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.

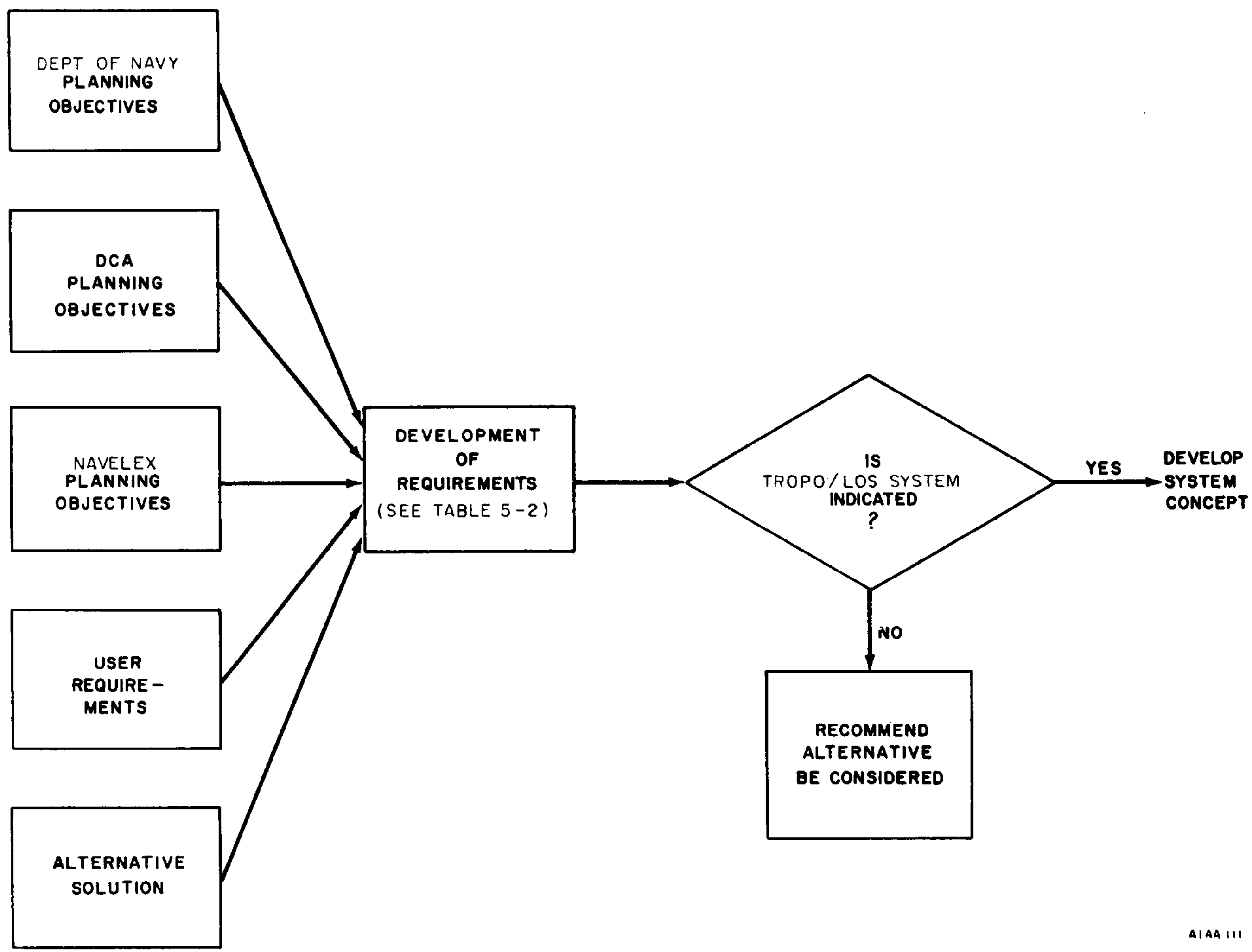

Figure 5-1. Analysis of Requirements

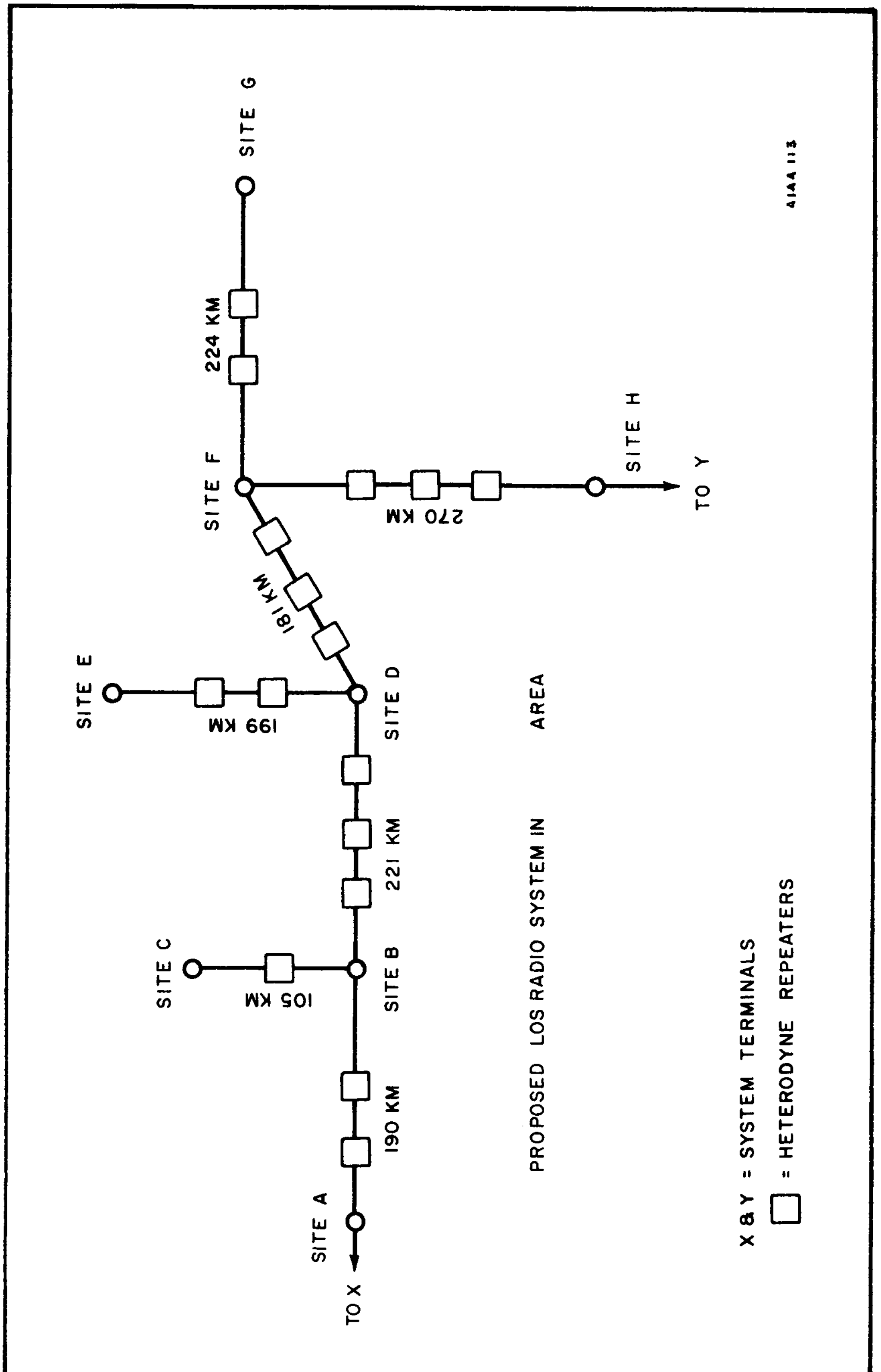

Figure 5-2. Initial System Concept, Typical

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).

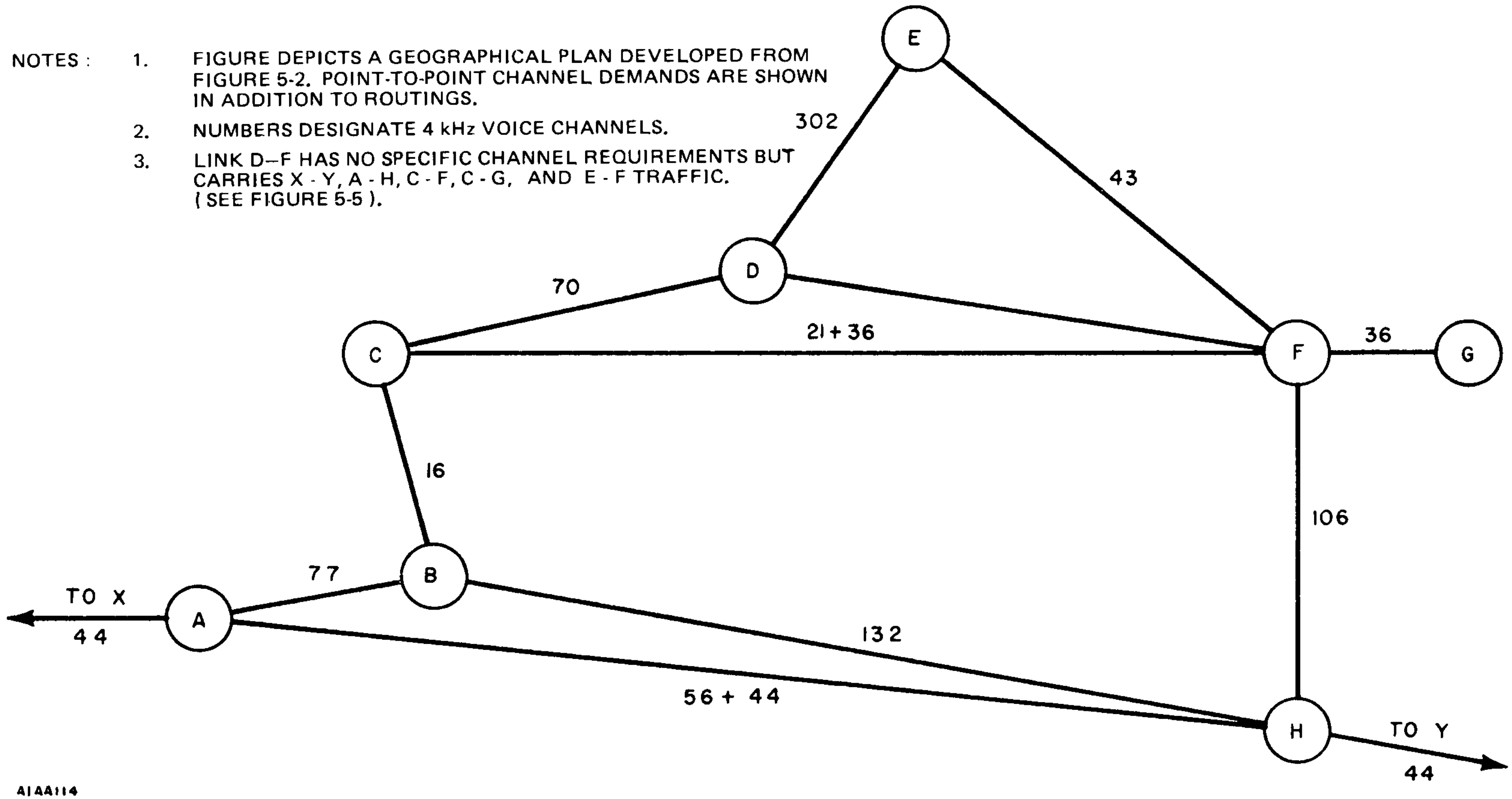

Figure 5-3. System Circuit Requirements, Sample

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.

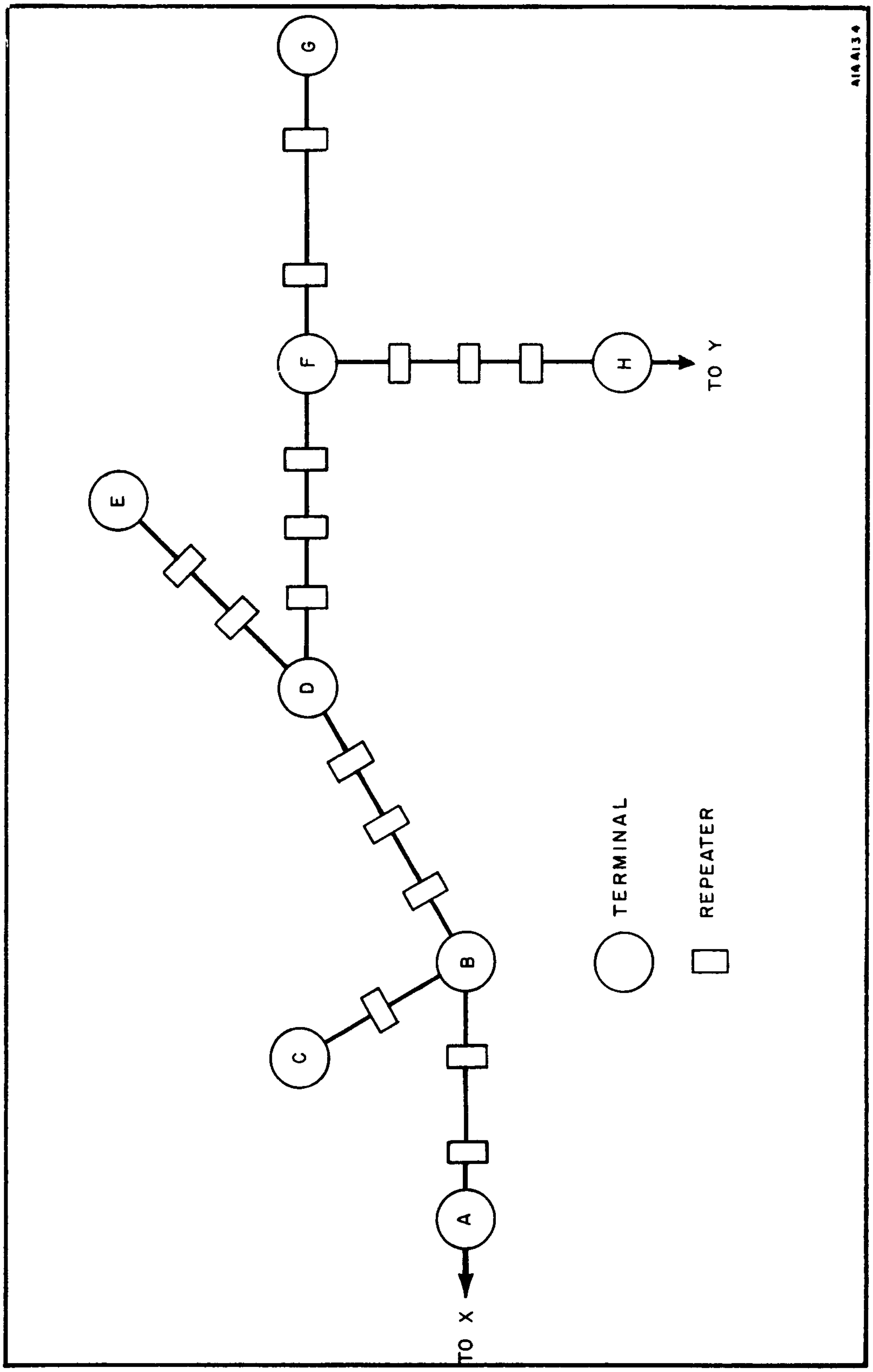

Figure 5-4. System Routing, Typical

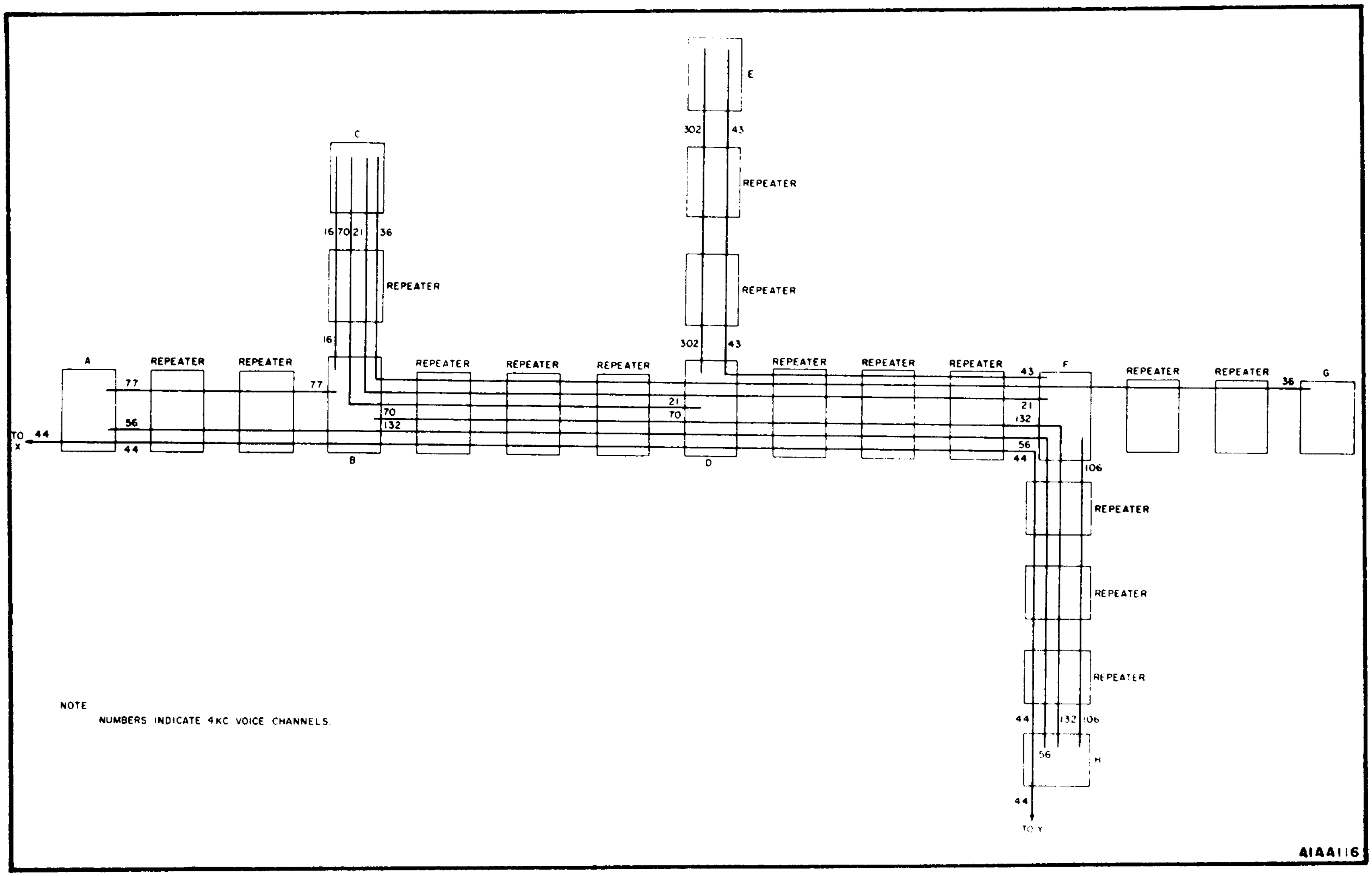

Figure 5-5. System Trunking Diagram, Typical

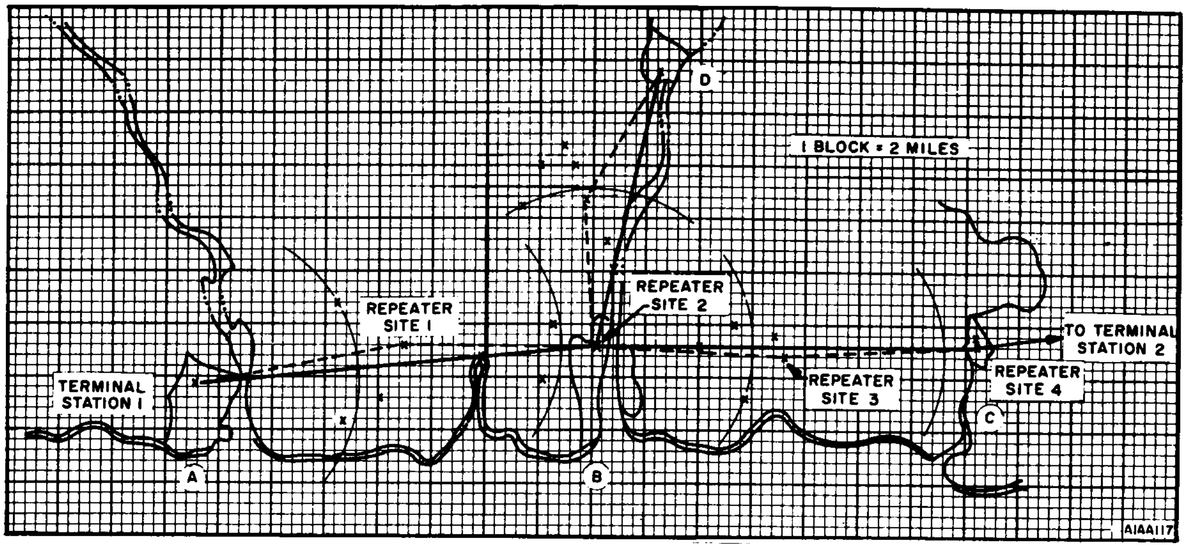

Figure 5-6. Map of System Area Showing Tentative Site Location

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.

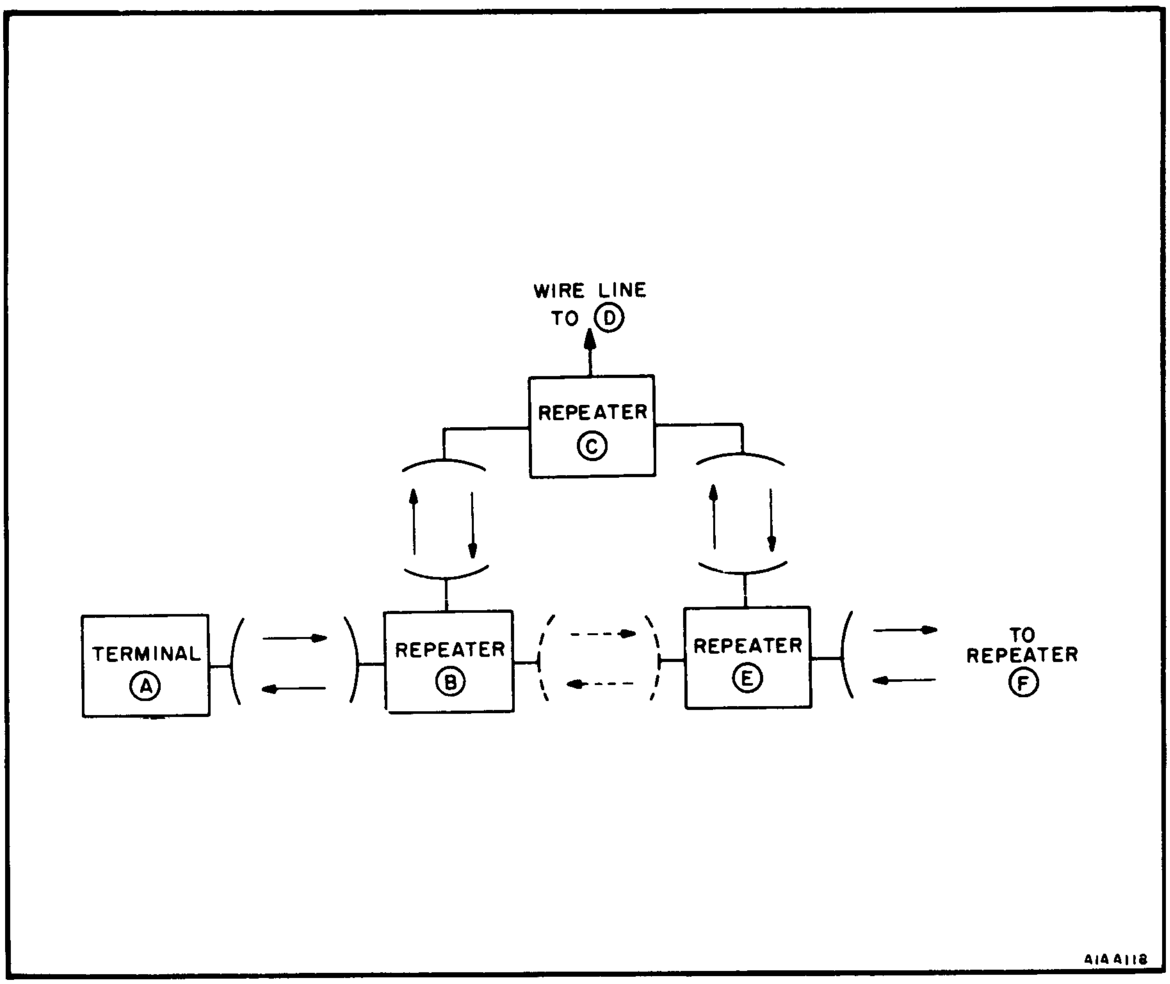

Figure 5-7. Tandem Repeater Spur

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.

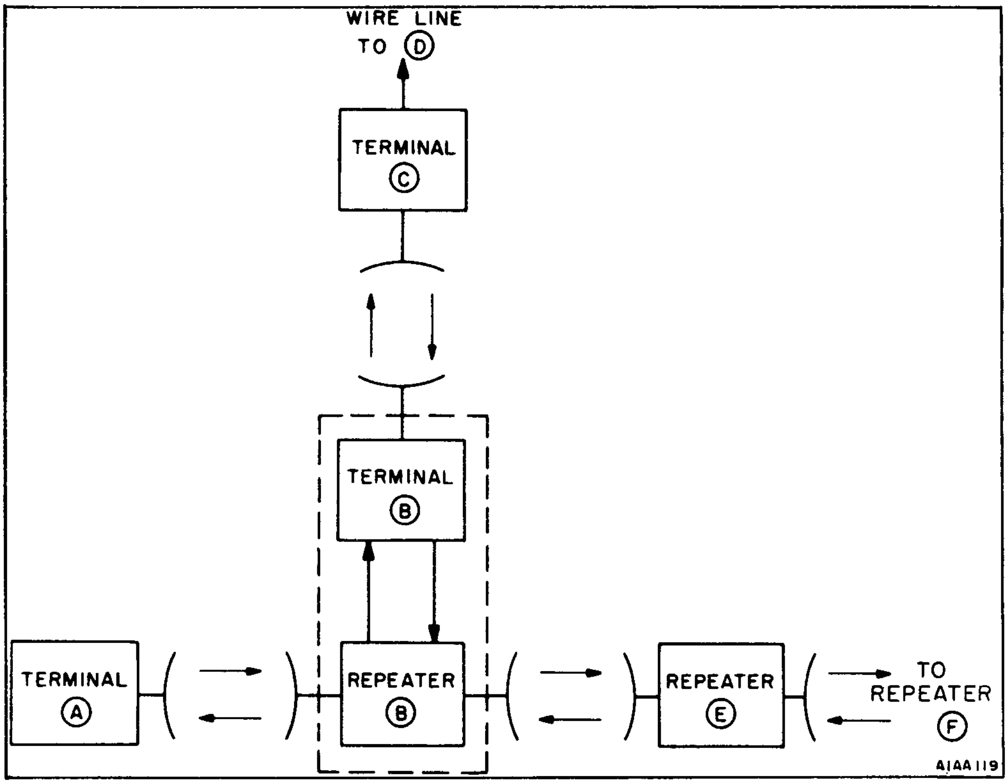

Figure 5-8. Terminal-to-Terminal Spur

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.

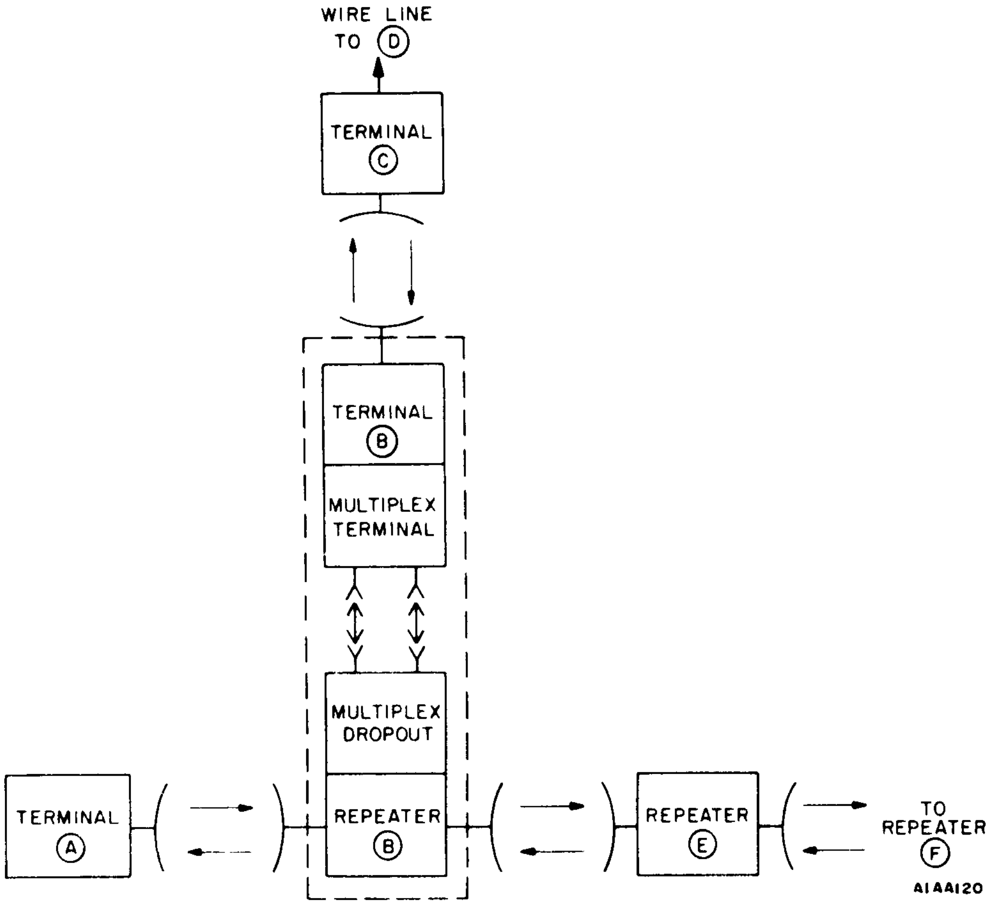

Figure 5-9. Drop Repeater With Terminal-to-Terminal Spur

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.

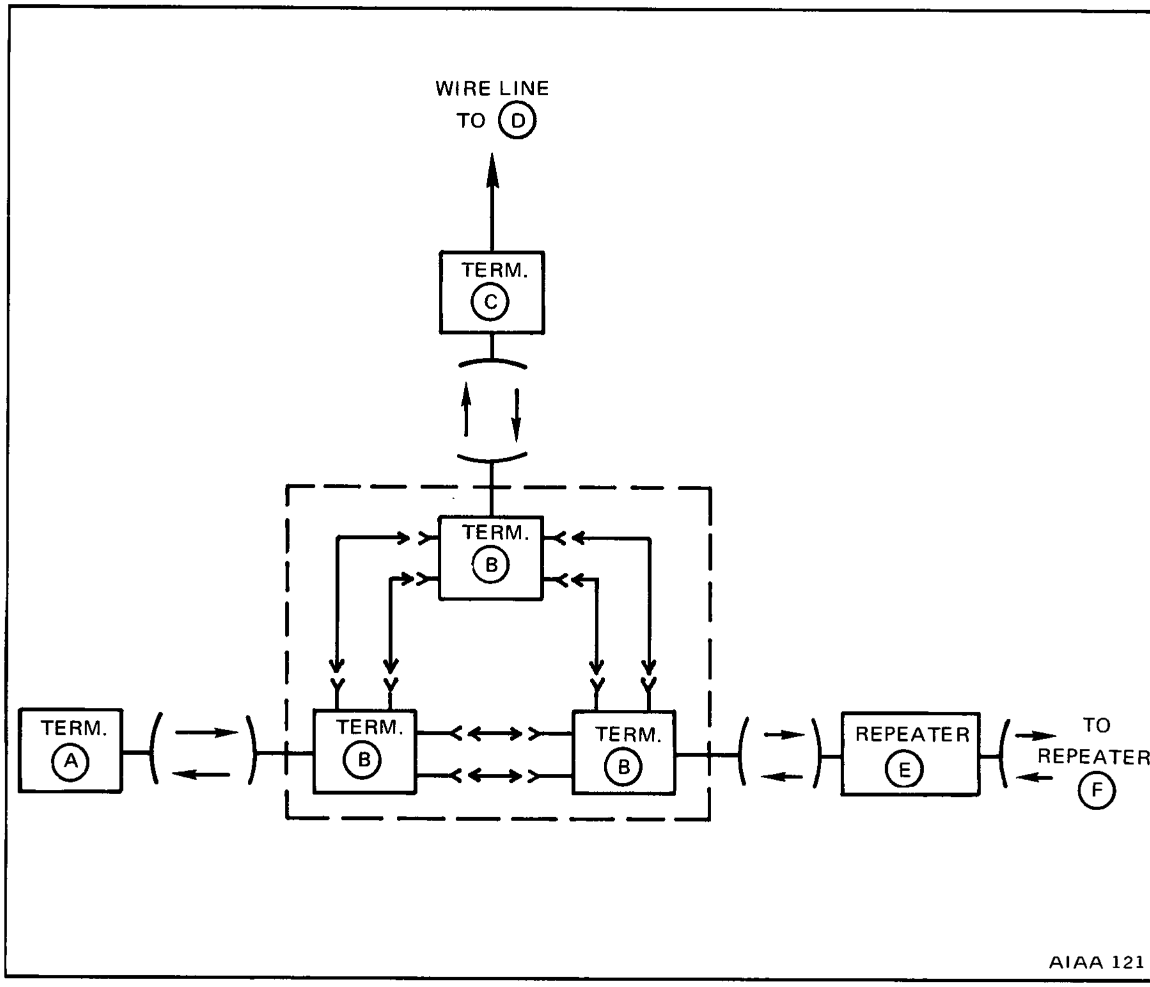

Figure 5-10. Back-to-Back Terminal With Terminal Spur

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.

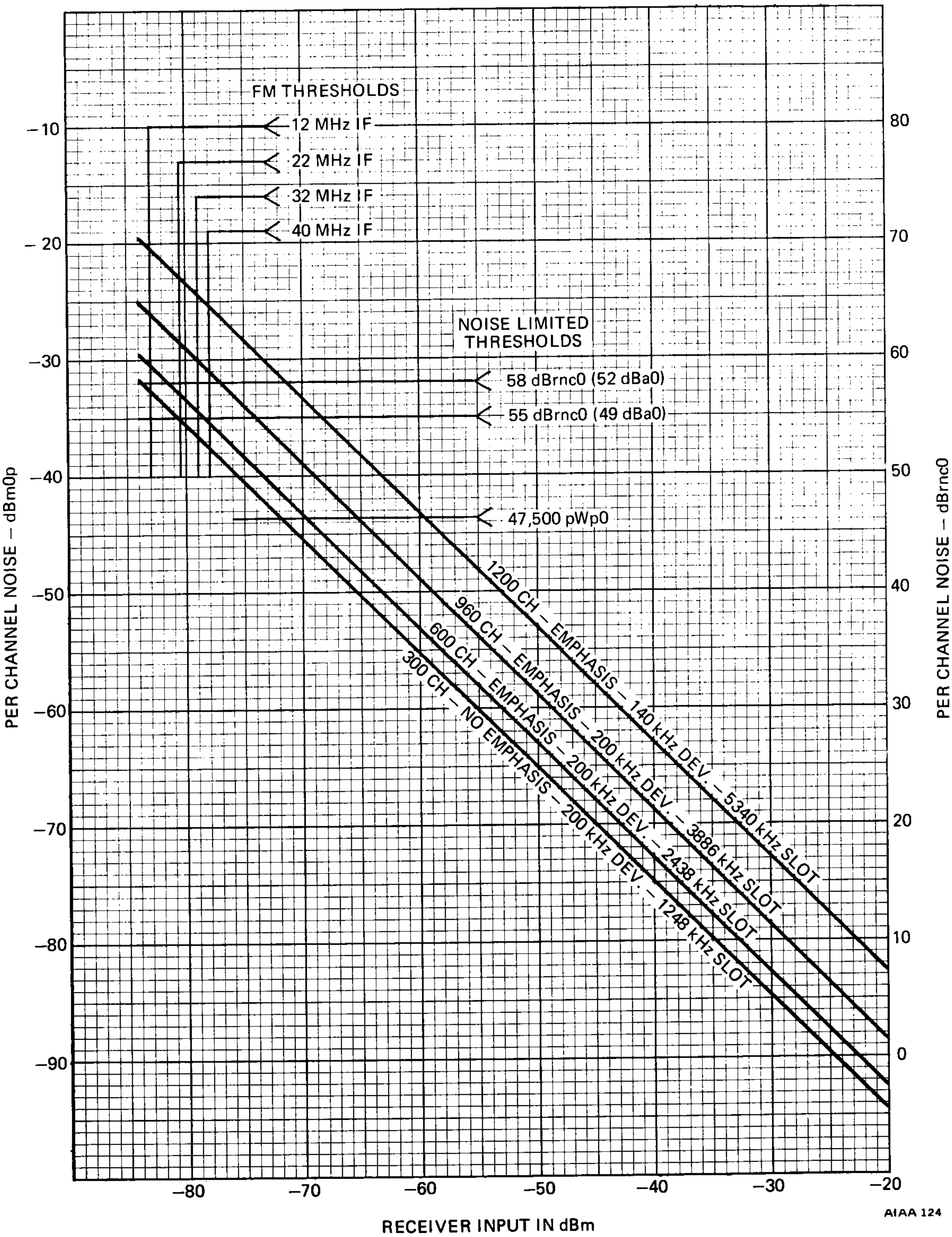

Figure 5-12. Receiver Thermal Noise (10 dB Noise Figure Assumed)

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.