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

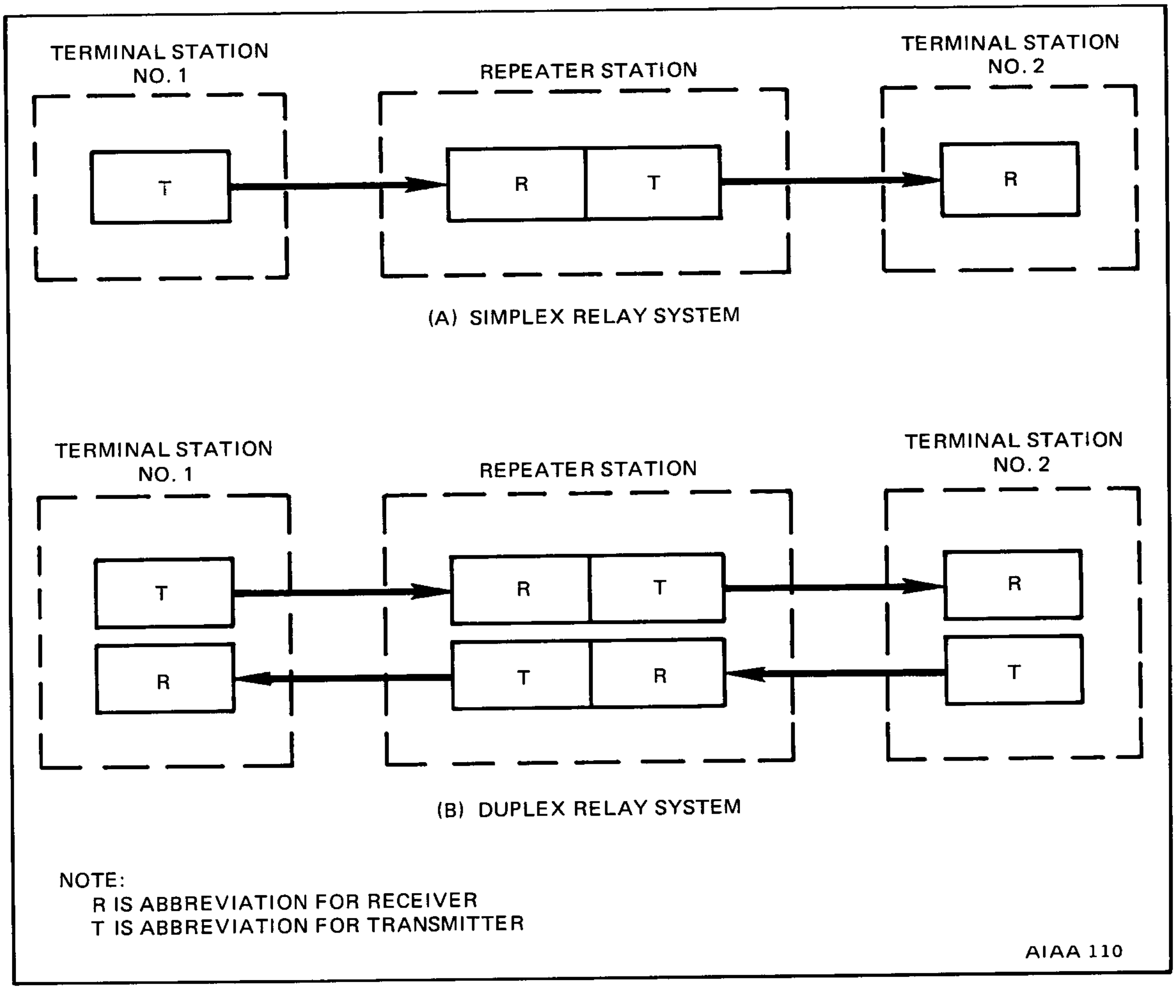


Figure 9-1. Basic Radio Relay System, Block Diagram

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.

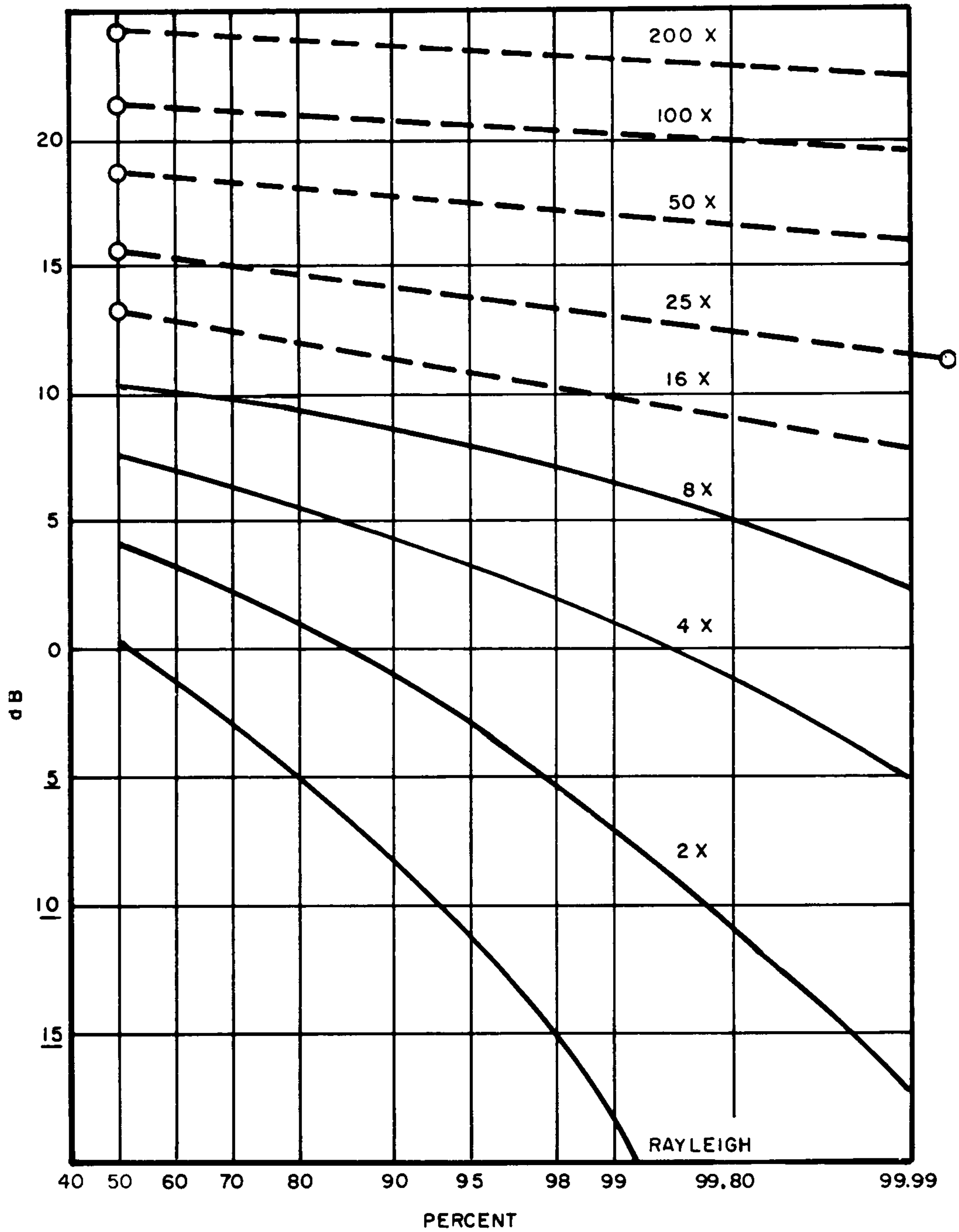
9.3.2 Frequency Diversity

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.



NOTE: DRAWN OUT LINES AND POINTS CALCULATED.
DOTTED LINES ESTIMATED
RAYLEIGH = NO DIVERSITY (ORDER 1)
X = QUANTITY OF DIVERSITY - CHANNELS

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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

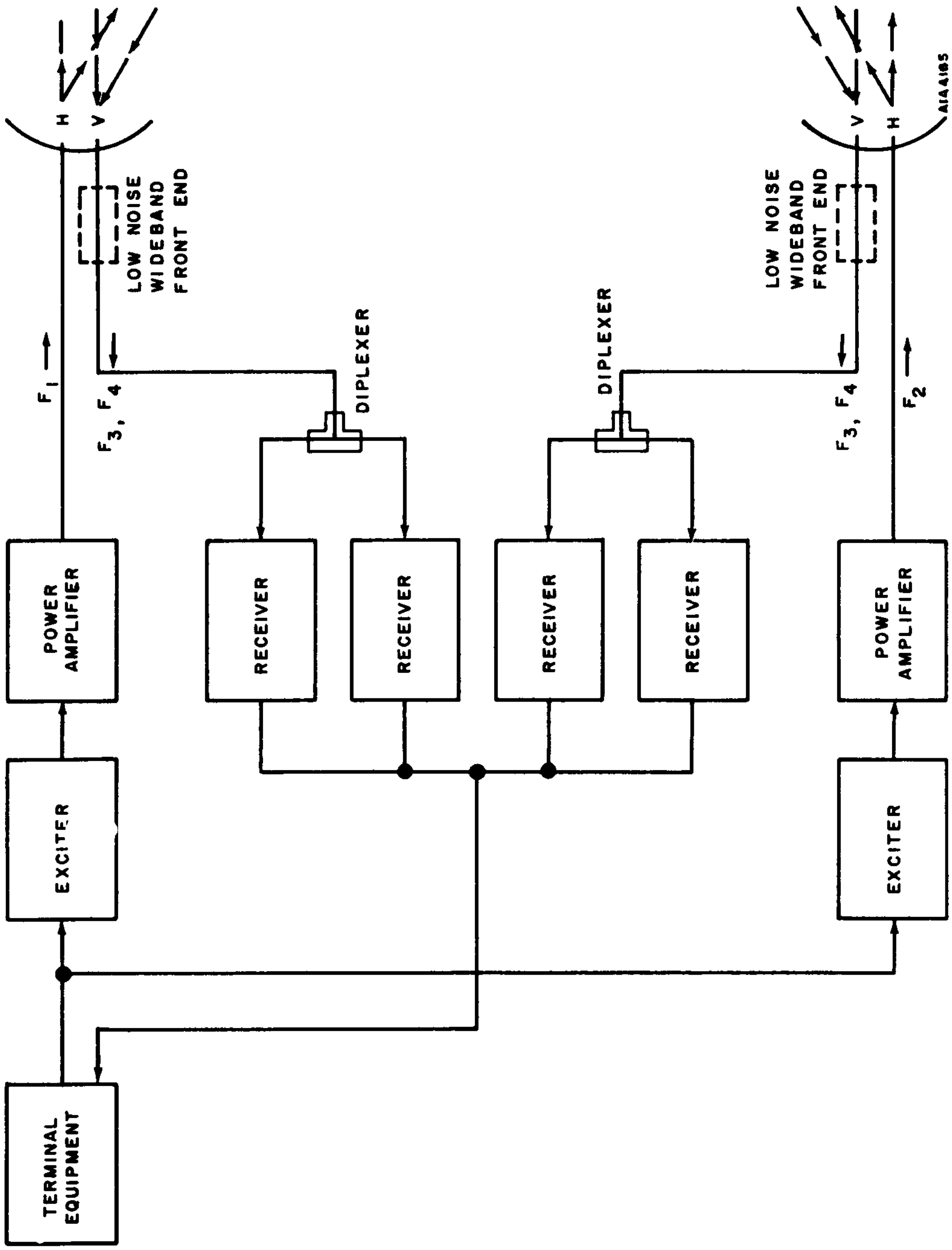

Figure 9-3. Quadruple Diversity Configuration, Receivers Diplexed

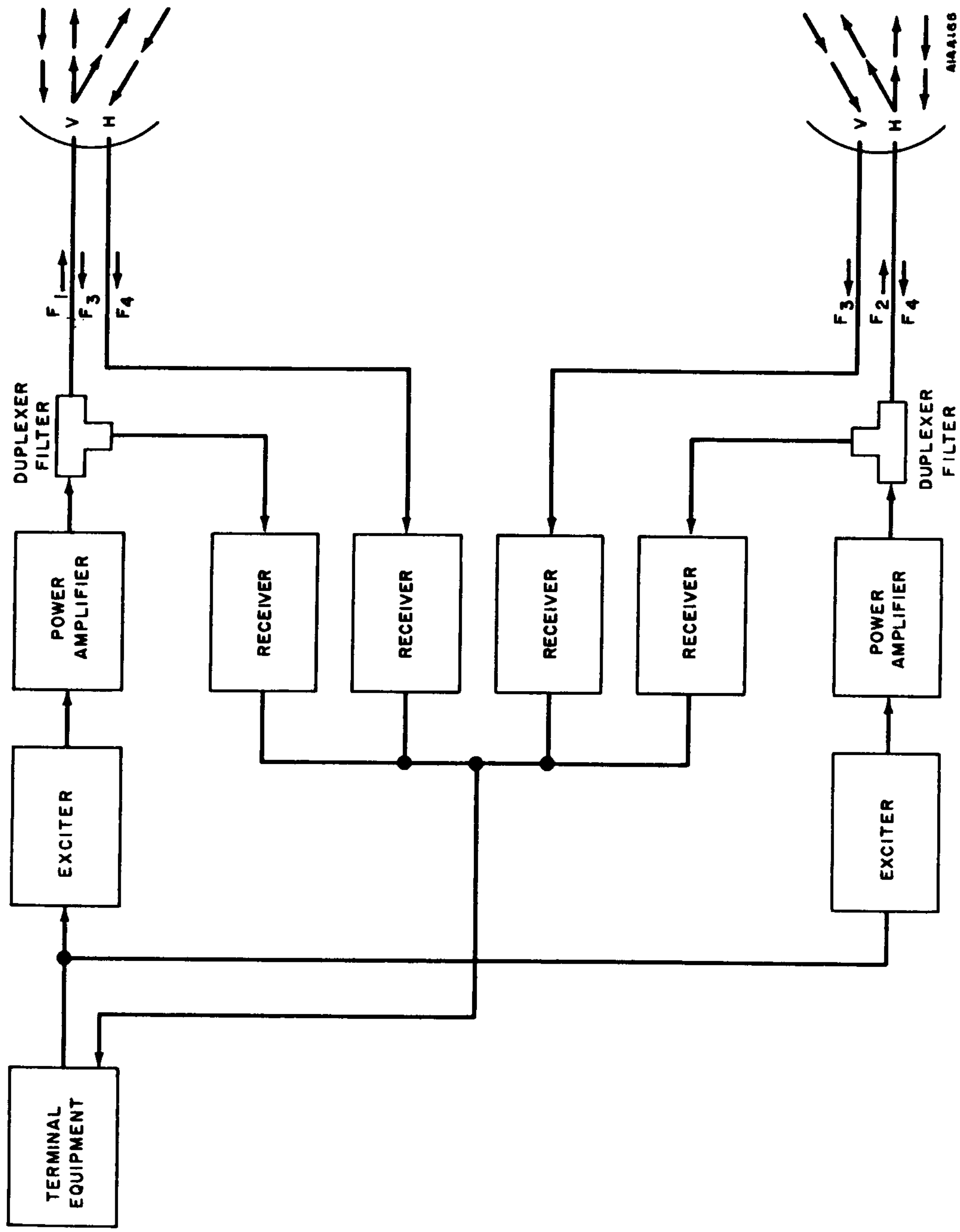

Figure 9-4. Quadruple Diversity Configuration, Two Receivers Duplexed

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.