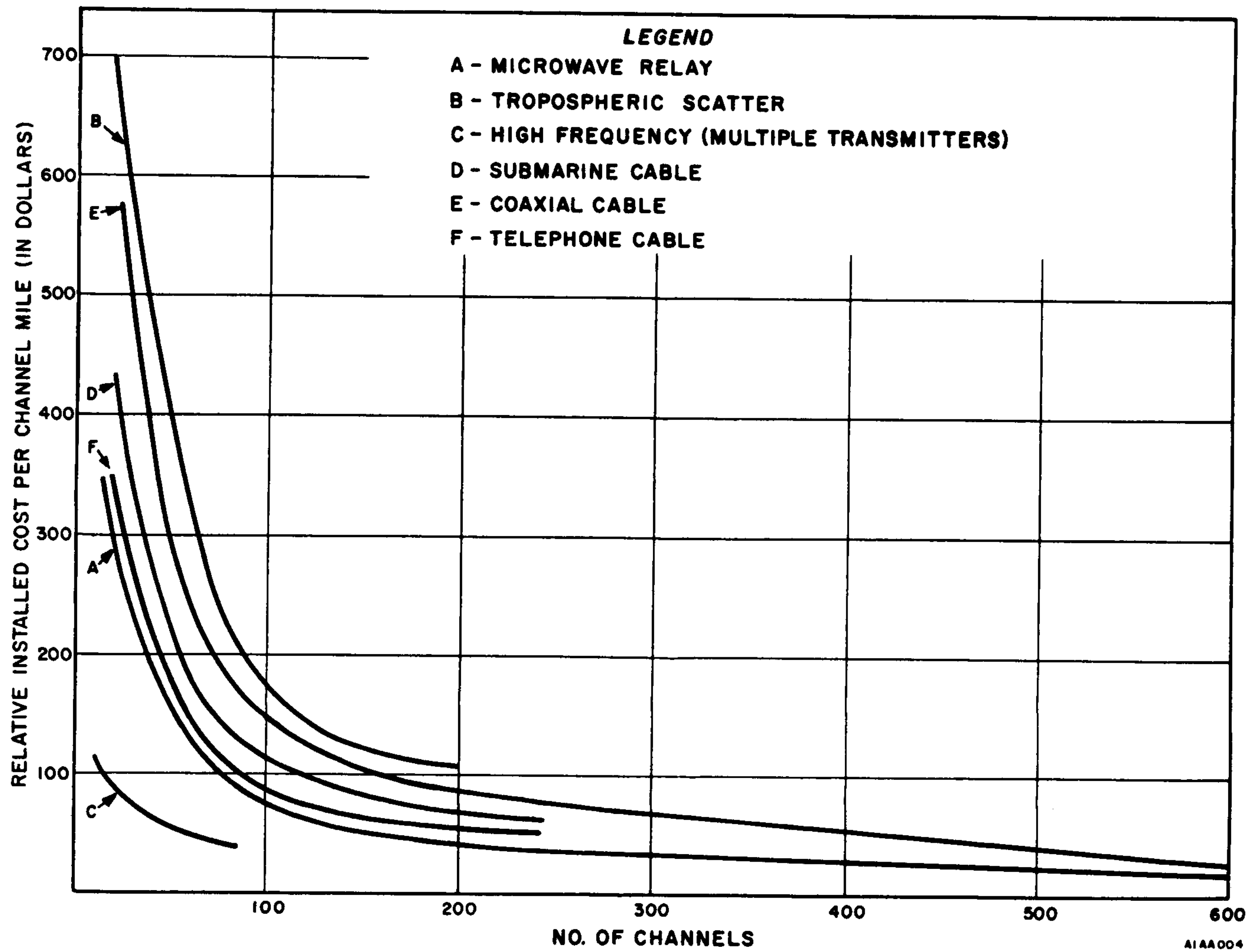


Figure 1-3. Relative Construction Costs for Various Media

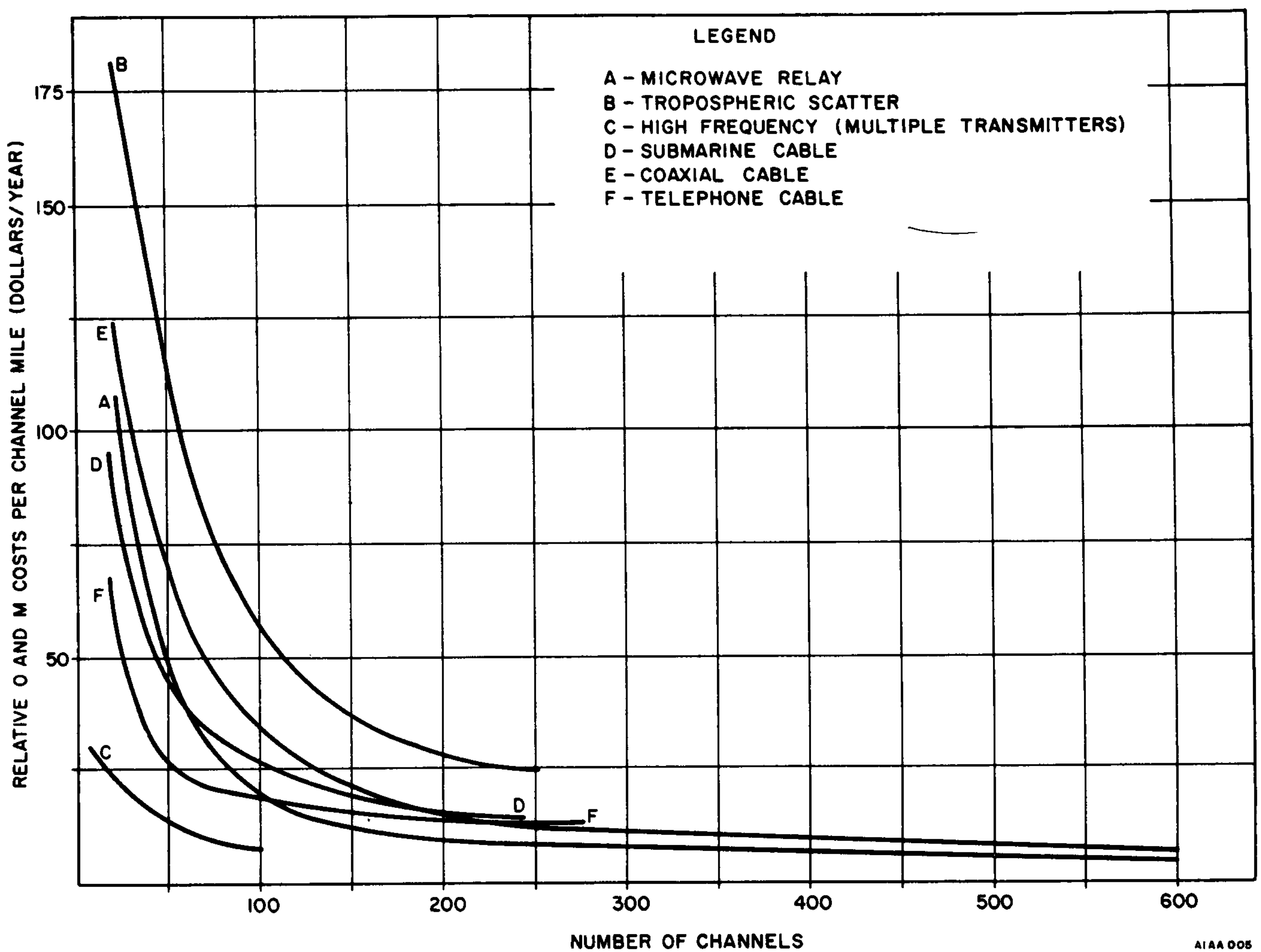


Figure 1-4. Relative Operation and Maintenance Costs for Various Media

tropographic conditions preclude the use of line-of-sight or adverse propagation conditions interfere with other transmission methods.

1.2 SYSTEMS TRANSMISSION STANDARDS

In order to assure high quality performance and to interface with the Defense Communications System, LOS and tropospheric scatter microwave communications equipments, facilities and systems shall meet the interface and performance requirements of the Defense Communications Agency (DCA) Engineering-Installation Standards Manual (DCA Circular 330-175-1).

1.2.1 Defense Communications System Reference Circuit

The DCS reference circuit for wideband systems consists of six links, each 1000 nautical miles, reference figure 1-5. The links are interconnected on an audio frequency and baseband (group) basis.

Each link is further subdivided into three sections nominally 333 nautical miles (NM) long consisting of radio/wire facilities with intermediate repeaters as required and equipped with Frequency Division Multiplex (FDM) equipment. Each section in figure 1-5 has different multiplex terminations to illustrate various interconnections that are possible. Transmission specifications for the DCS Reference Circuit are listed in Table 1-1.

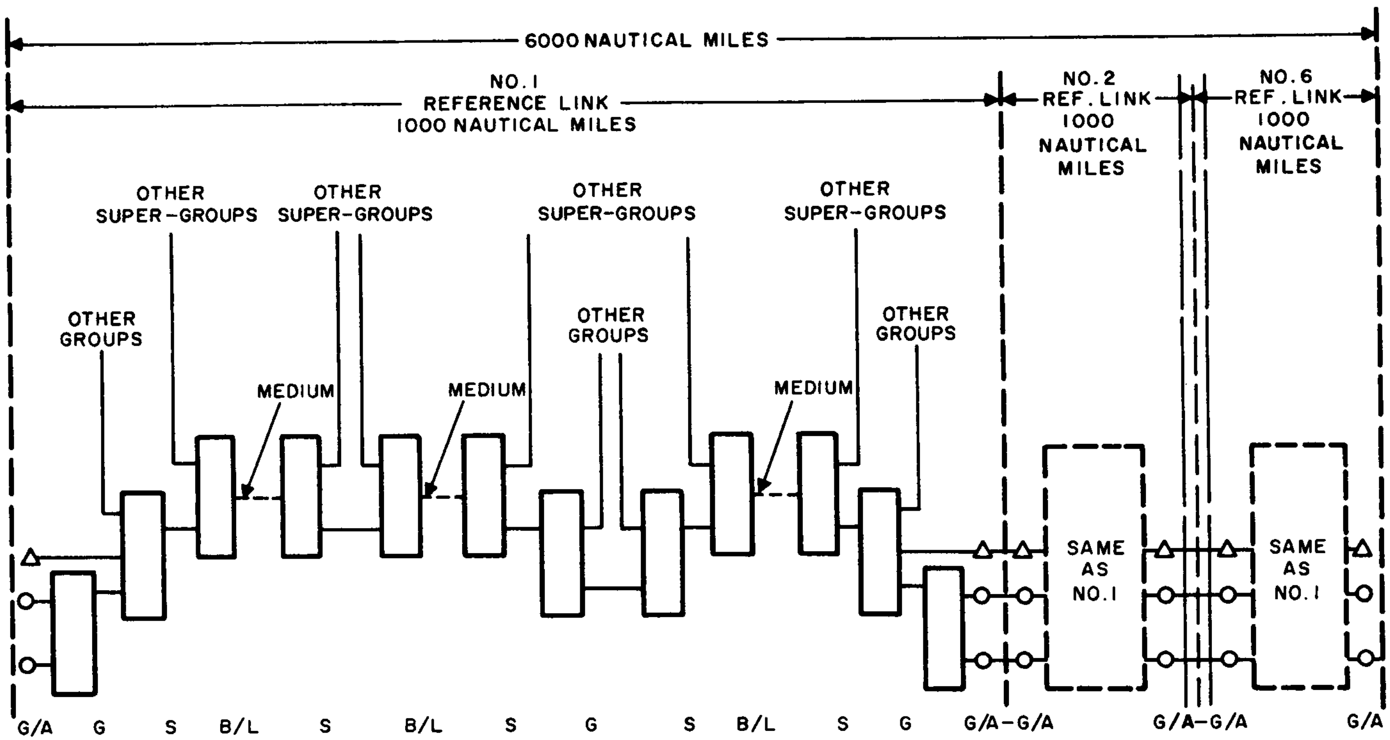
1.2.2 Line-of-Sight System Reference Circuit

The DCS Reference Circuit as applied to LOS microwave systems is illustrated in figure 1-6. The 333 NM Section is divided into 13 hops, each nominally 26 NM in length.

In practice, geographical and communications requirements will dictate the actual terminations and lengths. Figure 1-7 illustrates a typical case. Consequently the DCS transmission specifications must be pro-rated on a per mile, per hop or per section basis. The basic allowable transmission media noise for LOS sections is defined as:

Section Length in NM	Allowable Noise
$L > 151$ N M	3.33L pwpO
$27 < L < 151$ N M	2.76L pwpO + 85.5 pwpO
$L < 27$ N M	0.160 pwpO

This is a slight variation from that specified in Note 2, table 1-1, but it was found necessary since extremely short links sometimes necessary in LOS systems were not envisioned in the basic specification. Figure 1-8 shows a LOS hop and the interfaces between circuit links. Figure 1-9 lists the various interface parameters and their



A-AUDIO FREQUENCY FOUR-WIRE NOMINAL 4-Kc CIRCUIT
G-BASIC GROUP FREQUENCY BAND 60-108 Kc
S-BASIC SUPERGROUP FREQUENCY BAND 312-552 Kc
B-BASEBAND FREQUENCIES FOR RADIO TRANSMISSION
L-LINE FREQUENCY BAND FOR CABLE TRANSMISSION
O-ACCESS POINT, NOMINAL 4-Kc CIRCUIT
Δ-ACCESS POINT, NOMINAL 48-Kc CIRCUIT (THROUGH-GROUP SPEED DATA MODEM)

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Figure 1-5. DCA Reference Circuit - Transmission Subsystem, Nominal 4-kHz and 48-kHz Channels

Table 1-1. Transmission Specifications for DCS Reference Circuit Transfer Function

PARAMETER	OVERALL REFERENCE CIRCUIT 6,000 NM (6 LINKS)		NORMALLY ASSIGNABLE TO: TRANSMISSION MEDIUM, INCLUDING REPEATERS (6LINKS)	MULTIPLEX EQUIPMENT (1 LINK ONLY)	
Insertion loss-frequency, ref. to 1,000 Hz					
600-2400 Hz	+4.0	-4.0dB		+0.7	-0.7dB
400-3,000 Hz	+9.0	-4.0dB		+1.5	-0.7dB
300-3,400 Hz	+18.0	-4.0dB		+3.0	-0.7dB
Envelope Delay Distortion, 1,000 2,600 Hz max.	1,000 μsec			160 μsec	
Median noise level, from all sources, worst hour, worst month:				Term Only	Term & Intermed
Psophometrically weighted at OTLP, pwp	25,000		20,000	475	815
Equiv. white noise, F1A line wtg, dBaO	38.0		37.0	20.8	23.1
Harmonic distortion				-40 dBm	
Gain change for output level increase from 0 dBmO, to +3.5 dBmO				0.35 dB max	
+12.0 dBmO				5.0 dB min	
Net loss variation, max at 1,000 Hz audio, or at any baseband frequency.	±2.0 dB		±0.5 dB	±0.2 dB	
Level adjustability			±0.5 dB	±0.5 dB	
Max. overall change in any audio frequency.	± Hz			±2 Hz	
Stability of multiplex frequency generator: Initial setting to-				2 parts in 10^8	
Drift per month				2 parts in 10^7	
Single tone interference	24 dBaO				
Max. data/telegraph levels, single channel high speed.				(FSK) — 13 dBmO (AM) — 10 dBmO	
Speech level				— 15 dBmO	

Notes: 1. The noise power shall be divided such that 5,000 pwp is assigned to the multiplex equipment and 20,000 pwp to the transmission media.

2. The allowable transmission media noise in a section of length L nautical miles (L less than the 6,000 nautical mile reference circuit) is found by ---

$$\text{Noise} = \frac{L}{6000} \times 20,000 \text{ pwp} = 3.33L \text{ pwp}$$

3. The total noise shall not exceed 316,000 pwp (49 dBaO) 1-minute mean value more than a cumulative 0.01 percent of the worst month.

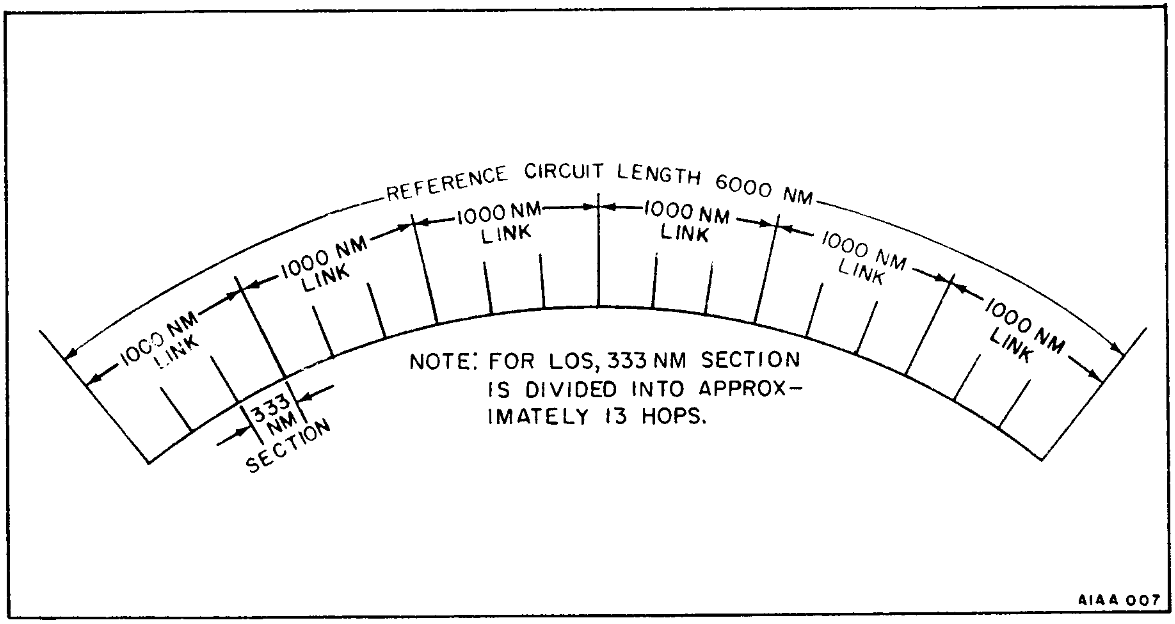


Figure 1-6. DCS Standard Reference Hop, Link and Section Allocations

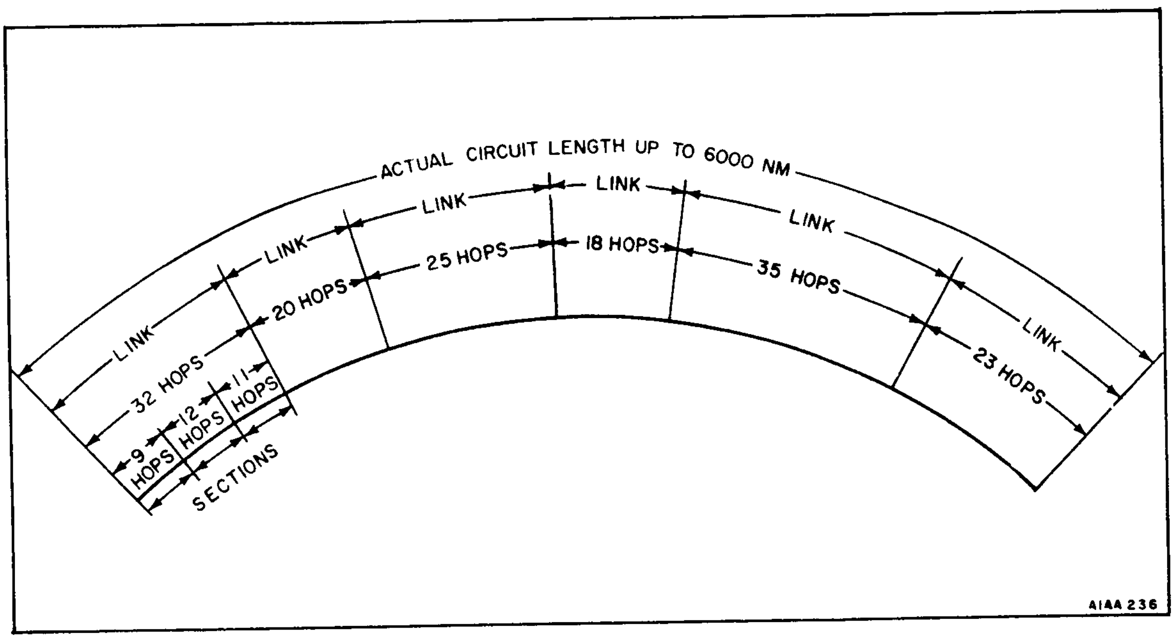


Figure 1-7. Typical Arrangements With Hops, Sections, and Links of Various Lengths

specifications. RF signal levels listed in the figure are only an indication of approximate value since the actual levels will be determined as part of the calculations included in this handbook.

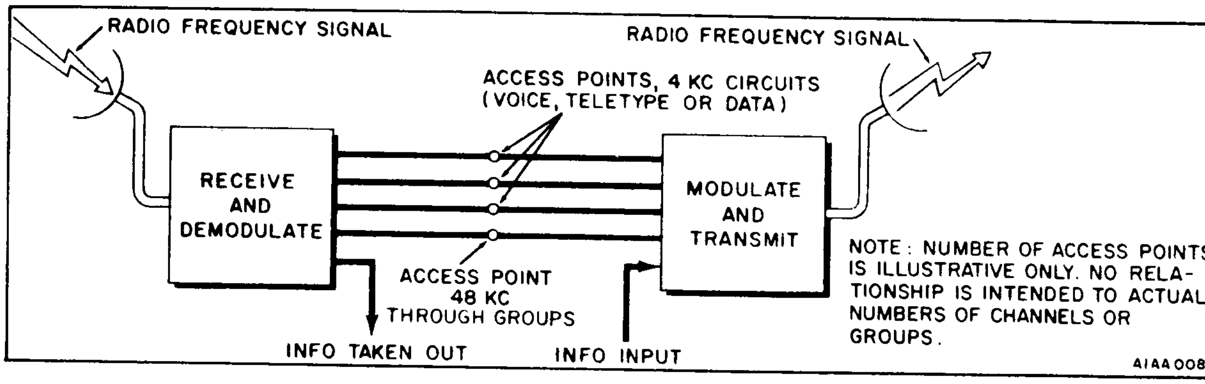


Figure 1-8. Interface Between Reference Circuit Links

1.2.3 Tropospheric Scatter System Reference Circuit

The DCS Reference Circuit as applied to tropospheric scatter microwave systems is illustrated in figure 1-6. The 333 NM Section is the nominal length of a tropospheric scatter hop.

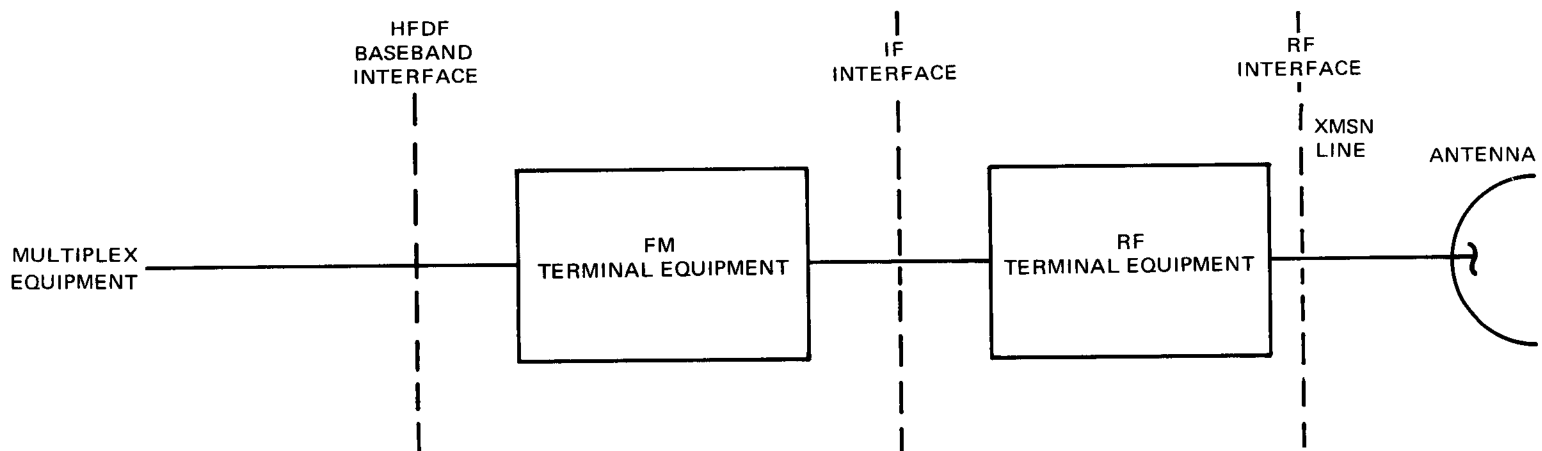
In practice, geographical and communications requirements will dictate the actual terminations and lengths. Consequently the DCS transmission specification must be pro-rated on a per mile, per hop or per section basis. The basic transmission media noise (N) for a tropospheric scatter hop (or section) shall not exceed

$N = 3.33L$ pwp median during time block 2

or exceed

316,000 pwp for more than a cumulative L (.02) percent of time block 2.

where L is hop length in nautical miles.



FREQUENCY	12–1300 kHz	70 MHz	MICROWAVE
TEST TONE LEVEL OR RMS DEVIATION			
TRANSMIT	–45 dBm 140 kHz (NOMINAL.)		
RECEIVE	–15 dBm 140 kHz (NOMINAL.)		
IF/RF SIGNAL LEVEL			
TRANSMIT		+1 dBm	+37 dBm (NOMINAL)
RECEIVE		+1 dBm	–27 dBm (nominal)
IMPEDANCE	75 OHMS UNBALANCED	75 OHMS UNBALANCED	WAVEGUIDE/OR 50 OHMS
RETURN LOSS (MIN.)	26 dB	26 dB	32 dB

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Figure 1-9. LOS Microwave Terminal Interface Parameters

It is not expected that each hop will meet these noise limits, some hops will be better and some worse, however, the cumulative noise power from all hops in tandem within the 1000 NM reference line shall meet the criteria. To achieve this it is often convenient to analyze the system performance in terms of tandem hop performance.

The basic transmission media noise (N) for tandem hop performance shall not exceed

a. N = 3.336 pwp median during time block 2

or b. 316,000 pwp for more than a cumulative $\frac{L}{100}$ (0.1) percent of time block 2

Figure 1-10 shows a nominal Troposcatter transmission section and figure 1-11 identifies the various interface parameters and their specifications. The RF signal levels are not specified since their levels are determined as part of the calculations included in this handbook.

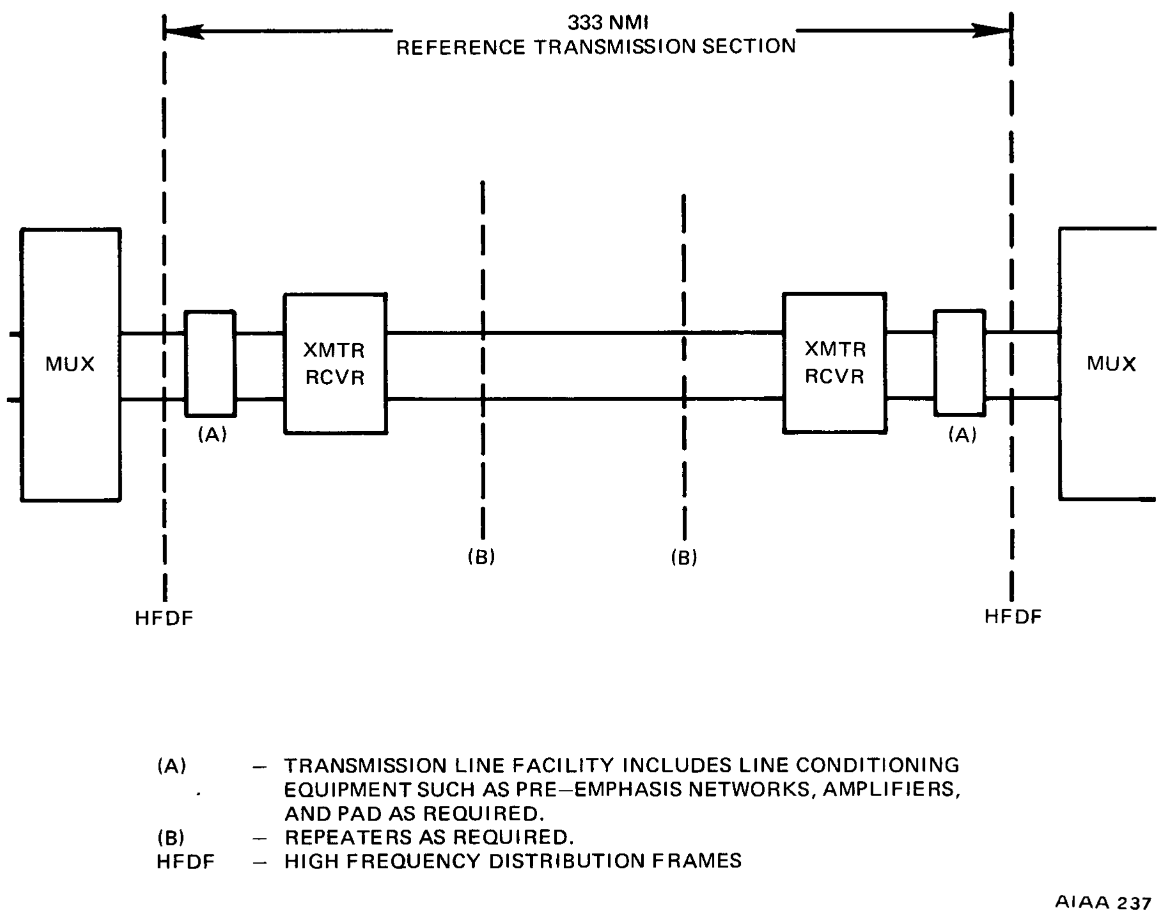


Figure 1-10. DCS Reference Transmission Section

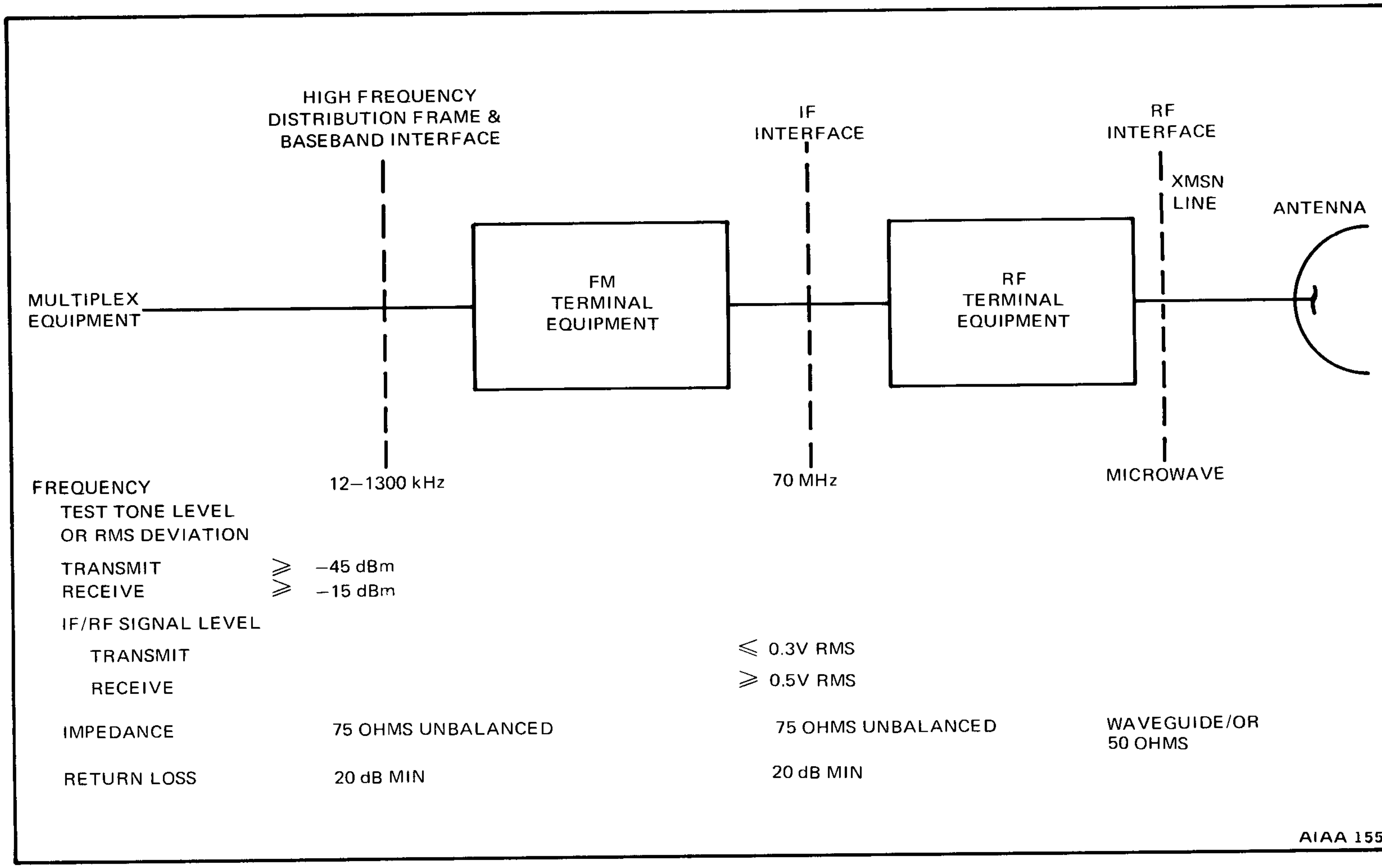


Figure 1-11. Troposcatter Terminal Interface Parameters

CHAPTER 2

LOS PROPAGATION PATH

2.1 BASIC THEORY

Radio waves are a form of electromagnetic radiation similar to heat and light radiation, but differ in the manner of generation, detection and frequency range. There are a number of mechanisms by which radio waves may propagate from a transmitting to a receiving antenna. The normal propagation paths which exist between two antennas are illustrated in figure 2-1. The various paths shown are dependent upon antenna directivity, launching angle, frequency range, and power levels. The surface (or ground) wave consists of electric and magnetic fields associated with currents induced in the ground. The space wave represents energy that travels from the transmitting to the receiving antenna in the earth's troposphere and usually consists of two components. One is a wave that travels directly from transmitter to receiver (direct wave), while the other is a wave that reaches the receiver as a result of reflection from the surface of the earth (ground reflected wave). The sky wave depends on the presence of the ionized layers above the earth that reflect back some of the energy that otherwise would be lost in outer space. The tropospheric scatter wave depends upon atmospheric turbulence to produce sections of the atmosphere with refractive indexes that are sharply different from those of the surrounding atmosphere. When irradiated by a microwave signal, these sections of the atmosphere reradiate the signal, scattering it in all directions. Some of this scattering is in the forward direction producing a wave at the receiver.

All of the possible paths shown in figure 2-1 exist in any radio propagation problem, but some are negligible in certain frequency ranges. At frequencies less than 1500 kHz, surface waves provide primary coverage, and the sky wave helps to extend this coverage at night when ionospheric absorption is at a minimum. At frequencies above 30 to 50 MHz, direct and ground reflected waves are frequently the only important paths. At these frequencies the surface wave can usually be neglected as long as the antenna heights are not too low, and the sky wave is ordinarily a source of occasional long distance interference rather than a reliable signal for communication purposes.

At frequencies of the order of thousands of megahertz, where the microwave systems under discussion operate, the direct wave is usually controlling on good optical paths. The tropospheric scatter wave is only utilized in systems with high power transmitters, large antennas, and sensitive receivers in multiple diversity arrangements.

Since radio transmission at microwave frequencies is generally confined to space waves, propagation paths are then limited to line-of-sight paths. A line-of-sight path is a path that provides optimum clearance, above the earth's surface or obstructions, for maximum transfer of the desired portion of the propagated energy.

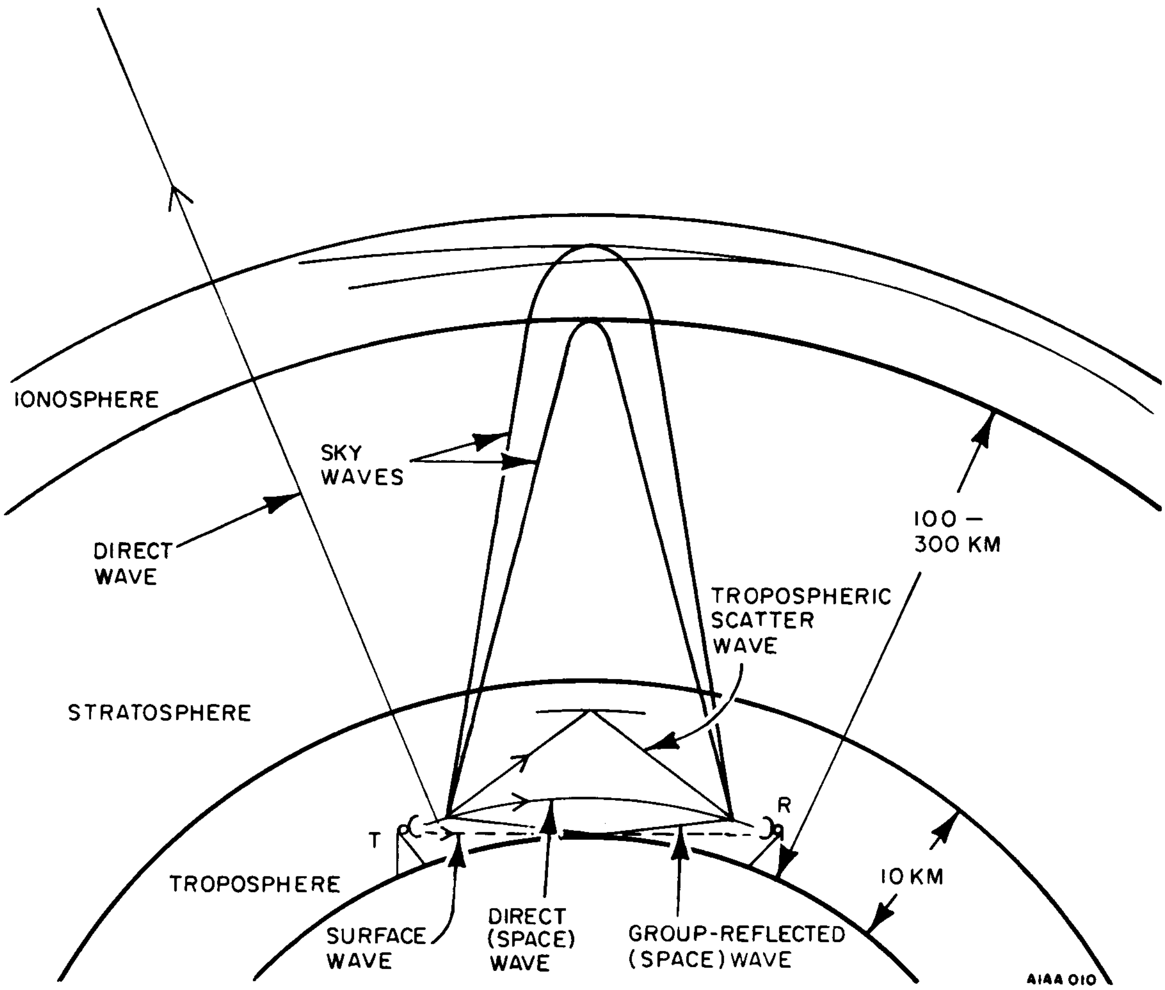


Figure 2-1. Normal Propagation Paths

Radio waves at microwave frequencies and light waves have many similar characteristics. Since the behavior of light waves is well known through the science of optics, and microwaves have many of the same properties, certain optical principles are useful in describing radio wave propagation. The most useful of these are refraction, defraction and reflection. Individually or in combination, these properties can greatly affect reception of the microwave signal at the receiver and, therefore, influence the per-hop or system propagation reliability.

2.1.1 Refraction (K Factor)

At microwave frequencies, radio energy travels along an approximately straight-line path, and the practical range of transmission is said to be limited to line-of-sight conditions. The limitation imposed on the transmission range is due, primarily, to normal earth curvature. At first, it might seem that microwave communication beyond the range at which the receiving antenna can actually be seen from the transmitting antenna would be impossible (that is, limited to the optical horizon). In actual practice, however, this is not true. The actual range extends considerably beyond the optical horizon because of the refractive effect of the earth's atmosphere upon the transmitted wave. This refractive effect causes radio waves to bend in a downward direction and to follow a path which closely approximates the earth's curvature. The point at which the radio waves become tangent to the earth's surface is known as the radio horizon. Under normal conditions in the lower atmosphere, called the troposphere, the line-of-sight path from a point of given elevation to the radio horizon is approximately 15 percent greater than the path to the optical horizon. The basic relationship between the optical and radio horizon is shown in figure 2-2.

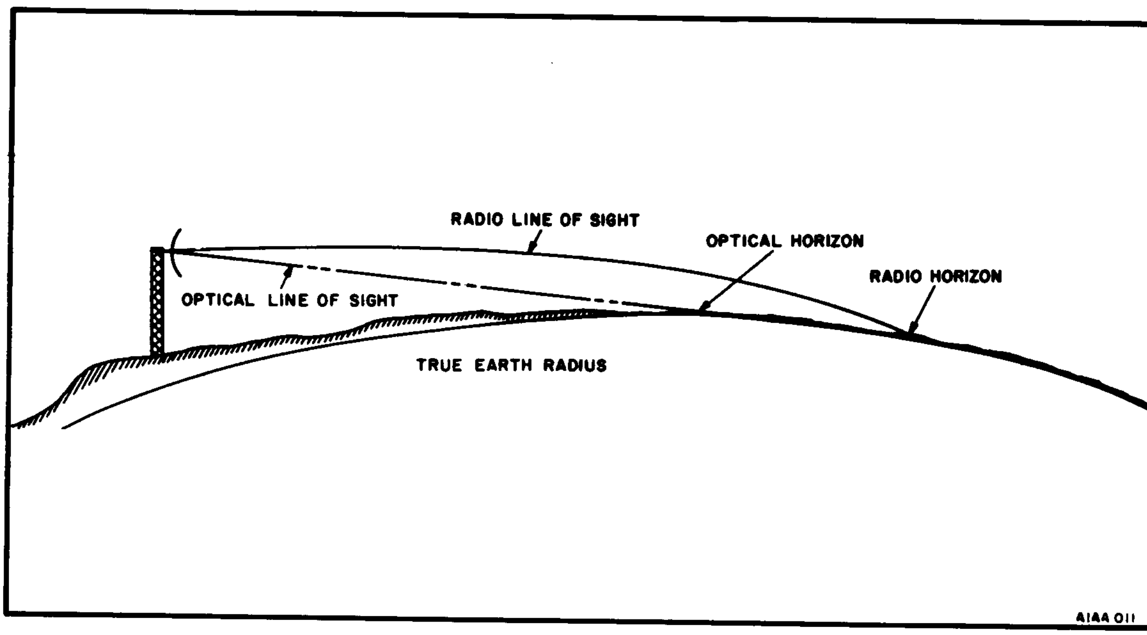


Figure 2-2. Optical and Radio Horizons Relationship

Angular refraction through the atmosphere occurs because radio waves travel with differing speeds in a media of varying dielectric constants. In free space (a vacuum) the speed is a maximum, but in the atmosphere where the dielectric constant is slightly larger due to the presence of gas and water molecules, the radio wave travels slower. In a standard atmosphere the pressure, temperature, and water vapor content (humidity) all decrease linearly with increasing altitude. The dielectric constant, being a single parameter combining the resultant effect of these three meteorological properties, also decreases with altitude. Since electromagnetic waves travel faster in a medium of lower dielectric constant, the upper part of a wave front begins to travel faster than that lower portion which is still in the denser region causing a downward deflection of the wave. In a uniform atmosphere where the change in air density is gradual, this bending or refraction of the radio wave may be essentially continuous, so that the beam is gently curved away from the thinner to the denser atmosphere. The beam then tends, generally, to follow the earth's curvature.

Under these conditions, the earth's radius appears to the microwave beam to be larger than the true radius; that is, the earth appears flatter because of the tendency of the beam to refract downward in the atmosphere and follow the earth. The ratio of this apparent or fictitious earth's radius to the actual earth's radius is referred to as the "effective earth's radius factor" and is designated K. K is approximately equal to 4/3 during the "standard" atmospheric conditions previously described in which the refractive gradient is uniform.

It is worth noting that if the atmosphere were homogeneous throughout the path, the microwave beam would travel in a straight line between the stations. This condition does often occur and is represented by the K=1, homogeneous atmosphere line of figure 2-3.

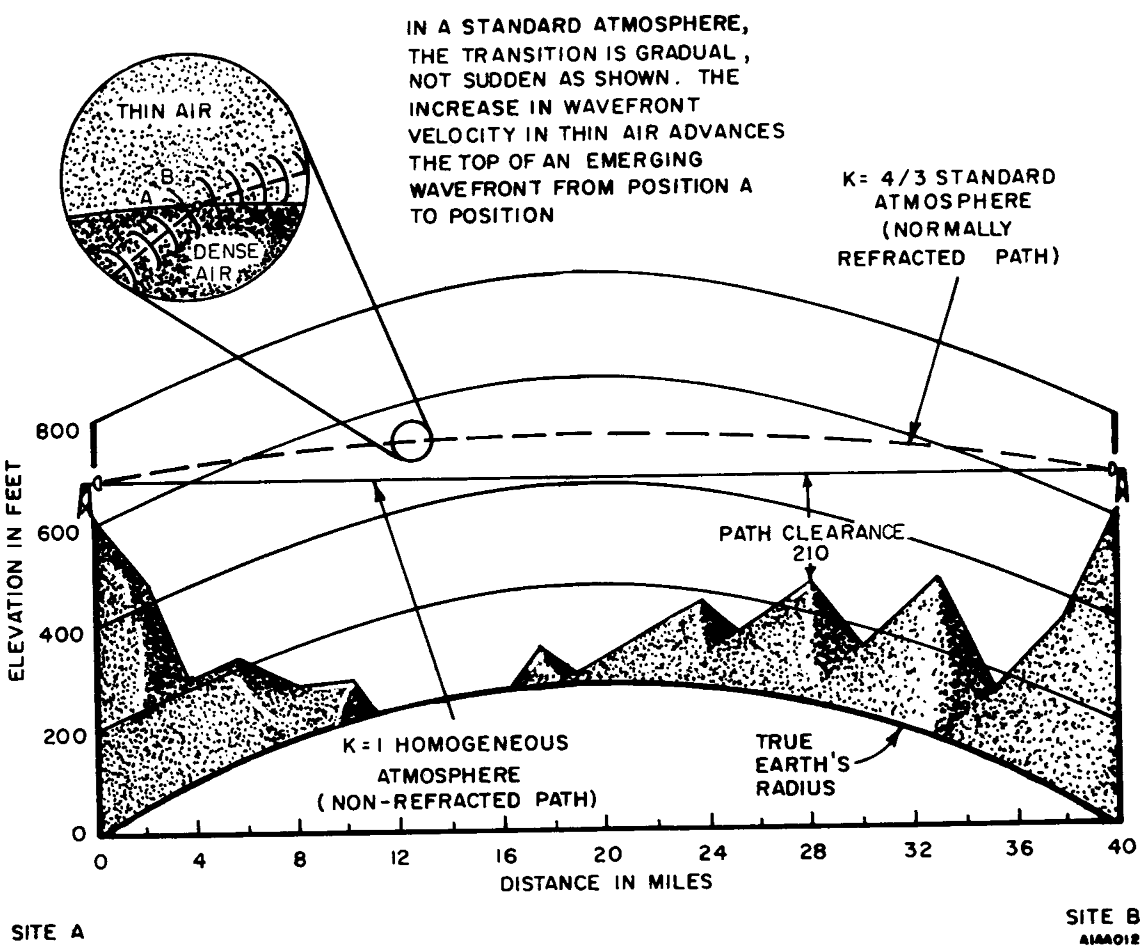


Figure 2-3. Refraction of the Microwave Beam Through Normal Atmosphere on True Earth's Radius of Curvature Profile Paper

Figure 2-4 displays the reconstruction of the profile shown in figure 2-3 based upon an apparent increase in the earth's radius of curvature by a factor of 4/3 (K = 4/3). The normally defracted microwave beam path geometrically becomes a straight line on this type of representation. This makes 4/3 earth's radius profile paper invaluable for studying path clearances, locating reflection points, and establishing antenna heights adequate for microwave propagation during standard atmospheric conditions prevailing up to 80 percent of the time in all parts of the United States. The disadvantage of this type of profile is that it fails to readily lend itself to investigation of path conditions when the microwave beam refraction is other than K = 4/3. In coastal and other areas characterized by high humidity and fog, or reflective terrain, or combinations of these, 4/3 earth's radius profile paper is commonly employed only for a cursory first look at the path.

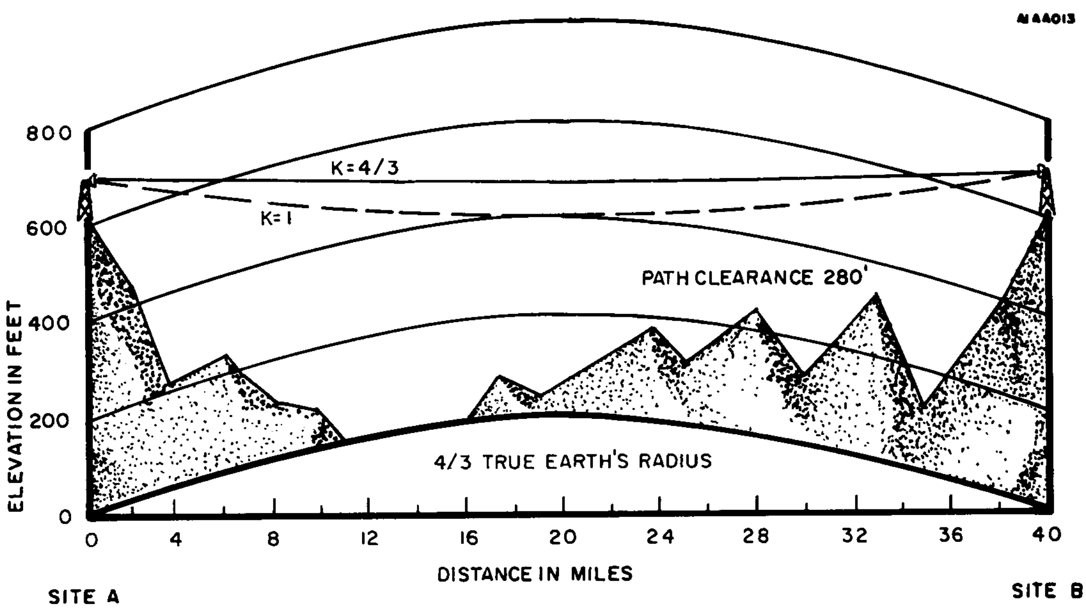


Figure 2-4. Reconstruction of Figure 2-4 on 4/3 Earth's Radius of Curvature Profile Paper

An interesting comparison between the K = 1 profile and the K = 4/3 profile (refer to figures 2-3 and 2-4) is that the apparent path clearance with the microwave beam represented as a straight line is less (210' versus 280') for the K = 1 than with the K = 4/3 profile. This results in more conservative path engineering evaluation (for example, higher antenna support structures for a given clearance). However, the latter properly assumes some clearance advantage due to standard refraction.

In practice, this nominal value of K = 4/3 is only a mean value occurring in temperate climates. K actually varies between 1 and 2, with lower values existing in cold or dry climates and at high altitudes. The higher values of K are common in coastal areas where the humidity is high. Superstandard values of K from 2 to infinity and substandard values from 1 down to 1/2 and less are encountered occasionally in the United States. This occurs mainly in tropical coastal areas typical of the Gulf of Mexico area and, to a lesser extent, along the East Coast and near the coast of Southern California.

The practical limits of refraction changes in a widely varying atmosphere typical of coastal areas is shown in figure 2-5. The end effect of these changes in K is a wide fluctuation in path clearance, from excessive as K approaches infinity to possibly grazing or less as K drops to 1/2.

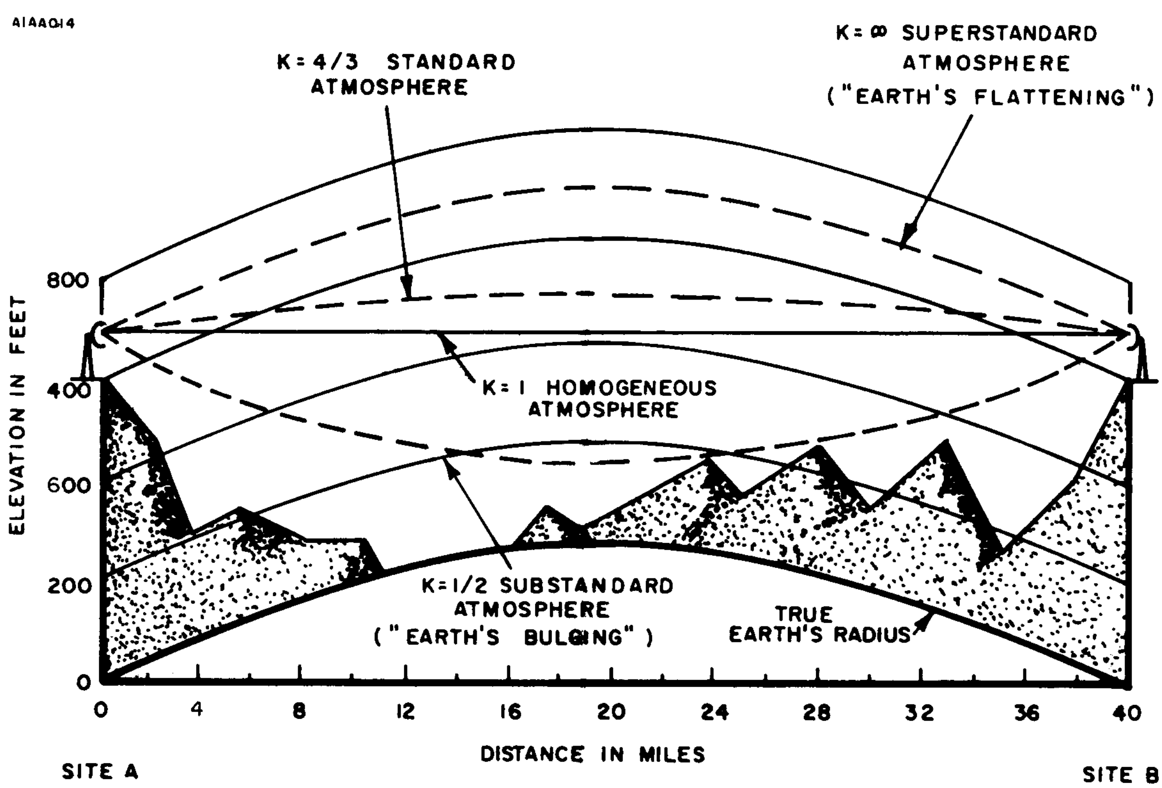
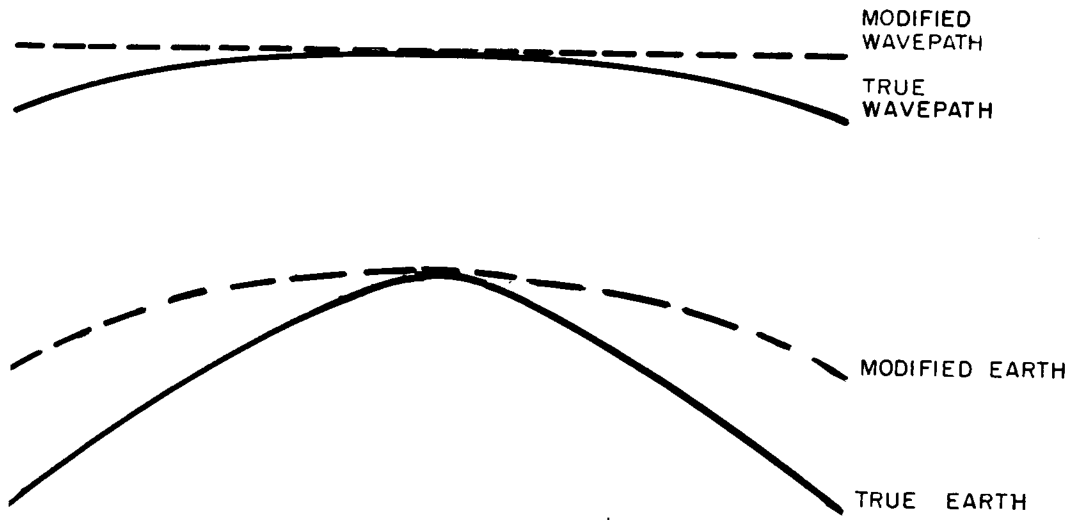


Figure 2-5. Refraction of the Microwave Beam Through Standard Homogeneous, Superstandard, and Substandard Atmospheres on True Earth's Radius of Curvature Profile Paper

Ranges of K and corresponding wave bending effects are illustrated in figure 2-6. It should be noted that, in cases where K is negative, the earth should be considered a plane without any curvature, since geometric optic methods do not hold for a concave surface.



WAVEPATH RADIUS $= \rho$

TRUE EARTH RADIUS $= r$

MODIFIED EARTH RADIUS $= r'$

$$K = \frac{r'}{r}$$

$$\frac{1}{r'} = \frac{1}{r} - \frac{1}{\rho}$$

$$K = \frac{\rho}{\rho - r}$$

$$K = \frac{\text{WAVE CURVATURE}}{\text{EARTH CURVATURE}} = \frac{1/\rho}{1/r} \qquad \text{WAVE BENDING}$$

$K = \frac{\rho}{\rho - r}$	$K = \frac{1/\rho}{1/r}$	WAVE BENDING
1/2	−1	SAME AS EARTH BUT UPWARD
1	0	NONE STRAIGHT LINE
1.33	.25	DOWNWARD 1/4 AS MUCH AS EARTH
∞	1	DOWNWARD PARALLEL TO EARTH
−1	2	DOWNWARD TWICE AS EARTH

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Figure 2-6. The Modified Earth's Radius

a. Superstandard Refraction. Superstandard or refraction greater than standard (also called super-refraction) results from such meteorological conditions as a rise in temperature with increasing height (temperature inversion), or a marked decrease in total moisture content in the air. Either of which will cause a reduction in the dielectric constant gradient with height. Under these circumstances K increases, resulting in an effective flattening of the equivalent earth's curvature. One of the conditions which may cause this type of abnormal refraction is the passage of warm air over a cool body of water. Water evaporation will cause an increase in moisture content and a decrease in temperature near the surface, thus producing a temperature inversion. But, it is not only the temperature inversion itself which causes the abnormal bending of the microwave beam. The large increase in water vapor content and, hence, in the dielectric constant near the surface further increases this effect.

In extreme instances of super-refraction, K approaches infinity, as shown in figure 2-5 and a microwave beam which starts parallel to the earth will remain parallel until obstructed or otherwise attenuated.

b. Substandard Refraction. Substandard or less than standard refraction occurs during certain meteorological conditions which cause the dielectric constant to actually increase with height. This condition causes an upward curvature of the microwave beam as shown in figure 2-5, (K = 1/2 curve) and is often called inverse beam bending. This unusual refractive condition is also called "earth bulging." A profile constructed with an effective earth's radius factor of K = 1/2 is graphically shown in figure 2-7. The microwave beam, substandardly refracted, is represented as a straight line with the K = 1/2 fictitious earth bulging to the path.

Substandard refraction occurs less frequently than super-refraction in the coastal areas. This is one of the parameters, along with path length and reflection characteristics, that must be considered in establishing the microwave antenna height. Even if substandard refraction causes path blockage for a total of only 1.4 minutes a day, the microwave reliability considering outages due to this alone will be reduced to 99.9 percent if suitable clearance is not provided.

A substandard atmospheric condition may exist when a low fog is formed by nocturnal cooling of the ground, since the contribution to the increase of the atmospheric dielectric constant due to water in the form of droplets is much less than that due to water in the form of vapor. The dielectric constant will then be lower near the ground than at higher elevations, causing an upward bending of the rays.

c. Radio Standard Atmosphere. The radio refractive index of air, n, is a function of atmospheric pressure, temperature, and humidity. Near the surface of the earth and for VHF-UHF frequencies, n is a number of the order of 1.0003. Since for air, n never exceeds unity by more than a few parts in 10^{+4}, it is convenient to consider climatic variations of n in terms of the "radio refractivity," N, defined as:

$$N = (n-1) \times 10^6 \qquad (2\text{-}1)$$

The average density of the atmosphere varies approximately exponentially with height and the mean values of the refractive index of the atmosphere may be approximated as a function of height by the following exponential function:

$$N(h) = N_s \exp(-ch) \qquad (2\text{-}2)$$

where, N_s is the surface value of refractivity, h is the height above the surface in kilometers, and c is determined by the relation:

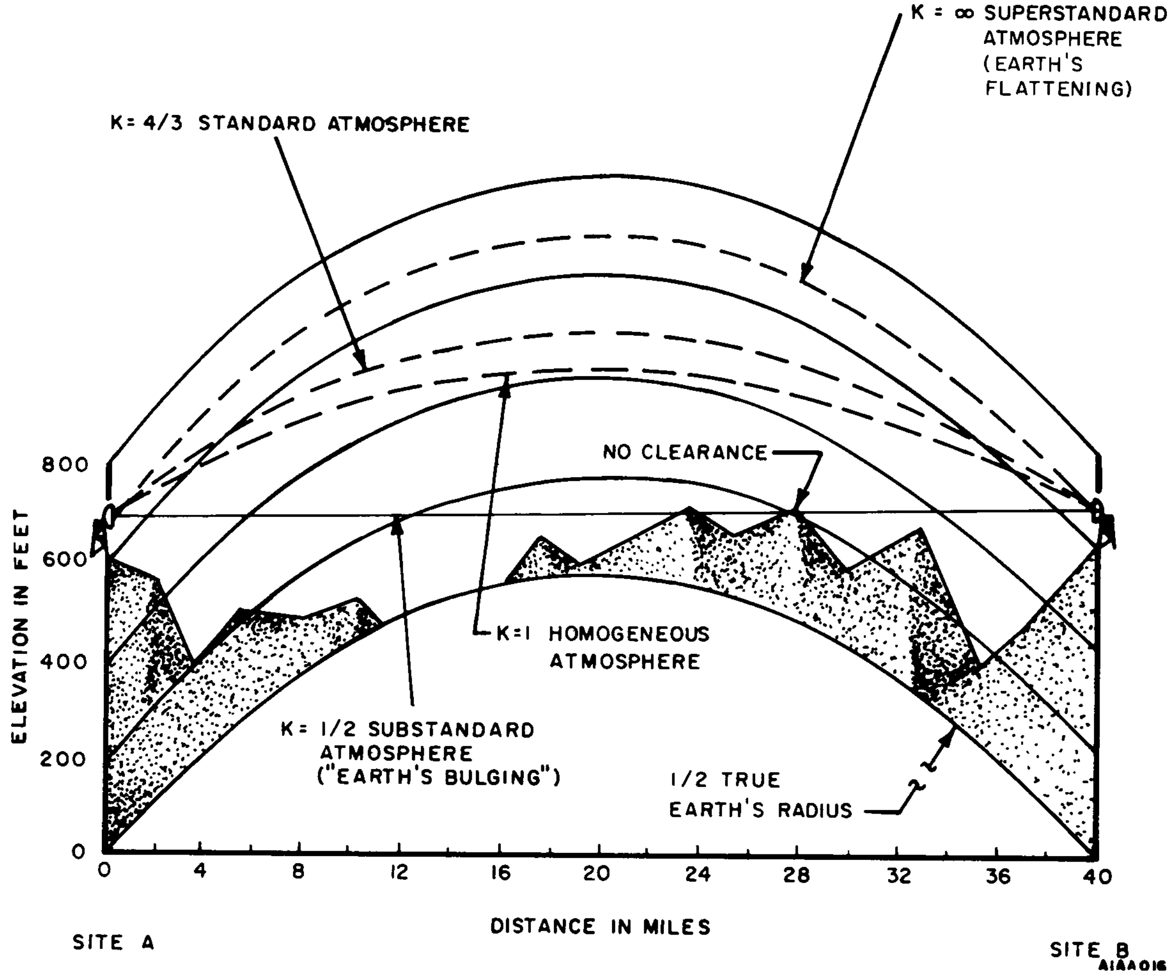


Figure 2-7. Reconstruction of Figure 2-5 on 1/2 Earth's Radius of Curvature Profile Paper

$$c = \ln \frac{N_s}{N_s + \Delta N} \tag{2-3}$$

where, ΔN is the difference in the N values at a height of one kilometer above the surface and at the surface.

N is, in general, correlated with the surface value N_s and may be estimated by the following:

$$-\Delta N = 7.32 \exp(.005577 N_s). \tag{2-4}$$

The effective earth's radius, K, is determined by:

$$K = [(1 - \frac{r_o}{n_s}(cN_s) \times 10^{-6})]^{-1};$$

$$n_s = 1 + N_s \times 10^{-6} \qquad (2\text{-}5)$$

and r_o is taken as 6373.02 km for all value of N_s; where the surface refractivity, N_s, is 289, c becomes 0.136, and the effective earth's radius factor, K, is equal to 1.3332410, or 4/3.

Thus, the Basic Exponential Reference Atmosphere is defined by the relationship:

$$N(h') = 289 \exp(-.136h') \qquad (2\text{-}6)$$

where, h' is the height above the surface in kilometers.

Table 2-1 lists the constant c and K for the CRPL exponential radio refractivity atmospheres.

Table 2-1. CRPL Exponential Radio Refractivity Atmospheres

$N = N_s \exp(-ch)$			
N_s	$-\Delta N$	K	C
200	22.33177	1.17769	.118399
250	29.33177	1.25016	.125626
289	36.68483	1.33324	.135747
300	39.00579	1.36280	.139284
320	43.60342	1.42587	.146502
350	51.55041	1.55105	.159332
400	68.12950	1.90766	.186719
450	90.01056	2.77761	.223256

The standard model of the atmosphere is obtained by assuming that N decreases linearly in the first kilometer above the surface:

$$N = N_s + \Delta N(h - h_s), \quad h_s \le h \le h_s + 1 \qquad (2\text{-}7)$$

where, ΔN is obtained from (2-4), h is the height above sea level and h_s is the height of the surface above sea level in kilometers.

It is assumed that N = 105 at 9 km above sea level and that refractivity decreases exponentially between 1 km above the earth's surface, $h_s + 1$, to the value of 105 at 9 km. This assumption means that N may be expressed by:

$$N = N_1 \exp[-c(h - h_s - 1], \; h_s + 1 \leq h \leq 9 \qquad (2\text{-}8)$$

where,

$$-c = \frac{1}{8 - h_s} \ln \frac{105}{N_1}$$

and, N_1 is the value of N at $h = h_s + 1$. Note that the only two variables in equation (2-8) are the height of the surface above sea level and N_1 which is a function of N_s.

Above 9 km the refractivity is determined by:

$$N = 105 \exp[-0.1424\,(h - 9)] \; h \geq 9 \text{ km}$$

This three part model of the atmosphere has been adopted for use at the National Bureau of Standards. The constants adopted are given in table 2-2 and specify the CRPL Reference Refractory Atmosphere.

Table 2-2. Constants for the Standard Reference Atmosphere

N_s	h_s FEET	a′ MILES	-ΔN	K	a_e MILES	c/km
0	0	3960.0000	0	1.00000	3960.00	0
200	10,000	3961.8939	22.3318	1.16599	4619.53	0.106211
250	5,000	2960.9470	29.5124	1.23165	4878.50	0.114559
301	1,000	3960.1894	39.2320	1.33327	5280.00	0.118710
313	900	3960.1324	41.9388	1.36479	5403.88	0.121796
350	0	3960.0000	51.5530	1.48905	5896.66	0.130579
400	0	3960.0000	68.1295	1.76684	6996.67	0.143848
450	0	3960.0000	90.0406	2.34506	9286.44	0.154004

Notes: a_e is the effective earth's radius and is equal to a K

$a' = a + h_s$ where h_s is the height of the earth's surface above sea level

a = 3,960 miles.

$$c = \frac{1}{8 - h_s} \ln \frac{N_1}{105}$$

N can be calculated from radiosonde data by:

$$N = \frac{77.6P}{T} + \frac{3.73 \times 10^5 e}{T^2} = \text{(Dry Term)} + \text{(Wet Term)} \qquad (2\text{-}9)$$

where:

P = atmospheric pressure in millibars

e = vapor pressure in millibars

T = temperature, degrees kelvin

Significant components of N are the "wet" and "dry" terms and the differential effects produced by them in the refractory gradient ΔN. Curvature and hence K, is dependent upon this gradient.

It will not be necessary to use the mean square gradient explicitly in transmission loss calculations. A set of "standard atmospheres" has been defined which show the height dependence of radio refractivity as a function of its value at the surface, N_s. Near the ground, the following empirical relationship is valid between N_s and the difference in refractivity, ΔN, between N_s and N at one kilometer above the earth's surface:

$$\Delta N/\text{km} = -7.32 \exp (0.005577 N_s) \qquad (2\text{-}10)$$

If (2-10) is inverted, N_s can be obtained as a function of the refractory gradient ΔN:

$$N_s = 412.87 \log|\Delta N| - 356.93 \qquad (2\text{-}11)$$

Estimates for N_s for winter afternoons (time block 2) may be obtained from figures 2-8 and 2-9 which show the distribution of a related quantity, N_o, for the continental United States, and for the entire world, respectively. In order to allow for climatic conditions different from the northern temperate zone, the N_o contours on figure 2-9 are plotted for the monthly minimum values in the northern temperate zone.

The quantity plotted on figures 2-8 and 2-9 is the surface refractivity reduced to zero elevation above mean sea level. It is related to the surface refractivity N_s at an elevation h_s above mean sea level by:

$$N_s = N_o \exp (-0.03222 h_s) \qquad (2\text{-}12)$$

where, the elevation h_s is expressed in thousands of feet. For within-the-horizon paths, h_s is the average of the horizon elevations.

Figure 2-10 is a plot of equation (2-12). Now, from N_o we can obtain surface refractivity N_s at any height. Using N_s equation (2-10) provides the refractory gradient per kilometer above the surface and this permits calculation of average values of K.

"K" is a function of the refractory gradient ΔN as well as the surface refractory values N_s. The relationships are given by the following expressions, where a is the actual radius of the earth (approximately 3960 statute miles) and a_e is the effective earth radius:

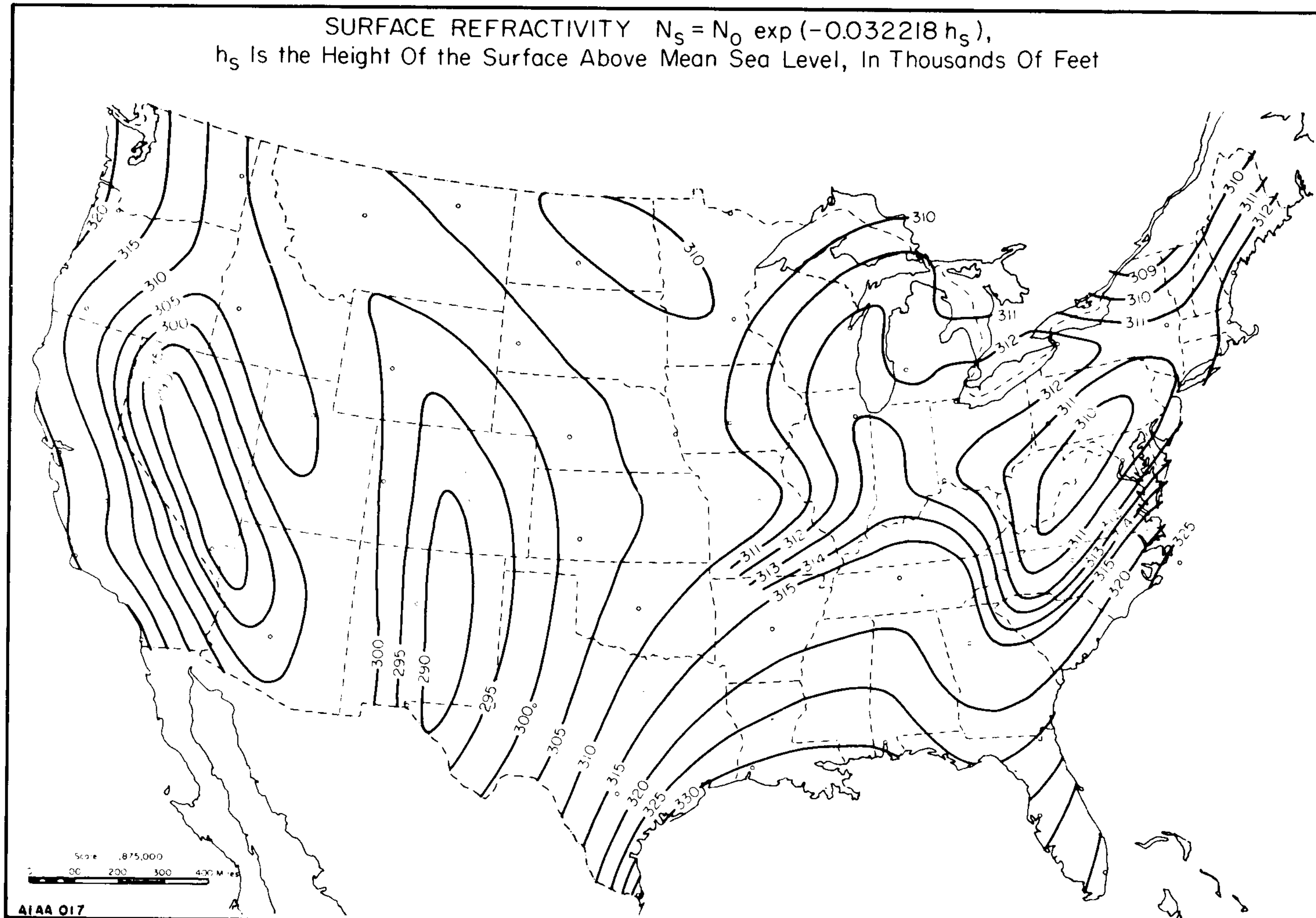


Figure 2-8. Surface Refractivity, November - April, 1 P.M. - 6 P.M. (Time Block No. 2)

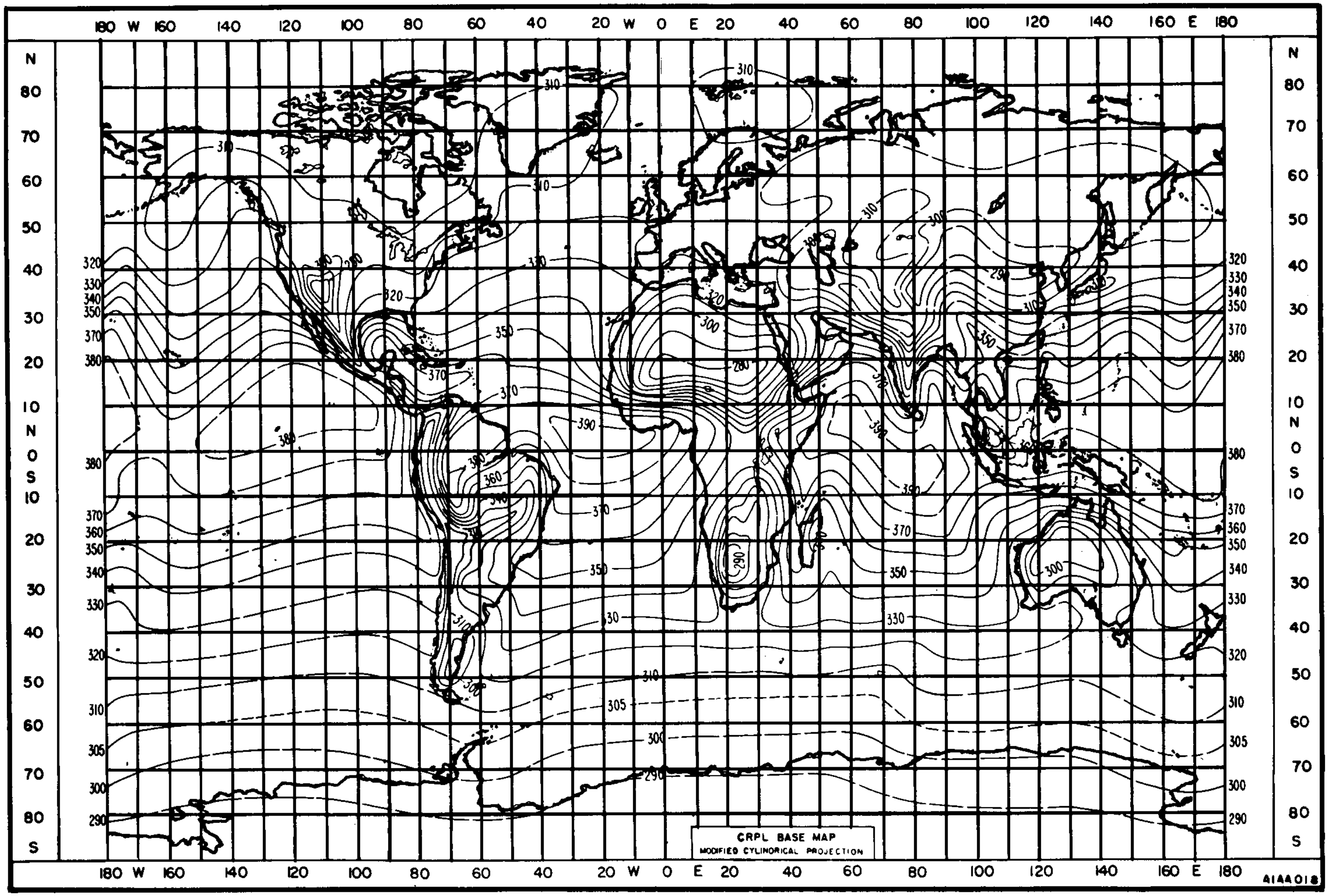


Figure 2-9. Minimum Monthly Mean N_o

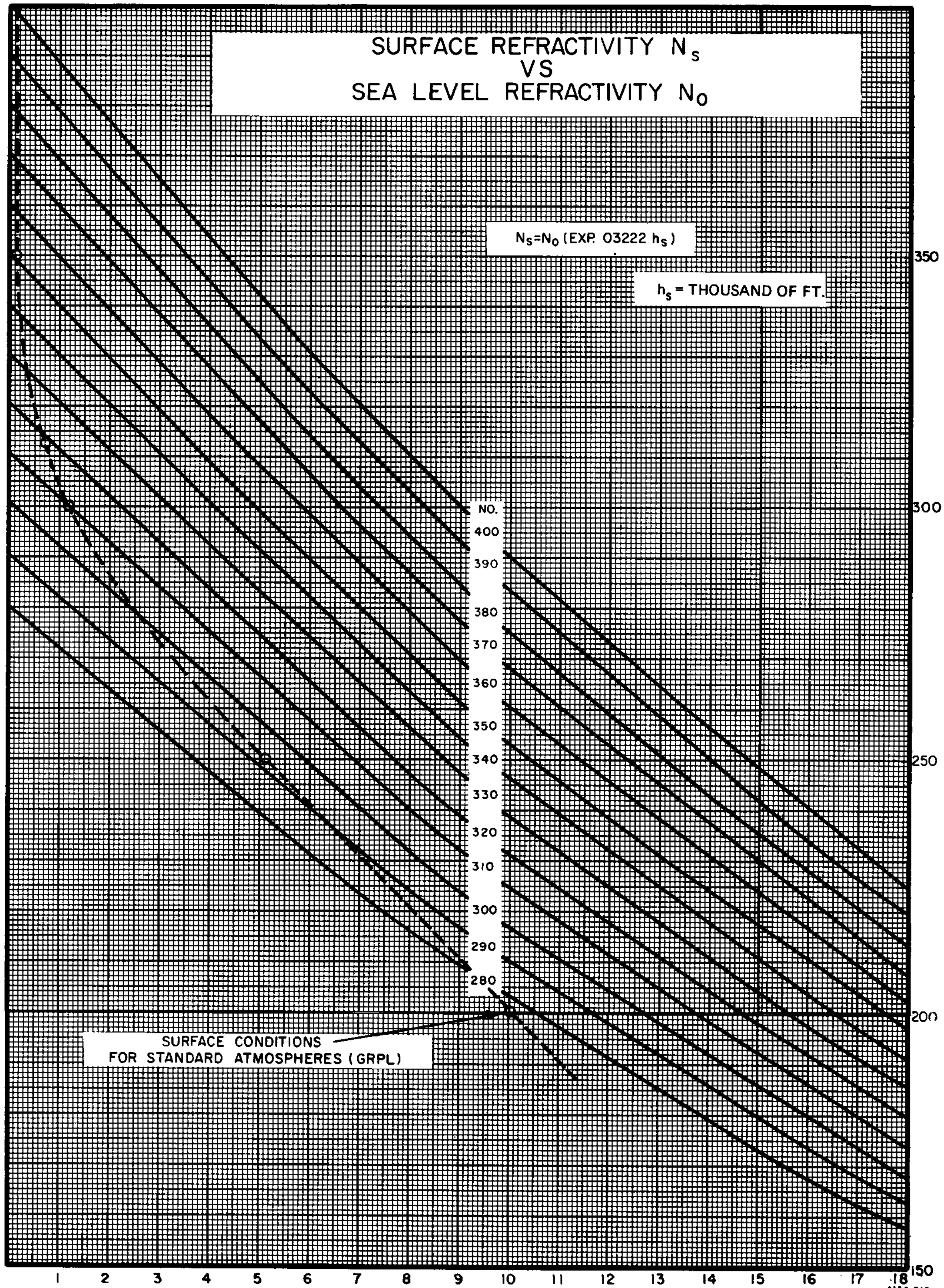


Figure 2-10. Surface Refractivity N_s Versus Sea Level Refractivity N_o

$$K = \frac{a_e}{a} = (1 + 0.00637 \frac{\Delta N}{km})^{-1} \qquad (2\text{-}13)$$

$$K = \frac{a_e}{a} = [1 - 0.04665 \exp (0.005577 N_s)]^{-1} \qquad (2\text{-}14)$$

Figure 2-11 is a plot of equation (2-13) illustrating the effect of the refractory gradient on K. These expressions will break down, when the quantities in the brackets approach zero. This corresponds to refractive conditions where the earth has become flattened out ($K = \infty$). In this case, as well as in cases where K would become negative, the earth is considered a plane without any curvature, as geometric optics methods used here do not hold for a concave surface.

Figure 2-12 is a plot of refractory gradient $\frac{\Delta N}{km}$ and "K" versus surface refractivity N_s. The limiting values are $\Delta N = 156.9$, corresponding to $N_s = 550$. The latter value rarely will be encountered in practical applications. If actual measurements of ΔN are utilized for calculation of within-the-horizon paths, limiting values may be encountered more frequently.

Table 2-3 lists parameters discussed above for several reference atmospheres, which will be used subsequently in transmission loss calculations.

The usual term "four-thirds earth radius," or "standard refraction" refers to the conditions where the surface refractivity is 301, the gradient is -39.23 N units per kilometer, and the ratio of the effective to the actual earth's radius "K" is very nearly 4/3. It is seen from table 2-3 that the effective earth's radius in this case is 5280 statute miles. This number is also useful in conversions from feet to statute miles.

Since K depends upon the refractivity gradient, it is subject to short and extreme variations with wind, clouds, daylight, etc. These variations must be estimated from rather limited statistical information and are important because they cause fading.

K variations are usually smaller in high, dry climates and greater in low humid areas. Figures 2-13, 2-14 and 2-15 represent a family of estimated K distributions for different local conditions.

2.1.2 Diffraction (Fresnel Zones)

Diffraction of light and radio wavefronts occurs when the wavefront encounters an obstruction which is large compared to the wavelength of the wave. At lower VHF frequencies, the wavefront will tend to bend or diffract around intervening objects with increased attenuation. At microwave frequencies above 3000 MHz, however, this attenuation increases so rapidly (with increasing obstruction such as earth bulge) that except for specialized systems designed for extreme path loss, the system becomes unusable. The amount of energy diffracter around the obstruction is negligible at these microwave frequencies. The actual amount of obstruction loss is dependent upon the area of the microwave beam obstructed as related to the total frontal area of the energy propagated, and to the coefficient of reflectivity of the obstruction.

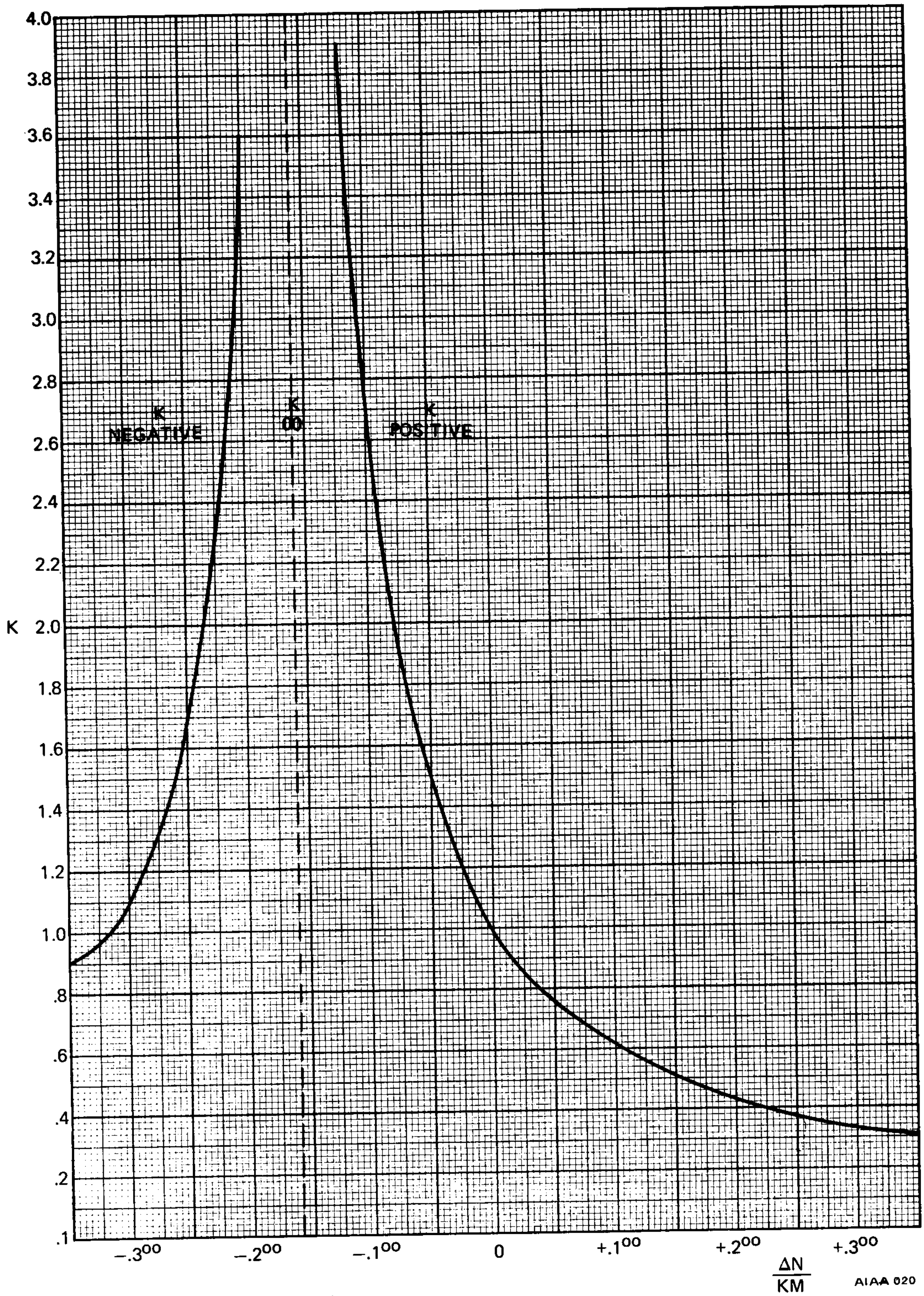


Figure 2-11. Effect of Refractivity Gradient on "K"

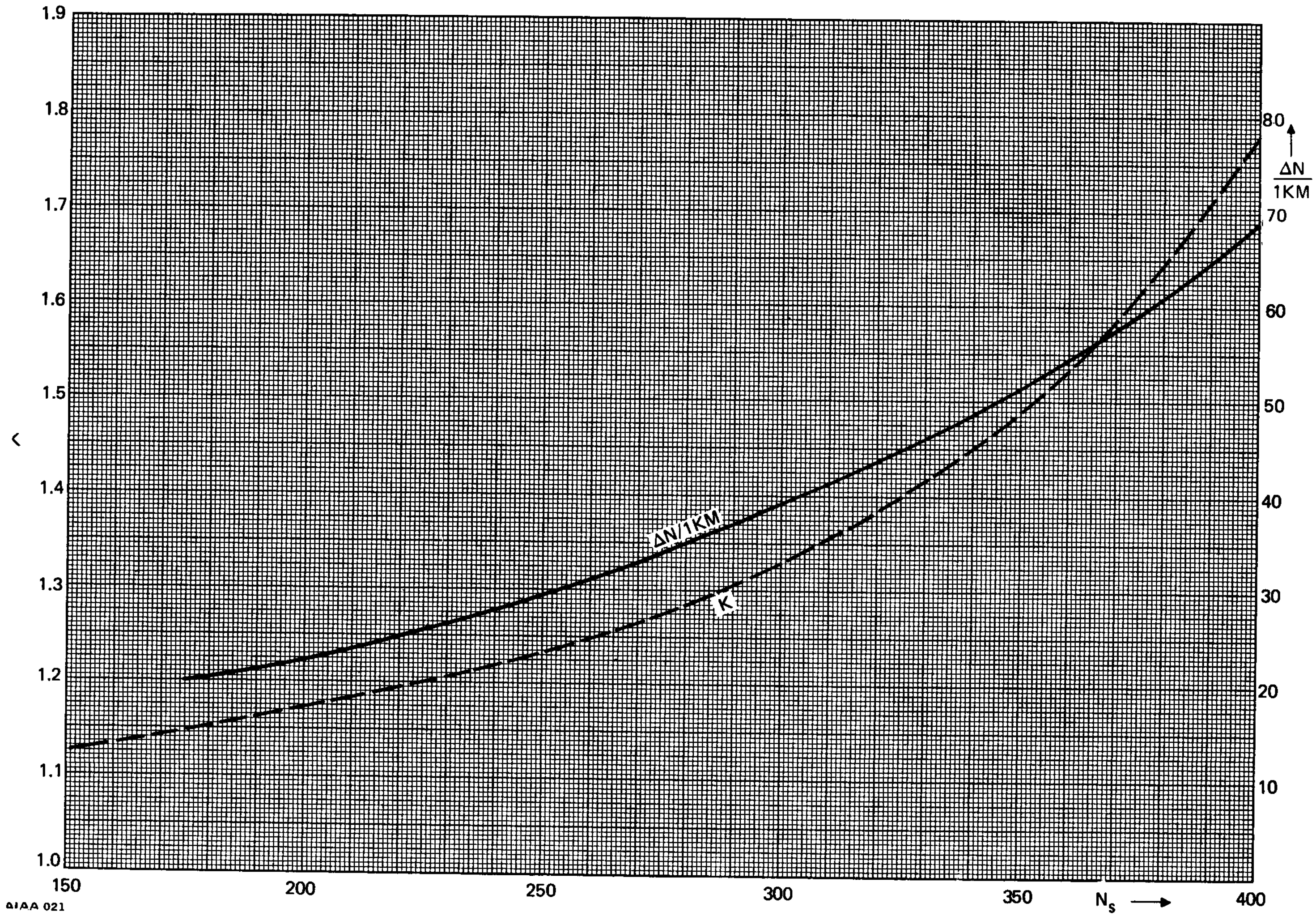


Figure 2-12. Refractivity Gradient ΔN/KM and "K" Versus Surface Refractivity N_s

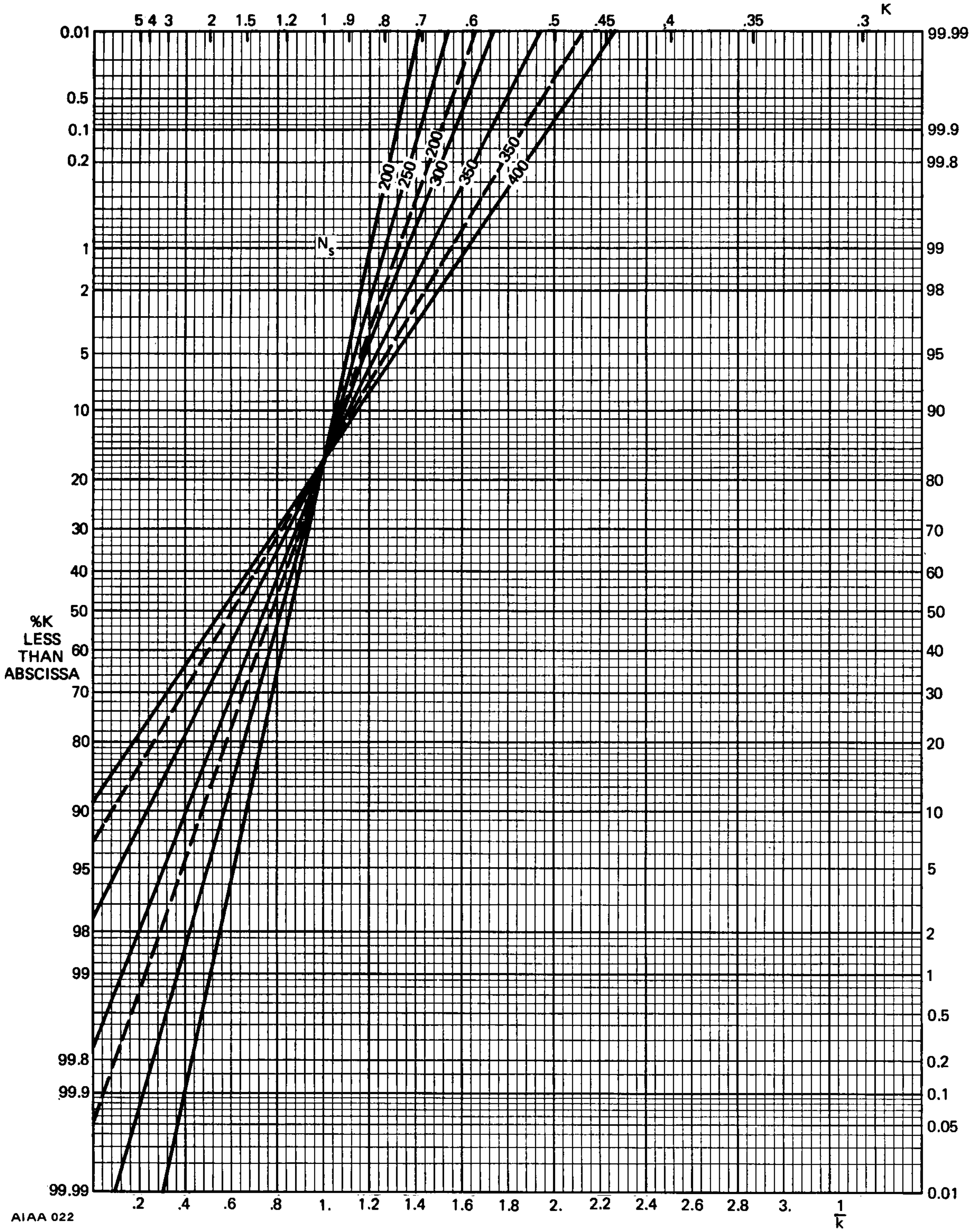


Figure 2-13. No Fog - 30 Miles

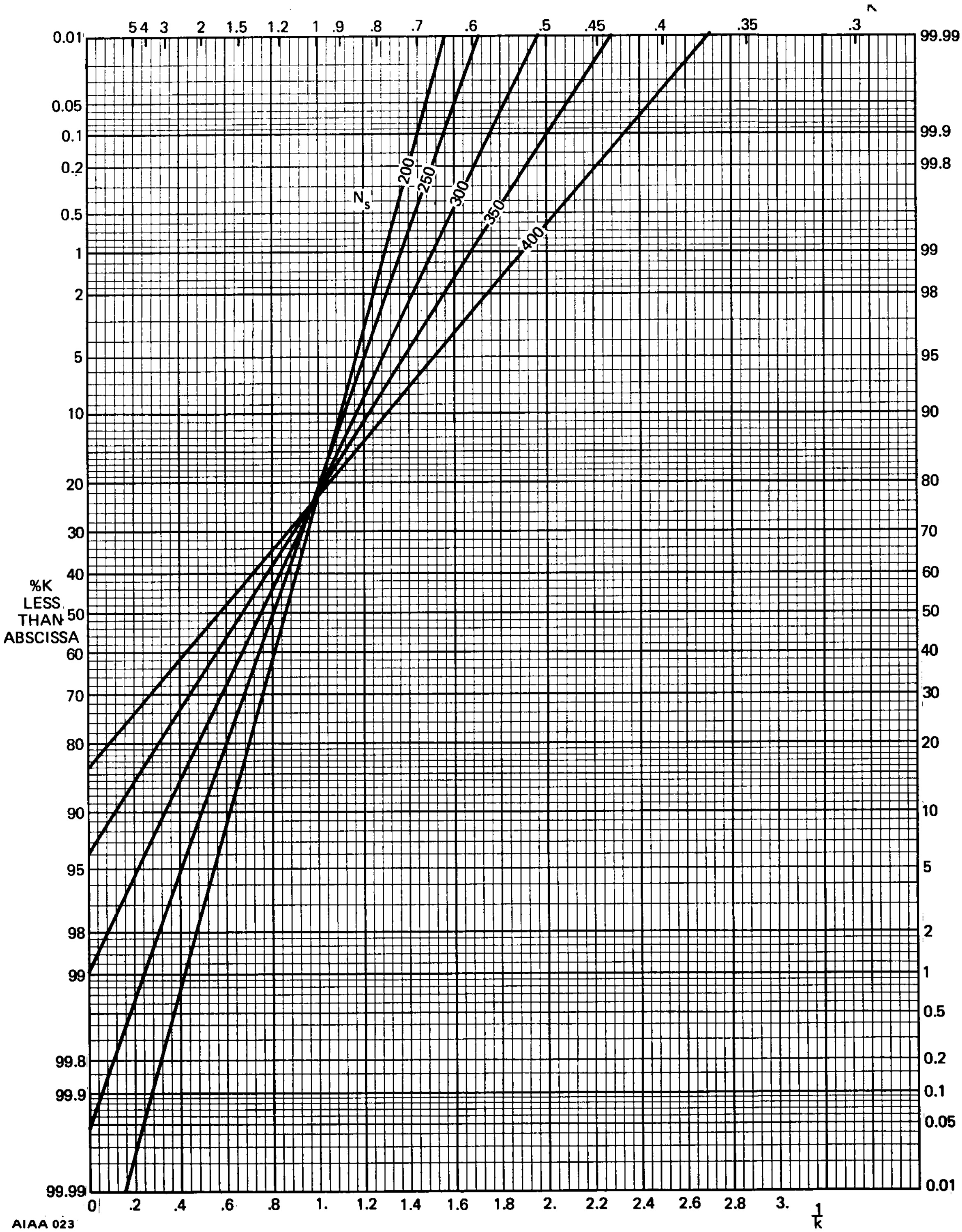


Figure 2-13. Some Fog - 30 Miles

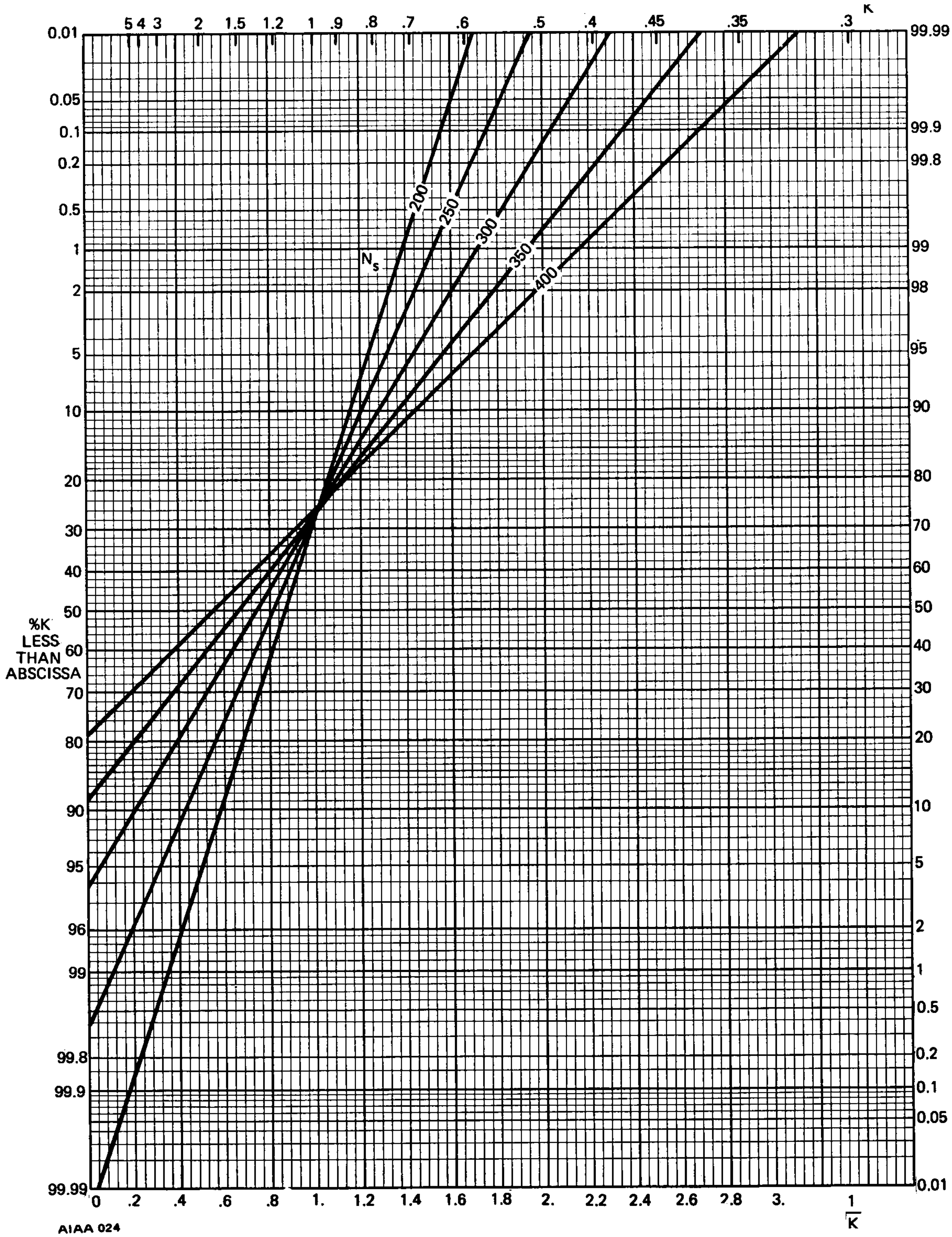


Figure 2-15. Heavy Fog - 30 Miles

Table 2-3. Standard Atmosphere Parameters

SURFACE REFRACTIVITY N_s	REFRACTIVITY GRADIENT NEAR SURFACE $\Delta N/km$	EFFECTIVE EARTH RADIUS a/n STATUTE MILES
250	-29.51	4878.50
301	-39.23	5280.00
350	-51.55	5896.66
400	-68.13	6996.67

Essentially free-space propagation exists when the frontal area of the wave bounded by the limits of six-tenths of the first Fresnel zone is clear of all obstructions on the path. Any obstruction extending into this circular region from any direction will cause significant attenuation of the microwave beam. The first Fresnel zone boundary is formed by the locus of all points from which a wave could be reflected with a total path length increase of 1/2 wavelength over the direct path. Each successive Fresnel zone boundary is described by the increase of reflected path length in multiples of 1/2 wavelength. For example, a ray reflecting at any point on the surface defining the fifth Fresnel zone is physically five 1/2 wavelengths longer than the direct path between antennas. Actually, there are an unlimited number of Fresnel zones on a wave front. However, the region described as the first Fresnel zone accounts for approximately one-quarter of the total received field energy. The first five Fresnel zones for a 40-mile path are shown to scale in figure 2-16. This microwave path is represented as partially obstructed by a hill at a distance of 14 miles from one terminal. This hill is shown at two heights for illustrative purposes. If the path clearance over this hill is equal to the radius of the fifth Fresnel zone (obstruction 1 in figure 2-16), arrival of the reflected wave will be delayed 3 wavelengths behind the direct ray, and the two will add in phase resulting in a received signal level increase of as much as 6 dB. This delay results from a 180° (1/2 wavelength) phase reversal or lag at point of reflection plus five 1/2 wavelengths difference in the physical path length for a total of six 1/2 wavelengths or 3 wavelengths.

If the obstruction were higher and a zero-clearance or grazing condition resulted, as represented by obstruction 2 in figure 2-16, the received signal would decrease from free space values by at least 6 dB and perhaps as much as 15 dB. The wide fluctuations in predicted signal level enhancements due to odd Fresnel zone additions and degradation due to even zone cancellations result from differences in the value of the coefficient of reflection (R) of various obstructions. Wider ranges of signal increase or decrease are apparent when the terrain is highly reflective (R = 0.8 to -1.0, the negative sign making reference to the 180° phase reversal at the reflection point). A special condition occurs at the lower ranges of R (0 to -0.3) when the obstruction is knife edge. Fluctuations in received signal level with varying clearances are attributed more to wavefront diffraction and Fresnel zone obstruction than to reflected ray interference patterns. Table 2-4 lists reflection coefficients of various categories of terrain together with attendant effect on receive signal level. Figure 2-17 is a re-plot of the upper right side of figure 2-16 depicting path attenuation versus path clearance.

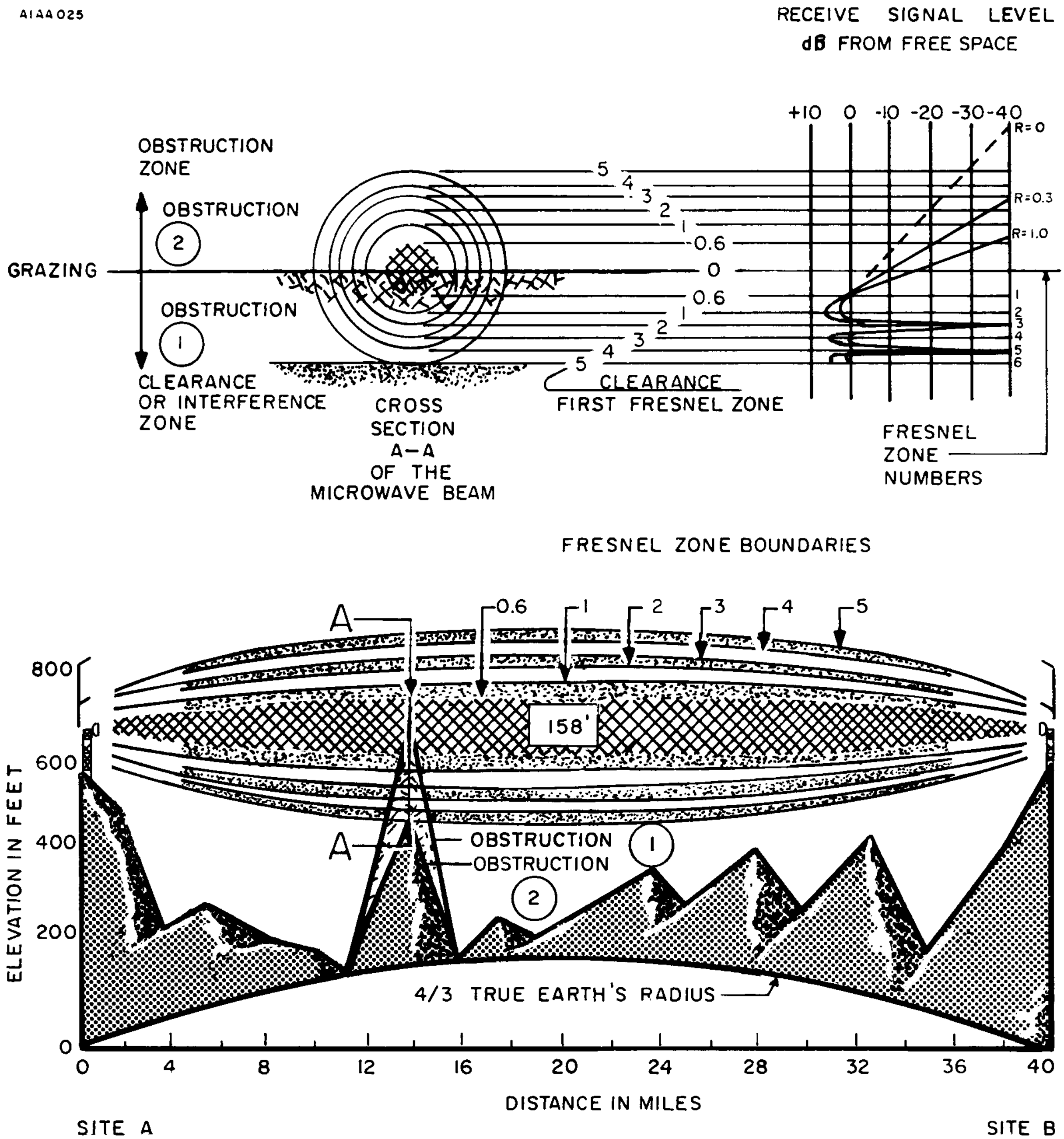


Figure 2-16. Fresnel Zones for a 40-Mile Microwave Path, Standard Atmosphere, on 4/3 Earth's Radius of Curvature Profile Paper (6 GHz)

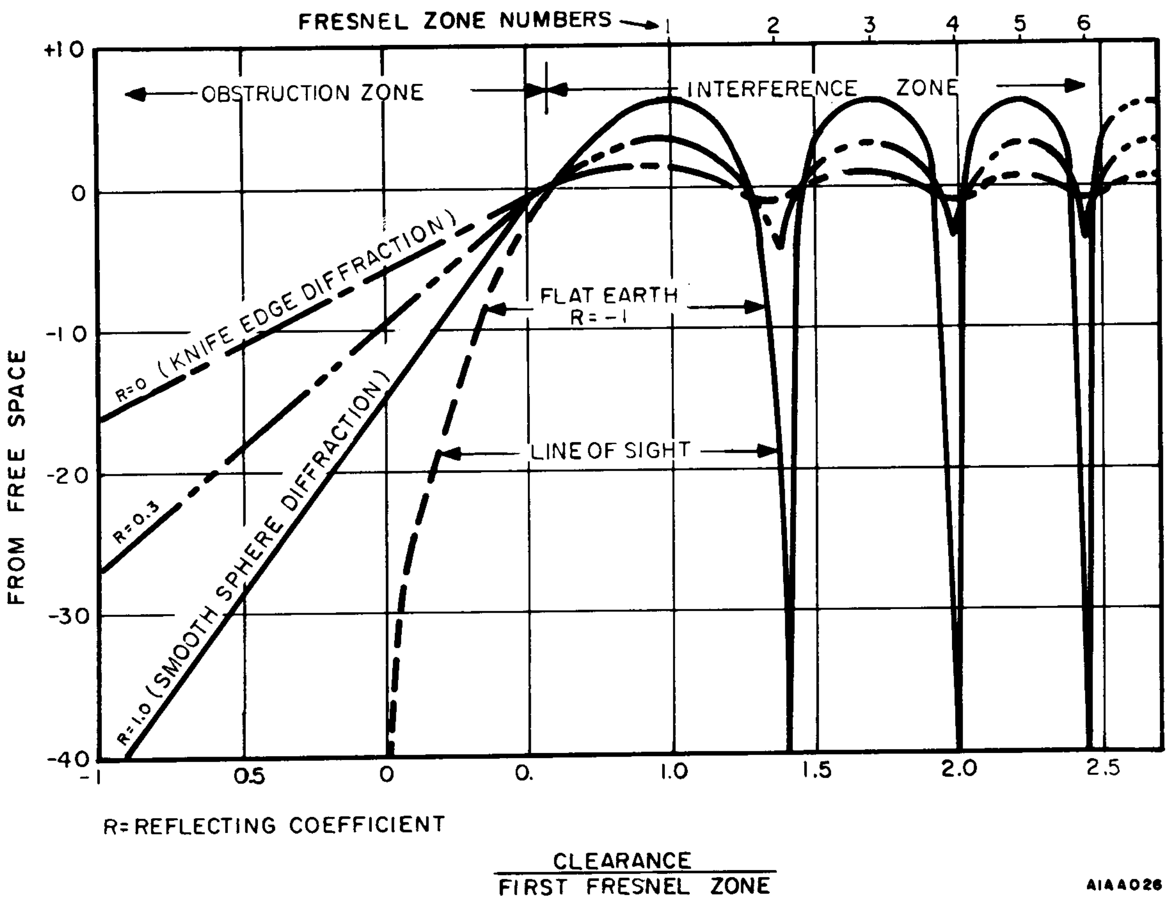


Figure 2-17. Path Attenuation Versus Path Clearance

Table 2-4. Approximate Values of R for Various Terrain

TYPE OF TERRAIN	R	APPROXIMATE DEPTH OF EVEN FRESNEL ZONE FADE dB
Heavily wooded, forest land	0 to -0.1	0 - 2
Partially wooded (trees along roads perpendicular to path, etc.)	-0.1 to -0.4	2 - 5
Sagebrush, high grassy areas	-0.5 to -0.7	5 - 10
Cotton with foliage, rough sea water, low grassy areas	-0.7 to -0.8	10 - 20
Smooth sea water, salt flats, flat earth	-0.9 +	20 - 40+

The values of R given in this table are approximate, of course, but they do give an indication of signal degradation to be expected over various terrain should even lumbered Fresnel zone reflections occur.

Bending or diffraction around obstructions can be explained using Huygens' Principle which states: "All points on a wavefront can be considered point sources for the production of spherical secondary wavelets. After a time, t, the new position of the wavefront will be the surface of tangency to these secondary wavelets."

Figure 2-18 is a free space example. At the time t = o, a portion of the wavefront is shown as ab. Several points (see dots) on the wavefront, ab, serve as centers of radiation (wavelets). At time t, the wavelets have reached the position ct. The new wave front, de, is made up of ct components normal to wave front ab. Vector components parallel to the wave front are equal in magnitude but opposite in direction and therefore cancel. When a knife-edged obstruction is located at a wavelet source as shown in figure 2-19, the components of ct parallel to wave front ab no longer cancel and a portion of the signal is transmitted behind the obstruction (shadow zone). If the obstruction is a smooth sphere instead of a knife edge, a portion of the signal in the shadow zone will be reflected from the spherical surface away from the receiving antenna with some cancellation taking place. The resulting received signal will be much less than in the knife-edge diffraction case.

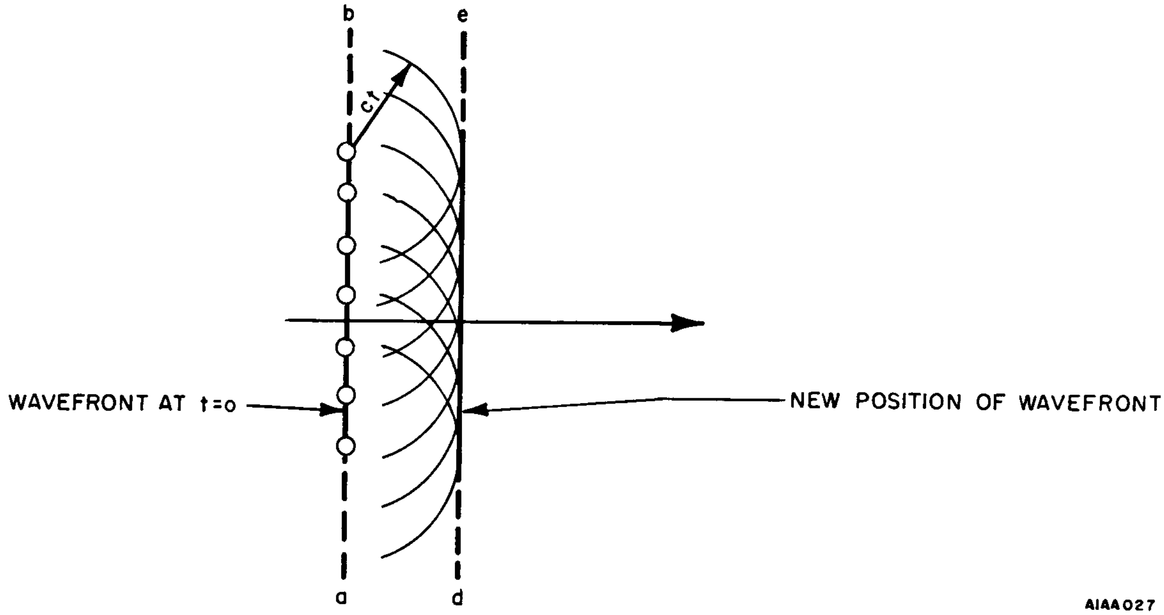


Figure 2-18. The Propagation of a Plane Wave in Free Space as Described by the Huygens' Principle

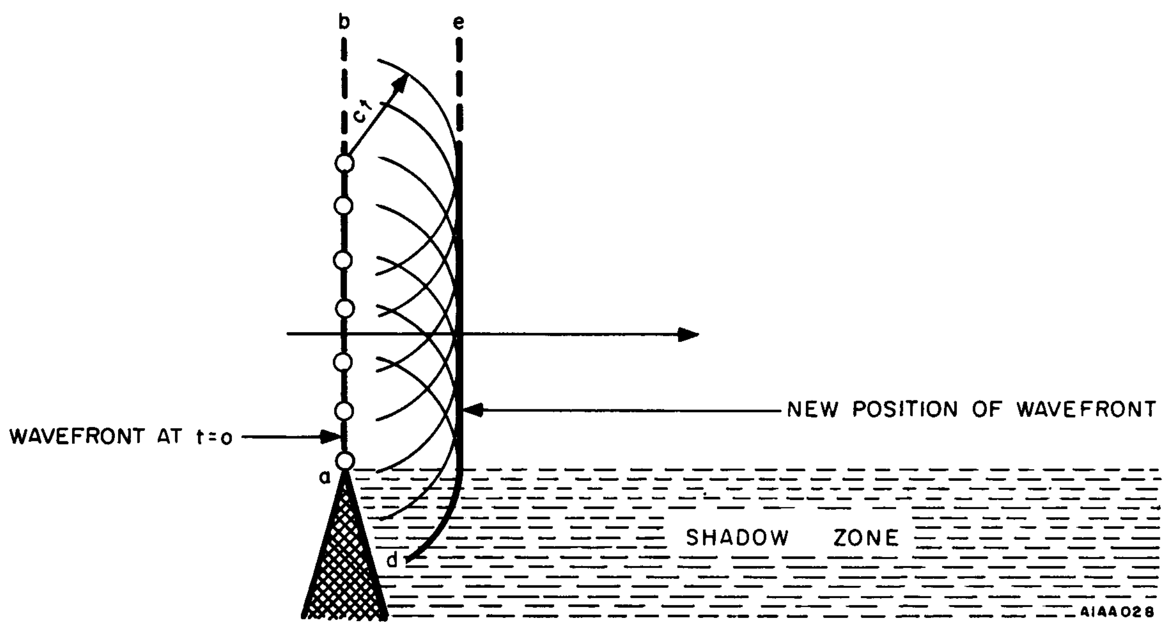


Figure 2-19. The Propagation of a Plane Wave Around a Knife-Edge Obstruction Using the Huygens' Principle

2.1.3 Reflections

When more than six-tenths first Fresnel zone clearance exists on a path, the received signal can be more or less than the free space calculated value depending upon the relative strength and phase of the reflected signal as discussed previously. The direct and reflected waves interfere and result in maxima and minima receive signal strength pattern as the path clearance is increased above grazing over reflective terrain. This condition is often referred to as reflected-ray or Fresnel fading and is illustrated in figures 2-16 and 2-17.

As the transmitting and receiving antennas are elevated simultaneously to increase path clearance from obstructed to free space, the received signal level increases linearly with clearance. Free-space clearance occurs when the actual received signal level corresponds to the previously calculated value assuming free-space propagation conditions. Path clearance over the obstruction at this point is about equal to six-tenths of the radius of the first Fresnel zone, shown cross-hatched in figure 2-16.

As the antennas are raised further, part of the beam may be reflected from the obstruction towards the receiving antenna, assuming the angles of incidence and reflection are equal (a procedure for locating points of reflection meeting this criterion will be discussed). When the length of the reflected path is longer than the direct path by 1/2 wavelength, these rays will arrive in phase, since an additional phase shift of about 180° lagging (1/2 wavelength) takes place at the reflection point. The result will be an increase in the received signal level of from 1 to 6 dB over free-space calculations, depending upon the magnitude of the reflected wave. This reflective surface may be located below the main beam (water or a barren hill), above the main beam (an atmospheric discontinuity or aircraft), or to one side of the path (a nearby building), and the locus of all of these points identifies the first Fresnel zone as previously discussed. The third, fifth, and all remaining odd-order zones occur at the point of reflection when the reflected ray arrives at the receiver in phase (even multiples of 1/2 wavelength) with the direct ray, thus, increasing the resultant signal level.

Conversely, clearance equal to the radii of even Fresnel zones (second, fourth, etc.) at the point of reflection may cause the addition of the main beam with out-of-phase or even-zone reflection components. This will result in a reduction in the received signal, which varies from just a few dB to an infinite amount, depending upon the value of the coefficient of reflection.

Path clearances in terms of Fresnel zone numbers for various values of K over points of reflection are extremely important parameters and must be determined. The nth Fresnel zone radius in feet for any point along a microwave path of length D is given by:

$$F_n = 2280\sqrt{\frac{nd_1 d_2}{fD}} \quad (2\text{-}15)$$

where:

D, d_1, and d_2 are distances in miles ($d_1 + d_2 = D$)

n = Fresnel zone number, and

f = Frequency, MHz

If the first Fresnel zone radius is known at a particular point on a path, the radius for the nth zone can be readily determined from the relationship;

$$F_n = F_1\sqrt{n} \quad (2\text{-}16)$$

Computer printouts have been prepared listing the solution of the above equations in tabular form.

Dimensions which are important in the practical engineering of microwave paths over reflective terrain are identified in figure 2-20. The direct ray, r_0, is shown as a straight line over a fictitious earth whose radius is a function of K. The length of the reflected ray r_2 is dependent upon path clearance over the point of reflection. If this clearance is equal to F_2 (the radius of the second Fresnel zone), the path of the reflected ray is physically one wavelength (about 1-3/4 inches at 6.75 GHz) longer than the direct ray. This almost infinitesimal (compared to a typical 20 mile path length) difference may result in almost complete cancellation of the received signal if the coefficient of reflectivity approaches -1. The position of the reflecting point over flat terrain and water is determined with the aid of figure 2-21 which locates this area as a fraction of the total path length for each value of K. As K becomes lower during substandard atmospheric conditions, the reflecting plane tangent is altered, moving the point of reflection toward the higher antenna.

When a radio wave is incident upon the earth's surface, it is not actually reflected from a point on the surface, but from a sizable area. This reflection area may be large enough to include several Fresnel zones, or it may be in the form of a ridge or peak including only a part of the first Fresnel zone. Where the wave is incident upon a plane surface, the resulting Fresnel zones formed on the reflecting surface take the form illustrated in figure 2-22A. Elliptical zones formed on the reflecting surface are similar to those which would be formed on an oblique plane placed between a transmitting source and a receiver in free space, as shown in figure 2-22B. Therefore, earth reflected Fresnel zones are simply a projected image of free space Fresnel zones at the plane of reflection. They may be determined by the same geometry used for free space Fresnel zones.

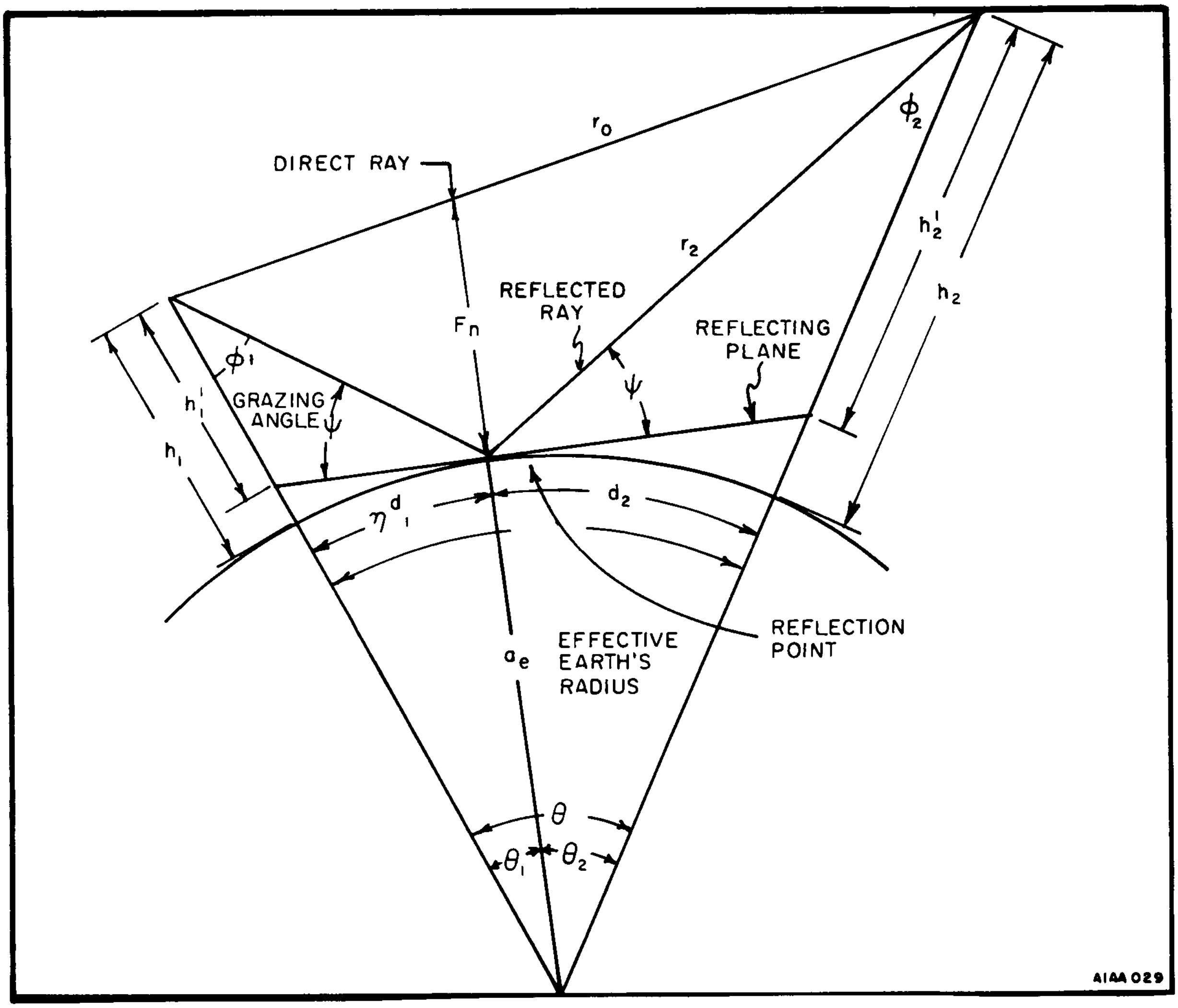


Figure 2-20. Geometry for Within-the-Horizon Paths

The significance of the ground-reflected Fresnel zones is similar to that mentioned for free space Fresnel zones. However, radio waves reflected from the earth's surface are generally changed in phase depending upon wave polarization and the angle of incidence. Horizontally polarized waves at microwave frequencies are reflected from the earth's surface and shifted in phase by approximately 180° effectively changing the electrical path length by 1/2 wavelength. On the other hand, for vertically polarized waves, there will be a considerable variation in the phase angle for different angles of incidence and reflection coefficients. This variation will be between 0° and 180° lag, depending upon ground conditions. Therefore, for horizontally polarized (and in some cases for vertically polarized waves), if the reflecting surface area is large enough to include the total area of any odd-numbered Fresnel zones, resulting wave reflections will arrive out of phase (at the receiving antenna) with the direct wave and cause fading interference.

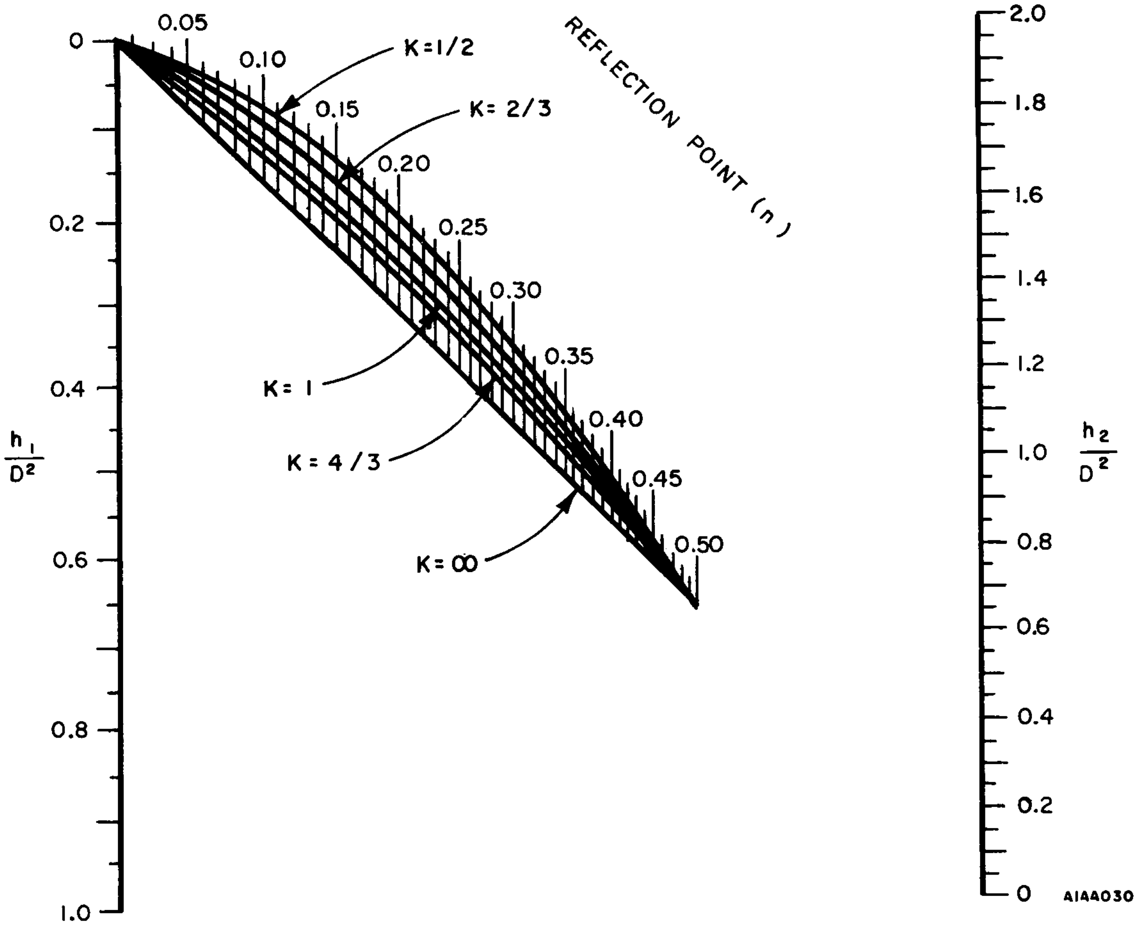


Figure 2-21. Point of Reflection on an Over-Water or Flat Terrain Path

The antenna radiation pattern near a reflecting surface, such as the ground, differs from the free space pattern primarily because of the existence of ground reflections. Since the direct path and reflected path will not be of the same physical length and there will be a phase change upon reflection, the two waves may arrive at the receiving antenna with any phase relationship. This phase relationship of the two waves will cause either an increase or a decrease in signal strength at the receiver. It will also produce the effect of distinct lobes and nulls in the radiation pattern, since the two rays add vectorially at the receiver.

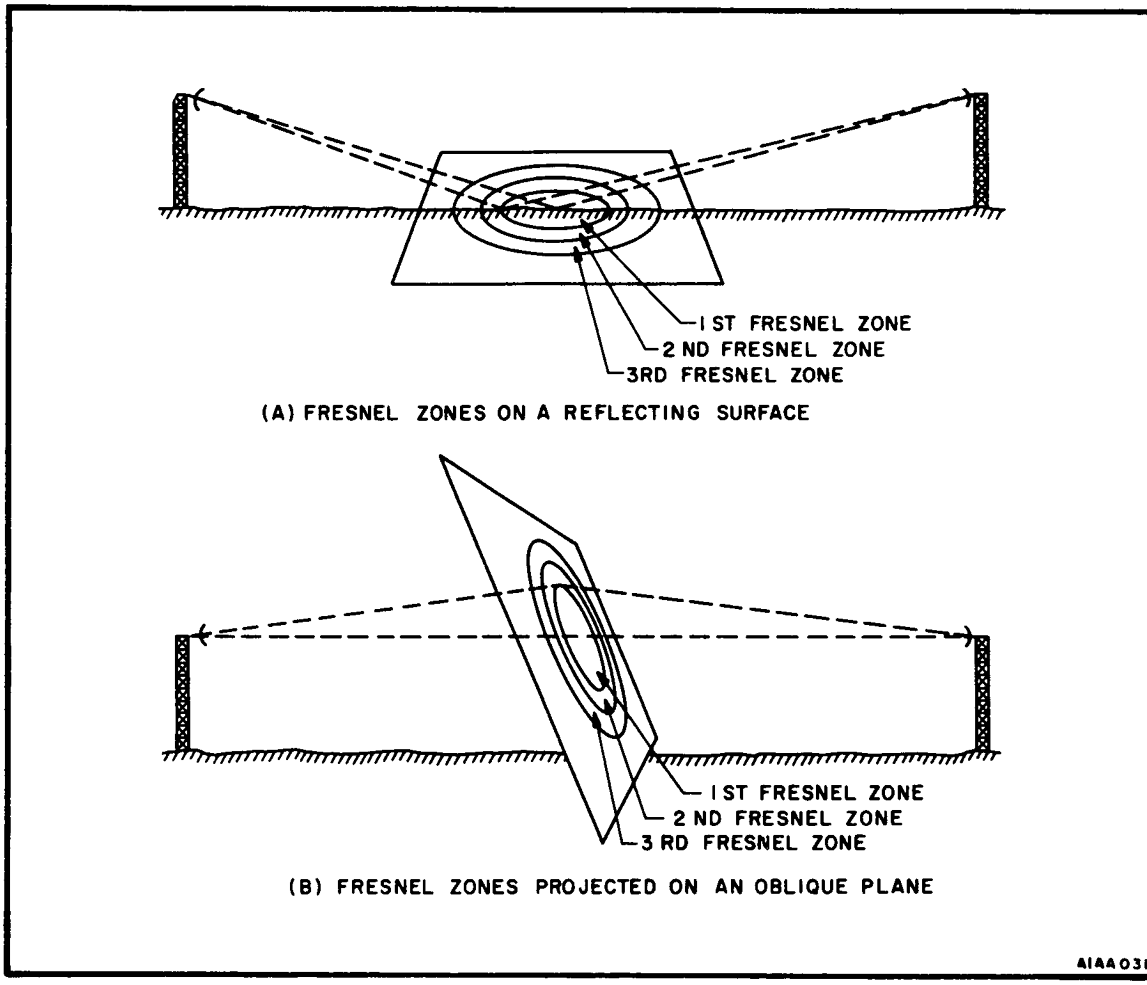


Figure 2-22. Earth Reflected Fresnel Zones

2.1.4 Polarization

In a simple qualitative way, energy radiated by an antenna may be thought of as consisting of packets of electric and magnetic lines of force. Electric lines of force (the E component of the electromagnetic wave) are a measure of force direction and magnitude exerted on a unit positive charge at any point in the field. In an analogous way, magnetic lines of force (H components) give vectorial force information exerted on a north seeking magnetic pole at the same point. If a unit positive charge always moves in a vertical direction when placed in an electromagnetic field (i.e., if the electric lines of force are vertical), the field is said to be vertically polarized. Similarly, if a unit positive charge moves in a horizontal direction (i.e., if the electric lines of force are horizontal), the wave is said to be horizontally polarized. In the radiated field, E and H components are mutually perpendicular and are perpendicular to the direction of wave propagation.

Energy radiated from an antenna may be vertically polarized, horizontally polarized, or in some cases, it may have both horizontally and vertically polarized components. In the latter case, if the horizontal and vertical components are at the same frequency, but not in time phase, elliptical polarization will result. When energy is being radiated on one polarization, a small portion may be converted to the other polarization due to small imperfections in the antenna system. The ratio of power in the desired polarization to the power converted to the other polarization is called cross-polarization discrimination.

2.2 PATH ATTENUATION

Power radiated from a transmitting antenna is ordinarily spread over a relatively large area. As a result, the power available at most receiving antennas is only a small fraction of the radiated power. This ratio of radiated power to received power is called the radio transmission loss, and its magnitude in some cases may be as large as 150 to 200 dB. The transmission loss between transmitting and receiving antennas determines whether the received signal will be useful. Each radio system has a maximum allowable transmission loss, which, if exceeded, results in either poor quality or poor reliability. Reasonably accurate predictions of transmission loss can be made on paths that approximate the ideals of free space or plane earth.

2.2.1 Free Space Transmission Loss

The following definition is based on recommendations of the National Bureau of Standards and CCIR. Transmission loss, L_b, is defined as power lost in transmission between a transmitting antenna at one point and a receiving antenna at a different point. It is measured as the difference between the net power passing the first point and the net power passing the second.

The basic concept in estimating free space transmission loss is the loss expected in a region free of all objects that might absorb or reflect radio energy. This concept is essentially the inverse square law in optics applied to radio transmission. For a one wavelength separation between isotropic (nondirective) antennas, the free space loss is 22 dB, and increases by 6 dB each time the distance is doubled. The basic transmission loss ratio at a distance d, is depicted in figure 2-23 and is given by:

$$L_b = 10 \log \frac{Pr}{Pt} = 10 \log \left(\frac{\lambda}{4\pi d}\right) \qquad (2\text{-}17)$$

where:

Pr, Pt = received power and radiated power, respectively, and measured in same units

λ = wavelength measured in same units as d.

Equation 2-17 is also written as,

$$L_b = 36.6 + 20 \log f + 20 \log d \qquad (2\text{-}18)$$

where:

f = frequency in MHz

d = distance in miles.

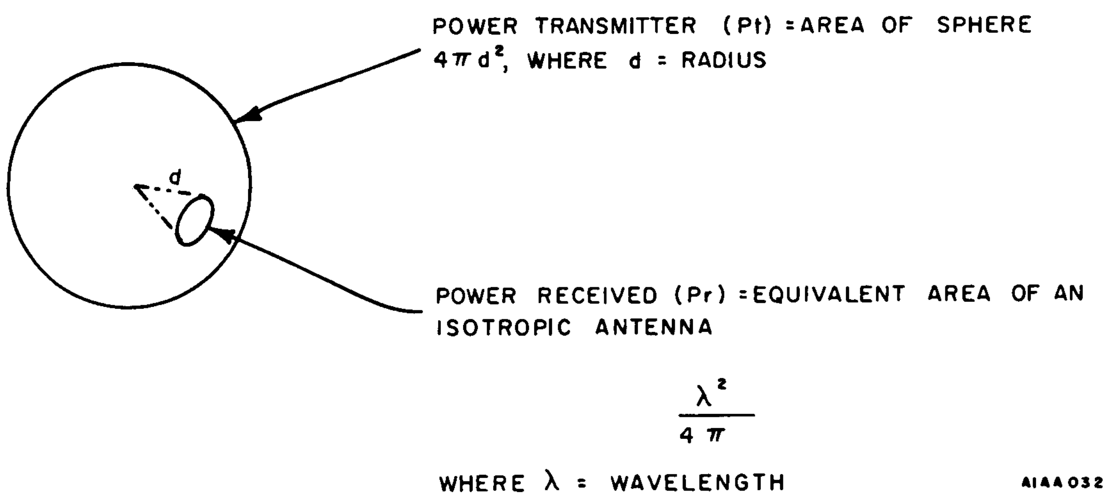


Figure 2-23. Transmission Loss Solid Geometry

A chart for the free space transmission loss between isotropic antennas is given in figure 2-24.

Free space transmission loss is not a loss in the dissipative sense, but rather, reflects the condition whereby the loss is the total energy radiated compared to the amount of energy picked up by the area of an isotropic antenna. The total energy radiated is proportional to area of a sphere, since energy is radiated equally in all directions. The amount of energy picked up is proportional to the equivalent area of an isotropic antenna.

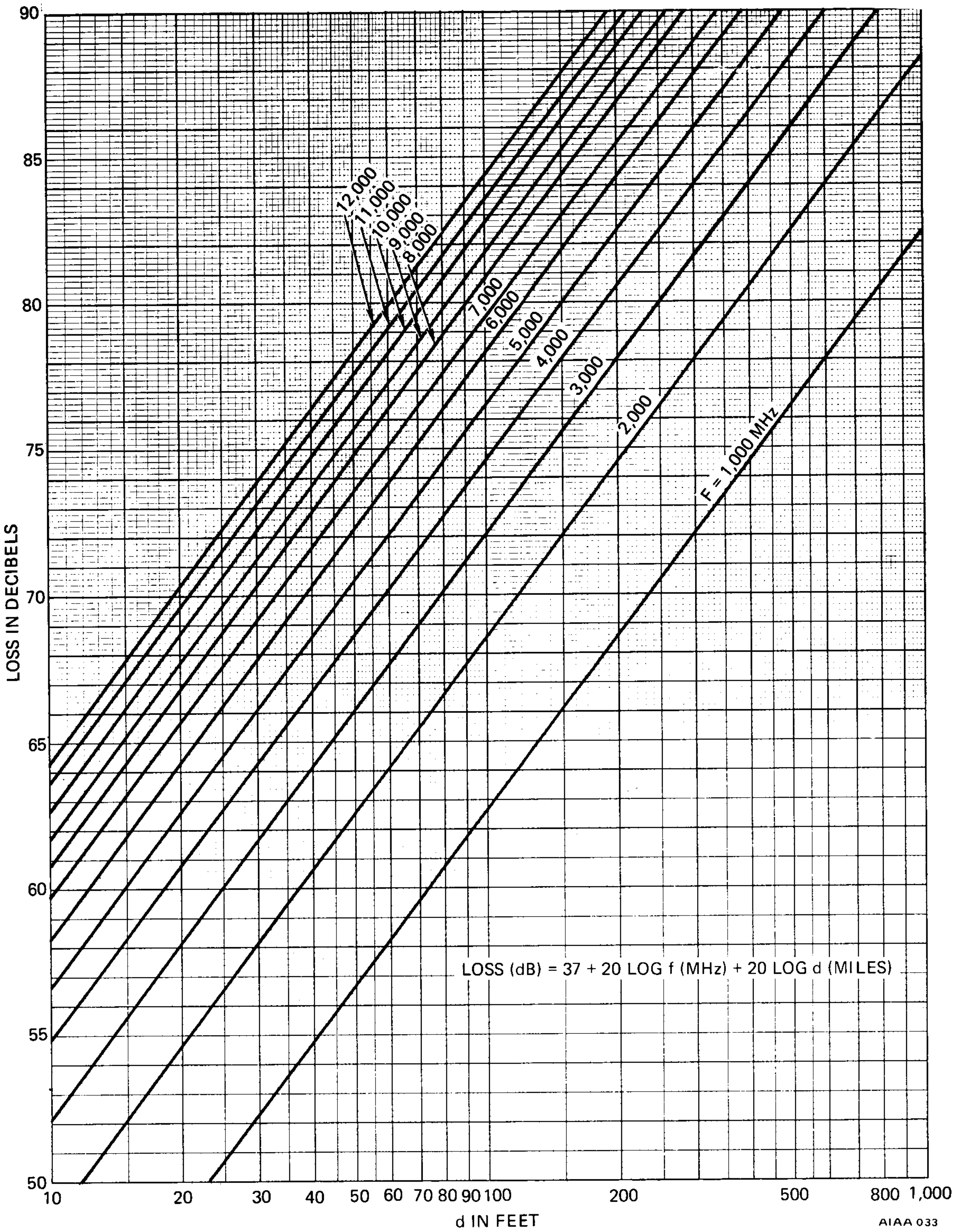


Figure 2-24. Free Space Transmission Loss

2.2.2 Median Received Signal

The median system noise per channel is the sum of noise contributions from individual radio hops plus noise from the multiplex equipment. A limiting noise level value of 38 dBa0 for all sources has been specified for the overall reference circuit (6000NM) not to be exceeded during 50% of all hours of time block 2.

The median noise contribution for noise assignable to just the transmission medium is 37 dBa0 and the remainder being assignable to multiplex equipment. The median transmission medium noise contribution for one link would therefore be 37 dBa0 - 10 log 6 = 29.22 dBa0. Next, dividing the remaining noise into contributions from the individual hops, we have, from chapter 1 that each link is comprised of three sections with each section divided into nominally 13 hops. Therefore, for a 3 x 13 = 39 hop nominal link, we have for the median transmission medium noise contribution for one hop a nominal value of 29.22 dBa0 - 15.91 dBa0 = 13.31 dBa0. The corresponding signal-to-noise (S/N) ratio would be S/N = 82 - dBa0 = 82 - 13.31 = 68.69 dB. The latter equation is defined in chapter 4.

To obtain a corresponding median received signal level for a per channel noise value of 13.31 dBa0, the noise characteristic for the particular radio equipment is required. All radio equipment has a characteristic of derived channel S/N ratio versus received RF signal level, or noise characteristic. Manufacturers supply a noise characteristic for any particular radio equipment, or one can be constructed from adequate specifications on noise contributions by their equipment. Transmitter deviation, baseband width, and load must be specified as they directly affect the noise characteristic. For this reason, there will often be more than one characteristic given for a single type of radio equipment. Refer to chapter 3 for a discussion on noise performance as related to noise characteristics.

2.2.3 Water Vapor

Attenuation due to water vapor (oxygen loss) in the air is negligible at frequencies below 10 GHz but reaches a first peak of about 0.2 dB per kilometer at 24 GHz. Absorption by oxygen in the atmosphere reaches a peak of about 10 dB per kilometer at 60 GHz, but attenuation is only about 0.015 dB per kilometer at 10 GHz decreasing rapidly for frequencies below 2 GHz. Figure 2-25 shows attenuation in dB per kilometer for water vapor and oxygen as a function of frequency.

2.3 FADING

During abnormal propagation conditions, the path loss may differ considerably from the normal. In some cases, the path loss may decrease a small amount (positive gain), but the more usual case is for increases (negative gain) of 10, 20, 30 dB or more to occur for short periods. These variations with time in the path loss are referred to as fading. Fading can be considered as a temporary diversion of energy to some other location rather than the desired location.

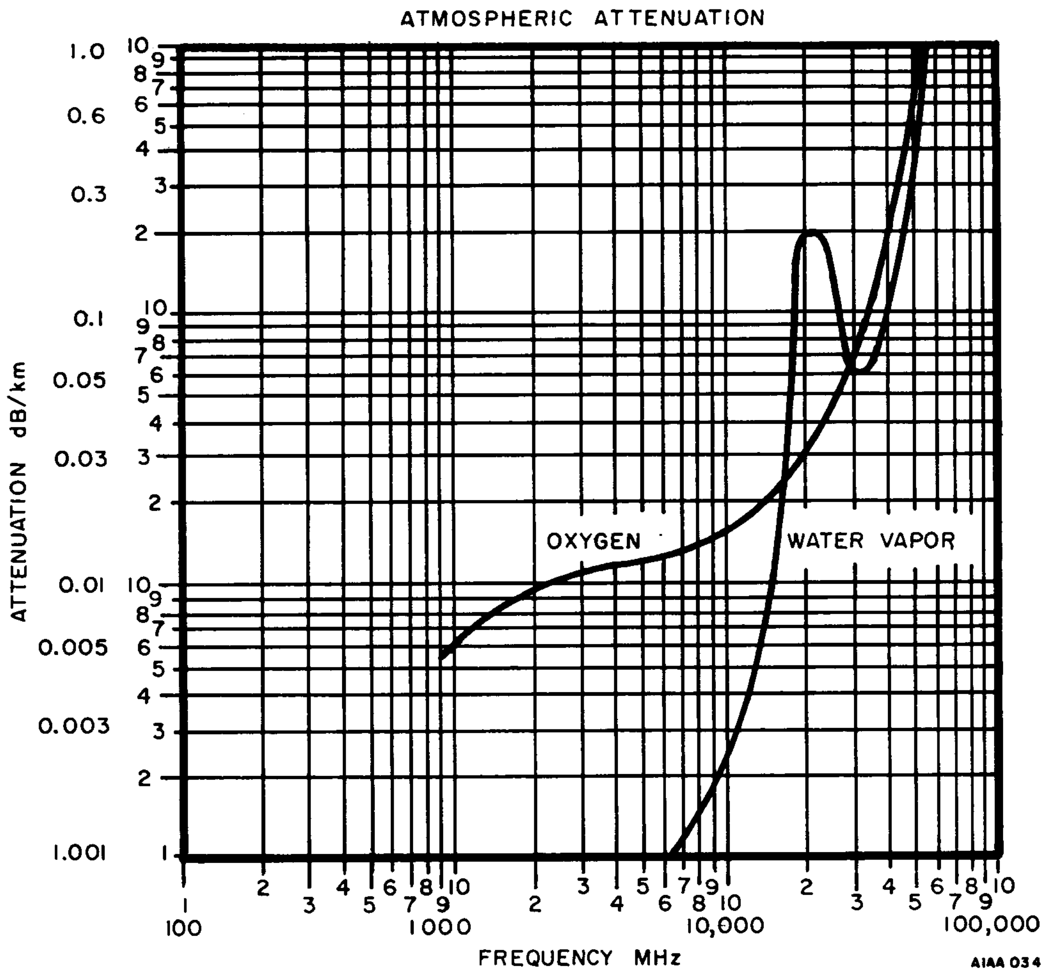


Figure 2-25. Attenuation Due to Atmospheric Gasses

The factors involved in fading phenomena are many and complex. Exact explanations for all fading phenomena are not yet available, but some general characteristics can be stated. It is known that during the daytime, when the lower atmosphere is thoroughly mixed by rising convection currents and winds, the signals on line-of-sight paths are normally steady and near the predicted free-space values. Also, when the humidity content of the atmosphere is low, signal variations are usually small. However, on clear nights with little or no wind, abnormal distributions of temperature and humidity can create steep dielectric constant (or refractory) gradients in the lower atmosphere, thus causing anomalous propagation and fading.

If it were possible to keep all conditions constant, it would be simple to plan the locations of transmitting and receiving antennas so that the difference in path length of two signals would be 1/2 wavelength. Then signals would always arrive at the receiving antenna enchanced to the greater than normal value. Unfortunately, both direct and reflected signals must travel through an atmosphere which is anything but homogeneous with respect to temperature, density, and moisture content. These factors are further subject to the many vagaries which determine our weather hour-to-hour, day-to-day, and season-to-season. The result is that microwaves are bent this way and that while traveling over paths constantly changing in direction and are sometimes longer or shorter, similar to a beam of light through an imperfect and somewhat cloudy lens. The received signal also varies from moment to moment, sometimes strong due to reinforcement and then very weak due to cancellation.

2.3.1 Multipath Fading

The most common type of fading is the result of multiple path transmission. The arrival of one or more interfering rays via atmospheric reflection or refraction paths may result in rapid fluctuations in the received signal level which are completely independent of path clearance. Since it is highly improbable that all transmission paths will be of the same length, phase interference can and often does occur. Signals arriving at the receiving antenna from slightly different angles reinforce or cancel each other, depending upon the phase relationship between them. Since the angle of convergence is small as compared with the antenna beamwidths, antenna pattern discrimination against secondary paths is negligible. Since the various propagation paths do not suffer greatly different attenuations, nearly complete cancellation can occur at the receiving antenna when two signals arrive 180 degrees out of phase.

The phase relationship of reflected rays with respect to the direct ray are completely random in nature. Path length differences between the direct ray and indirect rays of over 50 wavelengths have been measured. Therefore, when signals arrive having different delays, the received carrier level is the summation of all the arriving signals in both amplitude and phase. This leads to an amplitude distribution for which the Rayleigh distribution is a sufficiently accurate fit to measured data. After the multipath fading has reached the Rayleigh distribution, a further increase in either path distance or operating frequency increases the number of fades of a given depth, but decreases the duration so that the product is the constant indicated by the Rayleigh distribution. Representative values of fading on a path with adequate clearance are shown in figure 2-26. The curve shows that atmospheric multipath fades of 25 dB or more from normal may be expected to occur 0.2 percent of the time for frequencies of 4 GHz and higher. Occurrence of multipath fading is not primarily a matter of locality or path clearance. Generally it is much worse in the summer months than at other times of the year. For any particular day, fading is greatest in the early morning hours. Fading is frequency selective, and virtually no correlation is shown on frequencies separated by 160 MHz or more. The average maximum rate of change of fade was found to be 10 dB/second with rates as high as 100 dB/second occurring very seldom.

It is extremely unlikely that all hops of a multi-hop system will have the same worst month. Evidence indicates that probably no more than 30 percent of the hops are in simultaneous worst month or Rayleigh fading during any one month. The remaining hops are probably experiencing less than Rayleigh fading of varying severity.

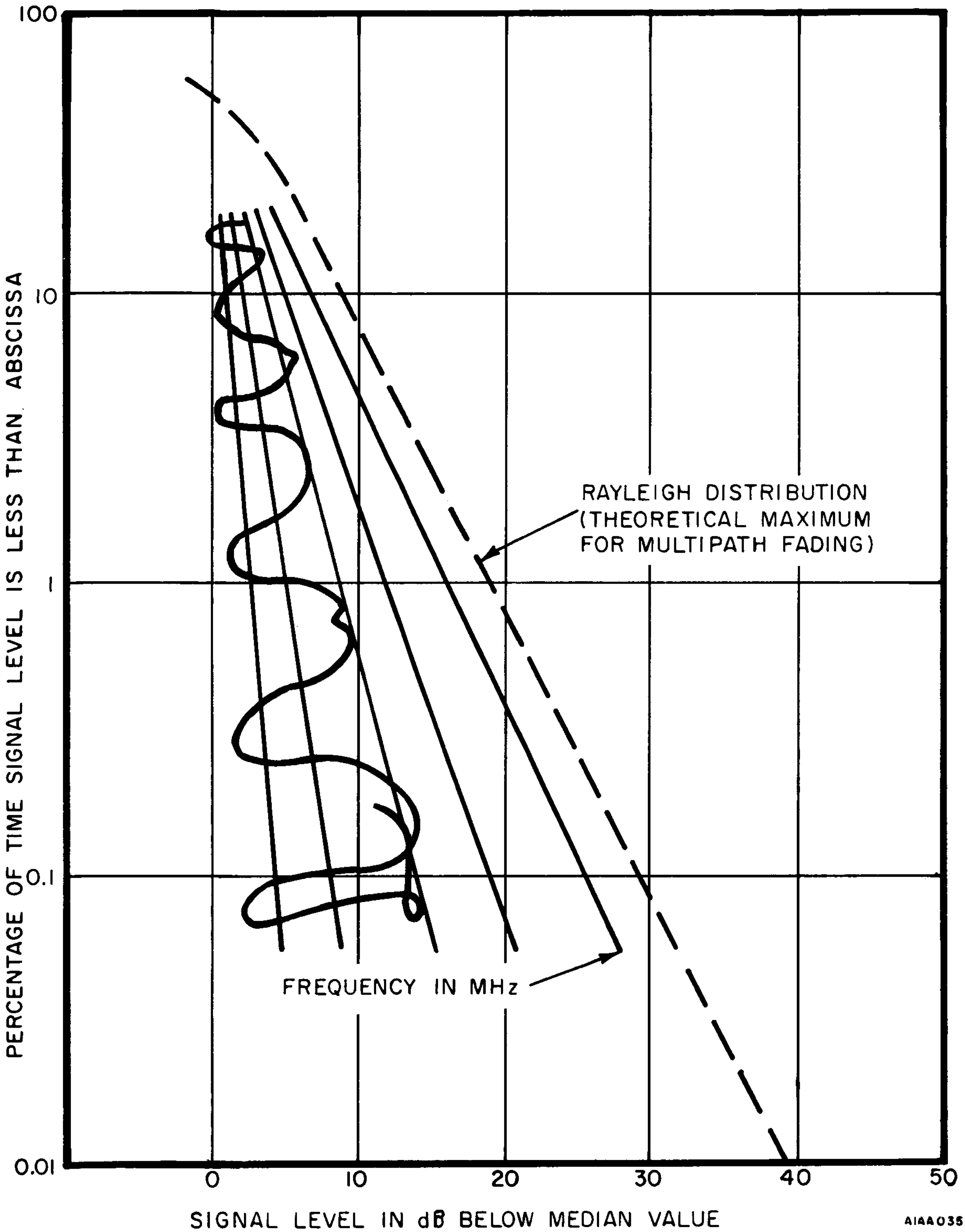


Figure 2-26. Typical Fading Characteristics in the Worst Month on a 30 - to 40 - Mile Line-of-Sight Paths With 50 - to 100 - Foot Clearances

2.3.2 Refractive Fading

Abnormal variations in the atmospheric refractive index cause other types of fading. Normally, the atmospheric refractive index decreases with altitude so that the direct path is usually curved in the direction of the earth's curvature. As discussed earlier, this is equivalent to a flattening of the earth's surface, and frequently an earth radius of 4/3 the actual radius is assumed as the average condition in appraising the path profile.

a. Earth Flattening Effect. If the index of refraction decreases with height more rapidly than normal, bending of the direct path towards the earth's surface will increase. This phenomenon was discussed earlier from the standpoint of origin and varying degrees of the effect as superstandard refraction.

Signal fading may result due to cancellation caused by the time (and hence phase) lag of refracted waves from the lower wavefront portion with the upper wavefront portion at the receiving antenna. Under extreme conditions, propagation path curvature due to downward bending may have a radius less than that of the earth causing the wavefront to strike the earth short of the receiving antenna. In this case, only reflected rays will reach the receiving antenna and fading will result.

b. Earth Bulging Effect. If the index of refraction increases with height in the lower atmosphere, a situation results where the wave is bent upward and away from the earth. This phenomenon was discussed from the standpoint of origin and varying degrees of the effect as substandard refraction.

The upper portion of the wavefront may actually lag so far behind the lower portion that the propagation path curvature is reversed. This form of wave bending is also referred to as "inverse beam bending." This condition also has the effect of reducing path clearance resulting in fading since optimum clearance will no longer exist. Under extreme conditions, the degree of bending may be so severe that the beam actually overshoots the receiving antenna. Fading due to earth bulging may last for several hours; however, the magnitude and frequency of occurrence can be reduced by increasing the normal path clearances. An equivalent earth's radius of 2/3 to 1/2 of the actual radius may have to be assumed in areas of the country where this effect is known to be prevalent.

2.3.3 Reflected Ray Fading (Fresnel Fading)

Another rare type of fading is observed when a reflecting layer forms above or comes into existence below the transmission path. The received signal is subject to interference between the reflected wave and the direct path wave. These reflections may come into existence periodically even though, under normal conditions, path geometry does not permit such reflection.

This condition can result in changes of received signal level up to 6 dB above free space values or to complete signal cancellation depending upon reflected ray phase and magnitude. In regions hwere K is nearly constant with time, the resultant received signal level could remain stable at a value somewhere in this range. As K varies, path clearance and point of reflection are altered with a resultant change in reflected signal amplitude and phase causing fading.

Reflected ray fading is easily identified by very deep, fairly rapid fluctuations in the received signal level as path clearance over the reflective surface changes through even Fresnel zone radii. This type of fading most severely affects the transmission of time-sequenced information (data and supervisory control information) over a microwave link, since its occurrence is somewhat random and may not follow a diurnal or other predictable pattern. Complete path failure lasting for seconds at a time or longer may occur in a varying atmosphere. Unlike ducting and substandard refraction fading, which often provide some semblance of warning minutes and perhaps hours prior to causing a path outage, unpredictability, rapidity and severity are characteristic of fades due to even Fresnel zone reflected ray fading. To circumvent this type of fading on paper is the most time-consuming task related to the path engineering of over-water microwave systems.

2.3.4 Ducting (Surface, Elevated)

Atmospheric focusing is another possible cause of fading which may occur occasionally. This condition occurs when moisture content of the air at the ground surface is very high, but decreases very rapidly with increasing height. In the region where abnormally steep gradients in the refraction index exist, curvature of rays passing through the atmosphere is greater than that of the earth. As a result, energy originating in this region, and initially directed approximately parallel to the earth's surface, tends to be trapped and propagate around the earth's curved surface in a series of hops involving successive earth reflections. This situation is similar to the direct waves being transmitted in a waveguide or duct formed by the earth and a reflecting layer.

When duct propagation exists, line-of-sight and diffraction-zone concepts no longer apply, and energy will travel great distances around the earth's curvature with relatively low attenuation. This concept involves the angle with which the propagated rays impinges on the top of the duct. The angle within which energy trapping occurs is, typically, of the order of 1 degree or less. Rays outside of this angular range ultimately pass out of the duct to the space above.

Typically, duct heights range from tens to hundreds of feet. Ducting may either increase or decrease the received signal level depending upon the antenna's relative position with relation to the duct. Surface ducts occur most commonly over water. In fact, it is believed that such ducts are nearly always present over the ocean, particularly in the trade-wind belts. Surface ducts can also occur over land, but this happens less frequently. It is always a temporary rather than a continuing condition when it does occur.

Under certain meteorological conditions, an elevated duct may occur. In this case, the upper limit is formed by the upper limit of a superstandard or inversion layer, and the lower limit by a substandard layer. During these conditions the beam will tend to remain within the duct limits due to bending toward the duct center. Radio energy concentration within a duct will cause an increase in received signal when both the transmitting and receiving antennas are within the duct. However, this effect cannot be relied upon for satisfactory propagation because conditions producing the duct are subject to change. The terms trapping, super-refraction, or guided propagation also describe the propagation phenomena associated with ducts.

2.3.5 Precipitation

In addition to the fading types discussed, rainfall, snowfall, and fog produce very pronounced effects at higher microwave frequencies. At about 2 MHz and above, the presence of precipitation introduces an absorption in the atmosphere which depends on the amount of moisture and on the frequency.

Rain attenuation increases with frequency and with an increasing rate of rainfall. Rain attenuation on a particular radio communication circuit depends on frequency. Rain attenuation depends on the number of drops per unit volume in the radio path, the square of the drop diameter, and a complex factor representing the ratio of total energy absorbed and scattered by a single drop to the energy in the wavefront area equal to the projected raindrop area.

Rain attenuation curves as a function of rainfall rate for frequencies of 4 MHz, 6 MHz, and 11 MHz are shown in figure 2-27. Below 8 MHz, a linear relationship exists between attenuation and rainfall rate, and attenuation may be expressed in dB/km per millimeter per hour of rainfall. At higher frequencies the loss increases more rapidly with rainfall rate.

Attenuation due to dry snow is a small fraction of that of rain at the same precipitation rate. Attenuation caused by dry snow is very small even at the snowfall rate of five inches (127 mm) per hour. Wet snow attenuation may be comparable with that of rain. Excess attenuation caused by hail is about 1/100 of that caused by rain.

Rain attenuation on a particular path can be estimated from figure 2-27 if the path length and frequency are known, and if the average rainfall rate along the path is known. Monthly rainfall rates for many areas of the world are available, and, in some cases, the time variation of various rainfall rates are also known. However, little information has been published on rain storm spatial distribution. Although it may be possible to determine the percentage of time that a certain rainfall rate may be exceeded at a given weather recording station, it is often difficult to determine over what area this rainfall rate is applicable. High rainfall rates lasting a comparatively short time are likely to be restricted to an area of perhaps a few miles in diameter. Whereas, low rainfall rates may extend over a region measured in hundreds of miles.

In general, it can be said that a rainfall rate of 4 mm/hour is moderate and 15 mm/hour may be considered as heavy. In certain temperate climates a rainfall rate as high as 30 mm/hour may be expected for a few minutes about once per year. In the tropics, however, a rate of several hundred mm/hour may occur for short periods once per year, while values as high as 100 mm/hour may last for an hour. Summary data on the estimated atmospheric absorption for various conditions of rainfall is shown in figure 2-28. It should be noted that the attenuation over any individual band is almost independent of frequency and, therefore, no protection is offered by use of frequency diversity.

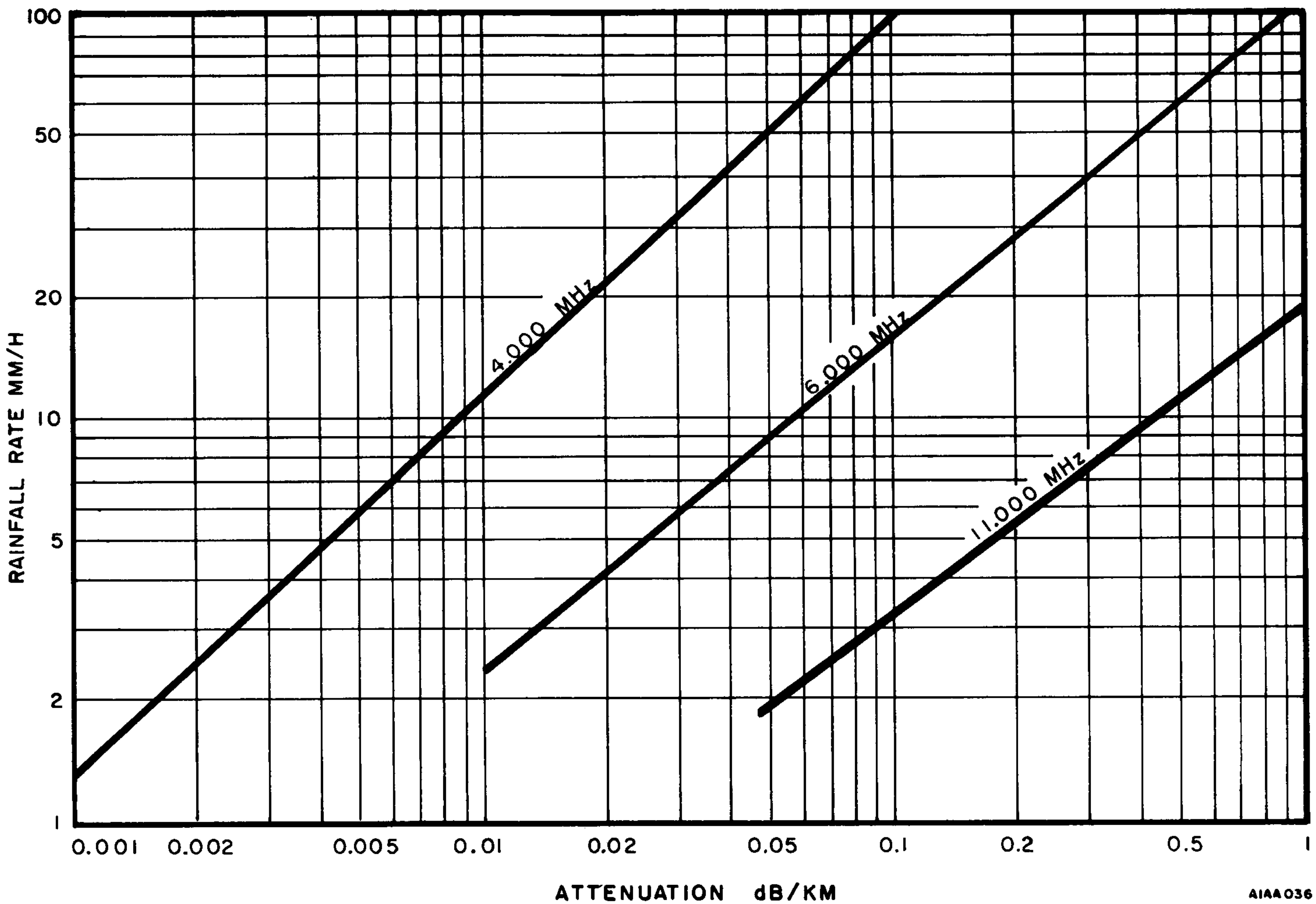


Figure 2-27. Rainfall Attenuation

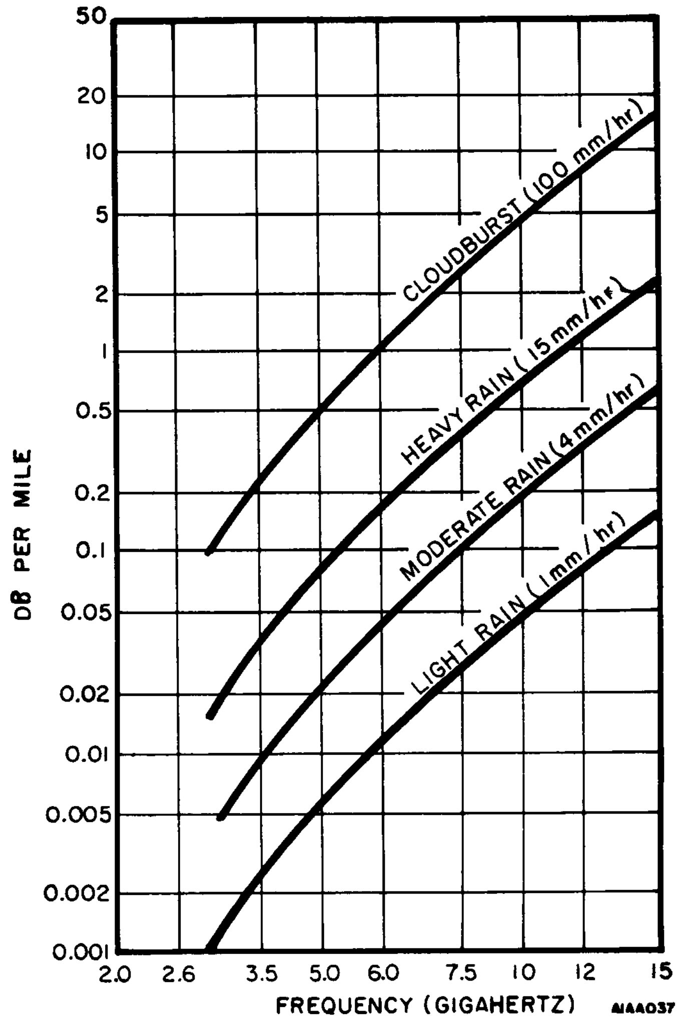


Figure 2-28. Estimated Atmospheric Absorption

Rain attenuation on a particular transmission path at a given time and frequency is proportional to the average rainfall along the path at that time. In order to estimate the rain attenuation exceeded, for example, 0.01% of the year, it is necessary to know what is the path rainfall rate that is only exceeded for about one hour per year. A path rainfall rate is defined as the space average of the point rates along the path. Figure 2-29 provides estimates of the instantaneous path average rainfall rate exceeded for 0.01, 0.1, 1.0 and 5 percent of the year as a function of the distance between terminals, normalized for a total annual rainfall of 100 centimeters. For other annual rainfalls, multiply the average rainfall rate of figure 2-29 by the ratio of 100 to the actual annual rainfall.

Data provided in figures 2-28 and 2-29 can be utilized for determining additional system margin in terminal performance.

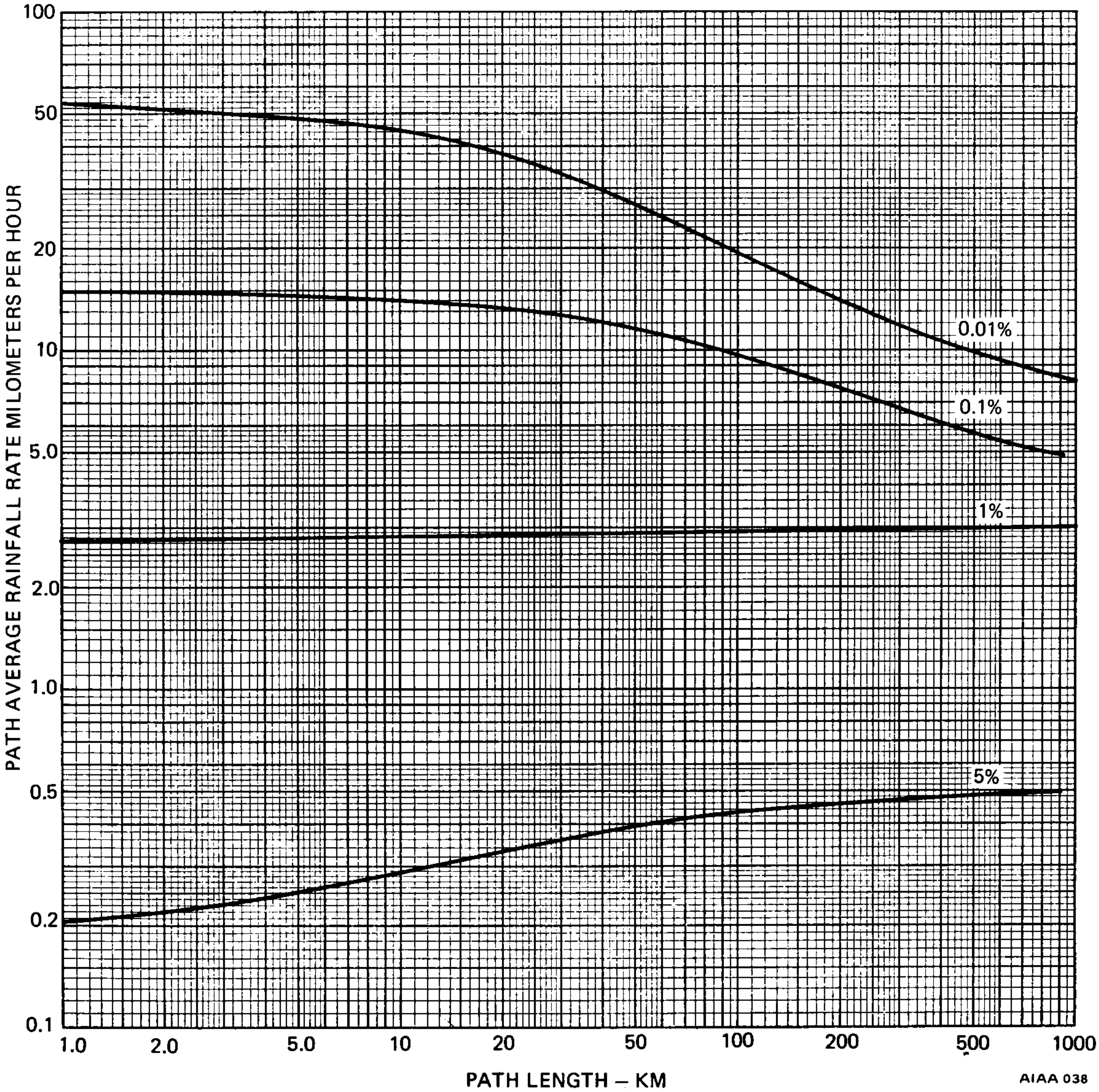


Figure 2-29. Percent of Year That Average Rainfall is Exceeded: Total Annual Rainfall = 100 cm

At frequencies as low as 388 MHz, attenuation due to absorption by condensed water in the air begins to be significant. The attenuation due to fog is about proportional to the visual range. Attenuation due to a dense fog exceeds that due to moderate rain. The drops are much larger in the rain, but the total water content of the dense fog greatly exceeds that of the rain. Little is yet known about the frequency of occurrence or area covered by fogs of various densities in different parts of the world.

In summary, it is evident that precipitation attenuation must be considered for any system at frequencies below 10 GHz in areas where heavy rain occurs frequently. In more temperate climates, rain attenuation effect is less pronounced and no additional fade margin beyond that which is normally provided for reliability against interference type fading would be required. In almost all cases, precipitation is accompanied by winds that minimize stratification and attenuation fading.

2.4 FADE MARGIN AND RANGE

The fade margin to the specified minimum acceptable noise performance point, i.e., 49 dBa0 (refer to table 1-1) is the difference between the received signal level corresponding to 49 dBa0, taken from the equipment noise characteristic and the median received signal also obtained from the noise characteristic. This is the significant fade margin for specification purposes as it is the only one referred to a clearly defined channel noise level.

In general, the number of fades per unit time increases as the path length between antennas and the transmitting frequency are increased. However, during severe fading conditions measurements have shown the duration of a fade of a given depth tends to decrease as path length and frequency are increased. Thus, the percent of time a system experiences a particular depth of fade tends to be independent of repeater spacing and frequency.

Most common in LOS microwave communication systems is for fades of 10 to 30 dB or more to occur for short periods.

Experience has shown that paths with adequate clearance exhibit fading that approaches the Rayleigh Distribution as a worst case. Military systems require a reliability of 99.99 percent, consequently, a fade margin, reference figure 2-30, of 38 dB should be provided.

2.5 TRANSMISSION PATH STUDY AND EVALUATION

It is necessary to have a clear line-of-sight between transmitting and receiving antennas to obtain satisfactory microwave transmission. The microwave transmission path survey allows the selection of suitable station sites and antenna heights. The survey consists of gathering and analyzing elevation data and other information on the possible sites and the intervening terrain.

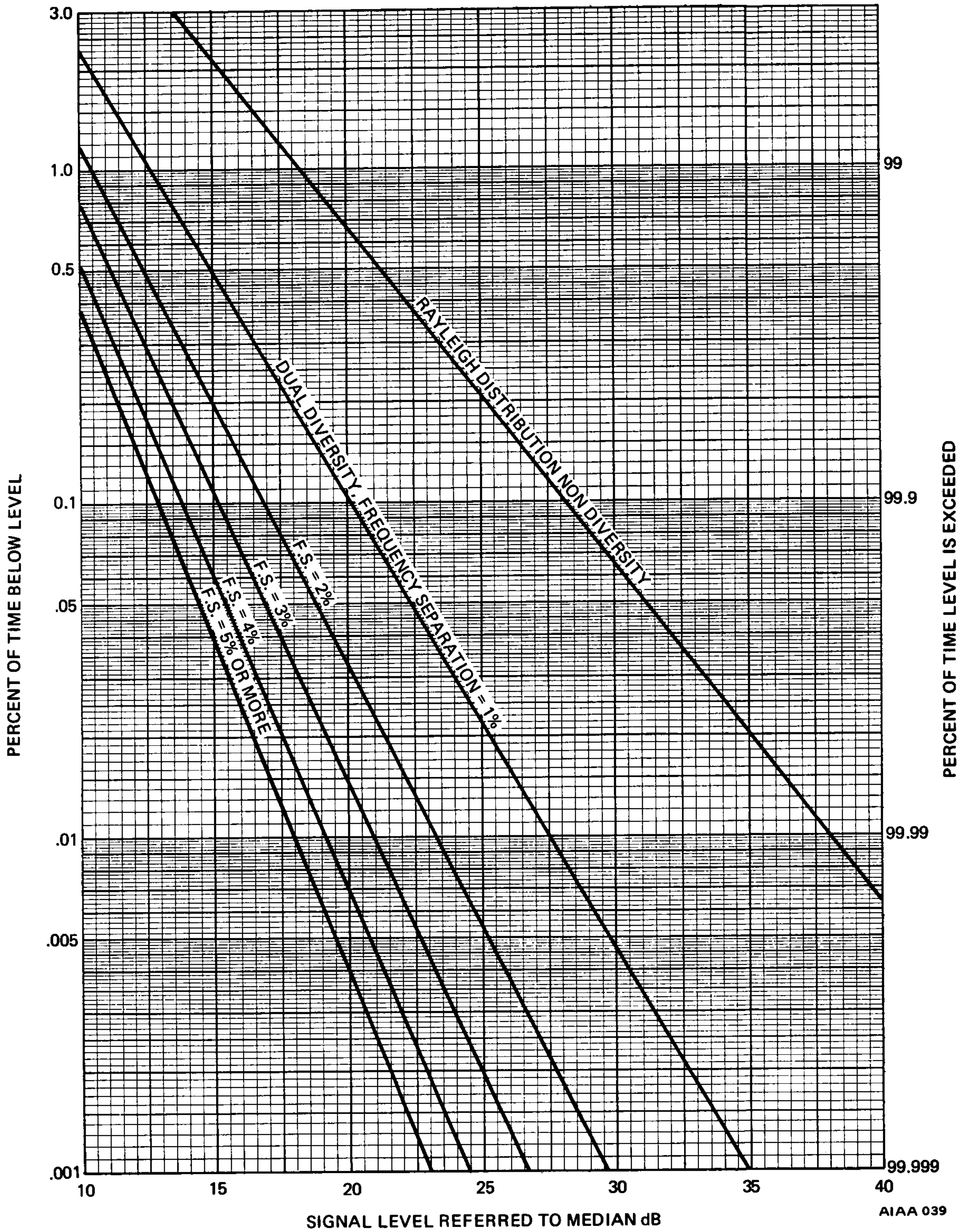


Figure 2-30. Approximate Interference Fading Distribution Versus Order of Diversity and Frequency Separation

A preliminary study is required by DCAC 330-175-1 and must be accomplished prior to actual site survey such that several alternate sites be selected. Maps shall be used with a scale of at least 1 in 250,000 (1 inch = approximately 4 miles) with contours to the nearest 20 meters (approximately 66 feet or 22 yards). Distance shall be determined to the nearest mile.

2.5.1 Feasibility Study

It is sufficient to know that for the purposes of preliminary route survey and site selection, path clearance greater than optical line-of-sight will be required on each radio path. All possible routes between two terminals should be studied, and all available elevation data about the intervening terrain for each radio path should be assembled. When selecting radio sites, availability of electrical power, existing road access, and other pertinent factors should be considered.

This task includes map studies, logistic and environmental considerations, and the requirements of the complete system which must be fulfilled by the station or stations under study. During the desk survey, station equipment is determined considering the approximate physical size. Support requirements of individual stations are outlined, and potential sites are chosen to be surveyed to establish their relative suitability. Based upon system requirements, characteristics of equipment to be installed, and other considerations, the scope of the field survey will be specified. This data is then compiled and supplied to the field survey team.

a. Topographic Map Study. Accurate topographic maps are available for many areas of the United States and some countries.

The Geological Survey is making a series of standard topographic maps for the United States, Alaska, Hawaii, and Puerto Rico. Under the general plan adopted, the unit of survey is a quadrangle bounded by parallels of latitude and meridians of longitude. Quadrangles covering 7-1/2 minutes of latitude and longitude are generally published at the scale of either 1:24,000 (1 inch = 2,000 feet) or 1:31,680 (1 inch = 1/2 mile). Quadrangles covering 15 minutes of latitude and longitude are published at the scale of 1:62,500 (1 inch = approximately 1 mile), and quadrangles covering 30 minutes of latitude and longitude are published at the scale of 1:125,000 (1 inch = approximately 2 miles). In some areas, maps of a new series covering one degree of latitude and two degrees of longitude have been published at the scale of 1:250,000 (1 inch = approximately 4 miles).

For each State and Puerto Rico, index circulars identify all maps distributed. They provide quadrangle location, survey date, name, and publisher (if not Geological Survey). Also listed are special maps and sheets with prices, map agents and federal distribution centers, addresses of map reference libraries, and detailed instructions for ordering topographic maps.

State index circulars and a folder describing topographic maps are furnished free on request. Private agents sell quadrangle maps at their own prices. Names and addresses of private agents are listed in the State index circulars. Special request should be made for copies of maps with woodland coverage.

Aeronautical charts are also useful as a source of information. In general, the Coast and Geodetic Survey publishes and distributes aeronautical charts of the United States, its Territories and Possessions. Charts of foreign areas are published by the USAF Aeronautical Chart and Information Center (ACIC) and are sold to civil users by the Coast and Geodetic Survey. A catalog of aeronautical charts is available from The Director, Coast and Geodetic Survey, Washington 25, D.C. This catalog also gives complete ordering information and a list of district offices from which charts may be obtained. These charts are also available at many airports. The contour lines on these maps are spaced farther apart and consequently do not give as much elevation information as the Geological Survey maps, but they do give much additional information about airports and hazards to air navigation that must be considered when planning a new tower installation.

Accurate topographic maps are available for many areas of Canada. The whole of Canada is covered by maps published on the scales 1:506,880 (8 miles to 1 inch) and 1:1,000,000 (15.783 miles to 1 inch), but coverage on other large scales is not complete. Many areas are covered by maps published on the scales of 1:50,000 (0.79 miles to 1 inch), 1:63,360 (1 mile to 1 inch), 1:126,720 (2 miles to 1 inch, and 1:253,440 (4 miles to 1 inch). The indices to these maps and the maps themselves may be purchased directly from the Department of Mines and Technical Surveys, Geographical Branch, Ottawa.

Additional maps may be obtained from the Department of Mines, Lands and Forests, or Department of Natural Resources of the Provincial Governments in the appropriate provincial capitals. Any available aerial photographs should also be obtainable at these places.

The aeronautical charts on scales 8 miles to 1 inch and 16 miles to 1 inch may also be a useful source of information. These are also obtainable from the Department of Mines and Technical Surveys, Ottawa.

In many areas, county highway maps are available. While these maps seldom give any detailed elevation information, they are useful in planning the exact route of a field survey and are helpful in plotting the exact field party location during the survey. These maps are usually current and contain detailed information on roads, buildings, bridges, and other structures. They are usually drawn to a scale of 1/2 mile to the inch and are quite accurate.

Additional information may be obtained from U.S. Forestry Service maps. Road maps and strip or profile maps available from railroad, oil, or power companies are another data source.

Any of the above maps are useful sources of information, and, for this reason, every available map of a given area should be assembled for study.

b. <u>Feasibility Study Equations and Calculations.</u> After all pertinent information related to the proposed sites has been assembled, preliminary map investigations are begun. Scope of the map study performed at this initial phase should be sufficiently broad to provide all necessary physical detail concerning the site and path areas. Preliminary information to be determined for each site includes:

- o Site elevation, location, and general topography characteristics at site areas
- o Path length and path azimuths, by means of great circle calculations, from coordinates determined from the mapping
- o Path profiles and reflection points
- o Accessibility

Feasibility study equations and calculation forms are contained in Appendix B.

2.5.2 Final Study

The final study effort consists of refining the feasibility study data. All preliminary site data must be further analyzed and evaluated for each site considered in a given area. Generally, no single site will satisfy all conditions for each of these factors. Site selection usually entails selecting the one site approximating optimum conditions for each path in the proposed system.

Microwave terminal and possible repeater sites should be plotted on each available map and a straight line should be drawn between adjacent sites. Mark off the distance between sites in miles and use a small paper scale to interpolate distances between marks. Elevation data should be taken from each map and plotted on a profile chart for additional study. The amount of field work required is determined by the amount of path clearance on the profile chart and the accuracy of the information plotted.

If the profile has been plotted from very accurate topographic maps (for example the 7.5 minute series Geological Survey maps), it will only be necessary to make a quick visual survey along the path to determine average tree height or other obstructions and gather information about the terminal sites. If the accuracy of the available maps is doubtful, or if the path has not been surveyed for trees and other possible obstruction, or the path clearance is marginal, it will be necessary to obtain additional information through more detailed field survey work.

Many of the quadrangle maps based on surveys made before 1970 have been found to contain errors in elevation and location of topographic details. In areas not covered by topographical maps, information on benchmarks can often be obtained at the County (or City) Surveyor's Office. In some states, this information is compiled in book form.

a. Path Profiles. After tentative antenna sites have been selected, and terrain relative elevation (and obstacles) between the sites has been determined, a profile chart can be prepared. In some cases, a complete profile will be necessary and in other cases only the end sites and certain hills or ridges need to be plotted.

The relative curvature of the earth and microwave beam is an important factor when plotting a profile chart. From previous sections, it has been shown that, although the earth's surface is curved, a beam of microwave energy tends to travel in a straight line. However, the beam is normally bent downward a slight amount by atmospheric refraction and the amount of bending varies with atmospheric conditions. The degree and direction of bending was defined by an equivalent earth radius factor, K, and fictitious earth curve. The curve was defined as being equivalent to the relative curvature of the microwave beam with respect to the curvature of the earth, that is, it was equal to the curvature of the actual earth minus the curvature of the actual beam of microwave energy. Therefore, any change in the amount of beam bending caused by atmospheric conditions was expressed as a change in K. This relative curvature could be shown graphically; either as a curved earth with radius Ka and a straight line microwave beam, or as a flat earth with a microwave beam having a curvature of Ka. The second method of plotting is preferred because it; permits investigation (and illustration) of the conditions for several values of K to be made on one chart, eliminates the need for special earth curvature graph paper, and facilitates the task of plotting the profile. It is convenient to plot the profiles on 11 x 17 or B size reproducible graph paper with 10 x 10 divisions to the inch.

b. Final Study Equations and Calculations. Pre-site survey data sheets should be completed prior to team departure to the field and should be developed during the system design phase. Coordinates of the site proposed for survey should be established from map studies and the degree of accuracy clearly stated. Actual values given should not imply greater accuracy than the method of attainment warrants.

Triangular point locations or other control points are imperative if an accurate baseline is to be established, and to verify the coordinates in the field.

Appendixes C and D contain the detail study equation and calculation forms, and the great circle calculation forms respectively.

c. Land Options. Assuming a proposed site is acceptable or an alternate site has been selected, proceedings should be initiated to acquire options to purchase or lease the sites. Otherwise, extensive planning would be wasted if the selected site is not obtainable at the time of equipment installation.

d. Field Survey. DCAC 330-175-1 requires that the selected sites be surveyed. A terrain profile must be constructed showing the distances and elevations including the path azimuth and be within an accuracy not less than the following:

- o Coordinates to third order accuracy
- o Elevations to the nearest 2 meters

The primary field survey objective is to obtain accurate data concerning microwave path clearance above all obstructions. The detailed survey not only verifies the results of the feasibility and final studies, but provides for accumulation of all pertinent field information that makes advanced planning possible. Specific objectives include conducting detailed observations, measurements, and inquiries at the selected station sites and along the microwave radio relay routes. Inquiries concerning weather data, air traffic, and commercial power information must be made. In addition, complete survey reports must be prepared for each site and each hop of the entire system.

(1) Site Survey. To ascertain that all necessary information is obtained when the site survey is made, a field survey notebook is usually issued to the survey group. It is necessary that the handbook be completed in every detail. The field survey notebook is contained in Appendix E.

Site location, dimensions, and contour must be shown, including the proposed shelter and tower location. The site must be large enough to permit the installation of guy anchors for a tower within site limits. Site terrain description is useful in shelter and tower planning. Proximity to airports and airways have a direct bearing on tower height and tower lighting plans. Site accessibility throughout the year must be known to determine the need for standby radio equipment and to determine fuel tank size for standby power equipment. The need for improving existing roads or for building new roads must also be indicated.

Weather information must be acquired to determine heating, cooling, and/or ventilating equipment needs. This information also governs tower design, and shows the need for antenna heaters or protective covers. An accurate altitude measurement should be made at the site. Photographs of the site and the terrain toward each adjacent station should be made for reference purposes. Power information should be collected from the local power company, and measurements made to determine the distance to be spanned to supply power to the site. Fuel types and availability for auxiliary power equipment should be determined.

Equipment shelter needs should be noted and if there is a shelter at the site, it should be described and photographed. The need for establishing telephone lines to the site should be ascertained. Specific site development and/or site improvement requirements should be identified. Another consideration is the need for protection of the site from vandalism.

Information gathered during the field survey of the terrain between stations is usually recorded on a hop report form. In this report, the hop should be defined and the compass bearing to at least one adjacent site should be given. A description of the terrain between sites is vital information, as is the naming of obstructions at critical points. Local agencies should be consulted to ascertain whether construction that might interfere with the microwave hop is contemplated. Any bodies of water along the path must be described, along with other pertinent details. Terrain features such as those just mentioned should be shown in a plan view sketch of the path, along with distance measurements. The altitude of critical points should be accurately measured. Finally, a profile of the hop should be prepared and included with the hop report. This profile is usually plotted on profile paper.

Practically all systems present unusual problems on one or more of the hops. The problem of surmounting or avoiding natural obstructions often requires special attention. Also troublesome is the overwater hop, particularly when the overwater distance is great. A choice must often be made between establishing a hop that is somewhat longer than average and adding another relay station (usually at much greater cost).

(2) Methods of Determining Path Clearances. Various methods of determining path clearances for the survey report are identified and discussed.

o Optical. Often the clearance of a path can be verified by visual sighting from one end to the other with the aid of a pair of field glasses or telescope. If a transit is used, the amount of clearance can be measured more accurately by measuring the depression angle to a high point in the path from both end sites and plotting this information on the profile chart. In other cases, it may be more convenient to carry the transit to the high point on the path and determine the clearance by forward and back sighting to the two end sites. Greater accuracy in measuring angles of depression (or any other angle) can be obtained using a theodolite.

When visibility is poor and restricts sighting directly with optical instruments, the line-of-sight path clearance can often be checked by flashing with a mirror. This technique requires a team at each end of the path with radio communication between the teams. One team should be equipped with a transit or other sighting instrument, and the other team should be equipped with a mirror about one foot square. The object is to reflect a beam of sunlight to the other end of the path so that the other team can take a sighting. This is done by nutating or panning the beam of light in the general direction until the other party indicates, by radio, that a sighting has been made. If a path is partially obstructed so that this technique cannot be used, it is sometimes possible to raise a balloon at one end until it can be sighted from the other end. The height of the balloon can be measured. For easier sighting, hang a piece of aluminum or other reflecting material from the balloon. Use a single cord allowing the reflecting material to swing freely. If sighting is done at night, a flare or any other type of light suspended from the balloon will be helpful. A helicopter can be used if a weighted measuring line is carried aloft and reeled out until it touches the ground when line-of-sight conditions are reached. The observer should be sure that the visual path is not through trees that are seasonably barren.

It should be noted that, like microwave radio beams, horizontal rays of light are refracted in the direction of the earth's curvature. The amount of bending for light is approximately one half as much as for a microwave radio beam. This factor should be considered when plotting optical sighting results. When optical line-of-sight conditions have been established and the data plotted on a profile chart, it is a simple procedure to add the required additional clearance and determine the height required for antennas.

o Altimeter. When information obtained from maps or optical sighting is not sufficient or accurate enough to determine adequate path clearance, the precision altimeter method of field survey should be used, if possible. This method can be used in all cases when critical elevations along a path are accessible by some means of ground transportation or by helicopter. The special equipment required consists of a portable precision surveying altimeter and a precision recording barometer (barograph) of the type available from American Paulin System, 1524 Flower Street, Los Angeles 15, California. Careful use of this equipment will yield elevation data with a probable error in the order of five feet. These instruments should not be confused with the ordinary aneroid altimeter and barograph which have insufficient accuracy for this purpose.

Measured elevations appear on topographic maps in the form of spot elevations at road intersections and other easily identified points, or as benchmarks. These benchmarks can often be located during a survey and are in the form of a concrete post or rock inlay containing a bronze disc about four inches in diameter inscribed with an identifying name. On many of the older benchmarks, the elevation has been stamped into the disc. Information about benchmarks in a given area can be obtained by writing to the Geological Survey Information Center, Washington 25, D. C. Where maps and benchmarks are not available, known elevations can often be found on railroad stations, post offices, water towers, or other structures. Elevation information from railroad stations should be used with caution since not all railroads use standard mean sea level as the basis for their surveys.

In general, the technique is to carry the altimeter to selected points along the microwave path and record indicated altitude, time, temperature, location, and other pertinent data at each point. The altimeter will measure only relative elevation. Therefore, to obtain elevations referred to mean sea level, it will be necessary to measure one or more points of known elevation in vicinity of the path.

Since this technique (called barometric leveling) is dependent on the measurement of air pressure, conditions other than changes in elevation that affect air density (and consequently pressure) introduce errors for which corrections must be applied. One such condition is the variation in barometric pressure caused by a change in local weather conditions, such as an approaching storm. It is impractical to attempt barometric leveling when thunderstorms are occuring or when whirlwinds are forming in the locality. Any measurements made under these conditions should not be relied upon. However, variations in pressure caused by the relatively slow movement of high and low pressure major storm centers and normal pressure changes due to the sun can be measured and automatically recorded with a portable barograph.

The portable barograph is self contained and driven by two clock type motors capable of running for 18 hours or more. This instrument should be set up as near as possible to the points to be measured and should not be disturbed while recording altimeter measurements including recheck of the starting point. The barograph recording identifies atmospheric pressure changes with respect to time that can be applied directly to altimeter measurements made at known times. Complete operating instructions are given in the manual that comes with the instrument.

When a barograph is not available, corrections can be obtained from a second altimeter located at a fixed reference point. This method requires a second operator to make recordings at regular intervals of 5 to 10 minutes of the indicated elevation at the fixed point. Changes in readings taken at the fixed point are the correction factors to be applied to the readings from the roving survey altimeter.

Another condition which affects air density is the ambient temperature. Air density varies inversely to absolute temperature. Therefore, when the air temperature differs from that for which the altimeter is calibrated (at a known elevation), a temperature correction must be applied. The error introduced is approximately 0.2 percent per degree Fahrenheit. Instructions for making this correction are contained in the instruction book included with the altimeter.

The number of altimeter measurements to be made on a given path is dictated by the nature of the terrain and the accuracy or availability of topographical maps. In the more difficult case, where suitable maps are not available, it is advisable to make more than one complete end-to-end and return path survey so that final profile accuracy will be improved. The separate surveys should start at opposite path ends and be conducted on different days. Any discrepancies found in the profile data should be rechecked before the field party leaves the area. In many cases, it will be necessary to check only a few points on a path and the field work will therefore be greatly simplified.

In those cases where there are good maps and many known elevations in the immediate path area, it may be unnecessary to use the barograph or to determine corrections for air density changes. A simplified technique is to make an altimeter measurement at a known elevation point near the unknown point, proceed quickly to the unknown point to make another measurement, and quickly return to the original known point to make a third measurement. The time should be recorded with the altimeter data at each point. If two altimeter measurements at the known elevation coincide, no measurement corrections at the unknown point is necessary. If the two measurements for the known point differ with very little accuracy loss, it can be assumed the change in atmospheric pressure was linear during the time of the measurements (provided the total time was only a few minutes and weather conditions fairly stable). The change (in feet) in altimeter calibration versus time can be obtained directly by dividing the difference between the two measurements at the known elevation by the time elapsed. This factor multiplied by the difference in time between the first measurement and the measurement at the unknown elevation will give the correction to be applied to the measurement made at the unknown point.

o Airborne. In areas where map coverage does not exist and the terrain prohibits travel or access, it may be convenient to search for possible sites by airplane. If a helicopter is available, it may be possible to occupy the sites and prove adequate path clearance by visual methods and by taking photographs.

When it is not possible to sight visually along the entire length of the path, it may be necessary to run path profiles by radar surveying from the air. This technique has been developed to a satisfactory degree. However, it is an expensive method due to the huge investment in airborne radar and other equipment. There are organizations equipped to perform radar surveys on a contractual basis.

Another technique for airborne surveys is the one often used for making topographic maps. This requires making a complete set of accurate stereoscopic photographs of the area from a photo-reconnaissance aircraft and interpreting these photos with special optical instruments to produce a topographic map or profile. This is the most accurate method mentioned, but is prohibitively expensive for microwave surveys.

e. Final Determination. DCAC 330-175-1 requires that final path parameters (path profile) be determined with an accuracy not less than the following:

- All distances to 0.1 mile

- All azimuths to 10 seconds

- Maps utilized shall have a scale of 1 in 25,000 with contours at 5 meter intervals. In areas where maps to this scale are not available, a scale of up to 1 in 100,000 with contours at not more than 30 meter intervals may be used.

f. Field Tests (Propagation). DCAC 330-175-1 requires that wherever requirement for a subsystem or a hop is such that time, funds, manpower and test equipment are available, a path loss measurement should be conducted to determine transmission losses, variability and propagation anomalies. To accomplish these tests, it is necessary to establish temporary microwave stations using portable equipment. Continuous or periodic signal measurements can be made to prove the feasibility of the tentative path. This type of test can provide valuable information for long hops, obstructed hops, or multipath hops (such as overwater hops which present a reflected wave problem). The practicability of employing diversity reception is often investigated in this manner.

CHAPTER 3

LOS SYSTEM NOISE CONSIDERATIONS

The performance of a multichannel microwave communication system should be evaluated by how well it meets the requirements of the user. Fundamentally, the purpose of a communications system is to transfer some form of intelligence, or "signal," from one point to another. An ideal system would deliver at the receiving end a signal identical in every detail to the signal applied at the transmitting end, with nothing altered and nothing added.

In a real communications system, this ideal performance is never completely achieved. In such a system every characteristic of the signal is altered to some degree, and there is always something added along the way. Thus, the received signal is always a somewhat less than faithful reproduction of the signal applied at the transmitting end, plus some other elements which are mostly unrelated to the original signal and which may be present even when the signal is completely absent.

Communications system performance is measured by how closely the received signal resembles the transmitted signal and how free it is of these other elements. The definition and measurement of the performance thus falls into two natural categories. In the first category would be considered technical characteristics which define accuracy or fidelity of the reproduced signal: amplitude-frequency response, level stability, phase response, delay distortion, etc. These characteristics are, more or less, under the control of the equipment designer and may be held to almost any desired value.

In the second category would be considered all the extraneous elements appearing at the channel output, not a part of the input signal. These elements are usually lumped together in a single category called "noise." The following material treats noise in terms of its appearance in the derived voice channels. Noise in a voice channel has been selected as a criterion even though most systems carry telegraph and data as well as voice.

The basic voice channel is familiar to all, is reasonably well standardized, and there is a large body of experience to draw on. Furthermore, the majority of equipments used for modern telegraph and data service are designed to operate over such a carrier-derived voice channel, or some fraction or multiple of it. It is not difficult to evaluate the effect on a data system of a particular level of noise in the 4 kHz band.

3.1 UNITS AND OBJECTIVES

Measurement of noise is an effort to characterize a complex signal. To specify the amplitudes of noise, it is convenient to define it at some reference point in the system.

Amplitudes at any other physical location can be related to this reference point if the loss or gain between them is known. Up to now, channel noise has been considered in terms of signal-to-noise (S/N) ratio, expressed in dB, with the "signal" understood to be a 1 kHz test tone with 0 dBm power at a 0 transmission level point, with noise being the unweighted noise in a 3 kHz bandwidth. The "signal" in S/N ratio really means "standard signal" taken as the test tone level.

Conceptually, S/N ratio is the significant end result and it is considerably more convenient for purposes of calculation to have the channel noise expressed in an absolute form. One such way is in terms of a unit identified as dBa, F1A-weighted. This reference level, or 0 dBa, is equivalent to a 1 kHz tone with a power of -85 dBm or of a 3 Hz white noise band with a power of -82 dBm.

A second way of expressing noise, developed by CCITT and CCIR, is in terms of picowatts psophometrically weighted (pwp). The reference level, 1 pwp, is the equivalent of an 800 Hz tone with a power of -90 dBm, a 1 kHz tone with a power of -91 dBm, or a 3 kHz band of white noise with a power of about -88 dBm. The shapes of the F1A weighting curve and the psophometric curve are essentially identical (see figure 3-1).

Using the following equation, dBa can be converted to picowatts, or vice versa:

$$\text{dBa} = -6 + 10 \log_{10} \text{pwp} \tag{3-1}$$

Since dBa and picowatt are both absolute units, it is necessary to relate them to some specific transmission level before they have real significance. One common way to do this is to add a zero to the unit to indicate that it is referred to as a zero transmission level point. The resulting units, written as dBa0 and pwp0, can be converted to S/N ratios identified by the formulas:

$$S/N = 82 - \text{dBa0} \tag{3-2}$$

$$S/N = 88 - 10 \log_{10} \text{pwp0} \tag{3-3}$$

These relations are correct only if the noise is essentially white noise. Noise produced in multichannel microwave systems is almost entirely of this type, so the correlations are valid for microwave noise. Table 3-1 correlates S/N ratio, dBa, and picowatts for noise which is essentially random (i.e., "white" noise, since only in this case is a summation on a power addition basis valid). Figures A-11 and A-12 in Appendix A gives dBa versus picowatts in graphical form.

The dBa and the psophometric picowatt are equally valid absolute noise units but differ somewhat in application, because one is logarithmic and the other linear. The linear unit, picowatt, has the advantage that addition of noise powers becomes a matter of simple arithmetical addition of the picowatts. Addition of powers expressed in logarithmic units, such as the dBa, is not quite so simple but can be done relatively easily by the use of figures A-11 and A-12 in Appendix A.

Table 3-1. Comparison of Noise Performance Units

S/N	dBa0	pw_p0	S/N	dBa0	pw_p0	S/N	dBa0	pw_p0
28	54	1,000,000	48	34	10,000	68	14	100.0
29	53	794,000	49	33	7,940	69	13	79.4
30	52	631,000	50	32	6,310	70	12	63.1
31	51	502,000	51	31	5,020	71	11	50.2
32	50	398,000	52	30	3,980	72	10	39.8
33	49	316,000	53	29	3,160	73	9	31.6
34	48	252,000	54	28	2,520	74	8	25.2
35	47	200,000	55	27	2,000	75	7	20.0
36	46	159,000	56	26	1,590	76	6	15.9
37	45	126,000	57	25	1,260	77	5	12.6
38	44	100,000	58	24	1,000	78	4	10.0
39	43	79,400	59	23	794	79	3	7.9
40	42	63,100	60	22	631	80	2	6.3
41	41	50,200	61	21	502	81	1	5.0
42	40	39,800	62	20	398	82	0	4.0
43	39	31,600	63	19	316	83	-1	3.0
44	38	25,200	64	18	252	84	-2	2.5
45	37	20,000	65	17	200	85	-3	2.0
46	36	15,900	66	16	159	86	-4	1.6
47	35	12,600	67	15	126	87	-5	1.3
48	34	10,000	68	14	100	88	-6	1.0

NOTE: Flat S/N ratio in a 3-kHz band; dBa0, F1A weighted; and psophometrically weighted picowatts.

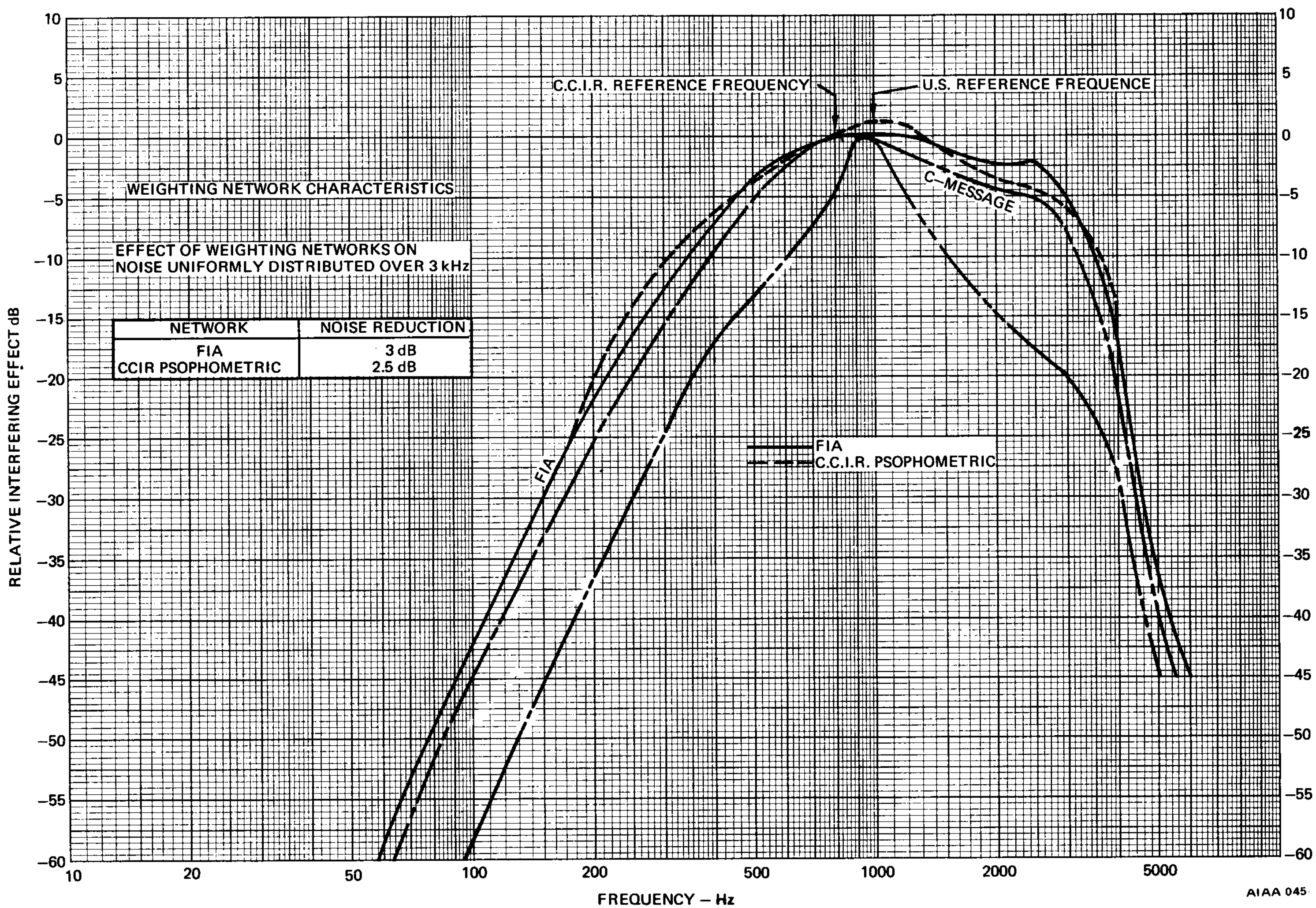


Figure 3-1. Weighting Network Characteristics

When only system-generated noise is considered with its measurement at the radio baseband output point, there is little difference whether weighting is used. For this noise, the effect of weighting is to reduce the noise by a fixed, known amount (3 dB for F1A weighting and about 2 dB for psophometric weighting). Using weighting changes the numerical value of a noise reading by that fixed amount. It is equivalent to changing the noise unit itself. A noise level giving a flat S/N ratio of 50 dB will give an F1A weighted ratio of 53 dB, but the noise quantity is the same.

When noise in the complete system and its measurement at the voice channel output is considered with all the multiplex equipment and drop equipment connected and functioning, weighting is far more significant. In this case there may be substantial amounts of noise which are not random. Much of this noise may be at very low or very high frequencies where the affect on measurements of noise power is far out of proportion to the affect on actual transmission quality. For this reason, telephone practice is to use weighted noise units.

To evaluate the affect of audio frequency noise on typical equipments when noise measurements are being made, weighting networks are used. In the case of FM, the weighting network is a 75-microsecond de-emphasize network. This is a simple rc network which starts to attenuate at about 400 Hz and has an attenuation of 17 dB at 15 kHz. For purposes of this discussion, the F1A weighting network and the CCITT weighting network apply. These networks are intended to simulate telephone set response. The networks are used only for noise measurements and are removed from the circuit when connections are made to the telephone network. The response of these networks are shown in figure 3-1. The weighting curve includes telephone frequency characteristics as well as the hearing of an average person. The remainder of the communication system is assumed to provide transmission which is essentially flat across the band of a voice channel. Significance of the weighting curves of figure 3-1 is that, for example, a 200 Hz tone of a given power is 20 dB less disturbing than a 1 kHz tone of the same power, Note how noise at the band edges affects unweighted measurements out of proportion to its actual interfering affect.

Even though weighting is based strictly on voice transmission, it is quite possible that for data transmission systems designed to operate over a voice channel, a weighted measurement may be as good a criterion as an unweighted one or perhaps even better. Because of phase effects near the band edges, such data circuits are usually located in the interior part of the band. This is an area where the weighting characteristic introduces the least change.

3.2 NOISE SOURCES

Noise which appears in a microwave system voice channel comes from a number of different sources, some of which vary in a rather complex manner. It is useful to consider three general types of noise classified in accordance with how they vary.

3.2.1 Thermal Noise

This is noise generated by the receiver "input termination" plus noise generated in the receiver "front end." In a microwave receiver, "input termination" is an antenna coupled to the atmosphere and "front end" noise is essentially that noise internal to the first active devices of the receiver. In an FM system, thermal noise varies in an inverse relation to the RF level at the receiver input and, therefore, is affected by fading. It is not affected by system loading; however, it sets the minimum level to which signals can be allowed to fall.

3.2.2 Intrinsic or Idle Noise

This noise, also thermal in nature, is generated by random current variations in the radio equipment and is present whether or not a modulating signal is being applied. Typical intrinsic noise sources would be thermal noise generated within low level amplifiers and mixer rectifiers, shot noise in tubes, noises in semiconductor multipliers, traveling wave tube (TWT) noise, and FM residual noise.

Figure 3-2 illustrates an oscillograph recording connected to a wideband intrinsic (thermal) noise source. Three general observations can be made about such a waveform.

a. Waveform Repetition. The waveform never repeats itself exactly during any period, therefore, it is nonperiodic.

b. Waveform Time Interval. Measuring the time interval between the various zero crossings and converting this data into frequency indicates that frequency components in the wave occur equally or are of equal magnitude across the noise source bandwidth. This result is in accordance with kinetic theory of heat predictions (the thermal noise source power spectrum is flat with frequency).

c. Waveform Amplitude. Peaks of various heights occur and if measurements are taken over a long enough period, all magnitudes can be recorded. This indicates that the thermal noise signal has no unique peak. If distribution of the various signal magnitudes were computed, results would indicate a normal or gaussian distribution is approached. This conclusion is not unreasonable when considering the physical mechanism of the noise generation process. The noise signal appearing across conductor terminals is due to a sum of a large number of current pulses caused by random flights of electrons between collisions with the conductor molecules. The statistical central limit theorum states that the distribution approached by the sum of a large number of individual independent random components is a normal or gaussian distribution. Hence, magnitudes occurring in the noise signal have such a distribution. Because of this, thermal noise is also referred to as gaussian noise. The probability density function of a normal distribution is shown in figure 3-3 and its equation is:

$$\text{prob}\,(e_n) = \frac{1}{\sigma_n\sqrt{2\pi}}\ \exp\left(\frac{-e_n^2}{2\sigma_n^2}\right) \qquad (3\text{-}4)$$

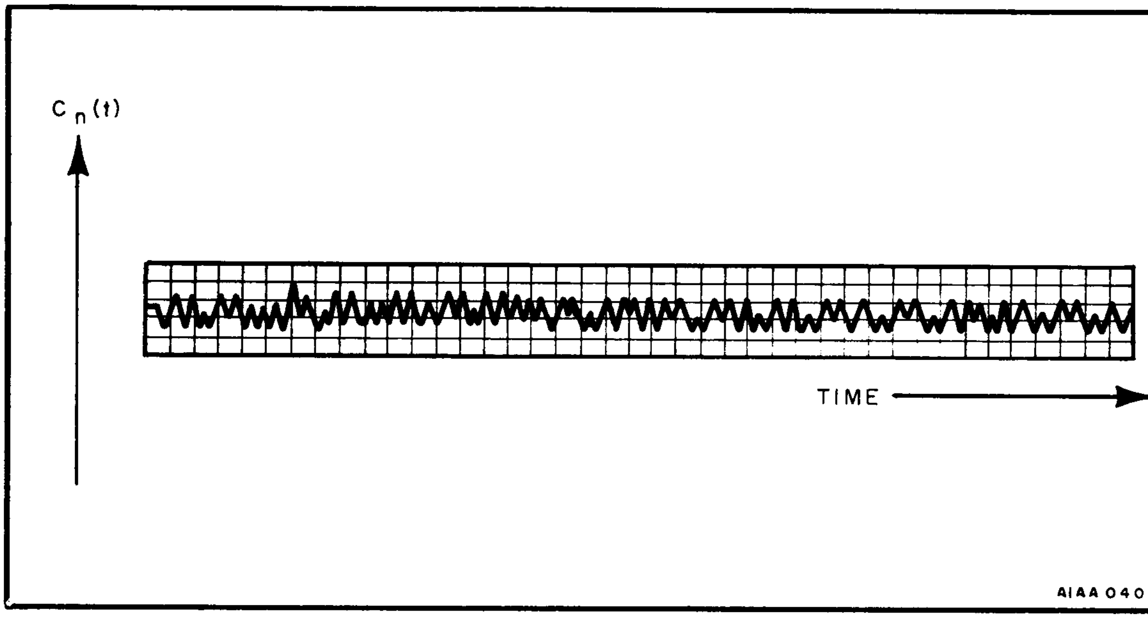


Figure 3-2. Oscillograph Recording of Wideband Thermal Noise

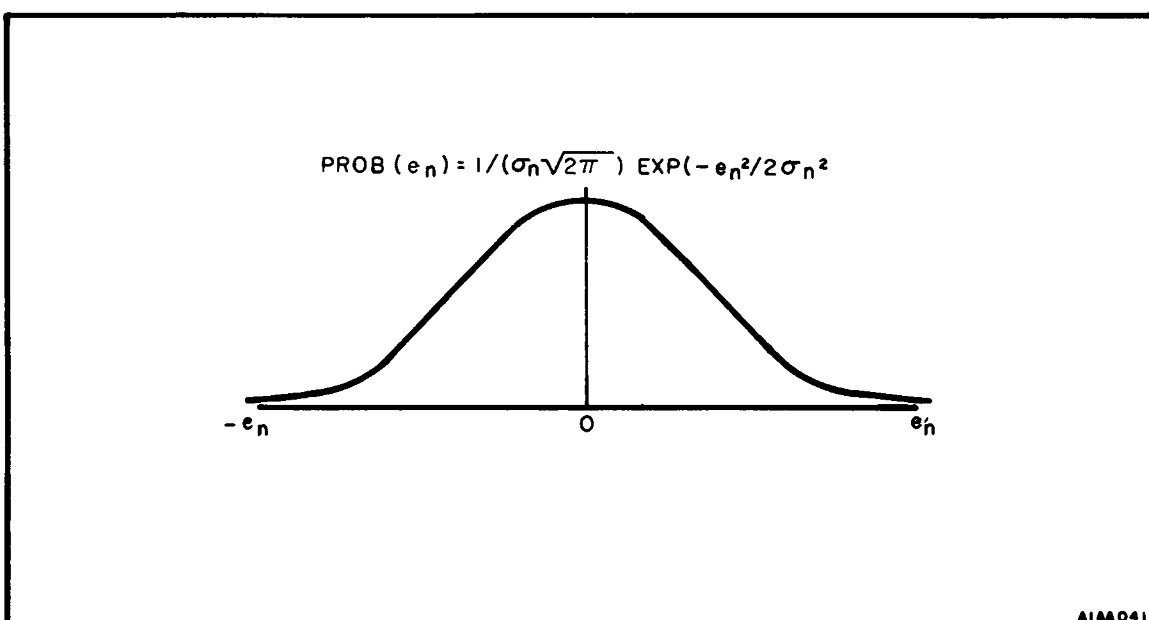


Figure 3-3. Gaussian Probability Density Function Distribution

The term σ_n is not only the standard deviation of the probability distribution described, but also the RMS magnitude of thermal noise signal having that distribution of signal magnitudes.

The amount of intrinsic noise generated is a characteristic of radio equipment that can be measured between terminals under conditions of no modulating signal and adequate received signal strength. It is not affected by the RF input level or system loading.

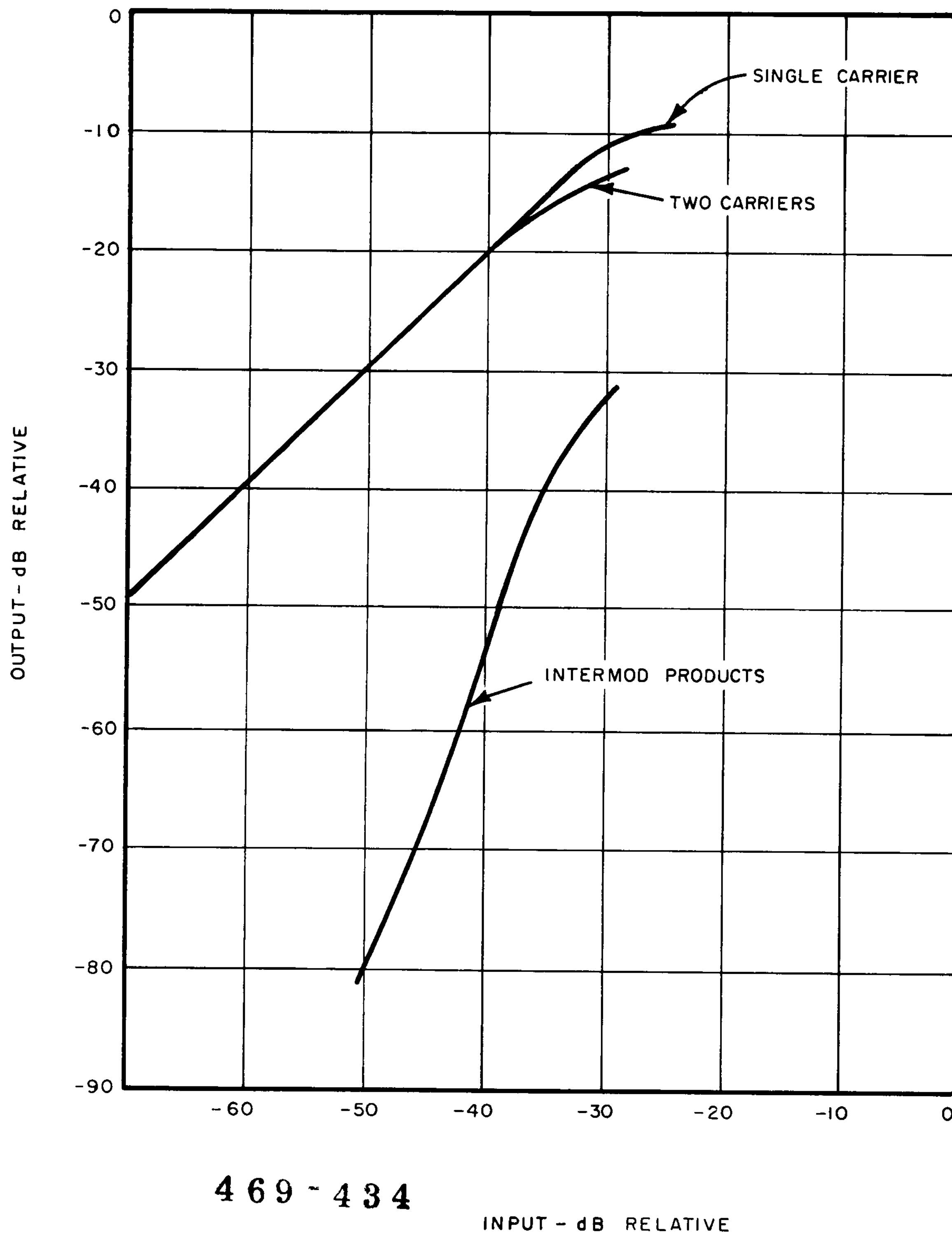
3.2.3 Intermodulation Noise

This noise is actually spurious signals created by intermodulation between the various frequency components of the total composite signal. Noise due to intermodulation products are generated by any nonlinearity in the receiver, transmitter terminal equipment, or transmission media. This nonlinearity will generate spurious frequencies in the receiver passband. The RF input stage, modulator, and detector in wideband FM systems always have some nonlinearity and tend to produce intermodulation products. If two or more RF carriers are put through a nonlinear element, typical resultant intermodulation products are shown in figure 3-4. Intermodulation product levels are determined by RF carrier levels and the degree of unit nonlinearity processing the signal. Since a multichannel system baseband spectrum is extraordinarily complex, the number of intermodulation products produced in such a system approaches infinity. Statistically this noise becomes very similar to intrinsic and thermal noise. Intermodulation noise increases as system loading increases, but it is not directly affected by the RF input level. Figure 3-5 illustrates the balancing of idle and intermodulation noise.

3.3 DCS REFERENCE CIRCUIT NOISE PARAMETERS

DCS Standards define performance requirements for the total communications system by transfer function parameters for the overall reference circuit. These overall parameters are distributed between two major subdivisions of the total system, i.e., transmission medium, and multiplex equipment. Consequently, when the transmission medium and multiplex equipment portions of the system are designed separately to measure up to performance characterisitcs defined by the respective parameters, the DCS Standards for the total system will be met.

The DCS Standards categorize noise sources in accordance with the two major subdivisions of the total system, identified in Table 3-2, and includes noise from all sources. However, noise from different sources is treated differently depending on its nature and magnitude. Transmitter and receiver noise is controlled by providing adequate signal levels. Radio and electrical interference must be discriminated against by equipment design which includes selective filtering, shielding, and directivity (in the case of antennas). Noise from the propagation path-atmospheric noise and path intermodulation noise (due to multipath signals) is relatively insignificant in line-of-sight radio propagation.



469-434

Figure 3-4. Typical Intermodulation Distortion Products - Third Order

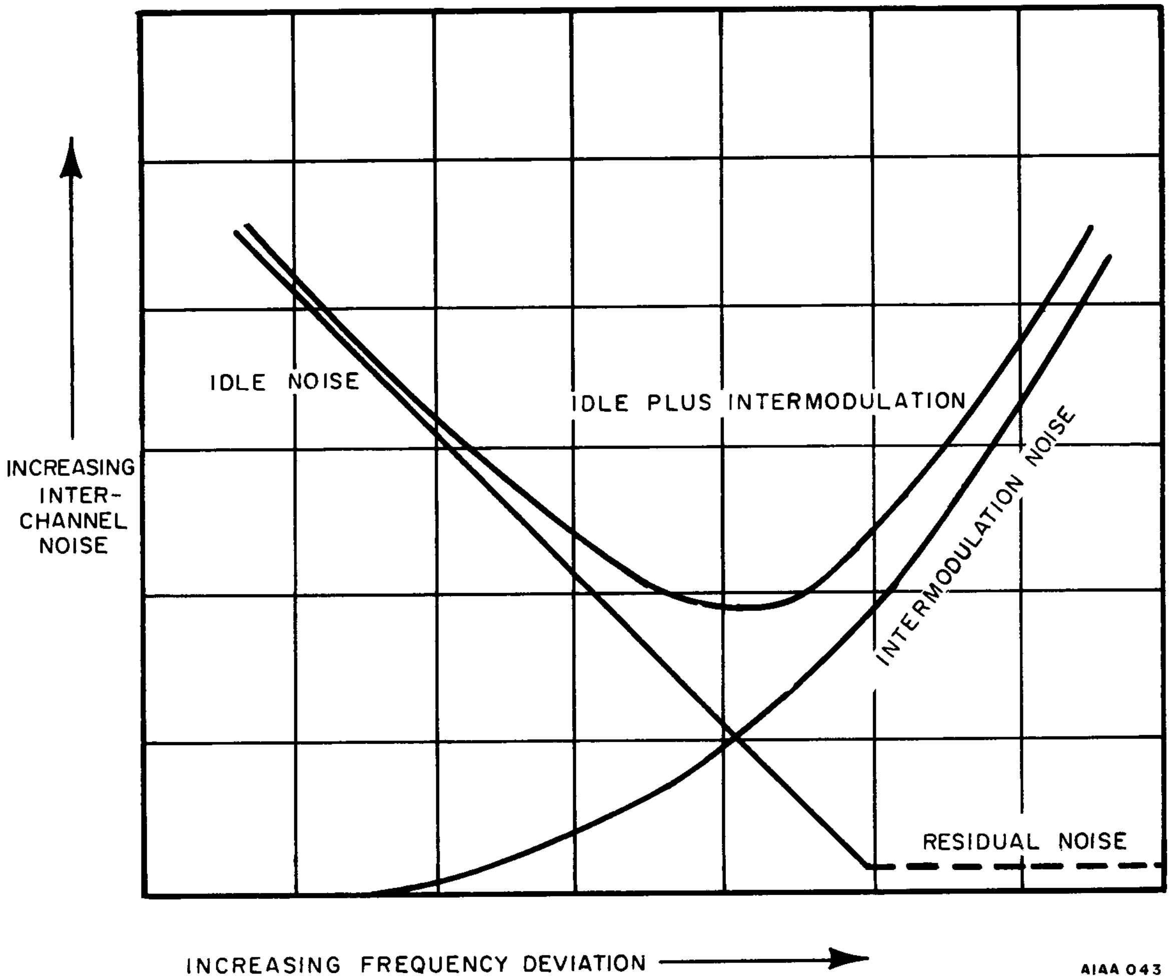


Figure 3-5. Per Channel Noise Versus Frequency Deviation

Table 3-2. Division of Noise Sources Used in Standards

CATEGORY	SOURCES
Transmission medium	Transmitters, receivers, propagation path, radio and electrical interference, feeder echo
Multiplex	Multiplex equipment

Basic noise allocation dictated by the DCS Standards is identified in Table 3-3. In addition to the basic allocations, the DCS Standards provide for prorating noise allowances on the basis of:

- o Transmission medium distance
- o Multiplexing stages for the multiplex equipment.

Table 3-3. Noise Allocations for DCS Reference Circuit

NOISE CATEGORY	MEDIAN NOISE ALLOCATION PER VOICE CHANNEL
Transmission medium	20,000 pwp* per 6,000 nautical miles
Multiplex equipment	5,000 pwp* distributed among all multiplex equipment
Total Noise	25,000 pwp*
*Picowatts psophometrically weighted (pwp) measured at, or referred to, a zero transmission level point.	

3.3.1 Transmission Medium Noise

Transmission medium noise is allocated on the basis of circuit length. Thus, 20,000 pwp of noise power is allowed for the transmission medium of the overall reference circuit length of 6,000 nautical miles. Allowance for circuits of lesser length is obtained from the relationship:

$$\text{Noise (pwp)} = \frac{L\ (NM)}{6,000} \times 20,000 = 3\ 1/3 \times L(NM) \qquad (3\text{-}5)$$

where L is the circuit length in nautical miles.

Converting to kilometers, the relationship becomes:

$$\text{Noise (pwp)} = 1.8 \times L' \quad \text{(km)} \tag{3-6}$$

where L' is the circuit length in kilometers.

The DCS Standards suggest a subdivision of transmission medium noise allowance into two equal parts for thermal and equipment intermodulation components, with provision that such subdivision be applied unless other tradeoffs are indicated. The intent is to attain the least total noise. Therefore, any proportionality between thermal and equipment intermodulation components which produces a smaller total noise than a balance of the two should be considered a suitable tradeoff.

3.3.2 Multiplex Equipment Noise

Multiplex equipment noise specifications in the DCS Standards are treated as follows:

- o Total transfer function noise allocation for the 6,000 MM DCS Microwave (LOS) Reference Circuit.

- o Total noise allocation for one Link of the Reference Circuit (Reference Link).

- o Maximum noise allowance, at a specified loading per multiplexed channel, for each stage of Frequency Division Multiplex (FDM) equipment.

In the design of a LOS system, the transfer function noise specification is the fundamental criterion as it gives the total noise allowance for the Reference Circuit. Based on the overall circuit allowance, the noise allocation per Reference Link and per mile is determined. The DCS Standards noise performance per FDM multiplexed stage is for a channel loading level that exceeds the operating channel loading capabilities of real systems. Consequently, in most cases, the DCS Standards FDM equipment noise levels are not directly applicable to FDM system design. Additional information on the foregoing major subdivision of the total system is presented in the system design considerations.

3.4 NOISE PERFORMANCE

Each of the three kinds of noise identified earlier affects system operation in a different way, as shown in figure 3-6. This graph shows noise performance for one hop of a high quality microwave system. Note: This is a plot of typical worst per-channel noise as a function of receiver input level and system loading. Noise is shown at the left as unweighted S/N ratio in a 3 kHz voice channel, and at the right in dBa, F1A weighted, at a 0 transmission level point. The curve is typical for the top channel (in which noise is usually the greatest) of a 300 channel system. The effect of the receiver front-end noise on the channel S/N ratio is shown by the long line starting at the lower left-hand corner and running to the upper right-hand corner. It is evident that this noise is the controlling factor when the RF input is lower than about -40 dBm. Threshold noise is almost entirely of this type.

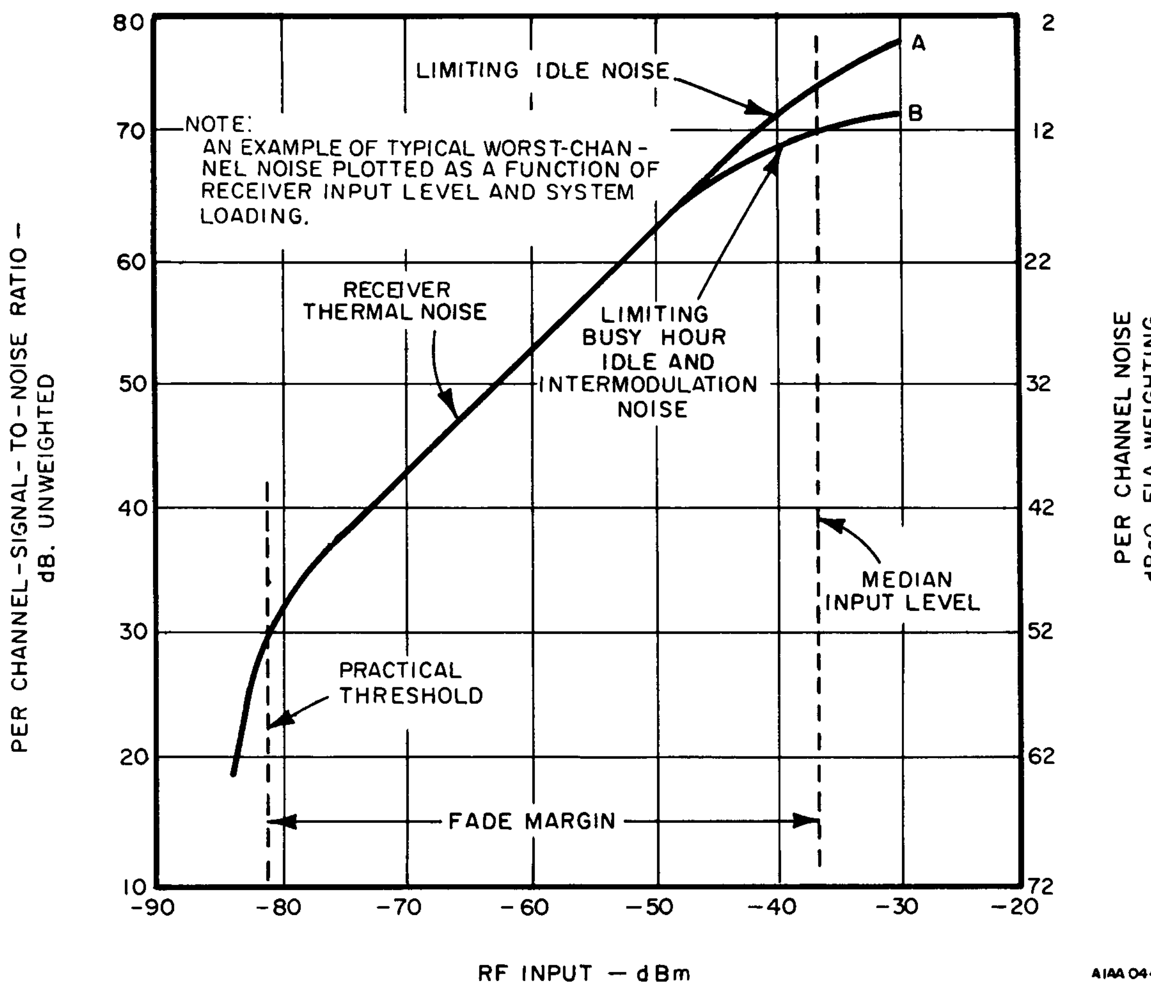


Figure 3-6. Noise Performance of One Hop of a High-Quality Microwave System

At high receiver input levels, idle noise becomes the controlling factor and limits the available S/N ratio as shown by the bend in the upper line at the upper right-hand corner. This noise sets an upper limit to the channel S/N ratio when the system is in an idle or unloaded condition.

The effect of intermodulation noise is shown by the lower branch line. This noise sets the limit to the channel S/N ratio when the system is loaded to simulate busy hour conditions.

A noise characteristic curve such as figure 3-6 assists understanding of microwave noise performance, since it includes, essentially, all of the noise effects shown for all operating conditions. Three significant bits of information derived from the curve are: noise level at the practical threshold point, noise level at the normal RF receiver input level point under busy hour loading conditions, and fade margin.

A microwave system meeting the requirements identified in figure 3-6 is usually engineered to have a median RF input level somewhere between -30 and -40 dBm. This level permits having a very high S/N ratio during periods of no fading or very little fading, a condition which exists for all but a very small percentage of the time. It also has a fade margin which permits the RF input level to drop by at least 40 dBm (about one ten-thousandth of normal) before the S/N ratio becomes objectionable.

With a typical median input level of about -37 dBm, as shown in figure 3-6, system S/N during non-fading periods will be very high. It approaches Curve A during periods of light loading and drops a few dB towards Curve B during heavy loading periods of the busy hour. Only after the input signal has faded several dB does the S/N ratio begin to drop significantly as receiver thermal noise begins to exceed the other noises. Over the straight line portion of the curve, the S/N ratio varies with the receiver input level. It is determined only by the receiver noise figure and the deviation ratio used for the particular channel. Over this curve portion, the unweighted S/N ratio in dB in the derived 3 kHz voice channel can be calculated from equation 3-7.

$$S/N\ (dB) = C + 136 - NF + 20 \log D \qquad (3\text{-}7)$$

where:

C = receiver input level in dBm,

NF = receiver noise figure in dB,

D = deviation ratio, or peak deviation for the channel divided by the carrier frequency of the channel.

Signal-to-thermal noise ratio can be improved in three ways: increasing input level with higher transmitting power or bigger antennas, lowering receiver noise figure, or increasing the deviation ratio. In practice, system and equipment designers raise effective power and lower receiver noise as far as economically practicable. The effect of increasing the deviation ratio is not so simple. It improves the S/N ratio for thermal and idle noise, but degrades for intermodulation noise. For this reason, the equipment designer must choose a deviation ratio which provides an optimum balance between the different types of noise.

When the receiver input signal becomes very high, a point is reached where the signal-to-thermal-noise ratio is no longer directly dependent on the receiver input level. This effect is indicated by the bend in the upper right branch of the curve. Here, thermal noise produced in transmitter circuits and those portions of the receiver circuits not affected by automatic gain control (AGC) provides an upper S/N limit for non-loaded conditions. This portion of the curve, though of some interest, is not really operationally significant since the S/N ratio makes little difference if the system is not being used.

In this area of high receiver input level, the lower branch is the significant operational curve. This gives the signal-to-total-noise ratio since it includes thermal noise, idle noise, and intermodulation noise under loaded conditions.

3.5 MULTIPLEX NOISE

The noise performance curve of figure 3-6 applies only to one hop of a microwave system, and does not include the noise contribution of the associated multiplex equipment. The multiplex noise must be added to the microwave noise (or transmission medium noise) to get the system S/N ratio. Multiplex noise under loaded conditions is approximately 20 to 23 dBa0 for a pair of carrier terminals (refer to Table 1-1). This noise is considerably higher than the noise shown for the single microwave hop. For a one or two hop system, overall noise is mainly that of multiplex. For a long microwave system in which the multiplex noise appears only once and the per-hop microwave noise many times, the latter becomes the controlling factor.

Refer to DCS Reference Link, 1,000 NM (figure 1-5) for the following assumed multiplex noise assessment.

Multiplex equipment for translating from a given frequency to a higher one and back is assumed to have total noise as follows (one terminal):

- o Channel translation, 345 pwp or 19.4 dBa0
- o Group modem equipment, 70 pwp or 12.5 dBa0
- o Supergroup modem equipment, 60 pwp or 11.8 dBa0
- o Through group filter and AGC equipment, 50 pwp or 11.0 dBa0.

Total noise for one link (excluding group filter and AGC equipment) is 475 pwp (one terminal). Thus, a set of equipment for translating from audio to baseband and back to audio at each terminal of a link will have the following noise allowance (two terminals):

- o Channel translation, 345 pwp
- o Group modem equipment (2 at 70 pwp), 140 pwp
- o Supergroup modem equipment (3 at 60 pwp), 180 pwp
- o Through group filter and AGC equipment (3 at 50 pwp), 150 pwp.

Total noise for one link = 815 pwp (two terminals). Total for six links = 4890 pwp or 30.9 dBa0. This compares with the standard allocation of 5000 pwp for multiplex noise over the reference circuit.

The above summations on a power-addition basis result from multiplex noise being essentially intermodulation products composed primarily of even order harmonics which are fully incoherent even on tandem hops. This incoherency is furthered by random interconnection of telephone channels, groups, and supergroups at the junctions between the homogeneous reference circuit sections.

Multiplex or terminal equipment noise is primarily due to intermodulation products resulting from a number of causes, such as:

- Improper level setting for individual channels.
- Nonlinearity of terminal modulator/demodulator.
- Improper alignment or failure of baseband amplifiers.
- Any AFC malfunction which results in operation off the IF baseband center.
- Amplifier amplitude and phase nonlinearities.

In summary, multiplex noise results from either a nonlinearity or a malfunction having a nonlinear effect. The concept of amplifier nonlinearity (figure 3-7) by contrasting the transfer characteristics of an ideal and an actual amplifier. These nonlinearities tend to produce undesirable frequency components (intermodulation products). These spurious products include the sums and differences of each frequency and its harmonics present in the modulating signal, and all of the other frequencies and their harmonics. In a multichannel radio system, intermodulation products are so varied that they resemble white noise. Intermodulation products from individual channels increase the noise levels in all channels.

The remainder of multiplex noise can be attributed to intrinsic or idle noise. These noise sources are listed in table 3-4. However, with the exception of thermal noise, the contribution of these sources is negligible.

3.6 INTERFERENCE

Interference is divided into two major categories: intentional interference and unintentional interference, with the following definitions:

- Intentional interference is deliberate in nature and utilized to curtail reception of desired signals.

- Unintentional interference is generally created by lack of sufficient frequency spectrum between RF equipments, RF energy emission at other than assigned frequencies, reception of energy at other than the assigned frequency at the receiver.

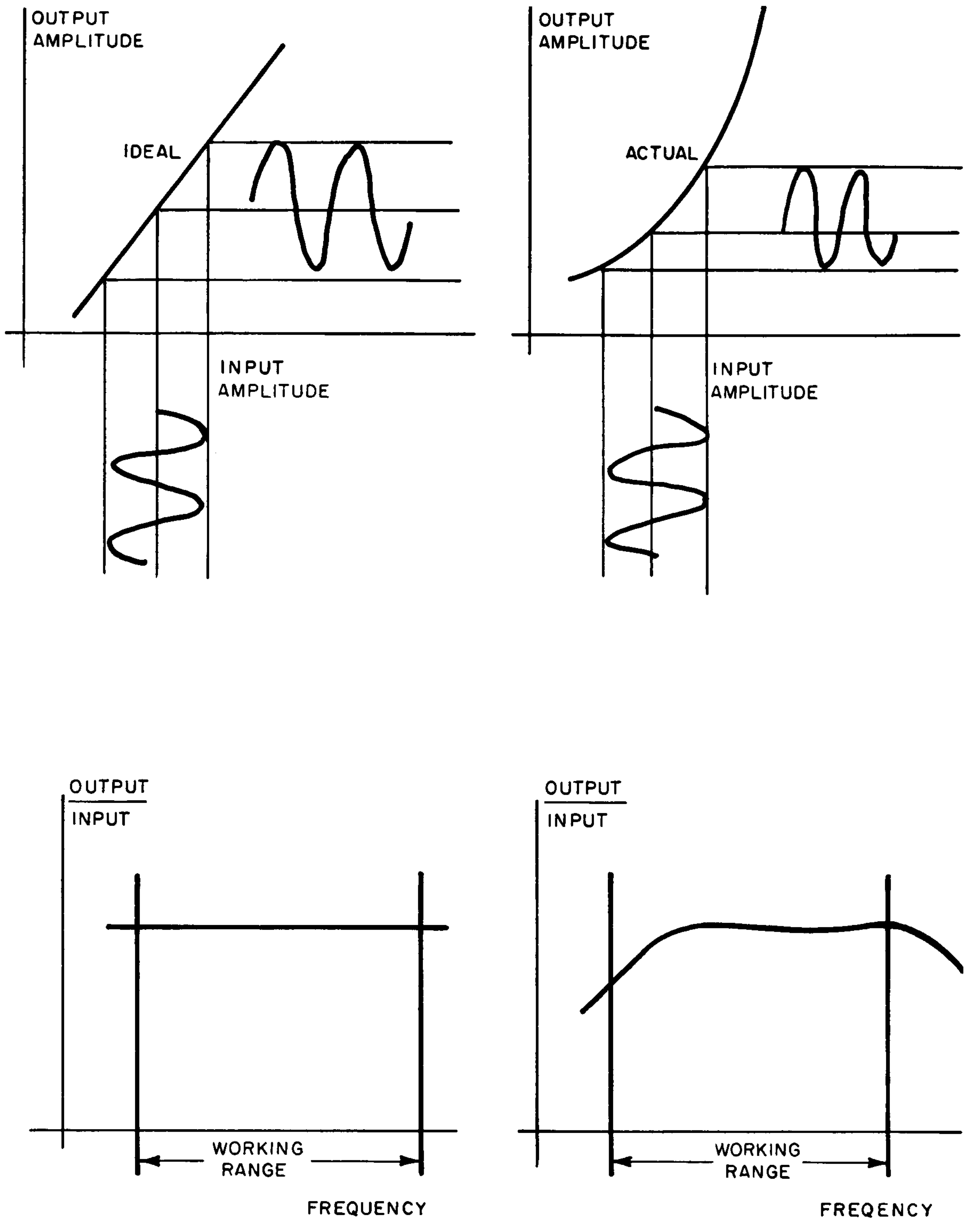


Figure 3-7. Nonlinearity in Amplifiers

Table 3-4. Multiplex-Intrinsic Noise Sources

TYPE	ORIGIN	CHARACTERISTICS	FOUND IN
Thermal	Random Thermal motion of carriers within conducting medium	White Gaussian amplitude distribution	All components
Shot	Random passage of carriers across discontinuity, such as semiconductor junction	White Gaussian amplitude distribution	Transistors, diodes, electron tubes
Excess	Produced by passage of current through semiconductor material	$1/f$ (i.e., noise power inversely proportional to frequency) Gaussian amplitude distribution	All semiconductor devices
Avalanche	Thought to be result of cascade (multiplying) of carriers in high voltage gradient which arrive at junction as bundles	White Gaussian amplitude distribution	Diodes, transistors, capacitors
Multistate	Mechanism unknown, is probably a surface phenomenon	No fixed relationship Non-Gaussian	Some diodes and transistors

Mutual interference between systems is the greatest source of radio frequency interference. In almost every case, this is identified as narrow band interference as compared to the broadband characteristics of non-system sources. This means that the interference is at a single frequency or only a very narrow portion of the spectrum. The number of system interference sources are relatively small, but the manner in which they combine provide a large number of mutual interference types.

Various types and sources of unintentional interference which may occur in a multichannel system are:

- o Same channel (cochannel) interference.
- o Image channel interference.

- o Adjacent channel interference.
- o Direct adjacent channel interference.
- o Limiter transfer action.

3.6.1 Same Channel (Cochannel) Interference

The problem of same channel interference illustrated in figure 3-8 shows, in block form, four consecutive repeaters and five typical interference paths. Separate receiving and transmitting antennas are shown although some systems use only a single antenna. The two most serious potential interference paths are labeled "1" and "2". Here, transmitting antenna high-level signals interfere with receiving antenna low-level signals. When determining permissible interference levels, it is important to note that the receiving antenna signal level should be the signal level expected when the desired channel is experiencing the deepest allowable fade. The high-level signal is reduced by back-to-back ratios of path 2 antennas, but only the side-to-side loss between path 1 antennas attenuates the signal.

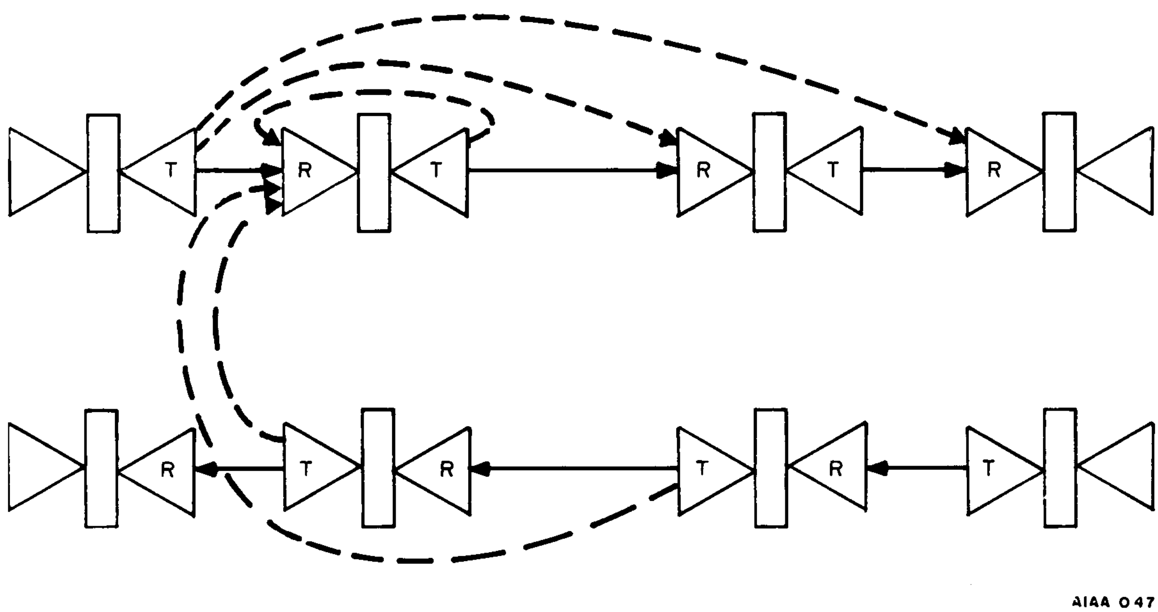


Figure 3-8. Same Channel Interference

In practice, the amount of loss is not adequate. Additional loss might be introduced if the desired signal is cross polarized with respect to the interfering signal, but this method is unreliable. This is due to the complex and unknown nature of the coupling path, particularly with respect to its influence on polarization direction. The problem of excessive coupling can be avoided by using different transmitting and receiving frequencies at a given repeater.

Another source of same channel interference is path 3 in figure 3-8. For this path, using a two-frequency allocation, two signals are received on the same frequency. Normally, the signal is about the same level at the receiving station. In this case, interference will be reduced by the front-to-back ratio of a single antenna which may be about 70 dB for a delay lens or horn reflector antenna but only about 40 to 50 dB for a parabolic antenna. Further advantage might be obtained by using orthogonal polarizations. As noted previously, this method is also unreliable.

Two other sources of same channel interference are identified by the paths 4 and 5 in figure 3-8. Path 4 type of interference presents no problem since frequency frogging is used in adjacent hops. Overreach interference, represented by path 5, is potentially troublesome but can be reduced to tolerable proportions by locating the transmission path in every thrid hop slightly out of line.

3.6.2 Image Channel Interference

Image channel interference is illustrated in figure 3-9. Two signals with carrier frequencies of 11,000 MHz are shown. These signals are separated with filters and applied to modulators for translation to 70 MHz intermediate frequency (IF). Assume a beat oscillator frequency of 11,070 MHz is used for the 11,000 MHz signal. If the filters are ideal, there will not be any problem. However, suppose rejection of the 11,140 MHz signal by filter 1 is inadequate, then, this signal would beat with the 11,070 MHz beat oscillator tone to give an unwanted 70 MHz IF interference. This is known as image channel interference, and is defined as the channel which differs in frequency from the beat frequency by the same amount as the desired channel, but is on the other side of the beat frequency.

One impractical way to avoid image channel interference is to leave the image channel empty. Alternatively, adequate filtering must be provided to prevent excessive interference even if a deep fade occurs on the desired channel. Cross polarization in adjacent channels is helpful here.

3.6.3 Adjacent Channel Interference

Adjacent channel interference occurs when two FM channels are placed close together in frequency so that the sidebands from one extend into the other. Figure 3-10 shows how this can happen by making use of the power spectral density of a carrier which has been phase-modulated by a baseband signal consisting of random noise. Interference can be prevented by removing the higher order sidebands with filters before the two signals are combined. However, this cannot be done without causing some signal distortion.

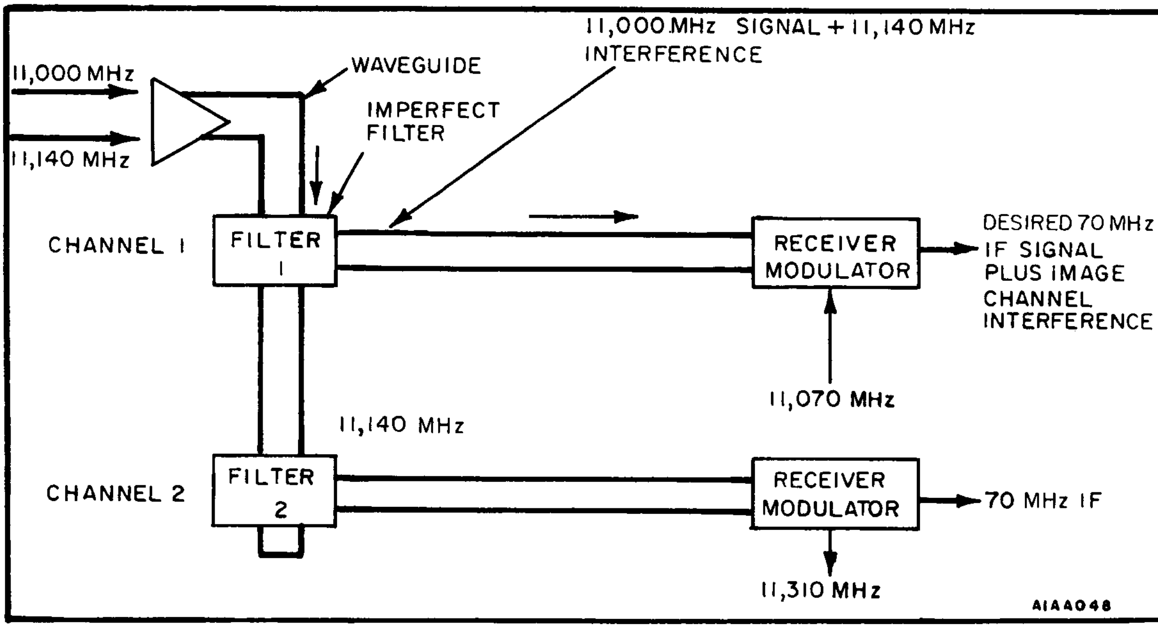


Figure 3-9. Image Channel Interference

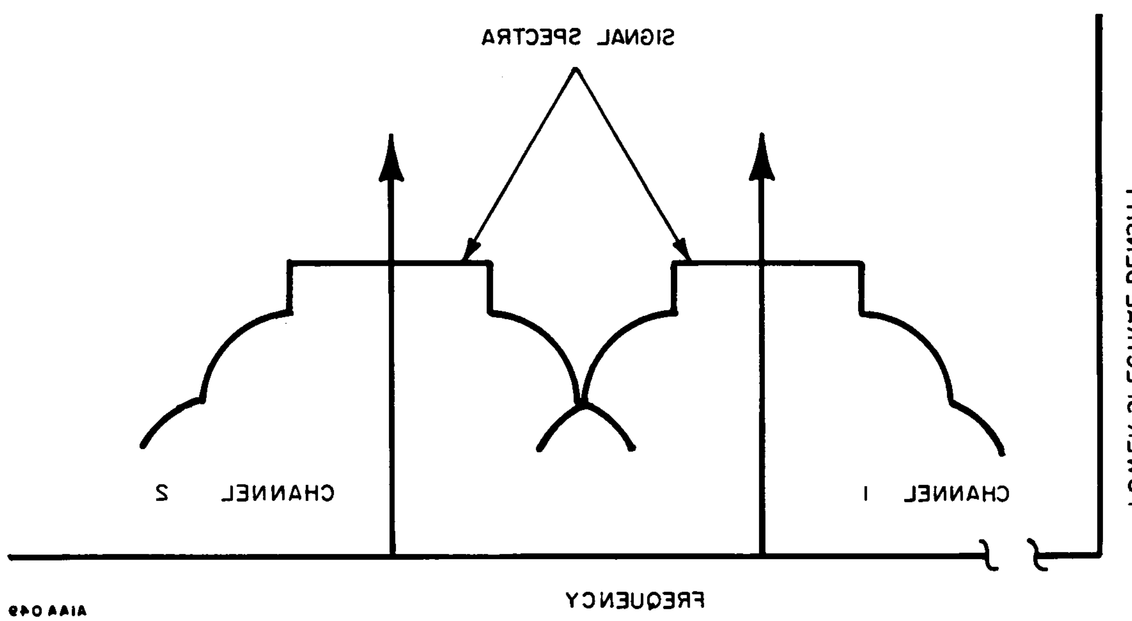


Figure 3-10. Adjacent Channel Interference

It is evident that channel spacing has an important influence on the problem of filtering overlapping sidebands. This fact has given rise to a rule which is sometimes used in the design of long-haul, heavy-route systems. The rule states that channel spacing should be at least three times the top baseband frequency. This ensures that second order sidebands from an interfering channel will not overlap first order sidebands in an adjacent channel. Applying this rule, generally leads to practically realizable channel filters.

3.6.4 Direct Adjacent Channel Interference

Interference due to overlapping sidebands will generally be garbled or unintelligible since the disturbing sidebands are inverted with respect to the disturbed carrier. In systems with very closely spaced channels, however, a more complicated form of adjacent channel interference has been noted in which the interference is intelligible. This type of interference, where the signal on the adjacent channel appears as an identical signal in the disturbed channel, is termed direct adjacent channel interference (DACI). The mechanism producing this type of interference, although not fully understood, is believed to involve phase to amplitude conversion of the interfering carrier and its sidebands in the selectivity "skirts" of the disturbed channel. This results in amplitude to phase conversion in the disturbed channel limiters or other nonlinear devices.

3.6.5 Limiter Transfer Action

Using limiters in the radio repeater may result in interference between channels and is often referred to as limiter transfer action. The basic mechanism of this interference is illustrated in figure 3-11. Three adjacent radio channels with carriers spaced 20 MHz are shown. Channel 2 is assumed to be cross-polarized with respect to channels 1 and 3. Assume that channel 1 is carrying a 7 MHz baseband tone with a sufficiently low index of modulation such that only first order sidebands need to be considered. At station A, channel 1 output will consist of a carrier and single frequency sidebands 7 MHz on each side of the carrier. At station B, channel 1 signal upper sideband appears as an interfering tone 13 MHz off center frequency in the channel 2 receiver. Amplitude of the tone reaching the channel 2 limiter depends on the cross-polarization discrimination between channels 1 and 2 on the station A to station B path, and the channel 2 receiver gain 13 MHz off center frequency. The channel 2 carrier and interfering tone represent a composite AM-PM signal at the limiter input. The AM component is removed by the limiter and the PM component remains. However, the limiter output has the carrier and sidebands, 13 MHz on each side of the carrier. This signal is transmitted by channel 2 at station B. At station C, channel 2 signal upper sideband appears as an interfering tone, 7 MHz off center frequency in the channel 3 receiver. Amplitude of this tone depends on cross-polarization discrimination between channels 2 and 3 on the station B to station C path, and the loss of the channel 2 radio transmitter 13 MHz off center frequency. Thus, a baseband signal in one channel may appear as interference at the same baseband frequency in another channel. In addition, the channel 2 lower sideband can couple back to the channel 1 receiver at station C. In either case, an analysis

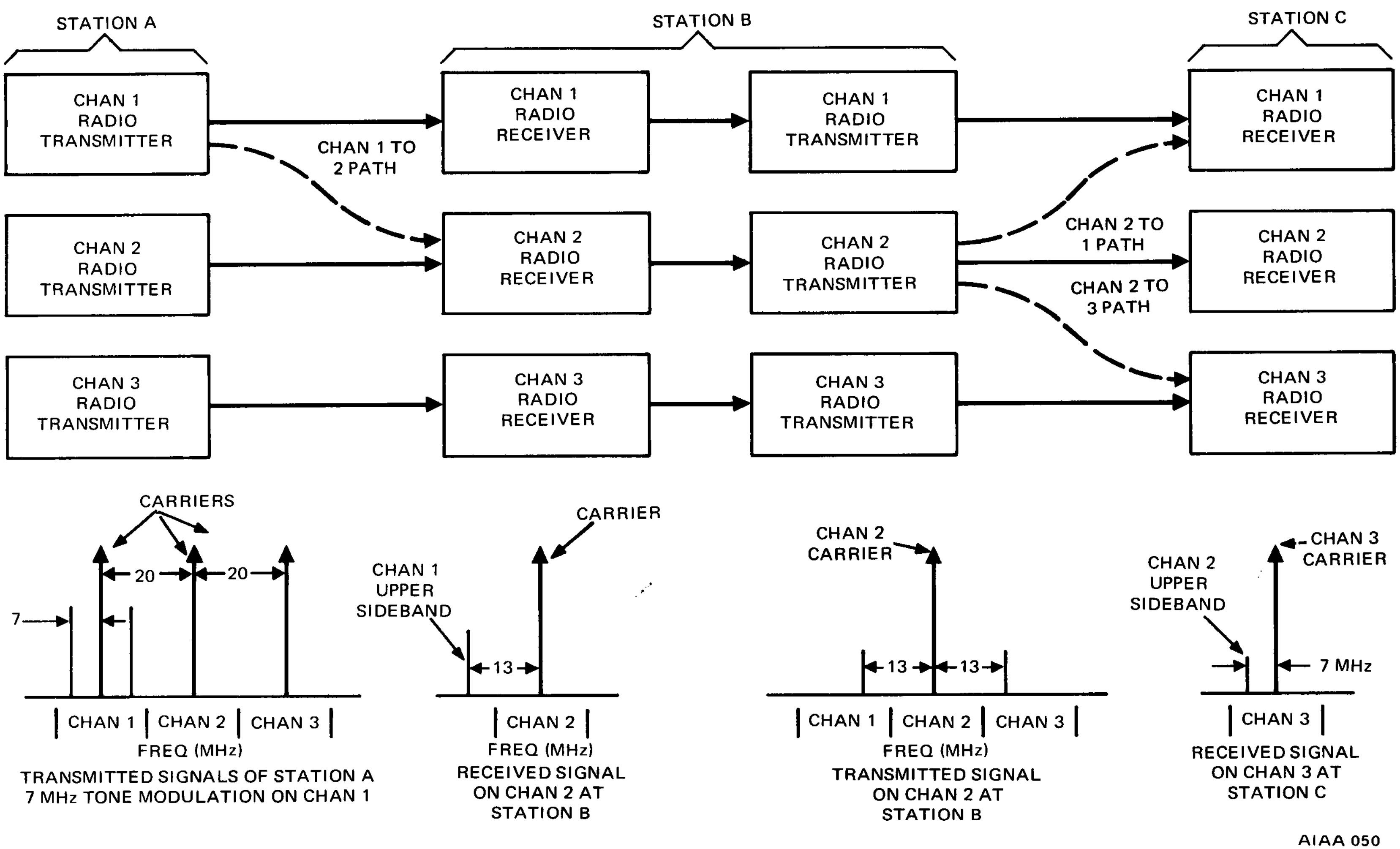


Figure 3-11. Limiter Transfer Action

should include a study of frequency tolerances of the various beat frequency oscillators used in the paths to determine actual frequency range about the nominal within which the interfering tone may appear at the third station.

Tests have shown that limiter transfer action is in exact accordance with elementary FM theory. The mechanism may become an important consideration when a high-level tone is present on a channel, or a carrier is located near the edge of a broadband radio channel.

3.6.6 Tone Interference

Tone interference, though possibly caused in several different ways, is essentially single frequency in nature. Important sources of this type of interference are the previously discussed same and image channel interferences, and beat oscillators in or near the equipments involved.

Unless the frequency allocation is carefully planned, a beat oscillator frequency for one channel may fall within the band of another RF channel. An extremely large amount of filtering will be required to keep the high-level beat oscillator output from leaking out of the converter where it is used and getting into the other channel at the same frequency. There are higher order products, possibly 4th or 5th order, which may be produced in a converter if the extraneous tones from other RF channels or other beat oscillators are present. Those products which fall in the frequency band of the desired output constitute tone interferences.

3.7 CROSSTALK

Crosstalk is unwanted coupling from one signal path onto another. Crosstalk may be due to direct inductive or capacitive coupling between conductors. It may also be caused by coupling between radio antennas, or by cross-modulation between channels and single frequency signals (carriers or pilots) in multichannel carrier systems. Such cross-modulation may occur in any nonlinear element, such as repeater electron tubes or terminal modulators. In many instances, the resulting interference in carrier systems is unintelligible due to the interfering signal being inverted, displaced in frequency, or otherwise distorted. In these cases, crosstalk is generally grouped with other noise type interferences.

When coupling paths give rise to intelligible (or nearly intelligible) interference, it is necessary to design the cable, open-wire line, antenna, repeater, or modulator so that the probability of hearing a "foreign" conversation will be less than a prescribed value. In normal practice, a one percent chance is considered tolerable and is based on an arbitrary judgment.

Three major crosstalk paths between physical four-wire systems are shown in figure 3-12. These are: the near-end path between the opposite directions of transmission, the interaction crosstalk paths from the output of one repeater into a paralleling cable pair (a voice circuit perhaps) and then into the input of the same or another repeater, and the far-end path from the output of one repeater to the input of another.

Two cables are used alternately to provide the pairs for each direction of transmission. By using physical isolation, the near-end crosstalk paths between the opposite directions of transmission are automatically eliminated. The interaction crosstalk path is effectively broken up by alternating ("frogging") the two directions of transmission between the two cables in successive repeater sections. In this way, the interaction path is made to terminate at the high-level point at a repeater output and is, therefore, less serious by the gain of a repeater. These measures do not, of course, affect the far-end crosstalk between carrier systems in the same cables. This last path is improved by rather elaborate carrier frequency balancing of the cable pairs.

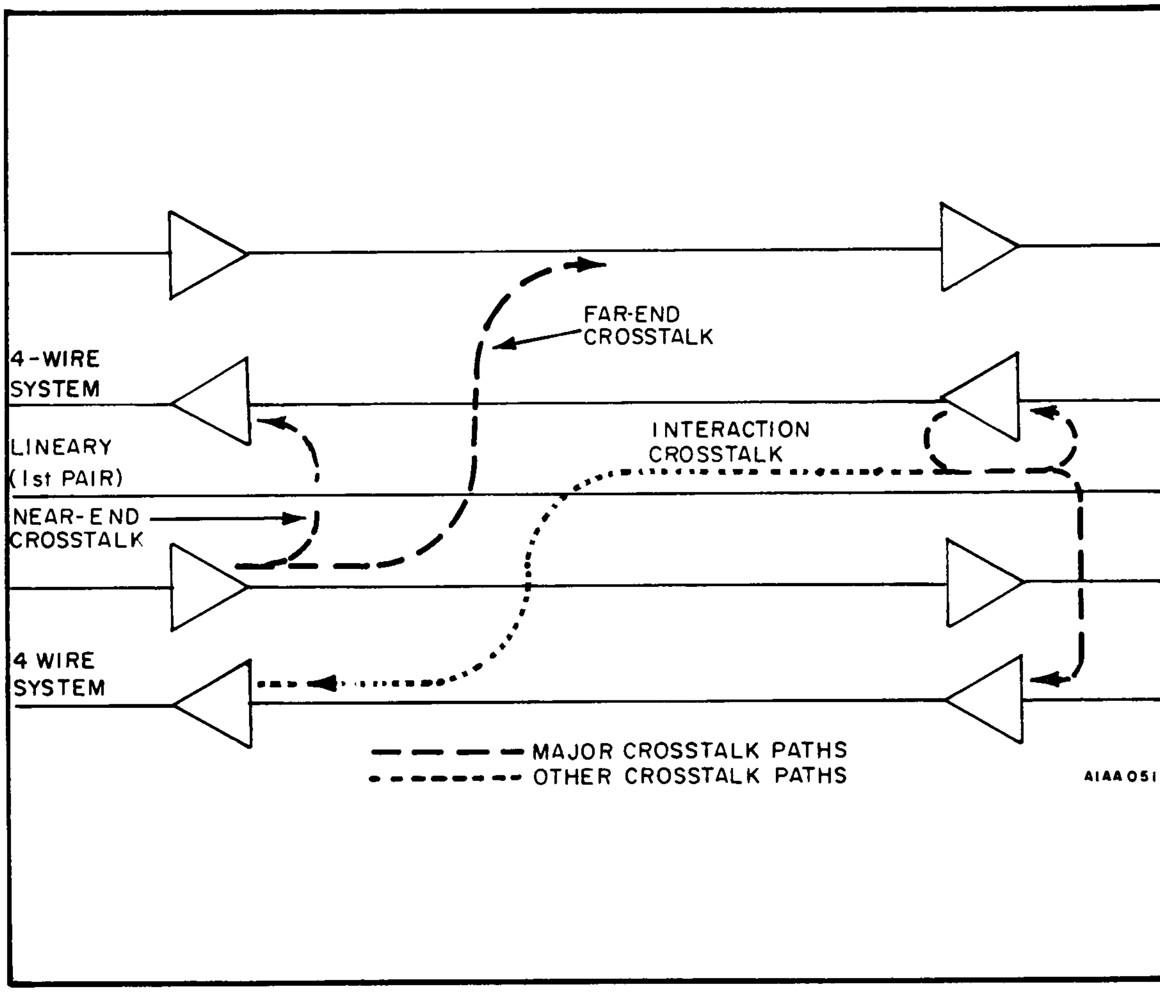


Figure 3-12. Physical Four-Wire Operation and Some Important Crosstalk Paths

3.8 DISTORTION

Distortion appears in a multichannel microwave system as intermodulation noise and attributed to two factors, delay and echoes. Any signal that carries intelligence is a composite signal; i.e., it contains a number of frequencies, often harmonically related, in some given phase relationship. If such a signal is passed through a system or component which has different delays at different frequencies, the output signal will not be identical in shape to the input signal. DCAC 330-175-1 requires that differential delay distortion (1000-2600 Hz) not exceed 1000 μsec over the 6000 NM reference circuit.

Echoes are generated by reflection from discontinuities in the transmission path. Because of this, the signal becomes modified in phase by the reflected energy. When the FM signal is translated to baseband, the signal will have a distortion component proportional to the frequency of the product (second or third order).

Various types of distortion which may occur in a microwave system are:

- o Feeder distortion
- o Path distortion
- o Group delay
- o AM to PM conversion
- o Telegraphic distortion

3.8.1 Feeder Distortion

Often a source of considerable noise in microwave high capacity systems is the transmission line (waveguide system). Microwave transmission lines are similar to cable pairs and coaxial tubes with regard to impedance match. Mismatches cause multiple reflections which add a delayed, attenuated replica (echo) of the desired signal. In an FM system, the effect of an echo is to introduce distortion into the message channels. The distortion level is a function of the round trip echo delay time, echo amplitude, number of message channels (baseband width), frequency band of the particular message channel being observed, RMS deviation of the radio, and the radio channel frequency. A typical relationship between time delay and distortion is shown in figure 3-13. Distortion is always directly proportional to the echo amplitude, which must be about 60 dB below the incidental signal to reduce distortion to an inconsequential value. Short time delay echoes are not as degrading as long time delay echoes, and a point is reached where increased echo delay no longer increases distortion. Note that the waveguide length is related to the interfering effect of an echo and, for that reason, should be held to a minimum.

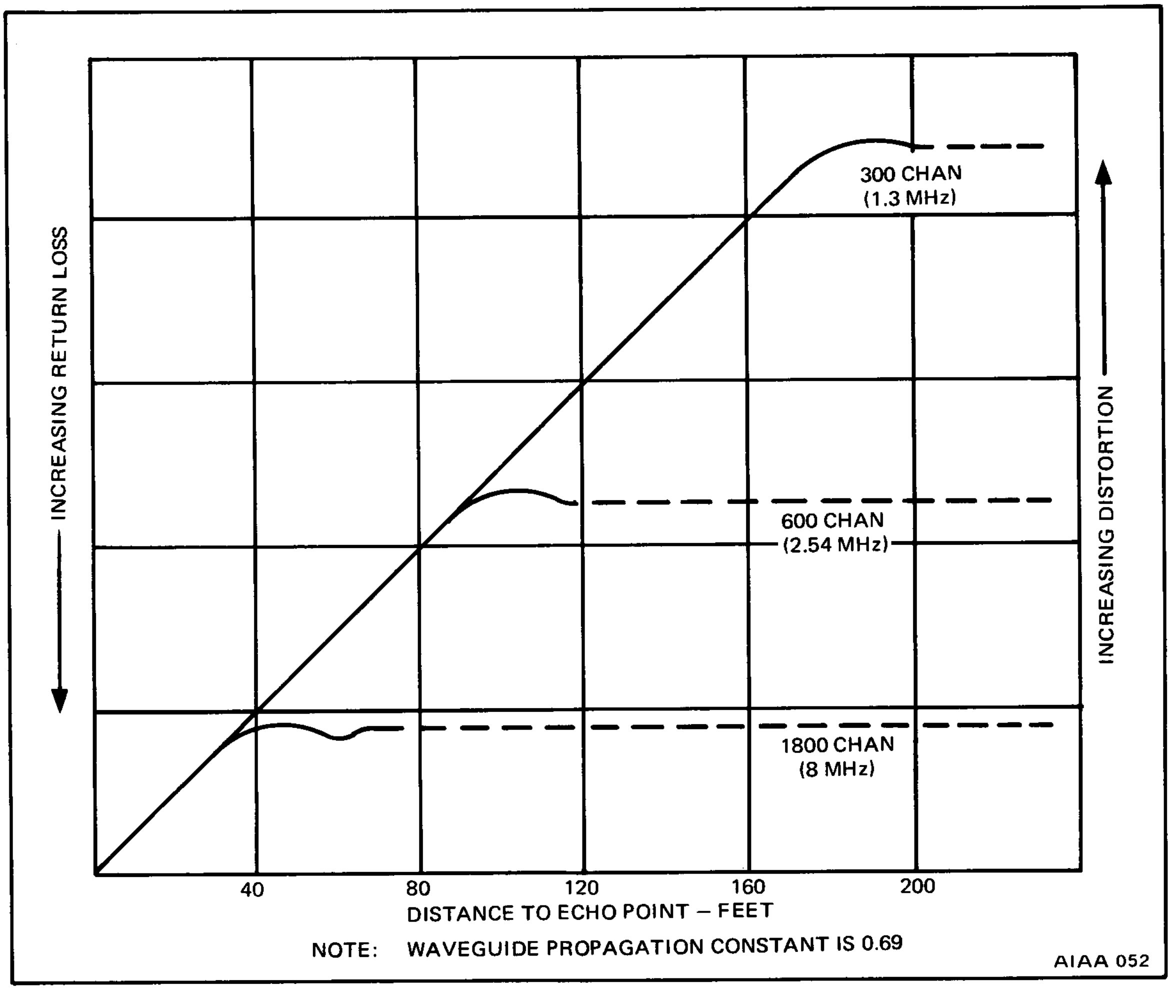


Figure 3-13. Typical Relationship of Echo Magnitude and Delay Versus Distortion

The difference in level between the incidental signal and the reflected signal is known as "return loss." Poor return loss results in signal cancellation due to the phase relation of the two signals, intermodulation distortion and other degradation to the microwave signal. Return loss (expressed in dB) is a measure of discontinuities in the transmission equipment, waveguide, antenna, and connecting flanges. It is defined by:

$$R_L = \text{return loss} = 20 \log_{10} \frac{1}{\text{reflection coefficient}} \qquad (3\text{-}8)$$

where:

$$\text{reflection coefficient} = \frac{\text{reflected signal}}{\text{incident signal}} \text{ (expressed as voltage or current)}$$

Reflection and re-reflection may occur at any point in the transmission path. The actual echo added to the desired signal is composed of many components with various amplitudes and phases. Since echo phasing is a function of distance and frequency, some radio frequency channels may experience more severe distortion than other channels. For this reason, it is necessary to specify component performance over the complete transmission band, and to adequately evaluate the antenna feed system after installation.

This discussion gives an idea of the physical mechanism associated with feeder distortion. A mathematical analysis of the phenomenon would show that the 2nd order distortion is proportional to the square of the line length, the 3rd order distortion to the cube of the line length, etc. For this reason, feeder noise increases so rapidly with line length. Poor feeder return loss performance is indicated by a high frequency ripple in the group delay pattern.

3.8.2 Path Distortion

The distortion producing phenomenon present in feeders occurs in a similar way in the propagation medium along the transmission path. The basic difference between feeder echoes and transmission path echoes is: the former comprise relatively weak echoes with delays ranging upward from approximately 0.1 μsec, and the latter comprise powerful echoes approaching the main signal level with very short time delays (usually less than 0.01 μsec) and is caused by atmospheric multipath transmission and ground reflections.

Selective fading is caused by destructive interference between a microwave signal and one or more lagging echoes. In addition, nonselective type of fading causes receiver FM noise to contribute to the total distortion. An efficient means of coping with multipath fading is diversity transmission.

Another cause of distortion involving the propagation medium, is the presence of RF interference generated within the microwave system or externally to the microwave link, but affecting its performance.

3.8.3 Group Delay Distortion

Nonlinearity of the IF and RF circuits phase characteristics produces nonlinear distortion in FM systems. If some of the frequencies which make up a given signal do not travel at the same speed in traversing a medium (tuned circuit, propagation path, transmission line, etc.), but are attenuated more than others, the signal arrives at its destination distorted. Ideally, the phase shift (θ) versus frequency (f) characteristic should be linear. If the phase shift through a device is a linear function of frequency, the group delay, $t_d = -d\,\theta/d\omega$ (figure 3-14) will remain constant. Therefore, a signal can be transmitted without distortion. In general t_d is not constant but a function of ω, which expressed in a power series can be written:

$$t_d(\omega) = t_{d1} + t_{d2}\left(\frac{\omega-\omega o}{B/2}\right) + t_{d3}\left(\frac{\omega-\omega o}{B/2}\right)^2 + - - - \qquad (3\text{-}9)$$

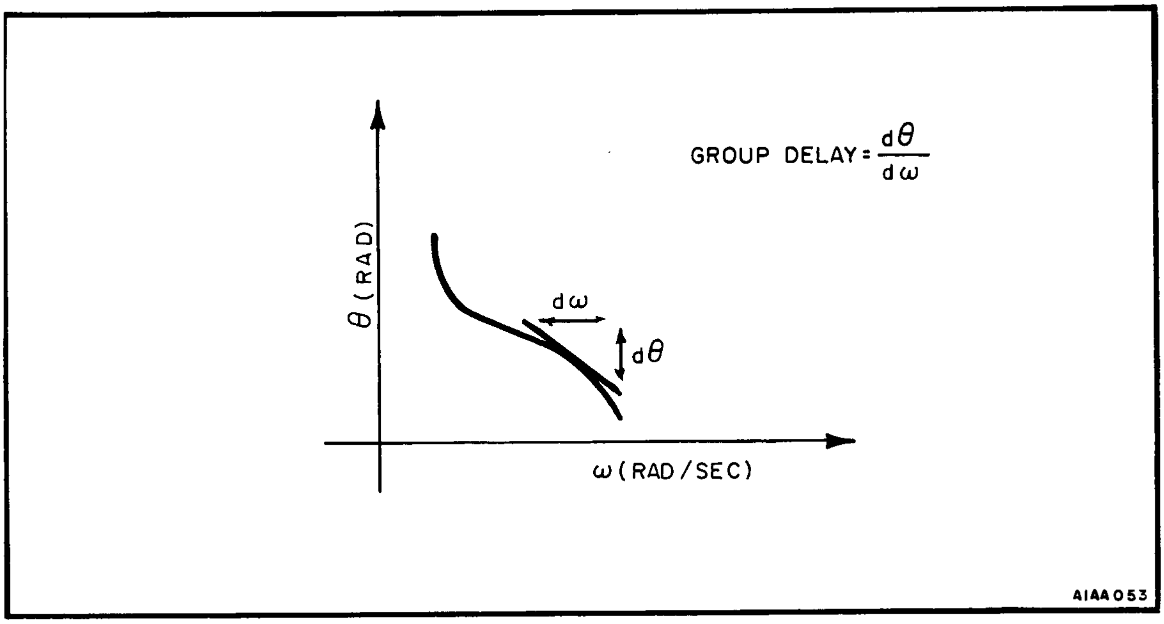


Figure 3-14. Phase Versus Frequency Through a Transmission Device

The meaning of the coefficients is shown on figure 3-15.

A network designed to make the group delay essentially constant over the desired frequency range is called a delay equalizer. Such an equalizer introduces compensating delays at certain frequencies and has minimal effect on the circuit amplitude response. Adequate uniformity of IF and RF circuits amplitude/frequency response is also necessary (measured at signal levels below limiting) so that the amplitude relationship of all significant sidebands are preserved.

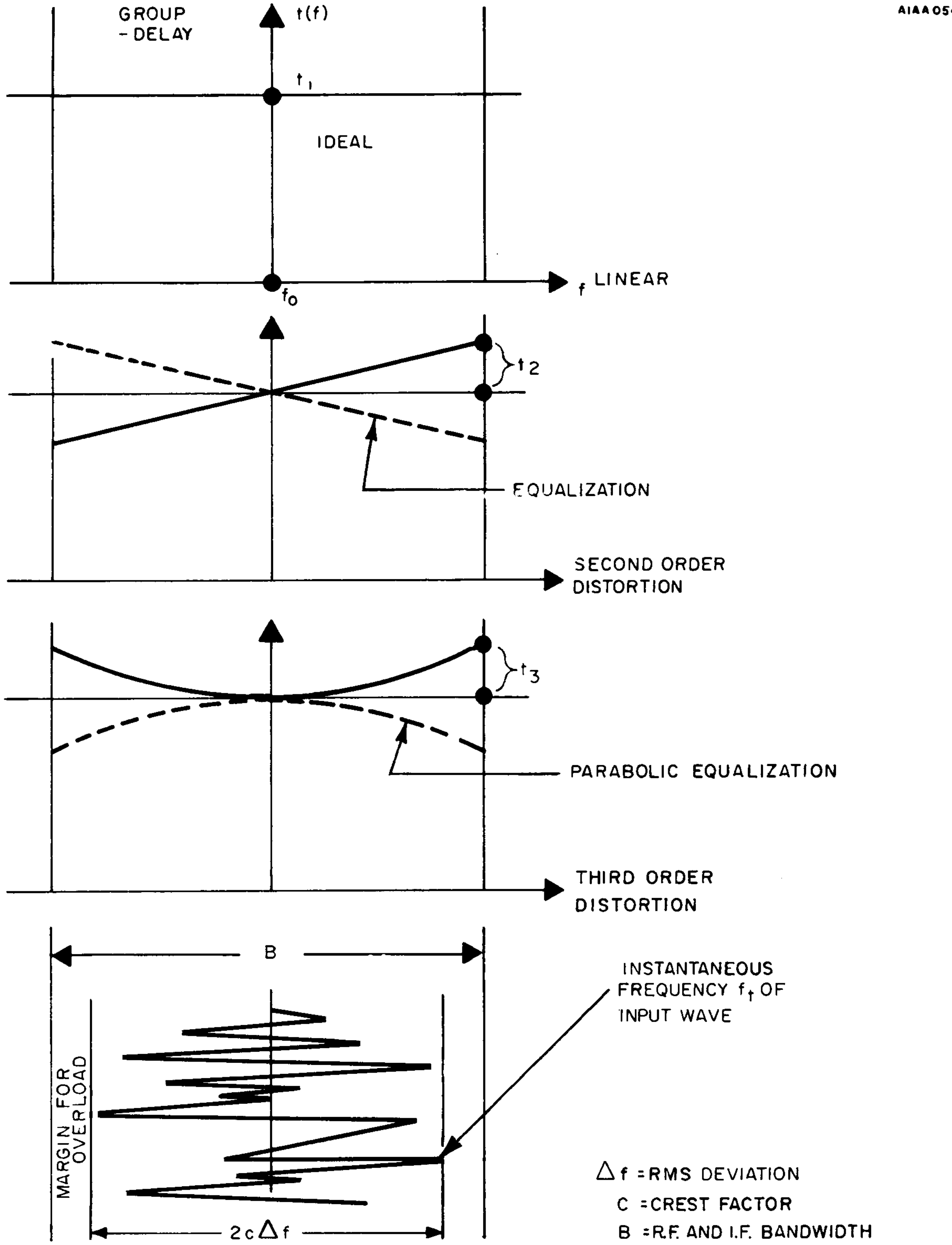


Figure 3-15. Group Delay Frequency Characteristics of Repeaters

3.8.4 AM to PM Conversion Distortion

Most active amplifying circuits exhibit a characteristic that will change the phase of a signal passing through as a function of the AM modulation on that signal. What is more important, it will also change the phase of any other signal passing through the amplifier at the same rate as the AM signal and in proportion to the percent of AM modulation. This amplifier characteristic is the AM to PM conversion coefficient (K_Θ), and is expressed in degrees per dB.

In any FM system there is some AM modulation generated on the carrier as the carrier is deviated in frequency because of the gain slope in the amplifier. This gain slope (K_G) is expressed in dB/Hz.

These two factors combine in an FM system to produce crosstalk between carriers that can be intelligible in the case of telephone traffic. The amount of phase modulation produced on a carrier from another FM carrier passing through a common amplifier is given by:

$$\Theta_1 = \Delta F_1 K_\Theta K_G \tag{3-10}$$

where, ΔF_1 is the peak frequency deviation of one carrier. The peak frequency deviation induced on the other carrier is given by:

$$\Delta f_2 = \Theta_1 F_b \tag{3-11}$$

where, F_b is the modulation frequency of the first carrier. The level of crosstalk between the two carriers is given by:

$$\frac{\Delta F_2}{\Delta f_2} = x = \frac{\Delta F_2}{K_\Theta K_G F_b \Delta F_1 \left[1 + \left(\frac{a_2}{a_1} \right)^2 \right]} \tag{3-12}$$

where, a_1 and a_2 are the carrier amplitudes.

The crosstalk ratio for a given system is a function of the baseband frequency. Therefore, it is only a factor for high channel capacities and at the higher groups of channels.

3.8.5 Telegraph Distortion

The term "telegraph distortion" originated long before data transmission became common, but it is equally applicable to digital telegraph (or data) signals, since this type is normal in the DCS.

In binary transmission, the signal is always in one of two states, marking or spacing. At various points in a transmission system, the signals may appear as DC signals, audio frequency signals, or RF signals. As DC, the two binary states can be either ON or OFF, or positive and negative. As AM audio or RF signals, the two binary states will be ON and OFF. As frequency-shift-keyed (FSK) or phase-shift-keyed (PSK) audio or RF signals, the two binary states will be two frequencies or two phase positions, respectively.

Any change in the duration of mark and/or space intervals as compared to their ideal durations is termed "telegraph distortion." Distortion may be introduced by the sending end instrument, the transmission medium, or any equipment between the sending and receiving end instruments. Telegraph distortion can occur to varying degrees in different parts of a system, so it is essential to minimize it in each part. The DCS Standards specify the amount which may be introduced by sending end instruments, and the amount which should be tolerated by receiving end instruments. Between these two extremes, it is controlled by specifying frequency response and envelope delay of various subsystems and components.

Most telegraphic distortion can be attributed to sending and/or receiving electro-mechanical teletype equipment. There are several different types of telegraphic distortion and are mainly caused by the end equipment. The remaining distortion is caused by combinations of the foregoing principal types of distortion and are identified for information purposes only.

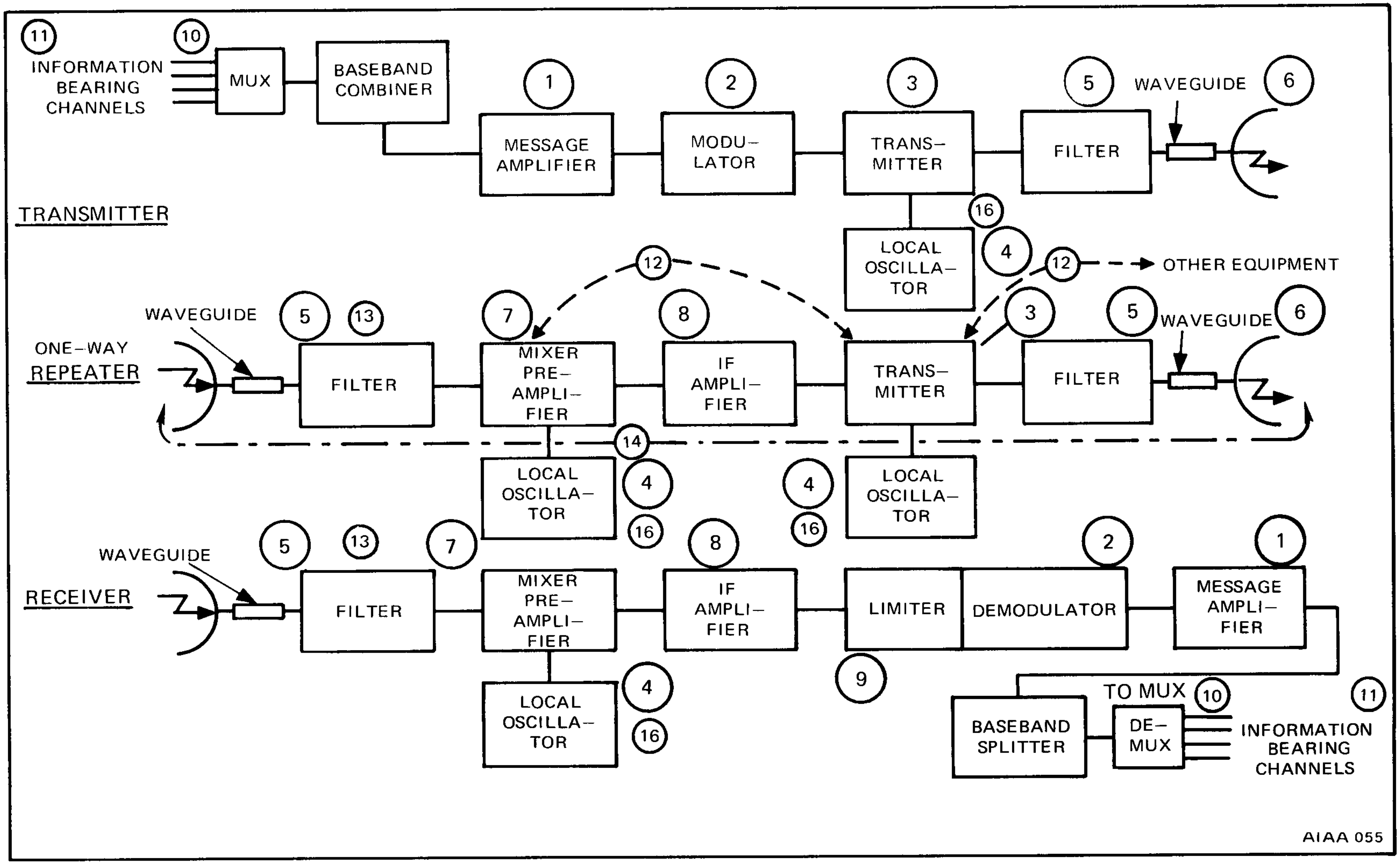
- o Bias distortion
- o End distortion
- o Characteristic distortion
- o Fortuitous distortion
- o Cyclic distortion
- o Speed distortion

3.9 SUMMARY

To catalog the various noise sources that comprise a multichannel microwave system noise budget, refer to Table 3-5 and figure 3-16. The various noise sources identified and discussed in this chapter are tabulated and keyed to a simplified block diagram of a multichannel communications system consisting of two terminals and one intermediate heterodyne repeater. The signal can be traced from the information bearing input channels at the transmitter terminal to the corresponding receiver terminal output channels.

Table 3-5. Sources of Noise

NUMERICAL KEY	NOISE TYPE	REFERENCE PARAGRAPH
1, 2	Intrinsic, Intermodulation	3.2.2, 3.2.3
3	AM to PM Conversion, Thermal	3.2.1, 3.8.4
4	Thermal	3.2.1
	Intrinsic	3.2.2
5	Feeder Distortion	3.8.1
6	Path Distortion	3.8.2
7	Thermal	3.2.1
8	Group Delay	3.8.3
9	Limiter Transfer Action	3.6.5
10	Multiplex Noise	3.5
11	Telegraph Distortion	3.8.5
12	Crosstalk	3.7
13	Image Channel Interference	3.6.2
14	Same Channel Interference	3.6.1
15	Adjacent Channel Interference, Direct Adjacent Channel Interference	3.6.3, 3.6.4


TRANSMITTER
INFORMATION BEARING CHANNELS
MUX
BASEBAND COMBINER
MESSAGE AMPLIFIER
MODU-LATOR
TRANS-MITTER
FILTER
WAVEGUIDE
LOCAL OSCILLA-TOR
OTHER EQUIPMENT
ONE-WAY REPEATER
WAVEGUIDE
FILTER
MIXER PRE-AMPLI-FIER
IF AMPLI-FIER
TRANS-MITTER
FILTER
WAVEGUIDE
LOCAL OSCILLA-TOR
LOCAL OSCILLA-TOR
RECEIVER
WAVEGUIDE
FILTER
MIXER PRE-AMPLI-FIER
IF AMPLI-FIER
LIMITER
DEMODULATOR
MESSAGE AMPLI-FIER
LOCAL OSCILLA-TOR
TO MUX
BASEBAND SPLITTER
DE-MUX
INFORMATION BEARING CHANNELS
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CHAPTER 4

TROPOSPHERIC PERFORMANCE CONSIDERATIONS

4.1 PATH PROPAGATION

Trans-horizon propagation can occur by refraction, by forward tropospheric scatter or by both. For transmission paths extending only slightly beyond line-of-signt diffraction will be the dominant mode and scatter may be neglected. Conversely for very long paths, the diffraction mode can be neglected. In intermediate cases, both modes must be considered and the results combined to obtain the reference transmission loss.

4.1.1 Basic Theory

The diffraction mode of propagation is discussed in chapter 2. Experiments conducted at distances well beyond the normal horizon, primarily during the years from 1935 to 1950 show that a remarkable persistant weak field in the VHF, UHF and SHF bands existed and were much stronger than could be explained on the basis of simple diffraction theory. In the early 1950's these persistant long distance fields came to be called "scatter" fields. The rapid and intense short-term fading characteristic naturally brings to mind the concept of multiple source scattering propagation. Many theorys have been presented to explain the mechanics of this type of communications. Some of those theories have been withdrawn or modified because of new data presented by the numerous agencies working on this phenomenon. The theory presented here is probably the most widely used.

Although the atmosphere becomes uniformly less dense with increasing height above the earth, certain irregularities exist in this gradient as evidenced by the twinkling of stars and sudden bouncing of aircraft. These perturbations occur in blobs which are large compared to the wavelength used in scatter communications and present an index of refraction which differs from that of the surrounding medium. This abrupt change in the index of refraction causes a refraction or "scattering" of an electromagnetic wave. This refraction is only partial at best, since most of the energy propagated continues in a forward direction; however, enough energy is scattered toward the earth for large area, narrow beam antennas to capture it. Direct airborne measurements of the refractive index variations indicate that they are characterized by a spectrum of scales extending over a range from a few centimeters to several kilometers, and the intensity decreases on the average exponentially with increasing height. Figure 4-1 illustrates the scatter model. Both the transmit and receive antennas are aimed to the same spot in the sky. Since the bending or scattering effects are small, more energy is deflected toward the receiving antenna if the scatter angle is small, that is if both the transmit take off and receiving antenna angles are small.

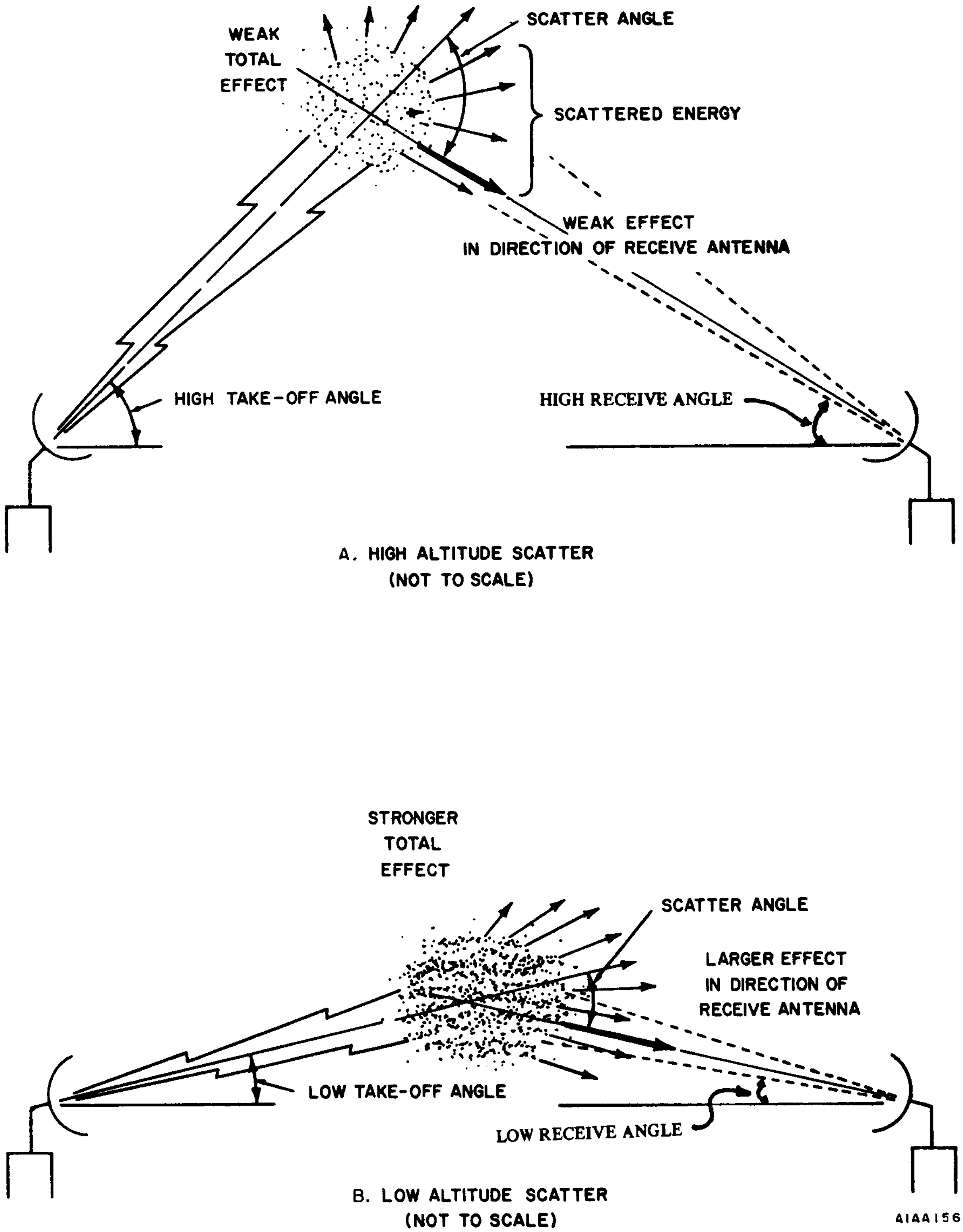


Figure 4-1. Effect of Take-Off Angle

If one or both antennas utilize a large take-off angle, the common scatter volume would be larger due to the increased distance, but the amount of energy deflected toward the receiving antenna would be reduced due to the much larger scatter angle. As stated previously, the higher altitudes exhibit much less scattering, consequently the effective received power decreases rapidly with increased altitude and scatter angle.

As stated in chapter 2, radio energy at microwave frequencies follows a slightly curved path. In a uniform atmosphere where the change radio refractive index is gradual. The bending or refraction of the radio wave may be essentially continuous, so that the beam is gently curved toward the earth.

Under that condition, the radius of the earth appears to the microwave beam larger than the true radius, that is, the earth appears flatter because of the tendency of the beam to refract downward in the atmosphere. The ratio of this apparent or fictitious earth's radius to the actual of the earth is referred to as the "K factor". The surface radio refractivity (N_S) during "Standard" atmospheric conditions is 301, the K factor is 1.333 (4/3). The effects of the variation in K is shown in figure 4-2. In practice, the value of $K = 4/3$ is only a mean value occurring in temperate climates. The usual variation in K is between 1 and 2, with the lower values existing in cold or dry climates and at high altitudes. The higher values of K are common in coastal areas where the humidity is high. Superstandard values of K from 2 to infinity, and substandard values from 1 down to 1/2 are encountered occasionally in the United States, mainly in tropical coastal areas.

An analysis of a troposphere scatter path requires the construction of a path profile containing all the obstructions in the line of propagation. To aid in the analysis, the effective earth's curvature should be used in order that the microwave paths can appear as a straight line.

To calculate the scatter loss, the scatter angle must first be determined. The derivation of the scatter angle θ_{OO} for the smooth earth case is shown in figure 4-3. The two obstacle path geometry shown in figure 4-4 is most common and is derived in a similar manner. Before starting calculations, a path profile should be constructed to determine the required antenna heights and the top of the highest obstructions in route.

4.1.2 Transmission Loss

The transmission loss is defined as the sum of the terminal losses and propagation losses. The propagation loss is the total loss in signal between an isotropic antenna located at the transmitting antenna site and a similar antenna located at the receiving site. At a later stage in the system calculations the terminal losses, antenna directivity gain, and antenna coupling losses are considered.

The long term median basic transmission loss in a forward tropospheric scatter path is:

$$L_{bsr} = 30 \log f - 20 \log d + F(\theta d) - Fo + Ho + Aa \text{ dB} \qquad (4\text{-}1)$$

where:

f is the transmitted frequency in megahertz
d is the mean sea level great circle distance in kilometers

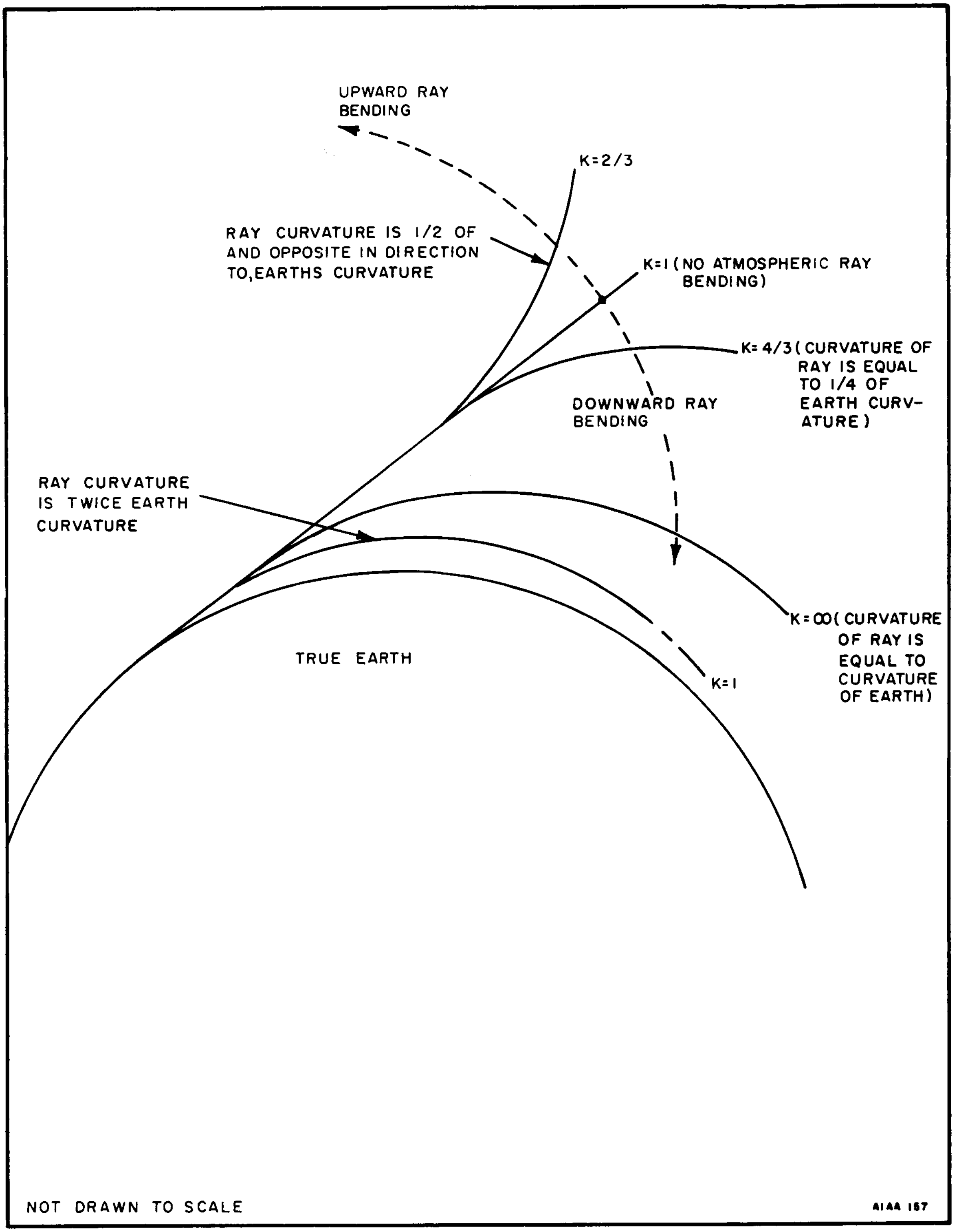
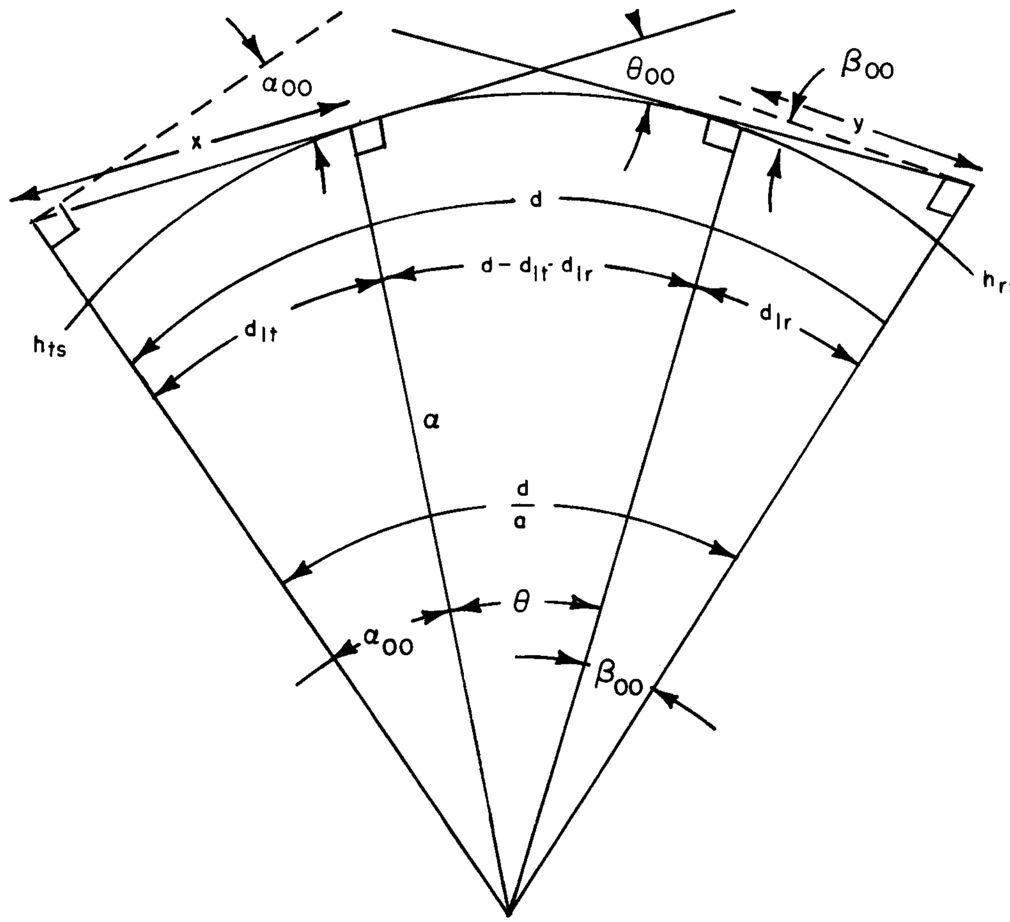


Figure 4-2. Kin Terms of Ray Bending



$$\theta_{OO} = \frac{d - d_{lt} - d_{lr}}{a} = \frac{d}{a} + \alpha_{OO} + \beta_{OO}$$ RADIANS (α_{OO}, β_{OO} ARE NEGATIVE QUALITIES)

$$x^2 + a^2 = (a + h_{ts})^2$$

$$x \approx d_{lt}$$

$$(d_{lt})^2 + a^2 = a^2 + 2a\,h_{ts} + h_{ts}^2$$

$$d_{lt}^2 = 2a\,h_{ts} + h_{ts}^2 \approx 2a\,h_{ts}$$

$$d_{lt} = \sqrt{2a\,h_{ts}}$$

SIMILARY, $d_{lr} = \sqrt{2a\,h_{rs}}$

$$\theta_{OO} = \frac{d}{a} \; \frac{\sqrt{2a\,h_{ts}}}{a} \quad \frac{\sqrt{2a\,h_{rs}}}{a}$$ RADIANS

WHERE: d, a, h_{ts}, AND h_{rs} ARE IN SAME UNITS

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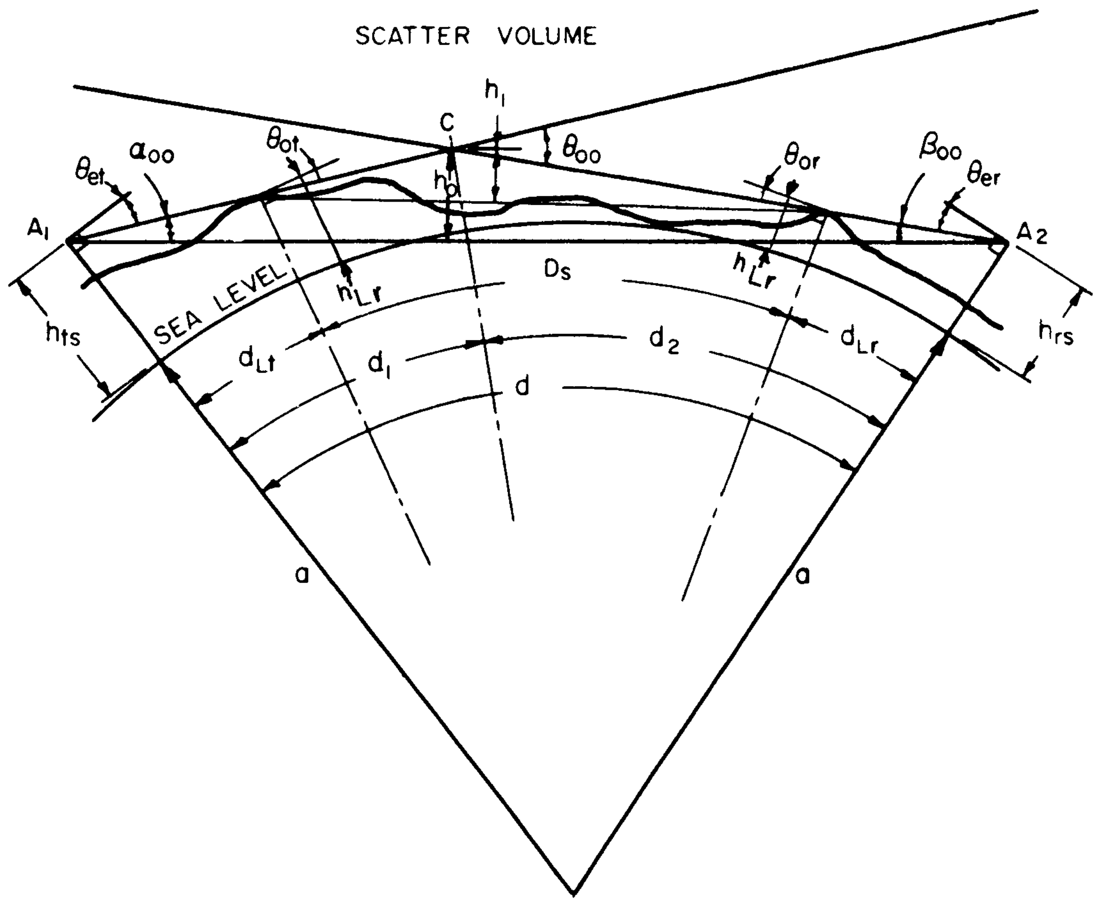
Figure 4-3. Derivation of θ_{OO} for Smooth Earth Case



DISTANCES ARE MEASURED ALONG A GREAT CIRCLE ARC.
DISTANCES AND HEIGHTS ARE MEASURED IN THE SAME UNITS.

$$\theta_{oo} = \frac{D_s}{a} + \theta_{ot} + \theta_{or} = \frac{d}{a} + \theta_{et} + \theta_{er}$$

$$\theta_{et} = \frac{h_{Lt} - h_{ts}}{d_{Lt}} - \frac{d_{Lt}}{2a} \text{ (rad)} \qquad \theta_{ot} = \theta_{et} + \frac{d_{Lt}}{a} \text{ (rad)}$$

$$\theta_{er} = \frac{h_{Lr} - h_{rs}}{d_{Lr}} - \frac{d_{Lr}}{2a} \text{ (rad)} \qquad \theta_{or} = \theta_{er} + \frac{d_{Lr}}{a} \text{ (rad)}$$

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Figure 4-4. Two Obstacle Path Geometry

F(θd) the scattering efficiency and Ho the frequency gain function are discussed in later sections.

As stated previously, the exact mechanism of tropospheric scatter propagation is complex and unknown. In addition to calculation of the propagation loss, while being the most critical computation in the system performance, is also the most ambiguous. There is no exact method to determine the scatter loss; rather, it can only be estimated from empirical data. In addition, the loss varies both on a fast, short term basis and on a long term slowly varying basis. A discussion of these will be made later in the text. For the present, it will suffice to say that the scatter loss for a given path is not constant. It is a time varying quantity with both long and short term statistical distributions. Therefore the propagation loss must be indicated as either a median value or as a value exceeded for some other percentage of time.

L_{bsr} in equation 4-1 is the median basic transmission loss in dB on a forward tropospheric scatter path, for winter afternoons. That is, if hourly median values of the total propagation loss (excluding terminal loss) are measured during the months of November through April, between the hours of 1 PM and 6 PM, then L_{bsr} would be the median of these values. This loss is approximately 3 dB higher than the yearly median value.

The attenuation function F(θd) depends upon the propagation path and the surface refractivity N_s. The function includes a small empirical adjustment to data available in the frequency range from 100 to 1000 Megahertz. Figure 4-5 may be used to determine F(θd) for all scatter links where θd ≤ 10. For values of θd ≤ 10 the curve is valid only for paths with symmetry factors (s) from 0.7 to unity the symmetry factor.

$$s = \alpha_o / \beta_{oo}$$

The last three terms in equation 4-1 may be neglected in most applications. The scattering efficiency term Fo corrects for the reduction in scattering efficiency at great heights in the troposphere. The Frequency Gain Functions Ho, is a correction term for ground reflection effects. If the antennas involved are sufficiently high, the reflections of radio energy by the ground increases the power incident on the scatters visible to both antennas and can increase the scattered power. As the frequency is reduced, the ground-reflected energy tends to cancel direct-ray energy at the lower part of the common volume of the antenna beam intersection and decreases the efficiency of the communications path.

At frequencies above 1 GHz attenuation of radio waves due to absorption or scattering by constituents of the atmosphere, and by particles in the atmosphere may seriously affect microwave links. At lower frequencies the total radio wave absorption by oxygen and water vapor for propagation paths of 1000 kilometers or less will not excees 2 decibels but may be appreciable at higher frequencies. Figure 4-6 is a plot of median oxygen and water vapor absorption losses based upon data taken in the Washington D. C. area.

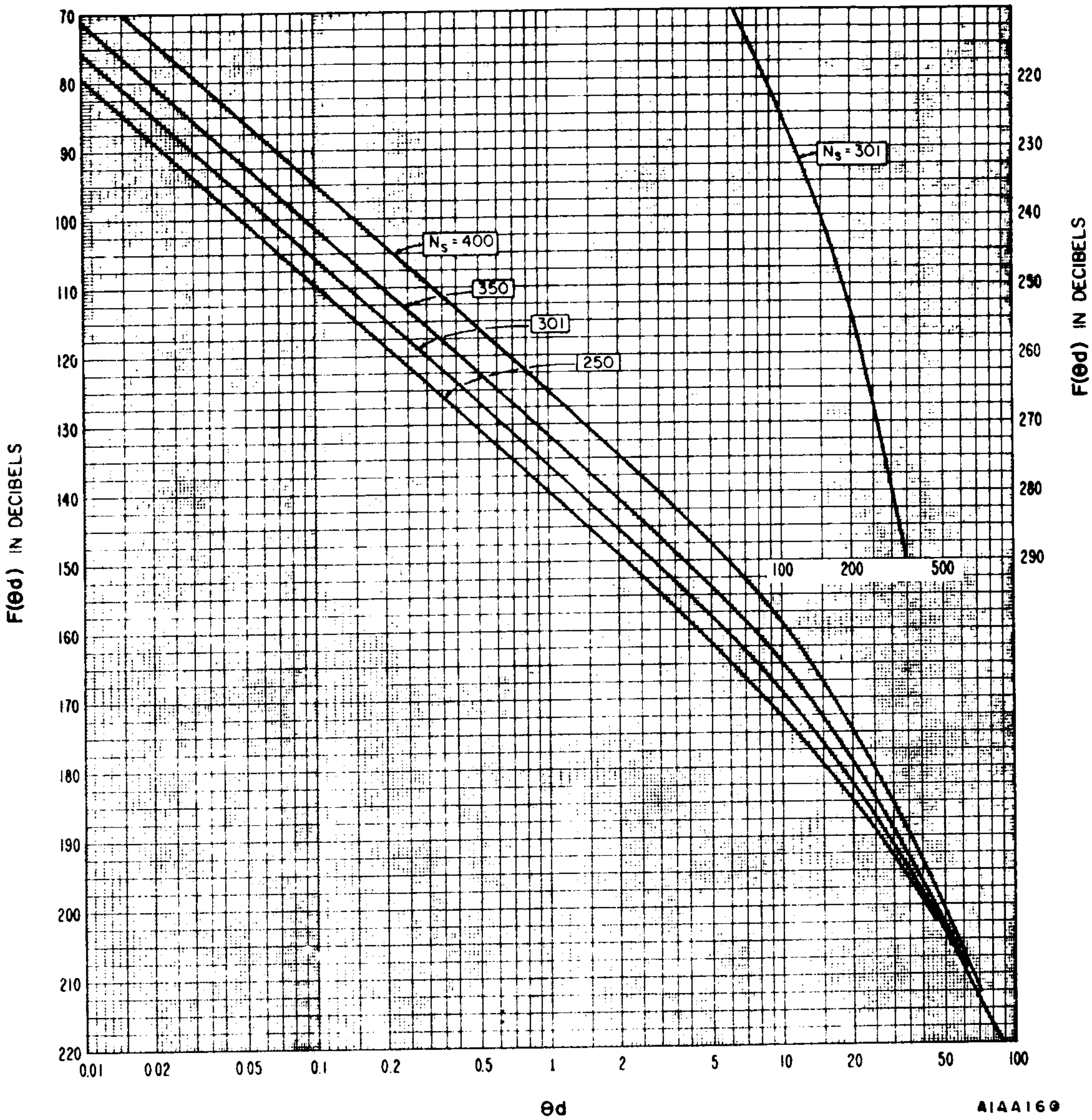

Figure 4-5. The Attenuation Function, F (θd) d is in Kilometers and θ is in Radians

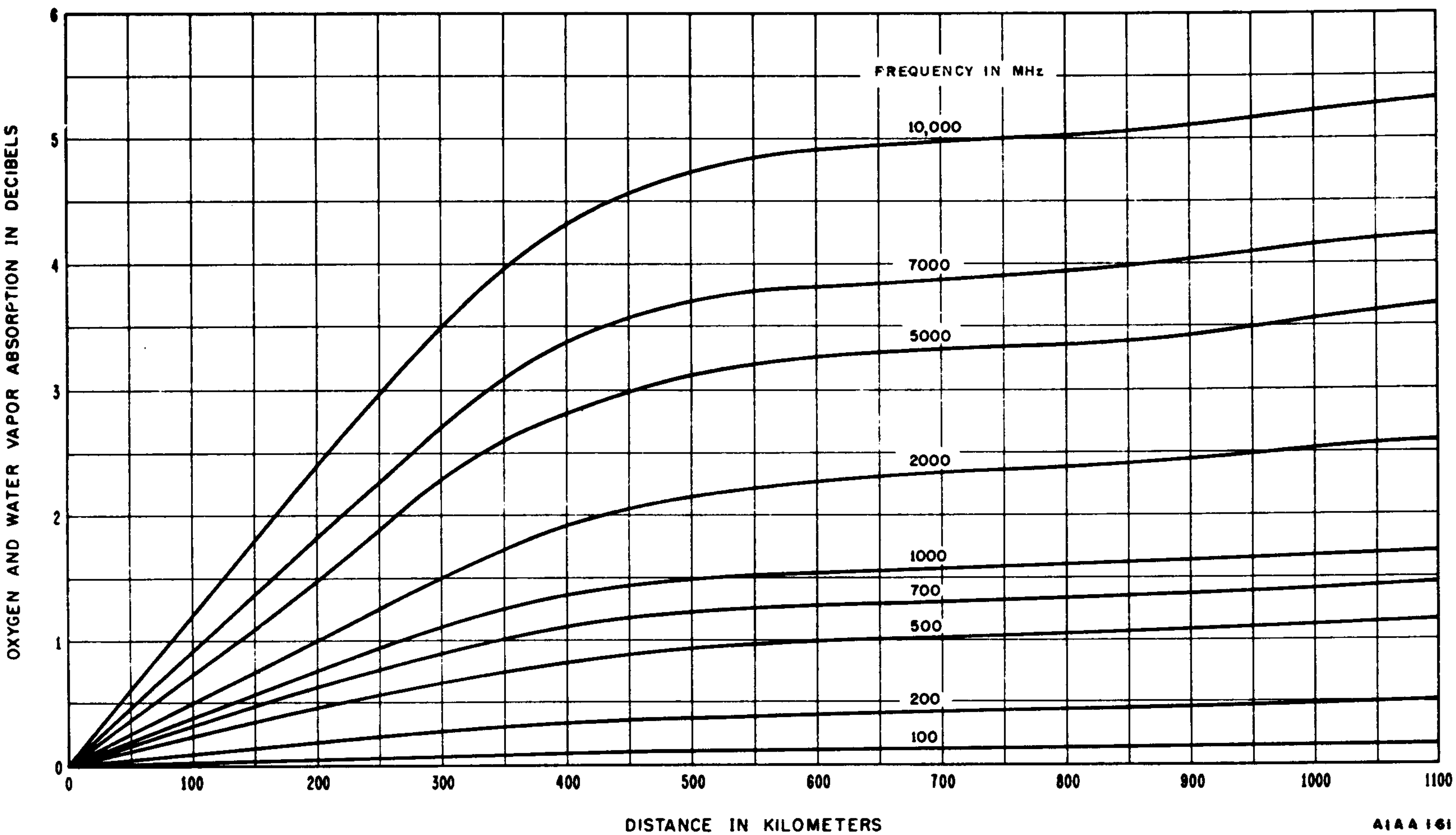

Figure 4-6. Median Oxygen and Water Vapor Absorption (August Data at Washington, D.C.)

4.1.3 Path Antenna Gain

The full plane-wave gain of an antenna, calculated on the basis of its diameter, in terms of wavelength and efficiency cannot be realized when used in the tropospheric scatter mode. The difference between the plane-wave gain and the realized gain is referred to as the aperture-to-median coupling loss. The aperture-to-median coupling loss arises from the fact that the scattered signal arriving at the receiver does not come from a point source, but from an extended volume subtending a measurable solid angle at the receiver. Thus, if the transmitting antenna is of very narrow beamwidth it will illuminate a volume of air space smaller than the effective size of the scatter volume when a broad beam antenna is used. Since the scatter volume is decreased, the signal arriving at the receiver will not increase in the same proportion as it would under free space propagation conditions. This difference between the free space expected-gain of a narrow beam antenna and its measured gain on a scatter circuit is termed "antenna gain degradation" or "antenna-to-medium coupling loss" and has been theoretically determined to be proportional to the ratio of the scatter angle (0) to the antenna beamwidth (Ω).

4.1.4 Fading

A scatter signal at a particular instant is the resultant of a number of individual signals arriving with random phase differences. For short periods of time the random variations of these phase differences produce a signal of varying amplitude, which tends to be Rayleigh distributed. Over long periods of time, the scatter signal assumes a log-normal distribution.

In the early stages of troposcatter communications it was soon recognized that the short term distribution always approximated to a Rayleigh curve. The short-term Ravleigh distributed signal variations are independent of the season but are brought about because of the nature of scatter propagation. The received signal is composed of components of random phase from different points in the scatter volume. The sum of these components is constantly varying. The effects of the short term fades were found to be minimized by diversity.

The short term fading of the scatter signal, during the hour, is assumed to follow a Rayleigh distribution. The cumulative Rayleigh distribution curve is shown in figure 4-7. This curve, identified as "Rayleigh Fading" in the figure, shows the percentage of the hour that a given received power level, in dB, is exceeded (upper abcissa scale). Power levels are given in dB with reference to the hourly median value.

A technique that is widely used in troposcatter systems to eliminate, to a large extent, the effects of this fast fading is known as diversity. Diversity consists of transmitting the same information over two or more communications paths that have uncorrelated fast fading. The fact that the fadings on the paths are uncorrelated allows the separate signals to be combined into a single signal which is much more stable with respect to time.

Where two separate paths are provided, the scheme is known as two-fold (or dual) diversity; four paths, four-fold (or quadruple) diversity, etc. The resultant curves for two fold diversity are shown in figure 4-7 along with the no-diversity Rayleigh distribution. The terms Maximal-Ratio, Equal Gain, and Selection Diversity refer to the

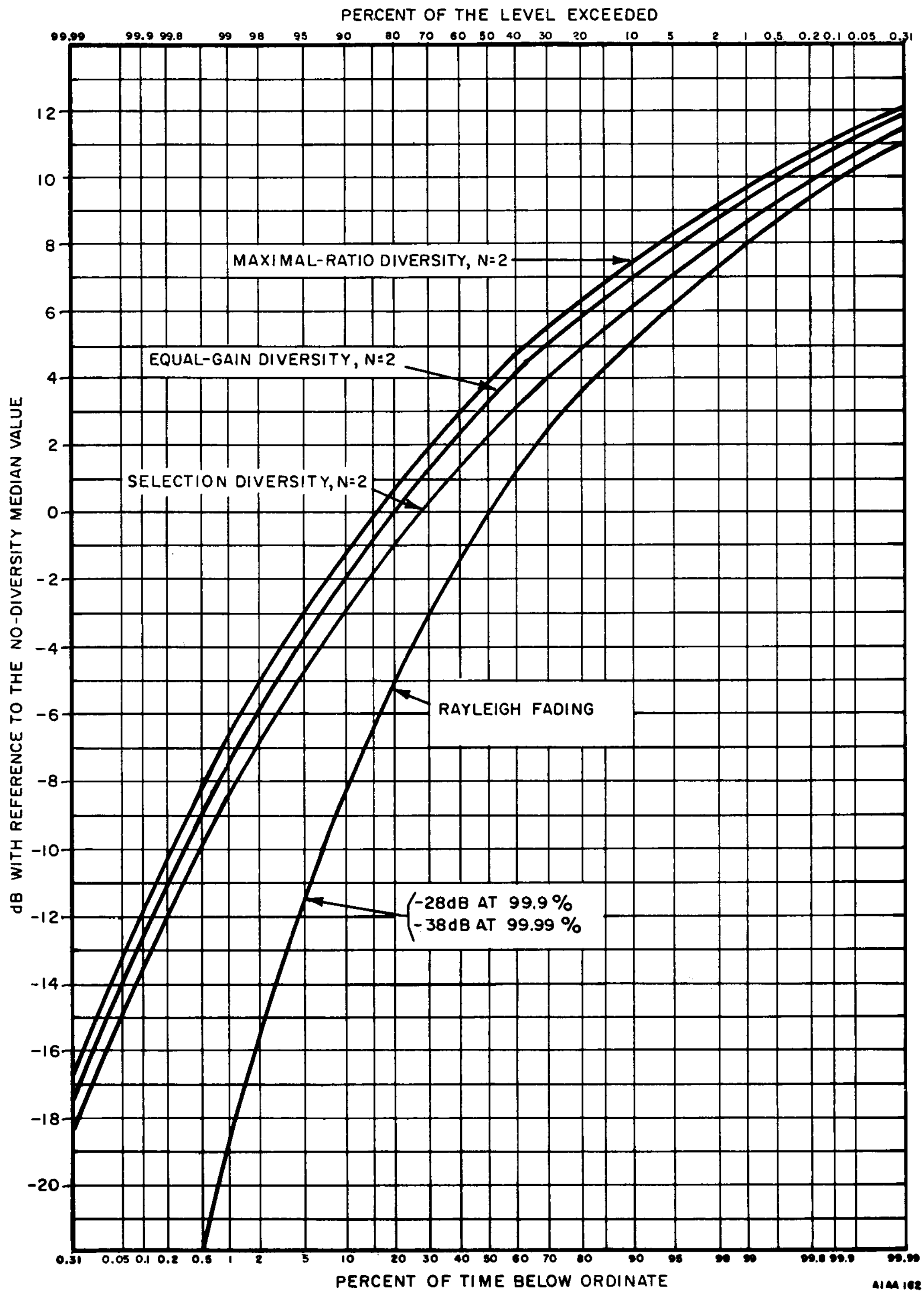

Figure 4-7. Short-Term Fading
(Two-Fold Diversity)

manner of signal combining employed. Briefly, a selector is a switching circuit that is continually choosing the signal with the higher power level; equal gain combining consists of the addition of the different signals to arrive at a single sum output; and, maximal ratio combining connotes the addition of the separate signals with the gain of each signal channel in the summing network proportional to the RMS signal level and inversely proportional to the mean square noise level, the same proportionality constant being used for each signal.

In figure 4-7 note that regardless of the type of combining used, a considerable provement is obtained by the use of diversity. Referring to the maximal ratio curve, it is seen that an hourly median (5 percent improvement, or gain, of 4dB is realized. (Note the median, or 50 percent point for the no-diversity Rayleigh curve is used as the 0 dB reference level). More important, we are concerned with the extreme fades occurring during the smaller percentages of the hour. For example, the level exceeded 99 percent of the hour stated in another way: the level which we are below for 1 percent of the hour is seen to be 18.5 dB below the reference median value where no diversity is used; whereas, for maximal ratio combining two-fold diversity, the 99 percent level is only 6.5 dB below the median reference level. Thus, a 12 dB gain is obtained when the 99 percent point is considered.

Clearly, the extent of improvement, or gain, that a diversity system provides is function of the percentage of the hour with which we are concerned; thus, so-called median gain values are sometimes misleading. The true value of diversity lies not in the median gain, but in the fact that it "flattens out" the no-diversity Rayleigh distribution. With diversity, short term signal fluctuations are almost negated, leaving only the long term signal variations to be contended with.

The fading distributions for four-fold diversity are given in figure 4-8. While the improvement obtained from two-fold diversity over no-diversity is considerable, the further improvement received by using four-fold diversity is also quite significant. The signal level exceeded for 99 percent of the hour with four-fold maximal-ratio diversity is almost 1 dB better than the signal exceeded 50 percent of the hour (i.e., median value) with no diversity.

In conventional tropospheric scatter systems four-fold diversity is usually used. Aside from the better performance provided, a redundant two fold diversity scheme is also maintained in this manner. This significantly reduces circuit outage time resulting from equipment failure. In post-detection combining schemes the maximal ratio technique is usually used, while in pre-detection combining, an equal gain combiner is normally utilized. Pre-detection equal gain combining gives almost the same gain as post-detection maximal ratio combining and at the same time decreases below-threshold outage time and reduces the size of the necessary equipment.

Aside from the short-term Rayleigh distributed fades, long term fading is encountered on tropospheric scatter paths. This is a variation in the hourly median received power level due to changes in refractive index, changes in the nature of the scatter volume, etc. Long term fading here will be used to connote variations from hour to hour while short term fading is used to identify signal fluctuations within the hour. To date, the use of diversity has not been found to have any appreciable effect on these long term

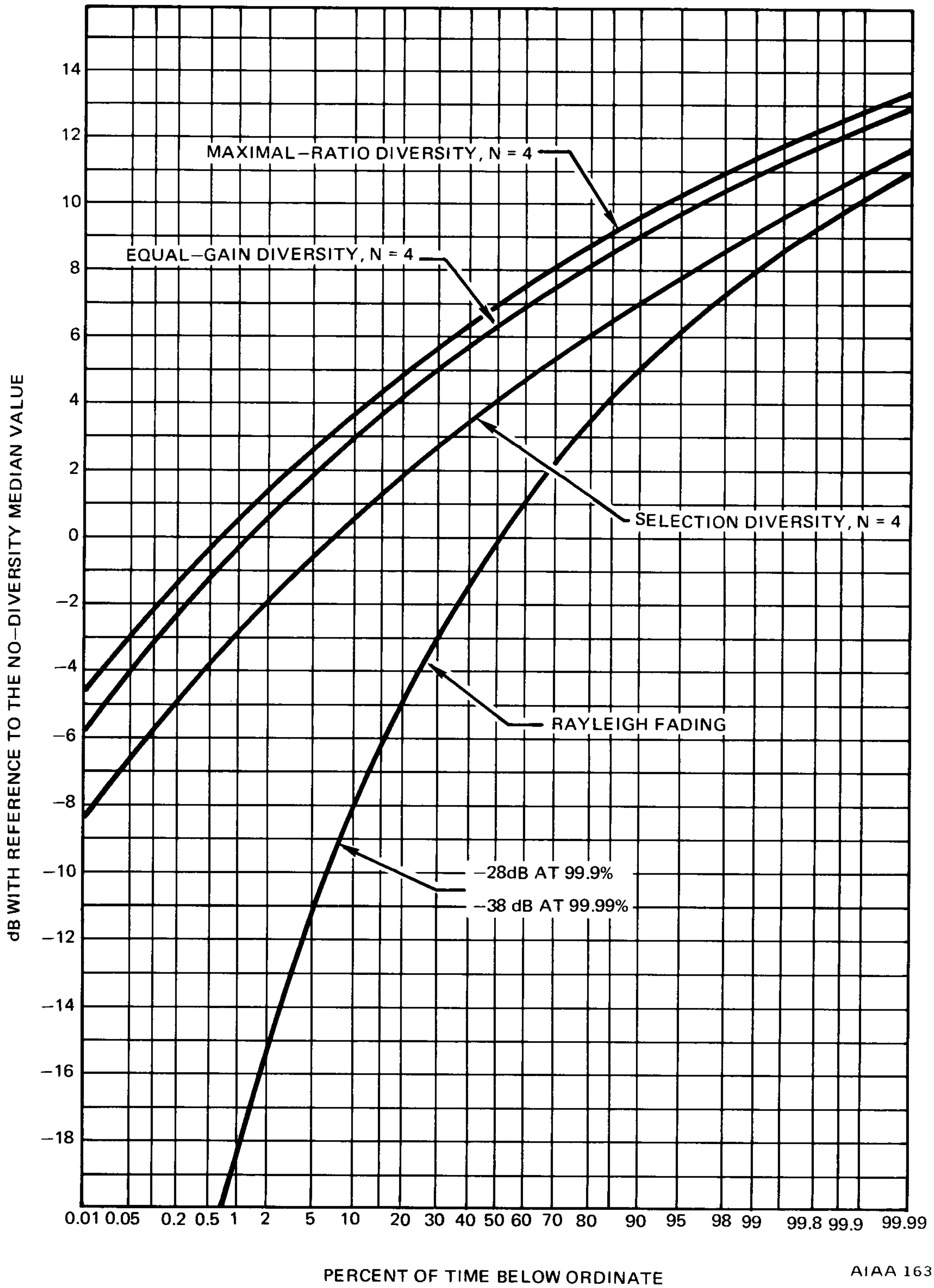

Figure 4-8. Short-Term Fading
(Four-Fold Diversity)

fades. The design procedure is generally to determine the maximum severity of fading to be encountered and then design the equipment complement to meet minimum performance requirements during the worst part of the year.

Long term median signal variations are due primarily to weather and seasonal changes. The slow signal fluctuations come about mainly because of the changes in atmospheric refraction.

The median path loss is usually greatest during the winter, being at times, of the order of 20 dB in excess of that observed for the equivalent period of measurement carried out during the summer. Upward bending of the radio beams in the colder portions of the year tend to increase the scattering angle of the path and thus increase the scattering loss. In addition extreme climatic variations could cause ducting or introduce new path obstacles which in turn could cause abrupt variations in the received signal.

4.2 NOISE

The total noise in any tropospheric scatter system is composed of the noise contributions of several types including thermal, intermodulation, interference and multiplex noise. Distortion appears intermodulation noise. With the exception of path delay distortion, all noise and intermodulation effects are treated in chapter 3.

The beam of microwave energy is not a single line but a wavefront extending for a considerable distance about the centerline. At 120 kilometers an antenna beam of 0.5 degrees would be approximately 1 kilometer wide. The received wave is the sum of a large number of reflections within the common scatter volume of the transmit and receive antennas. The path delay distortion is caused by the differences in path lengths from transmitter to receiver via the various scatter points within the common scatter volume. Using the path length along the centerlines of the two antenna beams as the median path. The maximum path delay error is based upon the energy along the most elevated edge of the antenna beams. This delay in seconds is defined as

$$\Delta = \left(\frac{d}{c}\right)\left(\frac{\Omega}{2}\right)\left(\frac{\theta}{2} + \frac{\Omega}{2}\right) \quad \text{seconds}$$

where

- d is difference in path lengths
- c is the velocity of light in Km/sec
- Ω is the beamwidth of the antennas in radians
- θ is the path angular distance in radians.

CHAPTER 5

LINE-OF-SIGHT SYSTEM PLANNING

This chapter provides a systematic approach to the problems involved in planning line-of-sight (LOS) microwave communications systems. The basic concept of systems planning is divided into several categories. Each category is organized in a logical fashion to describe the various tasks involved. Major tasks are presented in such a manner that each task presents information that must be considered in the development of succeeding tasks.

In the preliminary planning stages, the systems planner lays the groundwork for the proposed system. Investigations are conducted to determine the locations that must be connected by the particular system, the number and type of communications circuits required between the various locations, and the possible need for interconnecting the system with existing communications facilities. Based on the data compiled, a preliminary system plan and a channelization diagram showing the general system configuration and traffic pattern are prepared. These tentative diagrams show the basic system requirements and serve as a basis for the overall system plan. The preliminary system plan indicates the geographic locations to be linked by the proposed system. The next planning phase, route engineering, is concerned primarily with path evaluation and site selection. The tasks involved comprise those required to establish suitable transmission paths between the important system locations, and to select sites for the installation of required terminal and repeater stations. Feasibility path-loss calculations, together with the initiation of the BESEP (The Base Electronics System Engineering Plan) is also presented. Appendix B contains feasibility design data sheets with required equations. This chapter provides a numerical example of the calculations.

5.1 CHARACTERISTICS OF LOS RADIO SYSTEMS

Frequency modulated, microwave, LOS radio systems provide a flexible, reliable, and economical method of establishing point-to-point, multichannel communications. When the path is predominantly over land, and the terrain permits the use of intermediate repeater stations, these systems can be extended for several hundred miles. Aided by appropriate multiplex equipment, such systems can provide the transmission potential for a great number of voice, telegraph, facsimile, and data channels, accommodating basebands consisting of up to 1800, 4 kHz channels.

Typical systems, operating at frequencies currently in use (about 1 kMHz to 12 kMHz), use high-gain directional antennas, not normally exceeding 15 feet in diameter, low power transmitters (about 1.0 watt), and sensitive receivers which, through the use of suitable isolation units, share the antennas with the transmitters. Active repeaters of various types and passive repeaters are used to meet particular system requirements. Where no access to the baseband is necessary, heterodyne type (LF) repeaters are used. Where insertion or dropping of traffic at a repeater is called for, remodulating repeaters (back-to-back terminal equipments) are used. Passive repeaters, consisting of plane reflectors or back-to-back parabolas, are used to change direction of transmission to avoid obstacles or conflicts with other services. Plane reflectors are also frequently used in lieu of transmission lines or waveguides when tower heights and frequencies are such that transmission losses and costs would be excessive.

Primary power requirements for LOS radio stations are relatively light. Where inconvenient or uneconomical to obtain power from a local source, battery and motor-generator supplies are included as part of the station complement. Auxiliary battery and motor-generator power sources are normally provided at all sites for emergency use. Various combinations of operational and backup supplies are possible.

5.2 INITIAL EFFORTS

Planning functions include definition of the communications requirements, system concept, system trunking and routing, frequency considerations, support functions and preliminary implementation schedule preparation. Planning functions are presented in a logical sequence for task accomplishment and include data to facilitate preparation of the documentation required at various stages of system development. These activities are summarized in Table 5-1.

Table 5-1. Planner's Activities

ITEM NO.	ACTIVITY	COMMENT
1	Development of Requirements	May be a formal procedure documented in study, or informally documented in memo form.
2	Establishment of a Basic Concept	Early work in concept development is typically at a level indicated by figure 5-3.
3	Detailing the Plan	Basic information that must be generated: Trunking and Routing Plan Map Studies (Paper Terminal and Repeater Siting) Preliminary Site Survey Results Support Requirements Frequency Plan

The initial step in establishing system parameters is the interpretation and translation of the basic communications need into a realistic and feasible definition of the system requirements. This initial step is provided by concise statements of the items developed in Table 5-2, which provide an analysis and substantiation of the requirement. The analysis must consider the merits of competitive approaches. If, for example, an existing cable or LOS system can be extended and updated economically to fulfill the requirement, the planner is required to recommend consideration of this alternative. A graphic presentation of the factors considered and courses of action to which they may lead is shown in figure 5-1.

During this initial phase of project definition, broad guidance is needed to permit the planner to determine rapidly an appropriate means of transmission, taking into consideration distance and the number of channels required.

Table 5-2. Development of Requirements

ITEMS CONSIDERED	ELABORATION
Mission of the System	Include statement of authorized communications requirements that this system will satisfy, which are not satisfied, or only partly satisfied, by existing facilities.
Evaluation of Impact of the system on Overall Navy Communications	Consider budgeting requirements and the competing alternatives for the same funding. Consider impact of proposed system on other existing or proposed systems that it interfaces, replaces, or partially duplicates.
Interpretation of Long Range Effect of the Proposed System	Optimum use of proposed system may require that related facilities be designed; if so, this should be pointed out. The potential of the system for growth or modification to meet changing conditions should be developed.

When requirements have been analyzed and defined, a system concept is developed that meets the needs of the prospective communications users. Factors that must be considered and the steps to be followed in establishing the concept are shown in foldout 5-1. The system concept in the planning stage is sufficiently simple that it may be depicted in a single line drawing on which all known information is noted. Figure 5-2 shows one possible system concept presentation.

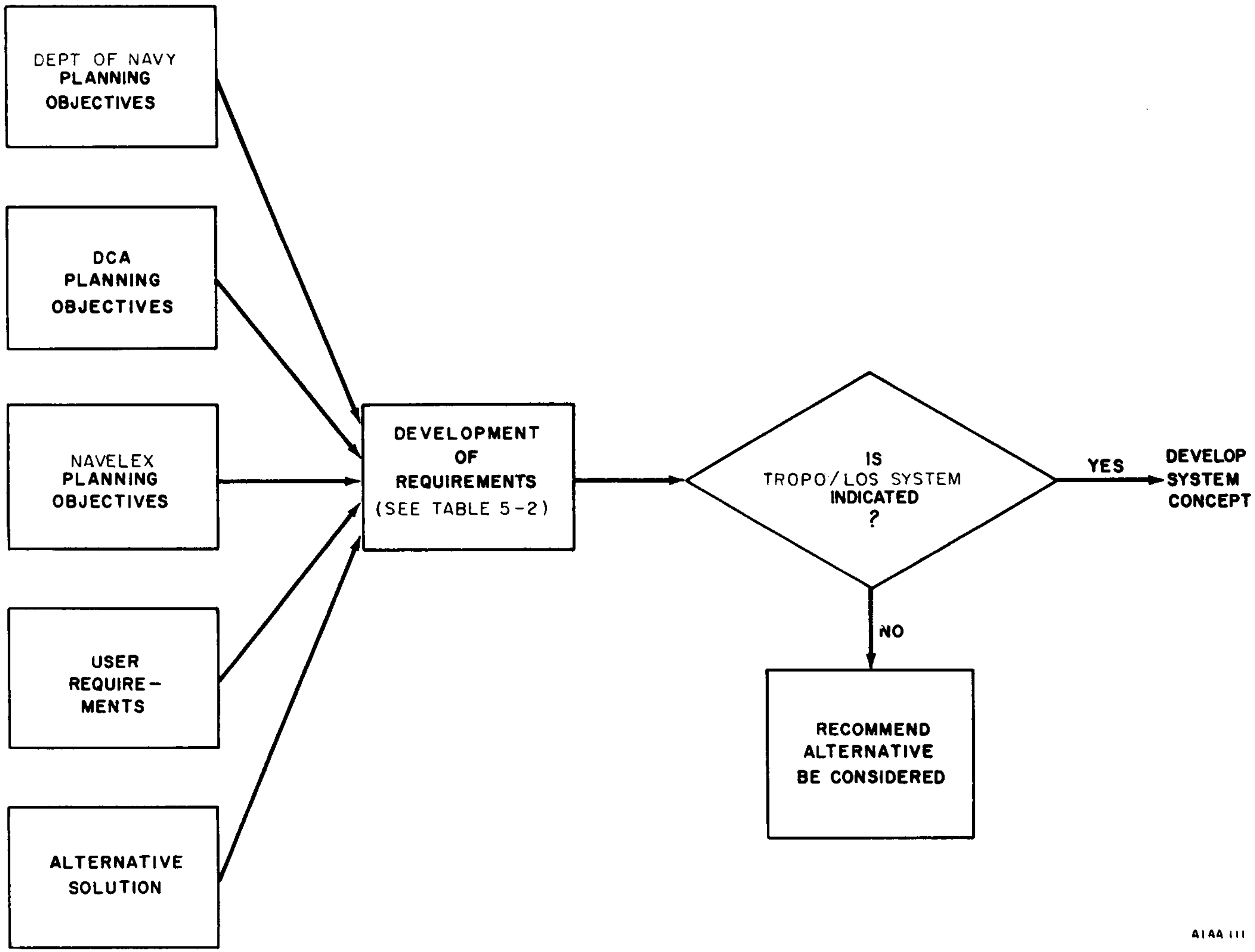

Figure 5-1. Analysis of Requirements

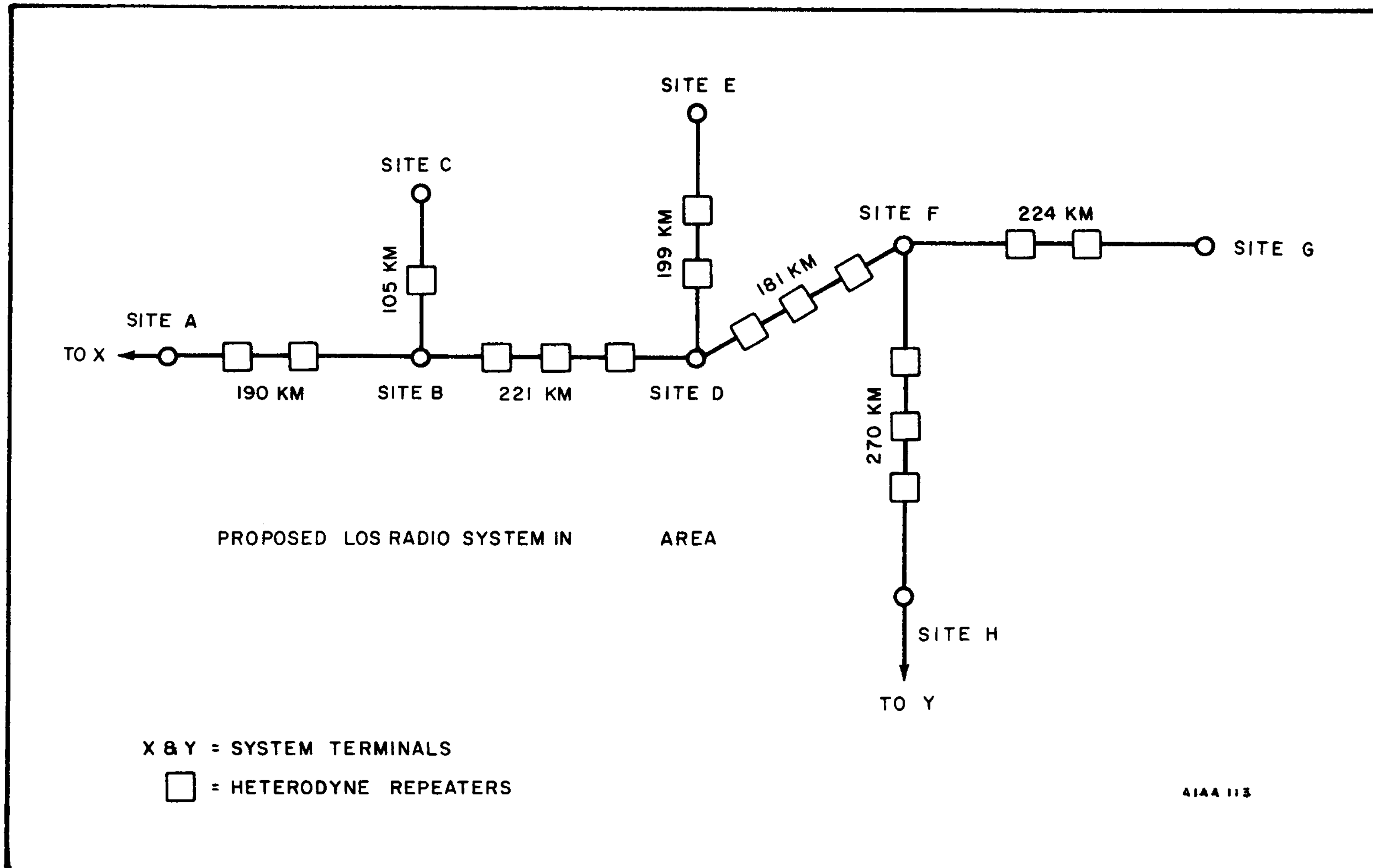

Figure 5-2. Initial System Concept, Typical

The feasibility survey, following preliminary system concept development, considers such questions as whether Site A or Site E is the most appropriate choice, and whether any one of the major hops might be impractical. If, for political or other reasons, there were no suitable radio sites in Site B, and the alternate choice might make the link to Headquarters Location in Site E impractically long, a two-hop link and the use of an additional site in the system would solve the problem.

5.2.1 Preliminary System Configuration

The steps in developing the preliminary system configuration and instructions for their implementation and obtaining the necessary documentation are provided in the following paragraphs.

The first step is to develop a system trunking plan based on approved user requirements. This plan will provide, in line diagram form, a layout of system channelization requirements and terminal locations. The steps involved in developing a trunking plan are best conveyed by an example. Figure 5-3 is a geographical plan of a sample system and Table 5-3 presents its circuit requirements. Both voice and teletype requirements are included. Teletype requirements are also translated into equivalent voice channel requirements on the basis of multiplexing 16 teletype channels into one voice channel.

The system routing plan is based on the trunking plan and portrays the system layout in terms of a definitive system configuration. The objective of the system layout analysis at this phase of systems planning is to determine the feasibility of installing LOS radio links between two or more locations and not necessarily to establish the final route of the system. Where it is apparent that certain stations will have to be located some distance from existing U.S. military facilities, requirements for auxiliary systems and construction should be determined to a degree sufficient for approximating overall systems costs.

It is seldom possible to establish the final location of all system sites during initial planning. For costing and other preliminary planning aspects, however, systems planning groups must determine locations, and ascertain the need for intermediate repeater stations. Systems engineering assistance should be obtained for this task. A simplified systems engineering procedure is given to enable engineers to make rapid determinations of site selection factors and other facets of the system configuration.

5.2.2 Preliminary (Paper) Siting of Terminals (Including Alternate Paths) and Repeaters

A map survey is of major importance in planning and selecting sites that offer the most promising technical and logistical possibilities. Careful analysis of maps that provide reliable topographical data will save much time and effort in the field. From map surveys it is possible to evaluate potential sites and to determine those

NOTES :

1. FIGURE DEPICTS A GEOGRAPHICAL PLAN DEVELOPED FROM FIGURE 5-2. POINT-TO-POINT CHANNEL DEMANDS ARE SHOWN IN ADDITION TO ROUTINGS.
2. NUMBERS DESIGNATE 4 kHz VOICE CHANNELS.
3. LINK D–F HAS NO SPECIFIC CHANNEL REQUIREMENTS BUT CARRIES X - Y, A - H, C - F, C - G, AND E - F TRAFFIC. (SEE FIGURE 5-5).

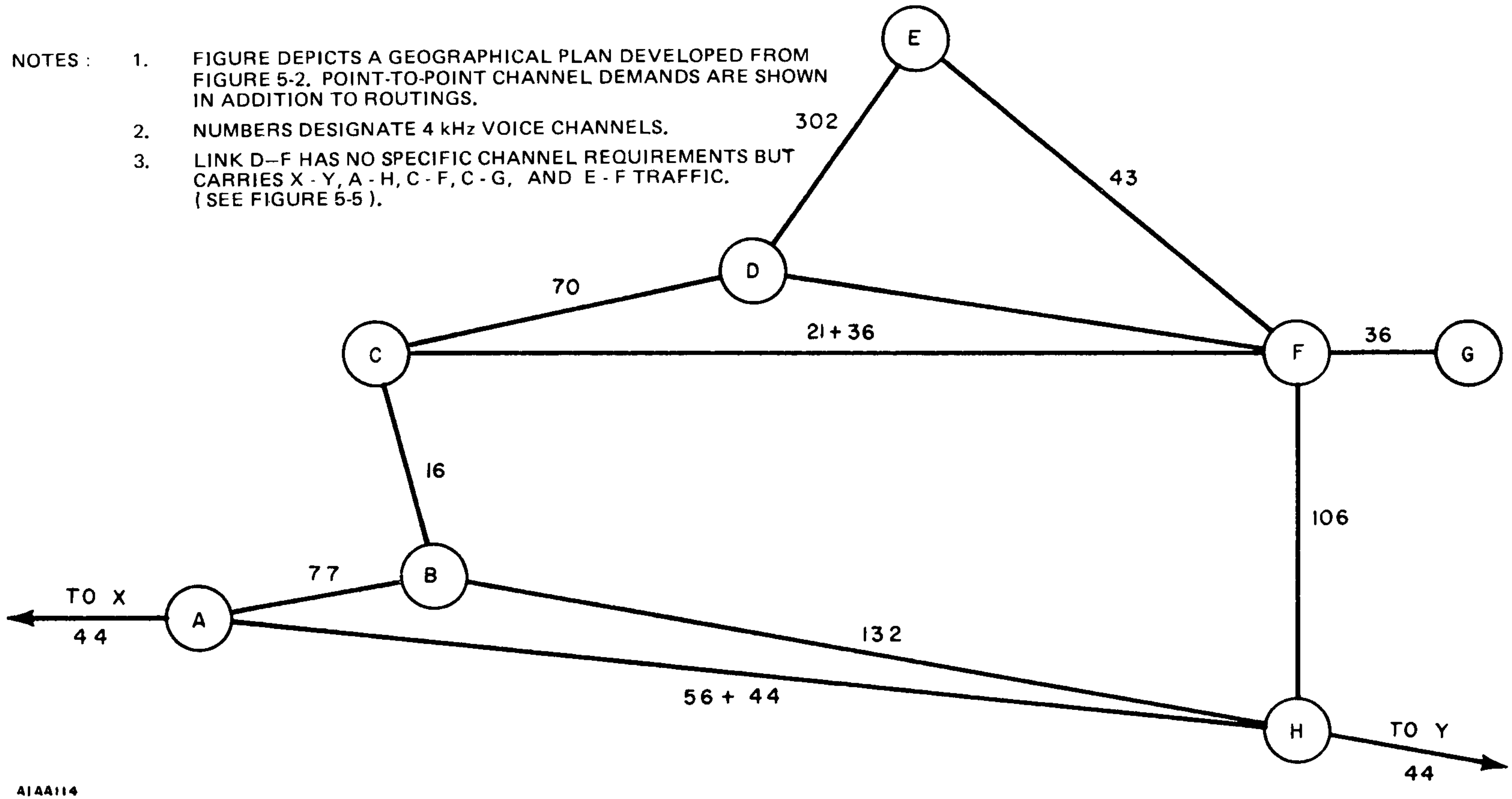

Figure 5-3. System Circuit Requirements, Sample

Table 5-3. Sample Circuit Requirements

BETWEEN STATIONS	VOICE	TELETYPE	VOICE EQUIVALENT TO TELETYPE	TOTAL VOICE
A-B	76	14	1	77
A-H	55	8	1	56
B-C	14	18	2	16
B-H	130	20	2	132
C-D	68	24	2	70
C-F	20	16	1	21
C-G	35	12	1	36
D-E	298	60	4	302
E-F	42	8	1	43
F-H	104	32	2	106
X-Y	42	26	2	44

to be visited by the field team. One or more alternate sites will be selected for each terminal or relay facility. The criteria for map acquisition and study is outlined in Chapter 2.

After appropriate maps are obtained, user locations are plotted. Insofar as practical, terminal stations of the LOS system are located close to the users. In many instances this will not be feasible, and a connecting wire line will be required. For example, where the user is located in a city or town or where for other reasons adequate space does not exist, the radio terminal will necessarily be remote. Furthermore, collocation of terminal sites with the user will frequently severely limit the site selection so as to preclude taking advantage of terrain features conducive to microwave radio propagation. Factors which will determine the adequacy of an LOS site are covered below. While all the factors listed may influence site selection, they cannot be considered to have equal weight; therefore, several sites should be evaluated in terms of their relative merits.

a. Topography of the area surrounding the site affects several factors such as antenna height, support of the site, construction cost of required housing, etc. Many compromises must be resolved, such as: selecting an excellent communications site or a good one offering better accessibility, utilities, and lower construction costs.

b. Vegetation is known to affect propagation, but the degree is relatively uncertain; sparse growth is more penetrable than heavy growth. The safest procedure is to consider vegetation such as trees, vines and high grass or weeds, as being impenetrable to RF energy above 100 MHz, and evaluate the site as if the vegetation were solid earth.

c. The proximity of an LOS link to other Communications-Electronics (C-E) facilities, such as radio transmitters or receivers, radar sets, industrial areas, diathermy equipment, etc., is of extreme importance. Fundamental and harmonic frequencies of all these sources may produce mutual interference. If analysis of the frequencies and levels of radiation indicate probable interference, it may be necessary to relocate one of the facilities.

d. The staff planner should evaluate sites with a view toward expansion of the radio facilities. Such expansion may require increased antenna sizes or, possibly, space for additional antennas and towers, or an enlargement of logistics and other capacities. Wherever possible, sites should be selected to give good line-of-sight conditions in all anticipated directions of communication. Foldout 5-2 depicts a typical site layout.

After tentative selection of the radio terminal locations and any required intermediate repeater sites, the preliminary routing plan is prepared. Figure 5-4 is a sample routing plan, based on the circuit requirements in Table 5-3. Figure 5-5 is a trunking diagram derived from circuit requirements and the routing plan. This diagram will be used in the system engineering phase as the basis for the multiplex channelization plan.

5.2.3 Plotting the Preliminary Route

The procedure outlined below may be used for plotting the tentative backbone route of the proposed system. When the general system layout indicates that a spur system is required, this procedure may also be employed for plotting the spur route.

a. Using a contour map and a sheet of transparent linear graph paper, prepare an outline drawing of the general system area. Figure 5-6 shows a representative portion of a typical outline map.

b. On the outline map, designate the locations of the terminal stations and all other main system locations, as determined in paragraph 5.2.2.

c. Locate the highest suitable elevation at, or close to, each terminal station and all other main system locations.

d. Starting at one terminal station, connect all main system locations with a solid line indicating the preferred (straight-line) route of the backbone system. Where a spur system is required, connect the spur station to the backbone system at a logical junction point.

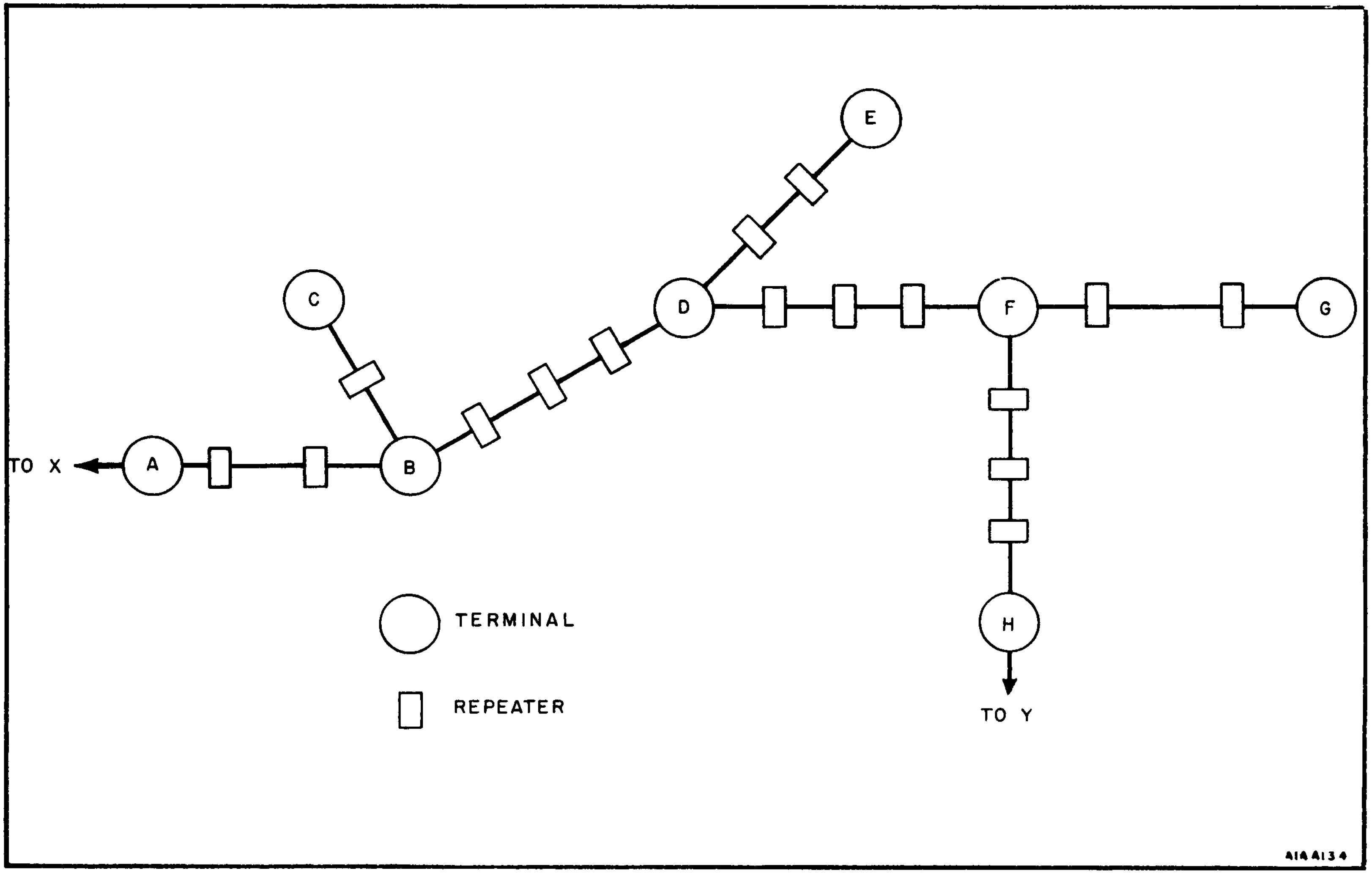

Figure 5-4. System Routing, Typical

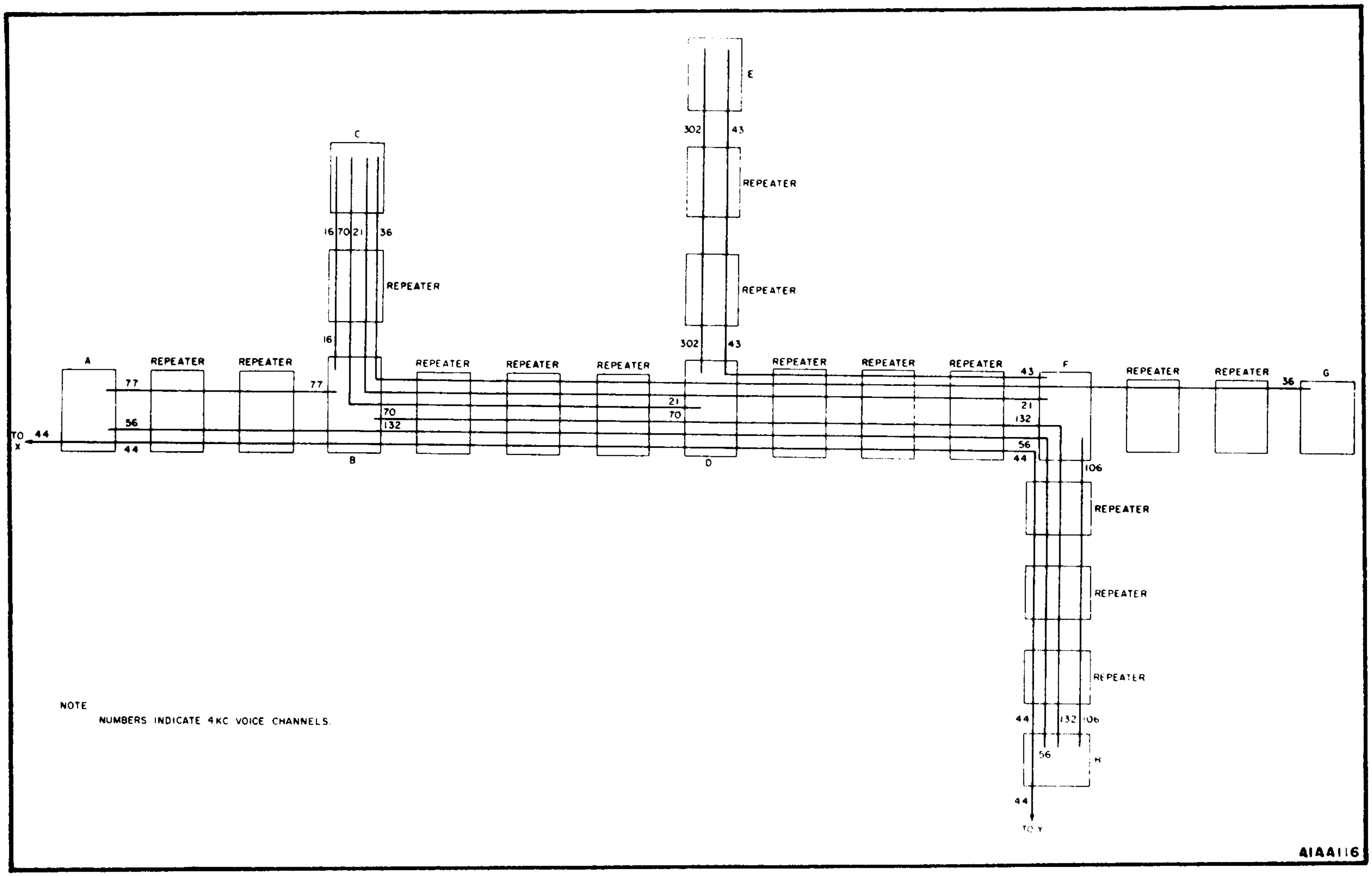

Figure 5-5. System Trunking Diagram, Typical

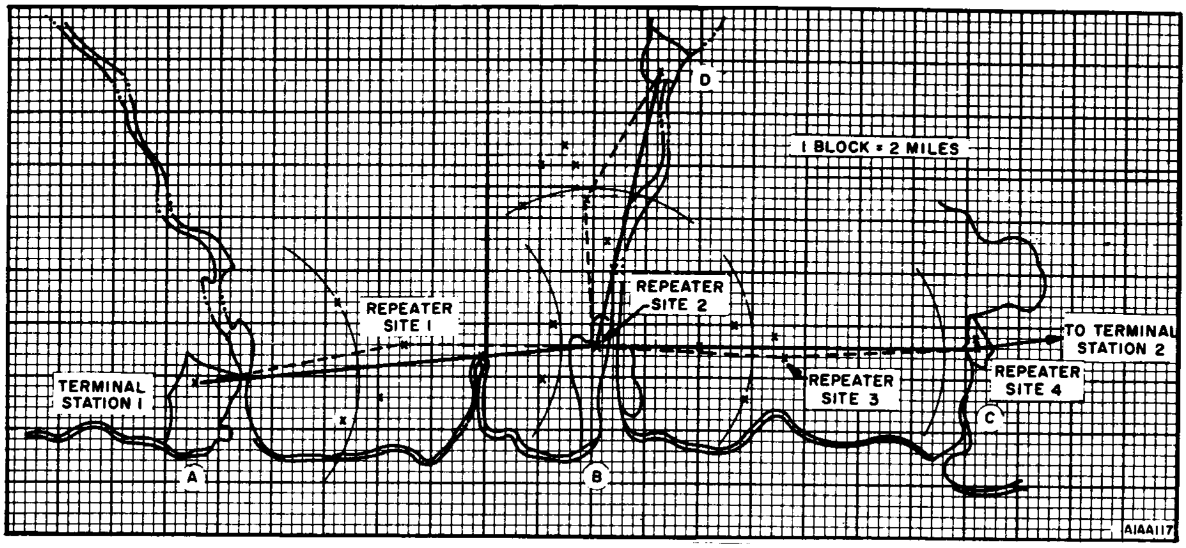

Figure 5-6. Map of System Area Showing Tentative Site Location

e. From the original map scale, assign a scale to the outline map. In figure 5-6 one block equals 2 miles.

f. From one terminal station, draw an arc having a radius of 30 miles which crosses the preferred backbone route in the general direction of the opposite terminal. Pick and plot all suitable elevations falling on or near the 30 mile arc (see figure 5-6).

g. Select a tentative site location from the elevations plotted above, and label this site Repeater Site 1. Connect the terminal station and Repeater Site 1 by means of a dotted line indicating a tentative path.

h. Using the procedure outline in Appendix E, plot an earth profile graph for the tentative hop between the terminal station and the relay point. Determine from the graph whether there is a line-of-sight path between the two sites. If a suitable path cannot be established, select an alternate location for Repeater Site 1, and repeat the above procedure.

i. When a suitable site is located, draw an arc with a 30 mile radius about this point in the direction of the next main system location or terminal station (see figure 5-6). Repeat the above procedure to locate Repeater Site 2.

j. When a suitable location for Repeater Site 2 is determined, locate Repeater Sites 3, 4, etc., as required to span the distance between the terminal stations. If a spur system is required, this procedure may be used for plotting the spur route.

The preliminary route plan resulting from the above calculations will provide planning personnel with an insight to the general requirements of the proposed system, and may be used for estimating purposes. The plan must be considered as tentative, and subject to changes based on field survey findings.

5.3 BASIC SYSTEM DESIGN DATA

The application of microwave equipment to a communications system is generally that of a radio-relay or radio-link function. A basic microwave system consists of two terminal stations and as many radio-relay stations (repeaters) as are required to span the distance beween the terminals. The total area traversed by the system is called a route. The distance between any transmitter and the receiver that receives its transmissions is called a hop. The terrain over which the transmissions in any hop travel is called a path. A basic system may consist of a single hop; more complex systems are made up of a number of hops. The system may be designed to provide simplex (one-way) or duplex (two-way) communication.

In planning the system layout, certain basic design criteria and standard system arrangements are used. The following paragraphs contain information relating to the important factors that must be considered.

5.3.1 Hop Length

For purposes of communication using microwave frequencies, radio transmission is generally confined to the troposphere, that portion of the earth's atmosphere directly adjacent to the earth's surface. The troposphere is generally considered to extend upward from the earth's surface to between 5 and 10 miles, depending on the geographic location. Radio waves transmitted within the troposphere are attenuated very rapidly with distance; therefore, useful transmissions within this region are generally limited to short distances (25-35 miles), commonly called "line-of-sight" paths. Because of this restriction, the permissible hop length between any transmitting and receiving equipment is somewhat critical, and is a primary consideration when preparing tentative system plans. As a general rule, an average hop length of 30 miles should be used in preparing the preliminary system layout. Longer hops may be considered where elevations and propagation conditions are suitable.

5.3.2 Backbone System

The main route between any two principal terminals is termed the "backbone" system. The backbone system may be of any length, as necessary to fit the general requirements of the area to be served. The backbone system should be planned to follow the shortest practical route between the terminal stations. System locations situated away from the logical backbone may be connected through the use of a side hop or spur system. Figure 5-6 shows the proposed backbone route of a typical system. A proposed spur system is shown connected at Site B.

5.3.3 Spur Systems

There are several methods by which a spur system may be connected with the backbone system. The method used will depend on one or more considerations, such as cost of installation, type of terrain, required system flexibility, and circuit requirements of the spur station.

a. Tandem Repeater. The most economical method of connecting a spur station to the backbone system is through the use of a tandem repeater arrangement (see figure 5-7). Note that the original linkage between Stations B and E is broken by reorienting the antennas toward the spur station (c); in other words, the spur station is simply made a part of the backbone. Such an arrangement requires a minimum amount of equipment since the spur station serves as another repeater. The tandem repeater is limited in application because it can be used only when the distances involved are relatively short and when the elevations and paths are suitable.

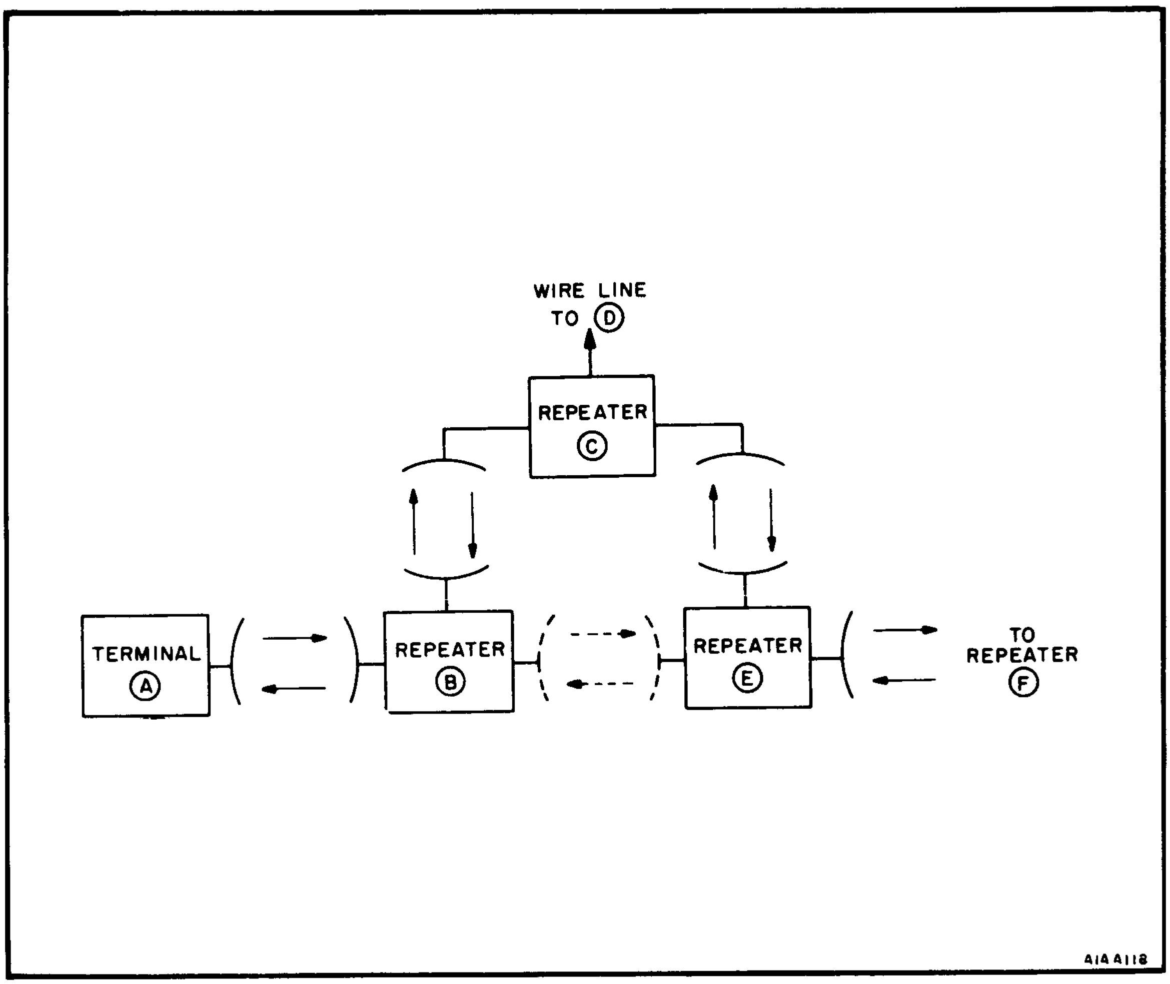

Figure 5-7. Tandem Repeater Spur

b. Terminal-to-Terminal Spur (see Figure 5-8). The spur system is connected to the backbone system by means of a junction station employing a microwave repeater and a microwave terminal. The connection between the repeater station in the backbone system and the terminal equipment feeding the spur system is accomplished through the use of a hybrid junction.

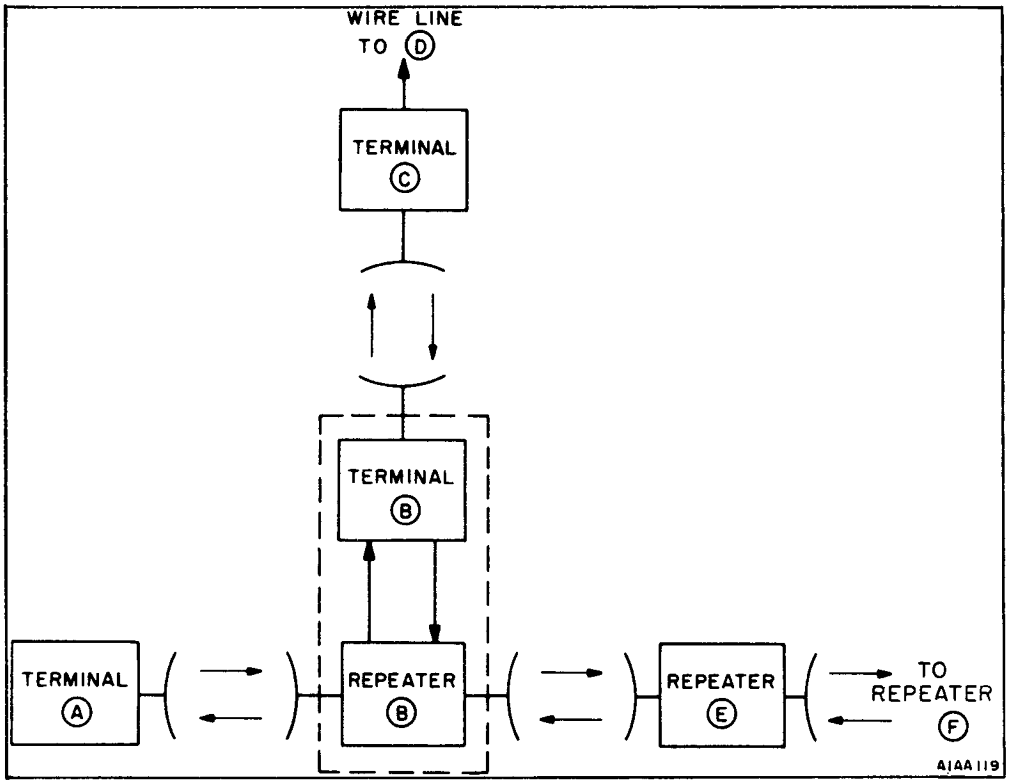

Figure 5-8. Terminal-to-Terminal Spur

c. Drop Repeater with Terminal-to-Spur. The spur system arrangement shown in Figure 5-9 is similar to the terminal-to-terminal spur; however, facilities are provided for dropping one or more channels at the junction station. Interconnection between the backbone system and the spur system is accomplished by means of an audio patch between the multiplex dropout equipment, in the backbone system, and the multiplex terminal that feeds the spur system.

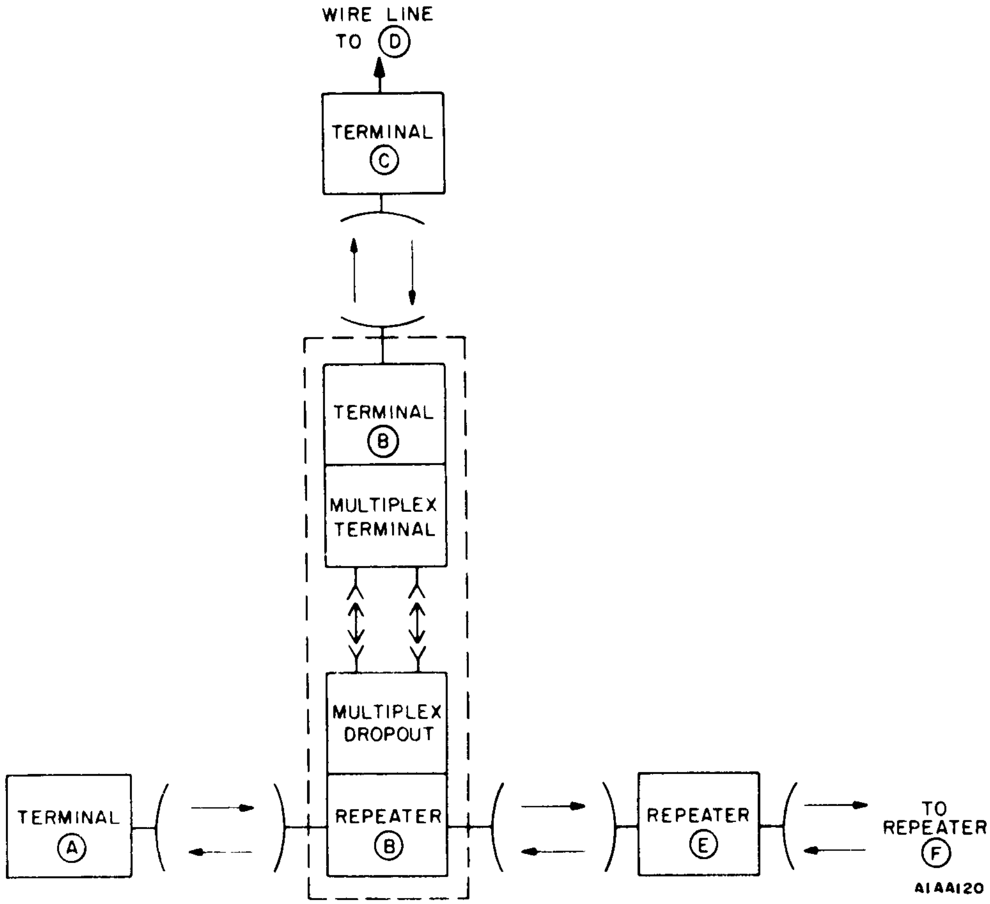

Figure 5-9. Drop Repeater With Terminal-to-Terminal Spur

d. Back-to-Back Terminal with Terminal Spur (see figure 5-10). This method of interconnection is commonly used in systems employing a central terminal. Signal interconnection for both the backbone and the spur system is accomplished by means of an autdio patch between the multiplex terminal equipments. This method of interconnection, although having large equipment requirements, provides the system with a high degree of flexibility. Circuit routing may be provided by a dial selective automatic switching arrangement or by a telephone switchboard.

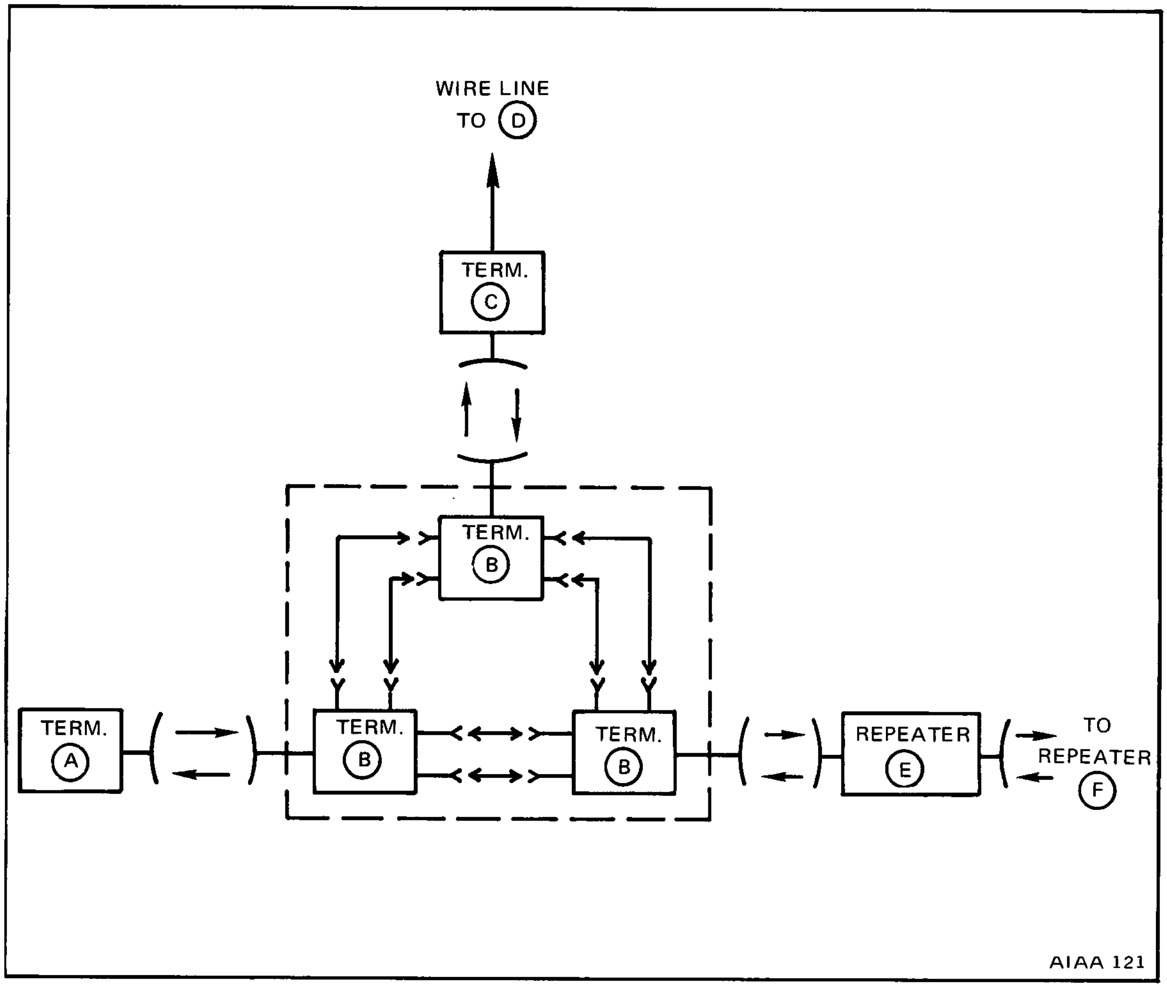

Figure 5-10. Back-to-Back Terminal With Terminal Spur

5.4 CHANNEL AND FREQUENCY ALLOCATION PLANS

A microwave radio relay system will perform within its specified requirements, provided the systems engineer has properly defined the system channel loading requirements, and provided he has allocated the most appropriate frequency plan.

5.4.1 Channelization

The term channel, as applied to microwave communications systems denotes that portion of the total communications bandwidth required for the transmission of a single voice-band signal between two or more stations. Voice-band signals are defined as those signals within a 100-3500 Hertz band, and include the signals normally used in telephone conversation, teletype, telegraph, telemetering, facsimile, etc. A standard voice-band channel, including guard bands, has a 4000 Hertz bandwidth.

Voice-band channelization in microwave systems applications is obtained through the use of multiplexing equipment. Multiplexing equipment provides the means of combining signals from a number of sources into a composite signal for transmission by the microwave carrier. The number of channel inputs or outputs required at a given station has a direct bearing on the quantity and type of multiplexing equipment required. In addition, the transmission bandwidth required for transmitting the composite multiplex, or baseband, signal determines the bandwidth requirements of the microwave transmitting equipment. Since the total number of channels required in a given system has a direct bearing on the equipment requirements, care must be exercised in determining the channel requirements. The channelization diagram is prepared for the purpose of summarizing the overall channel requirements of the system.

a. Channel Requirements. The traffic or trunking plan for the system (a typical trunking plan is shown in figure 5-5) outlines the operational requirements of the system and shows the proposed routing of all data. To determine the number of channels required to accomplish the desired distribution, the requirements of each station must be considered separately. The bandwidth required for transmitting each type of data must be determined, and one or more channels then allotted to each function. If the equipment types are known, the bandwidth required to the particular type of signal may be obtained from the equipment manuals or from manufacturers' specifications. In those cases where no specific technical information is available, estimates should be based upon the technical characteristics of the equipment employed in similar applications. The following paragraphs provide general information which may be used for determining the channel requirements of the average system.

(1) Telephone Channels. For satisfactory telephone transmission, the bandwidth provided by a full voice-band channel is required. Therefore, the number of individual telephone circuits required at a given station determines the number of channels which must be allotted to this function. If the telephone circuit is to be used on a party-line basis, the same channel is assigned to all stations designated to share the circuit. If a private-line telephone circuit is required, the channel is assigned at only those stations to be connected.

(2) Telegraph and Teletype Channels. The bandwidth required for satisfactory telegraph or teletype transmission will vary, depending upon the operational characteristics of the equipment employed. In general, a bandwidth of between 50 and 75 Hertz is adequate for satisfactory transmission of a single telegraph channel.

Through the use of standard voice-frequency telegraph equipment, a number of telegraph or teletype signals may be combined for transmission over a single voice-band channel. In these applications, a bandwidth of several hundred cycles is required. To determine the number of voice-band channels required, therefore, the quantity of information to be transmitted must be determined, and suitable carrier telegraph equipment selected. For example, using Navy standard 16-channel voice-frequency carrier telegraph equipment, a single voice-band channel can carry 16 separate telegraph-type signals. If 48 telegraph channels must be provided, three voice-band channels, each equipped with 16-channel carrier telegraph equipment, will be required.

(3) Telemeter Channels. The bandwidth required for transmission of a telemeter channel depends on the type of data to be transmitted, the degree of accuracy required, and the functional characteristics of the telemetering equipment used. In general, a single voice-band channel can be used for transmitting a number of high grade telemeters. In systems applications where great quantities of data must be transmitted, special encoding equipment is available that permits a number of telemeters to be transmitted in the bandwidth normally occupied by a single telemeter channel.

(4) Facsimile Channels. Facsimile is the transmission of graphic material such as pictures and text, by electrical signals. The bandwidth required for transmitting this type of information depends upon the type of facsimile equipment employed. Equipment is available which operates in the standard voice-band frequency range. When this type of equipment is used, each facsimile channel occupies a full voice-band channel. In applications where a high degree of resolution is required of the transmitted material, wideband facsimile equipment is used. This equipment requires about twice the transmission bandwidth required by standard equipment; thus, two voice-band channels are necessary for satisfactory transmission. The wideband channel required in this instance can be obtained through the installation of special multiplexing equipment at the sending and receiving stations.

(5) Other Channel Requirements. In addition to the above channel requirements, the average system requires one or more voice channels for maintenance communications purposes and to permit the transmission of various types of control data. One voice channel, connecting all stations with a responsible terminal station, is generally reserved for maintenance purposes. This channel is called the service, or order-wire, channel. In addition to providing a voice communication facility, the service channel, through the use of special equipment, may also be used for fault reporting (alarm) purposes and/or supervisory control functions. The fault alarm system permits operators at system control points to monitor equipment status at unattended stations; supervisory control circuits permit system operators to control remote functions.

b. Channelization Diagram. The channelization diagram (foldout 5-3) summarizes the voice-band channel requirements of a typical system. In addition to showing the overall channel requirements, the diagram is also used to designate system control points and the monitoring stations for the fault alarm system.

5.4.2 Frequency Allocation

In the United States, including its territories and possessions, the use of all radio frequencies is subject to the control of two government agencies, the Federal Communications Commission (FCC), and the Interdepartment Radio Advisory Committee (IRAC). Under their joint authority, the frequency spectrum from 10 kHz to 30 kMHz has been divided into bands and assigned to a general category for use, such as Marine, Broadcasting, Aeronautical and Radionavigation, Public Service and Government, and Experimental and Amateur.

Microwave communication system frequencies occupy the following bands: Common carrier, 5925-6425; Industrial 6575-6875; and Government 7125-8400. Non-governmental agencies or individuals desiring to use any frequency within the appropriate bands must apply to the FCC for permission, stating the frequency, power, and type of modulation or operation desired. Governmental agencies must apply to IRAC for frequency allocations in the Government bands.

Military users of microwave communication systems generally attempt to operate within the allocated Government frequency band, so that recourse to the FCC for permission to operate on a specific frequency is not necessary. A frequency assignment coordinator at the cognizant military headquarters is responsible for assigning frequencies to elements under the headquarters command. Frequency assignment is based on the frequencies allocated to, and the geographic location of, other government or non-government users in the same area.

Since microwave equipments are used worldwide, and since the frequency bands allocated for microwave systems may be different throughout the world, no specific rules can be established for all cases. However, the following general procedures should be adhered to as closely as is practicable.

a. Determine the frequencies desired, including suitable alternates, after consulting available records to determine the frequencies presently in use in the area.

b. Request the assignment of frequencies from the appropriate agency; i.e., the cognizant military headquarters, the FCC, IRAC, or the foreign equivalent of these agencies.

c. In the case of military systems, frequencies should be chosen in either the Industrial or Common Carrier band if it becomes necessary to select frequencies outside the Government band.

5.5 INITIATION OF BESEP

The foregoing planning efforts, together with all other aspects related to employing a microwave communications link, are usually organized in a comprehensive planning document entitled a "Base Electronic System Engineering Plan" (BESEP).

5.6 FEASIBILITY PATH LOSS CALCULATIONS

5.6.1 Path Data Sheet

Path data sheets provide a way of determining and recording all parameters affecting overall transmission loss. They are a useful tool for preliminary work, as well as for recording data for future reference. A separate sheet can be completed for each path, or the data for a number of paths can be combined into a single sheet (in the latter case, the data and calculations are for the individual paths and not for the overall system).

Figure 5-11 is an example of a completed path data sheet. The following discussion illustrates some of the planning details and the calculation methods.

The heading indicates that this was a one-hop system, operating in the 7125-8400 MHz frequency band, with a 960-channel design capacity.

The data in Items 2, 3, and 4 were determined during the path survey, which also produced a path profile and other data, allowing the engineer to determine the tower heights (Item 5), based on the desired clearance criteria. (From the disparity in tower heights at the two ends, it appears either the path was non-symmetrical, or that a high tower at Alpha was impractical.)

Items 7 and 8 were calculated from Items 2 and 3, and the path attentuation then calculated using equation E-1 in Appendix E (or read from the appropriate chart in Appendix A) and entered as Item 9.

Items 10 through 15 record separately, for each end of the path, the collective dB losses in all fixed-loss items between the equipment-connection flange and the antenna-connection flange, plus the fixed loss of the radome (if one is used, and its loss is not included in the antenna gain figure).

In the system design stage, the exact waveguide layout is usually not known, so reasonable estimates must be made at this time as to the amount and types of guide to be used. The fixed losses appear small in comparison to path attenuation, but are vitally important to the system loss and gain equation, and must receive very careful consideration. (A 3-dB increase in fixed losses is equivalent to cutting transmitter power in half, or a 6-dB increase in fixed losses is equivalent to doubling path length.)

The items from 10 on are not developed in the order in which they appear in the data sheet because of interactions between many of the items; actual selection usually involves evaluating several different combinations to find the one most suitable for the particular circumstance.

Thus, the remaining items are discussed in the sequence in which the transmission engineer might have developed them:

MICROWAVE PATH DATA CALCULATION SHEET

CUSTOMER ______

PROJECT NO. XXX FREQUENCY 6175 MHz

SYSTEM ALPHA TO BETA EQPT 78A

LOADING +14.8 dBm0 960 CHANNELS OF 46A

1	SITE		ALPHA	BETA
2	LATITUDE		34° 19′ 01″	33° 57′ 01″
3	LONGITUDE		84° 53′ 52″	84° 39′ 57″
4	SITE ELEVATION	FT.	125	240
5	TOWER HEIGHT	FT.	80	250
6	TOWER TYPE		SS	GUYED
7	AZIMUTH FROM TRUE NORTH		152° 11	332° 14
8	PATH LENGTH	MILES KMS	28.55 45.94	
9	PATH ATTENUATION		141.5	
10	RIGID WAVEGUIDE WR137	FT.	100	25
11	FLEXIBLE WAVEGUIDE	FT.	5	5
12	WAVEGUIDE LOSS	dB	2.5	1.0
13	CONNECTOR LOSS	dB	0.5	0.5
14	CIRCULATOR OR HYBRID LOSS	dB		
15	RADOME LOSS, TYPE*	dB	0.5u	0.5u
16	TOTAL FIXED LOSSES	dB	3.5	2.0
17	TOTAL LOSSES	dB	147.0	
18	PARABOLA HEIGHT	FT.	75	15
19	PARABOLA DIAMETER	FT.	10	6
20	REFLECTOR HEIGHT	FT.		245
21	REFLECTOR SIZE, TYPE**	FT.		10 x 15C
22	PARABOLA–REFL. SEP.	FT.		230
23	ANTENNA SYSTEM GAIN	dB	43.0	41.9
24	TOTAL GAINS	dB	84.9	
25	NET PATH LOSS	dB	62.1	
26	TRANSMITTER POWER	dBm	+28.0	
27	MED. RECEIVED POWER (±2 dB)	dBm	−34.1	
28	RECEIVER NOISE THRESHOLD	dBm		
29	THEORETICAL RF C/N RATIO	dB		
30	PRACTICAL THRESHOLD (55 dBrnc0)	dBm	−74.0	
31	FADE MARGIN (TO PRAC. THRES.)	dB	39.9	
32	RELIABILITY, SPACING***%			
33	PROFILE NUMBER		1	

*U – UNHEATED, H – HEATED, F – FEET HEATER
**F – FLAT, C – CURVED
***F – FREQUENCY DIVERSITY, S – SPACE, DIVERSITY, Q – SPACE & FREQ. DIVERSITY, N – NON-DIVERSITY

(RELIABILITY FIGURES ARE FOR RAYLEIGHT DISTRIBUTED FADING ONLY)

NOTES:

ENGINEER: DATE:

AIAA 123

Figure 5-11. Microwave Path Data Calculation Sheet

o He ascertained that the required (or desired) fade margin is 40 dB to the 55 dBrnc0 point. He entered the 55 dBrnc0 value in the parentheses of Item 30, to establish the practical threshold point. He also tentatively entered 40 dB in Item 31.

o He ascertained from manufacturer specifications, or from a curve such as figure 5-12, that the RF input required to give 55 dBrnc0 in the top (worst) channel was -74 dBm. He entered this value in Item 30.

o By algebraically adding Item 31 to Item 30, he determined a tentative value of -34 dBm as the received signal needed to give a 40 dB fade margin. It was also ascertained (from manufacturer specifications) that the recommended median receive signal level for 960-channel operation is -33 dBm. Since this was higher than the calculated -34 dBm, -33 dBm was tentatively entered in Item 27.

o From manufacturer specifications, it was determined that the transmitter had a minimum output power of +28 dBm, and this was entered in Item 26.

o By algebraically subtracting Item 27 from Item 26, he determined a maximum allowable value of 61 dB for net path loss, and tentatively entered 61 dB in Item 25.

o By algebraically subtracting the 61 dB in Item 25 from the 141.5 dB in Item 9, it was determined that total antenna gains, minus fixed losses, must be at least 80.5 dB to produce the desired value of net path loss.

o At this point a tentative selection of antenna system types was made. (If other considerations are not controlling, the choice will probably be based on the best combination, considering gaining-efficiency and economics. However, frequency congestion or other considerations might preclude the use of a periscope system, or dictated the choice of specific antenna arrangements.)

We assume that the choice was a direct radiating parabola at Alpha, mounted atop the tower, and a periscope system at Beta.

o Having chosen the antenna system, he must make a reasonably close estimate of the amount of waveguide and all other applicable fixed-loss items required. In this case he chose WR 137 rigid waveguide, and entered the estimated lengths in Item 10. He also entered estimated lengths of flexible waveguide losses, using 2.0 dB per 100 feet for the rigid and 0.1 dB per foot (typical value) for the flexible waveguide and entered the total losses in Item 12.

Item 13 is a catchall for small losses associated with pressure windows, bends, and flanges. (The 0.5 dB per end shown is a conservative estimate for most waveguide runs.)

In this case there were no circulators or hybrids external to the equipment; no entry was made in Item 14.

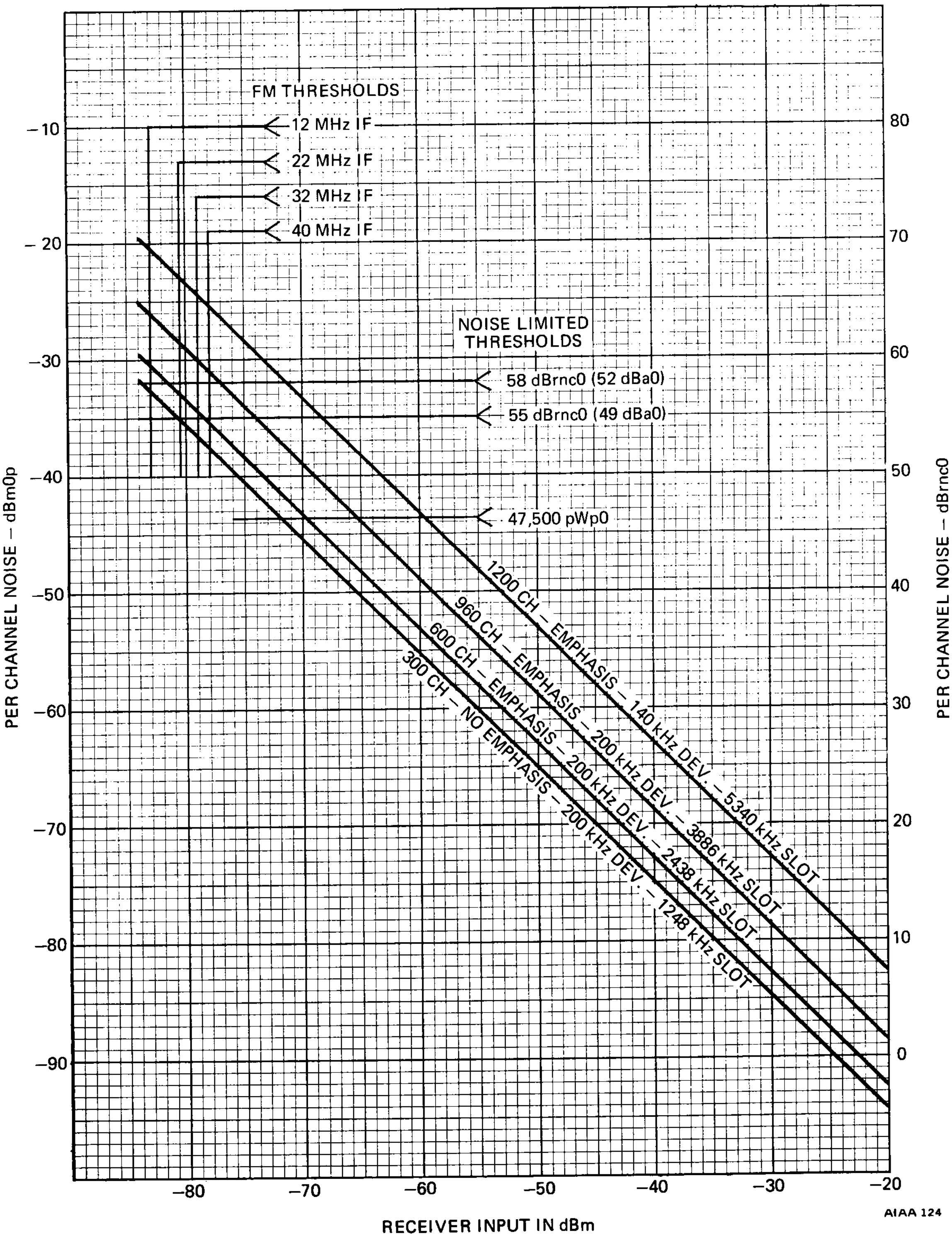

Figure 5-12. Receiver Thermal Noise (10 dB Noise Figure Assumed)

Item 15 will depend on the type of radome; 0.5 dB is typical for an unheated radome in this band.

o The fixed losses were totaled and entered in Item 16. He added the 5.5 dB total fixed losses to the 141.5 dB path attentuation of Item 9, and entered the 147.0 dB result in Item 17.

o He subtracted the tentative value of Item 25 (61 dB) from the total losses of Item 17 (147.0 dB), and obtained 86.0 dB as a tentative value of required total gain (Item 24).

o He divided 86.0 dB by two to obtain a tentative value of 43.0 dB as the required antenna gain at each end of the path. (It is usually most cost effective to have antenna gains divided about equally.)

o He determined that a 43.0 dB gain at 6175 MHz would require at least a 10-foot parabolic antenna. In this case he entered the gain figure as taken from charts in Appendix A, 43.0 dB, as the gain of the Alpha antenna in Item 23, and entered 10 feet in the Alpha column for Item 19.

o By subtracting this 43.0 dB from the tentative 86.0 dB of Item 24, it was found that 43.0 dB antenna system gain was needed at the other end. From charts in Appendix A, using the -0.7 dB gain factor and the 1.09 dB distance factor for the 6.175 GHz band, it was determined that a 12-foot x 17-foot reflector was needed to meet the 43.0 dB true gain requirement.

At an apparent (chart) distance of 230 feet x 1.09 feet = 251 feet, a 6-foot dish and either a C.R. or a C.E. reflector gave an apparent (chart) gain of about 44.5 dB (a true gain at 6.175 GHz of 44.5 - 0.7 = 43.8), somewhat better than the objective. If the requirements were absolute, this would have been the probable choice, but in this case the engineer did not want to use the very large and heavy 12-foot x 17-foot reflector. Instead, the next lower size (a 10 foot x 15 foot) was examined and it was determined that at the apparent distance of 251 feet, a 6-foot dish and a 10-foot x 15-foot C.E. reflector gave an apparent gain of about 42.6 dB (a true gain of 41.9 dB) at 6.175 GHz. After entering this value in Item 23 and carrying out the necessary calculation, the median received signal was found to be -34.1 dB instead of the desired 40 dB. The 0.1 dB difference in fade margin was insignificant because there was no stringent requirement and, since noise performance was also found to be satisfactory, the final choice was a 6-foot dish and a 10-foot x 15-foot reflector.

o The engineer entered a 6-foot parabola under Beta in Item 19, and a 10-foot x 15-foot curved reflector under Item 21. (Items 18, 20, and 22 were determined and entered prior to accomplishment of Step 13.) He entered 41.9 dB under Beta in Item 23, changed the tentative 86.0 dB in Item 24 to the final value of 84.9 dB, subtracted this from Item 17 to obtain the final value (62.1 dB) for Item 25; subtracted 62.1 dB from the +28.0 dBm of Item 26 to obtain the final median received signal level (-34.1 dBm), and subtracted from this the -74.0 dBm0 of Item 30, to obtain the final fade margin (39.9 dB) for Item 31.

Item 28, the "receiver noise threshold," and Item 29, the "theoretical RF C/N ratio," have been deliberately left blank in this example, since they play no part in the choices or calculations. They are on the sheet mainly for historical reasons, and because user specifications occasionally call for them. Item 28 is 10 dB lower than the "FM Improvement Threshold." In this example, the FM threshold is of no importance in the calculations, since the practical threshold determined from noise considerations is at a considerably higher level. (Figure 5-12, which shows that the FM threshold would fall at about -79 dBm, assuming a 32 MHz IF bandwidth, or at -78 dBm with a 40 MHz bandwidth.)

A hop which includes a passive repeater requires a somewhat more complicated approach in the path data sheet. For Items 1 through 9, and the pertinent Items from 17 through 23, it is treated as a two-path system, but from Item 24 on it is treated the same as a one-path system.

Space diversity hops also are more complicated than the example, because they have two separate antenna and waveguide systems at each end of the path, with different characteristics and, in some cases, different gains. Details of both antennas and guides are shown, and the subsequent calculations are made using the one with the lower gain for conservatism.

CHAPTER 6

TROPOSPHERIC SCATTER SYSTEM PLANNING

This chapter provides a systematic approach to the various problems involved in planning tropospheric scatter microwave communications systems. The basic concept of systems planning, as advanced in this chapter, is divided into several categories. Each category is organized in a logical fashion to describe the various tasks involved. The major tasks are presented in such a manner that each task presents information that must be considered in the development of succeeding tasks.

In the preliminary planning stages, the systems planner lays the groundwork for the proposed system. Investigations are conducted to determine the locations that must be connected by the particular system, the number and type of communications circuits required between the various locations, and the possible need for interconnecting the system with existing communications facilities. Based on the data compiled, a preliminary system plan and a channelization diagram showing the general system configuration and traffic pattern are prepared. These diagrams, although tentative in nature, show the basic system requirements and serve as a basis for the overall system plan.

The preliminary system plan indicates the geographic locations that are to be linked by the proposed microwave system. The next planning phase, that of route engineering, is concerned primarily with microwave path evaluation and site selection within the area to be served. The tasks involved comprise those required to establish suitable transmission paths between the important system locations, and to select sites for the installation of the required microwave terminal and repeater stations. Feasibility path loss calculations, together with the initiation of the BESEP (The Base Electronics System Engineering Plan) is also presented. An appendix will contain feasibility design data sheets with required equations. This chapter will provide a numerical example of the calculations.

6.1 CHARACTERISTICS OF TROPOSPHERIC SCATTER SYSTEMS

The dominant characteristic of tropospheric radio systems is the large, widely varying attenuation encountered in the propagation of microwave signals beyond the horizon. The magnitude of the attenuation is such that high system gain must be provided for successful wideband transmission; hence, the most obvious features of tropospheric radio stations - the large antennas. In addition to such outwardly apparent features, there are the transmitters capable of high power outputs at microwave frequencies and the highly sensitive and selective receiving systems. Besides the physically apparent features, there is the almost exclusive use of frequency modulation (FM), to provide high quality performance with respect to effective noise reduction. The rapid, wide variations in attenuation necessitate a diversity of radio paths for the satisfactory reception of the desired signal; therefore, a multiplicity of similar equipment is used at most tropospheric radio stations.

Tropospheric scatter is only one of the several mechanisms of beyond-the-horizon microwave propagation. The other mechanisms result from diffraction and are classified in accordance with the terrain over which the diffraction takes place. Thus, there is knife-edged diffraction, diffraction over rounded obstacles, diffraction over rough terrain, etc. Since there is no sharp, static dividing line between tropospheric scatter and the diffraction modes - often there is a combination of mechanisms - and since the same type of equipment is required in each of the mechanisms, tropospheric radio system engineering generally encompasses all beyond-the-horizon microwave hops.

The antennas used in tropopsheric radio systems consist of a feed element (usually a horn) and a parabolic reflector. The diameters of the reflectors range from 10 feet to 120 feet. The smaller antennas - up to 20 feet or so, are seldom used in strategic systems, where the installations are generally of a fixed-plant nature; they are more appropriate for tactical installations where mobility is the prime consideration. Antennas with diameters of 30 to 60 feet are used for the average tropospheric radio hop. The massive 120-foot antennas are used only on the most difficult hops. The feeder systems associated with the antennas use high quality waveguide.

The transmitters, designed specifically for tropospheric radio systems, have final power amplifiers whose average power outputs range from 500 watts to 100 kilowatts. Lower power outputs are available, but have little use in beyond-the-horizon transmission because of the high attenuations encountered. The input power requirements of the higher power amplifiers are large; consequently, high capacity primary power sources are required.

The receivers used in tropospheric radio systems are specially designed to provide high quality performance with low-level input signals. They have noise figures of only 8 to 14 dB. The receiver noise figures are often reduced to as low as 2 to 5 dB, depending upon frequency, by the use of tunnel-diode or parametric amplifiers. The pass-bands of the receivers are specially designed to produce low levels of intermodulation distortion in the complex wideband signals resulting from multichannel modulation. Diversity reception is always used in high grade tropospheric radio systems to level off the wide amplitude variations produced in the received signal by the variations in path attenuation. Successful diversity operation requires separate transmission paths, which are usually achieved through the use of multiple carrier frequencies and properly spaced multiple receiving antennas. Sophisticated combining schemes provide the maximum advantage from diversity reception.

6.2 INITIAL PLANNING

Planning functions include definition of the communication requirement, system concept, system trunking and routing, frequency considerations, support functions and manpower training requirements, project management, preliminary implementation schedule, and budgetary cost estimate. The planning functions are presented in a logical sequence for task accomplishment and to facilitate the preparation of documentation required at various stages of the system development. These activities are summarized in table 6-1.

Table 6-1. The Planner's Activities

ITEM NO.	ACTIVITY	COMMENT
1	Development of Requirements	This may be a formal procedure documented in a staff study. It may be informal and be documented in memo form. As the need crystalizes, the planner finds himself required to respond as to his solution to the problems.
2	Establishment of a Basic Concept	Early work in concept development is typically at a level indicated by Figure 4-4.
3	Detailing the Plan	Basic Information that must be Generated: Trunking and Routing Plan Map Studies Preliminary Site Survey Results Support Requirements Frequency Plan

The initial step in establishing system parameters is the interpretation and translation of the basic communication need into a realistic and feasible definition of the system requirement. This initial step is provided by a concise statement of the items developed in table 5-2 which provide an analysis and substantiation of the requirement. The analysis must necessarily consider the merits of competitive approaches. If, for example, a partially completed line-of-sight microwave system can be extended and updated more economically to do an equivalent task, the planner is required to recommend that this alternative be considered. Figure 5-1 illustrates in graphic fashion the factors considered and the courses of action to which they may lead.

During this initial phase of the project definition, broad guidance is needed to permit the planner to rapidly determine appropriate transmission means, taking into consideration, distance and the number of channels required. It is possible, for example, to use cable for carrying messages between terminals whatever the distance of separation of the two terminals involved. Further, more than one line-of-sight hop may be used in place of a single tropo hop.

When the requirements have been analyzed and defined, a system concept is developed that will meet the needs of the prospective communications users. The factors that must be considered and the steps to be followed in the establishing of the concept are shown in foldout 5-1.

The system concept in the planning stage is sufficiently simple that it may be depicted in a single line drawing on which all known information is noted. Figure 6-1 shows one possible presentation of the system concept. Large size drawings of this type are often made for planning purposes utilizing "flip-on" acetate information strips to indicate alternate concepts.

The feasibility survey which follows the development of a preliminary system concept considers such questions as whether Town A or a nearby Town E is the most appropriate choice, and whether there are reasons why any one of the major hops might be impractical. Thus, if for political or other reasons, there were no suitable radio site in City B, the alternate choice might make the link to Headquarters Location Town E, impractically long, requiring a two-hop link and the location of an additional site in the system.

6.2.1 Preliminary System Configuration

The steps in developing the preliminary system configuration and the resulting output documentation are provided in the following paragraphs.

The first step in preliminary system planning is to develop a system trunking plan based on approved user requirements. Such a system trunking plan will provide, in line diagram form, a layout of system channelization requirements and termination locations. The steps involved in developing a trunking plan are best illustrated by example. Figure 6-2 is a geographical plan of a sample system and table 6-2 presents its circuit requirements. Both voice and teletype requirements are included. The teletype requirements are also translated into equivalent voice channel requirements on the basis of multiplexing 16 teletype channels into 1 voice channel.

The system routing plan is based on the trunking plan and provides the system layout in terms of a definitive system configuration. The objective of the system layout analysis at this phase of systems planning is to determine the feasibility of installing a tropospheric radio link between two or more terminal locations and not necessarily to establish the final route of the system. Where it is apparent that

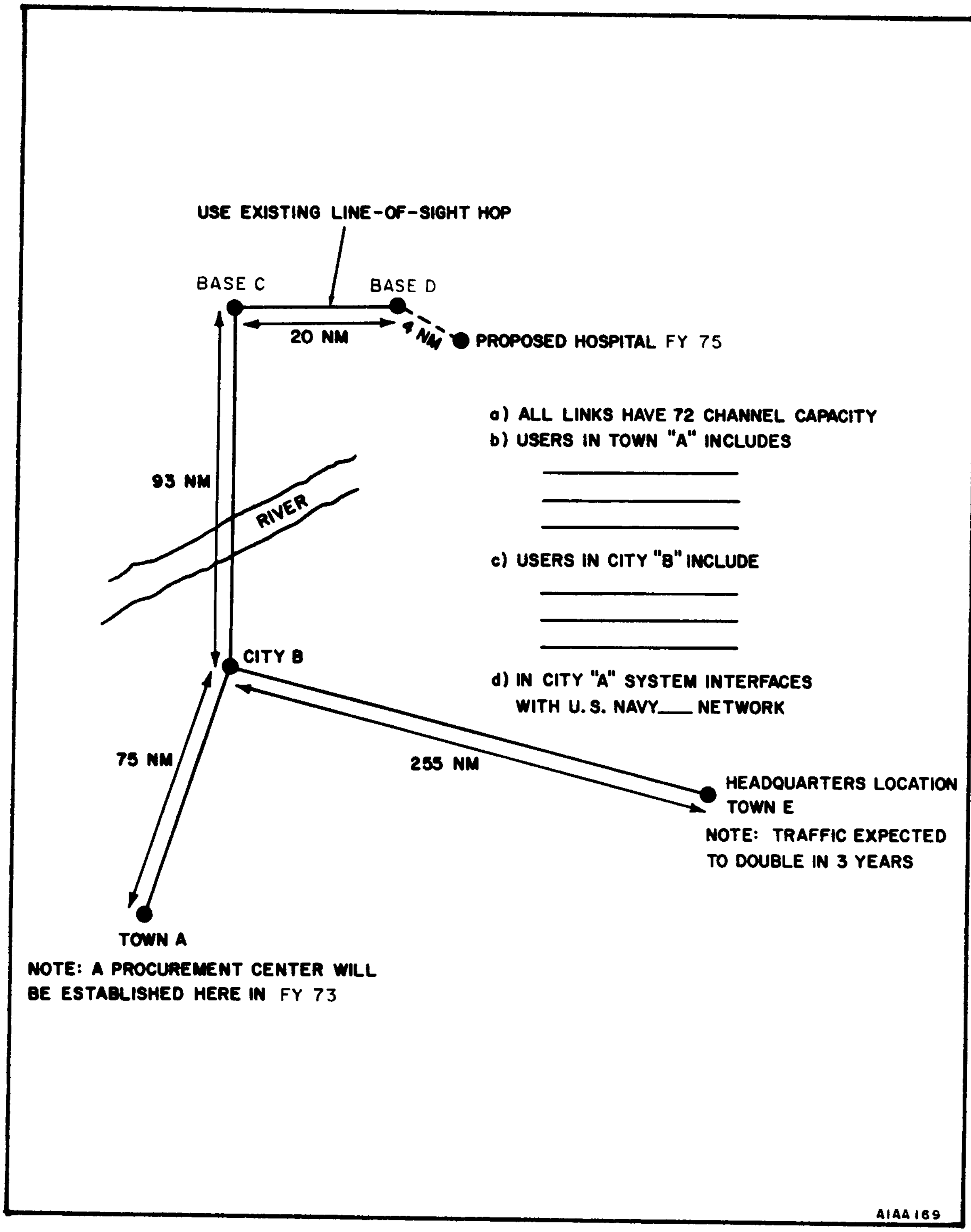

Figure 6-1. Initial System Concept, Typical

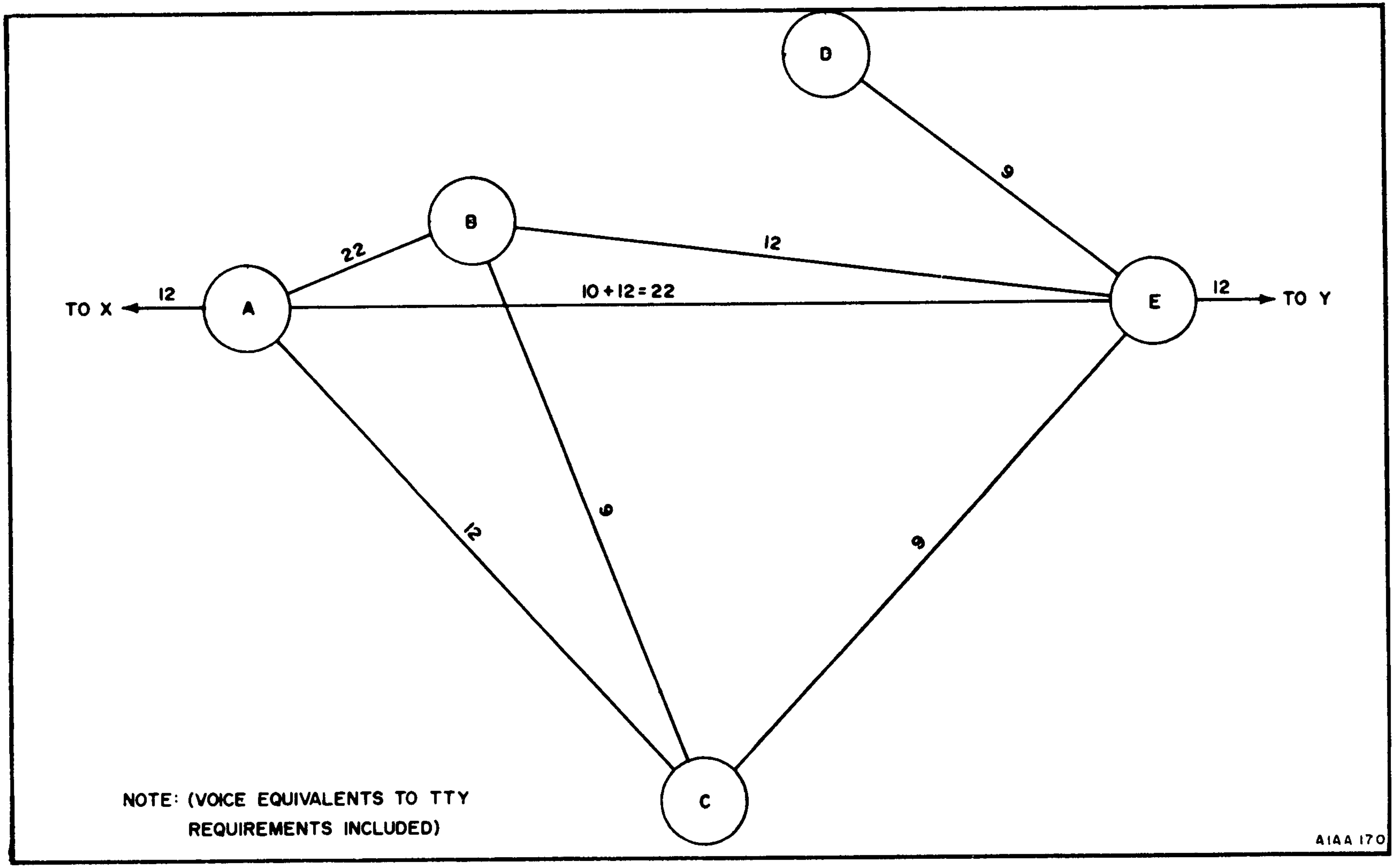

Figure 6-2. System Circuits Requirements, Sample

Table 6-2. Sample Circuit Requirements

BETWEEN STATIONS	VOICE	TELETYPE	VOICE EQUIVALENT TO TELETYPE*	TOTAL VOICE
A and B	20	30	2	22
A and C	10	24	2	12
A and E	9	12	1	10
X and Y	11	16	1	12
B and C	8	12	1	9
B and E	11	12	1	12
C and E	7	26	2	9
D and E	8	8	1	9

*1 voice channel can carry up to 16 teletype channels

certain stations will have to be located some distance from existing U.S. Military facilities the requirements for auxiliary systems and construction should be determined to a sufficient degree for approximating overall systems costs.

It is not practical at the planning level to finalize the location of all the sites of a system, because the precise site selections depend largely on the results of the definitive systems engineering described in chapter 8. For purposes of costing and other preliminary planning aspects, however, system planning groups must determine tentative terminal locations and the need for intermediate stations. Systems engineering assistance should be sought in carrying out this task. A simplified system engineering procedure is given which will enable systems engineers to make rapid determinations of the factors involved in site selection as well as other facets of system configuration.

6.2.2 Preliminary Siting of Terminals

A map survey is necessary in planning and selecting sites which offer the most promising technical and logistical possibilities. Careful analysis of maps that provide reliable topographical data will save much time and effort in the field.

From map surveys it is possible to evaluate potential sites and to determine those to be visited by the field team. One or more alternate sites will be selected for each terminal or relay facility. The criteria for map acquisition and study is outlined in chapter 2.

After obtaining the appropriate maps, the locations of the users are plotted. Insofar as practical, the terminal stations of the tropospheric radio system are located in close proximity to the ultimate users. In many instances this will not be feasible and a connecting link of wire line and/or line-of-sight radio will be required. For example, where the user is located in a city or town or where for other reasons adequate space does not exist, the tropospheric radio terminal will necessarily be remoted to a different location. Furthermore, the collocation of the terminal sites with the user will frequently severely limit the site selection so as to preclude taking advantage of terrain features conducive to tropospheric radio propagation. The factors which will determine the adequacy of a tropospheric radio site are covered in the following subparagraphs. While all of the factors listed may influence the selection of a site, they cannot be considered to have equal weight; therefore, several sites should be evaluated in terms of relative merits.

a. The topography of the area surrounding the site affects several factors, such as, antenna height, the support of the site, the cost of construction of the buildings required, etc. The terrain should be fairly level to aid in location of antenna foundations and waveguide runs. However, many compromises will have to be resolved; the first being a balance between a good communications location and a good location in terms of cost of construction and logistic support.

b. The take-off angle of the radio beam from each antenna is a factor of primary importance in tropospheric radio systems. This is the angle between a horizontal line extending from the radiation center of the antenna and a line extending from the same point to the radio horizon. (See figure 6-3.) The importance of take-off angle to tropospheric radio systems stems from its geometrical relationship to the so-called scatter angle. This relationship is illustrated in figure 4-1. It can be seen that any increase in take-off angle will result in a corresponding increase in scatter angle. Since path attenuation is roughly proportional to scatter angle, it follows that high take-off angles will produce higher path attenuation than low take-off angles. In fact, an increase of only one degree in take-off angle normally results in an increase of several dB in path attenuation. For this reason it is essential that take-off angles be considered very carefully. They can be computed from topographic maps for preliminary siting but optical surveying techniques must be used during the field survey. Since take-off angles can be negative under propitious circumstances, the order of precedence in site selection is as follows: Sites with the largest negative take-off angles are the first choice, and those with the largest positive take-off angles the last choice. Objects within the beam of the antenna will cause reflections which may be detrimental to system performance. Those objects that are directly along the path within the half power antenna beamwidth and cannot be removed, have to be considered in determining the take-off angle.

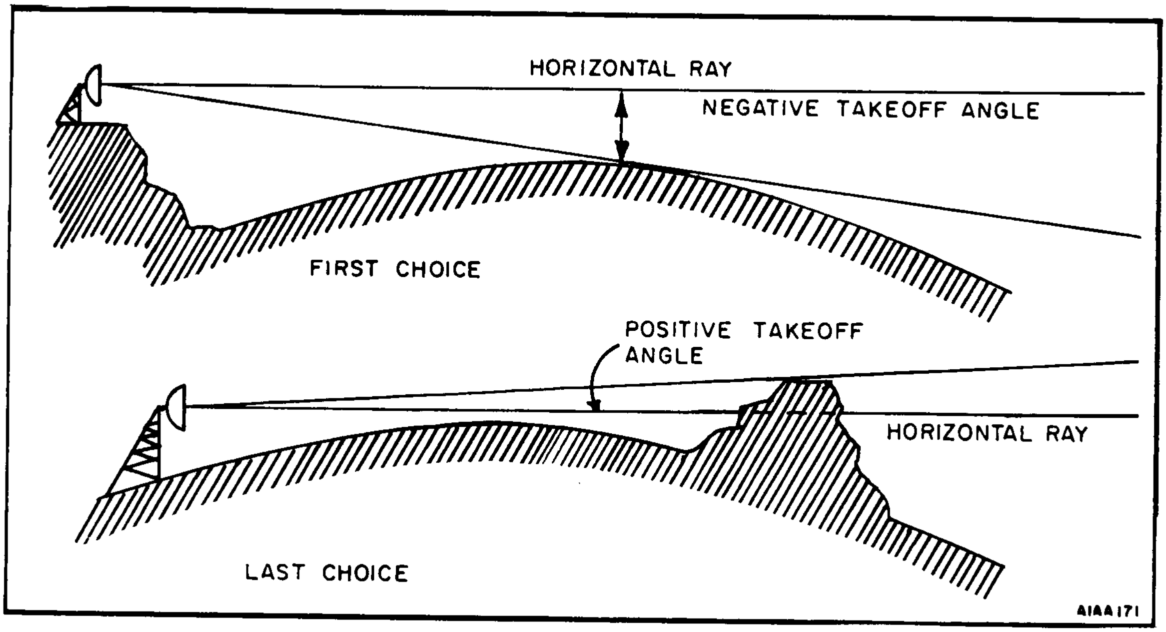

Figure 6-3. Site Choice Considering Take-off Angle

c. The effect of slight variations in path length is negligible for constant take-off angles; the transmission loss varies approximately 0.1 dB per mile. Consequently, decreasing the total path length by 10 miles only decreases the transmission loss by approximately 1 dB. The major effect of increasing or decreasing the total path distance is to change the scatter angle which does strongly affect the transmission loss.

d. Meteorology plays a very important part in tropospheric radio propagation, but its effect on siting a terminal is usually negligible because there are ordinarily no permanent sharp atmospheric boundaries in the troposphere and the general site area is presumably already established. There are exceptions to this rule, however, which require that a thorough analysis be made of the meteorological data available at each location being considered as a potential site. Ducting is a notable exception to the condition of gradual transitions between atmospheric layers, which can invalidate the most rigorous propagation analysis based on normal atmospheric physics.

e. The proximity of a tropospheric radio link to other Communication-Electronic (C-E) facilities, such as radio transmitters or receivers, radar sets, industrial areas and diathermy equipment, etc., is of extreme importance. Primary and harmonic frequencies of all these sources may produce mutual interference. If analysis of the frequencies and levels of the radiation indicates the probability of interference, it may be necessary to relocate one of the facilities.

f. In the siting of tropospheric radio communications terminals, careful consideration should be given to the harmful effects of electromagnetic radiation on the human body and on physical objects such as radio equipment, fuel storage or service areas and electrically detonated explosives. A level of 0.01 watts/cm^2 is the maximum average power which can be considered safe for personnel on a continuous exposure basis. The storage of explosive devices and fuel near the transmitting antenna presents a radiation hazard problem which requires careful observance of NAVELEX 0101,106, Naval Shore Electronics Criteria Electromagnetic Compatibility and Electromagnetic Radiation Hazards.

g. The planner should evaluate sites with a view towards future expansion of the tropo facilities. Such expansion may require an increase in antenna sizes or possibly space for additional antennas, increased logistic areas and other facilities. Wherever possible, sites should be selected to give good take-off angles in all anticipated directions. The layouts in figures 6-4 through 6-7 depict the simplicity of illustrations adequate in the preliminary planning. Similar coding and appropriate dimensions apply to all figures. The extent of the Restricted Area is usually defined in the preliminary site sketches. Two categories of restrictions are obstruction restriction and radiation hazard restricted area.

After tentative selection of the radio terminal locations and any required intermediate repeater sites, the preliminary routing plan is prepared. Figure 6-8 is a sample routing plan, based on the circuit requirements given earlier in table 6-2. Figure 6-9 is a trunking diagram derived from the circuit requirements and the routing plan. This diagram will be used in the system engineering phase as the basis for the multiplex channelization plan.

6.2.3 Plotting the Route

The procedure used in plotting the route of a proposed system for preliminary and final path determination differs only in the order of accuracy of measurements and calculations.

When a preliminary study is made prior to the actual site survey such that alternate sites are selected, maps with a scale of at least 1 in 250,000 with contours at not more than 60 meters shall be used. The distance determinations shall be to the nearest mile and coordinates to second order accuracy.

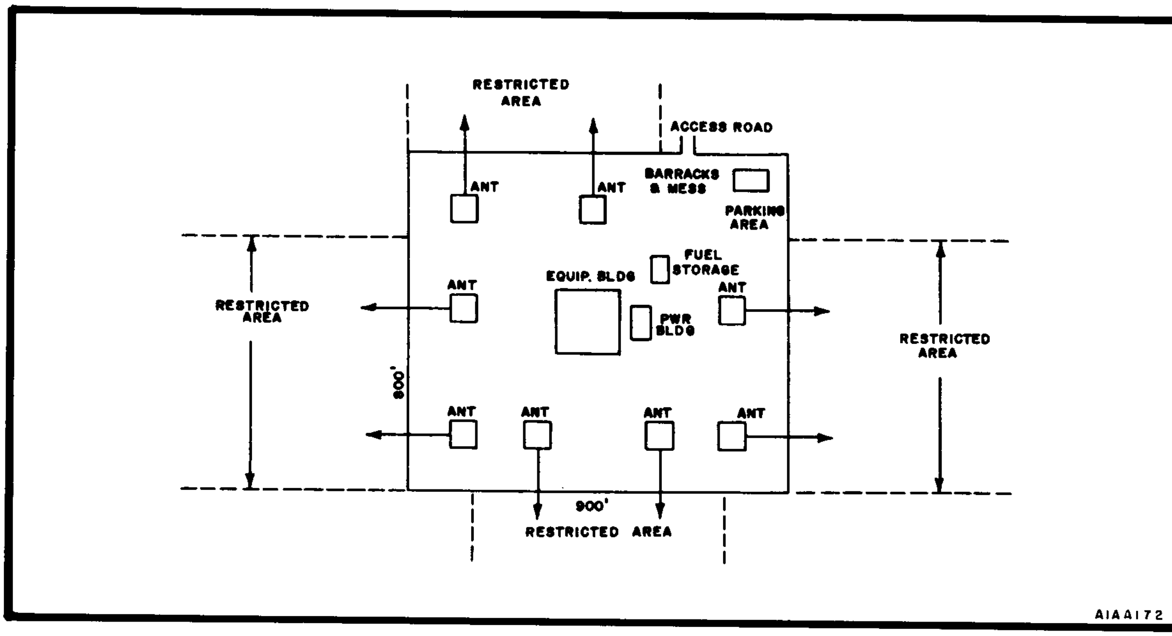

Figure 6-4. Four-Terminal Tropo Site,
60-Foot Antennas

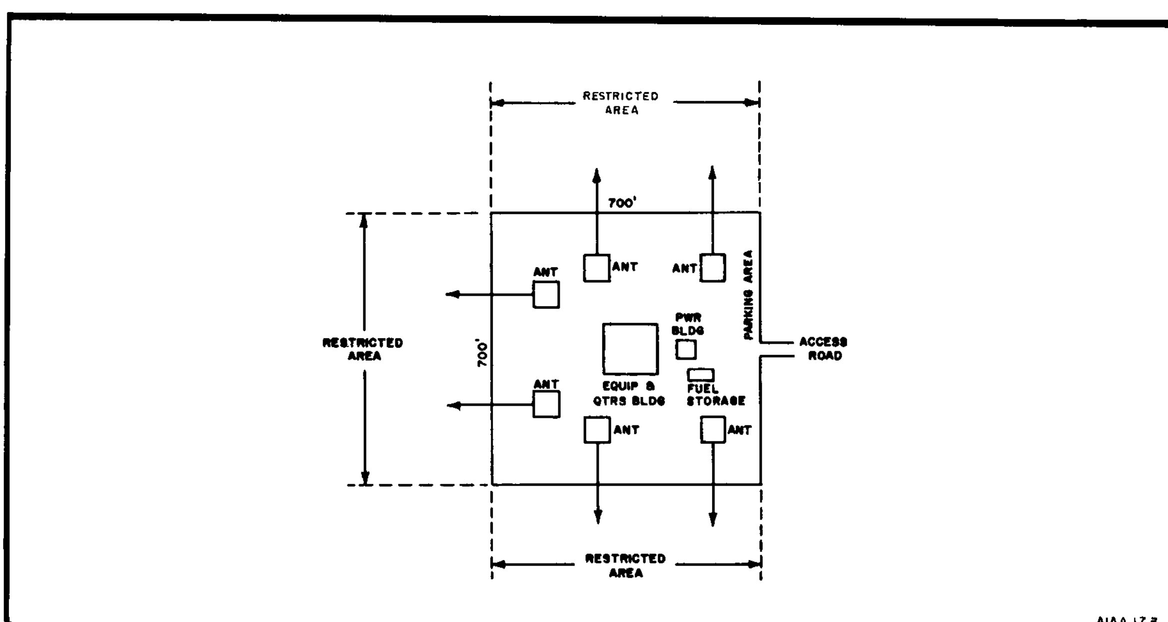

Figure 6-5. Three-Terminal Tropo
Site, 60-Foot Antennas

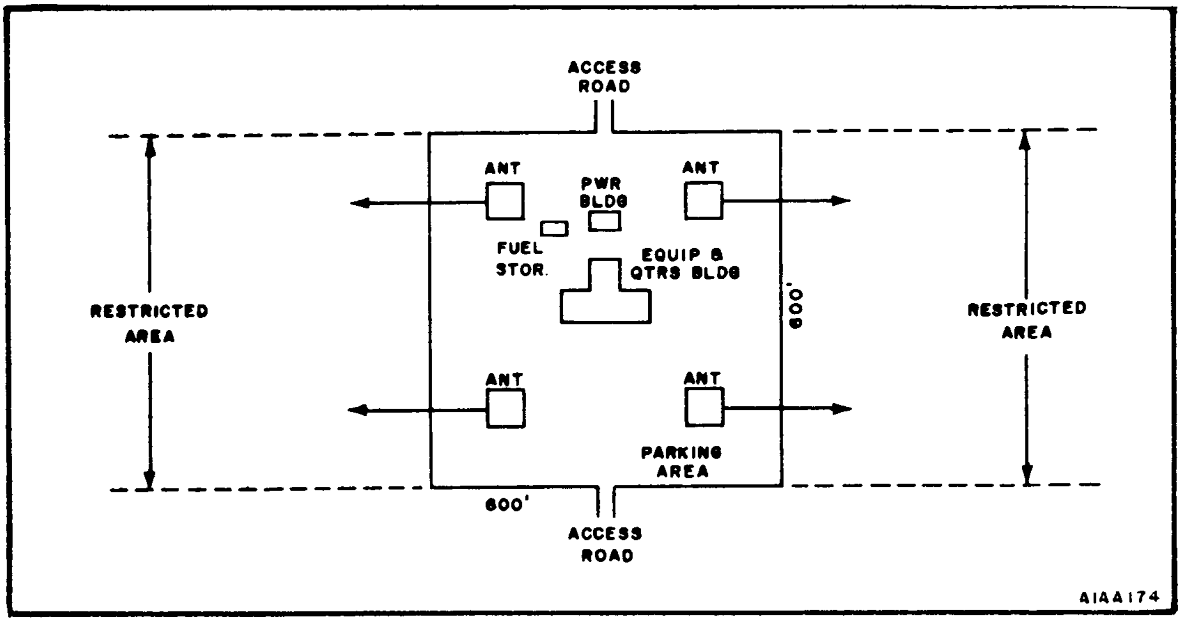

Figure 6-6. Two-Terminal Tropo Site,
60-Foot Antennas

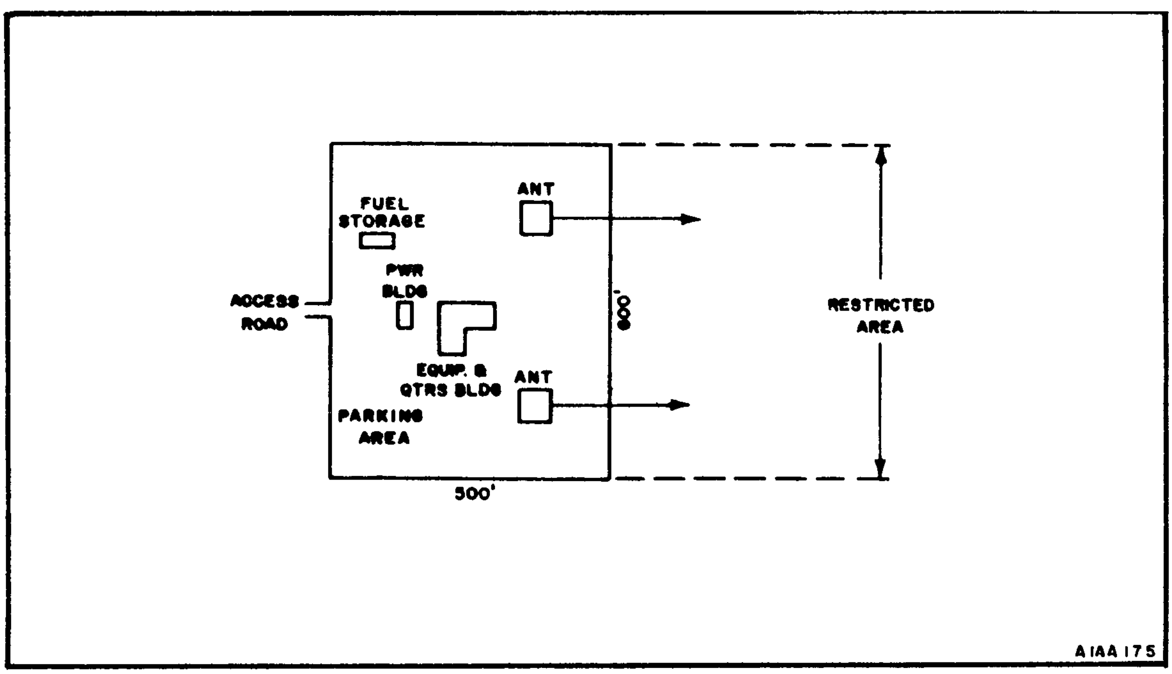

Figure 6-7. One-Terminal Tropo Site,
60-Foot Antennas

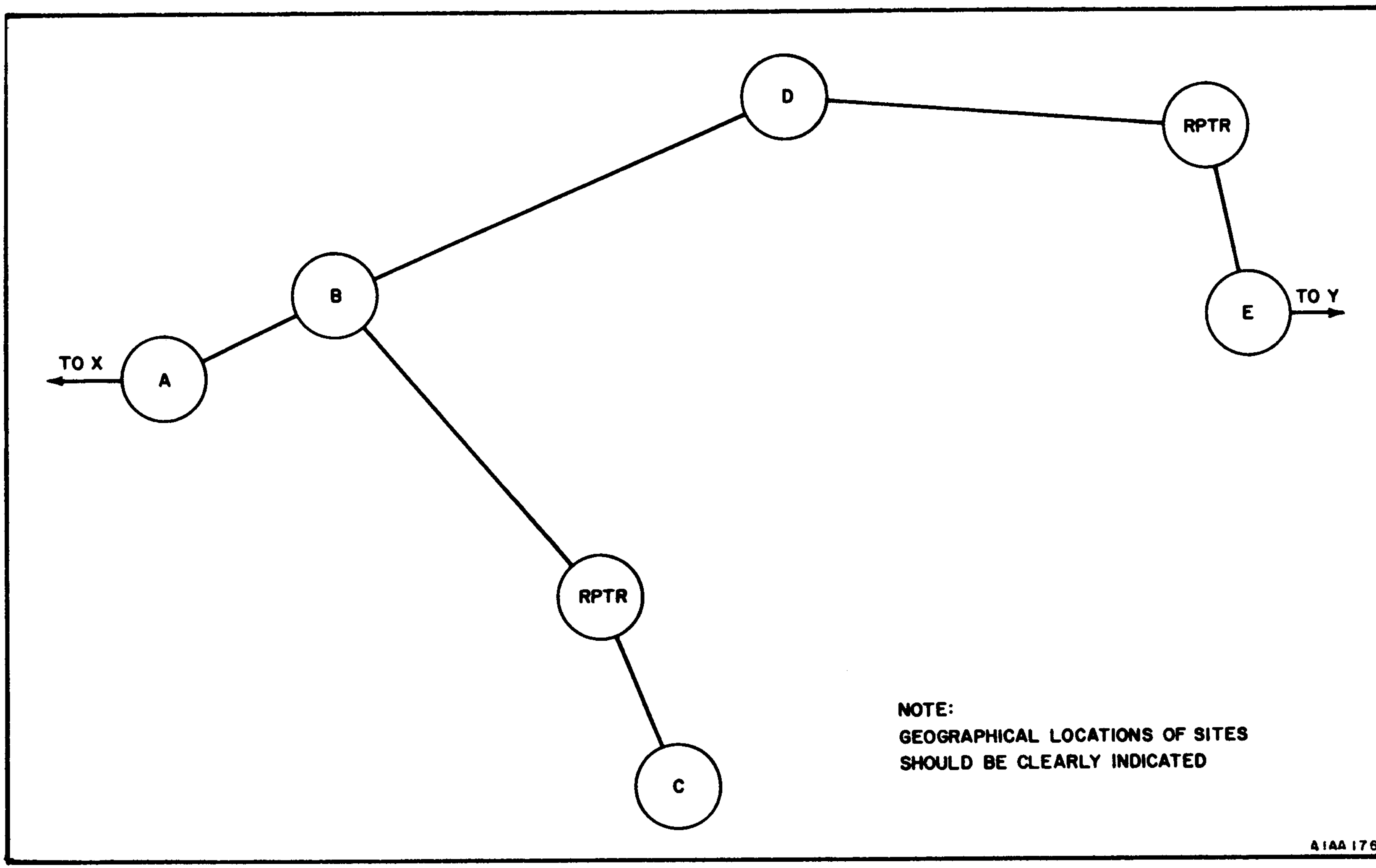

Figure 6-8. System Routing, Typical

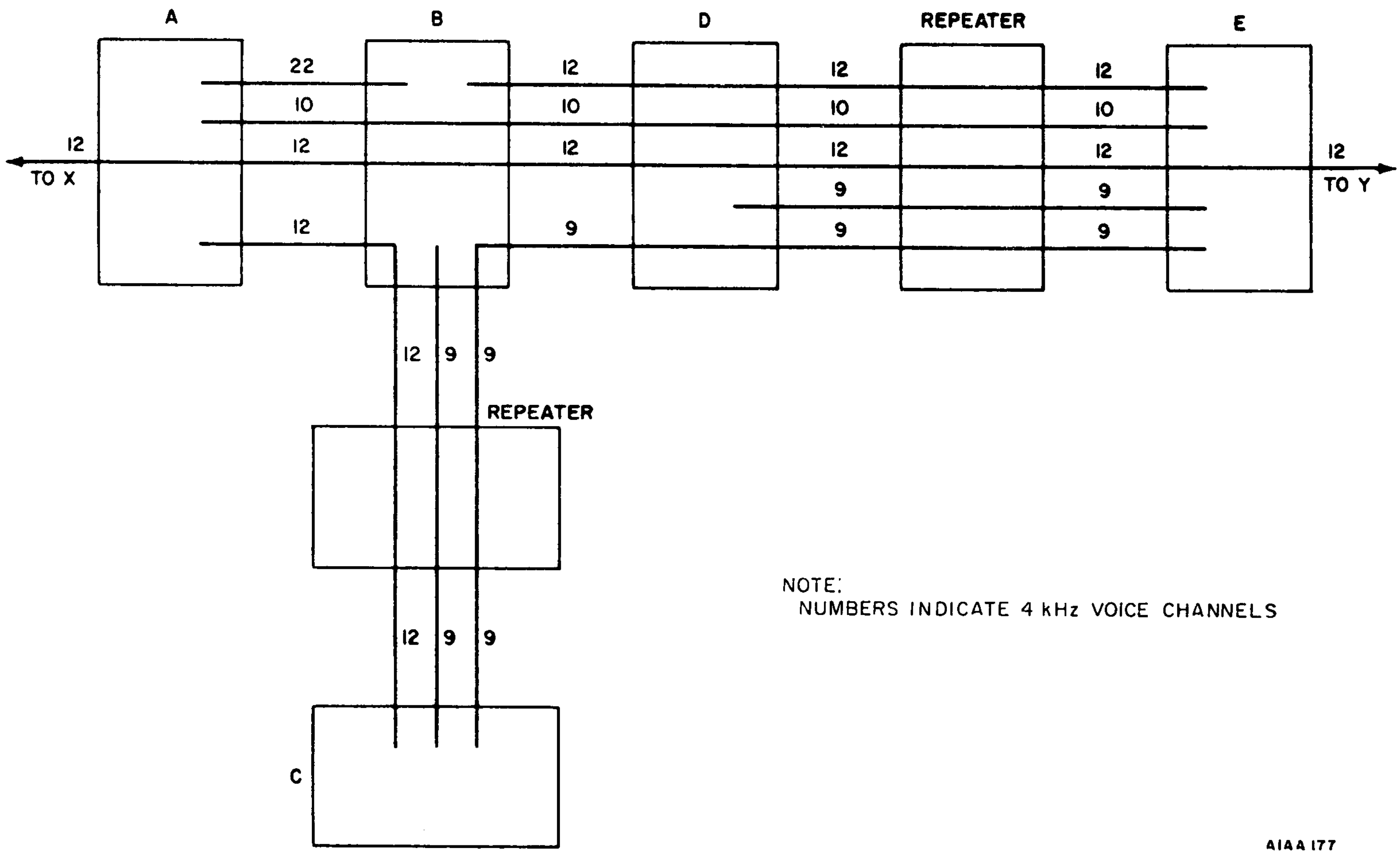

Figure 6-9. System Trunking Diagram, Typical

The selected sites shall be surveyed, so that a terrain profile may be constructed showing the distances and elevations along the path azimuth with an accuracy not less than:

- o Coordinates to third order accuracy.
- o Elevations to the nearest 5 meters.

The final path parameters (path profile) shall be determined with an accuracy not less than:

- o All distances to 0.1 mile.
- o All azimuths to 10 seconds.
- o Maps utilized shall have a scale of 1 in 25,000 with contours at 5 meter intervals.

The procedure outlined below may be used:

- o Using a small scale map such as is shown in figure 6-10, the proposed transmitter and receiver sites are plotted and a straight line (rhumb line) drawn connecting the two sites. A rhumb line is a line that intersects all meridians (degree of longitude) at the same angle. For distances less than 70 kilometers, the rhumb line approximates a great circle path. For greater distances, the true great circle path must be determined.
- o Using the rhumb line, select the detail topographic charts to be used in the path profile analysis. At the receiver site (in figure 6-10) quadrangle maps covering 7-1/2 minutes of latitude and longitude (scale 1:24,000) have been selected and at the transmitter site quadrangle maps covering 30 minutes of latitude and longitude (scale 1:125,000) have been selected for use.
- o Using the detail topographic charts, the highest suitable sites at or close to each terminal station must be located.
- o Using latitude and longitude of each site, the great circle distance, the transmit azimuth, and receive azimuth are calculated using the method in Appendix D.
- o To determine the radio horizon, the great circle path on the quadrangle charts must be plotted. The great circle path is approximated by a series of rhumb lines not exceeding 70 kilometers in length. To do this intermediate positions along the great circle path are caldulated and these positions interconnected by straight lines. Normally the positions selected are on the edges of the charts.

Figure 6-11 depicts the spherical triangle for these calculations.

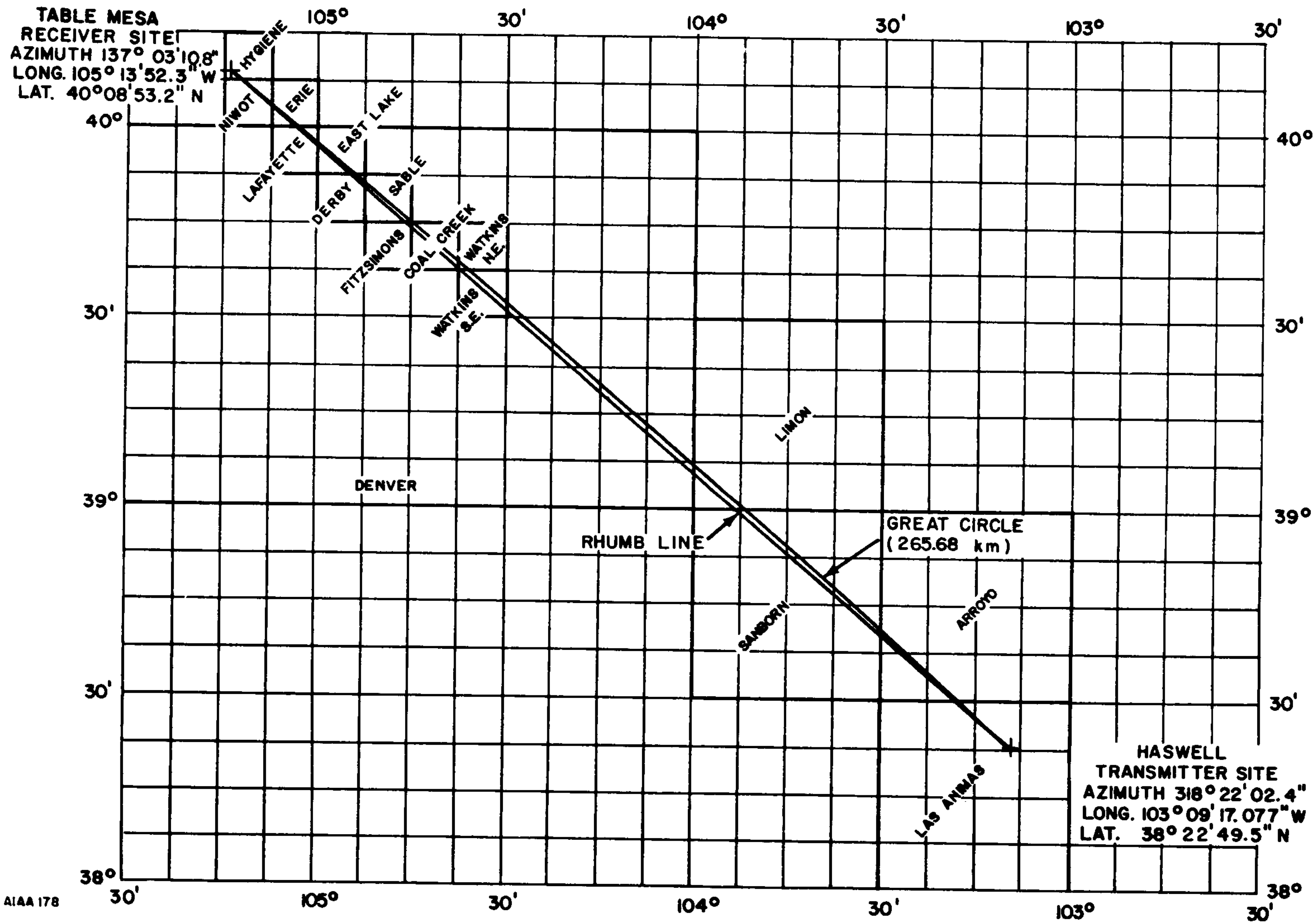

Figure 6-10. Map Study Organization

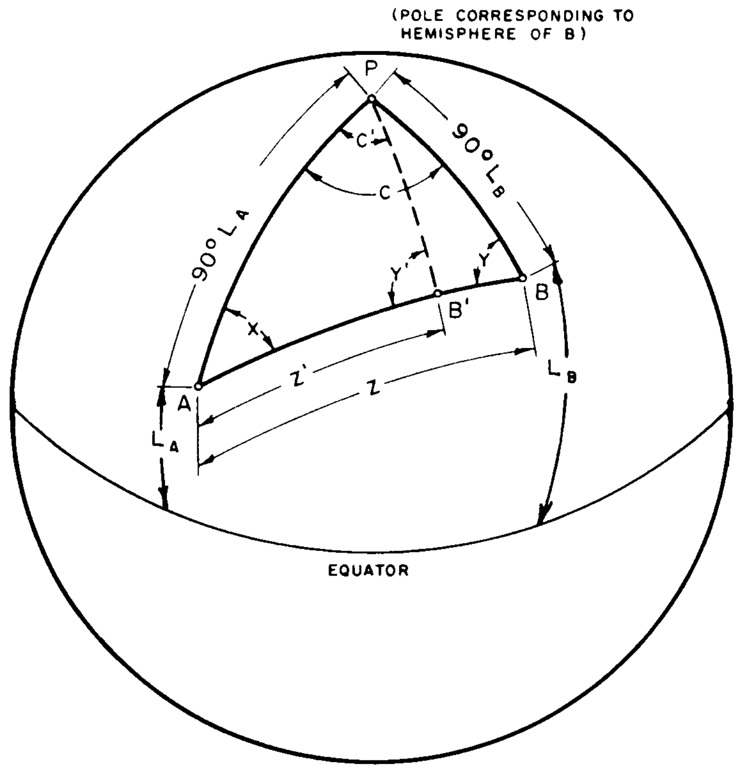

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Figure 6-11. Great Circle Path Computations, Spherical Triangle for

If the great circle path is predominately east-west a longitude is selected (longitude difference C') and latitude $L_{B'}$ is calculated from

$$\cos Y' = \sin X \sin C' \sin L_A - \cos X \cos C'$$

and

$$\cos L_{B'} = \frac{\sin X \cos L_A}{\sin Y'}$$

If the great circle path is predominately north-south, a latitude is usually selected (latitude difference L_B) and the longitude difference C^1 is then calculated from

$$\sin Y' = \frac{\sin X \cos L_A}{\cos L_{B'}}$$

and

$$\cot \frac{C'}{2} = \tan \frac{Y' - Y}{2} \left[\frac{\cos\left(\frac{L_{B'} + L_A}{2}\right)}{\sin\left(\frac{L_{B'} - L_A}{2}\right)} \right]$$

Where the path is close to 45 degrees either method may be used.

o The sea level refractivity of the atmosphere (N_o) is determined from figure 2-8 or 2-9. Using the average height of the transmitter and receiver sites above sea level and entering figure 2-10 with this height in kilometers and N_o, the surface refractivity N_s is determined.

o The elevations h_i of the terrain on the great circle route as read on the topographic maps are tabulated with their distances x_i from the transmitting antenna. The recorded elevations should include successive high and low points along the path.

The modified elevation y_i of any point h_i at distance x_i from the transmitter along a great circle path is:

$$y_i = h_i - \frac{x_i^2}{2a}$$

where the effective earth's radius a, in kilometers, is read from figure 6-12 as a function of N_s. A plot of y_i vs x_i on linear graph paper as shown in figure 6-13 provides the desired profile. The ray from each antenna to its horizon is a straight line if the elevation above sea level of the horizon and that of its antenna differs by less than one kilometer.

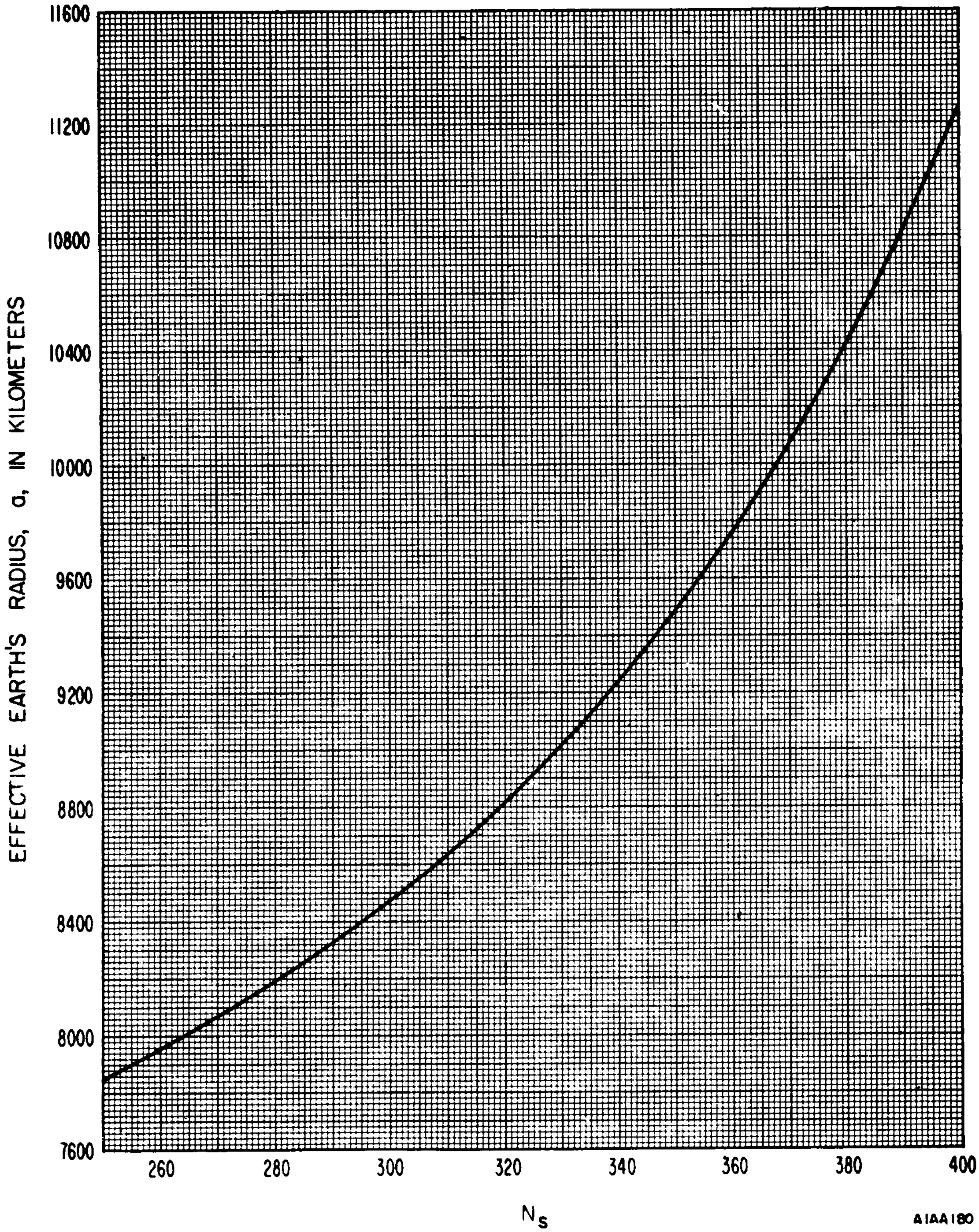


Figure 6-12. Effective Earth's Radius, a, Versus Surface Refractivity, N_S

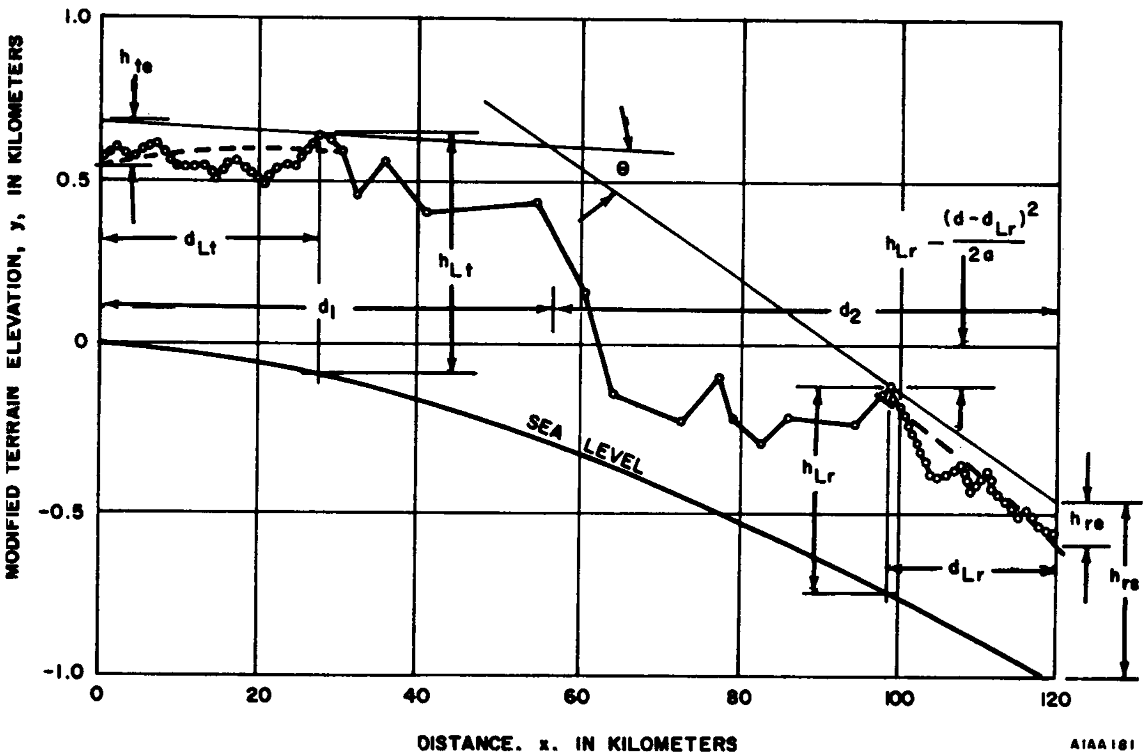


Figure 6-13. Modified Terrain Profile for a Double-Horizon Path

6.3 BASIC SYSTEM DESIGN

As a result of planning activities previously described, a basic communications requirement has been defined. The user locations, the number and type of channels needed, a tentative route and system layout have been established. The next step in the evaluation is the determination whether or not each radio frequency link is feasible. To do this:

- The transmitter power is assumed/or selected.
- The receiver sensitivity is assumed/or selected.
- The frequency or frequency band is assumed/or assigned.
- The antenna sizes and gains are assumed.
- The antenna heights are assumed.
- The degree of diversity is assumed.

Based upon these assumptions the RF attenuation of each path is calculated. The first result is almost always unsatisfactory requiring alteration of the propagation path, or one or more of the assumed parameters. When the preliminary calculations of path loss for each path in the proposed system show the paths are feasible, all the foregoing planning efforts are incorporated in a planning document entitled "Base Electronics System Engineering Plan" (BESEP). As the design progresses the BESEP is refined from a planning document to an implementation document.

6.4 PRELIMINARY PATH LOSS CALCULATIONS

Beyond the horizon propagation occurs by the mechanisms listed in table 6-3. The two major methods are forward scatter and diffraction over a knife edge obstacle. Paths just beyond the horizon are predominantly diffraction paths and long paths (more than θ = 15 milliradians) forward scatter. The area between is a combination of the two. In preliminary or path feasibility calculations the path is considered one or the other and calculated as such.

6.4.1 Forward Scatter

A forward troposcatter microwave link is proposed between points A and B. Figure 6-14 is an example of the Path Data Calculation Sheet.

a. The latitudes, longitudes and site elevations (items 2, 3, and 4) were determined from the map study of large scale maps (chapter 2).

b. The antenna launch azimuths and the path length (items 7 and 8) were computed using appendix D.

c. The frequency assigned for this path is 4.8 GHz.

d. The following parameters are assumed:

- 30 foot parabolic antennas at each end (item 19).
- Each antenna is 26 feet (8 meters) above the ground (item 18).

Table 6-3. Basic Design Considerations

POSSIBLE PROPAGATION MECHANISMS	COMMENT
Forward Scatter	Consider the following modifying factors: Possibility of reflections enhancing or weakening the forward scatter effect. Orientation of the antennas. Height of the antennas. Frequency effects. Effect of contributions from diffraction.
Trans-Horizon Diffraction Around a Smooth Earth	Distance at which diffraction and forward scatter are approximately equal is 65 $(100/f)^{1/3}$km. In general, for most paths having an angular distance (θ) greater than 15 milliradians, the diffraction calculations may be omitted.
Diffraction Over a Single Isolated Obstacle	Obstacles may be knife edge or rounded, different design approaches apply to the two cases. The possibility of reflections on either or both sides of the obstacle should be considered.
Diffraction Over Two or More Obstacles Ducting	Involves an extension of the method described above. This is a propagation anomaly which requires the engineer to investigate the climatology of an area in detail.

- o The transmitter is 1 kW (+60 dBm) (item 26).

- o The receiver noise threshold is -98 dBm (item 28) and the FM improvement threshold (-49 dBa) is -88 dBm (item 30).

- o Items 10 through 14 are assumed based upon antenna height, diversity and experience.

MICROWAVE PATH DATA CALCULATIONS

1	SITE		A			B
2	LATITUDE	N	36° 38' 23"			37° 09' 12"
3	LONGITUDE	W	6° 22' 02"			5° 35' 16"
4	ELEVATION	m	13			94.
5	TOWER HEIGHT	m				
6	TOWER TYPE					
7	AZIMUTH FROM TRUE NORTH.		50° 17'		230° 45'	
8	PATH LENGTH	km	89.75			
9	PATH ATTENUATION (L_{bsr})	dB	215.8			
10	RIGID WAVEGUIDE	Ft.		80	100	
11	FLEXIBLE WAVEGUIDE	Ft.		5	5	
12	WAVEGUIDE LOSS	dB		1.4	1.7	
13	CONNECTOR LOSS	dB		0.3	0.3	
14	CIRCULATOR OR HYBRID LOSS	dB			1.0	
15	RADOME LOSS, TYPE*	dB				
16	NEAR FIELD LOSS	dB				
17	CLOSE COUPLING LOSS (DOUBLE PASS.)	dB			10.	
18	TOTAL FIXED LOSSES	dB		1.7	13.	
19	TOTAL LOSSES	dB	230.5			
20	PARABOLA HEIGHT C_L AGL	m		8	8	
21	PARABOLA DIAMETER	Ft.		30	30	
22	REFLECTOR HEIGHT	Ft.				
23	REFLECTOR SIZE, TYPE	Ft.				
24	PARABOLA - REFLECTOR SEP.	Ft.				
25	NEAR FIELD GAIN	dB				
26	ANTENNA SYSTEM GAIN	dB		50.6	50.6	
27	TOTAL GAINS	dB	101.2			
28	NET PATH LOSS	dB	129.3			
29	TRANSMITTER POWER	dBm	+60			
30	MED. RECEIVED POWER (± 2 dB)	dBm	-69.3			
31	RECEIVER NOISE THRESHOLD	dBm	-98			
32	THEORECTICAL RF C/N RATIO	dB	28.7			
33	FM IMP. THRESHOLD (4.9 dBa)	dBm	-88			
34	FADE MARGIN (To FM Imp. Thresh.)	dB	18.7			
35	RELIABILITY SPACING† Q	%				
36	POLARIZATION ‡					
37	PROFILE NUMBER					

‡ V - Vertical, H - Horizontal

† F - Frequency Diversity, S - Space Diversity, N - Non-Diversity, Q - Space And Frequency Diversity (Reliability Figures Are For Rayleigh Distributed Fading Only)

* U - Unheated, H - Heated

CUSTOMER U. S. NAVY

PROJECT NO. 20631 FREQUENCY 4.8 GHz

SYSTEM ____ EQUIPMENT ____

LOADING ____ dBm0 (____ CHANNELS OF ____)

AIAA182

DATE ____ ENGINEER ____ Sheet ____ of ____

Figure 6-14. Microwave Path Data Calculation Sheet

e. The surface radio refractivity N_o is determined from figure 2-9 and N_s for the average surface refractivity from figure 2-10 is 301.

f. Using a preprinted form with the k factor determined from table 2-2, or using the method specified in paragraph 6.2.3, the path profile is plotted as shown in figure 6-15.

g. Based upon the path geometry defined in figure 4-4, the applicable values from the profile, figure 6-15, are shown on figure 6-16.

h. Figure 6-17 shows the computations to obtain the scatter angle (or path angle) θ. $\Delta\alpha_o$ and $\Delta\beta_o$ are obtained from figure 6-18. If N_s is other than 301 the correction of figure 6-19 must be applied.

i. Using the parameters previously calculated, the long term median transmission L_{BSR} (figure 6-20) is determined to be 215.8 dB which is entered as item 9 on figure 6-14. It must be noted that in these calculations, the scattering efficiency term F_o, the frequency gain function H_o, and the atmospheric absorption term A_a are omitted during the initial calculations.

j. The gain efficiencies of most commercial antennas with parabolic reflectors are on the order of 55 to 65 percent. With 55 percent efficiency, the gain of a parabolic antenna is:

$$G = 20 \log B + 20 \log F + 7.5$$

where

G = gain over isotropic in dB

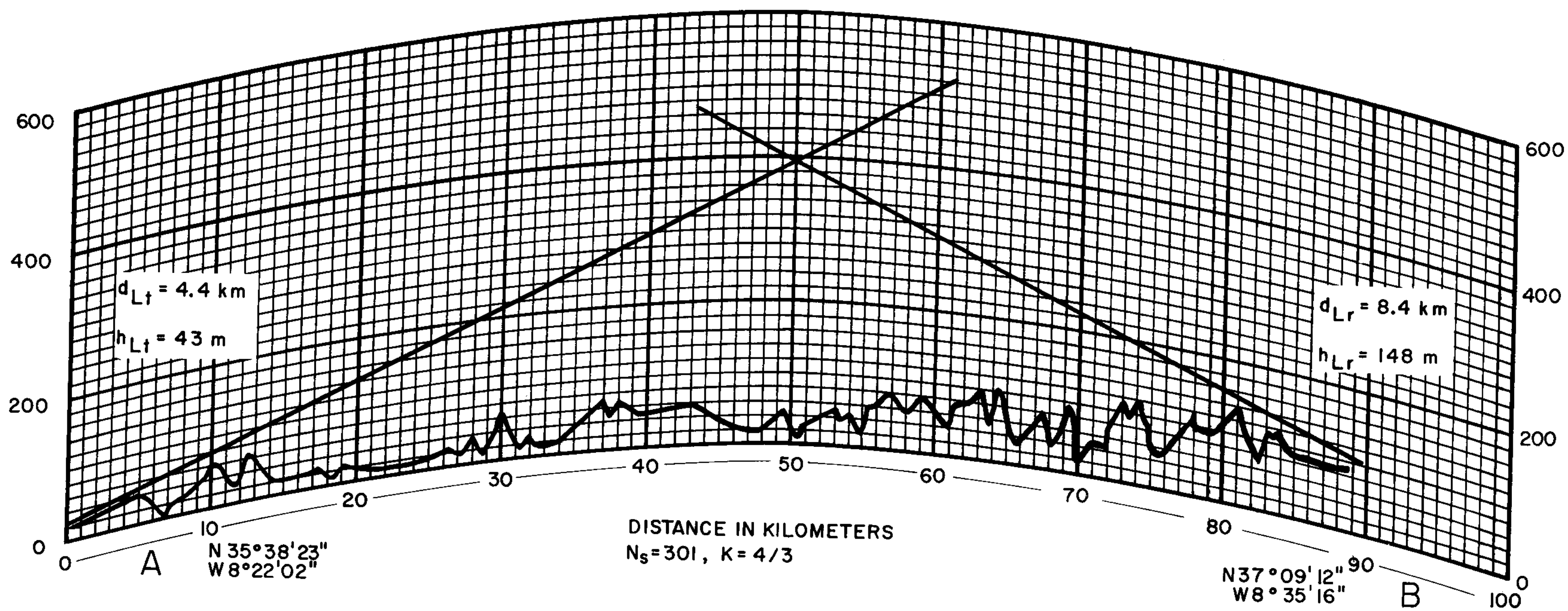
F = frequency in gigahertz

B = parabolic diameter in feet.

From this the gain of a 30 foot disk at 4.8 GHz is 50.6 dB which is entered under item 23 and totaled in item 24.

Although this formula can be used for estimating purposes, the actual gain determined from manufacturers' published specifications should be used during the final planning phases.

k. h_o and Ω are computed as shown in figure 6-21. Entering figure 6-22 with h_o and N_s determine η_s. Entering figure 6-23 with θ/Ω and η_s the antenna coupling loss L_{gp} is determined as 10 dB which is entered in figure 6-14, item 15.


600
400
200
0
600
400
200
0
d_{Lt} = 4.4 km
h_{Lt} = 43 m
d_{Lr} = 8.4 km
h_{Lr} = 148 m
0
10
20
30
40
50
60
70
80
90
100
A
N 35°38'23"
W 8°22'02"
DISTANCE IN KILOMETERS
N_s=301, K=4/3
N37°09'12"
W8°35'16"
B

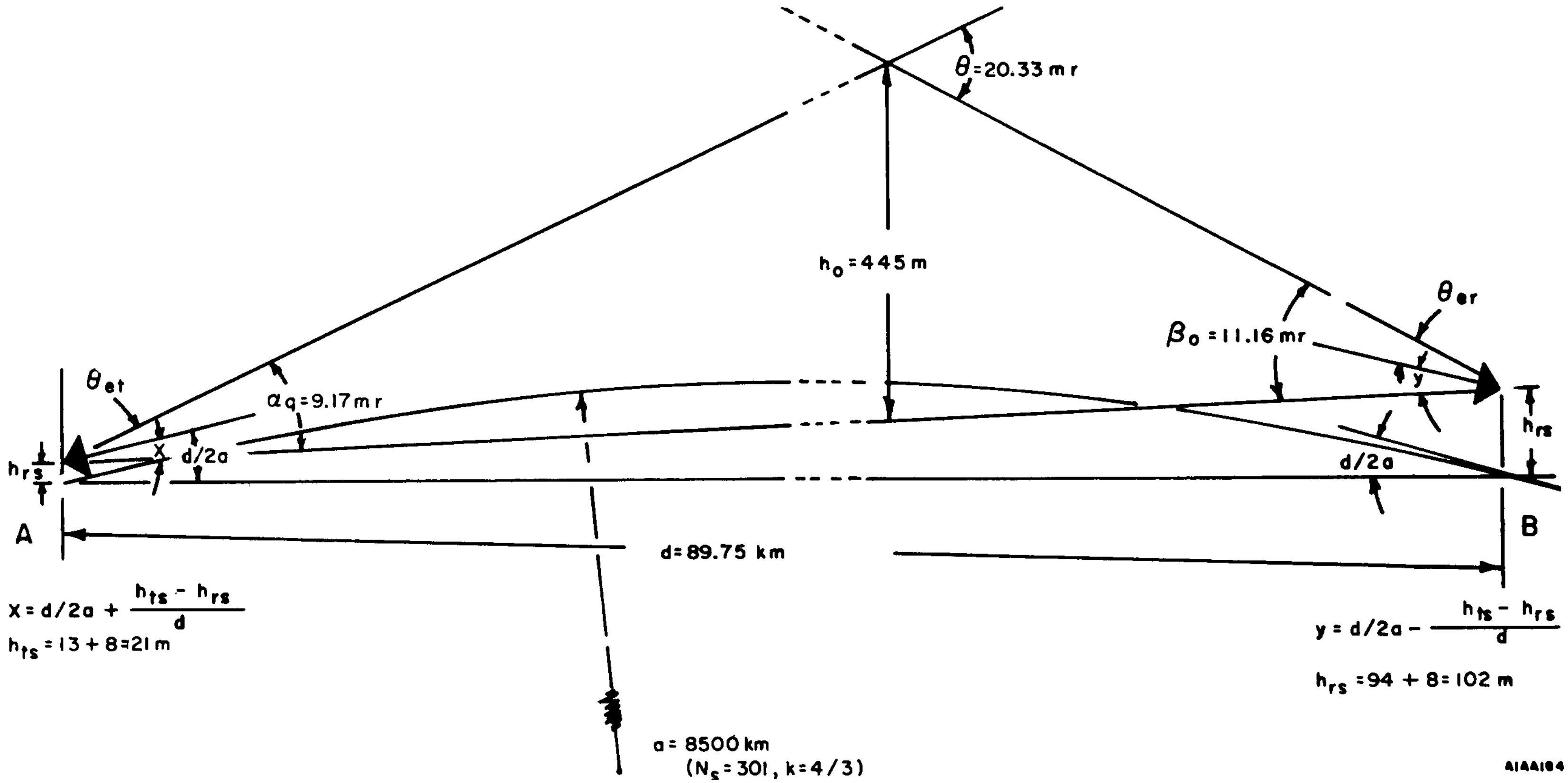


Figure 6-16. Troposcatter Path Geometry

(EXISTING TROPOSCATTER PATH)

d = 89.75 km
a = 8500 km

A	B
h_{ts} = 21 m h_{Lt} = 43.3 m h_{te} = d_{Lt} = 4.4 km d_{st} =	h_{rs} = 102 m h_{Lr} = 148 m h_{re} = d_{Lr} = 8.4 km d_{sr} =
$\theta_{et} = \frac{h_{Lt} - h_{ts}}{d_{Lt}} - \frac{d_{Lt}}{2a}$ $= \frac{43.3 - 21}{4400} - \frac{4.4}{2\ (8500)}$ $= 0.00506 - 0.00026$ $= \underline{4.80 \text{ mr}}$	$\theta_{er} = \frac{h_{Lr} - h_{rs}}{d_{Lr}} - \frac{d_{Lr}}{2a}$ $= \frac{148 - 102}{8400} - \frac{8.4}{2\ (8500)}$ $= 0.00546 - 0.00049$ $= \underline{4.97 \text{ mr}}$
$x = \frac{d}{2a} + \frac{h_{ts} - h_{rs}}{d}$ $= \frac{89.75}{2\ (8500)} + \frac{21 - 102}{89750}$ $= 0.00528 - 0.00091$ $= \underline{4.37 \text{ mr}}$	$y = \frac{d}{2a} - \frac{h_{ts} - h_{rs}}{d}$ $= \frac{89.75}{2\ (8500)} - \frac{21 - 102}{89750}$ $= 0.00528 + 0.00091$ $= \underline{6.19 \text{ mr}}$
$\theta_{ot} = \theta_{et} + \frac{d_{Lt}}{a}$	$\theta_{or} = \theta_{er} + \frac{d_{Lr}}{a}$
$\Delta\alpha \cong 0$ FROM FIGURES 6-18 AND 6-19	$\Delta\beta \cong 0$ FROM FIGURES 6-18 AND 6-19
$\alpha_o = \theta_{et} + x + \Delta\alpha_o$ $= 4.80 + 4.37$ mr $= \underline{9.17 \text{ mr}}$	$\beta_o = \theta_{er} + y + \Delta\beta_o$ $= 4.97 + 6.19$ mr $= \underline{11.16 \text{ mr}}$
$\theta_{oo} = \theta = \alpha_o + \beta_o = 9.17 + 11.16 = \underline{\underline{20.33 \text{ mr}}}$	

AIAA185

Figure 6-17. Tropospheric Path Angle Computations (Milliradians)

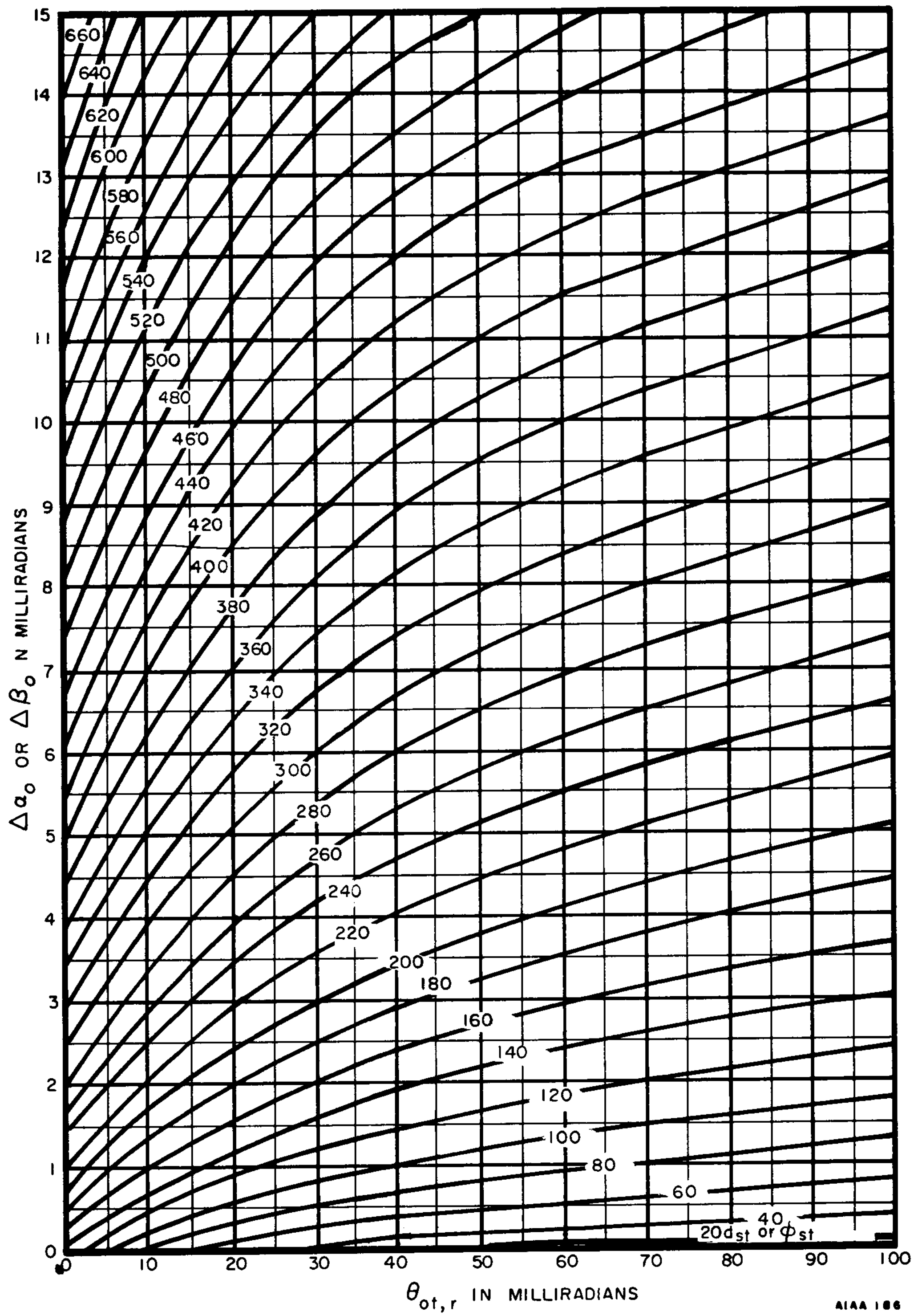


Figure 6-18. Correction Terms Δa_O, $\Delta \beta_O$ for $N_S = 301$

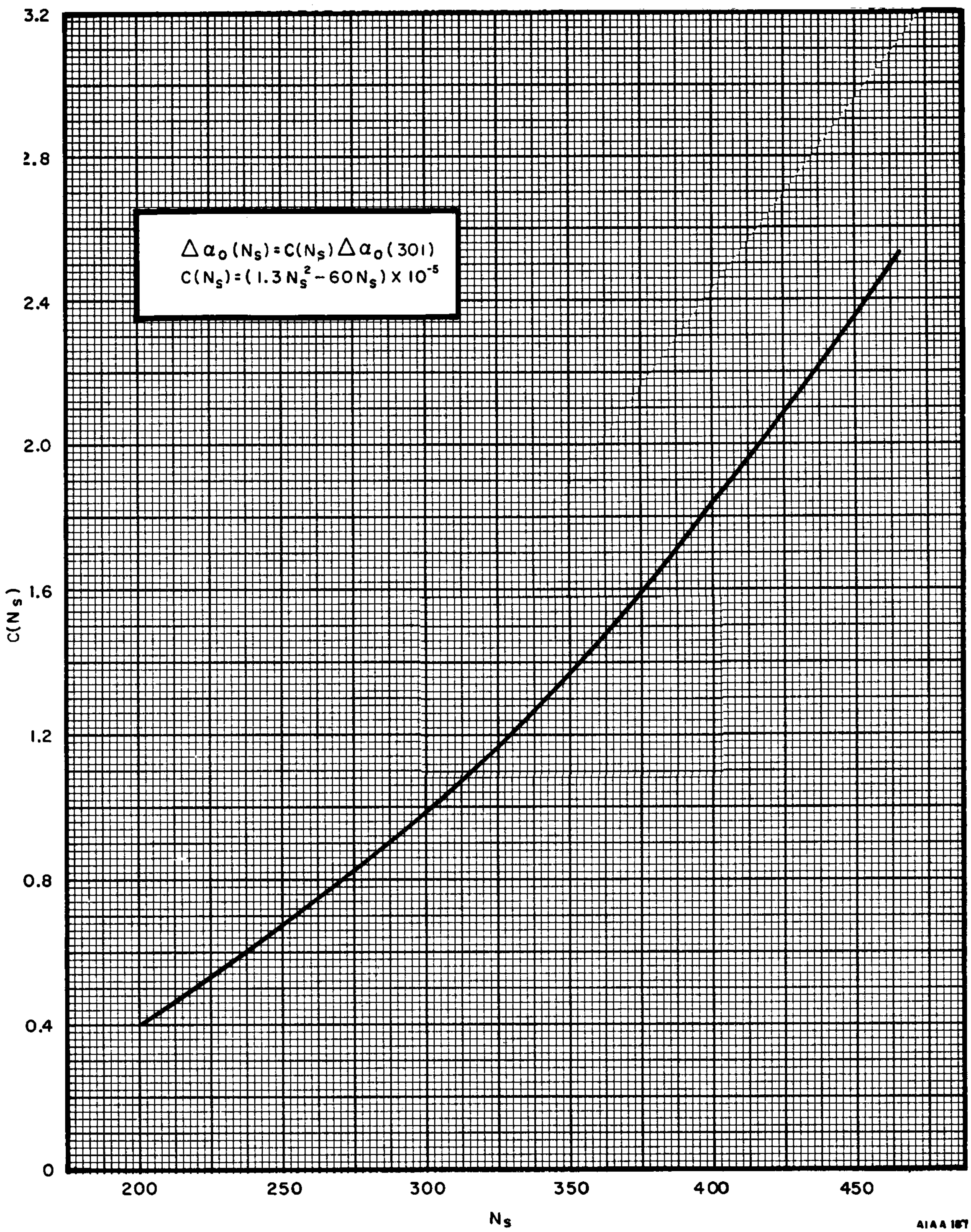


Figure 6-19. The Coefficient $C(N_S)$

PARAMETER	
DISTANCE d, km (From Figure 6-14)	89.75
SCATTER ANGLE θ, MILLIRADIANS (From Figure 6-17)	20.33
θ d , RADIANS (89.75) (20.33) x 10^{-3}	1.82
ATTENUATION FUNCTION F(θd) IN dB FROM FIGURE 4-5)	144.5
30 LOG f IN dB (f is frequency in MHz) (4800)	110.4
−20 LOG d in dB (d is distance in km) (89.75)	- 39.1
F_0, H, AND A_a CONSIDERED NEGLIGIBLE	
L_{bsr} dB 144.5 + 110.4 - 39.1	215.8

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$L_{bsr} = 30 \text{ LOG } f - 20 \text{ LOG } d + F(\theta d) - F_0 + H_0 + A_a$; dB

Figure 6-20. Computation of Long-Term Median Transmission Loss of Tropospheric Scatter

ANTENNA COUPLING LOSS (SCATTER LOSS)

$$S = \frac{\alpha_0}{\beta_0}$$

(FROM FIGURE 6-17)

$$S = \frac{9.17}{11.16} = 0.821$$

$$D_s = d - d_{LT} - d_{LR} \quad \text{km}$$

(FROM FIGURE 6-17)

$$D_s = 89.75 - 4.4 - 8.4$$
$$= 76.95 \text{ kilometers}$$

$$h_0 = \frac{S \; D_s \; \theta}{(1+S)^2} \quad \text{km}$$

$$= \frac{(0.821)\;(76.95)\;(.02033)}{(1 + .821)^2}$$

$$= .445 \text{ km}$$

THE HALF POWER BEAM WIDTH Ω OF A PARABOLIC ANTENNA IS APPROXIMATELY

$$\Omega = \frac{1222}{FB} \text{ MILLIRADIANS}$$

WHERE F = FREQUENCY IN GHz
B = PARABOLA DIAMETER FEET

(FROM FIGURE 6-14)

$$= \frac{1222}{(4.8)\;(30)} = 8.5 \text{ milliradians}$$

$$\frac{\theta}{\Omega} = \frac{20.33}{8.5} = 2.39$$

SCATTER LOSS Lgp
(FROM FIGURE 6-23)

AIAA190

Figure 6-21. Antenna Coupling Loss

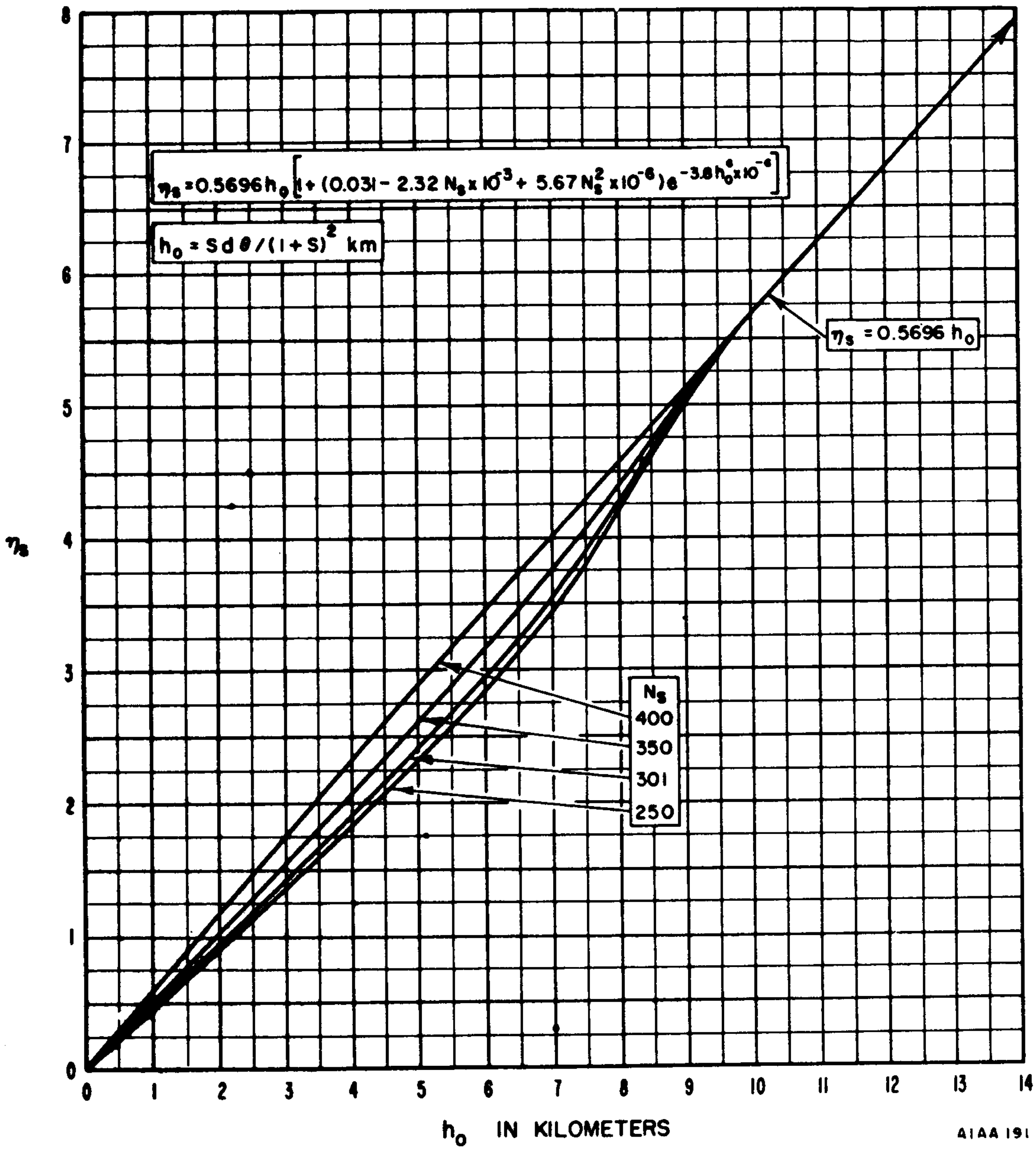

Figure 6-22. The Parameter N_S (ho) Used to Compute Ho

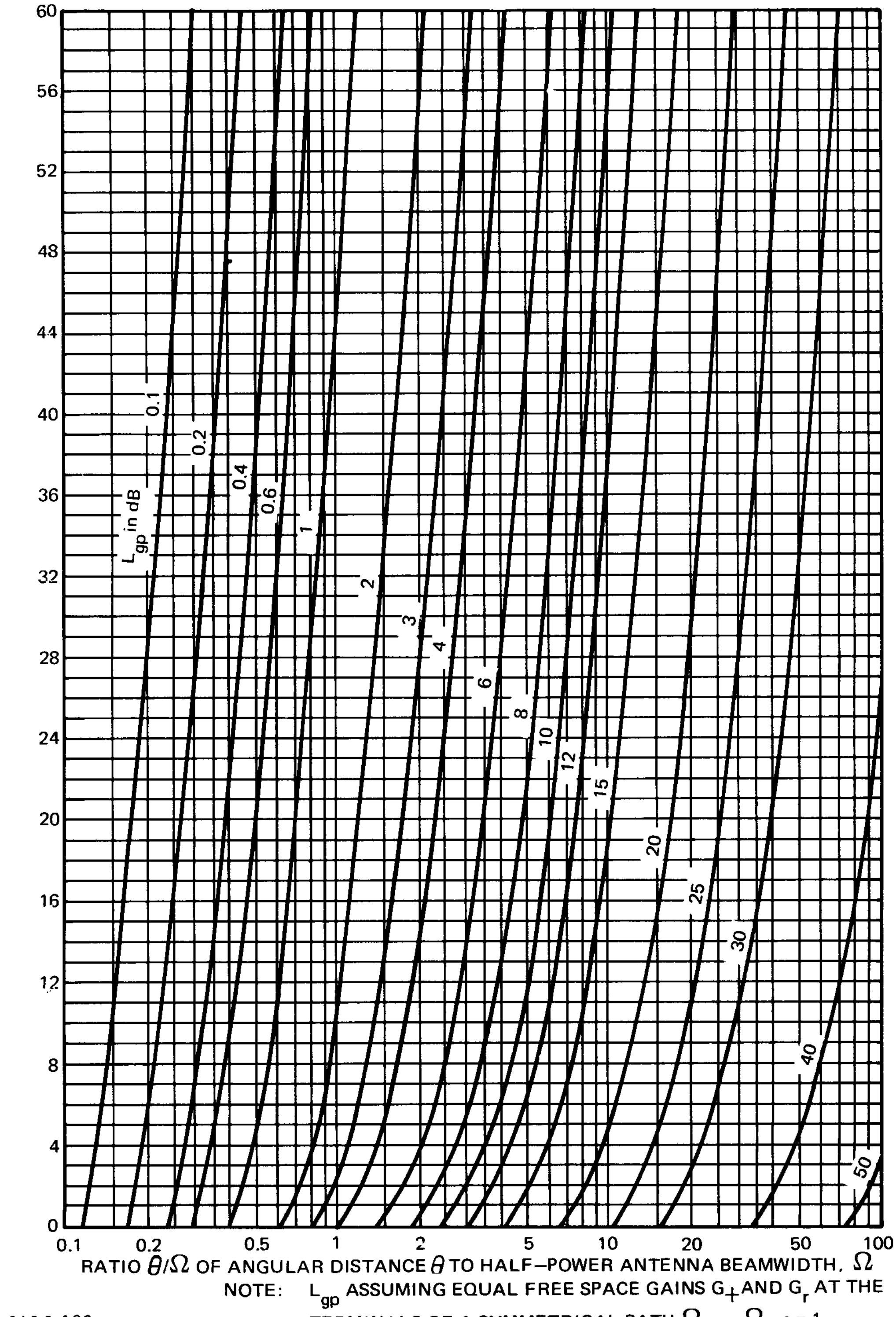

Figure 6-23. Loss in Antenna Gain, L_{gp} (Assuming Equal Free Space Gains G_1 and G_r at the Terminals of a Symmetrical Path $\Omega_t = \Omega_r$, s = 1)

l. In figure 6-14:

- o Items 12, 13, 14, and 15 are totaled and entered in item 16.

- o Items 9 and 16 are totaled in item 17.

- o The difference between items 17 and 24 is entered in item 25.

- o The median received power item 27 is the difference between items 25 and 26.

- o The difference between items 27 and 28 is the theoretical signal to noise ratio, item 29.

- o The difference between items 27 and 30 is the fade margin 18.7 dB.

m. Figure 7-1 indicates that for 99.99 reliability required by DCA standards, a fade margin for quadruple diversity of 5 to 9 dB is required, depending upon the combined methods. Hence, propagation along this path is possible.

6.4.2 Diffraction Path Calculations

A propagation path with a common horizon for both terminals may be considered as having a single diffracting edge. This diffraction loss can be estimated from Figure A-7. However, the transmission loss over a practical knife-edge diffraction path depends critically on the shape of the diffracting edge. Since a natural obstacle such as a mountain ridge may depart considerably from an ideal knife edge, the diffraction loss in practice is usually up to 20 dB greater than that estimated for the ideal case.

The initial path loss calculations for this type of path should be identical to that given in chapter 5 and appendix D except that an additional diffraction loss determined from figure A-7 and an added 10 dB loss for a departure from a theoretical knife edge should be added to the free space loss.

CHAPTER 7

LOS SYSTEM DESIGN

This chapter includes simplified procedural steps for establishing a LOS system to satisfy certain communication requirements between two points. The curves and nomographs are based on theoretical and empirical results; such readily predictable factors as free-space loss may differ from the calculated amount because of peculiar local conditions, and one cannot predict results exactly, because so many variables exist. However, by applying the methods and procedures presented here, an operational system may be successfully designed, installed, and operated.

Procedures for designing a LOS communications circuit can be organized into four major steps: determination of basic system requirements; analysis of proposed system configuration to determine path length, frequency, and optimum site location; prediction of system performance based on type of equipment used, path length, and required channel capacity, and actual installation procedures.

7.1 SYSTEM REQUIREMENTS

The first step in planning a LOS system between two given site locations is clarification of system requirements. The following questions should be answered:

- Will the link be used for voice, teletype, or high-speed data transmission?
- What is the required channel capacity?
- What is the minimum acceptable reliability?
- What carrier frequencies are available to be used?
- What is the required system availability?

With the answers to these questions, the system designer can select a basic transmitter and antenna as a first approximation.

7.2 SYSTEM CALCULATIONS

Before system predictions can be attempted, certain system calculations must be made to determine operating parameters peculiar to the particular system. System design is a process of balancing system gains with system losses to provide a minimum usable signal (MUS) at the receiver. The system losses are Free-Space Loss, Coupling Loss, and Miscellaneous System Losses. System gains are Transmitter Gain, Antenna Gain, and Diversity Gain. Such things, therefore as path length and receiver sensitivity must be known. Methods for determination of these parameters are presented in the following paragraphs.

7.2.1 System Losses

a. Free Space Loss. The attenuation (L_{FS}) between two isotropic radiators (in dB) is:

$$L_{FS} = 37 + 20 \log D + 20 \log f \qquad (7\text{-}1)$$

where D = distance (in statute miles)

f = frequency (in megahertz)

The requirements for true Free-Space Loss to be realized as presented in Equation 7-1 are:

o No large obstacles intervene between the antennas along an optical line-of-sight.

o No alternate transmission path can be followed by a substantial fraction of the radiated energy.

o The intervening atmosphere has a constant index of refraction so that no bending of the wave occurs at the frequency used.

o The intervening atmosphere does not absorb energy from the wave at the frequency used.

These conditions are closely approximated for the case of LOS systems where the total loss can be considered to be Free-Space Loss. For the case where the receiver is beyond the line-of-sight, an additional loss called Scatter Loss must be added to the Free-Space Loss.

b. Miscellaneous Losses. There are always losses associated with transmission lines, duplexers, etc. To allow for these losses in system design, a figure of 4 dB is usually given for systems using 1 kMHz and using waveguide, and 6 dB is used for 2 kMHz systems which use waveguides.

If the transmitter is more than 100 feet from the antenna, add to the miscellaneous loss additional transmission line losses.

7.2.2 Minimum Usable Signal (MUS)

When system losses have been calculated, system gain requirements must be evaluated to determine optimum system design based on requirements. The minimum usable signal, MUS, is a minimum signal level at the receiver input terminals which will provide a usable receiver output signal. The present state-of-the-art is such that a receiver output may be provided even if the transmitter signal is not received at the antenna. (Output will be developed from galactic, man-made, and thermal noise.) At LOS communication frequencies, galactic and man-made noise are of little consequence and are not considered in system calculations. However, thermal noise developed in the antenna and receiver input section, receiver generated noise, and a margin of signal-to-noise ratio required for FM threshold detection must be analyzed in developing the system design. The relationship of these factors is:

MUS = thermal noise + 10 log of the receiver bandwidth + receiver noise figure + FM threshold value carrier to noise. (7-2)

It has been determined that thermal noise is evenly distributed throughout the microwave spectrum and equals KT watts per hertz of bandwidth where:

K = Boltzman constant, 1.37×10^{-23}

T = Effective temperature in degrees Kelvin (for a typical microwave application 80° F, which equals 300° Kelvin, is used)

Thus noise power = 4.10^{-25} watt or KT = -204 dBW per Hz of bandwidth.

Since thermal noise is continuous and equal throughout the spectrum, a wider bandwidth will "see" more noise and subsequently require a higher minimum usable signal at the receiver input to overcome this noise. This factor is accounted for in the MUS calculations (Equation 7-3) by the second factor (10 log of the receiver bandwidth). In LOS systems this is usually a significant factor since bandwidth may be several MHz. The receiver front end will contribute noise to a system also, and this is accounted for in the third factor in the formula: receiver noise figure; high quality maser and parametric amplifiers will introduce as little as 2 dB noise; with more conventional vacuum tube amplifiers, the figure may be 8 to 12 dB. For an FM system the threshold level (fourth factor in Equation 7-3) is defined as the received input power which produces about a 10 dB RMS signal-to-noise ratio; to provide this margin the MUS must be increased by 10 dB. Using these factors, then, the MUS becomes:

MUS = -204 + 10 log BW + RNF + 10 dB (7-3)

where BW = bandwidth

RNF = receiver/noise figure

7.2.3 System Gains

When system losses have been estimated, and the minimum receiver signal requirements established, system design parameters to provide the necessary gains must be calculated.

a. Transmitter Gain. The gain of a power amplifier transmitted is given by:

$$G_{TR} = 10 \log \left(\frac{P}{1}\right) \text{ dBW} \qquad (7\text{-}4)$$

where P = RF power output in watts

Note that in order to standardize the system calculation, all gains are determined in dBW (1 watt = odBW reference).

b. Antenna Gain. Antenna gain is determined by:

$$G_A = (20 \log f + 20 \log D_A - 52.6) \text{ dB} \qquad (7\text{-}5)$$

where G_A = antenna gain over an isotropic radiator in dB

f = frequency in megahertz

D_A = diameter of reflector in feet

c. Diversity Gain. To minimize the affects of fast fading, the designer may use a form of diversity. The fast fading (multipath) phenomenon does not affect signals of different frequency or over different paths in a correlated manner. To reduce the overall affect of rapid fading, a diversity scheme can be used, whereby two or more essentially non-correlated signals are combined to produce a signal which is freer of fades than any individual signal. All types of diversity require the use of additional receivers and various other equipments; however, it is economical to use diversity on LOS systems where continuous, reliable service is required. By the use of maximal-ratio combiners, a gain in the median signal level can be obtained. The gain is theoretically 3.8 dB for dual-diversity, 6.0 dB for triple diversity and 7.2 for quadruple-diversity.

Quadruple-diversity is most economically obtained by using a form of space and polarization diversity. The four space paths are achieved by transmitting signals in the horizontal plane from one antenna and in the vertical plane from a second antenna. On the receiving end, two antennas are used, each antenna having dual-polarized feed horns for receiving signals in both planes of polarization. The net effect is to produce four independent signal paths which provide a diversity order of four.

Figure 7-1 shows the curves for dual-, triple-, and quadruple-diversity crossing the 50 percent reliability line at 3.8, 6.0, and 7.2 dB, respectively. The use of more

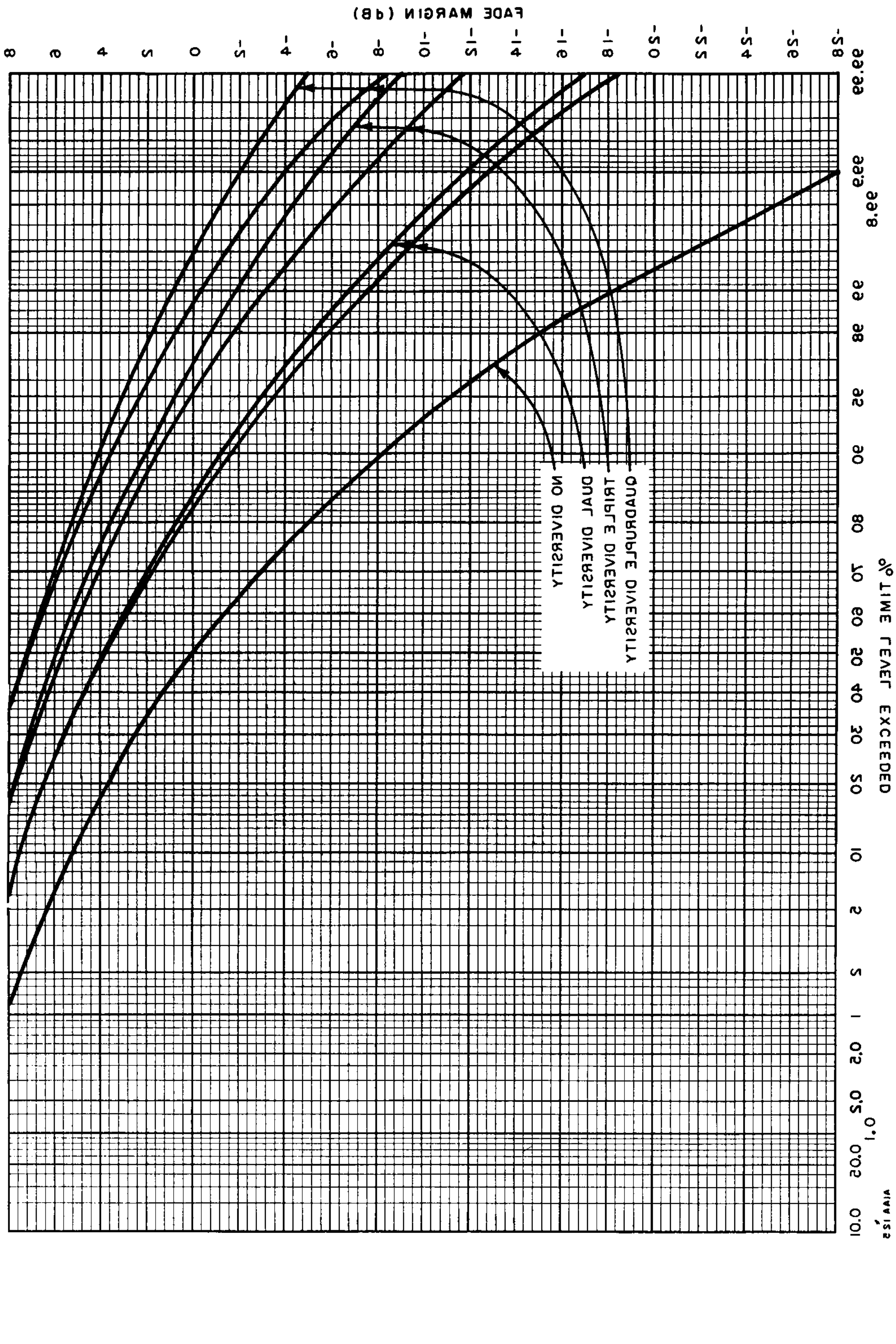

Figure 7-1. Short Term Fade Margin

than one antenna or more than one propagation path in conjunction with combining type receivers, therefore, produces a system gain of several dB.

7.2.4 System Performance

When the system gains and losses are tabulated, their algebraic total is the median received signal level. If this level is equal to the MUS, the system will function. However, the received signal will fluctuate rapidly, and will be obscured by noise at every fade. The reliability of such a system would be 50 percent, which is unsatisfactory for most military applications. If the median received signal is greater than the MUS, a fade equal to the difference between median received signal level and MUS will be absorbed without loss of the modulated information. The greater the difference of median received signal level and MUS (this difference is termed fade margin), the less is the likelihood that the received signal level will drop below the MUS.

7.2.5 Pre-emphasis (FM)

Pre-emphasis and the channel-loading factor are important considerations in determining the channel noise. While only a brief description of each is presented at this time, their use in the calculation of channel noise will be reserved for later paragraphs.

In order to assure that each channel has as near as possible the same signal-to-noise ratio, it is necessary to have the same deviation ratio in each channel. As the modulation frequency increases, the deviation ratio decreases. Thus, pre-emphasis must be added to make the frequency deviation in each channel a function of modulation frequency as well as modulation voltage. If the pre-emphasis is used, there is a gain in signal-to-noise in the top channel due to the increased deviation. A good engineering approximation is 4 dB average gain in a system using pre-emphasis over a system without pre-emphasis.

7.2.6 Channel Loading Factor

The load on a multi-channel system in terms of the number of telephone, teletype, and data channels in use will vary slowly with time. The multichannel system is also subjected to a rapidly varying instantaneous load resulting from the combination of the voltages in the various channels. A busy channel is one in which communications energy is actually flowing to a customer at the far end of the system. In the case of a telephone connection, busy channel time will be spent in ringing the far end, the near end talker upholding his portion of the conversation, and the rest of the time the talker at the far end will be talking, each pausing for breath and waiting between words and sentences. The fraction of time a busy telephone channel is active (termed activity factor) is obviously much less than one-half; thus indications are that a maximum telephone activity factor is 0.25.

7.3 SYSTEM CALCULATION EXAMPLE

To clarify the use of formulas and methods, a sample system calculation will be made. The system will be designed with line-of-sight calculations and consists of a path approximately 28 miles long in which the transmitter and receiver antennas are separated by path obstacles.

This system requires 72 full duplex voice channels and has been assigned a carrier frequency of 2 MHz between points A and B. The noise level must not exceed 38 dBa0 in any channel and the minimum acceptable carrier-to-noise ratio is 10 dB. The system must have a reliability of no less than 99.99 percent. As a first approximation, system design may be based on calculations, but noise levels in each channel must also be found to be within limits before the design can be accepted.

To begin, site information must be obtained. The site under consideration is located in the Mediterranean area; adequate topographic maps have been assembled and a path profile has been drawn from these. Terminal A was found to be 6450 feet above sea level and terminal B was found to be 3970 feet above sea level. The 28 mile path is within a temperate climate. These figures are obtained from maps, but should be verified by a site survey.

The basic approach will be to design a system such that the following equation will be satisfied:

$$\Sigma \text{ Gains} = \text{Losses} + \text{MUS} + \text{Fade Margin} \qquad (7\text{-}6)$$

$$= \text{Losses} + \text{AMUS (Actual Minimum Usable Signal)}$$

First, the terms on the right-hand side of equation 7-6 will be determined, then equipment will be selected which will provide the necessary gains to overcome their losses and produce the required reliability. The only piece of equipment which must be selected at this time prior to determining terms on the right side of equation 7-6 is the antenna. For paths of about 30 miles, a good starting antenna would be one which possessed a 2-foot dish. Consideration must be given in each case, to the number of channels required and geographical location (arctic regions being more lossy than temperate regions). Thus, initial consideration will be given to use of a 2-foot dish.

To begin system calculations, certain preliminary calculations must be made. These include the determination of the Great Circle Distance, the equivalent distance and the receiver bandwidth. These preliminary calculations appear in the following paragraphs.

Table C-1 in Appendix C is a convenient form for recording system parameters. The first calculation in the system design is determination of the Great Circle Distance. This can be determined by the method presented in Appendix D and has been found to be:

Great Circle Distance - 28.55 Miles

The Great Circle Distance will be used in the determination of Free-Space Loss and Scatter Loss.

The power spectrum of a FM radio carrier is dependent on the modulating waveform and the deviation ratio. Medhurst has shown that for a normally distributed modulating waveform and sufficiently large deviation ratio, the RF power spectrum of the FM carrier is Gaussian. This is true since the RF energy in a particular frequency band is proportional to the percentage of time that the instantaneous carrier frequency remains in that band.

The first decision to be made in the choice of bandwidth is the RMS deviation corresponding to the channel test tone, realizing that a high deviation yields a high FM improvement as well as a higher threshold. CCIR Recommendation Number 274 calls for the following RMS frequency deviation per channel, without pre-emphasis, for line-of-sight and near line-of-sight systems. (To be used as an indicator only for tropo-scatter systems):

MAXIMUM NUMBER OF CHANNELS	RMS DEVIATION PER CHANNEL (KHZ)
24	35
60	50, 100, 200
120	50, 100, 200

A multichannel FM system which uses no pre-emphasis has a per channel deviation ratio inversely proportional to the channel frequency in the baseband. The channel deviation ratio for a sine wave test tone with a peak value equal to the channel level which, when exceeded, is considered as instantaneous channel overload, is:

$$m_c = \frac{\sqrt{2}\,\Delta F_c}{f_c} \qquad (7\text{-}7)$$

where, ΔF_c is the RMS frequency deviation of the main carrier in Hz and F_c is the frequency in Hz of the channel sine wave modulating voltage in the baseband.

The RMS deviation of the RF carrier by the multichannel signal can be determined by taking the square root of the sum of the squares of the per channel mean deviations of the RF carrier. The RMS multichannel deviation will vary as the mean multichannel power. The peak deviation of the carrier may be determined by:

$$\Delta F_c \text{ (peak)} = \sqrt{2}\ \Delta f 1(N) \text{ Hz} \qquad (7\text{-}8)$$

where Δf = RMS deviation per channel in Hz

N = number of channels

$$1(N) = \text{antilog}\,\frac{L(N)}{20}$$

ΔF_c (peak) = peak carrier deviation

The bandwidth may then be determined by entering figure 7-2 with the deviation ratio or by using (7-9) below:

$$3\ \text{dB bw} = 2\,(\Delta F_c\ (\text{peak}) + 2f_m) \qquad (7\text{-}9)$$

where: f_m = maximum modulating frequency in Hz (see table 7-1)

As an example, consider 72 channels with an RMS deviation of 100 kHz per channel. The load factor, L(N), from figure 7-3, is 18.1 dB, thus 1(N) is about 8.05. Then the peak carrier deviation, ΔF_c (peak) is found from (7-8) above;

$$\Delta F_c\ (\text{peak}) = 1.414(100)(8.05)$$

$$\cong 1140\ \text{kHz}$$

The top channel frequency is 300 kHz so that the peak deviation ratio from (1) above is:

$$m_p = \frac{1140}{300} \cong 3.8.$$

The 3 dB bandwidth may now be determined using (7-9) above

$$3\ \text{dB bw} = 2(1140 + 600)$$

$$\cong 3480\ \text{kHz}$$

The bandwidth may also be determined by use of figure 7-2. Entering with a deviation ratio, m_p, of 3.8, curve (A) shows a ratio $\frac{b}{\Delta F_c\ (\text{peak})}$ of about 3.9, so the flat bandwidth is about 4440 kHz; Curve (B) shows a ratio $\frac{b}{\Delta F_c\ (\text{peak})}$ of about 3.05, so that the 3 dB bandwidth of 3480 kHz of equation (7-9) is verified; Curve (C) shows a ratio $\frac{b}{\Delta F_c\ (\text{peak})}$ of about 2.38, so the flat bandwidth for a distortion-to-signal ratio of -80 dB is about 2710 kHz. The 3 dB bandwidth required in the IF, b_{IF}, is about 3.5 MHz.

In the general case, the rms deviation per channel should be chosen so that the peak deviation ratio is around 3. The result of several cases is shown in table 7-1.

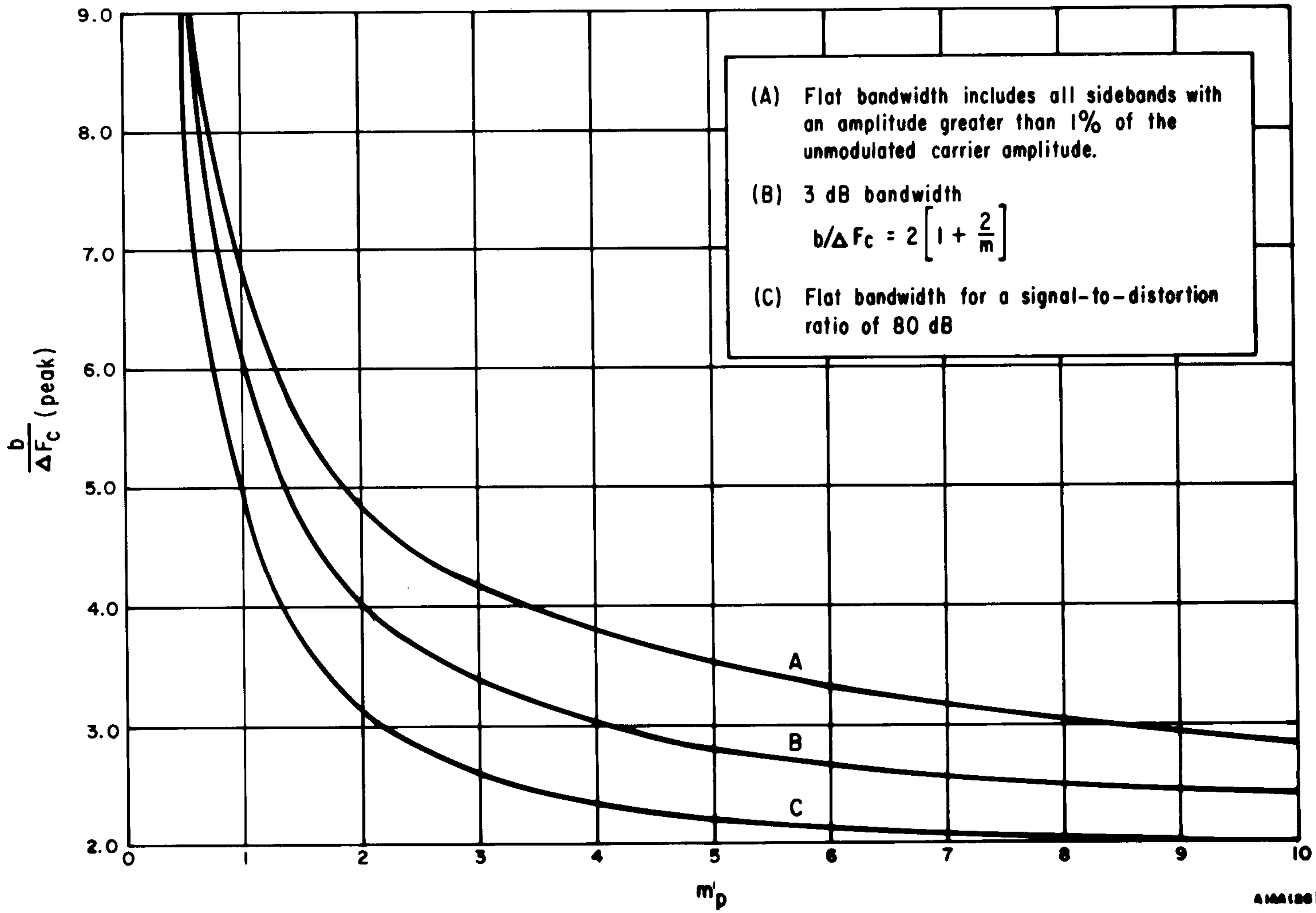

Figure 7-2. Bandwidth Determination

Table 7-1. Results of RMS Deviation Per Channel

NUMBER OF CHANNELS	MAXIMUM MODULATION FREQUENCY	LOADING FACTOR L(N) IN dB	l(N)	RMS DEVIATION PER CHANNEL (Hz)	PEAK CARRIER DEVIATION (Hz)	Fc (PEAK) fm	3 dB BAND-WIDTH, b, IN Hz	B(DB) = 10 LOG b
12	60	15.8	6.2	25	219	3.6	680	58.3
				35	306	5.1	850	59.3
24	108	16.8	6.9	25	244	2.3	920	59.6
				35	324	3.2	1120	60.5
36	156	17.2	7.25	35	360	2.3	1345	61.3
				50	514	3.3	1650	62.2
48	204	17.5	7.5	35	372	1.8	1560	61.9
				50	532	2.6	1880	62.7
				100	1060	5.2	2940	64.7
60	252	17.8	7.8	50	550	2.2	2110	63.2
				100	1100	4.4	3210	65.1
72	300	18.1	8.0	50	570	1.9	2340	63.7
				100	1140	3.8	3480	65.4
				200	2280	7.6	5760	67.6
120	492	19.1	9.3	50				
				100	1310	2.7	4580	66.0
				200				

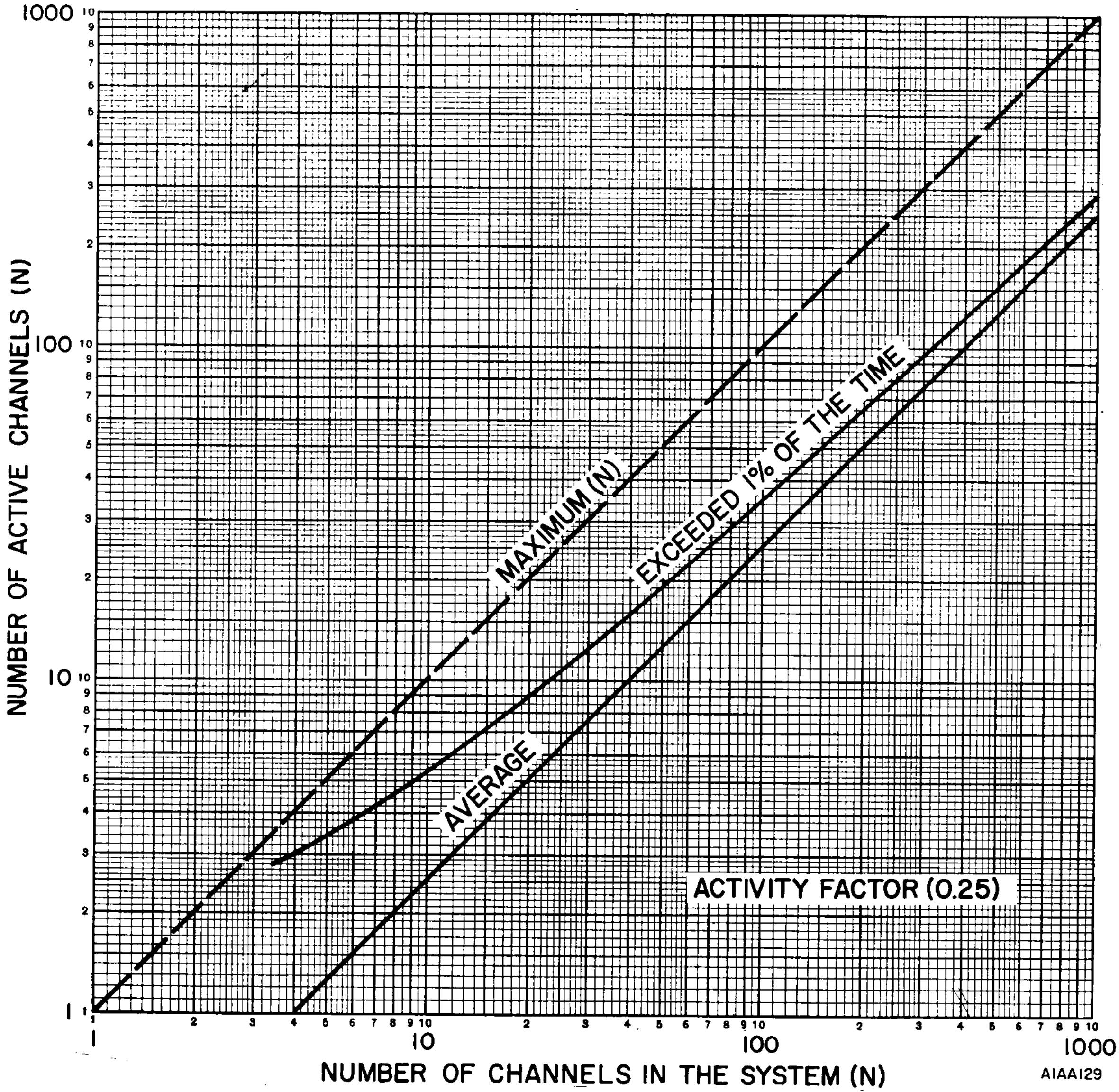

Figure 7-3. Number of Active Channels as a Function of the Number of Channels in the System

7.3.1 System Losses

Now we are ready to compute systems losses. The first loss considered is Free-Space Loss, obtained from Appendix A or from the relationship:

$$L_{FS} = 37 + 20 \log D + 20 \log f \quad (7\text{-}10)$$

$$= 37 + 20 \log 28.55 + 20 \log 1965$$

$$= 37 + 28.96 + 65.87$$

$$= 131.83$$

Free Space Loss = 132 dB

To the above loss we add the allowance (6 dB) for all miscellaneous losses (transmission lines, etc.)

Miscellaneous Losses = 6 dB

The losses are tabulated as shown below:

Losses	
Free-Space	132.0 dB
Miscellaneous	6.0 dB
Total Losses	138.0 dB

7.3.2 Actual Minimum Usable Signal

With the system losses determined, attention will now be given to the evaluation of the Actual Minimum Usable Signal (AMUS). The AMUS is composed of two factors:

- o the MUS
- o the additional gain required for obtaining the desired reliability (fade margin).

The minimum usable signal, MUS, is obtained from:

$$MUS = -204 \text{ dBW} + 10 \log BW + (\text{receiver noise figure in dB}) \quad (7\text{-}11)$$

$$+ (\text{carrier-to-noise ratio in dB})$$

$$= -204 + 10 \log 3.2 \times 10^6 + 12 + 10$$

$$= -204 + (10)(6.505) + 22$$

MUS = -117 dBW

The MUS represents the minimum usable signal level, in dB, for a system possessing 50 percent propagation reliability. The receiver noise-figure is 12 dB, and the carrier-to-noise ratio is 10 dB (by definition) for FM systems.

Since ordinary military systems require a propagation reliability greater than 50 percent, the MUS must be adjusted to meet the requirement. For the system under consideration, the adjustment necessary to increase the reliability to 99.99 percent is 38.0 dB as obtained from figure 2-30. Therefore:

Fade Margin = 38.0 dB

Thus, the AMUS for this system is:

$$\text{AMUS} = \text{MUS} + \text{additional gain to obtain } 99.99\% \text{ reliability (fade margin)} \quad (7\text{-}12)$$

$$= -117 + 38$$

$$= -79 \text{ dB}$$

7.3.3 System Design Parameters (System Gains)

Combining the total losses with the AMUS, equation 7-6 reveals that the system must produce a minimum gain of 59 dB if it is to be acceptable.

$$\text{Required Gains} = \text{Losses} + \text{AMUS} \quad (7\text{-}13)$$

$$\text{Required Gains} = 138 - 79 = 59 \text{ dB}$$

Gains. System gain is a function of transmitter power, antenna diameter, order of diversity and (when present) knife-edge gain.

A 1-watt transmitter is first considered and has a gain of 0 dB.

$$G_{TR} = 10 \log\left(\frac{1w}{1w}\right) = 0 \text{ dB} \quad (7\text{-}14)$$

Antenna gain, obtained from Appendix A or Equation 7-15, is:

$$G_A = 20 \log f + 20 \log D_A - 52.6 \quad (7\text{-}15)$$

$$= 20 \log 1965 + 20 \log 2 - 52.6$$

$$= 19 \text{ dB}$$

System antenna gain is (19.0) (2) = 38 dB.

Next, the order of diversity is given consideration. First, consider dual diversity. From figure 7-1, it is seen that a gain of 3.8 dB is realized if dual diversity is used. This calculation is median path loss; therefore, enter curve at 50 percent time level. Therefore:

Diversity Gain = 3.8 dB

Tabulating the above gains, a total gain of 41.8 dB is obtained:

Transmitter (1-watt)	0 dB
Antenna (2')	38.0
Diversity (dual)	3.8
Total Gain	41.8 dB

Comparing the total system gain (41.8 dB) with that required for 99.99 percent reliability (59.0 dB), indicates that the system does not meet the requirements. The next consideration is to find the simplest and cheapest method of obtaining the required increase. This may be accomplished by reducing the losses (difficult in most cases) or increasing the gains.

There are three direct methods of increasing gains: increasing the order of diversity; increasing antenna size; or increasing transmitter power.

7.3.4 Balance

Quadruple diversity may be used instead of dual diversity. With quadruple diversity a gain of 7.2 dB (3.4 dB over dual diversity) (see figure 7-1) is realized.

Retabulating system gain using the increase in gain due to quadruple diversity yields a total gain of 45.2 dB, as follows:

Transmitter (1-watt)	0.0 dB
Antenna (2')	38.0
Diversity (Quadruple)	7.2
Knife-Edge	0.0
Total Gain	45.2 dB

Again, comparing system gain (45.2 dB) with the gain required for 99.99 percent reliability (59.0 dB) indicates that further adjustment will be necessary.

Increasing antenna size will next be considered. Consider the use of 4-foot reflectors in place of 2-foot reflectors. As determined from equation 7-15, a gain of 50 dB (2) (25.0) results from this consideration.

Retabulating system gain using the increase in gain due to the larger antenna yields:

Transmitter (1-watt)	0.0 dB
Antenna	50.0 dB
Diversity (Quadruple)	7.2 dB
Total Gain	57.2 dB

Again, comparing system gain (57.2 dB) with the gain required for 99.99 percent reliability (59.0 dB) indicates that still further considerations will be necessary.

The third possibility of obtaining an increase in gain is through the use of higher power transmitters. If 2-watt instead of 1 watt transmitters are used, the system will experience a 3 dB gain (3 dB over a 1 watt transmitter). This will increase the total system gain to 60.2 dB, which exceeds the 59 dB required for 99.99 percent reliability. Thus, the requirements have been met.

Very often only one or two of the above considered methods for increasing gain will be sufficient to meet requirements. In such a case, the method selected to obtain the required reliability should be based on cost, availability of equipment and materials, ease of maintenance, and space and height limitations, as well as equipment dependability and power requirements. The three methods of achieving the required reliability must be analyzed in the light of the peculiarities of the individual sites.

Quadruple diversity may be effected without additional antennas by simultaneously transmitting horizontal and vertical modes. Both modes are received on each receiving antenna, using dual polarized horns feeding into combining-type receivers. This is an economical method of requiring only two additional waveguide runs and two additional receiver-combiners. The total space requirement is only slightly greater. Increased maintenance is necessary, causing additional down time which decreases reliability unless spare receiver(s) are provided.

The use of larger antennas is effective in providing increased gain. However, cost and space requirements are increased. Air hazards are also presented with the use of larger antennas. This method, however, provides increased gain with little additional maintenance or post-installation cost.

Transmitters of greater power may be considered as a means to increase the received signal level. However, additional building space is required for heat exchangers and prime power requirements are greatly increased. Replacement cost of klystrons over several years might prove to be very high.

7.3.5 Channel S/N Calculations

After reliability considerations have been established and a favorable system design completed, it is necessary to compute the expected channel noise. According to the DCA System Performance Specifications, the channel noise objective is 38 dBaO. The requirement states that:

> ...noise in any channel shall not exceed 38 dBa median at zero relative level (25,000 picowatts) in any channel during the worst month, and shall not exceed 49 dBa at zero relative level (316,000 picowatts) in any channel for more than 1.0 percent of the worst month.

The channel noise (Signal-to-Noise ratio (S/N)) may be computed after the Carrier-to-Noise (C/N) ratio of the path has been determined. The relationship between channel S/N and system C/N in an FM system is determined primarily by the bandwidth required for the particular type of information being transmitted and the degree of deviation produced in the system.

The Carrier-to-Noise defines the power relationship that exists between the received signal level and the noise. The total median C/N is obtained by adding the reliability fade margin (additional gain required for desired reliability) to the defined Carrier-to-Noise ratio of 10 dB.

In this case:

$$C/N = 10 + 38.0$$

$$= 48 \text{ dB}$$

With the total median C/N known, the S/N ratio may be obtained from:

FOR SSB

$$S/N = C/N + 10 \log \left(\frac{BW}{bw}\right) - L \qquad (7\text{-}16)$$

FOR FM

$$S/N = C/N + 20 \log (\text{Modulation Index}) + 10 \log \left(\frac{BW}{2bw}\right) + PF - L - MUX \qquad (7\text{-}17)$$

where,

C/N = Total Median C/N Ratio

BW = Receiver IF Bandwidth

bw = Voice Channel Bandwidth

L = Channel Loading Factor

PF = Pre-emphasis Gain

MUX = Multiplex Equipment Noise Insertion

For the system under consideration:

Modulation Index = 3

C/N = 48 dB

BW = 3.2 MHz

bw = 4 kHz

PF = 4 dB

L = 10.8 dB (See figure 7-4)

MUX = 2 dB (average factor)

Thus,

$$S/N = 48 + 20 \log 3 + 10 \log \left(\frac{3.2 \times 10^6}{8 \times 10^3}\right) + 4 - 10.8 - 2$$

$$= 20 \log 3 + 10 \log (4 \times 10^2) + 39.2$$

$$= (20)(.466) + (10)(2.602) + 39.2$$

$$= 9.54 + 26.02 + 39.2$$

$$= 74.76 \text{ dB}$$

Thus, the S/N ratio has been computed. Before proceeding to the determination of channel noise, it is important to briefly consider the meaning of the S/N ratio.

The term "signal-to-noise ratio" (S/N) originated in single-channel communications practice and generally took into consideration only background or residual noise in a single radio channel. With the growth of multichannel communications, it is also used to express total intermodulation and residual noise in a single radio channel and is frequently referred to as "per-channel flat signal-to-noise ratio." Basically, it expresses the ratio, in dB, of signal power to total noise power in a channel. It does not take into account the actual interfering affect of noise on the signal in complete circuits.

The channel noise factor is expressed in dBa0 Decibels adjusted, or dBa, originated in the telephone industry as an expression of overall system noise performance.

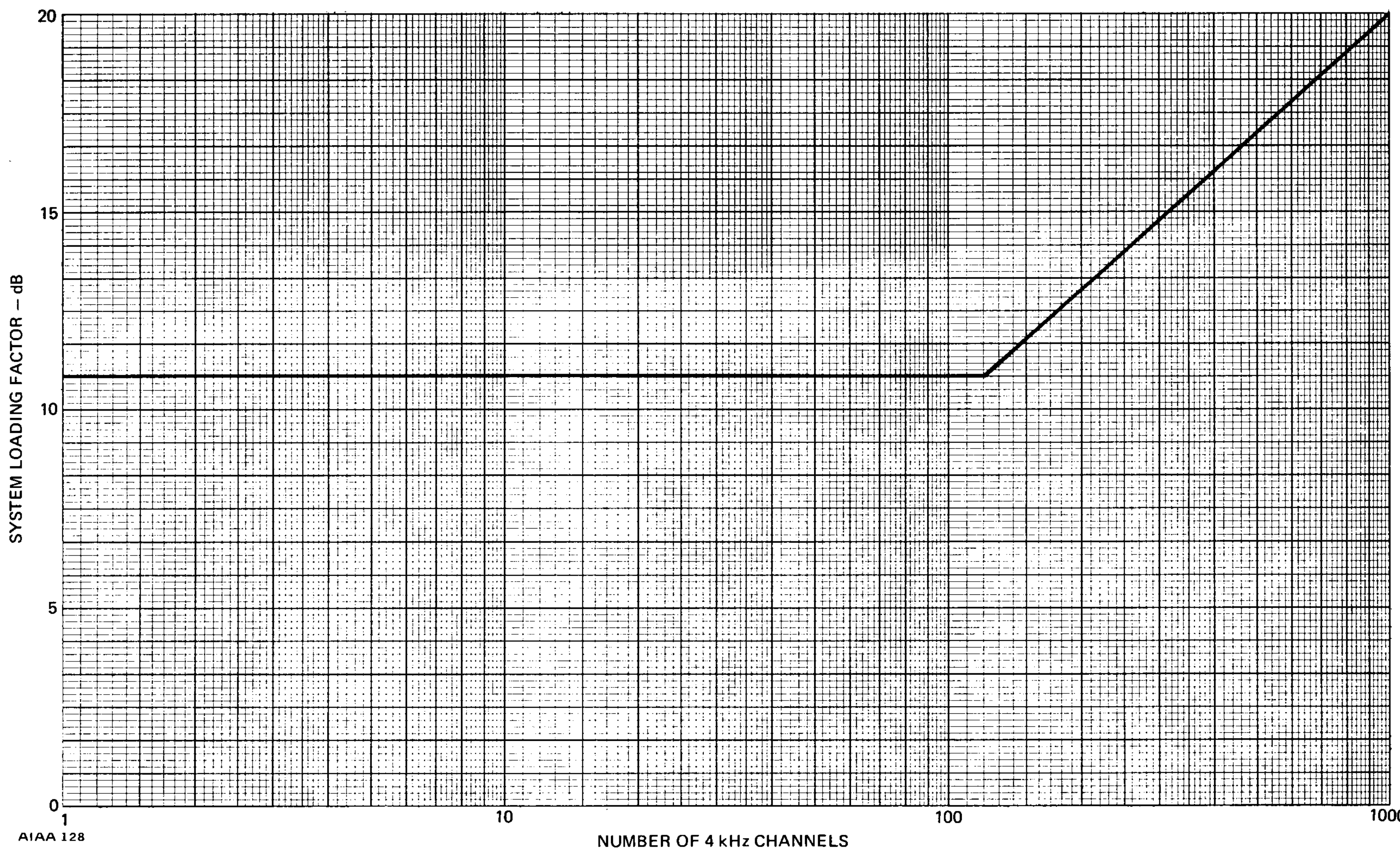

Figure 7-4. System Loading Factor

Strictly speaking, the term dBa implies that the frequency response or weighting of the voice frequency equipment used is "F1A" weighting. This method of noise performance is especially practical. It takes into account not only special types of noise or noise in particular items of equipment, but also the affects of all system noise.

By definition, dBa refers to decibels of noise power above a reference noise power, with an adjustment factor included to compensate for weighting. Even though the equipment from which F1A weighting was derived has been superseded by newer equipment having better performance, F1A weighting continues to be used extensively because it provides a very close approximation to the performance of most telephone equipment.

The reference noise power to which dBa is referred is -85 dBm. To obtain dBa0, it is only necessary to calculate how many dB above this reference power the signal is. For flat voice channels, the corrected reference level is -85 + 3 or -82 dBm. Therefore, in this case

$$\text{dBa0} = 82 - (S/N) = 82 - 74.76 = 7.24 \text{ dBa0} \qquad (7\text{-}18)$$

The allowable median noise in a real LOS hop specified by DCAC-330-175-1 is based on its actual length as follows:

hop length in NMI	Allowable Noise
L>151 NMI	3.33 L pWpO
27<L<151 NMI	2.76 L pWpO + 85.5 pWpO
L<27 NMI	160 pWpO

Where L is the hop length in nautical miles.

Therefore, for a 28.55 mile hop the allowable noise is:

= 2.76 (28.55) + 85.5 pWpO

= 164.4 pWpO

or 16.6 dBaO

Thus, a channel having a S/N ratio of 74.76 dB exhibits 7.24 dBaO noise. The allowable median noise is 16.6 dBaO and the channel noise requirement is met.

If the value of the channel noise factor did not meet the minimum specified for the system, it would be necessary to increase the basic peak channel deviation, or the preemphasis, or base the signal reliability on a greater C/N ratio. The choice will depend on the flexibility of the particular equipments involved. The affect on the bandwidth of adjusting the deviation ratio is shown in table 7-1.

The system calculations presented in this paragraph are provided as a guide and are a compilation of the most recent and reliable data available.

The data sheets (table 7-2) illustrate the foregoing example. Blank data sheets are included in Appendix C.

7.4 FREQUENCY PLANNING

In the design of any microwave communications system involving the use of two or more radio frequencies, it is necessary to develop a plan of frequency allocation that will preclude the possibility of interference. Such interference may be defined as the reception of an undesired signal with, or in place of, the desired signal. This undesired signal, or interference, should be considered in terms of its source and permissible level at the receiver.

Types of Undesired Signals. There are three types of undesired signals which must be considered by the system planner, two of which are directly under his control. The undesired signals are:

o Signals arriving at two or more receivers from two or more transmitters operating from the same location and in the same direction, that is, signals traveling parallel paths. These signals will arrive at about the same signal level, and will be affected equally by any fade that may occur along their path (assuming that frequency separation is not too great). These parallel signals will cause interference at the receivers unless the transmitting frequencies are chosen with the RF and IF rejection characteristics of the particular equipment in mind.

o Signals from other transmitters at the same station in close proximity to the receivers. The desired signal, in this case, may be very weak as compared with the signal radiated from the nearby transmitter (for example, -75 dBm as compared with 0 dBm). Also, the undesired signal is generally not subject to atmospheric fading, as is the desired signal. Allowing for a fading margin of 30 dB, the desired signal level might be as low as -105 dBm. Because of these factors, the frequency separation between the undesired locally transmitted signal and the desired received signal must be great enough to allow sufficient attentuation (about 25 dB) of the undesired signal below the minimum level of the desired signal.

o Signals originating from sources external to, or unrelated to, the microwave system under consideration. These undesired signals are the most difficult to eliminate. Military microwave systems, or commercial systems operating in the vicinity of military installations, may have interference from certain types of radar or other super-high-frequency equipment. In some instances, an undesired signal may be the fundamental frequency of the radar equipment, and, in certain types of radar, the peak amplitude of this signal may be as much as 60 dB above the peak RF output of the microwave equipment. Since it is improbable that a change in radar frequency can be effected, it follows that the microwave system frequency allocation must be reconsidered.

Table 7-2. LOS System Data Sheet

FROM: **Site A** TO: **Site B**

I. SYSTEM REQUIREMENTS

Type of Transmission (Voice, TTY, etc.)	Full Duplex Voice
Number of Voice Channels	72
Desired Reliability	99.99
Maximum Allowable Channel Noise 6000 mi. cct.	37 dBaO
Maximum Modulating Frequency, FM	400 kHz
RF Carrier Frequency, F	1965 MHz
Modulation Index	3

Site Coordinates:

LA ___° ___' ___" N Lat ___° ___' ___" W Long
LB ___° ___' ___" N Lat ___° ___' ___" W Long

II PRELIMINARY CALCULATIONS

Great Circle Distance, D ---------- 28.55 Miles
Revr. Bandwidth, $BW = 2(\Delta F_p + F_m)$ ---------- 3.2 MHz

III. LOSSES - dB

	Trial	Change	Change	Change
	1	Dual To Quad	Ant. 2' - 4' -	Xmtr 1 - 2 Watts
Free-Space Loss, L_{FS} = 37 + 20 log D (miles) + 20 log f (MHz)	132.0	132.0	132.0	132.0
Misc. Transmission Loss	6.0	6.0	6.0	6.0
TOTAL LOSSES	138.0	138.0	138.0	138.0

IV. MINIMUM USABLE SIGNAL, MUS

= 204 dBW+ 10 log BW + 12 dB + 10 dB--- -117 dBW

V. ADDITIONAL GAIN REQUIRED FOR 99.99% RELIABILITY (FADE MARGIN) ------- +38 dB

VI. ACTUAL MINIMUM USABLE SIGNAL, AMUS
= MUS + FADE MARGIN ------------ -79 dB

Table 7-2. LOS System Data Sheet (Continued)

VII. TOTAL REQUIRED GAIN in dBW = TOTAL LOSSES + AMUS

	Trial	Change	Change	Change
	1	Dual To Quad	Ant. 2' - 4' -	Xmtr 1 - 2 Watts
TOTAL REQUIRED GAIN in dBW = TOTAL LOSSES + AMUS	59	59	59	59

VIII. GAINS - dBW

	Trial	Change	Change	Change
	1	Dual To Quad	Ant. 2' - 4'	Xmtr 1 - 2 Watts
Xmtr Gain, $G_{TR} = 10 \log P_T$	0	0	0	3.0
Antenna Gain, $G_A = 20 \log f + 20 \log D_A - 52.6$	38.0	38.0	50.0	50.0
Diversity Gain, G_{DIV}	3.8	7.2	7.2	7.2
TOTAL GAIN	41.8	45.2	57.2	60.2

IX. SYSTEM FEASIBILITY

(Compare Step VIII and Step VII)

Adjustment Required: X X X
OK: X

X. MEDIAN CARRIER-TO-NOISE RATIO, C/N
= FADE MARGIN + 10 dB ------------ 48.0 dB

XI. SIGNAL-TO-NOISE RATIO, S/N

$$= C/N + 10 \log \left(\frac{BW}{bw}\right) + 20 \log (\text{Modulation Index}) + PF - L - MUX$$

---------------- 74.76 dB

XII. CHANNEL NOISE FACTOR
= 82 - S/N --------------------- 7.24 dBaO

XIII. ALLOWABLE MEDIAN NOISE

$L > 151$ NMI --------------------- 3.33 L pWpO
$27 < L < 151$ NMI ------------------ 2.76 L + 85.5 pWpO
$L < 27$ NMI---------------------- 160 pWpO
MAX ALLOWABLE NOISE------------ 16.6 dBaO

XIV. SUMMARY

Desired Reliability: 99.99%
Max. Allowable Channel Noise: 15.6 dBaO

Actual Reliability: 99.99%
Actual Channel Noise: 7.24 dBaO

Table 7-2. LOS System Data Sheet (Continued)

Recommended Design Parameters:

Transmitter Power: 2 watts
Antenna Size: 4 feet
Diversity, order of: Quadruple

GENERAL NOTES

- The maximum modulating frequency is the sum of the minimum modulating frequency (60 kHz); the voice channel bandwidth (a product of the number of voice channels and the nominal 4 kHz spacing); and the spacing between basic supergroups (12 kHz).

- See Appendix D if Great Circle distance must be determined exactly (to five place accuracy). Otherwise, measurements from a map with ∓ 10-mile accuracy will suffice.

- To allow for losses associated with transmission lines, coupling, transition, duplexers, etc., a figure of 4 dB is given for systems using 1 kMHz and a figure of 6 dB is used for 2 kMHz systems.

- In this equation 12 dB = receiver-noise figure and 10 dB = C/N figure. These are approximate values and may be changed to fit the specific case. For instance, if parametric amplifiers are used, the 12 dB receiver-noise figure is changed to 2 dB.

- In this equation C/N is that computed in Step X, BW is that computed in Step II, bw = voice channel bandwidth, PF = pre-emphasis gain, L = channel loading factor, and MUX = multiplex equipment noise insertion (about 2 dB.).

In the case of interference resulting from harmonics of nearby transmitters operating on a lower frequency, it is necessary to locate the offending equipment and attempt modifications or adjustments to suppress or prevent the generation of harmonics. If this cannot be done, it will become necessary to employ harmonic waveguide filters to eliminate the interference. Problems of this nature must be solved on an individual basis through cooperation with the cognizant government or commercial agency. The above types of interference and additional types are discussed in chapter 3. For additional information in reference to the Utilization of Frequency Spectrum, consult NAVELEX 0101, 106 "Electromagnetic Compatibility and Electromagnetic Radiation Hazards."

7.4.1 Frequency Assignment

When developing a radio-frequency allocation plan for a complex system, allowance should be made for the maximum number of channels that may be required by future expansion. This will permit orderly system expansion with the minimum amount of modification, and will eliminate major readjustments which might otherwise be required. Frequency assignment for military objectives (refer to DCAC 330-175-1) include channel spacing, transmit-receive frequency separation and IF interference.

a. Channel Spacing. The minimum RF channel spacing for any microwave system shall be as follows:

No. Voice Channels	Channel Separation
36	5.6 MHz
60	11.2 MHz
120	14.0 MHz
300 (or more)	29.0 MHz

b. Transmit-Receive Frequency Separation. If a transmitter and receiver are operated at the same frequency in the same station, the loss between the transmitter and receiver must be greater than 120 dB. All "go" channels shall be in one-half of the band, and all "return" channels shall be in the other half of the band. The terms "go" and "return" are used only to distinguish between the two directions of transmission.

For adjacent RF channels in the same half of the band, different polarization shall be used alternately. This means that the odd-numbered channels in both directions of transmission on a given section shall use H(V) polarization, and the even-numbered channels shall use V(H) polarization.

In order to prevent interference between the transmit and receive antennas on opposite sides of a station, each channel shall be shifted in frequency (frogged) as it passes through a repeater station as shown in table 7-3.

The minimum separation between a transmit and receive carrier frequency on a single hop shall be as shown in table 7-4.

c. IF Interference. The center frequency and the channel spacing of the RF carrier frequencies shall be chosen so as to prevent interference due to harmonics of the shift frequency. That is, harmonics cannot occur at f_n, the channel frequency, or at $f_n \pm 70$ MHz when the IF is 70 MHz.

Table 7-3. Minimum Frequency Shift as Channel Passes Through Station

NO. VOICE CHANNELS	RF CARRIER FREQUENCY, kMHz	
	2 to 4	6 to 8
120 or less	120	161
300 or greater	213	252

Table 7-4. Minimum Spacing Between a Transmit and Receive Carrier Frequency at a Single Station. (Minimum Guard Channel Width Between Upper and Lower Half of the Allocated RF Band.)

NO. VOICE CHANNELS	RF CARRIER FREQUENCY, kMHz	
	2 to 4	6 to 8
60 - 120	49	30
120	68	44.5

7.4.2 Frequency Plan

The Defense Communication Agency recommends the use of one of two frequency plans for the military, to be used under appropriate circumstances. The DCA frequency plans are illustrated in figures 7-5 and 7-6.

The DCA specifies that the frequency channels shall be assigned on a hop-by-hop basis such that the median value of the unwanted signal in the receiver, due to using the same or adjacent frequency channels in two relay sections shall be at least 10 dB below the inherent noise level of the receiver.

When the system requirement is such that a large number of voice channels must be handled and it is necessary to use all the RF carrier channels on a single hop, frequency plan 2 (illustrated in figure 7-6) is recommended. However, when the number

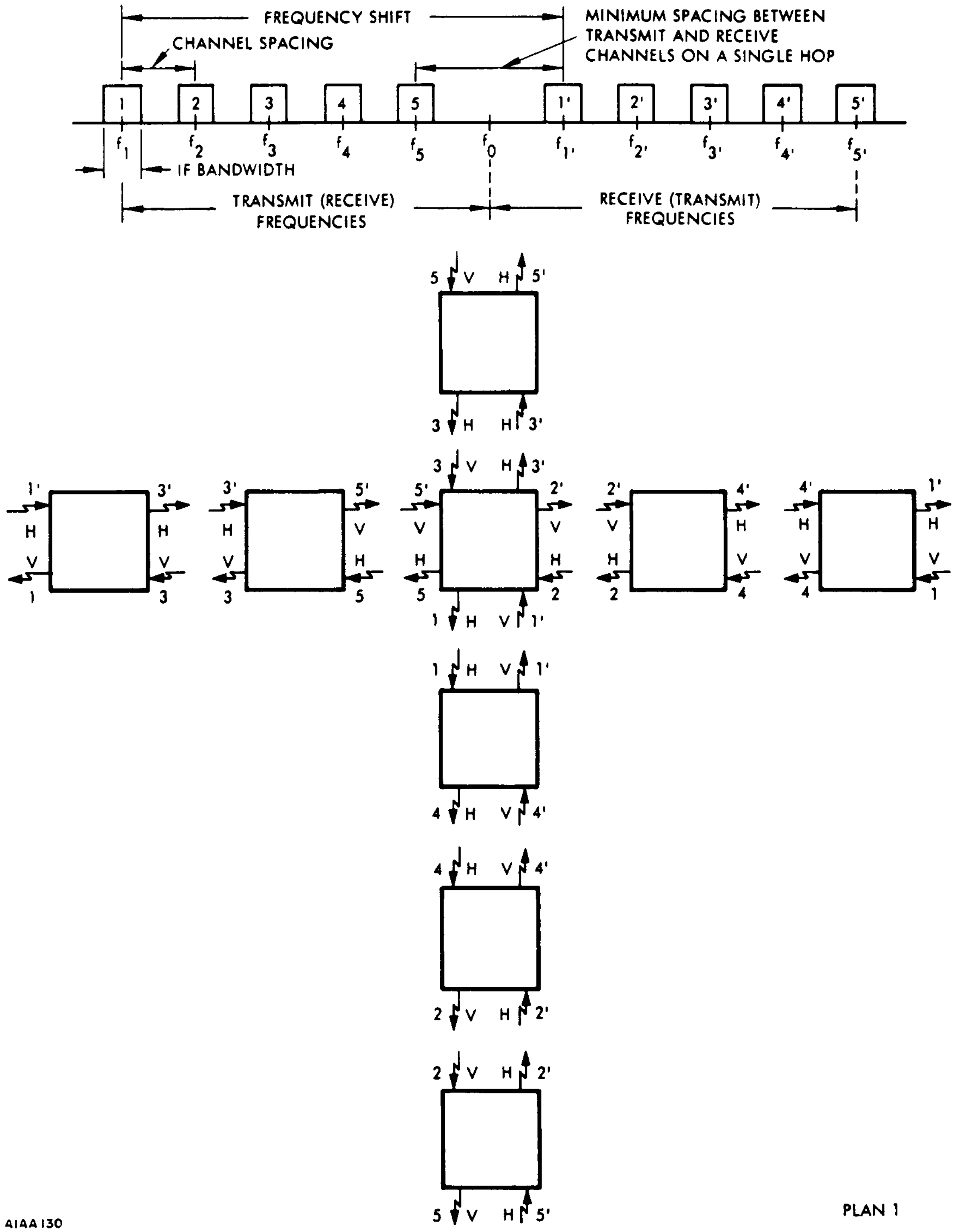

Figure 7-5. Recommended Frequency Plan for Small Capacity System (120 or Less Voice Channels)

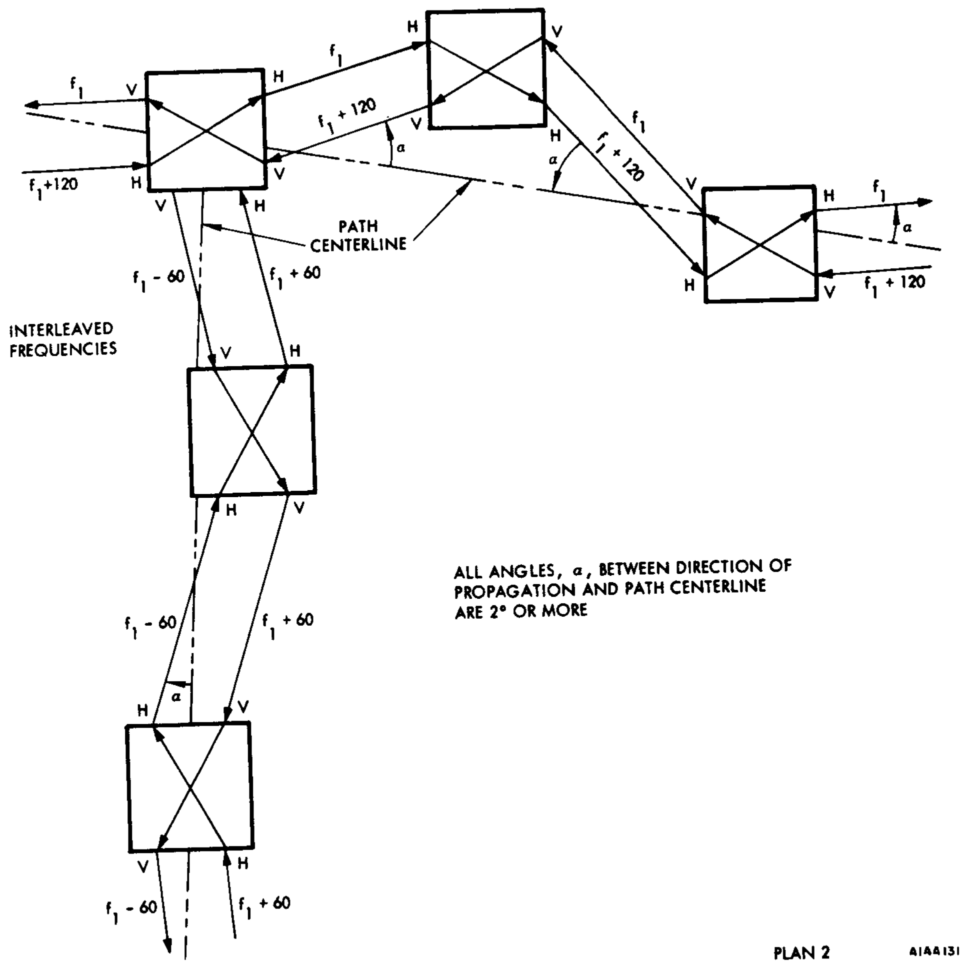

Figure 7-6. Recommended Frequency Plan for Large Capacity System (120 or More Voice Channels)

of voice channels is small, interference may be minimized by using frequency plan 1 (illustrated in figure 7-5), where alternate channels are used on alternate hops.

A basic computer model which may be used in developing frequency plans is included in Appendix H.

7.5 EQUIPMENT SELECTION CRITERIA

This paragraph provides information to be used for the specification and selection of a microwave system and associated equipments. Each item in the system is described in terms of its function, operating and physical parameters, and compliance with specifications. A summary of the specifications for major items of equipment is presented in table 7-5.

7.5.1 Antenna Systems

Antenna systems include some or all of the following equipments:

a. Antennas

(1) Parabolic (or modified parabolic) reflectors

(2) Antenna feed devices

(3) Passive reflectors

(4) Radomes with and without heating elements.

b. Waveguide Components

(1) Rigid waveguide

(2) Flexible waveguide

(3) Waveguide switches

(4) Ferrite load isolators

(5) Circulators

(6) Duplexers

(7) Diplexers.

c. Pressurizing and Dehydrating Equipment. Military microwave communications systems occupy the following frequency bands:

Table 7-5. Specification of Major Items of Equipment (Sheet 1 of 2)

SUBSYSTEM AND COMPONENT	FUNCTION	KEY PARAMETERS	APPLICABLE SPECIFICATIONS FROM DCAC 330-175-1	SPECIFIED BY EQUIPMENT DESIGNER
Antenna System Transmission Line/Waveguide Antenna Reflector Antenna Feed Horn Dehydrator and Pressurization Equipment	Transmission line transfers composite transmit signal from power amplifier via duplexer to the antenna feed horn for radiation; transfers composite receive signal from the antenna feed horn via the duplexer to the receiver input.	Antenna 1. Type 2. Characteristic Impedance 3. VSWR Transmission Line 1. Type 2. Characteristic Impedance 3. VSWR	 1. Para. 3.2.2.5.6.1 2. Para. 3.2.2.5.6.1.1 3. Para. 3.2.2.5.6.1.2 1. Para. 3.2.2.5.6.2 2. Para. 3.2.2.5.6.2.1 3. Para. 3.2.2.5.6.2.2	Dual Diversity Diameter of reflector Type of transmission line Spacing for diversity
Receiving Equipment Low Noise Pre-amp Mixer IF Amplifier Combiner FM Demodulator	Detects transmitted signals, amplifies them to required level, separates and recovers the composite information signal through demodulation.	1. RF Input Impedance 2. Frequency Stability 3. Image and out-of-band frequency rejection 4. Intermediate frequency characteristic a. IF center frequency b. Output Impedance	1. Para. 3.2.2.5.6.3.1 2. Para. 3.2.2.5.6.3.2 3. Para. 3.2.2.5.6.3.3 4. Para. 3.2.2.5.6.3.4	
Transmitting Equipment Exciter (RF Oscillator) Power Amplifier	Generates RF carrier, amplifies modulated carrier to desired level.	1. RF Output Impedance 2. Carrier Frequency Stability 3. Spurious Emission Suppression 4. Pre-emphasis Characteristic	1. Para. 3.2.2.5.6.4.1 2. Para. 3.2.2.5.6.4.2 3. Para. 3.2.2.5.6.4.3 4. Para. 3.2.2.5.6.4.4	Output Frequency Power Output Radio Frequency Bandwidth Deviation Capability
Multiplex Equipment Baseband Amplifiers Group-Through-Filters Group-Modems Group Patchboard Group Distributing Frames Supergroup Modems Multiplex Frequency Gen.	Accepts voice, telegraph, and/or data channel outputs from terminal subsystem; heterodynes and amplifies signals to provide composite, wide-band frequency division signal to transmitter for carrier modulation. Accepts received composite wideband frequency-division signal from receiver; separates and demodulates voice, telegraph and/or data channel signals comprising composite signal; amplifies and provides channel information in original form for reproduction or transmission to user by termination subsystem.	1. Input and Output Impedance levels and frequencies 2. Noise and Interference 3. Envelope Delay Distortion 4. Total Noise 5. Harmonic Distortion 6. Stability of Multiplex Frequency Generator 7. Net Loss Variation 8. Gain Change for Output Level Increase 9. Maximum Overall Change in Audio Frequency	1. Table 3.2.2.5.1.2 of Standards 2. Para. 3.2.2.5.2.2 3. Para. 3.2.2.5.1.1.2 4. Para. 3.2.2.5.1.1.3 5. Para. 3.2.2.5.1.1.4 6. Para. 3.2.2.5.1.1.9 7. Para. 3.2.2.5.1.1.6 8. Para. 3.2.2.5.1.1.5 8 9. Para. 3.2.2.5.1.1.8	Number and arrangement of channels, groups, and supergroups.

Table 7-5. Specification of Major Items of Equipment (Sheet 2 of 2)

SUBSYSTEM AND COMPONENT	FUNCTION	KEY PARAMETERS	APPLICABLE SPECIFICATIONS FROM DCAC 330-175-1	SPECIFIED BY EQUIPMENT DESIGNER
Termination Equipment Circuit Condition Monitoring Facilities VU meters and other level indicators Distortion measuring equipment Patching Facilities Distribution Frames Filters and channel termination sets Signalling Equipment Control Monitoring Equipment; i.e., fault alarm and automatic switch equipment	Interface control between and within multiplex subsystem and user's line.	1. Input and Output Impedance levels, and frequencies	1. Para. 3.2.2.5.1.2	As required
Power Generating Equipment Generators Switchgear Distribution Equipment Starting Equipment	Supply primary ac power for all technical electrical and electronic equipment and for all non-technical site requirements. Supply auxiliary power to technical load and various elements of nontechnical load.	1. Frequency regulation 2. Voltage regulation 3. Total load	1. Para. 3.6.1	Total primary power required
Environmental Control Heating and Air Conditioning Humidifiers and dehumidifiers Ventilation Air Filtering	Maintain proper environment - temperature, humidity, etc., for equipment and personnel comfort.	1. Temperature 2. Humidity 3. Pressure	1. Para. 3.6.1	As required

(1) 744 - 985 MHz

(2) 1.7 - 1.85 GHz

(3) 2.3 - 2.4 GHz

(4) 4.4 - 5.0 GHz

(5) 7.125 - 8.4 GHz

(6) 13.5 - 16.5 GHz

The most common antenna used in LOS systems operating over these frequency ranges is the parabolic reflector incorporating either a horn or dipole feed device. However, it is impractical to use dipole feeds above 3 GHz. Parabolic reflectors to cover the frequencies listed are available in diameters of 4, 6, 8, 10, and 12 feet.

Horn feeds are manufactured in both rectangular and circular configurations. The rectangular horn is energized from rectangular waveguide and circular type is usually energized from circular waveguide.

Feed devices are linearly polarized in either the vertical or horizontal plane (plane polarization), polarized in both planes (dual polarization), or circularly polarized (rotating).

Feed methods for parabolic reflectors are classified either front feed or rear feed and are illustrated in figure 7-7.

Plane and dual polarized feed horns are shown in figure 7-8. A plane polarized dipole feed is shown in figure 7-9. A parabolic reflector with "offset" feed (see figure 7-10).

Antennas less than 50 feet above ground are usually mounted on a mast or tower when used at the frequencies listed above. When antennas, operating at the higher microwave frequencies, are to be elevated more than 50 feet, various considerations point to the following advantages gained from using a parabolic dish and passive reflector combination (see figure 7-12).

o Long runs of expensive waveguide and associated pressurizing systems are eliminated.

o Maintenance procedures are reduced.

o High standing wave ratios present in long waveguide runs are reduced.

o The free space and reflector losses are less than losses resulting from long waveguide runs.

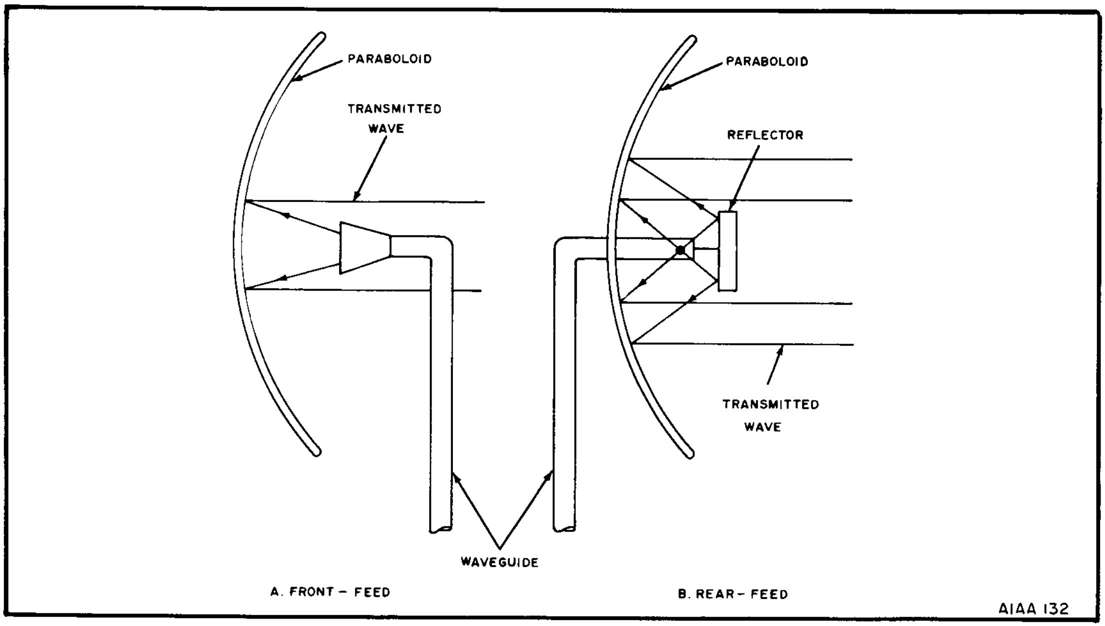

Figure 7-7. Parabolic Reflector Feed Methods

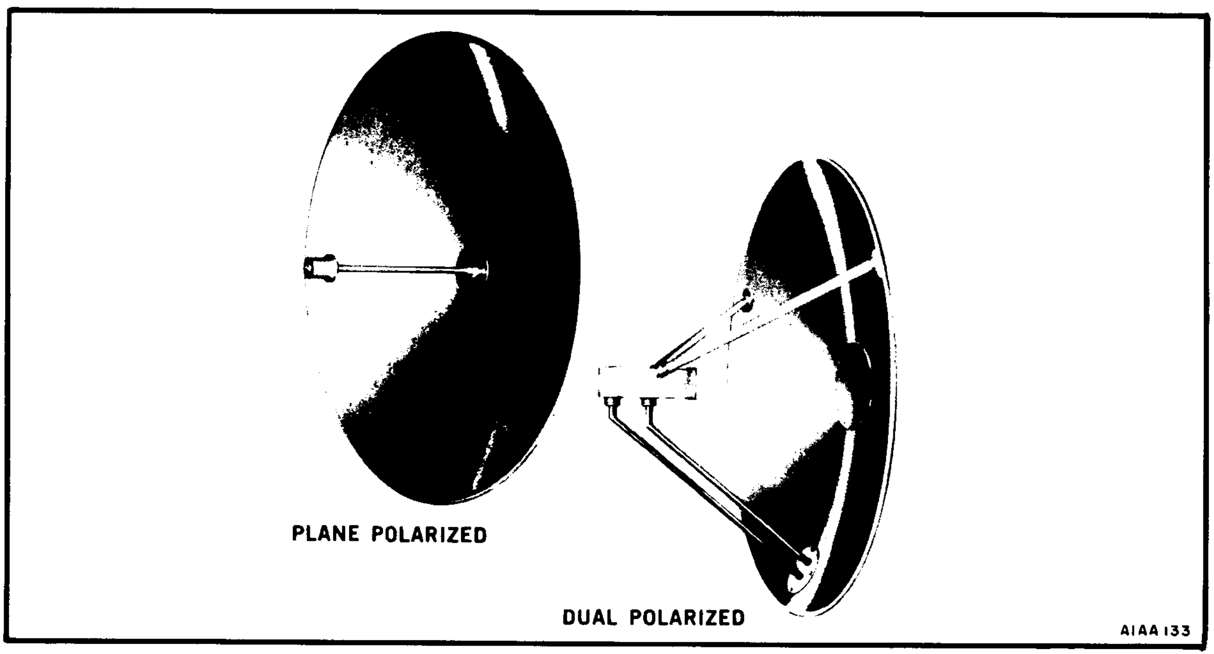

Figure 7-8. Polarized Feed Horns

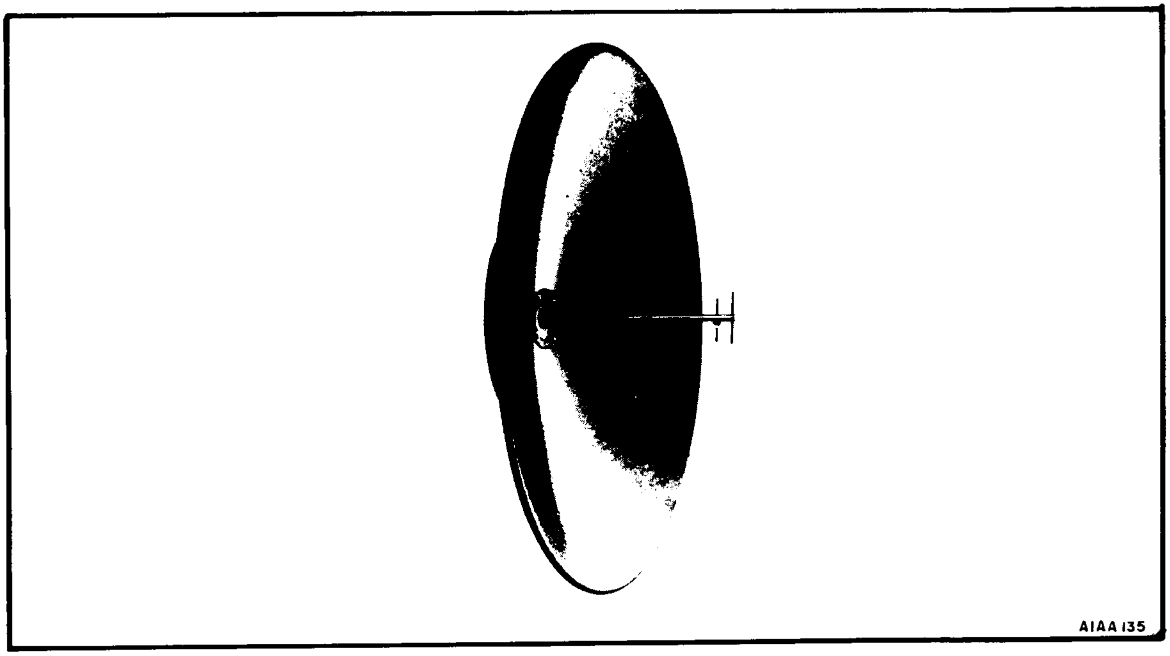

Figure 7-9. Plane Polarized Dipole Feed

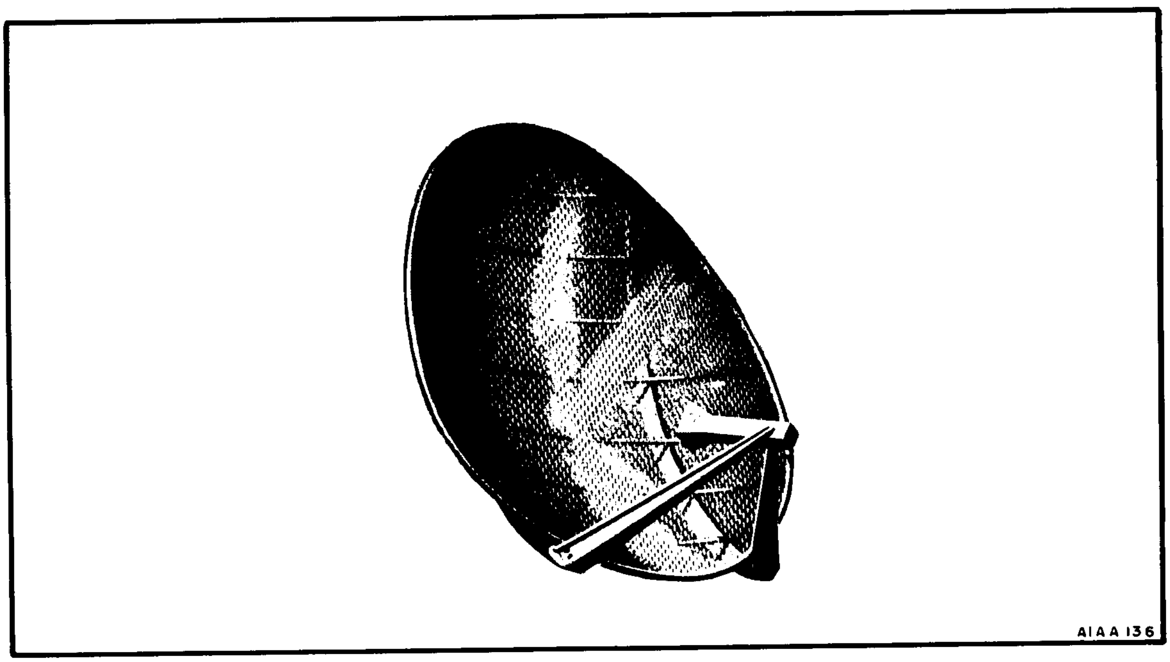

Figure 7-10. Offset Antenna
(Modified Parabolic Dish With Offset Feed)

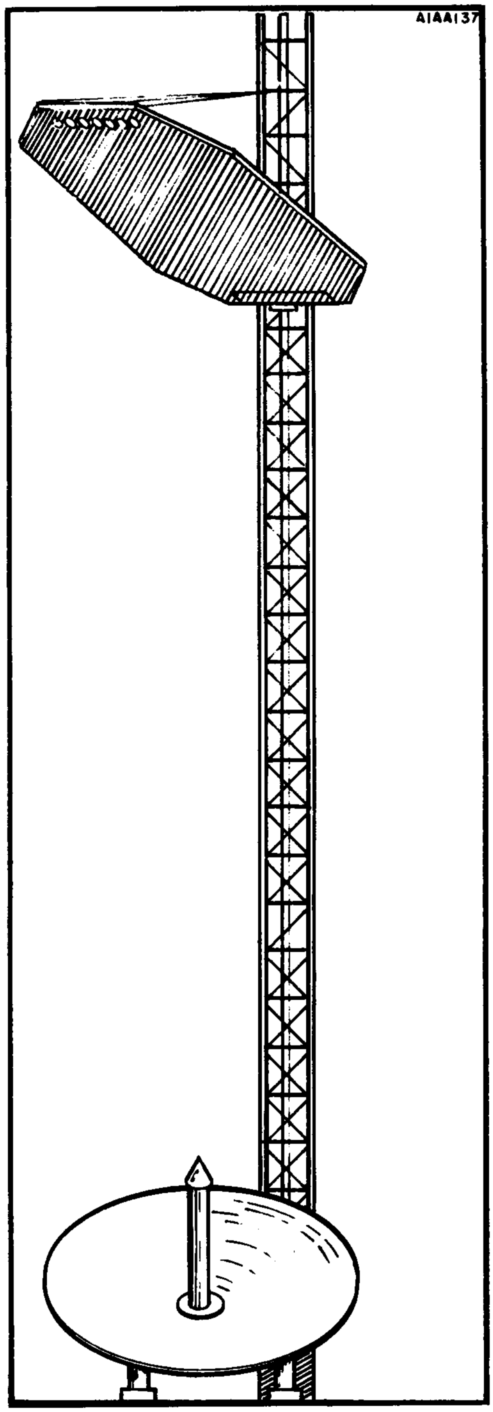

Figure 7-11. Parabolic Antenna and Passive Reflector Combination

Figures 7-12 and 7-13 depict some typical site layouts using passive reflectors. Figure 7-12 shows a standard layout with the parabolic antenna mounted near the tower base and the passive reflector atop the tower. A site layout where the equipment shelter is located at a lower elevation than the tower is illustrated in figure 7-13. This layout eliminates the need for a high tower to clear the obstruction between sites.

7.5.2 Transmission Lines/Waveguide

Three types of waveguides are available for use in microwave systems: standard rectangular, elliptical, and circular. Typical installation using these types of waveguide are shown in figure 7-14.

Data of rigid rectangular waveguide for the frequency range 3 to 10 GHz is presented in table 7-6, and an attenuation graph of high-conductivity waveguide is shown in figure 7-15.

For installations that use primary and standby microwave equipment, waveguide switches are used to connect either the primary or the standby equipment to the antenna, and to properly terminate the output of the unused equipment. Waveguide switches are usually electrically operated to provide for automatic switching applications.

A ferrite load isolator provides isolation between a signal source and its load with a resulting increase in power and improved frequency stability. The ferrite device accomplishes these results by reducing the standing wave ratio in the transmission line linking the signal source to the load. By placing the load isolator in the RF oscillator branch of the waveguide tee that links the antenna to the klystron RF oscillator and receiver input circuits, the RF oscillator is isolated from the other two branches of the tee.

When it is necessary to couple two or three microwave equipments to a single antenna, a waveguide circulator is used. This device, illustrated in figure 7-16, is similar to a duplexer. With an antenna connected to one arm and three microwave equipments connected to the other arms, or two equipments and shorting plate connected to the other arms, the following apply:

Attenuation from arms 1 to 2, 2 to 3, 3 to 4, and 4 to 1 is about 0.5 dB in each instance.

Attenuation between other combinations of arms is on the order of 20 dB.

7.5.3 Line Pressurization/Dehydration

Installations of rigid line are pressurized and dehydrated to eliminate chances of moisture accumulation and resulting changes in impedance or short circuits within the run. Dehydration is extremely important in runs subject to temperature changes due to either climatic conditions or indoors/outdoors runs. Dehydration will be accomplished with an automatic compressor/dehydrator unit.

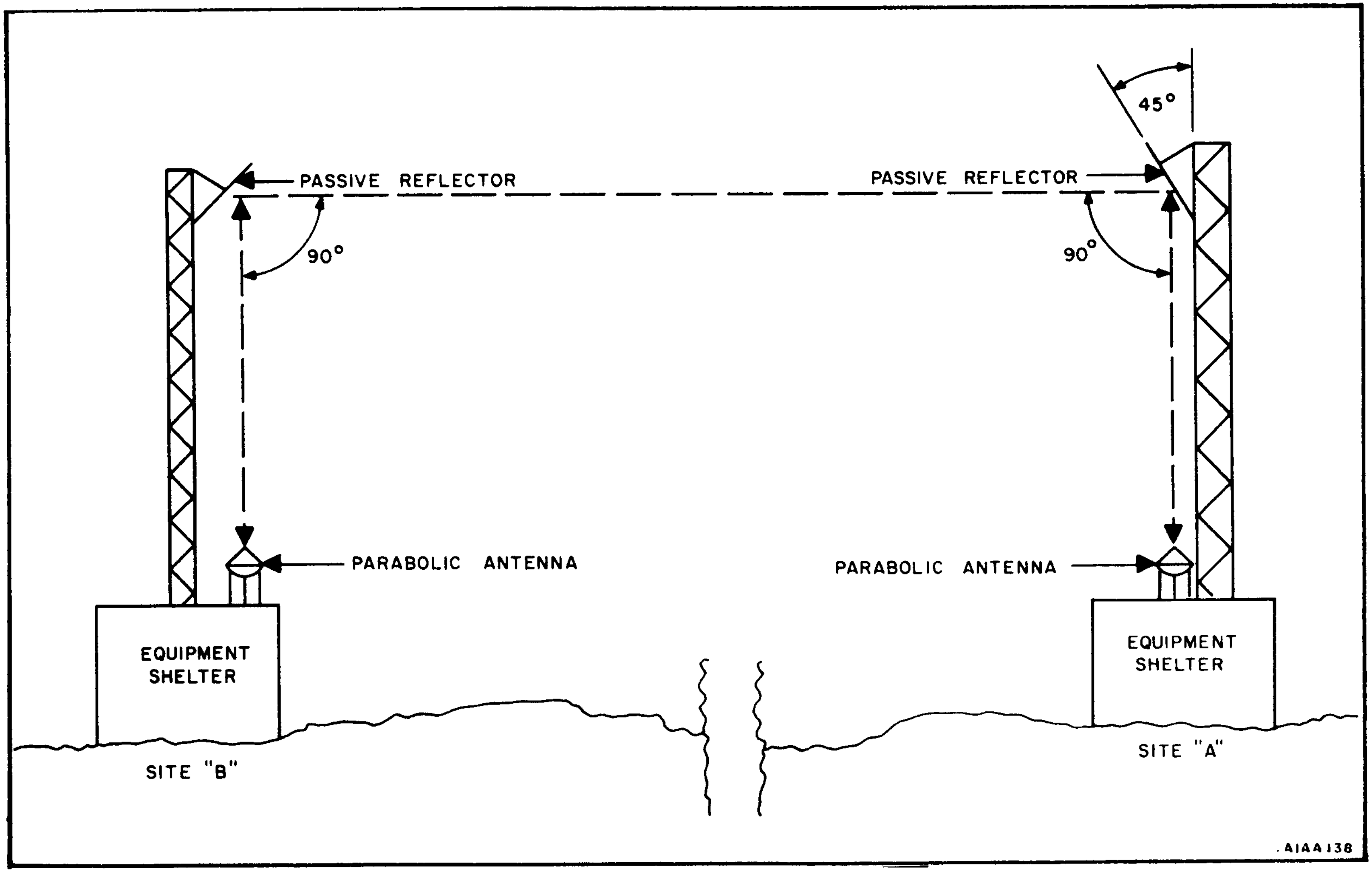

Figure 7-12. Passive Reflector Antenna Systems, Typical (Example 1)

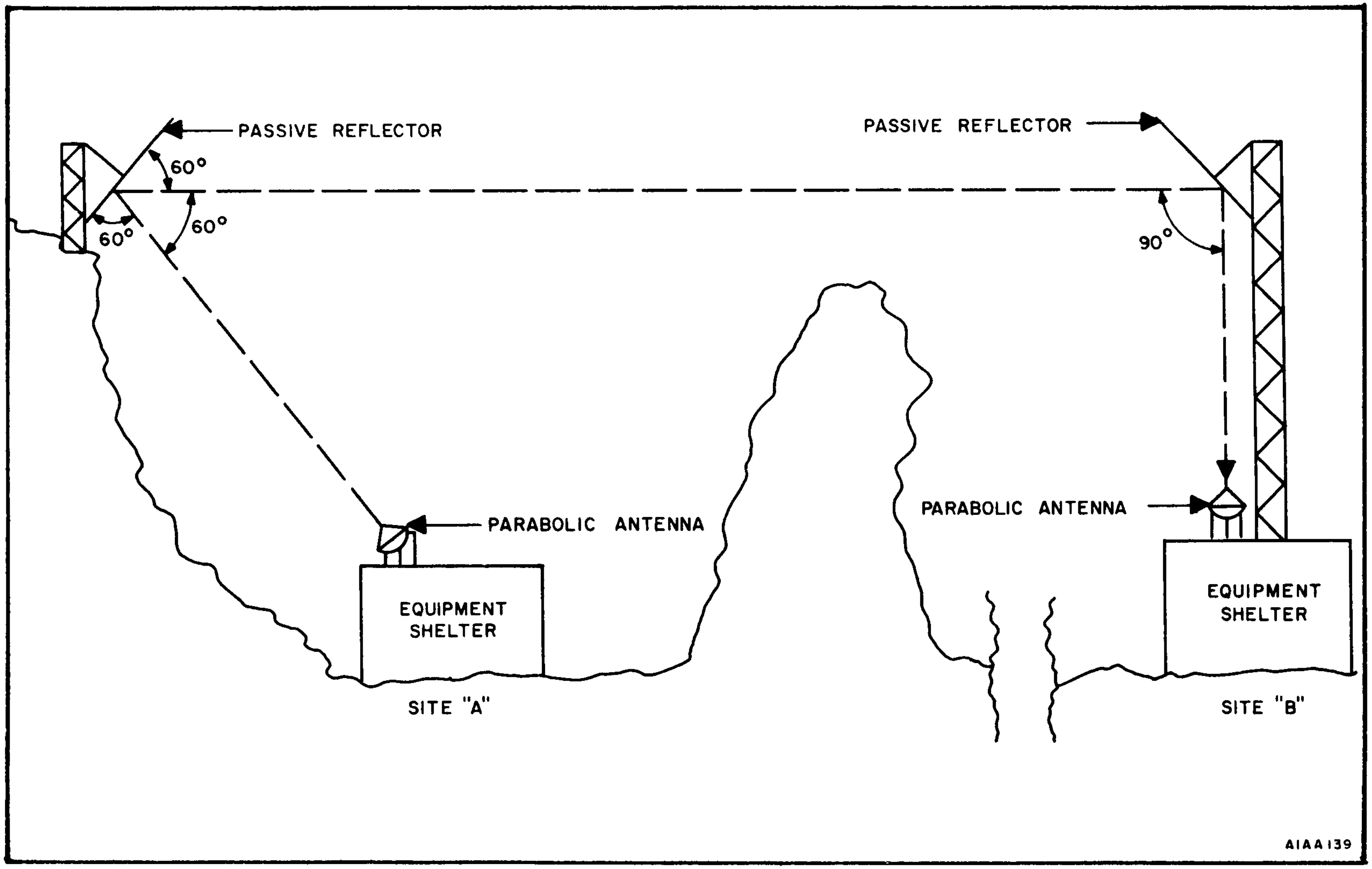

Figure 7-13. Passive Reflector Antenna System, Typical (Example 2)

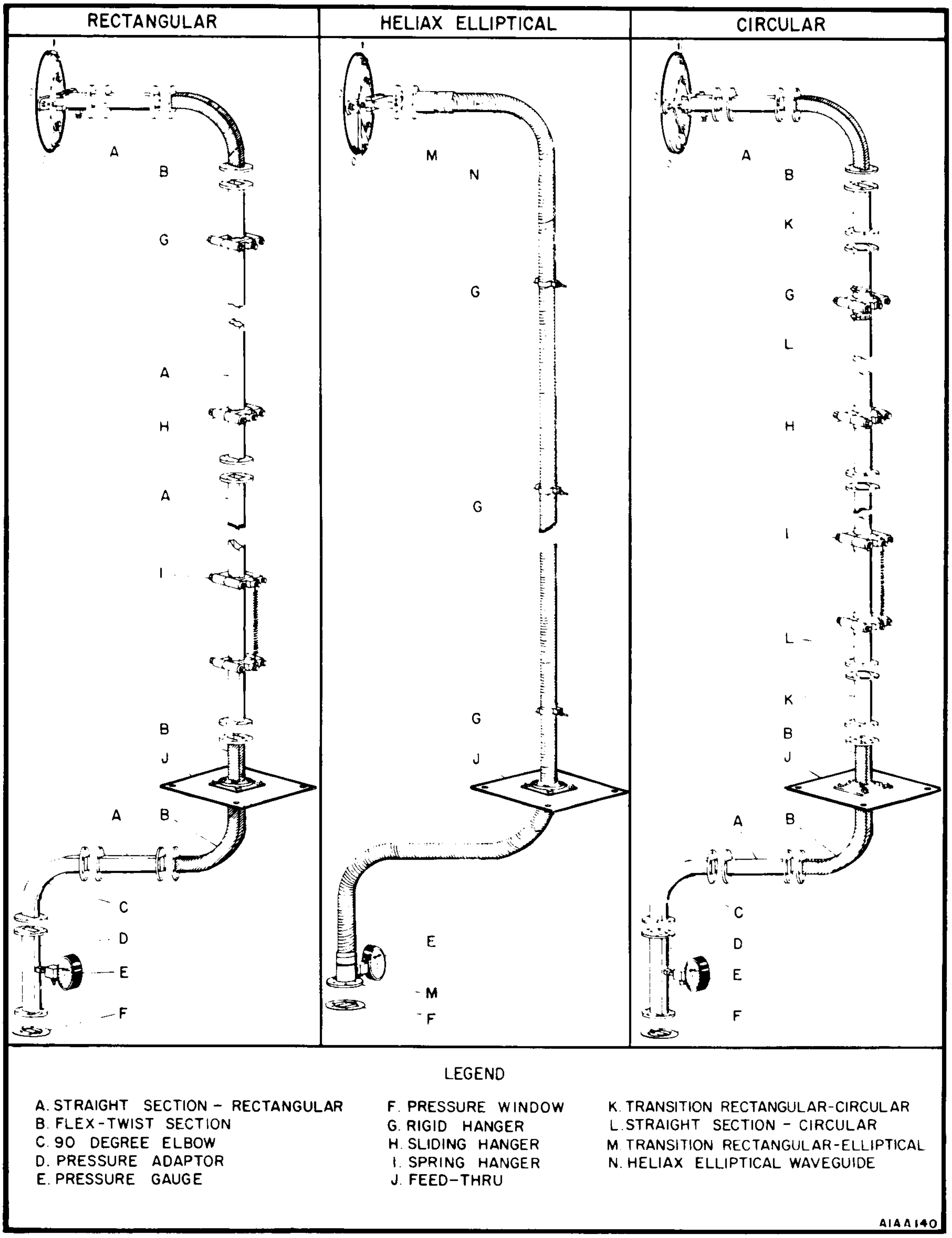

Figure 7-14. Waveguide Installations, Typical

Table 7-6. Rigid Rectangular Waveguide and Fittings

EIA WG Designation WR( )	Recommended Operating Range for TE_{10} Mode		Cut-off for TE_{10} Mode		Range in $\frac{2\lambda}{\lambda c}$	Range in $\frac{\lambda g}{\lambda}$	Theoretical cw power rating lowest to highest frequency megawatts	Theoretical attenuation lowest to highest frequency (db/100 ft)	Material Alloy	JAN WG Designation RG( )/U	JAN FLANGE DESIGNATION		EIA WG Designation WR( )	DIMENSIONS (inches)				Wall Thickness Nominal
	Frequency kHz	Wavelength (cm)	Frequency kHz	Wavelength (cm)							Choke UG( )/U	Cover UG( )/U		Inside	Tol.	Outside	Tol.	
340	2.20-3.30	13.63-9.08	1.736	17.27	1.58-1.05	1.78-1.22	3.1-4.5	.877-.572 .751-.492	Brass Alum.	112 113		553 554	340	3.400-1.700	±.005	3.560-1.860	±.005	0.080
284	2.60-3.95	11.53-7.59	2.078	14.43	1.60-1.05	1.67-1.17	2.2-3.2	1.102-.752 .940-.641	Brass Alum.	48 75	54A 585	53 584	284	2.840-1.340	±.005	3.000-1.500	±.005	0.080
229	3.30-4.90	9.08-6.12	2.577	11.63	1.56-1.05	1.62-1.17	1.6-2.2						229	2.290-1.145	±.005	2.418-1.273	±.005	0.064
187	3.95-5.85	7.59-5.12	3.152	9.510	1.60-1.08	1.67-1.19	1.4-2.0	2.08-1.44 1.77-1.12	Brass Alum.	49 95	148B 406A	149A 407	187	1.872-0.872	±.005	2.000-1.000	±.005	0.064
159	4.90-7.05	6.12-4.25	3.711	8.078	1.51-1.05	1.52-1.19	0.79-1.0						159	1.590-0.795	±.004	1.718-0.923	±.004	0.064
137	5.85-8.20	5.85-8.20	4.301	6.970	1.47-1.05	1.48-1.17	0.56-0.71	2.87-2.30 2.45-1.94	Brass Alum.	50 106	343A 440A	344 441	137	1.372-0.622	±.004	1.500-0.750	±.004	0.064
112	7.05-10.00	4.25-2.99	5.259	5.700	1.49-1.05	1.51-1.17	0.35-0.46	4.12-3.21 3.50-2.74	Brass Alum.	51 68	5[illegible] 137A	51 138	112	1.122-0.497	±.004	1.250-0.625	±.004	0.064

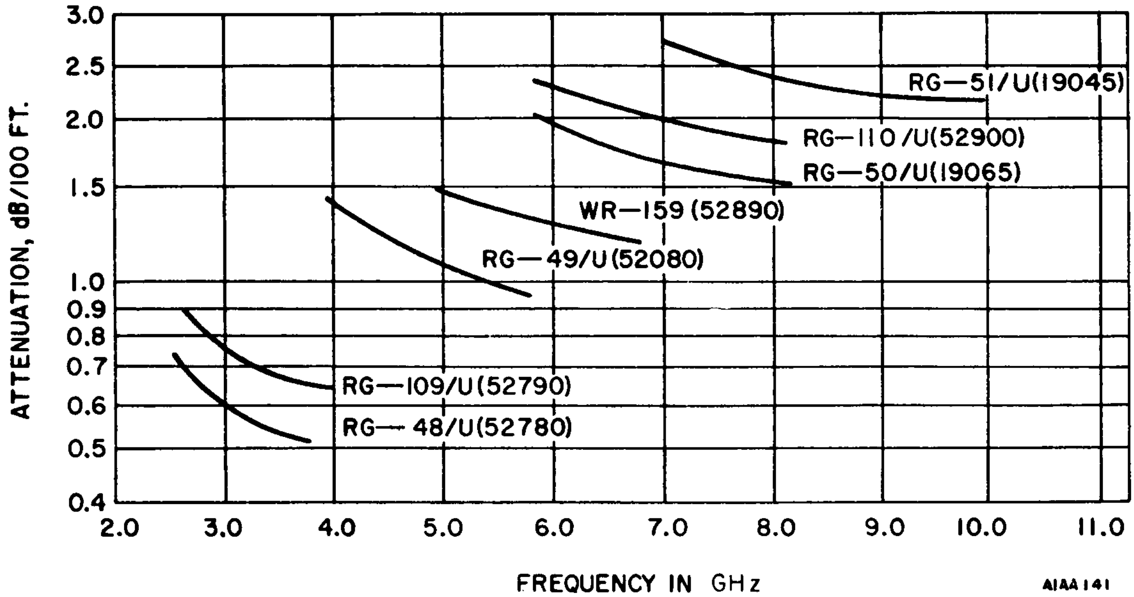

Figure 7-15. Attenuation of Oxygen - Free High Conductivity Waveguide

7.5.4 Radio Equipment

A microwave radio relay link is composed of two terminal stations and, in most cases, a number of repeater stations. Terminal stations are situated at the ends of a communication link and the repeater stations between.

The RF portion of a terminal and repeater station consists of RF transmitters, RF receivers, and associated power supplies, terminal and repeater stations, or between repeater stations.

Remodulating and IF heterodyne repeaters are used:

o A remodulating repeater consists of two terminal radio equipments back-to-back, the receiver output from one feeding the transmitter input of the other.

o In the heterodyne type of repeater, the incoming carrier is heterodyned down to frequency which may be easily amplified (usually 70 MHz), and after amplification heterodyned back up to the transmitting frequency.

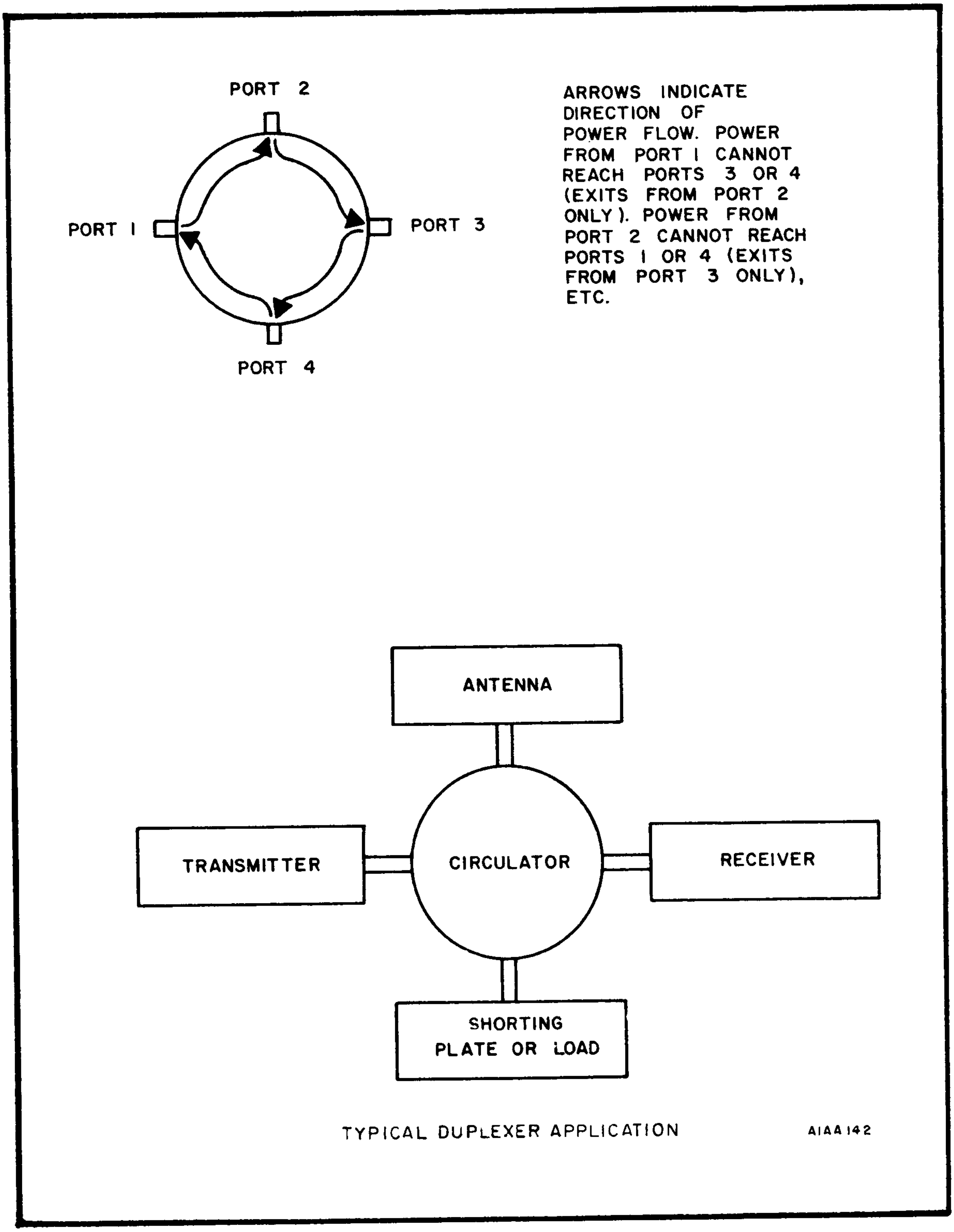

Figure 7-16. Four - Fort Circulator

The RF equipments in terminal and repeater stations are basically the same. Terminal equipment can be converted to repeater equipment and vice versa by making a few wiring changes on terminal boards provided for this purpose. Microwave equipments currently available reflect the latest "state-of-the-art" techniques in solid-state design and packaging and comply with the applicable portions of DCAC 330-175-1.

a. Transmitter. In general, a microwave transmitter includes:

- o Exciter baseband group.
- o Modulator group.
- o Power amplifier.
- o Power supplies.

In a typical microwave transmitter (see figure 7-17) the exciter baseband group includes a pilot oscillator and pilot tone detector for alarm functions, pre-emphasis network, and an insertion amplifier. The modulator group includes the klystron oscillator, linearizer, filters, automatic frequency control circuitry (AFC), and a power monitor. In operation, the output of a telephone multiplex terminal which consists of frequency multiplexed AM carrier signal, is applied to the terminal transmitter. This input signal (baseband signal) could also be a television signal or any other form of signal that is to be transmitted over a microwave radio path. A pre-emphasis network emphasizes the high baseband frequencies relative to the low, to gain certain signal-to-noise advantages in the radio system. The insertion amplifier accepts the pre-emphasized signal, amplifies and applies it to the klystron oscillator in the modulator group. With this method, the input signal from the multiplexer directly modulates the output frequency of the transmitter resulting in a frequency modulated wave. Since the klystron modulation characteristic becomes nonlinear with increasing deviation, a "linearizer" couples a nonlinear reactive component back into the klystron cavity and compensates for its nonlinearity. This "linearization" technique allows optimum performance for modulation densities as high as 1200 channels.

The transmitter output signal (on the order of 1 watt) is passed through an output filter to reduce spurious emissions to a negligible level, and then applied to the antenna. When higher power (5 watts) is required, particularly in heterodyne applications, a traveling wave tube (TWT) is used as a final amplifier. This device, comparable to a klystron, as far as ease of tuning and life-expectancy is concerned, can provide up to 40 dB of RF gain.

Modern microwave transmitters are designed to exhibit a high degree of frequency stability. Crystal-referenced AFC systems can correct transmitters to within 0.002 percent of their assigned output frequency. DCS Standard DCAC 330-175-1 states that carrier frequency stability shall be controlled to within 0.01 percent for all operating conditions. This degree of stability is required for full route development and for interference coordination with other systems. By sampling the RF output and mixing it with a crystal reference frequency, AFC is obtained. By sampling

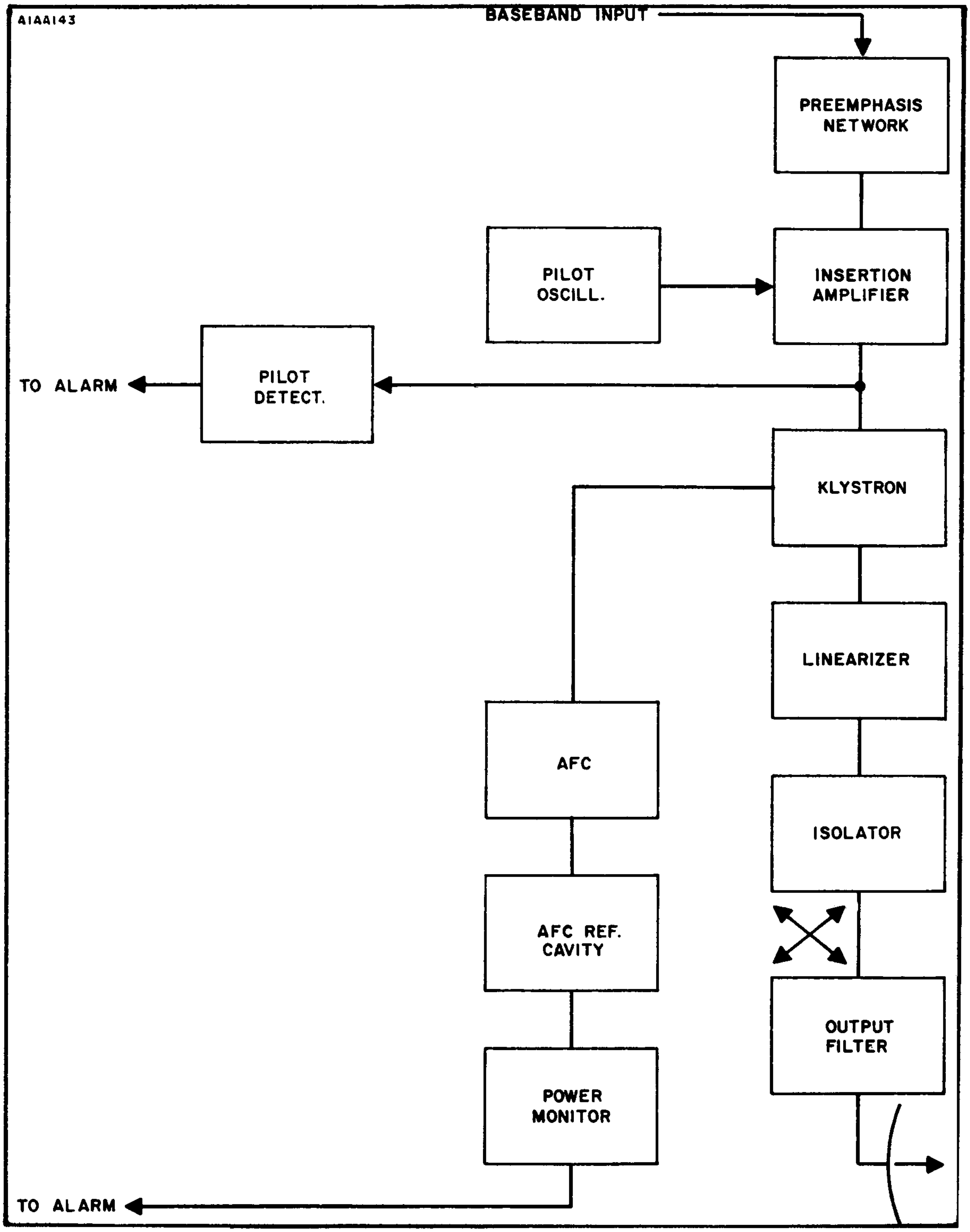

Figure 7-17. Microwave Transmitter, Typical

the RF output and mixing it with a crystal reference frequency, AFC is obtained. The resultant signal is converted to a lower frequency and applied to a discriminator. The DC error voltage output from this discriminator is amplified and applied to the klystron repeller grid.

Typical transmitter system performance specifications are shown in Table 7-7.

Table 7-7. Typical Transmitter Characteristics

PARAMETER	DESCRIPTION
Operating Frequency Range:	5.9 to 7.2 GHz 7.2 to 8.5 GHz
Type of Modulation:	FM (CCIR pre-emphasis)
Power Source:	24 VDC 48 VDC (optional) 115/230 VAC
Power Output:	+30 dBm (1 watt) min.
Frequency Stability:	±0.01%; ±0.002% with AFC option
Carrier Deviation:	±3 MHz
Input Impedance:	75 ohms unbalanced
Sensing Options:	RF carrier level, continuity pilot
Rack Dimensions:	Height: 8 feet Width: 19 inches Depth: 18 inches

b. Receiver. A microwave receiver consists of:

- o RF-IF Group
- o Local Oscillator Group
- o Demodulator Group
- o Receiver Baseband Group.

The RF-IF group includes a preselector filter, ferrite, isolator, mixer, and IF amplifier. The local oscillator group consists of a klystron oscillator and automatic frequency control (AFC) circuitry. The demodulator group consists of a limiter, discriminator, and de-emphasis circuitry. The receiver baseband group includes a pilot detector, noise limiting circuitry, a baseband amplifier, filters, and demultiplexing equipment.

In operation, a signal from the antenna passes through a waveguide preselector, that provides a high IF image rejection ratio and eliminates interference from adjacent RF channels, and enters a waveguide filter tuned to its frequency. The filter bandpass is designed to reject all unwanted signals. The signal next passes through a ferrite isolator which minimizes intermodulation noise and holds the antenna system VSWR to a reasonable value (less than 1.2:1) in accordance with DCAC 330-175-1 requirements. The incoming signal is mixed with the local oscillator output to produce the standard 70 MHz IF frequency. The IF output is amplitude limited and applied to an AFC discriminator, the output of which is used to control the frequency of the klystron oscillator. The limiter output is also applied to a signal (IF) discriminator, a de-emphasis circuit, and a noise muting (squelch) circuit that disconnects the baseband amplifier and demultiplexing equipment if system noise increases above a preset level. After the squelch circuit, the signal is passed to the baseband amplifier and then to the demultiplexing equipment where the original intelligence is retrieved.

Typical characteristics of a microwave receiver are shown in table 7-8.

Table 7-8. Typical Receiver Characteristics

PARAMETER	DESCRIPTION
Receiver	
Noise Figure	14 dB or less
Local Oscillator	Reflex Klystron with AFC loop
Preselector	5-section waveguide filter
IF Center Frequency	70 MHz
RF Bandwidth	15 MHz 3-dB bandwidth, standard receiver optional narrow band IF filters for low traffic application
Peak Deviation	±3 MHz
Capability	
Output Impedance	75 ohms unbalanced; 26 dB minimum return loss

A block diagram of a typical microwave receiver is shown in figure 7-18. Though not shown in the diagram, sensing and alarm functions are integral to all microwave communications.

7.5.5 Alarm Functions

In the transmitter these functions are provided by applying a pilot tone to the baseband input and monitoring the output. The power output of the klystron is also monitored. These monitored signals are applied to logic circuits that determine whether a variation in pilot tone or klystron power is a fault condition. If standby equipment is available, its condition will also be indicated. In the event of a transmitter failure, automatic switchover is effected. Should primary power fail, automatic switchover to a battery bank takes place. Usually terminal connections are available for remote switching of transmitters. Local control of switchover is accomplished by means of a manual switch. Pilot lights indicate which terminal unit is on the air and alarm contact provide for remote alarm.

In the receiver, the desired signal usually passes through a pilot bandstop filter and a standby switch prior to entering the demultiplexer. The standby switch connects the demultiplex circuits. A pilot bandpass filter and pilot detector are connected across the baseband output to monitor receiver operation. The output of this detector and the local oscillator power monitor are applied to an alarm sensing and switching unit. If either monitor indicates a fault and a fade does not exist, the switching unit will transfer to standby operation, if the standby unit itself is not at fault. As in the transmitter, both local and remote alarms as well as local control are provided.

Sensing Options:	Baseband noise level, continuity pilot; RF carrier level
Power Source:	24 VDC, 48 VDC (optional) 115/230 VAC
Frequency Stability:	$\pm 0.01\%$; $\pm 0.002\%$ with AFC option

7.5.6 Standby Equipment

A high degree of system reliability can be obtained when "standby" equipment is used to supplement the primary equipment. However, standby equipment should only be specified for stations where the greatest benefit will be realized, for example, an isolated station difficult to reach under adverse conditions. Automatic switching equipment (as mentioned previously) is available to place the standby equipment in operation if primary equipment fails.

7.5.7 Signalling

In-band signalling at 2600 Hz and 2280 Hz is commonly used in the United States and Europe, respectively. The 2600 Hz tone has been used commercially for some years,

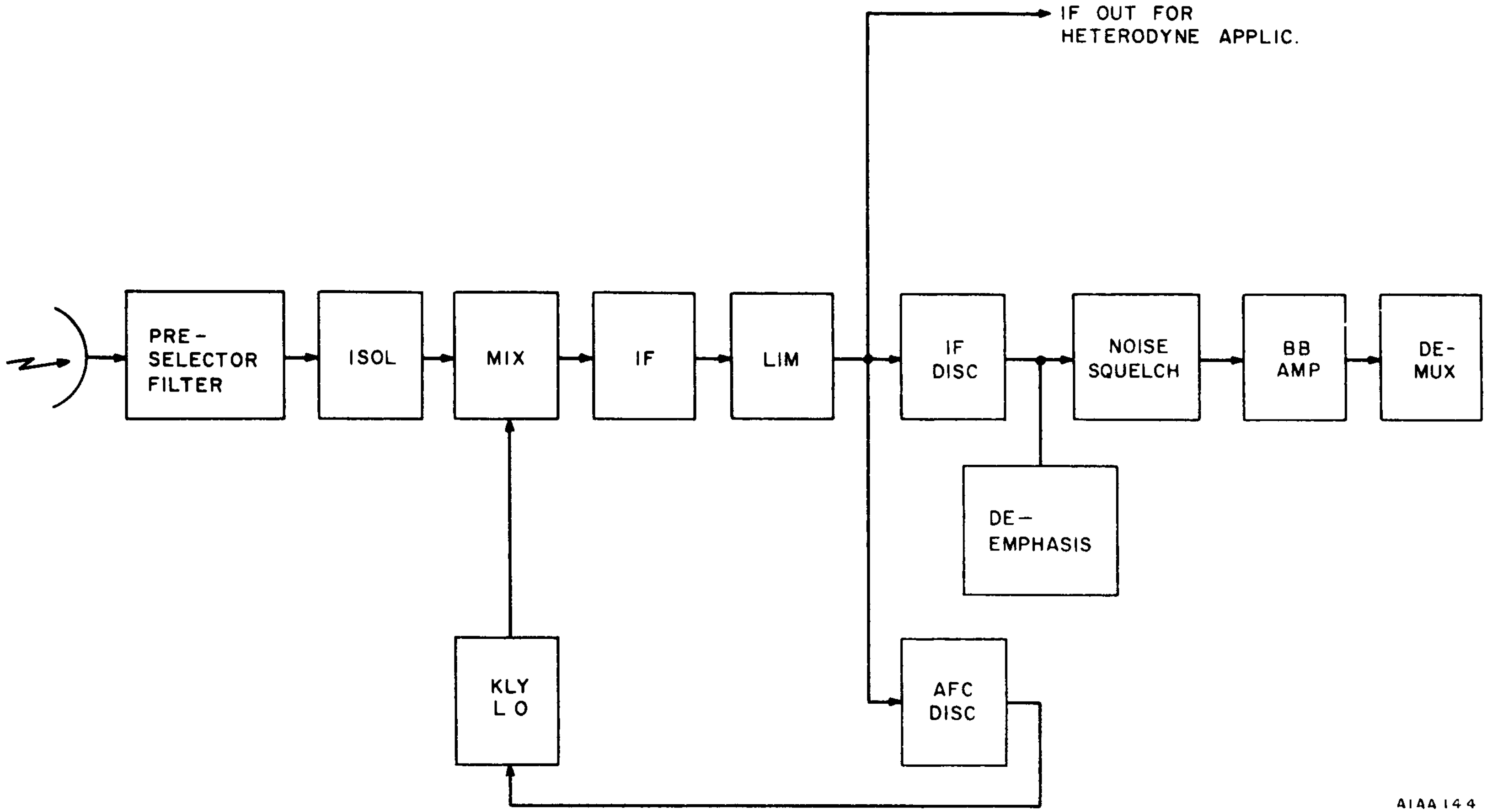

Figure 7-18. Microwave Receiver (No Diversity and Alarms), Typical

and where interface is required with this equipment, provisions for this form of signalling must be made. The International Telegraph and Telephone Consultative Committee (CCITT) provides for 2280 Hz "in-band" signalling on international circuits. With either type the entire voice band is available for intelligence at all times except during the signalling period. With "out-of-band" signalling, as specified by DCA Standards, the voice band is continuously available but with a narrower bandwidth to permit insertion of 3825 Hz tones. Regardless of the type of signalling selected (in-band or out-of-band), E and M signalling is normally provided on the user's lines. Ringdown, loop signalling, or subscriber signalling may also be provided depending on the user's equipment. Typical in-band signalling and ringdown loop signalling facilities are illustrated in figure 7-19.

7.5.8 Order Wire

In most relay systems, one voice channel will be withheld from voice transmission order to use it as a service wire, or order wire. This channel will inform the nearest terminal station of a fault existing at a relay station, together with some indication of the type of fault existing. A complicated system of blocking is used, so that two repeaters cannot "report" trouble at the same time, which would happen in the event of a failure of one station disrupting the operation of an adjoining station.

7.5.9 Spare Parts

During the course of preventive maintenance inspections, it will be noted from time to time that the performance of some components has deteriorated. Rather than wait for the component to become weaker or to fail completely and cause system interruptions, it is considered good maintenance practice to replace such weak components during the inspection. Although components are replaced before their full service life has been realized, service interruptions can be avoided in this manner. This practice will, in turn, increase the expected replacement parts cost for an operating system; however, the increase is justified on the basis of increased system reliability and the saving of additional manpower costs that would be incurred in making special rush trips to unattended stations to restore station operation.

Based on the known degree of component reliability of current installations, and considering a preventive maintenance program such as that described above, it can be expected that in a year's time a microwave system will require replacement parts equal in cost from 1 to 2 percent of the initial cost of the equipment, and replacement tubes equal in quantity from 25 to 30 percent of the total number of operating tubes. The tube replacement ratio, as noted above, is considerably higher than the part replacement ratio. This is generally to be expected because tubes have a higher failure incidence rate; and also, the relative performance of operating tubes is more easily checked than the relative performance of other components, so that more frequent tube replacements naturally result.

Supply depots should be established at convenient locations along the microwave system so that maintenance personnel will have the most frequently needed spare parts and supplies available. The stock carried at these depots should include components,

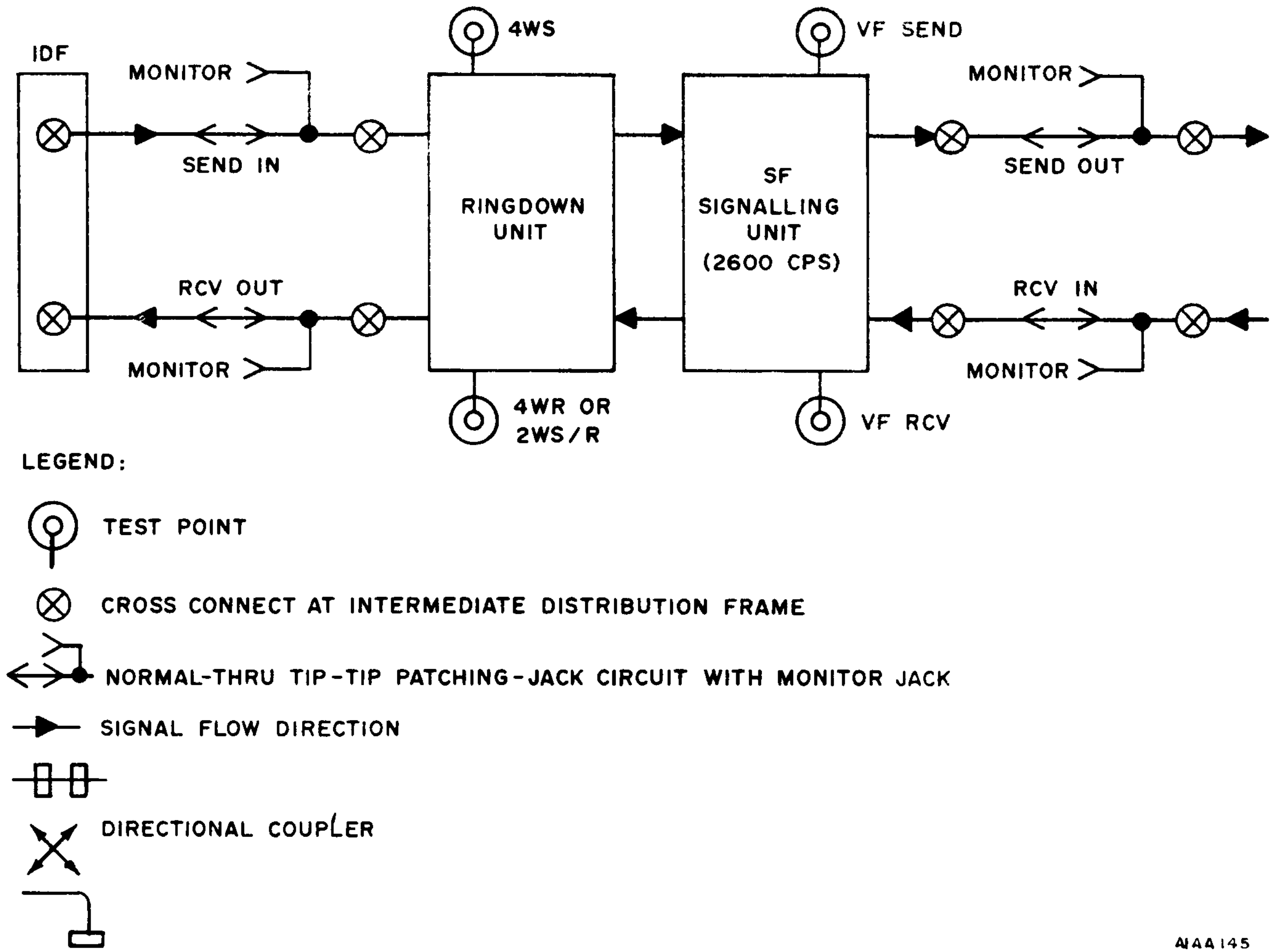

Figure 7-19. Jackfield and Signalling and Termination Units

subassemblies, and other parts that experience shows to have a high replacement factor. Some parts, such as tubes, crystals, critical relays, etc., should be stocked at the stations themselves in a ratio of at least 1:1.

7.5.10 Test Equipment

In order to properly test and service a microwave communications system, maintenance personnel should have a thorough understanding of the equipment's physical make-up, operational characteristics, capabilities, and limitations, and should be familiar with the circuit theory of operation. It is equally important that the proper test equipment be available for utilization by these personnel. Each field maintenance man should be equipped for making routine measurements. Typical equipments recommended for this purpose include a microwave test set, an IF/MF test set, a multimeter, and an oscilloscope; these units must be compatible with the microwave system in which they are used. As the area of maintenance progresses from on-site field maintenance to depot maintenance, the quantity and requirements of the test equipment to perform the maintenance procedures will increase.

A list of test equipment for use in the alignment and adjustment of a typical microwave communications system is given in table 7-9. This list is for use with systems employing microwave equipment and time-division multiplex equipment. It includes the type of test equipment necessary, and the required characteristics of this equipment. Those pieces of equipment which are applicable for general field maintenance are indicated with an asterisk (*).

Table 7-10 lists the test equipment required for laboratory (depot maintenance) measurements for a typical microwave system employing microwave equipment and time-division multiplex equipment. The item numbers under the EQUIPMENT NEEDED heading refer to the test equipment itemized in table 7-9.

7.5.11 Tools Required for Maintenance

It is important that maintenance personnel have a thorough understanding of the equipment utilized in the system, and that they have the proper test equipment to perform the required maintenance checks. In addition to the above, the maintenance personnel must have the proper tools to efficiently repair the malfunctioning equipment when the defects are located. Of course, the maintenance man should know how to properly use the tools required for maintenance.

Table 7-11 lists the quantity and type of tools generally included in a tool kit required by a field serviceman to properly maintain a microwave communications system. In addition to these tools, the special tools indicated in the equipment manuals should be included.

Table 7-12 lists the type of tools required at a typical microwave station. The quantity of these tools will depend on the amount and type of equipment installed. The special tools indicated in the equipment manuals should also be included. Where the maintenance schedules require work on gasoline engine-generators, shelters, towers, etc., additional tools may be required, depending on the type of equipment and hardware involved.

The tools required at a microwave system centralized maintenance depot are essentially the same as those required at a microwave station. However, the quantity of these tools will depend on the number of maintenance personnel assigned to the depot, the work load at the depot, and the type and quantity of equipment utilized in the system. In addition, special equipment such as a spray-painting equipment, a drill press, and other shop equipment may be required at the depot to facilitate the overhaul of the microwave system electronic and electrical equipment.

Table 7-9. Typical Test Equipment, List of

ITEM NO.	EQUIPMENT	NECESSARY CHARACTERISTICS
1	*Signal generator	Range: 10 Hz to 1 MHz; max output; 3V into 600 ohms.
2	*Multimeter	Volts: 2.5 to 1000V full scale (dc: 20K ohm/V, ac: 1K ohm/V); resistance: 0 to 0.6 megohm; current: 100 μa to 10 AMP. full scale.
3	*Vacuum-tube voltmeter	Volts: 1.5 to 1500V full scale (dc: 10 megohms, ac: 5 megohms); resistance: 0 to 100 megohms.
4	Oscilloscope	Vertical: 0.1V/in. (peak to peak), 3-dB bandwidth 10 Hz to 1 Hz; driven sweep or recurrent sweep 0.15 sec to 4 μ sec; voltage and time calibration.
5	Variable autotransformer	1.72 kva; nominal input: 115V, 60 Hz; output: 0 to 135V, 10 AMP. (max. 15 AMP.).
6	Square-wave generator	Freq: 100 kHz; max. output: 8V into 600 ohms; sync output.
7	Signal generator	Range: 70 to 110 mHz; max. output: 20 mv to 53 ohms.
8	Visual-alignment generator	Range: 70 to 110 mHz; max. sweep width: 15 mHz; marker osc; crystal calibrator; max. output: 50 mv
9	*Test sound-powered handset	4-wire; separate trans and rec plugs; impedance: 600 ohms.
10	*Volume-level indicator	Scale: minus 20 to plus 3 vu; scale zero: plus 4 to plus 20 vu in 28-vu steps; impedance: 7500 ohms.
11	Variable attenuator	Range: 2 to 20 dB; max. VSWR: 1.2; line: RG 50/U; freq range: 5.9 to 7.8 kmHz.
12	Directional coupler	Nominal coupling: 30 dB; line: RG 50/U; freq range: 5.9 to 7.8 kmHz.
13	Detecting section	Max VSWR: 1.5; line: RG 50/U; freq range: 5.9 to 7.8 kmHz.
14	Standing-wave detector	Slotted section: 8-25/32 in. insertion length; broad-band probe; line: RG 50/U; freq range: 5.9 to 7.8 kmHz.
15	Matching load	Max. VSWR: 1.05; line: RG 50/U; freq range 5.9 to 7.8 kmHz.
16	Cavity frequency meter	Loaded Q: 7000, accuracy: 0.01 percent freq range: 5.9 to 7.8 kmHz.
17	Directional coupler	Nominal coupling: 24 dB; line: RG 50/U; freq range: 5.9 to 7.8 kmHz.
18	Power meter	Range: 0.02 to 5 mw; accuracy: 5 percent of full scale.

Table 7-9. Typical Test Equipment, List of (Continued)

ITEM NO.	EQUIPMENT	NECESSARY CHARACTERISTICS
19	Silicon diode	Use with item 13 when item 13 is used as a crystal detector.
20	Barretter	Use with item 13 when item 13 is used as a barretter mount.
21	*Microwave test set	Range: 5825 to 7725 mHz (6 bands); FM modulation 1000 Hz, 0 -- 15-mHz deviation; power meter; freq meter; two transducers.
22	Klystron power supply	Input: 117V, 60 Hz; outputs (regulated): minus 750, 100 ma; minus 1075 VDC; variable - 75 v; 6.3 VAC isolated from ground.
23	Step attenuator	Range: 0 to 100 dB in 1 - dB steps; impedance: 600 ohms; audio.
24	Step attenuator	Range: 10 to 51 dB in 1 - dB steps; impedance: 53.5 ohms; freq: 50 to 110 mHz.
25	Standard voltmeter	DC; scales (full): 1.5, 15, and 150V; accuracy: 0.5 percent.
26	Standard voltmeter	DC; scales (full): 200, 500, and 1000V; accuracy: 0.5 percent.
27	*Standard voltmeter	AC; scales (full): 150 and 300V, rms; accuracy: 0.5 percent.
28	Noise meter (optional)	Range: minus 6 to plus 85 dBm; impedance: 600 ohms; "FIA" frequency weighting.
29	*Klystron tuning tool	Special insulated tool.
30	*Capacitor tuning tool	Corning Glass capacitor tool.
31	*Low-capacity screw driver	Insulated handle; small metal blade.
32	*Coaxial cable	RG 59/U (AN number).
33	*Coaxial cable	RG 55/U (AN number).
34	*Connector	UG 260/U, BNC plug (AN number).
35	*Connector	N. T. 49195, UHF plug (AN number).
36	*Test lead	Hook-up wire; pin plugs, test prods.

Table 7-10. Test Equipment for Laboratory (Depot Maintenance) Measurement

MEASUREMENTS	EQUIPMENT NEEDED (ITEM NO.)
MICROWAVE RADIO RELAY EQUIPMENT	
R-F Section	
Transmitter power	21
Transmitter frequency	21
Received signal strength	21
A-G-C vs received signal calibration	21
Klystron (bench tuning)	4, 11, 12, 13, 16, 18, 19, 20, 22, & 33
Wave-guide phaser and variable attenuator	2, 4, 11, 13, 15, 17, 19, 21, 22, & 33
Wave-guide discriminator	4, 15, 16, 17, 22, & 33
Wave-guide receiver leg	2, 3, 4, 11, 13, 16, 17, 19, 22, 31, & 33
Wave-guide transmitter tee	4, 11, 12, 13, 14, 16, 19, 22, & 33
I-F Section	
Signal-to-noise ratio	1, 3, 4, 7, 21, & 32
I-F discriminator	7, 8, 24, & 34
I-F sensitivity	2, 7, & 24
Receiver bandpass	7, 8, & 24
Video Section	
Video response	1, 4, & 23
Transient response	4 & 6
Insertion	1, 4, 9, & 23
Feed-back loop	1, 4, & 23
Modulation capability	1 & 4
Hum, ripple, and distortion	1, 3, 4, 23, 28, & 29
Miscellaneous Sections	
Power supplies	2 & 5
Servo chassis	2
Blowers	2
Heaters	2
Controls	2
TIME-DIVISION MULTIPLEX EQUIPMENT	
Over-all sensitivity (back-to-back)	1, 9, & 10
Channel characteristics	1, 3, 4, 23, 28, 29, 32, & 35
All other tests and measurements	2, 4, & 35
TELEPHONE EQUIPMENT	
Circuit noise	32
Circuit level	3, 9, & 32
SHELTER EQUIPMENT	
Lighting	2
Motor-generators	2 & 20
Primary power lines	2 & 30

Table 7-11. Field Maintenance Tool Kit, Typical

QTY	ITEM	QTY	ITEM
1	Tool case	1	Quickwedge screwdriver
1	1/4-in. utility electric drill	1	Scriber, double point
1	Threading kit, including taps and dies	1	Point screwdriver
	4-40 10-32 8-32	1	4-1/2 in. screwdriver, narrow
	6-32 1/4"-20	1	Solder gun
1	Plastic utility box, 9 compartments	1	Flashlight, with batteries
1	Drill gauge	1	Extension cord, 15 ft
2	No. 44 Drill	1	Alignment tool
2	No. 36 Drill	1	Hex and spline wrench kit
2	No. 33 Drill	1	Multimeter
2	No. 29 Drill	1	Soldering aid
2	No. 28 Drill	1	Tube puller
2	No. 21 Drill	1	7-pin tube straightener
2	No. 19 Drill	1	9-pin tube straightener
2	No. 11 Drill	1	Wire stripper
2	No. 7 Drill	1	Wrench kit
2	1/4-in. Drills	1	Slip pliers
12	Each - bolt w/nut and lockwasher	1	Hand Clamp tool
	4-40 3/4" 8-32-1"	1	6-ft pocket rule
	8 32 1" 10 32-1"	1	Roll rosin-core solder, 1 lb.
1	No. 410 Channel-lock gripping pliers	1	No. 99 Xcelite tool roll
1	No. TH-6 Hold-E-Zee screwdriver	1	Klystron tuning tool
1	No. TH-4 Hold-E-Zee screwdriver	1	IF discriminator tuning tool
1	No. TH-7 Hold-E-Zee screwdriver	1	Capacitor tuning tool
1	No. PS-2 Hole-E-Zee screwdriver	1	Roll electric tape
1	Small ball peen hammer	1	60-watt soldering iron with small tip
1	Diagonal cutters	1	Center punch
1	Pair long-noise pliers	1	File kit
1	6-in. adjustable wrench	1	Gram gauge
1	Electrician's knife	1	Burnishing tool

Table 7-12. Station Maintenance Tools, Typical

ITEM	TYPE
Channel-lock gripping pliers	9-1/2 in.
Screwdriver	6-in.
Screwdriver	4-in.
Screwdriver	8-in.
Screwdriver	1-3/4 in, stubby
Screwdriver	Phillips No. 2503 (for Phillips screws No. 10 to No. 16 incl)
Screwdriver	Phillips No. 2502 (for Phillips screws No. 5 to No. 9 incl)
Nail hammer	
Diagonal cutters	6-in.
Long-noise pliers	6-in.
Adjustable wrench	8-in.
Adjustable wrench	6-in.
Adjustable wrench	4-in.
Scriber	8-in, double point, style 3
Pocket screwdriver	2-in.
Narrow screwdriver	6-in.
Solder gun	
Flashlight	2-cell
Flashlight batteries	
Extension cord	15-ft.
Alignment tool	
Tool roll	Xcelite No. 99 or equivalent
Hex and spline wrench kit	
Multimeter	
Sound-powered handset	
Soldering flux	
Tube puller	7-pin
Tube puller	9-pin
Pin straightener	7-pin
Pin straightener	9-pin
Wire stripper	
Offset rachet handles and interchange-able adapters	
Offset screwdriver	4-in.
Tool case	
Soldering iron	150-watt
Temperature regulating stand	
Needle-nose pliers	5-in.
Combination pliers	6-in.
Dental mirror	
Socket contact gauge	
Neon circuit tester	
Capacitor tuning tool	
Klystron tuning tool	
Oil can and lubricating oil	3-in-1 type or equivalent
Coil tuning tool	
Pocket knife	
End wrench, ignition	3/8-in.
Ball peen hammer	1/2 lb.
Thermometer	Outdoor type with Fahrenheit scale
Mill file	10-in.
Paint brush	2-in.
Solder, rosin core	
Soldering paste	
Friction tape	
Polar relay adjusting tools, as follows:	
(1) contact burnisher	26S-C
(2) tool	34D
(1) file	KS-2662
(1) gauge	74D

CHAPTER 8

TROPOSPHERIC SCATTER SYSTEM DESIGN

Given the fundamental plans and study results, and the profiles, data and other information obtained from the field investigation, the next order or procedure concerns the transmission engineering plans, calculations and design specifications. Some of this work, such as planning, is actually accomplished prior to the route selection work. After the field investigation is finished, the final calculations concerning antennas, interference, system and channel noise, distortion and propagation reliability are made. If the final sites have not been selected from the field data at this point, this must be done prior to much of the other work. Also at this point it may be important that information about the choice of sites be made available to those responsible for obtaining the necessary property, as failure to obtain one site may affect some of the other selections.

The final objective for any microwave system is that it provides the best distortion-free and interference-free service continuity for the type of service to be assigned, and within the framework of the available economics.

Overall reliability or service continuity involves not only equipment failure rates and power failures, but also the propagation performance and the individual paths. This involves antenna sizes and elevations, frequency or space separations in diversity systems, path lengths and frequency-attentuation relationships. It also includes fading margins which, in addition to path parameters, are affected by noise figure, transmitter power, and attentuation of waveguide and filter arrangements.

Distortion may occur in the radio path, but more often it occurs due to poor return loss of amplifier components, waveguide filters and antennas. Also the characteristics of switching devices and/or combiners are involved.

System noise is affected by the same things which, in addition to interference, can have an adverse effect on overall system performance.

8.1 SYSTEM CALCULATIONS

Procedures for designing a tropospheric scatter communications circuit can be organized into five major steps. These are:

o The determination of the basic system requirements (the communications need)

o The preliminary analysis of the proposed system configuration to determine path lengths and possible site locations (feasibility study)

- The field surveys of the proposed sites and the paths between to accurately determine coordinates, and elevations of salient features and provide information not evident from a map study (site survey)

- Using the results of the first three steps, a final prediction of the link performance is made, based upon the type of equipment to be used, the path length, and channel capacity

- The actual installation procedures.

The first two steps were discussed in chapter 6, the field survey requirements are listed in Appendix E, and the final prediction is described in the following paragraphs.

The final design calculations are to be based upon the best information obtainable but shall have an accuracy not less than:

- Coordinates to third order accuracy

- Elevations to nearest 5 meters

- Distances to 0.1 miles

- All azimuths to 10 seconds.

Maps utilized shall have a scale not less than 1 in 25,000 with contours at 5 meter intervals. In areas where maps of this scale are not available a scale of 1 in 100,000 with contours at not more than 30 meter intervals may be used with care.

To clarify the use of the formulas and methods, a sample link calculation shall be made. The preliminary studies showed a transhorizon link was feasible between Dallas and Austin, Texas. Based upon the site survey the coordinates of the sites are as shown in figure 8-1.

Using figure 2-8 or 2-9 the radio refractivity N_o is determined as 315.

From the average heights above sea level of the antennas $h_{ts} = 280.4$ m and $h_{rs} = 243.9$ m.

the average antenna height

$$h_s = \frac{h_{ts} + h_{rs}}{2}$$

$$h_s = 261.9 \text{ m}$$

MICROWAVE PATH DATA CALCULATIONS

1	SITE		DALLAS		AUSTIN
2	LATITUDE	N	32° 28' 12"		30° 01' 48"
3	LONGITUDE	W	96° 28' 48"		97° 28' 12"
4	ELEVATION	m	270.4		234.1
5	TOWER HEIGHT	m	10.		9.8
6	TOWER TYPE				
7	AZIMUTH FROM TRUE NORTH.		149° 23' 25"		18° 52' 35"
8	PATH LENGTH	km	283.1		
9	PATH ATTENUATION (L_{bsr})	db	238.6		
10	RIGID WAVEGUIDE	Ft.	100		100
11	FLEXIBLE WAVEGUIDE	Ft.	—		—
12	WAVEGUIDE LOSS	dB	1.4		1.4
13	CONNECTOR LOSS	dB	.3		.3
14	CIRCULATOR OR HYBRID LOSS	db			1.0
15	RADOME LOSS, TYPE*	dB			
16	NEAR FIELD LOSS	dB			
17	CLOSE COUPLING LOSS (SCATTER)	dB			13.5
18	TOTAL FIXED LOSSES	dB	1.7		16.2
19	TOTAL LOSSES	dB	256.5		
20	PARABOLA HEIGHT ℄ AGL	Ft.			
21	PARABOLA DIAMETER	Ft.			
22	REFLECTOR HEIGHT 30 Ft.	Ft.			
23	REFLECTOR SIZE, TYPE	Ft.			
24	PARABOLA - REFLECTOR SEP.	Ft.			
25	DIV. IMP. FACTOR, QUAD. DIV.	dB			7
26	ANTENNA SYSTEM GAIN	dB	52		52
27	TOTAL GAINS	dB	111		
28	NET PATH LOSS	dB	145.5		
29	TRANSMITTER POWER (50 kw)	dBm	+77		
30	MED. RECEIVED POWER (± 2 dB)	dBm	-68.1		
31	RECEIVER NOISE THRESHOLD	dBm	-104		
32	THEORETICAL RF C/N RATIO	dB	35.9		
33	FM IMP. THRESHOLD (dBa)	dBm	-94		
34	FADE MARGIN (To FM Imp. Thresh.)	dB	25.9		
35	RELIABILITY SPACING† Q	%			
36	POLARIZATION ‡				
37	PROFILE NUMBER				

‡ V - Vertical, H - Horizontal
N - Non-Diversity, D - Space And Frequency Diversity
† F - Frequency Diversity, S - Space Diversity
• U - Unheated, H - Heated
(Reliability Figures Are For Rayleigh Distributed Fading Only)

CUSTOMER U. S. NAVY
PROJECT NO. ______ FREQUENCY 5000 MHz
SYSTEM ______ EQUIPMENT ______
LOADING ______ dBm0 (______ CHANNELS OF ______)

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DATE ______ ENGINEER ______ Sheet ______ of ______

Figure 8-1. Microwave Path Data Calculation Sheet

and from equation 2-12

$N_s = N_o \exp(0.03222\ h_s)$

$N_s = 306$

The effective earth's radius a = 8580 km is determined from figure 6-2. Using the map study method specified in section 6.2.3 the path profile is plotted as shown in figure 8-2. The troposcatter path geometry is shown in figure 8-3.

The tropospheric path angle (or scatter angle) θ is calculated as shown in figure 8-4. The parameters not calculated on the page are easily determined from the previous calculations or measurements. The correction terms $\Delta\alpha_o$ are determined from figures 6-18 and 6-19 as follows:

- o Enter figure 6-18 with θ_{ot} and d_{st} and obtain $\Delta\alpha_o$ (for $N_s = 301$)
- o If N_s is other than 301, enter figure 6-19 and obtain C (N_s)
- o Multiply (for $N_s = 30$) by C (N_s) to obtain

The median transmission loss (L_{bsr}) calculation is shown in figure 8-5. The attenuation function F(0d) is obtained from any one of figure 806 through 8-11 depending on the required N_s. The scattering efficiency factor F_o is usually small. It exceeds 2 dB only for distances and antenna heights so large that h_o exceeds h_i by more than 3 kilometers. The total loss in the example of figure 8-5 is 238.6 dB which is entered in item 9 of figure 8-1.

Other losses to be tabulated include:

100 feet of RG 49 waveguide for each terminal which has (from table 8-1)

1.4 dB per 100 feet at 5 GHz, waveguide connectors 0.3 dB per terminal and 1.0 dB for the circulator at the receiving end.

The antennas proposed for this link are 30 feet in diameter with a gain of 52 dB and a beamwidth Ω of 0.49 degrees (8.5 milliradians). The individual gains are entered in item 23, the diversity factor for quadruple diversity of 7 dB from figure 7-1 is entered in item 22, then the totals of these in item 24.

One additional loss must be considered that is the scatter coupling loss.

The ratio of $\frac{\theta}{\Omega}$ is obtained.

In this case

$$\frac{\theta}{\Omega} = \frac{32.151}{8.5} = 3.79.$$

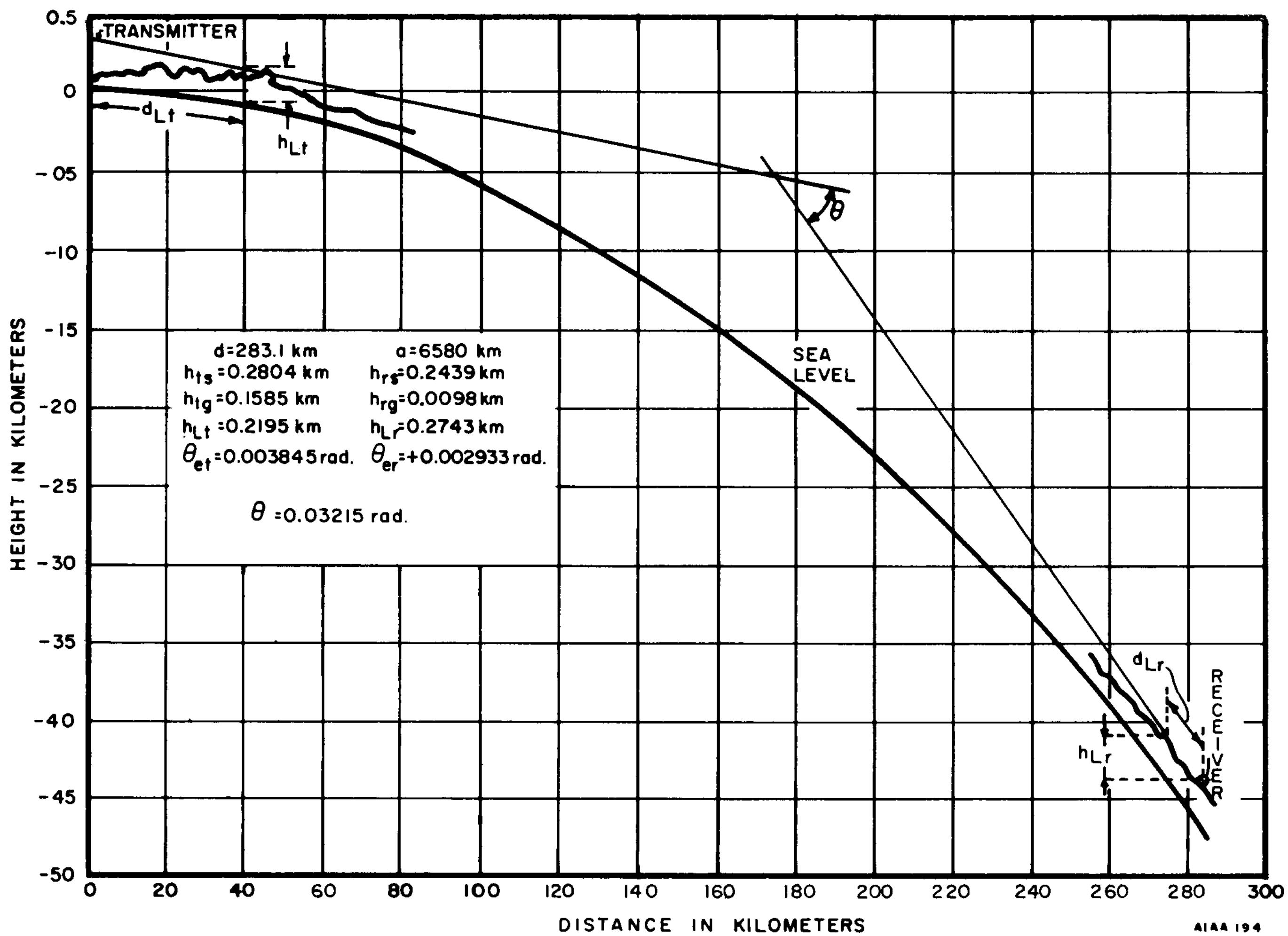

Figure 8-2. Profile of a Transhorizon Path

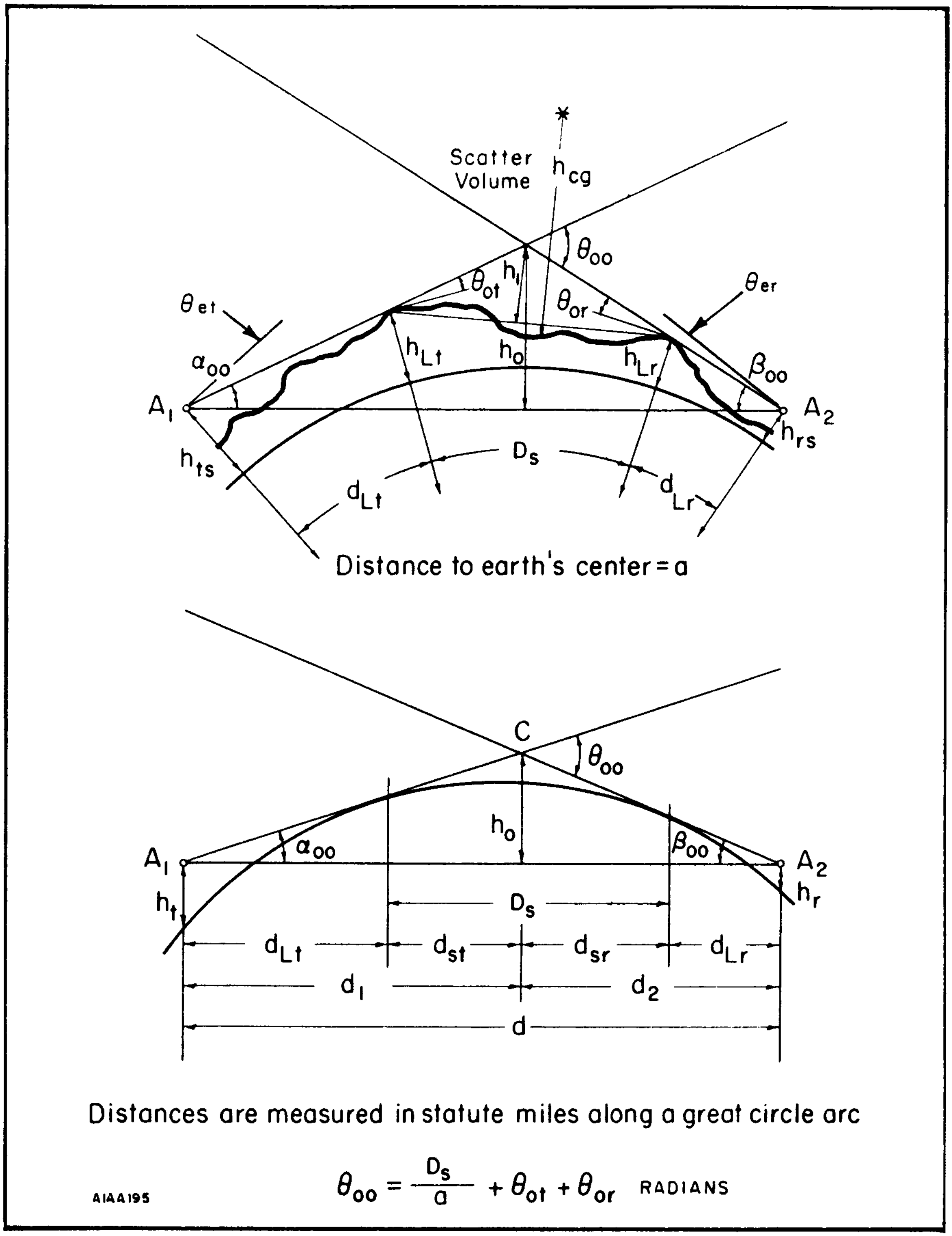

Figure 8-3. DCAC-330-175-1 Path Geometry

(EXISTING TROPOSCATTER PATH)

$d = 283.1$ km
$a = 8580$ km

AUSTIN	DALLAS
$h_{ts} = 280.4$ m $h_{Lt} = 219.5$ m $h_{te} = 135$ m $d_{Lt} = 39.6$ km $d_{st} = 130.72$ km	$h_{rs} = 243.9$ m $h_{Lr} = 274.3$ m $h_{re} = 9.8$ m $d_{Lr} = 8.8$ km $d_{sr} = 103.95$ km
$\theta_{et} = \frac{h_{Lt} - h_{ts}}{d_{Lt}} - \frac{d_{Lt}}{2a}$ $= \frac{219.5 - 280.4}{39600} - \frac{39.6}{2\ (8580)}$ $= -3.845$ mr	$\theta_{er} = \frac{h_{Lr} - h_{rs}}{d_{Lr}} - \frac{d_{Lr}}{2a}$ $= \frac{274.3 - 243.9}{8800} - \frac{8.8}{2\ (8580)}$ $= +2.933$ mr
$x = \frac{d}{2a} + \frac{h_{ts} - h_{rs}}{d}$ $= \frac{283.1}{2\ (8580)} + \frac{280.4 - 243.9}{283.1}$ $= 16.679$ mr	$y = \frac{d}{2a} - \frac{h_{ts} - h_{rs}}{d}$ $= \frac{283.1}{2\ (8580)} - \frac{(280.4 - 243.9)}{283.1}$ $= -10.013$ mr
$\theta_{ot} = \theta_{et} + \frac{d_{Lt}}{a}$ $= -3.845 + \frac{39.6}{8580}$ $= .768$ mr	$\theta_{or} = \theta_{er} + \frac{d_{Lr}}{a}$ $= 2.933 + \frac{8.8}{8580}$ $= 3.961$ mr
$\Delta\alpha \cong 0$ FROM FIGURES 6-18 AND 6-19	$\Delta\beta \cong 0$ FROM FIGURES 6-18 AND 6-19
$\alpha_o = \theta_{et} + x + \Delta\alpha_o$ $= 3.845 + .1455 + 0$ $= 12.834$ mr	$\beta_o = \theta_{er} + y + \Delta\beta_o$ $= +2.933 - .1125$ $= 19.317$ mr
$\theta_{oo} = \theta = \alpha_o + \beta_o = 12.834 + 19.317 = \underline{32.151\ \text{mr}}$	AIAA196

Figure 8-4. Tropospheric Path Angle Computations (Milliradians)

$L_{bsr} = 30 \text{ LOG } f - 20 \text{LOG } D + F(\theta d) - F_o + H_o + A_a$ dB

θ d IN RADIANS (283.1) (32.151) (10^{-3})	9.10	
PATH ASYMMETRY FACTOR $S = \frac{\alpha_o}{\beta_o} = \frac{12.834}{19.317}$	.664	
ATTENUATION FUNCTION F(θd) IN dB FROM FIGURE 8-6, 7, 8, OR 9		167 dB
30 LOG F IN dB = 30 LOG 5000		111 dB
− 20 LOG d IN dB = − 20 LOG 283.1		-49 dB
$h_o = \frac{S \; d \; \theta}{(1+S)^2}$ IN km $= \frac{.664 \; (9.10)}{(1 + .664)^2}$	2.18 km	
$r_1 = 41.92 \; \theta f \; h_{te} = 41.92 \; (.0321) \; (5000) \; (.135)$	19.01	
$r_2 = 41.92 \; \theta f \; h_{te} = 41.92 \; (.0321) \; (5000) \; (.0098)$	1.38	
$q = \frac{r_2}{s r_1} = \frac{1.38}{.664 \; (19.01)}$	1.09	
η_s FROM FIGURE 6-22	1.1	
$H_o = \frac{H_o(r_1) + H_o(r_2)}{2} + \Delta H_o$ IN dB $= \frac{.15^2 + 13.5}{2} + .61$ $H_o(r_1)$ & $H_o(r_2)$ FROM FIGURE 8-10 ; ΔH_o FROM FIGURE 8-11		7.4 dB
$D_s = d - d_{Lt} - d_{Lr}$ IN km = 283.1 − 39.6 − 8.8 km	234.7	
$L_1 = \frac{S \; D_s \theta}{(1+S)^2}$ IN km $= \frac{.664 \; (234.7) \; (.0321)}{(1 + .664)^2}$ km	1.82	
$F_o = 1.086 \left(\frac{\eta_s}{h_o}\right)(h_o - h_1 - h_{Lt} - h_{Lr})$ dB $= 1.086 \left(\frac{1.1}{2.18}\right)(2.18 - 1.82 - .219 - .274)$		≅ 0
A_a FROM FIGURE 4-6		2.2 dB
L_{bsr}		238.6 dB

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Figure 8-5. Computation of Long-Term Median Transmission Loss Trpospheric Scatter

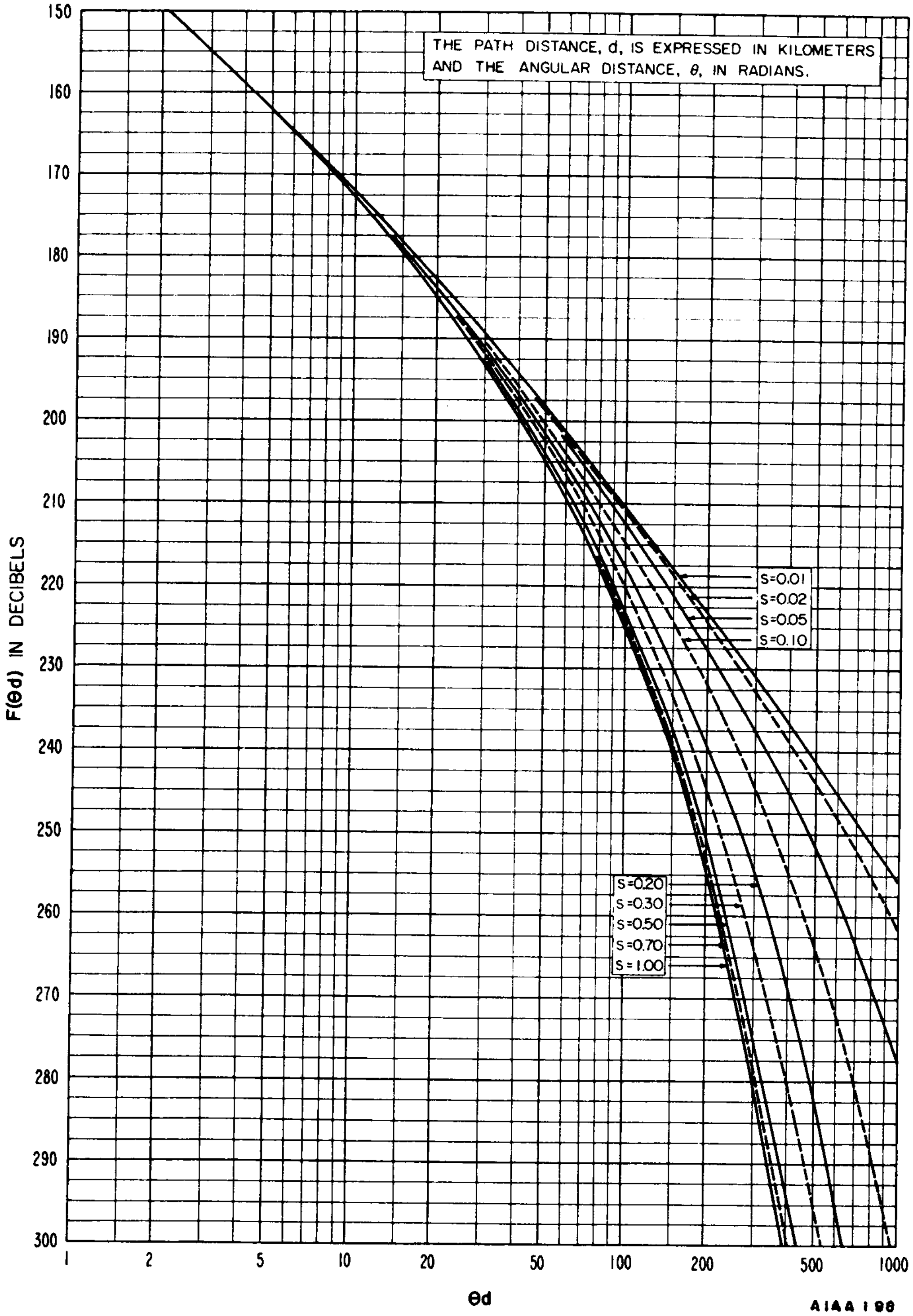

Figure 8-6. The Function $F(\theta d)$ for $N_s = 250$

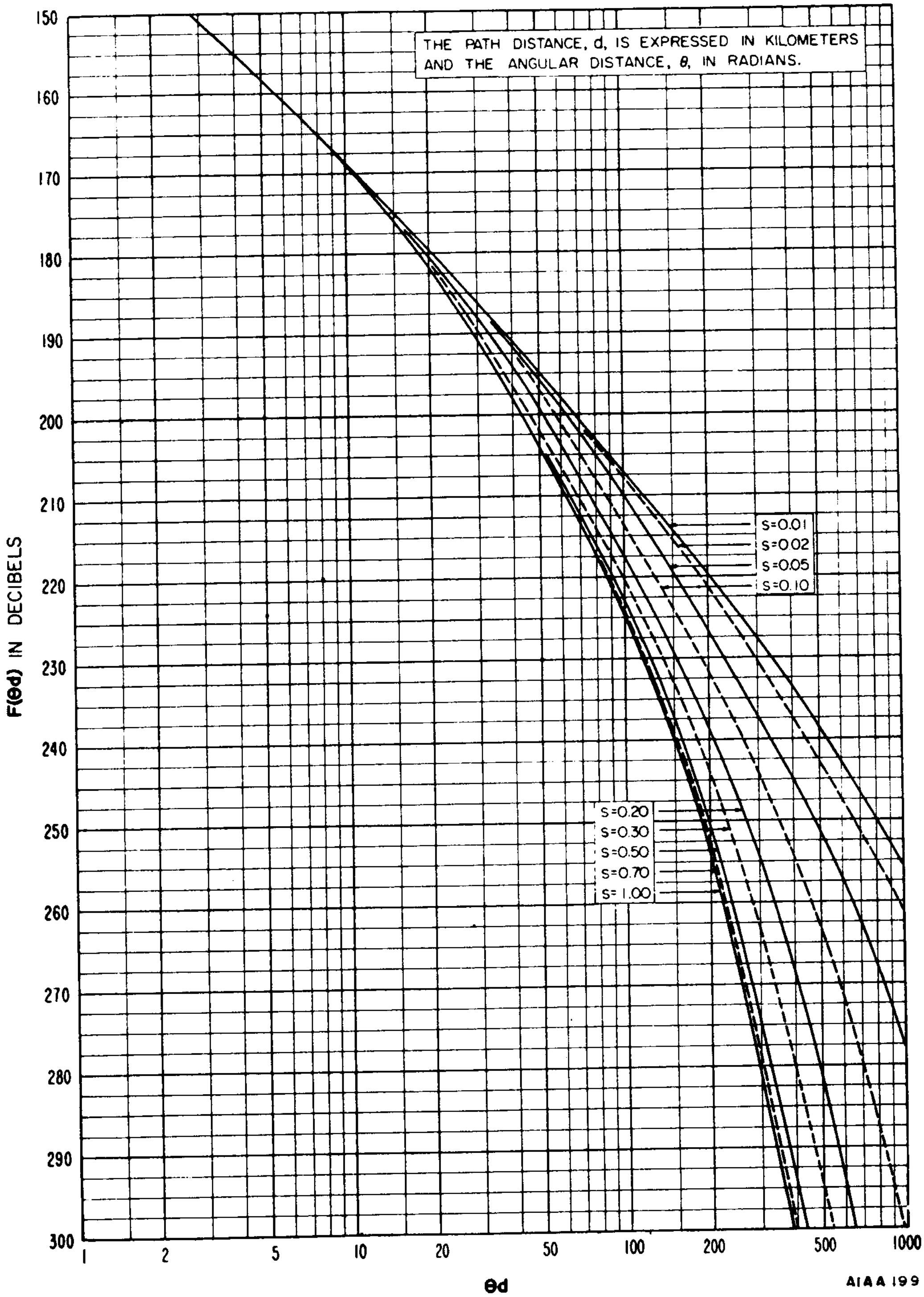

Figure 8-7. The Function F(d) for N_S = 301

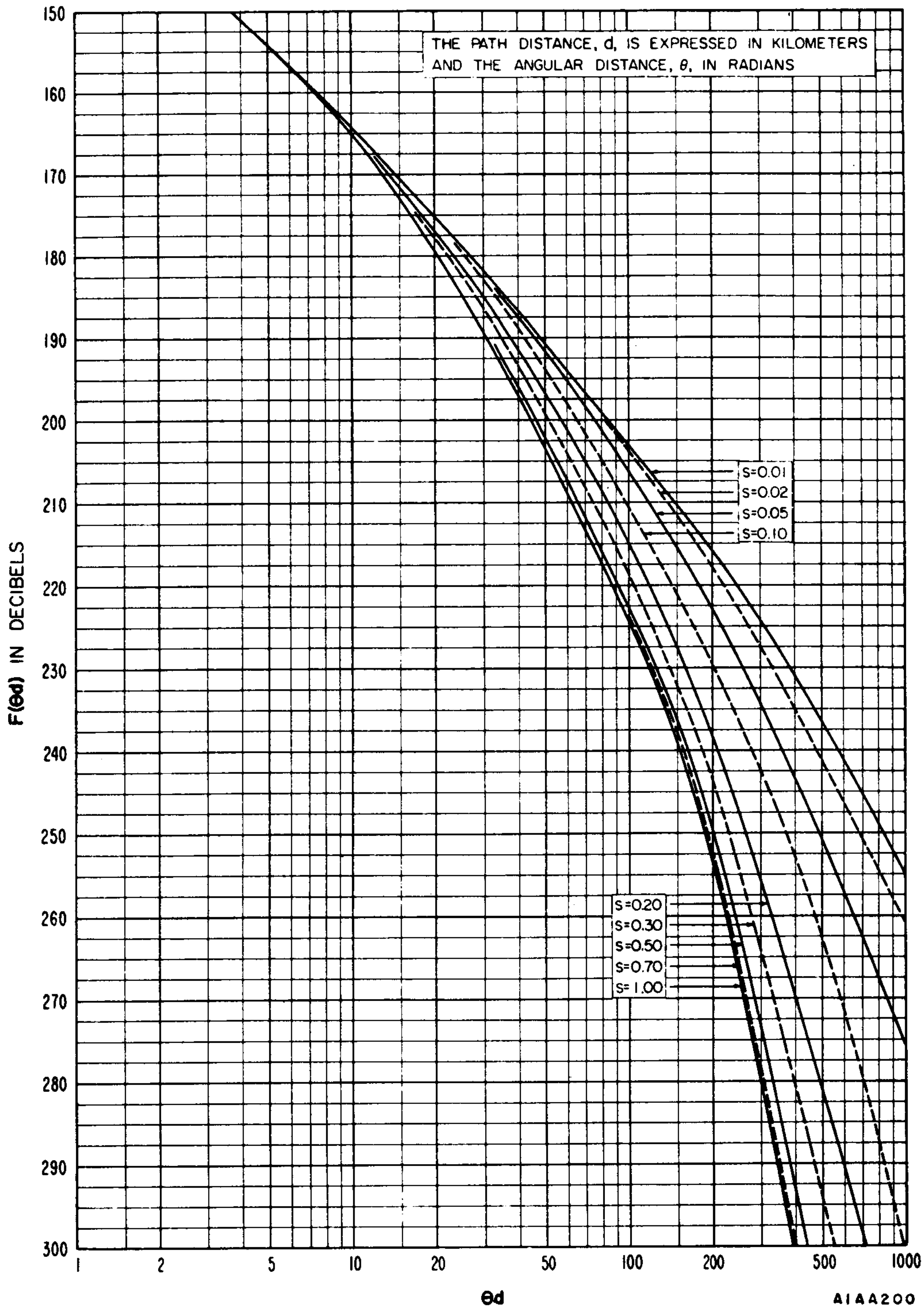

Figure 8-8. The Function F(θd) for N_S = 350

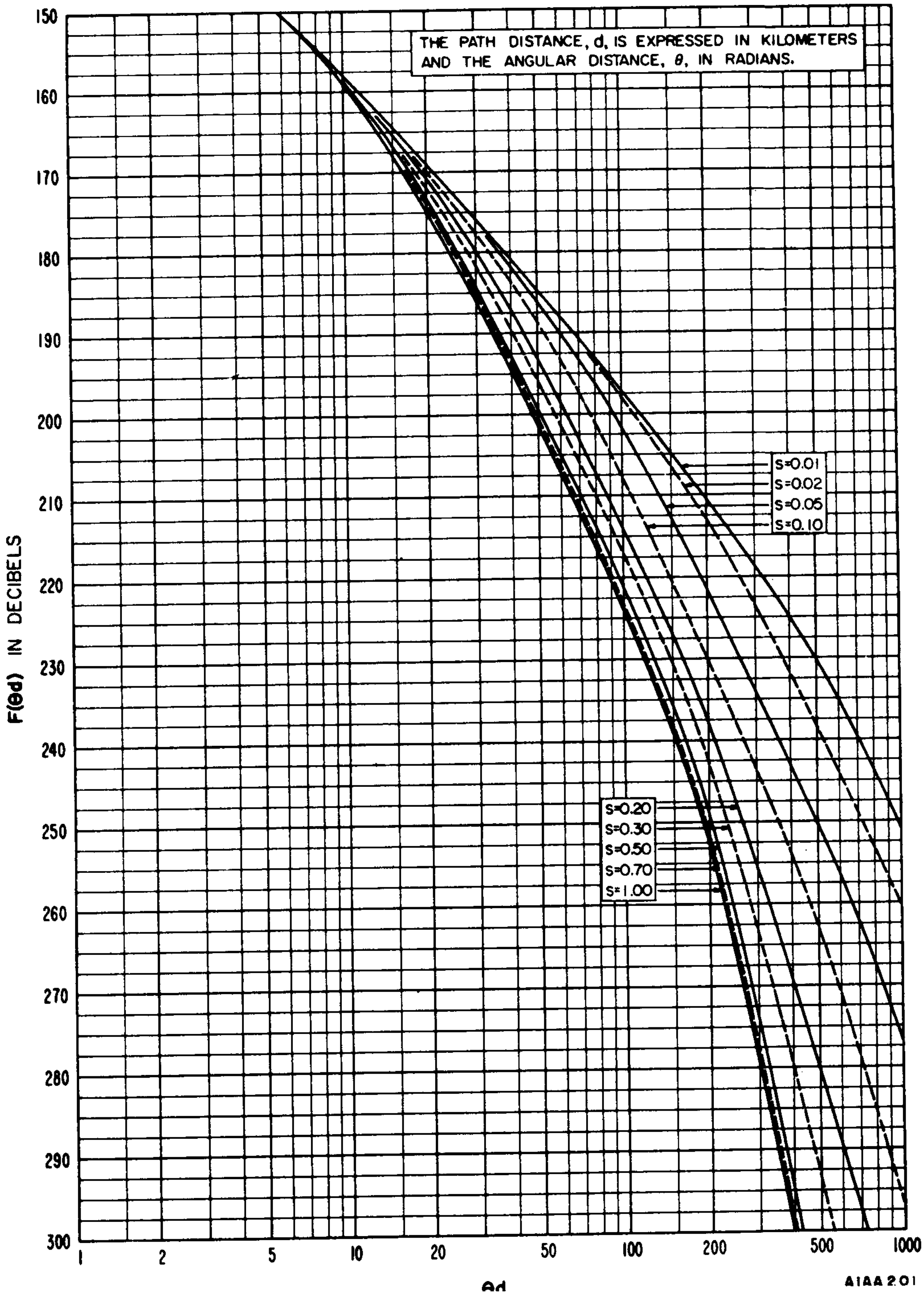

Figure 8-9. The Function F(θd) for $N_S = 400$

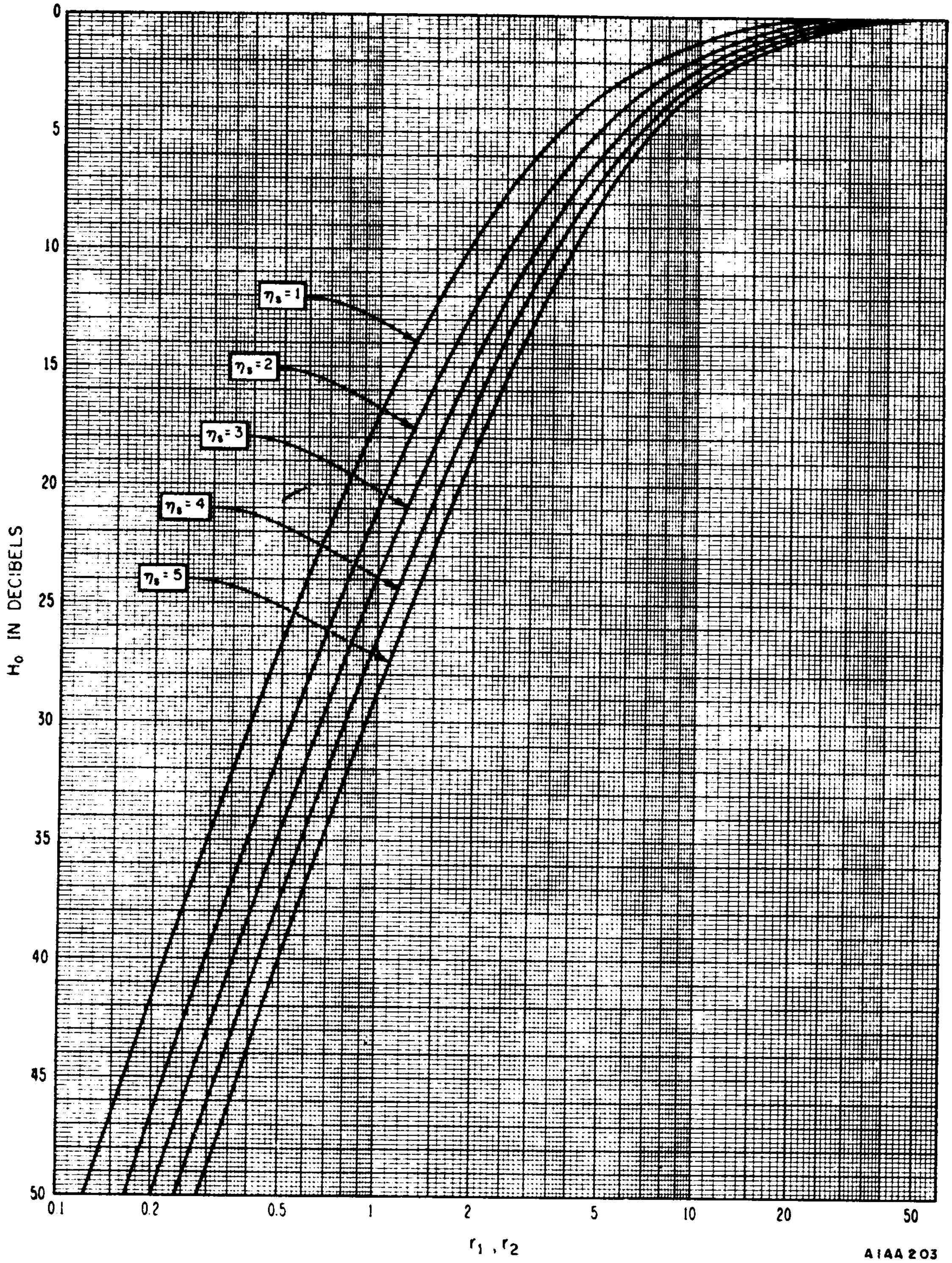

Figure 8-10. The Frequency Gain Function, H_O

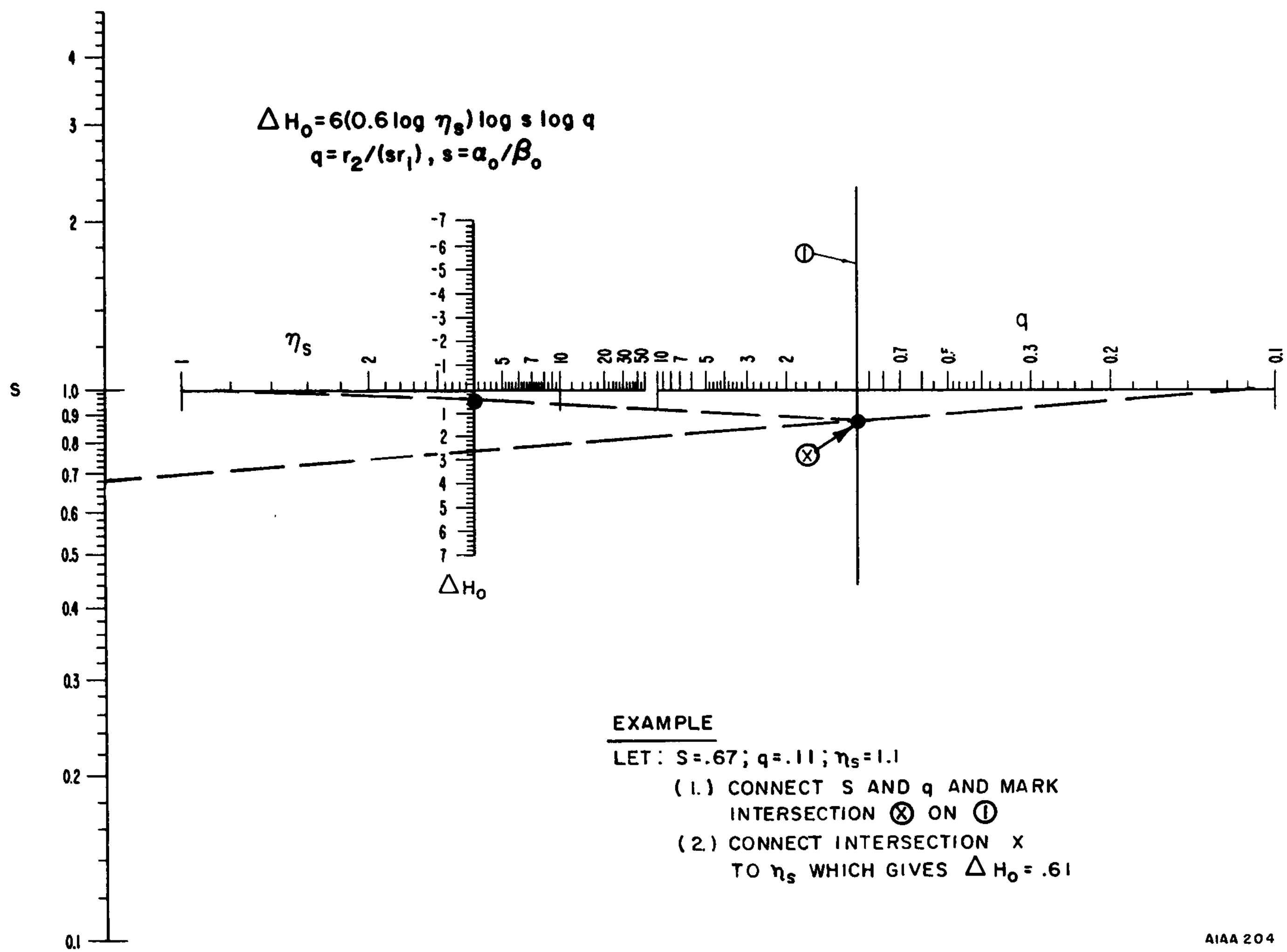

Figure 8-11. Nomogram to Determine ΔH_O

Table 8-1. Standard Waveguides

EIA WAVEGUIDE DESIGNATION	JAN WAVEGUIDE DESIGNATION	OUTER DIMENSIONS AND WALL THICKNESS (IN INCHES)	FREQUENCY RANGE IN GIGAHERTZ FOR DOMINANT ($TE_{1,0}$) MODE	CUTOFF WAVE-LENGTH λ_c IN CENTIMETERS FOR $TE_{1,0}$ MODE	CUTOFF FRE-QUENCY f_c IN GIGAHERTZ FOR $TE_{1,0}$ MODE	THEORETICAL ATTENUATION, LOWEST TO HIGHEST FRE-QUENCY IN dB/100 FT	THEORETICAL POWER RATING IN MEGAWATTS FOR LOWEST TO HIGHEST FREQUENCY*
WR-770	RG-205/U$^{\Psi}$	7.950X4.100X0.125	0.96-1.45	39.1	0.767	0.201-0.136	17.2-24.1
WR-650	RG-69/U	6.660X3.410X0.080	1.12-1.70	33.0	0.908	0.317-0.212	11.9-17.2
WR-510	-	5.260X2.710X0.080	1.45-2.20	25.9	1.16	-	-
WR-430	RG-104/U	4.460X2.310X0.080	1.70-2.60	21.8	1.375	0.588-0.385	5.2-7.5
WR-340	RG-112/U	3.560X1.860X0.080	2.20-3.30	17.3	1.735	0.877-0.572	-
WR-284	RG-48/U	3.000X1.500X0.080	2.60-3.95	14.2	2.08	1.102-0.752	2.2-3.2
WR-229	-	2.418X1.273X0.064	3.30-4.90	11.6	2.59	-	-
WR-187	RG-49/U	2.000X1.000X0.064	3.95-5.85	9.50	3.16	2.08-1.44	1.4-2.0
WR-159	-	1.718X0.923X0.064	4.90-7.05	8.09	3.71	-	-
WR-137	RG-50/U	1.500X0.750X0.064	5.85-8.20	6.98	4.29	2.87-2.30	0.56-0.71
WR-112	RG-51/U	1.250X0.625X0.064	7.05-10.00	5.70	5.26	4.12-3.21	0.35-0.46
WR-90	RG-52/U	1.000X0.500X0.050	8.20-12.40	4.57	6.56	6.45-4.48	0.20-0.29
WR-75	-	0.850X0.475X0.050	10.00-15.00	3.81	7.88	-	-
WR-62	RG-91/U	0.702X0.391X0.040	12.40-18.00	3.16	9.49	9.51-8.31	0.12-0.16
WR-51	-	0.590X0.335X0.040	15.00-22.00	2.59	11.6	-	-

*For these computations, the breakdown strength of air was taken as 15,000 volts per centimeter. A safety factor of approximately 2 at sea level has been allowed.

ΨAluminum, 2.83×10^{-6} ohm-cm resistivity. ‡ Silver, 1.62×10^{-6} ohm-cm resistivity. ζ Silver, with a circular outer cross section of 0.156-inch diameter and a rectangular cross-sectional bore of indicated dimensions. All other types are of a Cu-Zn alloy, 3×10^{-6} ohm-cm resistivity.

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Figure 6-23 gives this loss as 13.5 dB which is entered in item 15.

The total path losses then becomes 256.5 dB (items 9 and 16) less the total gain of 111 dB (item 24) giving a net path loss of 145.5 dB (item 25). If a to kW (+77 dBm) transmitter is used the median received signal (item 27) becomes -68.1 dBm.

The receiver bandwidth is considered next. Using a 72 voice channel system with a peak deviation ΔF_p of 1.2 MHz (modulation index of 3), the maximum modulating frequency is about 360 kHz. This is computed as follows:

Minimum modulating frequency	=	60 kHz
Voice channel bandwidth 72 (4 kHz)	=	288 kHz
Spacing between supergroups	=	12 kHz
The maximum modulating frequency Fm	=	360 kHz

The Bandwidth

$$BW = 2\ (\Delta F_p + F_m)$$

$$BW = 2\ (1.2\ \text{MHz} + 360\ \text{kHz}) = 3.12\ \text{MHz}$$

The receiver noise threshold is obtained from

$$\text{Threshold} = .174 + \log BW + (\text{Receiver Noise figure in dB})$$

$$= .174 + 10 \log 3.12 \times 10^6 + (5)$$

$$= .174 + 65 + 5 = .104\ \text{dBm}$$

which is entered in item 28 of figure 12-8 providing a theoretical carrier to noise ratio of 35.9 dB. The FM threshold is 10 dB above the receiver noise threshold or -94 dBm providing a fade margin of 25.9 dB.

After reliability considerations have been established and a favorable system design completed, it is necessary to compute the expected channel noise. According to the DCA System Performance Specifications, the channel noise objective is 38 dBaO. The requirement states that:

> ...noise in any channel shall not exceed 38 dBa median at zero relative level (25,000 picowatts) in any channel during the worst month, and shall not exceed 49 dBa at zero relative level (316,000 picowatts) in any channel for more than 1.0 percent of the worst month.

The channel noise (Signal-to-Noise ratio (S/N)) may be computed after the Carrier-to-Noise (C/N) ratio of the path has been determined. The relationship between channel

S/N and system C/N in an FM system is determined primarily by the bandwidth required for the particular type of information being transmitted and the degree of deviation produced in the system.

The Carrier-to-Noise defines the power relationship that exists between the median received signal level and the noise.

The signal to Noise ratio

$$S/N = C/N + 20 \log (\text{Mod index}) + 10 \log \frac{BW}{2BW} + PF - L - MUX$$

where,

C/N = Total Median Carrier-to-Noise Ratio

BW = Receiver IF Bandwidth

bw = Voice Channel Bandwidth

L = Channel Loading Factor

PF = Pre-emphasis Gain

MUX = Multiplex Equipment Noise Insertion

For the system under consideration

Modulation Index = 3

C/N = 25.5 dB

BW = 3.2 MHz

bw = 4 kHz

PF = 4 dB

L = 10.8 dB (See figure 7-3)

MUX = 2 dB (average factor)

Thus,

$$S/N = 35.9 + 20 \log 3 + 10 \log \left(\frac{3.2 \times 10^6}{8 \times 10^3} \right) + 4 - 10.8 - 2$$

$$= 20 \log 3 + 10 \log (4 \times 10^2) + 27.1$$

$$= (20)\ (.466) + (10)\ (2.602) + 27.1$$

$$= 9.54 + 26.02 + 27.1$$

$$= 62.76$$

Thus, the S/N ratio has been computed. Before proceeding to the determination of the channel noise, it is important to stop briefly consider the meaning of the S/N ratio.

The term signal-to-noise ratio (S/N) originated in single-channel communications practice and generally took into consideration only the background or residual noise in a single radio channel. With the growth of multichannel communications, it is also used to express the total intermodulation and residual noise in a single radio channel and is frequently referred to as "per-channel flat signal-to-noise ratio." Basically, it expresses the ratio, in decibels, of signal power to total noise power in a channel. It does not take into account the actual interfering effect of the noise on the signal the circuits.

The channel noise factor is expressed in dBaO. Decibels adjusted, or dBa, originated in the telephone industry as an expression of overall system noise performance. Strictly speaking, the term dBa implies that the frequency equipment used is "FIA" weighting. This method of noise performance is especially practical. It takes into account not only special types of noise or noise in particular items of equipment, but also the effects of all system noise.

By definition, dBa refers to decibels of noise power above a reference noise power, with an adjustment factor included to compensate for weighting. Even though the equipment from which the FIA weighting was derived has been superseded by newer equipment having better performance, FIA weighting continues to be used extensively because it provides a very close approximation to the performance of most of the world's telephone equipment.

The reference noise power to which dBa is referred is -85 dBm. To obtain dBaO, it is only necessary to calculate how many dB above this reference power the signal is. For flat voice channels, the corrected reference level is -85 + 3 or -82 dBm. Therefore, in this case

$$\text{dBaO} = 82 - (S/N) = 82 - 62.76 = 19.24 \text{ dBaO}$$

The path length in question is 283.1 kilometers which is 283.1 (.54) or 153 nautical miles.

The DCA standard allows noise N for a troposcatter link to be

$$N = \frac{L}{6000} \times 20,000 \text{ pWpO where L is in nautical miles}$$

therefore

$$N = 3.33\ (153) = 510\ \text{pWpO}$$

and

$$N\ (\text{dBaO}) = 10 \log \text{pWp} - 6\ \text{dB}$$

$$= 21\ \text{dBaO}$$

If the value of the channel noise factor did not meet the minimum specified for the system, it would be necessary to increase the basic peak channel deviation, or the pre-emphasis, or base the signal reliability on a greater carrier-to-noise ratio. The choice will depend on the flexibility of the particular equipments involved. The effect of adjusting the deviation ratio on the bandwidth is shown in figure 7-4.

The system calculations presented in this section are provided as a guide and are a compilation of the most recent and reliable information currently available.

8.2 FREQUENCY PLANNING

In the design of any microwave communications system, it is necessary to develop a plan of frequency allocation that will preclude the possibility of interference. Such interference may be defined as the reception of an undesired signal with, or in place of, the desired signal. This undesired signal, or interference, should be considered in terms of its source and permissible level at the receiver.

8.2.1 Types of Undesired Signals

There are three types of undesired signals which must be considered by the microwave system planner, two of which are directly under his control.

o Signals arriving at two or more receivers from two or more transmitters operating from the same location and in the same direction, that is, signals traveling parallel paths. These signals will arrive at approximately the same signal level, and will be affected equally by any fade that may occur along their path assuming that their frequency separation is not too great). These parallel signals will cause interference at the receivers unless the transmitting frequencies are chosen with the RF and IF rejection characteristics of the particular equipment in mind.

o Signals from other transmitters at the same station, or at other stations in close proximity to the receivers. The desired signal, in this case, may be very weak as compared with the signal radiated from the nearby transmitter (for example, -75 dBm for the desired signal as compared with O dBm for the undesired signal). The undesired signal is usually not subject to atmospheric fading, as is the desired signal. Allowing for a fading margin of 30 dB, the desired signal level might be as low as -105 dBm. Because of these factors, the frequency separation between the undesired locally transmitted signal and the desired received signal must be great enough to provide at least 25 dB attenuation of the undesired signal below the minimum level of the desired signal.

o Signals originating from sources external to, or unrelated to, the microwave system under consideration. These undesired signals are the most difficult to eliminate. Military microwave systems, or commercial systems operating in the vicinity of military installations, may have interference from certain types of radar or other UHF or SHF equipment. In some instances, an undesired signal may be the fundamental frequency of the radar equipment, and, in certain types of radar, the peak amplitude of this signal may be as much as 60 dB above the peak RF output of the microwave equipment. Since it is improbable that a change in radar frequency can be effected, it follows that the microwave system frequency allocation must be reconsidered.

In the case of interference resulting from harmonics of nearby transmitters operating on a lower frequency, it is necessary to locate the offending equipment and attempt modifications or adjustments to suppress or prevent the generation of harmonics. If this cannot be done, it will become necessary to employ harmonic waveguide filters to eliminate the interference. Problems of this nature must be solved on an individual basis through cooperation with the cognizant government or commercial agency.

A more complete discussion of these and other types of interference can be found in chapter 3.

8.2.2 Frequency Assignment

When developing a radio-frequency allocation plan for a microwave communication system, allowance should be made for the maximum number of channels that may be required by future expansion. This will permit orderly system expansion with the minimum amount of modification, and will eliminate major readjustments which might otherwise be required. The frequency assignment requirements for military objectives specified in DCAC-330-175-1 include:

a. The unit of frequency separation shall be .08 MHz and the spacing between frequency allocations used in a given system shall be an integral multiple of 0.8 MHz.

b. The minimum separation between a transmit and receive carrier frequency of the same polarization on the same antenna shall be 120 MHz.

c. Where two frequency channels are handled on separate antennas, or at different polarizations, the frequency separation in (b) above may be reduced by an amount corresponding to the increased loss between the two frequencies, but shall not be less than 50 MHz.

d. The minimum separation between a transmit and receive carrier frequency at a single station shall be 50 MHz, but in any case, an integral multiple of 0.8 MHz.

e. To avoid interference within a single station, separation of the transmit-receive frequencies shall not be near the first IF frequency of the receiver. The minimum separation of transmit or receive carrier frequencies shall be seven units (5.6 MHz) for systems with 36 channels or less. (Table 8-2 shows the recommended separation for a larger number of channels.)

Table 8-2. Transmit (or Receive) Frequency Separations

MAXIMUM NUMBER OF CHANNELS	MAXIMUM IF BAND-WIDTH	FREQUENCY SEPARATION
36 -----------	3 MHz	5.6 MHz
60 -----------	6 MHz	11.2 MHz
120 ----------	10 MHz	16.8 MHz

8.2.3 Frequency Plan

The frequency channels shall be assigned on a hop-by-hop basis such that the median value of an unwanted signal in the receiver, due to using the same or adjacent frequency channels in two relay sections, shall be at least 10 dB below the inherent noise level of the receiver. Figure 8-12 depicts a frequency plan recommended by DCA Cir. 330-175-1.

Within the Navy, responsibility for the procurement, assignment, and protection of radio frequencies is assigned to the Chief of Naval Operations. A frequency allocation must be approved prior to the procurement or installation of any C-E equipment designed to radiate or receive electromagnetic energy. For further information see NAVELEX 0101,106, "Electromagnetic Compatibility and Electromagnetic Radiation Hazards."

Table 8-3 lists the microwave bands available for government services within the United States. Frequency assignments outside of these bands for use in the U. S. requires FCC approval. All frequency assignments for locations outside the United States are assigned by the host country.

A basic computer program which may be used in developing frequency plans is included in Appendix H.

8.3 EQUIPMENT SELECTION CRITERIA

This section provides information to be used for the specification and selection of microwave systems and associated equipments. Table 8-4 summarizes the applicable performance standards for each subsystem and components.

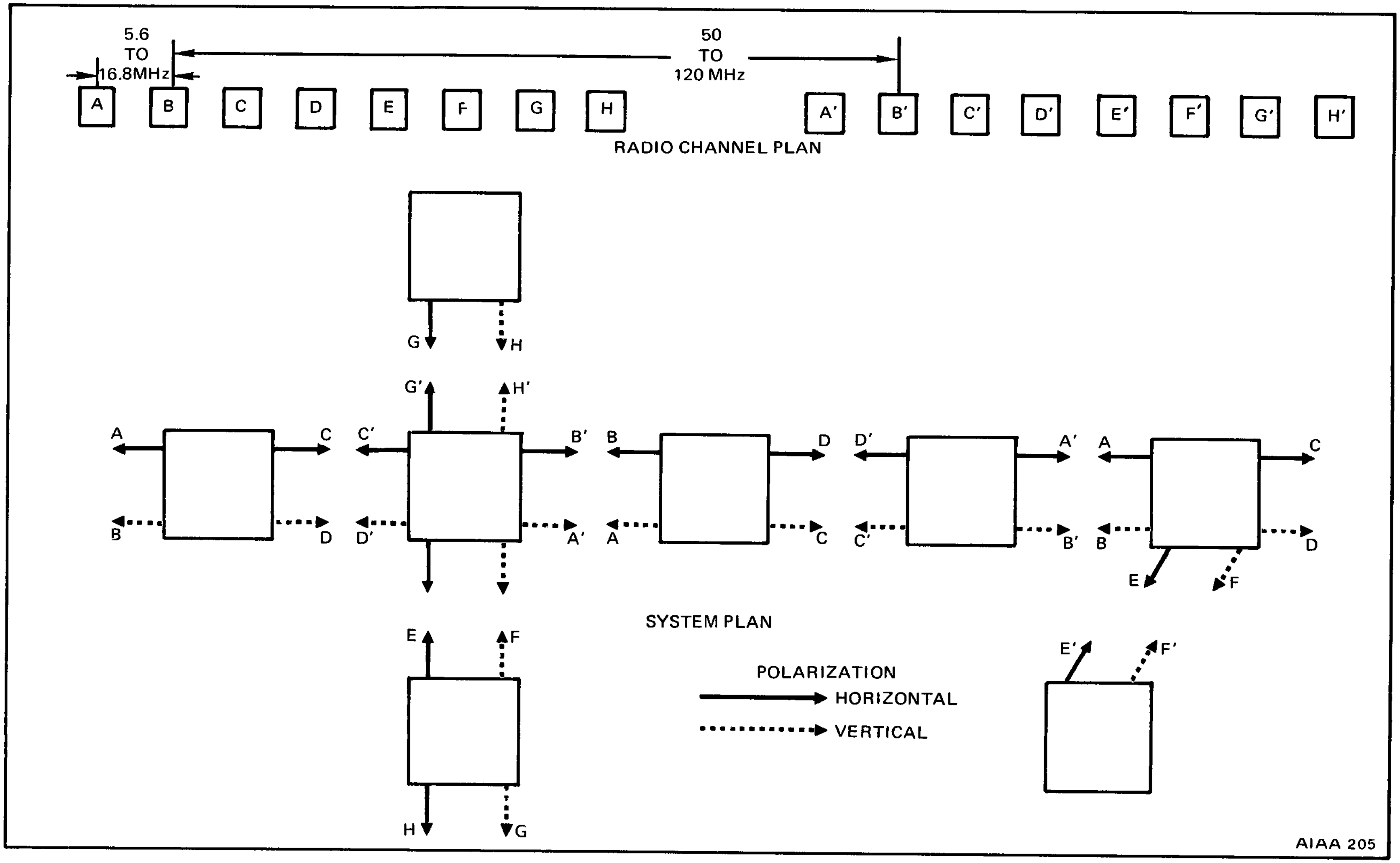


Figure 8-12. Troposcatter Frequency Plan Recommended by DCAC-330-175-1

Table 8-3. Microwave Bands Available for Federal Government Services Within U. S. A.

BAND NAME	RANGE GHz	CENTER FREQ GHz	ATT'N IN dB AT 1.0 MILE
2 GHz	1.71 - 1.85	1.780	101.6
	2.20 - 2.29	2.245	103.6
4 GHz	4.40 - 5.00	4.700	110.0
7-8 GHz	7.125 - 8.40*	7.750	114.4
14 GHz	14.40 - 15.25	14.825	120.0

* 7.25 - 7.30 GHz reserved for Satellite-to-Earth
7.975 - 8.025 GHz reserved for Earth-to-Satellite

8.3.1 Antenna Systems

The antenna systems include:

- Antenna feed
- Antenna reflector
- Transmission lines
- Load isolators
- Antenna tower

The most common antenna utilized in tropospheric scatter systems operating above 1 gigahertz is the parabolic reflector utilizing a horn feed.

Horn feeds are manufactured in both rectangular and circular configurations. The rectangular horn is energized from rectangular waveguide and the circular type from circular waveguide.

Feed devices are linearly polarized in either the vertical or horizontal plane (plane polarization), polarized in both planes (dual polarization), or circularly polarized (rotating). Feed methods for parabolic reflectors are classified as either front or rear feed.

These are illustrated in figure 7-7. For small antenna systems the feed horn is often an integral part of the reflector, but it is usually separate on larger dishes. This feature allows the feed polarization to be altered at installation.

Table 8-4. Specification of Major Items of Equipment

(From CCTM 105-50 Army Manual, 1 June 1965, p. 4-184)

SUBSYSTEM AND COMPONENTS	FUNCTION	KEY PARAMETERS	APPLICABLE SPECIFICATIONS FROM STANDARDS	SPECIFIED BY SYSTEM DESIGNER
Antenna Transmission Lines/Waveguide Duplexer Load Isolators Antenna Horns Antenna Reflector Dehydration & Pressurization Equipment	Waveguides/transmission line transfer composite transmit signal from power amplifier to duplexer and from duplexer to antenna feed horn for radiation; transfer received composite signal from antenna feed horn to duplexer and from duplexer to receiver preamp.	1. Type 2. Characteristic Impedance 3. Gain loss from deflection 4. Beamwidth 5. Polarization separation 6. Front-to-back ratio 7. Gain 8. Side Lobe Level 9. VSWR 10. Power Handling Capability	1. Para 3.2.2.4.6.4.1, 3.2.2.4.6.4.1.4, .6-.10, and -.14 2. Para 3.2.2.4.6.4.1.1 3. Para 3.2.2.4.6.4.1.2 4. Para 3.2.2.4.6.4.1.3 5. Para 3.2.2.4.6.4.1.5 6. Para 3.2.2.4.6.4.1.8 7. Para 3.2.2.4.6.4.1.9 8. Para 3.2.2.4.6.4.1.10 9. Para 3.2.2.4.6.4.1.12 10. Para 3.2.2.4.6.4.1.13	Diversity type - dual or quadruple Diameter of reflector Type of transmission line Spacing for diversity
		<u>Transmission Lines/Waveguide</u> 1. Type 2. Attenuation 3. Characteristics Impedance 4. Pressurization and Leakage Rate 5. VSWR	1. Para 3.2.2.4.6.4.2 2. Para 3.2.2.4.6.4.2.1.1 and 3.2.2.4.6.4.2.2.1 3. Para 3.2.2.4.6.4.2.1.2 4. Para 3.2.2.4.6.4.2.1.3 and 3.2.2.4.6.4.2.2.4 5. Para 3.2.2.4.6.4.2.1.4 and 3.2.2.4.6.4.2.2.5	
		<u>Duplexer</u> 1. Frequency Separation 2. Power Capability 3. Insertion Loss 4. VSWR 5. Load Isolation	1. Para 3.2.2.4.6.4.3.1 2. Para 3.2.2.4.6.4.3.2 3. Para 3.2.2.4.6.4.3.3 4. Para 3.2.2.4.6.4.3.4 5. Para 3.2.2.4.6.4.4	
Transmitter Exciter Intermediate Power Amp. Power Amp	Generate carriers, modulate carrier with composite signal containing the information from each input channel and amplify modulated carrier to required level.	1. Operating frequency 2. Exciter frequency Spacing 3. Exciter Power Output 4. Frequency Tolerance 5. Carrier Frequency stability 6. RF bandwidth 7. RF extraneous and spurious emissions 8. Deviation Ratio 9. Deviation Capability 10. Input and Output Power of Power Amp. 11. Exciter, Power Amplifier Interface impedance & VSWR 12. Residual FM 13. Residual AM 14. RF Frequency Response 15. 2nd Harmonic, Output 16. Exciter - Baseband input impedance 17. Baseband input level 18. Reliability-MTBF 19. Intermodulation 20. Pre-emphasis/deemphasis 21. Receiver-Transmitter Isolation	1. Para 3.2.2.4.5 and 3.2.2.4.6.1.2 of STDS 2. Para 3.2.2.4.5 of STDS 3. Para 3.2.2.4.6.2.3 of STDS 4. Para 3.2.2.4.6.2.1 of STDS 5. Para 3.2.2.4.6.1.5 of STDS 6. Para 3.2.2.4.6.2.11 of STDS 7. Para 3.2.2.4.6.2.2 of STDS 8. Para 3.2.2.4.6.2.4 of STDS 9. Para 3.2.2.4.6.2.5 of STDS 10. Para 3.2.2.4.6.2.6 of STDS 11. Para 3.2.2.4.6.2.8 of STDS 12. Para 3.2.2.4.6.2.7 of STDS 13. Para 3.2.2.4.6.2.10 of STDS 14. Para 3.2.2.4.6.2.12 15. Para 3.2.2.4.6.2.14 16. Para 3.2.2.4.6.2.16 17. Para 3.2.2.4.6.2.17 18. Para 3.2.2.4.6.2.18 19. Para 3.2.2.4.6.1.6 20. Para 3.2.2.4.6.1.7 21. Para 3.2.2.4.6.1.8	Operating Frequency Power Output Radio Frequency Bandwidth Deviation Capability

Table 8-4. Specification of Major Items of Equipment (Continued)

(From CCTM 105-50 Army Manual, 1 June 1965, p. 4-185)

Receiver Low Noise Preamp Mixer IF Amplifier Combiner FM Demodulator	Detect transmitted signals, amplify them to prescribed level, separate and recover composite information signal through demodulation.	1. Front End Noise Figure 2. Frequency Tolerance 3. Spurious Receiver Response & Image Rejection 4. FM Threshold 5. Receiver Noise Threshold 6. IF Center frequency 7. IF Bandwidth 8. Threshold Extension 9. Diversity Combiner 10. Automatic Gain Control 11. Baseband Frequency Response 12. Baseband Output Level 13. Reliability-MTBF	1. Para 3.2.2.4.6.3.1 2. Para 3.2.2.4.6.3.2 3. Para 3.2.2.4.6.3.3 4. Para 3.2.2.4.6.3.4 5. Para 3.2.2.4.6.3.5 6. Para 3.2.2.4.6.3.6 7. Para 3.2.2.4.6.3.7 8. Para 3.2.2.4.6.3.8 9. Para 3.2.2.4.6.3.9 10. Para 3.2.2.4.6.3.10 11. Para 3.2.2.4.6.1.4 12. Para 3.2.2.4.6.3.11 13. Para 3.2.2.4.6.3.12	Bandwidth Type of Receiver Front end and Noise Figure
Multiplex Baseband Amplifiers Group-through Filters Group-modems Group Patch Board Group Distributing Frames Super Group Modems Multiplex Frequency Generator	Accept voice, telegraph and/or data channel outputs from terminal sub-system; heterodyne and amplify signals to provide composite, wide-band frequency-division signal to transmitter for carrier modulation. Accept received composite wideband frequency-division signal from re-ceiver; separate and demodulate voice, telegraph and/or data channel signals comprising com-posite signal; amplify and provide channel information in original form for reproduction or trans-mission to user by termination sub-system.	1. Input and output im-pedance, levels and frequencies. 2. Noise and Interference. 3. Envelope Delay Dis-tortion. 4. Total Noise. 5. Harmonic Distortion 6. Stability of multiple frequency generator. 7. Net Loss Variation 8. Gain Change for output level increase. 9. Maximum Overall Change.	1. Table 3-2.2.4.1.2 of STDS. 2. Para 3.2.2.4.2.2 3. Para 3.2.2.4.1.1.2 4. Para 3.2.2.4.1.1.3 5. Para 3.2.2.4.1.1.4 6. Para 3.2.2.4.1.1.9 7. Para 3.2.2.4.1.1.6 8. Para 3.2.2.4.1.1.5	Number and arrangement of channels, groups and supergroups.
Termination Circuit Condition Monitoring Facilities VU meters and other level indicators Distortion measuring equipment Patching facilities Distributing frames Filters and channel termination sets Signalling equipment Control monitoring equipment; i.e., fault alarm and auto-matic switching equipment	Interface control between and within multiplex subsystem and users line.	1. Input and output im-pedances, levels and frequencies. 2. Noise.	1. Para 3.2.2.4.1.2 of STDS. 2. Para 3.2.2.4.2.2	As required.
Power Generator Generators Switchgear Distribution Equipment Starting Equipment	Supply primary ac power for all technical electrical and elec-tronic equipment and for all non-technical site requirements. Supply auxiliary power to technical load and various elements of non-technical load.	1. Frequency regulation. 2. Voltage regulation. 3. Total load.	1. Para 3.5.1	Total primary power
Environmental Control Heating and air conditioning Humidifiers and de-humidifiers Ventilation Air Filtering	Maintain proper environment - temperature, humidity etc. - for equipment.	1. Temperature 2. Humidity 3. Pressure	1. Para 3.6.3	As required

Parabolic reflectors for the antenna systems vary from 10 to 120 feet in diameter. The usual size is 10 to 30 feet with 60 and 120 foot units limited to extremely long and difficult paths. The beam-width is dependent upon the diameter and the transmitting frequency and varies from about 1.6 degrees for the larger ones. Radomes and heaters are not usually utilized on these larger antennas except in areas of extreme wind, snow or ice loading where distortion of the reflector (or tower) could substantially reduce the reliability of the path.

Tower construction and marking is detailed in chapter 15, in the Electronic Industries Association Standard RS-222A, and in Part 17 of the Rules and Regulations of the Federal Communications System.

Transmission lines between the transmitters and receiver and their associated antenna feeds are usually waveguides. Three types are available for use in microwave systems: standard rectangular, elliptical, and circular. A typical installation using these types of waveguides illustrating the various types of components is shown in figure 7-14. Table 8-1 lists the parameters of standard rigid rectangular waveguide. The use of flexible waveguide must be limited to only those areas where it is necessary and only short length should be considered due to the high attenuation.

For installations that utilize primary and standby microwave equipment, waveguide switches are used to connect either the primary or the standby equipment to the antenna, and to properly terminate the output of the unused equipment. Waveguide switches are usually electrically operated to provide for automatic switching applications.

A ferrite load isolator provides isolation between a signal source and its load with a resulting increase in power and improved frequency stability. The ferrite device accomplishes these results by reducing the standing wave ratio in the transmission line linking the signal source to the load. By placing the load isolator in the RF oscillator and receiver input circuits, the RF oscillator is effectively isolated from the two branches of the tee.

When it is necessary to couple two or three microwave equipments to a single antenna waveguide circulator is utilized. This device, illustrated in figure 7-16, is similar to a duplexer. With an antenna connected to one arm and three microwave equipments connected to the other arms, or two equipments and shorting plate connected to the other arms, the following apply:

Attenuation from arms 1 to 2, 2 to 3, 3 to 4, and 4 to 1 is approximately 0.5 dB in each instance.

Attenuation between other combinations of arms is on the order of 20 dB.

Installations of rigid line are pressurized and dehydrated to eliminate chances of moisture accumulation and resulting changes in impedance or short circuits within the run. Dehydration is extremely important in runs subject to temperature changes due to either climatic conditions or indoors/outdoors runs. Dehydration will be accomplished with an automatic compressor/dehydrator unit.

8.3.2 Radio Equipment

The radio equipment used in Tropospheric scatter is very similar to that described in chapter 7. The major differences are:

The receiver utilizes a low noise front end or preamplifier. Usually a parametric amplifier and/or a Tunnel Diode amplifier is used.

The transmitter utilizes a high power klystron amplifier to boost the transmitted power from 1 to 50 kilowatts or more.

8.3.3 Alarm Functions

Alarm functions similar to those used in line-of-sight systems are usually included in Tropo installations to allow rapid fault determination even through tropo installations are rarely unattended.

8.3.4 Multiplexing and Terminating Equipment

The system operation and performance will dictate the type, quantity and configuration of the multiples equipment used. If the system contains predominately one-way channels and no requirement exists for expansion of the return channel, do not provide these channels or limit the selection to equipment with common channel modems. Likewise, it should appear obvious that at a multi-direction terminal, complete multiplex terminal equipment for each direction of transmission should not be provided. Rather in this case, a common bay of equipment (correctly arranged with redundant amplifiers, power supplies and carrier oscillators) will be provided with separate banks of channelizing or grouping equipment for each path. Similarly at a location where there is no need for channel drops and a spur link may be provided, the correct design approach is to arrange the channelization and equipment for demodulating to the supergroup or group and pass through the station in the desired direction in this manner. The advantages gained by this procedure are economy and elimination of the noise that would be introduced in the modulation/demodulation process in the channel modems.

The multiplex equipment must be configured for the use of audio pads (usually 16 and 7 dB) external to the multiplex channel level adjustments to permit setting all circuits to the specified level at the "Zero Transmission Level Point." The need for synchronization, equalization, regulation and pilot tone interface also regulates the choices available for equipment configuration.

8.3.5 Standby Equipment

A high degree of reliability can be obtained in a microwave system when "standby" equipment is used to supplement the primary equipment. However, standby equipment should only be specified for stations where the greatest benefit will be realized, for example, an isolated station difficult to reach under adverse conditions. Automatic switching equipment (as mentioned previously) is available to place the standby equipment operation if primary equipment fails. The use of standby equipment is minimal at Tropo scatter sites. Multiple equipments are utilized in the quadruple diversity normally used in most links. Failure of one piece of equipment only reduces the degree of diversity and not necessarily the performance over a limited period of time (unless it occurs during a time of high fading). This allows corrective maintenance without interruption of service.

8.3.6 Spare Parts

During the course of preventive maintenance inspections, it will be noted from time to time that the performance of some components has deteriorated. Rather than wait for the component to become weaker or to fail completely and cause system interruptions, it is considered good maintenance practice to replace such weak components during the inspection. Although components are replaced before their full service life has been realized, service interruptions can be avoided in this manner. This practice will, in turn, increase the expected replacement parts cost for an operating system; however, the increase is justified on the basis of increased system reliability and the saving of additional manpower costs that would be incurred in making special rush trips to unattended stations to restore station operation.

Based on the known degree of component reliability of current installations, and considering a preventive maintenance program such as that described above, it can be expected that in a year's time a microwave system will require replacement parts equal in cost from 1 to 2 percent of the initial cost of the equipment, and replacement tubes equal in quantity from 25 to 30 percent of the total number of operating tubes. The tube replacement ratio, as noted above, is considerably higher than the part replacement ratio. This is generally to be expected because tubes have a higher failure incidence rate; and also, the relative performance of operating tubes is more easily checked than the relative performance of other components, so that more frequent tube replacements naturally result.

8.3.7 Test Equipment

In order to properly test and service a microwave communications system, maintenance personnel should have a thorough understanding of the equipment's physical make-up, operational characteristics, capabilities, and limitations, and should be familiar with the circuit theory of operation. It is equally important that the proper test equipment be available for utilization by these personnel. Each field maintenance man should be equipped for making routine measurements. Typical equipments recommended for this purpose include a microwave test set, an IF/MF test set, a multimeter, and an oscilloscope; these units must be compatible with the microwave system in which they are used. As the area of maintenance progresses from on-site field maintenance, the quantity and requirements of the test equipment to perform the maintenance procedures will increase.

A list of test equipment for use in the alignment and adjustment of a typical microwave communications system is given in table 7-9. This list is for use with systems employing microwave equipment and time-division multiplex equipment. It includes the type of test equipment necessary, and the required characteristics of this equipment. Those pieces of equipment which are applicable for general field maintenance are indicated with an asterisk (*).

Table 7-10 lists the test equipment required for laboratory (depot maintenance) measurements for a typical microwave system employing microwave equipment and time-division multiplex equipment. The item numbers under the EQUIPMENT NEEDED heading refer to the test equipment itemized in table 7-9.

8.3.8 Maintenance Tools

It is important that maintenance personnel have a thorough understanding of the equipment utilized in the system, and that they have the proper test equipment to perform the required maintenance checks. In addition to the above, the maintenance personnel must have the proper tools to efficiently repair the malfunctioning equipment when the defects are located. Of course, the maintenance man should know how to properly use the tools required for maintenance.

Table 7-11 lists the quantity and type of tools generally included in a tool kit required by a field serviceman to properly maintain a microwave communications system. In addition to these tools, the special tools indicated in the equipment manuals should be included.

Table 7-12 lists the type of tools required at a typical microwave station. The quantity of these tools will depend on the amount and type of equipment installed. The special tools indicated in the equipment manuls should also be included. Where the maintenance schedules require work on gasoline engine-operators, shelters, towers, etc., additional tools may be required, depending upon the type of equipment and hardware involved.

The tools required at a microwave system centralized maintenance depot are essentially the same as those required at a microwave station. However, the quantity of these tools will depend on the number of maintenance personnel assigned to the depot, the work load at the depot, and the type and quantity of equipment utilized in the system. In addition, special equipment such as a spray-painting equipment, a drill press, and other shop equipment may be required at the depot to facilitate the overhaul of the electronics and electrical equipment.

CHAPTER 9

MICROWAVE STATION CONFIGURATIONS

This chapter describes typical microwave (LOS and Tropo) station configurations.

9.1 SIMPLEX AND DUPLEX RELAY SYSTEMS

In the radio relay systems under consideration, microwave transmitters and receivers are used to relay multiplex signals from point to point. A simplex relay system provides one-way communication; it consists of a transmitting terminal, a number of repeaters (employing a receiver and a transmitter), and a receiving terminal (figure 9-1A). A duplex relay system provides two-way communication by using two simplex systems, one transmitting in one direction and the other transmitting in the opposite direction (figure 9-1B). The duplex system is further refined by using a single antenna for transmitting and receiving. This is accomplished by using different transmitting and receiving frequencies and by employing a duplexer in the transmission line. Under these conditions the transmitting and receiving functions can operate simultaneously.

9.1.1 LOS Equipment

A typical Tropospheric Scatter microwave communications link operating at microwave frequencies currently in use (approximately 1 gigahertz to 12 gigahertz) is subjected to large propagation losses. To overcome these losses and have a system with the required reliability, the effective transmitted power must be increased, the receiver sensitivity increased, and the fade margin decreased over that used in LOS transmission. (AFC) circuit is used to stabilize the carrier center frequency. A typical receiver is a superheterodyne type with an intermediate frequency between 30 and 90 MHz. The local oscillator is usually a klystron tube, with an associated AFC circuit to stabilize its frequency. The intermediate frequency is demodulated to obtain the multiplex signal, which is applied to associated de-multiplexing equipment. The receiver is often combined with the transmitter in a single rack or cabinet.

9.1.2 Tropospheric Scatter Equipment

A typical Tropospheric Scatter microwave communications link operating at microwave frequencies currently in use (approximately 1 gighertz to 12 gighertz) is subjected to large propagation losses. To overcome these losses and have a system with the required reliability, the effective transmitted power must be increased, the receiver sensitivity increased, and the fade margin decreased over that used in LOS transmission.

High gain directional antennas usually from ten to sixty feet in diameter are used. These usually have beam widths of from 0.3 to 1.6 degrees. The transmitter-exciter usually has an output power level of approximately two watts and drives a

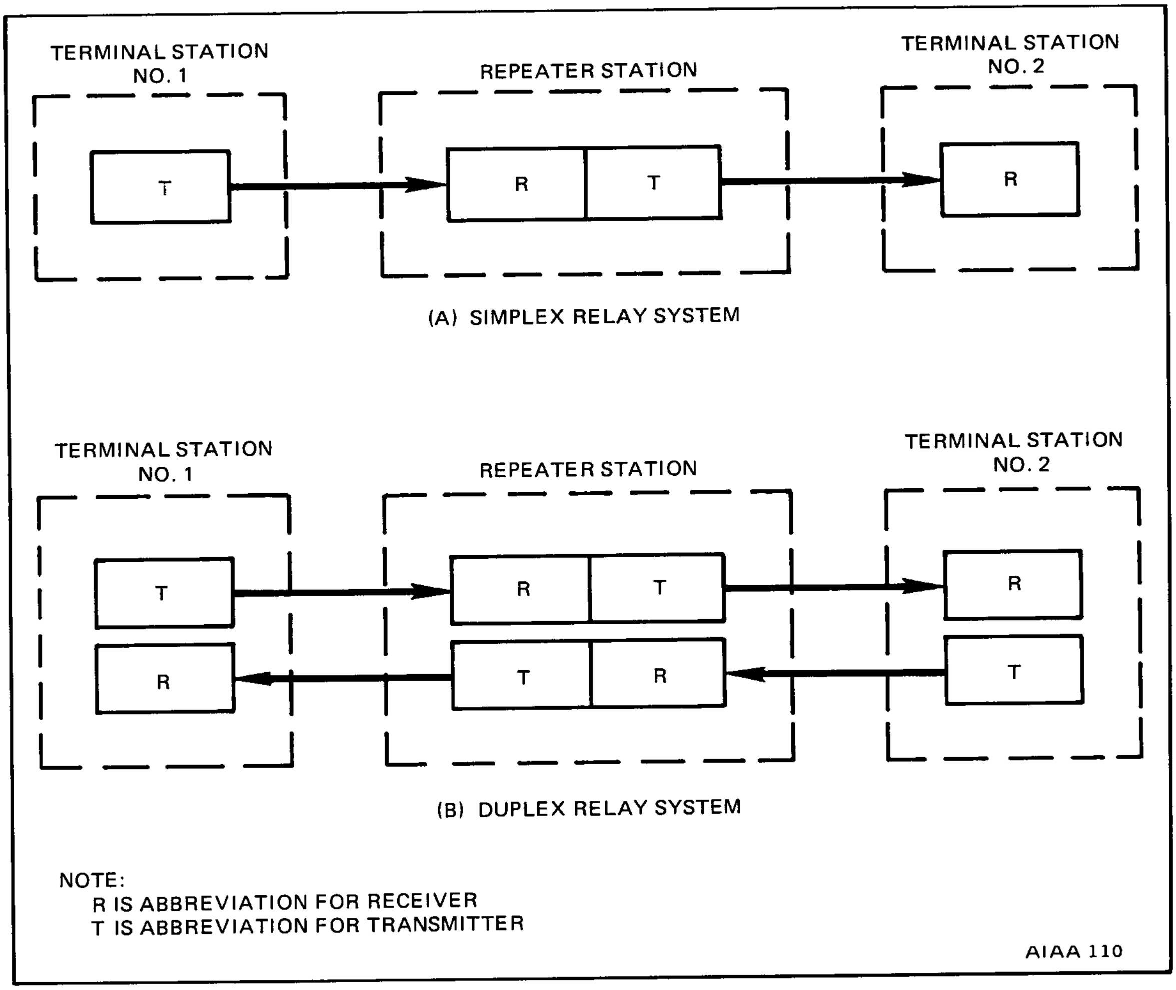


Figure 9-1. Basic Radio Relay System, Block Diagram

power amplifier. Low power, power amplifiers are rated at 1 and 10 kilowatts, and high power, power amplifiers at 50 or more kilowatts. These power amplifiers usually utilize klystrons.

To achieve the high sensitivity required of the receivers, low noise figure pre-amplifiers are used. These consist of parametric and tunnel diode amplifiers or tunnel diode amplifiers. A description of these devices is given in chapter 10.

The 38 (or 40) dB fade margin usually used in LOS transmission hops are prohibitive in tropospheric scatter links and must be reduced. This is done by using at least dual and more usually quadruple diversity which requires a fade margin of 18 dB for dual or 8 dB for quadruple diversity systems without sacrificing signal reliability.

A high degree of reliability can be obtained in a microwave system when standby equipment is used to supplement the primary microwave equipment. Although it is highly desirable to provide standby equipment at all stations in the system, such a practice may not be economically feasible. In this case, microwave equipment should be specified for those stations where the greatest benefit will be realized. Normally redundant equipment such as exciters, power amplifiers and receivers are not provided at troposcatter sites. Equipments that would be on standby as spares are utilized on-line to provide the required signal diversity. Failure of one of the equipments results only in the loss of part of the diversity improvement. For example, when one of the dual transmitter exciters fails in a quadruple diversity path, the operating mode of the distant receiver becomes dual space diversity instead of quadruple frequency and space diversity. When one of the four receivers is out of service, the operating model is reduced from fourth to third order diversity.

While present day tropospheric scatter radio communications systems seldom include completely unattended repeaters, radio subsystem fault alarms similar to those described in chapter 13 are usually installed. These visual and aural alarm systems provide designated monitor and control stations within the system, an automatic indication of major and minor faults at satellite stations. If unattended tropospheric repeaters are included in a system, a fault alarm system must be provided and must include in addition to radio fault alarms, fault alarms from accessory equipments, power sources, tower lighting, and other fault circuits deemed critical to that system.

9.2 STATION REQUIREMENTS

9.2.1 Terminal Station Requirements

The microwave equipment requirements of a basic terminal station are relatively simple. A transmitter and a receiver, often contained in a single equipment rack, are the basic requirements for the more common duplex relay system terminal station.

9.2.2 Repeater Station Requirements

Before stating the requirements of a basic repeater station, it may be advisable to consider the various means available for handling the signal at the repeater station.

Four types of repeater operation are logical, but only two are in common use. The simplest type of repeater is a straight-through repeater, in which the signal from the receiving antenna is amplified and applied directly to the transmitting antenna. This type of repeater is not used at microwave frequencies for two reasons: (1) noise-free amplifiers are not generally available for the frequencies used in microwave communications; (2) it is desirable to change the transmission frequency to prevent RF interference along the route, but this cannot be done with such a repeater.

An improved type of repeater uses the heterodyne principle. In this type of repeater, the received signal is heterodyned to an intermediate frequency which can be amplified efficiently, and a second mixer is used to raise the frequency to the desired microwave carrier frequency. This signal is amplified and transmitted. Although this method permits changes in transmission frequencies along the route, it is not always a suitable method because the final mixing and amplifying stages require mixers and microwave amplifiers.

The most commonly used method is to use a complete superheterodyne receiver and obtain the multiplex signal by demodulating the intermediate frequency. The multiplex signal can then be re-transmitted as it was in the terminal station. In addition, multiplex signals can be dropped or inserted at the repeater station by means of multiplex equipment. This flexibility in message handling is highly desirable and practical.

The final method is to receive and demultiplex all signals so that voice frequencies are obtained. These voice signals are patched to multiplex equipment which feeds a transmitter which retransmits the microwave signal. This method is more flexible than the third method, but it is also more expensive because it requires more multiplex and termination equipment. Therefore, this latter method is used mostly in special situations where the additional flexibility is most useful.

From the foregoing, it can be seen that the basic repeater station requires two complete microwave equipments, each containing a transmitter and a receiver, if duplex (two-way) communication is desired. A special type of repeater which uses only one RF oscillator for both transmitting and receiving is commonly used today for cost effectiveness. In this repeater, a small portion of the klystron output is used to provide the local oscillator function in the receiver, and the remainder of the output fulfills the transmitting function. A necessary requisite is that the received frequency differ from the retransmitted frequency by an amount equal to the receiver intermediate frequency. This imposes some restrictions on frequency allocation throughout the system but this is not a serious limitation.

9.2.3 Requirements of Primary Microwave Equipment

The most important considerations in the selection of specific microwave equipment are those dealing with RF matters and those concerning compatibility with multiplex equipment. In the RF category, the operating frequency range, frequency stability, power output, and receiver sensitivity are prime considerations. Equipment is readily available for operation in each of the standard microwave communication bands. Operation in a particular band can usually be obtained by selecting the appropriate RF panel or the appropriate klystron oscillator for placement in a standard microwave equipment rack. Also, it is possible to select either a complete equipment or an arrangement of panels in an equipment that will satisfy the requirements of either a terminal station or a repeater station. The RF power output and receiver sensitivity must be adequate to meet or surpass the requirements established in chapter 7. (The size of the paraboloidal antennas used with the equipment is determined by these characteristics of the equipment.) Frequency stability, obtained by means of an AFC system, must meet FCC regulations of ±0.05 percent. (The DCA requirements are $\pm 1 \times 10^{-6}$ for tropo systems and ±150 kHz for LOS systems.)

Concerning compatibility with multiplex equipment, consideration of RF bandwidth and multiplex signal levels are most important. The multiplex signal can be likened to the video signal of a TV system; because of the complexity of these signals, a relatively wide RF band is required to transmit them. Since bandwidth is a function of signal complexity, there is a practical limit to the amount of information, in multiplex signal form, that can be transmitted by a single microwave equipment. Of course, the type and design of the multiplex equipment enters into the problem, since this equipment affects the composition of the multiplex signal. Standards have been established within the communications industry so that economical microwave equipment can be designed to meet most signal-handling applications. The matter of matching signal levels, from multiplex equipment to microwave equipment, must also be considered, but this problem is minimized by standard design practices and/or by amplifier or attenuator design in one or both of the equipments.

Equipment manufacturers incorporate numerous features in their equipment to improve the performance and reliability of their product. Such features must be weighed in the light of system requirements. Other factors, such as ease of operation and ease of maintenance, are additional considerations of some importance.

9.2.4 Requirements of Standby Microwave Equipment

A high degree of system reliability can be obtained when standby microwave equipment is used to supplement the primary equipment. Although it is highly desirable to provide standby equipment at all stations in the system, such a practice may not be economically feasible. If this is the case, standby equipment should be specified for those stations where the greatest benefit will be realized. For example, an isolated station that is difficult to reach under adverse weather conditions should rate a higher priority than an attended station. (Automatic switching equipment is available to place the standby equipment in operation if the primary equipment fails.)

9.3 DIVERSITY METHODS

When fading is within narrow limits, and equally affects all frequencies in the transmission bandwidth, an automatic volume control (AVC) in the receiver is helpful in minimizing its affects. But when the fade is of such magnitude that the signal level falls to the noise level or below, AVC increases the receiver sensitivity as before, but cannot increase the signal-to-noise ratio. When such fading occurs, there is one technique which has proven effective in maintaining a suitable signal-to-noise ratio. It consists of using two or more "copies" of the desired signal, separated in time, in frequency, in phase, in polarization, or in spatial derivation, and is called diversity reception.

It has been shown that two or more radio channels sufficiently separated in frequency, space, polarization, time, or angle of arrival exhibit independent short term fading characteristics. Diversity systems make use of this fact to improve the overall performance by combining or selecting radio channels on a single circuit. The

Rayleigh Distribution in figure 9-2 is taken as the limiting value of single channel (no diversity) short term fading on a troposcatter path.

The fading phenomenon varies with both time and frequency, and it has been found that fading is not correlated at points separated by about 10 wavelengths or more at the transmission frequency. Since it is due to a random variation in path-length, the phase variation between two or more copies of the signal is also random. Finally, radio waves reflected from the ionosphere contain energy components which have been shifted in polarization, so at the receiving antenna there are both horizontally and vertically polarized signal "copies." Diversity may be designated as time, space, frequency, phase, or polarization diversity, depending on the method by which the signal replicas are obtained.

9.3.1 Time or Phase Diversity

Time diversity is the transmission of a signal more than once, either on an element-by-element or on a complete-message basis. At the receive site, the replicated transmissions are compared and combined to recover the total signal information. Time or phase diversity utilizes only one antenna and one receiver but requires complex circuitry to extract the optimum signal. Consequently, this type of diversity is seldom used in operational communications circuits.

9.3.2 Frequency Diversity

Frequency diversity requires signal transmission simultaneously on two or more frequencies. The frequencies may be separated so as to require a receiver for each transmitted frequency, or the frequency separation may be that between tones of a frequency division multiplexed (FDM) signal transmitted on a single carrier. In its simplest form, frequency diversity is obtained in the modulated carrier wave (MCW) keying method. The signal contains essentially three frequencies, the carrier (f_c), f_c plus 500 Hz, and f_c minus 500 Hz, all being interrupted by the same keying sequence. The likelihood of all three frequencies fading simultaneously is quite remote, so that one or more copies of the intelligence are always present.

Figure 7-3 shows the approximate improvement that can be achieved by using frequency diversity with various frequency separations. In practice, it is usually not feasible to have more than a 2 or 3 percent separation since the frequency band allocated to a particular service is limited.

9.3.3 Space Diversity

Space diversity requires the use of two or more antennas separated at least 70 wavelengths, but preferably 100 wavelengths. This separation must be perpendicular (horizontally or vertically) to the direction of propagation. Each antenna has its own receiver and the outputs are combined to provide the most reliable signal.

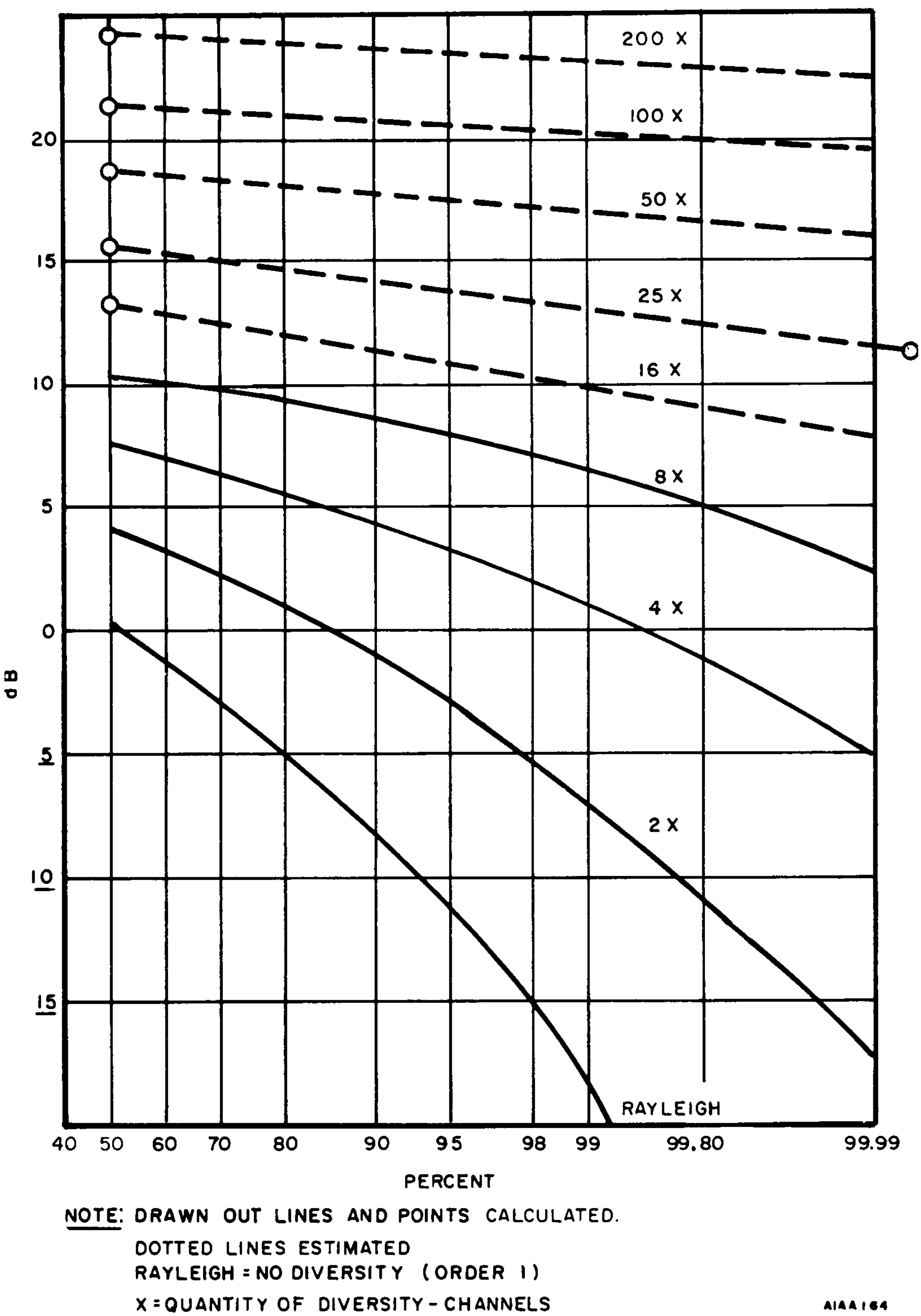


Figure 9-2. Theoretical Signal Distribution for Diversity in dB Diversity Relative to Median on one Antenna Versus Percentage of Time During Which Level ≥ Ordinate for Various Orders of Diversity

9.3.4 Polarization Diversity

Polarization diversity utilizes horizontally and vertically polarized antennas or antenna with dual polarization. The performance of this type of diversity is equivalent to space polarization.

9.3.5 Angle of Arrival Diversity

Angle of arrival diversity has been demonstrated experimentally. It employs a number of feeds to the transmitting antenna diverse in angle so the transmitted beam contains components at several angles. These are separated at the receiver and the resultant diversity effect is used to extract the optimum signal.

9.3.6 Hybrid Diversity

Hybrid diversity consists of standard frequency diversity path, in which the two transmitter-receiver pairs at one end of the path are separated from each other and connected to separate antennas which are located as in space diversity.

This arrangement provides a space diversity effect in both directions. In one direction the receivers are in space diversity and in the other direction, the transmitters are in space diversity. This arrangement combines the operational advantages of frequency diversity and space diversity.

9.3.7 Multiple Diversity

It is impossible to design a tropospheric scatter radio system complying to the Defense Communications System standards of performance and reliability without the use of diversity operation. Therefore, one of the major considerations facing the system designer is the equipment configuration to be used for diversity operation.

Quadruple diversity is normally used in tropospheric scatter systems. All forms of quadruple diversity used today require antennas with dual (or cross polarized) feed systems to permit transmit/receive isolation and the reception of four uncorrelated RF paths. Feed horns can be an integral part of the antenna or as completely separate structures as is done on the larger types. The type to be used is primarily dictated by the system antenna gain requirements. Figures 9-3 and 9-4 are examples of the two most commonly used quadruple diversity configurations. Both include maximal ratio combining.

The diversity arrangement shown in figure 9-3 uses the antenna feed horn isolation to completely separate the high power and low power (transmitting and receiving) equipment. The arrangement utilizes four receivers in space and frequency diversity on the same polarization at one end. The opposite terminal uses orthogonal polarization. Transmitters are connected to the same polarization of each of two antennas and transmit-to-receive isolation is dependent upon the isolation achieved in the feedhorn. Additional protection is provided in the form of filtering in the receive lines

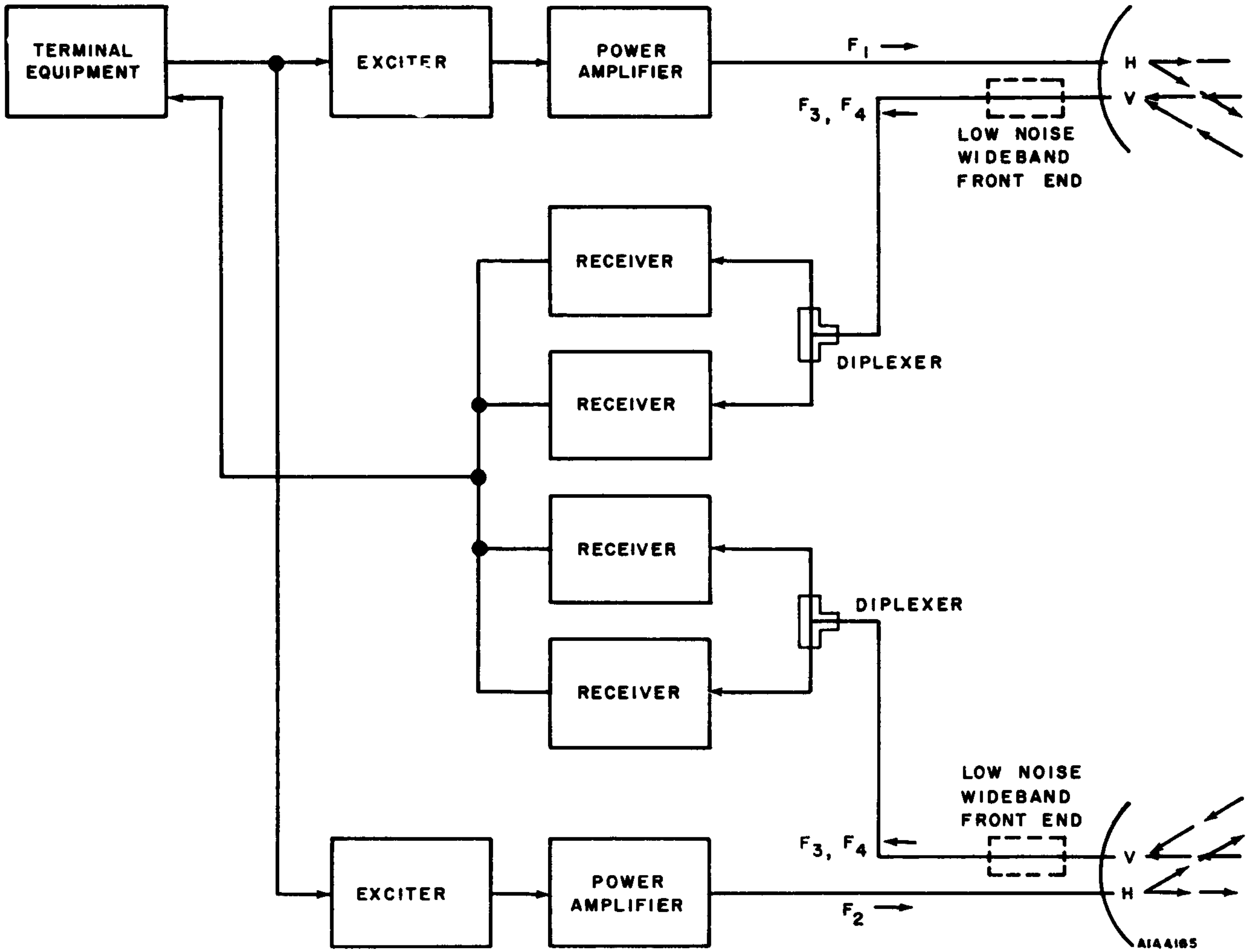


Figure 9-3. Quadruple Diversity Configuration, Receivers Diplexed

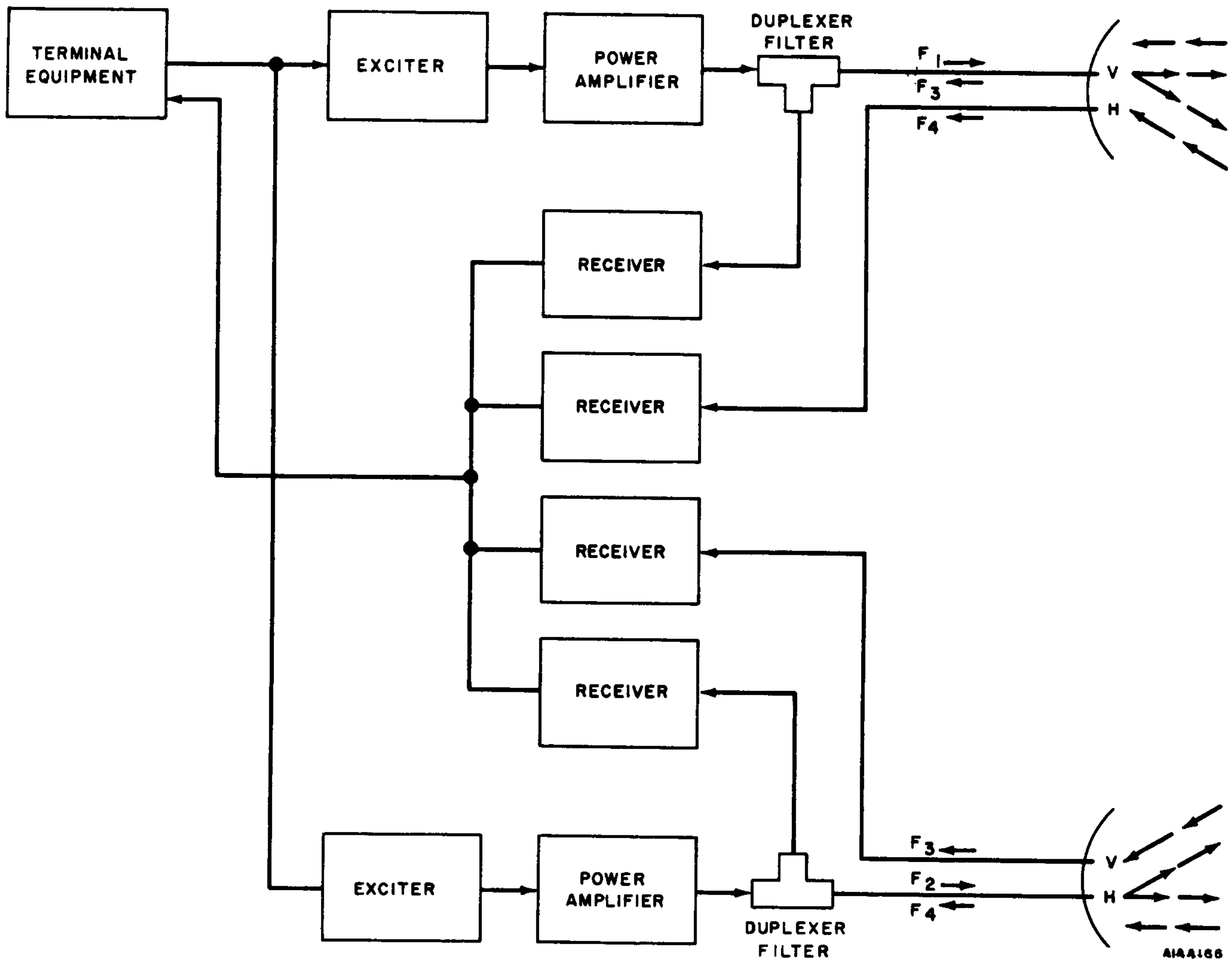


Figure 9-4. Quadruple Diversity Configuration, Two Receivers Duplexed

when sensitive low noise front ends are required and higher powered transmitters are used. Additional preselection and filtering is achieved in using tuned diplexers at the receiving elements.

Low noise front ends may be required to meet the system requirements. Maximum benefit is achieved by placing these parametric and/or tunnel diode amplifiers at or as near the antenna as practical to overcome the transmission line losses as indicated in figure 9-3. The low noise front end must be a wideband unit to receive both frequencies prior to splitting at the receive diplexer. The advantages are:

- o High power diplexing (duplexing and filtering not required).
- o Lowest system noise figure consistent with frequency.
- o Minimum length of transmission line.
- o Receive filtering and diplexing combined.

The disadvantages are:

- o The wideband low noise device and filtering limit the frequency spread and present design difficulties.
- o The failure of the low noise device disables two receivers.
- o Transmission in each direction is limited to different polarizations.
- o Maintenance and test of the antenna mounted low noise preamplifier is difficult.

Figure 9-4 presents an alternative configuration which permits quadruple diversity operation. Each transmitter feeds its own antenna at different polarizations and frequencies. Two receivers are duplexed to the transmitters and two are connected directly to the antenna operating on orthogonal polarizations. Unlike the configuration shown in figure 9-3, low noise devices are not usually placed at the antenna in this arrangement because of the difficulty of protecting the low noise device against the high transmitted power on the duplexed line. Individual devices are placed at the receiver proper after the necessary preselection/isolation filtering. Any degree of diversity is easily achieved, since there are no devices common to all four receivers. Spurious suppression and transmit isolation are achieved by low-pass and harmonic filters in the transmit line and the duplexer and feed horn in the receive line. The advantages to this configuration are:

- o The configuration lends itself to any form or degree of diversity.
- o All equipment is available for test and maintenance.

- o All transmission line components are readily available.

The disadvantages are:

- o The complexity of the duplexer increases with the transmitted power.

- o The lowest noise figure is not always achieved due to the placement of the parametric amplifier/tunnel diode amplifier between the receiver and the preselector/diplexer.

CHAPTER 10

MICROWAVE RADIO EQUIPMENT

It is obvious from the preceding discussions that there is a very close interrelationship between the characteristics of the various items of the equipment to be used, and the engineering choices and performance parameters of the paths themselves.

Thus it is desirable, in fact almost essential, that the path survey engineers have enough advance knowledge of the frequency bands to be considered (often only one, but in some cases more than one), the kind of service, the number of channels (both present and future) to be accommodated by the system, the kind of performance and reliability criteria desired, and the pertinent parameters of the microwave equipment to be used (for example, transmitter output power, receiver noise figure and bandwidth, per channel deviation, et cetera), to allow an intelligent approach to the problem of path engineering. Many choices are involved in path selection, and choices made without a thorough knowledge of all the pertinent circumstances may not be the best ones.

Microwave systems can range from as little as 5 or 10 miles to distances as long as 4000 miles. Facility requirements can be relatively small, requiring structures and equipment for only a light route, or they may be very heavy, requiring multi-channel, heavy route layout with sophisticated switching. They can be constructed for nominally good service during certain limited hours of the day with considerable economy, or they can be built for a very high quality of service on a 24 hour a day, year-in and year-out basis.

Some systems are of a "through" type, with all or almost all of the channels going end-to-end, while others require multiple access, with dropping and inserting of channels at most, if not all, repeater points.

The two types of FM microwave equipment in common use are the IF heterodyne type and the baseband (remodulating) type. The IF heterodyne type, by eliminating demodulation and remodulation steps at repeaters, contributes the least amount of distortion, and is the preferred choice for systems handling exclusively, or almost exclusively, long-haul traffic, with little or no requirement for drop and insert along the route. The heterodyne type is also preferable for systems carrying color TV, if more than a few hops are involved. Equipment of the baseband type is widely used for short haul or for distributive systems. The great flexibility for drop and insert, plus maintenance advantages, are the determining factors. Heterodyne systems are inherently at a considerable disadvantage in such applications.

Apart from the choice between heterodyne or baseband equipments, primary considerations in the selection of the best radio equipment for a particular system include:

(a) characteristic of the end-to-end baseband facility (including bandwidth, frequency response, loading capability, noise figure, and noise performance); (b) the amount of radio gain available, as determined by transmitter power output and receiver noise characteristic; (c) operating frequency band, and required frequency spacing between radio channels, as determined by transmitter deviation, receiver selectivity and frequency stability; (d) primary power requirements and options available; (e) supervisory functions available, including order wire, alarms and controls; (f) equipment reliability, including availability of redundant versions such as frequency diversity, 1-for-N or 2-for-N multiline switching, hot standby, or hot standby at transmitters and space diversity at receivers; and (g) provisions for testing and maintenance.

With the rapidly changing nature of the state-of-the-art, and the continuing development of new equipments and upgrading of old ones, specific data on microwave equipment characteristics can become outdated in very short order. Consequently, the foregoing should be viewed in that light.

10.1 RECEIVER

The receiver consists basically of RF amplifiers, local oscillators, IF amplifiers, detectors, and video or audio amplifiers, along with gain and frequency control circuits. This chapter discusses the characteristics of terminal receivers used in microwave relay systems and the principles by which they operate.

At frequencies ranging from 600 - 13,000 MHz a variety of differences in receiving conditions are found as compared to lower frequencies. The fluctuation noise of tubes and circuits in the receiver becomes greater than external noises, such as atmospheric disturbances and man-made interference. Therefore, receiver noise is one of the chief limitations of receiver sensitivity at such frequencies. The necessity of handling greater receiver bandwidths is also of great importance, both for determining the maximum rate at which information can be received and as a controlling factor of the total noise encountered. These greater bandwidths will increase the effective noise power originating in the resistors and tubes of the receiver as well as the received external noise.

10.1.1 Low Noise Preamplifier

There are few election tubes that will operate satisfactorily at 1 KMHz and above as RF amplifiers. Therefore, the use of RF pre-selection and a crystal mixer has been commonly used. The RF pre-selector is a tunable filter with low insertion loss to the operating frequency and high loss at undesired frequencies.

The limiting factor in the operation of RF amplifiers, especially at frequencies above 300 MHz, is the noise generated by the amplifier. Consequently, in certain applications (such as tropospheric systems) low noise devices such as parametric amplifiers have been used as RF amplifiers. Since the significant part of the noise generated in a cascaded operation is contributed by the first several stages, the use of such low noise devices is equivalent to improving receiver sensitivity thus permitting detection of extremely weak signals.

Probably the only significant parameters affecting RF-amplifier performance are noise figure and gain. Throughout this chapter all discussion relating to noise figure assumes that input noise is equal to KT. B and that this is the only noise contributed by the testing instrument or device - where the testing instrument output impedance is at room temerature (T_o = 290 K), K is Boltzman's constant (1.37×10^{-23}), and B is the bandwidth at 3 dB reference.

Although all parts of the receiver contribute noise to the output, the initial stages are the chief contributors. Unless the mixers and IF amplifiers have exceptionally high noise figures, the RF amplifier can be considered to be the determining factor. This is clearly indicated by the following expression for the total noise figure of cascade-connected multistage networks.

$$F_{1 \ldots n} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots + \frac{F_n - 1}{G_1 G_2 \ldots G_{n-1}} \qquad (10\text{-}1)$$

where:

F_1 = noise factor of the first stage

F_2 = second stage, etc., and

G_1 = gain of first stage

G_2 = gain of second stage, etc.

Noise Figure = 10 log noise factor

Thus, it is evident from the expression, that after any high gain network the overall noise figure is not influenced greatly by additional networks even though their individual noise figures are relatively high. Consequently, for this measurement, it is sometimes assumed that the RF amplifier is the major contributor, and that the noise figure reflects the noise added by the amplifier alone. Such an approximation may not be valid especially where parametric amplifiers and masers are used, since their contributions to overall receiver noise are very small with respect to the mixer and the IF amplifier.

a. Parametric Amplifier. When the received signal is low, receiving system performance is most degraded by the addition of noise. Consequently, low noise preamplifiers are used for the first active electronic components in the receiving system. A low noise preamplifier chain may consist of a parametric amplifier and a tunnel diode amplifier. Figure 10-1 is the block diagram of a typical 4-stage parametric amplifier. The input is filtered to remove any transmit signals that have entered the receive channels. This filtered signal and a high frequency "pump" are applied to the amplifier stages (see figure 10-2). Three circulators and two loads are included to give stability to the amplifier by preventing reflections. Circulators are microwave devices in which signals that enter one port flow only to the adjacent clockwise port.

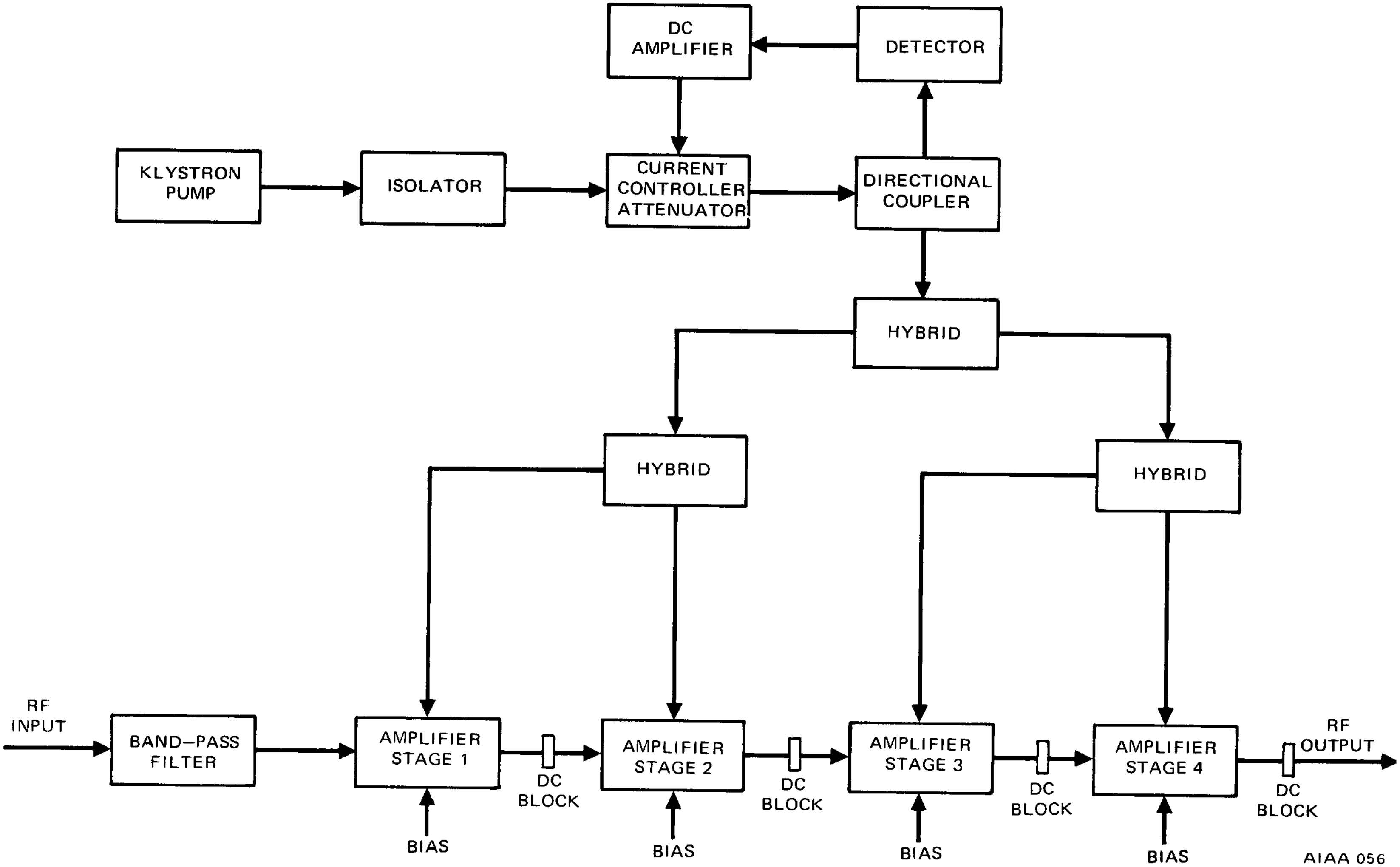


Figure 10-1. Parametric Amplifier, Block Diagram

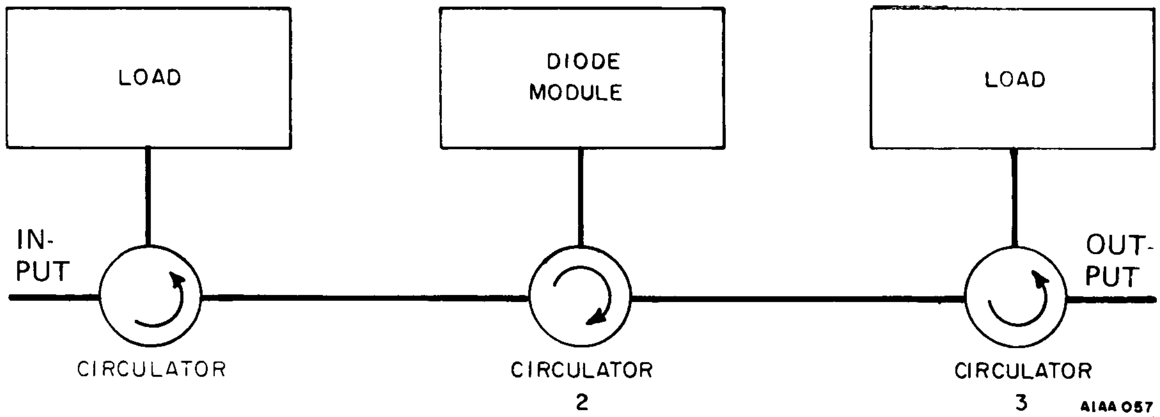


Figure 10-2. Amplifier - Stage Schematic

The device which amplifies is a varactor diode (see figure 10-3). The varactor diode is made part of two circuits, one resonant at the signal frequency and one resonant at the idler frequency (the difference between pump and signal frequencies). The junction capacitance of a varactor diode varies with the voltage across it. In a parametric amplifier, the capacitance is varied by application of the pump signal to the varactor diode. With the proper choice of pump level, pump frequency, and signal impedance matching, the diode presents a negative impedance to the incoming RF signal. This negative impedance causes the signal power reflected from the diode input impedance to be greater than the power incident on the impedance, thereby providing signal amplification.

The pump signal can be generated by a klystron oscillator or solid state source. A current-controlled attenuator in an automatic gain control (AGC) loop keeps the pump power to the amplification stages nearly constant despite changes in oscillator power. The pump power is sent through hybrids to all four amplifier stages. Each stage operates independently of the others. The frequency response of each stage is adjusted by setting the DC bias voltage to it. Blocking devices prevent the bias voltage from being sent along with the signal from one stage to the next. The amplifier stages are tuned separately and then together to give a combined gain of up to 30 dB across the receive bandwidth.

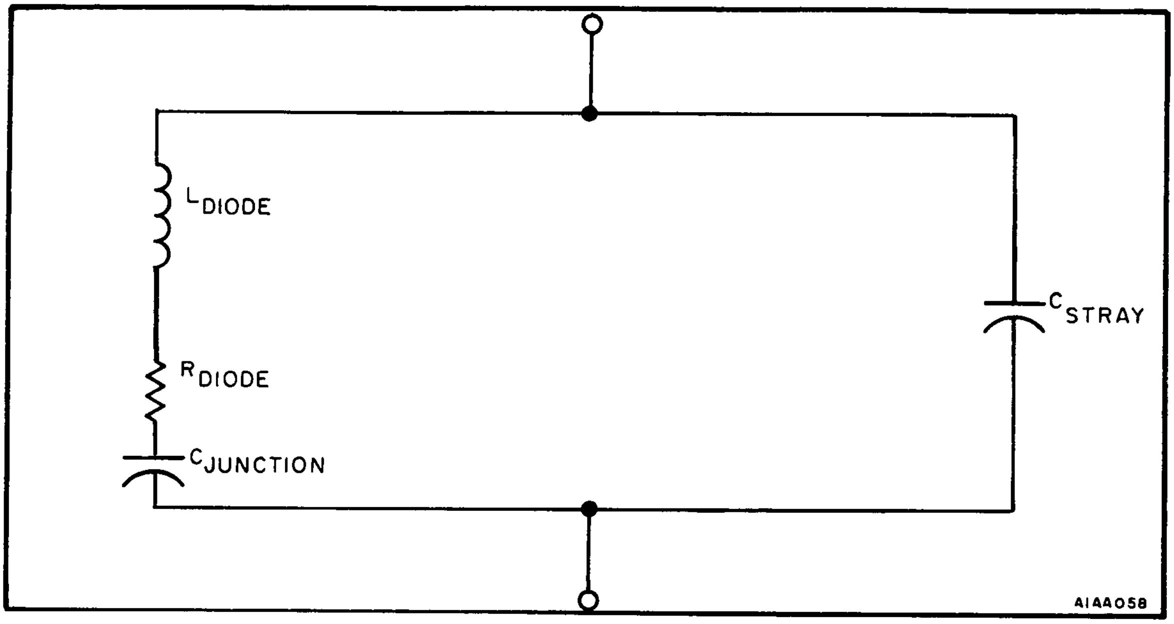


Figure 10-3. Varactor Diode Equivalent Circuit

To keep the parametric amplifier noise temperature as low as possible, some units are refrigerated. In very large systems, the physical temperature of the amplifying stages may be kept below 20K with a cryogenic refrigerating system consisting of helium compressor and expansion units. The expansion unit is insulated by a vacuum jacket. Metallic conductors transfer heat from the amplifier stages to the refrigerator. In smaller systems the more commonly used method is peltier cooling.

Electrical characteristics of a typical parametric amplifier are shown in table 10-1.

b. Tunnel Diode Amplifier. The parametric amplifier output is often further amplified by single-stage tunnel diode amplifiers. At microwave frequencies, a suitably-biased tunnel diode is basically a one-port device which can be used as a transmission-line termination. If the tunnel diode is used as a termination on a circulator port, the non-reciprocal properties of the circulator establish a one-way path along which signals may enter the circulator, undergo reflection at the tunnel diode port, and emerge from another circulator port (see figure 10-4). (The load shown on one port circulator is bypassed by the forward traveling signal, and is used only to absorb any reflected signals traveling in the reverse direction.)

Table 10-1. Typical Parametric Amplifier Characteristics

PARAMETER	CHARACTERISTICS
Gain	30 dB min
Instantaneous (0.5 dB) bandwidth	500 MHz min
Frequency band	3.7 to 4.2 GHz
Noise temperature without preselector filter	15 K max
Input or output SWR	1.3 max
Gain stability	± 0.2 dB/minute ± 0.5 dB/12 hours ± 1.0 dB/week
Gain flatness	± 0.2 dB/30 MHz
Amplitude response ripple	Less than 0.5 dB
Amplitude response slope	0.02 dB/MHz at any frequency in band
Dynamic range	Less than 1 dB compression for input signal from noise level up to -65 dBm
Spurious signals	60 dB below output level corresponding to -85 dBm input
Delay distortion	3 nanoseconds across any 200 MHz
	Slope of time delay shall not exceed 0.1 nanoseconds per MHz at any frequency across the band
Cool down time	About 4 hours
Phase Stability	± 2°/24 hours
Intermodulation Products	More than 60 dB down for two carriers at -85 dBm each
Recovery from Incidental Cryogenic failures	30 minutes

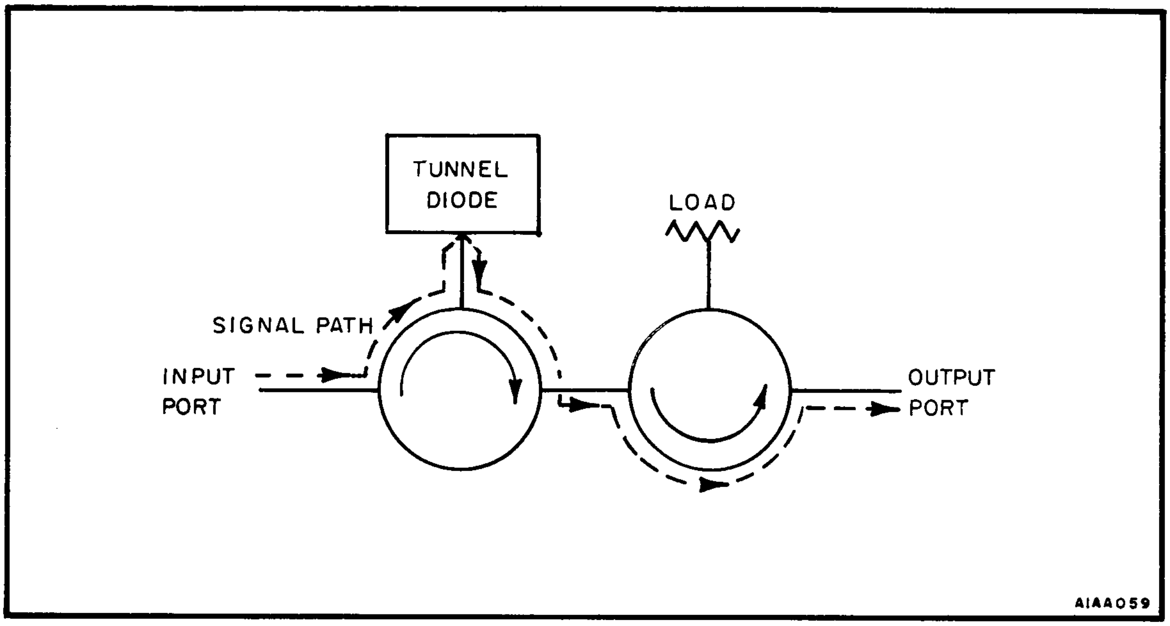


Figure 10-4. Tunnel Diode Amplifier Schematic

As with a parametric amplifier, a tunnel diode (see figure 10-5) has negative input impedance at its design frequencies and under its bias conditions. Reflection of signals from this negative impedance amplifies the signals. L_s and R_s are the series inductance and resistance, C_j is the junction capacitance, and $-R_n$ is the negative resistance of the tunnel diode. The input impedance, Z_{in}, consists of a real and an imaginary part, both of which are functions of frequency. According to semi-conductor physics, $-R_n$ and, to a lesser extent, C_j are both functions of the instantaneous voltage across the diode junction. Therefore, the input impedance depends on frequency, DC bias, and signal level. In practical amplifiers, resonant circuits and transformer sections are used with Z_{in} to produce an overall diode impedance. $Z_d = R_d + X_d$, which varies typically with frequency as shown in figure 10-6 for small-signal conditions, where the diode behavior is essentially linear.

Electrical characteristics of a typical tunnel diode amplifier used in a receiving system are listed in Table 10-2.

A limit to the tunnel diode amplifiers is that they become nonlinear above -40 dBm. Where amplification is necessary above -40 dBm, high peak-current tunnel diodes are used.

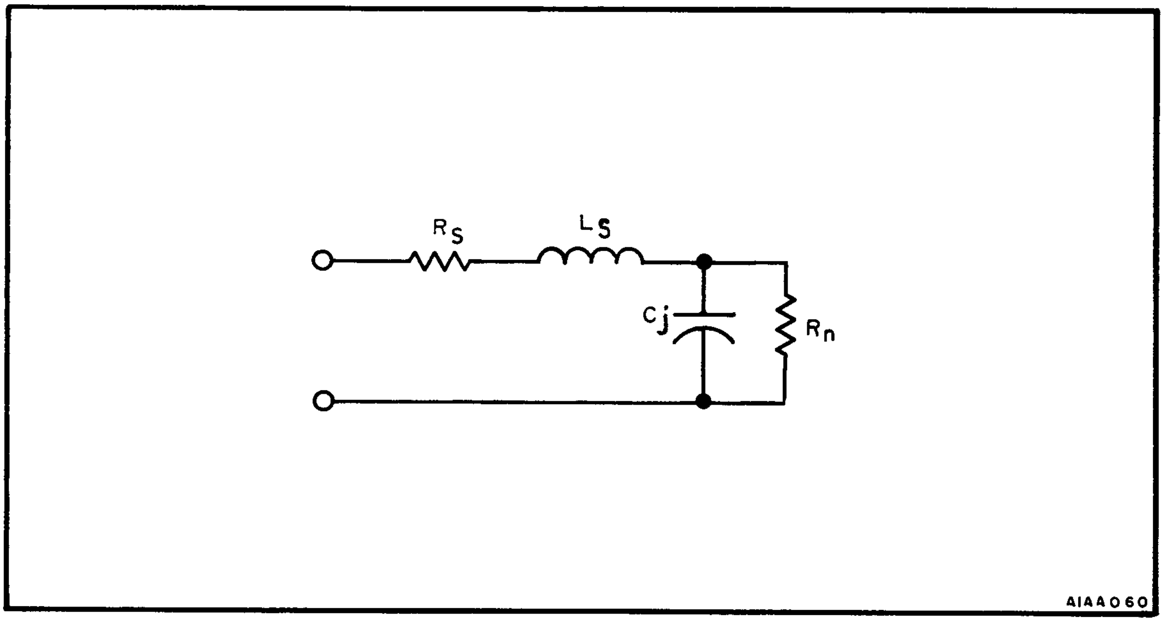


Figure 10-5. Tunnel Diode Equivalent Circuit

Table 10-2. Typical Tunnel Diode Amplifier Characteristics

PARAMETER	CHARACTERISTICS
Noise figure	5.0 dB max
Bandwidth, 0.5 dB	500 MHz min
Frequency band	3.7 to 4.2 GHz
Amplitude response ripple	Less than 0.5 dB
Amplitude response slope	0.02 dB/MHz max at any frequency in band
Gain	14 dB min
Gain stability	± 0.5 dB under all conditions
Burnout level	+ 10 dBm
Departure from linearity	0.01 dB up to -55 dBm input
Input match, SWR	1.2 max
Stability	Unconditionally stable with short or open at input or output at any phase
Delay slope	0.1 nanosec/MHz at any frequency in band

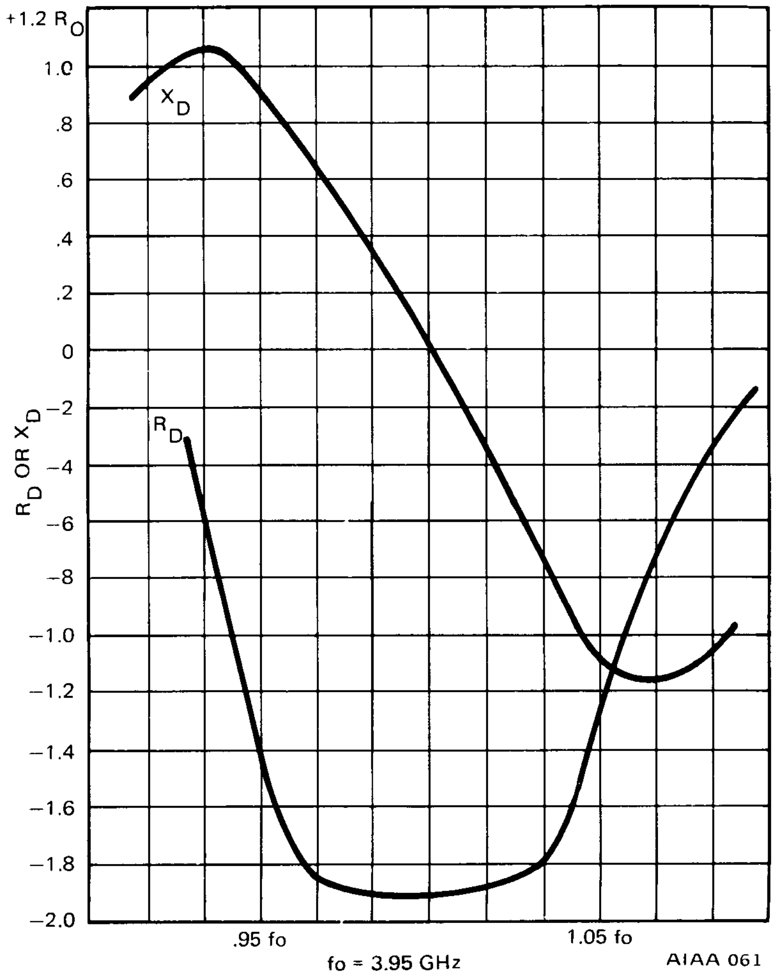


Figure 10-6. Tunnel Diode Impedance Versus Normalized Frequency

The basic difference between high-peak tunnel diodes and the others is that the area of the junction is larger. Although the negative resistance of high-current tunnel diodes is smaller than that of low-current tunnel diodes, causing lower gain, the large junction area lowers distortion and increases the power handling capability. A graph of output versus input for a high level tunnel diode amplifier is shown in figure 10-7. The graph also shows the magnitude of intermodulation products versus input for two carriers. The magnitude of the intermodulation products gives a measure of the nonlinearity of the tunnel diode amplifier.

10.1.2 Superheterodyne Receiver

The main type of receiver used at frequencies from 1 to 13 KMHz, as at lower frequencies, is the superheterodyne. Variations of the individual stages occur as the frequency is increased, but the general principles of operation remain the same.

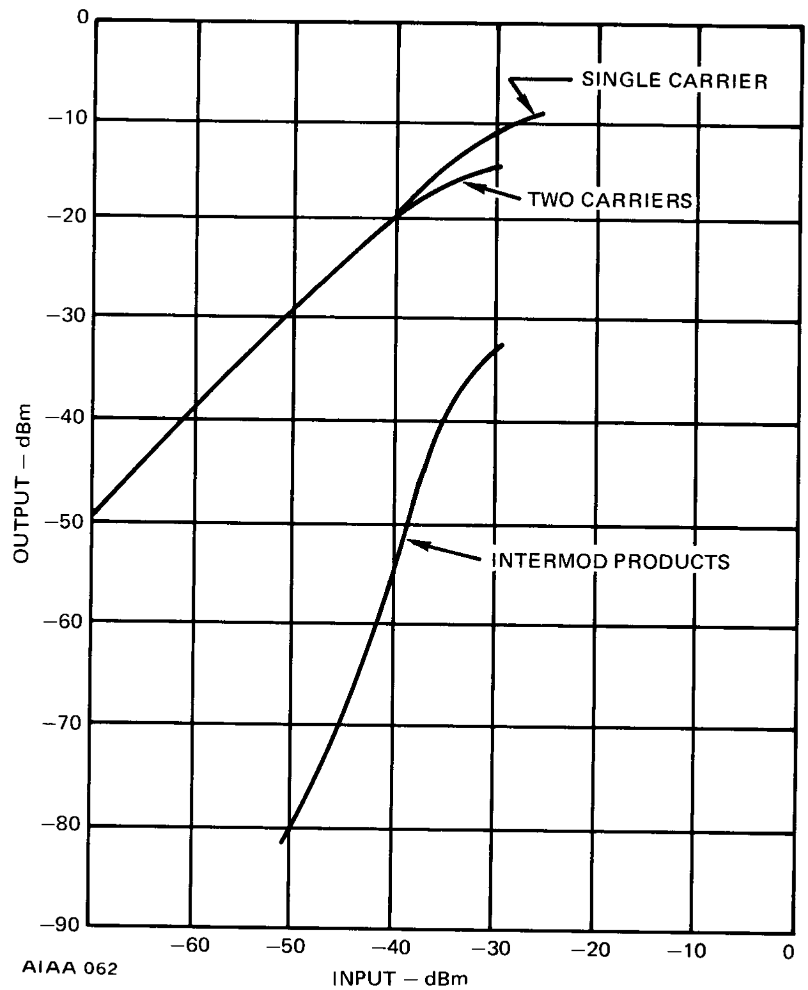


Figure 10-7. High Peak-Current Tunnel Diode Amplifier: Input Versus Output and Intermodulation Products

A superheterodyne receiver (see figure 10-8) operates by heterodyning, or mixing, the received RF signal with a locally generated RF voltage obtained from the local oscillator. These two voltages are combined in a non-linear device such as a crystal rectifier (mixer), producing, in addition to the original frequencies, the sum and difference frequencies. This process is identical with amplitude modulation as used in transmitters.

The difference frequency (lower sideband) is selected and amplified by a fixed tuned intermediate frequency (IF) amplifier system. The IF amplifier frequency remains the same in a given receiver regardless of the incoming signal frequency. This is accomplished by changing the local oscillator frequency so that the difference frequency between the desired signal and the local oscillator signal remains constant. Currently, the microwave receiver IF is specified to be 70 MHz by the Defense Communication Agency (DCA).

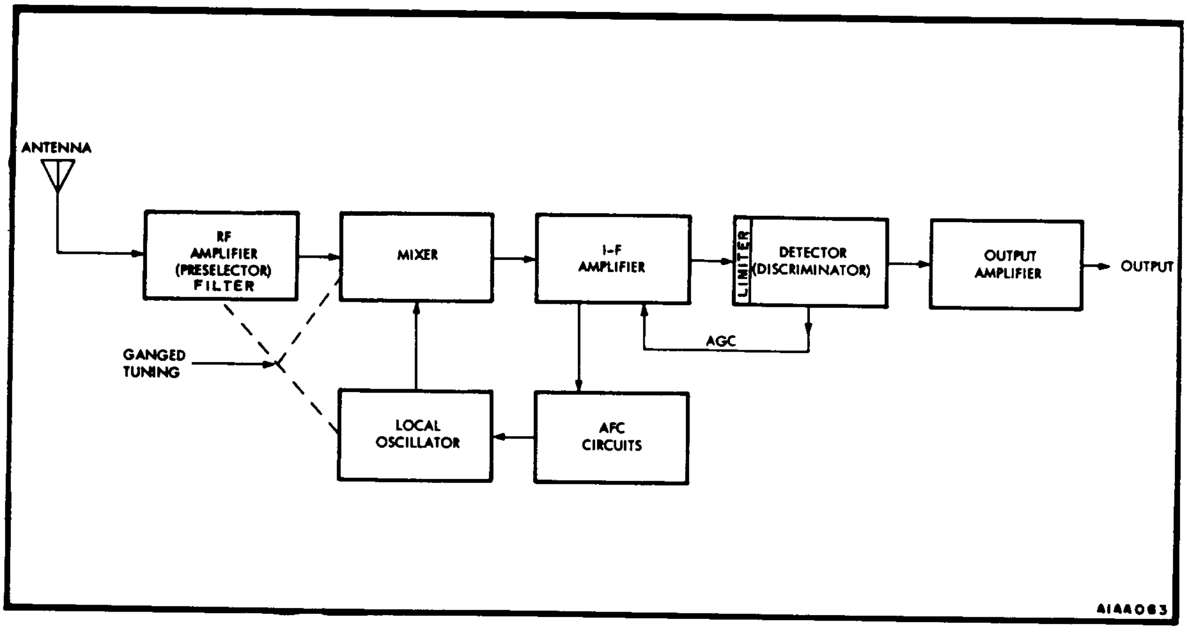


Figure 10-8. Superheterodyne Receiver, Block Diagram

After amplification, the IF signal is demodulated. The information and the carrier are separated and the signal containing the information is passed on to the output amplifier. Here the signal is amplified enough to be used as desired.

At some point in the frequency band about 1500 MHz, the use of an RF stage in a receiver results in a lower signal-to-noise ratio than without the stage. Klystrons produce amplification at these frequencies and are useful as transmitting amplifiers, but they are too noisy for use in receivers as RF amplifiers. Tube noise is important only when small signal levels are being handled. If the signal strength is of the same order as the noise produced in a stage, a large amount of distortion will result. However, if the signal level is of much larger amplitude than the noise, little if any effect will be produced. For this reason, noise produced in amplifiers is of importance only in low power level stages such as the initial stages of a receiver. Traveling wave tubes are useful as RF amplifiers in receivers and are made with as low a noise figure as the crystal mixers used for the first stages in receivers above 500 MHz. Receivers used for higher frequencies have as their first stages (1) the antenna, (2) a tuned circuit or preselector, and (3) a crystal mixer or traveling wave tube (TWT) for converting the signal to a lower intermediate frequency. The preselector is composed of one or more tuned circuits, which reject all frequencies except the desired frequency band. Coaxial cavities may be used for frequencies from about 500 MHz up.

a. Preselector. In general, a preselector is fed from a low-impedance source, the antenna, and is coupled to the higher impedance of a crystal mixer. The tuner must therefore act also as an impedance transformer to obtain maximum energy transfer. It must have a pass band that is at least as wide as the pass band of the IF amplifier and an off-frequency attenuation which produced the largest amount of image and harmonic rejection that can be obtained. If the desired attenuation characteristic cannot be obtained by a single-tuned circuit and still maintain the required pass band, double- or triple-tuned circuits must be used.

b. Local Oscillators. The local oscillator used in the receiver must operate at a frequency similar to the received frequency. The exact frequency of the oscillator is the desired signal frequency plus or minus the intermediate frequency. The local oscillator may operate either at a higher or a lower frequency than the received signal, since the difference frequency will remain the same. Klystron oscillators, usually of the reflex variety, are used as local oscillators almost exclusively above 3 KMHz. Additionally, solid-state oscillators are currently available for several frequency bands.

c. Mixers. The device used to produce the IF from the received signal and the local oscillator signal is the mixer (first detector). Any nonlinear device may be used for this purpose, although at frequencies above 500 MHz crystal mixers are appreciably superior to any triode mixers now available because of the small amount of noise generated. The conversion loss of type-1N26 crystals is low, even at 23 KMHz, with a maximum conversion loss varying from 5.5 to 7.5 dB in the frequency range from 3 to 16 KMHz. The maximum noise ratio (the amount of noise generated by the mixer compared to the noise produced in an equivalent impedance resistor) varies from 1.5 to 2.5 in the same frequency range. Silicon crystal mixers have the disadvantage that they are damaged by overloads.

d. IF Amplifiers. The difference frequency produced in the mixer may be any desired value. Selection of the frequency to be used in a given receiver will depend on several factors. A high IF is desirable to eliminate image response, but the selectivity and noise figure of an amplifier becomes worse with an increase in frequency, and ganged tuning of the local oscillator and preselector is thus a compromise between the desired image-rejection ration, on one hand, and the desired sensitivity, selectivity, and circuit simplicity on the other.

A method of obtaining both good image-rejection by using a high IF, and good selectivity and simplicity of circuits through the use of a low IF, is the double-conversion superheterodyne receiver. A high IF is first produced to obtain a good image-rejection characteristic. This frequency is further reduced by a second frequency conversion, bringing the IF down to a frequency that can be easily amplified and that provides good selectivity. The oscillator used to produce the second IF may be crystal controlled since it heterodynes with a fixed frequency. The disadvantage of this system is the additional local oscillator and mixer stages required.

e. Detectors. Some means of separating the carrier from the desired information must follow the IF amplifier. The second detector (demodulator) is used for this purpose.

Detectors used for FM are often called discriminators. A discriminator produces a DC voltage proportional to the frequency of an input signal. This may be accomplished in a number of ways. One method uses two tuned circuits, one tuned above the center frequency and one tuned below to obtain two IF voltages whose amplitudes depend directly on frequency. These voltages are rectified and combined so that zero voltage output is obtained at the center frequency. A difference voltage of the two IF voltages that is proportional to the frequency is obtained when the frequency of the IF signal is above or below the center frequency. A discriminator of this type is sensitive to amplitude variations in the input, so a clipper-limiter stage must be used preceding the discriminator to remove any AM. Another method of obtaining frequency discrimination is the use of the phase detector. This operates by comparing the phase relationships of two signals, one the IF signal and the other the IF signal phase-shifted in a resonant circuit tuned to the center frequency. The amount of phase shift will be proportional to the frequency of one signal. A limiter stage is also required for the phase detector.

To eliminate the need for a limiter stage, several types of discriminators have been developed that will respond to amplitude changes. The first of these is the ratio detector. Instead of the two rectified voltages of the ordinary discriminator being combined with opposite polarity, they are combined so as to add. The sum of the voltages is kept constant by a large-value capacitor. This eliminates any amplitude variations of the IF signal and makes the use of a limiter stage unnecessary. The ratio of the two voltages changes as the frequency input to the ratio detector changes and the output is taken from one of the rectifier loads.

f. AFC Systems. Receiver stability is even more important than transmitter stability. In contrast to the AFC systems used in transmitters, which tend to keep the operating frequency at an absolute value, receiver AFC systems usually compare the receiver's operating frequency to the received signal. This is done by using a discriminator in the IF channel to develop the error signal used to retune the oscillator. An FM receiver may use the same discriminator for signal detection and AFC provided the signal variation is averaged over a period of time so that the oscillator does not attempt to follow the modulation, but only slow frequency drifts. With the exception of the development of the error signal, AFC is obtained by the same methods as in transmitters and is discussed in that paragraph.

g. AGC Systems. Since received signal strength will vary over a wide range some means of automatic gain control (AGC) is required in the receivers. This is accomplished by rectifying the received carrier and averaging the voltage over several cycles of modulation. This voltage is used as bias for the IF amplifiers so that as the average signal strength increases, the gain of the IF amplifier is decreased. The bias is usually not applied to the first amplifier stage since the stage tends to become noisier with AGC applied. With some types of modulation, such as for TV, the rectified IF signal may be too large to make practical the use of the average value to control the receiver gain. Special techniques must be used to provide AGC in these cases.

h. Output Amplifiers. The detected modulation must be amplified for further use. The output amplifier must amplify the output frequency range, which in some equipment is up to 20 MHz wide, with uniform response. For pulse transmission, the bandwidth in MHz must be at least twice the reciprocal of the pulse duration in microseconds if the pulse is to approximate its original shape. Phase shift characteristics are as important as bandwidths. Since phase distortion will change the pulse shape by phase shifting the harmonics which make up the pulse difference angles.

10.1.3 FM Noise Threshold

FM threshold is defined as the point at which the received RF carrier signal peak, equals or exceeds noise peaks 99.999 percent of the time when the RF-RMS carrier level is 10 dB above noise threshold. The detector in an FM receiver is controlled by peak voltages. When noise peaks exceed signal peaks, the receiver follows noise peaks rather than the signal variations which are marked by noise. Peak noise is defined as the voltage level which is exceeded a certain percentage of the time, depending on the peak reference chosen. In a random noise distribution, the arbitrary ratio choice of noise peaks to noise RMS equal to 13 dB means that RF peak signal input equals or exceeds noise peak 99.999 percent of the time (figure 10-9). The ratio of peak to RMS for a sinusoidal signal is 3 dB. Therefore, the ratio of the RMS value of signal to RMS value of noise at threshold where noise peaks equal signal peaks is 10 dB.

Analytical Derivation of FM Threshold:

N_p = Peak Noise Voltage

RMS = Effective Noise Voltage at Noise Threshold

S_p = Peak Carrier Signal Voltage

S_{rms} = Effective Carrier Signal Voltage

From a statistical distribution of noise, the following statements can be made:

$N_p = N_{rms} + 13$ (Noise peaks are exceeded 0.001 percent of the time)

$S_p = S_{rms} + 3$

By definition at FM Threshold, the peak signal voltage shall be equal to or greater than the peak noise voltage 99.999 percent of the time.

$$Sp \geq Np$$

$$S_{rms} + 3 \geq N_{rms} + 13$$

$$S_{rms} \geq N_{rms} + 10$$

The expression arbitrarily defines FM Threshold. The RMS RF signal level, if 10 dB above noise threshold, means that noise peaks and noise bursts will exceed the peak signal level 0.001 percent or less of the time, or that the input signal voltage peaks will exceed noise peaks 99.999 percent of the time.

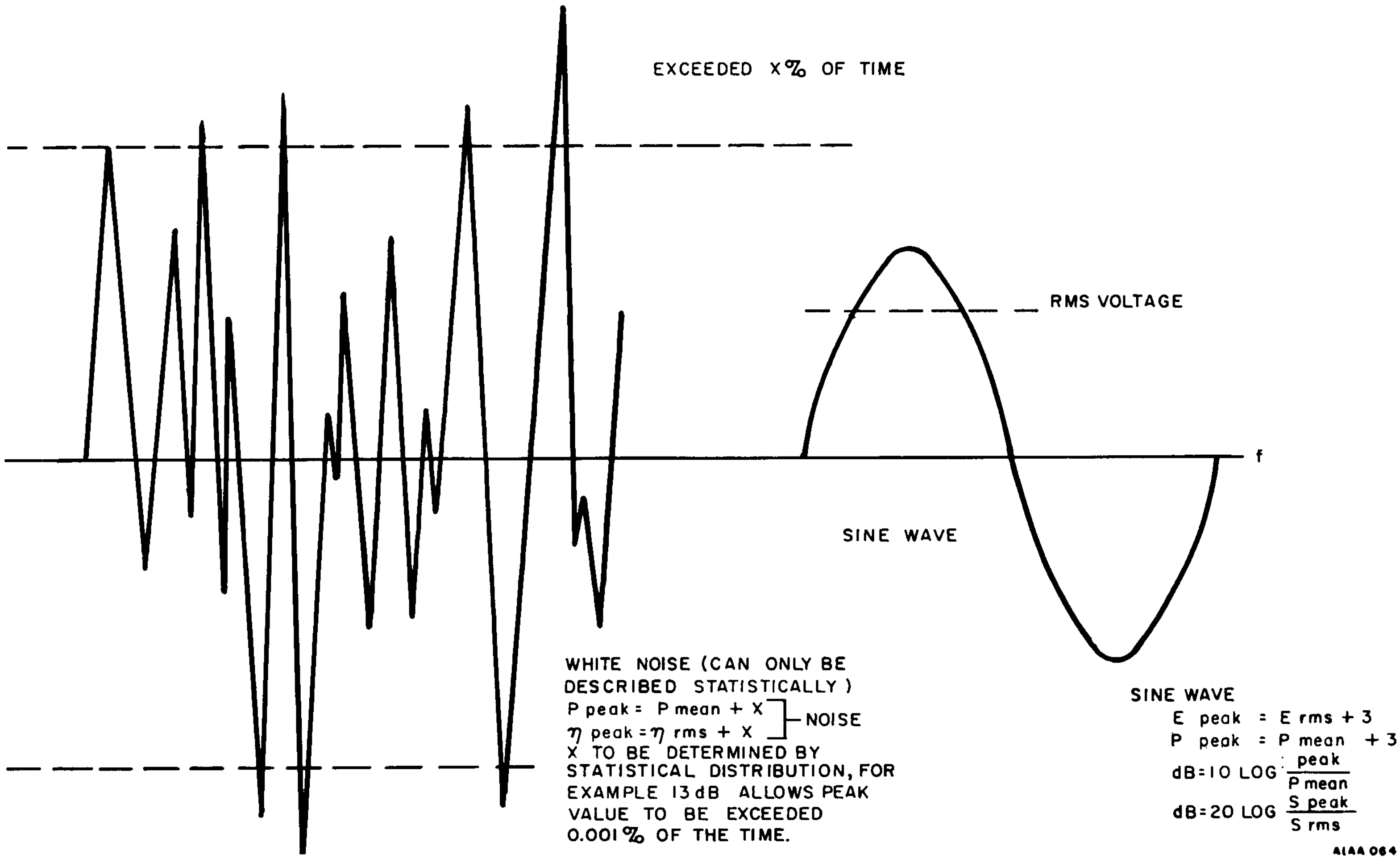


Figure 10-9. White Noise Versus Sine Wave

Noise Threshold - The RF input level at which signal power just equals the internally generated front end noise power or where RMS noise equals RMS signal.

10.1.4 Receiver Characteristics

To properly describe and evaluate overall FM receiver performance, it is necessary to analytically trace the curve of output signal-to-noise (S/N) ratio as a function of the input RF carrier, that is, S/N = f(C/N) and correlate this expression with experimental data. In many specifications, usually only one point is defined. This is insufficient to properly describe this function, with operation below FM threshold not discussed or described. To evaluate FM receiver performance the function must be described. For example, when a 3 dB threshold improvement is measured, what is a proper reference? This can be determined by use of this curve. In carefully analyzing experimental data and curves for many typical FM receivers, it appears reasonable to conclude that the curve [S/N = f(C/N] can be approximated by three asymptotic straight lines, each with a different slope. The curves can be defined analytically, and will be developed from noise threshold to receiver saturation.

Refer to figure 10-10 which shows the theoretical development of S/N = f(C/N).

a. Noise Threshold to FM Threshold

From Figure 10-10, Slope I, at noise threshold,

C/N axis,

$$\text{Noise Threshold} = 10 \log KTB + NF(dB) \qquad (10\text{-}2)$$

S/N axis,

$$(S/N)_1 = 0 \text{ (dB)} \qquad (10\text{-}3)$$

at FM threshold,

C/N axis,

$$\text{FM Threshold} = \frac{10 \log KTB + NF\ (dB) + 10\ dB}{\text{Noise Threshold}} \qquad (10\text{-}4)$$

S/N axis,

$$(S/N)_2 \text{ (Thermal)} = 10 + (10 \log \frac{B_{IF}}{2b} + 20 \log \frac{F}{FM} - L + P + W + \frac{C}{N}(dB)) \qquad (10\text{-}5)$$

where,

B_{IF} = Carson rule bandwidth = 2 F + 2 F_m, normally corresponds to IF bandwidth

F = Peak deviation

FM = Highest modulating frequency

b = Voice channel bandwidth = 3 KHZ

L = The multichannel loading factor

P = Pre/De-emphasis improvement

W = The weighting factor improvement or effective voice channel shaping for measurement purposes.

Equation 10-5 defines S/N ratio due to thermal noise in one voice channel for a multi-channel FDM system. Equations 10-2 through 10-5 therefore, locate the points connected by straight line I between noise threshold and FM threshold. The slope of line I is,

$$\text{Slope} = \frac{(S/N)_2 - (S/N)_1}{\text{FM threshold - noise threshold}} \qquad (10\text{-}6)$$

$$= \frac{(S/N)_2 - 0}{10 \text{ lot } KTB + NF + 10 - (10 \log KTB + NF)}$$

$$\text{Slope} = \frac{(S/N)_2}{10}$$

b. <u>FM Threshold to Receiver Saturation</u>

From figure 10-10, Slope II,

$$S/N\ (\text{THERMAL}) = C/N + \boxed{10 \log \frac{B_{i-f}}{2b} + 20 \text{ Log } \frac{F}{Fm} - L + P + W} \qquad (10\text{-}7)$$

The encircled portion of the equation can be described as a constant for a particular receiver once the variables are fixed. The equation can then be written as follows:

$$S/N = C/N + K$$

From this equation, it is apparent that a linear relationship exists between output S/N and input C/N. The coefficients of both are equal and the slope for curve II is equal exactly to one. It can also be stated that the slope is exactly one for all FM receivers when operating above FM threshold and up to receiver saturation; that is, assuming that the only variable is the received RF input (C/N) with the other variables held constant. In addition, it is possible to obtain a family of curves for one receiver by varying any one of the parameters B_{IF}, F, or Fm.

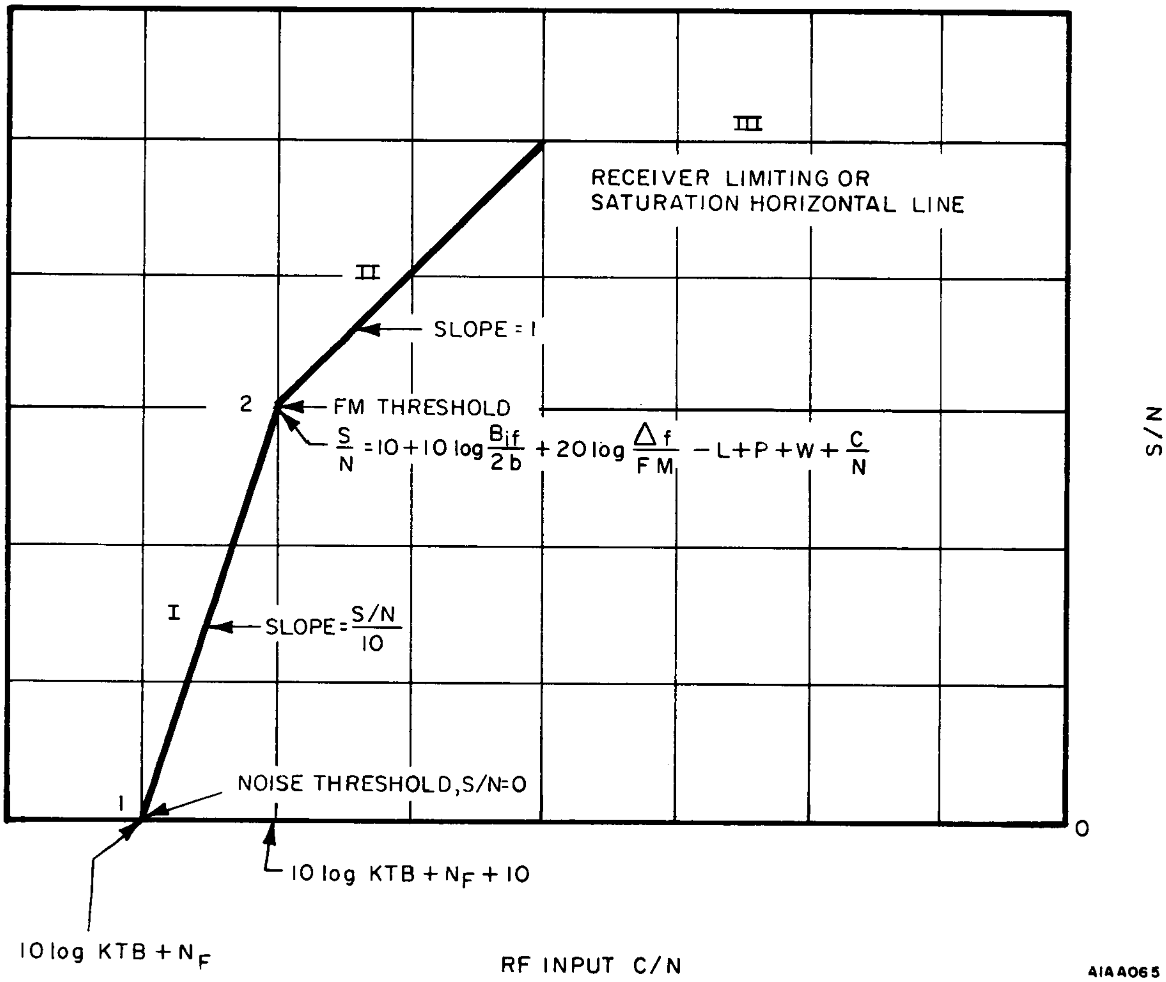


Figure 10-10. Analytically Developed Characteristic Curve of S/N Versus C/N for FM Receivers

c. Receiver Saturation

The output S/N ratio in one voice channel will keep increasing for a corresponding increase in received RF level, since this decreases the affects of thermal noise (see figures 10-11 through 10-14). The increase in RF input signal level increases the affects of AGC which then decreases receiver gain and thus the output thermal noise contribution will decrease, since output thermal noise is equal to KTBG. This process will continue until the received RF carrier level drives the RF amplifier beyond AGC control. At this juncture, an increase in received RF level does not decrease the affects of thermal noise and, consequently, the S/N ratio will be held virtually constant. It should be emphasized that the equation for output S/N is for a single FDM voice channel (3.1 kHz. This equation cannot be used for other applications, such as wideband signals, TV, PCM, radar video, etc. In practice, the receiver RF amplifier does not saturate completely but does saturate in a gradual asymptotic fashion; therefore,

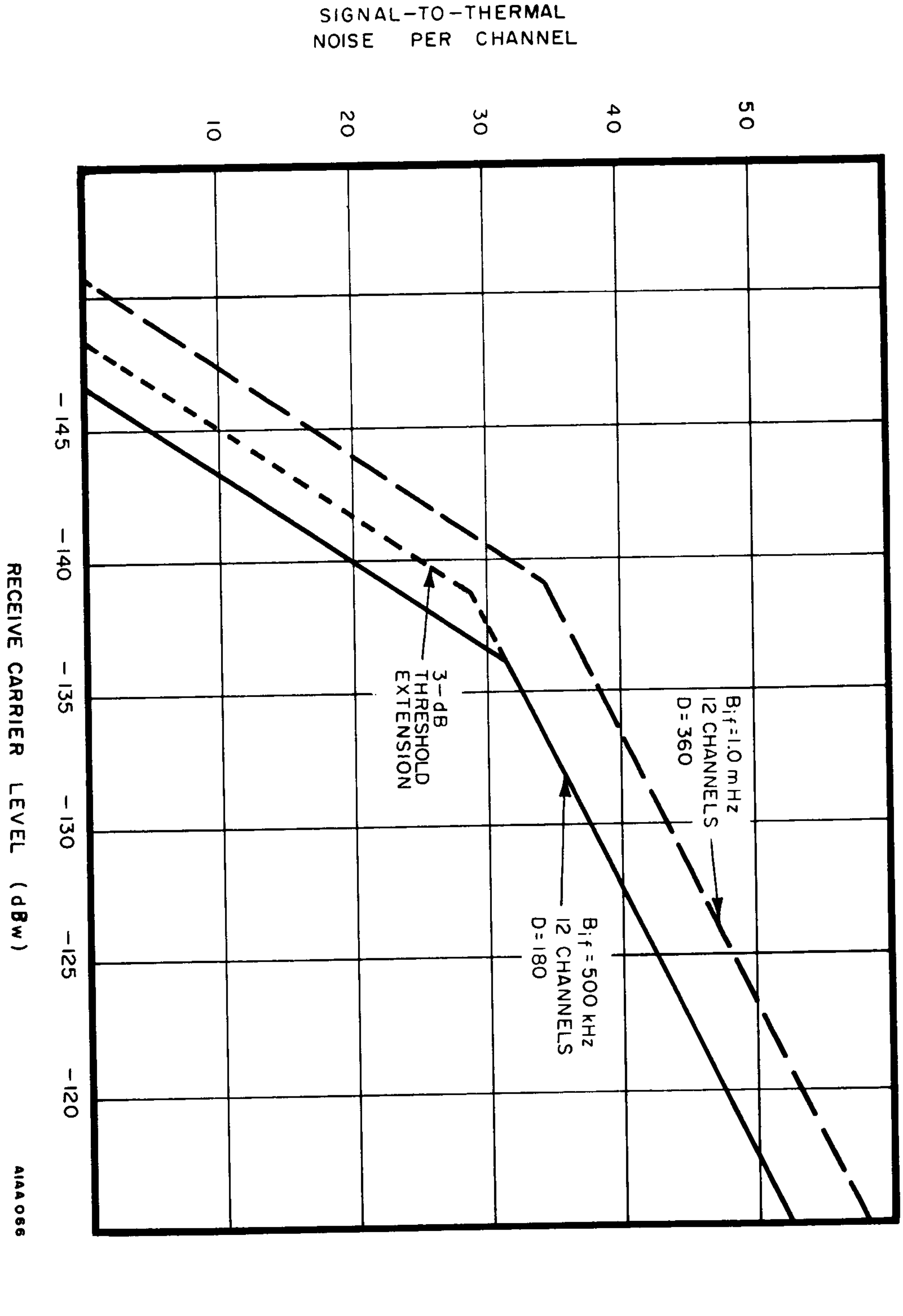


Figure 10-11. Receiver Comparison Using S/N to C/N Application

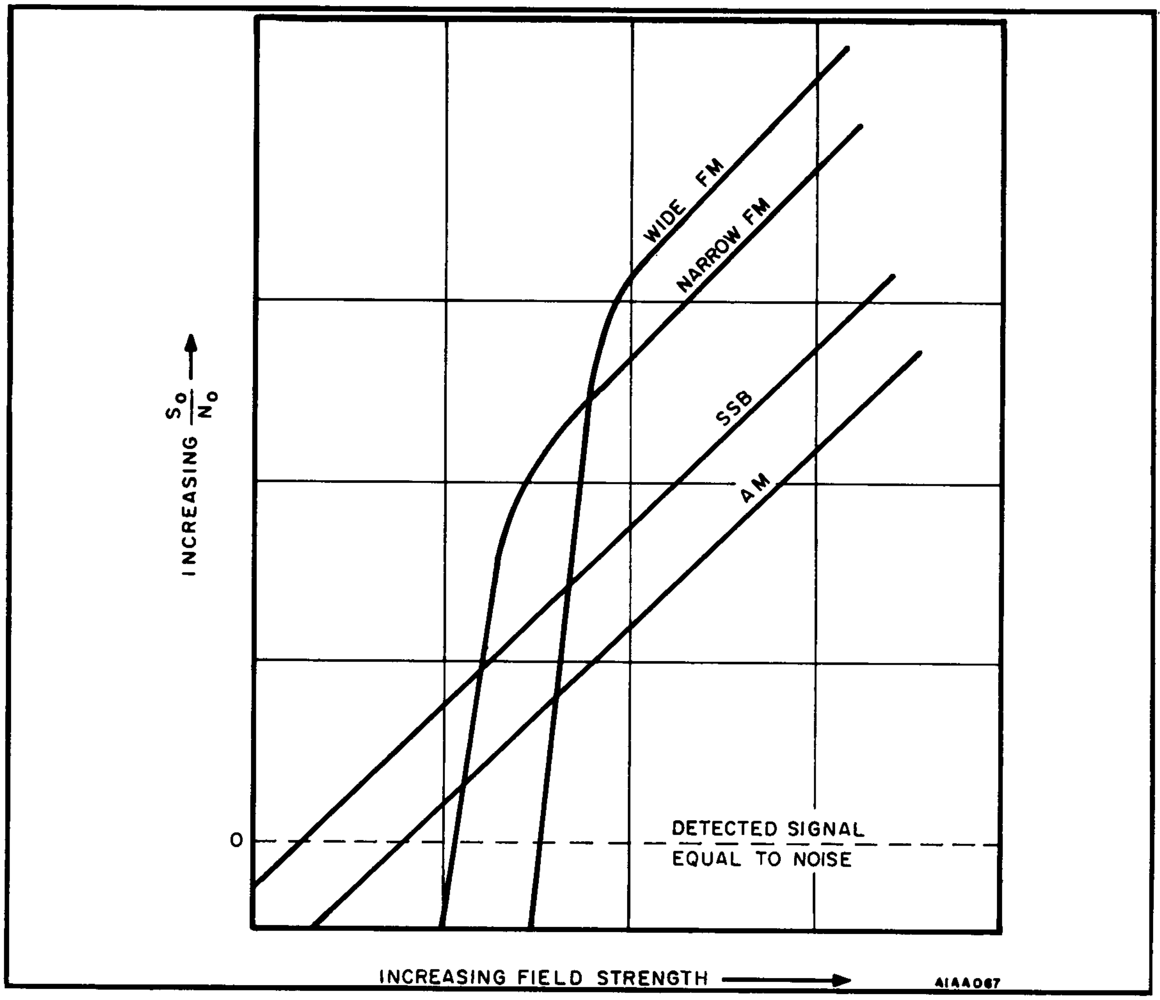


Figure 10-12. Relative S/N Ratio of AM and FM Systems as a Function of Field Intensity

the S/N at saturation is not a horizontal line. However, from a practical point of view, describing it in this manner will be reasonably accurate for most engineering considerations. The point at which receiver saturation occurs cannot be determined without having receiver design data available.

10.1.5 Threshold Extension

In a system with a perfectly linear input-output transfer characteristic, the noise bandwidth would be the bandwidth of the narrowest filter. Most receiving systems become non-linear below the point identified as the "threshold." It is therefore convenient to use two bandwidths when establishing system performance. The first is the noise bandwidth which is either the pre-detection bandwidth or the bandwidth inherent in the detection system itself, whichever is smaller; and the second is the base bandwidth

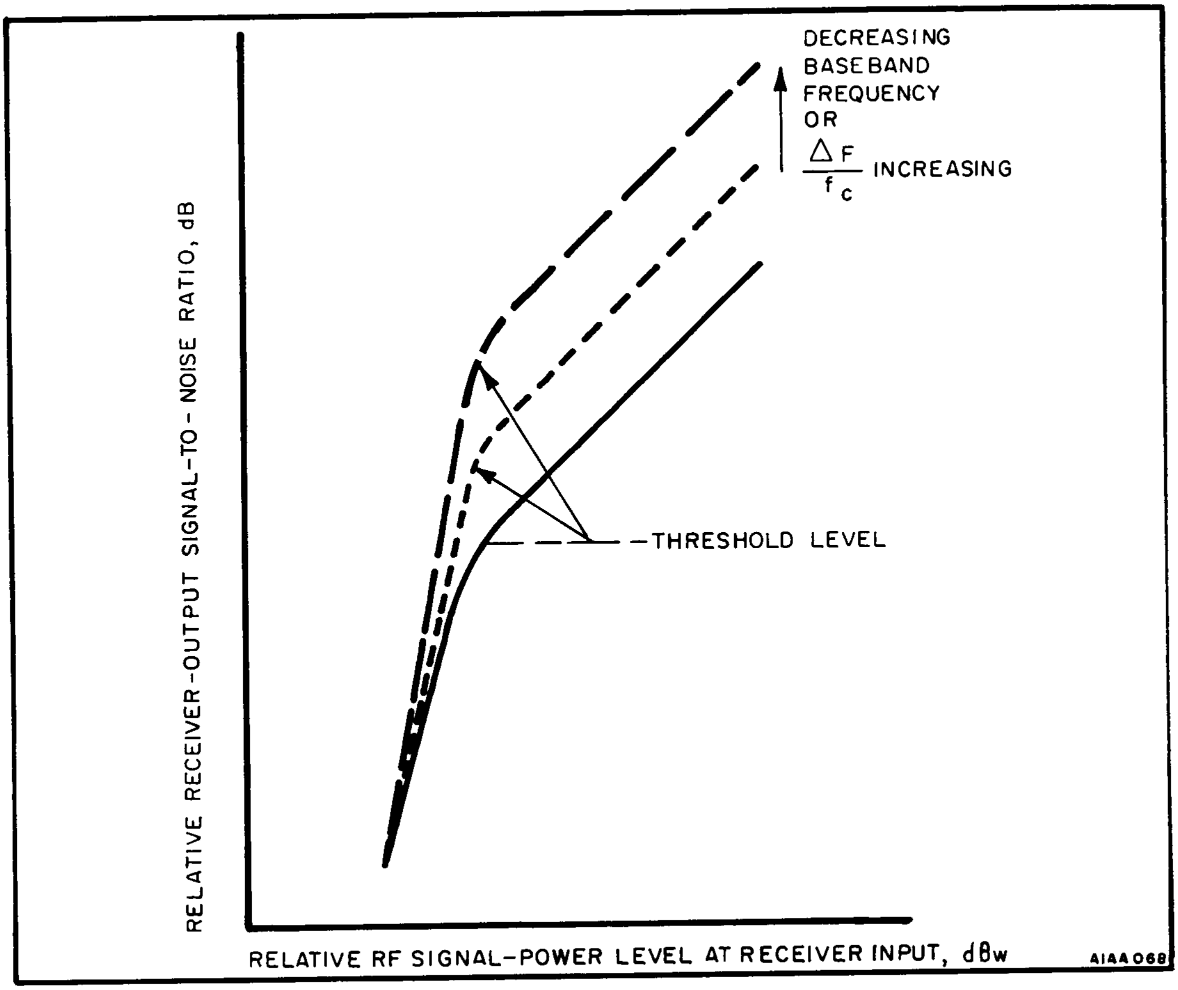


Figure 10-13. FM Receiver Characteristic Curves, Without Pre-emphasis

which is the effective bandwidth of the post-detection and instrument filters. To identify signal powers in each of these bandwidths, it is conventional to use the term "carrier" for the total signal power in the noise bandwidth and the term "signal" for the demodulated signal power in the base bandwidth. In the case of multiplex telephone, carrier means the total received signal while signal means the demodulated intelligence in one channel only, usually the highest. The conventional plots of receiver performance show the S/N ratio measured in the base bandwidth as the ordinate, and the C/N power ratio measured in the noise bandwidth as the abscissa. These plots are meaningless unless the noise bandwidth is precisely known. As this is seldom the case, it is much more meaningful to plot carrier power at the input terminals of the first amplifier as the abscissa. It is difficult to assign an exact number to the base bandwidth because of the effect of shaping networks, filters, and instrument characteristics. It is more meaningful to identify the frequency response of the entire post-detection circuit and also the actual measuring instrument.

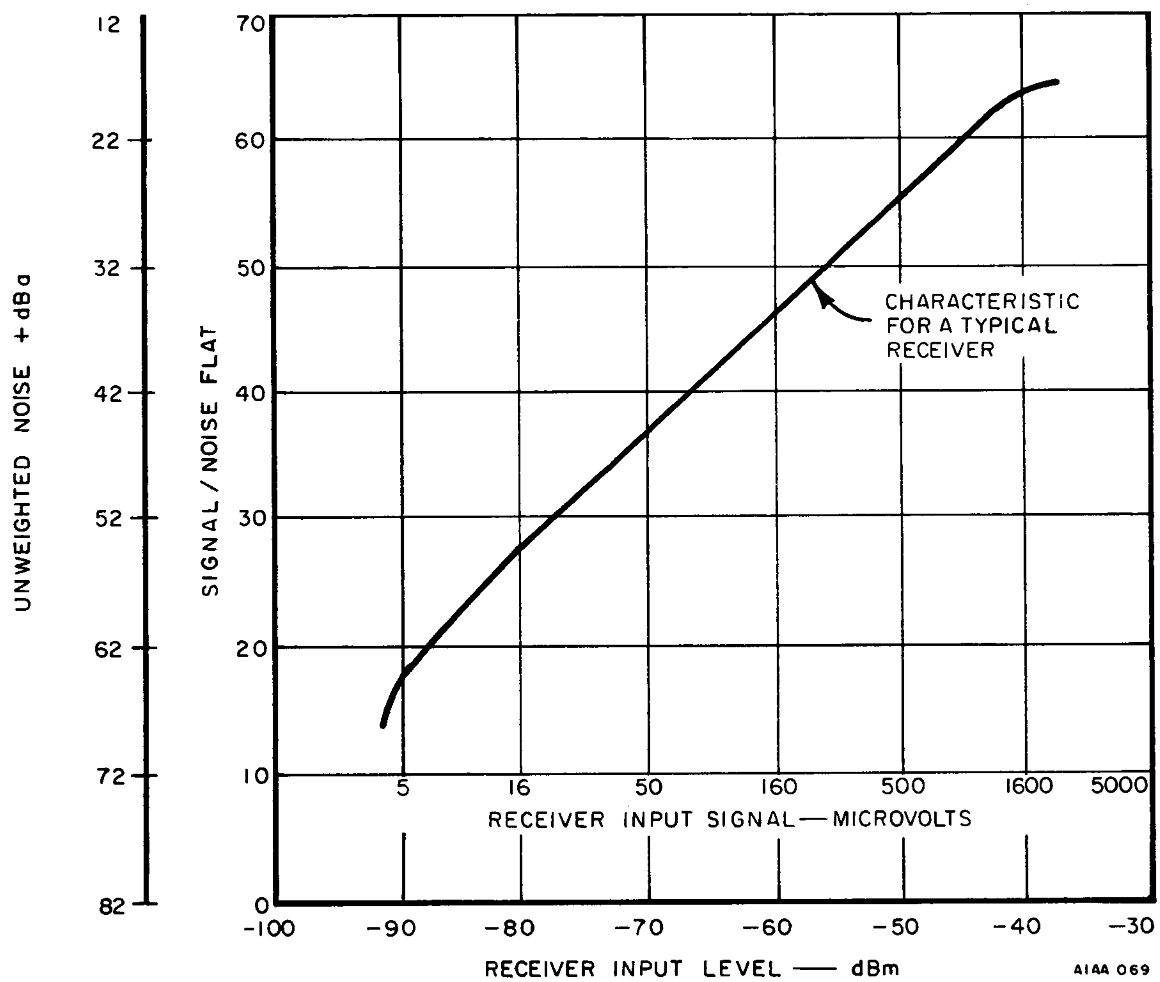


Figure 10-14. Thermal Noise Characteristics Showing Noise as a Function of Receiver Input Power

For design, the noise bandwidth must be known. When measuring a complete receiver using FM feedback, the noise bandwidth is not a simple measurement. The noise bandwidth of typical receivers can be estimated from Table 10-3.

Selection of noise bandwidths for a receiving system depends on the receiver threshold, which dictates how wide the bandwidth can be. The amount of information that must pass through the system dictates how narrow the bandwidth can be.

Threshold is the minimum C/N ratio that yields an FM improvement which is not significantly deteriorated from the value predicted by the usual small-noise S/N formulas. For comparison, the threshold is picked as that carrier power at which the output S/N ratio has dropped 1 dB below, i.e., departed from, the linear relationship between S/N ratio and carrier power.

Table 10-3. Noise Bandwidth of Receivers

TYPE OF RECEIVER	NOISE BANDWIDTH
Conventional	Same as 3 dB bandwidth of IF amplifier
F-M Feedback	1.57 times the 3-dB bandwidth of the filter in the feedback loop if it is a simple single-pole network; or 1.25 times the 3-dB bandwidth of the filter in the feedback loop if it is a double-tuned circuit.
Phase Lock Feedback	3.24 times the 3 dB bandwidth of the closed loop, provided that the damping factor of the loop is 0.707 and provided that the input noise is white, additive gaussian.

If the noise bandwidth is reduced below the base bandwidth by a simple filter, severe distortion results in the output unless the carrier deviation is reduced accordingly at the transmitter so that the base bandwidth is no longer wider than the noise bandwidth. Reducing the deviation, in turn, greatly reduces the advantages gained by using frequency modulation. A brief review of the basic fundamentals of frequency modulation shows that when modulation is applied, a theoretically infinite number of sidebands, spaced symmetrically above and below the carrier, are generated. In actual practice, only the significant sidebands, i.e., those containing significant power, are considered. The bandwidth required to convey this information by a frequency modulated carrier depends upon the amplitude and frequency of the modulating signal. This leads to the formation of the modulation index (m) which is defined as

$$m = \frac{F}{f_m} \tag{10-8}$$

where

F = carrier deviation

f_m = modulating frequency.

The modulation index, when applied to mathematical tables derived from Bessel functions, provides the number of significant sidebands that will be generated for the particular index, and therefore the required bandwidth. As shown in Table 10-4, a large index results in a large number of sidebands and a large bandwidth; a small index results in a smaller number of sidebands and a corresponding reduction in bandwidth requirements.

In a conventional FM receiver, the IF and demodulator bandwidth is made to be $2f_m(m + 1)$. A list of required bandwidths for several modulation indices is given in Table 10-4. To lower the threshold by decreasing receiver bandwidth, the modulation index must be reduced to ensure an undistorted output signal. This process is called threshold extension.

Table 10-4. Modified Bessel Chart

MODULATION INDEX (m)	NO. OF SIGNIFICANT SIDEBAND PAIRS	BANDWIDTH (bw) (f = MODULATING FREQUENCY)
0.01	1	2f
0.1	1	2f
0.4	1	2f
0.5	2	4f
1.0	3	6f
2.0	4	8f
3.0	6	12f
4.0	7	14f
5.0	8	16f
Note: When m>3, a reasonable approximation of occupancy is bw = 2f (1 + m)		

The term threshold extension is also used to define the performance of an FM feedback receiver with reference to a conventional receiver with a noise bandwidth equal to $2f_m(m + 1)$. The extension is given in terms of the reduced carrier power, referred to the carrier power at threshold in a conventional receiver, expressed in dB. Since designers have claimed both reduced noise bandwidth and reduced carrier-to-noise ratio in this bandwidth, the value of threshold extension must be given by:

$$TE = 10 \log \frac{\text{carrier power to reach threshold in conventional receiver}}{\text{carrier power to reach threshold in feedback receiver}} \qquad (10\text{-}9)$$

$$= 10 \log d/N_c = 10 \log C/N_t + 10 \log B_c/B_t$$

where TE = threshold extension in dB

C/N_c = C/N ratio measured on conventional receiver with noise bandwidth = B_c

C/N_t = C/N ratio measured on feedback receiver with noise bandwidth = B_t

B_c = noise bandwidth of conventional receiver

B_t = noise bandwidth of feedback receiver

One wideband FM system characteristic facilitates reducing effective bandwidth: although the incoming signal may occupy any position in the passband, the transmitted baseband information is restricted in the rate at which it may move from one passband position to another. This signal-modulation restraint is used to obtain effective bandwidth reduction in all currently used FM-feedback threshold-extension systems.

10.1.6 Noise Figure

Noise figure in dB (noise factor) is defined as:

$$N_f = \frac{(C/N)_{in}}{(C/N)_{out}} = \frac{C_{in}/N_{in}}{\frac{C_{in}G}{N_{out}}} = \frac{\text{NOISE OUT}}{\text{NOISE IN X G}} \qquad (10\text{-}10)$$

$$N_f = \frac{\text{NOISE IN X G} + N_x}{\text{NOISE IN X G}} = \frac{kT_\circ BG + N_x}{kT_\circ BG}$$

$$N_f = 1 + \frac{N_x}{kT_\circ BG} = 1 + \frac{T_e}{T_o} \ [\text{in dB}]$$

In a perfect device, the noise output and the noise input are equal, assuming unity gain. An actual amplifier has a finite noise contribution and that is why the noise figure >1.

G = Power Gain

T = Source Temperature assume 290°K

B = Bandwidth at 3 dB reference (in FM receivers, this is I_f bandwidth)

N_x = Noise power contributed by device that is being measured = K T_e BG

N_{in} = Input Noise power

N_{out} = Output Noise power from device

T_e = Effective input noise temperature, a measure of internal noise sources of device

The noise figure of a device is a function of temperature of the noise generator, and may be defined for any source temperature. Usual custom is to define noise figure in terms of standard temperature $T_\circ$ = 290K, and noise figure can be determined at different source temperatures T, by using the equation:

$$N_{fs} = 1 + \frac{N_x}{GKT_sB} \quad \text{or} \quad N_{fs} = \frac{T_o}{T_s}(N_f - 1) + 1 \quad \text{or} \qquad (10\text{-}11)$$

$$N_{fs} = \frac{T_o}{T_s}\left(\frac{N_x}{GKT_\circ B}\right) + 1.$$

Noise figure of a complete receiver

$$N_f = 10 \log n_f = n_{F_1} + \frac{n_{F_2} - 1}{G_1} + \frac{n_{F_3} - 1}{G_1 G_2} \cdots \frac{n_{F_n} - 1}{G_1 G_2 \cdots G_{n-1}} \qquad (10\text{-}12)$$

where

N_f = Voice Figure

G_1 = Gain of first stage

G_2 = Gain of second stage

F_1 = Noise factor of first stage, etc.

It is evident that the system noise figure is affected primarily by the first stage gain and noise figure, with each subsequent stage having a decreasing effect. When using a high gain, low noise, front end, the system noise figure is approximately equal to the noise figure of the front end (tunnel diode amplifier or parametric amplifier).

10.1.7 Emphasis

Pre-emphasis is an FM practice of increasing the amplitude of the higher frequency components of the baseband, according to a pre-determined plan (a pre-emphasis curve). An examination of the problems in FM which give rise to the necessity of using pre-emphasis is probably the best means of arriving at an understanding of this practice and the reasons for it. The fundamental problem necessitating the use of pre-emphasis lies in the output characteristics of an FM discriminator. If uniform white noise (constant amplitude with respect to frequency) is placed at the input of an FM discriminator, the output will be a finite band with linearly increasing amplitude with increasing frequency. Discriminator input and characteristics are shown in figures 10-15 and 10-16. The ramp-like output resulting from a white noise input of finite bandwidth is illustrated in figure 10-17. The problem results from the fact that white noise is applied at the discriminator along with the IF signal output. After detection, the higher frequency baseband components are degraded by the ramp-like noise output. The result is a decreasing S/N ratio with increasing baseband frequency. Since optimum performance requires constant S/N ratio across the baseband spectrum, this effect must be corrected. Pre-emphasis at the transmitter modulator is used to accomplish this purpose.

Since increasing peak frequency deviation (ΔF) will increase baseband amplitude, pre-emphasis is accomplished by increasing the peak frequency deviation in accordance with a curve design to effect compensation for the ramp-like noise at the discriminator output. A pre-emphasis curve is shown in figure 10-18. Note that the curve is in terms of deviation ratio (D) rather than ΔF, despite our previous statement that ΔF is the parameter which is varied for pre-emphasis. This apparent inconsistency is resolved when we examine the definition of D and note that in any given baseband configuration, the modulating frequency (F_m) is essentially constant, being taken by convention as either the middle or upper baseband subcarrier frequency. Drawing out pre-emphasis curve in terms of the deviation ratio (D) extends the usefulness of the curve by making it applicable to a variety of different baseband configurations with different subcarrier frequencies.

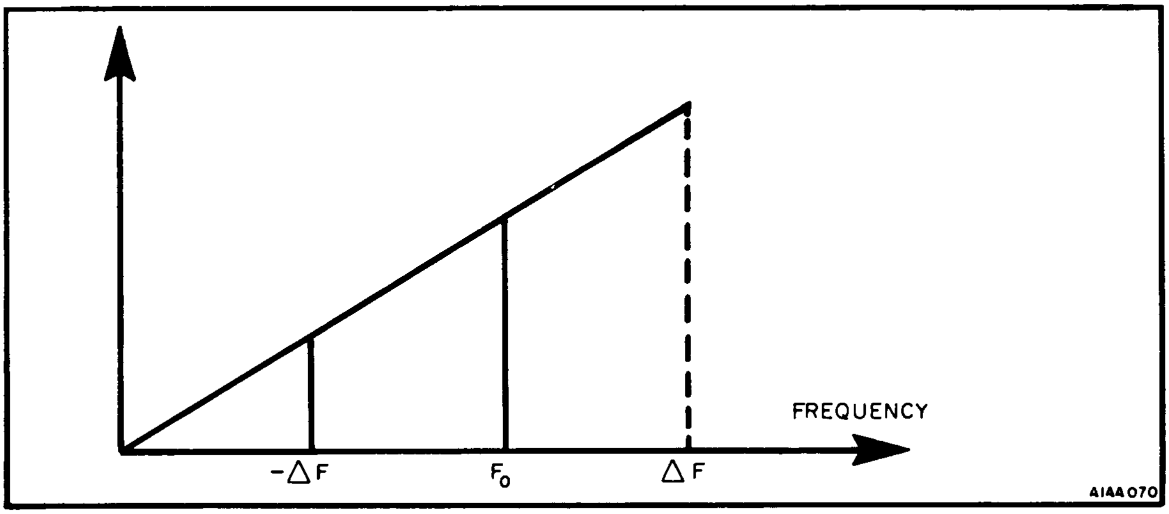


Figure 10-15. Discriminator Characteristics

Once pre-emphasis has been allowed to accomplish its purpose of preserving a constant S/N across the baseband, it is then necessary to restore the detected baseband to its original amplitude configuration. This restoration (de-emphasis) will affect both noise and the signal, preserving the original S/N ratio. The de-emphasizing process can be performed by a single passive network having an attenuation characteristic (de-emphasis curve) inverse to the pre-emphasis curve. Pre-emphasis and de-emphasis are also used for individual FDM voice channels. This is necessary because of the spectral amplitude distribution of speech which shows a high amplitude level concentration at the lower frequency end of the voice channel. This signal distribution, when applied to a baseband, can result in masking the higher frequency low-amplitude components by white noise present before modulation, and in the receiver after detection. The amplitude of the higher frequency components of the voice channels increased to compensate for this condition. De-emphasis is used at the demultiplexer to restore the proper amplitude configuration.

10.1.8 Selectivity

The selectivity of a receiver is its ability to differentiate between the desired signal and signals at other frequencies. Selectivity is usually defined as the ratio of the sensitivity for desired signals to the sensitivity for undesired signals, expressed in decibels. The sensitivity of the receiver for a range of frequencies about the desired frequency is often plotted as a selectivity curve whose shape is primarily determined by the response of the IF amplifiers.

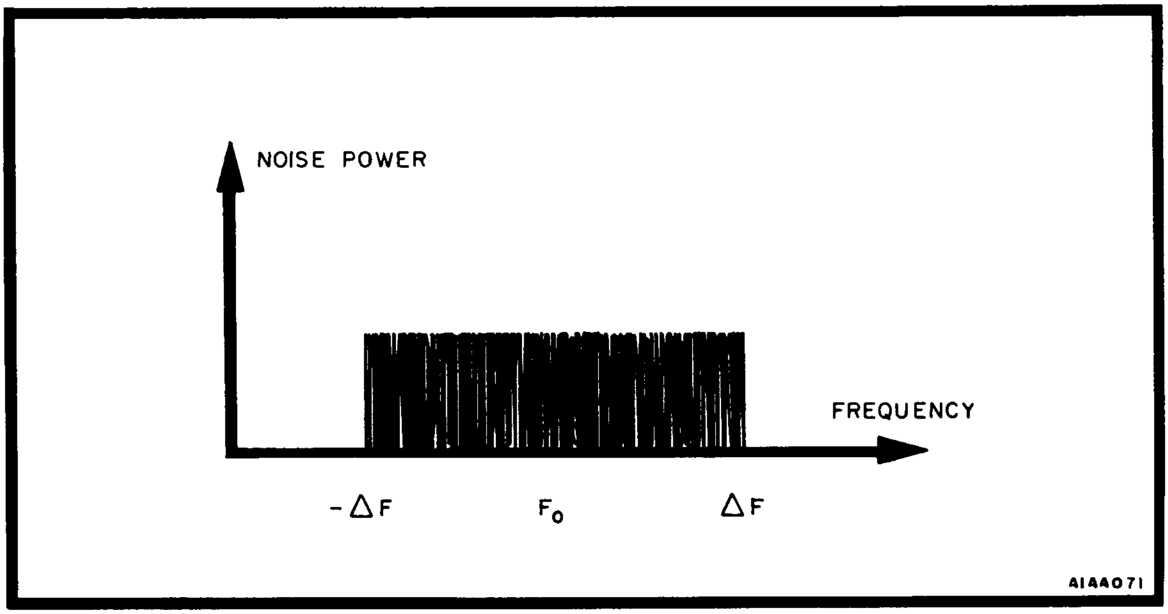


Figure 10-16. Limited Noise Input to Discriminator

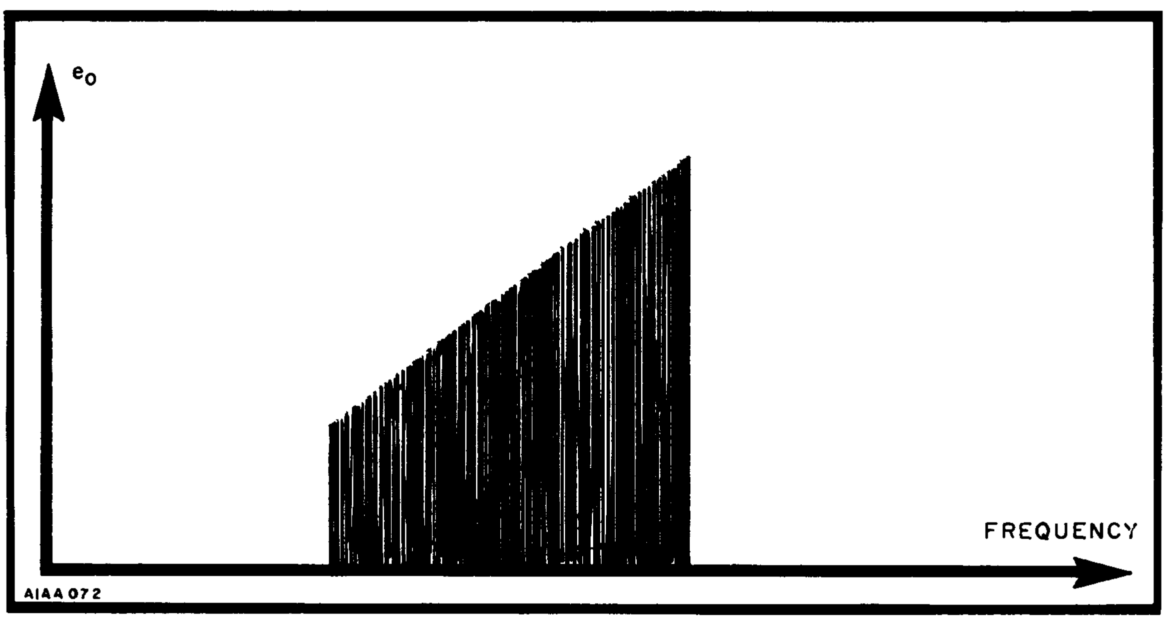


Figure 10-17. Discriminator Output Characteristics, Triangular Noise

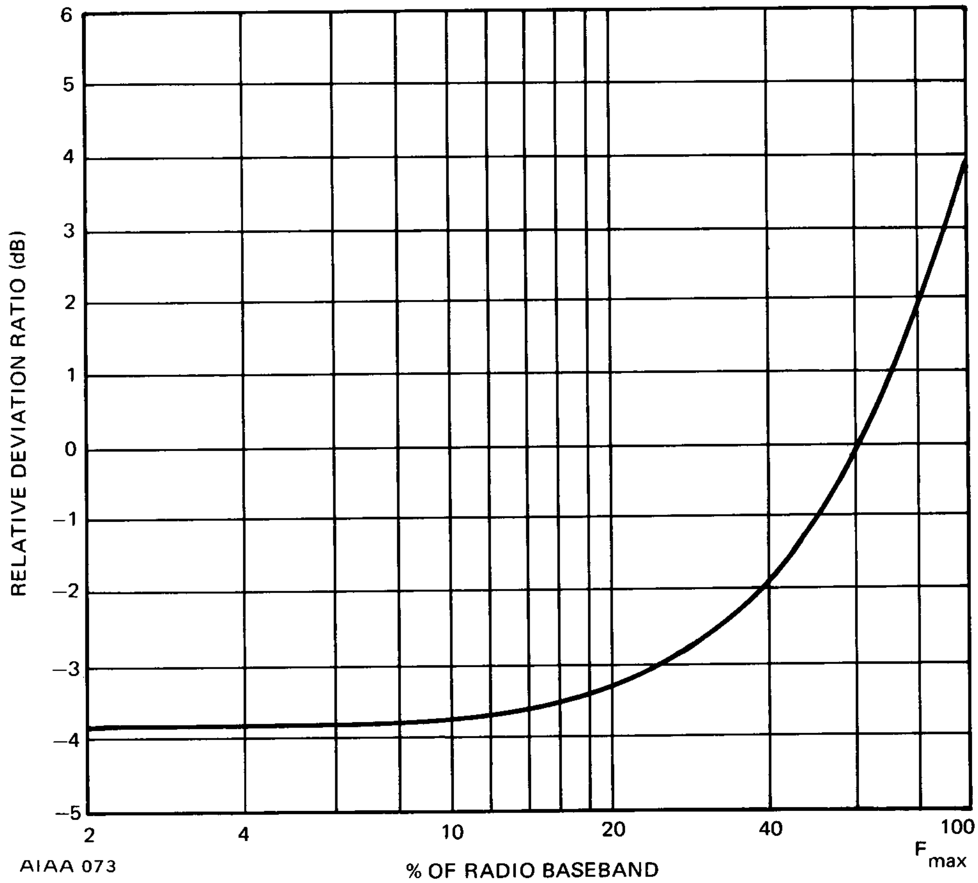


Figure 10-18. Normalized Pre- and De-emphasis Curve

10.1.9 Image Rejection and Spurious Response

The image ratio at the receiver is a measure of the rejection of that frequency which, when mixed with the local oscillator signal, produces the same IF as the desired signal. If the local oscillator is operated below the signal frequency, the image frequency will be the same amount below the local oscillator frequency that the signal frequency is above. The image rejection must take place prior to the mixer in the RF amplifier or preselector stages. Presently the DCA specifies that the image and out-of-band frequencies shall be rejected by at least 60 dB.

10.1.10 Frequency Stability

Frequency tolerance of the receiver shall be 1 part in 10^6 per day ($\pm$ 0.0001%) or better.

10.2 TRANSMITTER

The transmitter consists basically of an oscillator, modulator, and amplifier, with the complexity of these units depending on frequency, power output required, and type of modulation used. This section discusses oscillators as they apply to microwaves, methods of frequency stabilization, microwave modulators, and power amplifiers used in microwave transmitters.

10.2.1 Oscillators

As microwave frequencies are approached the triode coaxial oscillators begin to fall off in efficiency and again new systems must be resorted to in order to produce oscillations at these frequencies. Three general types of oscillators have been developed for use in these ranges: the klystron, the magnetron, and the traveling wave tube. While in the coaxial triode oscillators the problem of interelectrode transit time was encountered, these new types of oscillators take advantage of the finite speed of the electron.

a. Klystron. Two main categories of klystron oscillators exist: the reflex klystron and the 2-cavity klystron. The reflex klystron has low efficiency (about 1 percent) and generates relatively low power. It is primarily used in receivers, local oscillators, and test equipment. Two-cavity klystrons are much more efficient (from 20 to 40 percent) and can be designed to generate high power levels. Most of the limitations of conventional negative grid tubes do not exist in klystrons. The cathode and anode are outside the RF field and therefore may be made as large as desired. The cathode to anode spacing is of the order of one inch so that extremely high voltages may be used without danger of internal arcing. The only limiting factor in the amount of power which may be produced by a klystron is the loss in the dielectrics making up the windows between the output cavity and the load.

In a 2-cavity klystron, a stream of electrons from and electron gun passes through a resonant cavity called a buncher. This cavity is the input cavity and contains an RF field corresponding to the signal input. In the case of an oscillator, the input is fed back with the proper phase relationship from the output or catcher cavity. The buncher either accelerates or retards the electrons in the stream depending on the portion of the RF cycle. Following the buncher there is the drift space where the electron beam is unaffected except by the uniform accelerating force of the anode voltage. In this space the electrons form into bunches, the retarded electrons falling back and the accelerated electrons moving forward to the next bunch. When the electrons, now bunched, reach the catcher, they set up a varying electric field from which energy may be taken. The electrons themselves continue on to the anode, or collector, where their remaining kinetic energy is dissipated as heat.

A modified version of the 2-cavity klystron is the reflex klystron oscillator. The operating principles remain nearly the same. In this klystron the coupling between the input and the output is accomplished by the electron beam itself. In fact, the two resonating cavities are replaced by one cavity which functions both as buncher and catcher. The electrons are produced and accelerated by an electron gun as before. Then they pass through the cavity for the first time, being velocity modulated as in the buncher of a 2-cavity klystron. The electrons travel into the drift-space but instead of being further accelerated, they are in a uniform retarding field produced by the negative repeller plate. The electron beam slows to a stop and then reverses direction being accelerated back toward the cavity. As the bunched electrons pass through the cavity for the second time, they give up part of their energy to the cavity and are then stopped by the cavity, which also functions as the collector. The frequency of operation can be changed to a limited extent by changing the repeller voltage, thus changing the transit time in the drift stage.

The reflex klystron is less efficient than the 2-cavity klystron because a single resonator performs both functions of bunching and catching. On the other hand, the single resonator tuning and the ease of electrical tuning by varying the repeller voltage makes it better for use when only small amounts of power are required. Another advantage of the reflex klystron is its greater stability as compared to a 2-cavity klystron when used as a master oscillator.

b. Magnetron. To aid understanding of the principle of operation in a traveling-wave magnetron, the most commonly used, consider the movement of an electron in magnetic and electric fields. An electron moving at right angles to a magnetic field will be acted upon by a force perpendicular to both its direction of motion and the magnetic field. This force does not change the velocity of the electron but causes it to move in a circular path, the radius of the path being determined by the magnetic field strength and the velocity of the electron. An electron moving parallel to an electric field will be either accelerated, taking energy from the field, or retarded, giving energy to the electric field.

The magnetron is basically a fixed-frequency device, but certain of the newer types may be frequency modulated by changing the potentials on certain elements. Anode power is normally applied to a magnetron in very short pulses of very high amplitude. Voltages of 40 kilovolts and currents of 100 amperes are not unusual in pulsed magnetron service. It is possible to produce a peak power of 2.5 megawatts at 3000 MHz with an efficiency as high as 50 percent. At frequencies of 25,000 MHz, more than 50 kW may be obtained, but the efficiency will fall to about 25 percent.

The traveling wave tube (TWT) connected as an oscillator is essentially an amplifier which uses an electron beam and an RF wave traveling together in such a way that the wave accepts energy from the electron beam. In some ways it is similar to the linear magnetron discussed previously. The TWT consists of a helical coil inside a conductor. It may be considered as a coaxial cable with a helical inner conductor. In operation, the RF wave to be amplified travels along the helical coil which greatly reduces the velocity of the wave. This slower velocity causes the RF wave to travel at the same speed as an electron beam centered in the helical coil, which enables the RF wave to accept energy from the beam.

Assuming the electron velocity and the wave propagation velocity are the same, the electrons in the beam will be retarded or accelerated by the electric field. This will cause bunching to occur, with the electron bunches forming in alternate points of zero longitudinal electric field. In producing these bunches, as many electrons are retarded as are accelerated and no net transfer of energy is made in either direction. Since this would produce no amplification, some means must be found of obtaining a transfer of energy from the electron beam to the electric field. This can be done by a slight increase in the velocity of the electron beam. The electron bunches are now at a retarding point of the electric field and the electrons are retarded for a longer period of time than they are accelerated. This will produce a transfer of energy to the wave, and therefore the wave is amplified. A necessary addition to the TWT is some means of preventing the electron beam from spreading. This is done by using a longitudinal magnetic field. As long as the electron beam moves parallel to the magnetic field it has no effect on the electrons. When the electron strays from a parallel path, however, the magnetic field forces the electron back into the beam. By coupling the output to the input in the proper phase relationship, oscillation may be produced. The TWT can be used over a great range of frequencies with high gain, at a cost of low power output and efficiency.

10.2.2 Frequency Stability

An ideal oscillator would be one in which the frequency could be easily adjusted and, once set, remain at that frequency regardless of temperature, output load, or voltage input. At low frequencies these conditions are relatively easy to approach, but as operating frequencies are increased, stability of operating frequency becomes more difficult to obtain. Even by attaining the same percentage of stability, which in itself is hard to do, serious frequency shifts may occur at microwave frequencies. A frequency shift of 0.01 percent at 1 MHz is only 100 cycles which presents no problems, but this same percentage shift at 10,000 MHz is equal to 1 MHz which is enough to interfere with satisfactory operation.

Three primary factors affect the operating frequency of an oscillator. There are, first, geometric factors in which the effective inductance and capacitance are changed directly through mechanical motion; second, pulling factors in which reactance is coupled into the oscillatory circuit from the load; and third, pushing factors in which reactance is introduced by changes in input conditions, such as voltage, current, or magnetic field.

There are three means of insuring stable operating frequencies. One is by the use of frequency stabilizers that tend to maintain a constant frequency of oscillations; another is by automatic frequency control (AFC) systems that mechanically or electronically retune the oscillator when it shifts from a reference frequency; the third is the use of synthesizing circuits, where crystal control is necessary to maintain the required frequency stability.

As required by DCA standards, equipment design shall be such that the center frequency of the radiated signal from any transmitter which generates its own RF signal internally shall be maintained to within 150 kHz of the assigned frequency.

10.2.3 Emphasis

Both pre-emphasis and de-emphasis are defined and discussed in paragraph 10.1.7.

10.2.4 RF Extraneous and Spurious Outputs

The average power of any extraneous or spurious emissions in the $f_o \pm 5\% f_o$ band. MIL-STD-461 and Figure 14, Appendix C of MIL-STD-188C specify the out-of-band emission limits in terms of absolute power levels versus the transmitted power of the fundamental. Measurements shall be made taking full advantage of transmission line and antenna filtering characteristics. (For RF leakage, other undesired-emanation measurements and permissible limits refer to Military Standards 461 and 462.)

10.2.5 Deviation-Mod Index

In FM, the varied parameter of the carrier, which carries the amplitude of the modulating wave, is its instantaneous frequency, but the maximum deviation of frequency from its assigned value is limited arbitrarily and independently of the modulation. Thus, frequency allocations for FM broadcast are for a 200-kHz channel. A guardband of 25 kHz is used at each side of the channel, leaving a 150-kHz bandwidth, or plus and minus 75 kHz from the carrier resting frequency. Other allocations for FM services may limit the total band to 50 kHz, or 10 kHz. A function called "modulation index" is the ratio of the maximum frequency difference between the modulated and the unmodulated carrier, or deviation frequency to the modulation frequency. It is sometimes referred to as the "deviation ratio." The degree of modulation in an FM system is usually defined as the ratio of the frequency deviation to the maximum frequency deviation allowable, or the ratio of frequency deviation to the maximum deviation of which the system is capable. Degree of modulation in a frequency modulation system, therefore, is not a property of the signal itself.

10.2.6 Power Amplifiers

The modulated signal may be passed to an amplifier to increase the amplitude of the outgoing signal. The same limitations of conventional circuits at microwave frequencies that applied to oscillators apply as well to amplifiers. In the microwave region no amplification is possible with conventional vacuum tubes and circuits; either the oscillator itself must supply enough power, or specially designed amplifiers must be used.

a. Klystron Amplifier. The klystron amplifier may be a 2-cavity klystron as used for an oscillator or a special amplifier klystron used for high power, which is known as a cascade or 3-cavity klystron. This tube is effectively two klystrons connected in cascade within the same envelope, with the catcher for the first section functioning as the buncher for the second section. The signal to be amplified is applied to the first cavity and the power output is taken from the third cavity. The second cavity is energized by the bunched electron beam and is not supplied with external RF driving power. These tubes are capable of power gains up to 30 dB, efficiencies of 30 to 40 percent, with a power output of 12.5 kW.

b. Traveling Wave Tube Amplifiers. Traveling wave tube amplifiers are the second type of amplifier tube that may be used at microwave frequencies. The tubes have inherent regenerative feedback due to wave reflections in the tube. When designed for amplifier service, some means of attenuating the reflected wave must be provided. However, they are capable of large amplifications with a wide passband and high efficiency.

CHAPTER 11

MICROWAVE MULTIPLEX EQUIPMENT

Multiplex operation is the simultaneous transmission of two or more messages in either or both directions over the same transmission path. There are two general methods of accomplishing this: Frequency Division Multiplex (FDM) is the division of the available frequency spectrum into discrete bands, each of which carries one of the functions; Time Division Multiplex (TDM) is the division of the time available into discrete intervals that are assigned successively to the several functions.

11.1 FREQUENCY DIVISION MULTIPLEX

11.1.1 Functional Description

Telephone multiplex subsystems provide the overall communication system with the capability to transmit and receive a number of voice frequency channels over a single transmission subsystem. In FDM subsystems, all channels to be multiplexed onto a single broadband channel are "divided" in the frequency domain to keep the signal channels separated. The information contained in each channel within the composite FDM signal is transmitted during the same instant of time. That is, all FDM signal channels overlap in the time domain and, in effect, are transmitted in parallel. This is accomplished through the use of various frequency translations. Basically, frequency translation is the shifting of a band of frequencies from one part of the frequency spectrum to another. During the process of frequency translation, the information contained in the original band of frequencies is not changed. Frequency translation is obtained through the use of modulation techniques, and the translation may be to a higher or a lower band of frequencies.

Figure 11-1 illustrates the basic process of FDM for a 12 channel voice frequency system. With reference to the figure, it should be noted that each channel originally occupies a 4 kHz band of frequencies. During transmission, each channel is translated up in frequency to occupy a unique 4 kHz band in a continuous frequency region. For example, channel 12 is translated to occupy the 60 to 64 kHz band, channel 11 is translated to occupy the 64 to 68 kHz band, et cetera. The result of this translation process is the stacking of all 12 channels within a continuous frequency band of 48 kHz. The composite signal contained within the 48 kHz band may then be transmitted over a single transmission subsystem. One or more steps of frequency translation may be required depending on the multiplex and transmission subsystems that will be used.

During reception, each 4 kHz band of frequencies in the composite signal is translated down in frequency to obtain the 12 individual 4 kHz channels.

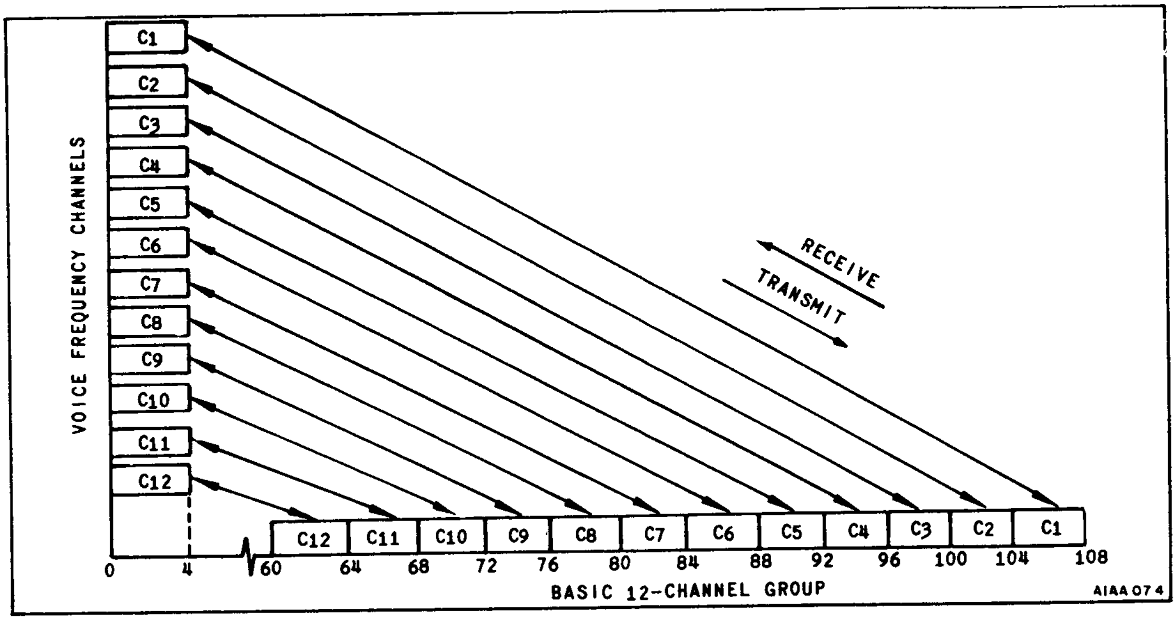


Figure 11-1. FDM Process for a Basic 12-Channel Group

All multiplex subsystems use some type of modulation scheme to translate the voice frequency signals to a composite signal of some suitable frequency range. The modulation scheme includes frequency allocations for the composite signal and the type of modulation used for frequency translation. The frequency allocation for the system shown in figure 11-1 represents the basic standard building block for long haul multiplex subsystems within the DCS. This standard, 60 to 108 kHz, 12 channel system is used to form systems with hundreds of channels by using additional steps of frequency translation.

The 12 channels contained within the 60 to 108 kHz band are commonly referred to as a 12 channel group, or simply a group. A 60 channel system, commonly called a supergroup, is obtained by translating five groups to another part of the frequency spectrum. The basic translation process is similar to that used to develop a group, the only difference being the frequency allocation and bandwidth of the composite supergroup signal. Figure 11-2 illustrates the structure of a 60 channel supergroup.

A 600 channel system is obtained by translating 10 supergroups using the same basic FDM process. The DCS standard frequency allocation for the 600 channel system is shown in figure 11-3. It should be noted that in the 600 channel system, supergroup 1 is translated down in frequency and supergroup 2 is transmitted without additional translation. All other supergroups are translated up in frequency by methods similar to the translation process for channels to group, and groups to supergroup. The use of guard bands between each supergroup when translated to the master group frequency spectrum should also be noted. Between supergroups 1 and 2, and 2 and 3, a 12 kHz guard band is used. An 8 kHz guard band is used between all other supergroups. In the case of translating from channels to group, and groups to supergroup, guard bands are not included in the composite frequency allocation.

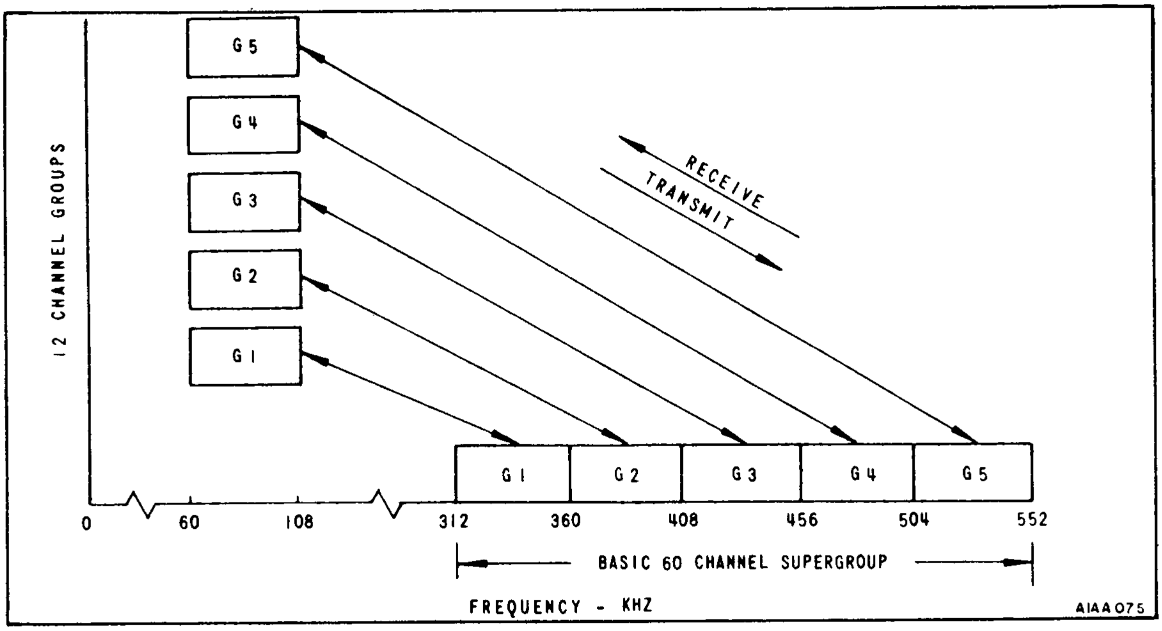


Figure 11-2. FDM Process for a 60-Channel Supergroup

The preceding discussion was intended to provide a broad functional description of the basic FDM process as applied to telephone channels. It should be noted that the actual frequency allocations for a particular telephone FDM multiplex system will be dependent upon:

- o The type of transmission subsystem
- o The number of channels required for the overall system.

Chapter 6, System Design, presents equipment performance criteria, including frequency allocation and interface parameters, for the various types of transmission subsystems used in the DCS.

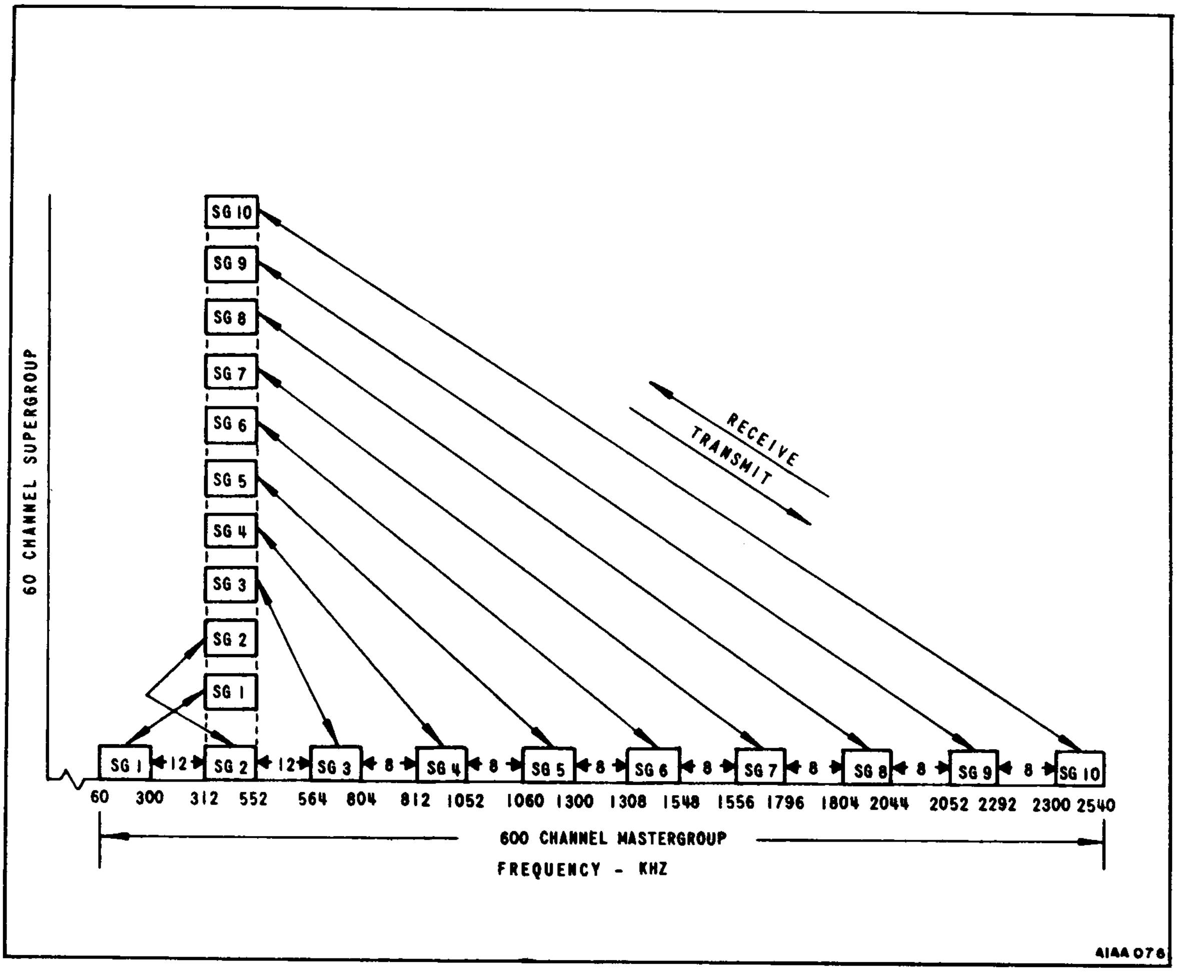


Figure 11-3. FDM Process for a 600-Channel Master Group

Telephone multiplex subsystems are designed primarily to handle voice frequency (VF) signals. DC telegraph signals, as found in teletypewriter operation, cannot be handled directly by telephone FDM equipment. By using the techniques of modulation and multiplexing, DC signals can be converted to AC tones in the VF range. The VF tones can be handled by the telephone FDM equipment. Voice frequency carrier telegraph (VFCT) equipment is used to provide this capability.

In FDM/VFCT operation within the DCS, a number of carriers within the VF range are modulated by DC signals from telegraph loops. Each telegraph loop is associated with a particular carrier. The nominal center frequencies of the carriers are generally spaced 170 Hz apart. With this spacing, it is possible to obtain 16 to 18 carriers within the VF range. Some VFCT equipments, such as the AN/FGC-75(V) and -76(V), use a phase modulation technique to transmit up to 32 telegraph channels over a single VF channel. This technique, however, is not specified in DCAC 330-175-1. In addition, such equipment is not compatible with conventional FDM VFCT equipment.

11.1.2 Theory of Operation

The basic technique used in FDM is frequency translation. Signals that occupy a particular band of frequencies are translated (shifted) to another part of the available frequency spectrum. The shifting of signals in frequency is accomplished through the process of modulation. Since AM is so important to the overall FDM process, the various forms of AM will be briefly described.

Basically, modulation is the process by which some property of a signal is varied in accordance with the intelligence to be transmitted. The signal that is varied by the intelligence is generally called the carrier signal, or simply the carrier. In AM systems, it is the amplitude of the carrier that is varied.

When a carrier is amplitude modulated, a complex signal is generated. In addition to the carrier frequency itself, an AM signal contains other frequencies commonly known as the upper and lower sideband frequencies. The upper sideband contains the sum of the carrier frequency and the frequencies in the modulating signal. The lower sideband contains the difference of the carrier and signal frequencies. Other sidebands centered at multiples of the carrier frequency are also generated, but are generally eliminated by filters.

Figure 11-4 illustrates the basic AM process. In this example, the intelligence to be transmitted contains frequencies up to 4 kHz, and the carrier frequency is 64 kHz. Both intelligence and carrier are mixed in the amplitude modulator in order to generate the AM signal. The resulting AM signal is centered around the carrier frequency of 64 kHz with the intelligence contained in the two 4 kHz wide sidebands. Thus, the intelligence is translated in frequency to another part of the frequency spectrum.

The AM process can be repeated to shift the signal frequencies to still another band, either higher or lower in frequency. It is this ability to translate signal frequency components to any part of the frequency spectrum that makes the process of modulation so important to FDM subsystems. The manner in which the sidebands are shown in figure 11-4 is the standard method when dealing with FDM subsystems. Upper sidebands are shown with the long side of the right triangle increasing in height from left to right. The reverse is true for lower sidebands. Also, it is common practice to call the upper sideband the erect sideband, and the lower sideband the inverted sideband. Furthermore, this AM process is also referred to as double sideband emitted carrier (DSBEC) in order to differentiate between certain variations of AM that are described below.

In AM systems, the carrier does not contain any intelligence. The carrier is used only to carry the intelligence to another band of frequencies. Furthermore, both the upper and lower sidebands contain identical information. Thus, the carrier and one of the sidebands are completely superfluous with regard to the intelligence contained in the AM signal. Because of this, certain FDM subsystems do not use AM directly but instead use variations of AM. The generally used variations of AM are:

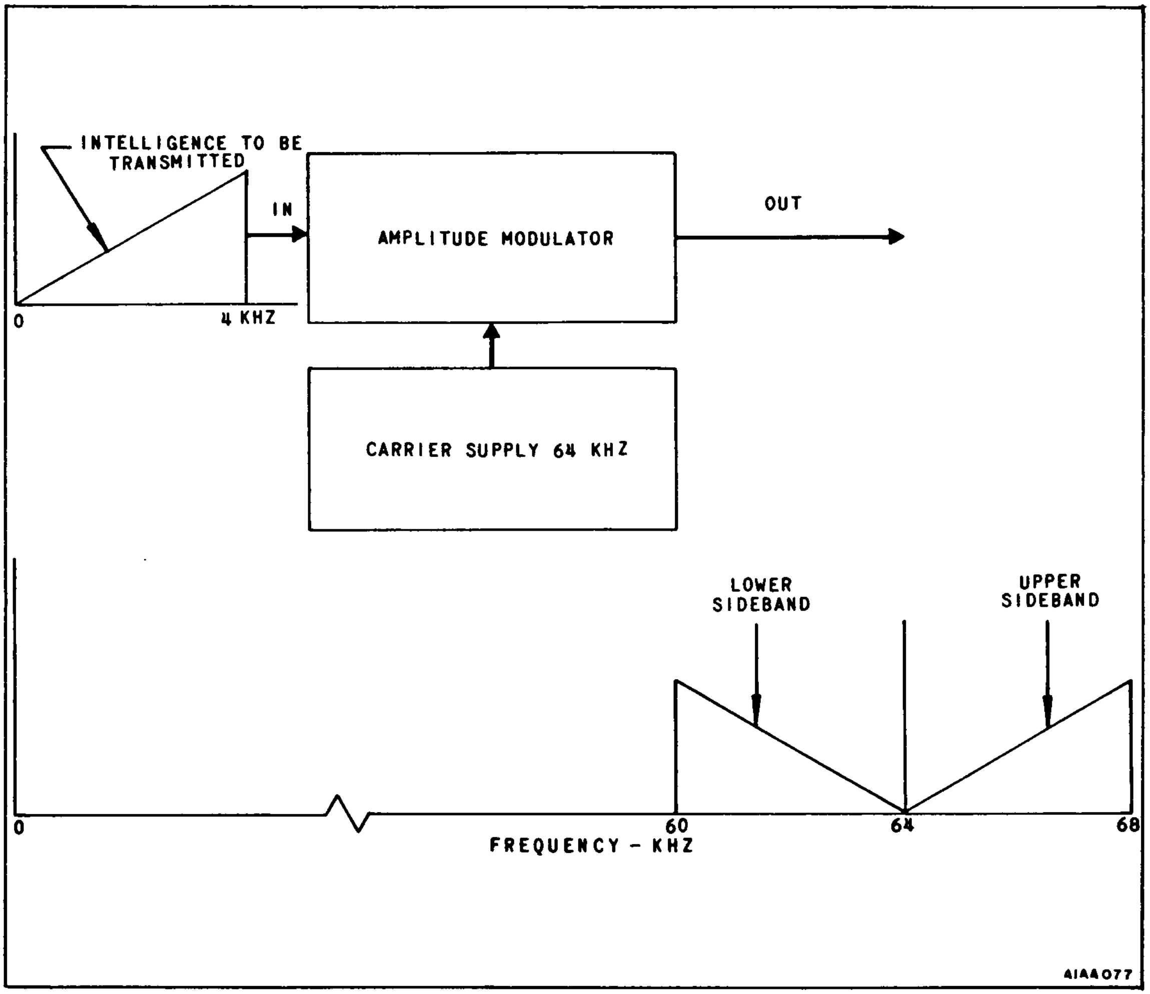


Figure 11-4. Basic Amplitude Modulation Process

- Single sideband suppressed carrier
- Double sideband suppressed carrier
- Independent sideband
- Single Sideband Suppressed Carrier (SSBSC).

With SSBSC, only one sideband is transmitted. The other sideband and the carrier are eliminated or suppressed. By transmitting only one sideband, the power required to transmit the signal is reduced. Also, the frequency band is effectively reduced to one-half of that required for a direct AM signal. It then becomes possible to transmit twice as many signal channels in the same multiplex frequency band.

Figure 11-5 illustrates a two channel SSBSC multiplex subsystem. Signals from each telephone transmitter pass through low-pass filters. These filters limit the upper end of the frequency band to about 4 kHz. The 4 kHz wide signals are applied to the balanced modulator where they are combined with their respective carriers as in conventional AM. By using a balanced modulator, the carrier is suppressed within and does not appear in the output signal spectrum. Therefore, the output of each balanced modulator contains only the upper and lower sidebands, centered around their respective suppressed carriers. Both sidebands are applied to a bandpass filter where the upper sideband is eliminated. The output of the bandpass filters are combined to form the composite FDM signal. The composite signal contains the intelligence from both telephone transmitters, and occupies an 8 kHz band between 60 and 68 kHz.

At the receiving end, the composite signals are applied to bandpass filters. The bandpass filter associated with channel 1 passes only the 60 to 64 kHz band, and that of channel 2 the 64 to 68 kHz band. The outputs of the bandpass filters are applied to balanced modulators where they combine with their respective carriers. This process is similar to that performed at the transmit end, and the carriers are suppressed within the balanced modulators. Therefore, the output of the balanced modulators contain only the upper and lower sidebands. The lower sidebands associated with each channel occupy the 0 to 4 kHz band, i.e., the original band of frequencies out of the low-pass filters at the transmit terminal. The upper sideband (associated with channel 1) occupies the 124 to 128 kHz band and that of channel 2 the 128 to 132 kHz band. The lower sidebands are then applied to the telephone receivers after the upper sidebands are removed by the low-pass filters.

The basic principles of operation for the illustrative two channel system apply to FDM subsystems that can handle hundreds of channels. This particular variation of AM is used in most high density FDM subsystems and is the standard FDM technique for international communication systems.

o Double Sideband Suppressed Carrier (DSBSC). In FDM subsystems that use the DSBSC variations of AM, both sidebands are used but the carrier is suppressed. This technique offers a saving in power required to transmit the composite multiplex signal but is still wasteful of frequency spectrum. However, DSBSC systems are less expensive to implement than the SSBSC variation. This is primarily due to the elimination of bandpass filters required to remove the unwanted sidebands in the transmit of the FDM equipment.

Both the emitted and suppressed carrier versions of the double sideband type of system find extensive use in multipair cable transmission subsystems. This is particularly true where transmission paths do not exceed 50 miles and the required number of channels is 24 or less.

The most widely used double sideband FDM subsystems fall into the category commonly known as the N-type of system. Various manufacturers offer FDM subsystems using the same frequency allocations and channel arrangements so that they coordinate back to back over the same transmission subsystem. Some systems are available that coordinate from a frequency standpoint with N-type systems, but that use single

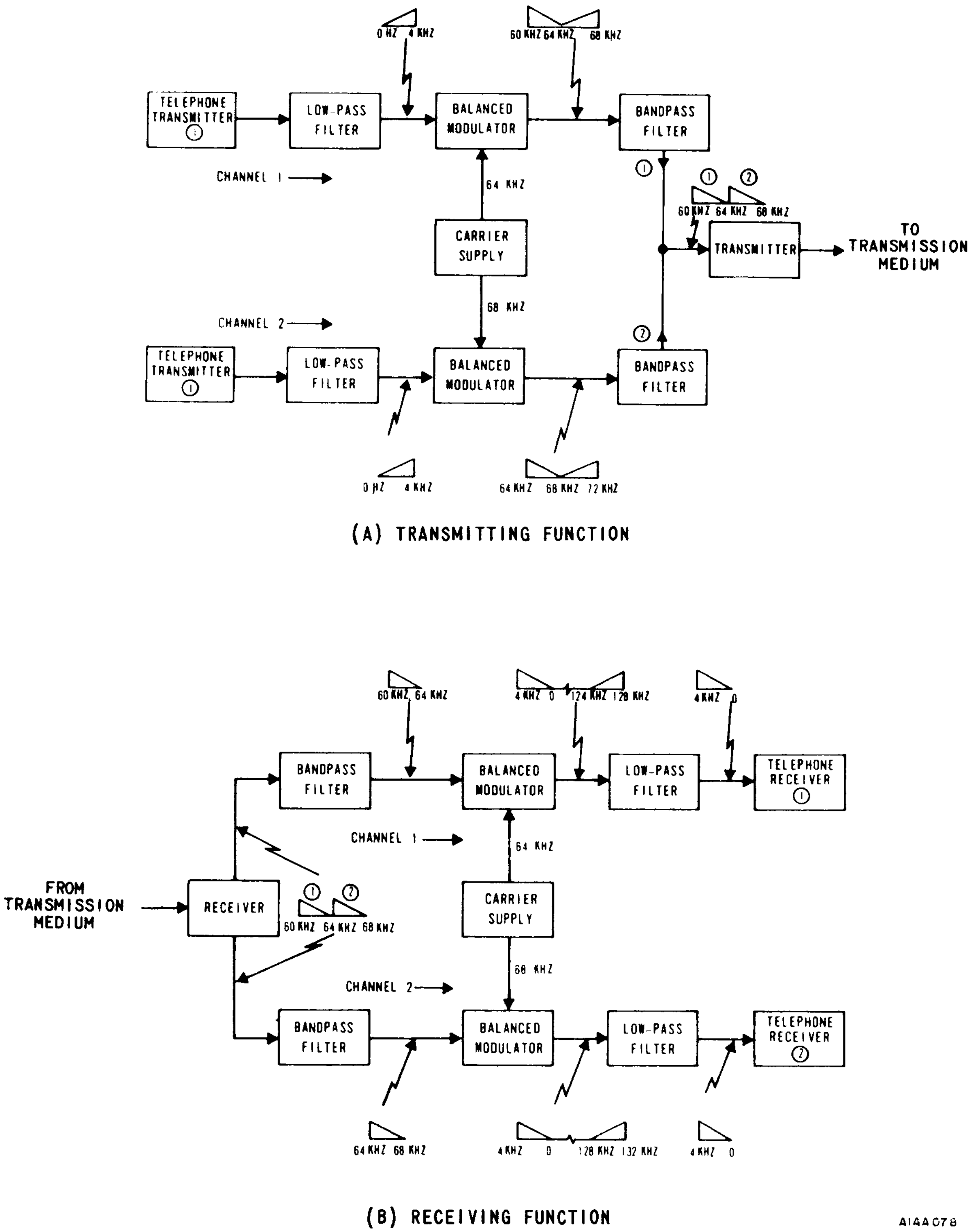


Figure 11-5. Two Channel SSBSC Multiplex Subsystem

sideband techniques. Therefore, the number of channels that can be handled on the transmission subsystem is doubled.

o Independent Sideband (ISB). With independent (twin) sideband modulation, a single carrier is used to generate two independent sidebands (the upper and lower sidebands centered around the same carrier contain different information). The same basic AM and filtering techniques described above are used to generate the ISB signal. The ISB method of modulation is used in high frequency (HF) subsystems and in certain high-density multiplexer sets.

In HF subsystems, the maximum authorized bandwidth in the HF spectrum is 12 kHz. Due to this narrow bandwidth and the need for the maximum number of channels within the 12 kHz spectrum, individual channels are limited to a bandwidth of 3 kHz. Using ISB, four channels can be accommodated within the 12 kHz spectrum. Two 2 kHz channels are first multiplexed into a 6 kHz band. Two such bands are used to modulate two independent sidebands of an HF ISB transmitter to produce four channels in the HF spectrum. Figure 11-6 illustrates the frequency spectrum of an HF ISB system.

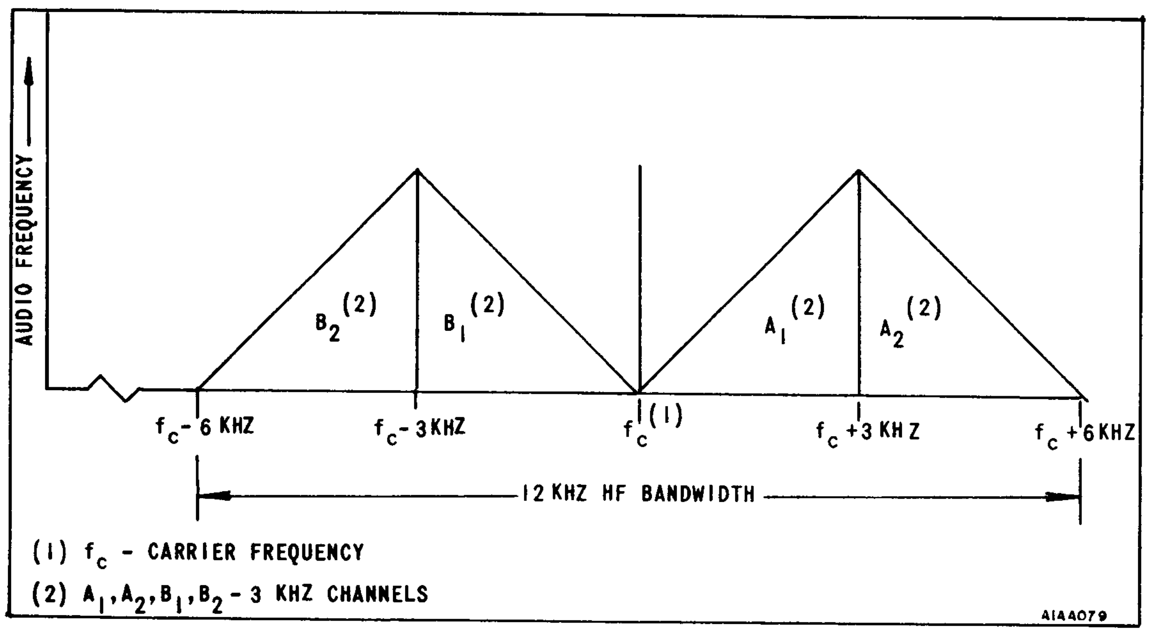


Figure 11-6. HF/ISB Frequency Spectrum

In high capacity multiplex sets (60 channels or greater) the group, supergroup, and line frequency allocations are in accordance with DCS and international standards. However, the channel multiplexing modulation is independent (twin) sideband as opposed to the all-lower sideband modulation that is the DCS and international standard. A later version of the AN/FCC-17 family, designated AN/UCC-4(V), provides an all-lower sideband capability. Figure 11-7 illustrates the difference between ISB and all-lower sideband modulation (note that 12 carriers are required to generate the standard basic group and only 6 carriers are required for the ISB basic group).

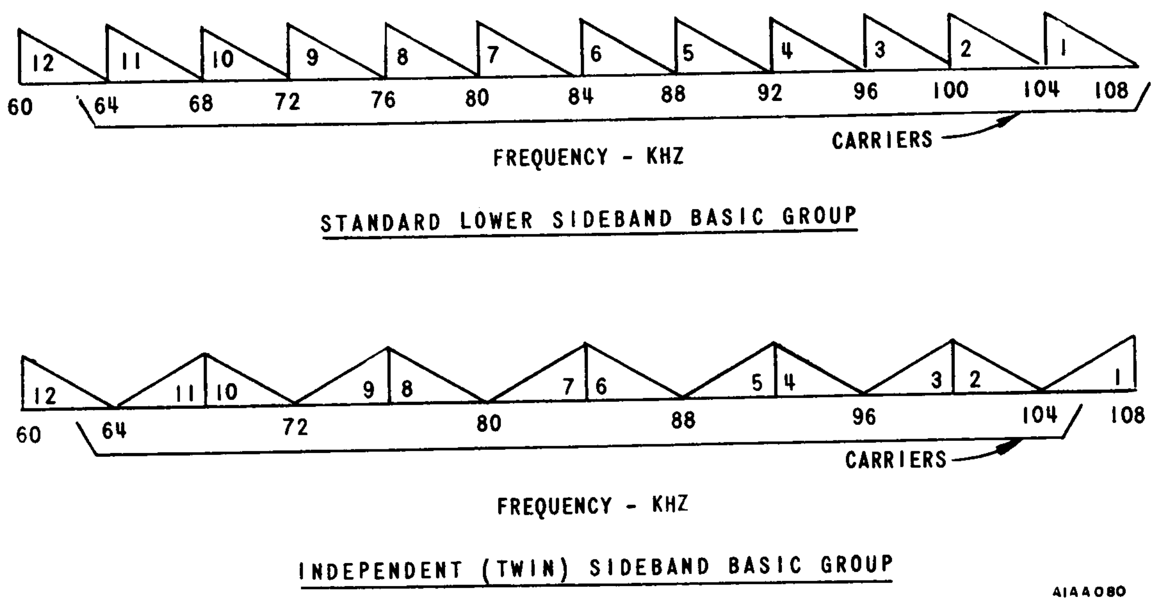


Figure 11-7. Comparison of Standard Basic Group With ISB Basic Group

11.2 TIME DIVISION MULTIPLEX (PULSE MODULATION)

11.2.1 Functional Description

In telephone TDM subsystems all voice frequency (VF) channels to be multiplexed are "divided" in the time domain. The information contained in each channel within the composite TDM signal is transmitted during a different instant of time but overlaps in a common frequency spectrum. That is, all TDM signal channels "time share" a common transmission channel and, in effect, are transmitted in a serial manner. The direct relationship of the composite signal to the original input signal found in FDM subsystems is not found in TDM subsystems due to the nature of the basic TDM process as described below.

The TDM method employs sampling techniques. If a signal is sampled at a rate twice its highest frequency component, an adequate representation of the signal may be obtained. If there are a number of channels to be sent over a common transmission path, the first channel is sampled briefly, then the second, and so on until the last channel. After the last channel is sampled, the process is repeated. Before each sample is applied to the common transmission path, some form of pulse modulation is used to form the composite TDM signal. Figure 11-8 illustrates the basic TDM transmission-process for a 12 channel telephone system.

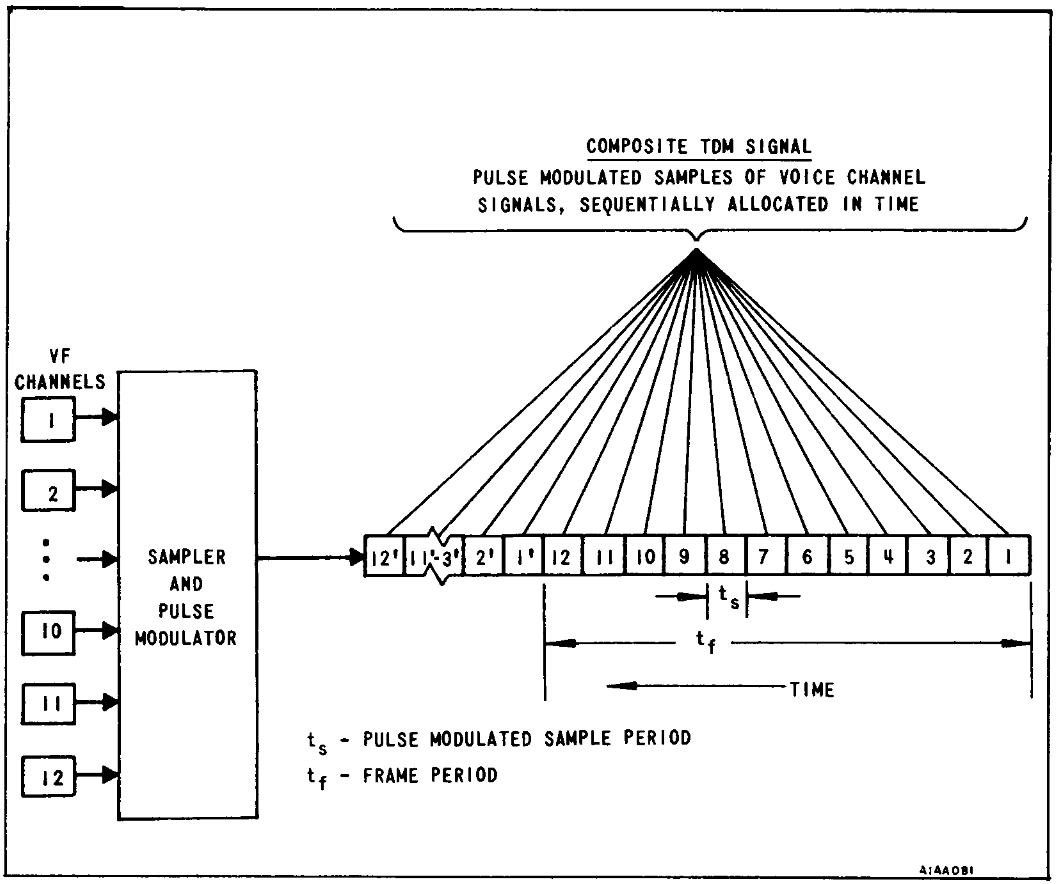


Figure 11-8. Basic Time Division Multiplex Process

Each voice channel occupies a 4 kHz bandwidth. Therefore, a sampler must scan and sample each of the voice channels at twice this figure, i.e., at 8 kHz. One complete set of samples (in this case, 12 samples) is generally called a frame. The time it takes to sample all 12 channels is called the frame period. In this example, the frame period, t_f, is equal to 125 microseconds.

$$t_f = \frac{1}{8\ \text{kHz}} = \frac{1}{8 \times 10^3}\ \text{seconds} = 125\ \text{microseconds}$$

Each sample within a frame period is pulse modulated before it appears sequentially on the composite TDM signal channel. For this example, the time available to represent the sample in a pulse modulated form is equal to one-twelfth of the frame period. Therefore, the pulse modulated sample period, t_s, is equal to about 10.4 microseconds. The pulse modulated sample period can be broken down into smaller subperiods depending upon the type of pulse modulation used in the TDM subsystem.

$$t_s = \frac{t_f}{12} = \frac{125\ \text{microseconds}}{12} = 10.4\ \text{microseconds}$$

At the receiving end, the reverse process takes place. Each sample is demodulated to obtain the original voice channel sample. The voice channel samples are filtered and sequentially applied to the corresponding voice channel to yield a restored voice signal.

Pulsed systems of modulation offer an attractive means of providing much greater density of information bits per channel than has been discussed. Consider a pulsed circuit in which the highest modulating frequency is to be 5000 cycles per second, comparable to the modulation band of a broadcast transmitter. The minimum sampling rate for pulse modulating such a wave is 10,000 samples per second, or twice the frequency of the highest modulation frequency. This gives an interval per pulse of 100 microseconds, but pulses need be only one or two microseconds long to transmit the essential information. Thus, if a pulse position modulated (PPM) system has pulses of 1-microsecond duration, and the maximum time displacement at peak modulation is 4.5 microseconds, the allocation of time per pulse must be about 10 microseconds. This leaves 90 microseconds of each pulse interval that is not needed for the channel considered, and that can be allocated to other channels. If, in this instance, we divide the available 100 microseconds into 8 time blocks of 12 microseconds each, we can accommodate eight 5 kc channels, with a 20 percent (2-microsecond) guardband between each channel, plus a 4-microsecond interval in which to transmit a synchronizing pulse. This synchronizing pulse if needed at the receiver to provide a reference by use of which the individual channel pulses may be separated.

A time-multiplexed signal can be obtained by generating the pulses for each individual channel just as if it alone is involved, with the addition of timing circuits to delay the individual channel pulses so that successive channels have a progressive time difference, in the above case a difference of 12 microseconds, and the addition of a 4-microsecond synchronizing pulse prior to each sequence of channel pulses. This mixture of pulses is then used to modulate the carrier, which may be either a wire line, a radio path, or a subcarrier of such transmission media. At the receiver, after demodulation and separation of the subcarriers, the detector-output will consist of a chain of pulses identical with the one at the transmitter. This output passes through a system of time gates, one for each channel, that are controlled by the synchronizing pulse. The control is such that the gate for an individual channel is open only during the 12-microsecond interval associated with that channel.

Other pulsed systems may be time-multiplexed by the same method. If, in a given system, there are "n" time-multiplexed channels on each of "m" subcarriers, the system will have a total number of channels equal to "mn." The total number of channels is an important consideration. However, for a frequency allocation of fixed bandwidth, an increase in the number of channels reduces the bandwidth available per channel and, depending upon the application, this will dictate the maximum number of channels to be generated.

Figure 11-9 shows a time-multiplexed PAM system. Figure 11-10 shows a series of typical waveforms in the TDM/PAM system. In figure 11-9 the commutator connects the input channels in sequence to the sampling circuit at the basic repetition rate established by the clock pulse generator, and separates each series of timed samples with a synchronizing pulse. The resulting pulse train is shown in B, figure 11-10. At the receiver the pulse train in duplicated at the detector output. The pulse-width discriminator isolates the synchronizing signal, and the synchronizing signal initiates a series of time delays corresponding to the channel pulse positions in the pulse train. Each gate circuit receives all pulses at one input, and a gating pulse for a specific channel at the other input opens the gate only, during the time interval that its corresponding signal pulse appears at the multiple pulse input. The output of each gate circuit is thus a sequence of signal pulses sampled from a single channel; this modulated waveform may be recovered by using a low-pass filter or a peak detector.

Any mode of pulse modulation lends itself to TDM. The requirement being that the receiving equipment must be able to separate the several channels so that the sample pulses may be used to reconstruct the original modulating signal with distortion within acceptable limits.

The basic principles of operation of TDM telegraph equipment are similar to that of TDM telephone equipment. DC signals from a number of telegraph loops are assembled (interleaved) sequentially for transmission over a single circuit. However, since DC telegraph signals are already in pulse form, the sampling and pulse modulation required in TDM telephone equipment is not needed. The process is simply one of interleaving telegraph channels into a composite TDM signal that is compatible with the particular transmission subsystem.

In its simplest form, the operation of telegraph TDM equipment is similar to that of parallel-to-serial and serial-to-parallel converters. That is, when sending, parallel inputs are converted to a single serial output. Conversely, when receiving, a single serial input is converted to a number of parallel outputs. The modulation rate of the single serial stream depends on the number of associated telegraph loops and the loop modulation rate. For example, if 16 unit interval signals of 75 bauds are time division multiplexed, the modulation rate of the serial stream would be 16 x 75 = 1200 bauds.

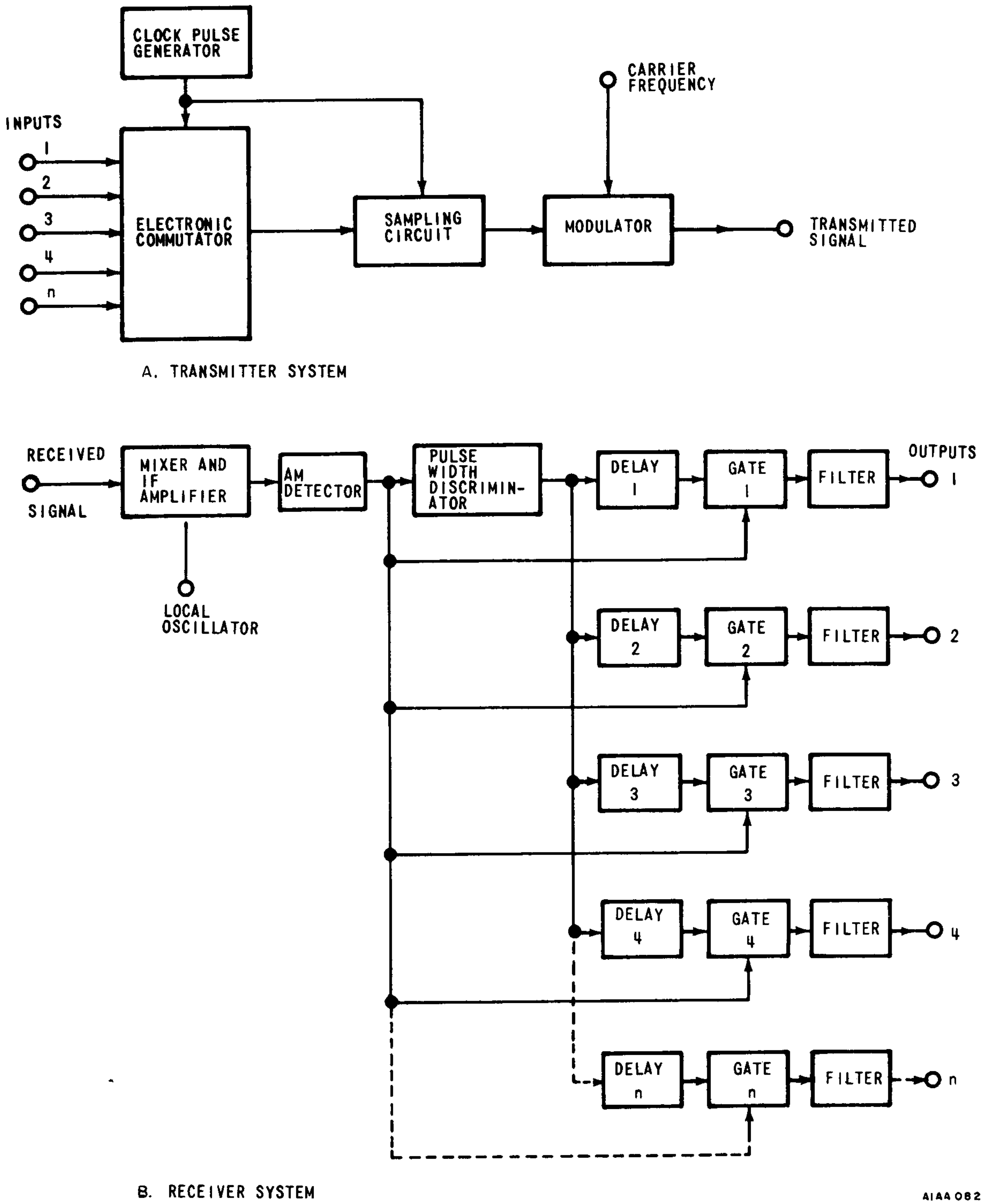


Figure 11-9. Time Multiplexed PAM System

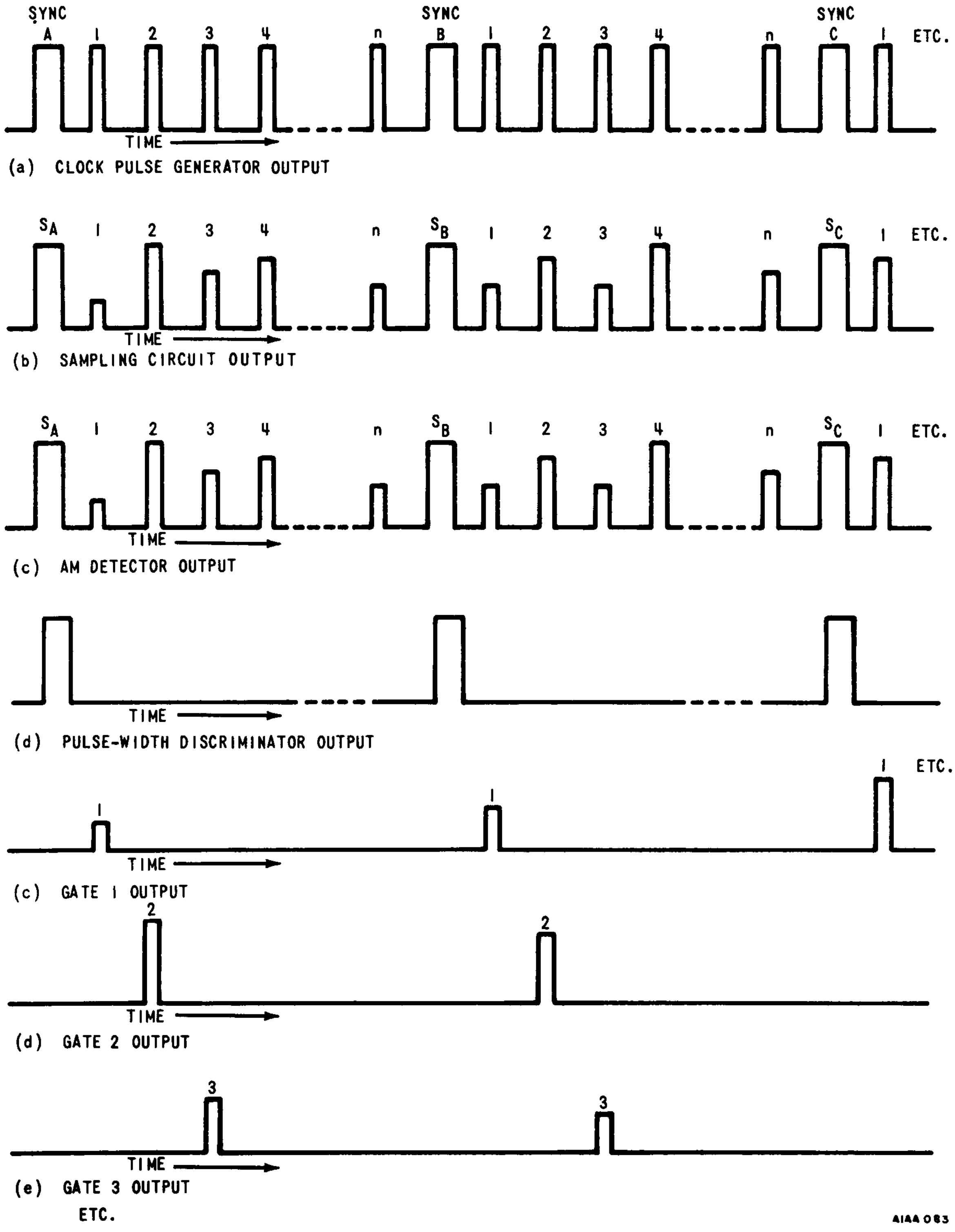


Figure 11-10. Waveforms in the FDM/PAM System

Typical telegraph TDM equipment used in the DCS can handle up to sixteen 60-, 75-, or 100-word-per-minute DC telegraph loops.

11.2.2 Theory of Operation

Earlier it was mentioned that all TDM subsystems are based on the principle of time sharing. Signals are multiplexed by sequentially allocating different time intervals for the transmission of each signal. The signals that are sequentially allocated are not a direct representation of the original signal, but only a sample of the original signal. Before each sample is applied to the common transmission path, some form of pulse modulation is used to form the composite signal. This paragraph will describe in greater detail the principles of pulse modulation techniques that can be applied to TDM subsystems.

With pulse modulation, one or more parameters of a pulse are varied in accordance with a modulating signal to transmit the desired information. The resultant modulated pulse train may then be used to modulate a carrier. This is done with AM or FM techniques, depending upon the transmission subsystem to be used. Pulse modulation that can be used to form composite TDM signals include:

o Pulse amplitude modulation (PAM) o Pulse duration modulation (PDM) o Pulse position modulation (PPM) PTM o Pulse frequency modulation (PFM)	} Analog Pulse Modulation
o Pulse code modulation (PCM) o Delta modulation (DM)	} Digital Coding

It should be noted at this point that PAM and PTM are truly analog pulse modulation techniques. Although the latter two, PCM and DM, are commonly referred to as pulse modulation techniques, they are really digital coding techniques. The following paragraphs discuss and compare the various pulse modulation techniques beginning with the concept of sampling.

a. Pulse Modulation Sampling Theorem. Figure 11-11 illustrates the spectrum of a sampled signal. Assume that the signal at (A), plotted as amplitude versus time, has a spectrum (B) which contains negligible energy outside some low-frequency bandwidth f_m. This is actually the case with most communication signals, though the location and width of f_m depends more or less on an arbitrary definition of "negligible energy." If the signal is now multipled by a periodic series of pulses, shown at (C), the product, shown at (E), is called a "sampled signal" and is obtained from (A) by "sampling." The period "T" between sampling pulses is called the "sampling interval" and its reciprocal 1/T is the sampling frequency, shown in (D). Inspection of the sampled spectrum at (F) shows that the free space called "margin" between the shifted

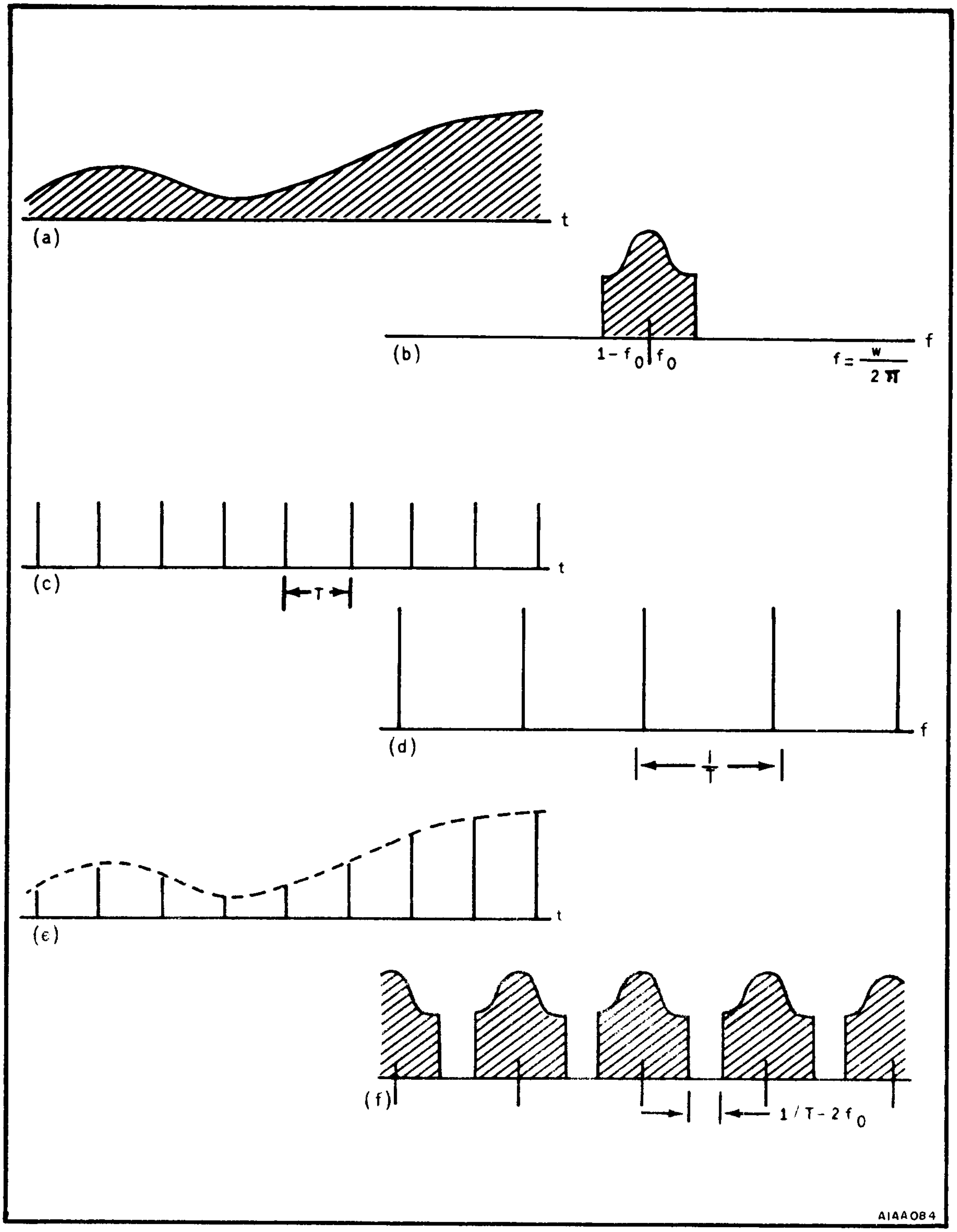


Figure 11-11. Spectral Characteristics of a Sampled Signal

replicas of the original spectrum is equal to the sampling frequency less twice the original frequency spectrum f_m. When such a margin exists -- that is, if the spectral replicas do not overlap - then spectrum (F) contains exactly the same information about the original signal as does the original spectrum (B), and the original signal (A) is recoverable from the sampled signal (E). One method of recovery is to pass the sampled signal through an electric wave filter, which passes frequencies below f_m without distortion, but rejects frequencies above f_m. When the spectral pulses of (F) overlap, the margin is negative and each pulse is contaminated by its neighbors. This contamination represents lost information concerning the original signal, and thus the original signal is no longer completely recoverable. To avoid such negative margin, the sampling frequency must be at least twice the highest modulation frequency. That is, the signal must be sampled at least twice during each cycle of its highest frequency component, in order that it may be recovered without recourse to highly complex circuitry.

b. <u>Pulse Amplitude Modulation (PAM)</u>. The sampling pulses of a sampled signal must be varied in some characteristic by the modulating signal, in order for the intelligence of the signal to be present in the pulsed wave. Figure 11-12 shows some of the ways in which pulses may be varied; (A) represents a sine wave of intelligence to be modulated on a transmitted wave; (B) shows the timing pulses which determine the sampling interval; (C) shows Pulse Amplitude Modulation (PAM) in which the amplitude of each pulse is controlled by the instantaneous amplitude of the modulation signal at the time of each pulse. (The other patterns of figure 11-12 will be discussed in subsequent paragraphs, as PAM is the present subject.)

Pulse amplitude modulation may be either unquantized, where the pulse amplitude is varied as a continuous function of the modulation signal, or quantized, where the continuous information to be transmitted is approximated by a finite number of discrete values, one of which is transmitted by each sampling pulse. Quantization will be treated in detail later in the following paragraphs. In figure 11-11 (E) and figure 11-12 (C) are shown examples of unquantized pulse amplitude modulation, in which the amplitudes of the successive pulses are proportional to the instantaneous values of the signal wave, at the time of sampling. It is apparent that these successive pulses will quite faithfully reproduce the signal wave, and that the fidelity of reproduction will be greater with increased sampling frequency. As previously stated, the sampling frequency must be at least twice the highest modulation frequency for full signal recovery.

As indicated in figure 11-11, each harmonic of the pulse frequency is amplitude modulated by the modulating signal, resulting in sideband signals displaced above and below each harmonic by the modulating frequency. After further modulating an RF carrier, either by amplitude or angle modulation methods, transmission and demodulation at a receiver by suitable amplitude or angle detection, the modulation signal may then be recovered by filtering or by peak detection methods.

The basic process of PAM will be applied to a hypothetical 4 channel TDM subsystem. For this example, it will be assumed that each of the four channels is band limited to 4 kHz; therefore, the sampling rate must be at least 8 kHz. Using an 8 kHz sampling rate, each channel is sampled once every 125 microseconds, i.e., each frame is 125

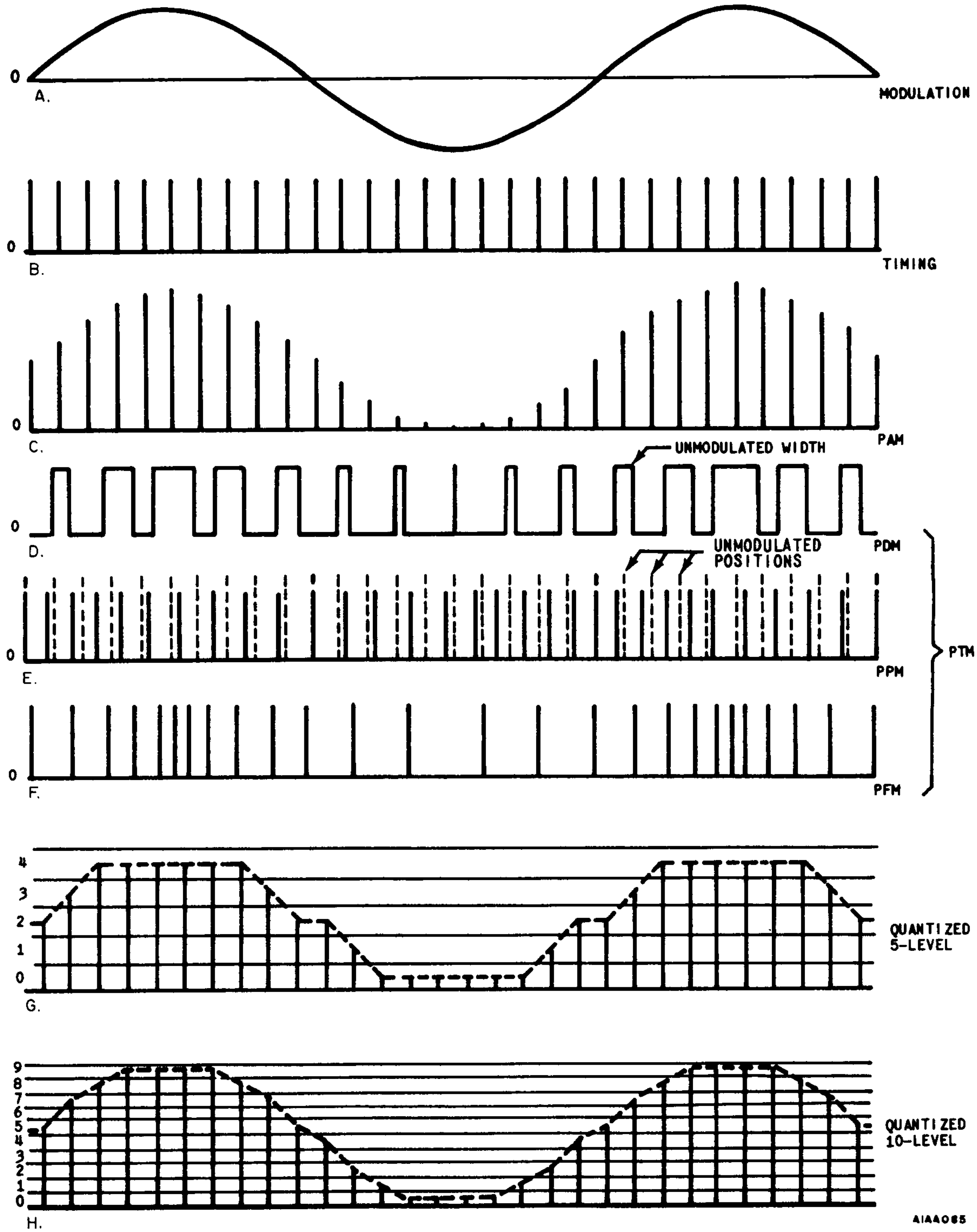


Figure 11-12. Pulse Modulation and Utilization

microseconds long. The channels are sampled sequentially with regard to signal amplitude as shown by the shaded areas S1, S2, S3, et cetera, on figure 11-13. Since there are 4 channels to be sampled during each frame, the time available to represent each signal amplitude in pulse form is 31-1/4 microseconds. As each channel is sequentially sampled, the signal amplitudes at each sampling instant amplitude modulate a repetitive pulse train. This results in the composite TDM signal shown in figure 11-14.

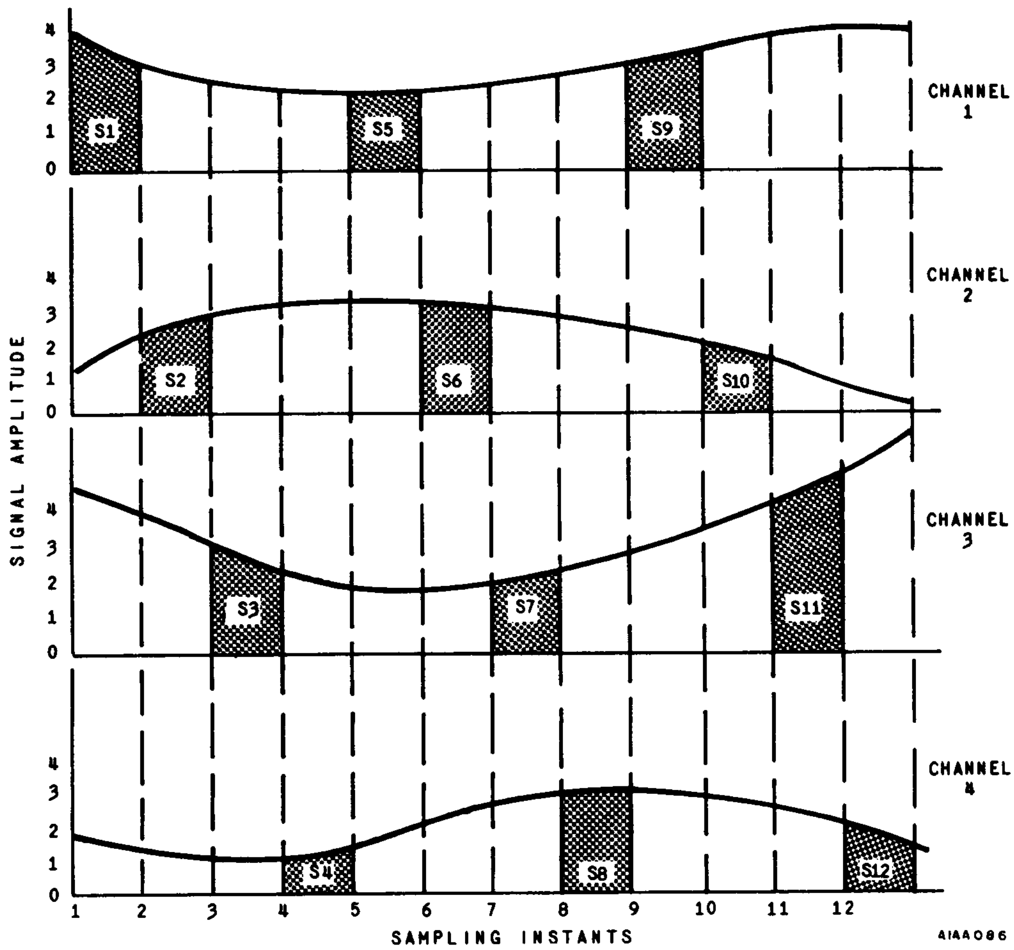
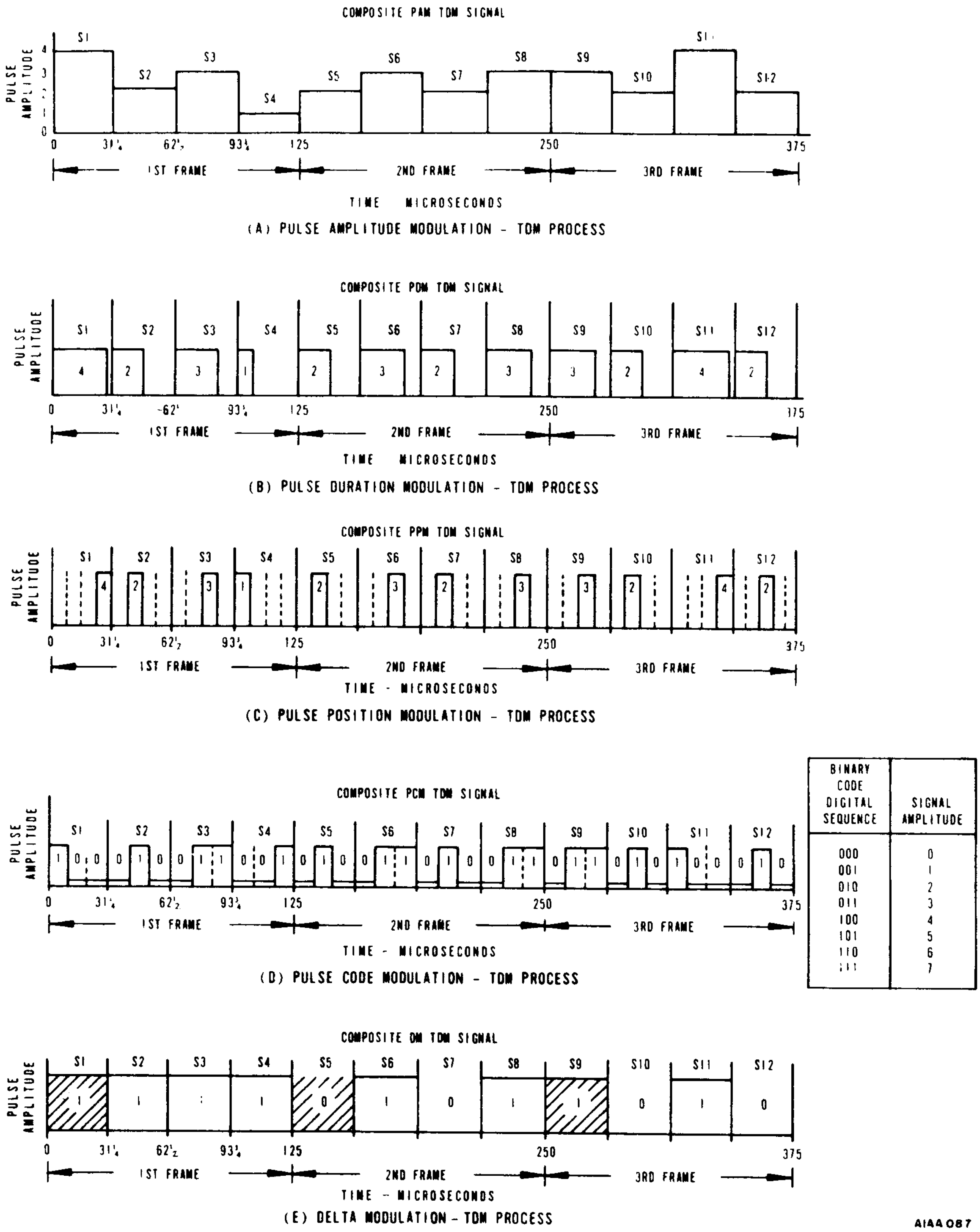


Figure 11-13. Analog Signal Channels



BINARY CODE DIGITAL SEQUENCE	SIGNAL AMPLITUDE
000	0
001	1
010	2
011	3
100	4
101	5
110	6
111	7

Figure 11-14. Comparison of TDM Processes

c. Pulse Time Modulation (PTM). In pulse modulated systems, as in analog systems, it is possible to impress the intelligence on the carrier by varying any of its characteristics. In the preceding paragraphs, it was discussed how a pulse train was modulated by varying its amplitude. The same intelligence could be used to modify the time characteristic of the pulses. There are two time characteristics which may be affected; the time duration of the pulses, which is called Pulse Duration Modulation (PDM), or Pulse Width Modulation (PWM); and the time of occurrence of the pulses, called Pulse Position Modulation (PPM), and a specific type of PFM called Pulse Frequency Modulation (PFM). Figure 11-12 shows these types of pulse time modulation at (D), (E), and (F).

(1) Pulse Duration Modulation (PDM). Pulse Duration Modulation (PDM), Pulse Width Modulation (PWM), and Pulse Length Modulation (PLM) are all designations for a single type of modulation in which the width of each pulse in a train is made proportional to the instantaneous value of the modulating signal at the instant of the pulse. Either the leading edges, the trailing edges, or both edges of the pulses may be modulated to produce the variation in pulse width. PDM can be obtained in a number of ways, one of which is illustrated in figure 11-15. By adding the modulating signal, figure 11-15 (A), to a repetitive sawtooth, (B), the waveform at (C) is obtained. This waveform is then applied to a circuit which changes state when the input signal exceeds a specific threshold level to produce pulses whose width is determined by the length of time that the input waveform exceeds the threshold level. The resulting pulse train is then as shown at (D), and in figure 11-12 (D).

Figure 11-14(B) illustrates the PDM process as applied to TDM subsystems. In this simplified example, only four distinct signal amplitudes are used, i.e., signal amplitudes of 1, 2, 3, and 4. This was also true in the PAM example described above. Therefore, to represent the four distinct signal amplitudes in PDM form, four distinct pulse durations are required. These can be obtained by designating the full pulse duration to represent a signal amplitude of 4, three-fourths of the pulse duration to represent a signal amplitude of 3, et cetera. This is illustrated in the composite TDM signal shown in figure 11-14(B). It should be noted that the trailing edge of the pulse is modulated in this example.

Demodulation of PDM signals also may be accomplished in a number of ways. Since the average value of the pulse train varies in accordance with the modulation, the same as in the case of PAM, the intelligence may be extracted by passing the width-modulated pulses through a lowpass filter that passes only the desired modulation frequencies.

(2) Pulse Position Modulation (PPM). Pulse Position Modulation (PPM) is a method in which each instantaneous sample of a modulating wave controls the time position of a pulse in relation to the timing of a recurrent reference pulse that coincides with the position of each unmodulated signal pulse. The pulse train is shown in figure 11-12(E) as solid lines and the reference positions are shown as broken lines. PPM can be obtained in several different ways, two of which will be discussed in the following paragraphs. One system uses a method similar to that used to obtain PDM. Figure 11-16 shows the curves for this method. The modulating signal is added to a repetitive sawtooth and a pulse of fixed duration is generated each time the

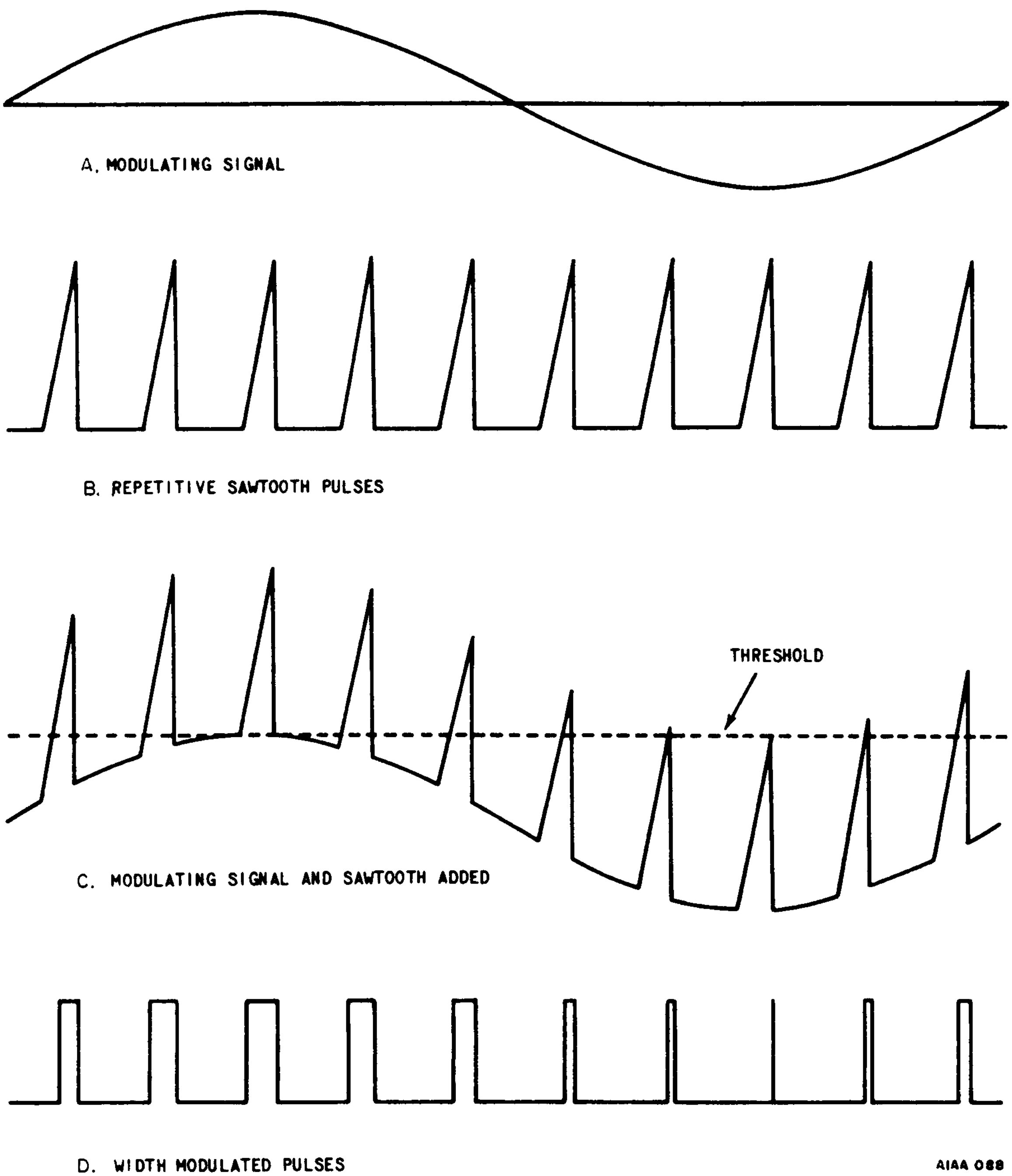


Figure 11-15. Method of Generating PDM

combined signal exceeds a fixed threshold level. PPM can also be obtained by taking a PDM pulse train that has fixed leading or trailing edges, differentiating the pulses and then using a rectifier to separate the pulses having the polarity corresponding to the differentiated modulated edge of the individual width-modulated pulses. This is illustrated in figure 11-17 using PDM with fixed leading and modulated trailing edges. The effect of pulse-position modulation upon the pulse frequency spectrum is to frequency modulate each of the harmonic components of the pulse spectrum as well as the DC term.

When the peak variation in pulse time occurrence is small compared to the interpulse period, PPM can be demodulated by passing the pulse train through a network having a frequency response with a slope of -6 dB per octave throughout the range of modulating frequencies. Alternative methods of demodulating a PPM wave are to convert the wave to either pulse-width or pulse-amplitude form, and then demodulating with a lowpass filter or a peak detector. The process involved in TDM subsystems using PPM is illustrated on figure 11-14(C). Once again, only four distinct signal amplitudes are used. Therefore, four distinct pulse positions are needed. Each sampling interval is broken up into four possible positions. A pulse present in the first position represents a signal amplitude of 1; a pulse in the second position represents a signal amplitude of 2, et cetera. This is illustrated on the composite TDM signal shown on figure 11-14(C).

(3) Pulse Frequency Modulation (PFM). Pulse Frequency Modulation (PFM) is a method of pulse modulation in which the modulating wave is used to frequency modulate a carrier wave consisting of a repetitive pulse train. The resultant pulse train is shown in figure 11-12(F). A comparison of this pulse train with that of the PPM train shown at (E) reveals that PFM is only a variation of PPM and can be demodulated by the same techniques.

d. Quantization. All of the pulse modulation systems discussed provide methods of converting analog wave shapes, such as audio, video, and facsimile systems products, to digital wave shapes; that is, pulses occurring at discrete intervals, some characteristic of which is varied as a continuous function of the analog wave. If the entire range of amplitude (or frequency or phase) values of the analog wave is arbitrarily divided into a series of standard values, and each pulse of a pulse train takes the standard value nearest its actual value when modulated, the modulating wave can be rather faithfully reproduced as shown in figure 11-12 at (G) and (H). The amplitude range has been divided into five standard values at (G), and each pulse is given whatever standard value is nearest its actual instantaneous value. At (H), the same amplitude range has been divided into 10 standard levels, and it is immediately apparent that the curve of (H) is a much closer approximation of the modulating wave (A) than is the five-level quantized curve at (G). From this it is evident that the greater the number of standard levels used, the more closely the quantized wave approximates the original. This is also made evident by the fact that an infinite number of standard levels exactly duplicates the conditions of nonquantization.

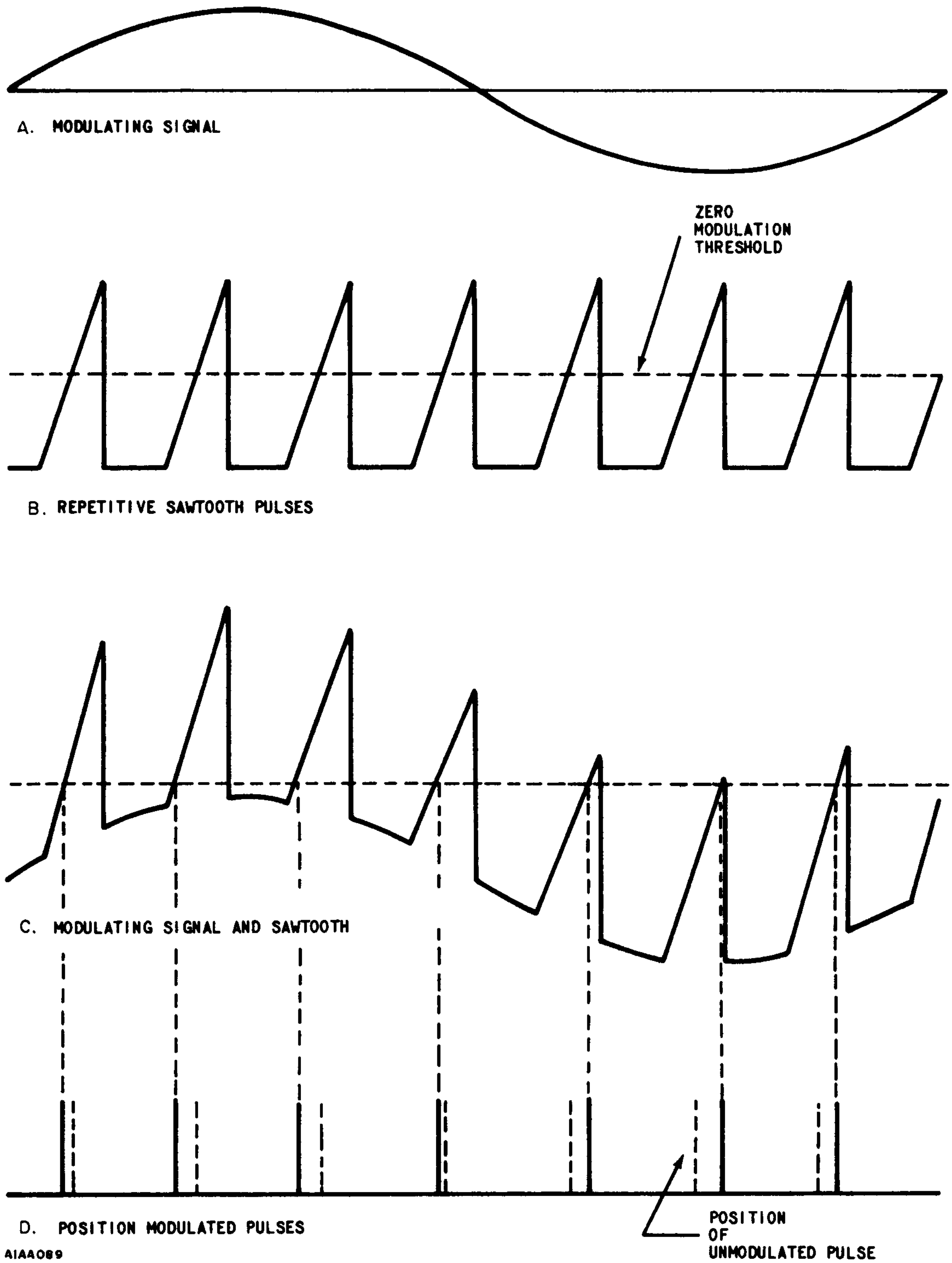


Figure 11-16. Method of Generating PPM

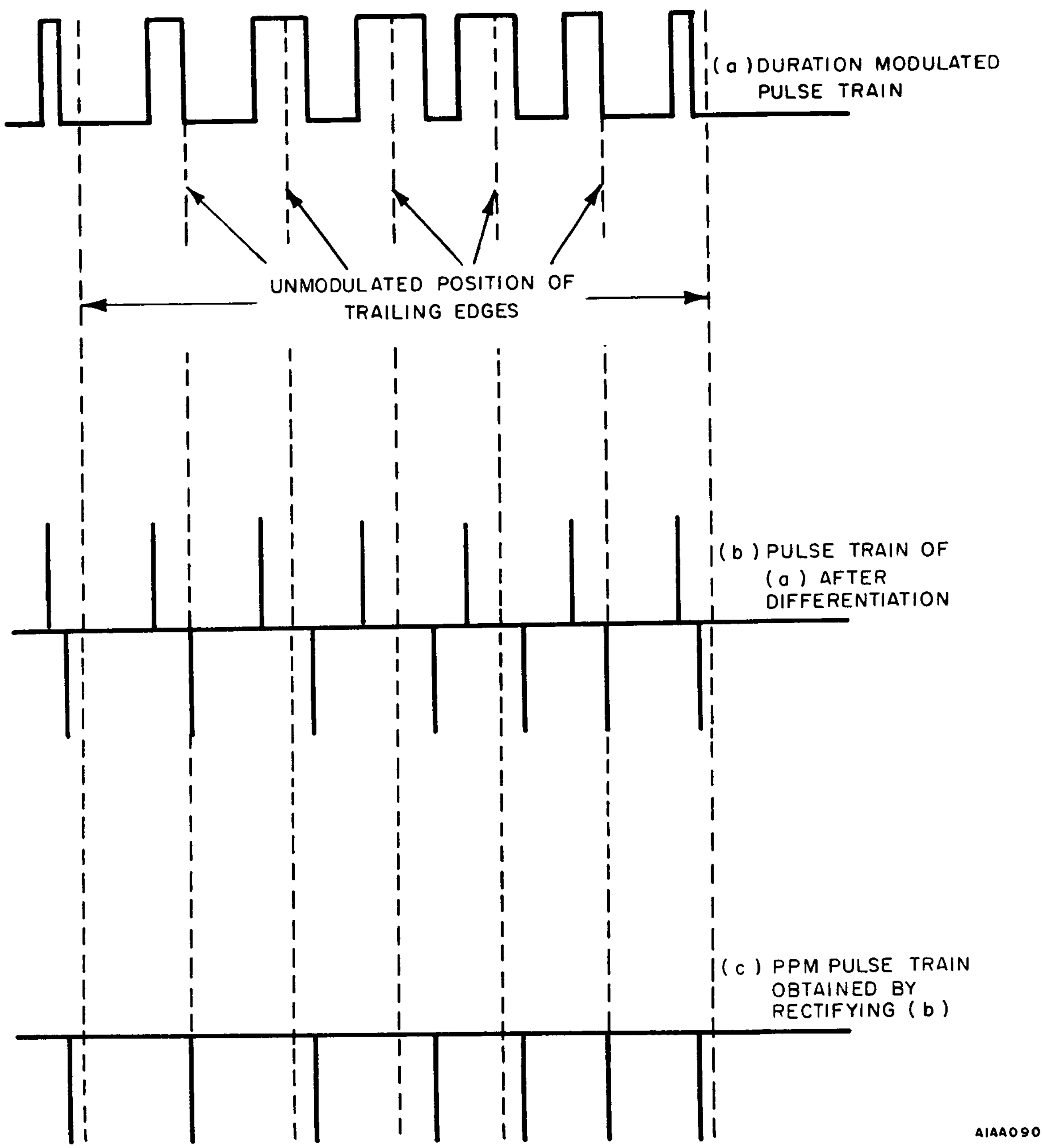


Figure 11-17. PPM Wave Obtained From PDM Wave by Differentiating

Although the quantization curves of figure 11-12 are based on five- and 10-level quantization, in actual practice the levels are usually established at some exponential value of 2, such as $4(2^2)$, $8(2^3)$, $16(2^4)$, $32(2^5)$ ... $N(2^n)$. The reason for selecting levels at exponential values of 2 will become evident in the discussion of pulse code modulation (PCM). Quantized FM is analogous in every way to quantized AM. That is, the range of frequency deviation is divided into a finite number of standard values of deviation, and each sampling pulse results in a deviation equal to the standard value nearest the actual deviation at the sampling instant. Similarly, for phase modulation, quantization establishes a set of standard values. Quantization is used mostly in amplitude- and frequency-modulated pulse systems.

e. Pulse Code Modulation (PCM). Pulse Code Modulation (PCM) refers to a system in which the standard values of a quantized wave are indicated in the modulated wave by a series of coded pulses that, when decoded, indicate the standard values of the original quantized wave so that it may be reconstructed. The codes may be binary, in which the symbol for each quantized element will consist of pulses and spaces; ternary, where the code for each element consists of any one of three distinct kinds or values, such as positive pulses, negative pulses and spaces; of N-ary in which the code for each element consists of any one of N distinct kinds or values. This discussion will be based on the binary PCM systems.

Figure 11-18 shows the relationship between decimal numbers, binary numbers, and a pulse-code waveform that represents the numbers. This is a 16-level code; that is, 16 standard values of a quantized wave could be represented by these pulse groups and only the presence or absence of the pulses are important. The next step up would be a 32-level code, with each decimal number represented by a series of five binary digits, rather than the four of figure 11-18. Six-digit groups would provide a 64-level code; seven digits a 128-level code, et cetera. Figure 11-19 shows the application of pulse coded groups to the standard values of a quantized wave.

In figure 11-19 the solid curve represents the unquantized values of a modulating sinusoid, the dashed curve is reconstructed from the quantized values taken at the sampling interval, and shows a very close agreement with the original curve. Figure 11-20 is identical to figure 11-19 except the sampling interval is four times as great, and the reconstructed curve is no longer so faithful to the original. As previously stated, the sampling rate of a pulsed system must be at least twice the highest modulating frequency in order to get a usable reconstructed modulation curve. At the sampling rate of figure 11-19, and with 4-element binary code, 128 bits (presence or absence of pulse) are transmitted for each cycle of the modulating frequency. At the sampling rate of figure 11-20, only 32 bits are used, and at the minimum sampling rate, only 8 bits are required.

As a matter of convenience, especially to simplify the demodulation of PCM, the pulse trains actually transmitted are reversed from those shown in figures 11-18, 11-19, and 11-20, that is, the pulse with the lowest binary value is transmitted first and the succeeding pulses have increasing binary values up to the code limit. Pulse coding can be performed in a number of ways, using fairly conventional circuitry or by means

DECIMAL NUMBER	BINARY EQUIVALENT 2^3	2^2	2^1	2^0
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
12	1	1	0	0
13	1	1	0	1
14	1	1	1	0
15	1	1	1	1

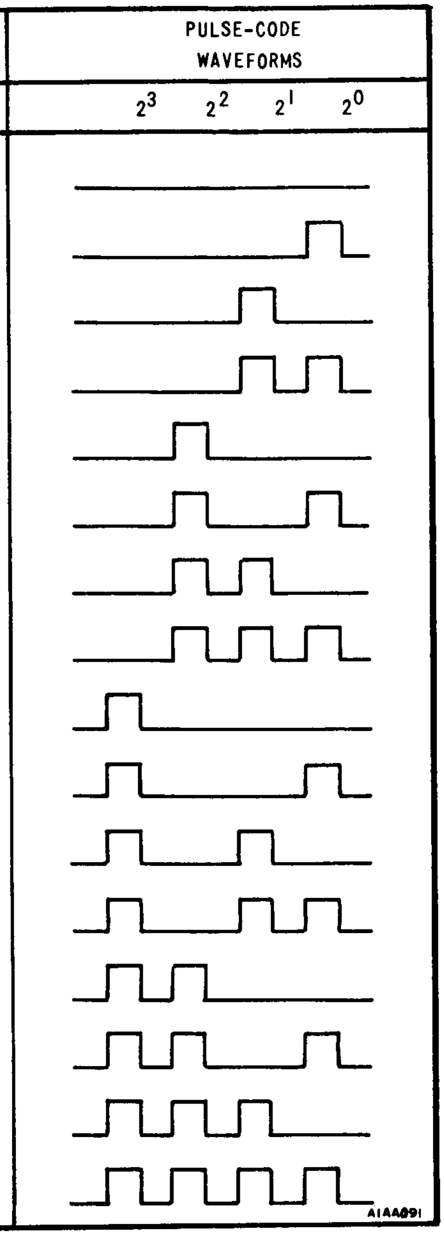


Figure 11-18. Binary Numbers and Waveform Equivalents

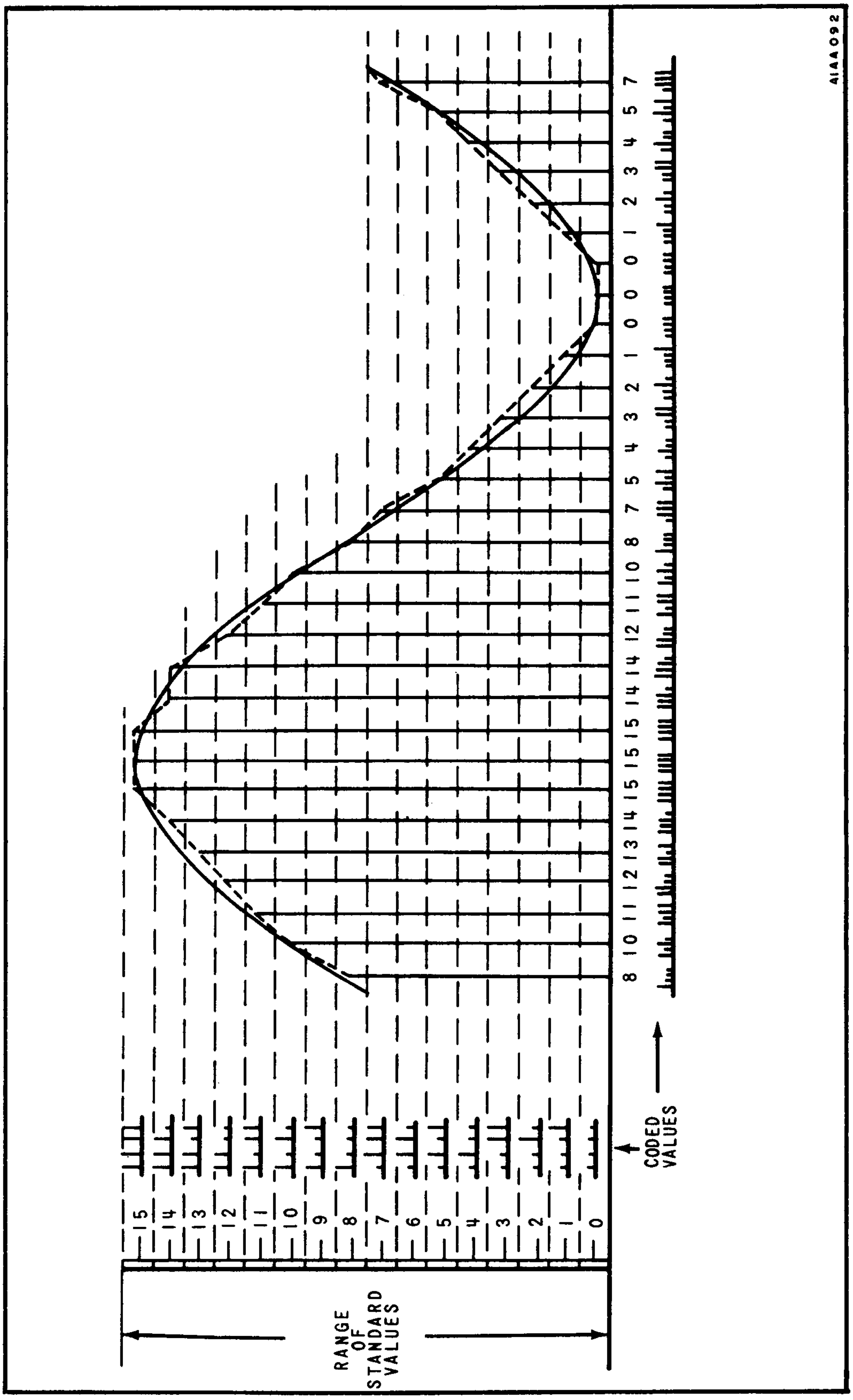


Figure 11-19. Pulse Code Modulation of a Quantized Wave (128 Bits)

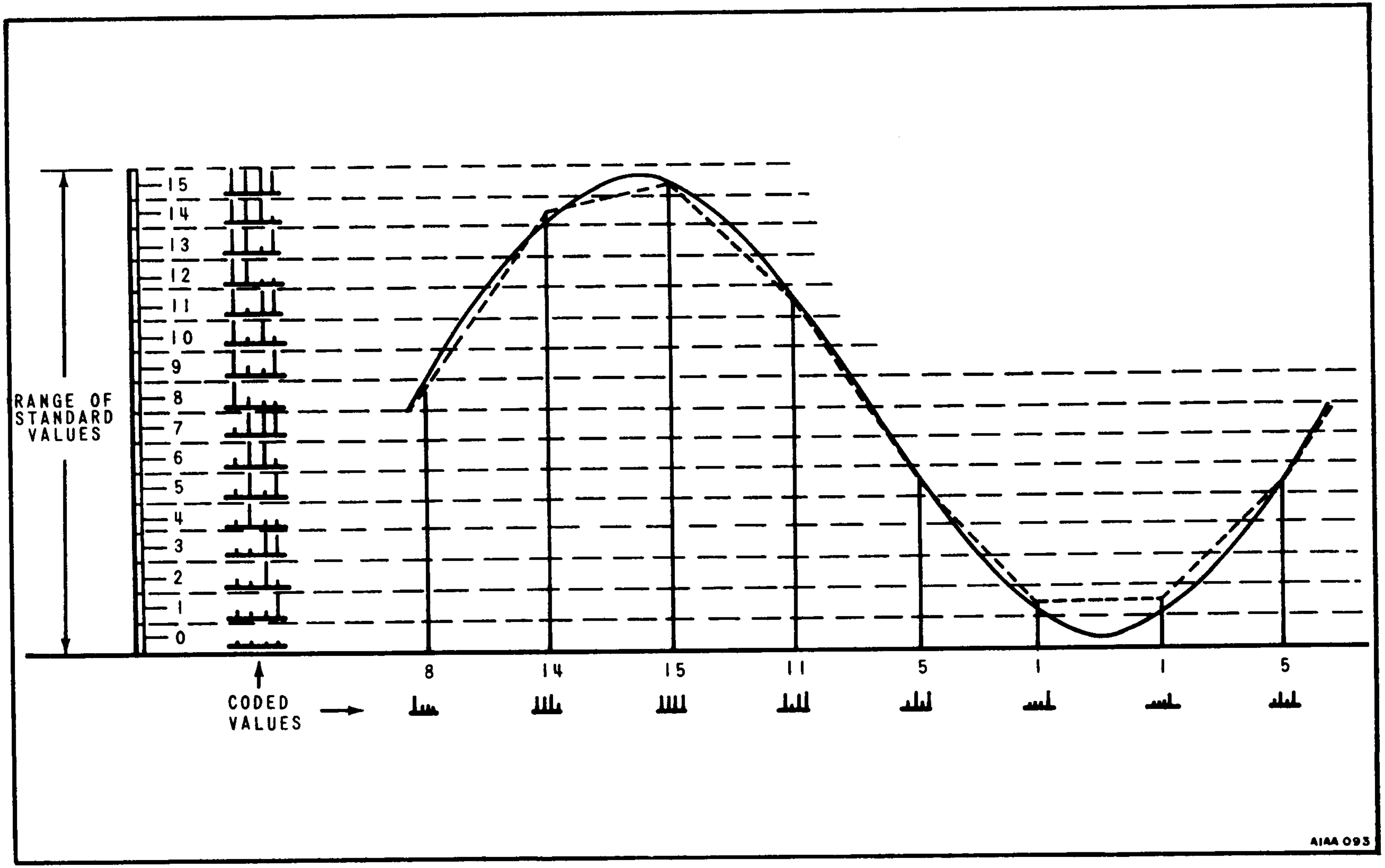


Figure 11-20. Pulse Code Modulation of a Quantized Wave (32 Bits)

of special cathode-ray coding tubes. One form of coding circuit is shown in figure 11-21. In this case, the pulse samples are applied to a holding circuit, a capacitor which stores pulse amplitude information, and the pulse duration modulator converts pulse amplitude to pulse duration. The PDM pulses are then used to gate the output of a precision pulse generator that controls the number of pulses applied to a binary counter. The duration of the gate pulse is not necessarily an integral number of the repetition pulses from the precisely timed clock-pulse generator, so the signal to the binary counter corresponding to each gate pulse may be a number of pulses plus the leading edge of an additional pulse. This "partial" pulse may have sufficient duration to trigger the counter, or it may not. The counter thus responds only to integral numbers, effectively quantizing the signal while encoding it. Each bistable stage of the counter stores a 0 or a 1 for each binary digit it represents (binary 1110) or decimal 7 is shown in figure 11-21. An electronic commutator samples the 2^0, 2^1, 2^2, and 2^3 digit positions in sequence and transmits a mark or space bit (pulse or no pulse) in accordance with the state of each counter stage. The holding circuit is always discharged and reset to zero before initiation of the sequence for the next pulse sample.

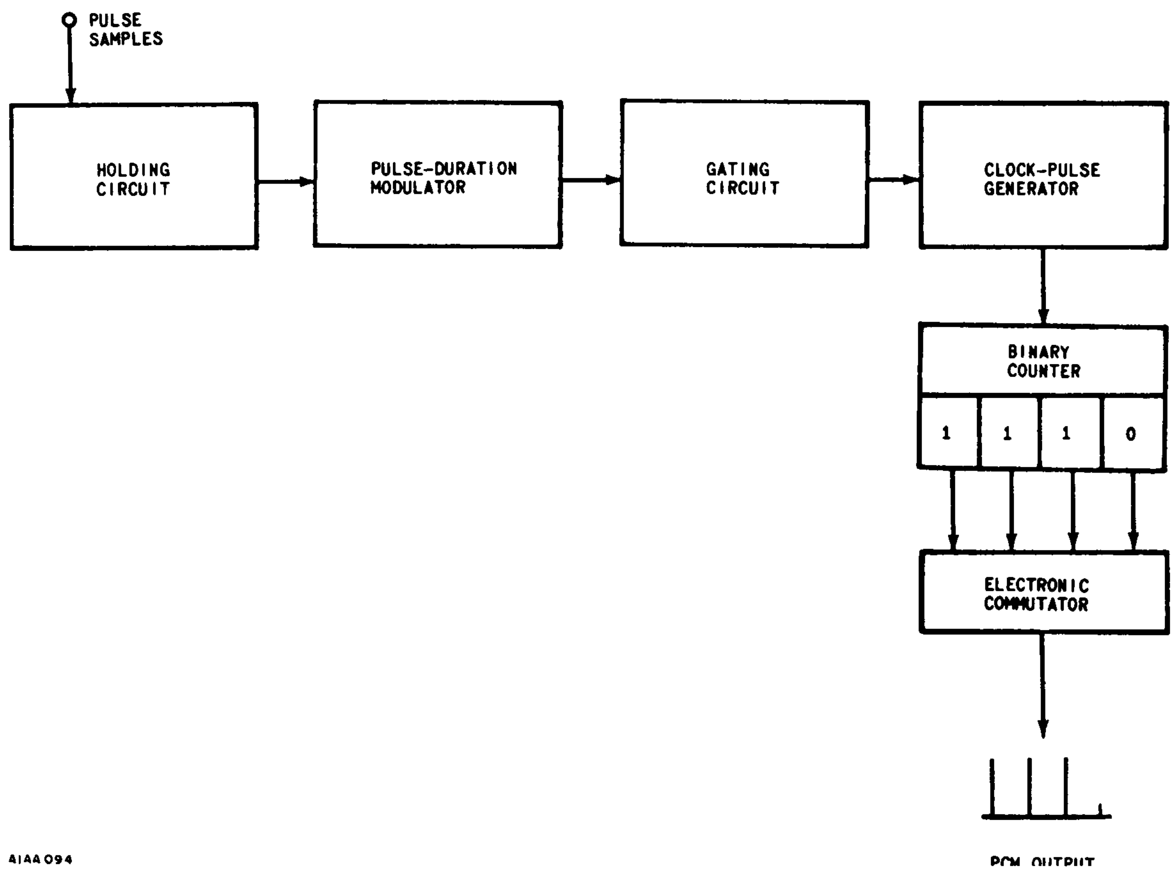


Figure 11-21. Block Diagram of a Quantizer and PCM Coder

At the receiver, after the complex wave has been demodulated and separated into discrete channels, each PCM channel has its code of pulses translated back to its corresponding standard amplitude. This is relatively simple when the pulse-code groups have been transmitted in "reverse" order; that is, if the unit pulse is transmitted first and the pulse with the highest digital value is transmitted last. A current source can be used to apply the pulse code to an RC circuit such as shown in figure 11-22 (A). The time constant of the RC circuit is such that the current leaks off to half-amplitude in the time corresponding to the interval between pulses. This value permits the capacitor charge from one pulse to decay to one-half its original value by the time of the next pulse position and to one-fourth its original value by the time of the second succeeding pulse time. The response to each of the four pulses shown in figure 11-22 (B), considered separately, are shown in (C) and represent binary numbers 0001, 0010, 0100, and 1000, equivalent to 1, 2, 4, and 8 in the decimal system. The peak amplitude of the response to each pulse, the RC time constant, and the sampling time were selected so that the responses would correspond to the decimal value of the voltage. In a linear circuit any number involving two or more pulses will have a total response equal to the sum of the individual responses at any given sampling time, after the last pulse; thus, at (d), the total response is 7 volts, composed of one volt from the first pulse (2^0 = 16 volts halved four times), two volts from the second (2^1 = 16 volts halved three times), and four volts from the third pulse (2^2 = 16 volts halved twice), and nothing from the fourth pulse position (2^3), except an additional time interval during which each of the preceding pulses is halved. The sampling time is not critical because the choice of RC time constant pulse interval assures binary weighting of the 4-digit positions at any time after the charging pulse of the highest binary position.

The process of TDM using PCM is illustrated in figure 11-14 (D). With the binary code, each signal amplitude is represented by a unique digital sequence, as shown on figure 11-14 (D). For example, the signal amplitude at sampling instant S1 is 4. Therefore, the digital sequence would be 100, as shown on the composite TDM in the S1 time interval.

The PCM demodulator will reproduce the correct standard amplitude represented by the pulse-code group provided that it is able to recognize correctly the presence or absence of pulses in each position. For this reason, noise introduces no error at all if the signal-to-noise ratio is such that the largest peaks of noise are not mistaken for pulses. When the noise is of random type (circuit and tube noise), it is possible to determine mathematically, for any ratio of signal-to-average-noise power, the probability of the appearance of a noise peak comparable in amplitude to the pulses. When this is done for 10^5 pulses per second, the approximate error rate for three values of signal-power to average-noise power is:

17 dB	-	10 errors per second
20 dB	-	1 error every 20 minutes
22 dB	-	1 error every 2000 hours

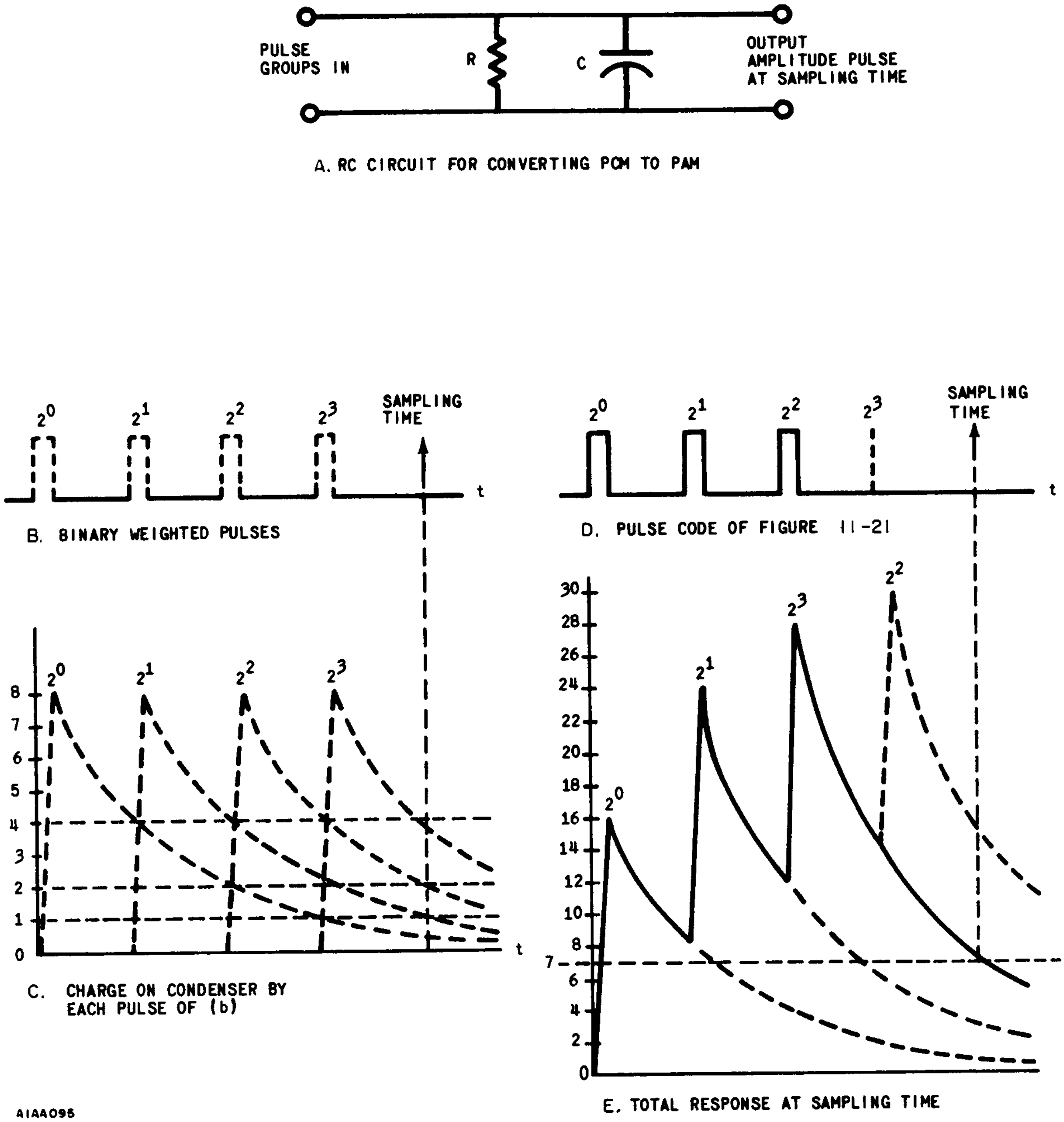


Figure 11-22. Decoding of PCM Pulse Groups

There is evidently a threshold of signal-to-noise ratio of about 20 dB above which virtually no errors occur. In all other systems of modulation, even with signal-to-noise ratios as high as 60 dB, the noise will have some effect. Moreover, the PCM signal can be retransmitted, as in a multiple relay link system, as many times as desired, without the introduction of additional noise effects; that is, noise is not cumulative at relay stations, as with other modulation systems.

There is, of course, the distortion introduced by quantizing the signal, since the standard values selected and the sampling interval both tend to make the reconstructed wave depart from the original. This distortion, called quantizing noise, is initially introduced at the quantizing and coding modulator and remains fixed throughout the transmission and retransmission processes. Its magnitude can be reduced by making the standard quantizing levels closer together. The relationship of the quantizing noise to the number of digits in the binary code is given approximately by the following relationship:

$$\frac{\text{Peak Signal Power}}{\text{Average quantizing noise power where n is the number of digits in the binary code}} = (10.8 + 6n)\ \text{dB}$$

Thus, with the 4-digit code of figure 11-19 and figure 11-20, the quantizing noise will be about 35 dB weaker than the peak signal which the channel will accommodate.

The advantages of Pulse Code Modulation are twofold. First, there is the almost complete elimination of noise interference when the pulse signals exceed noise levels by a value of 20 dB or more, since only the presence or absence of each pulse need be determined to find the exact value of the transmitted signal. Second, the signal may be received and retransmitted (relayed) as many times as may be desired without introducing progressive distortion and deterioration of the signal.

f. Delta Modulation (DM). The process of delta modulation is based on the comparison of signal amplitudes at two consecutive sampling instants. Based on this comparison, a determination is made as to whether to transmit a pulse, or to inhibit a pulse in a repititive pulse train. In its simplest form, a pulse is inhibited if the comparison shows that the signal level at the present sampling instant has decreased from the last sampling instant. If the comparison shows an increase, a pulse is transmitted.

The DM process as applied to TDM is shown on figure 11-14 (E). For the purpose of illustration, the sequence of pulses for channel 1 will be described. The comparison of the signal amplitude at S5 with that at S1 shows a decrease in signal amplitude. Therefore, during sampling interval S5 on the composite TDM signal, a pulse is inhibited. The comparison of amplitudes at S9 with S5 shows an increase, resulting in the transmission of a pulse during sampling interval S9. This sequence is shown cross-hatched on figure 11-14 (E).

11.3 COMPARISON OF MULTIPLEX TECHNIQUES

In single sideband FDM subsystems, the bandwidth of the composite FDM signal is equal to the number of channels times the bandwidth of each single channel. For example, in a 12 channel system, with 4 kHz bandwidths per channel, the composite signal will have a bandwidth of 48 kHz. In a double sideband FDM system, this bandwidth will be doubled, i.e., 96 kHz. These bandwidths are relatively narrow when compared to that required in practical TDM subsystems. In a 64 level PCM/TDM system handling twelve 4 kHz channels, the composite TDM signal would have frequency components exceeding 576 kHz, or 48 kHz per channel. This is 12 times greater than that required for single sideband FDM, and six times greater than the bandwidth required for double sideband FDM. When the available transmission subsystem bandwidth is restricted due to technical or economic reasons, FDM would be the proper choice. This would be true where the available bandwidth of the transmission subsystem is derived at substantial cost, such as present day tropospheric scatter radio and submarine cable systems. In cases where the available bandwidth is not restricted, TDM may be a better choice, since it is capable of providing better performance with regard to overall circuit noise.

11.3.1 Noise

From a performance standpoint, the noise in FDM systems increases as the system length is increased, i.e., noise is cumulative. The reason for this is that as noise is introduced into the system, it is added to, and amplified with, the signal at all repeater stations and terminals. As the system length is increased, more repeaters and terminals are required, resulting in high overall circuit noise between originating and terminating user terminals.

In TDM systems, the elements (bits) in the composite TDM signal are usually regenerated at each repeater station or terminal. As used here, regeneration refers to the process of generating a "clean" pulse upon receipt of a "noisy" pulse. Noise in TDM systems will stay relatively constant between terminals regardless of distance. This is true as long as the noise in the transmission subsystem links does not exceed the threshold of recognition for proper regeneration of the TDM pulse.

11.3.2 Future Prospects of TDM

The above comments were made with regard to the present state-of-the-art of TDM and applicable pulse modulation techniques. As new techniques in TDM become available, further comparison with FDM will be required. Furthermore, improvements in future transmission subsystems may provide wider bandwidths for transmission of information. If this indeed becomes a reality, the fact that TDM techniques are wasteful of frequency spectrum may become inconsequential.

CHAPTER 12

MICROWAVE ANTENNAS

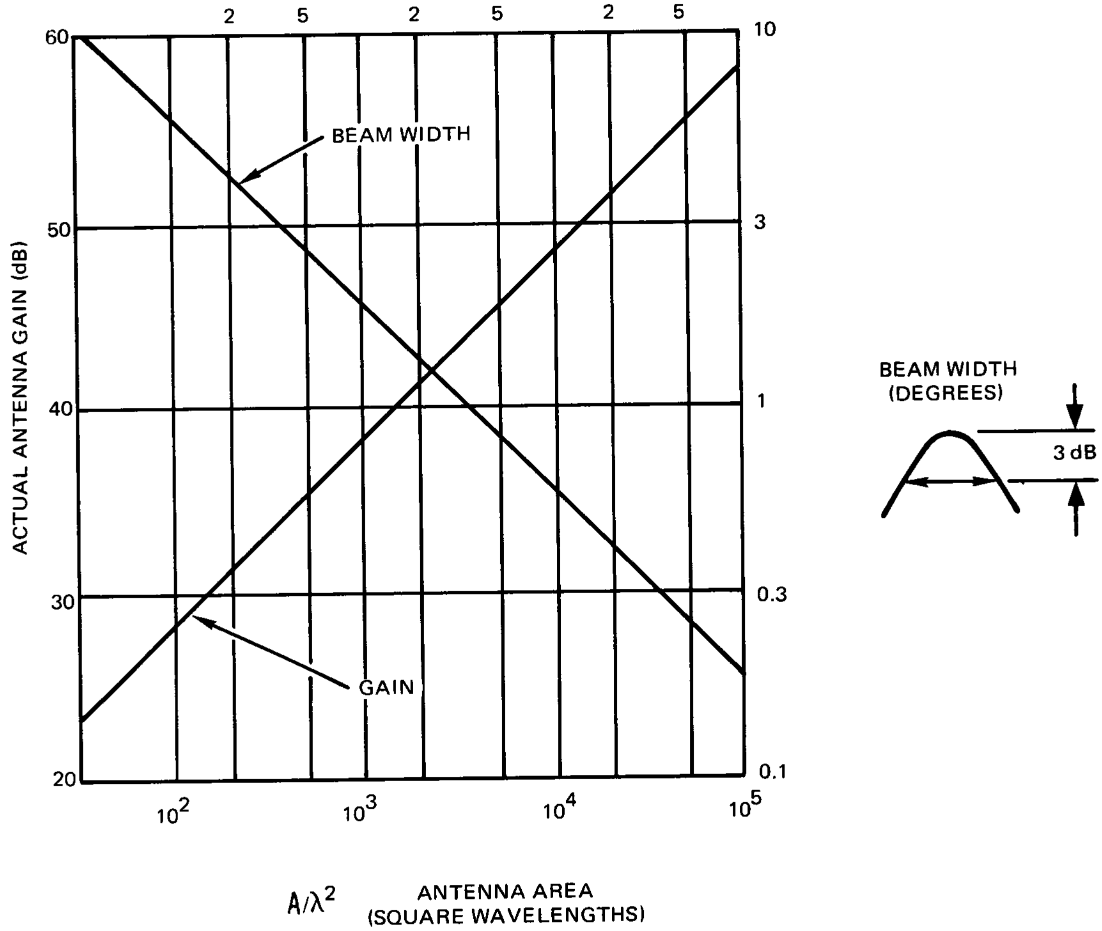
There are a number of antenna characteristics which are of primary importance in a microwave system. The first of these is antenna gain. An antenna has gain because it concentrates the radiated power in a narrow beam rather than sending it uniformly in all directions as an isotropic antenna does. Since it reduces the section loss, high antenna gain is obviously desirable. Antenna gain is increased by increasing the antenna area.

Closely associated with antenna gain is beamwidth. Since an antenna achieves gain by concentrating power in a narrow beam, the width of the beam must decrease as the antenna gain is increased.

Practical antennas comprise maximum achievable gain to obtain sidelobe radiation. For reflector type antennas, tapering of the reflecting illumination pattern is used to effect about 55% reflector illumination factor, hence, the actual gain is about 3 dB less than the maximum possible.

Antennas used in microwave systems ordinarily have half power beamwidths of the order of one degree (see figure 12-1). A narrow beam is desirable in order to minimize interference from outside sources and adjacent antennas. Too narrow a beam, however, imposes severe mechanical stability requirements and leads to problems in antenna alignment and signal fading. Not all of the energy from an antenna is in the direction of the main beam; however, some of it is concentrated in minor beams in other directions. These minor beams are called sidelobes and may be important sources of interference into other microwave paths. Figure 12-2 illustrates the relationship between the main beam and sidelobes for a horn reflector antenna.

There are several antenna characteristics which are important in evaluating the interference to be expected between adjacent transmitting and receiving antennas. One such property is the front-to-back ratio. This is defined as the ratio of the power received from (or transmitted to) the front side of the antenna to the power received from (or transmitted to) the back side, for the same incident field intensity, and is usually expressed in dB. Two front-to-back ratios may be given for an antenna. The ideal front-to-back ratio is the ratio that would exist if the antenna were isolated in free space. The effective front-to-back ratio is the ratio that would be measured in a typical antenna installation, and may be 20 dB to 30 dB below the ideal or free space ratio because of reflections from the foreground or from objects in or near the main beam of the antenna. The front-to-back ratios for the antennas described in the next section are effective ratios. One use of the front-to-back ratio in systems analysis is in computing the interfering effect between a transmitting antenna on one tower and a receiving antenna on the preceding tower.



NOTE: ABSCISSA IS ACTUAL ANTENNA AREA AND "ACTUAL ANTENNA GAIN" IS TAKEN TO BE 3 dB BELOW MAXIMUM ACHIEVABLE

ANTENNA REFLECTOR SIZE	$\frac{A}{\lambda^2}$ 4000 MHz	6000 MHz	11,000 MHz
8–FOOT DIAMETER PARABOLOID	$8(10)^2$	$2(10)^3$	$6(10)^3$
4–FOOT DIAMETER PARABOLOID	$5(10)^2$	$5(10)^2$	$1.5(10)^3$

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Figure 12-1. Approximate Antenna Gain and Beam Width

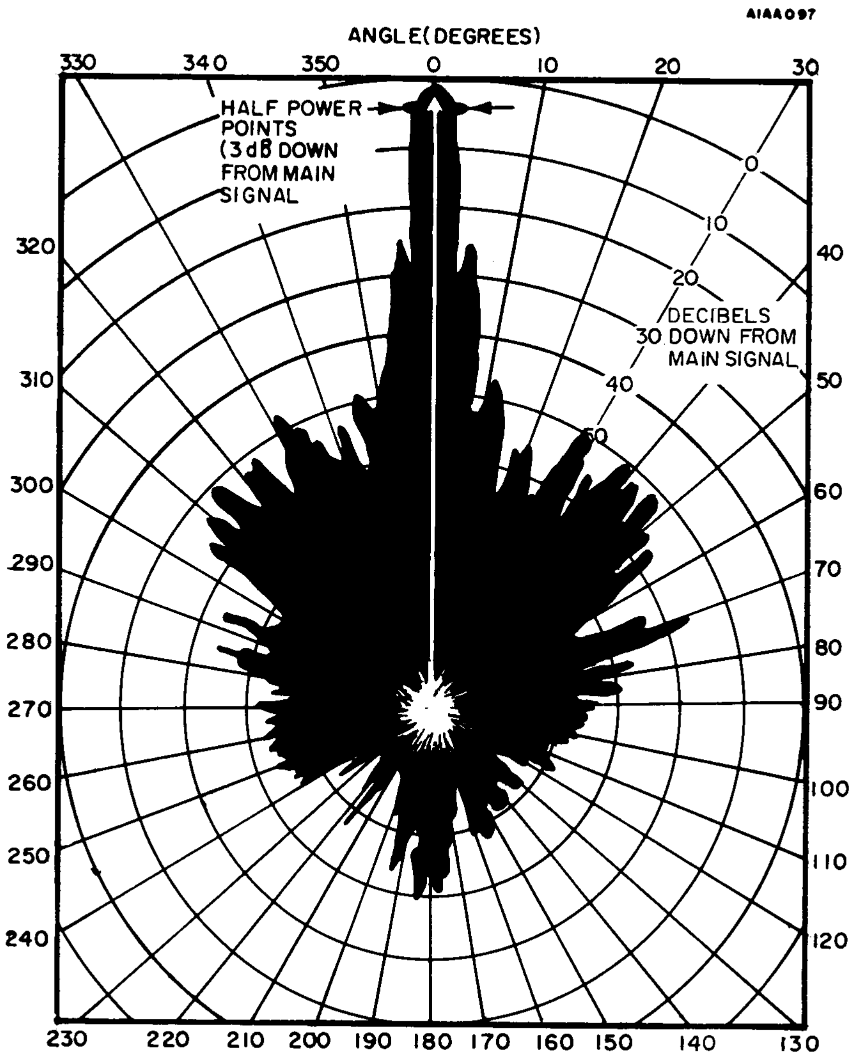

Figure 12-2. Horizontal Directivity of Horn Reflector Antenna at 3740 MHz

Side-to-side coupling expresses the fraction of transmitted power that is received by a second antenna located alongside the transmitting antenna. It is generally expressed in dB. The usual practice is to give the effective, rather than ideal, side-to-side coupling for the particular types of antennas, as measured for specific side-to-side orientations of these antennas.

Back-to-back coupling expresses, in dB, the fraction of the transmitted power received by a second antenna located to the rear of and facing away from the transmitting antenna, on the same tower. The value of back-to-back coupling quoted for a pair of antennas is normally the effective coupling as measured in a typical antenna installation. Both side-to-side and back-to-back couplings are useful in computing the interfering effects between transmitting and receiving antennas located on the same tower.

Some antennas must transmit or receive both vertically and horizontally polarized waves and their cross polarization discrimination is important. As previously defined, the cross polarization discrimination expresses the ratio, generally in dB, of the power in the desired polarization to the power which appears in the opposite polarization due to the residual conversion mechanisms in the antenna system.

Good impedance match must be maintained between the antenna, the waveguide feed, and the radio transmitter in order that reflections do not distort the transmitted signals. The problem of maintaining a good match has been reduced by the use of isolators, which are waveguide devices which pass the signal in the desired direction but effectively block (by absorption) the reflections traveling in the opposite direction.

The cost and complexity of the antenna system are important. The antenna tower and associated antenna mounting arrangements are sometimes an appreciable portion of the cost of a microwave system. When this is true, a balance must be made between the cost saving that can be achieved through the use of a lightweight antenna on a lightweight, inexpensive tower and the improved transmission performance which may result from using a larger and heavier antenna with a correspondingly more rugged and expensive tower. The cost of any antenna system is affected by the difficulty of construction and maintenance.

Consideration must be given to the mechanical tolerances which must be attained in production and maintained in the field under conditions of ice and wind loading. A common rule of thumb for mechanical tolerances on reflecting surfaces is that dimensions should be held within $\lambda/16$. Since at 11 GHz this is 1/16 inch, the construction of large antennas is not simple.

The choice of antenna for any particular system is a result of a careful weighing of the factors noted above to produce the most efficient arrangement within the cost framework dictated by system economics.

12.1 PARABOLIC ANTENNA (PLANE AND DUAL POLARIZED)

The parabolic antenna utilizes a reflector consisting of a paraboloid of revolution and a primary radiator at the focal point. The geometric properties of the parabola enable the reflector to convert the non-directional wave radiating from the focus to a directional coherent wave pattern across the aperture of the paraboloid to concentrate the energy in a beam which is basically the diffraction pattern of the aperature (much like a searchlight beam in the near field).

A plane-polarized antenna uses a single linearly-polarized signal. A dual-polarized antenna is one using two linear polarizations, perpendicular to each other.

Vertical polarization is a linear polarization in which the electric vector is perpendicular to the surface of the earth. Horizontal polarization is a linear polarization in which the electric vector is parallel to the surface of the earth. Normally, microwave systems employ plane-polarized antennas with either vertical or horizontal polarization. In practice, approximately 20 dB isolation may be obtained between signals of opposite polarizations.

12.2 UNIFORM AND TAPERED ILLUMINATION

The antenna 3 dB beamwidth and sidelobe characteristics are intimately related to the dependence of gain on the aperture field distributions. For constant phase distribution across the aperture, maximum gain is realized with uniform illumination. If the illumination over the aperture is modified so that the intensity is peaked in the central area of the aperture and tapered down in magnitude toward the aperture boundary, the diminution in gain is accompanied by an increase in beamwidth and a decrease in sidelobe intensity relative to the peak intensity of the main lobe. The prominence of the sidelobes can be traced to the discontinuity at the edge of the aperture.

12.3 RADOMES

At microwave frequencies the collection of ice or snow can have a deleterious effect on antenna performance. A dish full of soft snow can cause losses of 10 dB at 6 GHz. Worse than this, certain ice formations on the feed can result in high VSWR and considerable attenuation. Radomes are recommended for all antennas by some radio companies, to prevent ice formation in frigid or temperate climates and to reduce the antenna windload on the tower in warmer locations.

The conical fiberglas plastic radomes are attached to the rim of the reflector with steel brackets. Manufacturing methods vary, but stronger, lower loss radomes are fabricated of fiberglas cloth and bonding resins using hand lay-up methods. Lower labor cost radomes can be attained by spray-up manufacturing techniques using a mixture of chopped fiberglas fibers and resin; however, the extra thickness and surface irregularities of this type result in 1.5 to 2 times more attenuation than that of the more expensive hand lay-up radomes.

Higher quality radomes also include a dark gelcoat treatment which seals the surface, extends the life and improves the "slip" factor for shedding ice or snow.

While unheated radomes offer adequate protection in most of the United States, some users prefer heated radomes in areas subject to severe sleet or heavy snow storms. Heated radomes include resistance heating wires molded between the fiberglas layers which are activated by air sensing thermostats in the icing temperature range of $2^{o}C$ to $-4^{o}C$. Electronic Industries Association recommends heater powers range from approximately 600 W for a 4-foot radome to 3500 W for a 10-foot radome.

Radome heating wires should be wound in a circular or spiral pattern to eliminate the need for polarization adjustment of the radome during installation and to allow dual polarized operation if needed. Parallel wire radomes have been known to cause 3 dB or more attenuation if the heater wires are aligned parallel to the electric vector instead of perpendicular to it.

Most standard radomes are designed to withstand winds of 100 mph without damage. For systems subject to hurricane winds or problem locations with extreme wind gusts, special extra strength reinforced fiberglas radomes are available. These radomes will withstand 150 mph winds and introduce about 0.4 dB more attenuation.

Various manufacturers will achieve different attenuation figures, but typical guaranteed radome attenuations are given in Table 12-1. The better performance radomes normally cost more.

Table 12-1. Radome Attenuation Versus Frequency

	DIAMETER (FEET)	2 GHz	6 GHz	8 GHz	12 GHz
Unheated	6	.2 - .4 dB	.5 - 1.0 dB	.7 - 1.2 dB	1.1 - 1.5 dB
	8	.2 - .4 dB	.5 - 1.0 dB	.7 - 1.2 dB	1.2 - 1.5 dB
	10	.3 - .5 dB	.7 - 1.5 dB	.95 - 1.7 dB	1.4 - 2.0 dB
	12	.4 - .5 dB	.8 - 1.5 dB	1.0 - 1.7 dB	1.6 - 2.0 dB
Heated	6	.2 - .4 dB	.5 - .8 dB	.7 - 1.2 dB	1.1 - 1.5 dB
	8	.2 - .5 dB	.5 - 1.0 dB	.7 - 1.2 dB	1.2 - 1.5 dB
	10	.3 - .5 dB	.7 - 1.5 dB	.9 - 1.7 dB	1.4 - 2.0 dB
	12	.4 - .5 dB	.8 - 1.5 dB	1.0 - 1.7 dB	1.6 - 2.0 dB

Most fiberglas radomes have a minor effect on antenna VSWR, ranging from 0.01 to 0.02. In most cases the changes in pattern are negligible, only ±1 or 2 dB.

Dish and feed heaters have been used on some systems to eliminate the slight losses of radomes. However, the added power required in this age of low drain, solid state equipment and the difficulty of maintenance monitoring have made dish heaters less popular in recent years. Some users have reported that heater failures were not detected until after icing resulted in system outages.

12.4 SHROUDS

High performance antennas offer the high directivity for long haul systems using a two frequency plan for locations in which a better pattern is needed to reduce RF interference. The high directivity is achieved through the use of premium dishes and feeds, and a cylindrical metal shroud lined with absorbent material to attenuate side and back radiation, as shown in figure 12-3.

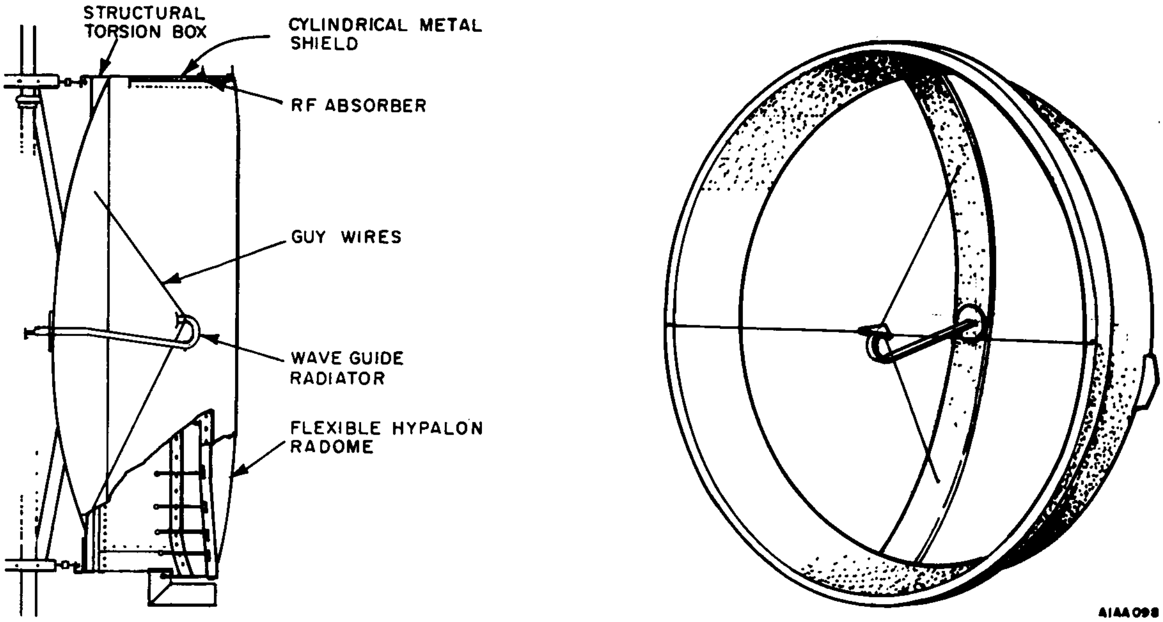

Figure 12-3. High Performance Antenna With Shroud

The antennas use deeper dishes with lower F/d (focal length to diameter) ratios and special low VSWR feeds with absorbent material and illumination shaping aids. Front-to-back ratios (over the region $180^{o} \pm 80^{o}$) have been achieved in the order of 67 to 72 dB for 8 foot and 10 foot shrouded antennas in the 6 GHz band. High performance antennas also include low pass, planar radomes with 0.1 dB attenuation and negligible VSWR contribution. The long life, Hypalon coated nylon radome is stretched across the opening of the cylindrical shield and spring loaded. The radome surface, under tension, flexes slightly in the wind and readily sheds ice and snow in most U.S. environments.

12.5 HORN REFLECTOR ANTENNAS

In the horn reflector antenna, a vertical mounted horn, located at the focal point, is used to illuminate a section of a parabolic surface which then reflects the energy outwards. Because of the design and size of the horn, the impedance of this antenna is very good, the return loss being between 40 and 50 dB. It is a broadband antenna and can be used with both vertical and horizontal polarization in the

4, 6, and 11 GHz bands. Its nominal characteristics are tabulated in Table 12-2. Due to its shielded construction, the horn reflector antenna has small sidelobes and radiates very little power to the rear, resulting in a nominal 70 dB front-to-back ratio. Measurements made at 6 GHz on a large number of antenna installations have shown that side-to-side and back-to-back coupling, as well as cross-polarization discrimination, of horn reflector antenna systems follow approximately normal distributions. The side-to-side and back-to-back coupling of the antenna system will vary considerably from location to location due to such factors as foreground reflections and leakage of energy at the joints of the waveguide run feeding the antennas. The cross polarization discrimination of the complete antenna waveguide system will be considerably lower than that of the antenna alone. This difference is due primarily to ellipticity of the circular waveguide run feeding the antenna.

Table 12-2. Horn Reflector Antenna Characteristics

FREQUENCY	4 GHz		6 GHz		11 GHz	
POLARIZATION	VERT	HOR	VERT	HOR	VERT	HOR
Midband gain (dB)	39.6	39.4	43.2	43.0	48.0	47.4
Front-to-back radio (dB)	71	77	71	71	78	71
Beam width (azimuth) (degrees)	2.5	1.6	1.5	1.25	1.0	0.8
Beam width (elevation) (degrees)	2.0	2.13	1.25	1.38	0.75	0.88
Sidelobes (dB below main beam)	49	54	49	57	54	61
Cross-polarization discrimination (dB)	50	46	51	51	57	51
Side-to-side coupling (dB)	81	89	120	122	94	112
Back-to-back coupling (dB)	140	122	140	127	139	140

These characteristics are for a particular pair of antennas without any waveguide system attached.

A disadvantage of the horn reflector antenna is its bulk (large surface area and weight) and difficulty in mounting. Construction is somewhat expensive.

12.6 REFLECTORS (PLANE, CURVED)

Periscope antennas, consisting of tower top 45° screens and ground based dishes, are popular for 6 GHz and 12 GHz systems. VSWR of the periscope configuration itself is negligible and the VSWR depends on the ground paraboloid antenna. The overall gain depends upon the reflector and paraboloid sizes, separation and frequency. A reflector-paraboloid combination will generally give more gain at less cost than competitive tower based paraboloids and long feeders.

Various aluminum passive reflector designs are available from several tower companies. Standard sizes are 6 x 8 feet, 8 x 12 feet, and 10 x 15 feet with rectangular, elliptical, or clipped edge designs. Curved face reflectors are more popular today than the flat face type because the curving results in a slight gain improvement when the curved surface resembles a section of a large parabola with the focal point at the position of the illuminating paraboloid. Gain curves are supplied by microwave equipment suppliers.

A set of typical gain figures are given in Table 12-3.

Table 12-3. Gain for 6.5 GHz Antenna Systems

PARABOLOID ANTENNA	ANTENNA GAIN	*FEEDER LOSS	NET GAIN
8 ft. at 100 ft.	41.9 dB	2.0 dB	39.9 dB
10 ft. at 200 ft.	43.9 dB	3.5 dB	40.4 dB
12 ft. at 300 ft.	45.5 dB	5.0 dB	40.5 dB
*25 ft. added for building to tower run.			
CURVED REFLECTOR ANTENNA SYSTEM	**PERISCOPE GAIN**	****FEEDER LOSS**	**NET GAIN**
4 ft. dish/8 x 12 ft. reflector, 100 ft.	41.1 dB	0.5 dB	40.6 dB
6 ft. dish/10 x 15 ft. reflector, 200 ft.	43.1 dB	0.5 dB	42.6 dB
8 ft. dish/10 x 15 ft. reflector, 300 ft.	42.8 dB	0.5 dB	42.3 dB
**25 ft. for building to pylon run.			

There are, however, some drawbacks in the relatively high side and back radiation characteristics of periscope antennas. High sidelobe levels sometimes cause false antenna alignment, and a high back radiation (about -45 dB) in the region 20^o to 180^o precludes the use of a 2 frequency pattern and exposes the system to more potential interference and difficulties in frequency coordination. In addition, the towers must have better stability and the initial alignment may be more difficult for passive reflectors as compared to tower top paraboloid antennas.

12.7 DUPLEXERS

A duplexer is a device which makes possible the use of a single antenna for simultaneous transmission and reception. Where pulse techniques are used and the requirement for simultaneous transmission and reception from the same antenna is not present, electronic switching devices may be used for the transmitter and receiver circuits, respectively. This manner of operation presupposes that the antenna is used for transmitting at one instant of time, whereas it is used for receiving at another instant of time.

A continuous wave (CW) system imposes more restrictive conditions on the duplexer than would a system involving pulse transmission. Where CW is used, a duplexer must effectively keep the transmitter disconnected from the receiver at all times and yet maintain maximum coupling between the transmitting and receiving antenna circuits. If the transmitted and received signals are on the same frequency and polarization, it can be shown that a lossless 3 terminal network cannot satisfy these requirements. A 4 terminal network, however, can satisfy these requirements, such a network being in nature of a magic T. However, the use of this device requires that the fourth terminal, the one not connected either to the transmitter, receiver, or antenna, be terminated in a matched load. This matched load dissipates both 1/2 of the transmitted power and 1/2 of the received power indicating that if the device is essentially lossless, then there is still an insertion loss of 3 dB whether the transmitted direction or the received direction be considered. Not only is this loss undesirable from the aspect of circuit efficiency, but this loss imposes severe requirements on a terminating load, especially where high powered transmitters are being used.

To avoid these restrictions, the transmitted signal and the received signal are usually separated in frequency and the frequency difference between these two signals makes possible their isolation one from the other while maintaining a good coupling factor to the antenna. Essentially, the device is so tuned that the receiver leg appears to have an admittance (electrical impedance) approaching zero at transmitting frequency, whereas the transmitter leg has an admittance approaching zero at the receiving frequency. The antenna must be sufficiently broadbanded so that both the transmitted frequency and the received frequency can be matched with a low VSWR.

Figure 12-4 illustrates the principle of operation of such a duplexer. The transmitter and receiver legs are connected in parallel to the antenna. The bandpass filter on the receiver leg is so constructed that it presents the characteristic admittance of the line at the center frequency of the received signal, yet presents an admittance approaching zero at the transmitted frequency. The bandpass filter in the transmitter leg is similarly constructed; the junction exhibits the characteristic admittance of the line at the center frequency of the transmitted signal, yet presents an admittance of essentially zero at the received frequency. Practically speaking, the receiver leg does not exist as far as the transmitter frequency is concerned, nor does the transmitter leg exist as far as the received frequency is concerned. Figure 12-4 illustrates the parallel combination; series coupling is also possible, but is not commonly used.

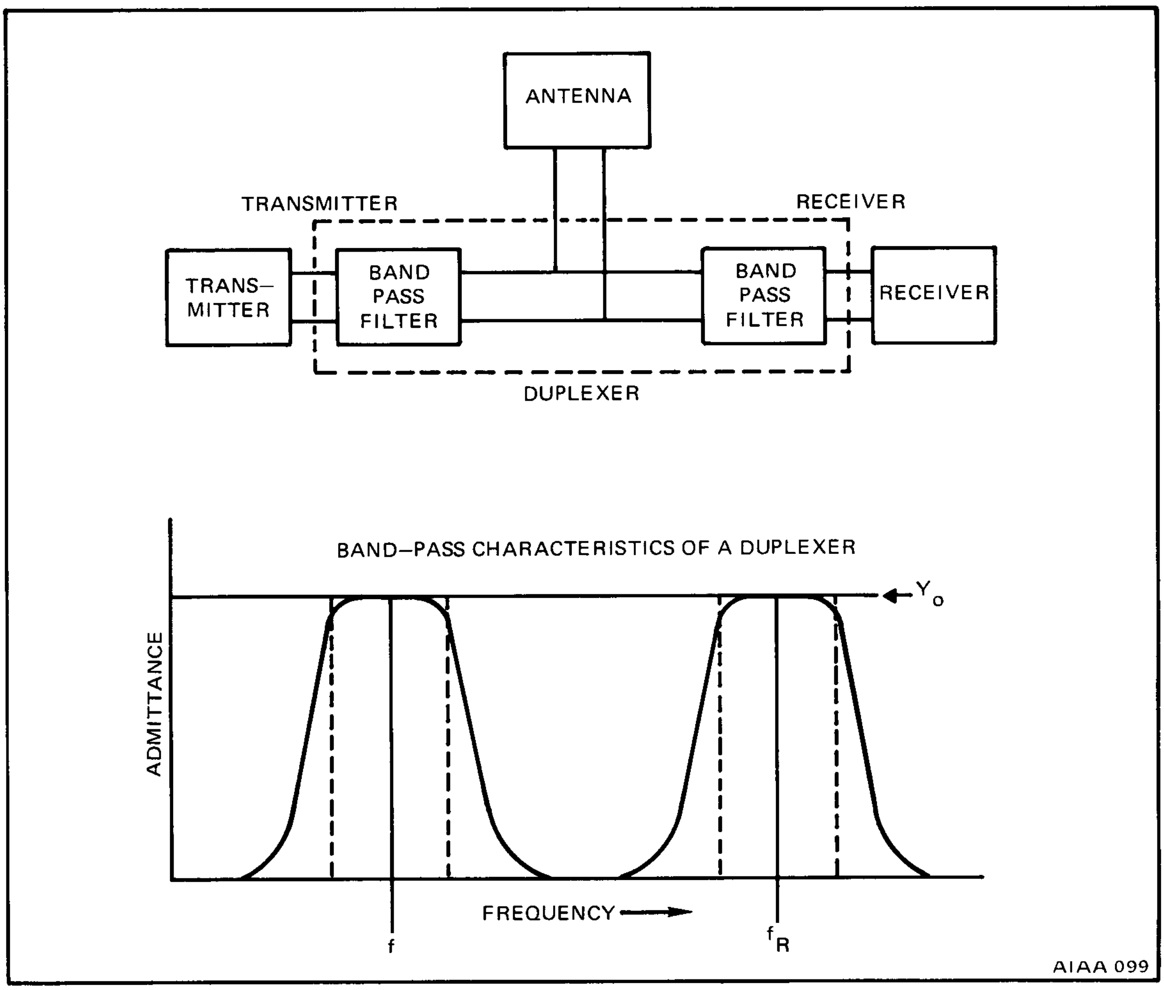

Figure 12-4. Operation of a Duplexer

Isolation between the transmitter and receiver is directly related to the quality of the bandpass filter used in each leg. From the standpoint of admittance matching, the object of the design is to keep the susceptance of the off-resonant branch as small as possible with the conductance essentially zero. With respect to the resonant frequency of each branch, the insertion loss should be kept at a minimum over a wide band, while the attenuation of the resonant frequency of the opposite leg should be maintained at a maximum. The bandpass filters are required to have a fairly flat top and very good selectivity; i.e., sharp skirts to the response curve as shown in figure 12-4.

The duplexer is essentially two bandpass filters terminated in the transmitter and receiver, respectively, and connected to the antenna in parallel. The coupling between the transmitter leg and the receiver leg is a function of the characteristic of the bandpass filters and the separation in frequency between the transmitter leg and the receiver leg.

This type of duplexing can be extended to include almost any arbitrary number of transmitters and receivers operating in this fashion, with each addition to the junction being characterized by its own particular bandpass filter. The method is exactly the same, with the exception that the antenna must be capable of increasingly broad-banded operation as the number of inputs increase. Where many of these inputs are required, a simple junction as illustrated in figure 12-4 will not suffice and these inputs usually are distributed along a transmission line. This requires more complicated matching since the sections of transmission line between the inputs can be critical where length is concerned with respect to the operating frequency of each input. Line stretchers can be used between inputs of this nature to tune the overall complex for optimum operation over the frequency ranges desired.

The following paragraphs concentrate on the simple duplexer; i.e., a single transmitter and a single receiver coupled to the antenna. Usually the duplexer is not field tunable and in manufacturing it is fixed-tuned to operate over the required frequency band; therefore, it is unnecessary to consider the different methods used to achieve this goal.

A duplexer can be made in different ways. Probably the most common uses coaxial transmission line for the bandpass filters. For simplicity of design, a duplexer using waveguide is advantageous since the filter can be built into the waveguide by means of irises. Irrespective of the type, the principles are exactly the same; what is considered with respect to waveguide duplexers applies equally well to coaxial duplexers. In measuring the characteristics of such a duplexer, it can be considered to be a 3-port black box with an antenna terminal, a receiver terminal, and a transmitter terminal. Important parameters to be considered when measuring a duplexer for satisfactory operation are:

- Coupling factor between the antenna and receiver.
- Coupling factor between the antenna and transmitter.

- o Attenuation in the receiver arm of the transmitter frequency.
- o Attentuation in the transmitter arm of the receiver frequency.
- o Bandpass characteristics of each arm centered on its own proper resonant frequency.

Even at relatively low frequencies, such as 300-500 MHz, waveguides have been used in the section for the duplexer. This utilizes the simpler construction techniques for incorporating the bandpass filters in the duplexer proper.

12.7.1 Insertion Loss or Coupling Factor of the Duplexer

Measurement of the coupling factor between the antenna and the transmitter and receiver ports, respectively, is a measure of insertion loss (attenuation factor) of the duplexer. A method for measuring insertion loss (coupling factor) must allow for any inherent directive qualities which the duplexer may have. Such a method consists of monitoring a signal fed from the antenna into the duplexer and monitoring the signal at the receiver port.

Conversely, a signal can be injected into the duplexer at the transmitter port and monitored at the antenna port. The difference between the input and output signals is a measure of duplexer insertion loss. A receiver whose power level can be monitored is used as a detector on the receiving leg, and a signal generator tuned to the receiving circuit center frequency is connected to the antenna terminal. A signal at the center frequency of the receiving system whose level is accurately monitored at the signal generator is fed through the antenna port and received at the receiving port, and the signal level is recorded at the receiver. If an output meter is not available at the receiver, provision can be made to measure the AGC voltage which can be used as the level determining reading. The signal generator is then connected directly to the receiver (the circuit remaining the same except that the duplexer has been removed from it). Again the same monitored signal is received at the receiver, and its level noted. The difference between the two levels would be the duplexer insertion loss. The same method would be used on the other duplexer leg with the signal generator connected to the transmitter port and the receiver connected to the antenna port. If an insertion loss greater than 1/2 dB is noted, the duplexer may not be in proper operating condition. (Since the duplexer is not adjustable, excessive insertion loss could indicate that the duplexer was not well designed. Remember that for this measurement the port which is not being measured must be terminated in the characteristic impedance of the line.)

12.7.2 Bandpass Characteristics of the Duplexer

The method of measuring duplexer insertion loss may be extended to measure the duplexer bandpass characteristics if a variable frequency receiver in the range of operation is available. Since the usual 1/2 dB bandwidth of the duplexer should be known, a number of points within the region of the center frequency should be sufficient to determine the flatness of the curve over its desired bandwidth. The signal generator could be tuned to several discrete frequencies and the receiver tuned to meet these frequencies. A comparison of the receiver output is then graphed to determine the bandwidth characteristics of the duplexer. It is recommended that these measurements include frequencies other than those contained within the 1/2 dB bandwidth. The nature of the selectivity of the filter can be well estimated if the 20 dB bandwidth is measured. This would entail measuring several additional points where the receiver response is down to as great as 20 dB below the response at the center frequency.

12.7.3 Isolation of the Duplexer

Since the attenuation necessary between the transmitter and receiver leg is extremely high (in excess of 100 dB), ordinary methods of measuring this isolation will not be adequate. Duplexer performance can best be determined while it is in use in the actual circuit. The necessity for a good degree of isolation can be illustrated by referring to figure 12-5. The response curve to the left is the idealized frequency response curve of the transmitter leg. The response curve to the right is the idealized receiving leg frequency response curve. It can be seen that the response of the receiver leg to the transmitter frequency should be maintained at a minimum. Response of the receiver leg to transmitted energy is illustrated by the shaded portion in the transmitter bandpass. The amount of area under this curve is indicative of the amount of energy from the transmitter that appears in the receiver leg. The isolation of the receiver leg from the transmitter leg is indicated by the distance A, the attenuation from the peak power of the transmitter. This attenuation should be maximum. Two effects will follow if attenuation A is not sufficient:

o Increased noise will appear in the bandpass of the receiver.

o If the energy associated with this unwanted signal in the receiver leg is sufficiently high, it can block the receiver RF stages. This situation is idealized in that it assumes that all the energy from the transmitter will be contained within the indicated bandwidth which, of course, is not necessarily true.

The method utilized in the following paragraphs constitutes an approximate determination of the change in noise level and in minimum detectable signal caused by the use of the duplexer.

The receiver will be connected to the receiver port, the transmitter to the transmitter port and the antenna to the antenna port. With the transmitter off, a recording of the noise output of the receiver should be determined; i.e., after the initial warmup time has elapsed, the receiver should be allowed to operate merely on the noise from the system. Then the transmitter should be turned on and should be adjusted to maximum operating power with full modulation. The noise level of the receiver should again be recorded for comparison with the first recording. If no discernible difference (less than 1 dB) is evident between the two recordings, it can be assumed that the isolation between the transmitter and the receiver is sufficient.

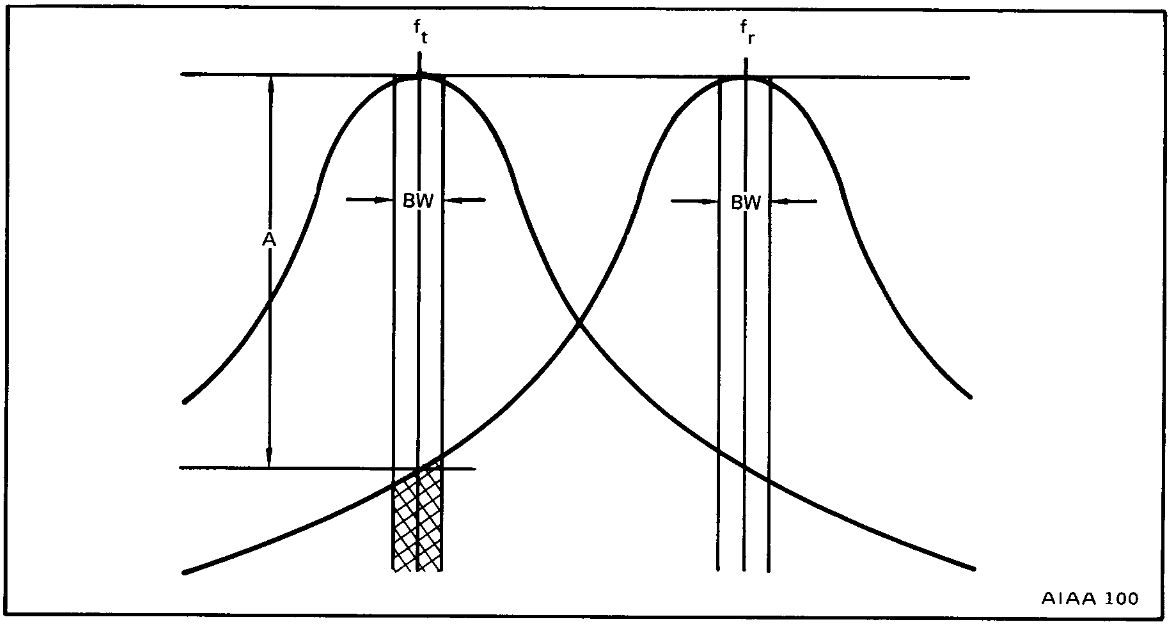

Figure 12-5. Relative Pass Bands of the Transmitter and Receiver Bands of a Duplexer

Receiver blockage due to excessive energy from the transmitter will be very apparent in that the receiver will tend to saturate, causing the receiver noise level to change markedly, indicating the duplexer to be inadequate.

Measurement of the receiver output should be made immediately after the IF amplifier or immediately after the detector. The degree of isolation is not only a function of the duplexer, but is also a function of the selectivity of the receiver.

If significant difference is noticed between the two recordings of the noise level of the receiver, it should be determined if this increased noise in the receiver on the second reading is due to the lack of isolation of the duplexer or due to the leakage or radiation of the transmitter. The following method may be used to determine the extent of isolation. The receiver is disconnected from the duplexer and both the receiver and the duplexer are terminated in good quality, matched terminations with the matched load. A record of the noise level is obtained. The transmitter is then turned on and adjusted to full power and full modulation. A second record of the noise level of the receiver is obtained. If there is any difference between these two readings; i.e., greater than 1 dB, it can be assumed that stray coupling between the transmitter and the receiver is excessive and the determination of the performance of the duplexer would be in error. It is extremely important, for the accuracy of this determination, that grounds be maintained between the duplexer and the transmission line to the receiver so that the paths of stray coupling experienced while the duplexer was in the system will not be disturbed. If excessive coupling is noted between the transmitter and receiver when they are not connected through the duplexer, steps must be taken to eliminate the stray coupling problem before the duplexer can be measured. If the increase in the noise level due to operation through the duplexer is in excess of 1 dB, the isolation should be considered inadequate.

12.7.4 Circulators

A waveguide circulator is used to couple two or three microwave equipments to a single antenna. Such an arrangement is useful when diversity equipment is employed or when additional microwave equipment is added to existing equipment to increase channel capacity. The particular type of waveguide circulator described here is a ferrite device which is similar in design to duplexers used in other microwave applications. The circulator (figure 12-6) consists of three basic waveguide sections combined into a single assembly. The end section that terminates in arms 1 and 3, is a modified magic T. The other two arms of the modified magic T are folded so that they are parallel and feed into the center section of the circulator. The center section is a ferrite non-reciprocal phase shifter. It consists of two parallel lengths of waveguide each containing a strip of ferrite material. An external permanent magnet causes the ferrite material to exhibit phase shifting characteristics. The third section of the circulator is a short slot hybrid which has a coupling slot in the common wall of the parallel lengths of waveguide.

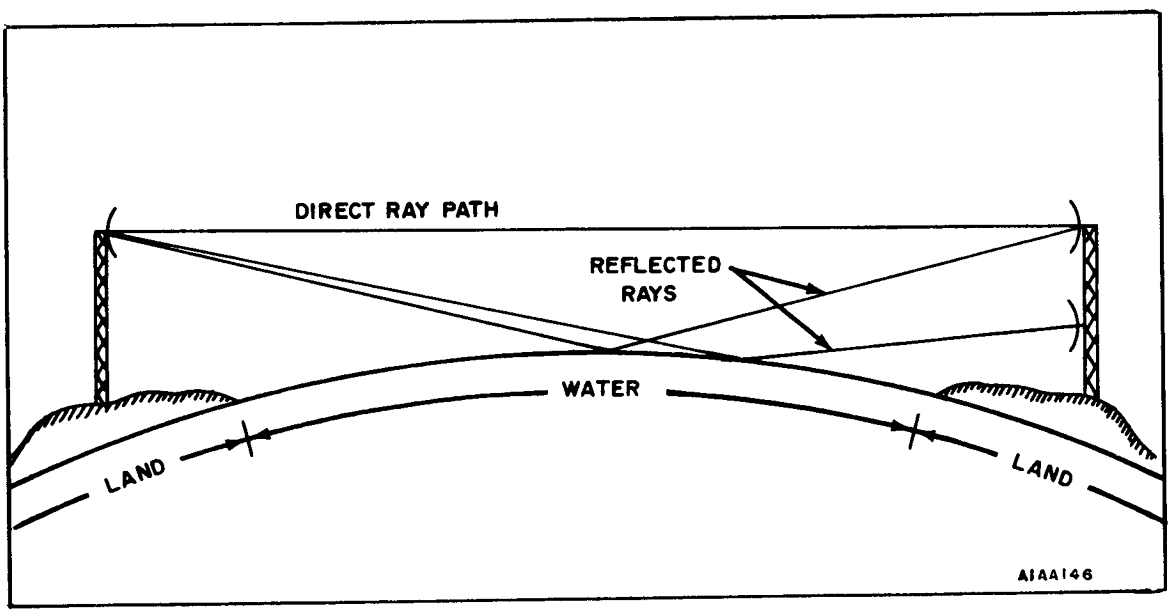

Figure 12-6. Waveguide Circulator

With an antenna connected to one arm and either three microwave equipments connected to the other arms or two equipments and a shorting plate connected to the other arms, the following rules apply: The attenuation from arms 1 to 2, 2 to 3, 3 to 4, and 4 to 1 is about 0.5 dB in each instance. Attenuation between other combinations of arms is considerably higher, on the order of 20 dB. For example, the attenuation between arms 1 and 3 is high because of the properties of the short-slot hybrid. Finally, the attenuation from arms 1 to 4, 4 to 3, 3 to 2, and 2 to 1 is high because of phase cancellation brought about by the combined effects of all three sections.

Assuming that the antenna is connected to arm 4, the net attenuation (approximately) of the circulator on transmission and reception is shown in Table 12-4. By using identical arrangements of circulators and transmitter-receivers at two or more stations, the circulator losses can be equalized for each parallel path. This is shown in the table since the transmission loss at one station plus the reception loss at the next station can be made to total approximately 2 dB for each of the three sets of equipment.

Table 12-4. Circulator Attenuation

	TRANSMISSION LOSS (dB)	RECEPTION LOSS (dB)	TOTAL T-R LOSS (dB)
Transmitter-Receiver No. 1 Connected to Arm 1	1.5	0.5	2.0
Transmitter-Receiver No. 2 Connected to Arm 2	1.0	1.0	2.0
Transmitter-Receiver No. 3 Connected to Arm 3	0.5	1.5	2.0

12.8 WAVEGUIDE

Waveguide and transmission line is important not only for its loss characteristics, which enter into the path loss calculation, but also for the degree of impedance matching attainable, because of the effect on echo distortion noise. The latter becomes extremely important with high-density systems having long waveguide runs.

In the 2 GHz bands coaxial cable is usually used, and, except for very short runs, it is usually of the air dielectric type. Typical sizes are 7/8 inch, with an attenuation of about 2 dB per 100 feet and 1-5/8 inch, at about 1.1 dB per 100 feet. It is normally ordered in the exact lengths required, with factory installed and sealed terminal connectors. When larger size cable is used, it is desirable to reduce to 7/8 inch with a suitable transition, for flexibility in connecting to the radio equipment. In some cases, similar treatment may be needed at the antenna end, though generally the use of a rigid right angle connector will allow sufficient flexibility for antenna orientation.

The other bands use waveguide almost exclusively, one of three basic types; rigid rectangular, rigid circular, and semiflexible elliptical. The elliptical type is of continuous construction, while the other types come in sections with flanges. Short sections of flexible waveguide are also used for the connections to the antennas and to the equipment. In all cases it is desirable to keep the number and length of flexible sections as small as possible, since they tend to have higher losses and poorer VSWR than the main waveguide types. (See figure 12-7.)

12.8.1 Rectangular Guide

Rigid rectangular waveguide is the most commonly used, with oxygen free, high conductivity copper (OFHC the recommended material. The types and approximate characteristics are as follows:

o 4 GHz bands. WR 229, standard for most installations, has a loss of about 0.85 dB/100 feet.

o 6 GHz bands. WR 137 (normally used) has a loss of about 2.0 dB/100 feet. In cases where, due to high towers, a reduced transmission loss is required, transitions can be supplied for use with WR159, which has a loss of about 1.4 dB/100 feet.

o 7-8 GHz bands. WR 112 is normally used. Attenuation is about 2.7 dB/100 feet.

o 11 GHz bands. WR 90 is normally used. Attenuation is about 3.5 dB/100 feet.

o 12-13 GHz bands. WR 75 is normally used. Attenuation is about 4.5 dB/100 feet.

For critical applications, where extremely low VSWR is required to meet stringent noise performance specifications, special precision waveguide, manufactured to a very tight tolerance, is recommended.

12.8.2 Circular Guide

Circular waveguide has the lowest loss of all, and in addition, it can support two orthogonal polarizations within the single guide. It is also capable of carrying more than one frequency band in the same guide. For example, WC281 circular guide is

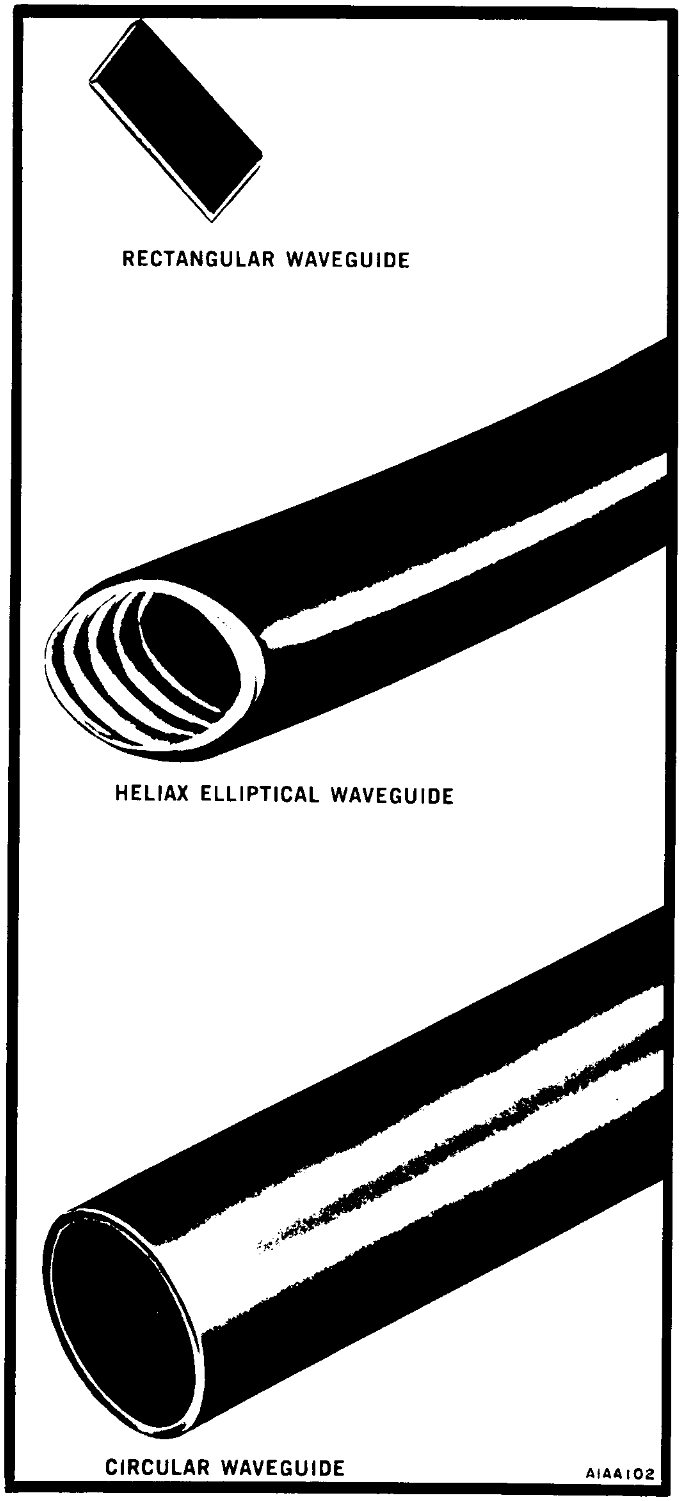

Figure 12-7. Types of Waveguide

normally used with horn reflector antennas to provide two polarizations at 4 GHz and two polarizations at 6 GHz. But circular guide has certain disadvantages. It is practical only for straight runs, requires rather complicated and extremely critical networks to make the transition from rectangular to circular, and can have significant moding problems, when the guide is large enough to support more than one mode for the frequency range in use. Consequently, though circular waveguide is available in several different sizes, and its low losses make it attractive, it is recommended that it be used with considerable caution.

12.8.3 Elliptical Guide

Semiflexible elliptical waveguide is available in sizes comparable to most standard rectangular guides, with attenuations differing very little from the rectangular equivalents. The distinctive feature of elliptical guide is that it can be provided and installed as a single continuous run, with no intermediate flanges. When very carefully transported and installed, it can provide good VSWR performance, but relatively small deformations can introduce enough impedance mismatch to produce severe echo distortion noise.

The most commonly used types and their approximate characteristics are as follows:

- o 4 GHz band. EW-37, about 0.85 dB/100 feet.
- o 6 GHz band. EW-59, about 1.75 dB/100 feet.
- o 7-8 GHz bands. EW-71, about 2.5 dB/100 feet
- o 11 GHz band. EW-107, about 3.7 dB/100 feet.
- o 12-13 GHz bands. EW-122, about 4.5 dB/100 feet.

In all types of waveguide systems it is desirable to keep the number of bends, twists, and flexible sections to a minimum. It is also vitally important to use great care in installation, since even very slight misalignments, dents, or introduction of foreign material into the guides can create severe discontinuities.

12.9 DEHYDRATORS AND PRESSURIZERS

Variation in temperature and humidity can cause condensation on the inside of a waveguide run or air dielectric cable if they are not pressurized. This condensation will seriously impair line electrical efficiency and, in the case where a section or line is filled with water, complete system failure can result.

12.9.1 Static Pressure System

The static system is one in which the transmission lines are pressurized by means of a dry air pump, a dehydrator or a nitrogen tank. After the desired pressure is reached, the system is sealed off by means of a valve, and the pressurization source is removed.

In a static system, the cable gauge pressure will vary with temperature and barometric pressure changes in accordance with the physical law governing the behavior or perfect gases. Therefore, system pressures must be adequate to accommodate the most extreme conditions.

Barometric pressure changes usually do not cause detectable changes in system pressures and they can be omitted from consideration for most situations.

Temperature differentials are more severe and can cause significant changes. Temperature change of 80^{o}F can lower internal system pressures 1 to 2 PSIG. An exact system pressure cannot be stated since environmental conditions vary; however, a system pressure of 3 PSIG is necessary for most conditions.

12.9.2 Dynamic Pressure System

A dynamic system is one that incorporates a pressurizing source which acts as a system reservoir. The pressurizing source, automatic dehydrator or nitrogen gas cylinder, remains in the system and maintains positive pressure in the line at all times.

A dynamic system may be accomplished with an automatic dehydrator or a nitrogen gas cylinder. Either medium can be connected into the system so that it maintains a pressure greater than atmospheric (3 PSIG is recommended) in the transmission line. It should be noted that for a dynamic system the pressure need only be nominally positive; higher pressures offer no advantage and increase the loss of pressurizing medium, since leakage rates increase rapidly with increases in internal pressure.

Dry air and nitrogen are very similar and either gas is satisfactory for pressurizing transmission lines. Nitrogen cylinders are recommended for use in simple installations. Automatic dehydrators are recommended for extensive waveguide runs and more complex installations.

12.10 DIVERSITY COMBINERS (PRE-DETECTION, POST-DETECTION)

The value of diversity systems is realized only if the opertions at the receiving site are such that the signal available at the output of the system is a better reproduction of the original modulating signal than that obtainable from using a single copy of the signal. So the problem becomes a question of how to utilize the available disturbed copies of the signal in order to achieve the least possible loss of signal information. The techniques available fall into three general classifications. These are: switching, combining, and a combination of the two; and may be accomplished on the noisy, fading carriers (pre-detection), or on the noisy, fading modulation components after extraction from the carrier (post-detection).

12.10.1 Switching Technique

In the switching technique, each of the signal copies available is scanned, compared to each of the others, and the one selected becomes the only signal effective in the following stages. In one such system, the waveforms of the available signals are scanned in sequence, and the first one in which the quality exceeds a predetermined threshold is switched in and is held in until its quality falls below the threshold, when the scanning process is repeated. In this system, the output signal is not necessarily the best, but will be above the threshold of acceptability. In another system, all available signals are scanned simultaneously and the one having the best quality is selected. These are known as the scanning-diversity and optimal-selection diversity techniques. In high frequency space-diversity systems, the several antennas feed several receivers that go to a common output. The receiver which has the strongest signal develops the AVC voltage which controls the gain of all the receivers, which gives, in effect, a switched system on an optimal selection basis.

12.10.2 Combining Techniques (Equal Gain, Maximal Ratio)

In the combining techniques, all of the available waveforms are utilized simultaneously. Of all the possible choices of combining signals, two are of most interest. First, if we assume no prior knowledge that any given copy will always be poorer than the others, all are weighted equally in the total signal summation, regardless of the quality fluctuations that will be experienced. Thus, equal mean values of signal level and equal rms values of noise being assumed, the combination is made and is known as equal-weight or equal-gain combining. Second, since the output of any of the channels is a function of the signal quality in the channel, each output is constantly adjusted to give the best signal-to-noise ratio before combining with other channels. This is called maximal-ratio combining. In the alternate switching and combining method, some of the signals are dropped when they become appreciably noisier than the others, with the remaining signals being combined to obtain the maximum possible signal-to-noise ratio in the output signal.

Figure 12-8 shows the improvement which may be expected in the average signal-to-noise ratio at the output of a diversity receiving system over that of a single channel system. The three methods of selection or combining previously discussed are shown in their relative effectiveness as the number of diversity channels is increased. Figure 12-9 is a percent-of-time plot of a two channel diversity system, with the same three methods of utilization, compared to a single channel system when random fading of the signal occurs.

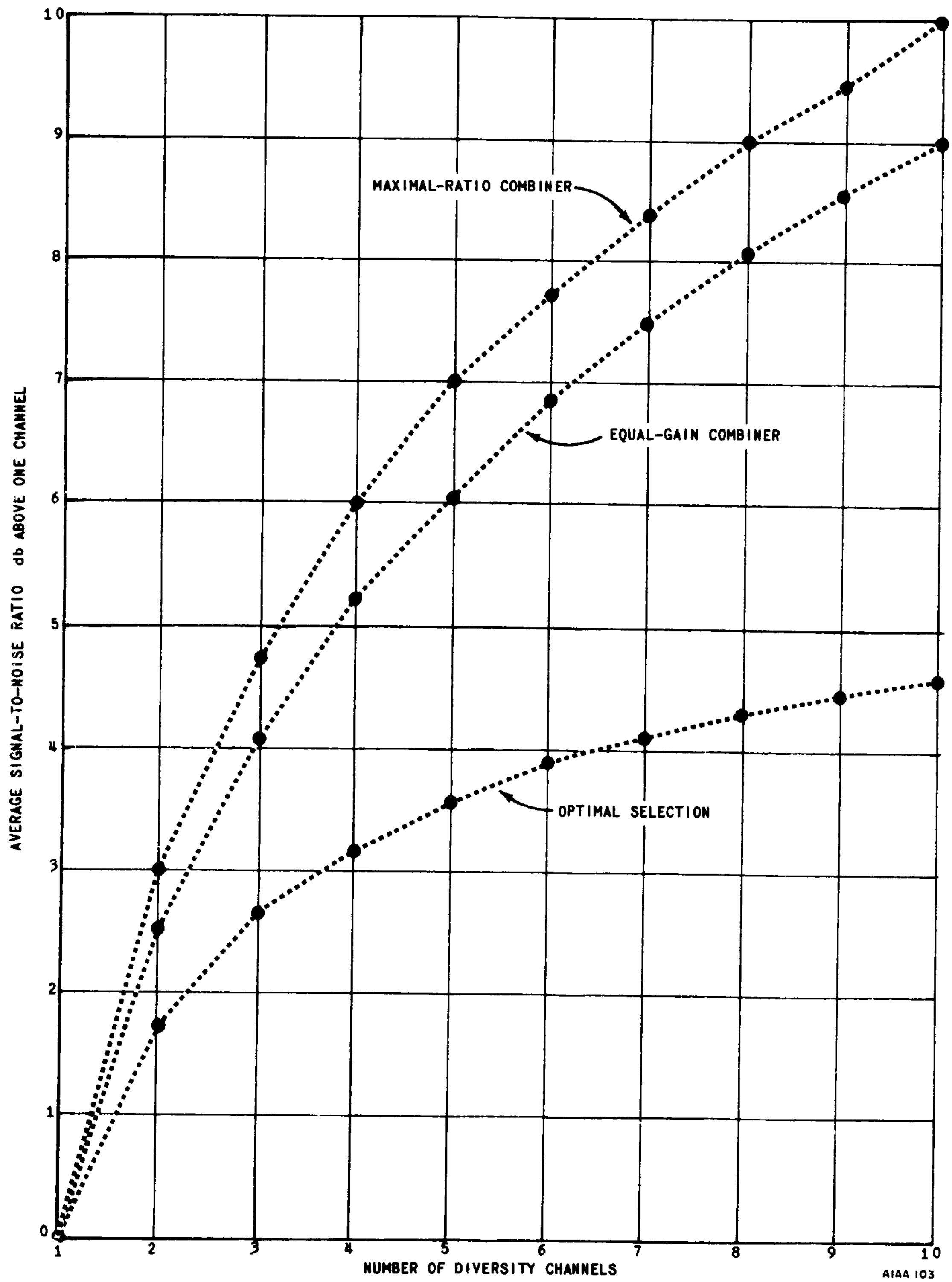

Figure 12-8. Improvement in Average Received Signal-to-Noise Ratio With Diversity

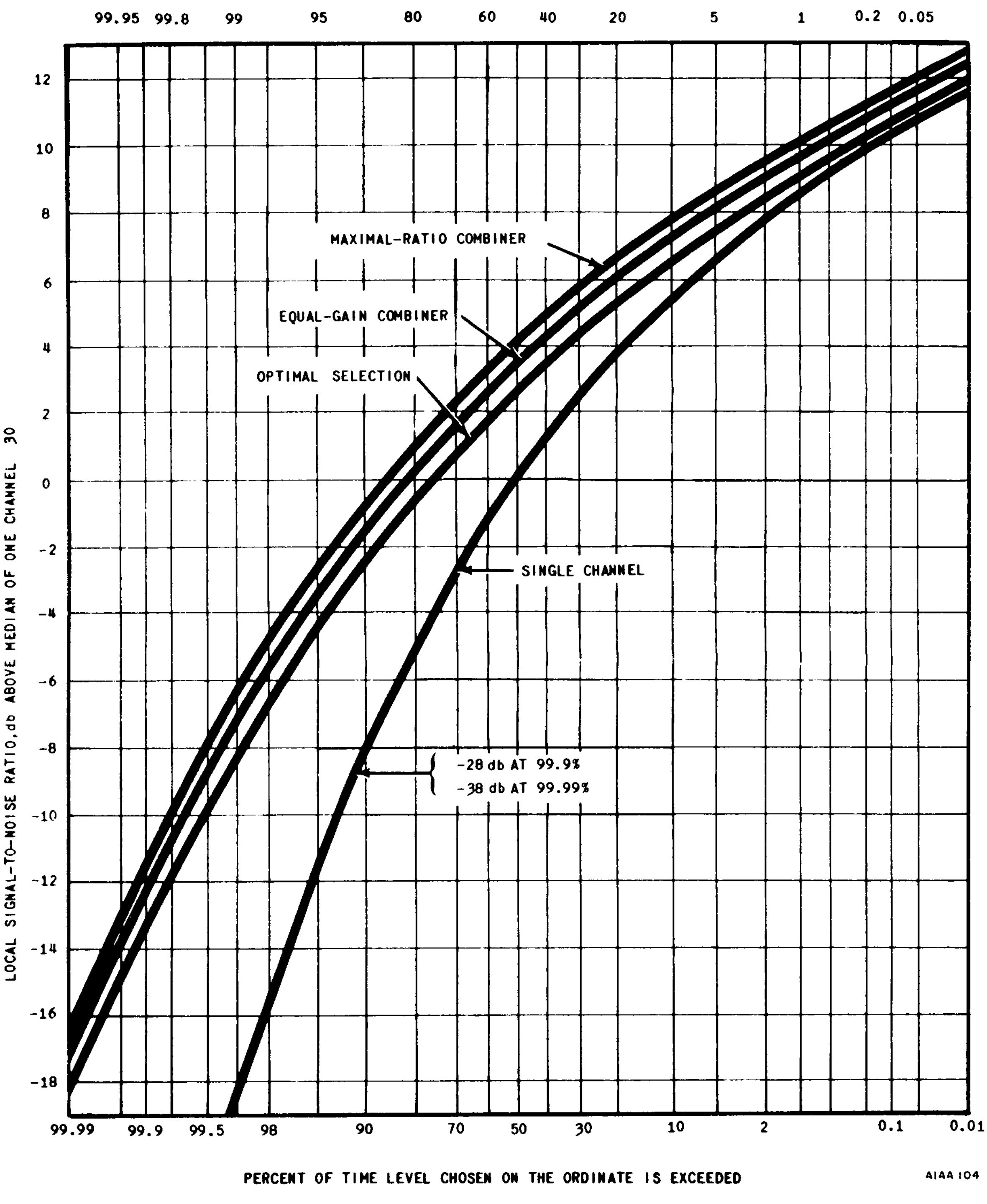

Figure 12-9. Percent-of-Time Distribution of Received Signal-to-Noise Power Ratio for Single Channel and Two-Channel Diversity Using Three Combining Methods

CHAPTER 13

MICROWAVE TECHNICAL CONTROL

13.1 VOICE ORDER WIRE

The average system requires one or more voice channels for maintenance communications purposes and to permit the transmission of various types of control data. One voice channel, connecting all stations with a responsible terminal station, is generally reserved for maintenance purposes. This channel is called the service, or order-wire, channel. In addition to providing a voice communication facility, the service channel, through the use of special equipment, may also be used for fault reporting (alarm) purposes and/or supervisory control functions. The fault alarm system permits operators at system control points to monitor the status of equipment at unattended stations; supervisory control circuits permit system operators to control remote functions.

13.2 SIGNALING (TERMINATION EQUIPMENT)

Termination equipment is required in radio relay systems to interconnect multiplex equipment and telephone equipment. The functions of such termination equipment will be described in this section, along with considerations that have to do with the use of standard telephone circuitry and facilities with radio relay equipment. The first consideration is that input signals applied to multiplex equipment and output signals from demultiplex equipment are limited to a frequency range of approximately 50 to 3500 Hz per channel. This frequency range is compatible with telephone equipment specifications for voice transmission; however, it is not compatible with telephone signaling requirements, since telephone signaling is normally accomplished by means of 20 Hz signals or DC pulses. Other considerations are those concerned with impedance matching, two-wire to four-wire transformation, and signal levels.

The basic functions performed by termination equipment are as follows: to transform two-wire telephone lines to four-wire multiplex lines, a pair for sending and a pair for receiving, and vice versa; and to convert DC or 20-Hz ringing voltages to voice-frequency signals, for transmission purposes, and vice versa. Because of the nature of the functions performed by the equipment, a more descriptive name such as Signaling and Terminating Equipment is also used. Industry standards for adapting microwave communication systems to telephone equipment are contained in Electronic Industries Association (EIA) Standard RS-210.

The number of signaling and terminating equipments required can be determined with ease, since one such equipment is used in conjunction with each voice channel being transmitted, and, likewise, one is used in conjunction with each voice channel being received. The telephone equipment required can be determined on the same basis if only individual telephone sets are to be used. In more complex systems, the use of switchboards, extension phones, etc., may enter into these considerations. In describing the functional operation of typical signaling and terminating equipment, the presentation will be simplified by discussing the receiving and the transmitting functions separately. It should be remembered that only one voice channel will be considered, and that similar equipment will be used in conjunction with each of the other voice channels that work into or out of the multiplex equipment. A single telephone set is common to both functions.

13.2.1 Transmitting Function

The transmitting function of typical signaling and terminating equipment is shown in figure 13-1. To transmit a ringing signal, the operator causes the transmit relay to be energized or keyed by means of a telephone key or a telephone dial. As a result, a 3500-Hz signal is applied to the multiplex equipment by way of the relay contacts. The transmit filter prevents these signals from affecting other circuits shown to the left of it. When the operator speaks into the telephone, the voice signals are passed by the hybrid coil, the transmit pad, the limiters, and the transmit filter, and are applied to the multiplex equipment. The hybrid coil in this instance provides two-wire to four-wire transformation and impedance matching. The transmit pad, a variable attenuator, is provided to prevent abnormally high signal levels, possibly caused by shouting into the telephone, from exceeding the design limits for signal levels. The transmit filter removes any 3500-Hz components of the voice signal which might cause ringing to occur.

13.2.2 Receiving Function

The receiving function of typical signaling and terminating equipment is shown in figure 13-1. When a 3500-Hz ringing signal is received from the demultiplex equipment, it is applied to the receive filter. This filter permits the 3500-Hz signal to pass to the amplifier and detector, but not to the receive pad. The amplified and detected ringing signal energizes the receive relay, and, as a result, a 20-Hz signal source rings the telephone bell. When voice signals are received from the demultiplex equipment, they are passed by the receive filter to the receive pad, but not to the amplifier and detector. The receive pad is a variable attenuator which is adjusted to provide the desired signal level. The voice signals are applied, in turn, to the hybrid coil. The hybrid coil, common to both the receiving and the transmitting functions, provides impedance matching and four-wire to two-wire transformation. The voice signals from the hybrid coil are applied by way of relay contacts (of the unenergized receive relay) to the telephone receiver.

13.2.3 Interoffice Carrier Circuits

In many cases, the use of carrier or radio to provide the interoffice circuit precludes subscriber loop signaling methods. Usually some form of E and M signaling may be used. E and M signaling derived its name from arbitrary letter designations appearing on early circuit drawings for systems using this type signaling.

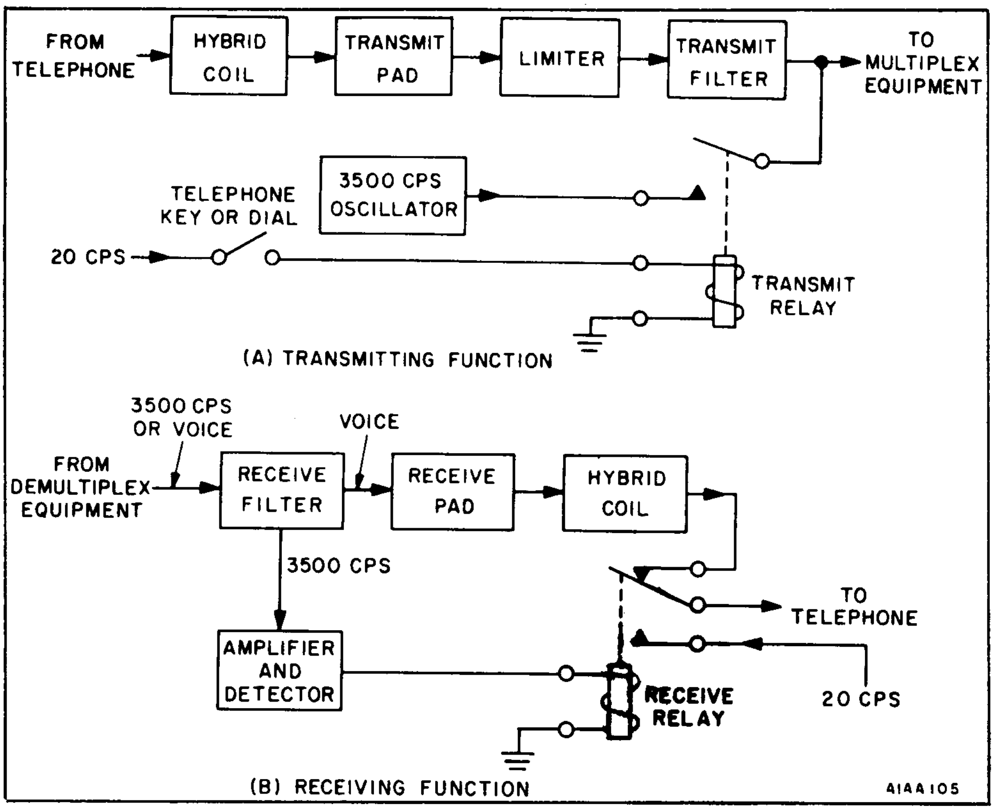

Figure 13-1. Functions of Signalling and Terminating Equipment

E and M signaling is characterized by the use of separate paths for the signaling and the voice signals. The M lead transmits ground or battery to the distant end of the circuit, while incoming signals are received as either a grounded or open condition on the E lead. With this method of signaling, the M lead reflects local conditions, while the E lead reflects the conditions existing at the far end of the circuit.

13.2.4 Signaling in Carrier (In-Band, Out-of-Band)

Some communications systems use separate channels to convey information used in controlling the operation of others. Thc communications industry considers it more economical and much more flexible if each channel carries its own signaling. In local telephone circuits, this can be achieved by direct currents which share the line with the signal voltages. In multi-channel carrier transmission, different techniques are required.

Voice channels occupy a bandwidth of 4-kHz. Some of this bandwidth is used for isolation from adjacent channels. The rest, usually about 3700 cycles, must carry both speech and signaling. In some cases, this channel bandwidth is used not only for voice, but also for one or more telegraph or teletypewriter circuits; these circuits are called speech-plus. These circuits must contain channel filters designed to prevent mutual interference between the speech, telegraph, and supervisory signals which share the channel.

In most carrier systems, one of three basic methods may be used for signaling: in-band, out-of-band, or separate channel signaling. Generally, separate-channel signaling is only used on very high density backbone routes or under special circumstances where signaling cannot be conveniently handled with the communications channels themselves.

The two most widely used signaling methods are called in-band and out-of-band methods. With out-of-band signaling, channel filters are designed with an upper cutoff frequency well below the top edge of the channel. This leaves a portion of the spectrum free to transmit signaling tones. Generally, a single tone is used and this is keyed to convey signaling information.

Some equipment takes advantage of the existence of a separate signaling channel above the voice frequency portion to perform other functions. In Lenkurt 45-class equipment, for example, two tones can be used. Signaling information is transmitted by alternations between the two tones. Since one or the other of the two tones is always present, it becomes possible to use the signaling tone as a reference pilot for regulating the individual channel level.

By completely separating signaling from the speech portion of the channel, it is possible to maintain relative freedom from mutual interference between the speech and the signaling tones; signaling tones can be transmitted during the conversation, thus permitting extra functions such as regulation.

In addition to being more flexible, out-of-band signaling can be much easier and more economical to accomplish, particularly if some sacrifice in channel bandwidth is allowed. In telephone circuits, there is very little speech energy present at the upper end of the channel. Accordingly, filtering requirements may be somewhat relaxed (telephone instrument weighting also provides a degree of filtering). This makes it possible to provide good quality transmission for relatively little equipment cost, since the greatest cost of carrier systems is in the channel filters.

One disadvantage of out-of-band signaling is that it requires some kind of DC repeater at the end of each link. That is, the signal pulses are detected and made to operate a relay. The relay, in turn, keys the signaling equipment in the succeeding link. Therefore, signaling terminals are required at both ends of each link. This has the disadvantage of increasing the cost, complexity, and possible distortion of the signals.

The use of in-band signaling appears to be a natural evolutionary step away from the use of separate channels for signaling. With in-band signaling, speech and signaling are intimately merged. Signaling tones are transmitted at a frequency within the speech band, usually either 1600, 2400, or 2600 Hz. The principal objection to in-band signaling is that the signaling tones lie right in the speech band. This leads to the possibility that speech energy at the signaling frequency may be able to cause false signals with voice energy (called talk-down signaling). Conversely, signaling tones are audible and thus cannot be using during conversations.

The biggest advantage of in-band signaling is the extreme flexibility that it provides. The speech and supervisory signals share the same transmission facility, but at different times. The system is arranged so that supervisory signals are on the line only before or after a call. Since the signaling becomes a part of the transmission, it is not necessary to use DC repeaters. At branching points, a similar flexibility is obtained.

In-band signaling provides unusual flexibility and economy in large offices because it is then unnecessary to cable the E and M (receive and transmit) signaling leads through the office. The signaling equipment can be associated directly with the switching equipment, allowing a trunk circuit to be obtained from any available transmission medium, rather than being restricted to certain carrier systems.

13.2.5 Ringdown Signals

Ringdown signals are spurts of ringing current (16 to 25 Hz) applied usually through the ringing key of an operator and intended to operate a bell, ringer, or drop at the called end. The current may be generated by a manually operated magneto or by a ringing machine with or without automatically inserted silent periods. Ringing to telephone subscribers in automatic central offices is stopped or "tripped" automatically by relay action resulting from the subscriber's off-hook condition. Ringing signals may be converted to 500 or 1000 Hz, usually interrupted at a 20 Hz rate, to pass through voice channels of carrier equipment. A ringing signal to a manual switchboard usually lights a switchboard lamp, which can be darkened again only by local action and not by stopping or repeating the ringing signal. This characteristic makes ringdown operation unsuitable for fully automatic operation. Ringdown signaling over carrier circuits has the advantages of simplicity and of not requiring the distinct signaling channels of E and M systems.

13.3 SYSTEM ALARMS

In a typical microwave communications system, many of the repeater stations are designed for unattended operation. To ensure reliability of operation at these unattended locations, a fault-alarm system should be incorporated into the overall system design. The primary function of the fault-alarm system is to permit supervisory and operating personnel at the system control stations to monitor the operational status of the unattended locations. The fault-alarm system may be used to monitor the functional status of primary or standby microwave equipment, various accessory equipments, primary or standby power sources, or tower lighting circuits, or to provide illegal-entry alarm circuits for station buildings, site area, et cetera. Through the use of fault-alarm circuits, system outage time may be reduced to a minimum, since the type and location of faults are immediately reported to the monitoring stations from which maintenance personnel may be dispatched. In addition, maintenance departments may be established at strategic locations, and personnel deployed more efficiently. The following paragraphs provide planning personnel with an insight to fault-alarm system design. A typical example of a basic fault-alarm system is also provided.

The number and type of faults to be monitored in a given system will vary, depending upon the length of the system, the number of unattended stations, and the degree of system reliability required. Therefore, a careful study of the proposed facilities must be made in order to determine individual needs. It is normal practice to monitor at least three functions from each unattended station. The functions normally monitored are: primary power failure or standby generator operation, primary RF equipment failure or standby RF equipment operation, and tower obstruction light failure. Other typical faults for which alarm facilities may be required are failure of multiplex equipment, illegal entry into station buildings or the site area, insufficient fuel levels in storage tanks for standby power generators, and excessive ambient operating temperature in station equipment building.

The number of monitoring stations required is dependent upon the overall system length, the number of unattended stations involved, and the number of fault-reporting circuits required. The monitoring stations may be located at the ends of the system (terminal stations) or at intermediate points (central terminal) throughout the system, as necessary to meet individual requirements. In long systems involving many hops, it is recommended that at least two monitoring stations be established, each equipped with maintenance communications facilities, and that they be located at opposite ends of the system. This arrangement prevents total loss of the fault-monitoring facilities due to operational failure within the system.

In any microwave system, the number of stations that may be equipped with fault-reporting facilities is limited by certain factors, the most significant of which are as follows: the number of multiplex voice-band channels allotted to the fault-alarm system, the usable bandwidth of the allotted channel or channels, and the frequency spacing required for individual fault tones. Although more than one voice-band channel may be used for fault-tone transmission, it is generally considered impracticable to use more than one unless absolutely necessary. For an average system using time-division multiplexing, the service channel (channel 1) will generally provide sufficient usable bandwidth for the transmission of the necessary fault tones. In systems employing frequency-division multiplexing, a portion of the microwave baseband is normally allocated to fault-reporting functions.

The allocation of specific fault-tone frequencies in a given system is governed by the requirements of the particular fault-alarm equipment used. A variety of equipments are available for use in fault-alarm applications; in general, the manufacturer's recommendations for the particular equipment selected should be followed when frequency assignments are made.

Each station from which faults are to be reported must be assigned a specific fault-tone frequency so that when faults occur, system operators at the monitoring stations can easily determine which unattended station is reporting. As an example, consider the fault-tone frequency assignment plan used in a typical system employing time-division multiplexing. In this system, a portion of the service channel bandwidth (between 2.0 and 3.0 kHz) is allotted to fault-alarm functions, and fault-alarm equipment requiring 100-cycle spacing between individual fault tones is employed. It is evident that within the allotted bandwidth (1000 cycles) space is available for 11 separate fault tones, using the required spacing (2.0 kHz, 2.1 kHz, 2.2 kHz, etc.). Therefore, a separate fault-tone frequency may be assigned to a maximum of 11 stations. So that more than one fault may be reported on each assigned frequency, a simple coding device, such as a fault-interrupter panel, may be used at each assigned station. However, other types of systems provide an alarm which does not require a separate frequency per terminal. This type of alarm is particularly useful on large systems where the service channel frequency spectrum will not handle one discrete tone frequency per terminal.

If supervisory control functions are required in the system, a portion of the service channel bandwidth normally allotted to fault-alarm functions may be used for transmitting control data. This will reduce the number of frequencies available for fault-reporting purposes. When both fault-alarm and supervisory control data are transmitted simultaneously in the service channel, it is recommended that the higher frequencies be used for fault tones and the lower frequencies for control functions. If voice (maintenance) communications are also being accomplished on the service channel, the number of fault tones should be limited to six, located between 2.5 and 3.0 kHz to prevent mutual interference between the two functions.

13.3.1 Basic Fault-Alarm Equipment

The following paragraphs describe the functions and applications of the basic equipment used in typical fault-alarm systems.

13.3.2 Fault-Tone Transmitter

The fault-tone transmitter consists basically of a fixed-tuned tone generator and amplifier designed to operate within a specific frequency rate. The unit is normally installed at unattended stations from which fault conditions are to be reported. If more than one fault is to be reported, the fault-tone transmitter may be operated in conjunction with a keying device such as a fault-interrupter panel.

13.3.3 Fault-Tone Receiver

The fault-tone receiver consists of a highly sensitive fixed-tuned receiver designed to detect the fault tones generated by the fault-tone transmitter, and to operate fault-indicating devices. This unit is normally installed at monitoring stations. One receiver is required for each unattended station which is monitored.

13.3.4 Duplex Signaling Unit

The duplex signaling unit consists of a fault-tone transmitter and a fault-tone receiver. This unit is designed for use in a duplex signaling system, for transmitting control data and detecting fault signals on two-way audio channels. The unit may also be operated on a simplex basis, in which case only the transmitting portion is used at unattended stations, and the receiving portion at monitoring stations.

13.3.5 Fault-Interrupter Panel

The fault-interrupter panel is a keying device used in conjunction with fault-tone transmitting equipment to facilitate the transmission of more than one fault on a single fault-tone frequency. Two general types of fault-interrupter panels are available. One type is used in fault-alarm systems employing the tone-off method of fault reporting, and the other is used in systems employing the tone-on method. Figure 13-2 shows simplified schematics of the two types of panels.

Although the system applications of the tone-off (A) and tone-on (B) panels differ, the units are similar. Each unit consists of a set of motor-driven cams and contacts, and fault-interrupter relays, which are connected in series with the keying circuit of the fault-tone transmitter. Each cam has a different configuration, and, when activated, opens and closes its associated contacts at a different rate. The field coils of the fault-interrupter relays are connected via the external fault-sensing circuits to the power line, so that when a fault occurs, power is applied to the coil of the appropriate relay. When no faults are present, all relays and cam motors are de-energized, and the fault circuits remain in a stable state. When a fault occurs, power is applied to the coil of the appropriate fault-interrupter relay by means of the external fault-sensing circuit. When the relay is energized, it interrupts the continuity of the fault-tone keying circuit and applied power to the cam-drive motor. The fault-tone circuit is then completed and the fault-tone transmitter is keyed in accordance with the keying rate generated by the associated cam-operated contacts. Should more than one fault occur simultaneously, the coded signals for each fault follow each other in such a manner that all faults can be positively identified.

13.3.6 Fault-Light Panel

As the system monitoring station, the outputs of the fault receivers for the unattended stations are connected to a fault-light panel. A light is provided for each station from which faults are to be monitored, and each light panel is equipped with a buzzer. In the event of a failure (fault) at a station, the light on the panel associated with that station flashes on and off in a predetermined sequence, which serves to identify the particular fault. The buzzer on the light panel also sounds in synchronism with the light, thereby drawing immediate attention to the fault occurrence.

13.3.7 Filter Panel

Filter panels are required in alarm systems where the fault-tone channel is also used for voice communications (service, maintenance, etc.). The filter panel is used to separate the tone and voice frequencies, and must be selected to fit individual needs.

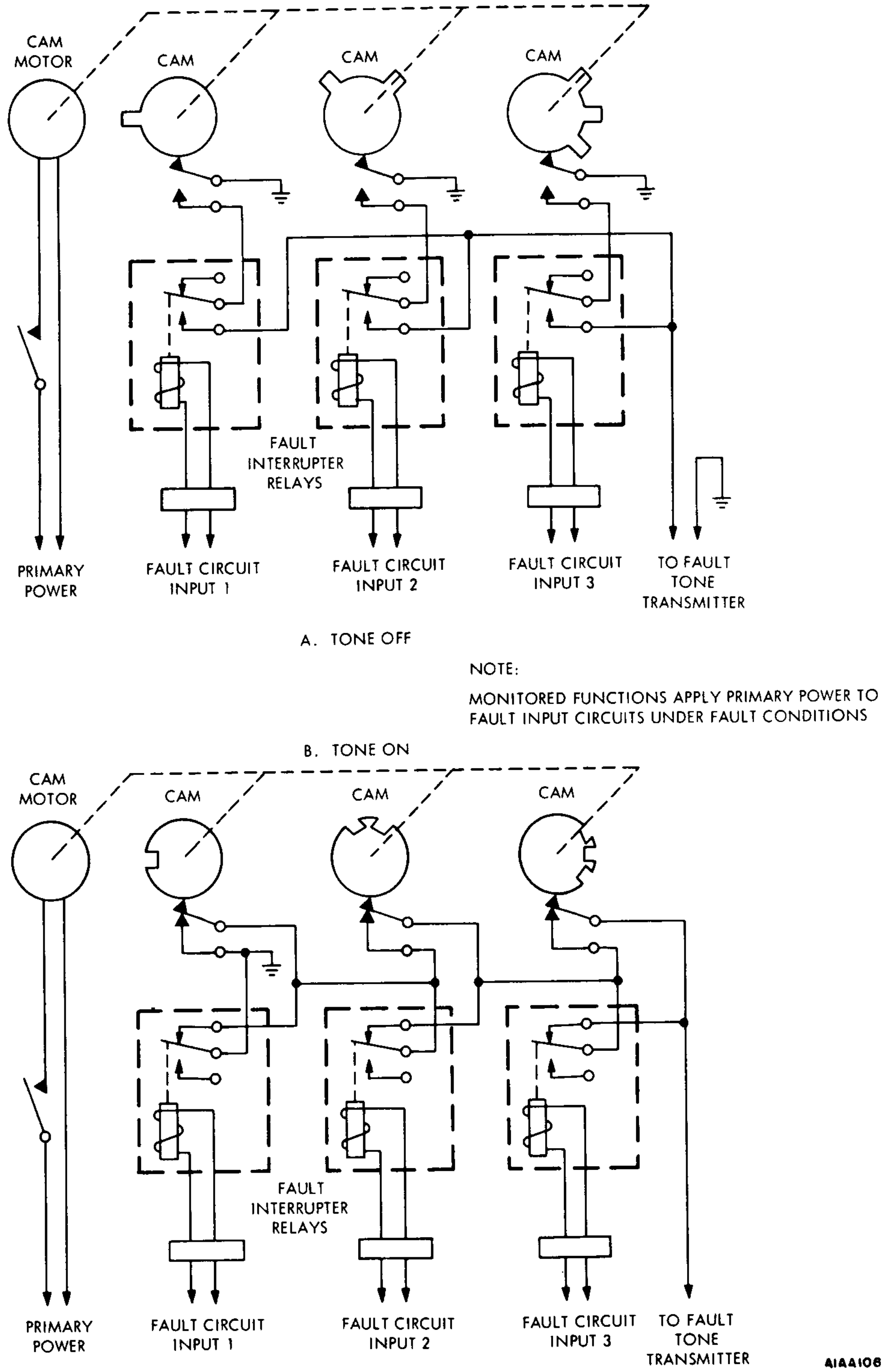

Figure 13-2. Schematic Diagram of Tone-Off Type Fault Interruptor Panel (Sheet 1 of 2)

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CHAPTER 14

MICROWAVE POWER SUPPLIES

The reliability of a microwave radio relay system depends to a large degree upon the reliability of the source of power at each station. Since the reliability of the power source can be made to approach 100 percent through the use of primary and standby power sources and automatic switching devices, the determination of primary and standby power requirements must be made on the basis of system reliability specifications and economic considerations. The most common sources of primary and standby power will be discussed here, and comparisons will be made between several types of generating mechanisms. Recommendations will also be made in an effort to reduce the number of options and thereby simplify the task of the system planner.

14.1 ANALYSIS OF PRIMARY POWER SOURCES

Two primary power sources will be considered: one is a large scale commercial (or possibly private or military) power plant and the other an independent on-the-site generating plant. Of course, one usually thinks of the commercial power source in terms of the nearest power transmission line. For the larger terminal stations in the United States, the choice of commercial power is almost taken for granted because power lines are likely to be available at such sites. For stations at remote sites, the choice of an independent power plant may also be taken for granted since power lines are not likely to be nearby. But for the majority of stations, a comparison must be made between the installation and occasional maintenance costs of service lines to existing power lines and the installation, regular maintenance, and depreciation costs of an independent power plant, before a decision can be made. The following paragraphs present the factors which should be considered in order to arrive at the most satisfactory conclusions.

14.2 COMMERCIAL POWER

The use of power from a large scale commercial power plant is highly desirable if commercial power lines are available and if the power characteristics are compatible with radio relay equipment requirements. Information concerning commercial power lines and power characteristics can be obtained from the report of the field survey. The frequency must be between 50 and 60 Hz, and the nominal voltage should be 115 volts or 230 volts. If the radio relay equipment is not adaptable to 230-volt operation, a 2:1 stepdown transformer can be employed to provide 115 volts. Likewise, single-phase requirements can be met by means of transformer arrangements. The line-voltage tolerance need not meet the system requirements of $\pm 5\%$, but it must meet the input range of available voltage regulators 95 to 130 volts. The power handling capacity of the lines must also be ascertained; this is particularly important for long lines in remote areas and for large stations with heavy power demands. Commercial power must also meet the standards of dependability that can be established by the system planner. Obviously, the outage time of primary power cannot exceed the maximum operating period of standby power equipment. This requirement should not be difficult to meet if weather conditions are not unusually severe. The measure of dependability will therefore be based on an estimate of the line maintenance problems that will be encountered in times of heavy snow or ice, high wind, or high water. The possible frequency of such occurrence will naturally enter into this estimate.

In addition, the initial cost of installing power lines from existing lines to the radio relay site and the cost of maintaining these lines must be calculated and/or estimated.

14.3 INDEPENDENT PRIMARY POWER (SIZING)

An alternative to the use of commercial power is the generation of primary power on the site. One of the most economical and convenient methods of doing this is by the use of an internal combustion engine and a generator. The diesel engine generator is preferred for primary power service.

A recommended independent power source uses two separate diesel engine generator sets, connected through a common panel so that the load can be transferred from one to the other every 48 hours, or whenever the failure of one of the units makes such a transfer necessary. The output voltage of these generators should be 115 volts AC, regulated within the limits of $\pm 5\%$ to eliminate the need for separate voltage regulators.

The size of the engine generators depends upon the power requirements of the station. The capacity of the fuel tank for these units depends upon the accessibility of the site and the size of the engine generators. It should not be necessary to refill the fuel tanks more than once a month. If inclement weather or undue hardship makes necessary a longer period of time between refuelings, a larger tank is recommended. The approximate rate of fuel consumption, in gallons per hour, of a diesel driven generator can be calculated by multiplying the output in kilowatts by 0.136; this calculation will be helpful in determining the size of tank needed.

14.4 STANDBY POWER (EMERGENCY POWER) SOURCES

Several secondary power sources for standby or emergency service are considered here. The most common standby setup is described first; this setup can be used only when a short outage time for switchover purposes is permissible. Two other equipment arrangements, which are applicable when no outage time is permitted, are then described.

14.5 COMMON STANDBY POWER SOURCE

When the system reliability requirements are not too stringent, a gasoline engine generator set is adequate for standby service. An automatic transfer panel is required for proper utilization of the standby engine generator. This panel normally connects the load to the primary power source. If the line voltage falls below the required minimum value for a period of 3 to 5 seconds, the engine is started. When the engine generator output exceeds the minimum voltage value, the load is transferred from the primary power terminals to the standby generator terminals. Normally, the load is supplied by the standby engine generator for approximately 15 minutes, then is switched back to the original condition if primary power is restored. The size of the engine generator required depends on the power requirements of the station.

In addition to the automatic transfer panel, a starting battery and battery charger must be provided. Protective controls usually include an over-cranking limiter, a low-oil-pressure cutout, and a high-temperature cutout. Radio interference suppressors are normally furnished. Crankcase immersion heaters are available for quicker cold weather starting. The capacity of the fuel tank depends upon the size of the engine generator and the reliability of the primary power source.

14.6 CONTINUOUS SERVICE POWER SOURCES

For system specifications that call for a high degree of reliability, where engine starting time and switching interruptions cannot be tolerated, a more extensive standby power source is required. At least two types of continuous service power systems are available. One type employs an AC motor, an AC generator, and a gasoline engine (figure 14-1). The motor is mechanically connected to the generator, and the engine is linked to the generator by means of a magnetic clutch. When primary power is available, the AC motor drives the generator, which furnishes power to the station load. In this condition, the magnetic clutch is de-energized; therefore, the engine is disconnected from the generator. If the primary power fails, the magnetic clutch is energized, and the engine is cranked by the rotational energy of the generator. The engine starts and becomes the prime mover of the generator, which continues to furnish power to the load throughout the operation. In addition, the AC motor is disconnected from the primary power line. When primary power is restored for a continuous period of at least 10 minutes, the magnetic clutch is de-energized, the AC motor is reconnected to the primary power line, and the engine is stopped.

Another type of continuous service power system employs an AC motor, an AC generator, a DC motor, and a group of storage batteries. The two motors and the generator are mechanically connected so that they rotate together. Normally, the AC motor, which is supplied by the primary power source, is the prime mover, and the AC generator furnishes power to the load. In this condition the DC motor acts as a DC generator which charges the batteries. If the primary power fails, the DC motor receives power from the batteries and becomes the prime power. The AC generator continues to furnish power to the load. The batteries must have sufficient capacity to supply power for the maximum anticipated outage time of the primary power source. For stations where it is impracticable to meet this requirement, a separate engine generator can be employed to supply power to the DC motor and batteries if the primary power failure is of long duration.

14.7 COMPARISON OF ENGINE GENERATORS

The selection of an engine generator for use as an independent power source (primary and/or standby) will depend on several factors. The selection is usually between

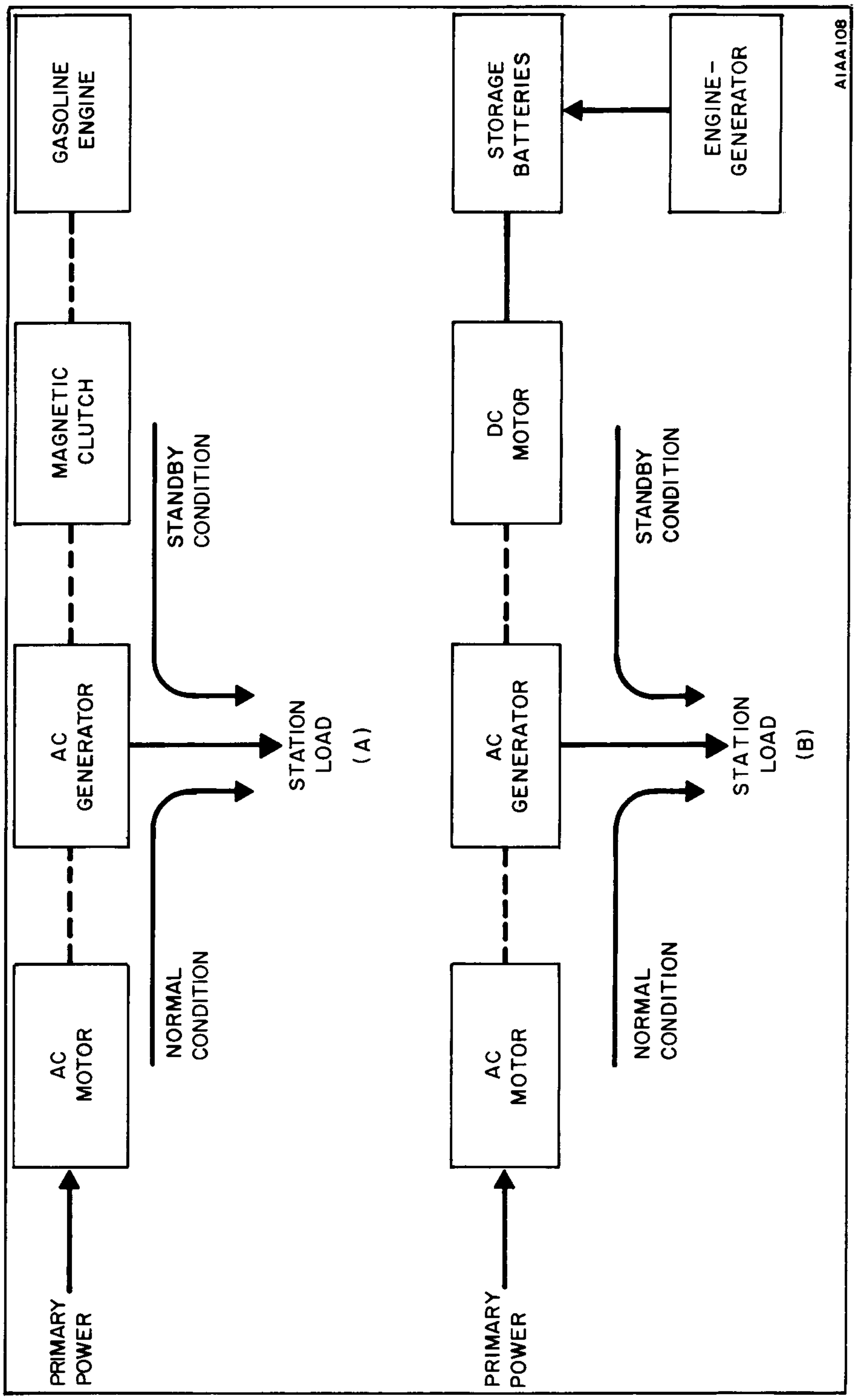

Figure 14-1. Continuous-Service Power Sources, Block Diagram

a diesel and a gasoline engine. Each has its own characteristics which determine its suitability for a particular application.

The diesel engine is suitable for either continuous or part-time service. The initial cost of a diesel engine is slightly higher than that of a comparable gasoline engine. For certain applications, however, this disadvantage is more than offset by other advantages. The diesel engine is extremely rugged, it uses less and lower cost fuel, it has a long life expectancy, and it offers maximum reliability. Several reasons for these advantages are: diesel fuel has a higher energy content than gasoline or liquid petroleum, the operating speed of the diesel engine is approximately half that of the gasoline engine, and the diesel engine does not require an electrical ignition system. The last two factors mentioned account for the lower maintenance and overhaul costs for the diesel engine. Engine starting time is comparable for diesel and gasoline engines.

Gasoline engines can be used for continuous duty, but are better suited for standby use. As previously mentioned, the gasoline engine is lower in initial cost, but has a shorter life expectancy. It has a higher operating speed, which wears the engine out more rapidly. It uses more and higher cost fuel, and it is not as reliable as a diesel engine. This is true because a gasoline engine uses the well known electrical ignition system which is subject to failure due to dampness, age, and carbon buildup.

Liquid petroleum engines are basically gasoline engines with a modified fuel intake system. The conversion cost to liquid petroleum is modest, but the conversion results in a 10 percent reduction in horsepower. This is true because there is less energy per gallon in liquid petroleum than in gasoline. Liquid petroleum is a highly volatile type of fuel consisting of butane and propane combined in varying percentages, depending on the operating temperatures and geographical locations. Engines using this fuel are generally not economically competitive with gasoline or diesel engines.

Fuel energy is measured in British thermal units; this system of measurement gives a comparison of the power possibilities of different fuels.

The factor of personnel safety is also an important consideration in the choice of fuel. Gasoline and liquid petroleum are very volatile, and constitute a safety hazard. The possibility of fires or explosions, therefore, is much greater with these fuels than with diesel fuel. Diesel fuel is not highly volatile, and is, therefore, quite safe.

The two graphs shown in figure 14-2 show the initial cost plus cumulative fuel costs, plotted against time of operation for diesel and gasoline engine generators.

The graphs are for a 10 kW generator operating at full load and at half load. The fuel prices used were 15 cents per gallon for diesel fuel, and 25 cents per gallon for

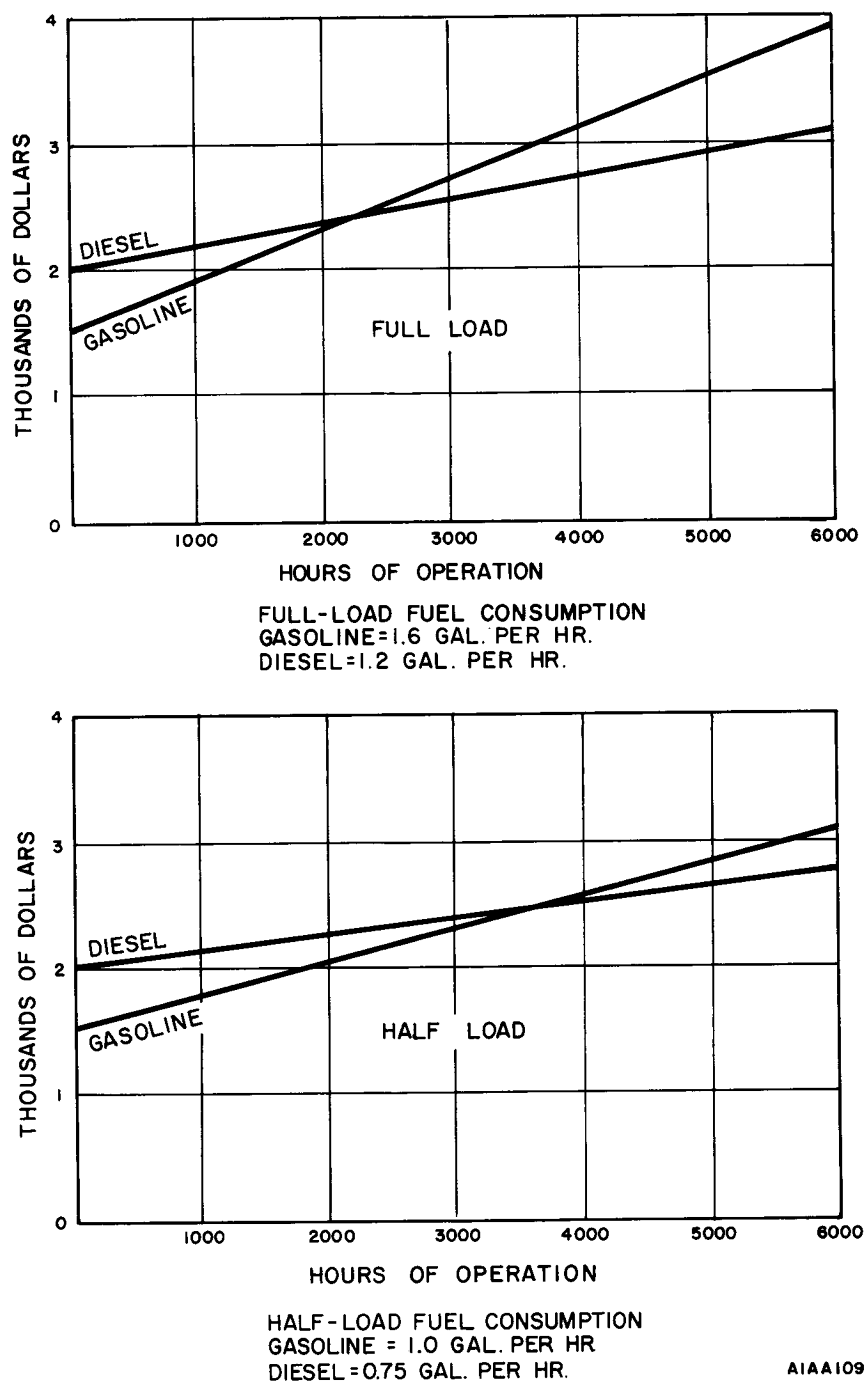

Figure 14-2. Comparison of Engine-Generators, Diesel and Gasoline

gasoline. The crossover point, which shows the number of hours of operation required to equalize the costs, can be computed as follows:

$$\left(\text{Gallons of gasoline used per hour} \times \text{Cost of gasoline}\right) - \left(\text{Gallons of diesel fuel used per hour} \times \text{Cost of diesel fuel}\right) = \text{Net savings per hour using diesel engine generator}$$

$$\frac{\text{Extra cost of diesel engine generator}}{\text{Net savings per hour using diesel engine generator}} = \text{Number of hours needed to equalize costs}$$

CHAPTER 15

MICROWAVE INSTALLATION CRITERIA

This chapter covers the development and preparation of detailed installation plans for microwave radio communication stations. Constraints placed upon the installation due to the system design requirements will also be discussed.

Information and data are provided as facility design criteria in accordance with current Navy regulations, and updated on a continuing basis until finalized. A&E drawings, utilized for the station implementation phase, become the station "plant-in-place" records upon completion of the installation.

Facility design criteria, supplied by the communications system engineering activity, include site location and layout information, building location and layout information, site leveling and grading requirements, AC power requirements, utilities, water and sewage requirements, proposed manning, and, when appropriate, plans for future station expansion.

When a station is to be installed in existing buildings, the physical dimensions and layout of the buildings are supplied to the Navy planners who determine if modifications are needed. Orientation of the equipment and buildings must be considered to provide the optimum antenna arrangement. Distribution of AC power in the building must be investigated to assure ample power for the equipment. The equipment layout must be reviewed to verify the availability of sufficient floor space and overhead for equipment installation.

The detailed installation drawings prepared by the system engineering activity will contain all information required to accomplish not only the entire inside plant installation but also that portion of the outside plant under cognizance of the system engineering activity. Engineering information affecting the A&E design contained in these drawings is provided to the Navy planners prior to generation of the A&E drawings. Installation drawings specify where and how to install cable trays, cables, distribution frames, equipment, system grounds, and AC power distribution. Each drawing also includes a List or Bill-of-Material (LOM or BOM) required to accomplish the installation.

The engineering activity, engaged in development of a communication system, is responsible for providing the Navy planners with definitive facility design criteria, covering the scope of development work involved. The extent of plans and specifications required for this development work, depends upon the individual station and system requirements. The categories of activity required for total development and construction of a communication station are as follows:

- o Site Layout and Plot Plan, RADHAZ Clearances
- o Access Roads and Parking Areas
- o Site Preparation, Clearing and Grading (maximum slope of 5%)
- o Building Design
- o Water Supply and Sanitation System
- o Antenna Footings and/or Structures
- o Prime and Auxiliary Power
- o Heating and Air Conditioning (Environmental Control)
- o Site Security Fencing and Lighting

General information, relative to a proposed station, needed by the Navy planners for the development of facilities, plans and specifications includes:

- o Expected life of station
- o Location of station
- o Elevation of station
- o Meteorological conditions
- o Personnel housing requirements
- o Total assigned personnel
- o Number and functions of "on-duty" personnel

15.1 SITE LAYOUT REQUIREMENTS AND RESTRICTIONS

Development of site plans requires close coordination of all aspects of civil and communications system engineering to determine the optimum site configuration. Site plans are developed by the system engineering activity and provided to the Navy planners as guidance. This compatibility is based on various factors that affect or control the logical arrangement of system components with respect to activity and operational requirements. These factors include:

- o Site topography
- o Available area
- o Size, number, and types of buildings

- o Direction and number of transmission paths
- o Size, number, and height of antennas and supporting structures
- o Obstructions to radio paths.

15.1.1 Antenna Spacing

A typical site layout, prepared by the Navy planners is based on making the equipment building the center of site operations, with the antenna structures as close to this building as practicable to minimize the transmission line lengths required between equipment and antennas. Diversity antennas require vertical separation from each other by a distance, h, determined as follows: In a space diversity system, only one signal is transmitted but it is received by two (or more) receivers connected to separate antennas. The antennas are widely spaced in elevation, so that propagation effects or path reflections are not likely to be the same at the different elevations. An approximation of the spacing required is given by the following formula:

$$h = \frac{1.3 \times 10^6 d}{f \times h_t} \qquad (15\text{-}1)$$

where:

h = diversity spacing in feet

d = distance between stations, in miles

f = operating frequency, in megacycles

h_t = height of transmitting antenna, in feet, above a reflecting plane tangent to the earth at the point of geometrical reflection.

Figure 15-1 illustrates a space diversity antenna arrangement. Figure 15-2 is a block diagram of a typical space diversity system.

15.1.2 Buildings

The number and direction of transmission paths specified normally determine orientation of the equipment building with respect to the site. Power generator buildings require separation from the equipment building, but are located sufficiently close to minimize power cable voltage drops between generators and equipment. Fuel storage areas should be located where the RF power density is less than 5.0 watts per square centimeter. Living quarters are to be located sufficiently remote from equipment and power buildings to assure isolation of living and work areas.

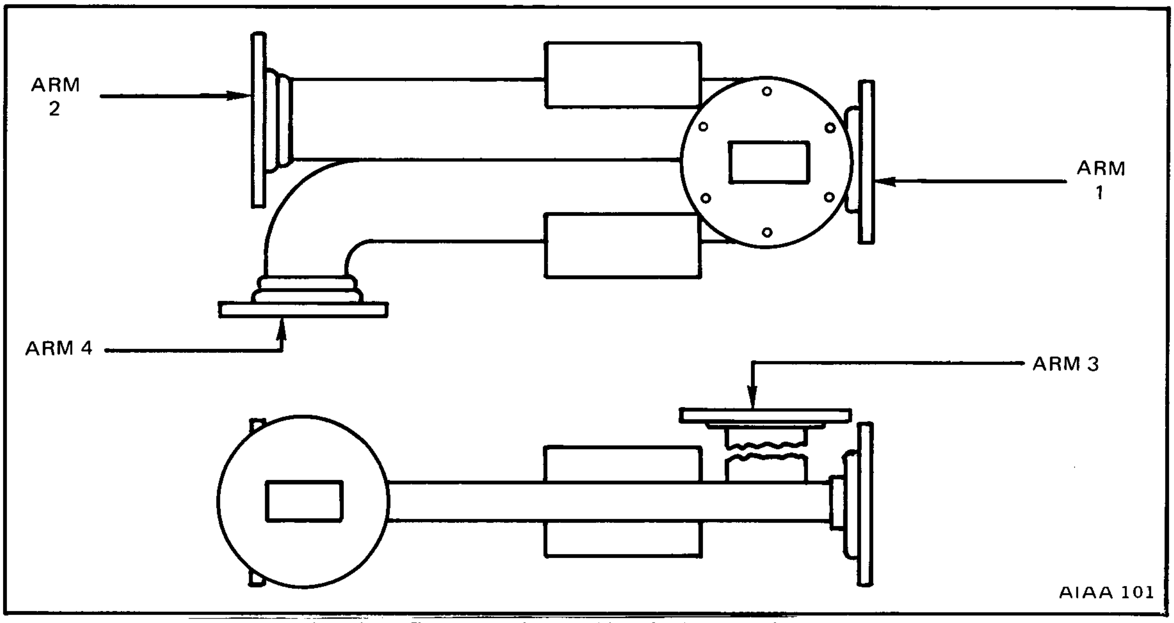

Figure 15-1. Space Diversity Antenna Arrangement

15.1.3 Topography

The topography of the site area has an important effect upon the site layout. When necessary, compromises in site layout are effected to keep site preparation and grading within reasonable limits.

15.1.4 RADHAZ Clearances

Since microwave line-of-sight transmitters presently operate with relatively low output powers (one to five watts are typical values) the radiation levels which are considered hazardous to personnel (0.01 watts per square centimeter) are not present. The equation used to determine the radiation intensity at the center of a beam in the near field is:

$$W = \frac{4P}{A} \qquad (15\text{-}2)$$

W = Power density in watts per square centimeter

P = Transmitter output power in watts

A = Antenna area in square centimeters

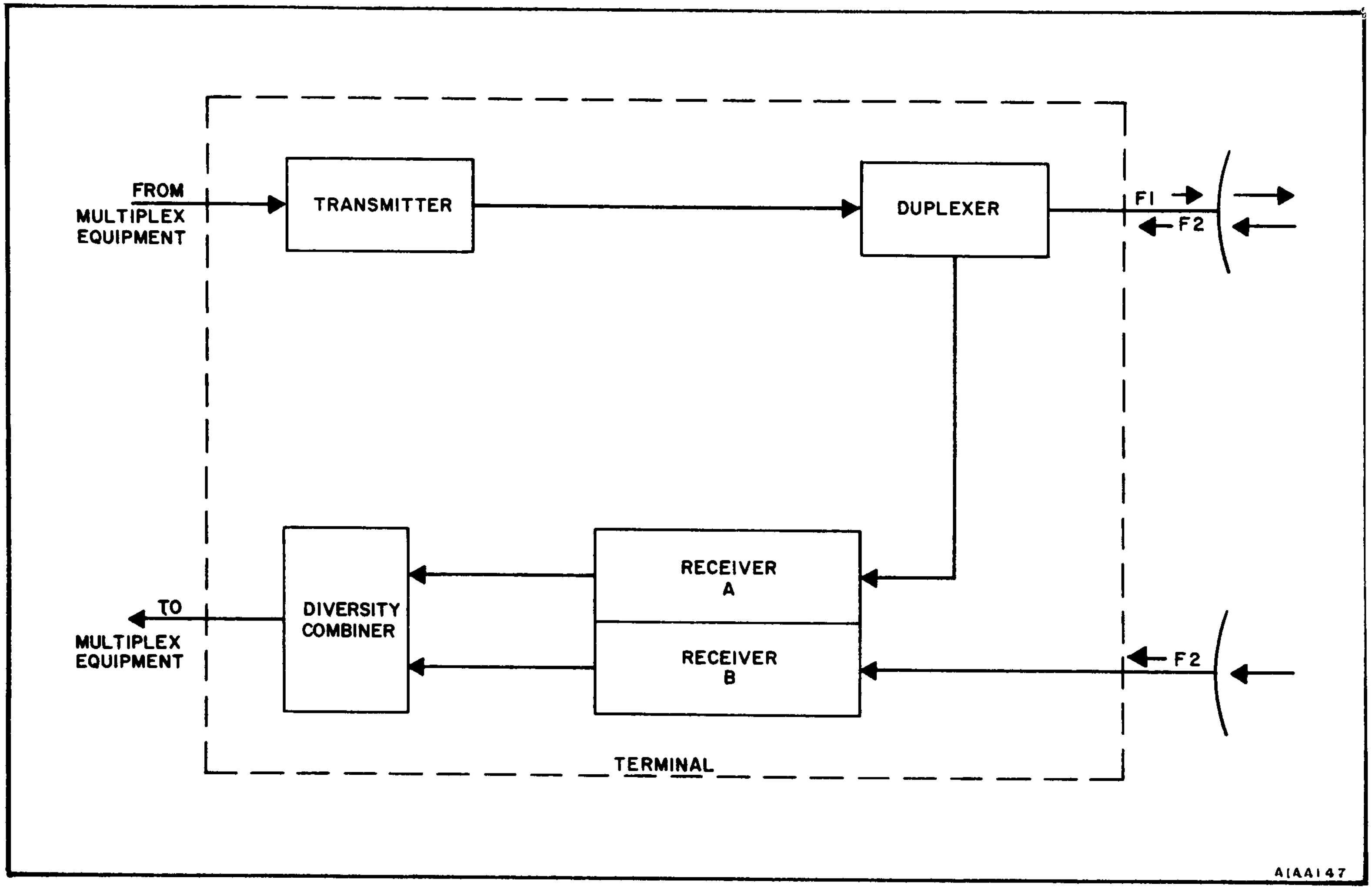

Figure 15-2. Typical Space Diversity Operation

This subject is covered in detail in Volume II, Tropospheric Radio Communication Systems, since the radiated energy for tropo-scatter systems does create significant hazards to personnel, fuel, and explosive storage.

15.1.5 Final Site Plan

A final site plan is prepared by the Navy planners using the preliminary site layout prepared by the communications system engineering activity, site survey information, and the criteria discussed above. The final site plan includes the following data in addition to the physical positioning of various site components:

- o Site boundary and property lines
- o Base line and benchmarks
- o Access roads and parking areas
- o Elevation, azimuth, and coordinates for the center of each antenna
- o Underground utilities
- o Underground services
- o Existing buildings and facilities.

A typical site plan is illustrated in figure 15-3.

15.2 ACCESS ROADS

The design of access roads to a communications station is accomplished by the Navy planners. A preliminary engineering study, prior to the development of site access roads and parking areas, should take into account vehicular traffic demands. Although the final access road position will depend primarily on site location, layout, and topography, the final design should offer direct routing, adequate right of way visibility, good foundation, proper drainage, and degrees of curvature and grade consistent with good highway engineering practice.

15.3 SITE PREPARATION

Site preparation includes clearing and grubbing, roadway excavation, structure excavation, burrow and fill excavation, site grading, and drainage operations. Site topographical information and other survey data provided by the systems engineering activity, form the basis for site clearing and grading drawings.

15.4 BUILDING DESIGN-CONSTRUCTION CRITERIA

The size of a building used to house microwave equipment depends upon the station function. In particular the following factors must be considered:

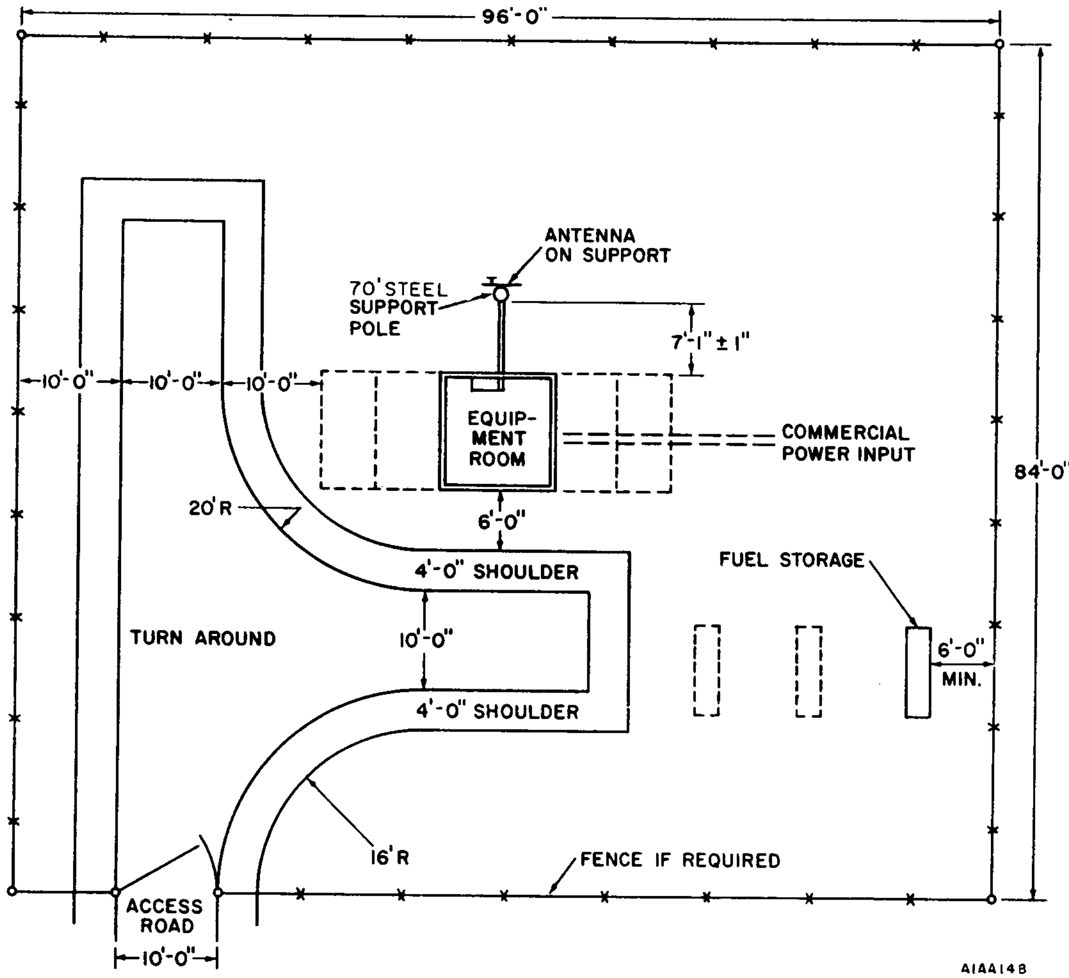

Figure 15-3. Typical Site Plan

- Size and quantity of required equipment and possible future equipment
- Necessary working space around equipment
- Required space for maintenance purposes
- Personnel requirements (desk space, sanitary facilities)
- Housing of power equipment.

At some sites, contemplated use of existing buildings necessitates investigation of load bearing capabilities of the floor. The need for heavy antenna mounts on the building may require building reinforcement.

At remote sites new buildings must be erected, the type of construction depending upon physical conditions peculiar to the locality, and availability and relative cost of construction materials. Other considerations include the required strength and durability of the building, and necessary maintenance. Additional factors affecting the type and strength of a structure are: climatic conditions, temperature range, wind velocities, and amount of rainfall and/or snowfall. Transportation and handling costs and site accessibility affect the selection of construction materials. Local codes governing the use of certain materials and methods of construction must be investigated. The availability of skilled labor may be a deciding factor. For small stations the above requirements can be met by using either sheet metal or masonry construction. Sheet metal buildings can be prefabricated, easily erected, and readily enlarged. Masonry buildings have greater durability. For each building, the Navy planners prepare an A&E drawing package that includes the following categories of plans:

- Architectural Plans. Floor plans, elevations, details, schedules
- Structural Plans. Foundations, section, construction details
- Electrical Plans. Power distribution, control panels, lighting, schematics
- Mechanical Plans. Heating, ventilation, air conditioning
- Plumbing. Water supply and sanitation facilities and systems.

Actual building design is accomplished by the Navy planners using the space requirements, room configurations, and other facilities design criteria provided by the communications system engineering activity. The design includes a future station expansion capability of 25 percent. Various architectural standards and specifications are utilized. Specific building design criteria associated with communications station requirements are discussed in the following paragraphs. In new facilities a 100 percent equipment expansion should be anticipated.

Buildings of single story, rectangular construction are most desirable for microwave radio communications equipment installation. Normally, equipment buildings are physically separated from other site buildings such as power generator buildings and living quarters. When a single building is employed, use of one end as the equipment room minimizes interference by off-duty personnel, and power generators. The center of the building is then utilized for maintenance and storage, the opposite end for administrative functions at the station.

To determine the space requirements and layout of the building, floor plans are developed showing the location of all equipments in the operations and maintenance areas. Requirements for spare parts storage space are determined by the types of equipment, and level of maintenance to be performed at the station. Consideration is given to the reduction of spare parts storage requirements resulting from improved equipments, and streamlines maintenance and supply techniques now being employed. Space requirements for administrative and sanitation facilities are determined from the number of personnel programmed for normal operation and maintenance duty at the station.

At least one outside door to the equipment room, capable of passing the largest single component that may be moved into the station, is required. A loading ramp must be provided immediately outside this door to facilitate loading and unloading heavy equipment from trucks.

Ceilings in the equipment area should be at least 10 feet above the floor level for adequate ventilation of standard eight-foot equipment racks. This height also provides proper diffusion of light throughout the equipment area from ceiling luminaires.

The building floor must be designed to support the heaviest equipment likely to be placed upon it. Overall, the floor should support the entire weight of all equipment, and provide a 50 percent overload factor to accommodate any expansion of facilities. A minimum floor loading of 200 pounds per square foot is considered desirable. Provisions must be made in the walls, ceiling and roof of the equipment building for installation of transmission lines running to the outside of the building. These exit ports require "tailoring" to the installation at each station, and may include RF shielding.

Incandescent lights will be used in electronic equipment areas to preclude fluorescent light radiation interference. A minimum of 30 foot-candles of light will be provided at a distance of 26 inches above the floor. A battery-powered emergency lighting system is required during power failures, pending activation of auxiliary power plants.

The building must be provided with a good station ground system in accordance with NAVELEX 0101, 102, Naval Communication Station Design.

15.5 ELECTROMAGNETIC COMPATIBILITY (EMC)

Although many specifications and standards exist which may be applied against individual electronic equipments for the purpose of interference control, these documents do not necessarily insure electromagnetic compatibility when a multiplicity of equipments are located in a common electromagnetic environment. Many cases have been recorded where a well-designed piece of equipment failed to perform its intended function because of electromagnetic incompatibility with another equipment at the intended location. The application of interference control measures to individual equipment, without regard for those measures already applied at interfacing equipment, can also result in redundancy, with associated increased cost, weight, and design time.

The system design approach avoids problems because system design for EMC means approaching the problem at the very beginning of project activity, wherein a detailed functional design study is made of the overall system, its constituent subsystems and equipments, and the intended operational environment. At that time, the EMC problem is defined, possible contributory factors are analyzed, and necessary goals are established. In general, the desired goals in the achievement of optimum compatibility are:

- o Minimization of electromagnetic emissions which may affect other equipment (effects of the system upon external elements - inter-system) o Minimization of susceptibility to emissions (e.g., effects of external elements upon the system inter-system)

o Minimization of emissions and susceptibility between equipments within a system (internal effects - intra-system).

System designs also mean that EMC must be integrated into all project activities throughout the project life to assure the accomplishment of these goals from a preventive-measures approach rather than the use of inefficient, costly, after-the-fact remedies.

The implementation of EMC, therefore, calls for the establishment of a formal program having well-defined objectives and controls. Such a program is discussed in the following paragraphs. A summary of the salient features of EMC programs and their objectives follows.

The establishment of an EMC program within the framework of an overall project must include a clear statement of the objectives of such a program. In general, a formal program will have the following objectives:

o Gathering of information and data, including spectrum signature measurement data on the equipment or system and on the intended operational electromagnetic environment

o Selection, interpretation and application of EMC specifications and standards, engineering methods, and testing procedures which may be applied toward the selection or design of equipments

o Selection and application of methods of prediction of both interference and radiation hazards in the intended environment, based on information gathered

o Dissemination of gathered information to all personnel concerned with the planning, design, or installation of the equipment or system

o Generation of an EMC program plan when required, which states the specific practices, procedures, design criteria, etc., to be used (and to be avoided) to achieve EMC throughout all phases of a program.

15.6 ANTENNA FOOTINGS AND/OR STRUCTURES

Supporting structures, foundations, lighting system, and antenna interfaces are designed by the Navy planners. Design factors include: height of structure, size and type of antennas, obstruction lighting regulations, path azimuths, and wind and ice loading. Foundation design is based on results of a soil analysis performed during the site survey. The Navy planners prepare specifications for the supporting structures and foundation design, and construction drawings for installation of structures at the Station. Erection drawings and procedures for the structures and antenna interfaces with the towers, are normally supplied by the antenna component manufacturer.

15.7 PRIMARY AND AUXILIARY POWER (TECHNICAL POWER)

DCS requirements for power systems are contained in paragraph 3.6 of DCA Standard 300-172. Primary power requirements for a communications facility are determined by the system configuration, and include equipment loads (technical power), utility and domestic loads, and provisions for future expansion. The A&E design agency is responsible for design of the site primary power system and its distribution. One of the most economical and convenient sources of auxiliary power is the diesel engine-generator. However, an engine-driven-generator requires time to start and warmup, causing a delay before taking the load after a power failure. NAVELEX practice is to use storage batteries to provide power instantly and economically. They are kept fully charged by the primary power source during normal operation and, when a failure occure, the batteries assume the load instantly without interruption to service. Batteries lack the capacity to supply power for a long period of time and it is necessary to have available an auxiliary generator. Figure 15-4 illustrates the arrangement of a typical DC power plant, containing the 24-volt and 48-volt system, required to satisfy the demands of current transistorized equipments. The figure also shows the "standby" generator input to the distribution panel. The "end cells" are employed in battery systems to offset the effect of dropping voltage as the batteries discharge. End cells are switched into the regular battery circuit one cell at a time, as needed, to raise the battery voltage to a proper level.

15.8 ENVIRONMENTAL CONTROL (HEATING AND AIR CONDITIONING)

Design of the environmental control system is accomplished by the Navy planners. The communications system design activity is responsible for specifying the required environmental limits for equipment operating conditions, and personnel requirements. This includes detailed information concerning the heat dissipation figures for all equipments.

The heating system will vary as to type of fuel employed and method of heat distribution. Oil is usually the best fuel choice. If the microwave station is located on or near an existing Government facility, it may be possible to obtain piped steam heat from the facility central heating plant. Forced hot air is the preferred method of distribution and has the following advantages:

- o The ducts, blower, and outlets may also be used for the air conditioning system. Compactness and economy are realized by this approach
- o Dust control is maintained by means of filters
- o The Navy planners determine the capacity of the heating system.

Heating evaluations include personnel comfort provisions under regional extremes of humidity, high wind, and low temperature. Individual controls for each room should be specified where required to achieve proper temperature control, especially for equipment rooms which require less heat when the equipment is operating.

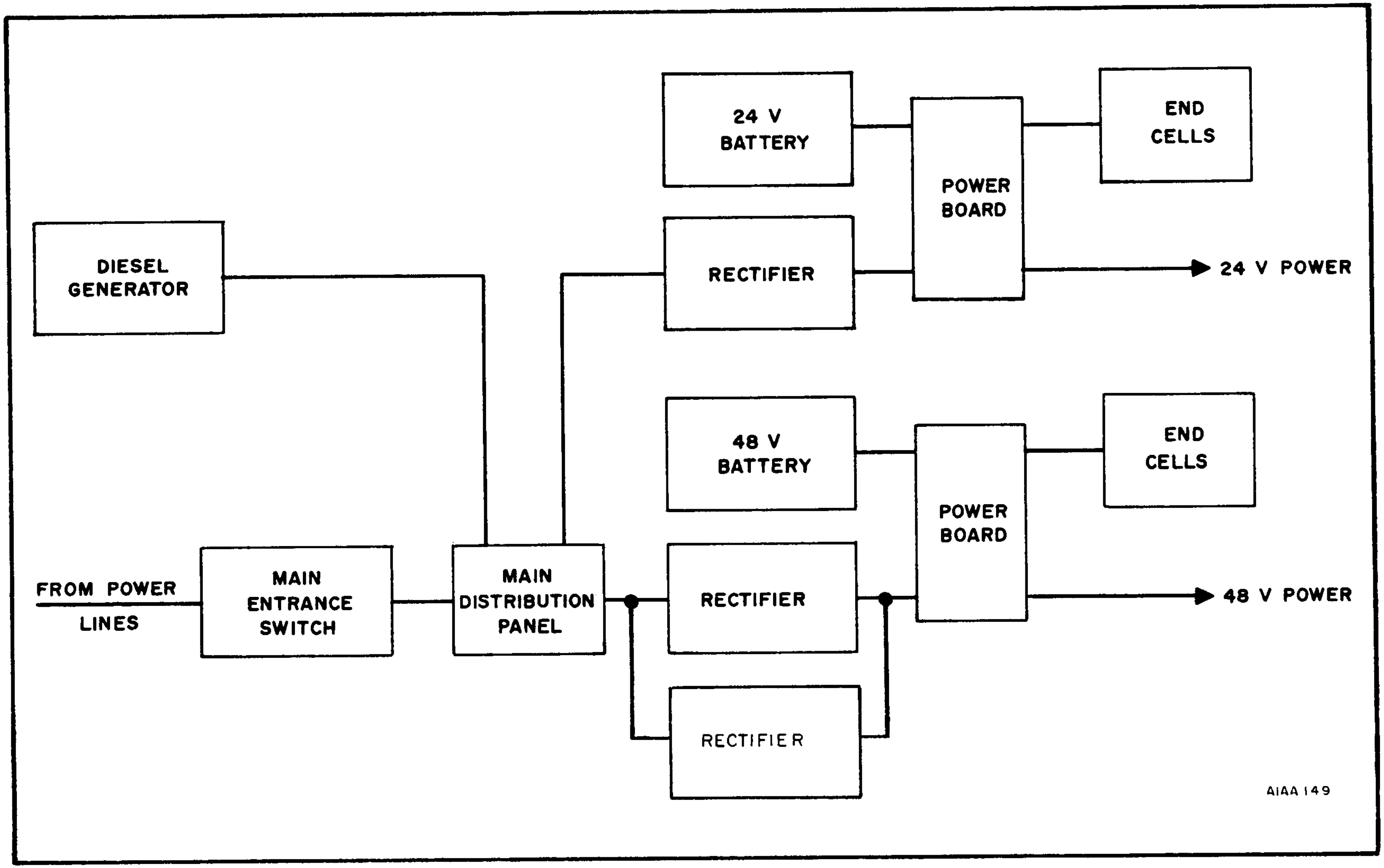

Figure 15-4. Typical DC Power Plant

Air conditioning must be provided to remove sufficient heat from the building to bring the temperature within an acceptable range for equipment and personnel, and condense sufficient water vapor from the air to bring the relative humidity within acceptable limits. Air conditioning units employing the compressor-condenser-evaporator cycle are preferred. The compressor is driven by an electric motor.

15.9 SITE SECURITY AND PROTECTION

The extent of site security and protection required depends upon the nature, size, and location of the communications facility. The A&E design agency is responsible for the design and implementation of security facilities, and protective devices required by the system design agency. This may include site security fencing, security lighting, fire detection and alarm systems, fire-fighting equipment, and personnel safety and protection features.

15.10 INSTALLATION PLANS

Installation drawings contain all the information required to accomplish the "inside plant" installation, and that portion of the "outside plant" installation under the cognizance of the system engineering agency.

15.10.1 Installation Plan (Inside-Plant) Installation Drawings

Drawings provide complete information to make the station or system installation as planned and in accordance with approved installation practices; a listing of the specific types and quantities of installation materials and hardware required for installation of the individual equipments; a complete "as-installed" record of the installation including the following drawings:

- Floor Plans
- Cable Rack Installation Drawings
- Cable Termination Lists
- Cross-connect Lists
- Power Distribution Drawings
- Grounding and Bonding Plans.

15.10.2 Floor Plans

Floor plans are prepared to provide a pictorial representation of equipment placement. Equipment racks are usually arranged side by side in a row (or rows). Microwave transmitter and receiver racks are arranged to provide short waveguide runs to the antenna(s). All racks are arranged to minimize inter-rack cabling. Minimum requirements for front and rear clearance are obtained by consulting the equipment handbooks. Equipment lineups require a break at least every 20 feet.

Exceptions to these procedures are equipments subject to mutual interference. These are physically separated. Equipment is arranged to minimize interconnecting cable lengths. Attended equipment should be arranged for operating convenience and minimum personnel requirements.

Auxiliary equipment, such as voltage regulators, are often wall-mounted and arranged to simplify power distribution wiring. Other items or furnishings that should be shown on a floor plan are: workbenches, storage racks for test equipment and spare parts, desks, ventilating fans, air conditioners, and space heaters. A separate, ventilated room should be provided for battery storage and use. When the station is confined to one large building, rooms will be provided to accommodate the attendant personnel.

All required dimensions must be specified on the floor plan. Sufficient details are included, relative to obstructions, to preclude interference with equipment placement. Notes should be included to clarify the drawings and installation requirements for installation personnel.

15.10.3 Cable Rack Layouts

Cables for interconnecting and terminating equipments are distributed by one or a combination of two methods: overhead open rack, or floor trenches in order of preference. The advantages and disadvantages of each method are compared in Table 15-1.

Selection of one or a combination of the above cable distribution methods is dictated by individual station environment. Layout drawings are prepared for cable rack distribution. The A&E drawings of the building include floor trenches so no additional layout drawings are generated for this type of distribution. Information provided on the rack layout includes:

- Overhead view of rack layout superimposed on floor plan
- Detailed two-dimensional and perspective three-dimensional views of rack arrangements such as elbows, splits, tee sections, reducing sections, and dropouts
- Equipment distribution frames and AC branching panel access details
- Rack and hardware bill of materials keyed to layout and details
- Notes required to assure that the drawing is completely self-explanatory.

15.10.4 Cable Termination Lists

Terminating information for multipair cables on a distribution frame is provided by these lists. The base and mate of each individual pair are given specific punching assignments on a specific distribution frame termination block.

Table 15-1. Distribution Comparison

Type Distribution	Advantages	Disadvantages
Overhead Open Rack	Flexibility in arrangement and rearrangement of cables	Time consuming for cable installation
	Rapid economical installation of racks and cable	Difficult to maintain clean, neat appearance
	Cable expansion accommodated readily	Separate racks required for separation of signal and power cables
Floor Trench	Rapid, economical installation of cable	Equipment arrangement dictated by trench layout
	Provides neat, clean appearance	Cable expansion limited by trench size
		Extremely difficult to separate power and signal cables

15.10.5 Cross-Connect Lists

The jumpers required on a distribution frame are specified on a cross-connect list. Separate lists are prepared for each distribution frame, so lists vary in length from a single wire to several pairs. Cross-connects are used to describe the connection of a particular equipment group in a prescribed manner. Typical Cross-Connect lists are shown in Table 15-2.

15.10.6 Power Distribution Drawings

Power wiring from the power distribution panel to each equipment is completely described by the power distribution drawings, including the method to be used by the installer in wiring individual electronic equipments to the AC power source. They specify:

Table 15-2. Station Cross-Connect List

FROM								TO						
ITEM NO.	EQUIPMENT		CKT	PIN STENCIL	BLOCK	ROW	PIN	BLOCK	ROW	PIN	PIN STENCIL	EQUIPMENT		CKT
1	SBC-1 (NORMAL)	REC #1	A	T / R	3F	2	A / B	2G	1	A / B	1 / 2	AF PATCH & MON.	REC #1	A
2	↓	↓	B	T / R	↓	↓	E / F	↓	↓	G / H	7 / 8	↓	↓	B
3	AF PATCH & MON.	REC #1	A	3 / 4	2G	1	C / D	3F	2	C / D	T / R	DEMUX INPUT	REC #1	A
4	↓	↓	B	9 / 10	↓	2	A / B	↓	↓	G / H	T / R	↓	↓	B
5														
6	DEMUX OUTPUT	REC #1	A_1	T / R	3F	3	A / B	2G	2	E / F	13 / 14	AF PATCH & MON.	REC #1	A_1
7			A_2	T / R			E / F		3	C / D	19 / 20			A_2
8			B_1	T / R		4	A / B		4	A / B	25 / 26			B_1
9	↓	↓	B_2	T / R	↓		E / F	↓	4	G / H	31 / 32	↓	↓	B_2
10														
11	AF PATCH & MON.	REC #1	A_1	15 / 16	2G	2	G / H	3B	12	A / B	TN / R	VFTG	REC	X
12			A_2	21 / 22		3	E / F	4G	3	A / B	T / R	1ST DETAIL M	BAY 11	5
13			B_1	27 / 28		4	C / D		1	E / F	T / R			2
14	↓	↓	B_2	33 / 34	↓	5	A / B	↓	4	E / F	T / R	↓	↓	8
15														
16	1ST DETAIL M	BAY 11	2	T1 / R1	4G	1	G / H	3E	3	A / B	T / R	AN/FTA-15	4WR	1
17			5	T1 / R1		3	C / D			C / D	T / R			2
18	↓	↓	8	T1 / R1	↓	4	G / H	↓	↓	E / F	T / R	↓	↓	3
19														
20														

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- Type and size of wire to be used

- Routing of wires

- Specific circuit breakers associated with each equipment

- Diagrams of each panel board, indicating equipment connected to each circuit breaker, rating of the breaker and the load connected to each breaker

- Tabulation of total loads on each phase of the panel feeder and the total load on all phases

- Itemized list of materials required to accomplish the installation.

Most electronics equipment in a microwave radio system requires a source of single phase, 115-volt, 50 to 60-cycle AC power. The non-technical load equipments require three-phase power. Since most commercial power units furnish three-phase power, the station load must be evenly divided between the three legs. With modern solid-state equipments, a 24-volt DC or 48-volt DC (optional) requirement exists for an auxiliary power source in event of prime power failure.

Power distribution from a panel board is protected by means of automatic circuit breakers. Individual equipments are connected to the panel boards by running the wiring in cable racks or conduits, or a combination of both.

Insure that power wiring and signal wiring are run in separate ducts. Any conduit used must be of sufficient size to permit ready installation or withdrawal of the conductors. Consideration should be given to dissipation of the heat generated in wire "bundles" without injury to insulation.

The wiring to each equipment will be sized to carry the load current with no noticeable voltage drop. Circuit breakers must be rated in accordance with the current carrying capacity of the conductor. Signal leads will consist of individually shielded pairs of a size consistent with good commercial practice.

Convenience outlets will be provided in the base of equipments in sufficient number to provide maintenance personnel ready access to power for test equipment or tools. Power distribution systems will be designed in complete conformance with the requirements of the National Electric Code (NEC) of the National Board of Fire Underwriters.

15.10.7 Grounding Drawings

The station grounding system is shown by a grounding diagram that specified ground system routing, cable sizes, type and position of all ground connectors and an itemized list of materials required to install the grounding system. The station ground shall be in accordance with NAVELEX 0101,102 Naval Communication Station Design.

15.10.8 Equipment Installation Drawings

All necessary information to accomplish installation of an equipment is provided by the equipment installation drawing. It contains installation details peculiar to a specific equipment and illustrates the planned procedures for accomplishing each portion of the installation effort. When several different equipments require identical basic installation information, a common installation drawing may be submitted for individual equipment drawings. In either case, the drawing provides the list of materials required to accomplish the individual equipment installation efforts.

15.10.9 Transmission Line Layout

Details for the RF transmission line installation are provided by a transmission line layout. This drawing shows transmission line routing. The layout shows what size "pieces" to use at each point along the route and where bends and flexible sections are to be located. The location of gas barriers and the arrangement of the pressurizing system are also included on this drawing. The major consideration in planning coaxial transmission line runs is to keep them as short as possible. Waveguide planning is subject to certain restrictions. Some general rules for planning the layout of waveguide systems follows:

o Waveguide runs should be made as short as possible to achieve minimum line loss

o Waveguide clamps should be spaced every four feet to support waveguide runs

o Allowance must be made for the expansion and contraction of waveguide. For a change in temperature of 100 degrees Fahrenheit, the change in length is approximately 1-1/2 inches per 100 feet. Under the same conditions, the change in length of the waveguide relative to the change in height of a steel tower is approximately 1/2 inch per 100 feet.

When sections of waveguide are joined, the rectangular openings must be made to coincide and a choke flange should be mated with a plain flange. In vertical runs, the choke flange should be uppermost so that moisture cannot collect in the slot of the choke.

Sharp bends in flexible waveguide sections should be avoided.

Flexible waveguide sections should be used only where freedom of motion is required. A typical installation has the rigid waveguide attached to the midpoint of the tower; waveguide clamps above and below this point permit the waveguide to expand or contract; a flexible section at the antenna not only permits the waveguide to change length, but also permits antenna alignment; a flexible section at the base of the tower has two functions - to permit changes in length and to provide for any motion of the tower with respect to the equipment building. Inside the building, a flexible section(s) may be used to relieve strain between the microwave equipment and the building, and also to serve as an odd length of waveguide.

Pressurizers and automatic dehydrators should be used where the total waveguide length to a single equipment exceeds fifty feet. This figure should be adjusted according to prevailing humidity conditions. Pressure windows are available to isolate pressurized and unpressurized portions of the waveguide.

15.11 TOWER REQUIREMENTS

In addition to the calculation of tower heights, it is necessary to consider the types of towers (or similar structures) available, the structural requirements of the towers, government regulations concerning such structures, and the preparation of installation specifications. These matters are important in that they have a significant effect upon the cost, performance, and reliability of the entire microwave radio-relay system. Fortunately, many of the engineering problems have been simplified by industry-wide acceptance of EIA (Electronic Industries Association) standards, and as a result, standard towers are readily available to suit most needs. For special problems, technical assistance can be obtained from the engineering departments of tower manufacturers.

15.11.1 Types of Towers

Any structure that is sufficiently high to meet the clearance requirements of the microwave signal path, and that provides a stable mounting place for an antenna or plane reflector, may be used as, or in place of, a tower. The antenna or plane reflector must remain rigid within a specified tolerance to assure maximum directivity of the radiated beam. Grain elevators, office buildings, mountains, wooden poles, and steel structures have been successfully used to provide the required elevation and to maintain the necessary rigidity.

For lower tower height requirements (30 to 60 feet), wooden poles of good quality, properly preserved, may be used if they are available in the required lengths. Consideration must be given to guying arrangements in order to obtain the required rigidity. It is often necessary to use H-frame or other special construction techniques to attain this rigidity.

Generally, a hot-dipped galvanized-steel tower is the most desirable support for an antenna or plane reflector. This type of tower is easily shipped in sections 10 or 20 feet in length, it is durable, it can be easily climbed, and it can be procured to meet the exact height requirements. Both the guyed and self-supporting types of towers may be obtained to support the antenna or plane reflector in increments of height up to several hundred feet. In general, it is not economically advisable to go above 300 feet because of the rapidly increasing cost of suitable towers. Guyed towers are generally preferred over the self-supporting type because they are more economical and because they can be installed more easily (foldout 15-1). The guyed tower can usually be placed closer to a shelter; this is advantageous when a roof-mounted antenna and a tower-mounted plane reflector are to be used. Of course, the guyed tower requires a larger site because of the need for installing guy anchors to which the guy wires can be attached. It can be seen that self-supporting towers are more likely to be required where real estate is at a premium or where the tower is to be placed on a roof of limited area.

15.11.2 Physical Factors and Design Considerations

The specifications for antenna towers will depend somewhat upon the terrain features (soil bearing pressure) of the location chosen, but they are mainly dependent upon the size, physical arrangement, and beam width of the paraboloidal antenna or passive reflector to be mounted at the top of the tower and upon the meterological conditions to be expected.

15.11.3 Foundations and Soil Bearing Capacity

Tower installation specifications usually include a statement of the minimum allowable value of bearing pressure for the soil upon which the foundation will be placed. Table 15-3 may be used as a guide in determining whether the intended location has sufficient bearing capacity to support a tower of standard design, or whether a special base design is needed. Because of the arbitrary nature of soil designations, an adequate safety margin should be allowed when using the table. As an example, assume that the tower to be used is designed for 4000 pounds per square foot soil-bearing pressure and that the soil at the site will withstand a maximum of only 3000 pounds per square foot. To be conservative, the design bearing pressure of the soil would be taken as 2000 pounds per square foot. These values indicate that the area of the base should be slightly more than doubled in order to reduce the design pressure by one-half. (The additional concrete added to the base in enlarging it keeps the variation between area and pressure from being exactly inverse.) A good approximation is obtained by a factor of 1.6. Whenever possible, expert advice should be obtained to substantiate such findings. Standard foundations should be of reinforced concrete, with anchor bolts firmly embedded, and should be of such dimensions as not to exceed a soil pressure of 4000 pounds per square foot under the specific loading area of the tower. A typical example of a concrete base for a microwave tower is illustrated in foldout 15-1. The relative dimensions of the foundation shown are typical for a 250-foot tower; these dimensions will vary, depending on the tower height, design load, and soil conditions. The height of the foundation above the ground line will be governed by ground-water conditions, but in any event should be not less than 6 inches. In warm climates, where frost is not a problem, the depth of the foundation will be governed only by tower-load and soil-bearing characteristics, but in colder climates it will be necessary to extend the depth of the foundation below the frost line or to firm ground.

15.11.4 Wind Loading

Towers are generally designed for a wind load of 30 pounds per square foot of flat surfaces without ice coatings. For areas subject to tornadoes or hurricanes, or where ice loads may be excessive, heavier towers are necessary. Wind loads are defined as the maximum forces and torques produced by a specified unit horizontal wind pressure acting on the tower, antenna assemblies, reflectors, and other members (additional radio antennas, etc.), which may be attached to the tower. Meteorological wind data is usually given in terms of wind velocity in miles per hour. If the wind velocity is known, the wind pressure that is exerted on a tower can be calculated by means of the following formula:

Table 15-3. Maximum Soil Bearing Capacity

MATERIAL	MAXIMUM ALLOWABLE BEARING VALUE (LB PER SQ FT)
Bedrock (sound) without laminations	200, 000
Slate (sound)	70, 000
Shale (sound	20, 000
Residual deposits of broken bedrock	20, 000
Hardpan	20, 000
Gravel (compact)	10, 000
Gravel (loose)	8, 000
Sand, course (compact)	8, 000
Sand, coarse (loose)	6, 000
Sand, fine (compact)	6, 000
Sand, fine (loose)	2, 000
Hard clay	12, 000
Medium clay	8, 000
Soft clay	2, 000

$$P = KV^2 \tag{15-3}$$

where:

P = the wind pressure in pounds per square foot

K = the wind conversion factor (considered to be 0. 004 for flat surfaces, and 2/3 of 0. 004 for cylindrical surfaces)

V = the wind velocity in miles per hour.

Table 15-4 indicates the wind loading that can be expected for several wind velocities. The expected wind velocity is taken from meteorological records. The projected area for towers having a triangular cross section is generally assumed to be 1. 5 times the area of one face, and the projected area for towers having a square cross section is generally assumed to be 1. 75 times the area of one face.

Table 15-4. Wind Loading Values for Flat Surfaces

WIND (MPH)	LOADING (LB PER SQ FT)
25	2.5
50	10.0
80	25.6
88.6	30.0
100	40.0

Meteorological data, which is representative of peak and average wind velocities and icing conditions for areas throughout the world, can be obtained from prepared charts and graphs. An example can be found in EIA Standard RS-222, which includes a map of the United States and related data showing wind-loading zones and values.

15.11.5 Twist and Deflection

The twist and deflection tolerances of the tower structure depend upon the characteristics of the antenna system. The maximum value of these tolerances is also determined by the required reliability of the overall communications system. Tower twist at any specified elevation is defined as the horizontal angular displacement of the tower from its no-wind-load position at that elevation is defined as the angular displacement of a tangent to the tower axis at that elevation from its no-wind-load position at that elevation.

The importance of twist and deflection tolerances can easily be understood when the antenna beam width is considered. Experience indicates that it is satisfactory to provide sufficient tower stability to limit the decrease in signal strength caused by deflection of the antenna to 3 dB for winds up to 50 mph, and to 10 dB for winds up to 80 mph. The resulting occasional decrease in signal strength does not impair system performance because a good system will be designed for a fading margin of approximately 30 dB. Tropospheric fading and the decrease in signal strength caused by tower motion do not occur simultaneously; during periods of severe tower motion, therefore, the fading margin is available to compensate for the deflection of the antenna beam from the norm.

For antenna systems, the twist and deflection specifications must conform with the limitations dictated by the beam width, which is inversely proportional to the size of the antenna or reflector. The specifications for 4-, 6-, and 8-foot systems are given in Table 15-5.

For systems using directly beamed paraboloids without plane reflectors, the deflection tolerance may be reduced to the same value as the twist tolerance. In general, towers designed to meet required wind-load and ice-load specifications are sufficiently rigid to meet twist and deflection tolerances. For increased rigidity, it is advisable to use rigid torque braces in the guying system, and six guy wires at the top of the tower instead of three guy wires. When cross-connected, these guys will maintain a high degree of rigidity. The guy anchors should be capable of withstanding the maximum load imposed by the guy wires, with an adequate margin of safety. Furthermore, the guys must be evenly tensioned and the turnbuckles securely locked, to prevent turning and resultant loosening of the guys. A typical guyed microwave tower is illustrated in foldout 15-1. Note the guying arrangement for maximum stability, and the requirements set forth for proper installation of the guy anchor section.

Table 15-5. Antenna-Tower Twist and Deflection Specifications for Antenna Systems Using Plane Reflectors

PARABOLOID DIAMETER (FT)	WIND VELOCITY (MPH)	PERMISSIBLE TWIST (DEGREES ±)	PERMISSIBLE DEFLECTION (DEGREES ±)
4	50	1.5	0.75
	80	2.5	1.25
6	50	1.0	0.50
	80	1.7	0.80
8	50	0.75	0.40
	80	1.25	0.60

15.11.6 Lightning Protection

Lightning protection must be considered as part of each tower installation. Tower grounding procedures establish an electrical connection between the tower and the earth to provide proper lightning protection. In the case of directly beamed paraboloidal antenna systems, the waveguide path down the tower cannot be considered as a reliable path to ground. Steel tower installations should be protected by the use of a low-resistance ground connection at the base of the tower. When wooden poles are used for towers. copper wire should be connected from the top of the pole to a low-resistance ground arrangement at the base of the pole. The steel tower should be grounded in the following manner: Install ground rods on opposite sides of each tower foundation at a distance not greater than 12 inches from the foundation. Use 5/8-inch-diameter ground rods, or equivalent. and drive them not less than 8 feet into the ground. Bond each leg or the common base of the tower to the ground rods by means of No. 6 AWG or larger copper wire. Using the same size wire, connect the tower ground system to the station ground system. Specifications for the station ground system are in NAVELEX 0101,102. Install ground rod in the same manner at each concrete guy anchor; the metal portion of the guy anchor should be bonded to the ground rod. Where steel or other metallic anchors are in direct contact with the earth, no additional ground rods are required.

Any and all equipment mounted on a tower shall be so fastened that it is effectively grounded through the tower. On structures provided with obstruction lights, it may be desirable to place suitable lightning arresters on the wires supplying these lights, at least between the lower portion of the tower and the power-supply source, and in some cases also at the top of the tower.

The above-mentioned standards as set forth by the EIA, through the mutual cooperation of electronics equipment manufacturers, are the minimum requirements for such installations. These standards, in addition to sound engineering judgment, will determine the specific requirements for any tower installation.

As a general rule, the maximum resistance that is permissible between any two ground rods prior to connection to the tower is 2 ohms. If the resistance between rods is found to be greater than 2 ohms, it will be necessary to increase the conductivity of the soil. One method of lowering the resistance path between ground rods is as follows: Dig a tapered trench around each ground rod. (The trench should be approximately 2 feet deep, with a bottom radius of 1 foot and a top radius of 2 feet). Then place approximately 40 pounds of rock salt in the trench and backfill the trench.

15.11.7 Painting and Lighting Requirements

In order to prevent excessive hazards to air commerce, antenna towers and similar structures must be marked in such a way as to make them conspicuous when viewed from aircraft. The type of marking to be used depends, in part, on the height of the structure, its location with respect to other nearby objects, and its proximity to aircraft traffic routes near landing areas.

Requirements and specifications for the marking and lighting of potential hazards to air navigation have been established through the joint cooperation of the Federal Aviation Agency (FAA), the Federal Communications Commission (FCC), the Department of Defense (DOD), and appropriate branches of the broadcasting and aviation industries. The specifications determined by these groups aid in the final decisions as to whether or not a structure constitutes an obstruction to air navigation.

In the conduct of the preliminary survey of main and alternate routes for microwave sites, it is advisable to determine the prevailing ordinances concerning such structures, and perhaps to discuss them with local government and building authorities. When dealing with locations within the continental limits of the United States, the latest copies of Government Rules and Regulations (FCC FORM 715 and FCC Rules Part 17, and FAA Standards for Marking and lighting Obstructions to Air Navigation), with all revisions, should be consulted. These rules not only apply to specifications for antenna structures, but also set forth the forms which must be submitted to the FCC, FAA, and U.S. Coast and Geodetic Survey (FCC Form 4-1A Revised, FAA Form 117, FAA Form ACA-114, and C & G. S. Form 844).

a. Day Marking. In order to warn airmen of the presence of obstructions during daylight hours in good weather conditions, all structures that may present a hazard to air commerce should be painted from top to bottom with alternate bands of orange and white aviation surface paints, terminating in orange bands at both top and bottom. The width of the orange bands should be approximately one-seventh the height of the tower structure, provided, however, that the bands shall be not more than 40 feet nor less than 1-1/2 feet in width. If the height of the tower causes the width of the color bands to fall outside these limits, a larger or smaller number of bands should be used, depending on whether the structure is greater than 280 feet or less than 35 feet in height. The surface coatings used should be selected in accordance with the applicable specifications and existing approved aviation surface paints.

b. Night Marking. The purpose of lighting a structure that is a hazard to aircraft operations is quite obvious. Both the FCC and FAA lighting specifications are set forth in terms of the heights of the antenna structures. Figure 15-5 illustrates the requirements for the placement of obstruction lights on towers up to 600 feet in height. The specifications further stipulate that the placement of the lights on either square or rectangular towers shall be such that at least one top or side light be visible from any angle of approach. When a flashing beacon is required, it shall be equipped with a flashing mechanism capable of producing not more than 40 nor less than 12 flashes per minute, with a period of darkness equal to one-half the luminous period.

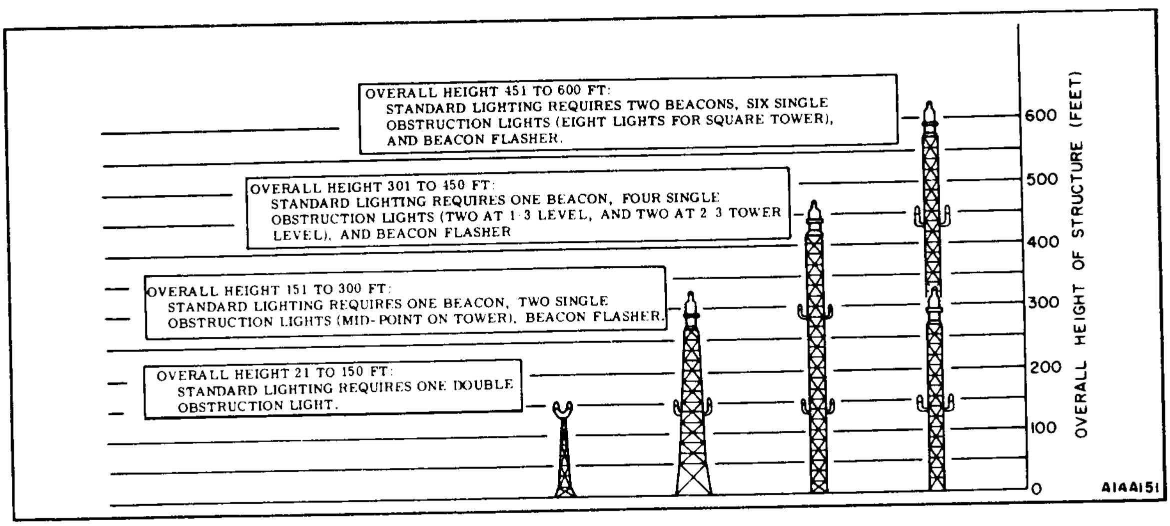

Figure 15-5. Tower Lighting Specifications

When the tower structure is in the process of construction, the FCC and FAA require that temporary lights, consisting of at least two 100-watt lamps enclosed in aviation red globes, be displayed at the top of the structure from sunset to sunrise. Lights must also be installed at intermediate heights, if necessary, in accordance with the general specifications indicated in figure 15-5.

(1) Lamp Requirements. The lamps most commonly used for tower lighting have a rated operating voltage of 115 volts. The specifications state that the maximum voltage variation at the lamps should not exceed 5 percent, i.e., the regulation above and below the rated voltage should not exceed 2.5 percent. It is quite possible that the regulation of the primary voltage source will not fall within these limits; however, these values are useful in determining the allowable voltage drop in the wiring to be selected for lighting a particular obstruction. The stated requirements for obstruction lights and beacons are 111 and 620 watts, respectively; special lamps are designed to meet specifications for reliability and long life expectancy (3000 hours). The lamps should be encased in a beacon assembly or obstruction light assembly which uses approved aviation-red globes in ruggedized, watertight housings.

(2) Light Control. The FCC requires that the tower lighting be exhibited during the period from sunset to sunrise unless otherwise specified. At unattended microwave installations, a dependable automatic obstruction-lighting control device must be provided. A light-sensitive control device or an astronomic dial clock and time switch may be used to control the obstruction lighting in lieu of manual control. This requirement can be met in microwave installations by employing a photoelectric control unit that applies power to the lights when the north skylight intensity is less than approximately 35 foot-candles, and that disconnects the power when the north skylight intensity is greater than approximately 58 foot-candles.

(3) Fault Indication. To insure the proper operation of tower lights, the FCC specifies that the lights be inspected at least once every 24 hours; the inspection can be performed either by direct observation or by observation of an automatic and properly maintained indicator designed to register failure of such lights. Where obstruction lighting is not readily accessible for periodic inspection, the rules permit the use of electric signaling devices to indicate lamp failure. Should the fault alarm system register a failure in obstruction or beacon lighting, the failure must be reported to the nearest Airways Communication Station of the Federal Aviation Agency. The FAA must be notified of any code beacon, rotating beacon, or top light failure if not corrected within 30 minutes after failure.

(4) Tower-Lighting Control Circuits. The block diagram of a typical tower-lighting control circuit is shown in figure 15-6. The operation of the circuit is as follows: When the photoelectric control unit senses a light intensity of less than 35 foot-candles, a relay within the unit applies AC power to the coil of an obstruction lamp relay and to the motor of a flashing mechanism. As a result, the relay is energized and its contacts apply power to the obstruction lamps. Also, the motor of the flashing mechanism causes power to be applied intermittently to the beacon lamps by way of the fault relay, and the beacon lamps flash on and off. If the flashing mechanism fails to function or the beacon lamps burn out, the fault relay signals the failure to the fault alarm system, which sounds an alarm at a remote control center. Should any problem arise concerning the proper procedure to be followed in the marking or lighting of tower structures, the FAA will provide professional guidance for obstruction marking. Since the FCC specifications for tower marking and lighting are, in general, more rigid than those of the FAA, and the proposed lighting must be approved by the FCC before that agency will issue a construction permit, it may be expected

that the FCC specifications will apply in those cases where FAA and FCC specifications differ. In overseas installations, regulations imposed by cognizant military and/or governmental agencies must be studied.

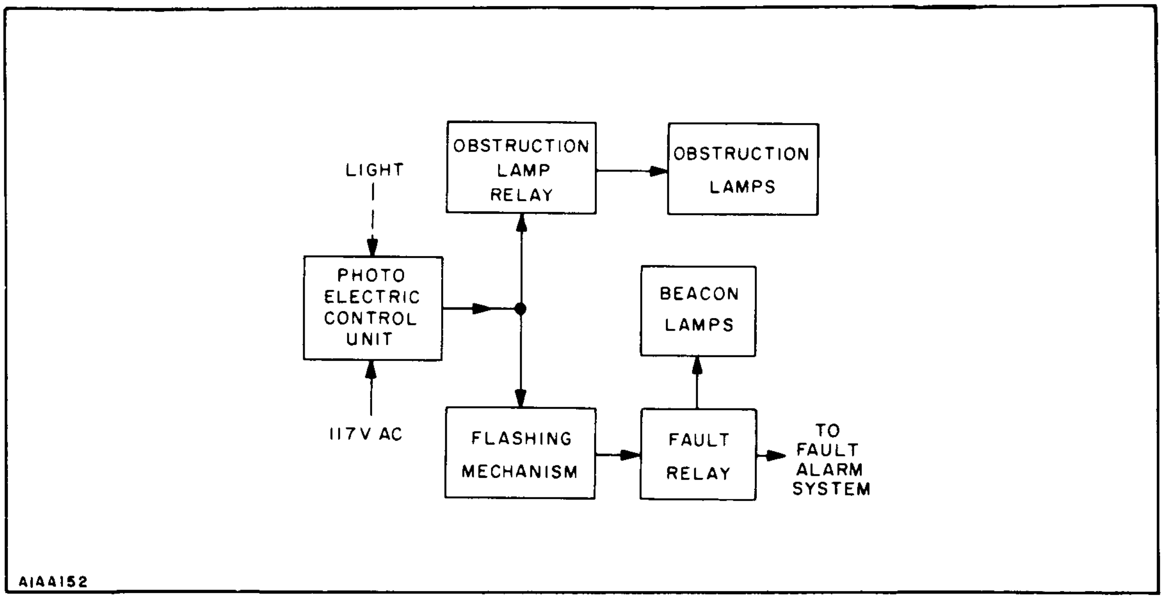

Figure 15-6. Tower Lighting Control Diagram

15.11.8 Tower Specifications

If a tower is to be furnished and/or installed by an outside contractor, specifications must be prepared to define the extent of the work and to establish responsibility. Written specifications such as those given in the following paragraphs, and any applicable drawings, can be said to constitute the tower specifications, provided, of course, that they are presented in the proper format as given in NAVFAC DM-2.

The tower shall be a guyed, steel, non-insulated structure of uniform cross section. A pivoted base type tower shall be considered preferable but not mandatory. The tower shall be supplied with guys, anchors, and all necessary hardware for erection. When erection is specified the tower shall be erected at sites specified by the purchaser, and the contractor shall provide all material, labor and tools necessary to install the complete tower, plan reflectors and accessories, such as tower lighting equipment and VHF antenna as required by the purchase order.

15.11.9 Design Specifications

In general, all material, loading, unit stresses, manufacture, workmanship, finish, plans, markings, foundations and installation shall conform with EIA standard RS-222 as amended to date. For towers in excess of 300 feet in height, the requirements of NAVPAC DM-2 shall apply.

Loading shall be based on the coaxial VHF antenna and transmission line, obstruction lighting equipment including wiring, and two plane reflectors.

With the tower fully equipped but with a wind load of 20 pounds per square foot on flat surfaces and 13.3 pounds per square foot on cylindrical surfaces, the tower shall not exceed the following limits of twist and deflection at the elevation of reflector attachment.

- o Twist - 1.25 degrees
- o Deflection - 0.60 degrees.

The angle of twist shall be defined as the horizontal angular displacement of the tower from its no wind load position at the specified elevation. The angle of deflection shall be defined as the angular displacement of a tangent to the tower axis at the specified elevation from its no wind load position.

The path from paraboloidal antennas (located near base of tower) to plane reflectors must be unobstructed by any member of the tower structure but may be obstructed by guy wires.

The two passive reflectors shall be mounted at the top of the tower at any angle of approximately 45 degrees from the vertical. The mounting for the two reflectors shall be designed to permit orientation of the reflectors in azimuth so that the included angle with respect to each other covers a range of 90 degrees to 180 degrees. Each reflector shall be capable of rotating through a range of 90 degrees in azimuth about its own pivot point.

a. Tower Height. Shall be specified by purchase order.

b. Plans. One complete set of prints shall be submitted to the purchaser for approval prior to fabrication. Complete bill of material, plans, and erection drawings, including guy tension data, shall be supplied showing all necessary details for installation. One set of prints or reproduced tracings shall be supplied to the purchaser.

NOTE

When tower manufacturer does not install tower, one complete set of erection prints shall be shipped with each tower.

c. Calculations. The tower manufacturer shall submit stress calculations and twist and deflection calculations which must be approved by the purchaser prior to fabrication.

Sample approval by the purchaser is required but this approval does not release the manufacturer of responsibility for failure under conditions covered by the specifications.

d. Tower. The tower manufacturer shall specify the warranty life of tower and necessary maintenance procedures.

The tower manufacturer shall supply foundation and guy anchor design specifications, calculations, and drawings for each height of tower for approval by the purchaser. All towers shall provide suitable climbing facilities to the top of the tower, including access to any beacons or antennas mounted thereon.

e. Grounding. The tower manufacturer shall supply the following as a minimum amount of grounding material for each tower:

- Two 8-foot long, 5/8 inch diameter copper covered ground rods or equivalent for each tower base
- One 8-foot long, 5/8 inch diameter copper covered ground rod or equivalent for each guy anchor
- Grounding wire, No. 6 AWG copper wire as required (minimum length 30 feet)
- Two grounding clamps per ground rod for attaching the grounding wire from the ground rod to the guy anchor or tower mast.

f. Installation. Erection of tower when specified by the purchase order shall be in accordance with the following specifications:

- The foundation and guy anchors shall be installed in accordance with approved drawings as furnished under paragraph 3-544, and shall conform to EIA standard RS-222.
- Prior to installation, soil conditions shall be reviewed and determined through data submitted on the site plan and/or by contractor's survey. Where actual soil conditions are not normal, the contractor shall supply complete information of soil conditions and the remedial measures that are to be taken. When construction has been started and abnormal soil conditions are encountered, the contractor shall immediately notify the purchaser and modify the construction to suit conditions, after obtaining permission from the purchaser
- The tower shall be erected in accordance with best modern practices for similar structures and shall conform to the erection drawings

o The ground rods shall be driven into the ground at 12 in. minimum distance from each side of the foundation and approximately 6 ft. to 8 ft. apart. Ground rods shall be connected to each of two tower legs and form a good electrical and mechanical contact

o Tower lights, when specified, shall be installed in accordance with EIA specifications

o VHF antenna and coaxial transmission line, when specified, shall be installed in accordance with the specifications

o Painting of tower, when specified, shall conform with latest CAA and FCC regulations

o Passive reflectors shall be installed in accordance with the site plan and as specified on the purchase order.

15.12 SAFETY

15.12.1 Safety Measures

Safety implies the absence and/or control of conditions that can cause personal injury or death or damage to or loss of equipment or property. Within the system safety is concerned with the elimination or control of those factors affecting the safe and efficient operation of personnel, equipment and facilities organized to attain a common goal. The criteria established in the safety engineering portions of MIL-STD-1472, MIL-STD-882, MIL-STD-454 followed in the test, checkout and operation of the equipment.

15.12.2 Safety Plan

The objective of safety is to assure maximum freedom from inadvertent and possibly destructive mishaps resulting from facilities, equipment, procedural or personnel deficiencies during all phases of system operation.

15.12.3 Electrical Safety

Provisions are normally incorporated in the equipment to protect personnel from accidental contact with dangerous voltages while operating the equipment or performing maintenance. Some of the features provided for this assurance are:

o Each equipment cabinet grounded

o Convenience outlets will be the 3 wire type to automatically ground the case or frame of any tools and equipment

o AC power plugs equipped with safety ground

- o All subsystem drawers equipped with circuit breakers. The AC input terminals appropriately covered for protection during maintenance periods

- o Voltages greater than 70 volts are protected by barriers that are labeled with the highest voltage encountered upon removal

- o Voltages greater than 500 volts marked with danger labels and completely inaccessible to personnel

- o Interlocks provided, when voltages in excess of 70 will be exposed to personnel. Interlocks are two piece type and when bypass devices are required, returning the door or cover to its operating position automatically opens the bypass switch and leaves the interlock in its normal functioning position

- o Provision for capacitor discharge devices

- o No voltages will be exposed when equipment connectors are removed from cabinets

- o Utilization of step down circuitry for measuring high voltages

- o Maintenance telephone system provided to allow coordination of activity during servicing.

15.12.4 Mechanical Safety

A number of simple features should be provided to protect personnel from mechanical hazards. Equipment cabinets are designed without sharp corners. Slide mounted drawers are provided with automatic stops to prevent accidental disengagement of the slides. Some additional mechanical safety measure deals with lighting, provision of fire extinguishers, adequate exits in case of emergency, environmental control, use of non-slip mats in front of equipment cabinets.

15.13 PERSONNEL REQUIREMENTS

Personnel should be selected whose background and basic skills lend a high degree of assurance that all the qualifications can be met after training, thus meeting the functional organizations minimum requirements. Some job descriptions and qualifications for microwave communication systems personnel deployed at active terminals would be the following:

15.13.1 Operations Section Head

The Operations Section Head is responsible for effective operations and maintenance of the continuous communication service. This includes directing continuous shift operations; enforcing maintenance methods and procedures; and utilizing personnel in an efficient manner. In the absence of the Assistant Station Manager he will assume those duties.

In addition, he has parallel responsibilities to the Support Section Head, which include, but are not limited to:

- o Gives direction and assists in the calibration, check-out and test trouble analysis, adjustment and alignment of the basic equipment
- o Establishes and supervises maintenance and operations activities
- o Analyzes system operating trends based on operations records
- o Evaluates system and subsystem discrepancies and/or failures and takes appropriate action for changes
- o Reviews and makes changes to operating and maintenance procedures
- o Evaluates technical logistic problems
- o Enforces and recommends quality control procedures
- o Evaluates and makes changes in supporting documentation of the communications equipment and support equipment
- o Coordinates all maintenance activities in both sections.

15.13.2 <u>Support Section Head</u>

The Support Section Head, through three or four Maintenance Leaders:

- o Establishes and supervises the more complex maintenance work areas
- o He directs and assists with the in-depth maintenance routines
- o Analyzes system operating trends based on operating records
- o Responsible for the maintenance of all equipment histories, test data collection, and data documentation
- o Reviews and recommends changes to operating and maintenance procedures
- o Evaluates technical logistics problems
- o Recommends quality control procedures
- o Evaluates and makes changes in supporting documentation on the communications equipment and support equipment
- o Responsible for spares inventory, teletype repair, and test equipment maintenance/calibration.

In addition to this function devoted to the basic equipment, he must be capable of directing the maintenance of facilities through the Facilities Leader. This requires giving direction in the maintenance of all heavy equipment as follows: continuous duty power generating equipment; heating, air-conditioning and ventilating units; and heat exchangers.

15.13.3 Maintenance Leader

The Maintenance Leader is responsible for the performance of in-depth preventive maintenance routines on the equipment that requires specialized knowledge not possessed by the Operations Section personnel. He is responsible for specifically assigned communications equipments requiring complex alignment, adjustment, and calibration procedures. He performs preventive maintenance routines himself; and he has Communications Shift Supervisors and Communication Technicians assigned to him for the performance of routine tasks. These are the tasks that can be assumed by the shift personnel after procedures are learned. He must cross-train these personnel in the more complex maintenance tasks in which he is knowledgeable, and monitor the performance of the various routine maintenance he has given them. He directs work which may involve disassembly of significant portions of the communications equipment. He provides back-up to the Communications Shift personnel when communications problems occur.

15.13.4 Facilities Leader

The Facilities Leader supports his Section Head through independent maintenance activities performed on heat, ventilation, and air-conditioning equipment. He is responsible for the all-important maintenance of uninterrupted power. This includes the care, repair and overhaul of the diesel engines. He is provided help in this by having the Electrician-Machinist assigned full time to him. Cross-support is given by four shift Electrician-Technicians. In addition, he directs the housekeeping and groundskeeping personnel required for the maintenance of buildings, structures, water, sanitation, and lighting, as well as fire-fighting, roads, and grounds, when required.

15.13.5 Communications Shift Supervisor

The Communications Shift Supervisors are responsible for continuous operation of the station, including all communications circuits and the equipments supporting communications, including Message Center. He directs activities from the control center. In order to accomplish this, he performs calibration, checkout, trouble-shooting, testing, and operations of the communications equipment himself and with the aid of the Communications Technicians. He sets up new communications channels as traffic routing changes, and provides the basic quick-reaction fault location and correction leadership. He is responsible for the station log and careful documentation of significant events on his shift.

Typically, he monitors communications circuits using idle channel noise measurements. He makes deviation and level adjustments. He monitors the spectral display of all transmit and receive sub-carriers to detect intermodulation anomalies produced by saturation effects. He monitors television transmissions, establishing routing for it and adjusting its baseband parameters.

Additionally, he performs preventive maintenance work assigned to him by the Operations and/or Support Section Head.

15.13.6 Communications Technician

The Communications Technician performs routine calibration, troubleshooting, testing and operation of the communications equipment, and the message center equipment. He is able to quickly analyze and isolate communication faults and equipment anomalies independently. He has detailed knowledge in the total variety of patching and use of replaceable modules. Typically, he performs tasks parallel to those of the Communications Shift Supervisor, and provides cross-support to the Support Section by doing routine maintenance himself and giving hands-on assistance to Maintenance Leaders in the more complex and/or time consuming routines.

15.13.7 Electrician-Technician

The Electrician-Technician is required to directly monitor the operation of the diesel-driven power generating plant in the power building. He performs generator phasing and cutover operations as required by preventive and corrective maintenance schedules. He is necessary for quick-reaction failure correction in the power generating plant. He detects faults beyond the capability of monitoring devices supplied with the diesel-driven power generating equipment. He provides cross-support, hands-on repair and overhaul of heavy equipment, and maintains power building logs and records.

15.13.8 Electrician-Machinist

The Electrician-Machinist is assigned full time to the Facilities Leader to accomplish preventive maintenance of the support facilities. In addition, he fabricates semi-precision special parts and assemblies and makes repairs using the shop power tools available to him. He provides hands-on repair and overhaul of the diesel driven power generating plant including the diesel engines.

15.13.9 Spareskeeper

The Spareskeeper is directly responsible for the maintenance of the spares inventory and attendant record keeping. In addition, he provides hands-on maintenance, repair, and on-site calibration of all electronic test equipment. He takes care of all the necessary arrangements for off-site maintenance and coordinates factory repair and returned goods activity. He does the repair and maintenance of teletype equipment.

APPENDIX A

REFERENCE DATA

A.1 INTRODUCTION

This appendix contains reference material required in connection with the engineering of Microwave and Tropospheric Communication Systems.

A.2 STATISTICS

Appropriate definitions and formulas used in determining Binomial, Normal, and Poisson distributions are given in figure A-1.

A.3 REFERENCE CURVES AND NOMOGRAPHS

Reference curves and nomographs most commonly used in the engineering of Microwave and Tropospheric Systems are given in figures A-2 through A-18.

A.4 EQUATIONS

A compilation of common equations are shown in figure A-19.

A.5 CONVERSION TABLES

Conversion tables of various frequency, wavelength, and metric units are shown in figure A-20.

STATISTICS

A. DEFINITIONS

Arithmetic Mean —

The arithmetic mean of a set of numbers is defined as follows:

$$\overline{X} = \frac{X_1 + X_2 + X_3 \ldots + X_n}{n} = \frac{\sum_{i=1}^{n} X_i}{n}$$

Weighted Arithmetic Mean —

$$\overline{X} = \frac{W_1X_1 + W_2X_2 + W_3X_3 \ldots W_nX_n}{W_1 + W_2 \ldots W_n}$$

$$\overline{X} = \sum_{i=1}^{n} W_iX_i \Big/ \sum_{i=1}^{n} W_i$$

Standard Deviation —

The standard deviation of a set of numbers is defined as follows:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n}}$$

Variance $= \sigma^2$

Geometric Mean —

The geometric mean of a set of N numbers, $X_1X_2X_3$. X_n is the *nth* root of the product.

$$G = \sqrt[N]{X_1X_2X_3 \ldots X_n}$$

Harmonic Mean —

The harmonic mean of a set of numbers X_1, X_2, $X_3, \ldots X_n$ is the reciprocal of the arithmetic mean of the reciprocal of the numbers:

$$H = \frac{1}{\frac{1}{N} \sum_{j=1}^{N} \frac{1}{X_j}}$$

Root Mean Square —

The root mean square (RMS) of a set of numbers $X_1, X_2 \ldots X$ is defined as follows:

$$RMS = \sqrt{\sum_{j=1}^{N} \frac{X_j^2}{N}}$$

Median —

The median is the middle value, or the arithmetic mean of the two middle values.

Example 1:

3, 4, 4, 5, 6, 8, 8, 8, 10 median = 6

Example 2:

5, 5, 7, 9, 11, 12, 15, 18 median $= \frac{9 + 11}{2} = 10$

Mode —

The mode is the number which occurs with the greatest frequency and may not exist or there may be more than one value:

Example 1:

2, 2, 5, 7, 9, 9, 9, 10, 10, 11, 12, 18; mode = 9

Example 2:

3, 5, 8, 10, 12, 15, 16; no mode

B. BINOMIAL DISTRIBUTION

If p is the probability that an event will happen in any single trial (called the probability of a *success*)

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Figure A-1. Statistics (Sheet 1 of 3)

and q = 1 − p is the probability that it will fail to happen in any single trial (called the probability of a *failure*) then the probability that the event will happen exactly X times in N trials (*i.e.*, X successes and N − X failures will occur) is given by

$$p(X) = {}_N C_X p^X q^{N-X} = \frac{N!}{X!\,(N-X)!} p^X q^{N-X}$$

where X = 0, 1, 2, . . . , N and N! = N(N−1) (N−2) . . . 1. 0! = 1 by definition.

Example 1: The probability of getting exactly 2 heads in 6 tosses of a fair coin is

$${}_6C_2(1/2)^2(1/2)^{6-2} = \frac{6!}{2!\,4!}(1/2)^6 = 15/64$$

with N = 6, X = 2, and p = q = ½.

Example 2: The probability of getting at least 4 heads in 6 tosses of a fair coin is

$${}_6C_4(1/2)^4(1/2)^{6-4} + {}_6C_5(1/2)^5(1/2)^{6-5} + {}_6C_6(1/2)^6 = 15/64 + 6/64 + 1/64 = 11/32$$

Some properties of the binomial distribution are listed as follows:

Mean	$\mu = Np$
Variance	$\sigma^2 = Npq$
Standard deviation	$\sigma = \sqrt{Npq}$
Moment coefficient of skewness	$\alpha_3 = \frac{q-p}{\sqrt{Npq}}$
Moment coefficient of kurtosis	$\alpha_4 = 3 + \frac{1-6pq}{Npq}$

C. THE NORMAL DISTRIBUTION

One of the most important examples of a probability distribution is the *normal distribution, normal curve* or *Gaussian distribution* defined by the equation

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$$Y = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\tfrac{1}{2}(X-\mu)^2/\sigma^2\right]$$

where μ = mean, σ = standard deviation, π = 3.14159 . . . , e = 2.71828 . . .

The total area bounded by the curve and the X axis is one; hence the area under the curve between two ordinates X = a and X = b, where a < b, represents the probability that X lies between a and b, denoted by Pr{a < X < b}.

When the variable X is expressed in terms of standard units, $z = (X-\mu)/\sigma$, the so-called *standard form* is expressed as

$$Y = \frac{1}{\sqrt{2\pi}} \exp\left(-\tfrac{1}{2} z^2\right)$$

In such case we say that z is *normally distributed with mean zero and variance one.*

A graph of this standardized normal curve as shown in Figure 114 has indicated the areas included between z = − 1 and + 1, z = − 2 and + 2, z = + 3 and − 3 are equal respectively to 68.27%, 95.45% and 99.73% of the total area.

Example of Normal Distribution

The mean weight of 500 students is 151 lbs and σ = 15; assume normal distribution, determine how many students weigh (a) between 120 and 155 lbs and (b) more than 185 lbs.

a.

$$Z = \frac{(119.5 - 151)}{15} = -2.10$$

$$Z = \frac{(155.5 - 151)}{15} = .30$$

Area from − 2.10 to .30 = 0.600

The number of students = 500 (0.600) = 300

b. Students weighing more than 185

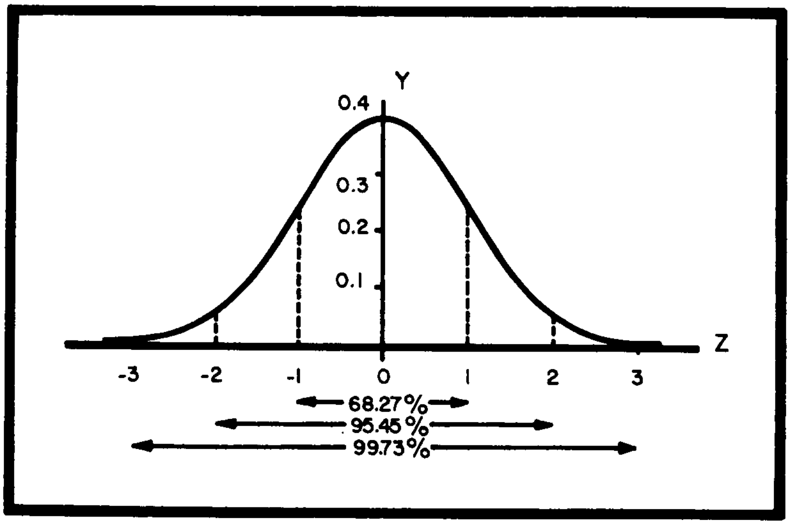
$$Z = \frac{185.5 - 151}{15} = 2.30$$

Area between 0, and 2.30 = 0.4983

= 0.5 − 0.4893 = 0.0107

The number of students = 500 (0.0107) = 5

Figure A-1. Statistics (Sheet 2 of 3)



MEAN	μ
VARIANCE	σ^2
STANDARD DEVIATION	σ
MOMENT COEFFICIENT OF SKEWNESS	$\alpha_3 = 0$
MOMENT COEFFICIENT OF KURTOSIS	$\alpha_4 = 3$
MEAN DEVIATION	$\sigma\sqrt{2/\pi} = 0.7979$

Some Properties of the Normal Distribution

D. RELATION BETWEEN BINOMIAL AND NORMAL DISTRIBUTIONS

If N is large and if neither p nor q is too close to zero, the binomial distribution can be closely approximated by a normal distribution with standardized variable given by

$$z = \frac{X - Np}{\sqrt{Npq}}.$$

E. THE POISSON DISTRIBUTION

The discrete probability distribution

$$p(X) = \frac{\lambda^X e^{-\lambda}}{X!} \qquad (X = 0, 1, 2, \ldots)$$

where e = 2.71828 . . . and λ is a given constant, is called the *Poisson distribution.*

Some properties of the Poisson distribution are listed in the following table.

Mean	$\mu = \lambda$
Variance	$\sigma^2 = \lambda$
Standard deviation	$\sigma = \sqrt{\lambda}$
Moment coefficient of skewness	$\alpha_3 = 1/\sqrt{\lambda}$
Moment coefficient of kurtosis	$\alpha_4 = 3 + 1\lambda$

F. RELATION BETWEEN BINOMIAL AND POISSON DISTRIBUTIONS

In the binomial distribution, if N is large while the probability p of occurrence of an event is close to zero so that $q = (1-p)$ is close to 1, the event is called a *rare event.* In practice we shall consider an event as rare if the number of trials is at least 50 ($N \geqq 50$) while Np is less than 5. In such cases the binomial distribution is very closely approximated by the Poisson distribution with $\lambda = Np$.

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Figure A-1. Statistics (Sheet 3 of 3)

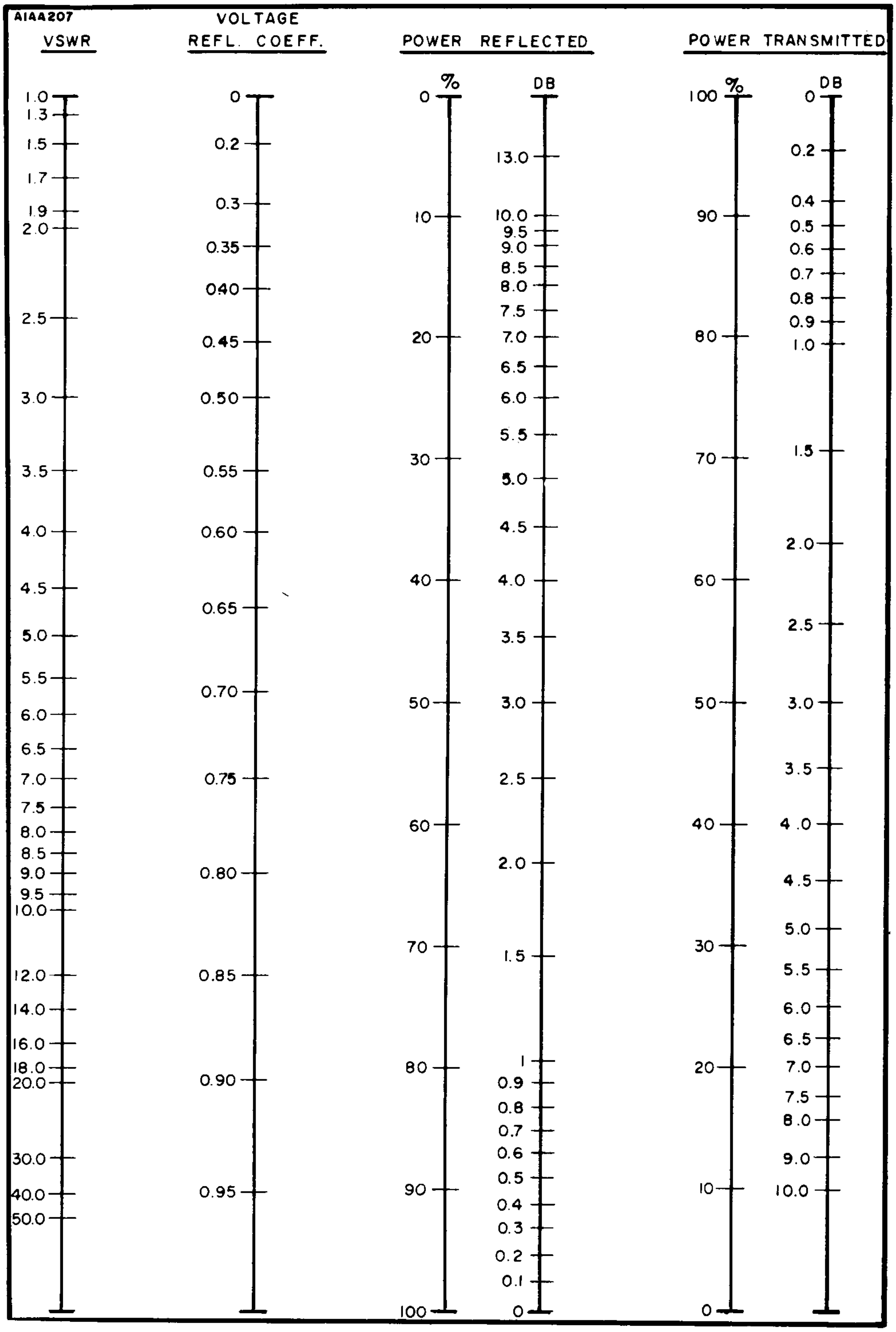

Figure A-2. VSWR Nomograph #1

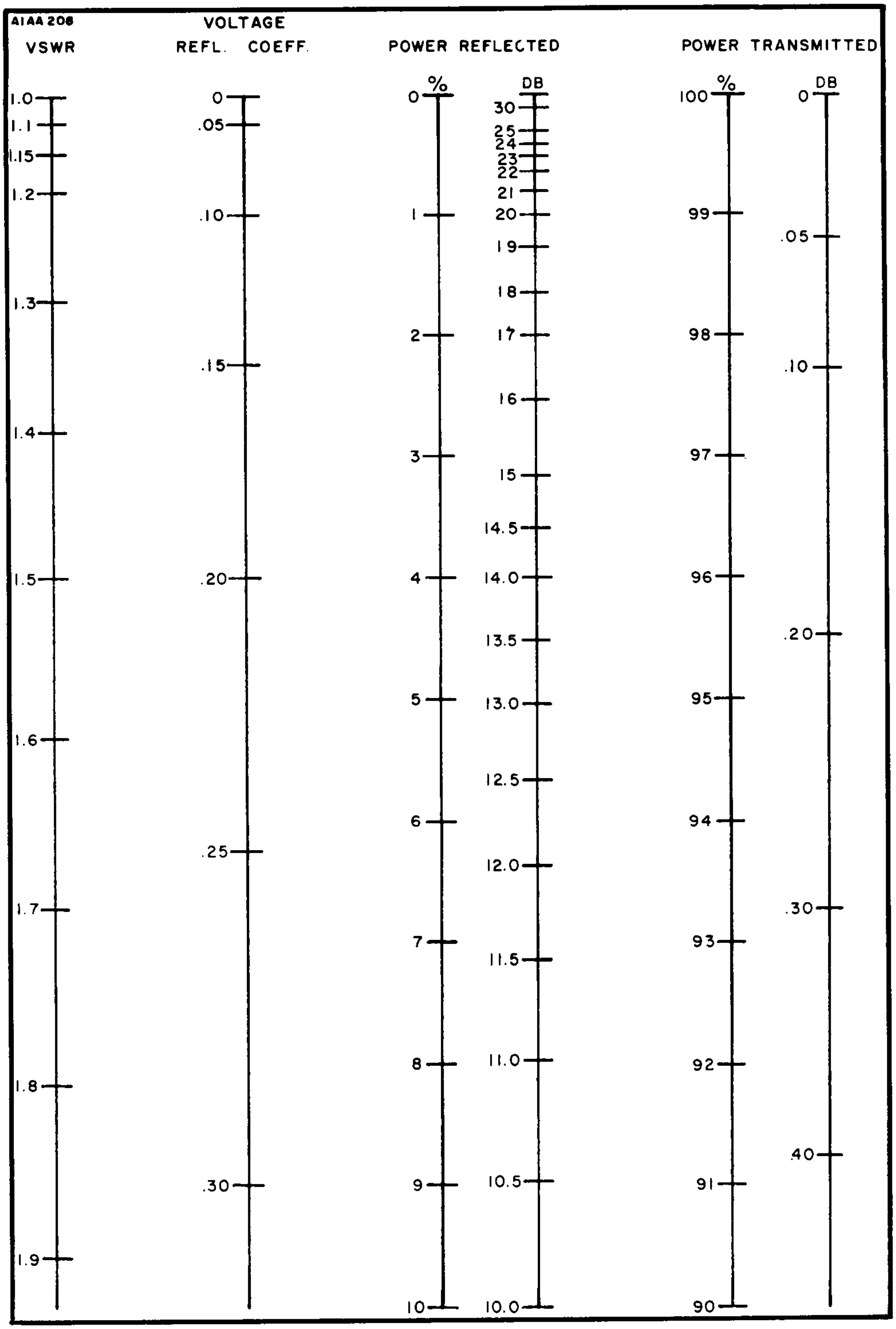

Figure A-3. VSWR Nomograph #2

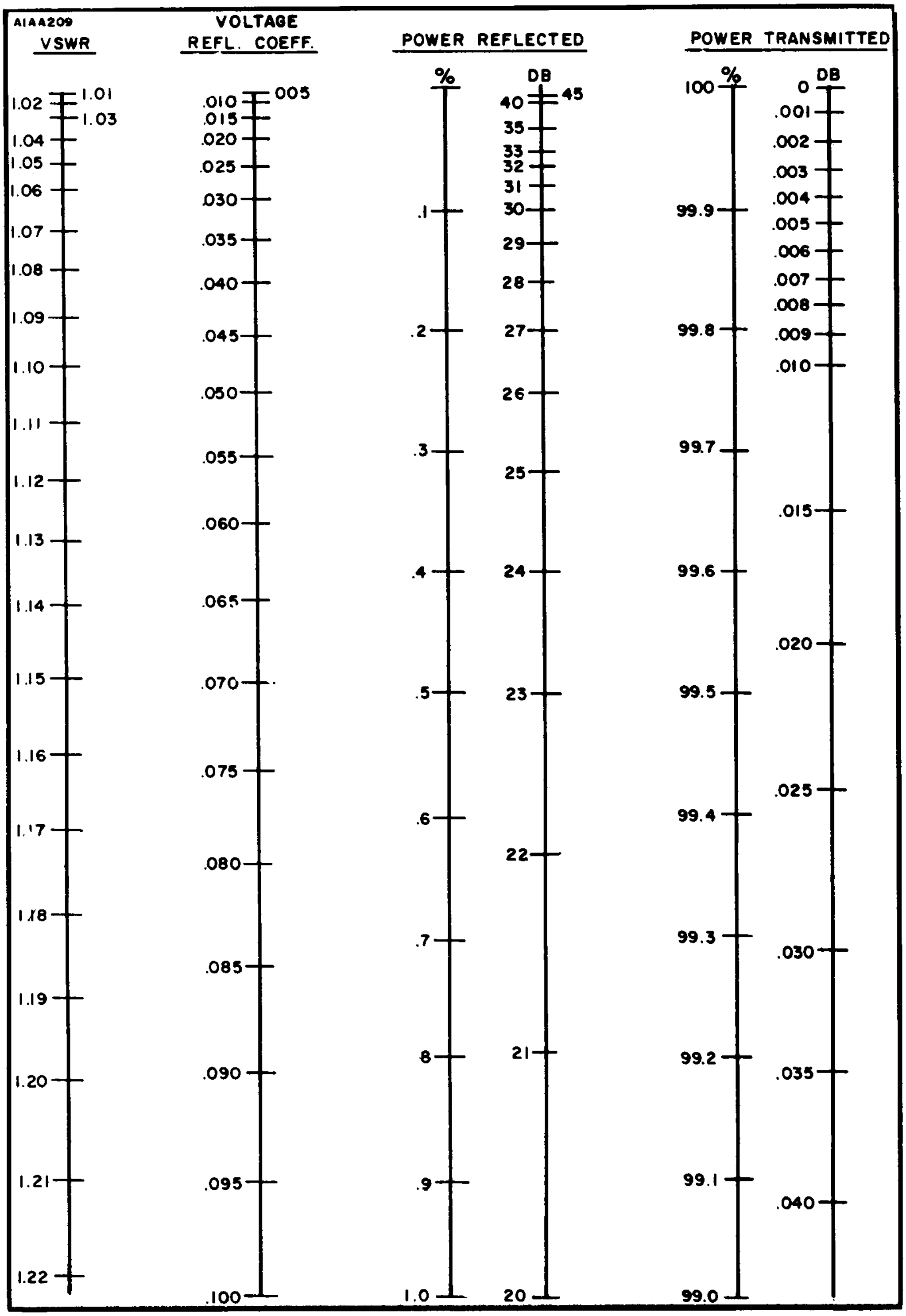

Figure A-4. VSWR Nomograph #3

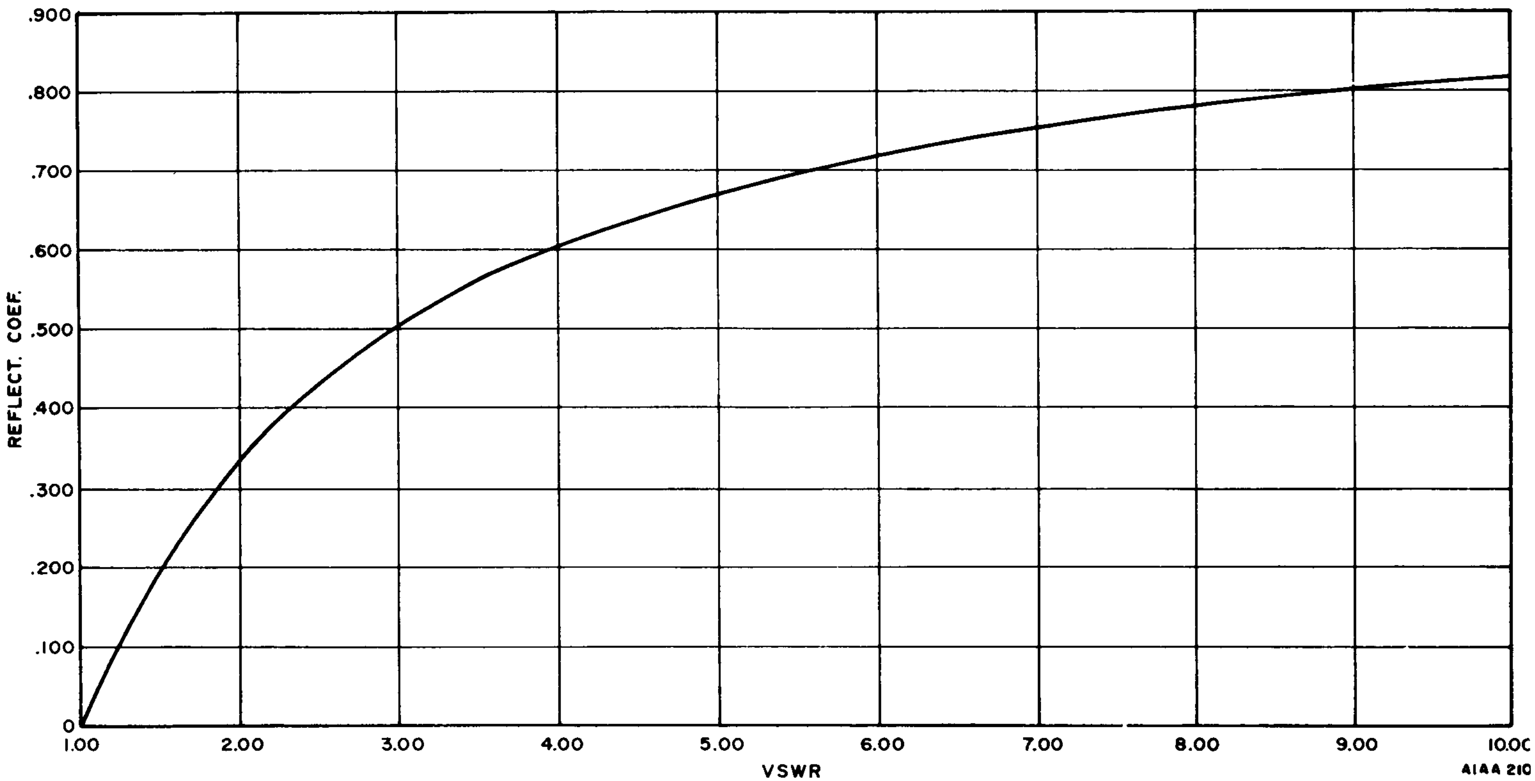

Figure A-5. VSWR Versus Reflection Coefficient

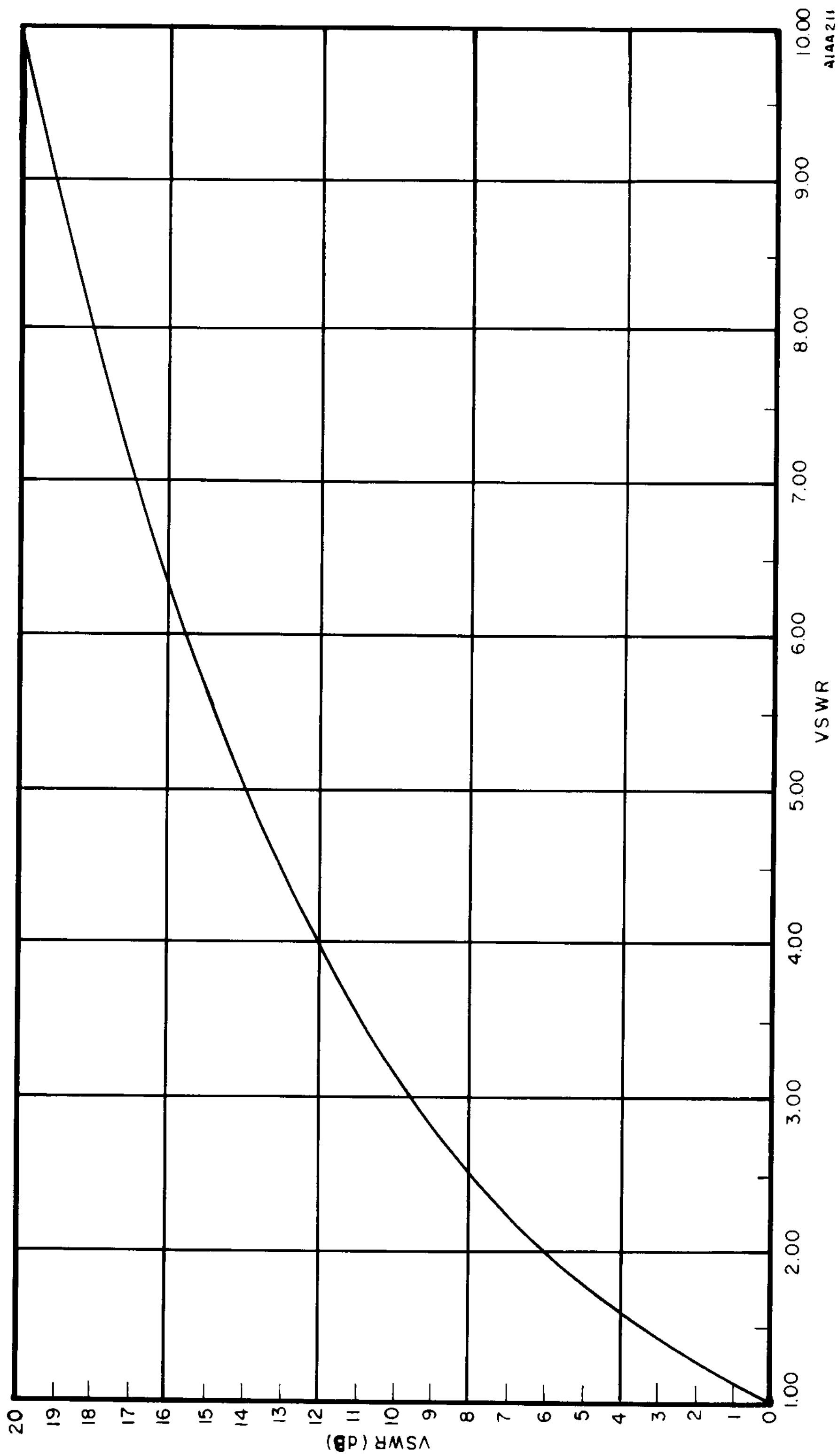

Figure A-6. VSWR Versus VSWR (dB)

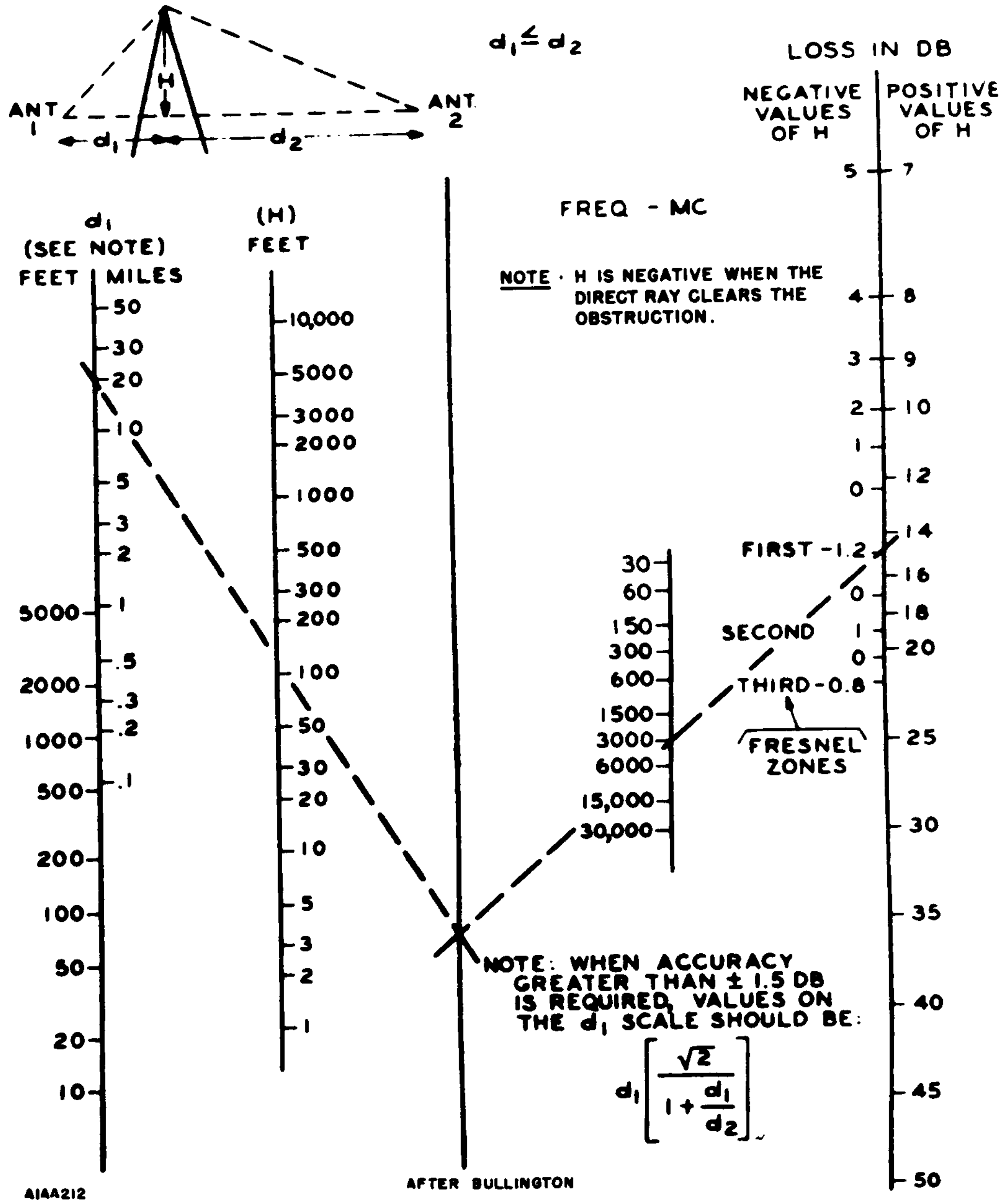

Figure A-7. Knife-Edge Diffraction Relation to Free Space

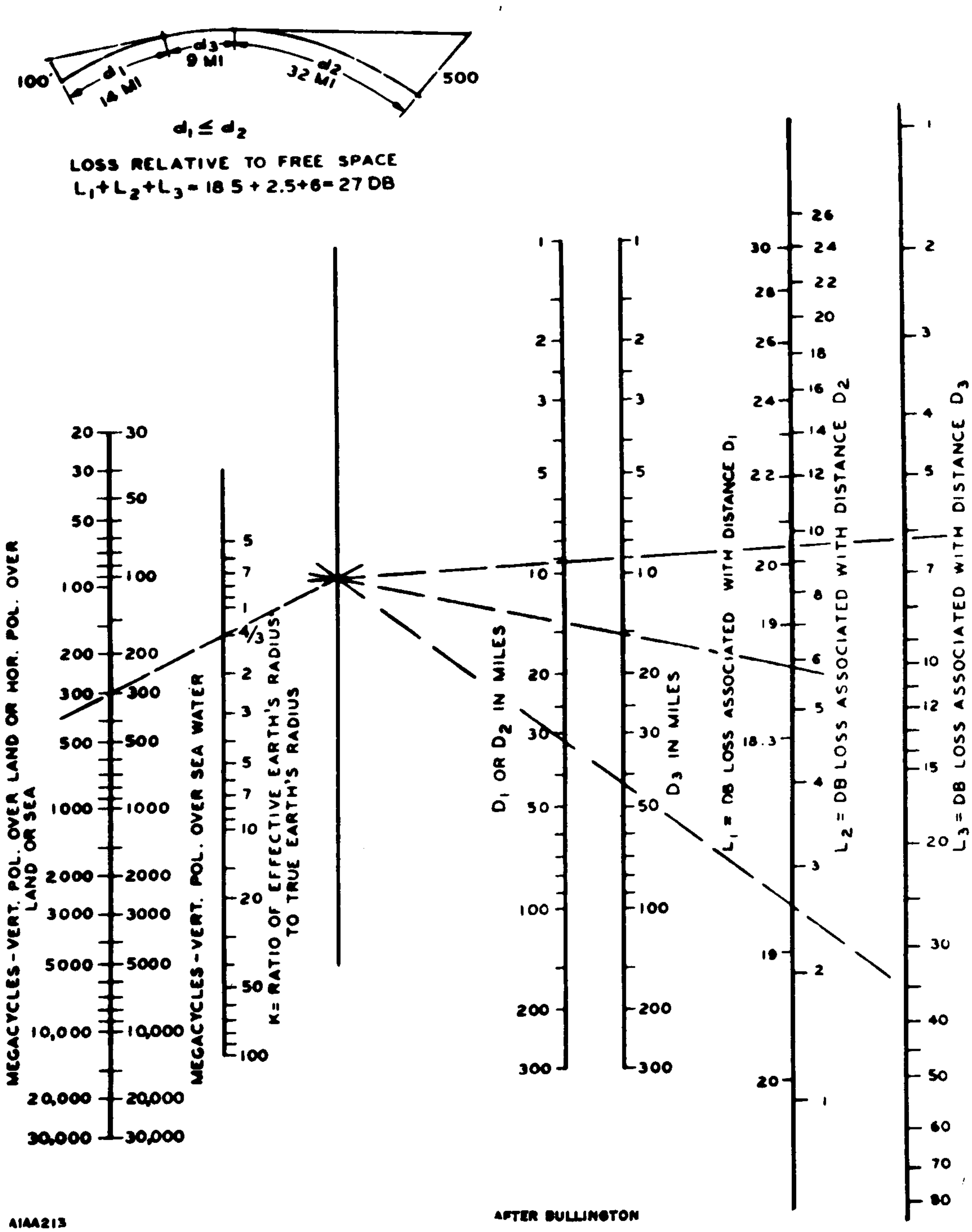

Figure A-8. Diffraction Loss Relative to Free Space Transmission at all Locations Beyond Line-of-Sight Over a Smooth Sphere

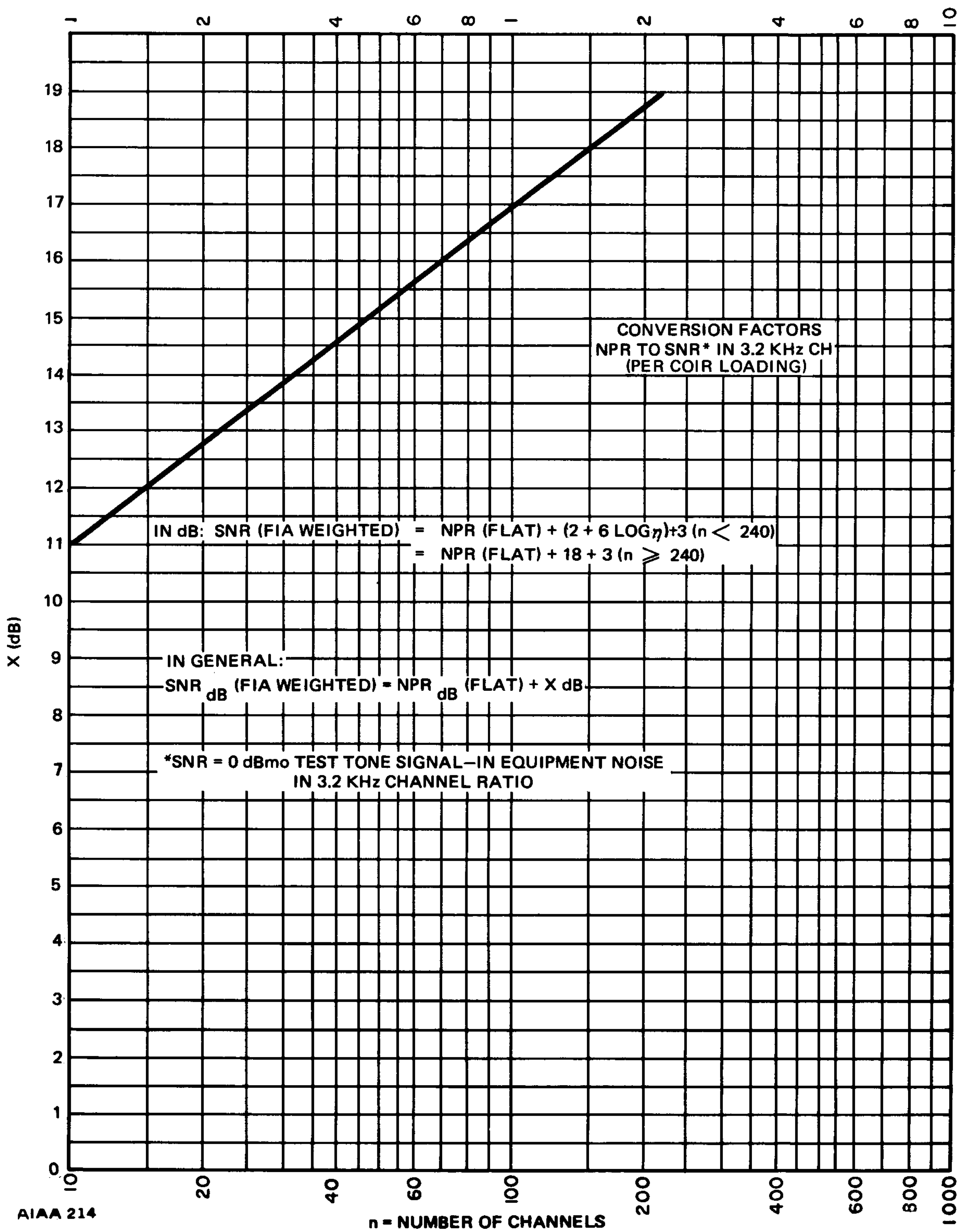

Figure A-9. Conversion Factors, NPR to SNR

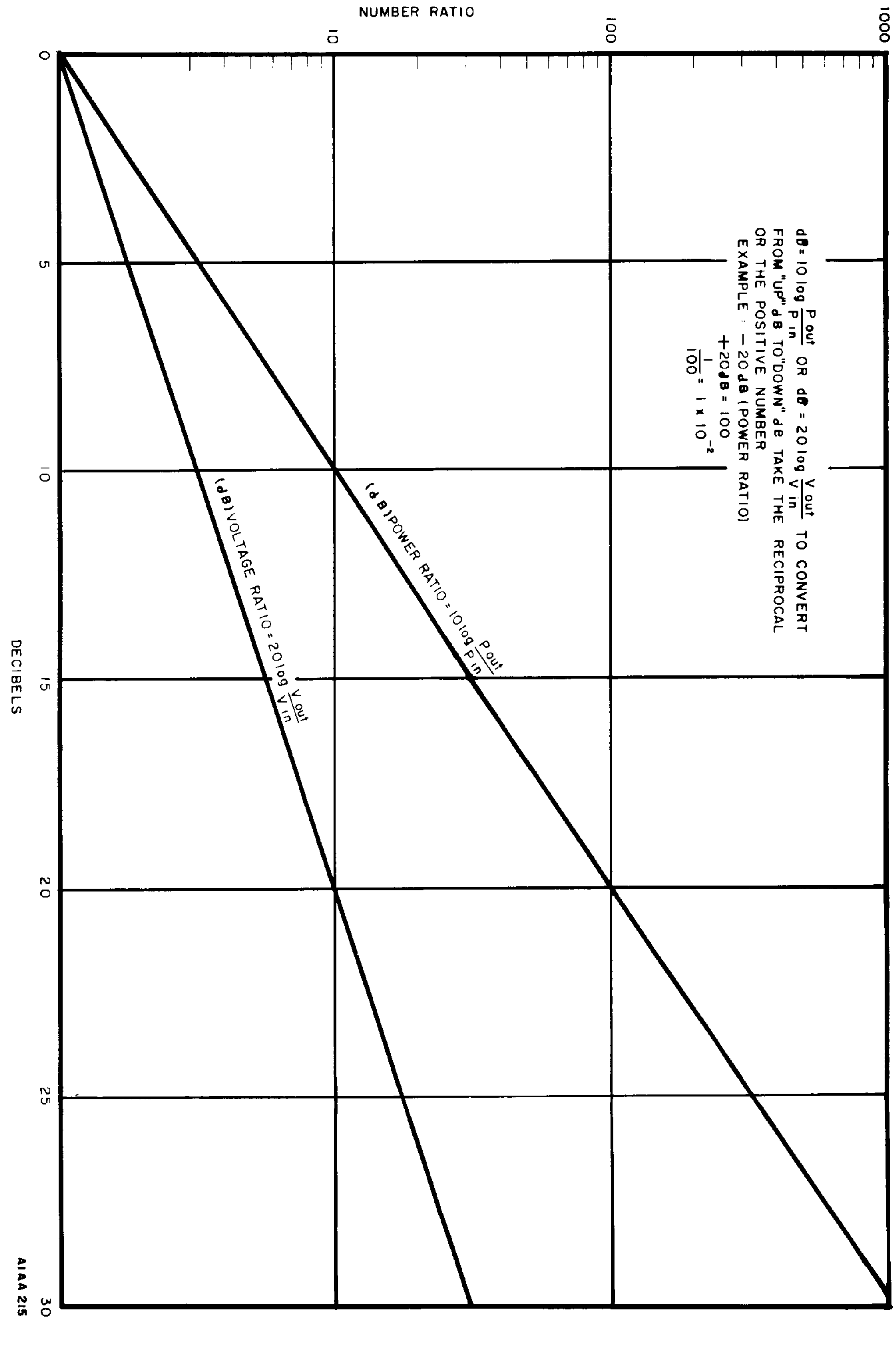

Figure A-10. Power Ratio and Voltage Ratio in Natural Numbers and Logarithms

Figure A-11. Noise in Picowatts Psophometrically Weighted #1

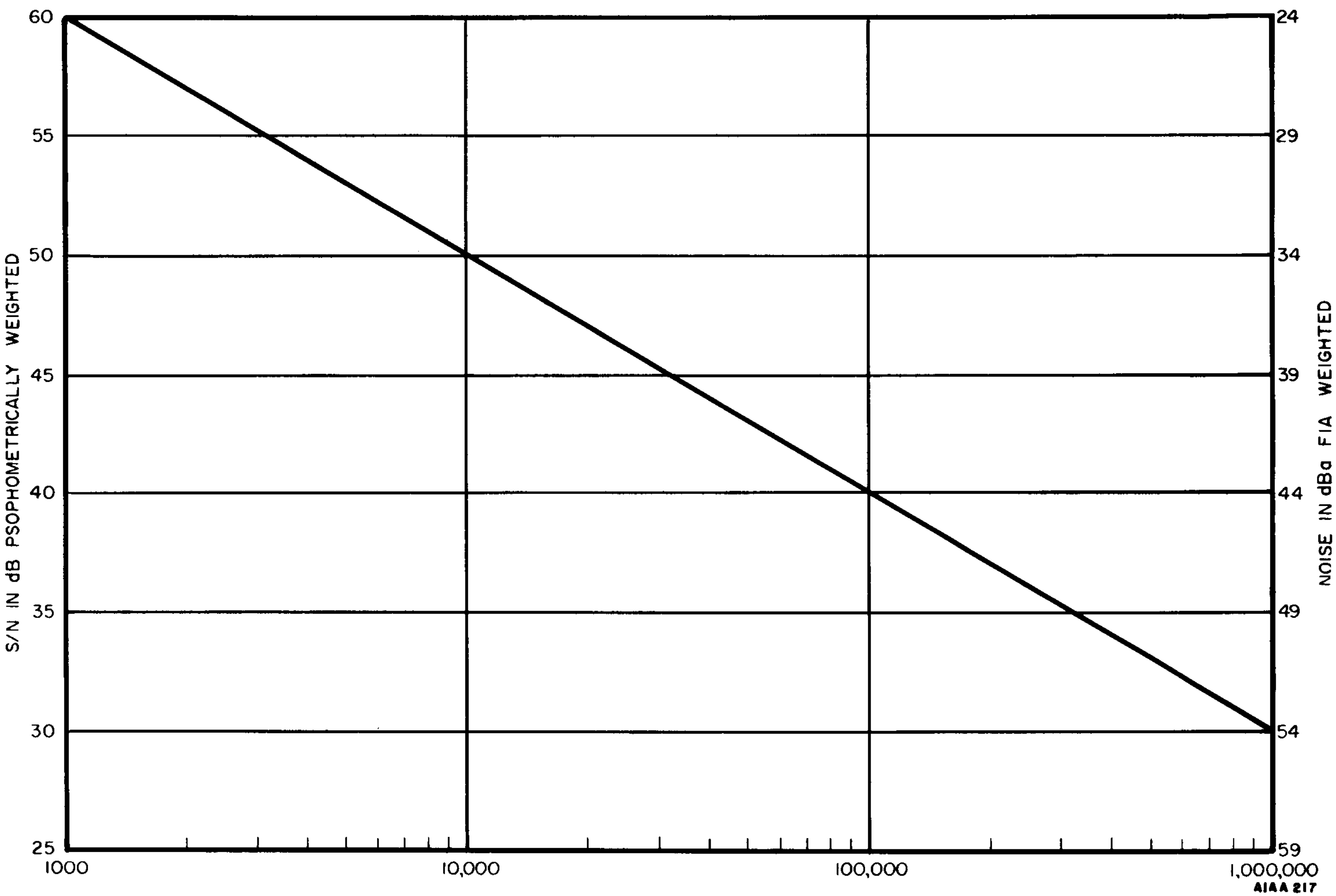

Figure A-12. Noise in Picowatts Psophometrically Weighted #2

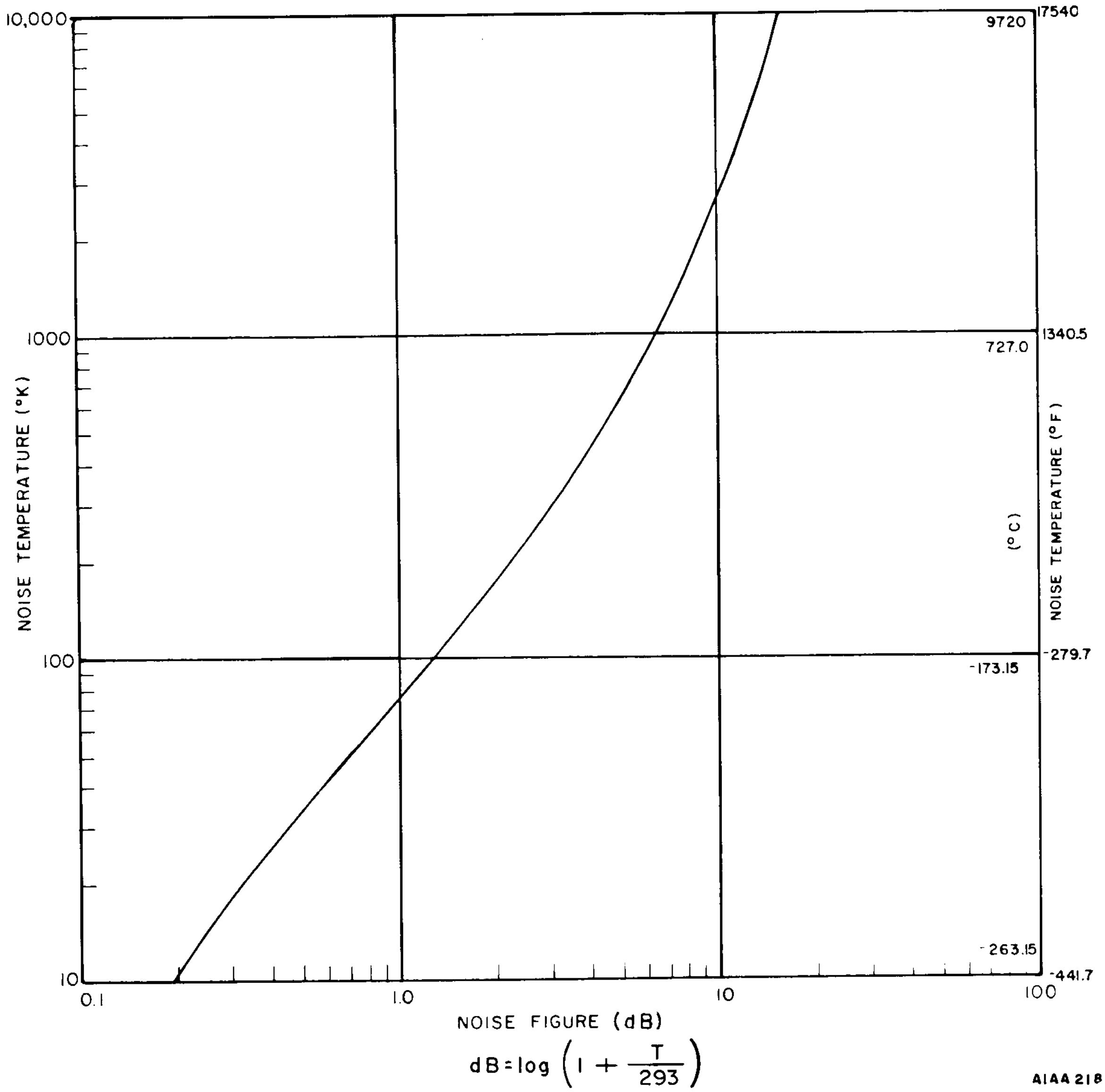

Figure A-13. Noise Figure (293°K) Versus Noise Temperature (°K)
$dB = 10 \log\left(1 + \frac{T}{293}\right)$

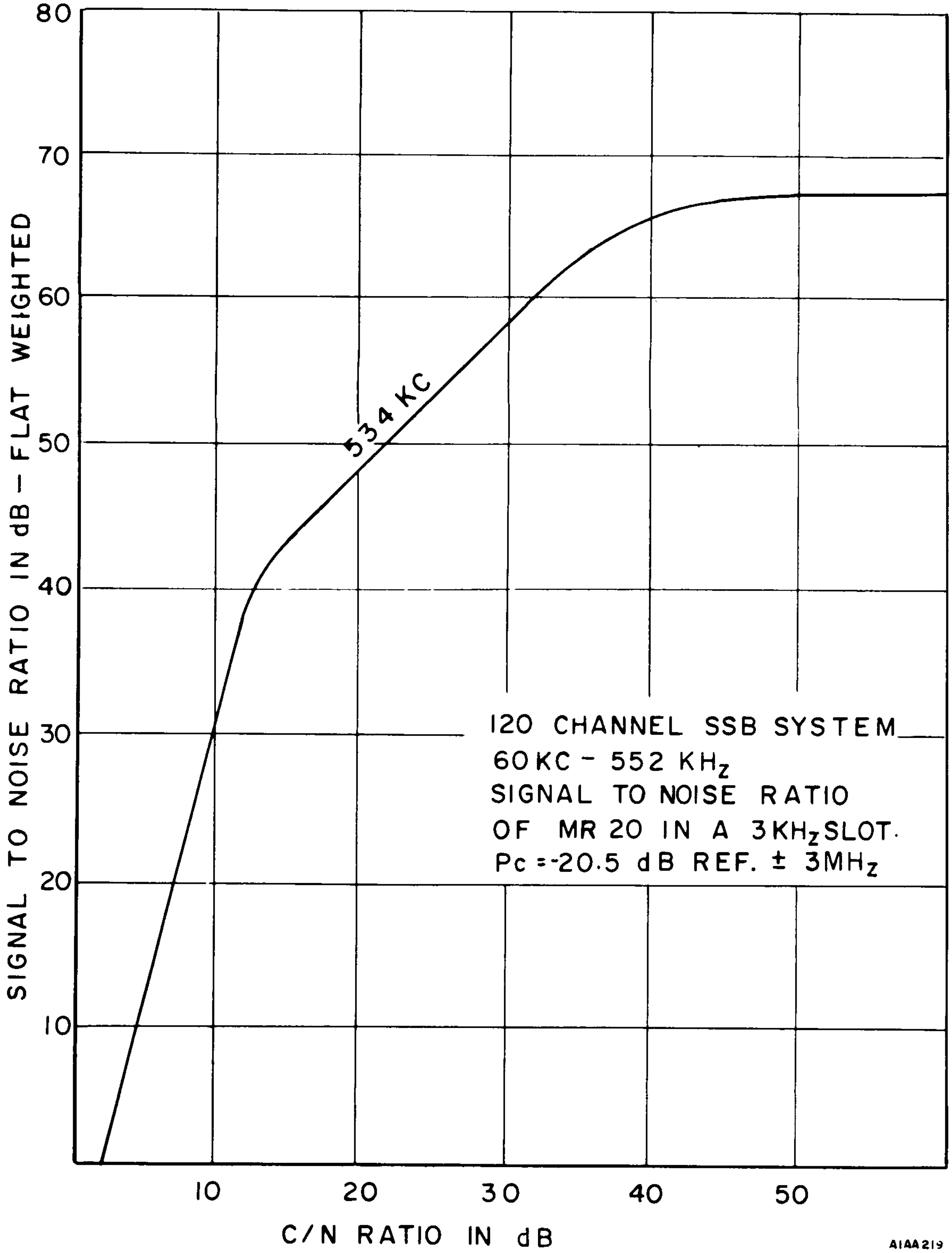

Figure A-14. FM Receiver Characteristic Curves

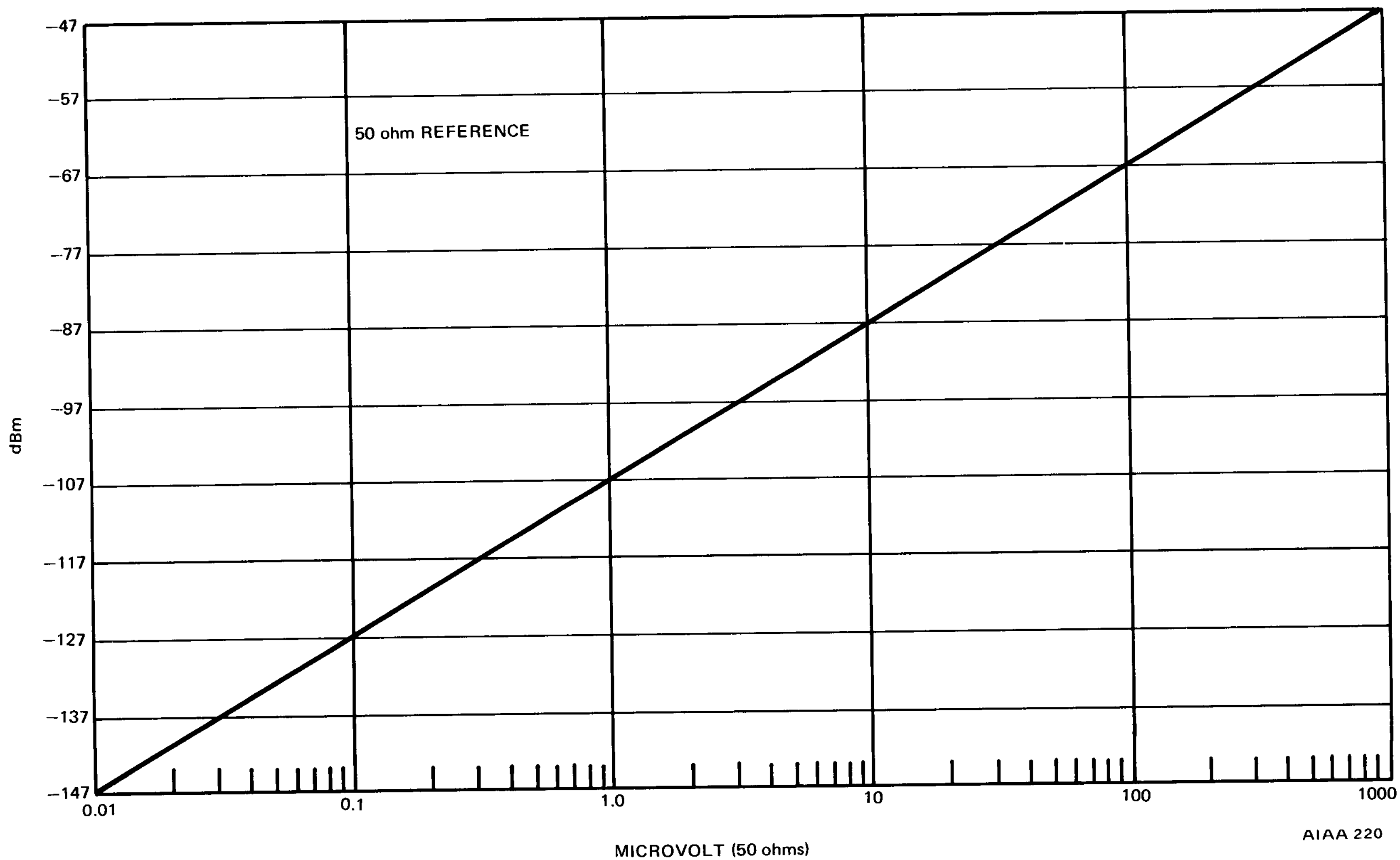

Figure A-15. Microvolt/dbm Conversion

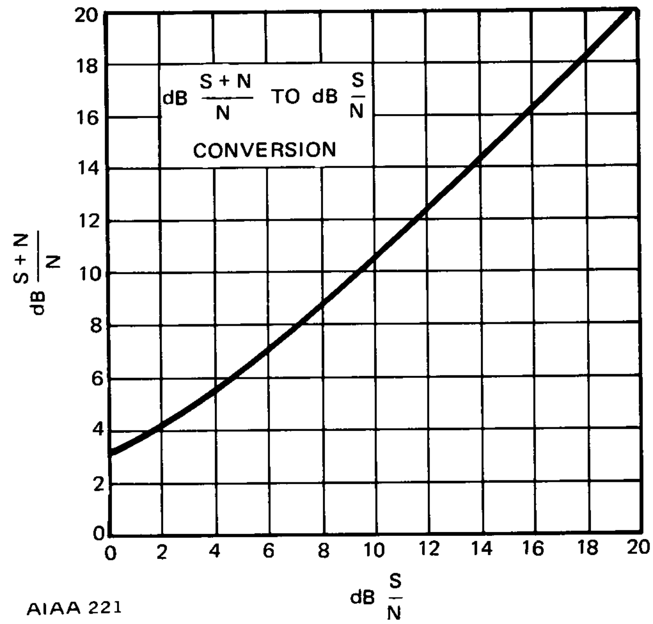

Figure A-16. Conversion of S + N/N (dB) to S/N (dB)

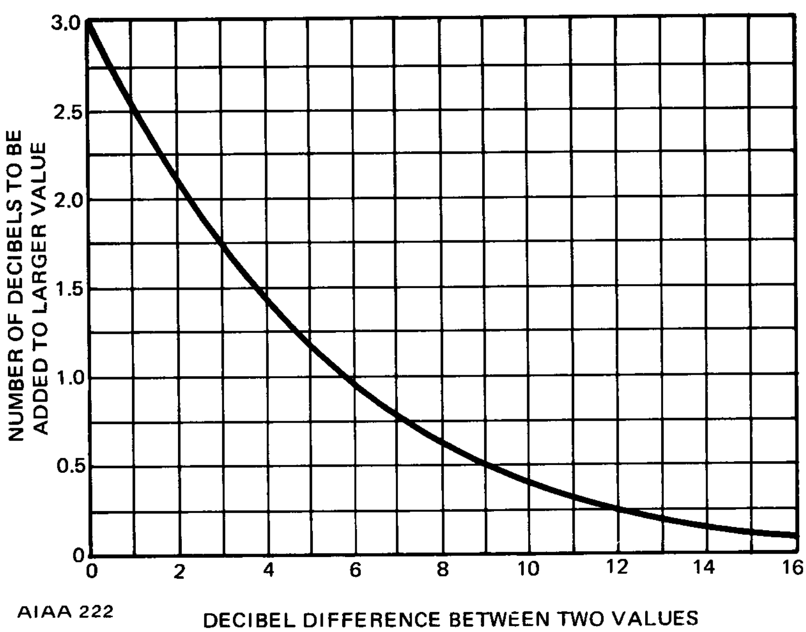

Figure A-17. Addition of Noise

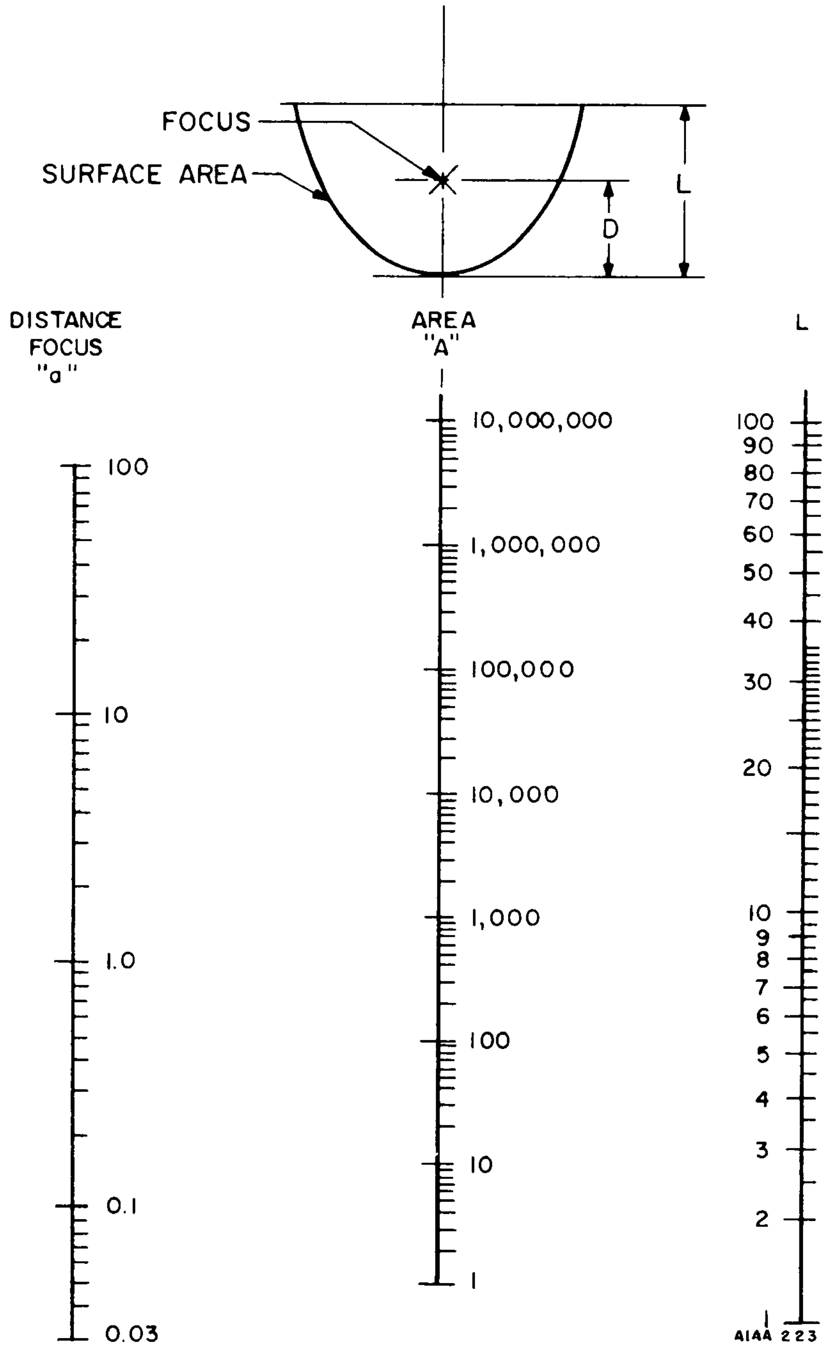

Figure A-18. Nomograph for Determining Surface Areas of Paraboloid Devices

Loading CCIR Standard

$L\ (\text{mean}) = -1 + 4 \log N \qquad N < 240$

$L\ (\text{mean}) = -15 + 10 \log N \qquad N \geq 240$

Loading Military Standard

$L\ (\text{mean}) = -5 + 10 \log N$

$S/N\ (\text{thermal}) = C/N + 10 \log \frac{B_{if}}{2b} + 20 \log \frac{\Delta F}{Fm} - L\ (\text{peak}) + P + W + C$

$S/N\ (\text{intermodulation}) = NPR + 10 \log \times \frac{B_b}{b}$ − NLR (Noise Loading Ratio)

dBa = dBm + 85 F1A (1000 cycle reference)

dBa = dBm + 82 flat weighted (one voice channel)

dBa = dBm + 90 144 weighted

dBa = dBm + 90 C message weighted (1000 cycle reference)

dBa = − S/N + 82 F1A weighted, 144 weighted (1000 cycle reference)

dBrm (C message) = − S/N + 88.5 (1000 cycle reference)

$\text{FM Threshold} = 10 \text{ Log } KTB + N_F + 10$

$\text{Noise Threshold} = 10 \text{ Log } KTB + N_F$

$\text{System Noise Figure} = N_{f1} + \frac{N_{f2} - 1}{G_1} + \frac{N_{f3} - 1}{G_1 G_2} \cdots \frac{N_{fn} - 1}{G_1 G_2 \ldots G_{n-1}}$

$°R = °F + 459.67$

$°F = 9/5\ °C + 32$

$K = 5/9\ R$

$\log MN = \log M + \log N$

$\log M/N = \log M - \log N$

$\log M^P = P \log M$

$S/N(dB) = \text{Log}\left[\text{Log}^{-1} \frac{S + N(dB)}{N} - 1\right]$

$\frac{S + N}{N}(dB) = \text{Log}\left[\text{Log}^{-1} \frac{S}{N}(dB) + 1\right]$

Equivalent Noise Temperature = Antilog insertion loss × 290°K

$B_{IF} = 3.4\ (F_m + \Delta F)$; empirical approx.

$B_{IF} = F_m \times S_1$

$D = \frac{\Delta F}{F_m}$

$S/N\ (P) = 10 \text{ Log } \frac{1 \times 10^{-3}}{Np}$

(when the signal power is 1 mw)

$\text{Allowable noise (pwp)} = \frac{l}{6000} \times 20{,}000 \times 10^{-12}$

$\text{Log}^{-1}\left[\frac{dBa + 6}{10}\right] = pwp$

$pw = 1 \times 10^{-12}$ watts

$L\ (\text{peak}) = 20 \log \frac{\Delta F\ (\text{peak})}{\Delta F_b}$

$L\ (\text{mean}) = 20 \text{ Log } \frac{\Delta F\ (\text{rms})}{\Delta F_b}$

$\frac{\Delta F}{F_m} = 2.404$ (Carrier goes through first null, all transmitted power in sidebands)

temperature

$°C = 5/9\ (°F - 32)$

$°K = °C + 273.15$

Conversion from dBm to Volts

$E = \sqrt{\text{Log}^{-1} \frac{dBm}{10} \times R \times 10^{-3}}$

Conversion from Volts to dBm

$dBm = 10 \text{ Log } \frac{E^2}{R \times 10^{-3}}$

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Figure A-19. Common Equations

A. MICROWAVE FREQUENCIES AND CORRESPONDING WAVEGUIDE SIZES

BAND	FITS WAVEGUIDE SIZE (inches)	RANGE FREQUENCY (KMC)
"S"	3 × 1½	2.6 to 3.95
"G"	2 × 1	3.95 to 5.85
"J"	1½ × ¾	5.3 to 8.2
"H"	1¼ × ⅝	7.05 to 10.0
"X"	1 × ½	8.2 to 12.4
"P"	0.702 × 0.391	12.4 to 18.0
"K"	0.500 × 0.250	18.0 to 26.5
"R"	0.360 × 0.220	26.5 to 40

B. CONVERSION TABLE WAVELENGTH FREQUENCY BANDS

WAVELENGTH BAND (meters)	FREQUENCY BAND (kilocycles)	APPROXIMATE NUMBER OF KILOCYCLES PER METER CHANGE IN WAVELENGTH	APPROXIMATE NUMBER OF METERS PER KILOCYCLE CHANGE IN FREQUENCY	OFFICIAL FCC BAND ABBREVIATION (frequency)
VERY LONG WAVES (Infinity to 10,000)	0 to 30	Below 0.01	Over 333	VERY LOW (VLF)
LONG WAVES (10,000 to 1000)	30 to 300	0.05	20	LOW (LF)
MEDIUM WAVES (1000 to 100)	300 to 3000	5	0.2	MEDIUM (MF)
SHORT WAVES (100 to 10)	3000 to 30,000	500	0.002	HIGH (HF)
VERY SHORT WAVES (10 to 1)	30,000 to 300,000	50,000	0.00002	VERY HIGH (VHF)
ULTRA SHORT WAVES (1 to 0.1) (microwaves)	300,000 to 3,000,000	5,000,000	0.0000002	ULTRA HIGH (UHF)
SUPER SHORT WAVES (0.1 to 0.01) (microwaves)	3,000,000 to 30,000,000	500,000,000	0.000000002	SUPER HIGH (SHF)

Figure A-20. Conversion Tables (Sheet 1 of 2)

C. CONVERSION TABLE OF METRIC UNITS

METER	DECIMETER	CENTIMETER	MILLIMETER	MICRON	MILLI-MICRON	ANGSTROM UNIT
1 METER	10	100	1,000	1,000,000	1,000,000,000	10,000,000,000
0.1	1 DECIMETER	10	100	100,000	100,000,000	1,000,000,000
0.01	0.1	1 CENTIMETER	10	10,000	10,000,000	100,000,000
0.001	0.01	0.1	1 MILLIMETER	1,000	1,000,000	10,000,000
0.000001	0.00001	0.0001	0.001	1 MICRON	1,000	10,000
0.000000001	0.00000001	0.0000001	0.000001	0.001	1 MILLI-MICRON	10
0.0000000001	0.000000001	0.00000001	0.0000001	0.0001	0.1	1 ANGSTROM UNIT

D. WAVELENGTHS OF VARIOUS RADIATION REGIONS

REGION	WAVELENGTH LIMITS (centimeters) Maximum	Minimum	FREQUENCY LIMITS (kilo-megacycles) Minimum	Maximum	REMARKS
RADIO	3,000,000	0.1	0.0001	300	VLF/LF/MF/ HF/VHF/UHF/SHF/Exp.
INFRA-RED	0.1	0.00008	300	375,000	Heat & Black Light
LIGHT (visible)	0.00008	0.000038	375,000	790,000	Starts with Red, progresses through Orange, Yellow, Green, Blue & Violet
ULTRA-VIOLET	0.000038	0.0000012	790,000	22,500,000	Chemical & invisible
X-RAYS	0.0000012	0.0000000006	22,500,000	45,000,000,000	——
GAMMA-RAYS	0.000000014	0.0000000001	45,000,000,000	270,000,000,000	Radioactive
COSMIC RAYS	0.0000000001	indefinite	270,000,000,000	indefinite	Little known

E. CONVERSION TABLE OF METRIC UNITS INTO WAVELENGTH UNITS

WAVELENGTH UNIT	EQUIVALENCE IN INCHES	EQUIVALENCE IN KILOCYCLES
1 meter	39.37″	300,000
1 decimeter	3.937″	3,000,000
1 centimeter	0.3937″	30,000,000
1 millimeter	0.03937″	300,000,000
1 micron	0.00003937″	300,000,000,000
1 milli-micron	0.00000003937″	300,000,000,000,000
1 angstrom unit	0.000000003937″	3,000,000,000,000,000

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Figure A-20. Conversion Tables (Sheet 2 of 2)

APPENDIX B

LOS PATH DATA CALCULATIONS

By appropriate substitutions and by converting d to miles and frequency in GHz as an inverse function of wavelength, the frequency path loss between two isotropic antennas becomes:

$$A = 96.6 + 20 \log_{10} F + 20 \log_{10} D \qquad \text{(B-1)}$$

where

A = free space attenuation between isotropics, in dB

F = frequency in GHz

D = path distance, in miles

Figure B-1 is a path data form. Utilization of the form, together with a numerical example, can be found in chapter 5.

MICROWAVE PATH DATA CALCULATIONS					
1	SITE				
2	LATITUDE				
3	LONGITUDE				
4	ELEVATION	Ft.			
5	TOWER HEIGHT	Ft.			
6	TOWER TYPE				
7	AZIMUTH FROM TRUE NORTH.				
8	PATH LENGTH	Mi.			
9	PATH ATTENUATION	dB			
10	RIGID WAVEGUIDE	Ft.			
11	FLEXIBLE WAVEGUIDE	Ft.			
12	WAVEGUIDE LOSS	dB			
13	CONNECTOR LOSS	dB			
14	CIRCULATOR OR HYBRID LOSS	dB			
15	RADOME LOSS, TYPE*	dB			
16	NEAR FIELD LOSS	dB			
17	CLOSE COUPLING LOSS (DOUBLE PASS.)	dB			
18	TOTAL FIXED LOSSES	dB			
19	TOTAL LOSSES	dB			
20	PARABOLA HEIGHT	Ft.			
21	PARABOLA DIAMETER	Ft.			
22	REFLECTOR HEIGHT	Ft.			
23	REFLECTOR SIZE, TYPE	Ft.			
24	PARABOLA - REFLECTOR SEP.	Ft.			
25	NEAR FIELD GAIN	dB			
26	ANTENNA SYSTEM GAIN	dB			
27	TOTAL GAINS	dB			
28	NET PATH LOSS	dB			
29	TRANSMITTER POWER	dBm			
30	MED. RECEIVED POWER (± 2 dB)	dBm			
31	RECEIVER NOISE THRESHOLD	dBm			
32	THEORECTICAL RF C/N RATIO	dB			
33	FM IMP. THRESHOLD (dBa)	dBm			
34	FADE MARGIN (To FM Imp. Thresh.)	dB			
35	RELIABILITY SPACING†	%			
36	POLARIZATION ‡				
37	PROFILE NUMBER				

‡ { V - Vertical, H - Horizontal }
† { N - Non-Diversity, F - Frequency Diversity, S - Space Diversity, Q - Space And Frequency Diversity }
* { U - Unheated, H Heated }
(Reliability Figures Are For Rayleigh Distributed Fading Only)

CUSTOMER ____________
PROJECT NO. ________ FREQUENCY ____________
SYSTEM ____________ EQUIPMENT ____________
LOADING ________ dBm0 (________ CHANNELS OF ________)

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DATE ________ ENGINEER ____________ Sheet ____ of ____

Figure B-1. Microwave Path Calculation Sheet

APPENDIX C

LOS SYSTEM DATA SHEET

The data sheets of Figure C-1 may be used in the calculation of the LOS System parameters.

FROM: TO:

I. SYSTEM REQUIREMENTS

Type of Transmission (Voice, TTY, etc.)
Number of Voice Channels
Desired Reliability
Maximum Allowable Channel Noise 6000 mi. cct.
Maximum Modulating Frequency , FM
RF Carrier Frequency, F
Modulation Index
Site Coordinates:

LA ____° ____' ____'' N Lat ______° ____' ____'' W Long
LB ____° ____' ____'' N Lat ______° ____' ____'' W Long

II PRELIMINARY CALCULATIONS

Great Circle Distance , D
Revr. Bandwidth, $BW = 2(\Delta F_p + F_m)$

III. LOSSES - dB

	Trial	Change	Change	Change
Free-Space Loss, $L_{FS} = 37 + 20 \log D$ (miles) + $20 \log f$ (MHz)				
Misc. Transmission Loss				
TOTAL LOSSES				

IV. MINIMUM USABLE SIGNAL, MUS

= 204 dBW+ 10 log BW + 12 dB + 10 dB

V. ADDITIONAL GAIN REQUIRED FOR 99.99% RELIABILITY (FADE MARGIN)

VI. ACTUAL MINIMUM USABLE SIGNAL, AMUS = MUS + FADE MARGIN

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Figure C-1. Line-of-Sight System Data Sheet (Sheet 1 of 3)

	Trial	Change	Change	Change
VII. TOTAL REQUIRED GAIN in dBW = TOTAL LOSSES + AMUS				

VIII. GAINS - dBW

	Trial	Change	Change	Change
Xmtr Gain, $G_{TR} = 10 \log P_T$				
Antenna Gain, $G_A = 20 \log f + 20 \log D_A - 52.6$				
Diversity Gain, G_{DIV}				
TOTAL GAIN				

IX. SYSTEM FEASIBILITY

(Compare Step VIII and Step VII)

Adjustment Required	
OK	

X. MEDIAN CARRIER-TO-NOISE RATIO, C/N
= FADE MARGIN + 10 dB

XI. SIGNAL-TO-NOISE RATIO, S/N

$$= C/N + 10 \log\left(\frac{BW}{bw}\right) + 20 \log (\text{Modulation Index}) + PF - L - MUX$$

XII. CHANNEL NOISE FACTOR
= 82 - S/N

XIII. ALLOWABLE MEDIAN NOISE

L > 151 NMI
27 < L < 151 NMI
L < 27 NMI
MAX ALLOWABLE NOISE

XIV. SUMMARY

Desired Reliability: 99.99% Actual Reliability: ______
Max. Allowable Channel Noise: 15.6 dBa0 Actual Channel Nose: ______

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Figure C-1. Line-of-Sight System Data Sheet (Sheet 2 of 3)

Recommended Design Parameters:

Transmitter Power: ____ watts
Antenna Size: ____ feet
Diversity, order of: ________

GENERAL NOTES

o The maximum modulating frequency is the sum of the minimum modulating frequency (60 kHz); the voice channel bandwidth (a product of the number of voice channels and the nominal 4 kHz spacing); and the spacing between basic supergroups (12 kHz).

o See Appendix D if Great Circle distance must be determined exactly (to five place accuracy). Otherwise, measurements from a map with $\mp$ 10-mile accuracy will suffice.

o To allow for losses associated with transmission lines, coupling, transition, duplexers, etc., a figure of 4 dB is given for systems using 1 kMHz and a figure of 6 dB is used for 2 kMHz systems.

o In this equation 12 dB = receiver-noise figure and 10 dB = C/N figure. These are approximate values and may be changed to fit the specific case. For instance, if parametric amplifiers are used, the 12 dB receiver-noise figure is changed to 2 dB.

o In this equation C/N is that computed in Step X, BW is that computed in Step II, bw = voice channel bandwidth, PF = pre-emphasis gain, L = channel loading factor, and MUX = multiplex equipment noise insertion (about 2 dB.).

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Figure C-1. Line-of-Sight System Data Sheet (Sheet 3 of 3)

APPENDIX D

GREAT CIRCLE CALCULATIONS

A simple and direct method of performing the great-circle calculations required in siting line-of-sight and scatter communication stations is presented here. An understanding of how the method is derived is not needed.

The calculation of the great-circle path length and azimuths between the transmitter and the receiver sites can be easily made if the latitudes and longitudes of the sites are known. Usually these coordinates can be obtained with sufficient accuracy from reliable maps of the areas involved. It is worthwhile for two persons to make the computations independently, comparing their results after each step. If only one person is making the computations, he should check each step thoroughly as it is completed. The computations require the addition, subtraction, multiplication, and divisions of positive and negative numbers and the use of tables of functions.

An accuracy of two minutes of arc is usually adequate for the great-circle calculations needed in siting line-of-sight scatter communication stations. This accuracy can be obtained by using five-place tables of logarithms and trigonometric functions. The tables should be graduated for every minute or every one-hundredth of a degree of arc. If five-place tables are used, it is recommended that six decimal places be carried in performing the arithmetical operations of the great-circle calculations and that interpolation be used to obtain all functions to six places and all angles to the nearest tenth of a minute or one-thousandth of a degree of arc. The computed azimuths should then be rounded to the nearest minute or one-hundredth of a degree of arc and the path length should be rounded to one decimal place, although the last digit will not always be significant.

The procedure presented here requires the uniform system of nomenclature shown in figure D-1. The location having the more westerly longitude is designated point A and the location having the more easterly longitude as point B. The North Pole is always used as the third point of the terrestrial triangle, regardless of the latitude of point A or B, and is designated as P.

The equations upon which the great-circle computations are based are the law of cosines. In terms of the terrestrial triangle PAB shown in figure D-1, these are

$$\frac{\sin A}{\sin a} = \frac{\sin P}{\sin p} = \frac{\sin B}{\sin B} \qquad \text{(D-1)}$$

and

$$\cos p = \cos a \cos b + \sin a \sin b \cos P \qquad \text{(D-2)}$$

where equation (D-1) is the law of sines and equation (D-2) is the law of cosines. Since $a = (90^\circ - \text{Lat B})$ and $b = (90^\circ - \text{Lat A})$, equations (D-1) and (D-2) may be rewritten as

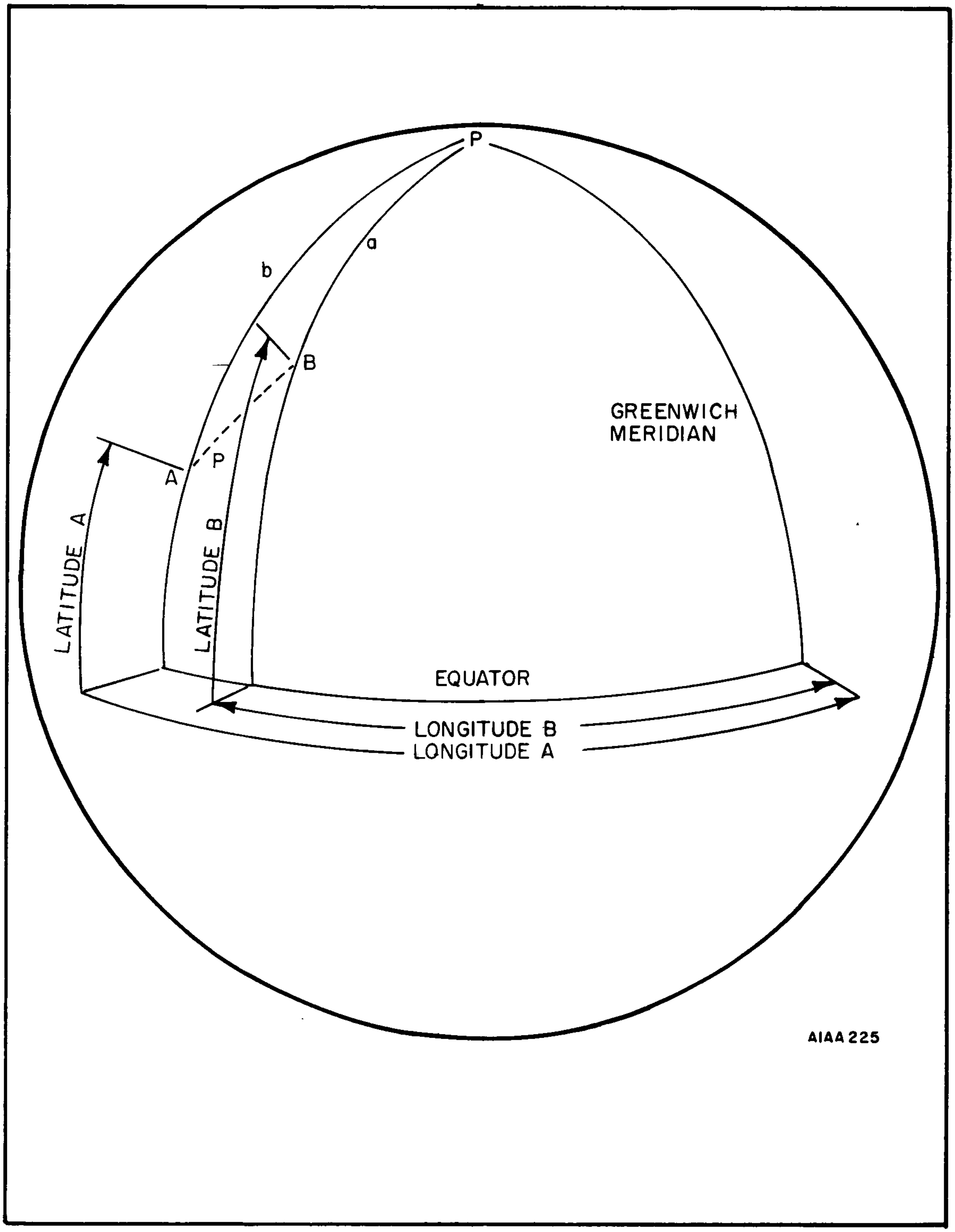

Figure D-1. Geometry for Great-Circle Calculations

$$\cos p = \sin (\text{Lat B}) \sin (\text{Lat A}) + \cos (\text{Lat B}) \cos (\text{Lat A}) \cos P \qquad \text{(D-3)}$$

and

$$\frac{\sin A}{\cos (\text{Lat B})} = \frac{\sin P}{\sin p} = \frac{\sin B}{\cos (\text{Lat A})}$$

from which the following equations for sin A and sin B are obtained:

$$\sin A = \frac{\sin P}{\sin p} \cos (\text{Lat B}) \qquad \text{(D-4)}$$

and

$$\sin B = \frac{\sin P}{\sin p} \cos (\text{Lat B}) \qquad \text{(D-5)}$$

Application of the law of cosines to angles A and B results in the equations

$$\cos A = \frac{\sin (\text{Lat B}) - \cos p \sin (\text{Lat A})}{\sin p \cos (\text{Lat A})} \qquad \text{(D-6)}$$

and

$$\cos B = \frac{\sin (\text{Lat A}) - \cos p \sin (\text{Lat B})}{\sin p \cos (\text{Lat B})} \qquad \text{(D-7)}$$

Angle P is equal to the algebraic difference of the longitudes of points A and B; that is, angle P = Long A - Long B and can have any value between 0° and 360°. Longitudes west of Greenwich are considered to be positive and those east of Greenwich are nagative. Likewise, latitudes north of the equator are positive and those south of the equator are negative. An arc above two capital letters is used to indicate the shorter great-circle are between two points on the earth, and the direction of the arc is indicated by the order in which the capital letters are written. For example, AB represents, and is read as, "the shorter great-circle arc from point A to point B."

For the purpose of this appendix, the azimuth at point A of AB is defined to be the angle at A between AP and AB, measured eastward from north. The azimuth at point B of BA is defined in a similar manner. These azimuths may have any value between 0° and 360°. For example, in figure D-1, the azimuth at point A of AB is the interior angle A, while the azimuth at point of B of BA is 360° minus the interior angle B. In general, these azimuths do not differ by 180°.

Angles A and B are special angles introduced to simplify the computation of azimuth. They are positive angles between 0° and 90° and are, by definition, equal to the values of angles A and B respectively, when these latter angles are obtained directly from the tables without regard to quadrant. Use of the trigonometric tables is thus simplified and large angles need not be dealt with until the last steps of the computation. For example, if sin A = -0.5, then A = 30°, not -30°. Similarly, if cos B = 0.5, then B = 60°, not 120°. The computation of both the sines and cosines of angles A and B from equations (D-4), (D-5), (D-6), and (D-7) allows the formulation of rules for the summarized in the tables below and on the computation forms.

Two examples are given, using forms especially designed to facilitate the computations. One illustrates the use of five-place tables of logarithms, the other a calculating machine (figure D-2 and figure D-3). The latter is also applicable if it is necessary to make the calculations by longhand (see figure D-4). If accurately followed, the indicated procedures will automatically eliminate any ambiguity in the quadrant of angles computed.

A typical computer program which may be used in great-circle calculations is shown in figure D-5. This program has been developed by the INFONET Division of Computer Sciences Corporation and it is reprinted here with their permission.

Given:

	Site	Latitude*	Longitude*
A.	Singapore	+01°18'N	-103°51'E
B.	Bali	-03°06'S	-115°05'E

I. Solve for P.

P = Long A - Long B = 11°14'

log sin P = (+)9.28960 - 10 .... (1)

II. Solve for p.

	Log Sine		Log Cosine	
Lat A = + 01°18'	(+)8.35578 - 10	(2)	(+)9.99989 - 10	(4)
Lat B = -08°06'	(-)9.14891 - 10	(3)	(+)9.99565 - 10	(5)
P = 11°14'			(+)9.99160 - 10	(6)

(2) + (3) = (-)17.50469 - 20 .... (7)

(4) + (5) + (6) = 29.98714 - 30 (8)

antilog of (7) = -0.00320 .... (9)

antilog of (8) = 0.97083 .... (10)

cos p = (9) + (10) = 0.96763 .... (11)

p = 14°37.1' .... (12)

log sin p = 9.40205 - 10 .... (13)

log cos p = 9.98571 - 10 .... (14)

III. Solve for $\tilde{A}$ and $\tilde{B}$ from log sines of A and B.†

log sin A = (1) + (5) - (13) = 9.88320 - 10 .... (15)

$\tilde{A}$ = 49°50.1' .... (16)

log sin B = (1) + (4) - (13) = 9.88744 - 10 .... (17)

$\tilde{B}$ = 50°30.3' .... (18)

IV. Solve for $\tilde{A}$ and $\tilde{B}$ from cosines of A and B.†

cos A = antilog [(3) - (13) - (4)]
- antilog [(14) + (2) - (13) - (4)] = -0.64544 (19)

$\tilde{A}$ = 49°48.1' .... (20)

cos B = antilog [(2) - (13) - (5)]
- antilog [(14) + (3) - (13) - (5)] = 0.63646 (21)

$\tilde{B}$ = 50°28.5' .... (22)

V. Compute the azimuths using the following tables.

Log Sin A	Cos A	Azimuth at A of $\widehat{AB}$
+	+	$\tilde{A}$
+	-	180° - $\tilde{A}$
-	+	180° + $\tilde{A}$
-	+	360° - $\tilde{A}$

Log Sin B	Cos B	Azimuth at B of $\widehat{BA}$
+	+	360° - $\tilde{B}$
+	-	180° + $\tilde{B}$
-	-	180° - $\tilde{B}$
-	+	$\tilde{B}$

If 0° ≤ $\tilde{A}$ ≤ 10°, use (16) for $\tilde{A}$.
If 10° < $\tilde{A}$ < 80°, use either (16) or (20) for $\tilde{A}$.
If 80° ≤ $\tilde{A}$ ≤ 90°, use (20) for $\tilde{A}$.

If 0° ≤ $\tilde{B}$ ≤ 10°, use (18) for $\tilde{B}$.
If 10° < $\tilde{B}$ < 80°, use either (18) or (22) for $\tilde{B}$.
If 80° ≤ $\tilde{B}$ ≤ 90°, use (22) for $\tilde{B}$.

Azimuth at A of $\widehat{AB}$ = 130°10'

Azimuth at B of $\widehat{BA}$ = 309°30'

VI. Compute path length.

p = (12) = 14°37.1' = 877.1 minutes of arc .... (23)

log (23) = 2.94305 .... (24)

Statute miles = antilog of [(24) + 0.061302] = 1010.1

Kilometers = antilog of [(24) + 0.267932] = 1025.5

Nautical miles = (23) = 877.1

*Latitudes north of the equator are considered to be positive and those south to be negative. Similarly, longitudes west of Greenwich are considered to be positive and those east to be negative.

†Angles $\tilde{A}$ and $\tilde{B}$ are positive angles between 0° and 90° and are by definition, equal to the values of angles A and B respectively, when these latter angles are obtained directly from the tables without regard to quadrant.

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Figure D-2. Great-Circle Calculations, Using a Computer Machine

Given:

	Site	Latitude*	Longitude*
A.	Singapore	+01°18'N	-103°51'E
B.	Bali	-03°06'S	-115°05'E

I. Solve for P.

P = Long A - Long B = 11°14'

sin P = 0.19481 .... (1)

II. Solve for p.

Lat A =	+01°18'	0.022690	(2) 0.999740	(4)
Lat B =	-08°06'	-0.140900	(3) 0.990020	(5)
P =	11°14'		0.980840	

cos p = [(2) x (3)] + [(4) x (5) x (6)] = 0.967602 (7)

p = 14°37.5' .... (8)

sin p = 0.252490 .... (9)

III. Solve for $\tilde{A}$ and $\tilde{B}$ from sines of A and B.†

$\frac{\sin P}{\sin p} = \frac{(1)}{(9)}$ = 0.771555 .... (10)

sin A = (10) x (5) = 0.763855 .... (11)

$\tilde{A}$ = 49°48.3' .... (12)

sin B = (10) x (4) = 0.771354 .... (13)

$\tilde{B}$ = 50°28.5' .... (14)

IV. Solve for $\tilde{A}$ and $\tilde{B}$ from cosines of A and B.†

cos A = $\frac{(3) - [(7) \times (2)]}{(9) \times (4)}$ = -0.645104 (15)

A = 49°49.3' .... (16)

cos B = $\frac{(2) - [(7) \times (3)]}{(9) \times (5)}$ = 0.636176 (17)

B = 50°89.6' .... (18)

V. Compute the azimuths using the following tables.

Sin A (11)	Cos A (15)	Azimuth at A of $\widehat{AB}$
+	+	$\tilde{A}$
+	-	180° - $\tilde{A}$
-	-	180° + $\tilde{A}$
-	+	360° - $\tilde{A}$

Sin B (13)	Cos B (17)	Azimuth at B of $\widehat{BA}$
+	+	360° - $\tilde{B}$
+	-	180° + $\tilde{B}$
-	-	180° - $\tilde{B}$
-	+	$\tilde{B}$

If 0° ≤ $\tilde{A}$ ≤ 10°, use (12) for $\tilde{A}$.

If 10° < $\tilde{A}$ < 80°, use either (12) or (16) for $\tilde{A}$.

If 80° ≤ $\tilde{A}$ ≤ 90°, use (16) for $\tilde{A}$.

If 0° ≤ $\tilde{B}$ ≤ 10°, use (14) for $\tilde{B}$.

If 10° < $\tilde{B}$ < 80°, use either (14) or (18) for $\tilde{B}$.

If 80° ≤ $\tilde{B}$ ≤ 90°, use (18) for $\tilde{B}$.

Azimuth at A of $\widehat{AB}$ = 130°11'

Azimuth at B of $\widehat{BA}$ = 309°30'

VI. Compute path length.

p = (8) = 14°57.5' = 877.5 minutes of arc .... (19)

Statute Miles = (19) x 1.1516 = 1010.5

Kilometers = (19) x 1.85325 = 1626.2

Nautical Miles = (19) = 877.5

*Latitudes north of the equator are considered to be positive and those south to be negative. Similarly, longitudes west of Greenwich are considered to be positive and those east to be negative.

† Angles $\tilde{A}$ and $\tilde{B}$ are positive angles between 0° and 90° and are by definition, equal to the values of angles A and B respectively, when these latter angles are obtained directly from the tables without regard to quadrant.

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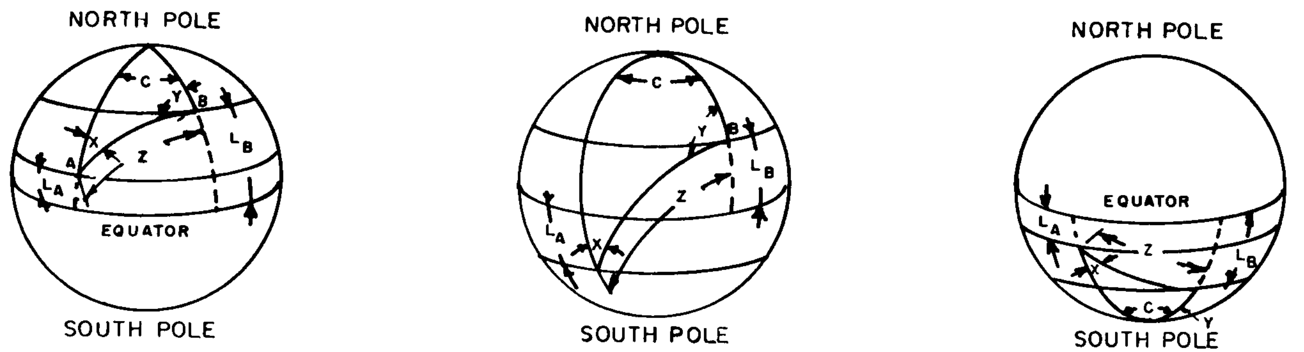
Figure D-3. Great-Circle Calculations, Using Logarithms



THREE GLOBES REPRESENTING POINTS A AND B BOTH IN THE NORTHERN HEMISPHERE, IN OPPOSITE HEMISPHERES, AND BOTH IN THE SOUTHERN HEMISPHERE. IN ALL CASES, L_A = LATITUDE OF B, C = DIFFERENCE OF LONGITUDE.

$$\text{TAN } \tfrac{1}{2}(Y-X) = \text{COT } \tfrac{1}{2}C \; \frac{\text{SIN } \tfrac{1}{2}(L_B-L_A)}{\text{COS } \tfrac{1}{2}(L_B+L_A)} \quad \text{AND} \quad \text{TAN } \tfrac{1}{2}(Y+X) = \text{COT } \tfrac{1}{2}C \; \frac{\text{COS } \tfrac{1}{2}(L_B-L_A)}{\text{SIN } \tfrac{1}{2}(L_B+L_A)}$$

$$\tfrac{1}{2}(Y+X) + \tfrac{1}{2}(Y-X) = Y$$

$$\tfrac{1}{2}(Y+X) - \tfrac{1}{2}(Y-X) = X$$

$$\text{TAN } \tfrac{1}{2}Z = \text{TAN } \tfrac{1}{2}(L_B-L_A) \; [\text{SIN } \tfrac{1}{2}(Y+X)] \; [\text{SIN } \tfrac{1}{2}(Y-X)]$$

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Figure D-4. Great-Circle Calculations (Sheet 1 of 3)

Site ______ ______ ° ______ ' ______ " N Lat ______ ° ______ ' ______ " W Long

Site ______ ______ ° ______ ' ______ " N Lat ______ ° ______ ' ______ " W Long

C = ______ ° ______ ' ______ "

$L_B + L_A$ = ______ ° ______ ' ______ "

$L_B - L_A$ = ______ ° ______ ' ______ "

$\frac{L_B + L_A}{2}$ = ______ ° ______ ' ______ "

$\frac{L_B - L_A}{2}$ = ______ ° ______ ' ______ "

$\frac{C}{2}$ = ______ ° ______ ' ______ "

$\log \cot (\frac{C}{2})$ ______ ° ______ ' ______ " = ______

$+ \log \cos \frac{L_B - L_A}{2}$ ______ ° ______ ' ______ " = ______

$- \log \sin \frac{L_B + L_A}{2}$ ______ ° ______ ' ______ " = ______

$\log \tan \frac{X + Y}{2}$ = ______

$\frac{X + Y}{2}$ = ______ ° ______ ' ______ "

$\log \cot (\frac{C}{2})$ ______ ° ______ ' ______ " = ______

$+ \log \sin \frac{L_B - L_A}{2}$ ______ ° ______ ' ______ " = ______

= ______

$- \log \cos \frac{L_B + L_A}{2}$ ______ ° ______ ' ______ " = ______

$\log \tan \frac{X - Y}{2}$ = ______

$\frac{X - Y}{2}$ = ______

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Figure D-4. Great-Circle Calculations (Sheet 2 of 3)

Azimuth from Site ________

$\frac{X+Y}{2}$ = ______° ______' ______"

$+\frac{X-Y}{2}$ = ______° ______' ______"

______° ______' ______"

Azimuth from Site ________

$\frac{X+Y}{2}$ = ______° ______' ______"

$-\frac{X-Y}{2}$ = ______° ______' ______"

______° ______' ______"

$\log \tan \frac{L_B - L_A}{2}$ ______° ______' ______" = ________

$+ \log \sin \frac{X+Y}{2}$ ______° ______' ______" = ________

$- \log \sin \frac{X-Y}{2}$ ______° ______' ______" = ________

$\log \tan \frac{Z}{2}$ = ________

$\frac{Z}{2}$ = ______° ______' ______"

Z = ______° ______' ______"

d = ______° x 69.093 = (Statute Miles) ______

AIAA 228

Figure D-4. Great-Circle Calculations (Sheet 3 of 3)

***SPHERE
SPHERICAL TRIANGLES
Geometry 02.03
Program No. 01-0640

ABSTRACT

***SPHERE solves spherical triangles having an apex at the North Pole and the other two corners defined by their respective latitudes and longitudes. Program output includes great circle distances, true bearings, and the hour angle at the North Pole.

DESCRIPTION

***SPHERE solves spherical triangles having an apex at the North Pole. Input consists of:

- Local latitude and longitude
- Remote latitude and longitude
- Observed altitude, if any

Output consists of:

- Local hour angle at the North Pole
- Zenith (great circle) distances
- True bearings (great circle courses)
- Altitude (remote celestial position above the local horizon)
- Line of position

INSTRUCTIONS

After the program description has printed, enter input data in the following format:

```
10 DATA LTD, LTM, LGD, LGM, RLTD, RLTM, RLGD,
RLGM, ALD, ALM
```

E00004-00.016-00

1 of 5

Figure D-5. Great-Circle Distance, Computer Program (Sheet 1 of 5)

***SPHERE

SPHERICAL TRIANGLES

where

LTD, LTM = local latitude (degrees, minutes)

LGD, LGM = local longitude (degrees, minutes)

RLTD, RLTM = remote latitude (degrees, minutes)

RLGD, RLGM = remote longitude (degrees, minutes)

ALD, ALM = observed altitude (if any) (degrees, minutes)

Each pair of numbers specifies the degrees and the minutes of each associated location.

For South latitudes and East longitudes, enter the degree values as negative numbers. If there is no observed altitude, set ALD and ALM equal to zero.

The first DATA statement used must be numbered 10. DATA for as many cases as desired can be entered successively in succeeding DATA statements. DATA statements can be numbered 10-99.

After all DATA statements have been entered, type RUN (followed by a carriage return) and program execution will continue. To re-execute the program, enter the desired new DATA statements and type RUN again.

SAMPLE RUN

Solve the spherical triangle problem using the following data:

Local Latitude: 40 degrees 50 minutes North Latitude

Local Longitude: 73 degrees 30 minutes West Longitude

Remote Latitude: 23 degrees 26 minutes North Latitude

Remote Longitude: 133 degrees 30 minutes West Longitude

Observed Altitude: 37 degrees 20 minutes

2 of 5

E00004-00.016-00

Figure D-5. Great-Circle Distance, Computer Program (Sheet 2 of 5)

***SPHERE
SPHERICAL TRIANGLES

```
RUN ***SPHERE

***SPHERE      11:39      05/12/70

        SØLUTIØN ØF SPHERICAL TRIANGLES
  #01-0640; VERSIØN 2

DETAILS (YES,NØ) ?YES


     ***SPHERE SØLVES SPHERICAL TRIANGLES HAVING THE
APEX AT THE NØRTH PØLE AND THE ØTHER TWØ CØRNERS DEFINED
BY THEIR RESPECTIVE LATITUDES AND LØNGITUDES.
MULTIPLE CASES MAY BE ENTERED SUCESSIVELY IN DATA
STATEMENTS 10-999 IN THE FØLLØWING FØRMAT:

   10 DATA  LTD,LTM, LGD,LGM, RLTD,RLTM, RLGD,RLGM, ALD,ALM

WHERE EACH PAIR ØF NUMBERS SPECIFIES A LØCATIØN IN THE FØRM
'DEGREES,MINUTES' AS FØLLØWS:

   LTD,LTM     = LØCAL LATITUDE
   LGD,LGM     = LØCAL LØNGITUDE
   RLTD,RLTM   = REMØTE LATITUDE
   RLGD,RLGM   = REMØTE LØNGITUDE
   ALD,ALM     = ØBSERVED ALTITUDE (IF ANY)

SØUTH LATITUDES AND EAST LØNGITITUDES ARE SPECIFIED
WITH NEGATIVE DEGREES AND PØSITIVE MINUTE VALUES.
IF THERE IS NØ ØBSERVERED ALTITUDE, SET ALD AND ALM
EQUAL TØ ZERØ.

END ØF ***SPHERE
NØW AT *END*

11:41    RAN 0 MINS  0.32 SECS



READY
10 DATA 40,50,73,30,23,26,133,30,37,20
RUN

***SPHERE      11:42      05/12/70

        SØLUTIØN ØF SPHERICAL TRIANGLES
  #01-0640; VERSIØN 2
```

E00004-00.016-00

3 of 5

Figure D-5. Great-Circle Distance, Computer Program (Sheet 3 of 5)

```
***SPHERE
SPHERICAL TRIANGLES


   CASE NUMBER 1


   LØCAL PØSITIØN:

    40 DEG     50 MIN   NØRTH LATITUDE
    73 DEG     30 MIN   WEST LØNGITUDE


   REMØTE PØSITIØN:

    23 DEG     26 MIN   NØRTH LATITUDE
    133 DEG     30 MIN   WEST LØNGITUDE


   LØCAL HØUR ANGLE (AT NØRTH PØLE):

    60 DEG
    60 DEG     0 MIN
    4 HRS    0 MIN     0 SEC


   ZENITH (GREAT CIRCLE) DISTANCES:

    52.6 DEG
    52 DEG     37 MIN
    3157 NAUTICAL MILES
    3635.5  STATUTE MILES


   TRUE BEARINGS (GREAT CIRCLE CØURSES):

    REMØTE PØSITIØN FRØM LØCAL PØSITIØN:
    270.1 DEG
    270 DEG     4 MIN

    LØCAL PØSITIØN FRØM REMØTE PØSITIØN:
    55.6 DEG
    55 DEG     33 MIN


   ALTITUDE (REMØTE CELESTIAL PØSITIØN
      ABØVE LØCAL PØSITIØN HØRIZØN):

    37.4 DEG
    37 DEG     23 MIN
```

4 of 5 E00004-00.016-00

Figure D-5. Great-Circle Distance, Computer Program (Sheet 4 of 5)

***SPHERE
SPHERICAL TRIANGLES

```
ØBSERVED ALTITUDE:

 37 DEG     20 MIN
 37.33 DEG


LINE ØF PØSITIØN:

 3 MILES AWAY  ØN LINE BEARING   90.1 DEGREES TRUE

END ØF ***SPHERE
NØW AT *END*

11:43   RAN 0 MINS  0.12 SECS
```

E00004-00.016-00

5 of 5

Figure D-5. Great-Circle Distance, Computer Program (Sheet 5 of 5)

APPENDIX E

LINE-OFF-SIGHT AND TROPOSCATTER SITING SURVEY

The purpose of the accompanying forms is to facilitate the on-site survey phase of site selection. No attempt has been made to produce a text on the subject, nor is it intended as a replacement for any known USN document. Rather, this collection of forms is intended as an aid in assembling the pertinent field data for engineering design of either a line-of-sight or a tropospheric communications system, regardless of the locale, or agency making the survey.

Dependent upon the purpose of survey or the geographic area, some of the included data is not applicable (e.g., import data for sites within the U.S.Z.I.) and should, therefore be removed from the forms prior to issuance to the survey teams. A suggested list of required equipment, for field survey, is shown in Figure E-1.

In the preparation of these forms, it has been assumed throughout that competent field teams would be utilized in making the surveys. There is no reliable short-cut method for selecting line-of-sight or tropospheric scatter sites since no two sites present identical problems. In the final selection, a compromise is usually necessary between the purely electronic considerations and those involving site accessibility and the costs of procurement and construction, with certain minimum transmission requirements as the one inflexible parameter. An orderly and logical approach to the selection of sites is outlined in the following steps.

- Preliminary Design. Engineering design, based on thorough map studies, taking into consideration path loss calculations, anticipated transmitter power, antenna size, approximate site location, zone of radiation hazard, and where applicable, the great circle bearings to adjacent sites.

- On-Site Survey. Working from the preliminary design, features of an area such as line-of-sight visibility, accessibility, topography, construction and support facilities, and other considerations essential to the selection are evaluated from a physical survey. These forms are intended for use in this phase of the work.

- Path Loss Measurements. These measurements are obtained by actually measuring the propagation losses between adjacent sites when on-site survey or prediction techniques fail to provide clear assurance of adequate field strengths at otherwise acceptable site locations.

EQUIPMENT DESCRIPTION	MILITARY STOCK NO.	EQUIPMENT DESCRIPTION	MILITARY STOCK NO.
Theodolite (Kern)	6675-580-3838	Shovel	5120-293-3336
Tripod	6675-641-5715	Hand Pick	5120-194-9458
Solar Attachment (DKM-1 recommended)	Not listed	Flashlight	6230-163-1856
Grid Lamp & Batteries (For Kern)	Not listed	Drafting Equipment	6675-286-0603
Level Rod	6675-171-5158	Sketch Pad	7530-286-6902
Range Pole	6675-283-0013	Thermometer	6685-174-6238
100 ft. Chain	5210-293-3505	Brunton Compass	6675-171-5122
Hatchet	500-222-0457	Altimeter	6675-551-4691
6 ft. Rule	5210-541-3324	Ephemeris or Nautical Almanac	Not listed
Stakes (50)	5510-171-7701	Tables and Books	Not listed
Marking Keel	7510-272-9254	Brush Hook, Machete	5110-595-8427
Tacks or Nails	5315-664-1458A	Flagging Cloth, 10 yds.	8305-680-0985
Field Book	7530-243-0369	Chronometer	6645-556-1863
Twine	4020-291-5896	2 sets of Portable UHF Transceivers (or equivalent for interparty commun-ications)	Not listed
Binoculars	6650-530-0959	Cement for Markers	Not listed
Camera (Land pre-ferred)	Not listed	Paint (Spray can)	8010-619-2877
Film	Not listed		
Plumb Bob	5210-224-8794		

A144619

Figure E-1. Field Survey Equipment

o Site Acquisition. This involves the negotiations for purchase or lease, for right-of-way, etc. When the survey is undertaken for a government agency this phase is accomplished by offices of the U.S. Government and under no circumstances are survey teams to anticipate or enter into any part of these negotiations.

Ideally, a site survey team should include an electronic engineer and a civil engineer, and for obvious reasons, it is recommended that these men be thoroughly familiar with the area maps, plats, and path calculations as well as the preliminary design prior to the actual field survey.

o Data Book. The Survey Data Book included in this appendix, consists of forms and check-lists for the collection of information that is required regardless of the type of site.

The following table lists the forms of the Data Book as they appear in this Appendix.

	Form	Figure Number	Page Number
I.	Pre-Site Survey Data	E-2	E-4
II.	Electronic Engineering Survey Data	E-3	E-7
III.	Civil Engineering Survey Data	E-4	E-18
IV.	Support Data	E-5	E-24

I. PRE-SITE SURVEY DATA

A. GENERAL SURVEY DATA

The following data is to be on hand and available to the survey team prior to their departure for the field. When at al possible, marked maps and plats will be furnished which indicate proposed sites, antenna bearings, radiation hazard area, and horizontal profile constructed from map studies.

1. Name of Project ____________________
2. Task Number ____________________
3. Site Name ____________________
4. Location of Site ____________________
5. Owner ____________________
6. Date of Survey ____________________
7. Survey Party Members:

	Name	Affiliation
a.	____________	____________
b.	____________	____________
c.	____________	____________
d.	____________	____________
e.	____________	____________
f.	____________	____________
g.	____________	____________
h.	____________	____________
i.	____________	____________
j.	____________	____________
k.	____________	____________
l.	____________	____________

8. Description of coordinates of established geographic points in the area to be surveyed and the bearing and distance from these points to the proposed site. ____________________
____
____
____
____

9. Latitude ____________ Longitude ____________ Elevation ____________
(Obtain latitude, longitude, and elevation from map study)

10. Code Designation ____________________
11. Type of Station ____________________
12. Required Area in Acres ____________________
13. Alternate Site Name ____________________
14. Description of coordinates of established geographic points in the area to be surveyed and the bearing and distance from these points to the proposed alternate site. ____________________
____
15. Latitude ____________ Longitude ____________ Elevation ____________
(Obtain latitude, longitude, and elevation from map study)

AIAA620

Figure E-2. Pre-Site Survey Data (Sheet 1 of 3)

B. TABLE OF MAPS AND PLATS FURNISHED COMPANY OR ACQUIRED BY SURVEY TEAMS

1. Title____
   Descriptive name of map
   a. Map Series______________________________
   b. Type___________________________________
      Geographic, Geodetic, Topographic, Profile, Plot, etc.
   c. Territory_______________________________
   d. Source_________________________________
   e. Scale____________________ Date____________
   f. Special Data (Plot size, antenna bearing, etc.)____________

2. Title____
   Descriptive name of map
   a. Map Series______________________________
   b. Type___________________________________
      Geographic, Geodetic, Topographic, Profile, Plot, etc.
   c. Territory_______________________________
   d. Source_________________________________
   e. Scale____________________ Date____________
   f. Special Data (Plot size, antenna bearing, etc.)____________

3. Title____
   Descriptive name of map
   a. Map Series______________________________
   b. Type___________________________________
      Geographic, Geodetic, Topographic, Profile, Plot, etc.
   c. Territory_______________________________
   d. Source_________________________________
   e. Scale____________________ Date____________
   f. Special Data (Plot size, antenna bearing, etc.)____________

4. Title____
   Descriptive name of map
   a. Map Series______________________________
   b. Type___________________________________
      Geographic, Geodetic, Topographic, Profile, Plot, etc.
   c. Territory_______________________________
   d. Source_________________________________
   e. Scale____________________ Date____________
   f. Special Data (Plot size, antenna bearing, etc.)____________

AIAA621

Figure E-2. Pre-Site Survey Data (Sheet 2 of 3)

C. ENGINEERING DESIGN DATA

1. Anticipated Frequency____________________MHz
2. Proposed Transmitter Power____________________kw
3. Antenna Size________________diameter in feet
4. Tower Height________________feet
5. Radiation Hazard Zone________________feet in front of antenna
6. Approximate Layout of Fixed Plant________________
7. Other Pertinent Data________________

D. IMPORT AND CUSTOMS REQUIREMENTS

1. Bills of Lading Required Yes________ No________
2. Consular Invoices Required Yes________ No________
3. Gross Weights Required Yes________ No________
4. Net Weights Required Yes________ No________
5. Special Classifications (Describe special classifications required by types of materials, countries of origin, processing, references to import classifications, etc.)________
6. Duties (List only fees to be paid by NAVELEX or its contractors)
7. Import License Requirements (List only those pertaining to the NAVELEX and its contractors)
   a. Title and date of regulations________________
   b. Source from which regulations may be obtained________________
   c. Summary of regulations________________

AIAA 622

Figure E-2. Pre-Site Survey Data (Sheet 3 of 3)

The objective of this survey is to determine the radio horizon, that is, the minimum angle of take-off of the radio beam above or below the horizontal. Line-of-sight requires that the center of the beam be above all obstructions from one station to the next. For tropo, it is highly desirable to have a negative take-off angle, with a maximum of $+1^{\circ}$ being the usual limit.

With this in mind, the transit is set in position at the selected antenna site, and the vertical angle, above or below the horizon, of all obstructions for 360° of azimuth, are plotted on the polar coordinate paper (included in this appendix) as indicated in the following instructions. Distances to the obstacles are not required.

o Horizon Profile Requirements

a. Shall be plotted on polar coordinate graph paper
b. Shall be plotted with respect to true north
c. Shall include bearing to magnetic north
d. Shall include azimuth bearing to adjacent stations
e. Elevations shall be plotted to the smallest direct reading of the instruments used at ten degree increments of azimuth except on the path to adjacent stations where elevation increments shall be at least six minutes at one-degree increments for five degrees on either side of the true bearing of the adjacent stations. Where abrupt changes occur within increments readings are to be made to reflect this change.

o Path Profile for Line-of-Sight Site. The number and accuracy of measurements required to establish a meaningful path profile are matters of good engineering judgment. In the event that highly accurate maps are available from which graze point and Fresnel Zone interference points can be scaled, it is necessary only to establish accurate path clearance optically. Where optical sightings are not feasible, or when accurate maps of the area under investigation are not available, the engineer must determine the altitude of the adjacent sites and all intervening heights which could affect the transmission characteristics of the path. In either case a profile graph of the proposed path shall be included in the data obtained.

o Path Profile for Tropospheric Scatter Sites. The distance between tropospheric scatter sites makes it impractical for site survey teams to field-plot path profiles between stations. Such profiles are best constructed from engineering map studies. However, it is desirable that the terrain adjacent to the site be compared to the profile provided by the engineering study. Minimum requirements are elevation of site and angles to visible obstructions along the path. Notations should be made on the profile where deviations are noted.

In the event that a site (other than the one selected by the map study) is surveyed, a profile graph of the new path must be constructed.

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Figure E-3. Electronic Engineering Survey Data (Sheet 1 of 11)

As in surveying a line-of-sight site, engineering judgment dictates the detail required for the profile graph. Generally speaking, all heights masked from the observer's view along the proposed path by adjacent heights lose their significance. In flat or rolling terrain, heights protruding six minutes above the theoretical earth curvature to a distance of thirty miles are of interest.

o Use of Path Profile Chart. A path profile chart is used in the following manner:

a. The path route is established.

b. The elevations of all high points along the path are determined.

c. The distance from the selected site to the obstruction is calculated. (Usually good topographic maps will give results of sufficient accuracy).

d. These elevations and distances are plotted on the profile chart.

e. Horizon (tangential) lines are constructed on the chart, from each plotted site, to establish line-of-sight without obstructions.

Map elevations should not be used in areas of tall trees or other obstructions that extend above the indicated map elevation. The elevation of the top of the highest obstruction should be plotted.

A blank profile chart is provided in this manual in the event that a profile must be constructed in the field. In order to provide the maximum flexibility for using the charts, a graph has been provided for selecting the proper scales. The examples below illustrate the use of these charts.

o Example. Assume sites are approximately 40 miles apart. On scale 1-a at '40 miles', read elevation opposite on scale 1-b '1600 ft.'. Since this represents full-scale elevation on the profile chart, each major elevation division on the profile chart will then be marked in increments of 160 ft. The major division of the "Distance Between Stations" scale on the profile chart will be marked in increments of 2 miles, i.e. 40 miles is 20 divisions.

o Example 2. Assume that the available maps are scaled in kilometers and that the sites are approximately 100 kilometers apart. Step A: On scale 3-a, opposite 100 kilometers, read 62.2 miles on scale 3-b. Step B: Opposite 62.2 miles on 1-a, read 3830 feet on 1-b. Step C: Opposite 3.83 thousand feet on 5-b, read 1150 meters on scale 5-a. The profile chart can now be marked off with a full horizontal scale (distance between stations) of 100 kilometers, and a full vertical scale (height above sea level) of 1150 meters with increments of 115 meters.

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Figure E-3. Electronic Engineering Survey Data (Sheet 2 of 11)

1. Horizon Profile Data

a. Azimuth bearing of Magnetic North ______________________
b. Azimuth bearing of adjacent station East (ASE) ______________________
c. Azimuth bearing of adjacent station West (ASW) ______________________
d. Instrument data

Instrument type ______________
Instrument serial no. ______________ Date of Last Calibration ________

e. Horizon data

Az.	Elev. of Horizon	Az.	Elev. of Horizon	Az.	Elev. of Horizon
0	________	130	________	250	________
10	________	140	________	260	________
20	________	150	________	270	________
30	________	160	________	280	________
40	________	170	________	290	________
50	________	180	________	300	________
60	________	190	________	310	________
70	________	200	________	320	________
80	________	210	________	330	________
90	________	220	________	340	________
100	________	230	________	350	________
120	________	240	________		

Az.	Elev. of Horizon	Az.	Elev. of Horizon	Az.	Elev. of Horizon	Az.	Elev. of Horizon
ASE	________	ASE	________	ASW	________	ASW	________
-5	________	+1	________	-5	________	+1	________
-4	________	+2	________	-4	________	+2	________
-3	________	+3	________	-3	________	+3	________
-2	________	+4	________	-2	________	+4	________
-1	________	+5	________	-1	________	+5	________

(This data should be plotted on the polar chart.)

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Figure E-3. Electronic Engineering Survey Data (Sheet 3 of 11)

PROFILE CHART SCALES

THESE CONVERSION NOMOGRAPHS ARE TO BE USED TO ESTABLISH APPROPRIATE SCALES ON FOUR-THIRDS EARTH'S RADIUS GRAPH PAPER FOR CONSTRUCTING RADIO TRANSMISSION PROFILE CHARTS.

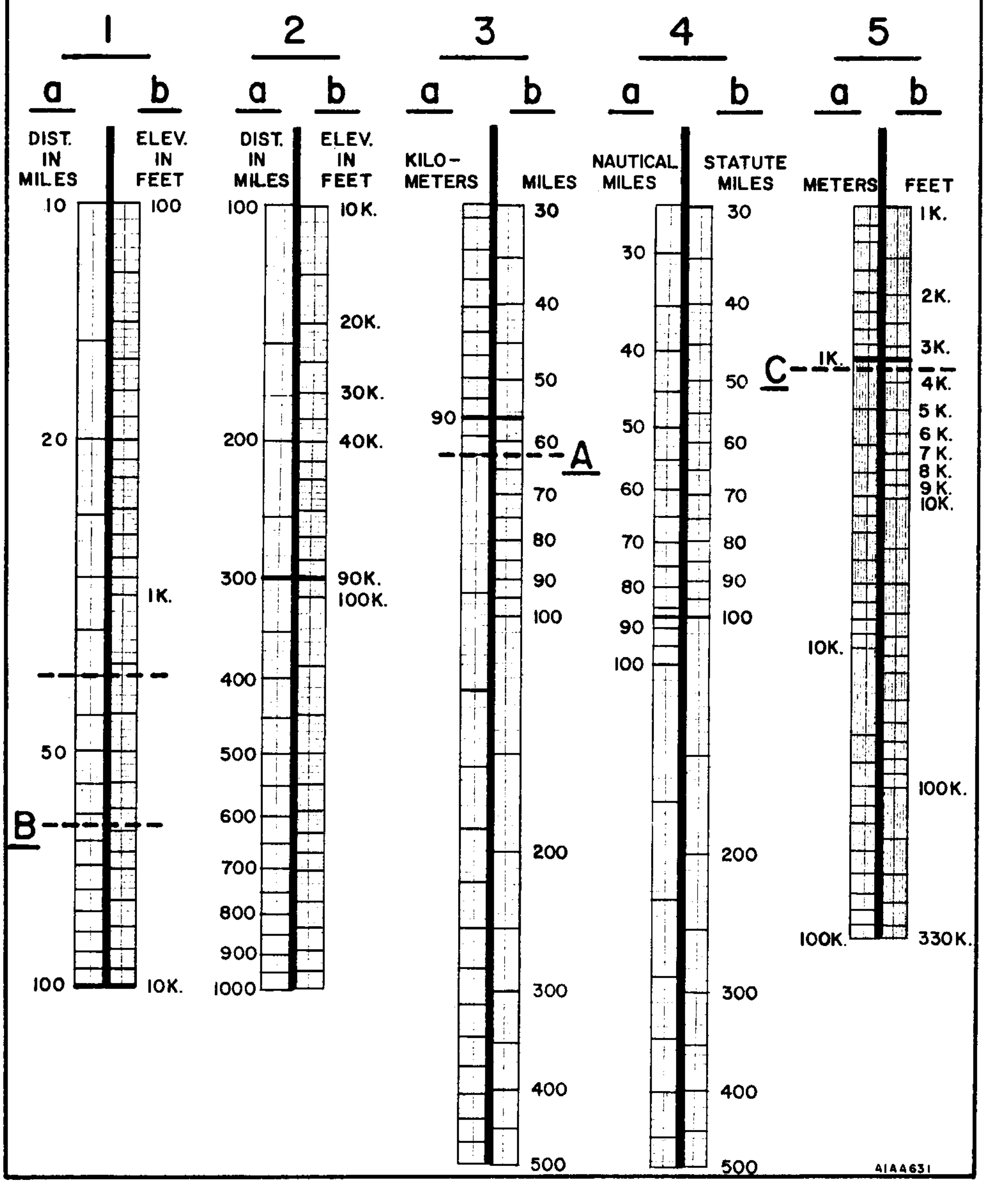

Figure E-3. Electronic Engineering Survey Data (Sheet 4 of 11)

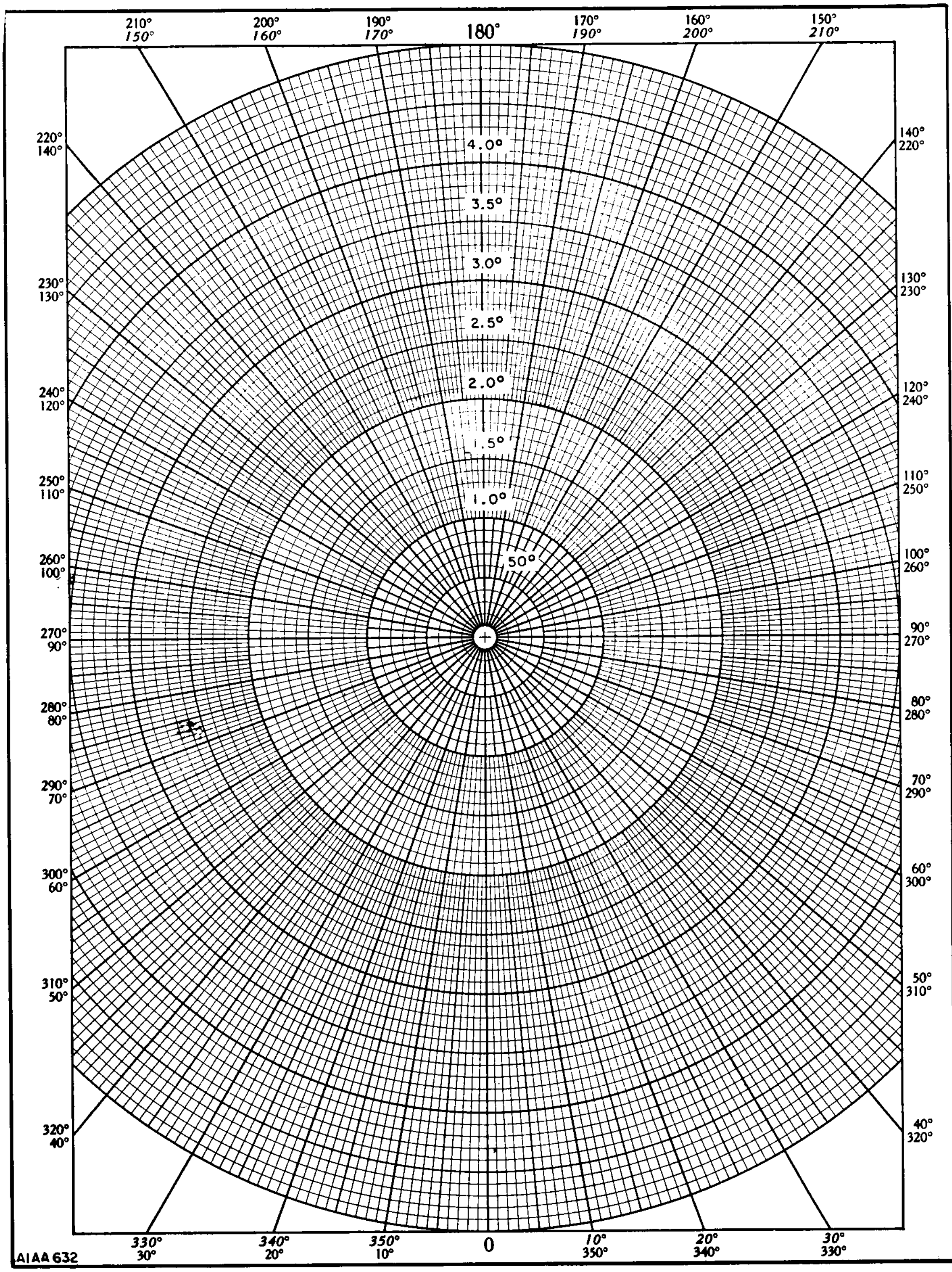

Figure E-3. Electronic Engineering Survey Data (Sheet 5 of 11)

B. PHOTOGRAPHS

The purpose of photographing the site is to visually display a 360° panoramic view of the forward area and the area within the site boundary. Care should be used in photographing the panoramic view in order that individual photos can be matched to display 360° of azimuth. One satisfactory method involves fastening a chalk-board (on which are written the pertinent facts of site and bearing) to the stadia rod which is targeted for horizontal level. Obviously, the task will be simplified if the camera (preferably Polaroid) is mounted on the transit in such a manner that azimuth adjustments can be accurately and simply made. A cable release for the camera is essential.

The number of shots required to complete a 360° arc of the site is dependent upon the camera used and should be determined before the photographs are made. Approximate vertical angles of obstructions and other useful information can be derived from photographs taken in this manner.

1. Photograph Data (Every effort should be made to obtain aerial photographs of the site and vicinity. Photographs covering 360° of azimuth from near the center of the site must be included.)

a. Title__________
   1. Source__________
   2. Date__________
   3. Availability__________
   4. Shows__________

b. Title__________
   1. Source__________
   2. Date__________
   3. Availability__________
   4. Shows__________

c. Title__________
   1. Source__________
   2. Date__________
   3. Availability__________
   4. Shows__________

d. Title__________
   1. Source__________
   2. Date__________
   3. Availability__________
   4. Shows__________

(Add Additional Sheets If Necessary)

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Figure E-3. Electronic Engineering Survey Data (Sheet 6 of 11)

C. RADIO INTERFERENCE DATA

1. Radio or Radar Transmitters
   a. Distance ________________ miles
   b. Direction ________________ degrees
   c. Frequency ________________ kHz
   d. Power ________________ kW
   e. Antenna pattern - attach radiation pattern when critical.

2. Radio Receiving Stations
   a. Distance ________________ miles
   b. Direction ________________ degrees
   c. Receiving frequencies ________________ kHz ________________ kHz
      (attach sheets if required)
   d. Type of station and operation organization
      ____

3. Distance from Roads or Highways in Front of Antenna ________________

4. Distance from Power Lines ________________

5. Distance from Ordnance Areas ________________

6. Distance to Airports ________________

7. Existence of Airways or Traffic Patterns in Antenna Quadrant ________________

8. Average Number of Flights per Day ________________

9. Type of Aircraft
   Preponderantly jet ________________
   Preponderantly propeller ________________
   Commercial airline ________________
   Private light plane ________________

10. Anticipated Industrial Noise Level ________________
    High ________________ Low ________________

11. Radiation Hazard Zone (zone determined from engineering design)
    Occupied dwelling ________________ Thoroughfare ________________
    Live-stock grazing area ________________

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Figure E-3. Electronic Engineering Survey Data (Sheet 7 of 11)

D. UTILITIES

1. Electric Power

a. Primary power available________________________________

b. Operating company________________________________

c. Address________________________________

____

d. Distance to nearest transformer or substation where take-off of usable power can be effected________________

e. Equipment power plan drawing no. ____________(where applicable)

Standby available Yes____________ No________________

f. Other services (light, heat, etc.)

Standby available Yes____________ No________________

SERVICE	VOLTS	AMPS	PHASE	FREQUENCY

g. Equipment power characteristics

Regulation____________% Primary__________% Standby________

h. Power outages____________________hours yearly

i. Is there adequate power capacity to accommodate site load?

Yes____________ No____________

j. Joint usage of pole lines or underground cable Yes______No________

k. Estimated cost of power line construction from "d" above to site substation________________________________

show calculations and source of cost data

____

____

2. Telephone Service

a. Distance to nearest telephone service connection________________miles

b. Type of line construction Open wire________________

Cable________________

Number of pairs available________________

c. Estimated cost of line extension $________________

d. Remarks________________________________

____

____

____

____

____

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Figure E-3. Electronic Engineering Survey Data (Sheet 8 of 11)

E. PROPERTY OWNERSHIP

1. Private__________________ Government_____________________ (Check one)
2. Name of Owner(s) (if privately owned)____
3. Description of All Improvements on Land Areas Selected (including buildings and structures on property. Identify any problems of riparian or mineral rights).

NOTE

The proposed purchase or lease of property by the Federal Government is considered classified data. Survey party personnel shall not inquire into the availability or cost of property nor shall they divulge the suitability of the site to indigenous personnel. Inquiries and negotiations for real estate shall be handled by personnel designated by the interested agency. When specifically requested by NAVELEX, approximate lease or purchase prices may be obtained from the District or Division Corps of Engineers. Concurrence of the site selection should also be obtained from the U. S. Military Commander to prevent a conflict of interest in siting.

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Figure E-3. Electronic Engineering Survey Data (Sheet 9 of 11)

F. WEATHER DATA

1. Location of Recording Weather Station ______________________
city - town

2. Recording Station Elevation ______________________

3. Recording Station Distance from Survey Site ______________________

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
4. Rain Fall (inches) Max. recorded ____/____/____ inch/month/year												
5. Snow Fall (inches) Max. recorded ____/____/____ inch/month/year												
6. Humidity (%) Mean ave. May/Sept. ______ Oct./Apr. ______												
7. Temperature Max. ______ Mean Ave. ______ May/Sept. ______ Oct./Apr. ______	max / min.											
8. Wind Velocity (mph Max. ______ Direction ______	mph / dir.											

9. Presence of Permafrost Yes ________ No ________

10. Average Frost Line Depth Winter ________ Summer ________

11. Location of Nearest Site Making Upper Air Sounding ______________________

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Figure E-3. Electronic Engineering Survey Data (Sheet 10 of 11)

G. REMARKS AND PERTINENT DATA NOT COVERED BY PRECEDING SHEETS

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Figure E-3. Electronic Engineering Survey Data (Sheet 11 of 11)

III. CIVIL ENGINEERING SURVEY DATA

A. SITE CONDITIONS

1. Topography

a. Highest elevation (above sea level)__________feet

b. Lowest elevation (above sea level)__________feet

2. Terrain

a. Heavy vegetation______Light vegetation______None______

b. Heavily wooded______Lightly wooded______None______

c. Steep slopes______Gentle slopes______Rolling______Flat______

d. Vegetation to be removed: Heavy______Light______None______

e. Remarks______

3. Soil Data

a. Rock______Clay______Gravel______Sand______Silt______Other______

b. Water table (feet below mean surface of site) High______Low______

4. Drainage

a. Surface characteristics______

b. Sub-surface characteristics______

5. Corrosion and Erosion

Salt air______Sand storms______Dust storms______Ice______Tornados______Hurricanes______Monsoons______Tidal wave______Chemical fumes______Earthquakes______Others______

6. Water

a. Drinking water source: Wells______Piped______Springs______Rain______Muncipal______Government______Private______Springs______Rain______

b. Name and address of supplier______

c. If existing wells, Capacity______(gals/min.) Depth______feet

d. If existing pipe lines, Pressure______psi Quantity______cfm

e. Distance to supply______miles

AIAA 634 (A)

Figure E-4. Civil Engineering Survey Data (Sheet 1 of 6)

f. Remarks (Reliability, etc.)__________

7. Other Water Available
   a. Lake_____ River_____ Stream_____ None_____ Other_____
   b. Pumping required Yes_____ No_____ Approximate head in feet_____
   c. Potable Yes_____ No_____
   d. Distance to supply__________ miles
8. Sanitary Facilities
   a. Existing Yes_____ No_____
   b. Type: Septic_____ Treated_____ Open drain_____
   c. None_____ Other__________
   d. If treated, name and address of owner__________
   e. Size of main__________ inches diameter
   f. Capacity of main__________ cfm
   g. Distance to main__________ miles
   h. Pumping station required Yes_____ No_____
   i. Distance to probable outfall for a new sewer__________ miles
   j. Pumping station required Yes_____ No_____ Approximate head feet_____
      How many_____
9. Storm Sewers
   a. Existing_____ Required_____
10. Natural Drainage
    a. Good_____ Poor_____
11. Method of Garbage Disposal Required__________
12. Method of Rubbish Disposal Required__________
13. Remarks__________

B. <u>EXISTING SITE FEATURES</u>

1. Towers
   a. Type and number__________
   b. Maximum heights__________

AIAA 634 (B)

Figure E-4. Civil Engineering Survey Data (Sheet 2 of 6)

2. Fence Enclosures
   a. Owner ____________________
   b. Type and heights ____________________
   c. Identification ____________________
3. Buildings
   a. Type ____________________
   ____
   ____
   b. Use ____________________
   ____
4. Other Projections or Obstructions
   ____
   ____
   ____
   ____
   ____
5. Can existing towers be utilized
   a. Modification required ____________________
   ____
   ____
   ____
   ____
6. Remarks ____________________
   ____
   ____
   ____
   ____

C. ROADS

1. Highways
   a. Distance from site to main highway ____________________ miles
   b. Classification: Paved highway __________ Rural __________ Other __________
   c. Types: Concrete __________ Asphalt __________ Dirt __________ Other __________
   d. Minimum widths ____________________ feet

AIAA 634 (C)

Figure E-4. Civil Engineering Survey Data (Sheet 3 of 6)

e. Paved shoulders Yes__________ No__________

f. Maximum grades______________________________________ percent

g. Bridge or tunnel limits: Load__________ Tons/axle Clearance__________ feet

Total width______________ feet Lanes______________

h. Reliability: Months of year usable__________

Improvements required______________________________________

____

2. Existing Access Roads (From site to highway)

a. Distance to nearest existing road______________ miles

b. Type: Paved__________ Dirt__________ Rock__________

Width______________ feet Capacity: Heavy__________ Light__________

c. Months of year usable______________________________________

d. Drainage: Excellent__________ Good__________ Poor__________

e. Improvements required______________________________________

____

3. Construction of New Access Roads (if required)

a. Length______________ miles

b. Type: Paved__________ Dirt__________ Rock__________

Width______________ feet Capacity: Heavy__________ Light__________

Maximum grade______________ percent

c. Culverts required: Quantity__________ Average Fill______________ in yards

Bridges required: Quantity__________ Average Length______________ feet

d. Construction period

Summer months only______________________________________

Year round______________________________________

4. Cable Railways Yes__________ No__________

a. Capacity Cubic feet__________ Weight__________

5. Remarks____

____

____

____

____

____

AIAA634 (D)

Figure E-4. Civil Engineering Survey Data (Sheet 4 of 6)

D. LOCAL CAPABILITIES

1. Local Contractors

a. Obtain local contractor's directory, if feasible Yes_____ No_____

b. Nearest source of contractors_____

c. Distance from site_____ miles

d. Names and addresses_____

_____

e. Type: Heavy_____ Light_____ Building_____

f. Capabilities: 0 - $100,000_____ $100,000 and up_____

g. Construction equipment available

Cranes_____ Bulldozers_____ Trucks_____ None_____ Others_____

2. Engineers and Surveyors

a. Obtain more than one, if available, and evaluate on separate sheets.

b. Nearest source and name and address_____

_____

_____

c. Qualifications: 1st Order_____ Lower_____

3. Labor Supply

a. Unlimited skilled_____ Unlimited unskilled_____ None_____

Limited skilled_____ Limited unskilled_____

b. Union_____ Non-union_____

c. Rates: Skilled $_____/hr. Unskilled $_____/hr.

Overtime rates_____

4. Fuel

a. Type available: Gas_____ Petroleum_____ None_____ Other_____

b. Supply: Local_____ Haul_____ Piped_____ Other_____

c. Method of hauling_____

_____

_____

AIAA634 (3)

Figure E-4. Civil Engineering Survey Data (Sheet 5 of 6)

5. Materials Available

ITEMS	PLENTIFUL	SCARCE	NONE	COST	SOURCE
Sand and Gravel					
Rock					
Ready-mix Concrete					
Cement					
Steel					
Lumber					
Miscellaneous Hardware					
Crushing Facilities					

6. Remarks

4IAA634 (F)

Figure E-4. Civil Engineering Survey Data (Sheet 6 of 6)

IV. SUPPORT DATA

A. TRANSPORTATION

1. Waterway

a. Open sea _____ River _____ Canal _____ Lake _____ Bay _____ None _____ Other _____

____

b. Channel depths: Daily high water _____ feet Daily low water _____ feet Mean yearly high water _____ feet Mean yearly low water _____ feet

c. Name of shipping company ______________________

d. Docking facilities. Excellent _____ Good _____ Poor _____ None _____

e. Distance from site to dock. Air miles _____ Road miles _____

f. Reliability: Months of year usable _____

g. Distance from site to waterway. Air miles _____ Road miles _____

h. Remarks ______________________

____

2. Railway

a. Existing railway facilities

Government _____ Municipal _____ Private _____ None _____

b. Name and address of nearest terminal ______________________

____

c. Passenger ____________ Freight ____________

d. Distance to terminal: Air miles _________ Road miles _________

e. Distance to tracks: Air miles _________ Road miles _________

f. Regular passenger runs: Yes _____ No _____

g. How often? ______________________

h. Type rails: Standard gauge _________ Other _________

i. Reliability: Months of year usable ______________________

j. Remarks ______________________

____

3. Airway

a. Existing airports

Government _________ Municipal _________ Private _________ None _________

b. Name and address ______________________

____

AIAA 635 (A)

Figure E-5. Support Data (Sheet 1 of 5)

c. Type of air strip: Concrete _____ Asphalt _____ Dirt _____ Ice _____ Other _________

d. Length of runway __________ feet

e. Maximum size planes accommodated ________________________

f. Terminal facilities: Passenger _____ Freight _____ Radar control _____ None _______

g. Maintenance and fueling facilities ____

____

h. Reliability: Months of year usable ____

i. Distance from site: Air miles __________ Road miles __________

j. Remarks ____

____

4. Passenger Service

a. Scheduled bus service _____ Taxi _____ None _____ Other _____

b. Distance to nearest terminal __________ miles

c. Remarks ____

____

5. Commercial Trucking

a. Availability: Unlimited __________ Limited __________ None __________

b. Nearest terminal __________________________________ Miles _________

c. Name and address of companies ____

____

d. Remarks ____

____

B. IMPORT AND CUSTOMS REGULATIONS (Foreign Countries Only)

Include here notes on special problems or procedures which were not covered under this heading in Part I, Pre-survey Data.

____

____

____

____

____

____

____

____

____

4IAA635(8)

Figure E-5. Support Data (Sheet 2 of 5)

C. SUPPORT CONSIDERATIONS

1. Living Standards: High _________ Modest _________ Poor _________

2. Housing

a. Hotels: Plentiful _________ Scarce _________ None _________

Accommodations: Excellent _________ Adequate _________ Poor _________

Lodging, average price per day _________

Food, average price per day _________

b. Private Homes: Plentiful _________ Scarce _________ None _________

Accommodations: Excellent _________ Adequate _________ Poor _________

Average price per month $ _________

3. Food Supply (USA - N/A)

a. Local restaurants: Yes _____ No _____

Prices compared to U.S. % Higher _____ Same _____ % Lower _____

b. Local merchants: Plentiful _________ Scarce _________ None _________

Prices compared to U.S.: % Higher _________ Same _________ % Lower _________

c. Import Supplies: Yes _____ No _____

From where: ______________________________

____

d. Remarks: ______________________________

____

____

____

4. Banking

a. Nearest large bank _________ air miles _________ road miles _________

b. Name and address: ______________________________

____

c. Local banks: Plentiful _________ Scarce _________ None _________

5. Clothing

a. Local merchants: Plentiful _________ Scarce _________ None _________

b. Prices compared to U.S.: % Higher _________ Same _________ None _________

c. Import: Yes _____ No _____

d. From where? ______________________________

e. Remarks: ______________________________

____

AIAA635 (C)

Figure E-5. Support Data (Sheet 3 of 5)

6. Recreation

   a. Types available: Government _____ Municipal _____ Private _____

   b. Describe: ____

   ____

   ____

7. Medical facilities

   a. Nearest hospital __________ Air miles __________ Road miles

   b. Name and address: ____

   ____

   c. Dispensary facilities or doctors: Yes _____ No _____

   d. Distance: __________ Air miles __________ Road miles

   e. Remarks: ____

   ____

8. Schools

   a. Existing: Grade School __________ High Loaf __________ College __________

   b. Private tutors __________________ None __________________

   c. Distance __________________

   d. Standards: Excellent _____ Satisfactory _____ Poor _____

   e. Sponsor: Government _____ Private _____ Municipal _____

   f. Name of Sponsor: ____

9. Probable Support from a U.S. Military Base for Supplies and Services

   a. Site ____

   b. Type ____

   c. Location ____

   d. Type Support

Type Support	Support Base
Automobile maintenance: Field depot ____________	____________
Clothing equipment and repair ____________	____________
Clothing supply ____________	____________
Commissary ____________	____________
Communications & electronics supply ____________	____________
Dry cleaning ____________	____________
Heating fuel ____________	____________
Laundry ____________	____________
Maintenance: Radar, Comm. ____________	____________
Mortuary ____________	____________

AIAA 635 (D)

Figure E-5. Support Data (Sheet 4 of 5)

P. O. L. ______________________ ______________

Post exchange ______________________ ______________

Purchasing & contracting ______________________ ______________

Rations: Field ______________________ ______________

Repair & utilities ______________________ ______________

Salvage ______________________ ______________

Shoe Repair ______________________ ______________

T/A Supply ______________________ ______________

TO&E Supply ______________________ ______________

Technical publications ______________________ ______________

10. Population Data

a. Distance to nearest large city __________ miles

b. Name of nearest large city ______________________

c. Population of nearest large city __________

d. Distance to nearest town __________ miles

e. Name of nearest town ______________________

f. Population of nearest town ______________

g. Prevailing nationality of population ______________________

h. Principal language spoken ______________________

D. REMARKS AND PERTINENT DATA NOT COVERED BY PRECEDING SHEETS

AIAA635(E)

Figure E-5. Support Data (Sheet 5 of 5)

APPENDIX F

TROPOSPHERIC SCATTER EQUATIONS

This appendix contains appropriate forms to be used in reference to a Feasibility and System Design Study.

MICROWAVE PATH DATA CALCULATIONS

1	SITE				
2	LATITUDE				
3	LONGITUDE				
4	ELEVATION	Ft.			
5	TOWER HEIGHT	Ft.			
6	TOWER TYPE				
7	AZIMUTH FROM TRUE NORTH.				
8	PATH LENGTH	Mi.			
9	PATH ATTENUATION	dB			
10	RIGID WAVEGUIDE	Ft.			
11	FLEXIBLE WAVEGUIDE	Ft.			
12	WAVEGUIDE LOSS	dB			
13	CONNECTOR LOSS	dB			
14	CIRCULATOR OR HYBRID LOSS	dB			
15	RADOME LOSS, TYPE*	dB			
16	NEAR FIELD LOSS	dB			
17	CLOSE COUPLING LOSS (DOUBLE PASS.)	dB			
18	TOTAL FIXED LOSSES	dB			
19	TOTAL LOSSES	dB			
20	PARABOLA HEIGHT	Ft.			
21	PARABOLA DIAMETER	Ft.			
22	REFLECTOR HEIGHT	Ft.			
23	REFLECTOR SIZE, TYPE	Ft.			
24	PARABOLA - REFLECTOR SEP.	Ft.			
25	NEAR FIELD GAIN	dB			
26	ANTENNA SYSTEM GAIN	dB			
27	TOTAL GAINS	dB			
28	NET PATH LOSS	dB			
29	TRANSMITTER POWER	dBm			
30	MED. RECEIVED POWER (± 2 dB)	dBm			
31	RECEIVER NOISE THRESHOLD	dBm			
32	THEORECTICAL RF C/N RATIO	dB			
33	FM IMP. THRESHOLD (dBa)	dBm			
34	FADE MARGIN (To FM Imp. Thresh.)	dB			
35	RELIABILITY SPACING†	%			
36	POLARIZATION ‡				
37	PROFILE NUMBER				

‡ { V - Vertical, H - Horizontal }

† { F - Frequency Diversity, S - Space Diversity } N - Non-Diversity Q - Space And Frequency Diversity

(Reliability Figures Are For Rayleigh Distributed Fading Only)

* { U - Unheated, H Heated }

CUSTOMER ______________________

PROJECT NO. __________ FREQUENCY ______________________

SYSTEM ______________________ EQUIPMENT ______________

LOADING __________ dBm0 (__________ CHANNELS OF ______________)

AIAA 229

DATE ______________ ENGINEER ______________________ Sheet ____ of ____

Figure F-1. Microwave Path Data Calculation Sheet

PARAMETER	
DISTANCE d, km	
SCATTER ANGLE θ, MILLIRADIANS	
θ d RADIANS	
ATTENUATION FUNCTION F(θd) IN dB (FROM FIGURE 4-5)	
30 LOG f IN dB	
−20 LOG d IN dB	
F_o, H, AND A_a CONSIDERED NEGLIGIBLE	
L_{bsr} dB	

$L_{bsr} = 30 \text{ LOG } f - 20 \text{ LOG } d + F(\theta d) - F_o + H_o + A_a$; dB

AIAA 230

Figure F-2. Computation of Long Term Median Transmission Loss Tropospheric Scatter (for) Preliminary Design Purposes)

ANTENNA COUPLING LOSS (SCATTER LOSS)

$S = \frac{\alpha_o}{\beta_o}$

(FROM FIGURE 6-17)

$D_s = d - d_{LT} - d_{LR}$ km

(FROM FIGURE 6-17)

$h_o = \frac{S \; D_s \, \theta}{(1 + S)^2}$ km

THE HALF POWER BEAM WIDTH Ω OF A PARABOLIC ANTENNA IS APPROXIMATELY

$\Omega = \frac{1222}{FB}$ MILLIRADIANS

F = FREQUENCY IN GHz

B = PARABOLA DIAMETER FEET

(FROM FIGURE 6-14)

$\frac{\theta}{\Omega} =$

SCATTER LOSS Lgp

(FROM FIGURE 6-23)

AIAA231

Figure F-3. Antenna Coupling Loss
(Scatter Loss)

$L_{bsr} = 30 \text{ LOG } f - 20 \text{ LOG } D + F(\theta d) - F_o + H_o + A_a$ dB

θd IN RADIANS		
PATH ASYMMETRY $S = \frac{\alpha_o}{\beta_o} =$		
ATTENUATION FUNCTION $F(\theta d)$ IN dB FROM FIGURE 8-6, 7, 8, OR 9		
30 LOG F IN dB =		
− 20 LOG d IN dB =		
$h_o = \frac{S \; d \; \theta}{(1+S)^2}$ IN km		
$r_1 = 41.92 \; \theta f \; h_{te} =$		
$r_2 = 41.92 \; \theta f \; h_{te} =$		
$q = \frac{r_2}{s r_1} =$		
η_s FROM FIGURE 6-22		
$H_o = \frac{H_o(r_1) + H_o(r_2)}{2} + \Delta H_o$ IN dB $H_o(r_1)$ & $H_o(r_2)$ FROM FIGURE 8-10 ; ΔH_o FROM FIGURE 8-11		
$D_s = d - d_{Lt} - d_{Lr}$ IN km		
$L_1 = \frac{S \; D_s \theta}{(1+S)^2}$ IN km		
$F_o = 1.086 \left(\frac{\eta_s}{h_o}\right)(h_o - h_1 - h_{Lt} - h_{Lr})$ dB		
A_a FROM FIGURE 4-6		
L_{bsr}		

AIAA 232

Figure F-4. Computation of Long Term Median Transmission Loss Tropospheric Scatter (for Design Purposes)

(EXISTING TROPOSCATTER PATH)

$d =$
$a =$

$h_{ts} =$ $h_{Lt} =$ $h_{te} =$ $d_{Lt} =$ $d_{st} =$	$h_{rs} =$ $h_{Lr} =$ $h_{re} =$ $d_{Lr} =$ $d_{sr} =$
$\theta_{et} = \frac{h_{Lt} - h_{ts}}{d_{Lt}} - \frac{d_{Lt}}{2a}$	$\theta_{er} = \frac{h_{Lr} - h_{rs}}{d_{Lr}} - \frac{d_{Lr}}{2a}$
$x = \frac{d}{2a} + \frac{h_{ts} - h_{rs}}{d}$	$y = \frac{d}{2a} - \frac{h_{ts} - h_{rs}}{d}$
$\theta_{ot} = \theta_{et} + \frac{d_{Lt}}{a}$	$\theta_{or} = \theta_{er} + \frac{d_{Lr}}{a}$
$\Delta\alpha \cong$ FROM FIGURES 6-18 AND 6-19	$\Delta\beta \cong$ FROM FIGURES 6-18 AND 6-19
$\alpha_o = \theta_{et} + x + \Delta\alpha_o$	$\beta_o = \theta_{er} + y + \Delta\beta_o$
$\theta_{oo} = \theta = \alpha_o + \beta_o$	AIAA 233

Figure F-5. Tropospheric Path Angle Computations (Milliradians)

APPENDIX G

COMPUTER INTERFERENCE/FREQUENCY ANALYSIS

This appendix contains a basic computer model which may be used in studying new frequency allocation plans and their effects on the existing electromagnetic structure.

This appendix has been reproduced in its entirety from the following document: "Frequency Assignment Techniques for Microwave Systems," Volume I and Volume II. Prepared for: The Federal Communications Commission under Contract No. RC-100900. By: Communications and Systems, Inc., subsidiary of Computer Sciences Corporation. Report No. CSC-70-576, dated August 1970.

APPENDIX X-1. COMPUTER INTERFERENCE MODEL ANALYSIS

1.0 INTRODUCTION

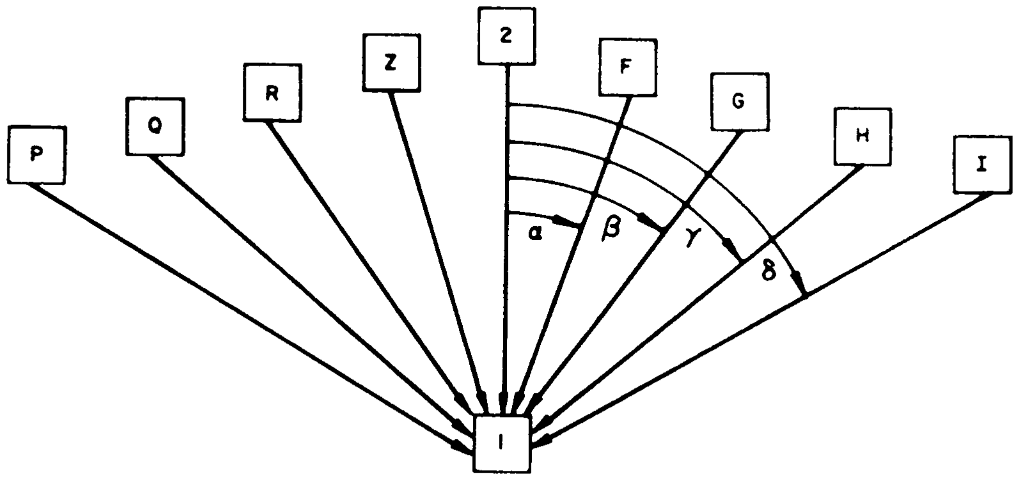
To perform his frequency engineering function the spectrum manager requires a model which analyzes the electromagnetic environment for him when the deployment of stations and the use of multiple frequencies and equipment types in changing terrains produce a complex situation. Such a model can be made useful for interference prediction, frequency selection, and engineering planning activities.

In interference prediction a model can contribute to understanding the nature of the sources and the susceptibility of the receivers, and therefore can assist in determining what course of action would best eliminate the interference. A model can also be made to select the best set of frequencies to ensure minimum potential interference. Similarly for engineering planning activities, a model can be used to study the effects of proposed new allocation plans, increased user density, increased traffic, etc., on the existing electromagnetic structure.

The model presented herein is a basic one and is not offered as the optimum model for satisfying all the needs of the spectrum manager. It is presented to show that mathematical/computer models can offer the spectrum manager a potentially powerful tool in his work and that, without some such model, the calculations and prediction methods become intractable.

2.0 CONFIGURATION MODEL

The computer model developed herein examines the interference environment for multiple variations of topography, frequency and equipment (transmitter, receiver and antenna) characteristics, and has been applied to several hypothetical microwave link configurations (Figure 1). The configuration of the model is geographically symmetrical and uses Site 1 as the common site for nine links. The topographical symmetry permits examination of the joint effects of several simultaneous variations: in this case azimuthal offset and



MICROWAVE NODE MODEL

FIGURE 1

carrier frequency difference on relative interference levels. The primary link is designated Link 2-1, and is, for this analysis, geographically situated in a direct north-south direction (i.e., from 1 to 2) at an azimuth of 0° 00' 00". Each link has a path length of approximately 26.9 miles and the following azimuths (see Figure 1).

Link	Azimuth
F-1	0° 55' (α)
G-1	1° 50' (β)
H-1	2° 45' (γ)
I-1	4° 35' (δ)
Z-1	359° 05'
R-1	358° 10'
Q-1	357° 15'
P-1	355° 25'

Interference calculations are initially performed using a particular set of parameters. The interference calculations are then repeated with successive variation of these parameters. The resultant output from the computer program shows total interference levels at the receiver(s) at every site as a function of each parameter variation. Details of the computer program are discussed in paragraph 3.0.

The following parameters were chosen for the computer runs performed.

(a) The transmitter frequency at Site 2 always is equal to 6060 MHz.

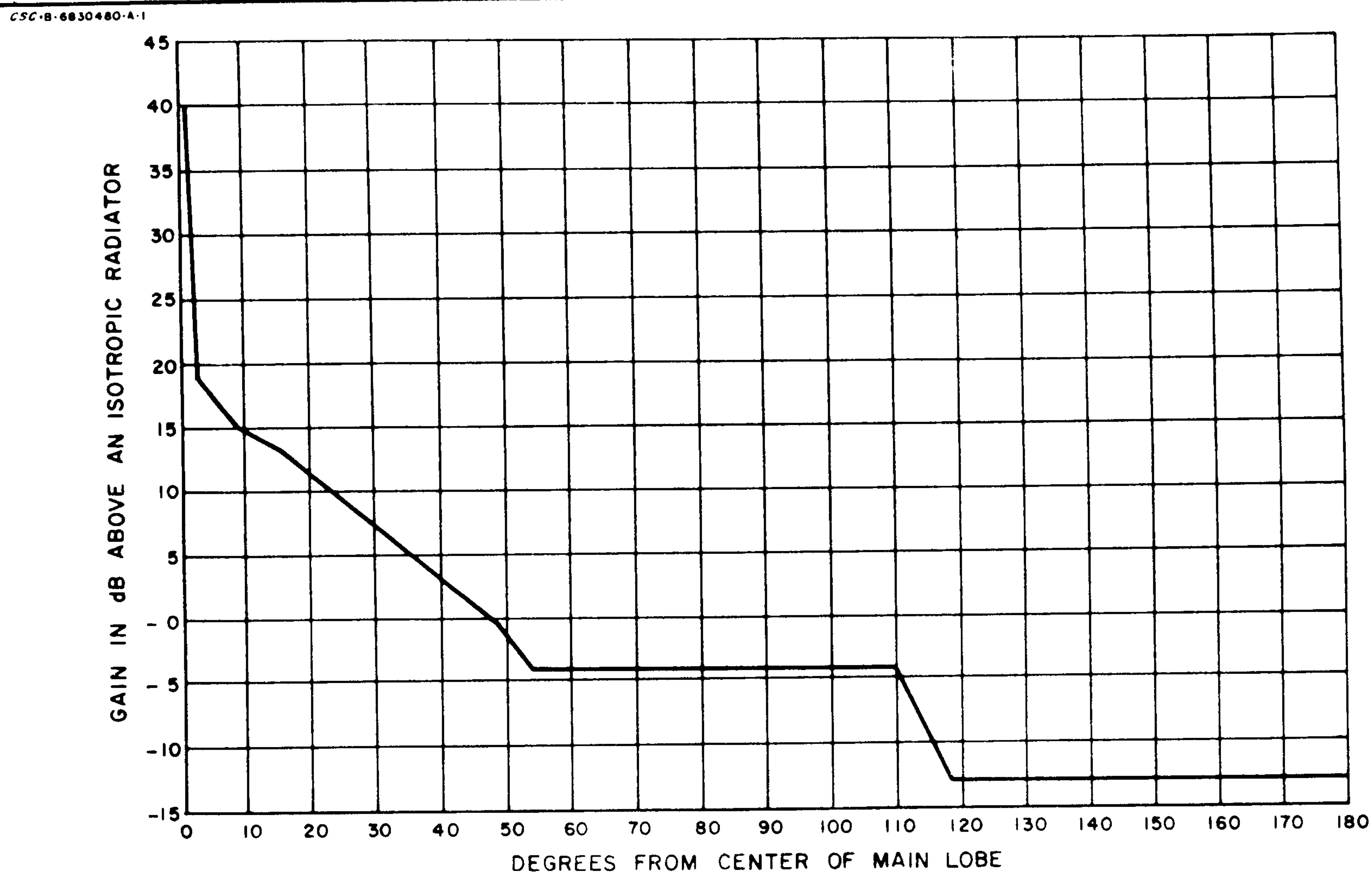
(b) The transmitter frequency at Sites F, G, H and I was chosen as 6060 MHz for run one and as 6040 MHz for run two.

(c) The transmitter frequency at Sites Z, R, Q and P was chosen as 6030 MHz for run one and 6050 MHz for run two.

(d) The frequency stability for both runs was chosen as ±1.8 MHz (i.e., approximately 3×10^{-2} percent).

(e) The transmitted power level for both runs was 5 watts (37.0 dBm) for all transmitters.

(f) The receiver and transmitter antenna patterns assumed for both runs were adapted from the Western Union 8-foot parabolic reflector at 6 GHz, vertically polarized, and are shown in Figure 2.



ANTENNA PATTERN
ADAPTED FROM WU 8 FT. PARABOLIC REFLECTOR AT 6 GHz, VERTICALLY POLARIZED

FIGURE 2

(g) The receiver selectivity curve employed for both runs was adapted from the General Electric TRS-696 receiver (960 VF channels), and is presented in Figure 3.

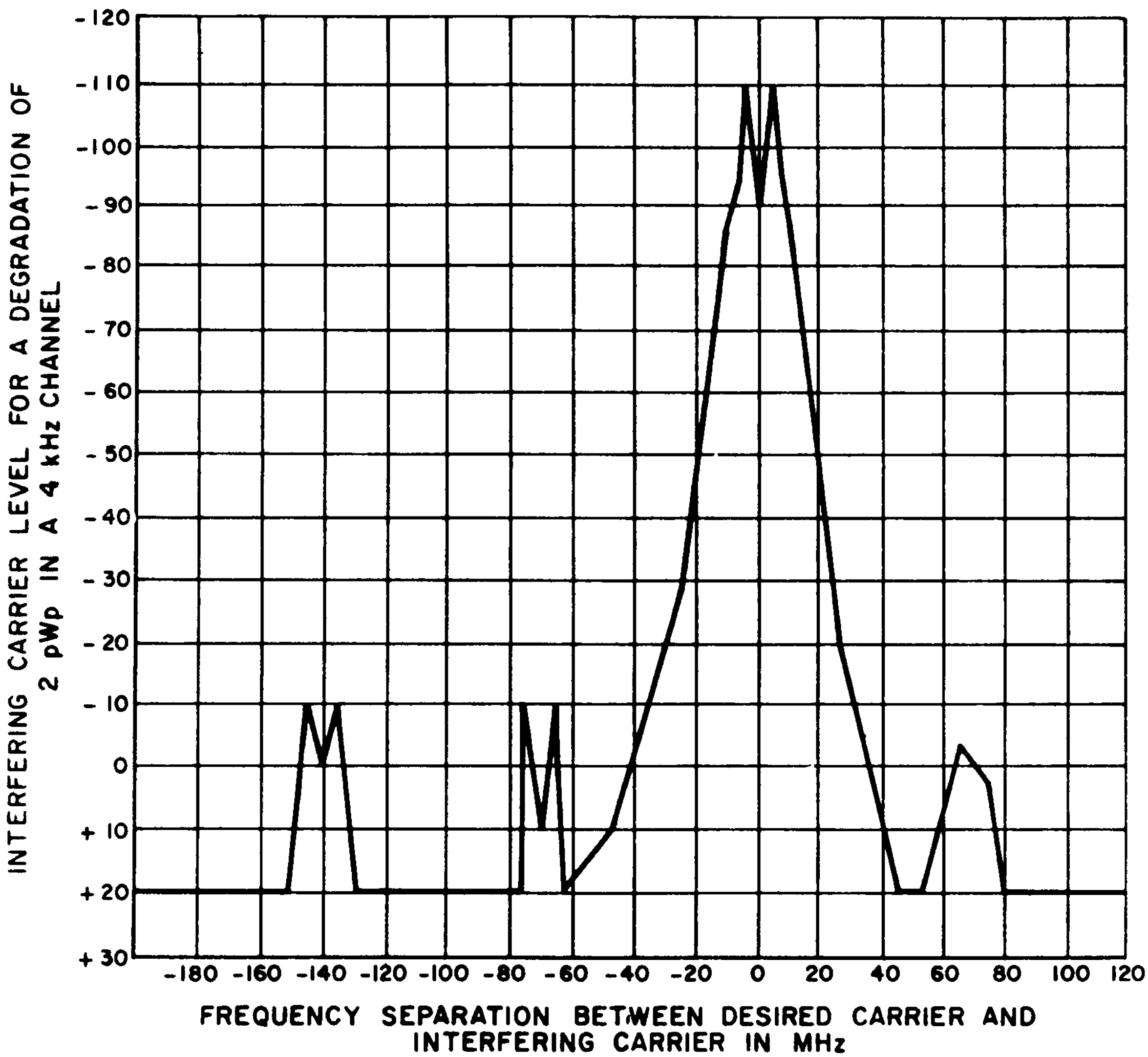
In the particular computer analyses performed, the most important results are the interference levels at the receiver of primary link 2-1 at Site 1, caused by all other secondary link (i.e., F-1, Z-1, G-1, H-1, etc.) transmissions to their respective receivers, which are located at Site 1. The interference levels at all other sites were also determined but, as expected, were well below those obtained at Site 1.

The pertinent computer print-out segments of runs one and two are presented in Figures 4 and 5 respectively. Figure 4 presents the interference level (i.e., relative interference) caused by secondary links transmitting at 6060 MHz (Δ f = 20 MHz) and 6050 MHz (Δ f = 10 MHz). For both runs the "desired signal strength" output is the wanted primary link signal (i.e., -23.6 dBm). All other dBm entries represent interfering signal strengths.

The results have been summarized and plotted in Figures 6 and 7. Figure 6 is a plot of the interference level at the Site 1 receiver of link 2-1 as a function of frequency separation between desired carrier and interfering carrier in MHz, with change in azimuth as a parameter. Figure 7 is a plot of the interference level at the Site 1 receiver of link 2-1 as a function of the change in azimuth between the primary link 2-1 and each of the interfering secondary links, with frequency separation as a parameter.

The zero dB interference level in both Figures 6 and 7 is referenced to a power level of 2 pWp at a zero transmission level point. A value of 2 pWp was arbitrarily used as a minimum tolerable interference level. Its selection does not bias the absolute levels of interference, but is used simply as a limit for the computer operation.

As an example of how the results of the computer runs may be employed in determining appropriate microwave link configurations for given interference level constraints, a 2-link system with a total



SELECTIVITY CURVE
ADAPTED FROM GENERAL ELECTRIC TRS-696 RECEIVER (960 VF CHANNELS)
FIGURE 3

CSC-B-6830481-4-1

PRIMARY LINK STATION 1 - STATION 2 RECEIVING ON 6060.0 MC AT STATION 1

SECONDARY LINK A		SECONDARY LINK B	TRANSMIT FREQ AT A	INTERFERENCE DBM	INTERFERENCE RELATIVE
STATION 2	-	STATION 1	6060.0	-23.6	75.4
STATION F	-	STATION 1	6060.0	-26.6	72.4
STATION G	-	STATION 1	6060.0	-35.4	63.6
STATION H	-	STATION 1	6060.0	-44.2	54.8
STATION I	-	STATION 1	6060.0	-47.4	51.6
STATION P	-	STATION 1	6030.0	-47.4	-25.5
STATION Q	-	STATION 1	6030.0	-44.2	-22.3
STATION R	-	STATION 1	6030.0	-35.4	-13.5
STATION Z	-	STATION 1	6030.0	-26.6	-4.7

DESIRED SIGNAL STRENGTH = -23.6 DBM

COMPUTER RUN 1

FIGURE 4

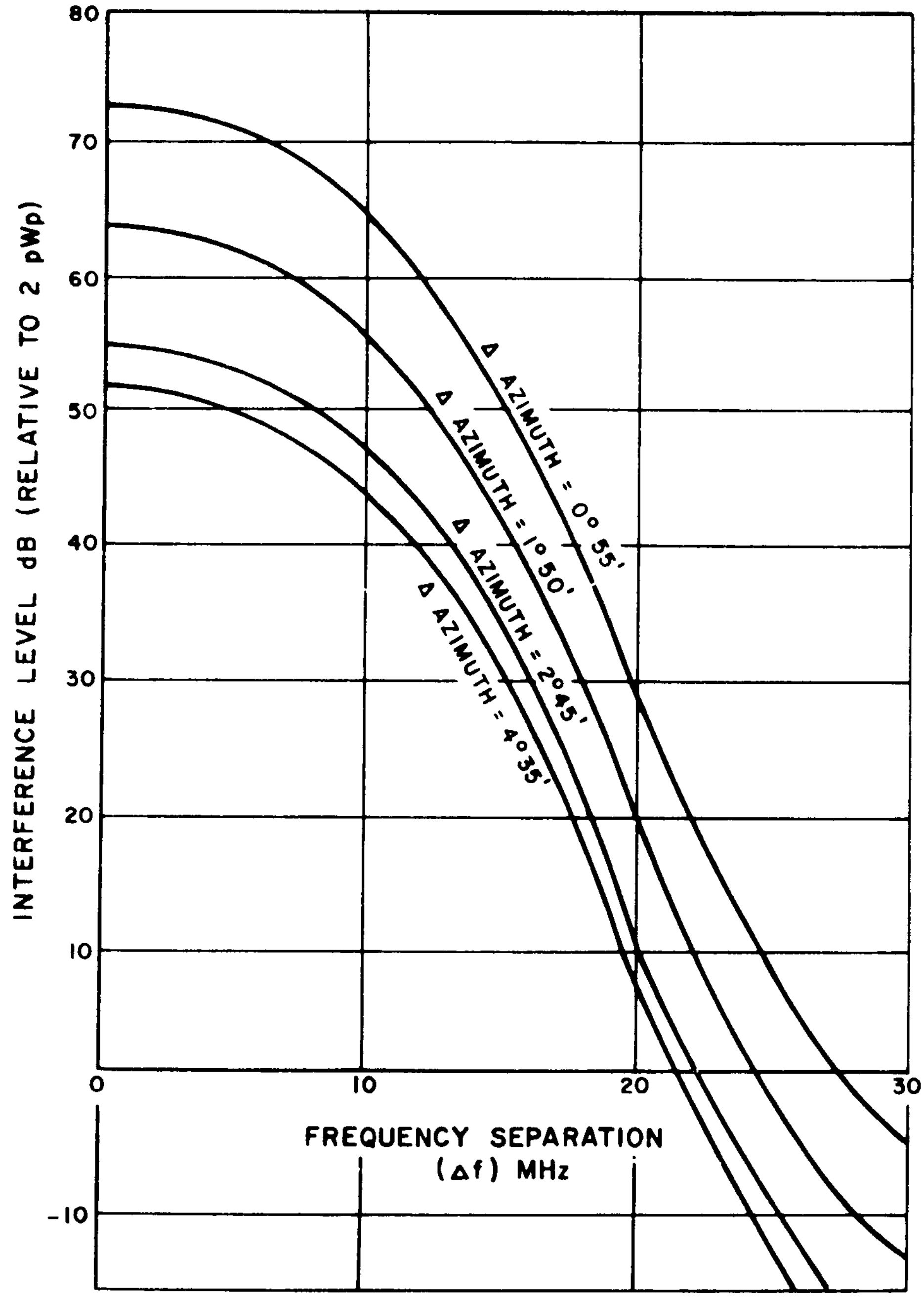
PRIMARY LINK STATION 1 - STATION 2 RECEIVING ON 6060.0 MC AT STATION 1

SECONDARY LINK A	B	TRANSMIT FREQ AT A	INTERFERENCE DBM	RELATIVE
STATION 2	- STATION 1	6060.0	-23.6	75.4
STATION F	- STATION 1	6040.0	-26.6	27.7
STATION G	- STATION 1	6040.0	-35.4	18.9
STATION H	- STATION 1	6040.0	-44.2	10.1
STATION I	- STATION 1	6040.0	-47.4	6.9
STATION P	- STATION 1	6050.0	-47.4	44.0
STATION Q	- STATION 1	6050.0	-44.2	47.2
STATION R	- STATION 1	6050.0	-35.4	56.0
STATION Z	- STATION 1	6050.0	-26.6	64.8

DESIRED SIGNAL STRENGTH = -23.6 DBM

COMPUTER RUN 2

FIGURE 5



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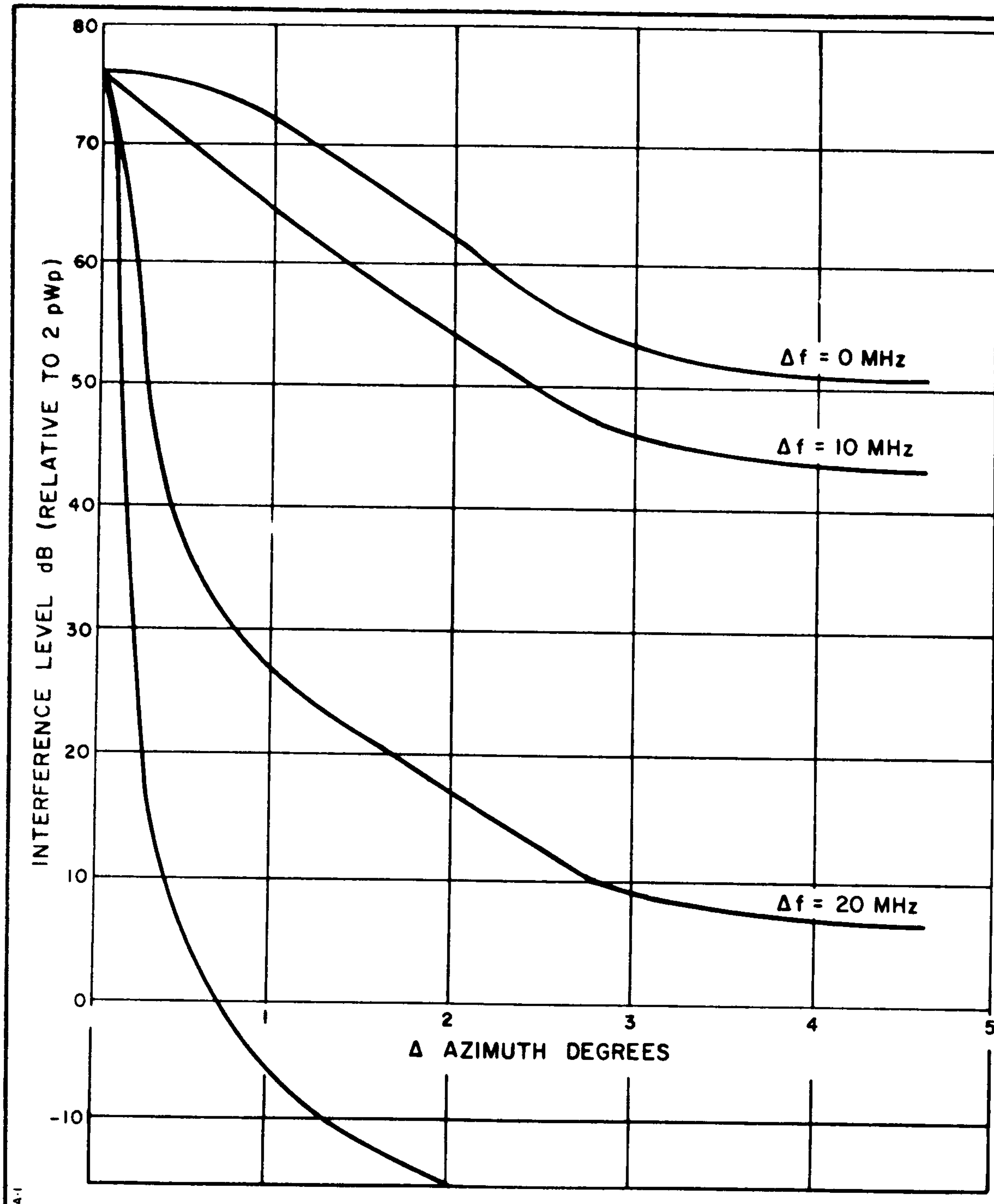
INTERFERENCE LEVEL VS FREQUENCY SEPARATION

FIGURE 6



INTERFERENCE LEVEL VS Δ AZIMUTH

FIGURE 7

interference level limit of 8 pWp (6 dB) is assumed. If the primary link operates with a transmitting frequency of 6060 MHz, then a second link transmitting at 6039.8 MHz must have an azimuth differential of at least 4° 35' to assure that the 8 pWp interference level is not exceeded. Alternatively, if a second site is located with a differential azimuth of only 2° 45', then it must transmit with a frequency difference of at least 21 MHz (6039 or 6081 MHz).

Multi-link configurations are examined by iteration of the same technique.

3.0 DESCRIPTION OF COMPUTER PROGRAM USED FOR INTERFERENCE MODEL

The program used for the calculations described in the preceding paragraph consists of two phases: a basic program and a modified program, both of which are described below. It is the modified program which has been used to perform the required calculation. The source language employed is FORTRAN IV for the IBM 7094.

3.1 FUNDAMENTAL PROGRAM

In a 9-link radio system, confined to a geographically limited area, there are at least 18 receivers, each of which may receive interference from as many as 17 transmitters. This situation can produce 306 potential interference cases. Most of these interference cases can be eliminated immediately by inspection, and a systematic approach to frequency selection can sometimes be used to assure that only a few potential significant interference cases occur. A severe problem arises when the network becomes extremely dense, and is co-located with existing installations that must be protected, such that systematic manual approaches no longer yield workable frequency plans. The feasibility of a plan depends on antenna patterns, reciever interference rejection characteristics and the network geometry. This computer program makes a routine calculation of the interference level at each receiver due to each transmitter, taking into account the antenna characteristics and relative path angles, the transmitter power, the free space propagation loss and the receiver characteristics. The cumulative signal level and the margin above or below the allowable level are printed.

Another printout from this program presents only those cases where the computed interference level is greater than a predetermined allowable level. Based on prior study of the network the planner may have a fairly good idea which transmitter-receiver combinations will appear on this list. Its main use is to point out cases he has overlooked and to indicate the expected magnitude of the interference.

The program assumes that free space line-of-sight propagation prevails between all stations of the network with intervening obstacles not protruding into the beam any deeper than the 0.6 Fresnel radius. This conservative assumption infers an infinite effective earth radius for some links: the engineer can through further investigation then decide to ignore computed interference cases he knows to be negligible because of terrain masking.

3.1.1 Limitations

In addition to the propagation calculation limitations, the following should be noted:

1. Inter-station interference due to carrier frequency fundamentals only are considered. Cross-band (i.e., 2 GHz to 4 GHz interferences) are not properly computed because antenna patterns and the propagation loss equation do not apply. This is generally not a limiting factor since the amplitudes of harmonics are well below that of the fundamental frequency.

2. Polarization isolation is not considered. Any polarization discrimination, therefore, adds to the interference protection.

3. Harmonics, intermodulation, man-made or solar noise are not considered.

4. Terrain backscatter or antenna misalignment are not considered.

3.1.2 Overall Program Flow

The entire program consists of three routines (jobs) that are sequentially executed on the IBM 7094. The input for Job 1 consists of station indices and map coordinates in latitude and longitude. Its output is a listing of bearing and ranges from each station to every other station. Up to fifty stations (sites) may be simultaneously accepted. The listing is used mainly for cross checking and reference; the main output is a magnetic tape in binary format used as input to Job 2.

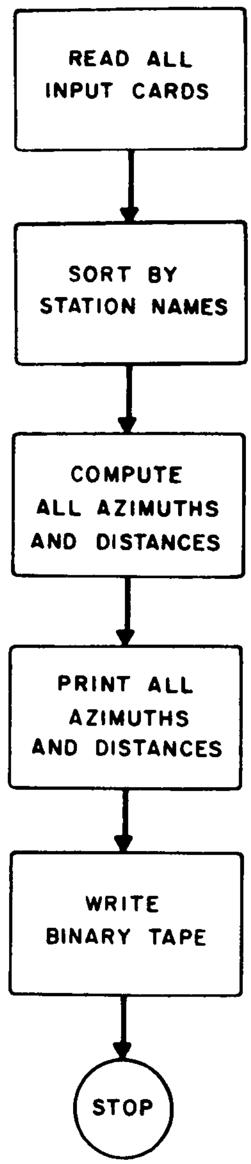
Job 2 accepts link defining cards that specify the topology of the network. From these and the output of Job 1, it computes relative angles for side lobe computation from each antenna to every other antenna. A frequency independent component of the path loss [20 LOG (distance)] is computed for later use in Job 3. A binary tape of distance, 20*ALOG10 (DIST), and the relative antenna angles are written as input to Job 3. A listing of this data is printed for reference.

One input for Job 3 is a card which defines the frequency band and the allowable limit of interference above receiver threshold. Another input is a set of cards which defines the characteristics of a set of receivers and antennas, specifying allowable interference level in dBm versus frequency and gain relative to isotropic for angles from the center of the main beam. Each receiver and antenna is given a unique number used in the next set of cards that specifies the frequency, transmitter power, receiver type and antenna types (at transmitter and receiver) used on each link of the system to be computed. Job 3 uses these cards, with the preprocessed geographic information from Job 2 to produce the final desired output.

In each job, the stations are identified by alphanumeric names which may contain as many as 12 characters. The programs search for the relevant data by these names, hence the spelling in Jobs 2 and 3, must be identical with the spelling in Job 1.

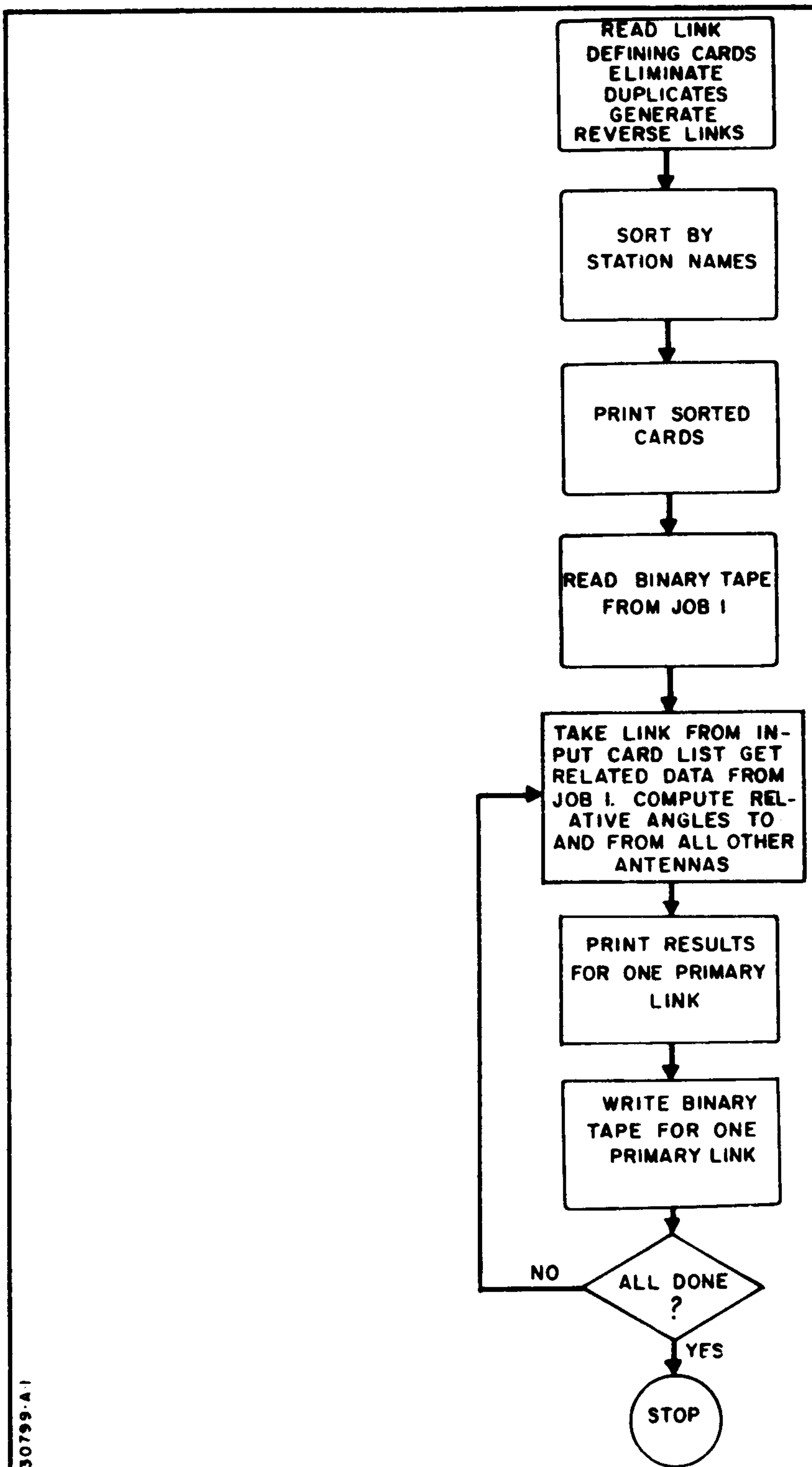
3.1.3 Flow Charts

Figues 8, 9, and 10 give simplified flow charts of the 3 jobs. Each block is a distinct segment with no branching to other blocks except as shown. The individual blocks may be fairly complicated internally, but the source program has liberal comments



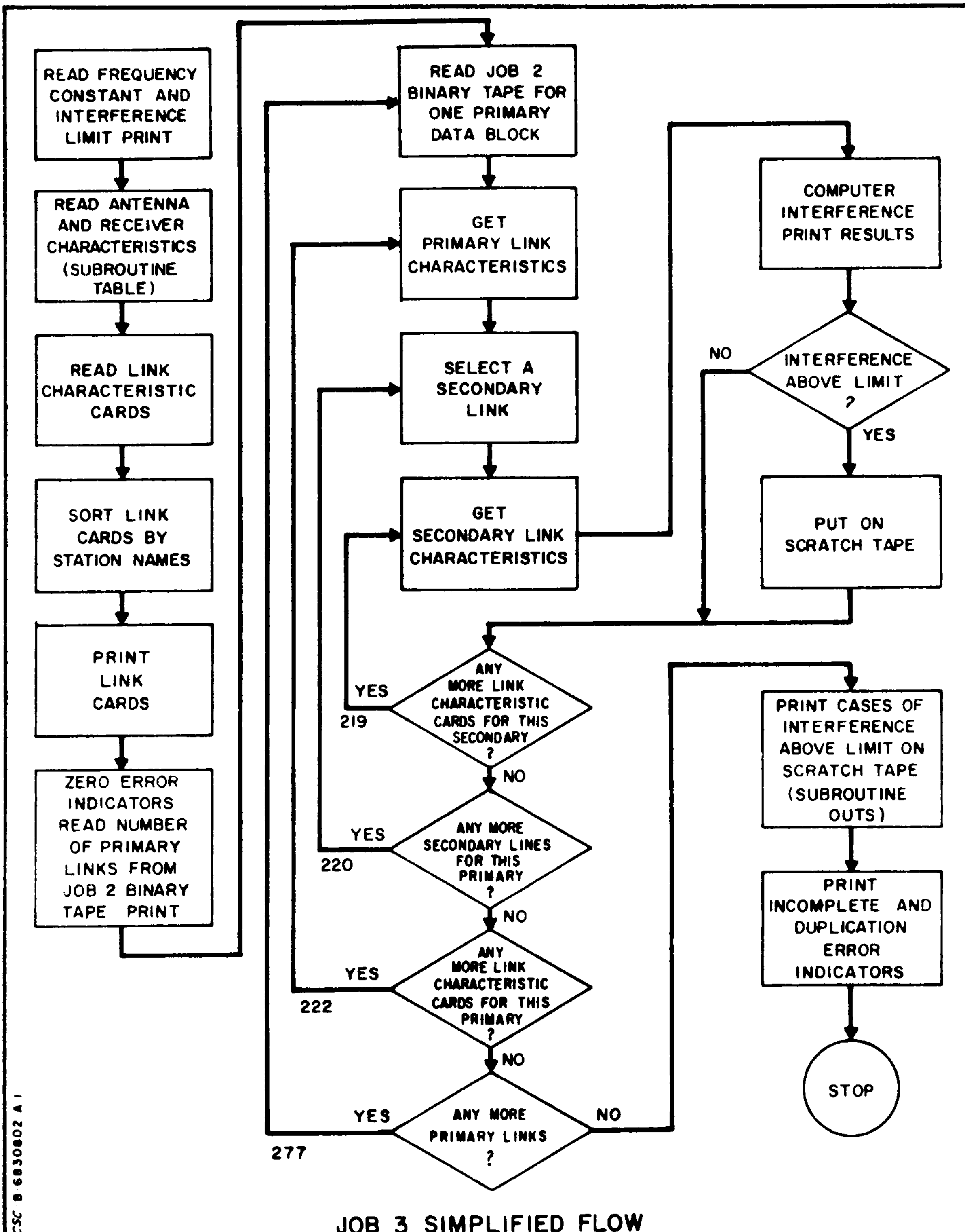
JOB 1 SIMPLIFIED FLOW

FIGURE 8



JOB 2 SIMPLIFIED FLOW

FIGURE 9



JOB 3 SIMPLIFIED FLOW

FIGURE 10

and, with the detailed statement-by-statement flow charts, can be easily followed. Two kinds of links are referred to:

A primary link is a transmitter at one station sending a desired signal to a receiver at another station; a secondary link is a transmitter-receiver pair sending an undesired (potentially interfering) signal to the receiver of the primary link. Note that links are unidirectional as far as the program is concerned. The usual two-way radio link is treated as two separate links.

3.2 MODIFIED PROGRAM

The modified program incorporates several changes to the fundamental program. These changes result in an output that is suitable for use by personnel not familiar with computer programming and processing. The basic part of this program is identical to the original program with two exceptions:

1. An additional scratch tape is used to record information on all interference links on the system.
2. Near the end of the program a subroutine is called which uses the information written on the scratch tape to evaluate the degree of interference at each station.

The program operates on the assumption that the receiver sensitivity characteristics are given as follows:

The receiver sensitivity characteristics is a plot of interference level vs. frequency spacing from the desired signal. Specifically, the curve should indicate the level of RF interference required to produce the maximum acceptable interference noise in any of the channels in the baseband of the receiver.

Each link is analyzed according to this specification and the results are printed based on the following criteria:

1. If the total interference noise on any link is less than the previously defined maximum baseband interference level, no interference information is listed.
2. If the total interference noise exceeds that level, then each link which contributes more than five percent of the total noise is listed, in order of descending noise contribution. All pertinent parameters, such as antenna type, distance, receiver type, azimuth, etc. are listed for the interference paths.

3. Additionally, the program provides a drift simulator. This part of the program makes slight changes in the values of the assigned transmitter and receiver frequencies to simulate the frequency stability characteristics. Presently, the program assumes and selects the worst case interference when the system drifts within the programmed limits. The value can be changed to simulate other stability characteristics.

3.2.1 Overall Program Flow

The basic program follows the same philosophy of the original program. The major change occurs when subroutine FORMA is called by the main program. At this point subroutine FORMA acts as an executive program to control the operation of sorting and printing the essential interference data on each primary link in the system. The basic operation of the executive program is as follows:

1. Initially, the program loads all pertinent data on a single primary link into a common one-dimensional array. This data has been previously written in binary format on scratch tape KUT 20.

2. Next the program proceeds to read another block of data representing a secondary interference link into another two-dimensional array (A). The program continues to read in blocks of data on secondary links until it senses that there are no more secondary links. This is done by testing each secondary link for a combination of variables which are unique to primary links. If a primary link is found, the tape is backspaced one logical record and the system stops reading links and proceeds to the next part of the program. During the time each logical record of the secondary links is being stored in the array A, a running total of the noise level in pWp is maintained.

3. At this point a check is made on the total noise of the system. If it is insignificant (i.e. below the assigned maximum level), the system abandons further processing of the primary link and proceeds to step 1 where it begins to process the next primary link. If a significant amount of noise is present, the system proceeds to step 4.

4. The program now calls subroutine SORT. This subroutine begins to scan array A to find the secondary link with the greatest amount of interference noise (pWp). This link is exchanged with

the first link in the array. The process is repeated for the next highest link and transfers made with the second link in the table, etc. Each time a change is made the noise is inspected to see if it is higher than the five percent level. If it is not, then the sorting process is stopped, since levels below this figure are insignificant and will not be printed in the final output.

5. After the sorting process stops, the SORT subroutine takes note of the number of significant secondary links which have been sorted and passes control back to the main program.

6. The main program then calls subroutine PRINT and transfers the sorted secondary array data and the primary link data to the PRINT subroutine. The final subroutine consists mainly of format statements, line counting and page numbering routines. Basically it takes the primary link data and prints it at the top of the page, then lists the significant secondary links in the order of importance, i.e., highest interference noise. Miscellaneous data on the total noise, difference, allowable limits, etc., are also computed and printed. After all significant interference links have been printed, control is passed back to executive subroutine FORMA where the system returns to the beginning of the subroutine. The next primary link and associated secondaries are read from tape KUT 20 and processed in the same manner.

The entire process is repeated until all primary and secondary links have been processed. When all links are printed, the executive program returns to the main program. The location in the main program is near the end, so for all practical purposes the program is finished and program execution is terminated by the main program.

APPENDIX H

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GLOSSARY

The following are the definitions of the more commonly used microwave terms. Note that figure Glossary - 2 is a tabulation of microwave terms and equations.

Antenna (Gain). The ratio of the maximum radiation intensity in a given direction to the maximum radiation intensity produced in the same direction from a reference (isotropic) antenna with the same power input.

Antenna (Isotropic). A hypothetical antenna which radiates or receives equally in all directions. It can represent convenient reference antennas for expressing directional properties of actual antennas.

Antenna (Parabolic). An antenna consisting of a radiating element (dipole or horn) and a reflector in the general shape of a parabola to concentrate the energy into a narrow beam.

Attenuation. A general term used to denote a decrease in magnitude of current, voltage, or power of a signal in transmission from one point to another. It may be expressed as a ratio or, by extension of terms, in decibels (dB).

Attenuation Constant. For a traveling wave at a given frequency, the real component of the propagation constant; the relative rate of exponential decrease of amplitude of a field component (voltage or current) in the direction of propagation expressed in nepers or dB per unit length.

Azimuth. Direction, specified in degrees clockwise from north. Thus, due west would be 270° azimuth.

Bandpass Filter. A circuit that allows certain frequencies to pass and reduces in amplitude all frequencies above and below the bandpass region. The power level applied to a filter is very important. Excessively high levels can completely negate the operation of the filter. (Filter rated as having a given loss at a specified frequency-deviation outside pass band.)

Bandwidth. The range of frequencies of a device within which performance with respect to some characteristic conforms to a specified standard. General practice is to specify bandwidth at half-power (3-dB) points.

Baseband. The sum of the frequencies that make up a composite multiplex signal. In the process of modulation, the frequency band occupied by the aggregate of the transmitter signals when first used to modulate the carrier. The term is commonly applied to cases where the ratio of the upper to the lower limit of the frequency band is large compared to unity.

Beam. The focusing of electromagnetic energy into space as radiated from a directional antenna.

Bend, E Plane. A bend in a waveguide in the plane of the electric field. Commonly called an "easy" bend.

Bend, H Plane. A bend in a waveguide in the plane of the magnetic field. Commonly called a "hard" bend.

Bolometer. A barretter, thermistor, or any other instrument using the temperature coefficient of resistivity to measure power. It contains an element, the resistance of which changes as a result of heating by RF power.

Channel (RF). That portion of the frequency spectrum that is assigned to a particular transmitter or receiver.

Choke Joint. A connector between two sections of transmission line in which the gap between the sections is built out to form a series-branching transmission line carrying a standing wave, in which contact is at or near a current minimum.

Coaxial Line. A transmission line where one conductor completely surrounds the other, the two being coaxial and separated by a dielectric or dielectric spacers. Such a line has no external field and no susceptibility to external fields from other sources.

Coupler, Directional. A transmission coupling device for separately sampling (through a known coupling loss for measuring purposes) either the forward (incident) or the backward (reflected wave in a transmission line. Similarly, it may be used to excite in the transmission line either a forward or backward wave. (See figure Glossary - 1.)

Crosstalk. The phenomenon in which a signal transmitted on one circuit or channel of a transmission system is detectable in another circuit or channel.

Cutoff Frequency (Waveguide). The lowest frequency at which energy will propagate in some particular mode without attenuation.

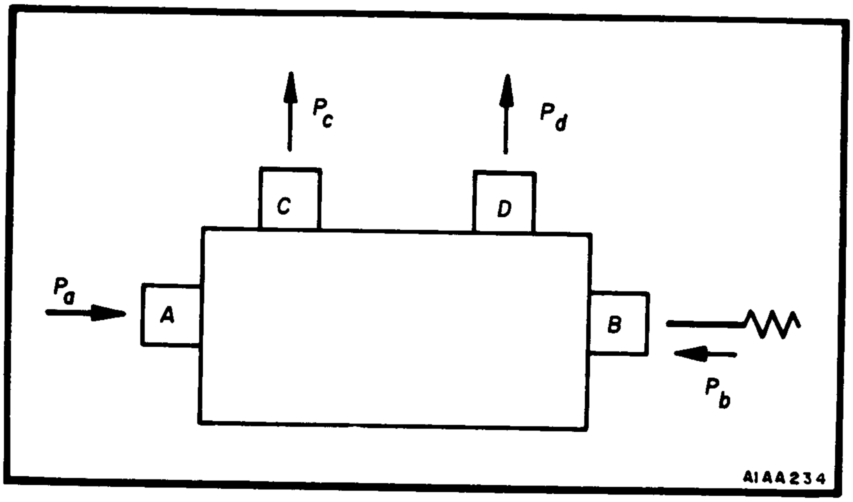
Cutoff Frequency of Amplifier. The highest and the lowest frequencies at which amplifier gain begins to decrease sharply.

Cutoff Frequency of Filter. The frequency at which the filter attenuates applied frequencies by a stated amount.

Cutoff Wavelength. The ratio of the velocity of electromagnetic waves in free space to the cutoff frequency.

Diffraction. The phenomenon produced when waves pass the edge of an opaque body, in which the wave appears to be deflected, producing fringes of parallel waves.

Diplexer. A device that permits an antenna system to be used simultaneously or separately by multiple transmitters operating on different frequencies. Not a duplexer.



GL-1. Power Flow in Directional Coupler

Directional Coupler. see Coupler, Directional.

Duplexer. A device which permits a transmitter and a receiver to operate on a single transmission line or antenna. It effects a mismatch in the receiver section of the transmission line when the transmitter is operating and restores matching in this section when the transmitter is quiescent. (Not a diplexer.)

Equalization. The process of obtaining a flat frequency response over a frequency band.

Equalizer. A device that corrects for the nonlinear response of an electrical circuit.

Four-Wire Circuit. A two-way sending and receiving circuit which uses an individual pair of wires to carry transmitted intelligence in one direction and received intelligence in the opposite direction. This method provides the highest grade circuits, but requires twice as many pairs of wire as 2-wire operation, in which sending and receiving are accomplished over a single pair of wires.

Frequency Division Multiplex (FDM). A method of deriving two or more simultaneous, continuous channels from a medium connecting two points by assigning separate portions of the available frequency spectrum to the several channels. (Each signal channel modulates a separate subcarrier.)

Frequency Modulation (FM). The form of modulation in which the instantaneous frequency of a sine wave carrier is caused to depart from the carrier frequency by an amount proportional to the instantaneous value of the modulating signal.

Frequency Shift Keying (FSK). A method of transmitting the mark and space portions of a teletype (TTY) signal by shifting the carrier frequency a fixed amount. It is characterized by continuity of phase during the transition from one signaling condition to another.

Fresnel Zone. The cigar-shaped zone (or region) between an antenna and the Fraunhofer region, the center of which is the direct beam path between a microwave transmitting and receiving antenna. If the antenna has a well-defined aperture D in a given aspect, the Fresnel zone in that aspect is commonly taken to extend a distance $2D^2/\lambda$ in that aspect, where λ = wavelength. The total distance from any point on the first fresnel zone to the transmitting and receiving antenna is one-half wave length longer than the direct path.

High Pass Filter. A filter that allows all frequencies above a certain (cutoff) frequency to pass with very little attenuation and attenuates all frequencies below that frequency.

Horizontal Polarization. A radio wave in which the electrostatic field (E vector) is in a horizontal plane. The transmitting antenna will be horizontal, and the receiving antenna should also be in this plane.

Impedance, Characteristic (of a rectangular wave-guide). A pure resistance, whose magnitude is dependent on the dimensions of the cross-section of the guide and on the medium in which the wave is transmitted, but is independent of frequency. For the dominant (TE_{10}) mode at any specific frequency above cut-off frequency, it is the ratio of the square of the rms voltage between midpoints of the two conductor-faces normal to the electric vector to the total power flowing when the guide is match-terminated. For modes other than TE_{10}, the impedance must be derived from analysis of the particular geometric structure of the guide relative to the specific frequency.

Impedance, Characteristic (of a two-conductor transmission line). The square root of the product of the inductance per unit length and the capacitance per unit length. For a traveling, transverse electromagnetic wave, the ratio of the complex voltage between the conductors to the complex current on the conductors in the same transverse plane, with the sign so chosen that the real part is positive.

Impedance, Normalized. The impedance of a system divided by the characteristic impedance.

Incident Power or Signal. Power from the generator transmitted to the load.

Ionosphere. That part of the outer atmosphere (25 or more miles above the earth) where ions and free electrons are normally present in quantities sufficient to affect radio-wave propagation. It is divided into several regions or layers which can absorb or reflect electromagnetic radiation.

Isolator, Ferrite. A device which allows RF energy to pass through in one direction with very little loss; RF power in the reverse direction is greatly attenuated.

Junction Hybrid. A waveguide arrangement with four branches which has the property that energy can be transferred from any one branch into only two of the remaining three branches.

Line of Sight (LOS). An optical path between two points.

Lobe. One of the three-dimensional sections of the radiation pattern of a directional antenna bounded by one or two cones of nulls. (The size, shape, and relative power are dependent on antenna characteristics.) The lobe containing the direction of maximum radiation or reception is called the major lobe; all other lobes are called minor lobes.

Loss, Mismatch (reflection loss). The ratio, in dB, of the incident power to the difference between incident power and reflected power; a measure of the loss caused by reflection.

Lower Sideband. The difference-frequency produced by the combination of the carrier and the modulating frequencies when amplitude-modulation is used.

Low Pass Filter. A circuit that allows all frequencies below a certain (cutoff) frequency to pass with very little attenuation and attenuates all frequencies above the cutoff frequency.

Matched Termination (Waveguide). A termination producing no reflected wave at any transverse section of the waveguide; i.e., the real power is totally absorbed by the termination. (To achieve this, the termination must present a purely resistive load equal in magnitude to the characteristic impedance of the associated waveguide.)

Microstrip. A microwave transmission component using a single conductor supported above a ground plane.

Microwave Region. That portion of the electromagnetic spectrum lying between the far infra-red and the conventional RF portions - commonly regarded as extending from 1 MHz (30 cm) to 300 kMHz (1mm).

Mode (of transmission propagation). The mode of propagation of electromagnetic waves through waveguide is described by the configurations of electric (E) and magnetic (H) fields existing in a plane perpendicular to the waveguide axis. These modes are further identified by double-subscripts that indicate the electric- and magnetic-field distribution in half-cycles along the x- and the y-axis, respectively, of the waveguide. The modes are: TE (transverse-electric) waves; TM (transverse-magnetic) waves; and TEM (transverse-electromagnetic) waves. A typical mode-designation might be $TE_{1,0}$, which indicates a TE mode with one half-cycle of E-field along the x-axis, and zero half-cycles along the y-axis.

Modem. A contraction of "modulator-demodulator," for a device which performs both functions. It is mounted in a single panel and usually has some circuits which are common to both functions.

Multipath Effect. The condition produced when a radio signal transmitted from a point is received at a distant station as two separate signals varying slightly in phase (time) due to their traveling over paths of different length.

Multiplex. A method to provide more than one communications channel on a single-carrier circuit.

Profile Chart. Vertical cross-sectional drawing of the terrain between two microwave stations showing distance between stations, location, and elevation of obstructions, etc.

Propagation Constant. A transmission characteristic of a line which indicates the effect of the line on the wave being transmitted along the line. It is a complex quantity having a real term, the attenuation constant and an imaginary term, the phase constant. 1. Per unit length of a uniform line, it is the natural logarithm of the ratio of the current at a point of the line, to the current at a second point, at unit distance from the first point along the line in the direction of transmission, when the line is infinite in length, or is terminated in its characteristic impedance. 2. Per section of a periodic line, it is natural logarithm of the ratio of the current entering a section, to the current leaving the same section, when the periodic line is infinite in length, or is terminated in its iterative impedance. 3. Of an electric transducer, it is the natural logarithm of the ratio of the current entering the transducer, to the current leaving the transducer, when the transducer is terminated in its iterative impedance.

Radiation Pattern. A polar graphical representation displaying the relative intensity of radiation from an antenna in any direction.

Reflected Power or Signal. Power flowing from the lead back to the generator.

Reflection Coefficient. The vector ratio of the electric field associated with the reflected wave to that associated with the incident wave.

Reflectometer. A system so arranged to measure the incidental and reflected voltages and indicate their ratio.

Reflector (Passive). A flat surface placed at an angle in the beam path of a signal to change its direction.

Refraction. The change in direction of propagation of a wave front due to its passing obliquely from one medium into another of different density.

Resonator, Cavity. A region enclosed by conducting walls, within which resonant fields may be excited and whose frequency is determined by the geometry of the enclosure.

Sidebands. Two bands of frequencies, one above and one below the carrier frequency, produced as a result of modulation of a carrier. The upper sideband contains the frequencies that are the sums of the carrier and modulated frequencies. The lower sideband contains the eifference of these frequencies.

Simple Sideband Suppressed Carrier Modulation (SSB). A type of amplitude modulation in which the carrier and one sideband are eliminated before the RF signal is transmitted.

Slotted Section. A length of waveguide, in the wall of which is cut a non-radiating slot (used for standing wave measurements).

Smith Diagram. A diagram with polar co-ordinates, developed to aid in the solution of transmission-line and waveguide problems.

Subcarrier. A carrier that is modulated and in turn modulates a second carrier.

Telemetering. The process of transmitting intelligence of a type that is normally read on meters or gauges to a remote point and producing the desired information at that point.

Thermistor. A resistance element made of a semi-conducting material which exhibits a high negative temperature coefficient of resistivity.

Time Division Multiplex (TDM). A method of deriving several channels from a given frequency spectrum, by assigning discrete time intervals in sequence to the different channels. During a given time interval the entire available frequency spectrum can be used by the channel to which it is assigned. In general, TDM systems use pulse transmission. The multiplex pulse train may be considered to be the interleaved pulse trains of the individual channels. The individual channel pulses may be modulated either in an analog or a digital manner.

UHF. Ultra-high frequency, the band of frequencies between 300 and 3000 mHz.

Upper Sideband. The frequency produced from the sum of the carrier and the modulating frequencies when amplitude-modulation is used.

VHF. Very high frequency, the band of frequencies between 30 and 300 mHz.

Voltage Standing-Wave Ratio (VSWR). The ratio of the amplitude of the electric field or voltage at a voltage minimum to that at an adjacent maximum in a stationary-wave system, as in a waveguide, coaxial cable, or other transmission line.

Wave, Dominant. The guided wave having the lowest cutoff frequency; the only wave which will carry energy when excitation is between the lowest cutoff frequency and the next higher frequency of a waveguide.

Waveguide Tee. A junction used to connect a branch section of waveguide in series or parallel with the main transmission line.

Waveguide Tuner. An adjustable device added to a waveguide to effect an impedance transformation.

Waveguide Wavelength. For a traveling plane wave of a given frequency, the distance along the waveguide between points at which a field component (or the voltage or current) differs in phase by two radians.

Wave, Transverse Electric (TE Wave). In a homogeneous isotropic medium, an electromagnetic wave in which the electric field vectors are everywhere perpendicular to the direction of propagation.

Wave, Transverse Electromagnetic (TEM Wave). In a homogeneous isotropic medium, an electromagnetic wave in which both the electric and magnetic field vectors are everywhere perpendicular to the direction of propagation.

Wave, Transverse Magnetic (TM Wave). In a homogeneous isotropic medium, an electromagnetic wave in which the magnetic field vector is everywhere perpendicular to the direction of propagation.

Wave, TE_{mm} (In Rectangular Waveguide). The transverse electric wave for which m is the number of half-period variations of the electric field along the longer transverse dimension and n is the number of half-period variations of the electric field along the shorter transverse dimension.

Wave, TM_{mm} (In Rectangular Waveguide). The transverse magnetic wave for which m is the number of half-period variations of the magnetic field along the longer transverse dimension, and n is the number of half-period variations of the magnetic field along the shorter transverse dimensions.

Wavemeter, Absorption. A device using the characteristics of a resonator which cause it to absorb maximum energy at its resonant frequency when loosely coupled to a source.

MICROWAVE TERMS AND EQUATIONS

α	Attenuation
α_o	Attenuation of air filled copper transmission line = 0.35×10^{-9} nepers/meter = 0.3×10^{-5} db/kilometer
Γ	coefficient of reflection = −1 for short circuit = +1 for open circuit = 0 for matched load
δ	skin depth
ϵ	Dielectric constant
ϵ_o	Dielectric constant for air
λ	Wavelength
λ_g	Guide wavelength
λ_c	Cutoff wavelength
μ	Permeability
μ_o	Permeability of air = $4\pi \times 10^{-7}$ henries/meter
K	Coupling coefficient
ρ	Resistivity = 1.74×10^{-8} ohm-meters for copper
σ	Electrical conductivity
κ_o	Permittivity of air — 8.854×10^{-12} farad/meter
v	Velocity of propagation
v_o	Velocity of propagation in air = 2.998×10^8 centimeter/second = 2.998×10^8 meters/second = 186,280 miles/second = 11.808×10^9 inches/second
ϕ	Phase angle
β	Phase constant
Z_0	Characteristic impedance = 376.7 ohms for free space = 120π
D	Directivity
P	Power
V	Voltage
I	Current
R	Resistance
C	Capacitance
G	Conductance
B	Susceptance
X	Reactance
Y	Admittance
L	Inductance
f	Frequency
ω	Angular frequency = $2\pi f$
Q	Figure of Merit of a resonator = $2\pi \dfrac{\text{energy stored}}{\text{energy dissipated per cycle}} = \dfrac{\Delta f}{f_o}$
H	Magnetic vector
E	Electric vector
a	Broad waveguide dimension
b	Narrow waveguide dimension
z	Direction of propagation
n	Mode designation (for TE_{10} m = 1, n = 0)
m	Mode designation (for TE_{10} m = 1, n = 0)
VSWR	Voltage Standing Wave Ratio
PSWR	Power Standing Wave Ratio

Wavelength in meters $\lambda_m = \dfrac{300{,}000}{\text{f in kilocycles}} = \dfrac{300}{\text{f in megacycles}}$

Wavelength in centimeters $\lambda_{cm} = \dfrac{30{,}000{,}000}{\text{f in kilocycles}} = \dfrac{30{,}000}{\text{f in megacycles}}$

Wavelength in inches $\lambda_{in} = \dfrac{11{,}808{,}000}{\text{f in kilocycles}} = \dfrac{11{,}808}{\text{f in megacycles}}$

$$\delta = \frac{1}{2\pi}\sqrt{\frac{4\pi\rho\lambda_{meters}}{\mu c_{meters}}}$$

$$Z_o = (\mu_o/\kappa_o)^{1/2}$$

$$db = 10\log\frac{P_1}{P_2} = 20\log\frac{V_1}{V_2} = 20\log\frac{I_1}{I_2}$$

$$\lambda = \frac{v}{f} \qquad Z_o = \sqrt{\frac{\mu}{\kappa}}$$

In a lossless medium of dielectric constant ϵ

$$v = \frac{v_o}{\sqrt{\epsilon}}$$

$$\lambda = \frac{v_o}{f\sqrt{\epsilon}} \qquad Z_o = \sqrt{\frac{\mu_o}{\kappa_o\epsilon}} = \frac{120\pi}{\sqrt{\epsilon}}$$

$$|\Gamma| = \sqrt{\frac{P_{reflected}}{P_{incident}}} = \frac{VSWR - 1}{VSWR + 1}$$

$$\therefore VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$\%\ \text{Power reflected} = \left(\frac{VSWR - 1}{VSWR + 1}\right)^2 \cdot 100$$

$$PSWR = (VSWR)^2$$

For waveguides

$$(\lambda_{mn})_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}$$

$$\beta_{mn} = \frac{2\pi}{\lambda}\sqrt{\epsilon - \left[\frac{\lambda}{(\lambda_{mn})_c}\right]^2} = \frac{2\pi}{\lambda_g}$$

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon - \left[\frac{\lambda}{(\lambda_{nm})_c}\right]^2}}$$

For TE_{10} in air filled waveguide

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}}$$

$$\lambda_c = 2a$$

$$\alpha = \frac{4\alpha_o A}{a}\left(\frac{a}{2b} + \frac{\lambda^2}{\lambda_c^2}\right) \quad \text{where } A = \frac{\sqrt{c/\lambda}}{\sqrt{1 - (\lambda/\lambda_c)^2}}$$

A termination is connected to terminal B, and a signal P_a is applied to terminal A. P_a will flow through the device and be reflected by the termination resulting in P_b and a standing wave. A small portion of the input signal P_a is extracted at terminal C, unaffected by the reflection from the termination and

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GL-2. Microwave Terms and Equations (Sheet 1 of 2) proportional to the magnitude of the input signal. A similar portion of the reflected signal P_b is extracted at terminal D, proportional to the magnitude of the reflected signal and vanishing when the termination is adjusted for unity VSWR.

Coupling —

The ratio of power supplied to the power output at the auxiliary line output.

$$\text{Coupling (db)} = 10 \text{ Log } \frac{P_a}{P_c} = 10 \text{ Log } \frac{P_b}{P_d}$$

Directivity —

A measure of the discrimination of a directional coupler between waves traveling in two directions in the main line. It is measured as the ratio of the two power outputs from an auxiliary line when a given amount of power is successively applied to each terminal of the main line.

$$\text{when } P_b = 0, \text{ Directivity (db)} = 10 \text{ Log } \frac{P_c}{P_d}$$

Formulas —

The directional coupler is employed to measure the magnitude of the reflection coefficient by measuring the magnitude of the direct and reflected voltages.

$$K = \frac{E_r}{E_d}$$

where

K = magnitude of reflection coefficient
E_r = magnitude of reflected voltage
E_d = magnitude of direct voltage

The resultant VSWR, return loss, and mismatch loss, may be computed as follows:

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$\text{Return Loss (db)} = 10 \text{ Log } \frac{1}{K^2}$$

$$\text{Mismatch Loss (db)} = 10 \text{ Log } \frac{1}{1 - K^2}$$

Down Converters —

THEORY: A down converter is a crystal holder with two RF inputs. A local oscillator signal of known frequency is applied to one input, the RF signal to the other. The two signals are mixed in the nonlinear crystal. The result of the mixing is to produce, among other frequencies, the difference frequency between the RF and LO (local oscillator) signals at the IF output. The mixer thus converts an RF signal to a much lower frequency IF signal which is more conveniently amplified and otherwise handled.

DESIGN: The schematic circuit of the XR mixers is shown in Figure 100.

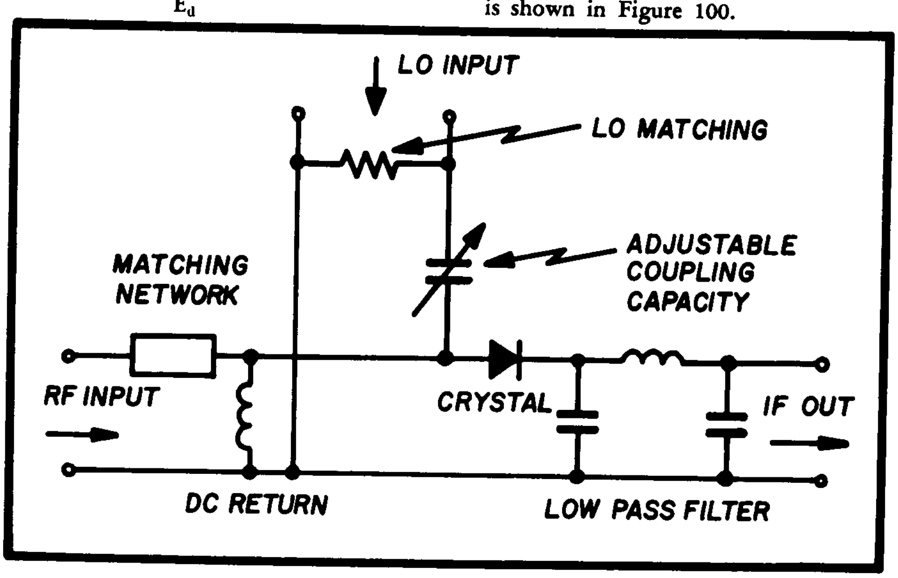

Figure 100. Down Converter

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GL-2. Microwave Terms and Equations (Sheet 2 of 2)

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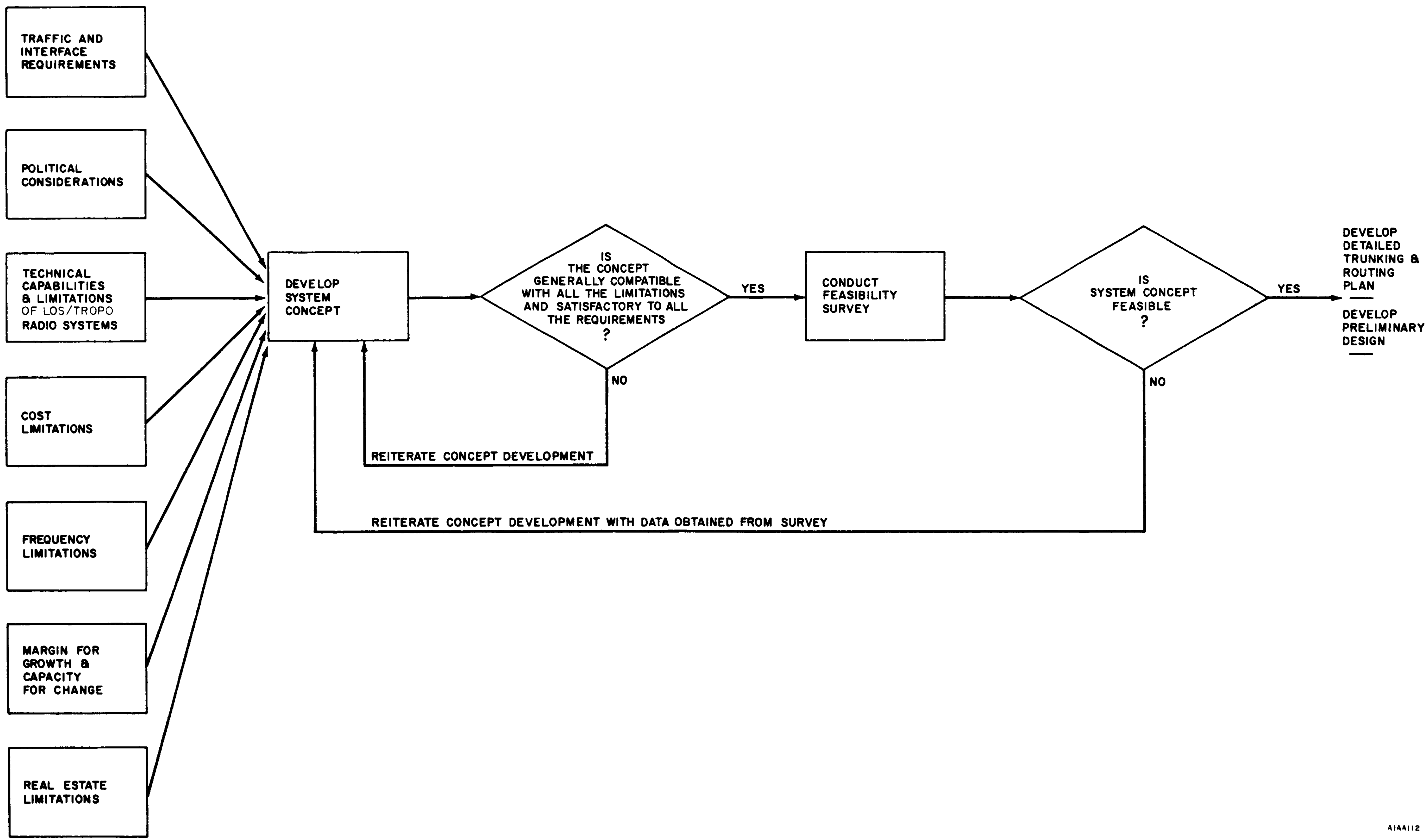
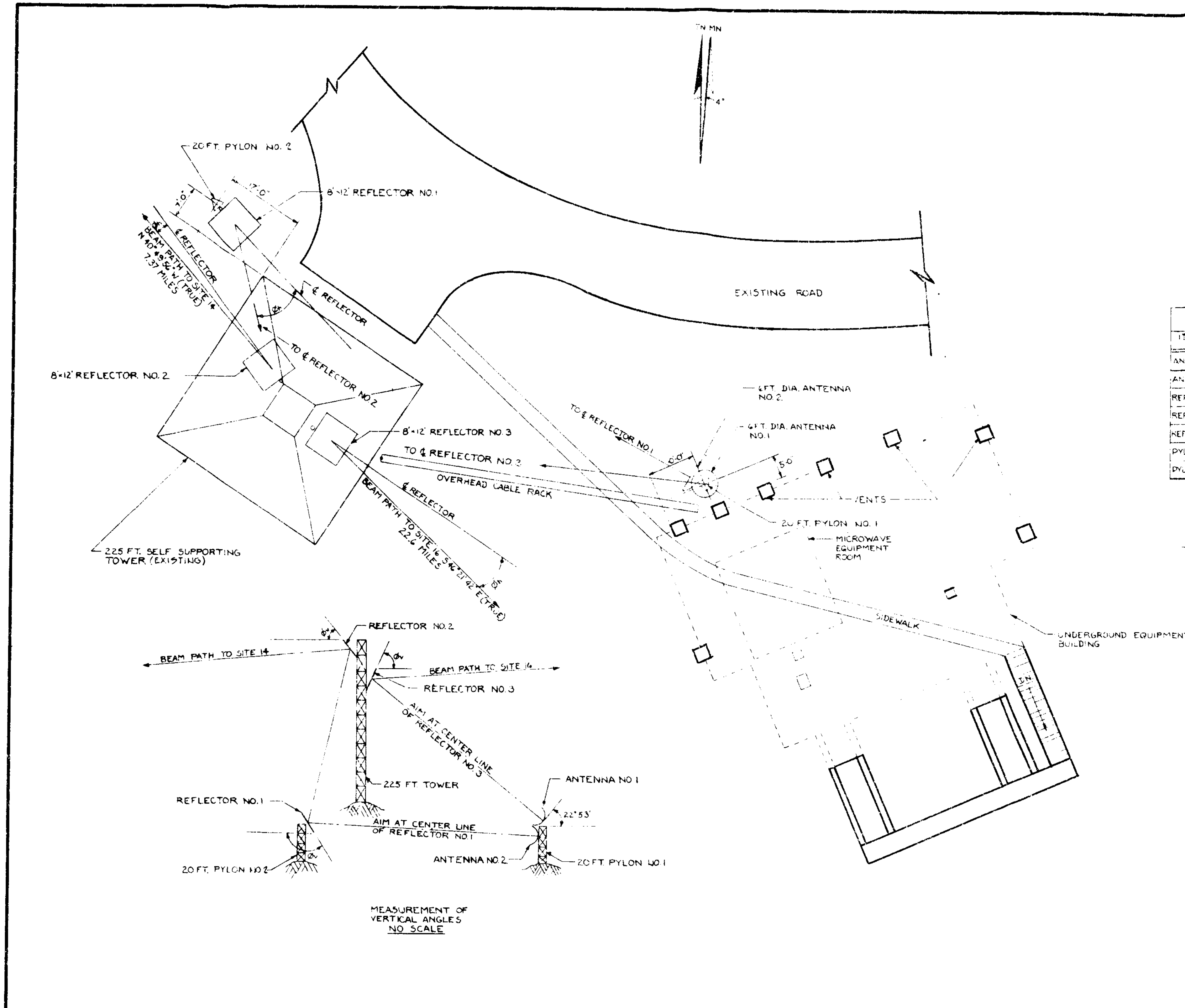


Foldout 5-1. Basic System Concept



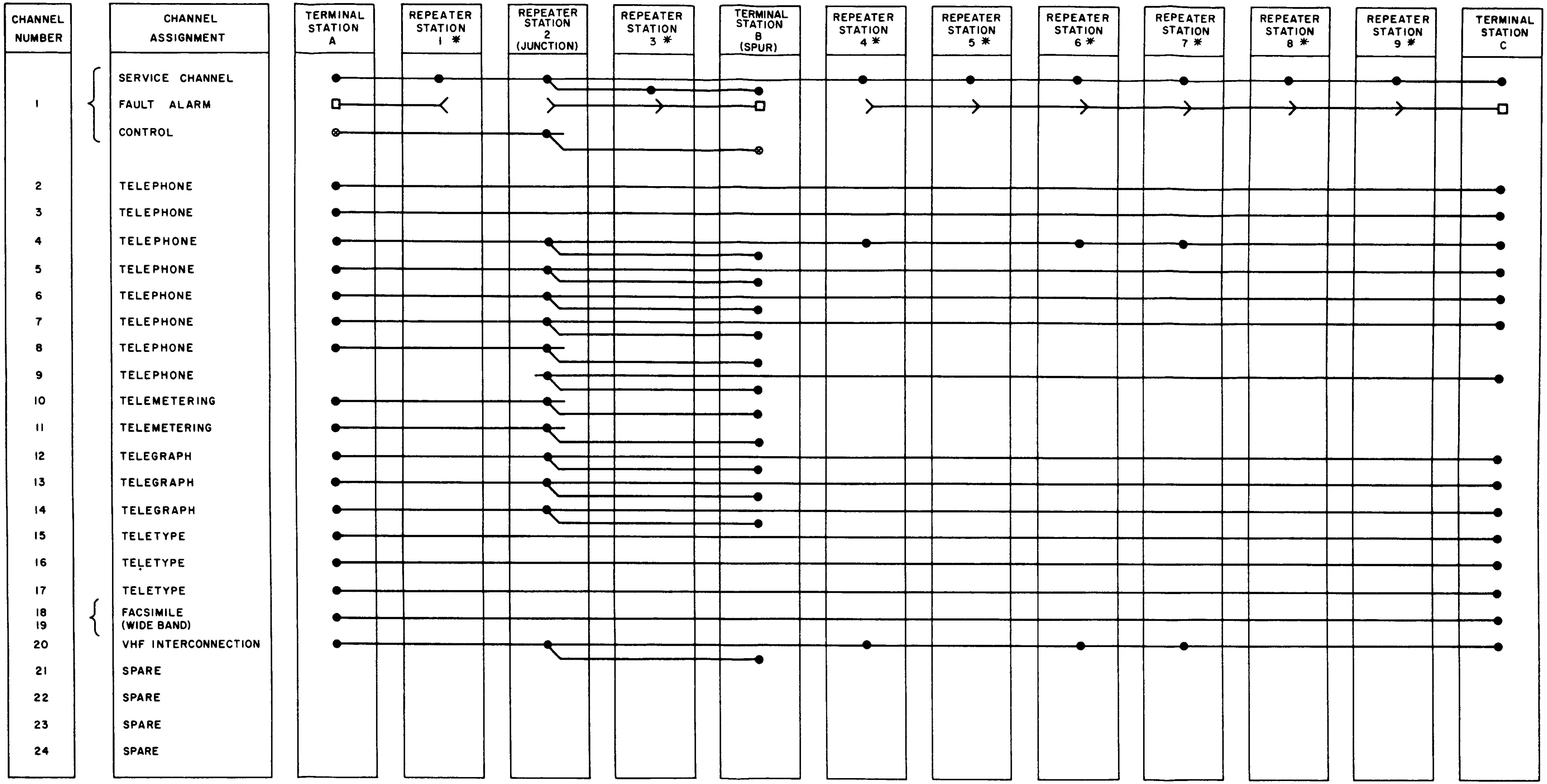
REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED

EQUIPMENT SCHEDULE

ITEM NO.	SIZE	PART NO.	Øh	Øv	REMARKS
ANT. NO. 1	6' DIA	V026 12D008-005	—	—	
ANT. NO. 2	6' DIA	V026 12D008-005	—	—	
REFL. NO. 1	8'x12'	V026 24P002-002	29°15'	118°26'	MOUNTED ON 20 FT. PYLON
REFL. NO. 2	8'x12'	V026 34P002-001	3°16'	41°35'	MOUNTED AT 225 FT. LEVEL
REFL. NO. 3	8'x12'	V026 34P002-002	9°52'	55°25'	MOUNTED AT 200 FT. LEVEL
PYLON NO. 1	20'	V026 12P012	–	–	
PYLON NO. 2	20'	V026 12P012	–	–	

NOTE:
1. ALL BEARINGS ON THIS SITE PLAN ARE TRUE BEARINGS
2. REFER TO TOWER MANUFACTURER'S DRAWINGS FOR DETAILS ON INSTALLATION OF PYLON FOUNDATIONS.
3. REFER TO DRAWING NO. 5502-3 FOR WAVEGUIDE INSTALLATION DETAILS
4. REFER TO DRAWING NO. 5512-13 FOR TOWER MODIFICATION.

Foldout 5-2. Typical Site Layout



NOTES

1. DENOTES CHANNEL DROPPED OR INSERTED
2. DENOTES SPUR SYSTEM JUNCTION POINT
3. □ DENOTES FAULT ALARM MONITORING STATION
4. > DENOTES FAULT REPORTING STATION
5. * DENOTES UNATTENDED STATION
6. DENOTES CONTROL FUNCTION

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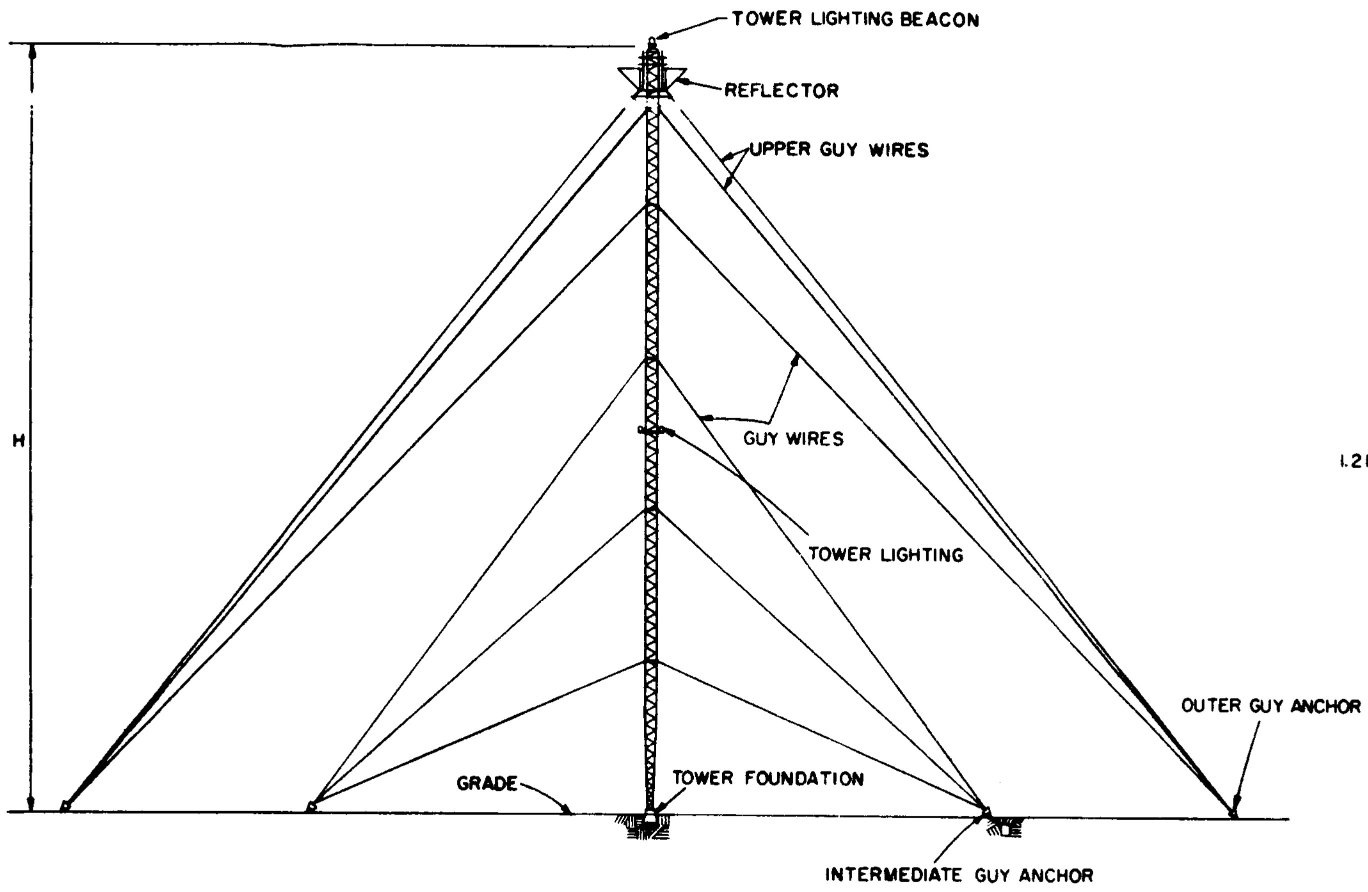
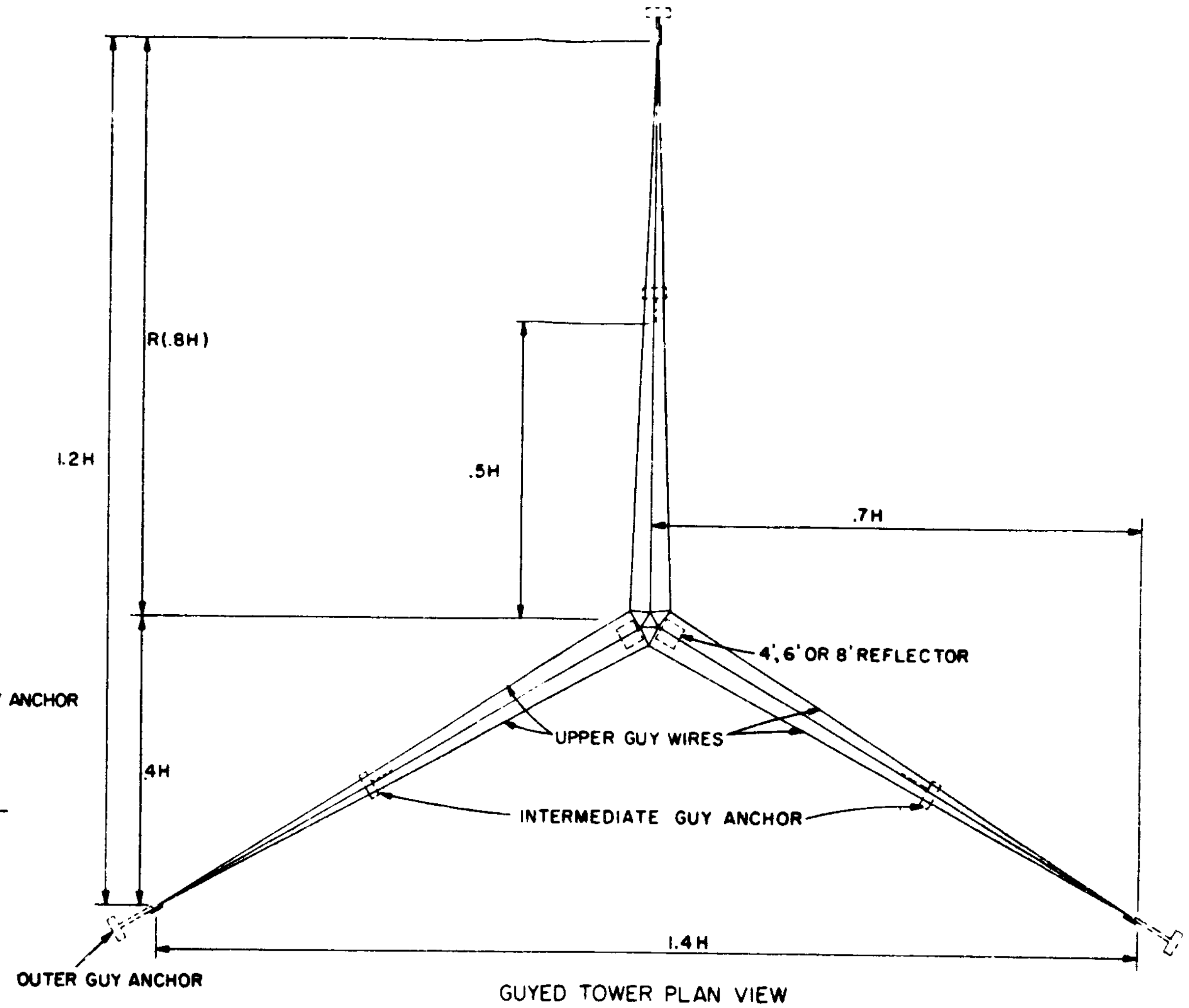
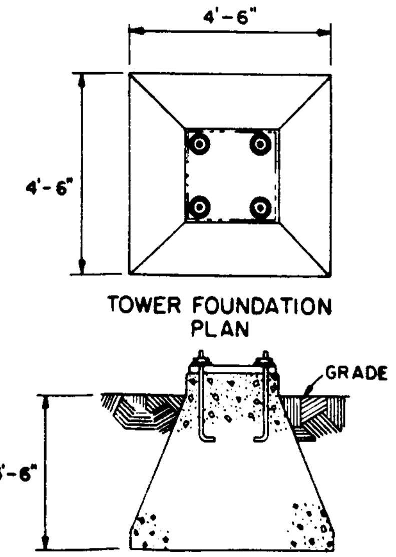
Foldout 5-3. Channelization Diagram



GUYED TOWER ELEVATION

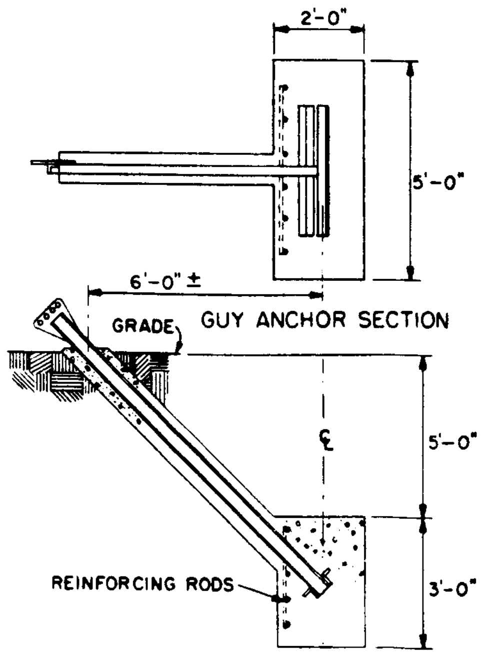


GUYED TOWER PLAN VIEW



TOWER FOUNDATION PLAN

TOWER FOUNDATION SECTION



GUY ANCHOR SECTION

GUY ANCHOR SECTION

NOTES

1. FOR COMPUTING GUYING AREA REQUIREMENTS AS INDICATED ON PLAN VIEW:
   H = HEIGHT OF TOWER
   R = GUY RADIUS - MAY EQUAL "H" AND SHALL NOT BE LESS THAN .8H
2. SIZE OF TOWER FOUNDATION & GUY ANCHORS SHOWN ARE TYPICAL FOR 250' TOWER AND WILL VARY DEPENDING ON TOWER HEIGHT, DESIGN LOAD, AND SOIL CONDITIONS.
3. TOWERS ARE PAINTED AND LIGHTED AS REQUIRED BY FCC & CAA REGULATIONS.
4. INTERMEDIATE GUY ANCHORS ARE NORMALLY REQUIRED FOR TOWERS OVER 200 FT. IN HEIGHT.
5. TOWERS ARE OF TRIANGULAR CROSS-SECTION WITH A 36" NOMINAL FACE WIDTH.
6. TOWERS AT LEVEL OF TOP GUY ATTACHMENT HAVE EXPANDED SECTION TO PROVIDE INCREASED TORQUE RESISTANCE.

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Foldout 15-1. Typical Guyed Tower