RADIO ENGINEERING

POINT-TO-POINT RADIO

GENERAL CONSIDERATIONS AND TRANSMISSION DESIGN

CONTENTS PAGE

1. GENERAL

A. Application

1.01 The use of VHF and UHF radio facilities to provide short haul toll, rural subscriber, or other point-to-point services may be attractive for several reasons and should be considered where small numbers of circuits are required over distances up to about 40 miles, or somewhat further in exceptional cases. Propagation characteristics of frequencies used in this service are such that optical line of sight beween transmitting and receiving antennas is desirable; however, this is not a mandatory requirement and the absence of such an optical path need not necessarily rule out the use of VHF transmission. These facilities are most useful in situations where natural obstructions or other conditions make construction of wire plant over a direct route impossible or where the nature of the terrain is such that installation of new pole line facilities would involve greater than average cost. Use of radio to supply entire circuit groups or to supplement other types of plant may also be indicated in cases where service continuity is an important consideration, or where sudden or seasonal demands can not be met by other means. In common with other types of radio equipment, VHF and UHF circuits offer an advantage from a maintenance viewpoint since all parts of a particular installation are concentrated at only a few locations, reducing traveling and access problems to a minimum.

1.02 Information in this section was formerly covered in Section 940-102-101.

B. Frequency Choice

1.03 Radio toll and subscriber's services will generally be provided using frequencies in the 150- or 450-megahertz regions. Transmitters, receivers, and control apparatus will ordinarily be those produced commercially for mobile radio base station application. When used for multiplexed systems, the radio equipment must be modified to provide a suitable baseband for the carrier equipment chosen. Radio units will be connected to wire facilities through terminating equipment designed to maintain satisfactory voice-frequency transmission and to permit signaling and supervision as required.

1.04 Point-to-point radio installations associated with private mobile systems may operate on frequencies in several ranges depending upon the individual situation and the class of service. They can be used on a two-way basis to provide control and talking facilities between a control point and a remote base station, or they may be used on a one-way basis to connect a remote base receiver into a network or to perform other similar functions. Since each private radio system is apt to be custom-built to meet the requirements of the particular user, specific details of operation will not be included in this section.

1.05 Frequencies assignable to point-to-point installations in the United States are available to these services only on a shared basis and must be used in such a way as to assure that interference will not occur.

1.06 When point-to-point installations operating on frequencies below 470 megahertz are wholly or in part to supply common carrier channels or services auxiliary to common carrier installations (order-wire, or alarm, etc), they will operate on frequencies available to common carriers. In addition, the Telephone Companies are sometimes called upon to install and maintain point-to-point facilities using frequencies assigned to the industrial, safety, government, or other noncommon carrier services. Frequency choice will be dictated by transmission requirements within the limitations of the appropriate FCC regulations.

1.07 The use of frequencies in the 72- to 76-megahertz region is not permitted at locations near television stations operating on Channels 4 and 5. It should also be recognized that television receiving techniques are such that the use of these frequencies at all but the most remote locations, where no attempt is made to receive television Channels 4 and 5, will result in interference to television reception. This interference will become progressively more severe as the distance to the television transmitter increases and the use of these frequencies is not recommended in other than very exceptional circumstances.

1.08 Situations may be found in which systems operating in either the 150- or 450-megahertz range are received by television receivers. This is possible because of the relatively poor selectivity of such receivers and the relatively high sensitivity at their many spurious response frequencies. When such conditions are found, they can frequently be corrected by the use of "traps" or filters cut from transmission line and installed at the television receiver. Such traps would be tuned to the frequency of the interfering transmitter. In situations where this is not effective in preventing the reception of telephone conversation by unauthorized persons, it may be desirable to install B3 privacy units on the voice-frequency channel of point-to-point radio systems. Such privacy units, of course, will not be required on carrier derived channels.

2. BASIC ARRANGEMENTS

A. General

2.01 Point-to-point systems, whether used as part of the general telephone network or as part of a private communication system, may have many similar characteristics. This section discusses a few of the more important of these and provides a number of block diagrams of arrangements which might be used to satisfy specific requirements.

2.02 In cases involving short jumps, it may be possible to locate radio equipment at existing central offices or in other existing buildings, taking advantage of available land, building, and power supplies. In case of longer circuits or in cases where short radio paths are not satisfactory, it will be necessary to weigh the cost of higher antenna structures near existing buildings or of greater transmitter power against the cost of land, buildings, etc, at a more favorable location.

2.03 It is generally desirable to have radio transmitters and receivers at the same location. In the case of systems using simultaneous transmission and reception, it is necessary to isolate the receiver radio frequency input circuit from the transmitter output. This may be accomplished by the use of separate transmitting and receiving antennas with suitable physical separation or through the use of filter networks or diplexers. (See Part 7 of this section.)

2.04 Antennas having directional characteristics are generally employed for both transmitting and receiving because of the "gain" obtainable. They may be supported by towers, poles, buildings, or by short structures of various types on existing buildings, as appropriate.

2.05 Signaling on single-channel VHF radio circuits may be transmitted by "carrier on" — "carrier off" conditions where only "on-off" supervision is required. Dial pulsing, telegraph, or other data must be transmitted by means of tone arrangements because of equipment characteristics. Channel signaling (dial or ringdown) in multiplexed installations will always require tone arrangements. These details are discussed in Bell System Practice, Section 940-250-103.

B. General Service

2.06 The VHF radio toll and rural subscriber systems operate on a "4-wire" basis with transmission in opposite directions utilizing separate frequencies. Receivers in all cases operate continuously and it is common practice to operate transmitter filaments or heaters continuously. Figures 1 to 7 show typical layout diagrams while separate Bell System Practice Sections will cover detailed equipment arrangements for standardized systems.

C. Private Systems

2.07 Facilities associated with private radio installations may operate on a 4-wire basis or they may be used on a single-frequency switched carrier basis to provide a "2-wire shared time" arrangement. Some installations may be made on a two-frequency switched carrier basis in order to provide a signaling channel along with the voice-frequency path. Figures 8 to 12 show several possible service arrangements. Other applications of radio will occur to the engineer and the individual installation will involve application of the principles of this section within the general limits of FCC regulations.

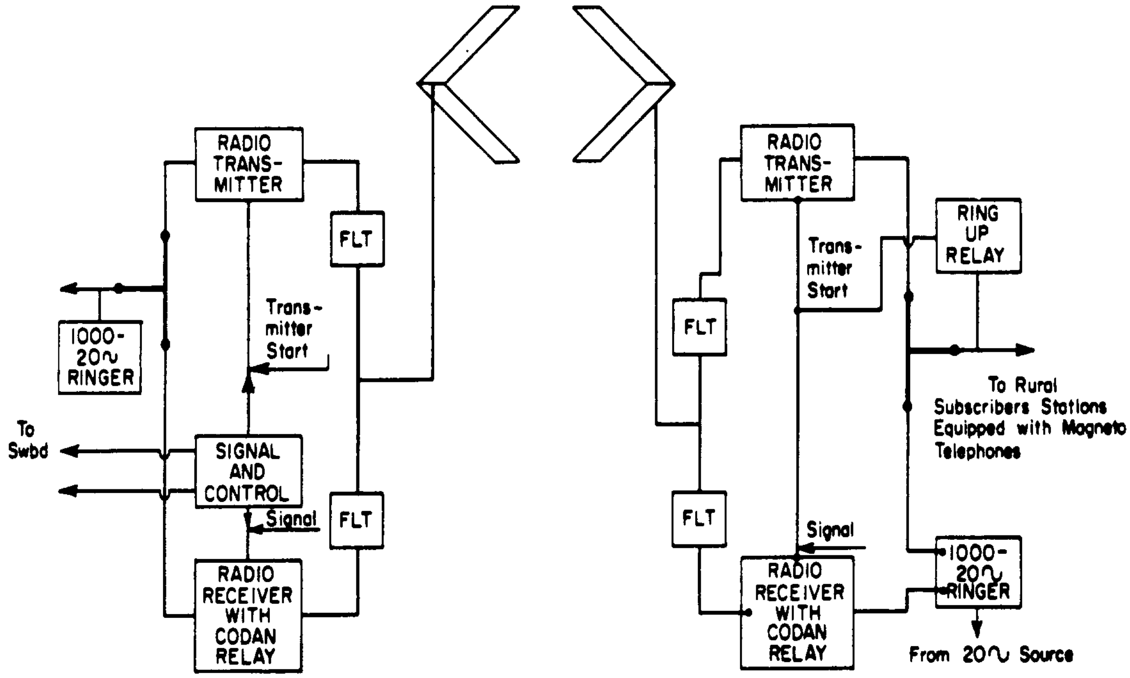


Fig. 1 — Typical Rural Subscriber's Circuit with Both Transmitters under Control of Operator

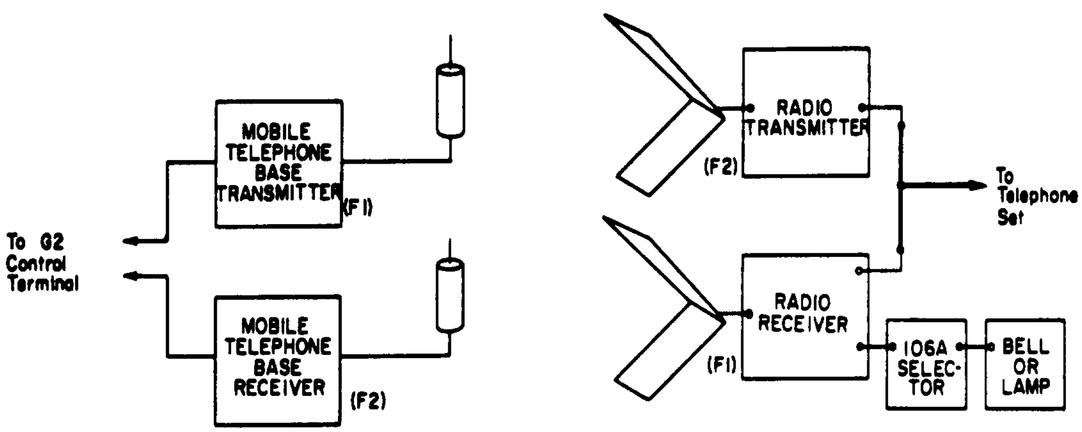


Fig. 2 — Rural Subscriber's Station Arranged to Operate with Existing Mobile Service Base Station — Subscriber's Station May Be Continuous Carrier or Push-to-Talk — (Requires Modification of Base Station License)

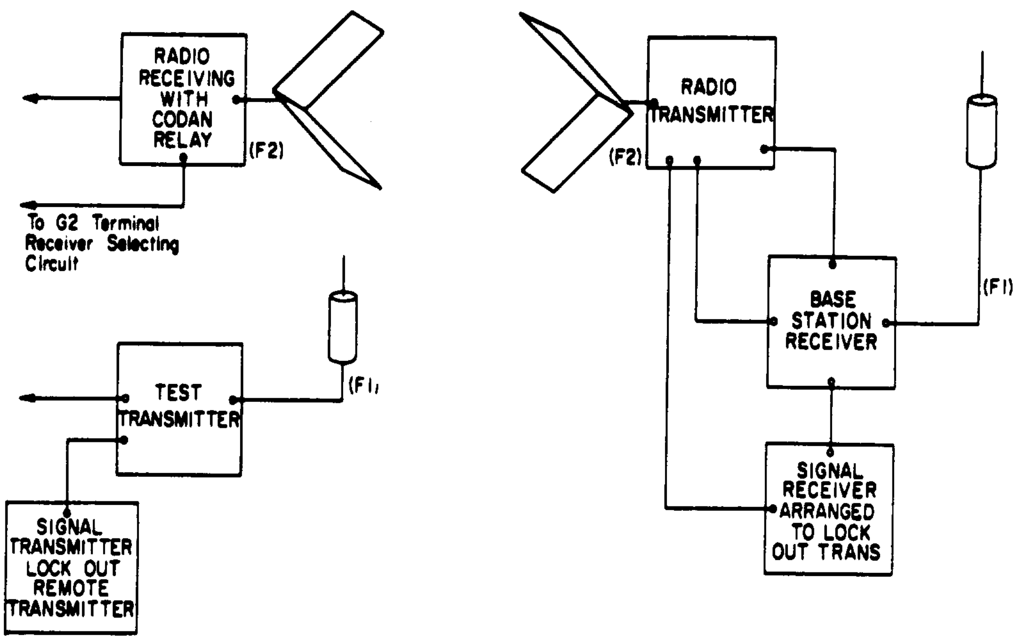


Fig. 3 — Point-to-Point Installation Arranged to Connect Base Receiver of a Mobile Telephone System to the G2 Terminal — Supervision of the Remote Transmitter Is Provided through Existing Test Transmitter

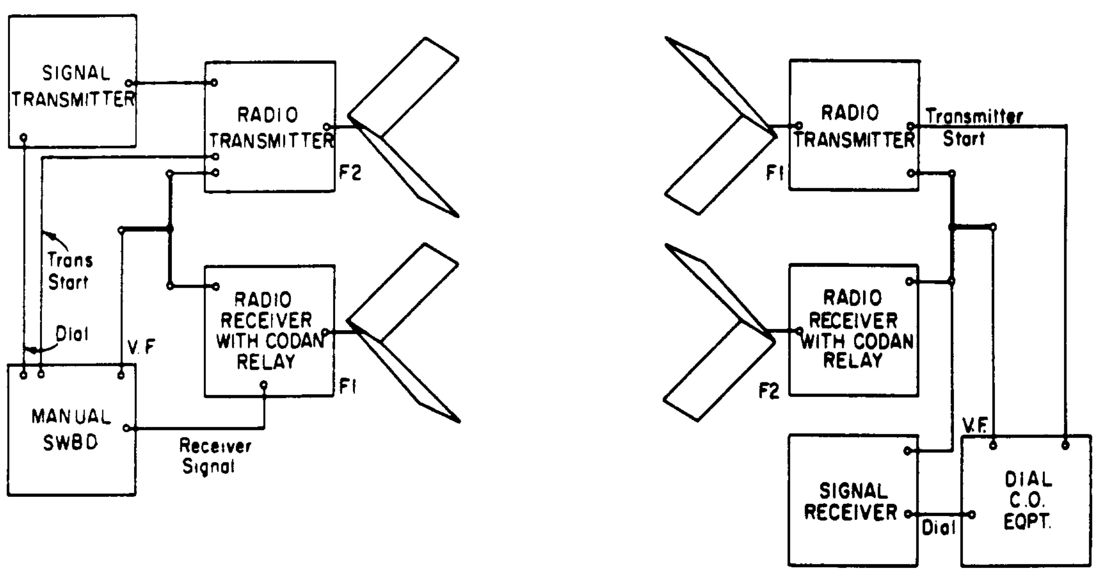


Fig. 4 — Short Haul Toll Circuit — Manual to Dial — May Be Arranged for Ringdown or Automatic Signaling from Dial Equipment to Manual Office

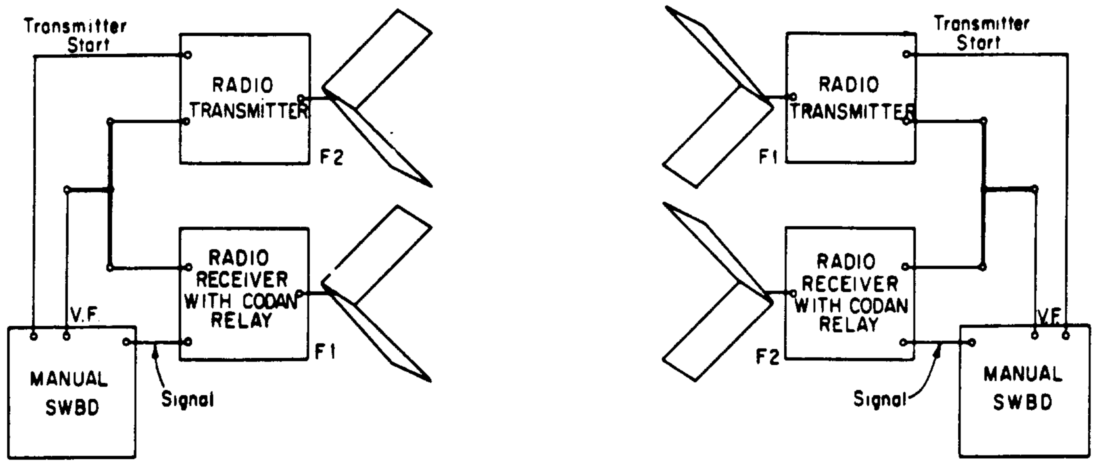


Fig. 5 — Short Haul Toll Circuit — May Be Arranged for Ringdown or Automatic Signaling

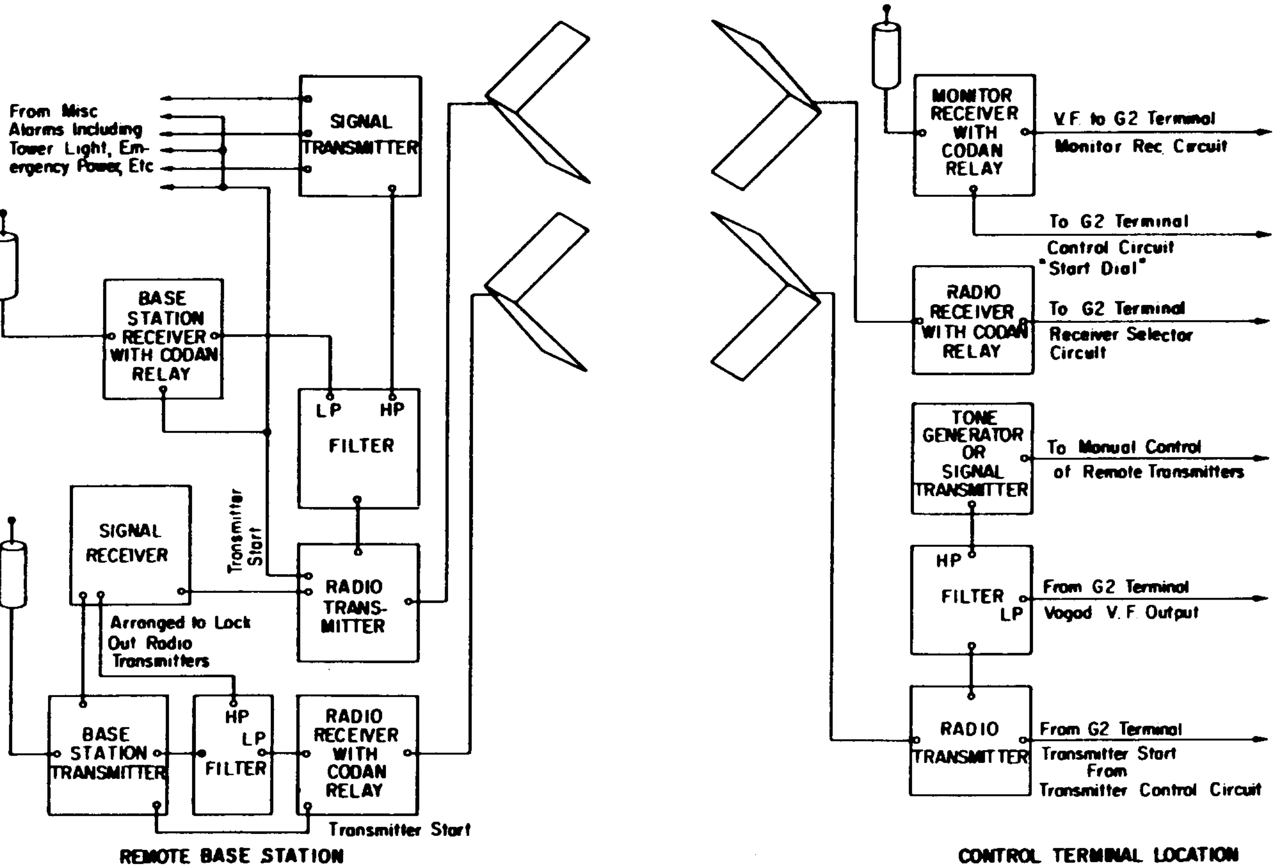


Fig. 6 — Point-to-Point Installation Arranged to Connect Mobile Telephone Base Station to Control Terminal and to Provide Supervision of Remote Transmitter

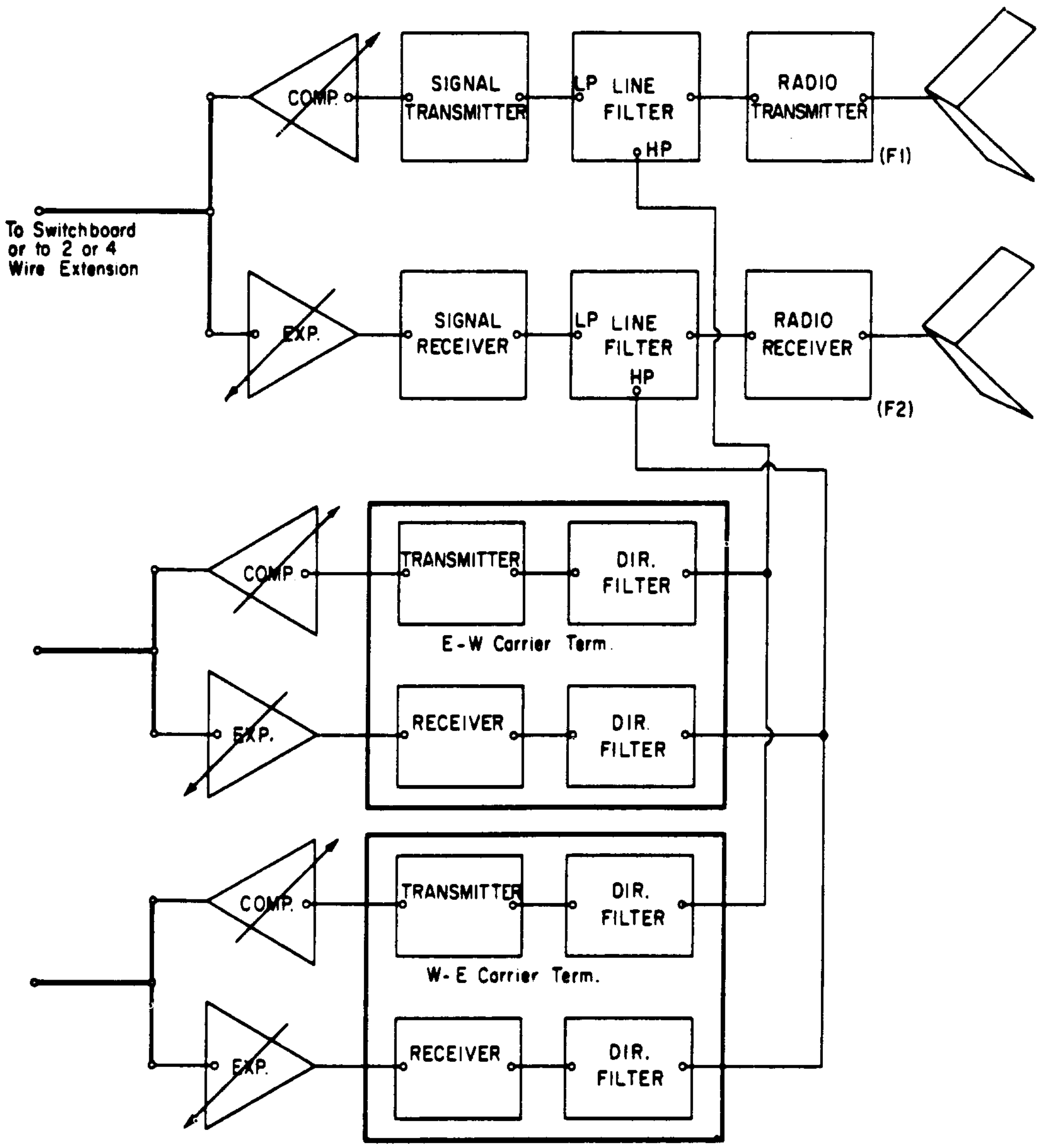


Fig. 7 — VHF Radio Terminal Arranged to Provide Voice–Frequency Channel Plus Two Carrier Derived Channels — Signaling May Be Ringdown or Dial as Required — May Operate with Continuous Radio Carrier or with Transmitters under Control of Associated Telephone Equipment

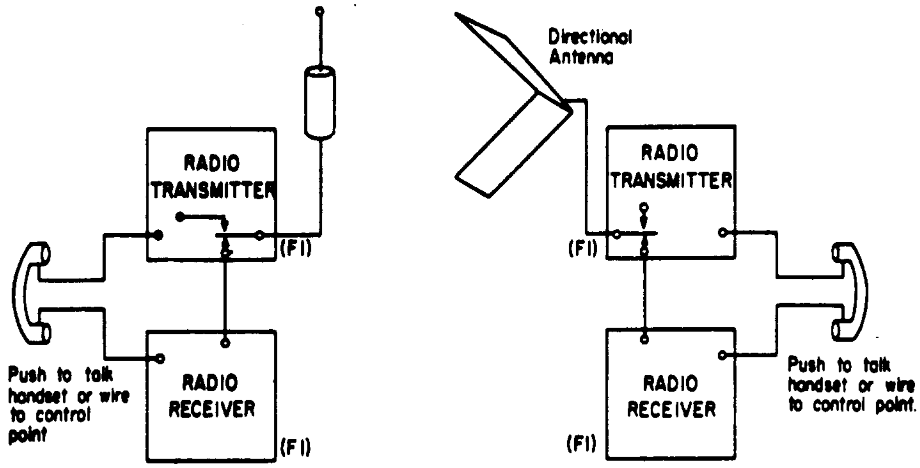


Fig. 8 — Point-to-Point Station Arranged to Operate on Single-Frequency Switched Carrier Basis in Conjunction with a Private Mobile Service Base Station

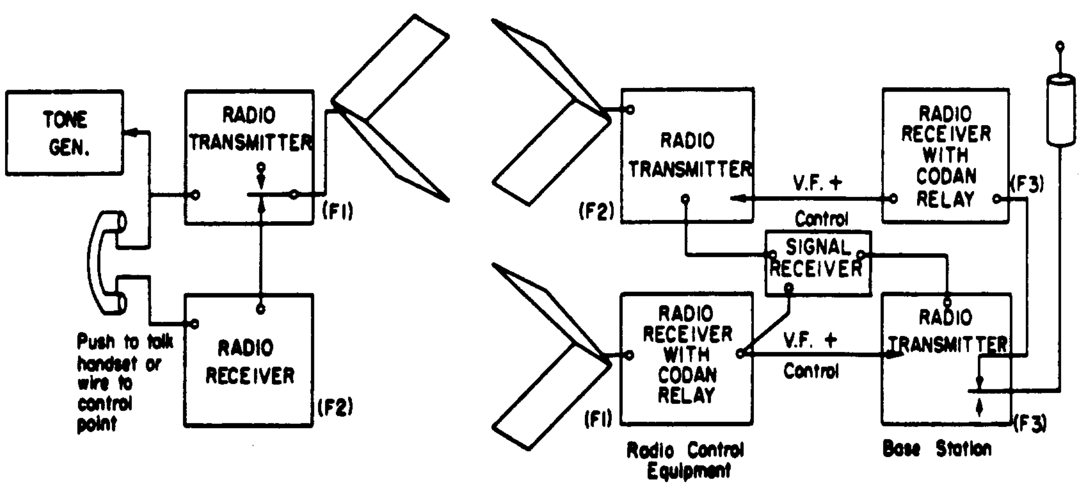


Fig. 9 — Point-to-Point Station Arranged to Operate on a Two-Frequency Switched Carrier Basis Connecting Control Point with a Private Mobile Base Station — Signaling Equipment Arranged to Lock Out Remote Transmitters under Control of Operator

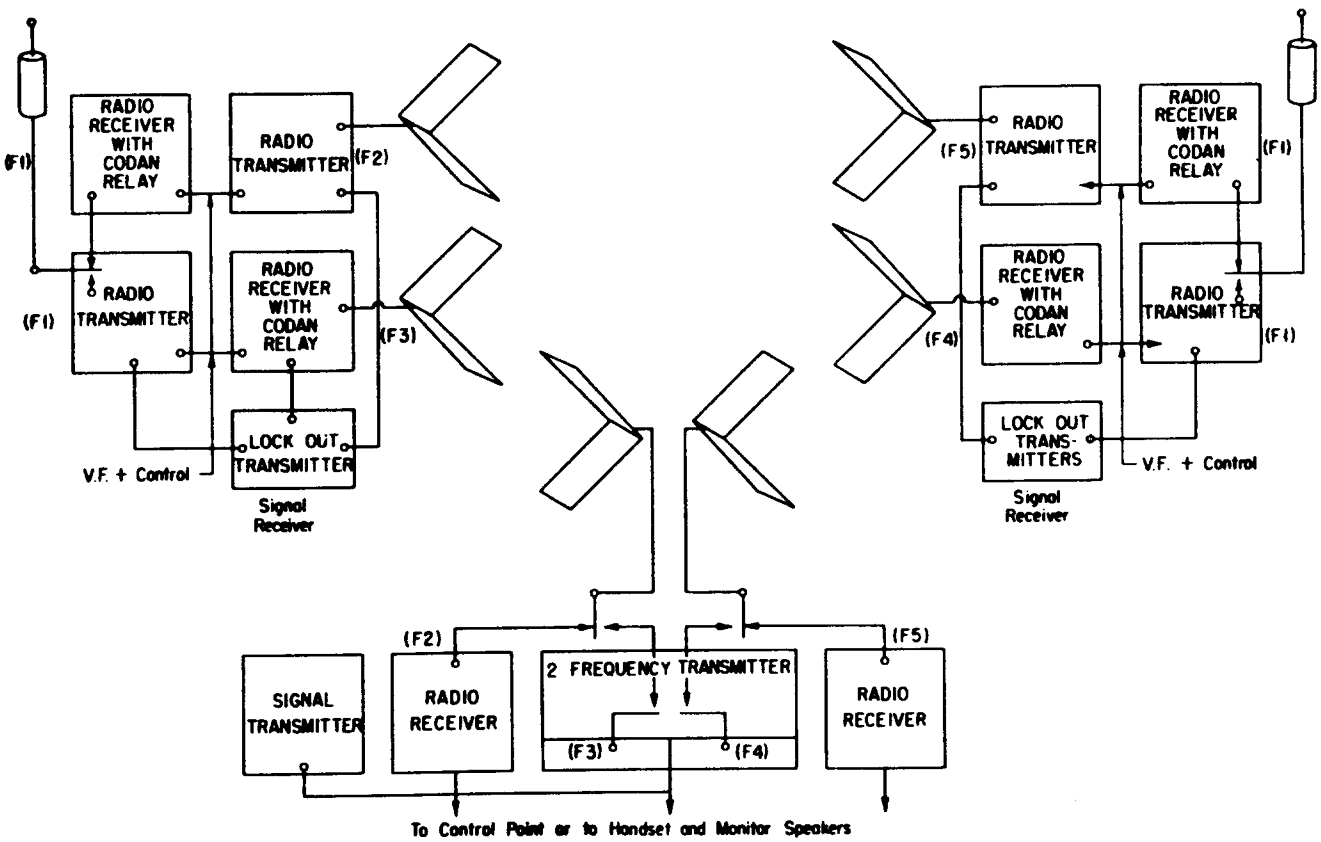


Fig. 10 — Point-to-Point Radio Installation Arranged to Connect Control Point to Either of Two Base Stations of a Private Mobile Radio System — Tones Provide Lockout Control of Unattended Transmitters

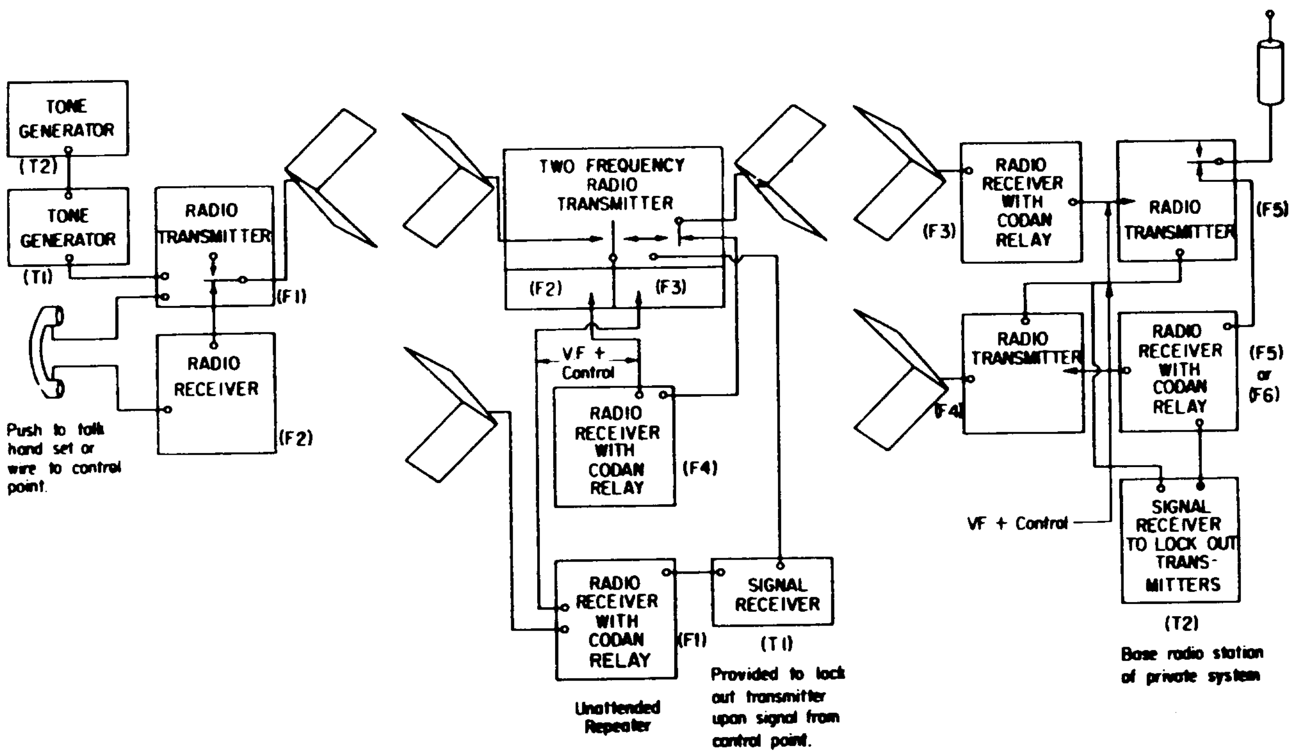


Fig. 11 — Repeatered Point-to-Point Installation Arranged to Control Base Station of Private Mobile Radio System — Two-Frequency Switched Carrier Control Circuit — One– or Two–Frequency Switched Carrier Mobile System — Tone Lockout Control of Unattended Transmitters

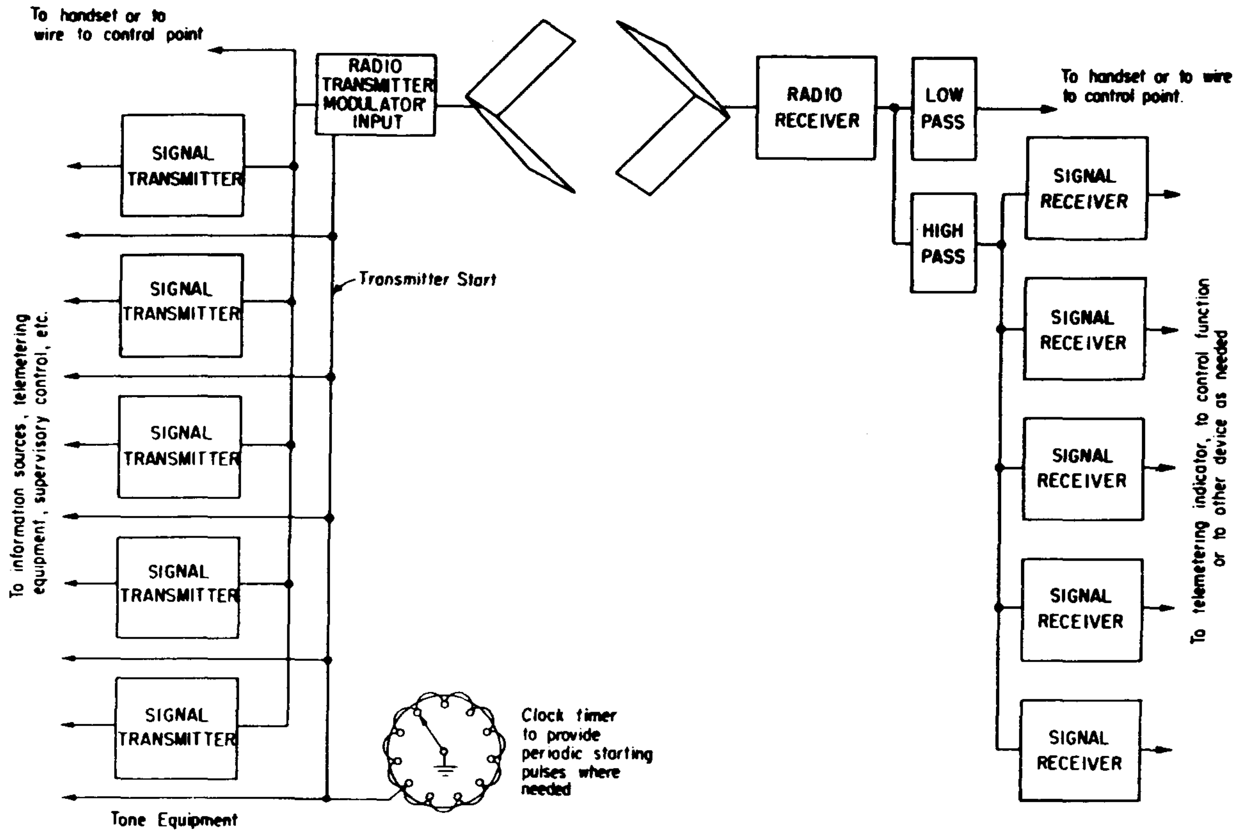


Fig. 12 — Point–to–Point Radio Installation Arranged for Periodic Transmission of Control or Telemetering Information with Alarm Transmission if Needed — May Be Installed as a Separate System or with Radio Control Facility of Fig. 9 and 10

3. FACTORS INFLUENCING SYSTEM DESIGN

3.01 Factors of greatest interest in radio system design concern physical arrangements and transmission characteristics.

3.02 Physical arrangements, including station location, use of existing buildings versus construction of new buildings, nature of antenna supports, and other similar considerations will be determined first by the service requirements of the particular installation and by economic factors. Such major physical items as land and buildings, and radio and terminating equipment are discussed in appropriate sections of the Bell System Practices.

3.03 Service requirements include the length and nature of the radio path, the type of service to be rendered, the signaling arrangements needed, the number of circuits required, necessary service continuity, and similar factors.

3.04 Use of multiplexed installations versus several single-channel units will depend upon circuit length, size of circuit group, radio frequency channel availability, and other factors, all related to the basic transmission objectives and largely dependent upon them. Figure 13 shows the relative range over which typical one- and three-channel systems will provide a toll grade facility, assuming 50 watt, 150-megahertz transmitters, antennas having 7.5-dB gain

Fig. 13 — Estimated Distance Spanned for Various Type Systems Assuming 50–Foot Antenna Height and Smooth Earth

supported 50 feet above average terrain, and relatively smooth earth between terminals. Distance which might be spanned is shown for three typical conditions of receiving site noise.

4. TRANSMISSION OBJECTIVES

A. General

4.01 As a preliminary to our discussion of the transmission design of radio systems, we should establish our design objective. The transmission objective for any type of facility is not an absolute goal but is a balance between performance and cost. Experience in providing various types of communication service has made it possible to establish minimum transmission standards for substantially unimpaired service for the average customer. The required performance may vary somewhat between different types of service and while obviously no single objective can cover all types of service provided by Bell System plant, it is felt that many of the circuits derived from VHF or UHF radio links will fall in the short haul message toll circuit category, serving as tributary trunks. Objective will be stated on that basis. Where other types of circuits are to be provided, the objectives should be reviewed.

B. Channel Noise

4.02 Noise on message circuits at the receiving toll switchboard in excess of 29 dBa at the —9 dB transmission level (equivalent to 38 dBa at zero transmission level) is presently considered to introduce a transmission impairment. Since this is an overall value, the noise contribution of any particular section should be such that the total noise on any connection will not result in a transmission impairment. Other types of service, such as programs, may be more susceptive to noise and therefore, may impose a more severe requirement. The selection of a practicable message circuit noise objective is based not only on the avoidance of impairment but represents the minimum noise that can be achieved without undue economic penalty. This balance point has not been established for radio links but it would appear reasonable to strive for a performance comparable to that of other types of short haul facilities. This establishes an objective of about 34 dBa effective at the zero transmission level point (0TLP) as measured with a two-type noise set.

C. Miscellaneous Requirements

4.03 The minimum channel net loss which can be achieved will depend on the stability of the radio and terminal equipment.

4.04 The circuit loss in the frequency range 300 to 3000 Hz should not be more than 3 dB greater or 1 dB less than the 1000-hertz loss.

4.05 Distortion caused by nonlinearity results in the generation of frequencies other than those intended for transmission. It is convenient to measure channel distortion in terms of harmonic distortion. This should not exceed 5 percent or, expressed differently, the total harmonic power in the band should be at least 26 dB below the level of the 1000-hertz test tone. (Measurements will customarily be made with 0 dBm, 1000 Hz tone at a 0TLP.)

5. TRANSMISSION DESIGN

A. General

5.01 The transmission design of radio systems, in common with the design of other types of telephone transmission systems, has as its primary objective the achievement of a satisfactory channel noise performance. This is directly governed by the magnitude of three factors:

(a) Radio frequency signal input to the radio receiver.

(b) Total effective noise at the input to the radio receiver.

(c) Transmitter deviation produced by signal modulation.

These may vary widely between various equipment arrangements and this section will discuss the influence of each. It will also provide sample computations of the theoretical channel noise performance of two typical types of systems. These are:

(a) A single-channel single link system.

(b) A three-channel single link system.

5.02 The computation of theoretical system performance will be based upon the assumption of properly aligned equipment and a noise-free receiving site. These conditions can rarely be expected in practice but it is possible to compute theoretical system performance and to adjust these results to practical conditions. These adjustments will include allowances for:

(a) Man-made and atmospheric noise having its origin outside of the equipment.

(b) Power supply hum and other types of noise originating within the equipment.

(c) Maintenance considerations.

5.03 The performance of radio systems operating at frequencies below about 500 megahertz will usually be limited by "site noise." This is a term applied to the broad combination of man-made and atmospheric noise which originates outside of the radio equipment and which adds to the thermal noise generated in the first circuits of the receiver to limit system performance. Part 6 of this section discusses "site noise" and its control while Bell System Practice, Section 940-250-102 describes a means for determining its magnitude.

5.04 The hum level in commercial radio equipment will usually establish a minimum noise level which is not economically reducible. It results from the effect of the power supply frequency and its harmonics upon the transmitter and receiver. Because of their low frequency and the weighting effect of the telephone equipment, the hum will rarely limit system performance.

5.05 Operation of electronic equipment will frequently be accompanied by conditions tending to increase channel noise to values higher than anticipated. Such items as vacuum tube aging, equipment misalignment, temperature changes, power supply voltage variations, and changes in site noise may account for increases in channel noise. In this discussion such factors are identified as "Maintenance Factors." Good engineering practice requires that some margin should be included in system design to provide for their effect. A value of 5 dB will be taken to be typical in the computations in this section, but the engineer may adjust this value upward if conditions in a particular area warrant.

B. Summary of Basic Factors

5.06 This subpart discusses some of the basic factors involved in the computation of the theoretical channel noise performance of radio systems.

5.07 Communication equipment of the type used in mobile and point-to-point applications may be either frequency modulated (FM) or phase modulated (PM). Basically, the operation of these systems is similar with the power output of the transmitter remaining constant during modulation and its instantaneous frequency varying with the amplitude and frequency of the modulating signal. The ratio between the frequency deviation of the carrier and the modulating frequency is termed the "deviation ratio." In a phase-modulated transmitter, the deviation ratio varies with modulation level and is independent of the modulating frequency. Thus, the radio frequency bandwidth required for phase-modulated transmission depends both upon the frequency and level of the modulating signal. In a frequency-modulated system, the deviation ratio not only varies with modulation level but also varies inversely with the modulating frequency in such a manner that the radio frequency bandwidth is a function only of the modulating signal level. Practical single-channel systems will usually have a compromise characteristic between frequency modulation and phase modulation, while systems modified for multichannel operation may have either characteristic.

5.08 The use of frequency or phase modulation normally permits the achievement of a considerable improvement in the signal-to-noise ratio as compared with an amplitude modulation system, assuming reasonable values of radio frequency carrier input to the radio receiver. At very small carrier inputs, well below useful signal levels, this advantage will disappear. In the case of a single channel frequency-modulated system (or a phase-modulated system, assuming that we are concerned only with weighted noise) this improvement, I, can be expressed in dB:

$$I = 5\text{ dB} + 20\text{ LOG. } D$$

where D = the deviation ratio

$$D = \frac{\text{the deviation from center frequency due to modulation}}{\text{the highest modulation frequency}}$$

In the case of multichannel installations, the 5-dB basic improvement applies to the entire baseband with the smallest advantage benefiting the highest frequency channel. As a result, the improvement factor is generally taken to be:

$$I = 20\text{ LOG. } D$$

where D is as above. Since the frequency-modulated improvement which is available is a function of the deviation ratio and, since the maximum deviation or swing is limited by restrictions of the equipment and of the license, it follows that the improvement will decrease as the modulating frequency increases. In a frequency-modulated system, assuming a constant modulating level, this has the effect of causing poorer noise performance with higher modulating frequencies, resulting in a "triangular" noise spectrum with the noise level rising 6 dB per octave relative to the desired signal. The relationship of noise to frequency is shown in Fig. 14. This is the typical "6 dB per octave" frequency-modulation characteristic and provides a means of relating channel noise at the 1000-hertz point of the voice-frequency channel to channel noise at the same point of a carrier derived channel, recognizing, of course, that signal level will remain independent of signal frequency. In a phase-modulated system on the other hand, the deviation ratio remains constant (for a given input level) with increased frequency, and the system is said to have a "flat" noise spectrum. For a given maximum modulating frequency and a fixed deviation, the noise performance of the top channel in phase-modulated and frequency-modulated systems is about the same; however, at lower modulating frequencies, the performance of the frequency-modulated system improves while in a phase-modulated system the performance of the lower channels is equal to that of the top channel.

5.09 In the absence of other noise sources, the performance of a radio system is limited by the "thermal noise power" generated in the

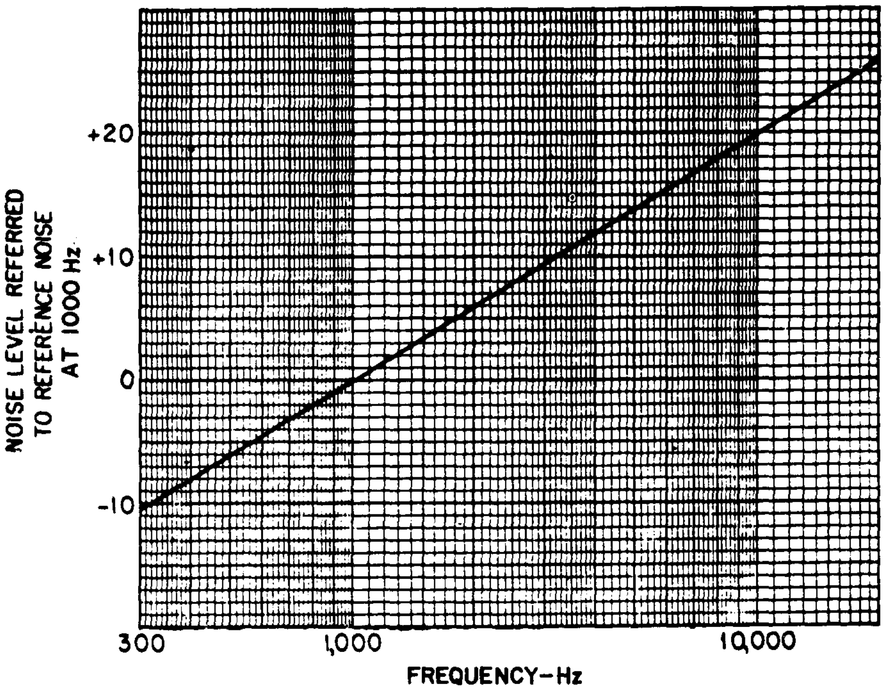


Fig. 14 — Distribution of Noise Power in Frequency–Modulated Radio System Baseband

input resistance of the receiver. Its value is —174 dBm per hertz of bandwidth at ordinary room temperatures. If we assume a 3000-hertz audio band, requiring a bandwidth of 6000 hertz to transmit the modulated carrier and its two sidebands, thermal noise power present at the receiver input will be:

Thermal Noise Per Hertz + Bandwidth Factor

—174 dBm + 10 LOG. 6000 dB = —174 dBm + 38 dB = —136 dBm

and, while this is a value which can not be reached in practice because of limitations in the design of present day commercial VHF radio receivers and other factors, it does serve as a basis for our noise computations.

5.10 The difference (expressed in dB) between the theoretical noise performance of a receiver and that obtained in practice with a particular unit is termed the "receiver noise figure." It will vary between very low values and a maximum of perhaps 14 dB, increasing with frequency. Typical values of 8 and 10 dB apply at 150 megahertz and 450 megahertz, respectively.

5.11 It is customary in the Bell System to express channel noise levels in terms of dBa as measured with the 2B noise measuring set, equated to the receiving zero transmission level point (0TLP) (the point at which a tone, customarily 1000 Hz at 0 dBm applied at the transmitting switchboard of a circuit adjusted to a 0 dB loss, will produce a received signal of 0 dBm). A noise power of 1 mW weighted by the F1A network of the 2A or 2B noise set is equal to 82 dBa or conversely, 0 dBa of noise can be stated to be 82 dB below 1 mW.

5.12 Part 8 of this practice will discuss "channel load capacity" or the relation between the single-frequency tone required to produce full modulation of the radio transmitter and the channel 0TLP. For the purpose of these calculations, a load capacity allowance of 9 dB will be assumed in the single channel case, while 6 dB will be assumed in the case of the highest frequency channel of a typical 3-channel system.

C. Single-Channel Noise Performance (Theoretical Computation)

5.13 The computation of channel noise affecting a single-channel system will be based upon parameters typical to 150-megahertz operation. If we assume a radio frequency carrier input power of —85 dBm to the receiver, a receiver noise figure of 8 dB, audio bandwidth of 3000 hertz, and maximum deviation of ±15 kilohertz, the channel noise may be computed as follows:

(a) Effective noise at receiver input =

THERMAL NOISE		BANDWIDTH FACTOR		RECEIVER NOISE FIGURE	
—174 dBm	+	38 dB	+	8 dB	= —128 dBm

(b) Carrier input to receiver, taken to be —85 dBm

(c) Carrier-to-noise ratio (C/N) in 6000-hertz band, prior to detection

(b) — (a) = 43 dB

(d) Frequency-modulation improvement assuming ±15-kilohertz deviation, maximum modulation frequency.

$$3000 \text{ hertz} = 5 \text{ dB} + 20 \text{ LOG.} \frac{15000 \text{ Hz}}{3000 \text{ Hz}} = 19 \text{ dB}$$

(e) Taking FM improvement into account, C/N in a 6000-hertz band, prior to detection.

(c) + (d) = 62 dB

(f) C/N in a 6000-hertz bandwidth prior to detection is equal to S/N in a 3000-hertz bandwidth after detection, where S is the signal required to fully modulate the transmitter.

(g) Assuming a channel load capacity of 9 dB, the ratio between channel noise power at the transmitting 0 TLP and a test tone having a level of 0 dBm at the same point is:

SIGNAL-TO-NOISE RATIO	—	LOAD CAPACITY	
62 dB	—	9 dB	= 53 dB

(h) This is equal to 82 dBa — 53 dB = 29 dBa of noise at the 0TLP.

5.14 The value of 29 dBa at the equivalent 0TLP is 5 dB better than the objective of 34 dBa. Within the range of useful receiver input levels, the signal-to-noise ratio in the telephone channel will vary with the carrier-to-noise ratio, approximately dB for dB. On this basis, it will be permissible to reduce the carrier input by 5 dB to meet the 34 dB objective. This would result in a theoretical receiver input power requirement of —90 dBm. This is not a practical value since such factors as equipment alignment, vacuum tube aging, and power supply voltage variations can all be expected to result in circuit degradation. These factors as well as the effects of site noise and compandors are taken into consideration in the tables of paragraph 5.16 of this section.

D. Three-Channel System Noise Performance (Theoretical Computation)

5.15 The computation of channel noise performance for three-channel service assumes the use of a frequency-modulated radio system. Performance of a phase-modulated system or of a frequency-modulated system employing channel or system load capacity allowances different from those assumed would, of course, differ from that shown in this computation. Because of the rising or "triangular" noise characteristic of a frequency-modulated system, the noise performance of the top channel will control system performance and is taken as the basis for this computation. Performance of all other channels will be better than this. Assuming the following conditions:

(a) Radio frequency carrier input to receiver; —75 dBm.

(b) Receiver noise figure (150 megahertz); 8 dB.

(c) Lenkurt 33B carrier; bandwidth 3000 hertz between 11.2 kilohertz and 8.2 kilohertz.

(d) Full deviation; ±15 kHz.

(e) Channel load capacity; 6 dB.

The channel noise in the worst channel may be computed as follows:

(a) Effective noise at receiver input =

THERMAL NOISE	+	BAND-WIDTH FACTOR	+	RCVR NOISE FIGURE		
−174 dBm	+	38 dB	+	8 dB	=	−128 dBm

(b) Carrier input to receiver, taken to be −75 dBm

(c) C/N at receiver input (b) − (a) = 53 dB

(d) Frequency-modulation improvement, assuming ±15-kilohertz deviation, maximum modulating frequency 11.2 kHz:

$$20 \text{ LOG.} \frac{15000 \text{ Hz}}{11200 \text{ Hz}} = 2.5 \text{ dB}$$

(e) C/N in a 6000-hertz band prior to detection (c) + (d) = 55.5 dB

(f) C/N in 6000 hertz of bandwidth prior to detection is equal to S/N in 3000 hertz of bandwidth after detection, where S is signal required to ***fully*** modulate the transmitter.

(g) Assuming a channel load capacity of 6 dB, the ratio between channel noise power at the receiving 0TLP and test tone at a level of 0 dBm at the same point is:

SIGNAL-TO-NOISE RATIO	−	CHANNEL LOAD CAPACITY	
55.5 dB	−	6 dB	= 49.5 dB

(h) And the noise expressed in dBa at the receiving 0TLP is:

82 dBa − 49.5 dB = 32.5 dBa

Since this performance is 1.5 dB better than the 34 dBa objective, it would be permissible to decrease, by that amount, the carrier input level to the receiver which was assumed in this computation with system performance remaining within the desired limits. On this basis, the minimum signal which would be acceptable at the receiver input would be: (−75 dBm − 1.5 dB = −76.5 dBm). As was indicated in the single channel case, other factors also influence system performance, and these are taken into account in the tabulation of paragraph 5.16. It should be noted that this computation does not include a correction for the effect of channel compandors, the use of which is felt to be essential in very light route multichannel installations, and which has been included in the values shown in Table 1.

TABLE 1

SINGLE–CHANNEL RADIO SYSTEMS

INPUT SIGNAL IN DBM REQUIRED AT RADIO RECEIVER

TO MEET 34 DBA AT 0TLP NOISE OBJECTIVE

TYPE OF SITE	72-76 WITHOUT COMPANDOR	72-76 WITH COMPANDOR	150-174 WITHOUT COMPANDOR	150-174 WITH COMPANDOR	450-470 WITHOUT COMPANDOR	450-470 WITH COMPANDOR
Rural	−75	−95	−83	−104	−86	−107
Suburban	−48	−71	−55	−78	−65	−88
Urban	−38	−61	−45	−68	−55	−78

Site categories are defined as follows:

Rural: A suburban location, the antenna at least 500 feet from a major highway, and with no intervening aerial power, telephone, or other wires.

Suburban: A residential area same distance from major highway, dial telephone equipment, or industrial activity.

Urban: A busy downtown area, industrial location, or similar situation.

E. Practical Application

5.16 Practical radio systems operating at frequencies under about 500 megahertz will rarely be limited in performance by the thermal noise generated at the input circuits of the radio receiver itself. Instead, the limiting noise power, as indicated in paragraph 5.02, will originate outside of the radio equipment. It is categorized as "site noise" and because of its importance in system engineering, Part 6 of this section will discuss its nature and control. If the absolute value of site noise in terms of dBm at the receiver input is known, it can be added on an rms basis to the thermal noise power at the receiver input, and the resultant noise power used in computation of system noise performance. Determination of the absolute noise power is not always a practical field procedure and engineering purposes will best be served if we evaluate site noise in terms of radio frequency input to the radio receiver which is needed to provide the objective channel noise performance at a given receiving site. Bell System Practice, Section 940-250-102 describes a method of determining this value at any particular radio receiving site.

Values shown in the table are based on the assumption that a channel load capacity allowance of 9 dB has been used in system lineup. An additional margin of 5 dB is allowed for maintenance reasons. This allowance is considered to be sufficient to protect against such maintenance conditions as vacuum tube aging, equipment misalignment, and variations due to extremes of temperature. It will usually care for minor variations in power supply voltage, but does not provide for such basic design considerations as variations in site noise or errors in the predicted path loss nor for fading which may be encountered on long, overwater, or obstructed paths.

5.17 In many cases the precision of measurement which this procedure permits is not needed in the preliminary stages of system planning. Where this is true, Table 1 will provide representative values of radio receiver input required to meet the 34 dBa at the 0TLP noise objective. Values given are of such accuracy that they are satisfactory for a first approximation of system performance. Where a prediction of the performance of a 3-channel system of the type discussed in other parts of this section is required, the values shown in Table 1 for a single channel uncompandored system may be decreased by 5 dB; thus, at a rural location, such a system operating at 150-megahertz would require a signal input of: —83 dBm — 5 dB = —88 dBm to meet the 34 dBa channel noise objective. Application of the data of Table 1 may in some cases require at least a rough confirmation of the engineer's judgment in evaluating the noise at a particular site. Such an approximation may be obtained by various means without performing quantitative tests. For example, in an area served by a mobile radio system, either general or private, listening tests made by a mobile station at the proposed receiving location may help to make a categorical approximation of site noise. Alternatively, talking tests between two hand carried or pack sets separated by some distance and working on a frequency near that proposed for the system may assist the engineer to judge whether the noise at a given site should be considered to be "rural," "suburban," or "urban" in magnitude.

5.18 When it is necessary to operate two transmission systems in tandem, as in the case of repeatered radio installations or of point-to-point installations serving as control circuits for mobile radio installations, the effective noise at the receiving end of the combined circuits equals the rms sum of the individual noise powers in the two circuits. Figure 15 provides a means of obtaining this sum readily. In using this figure, the smaller of the two noise quantities is subtracted from the larger and the difference in dB

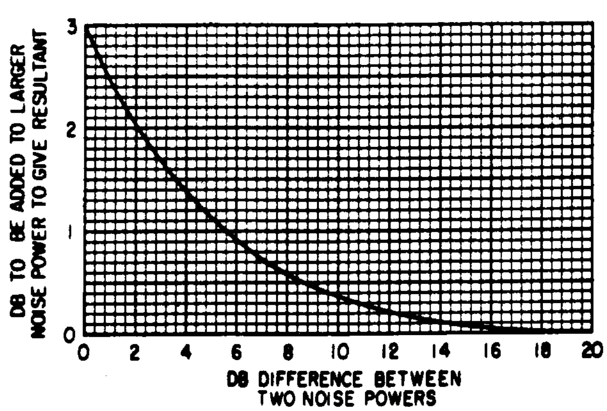


Fig. 15 — Chart for Summation of Two Noise Powers (RMS Addition)

is read into the abscissa. The value in dB found on the ordinate is then added to the larger noise power. Where more than two quantities are to be added, the first two are added and succeeding quantities are then added to the sum in the same manner.

6. SITE NOISE AND ITS CONTROL

A. General

6.01 Site noise is the term applied to noise of all types which has its origin outside of the radio equipment itself. Site noise may be man-made in its origin or may be atmospheric. Since it may effectively limit the performance of radio installations, it is important that we have a complete understanding of the noise problem at any radio receiving site, that we evaluate conditions carefully, and that our design for any particular installation provides the best balance between cost and performance.

6.02 Site noise decreases in magnitude with increasing frequency; it will generally control system performance at frequencies near 30 megahertz, it is of lesser consequence at frequencies of 150 megahertz, and it is rarely noticeable at frequencies above 500 megahertz where set noise usually assumes control of system noise. Table 1 of paragraph 5.16 indicates approximate signal strengths required to override noise at typical locations and on three frequencies most commonly used for very light route point-to-point service.

B. Man-Made Noise

6.03 Man-made noise is a direct outgrowth of human activity. It consists of a random combination of the noise output from innumerable sources including automobile ignition systems, power switches, power distributing systems, electric motors, industrial equipment of all sorts and, near telephone offices, equipment including relays, dial switches, ringing machines, busy tone generators, battery charging machines, or rectifiers, etc. By its nature, man-made noise will generally be higher in level in densely populated areas than in rural areas and will be greater in industrial areas than in residential localities. Its intensity will vary with time of day and frequently follows a pattern peculiar to each location. It consists of a random combination of discrete impulses with each interference source contributing on a power basis and weighted as a function of its distance from the receiving site. Since the noise has both magnetic and electric components, it is transmitted by radiation through space or by conduction along wires in the same manner as a radio signal. Many noise sources are directly connected to power distribution circuits which serve as an effective noise distribution medium, and where aerial construction is employed, power lines will act to radiate some of the noise energy along their entire length. Aerial telephone plant acts similarly, radiating switching and dialing noise directly, and power noise as a result of secondary excitation.

6.04 Also classed as man-made noise, but differing in character is the radiation from medical diathermy machines and industrial heating devices such as plastic preheaters, fabric driers, and the like. These devices are presumed to operate within narrow frequency bands and to have their radiation sharply limited in amplitude. Such equipment is subject to faults which will sometimes permit the radiation of substantial amounts of power on frequencies allocated to other services. Similarly, spurious radiation from radio transmitters can be a source of trouble.

6.05 It may sometimes be desirable to locate point-to-point radio receiving antennas near radio transmitters operating in other services such as AM, FM, or TV broadcasting. FCC requirements for transmitters in these services limit spurious emission and extraband noise to reasonable values but because of the high transmitting power involved, the interfering field at short distances may be sufficient to limit point-to-point system performance. Because of this, it is recommended that tests be made wherever a receiving installation is to be made on the premises of or near a high-powered radio transmitter; that these tests be made on the proposed frequency with a receiver of the type to be used in order to assure that combinations of spurious emissions and of spurious receiver responses do not bring about major difficulties; and that tests continue for a reasonable period of time, including at least one on-off cycle of high-powered station operation. If tests disclose interference of this type, it may be due to "receiver desensitization" and can be treated in the same manner as would be used if the interfering signal originated in the communication system. (See Part 7.) In other cases, the trouble may be due to extraband noise radiation from the transmitter. In some cases such measures as filters between the interfering transmitter and its antenna or between the power line and the transmitter may be helpful. In other cases, shielding of the transmitter (or of some particular stage of the transmitter) may be of value, but if tests indicate a large impairment due to interference of this sort, it may be economical to select another receiving location.

6.06 A special case of noise interference occurs where a radio transmitter of the same service operates in close proximity to the receiver. This is discussed in Part 7 of this section.

C. Atmospheric Noise

6.07 Atmospheric noise is of greater importance at the lower radio frequencies where a receiver may be influenced by thunderstorms occurring even at great distance. At frequencies above about 30 megahertz, it becomes of less importance and is rarely a design factor except for the effects which are felt just before and during local thunderstorms when high intensity crackling noise will accompany lightning flash. Figure 16 gives an indication of the receiver signal input which will be required to meet the objective of 34 dBa of noise at a zero transmission level point 95 percent of the time during local thunderstorms. Figure 17 provides approximate data concerning the frequency of thunderstorms in the United States. Isoceraunics (lines of equal thunderstorm incidence) of annual thunderstorm days give an indication as to the relative importance of this noise source in various parts of the country. In evaluating these data, it should be recognized that most thunderstorms occur during heavy traffic periods and that about 80 percent of the thunderstorms in most sections of the country occur during the spring and summer months.

6.08 When charged wind-blown particles such as sand, dust, or snow come into contact with an antenna, their charge is transferred to the antenna and the transfer of energy results in the generation of a radio frequency noise potential. This condition, classed as precipitation static, is most noticeable at the lower VHF frequencies, but may be of importance at frequencies as high as 150 megahertz. Its effect appears to vary directly with the height of the antenna above ground and is more important in very dry climates than in areas of high humidity. The effect may be reduced but probably not eliminated by coating the antenna with a dielectric and by assuring that the antenna, its supporting structure, the transmission line, and the receiver itself are all connected to a low impedance ground.

6.09 Operation at frequencies below about 75 megahertz may also be subject to "corona noise" which occurs during periods of high atmospheric potential and which may result in very high level interference particularly during or just before local thunderstorms. The magnitude of the interference increases with increases in the antenna height above ground, and is markedly worse at frequencies near 30 megahertz, than at higher VHF frequencies. This noise is not the crackling noise referred to in paragraph 6.07, but is a continuous phenomenon which changes in level, building up to a high point and dropping suddenly, particularly after a lightning discharge. Some reduction of this condition has been effected by removing all sharp points and edges from the antenna, by coating the antenna with a dielectric, and by equipping the ends of all antenna elements with metal balls 1 inch or more in diameter. These measures will reduce the opportunity for corona discharge, and to the extent that they succeed in this, will reduce the effect. Some additional improvement in this condition may be obtained by the use of an effective low impedance ground; also there is evidence that for a given height above ground, antennas located below the top of metal towers are less subject to this condition than are those located at the top of the towers.

6.10 Reception in the range of frequencies between 30 and 300 megahertz may be affected, although not generally limited, by another form of natural noise, identified as originating outside of our planet. It is called cosmic or galactic noise and has its source in the Milky Way. It resembles thermal noise in its nature

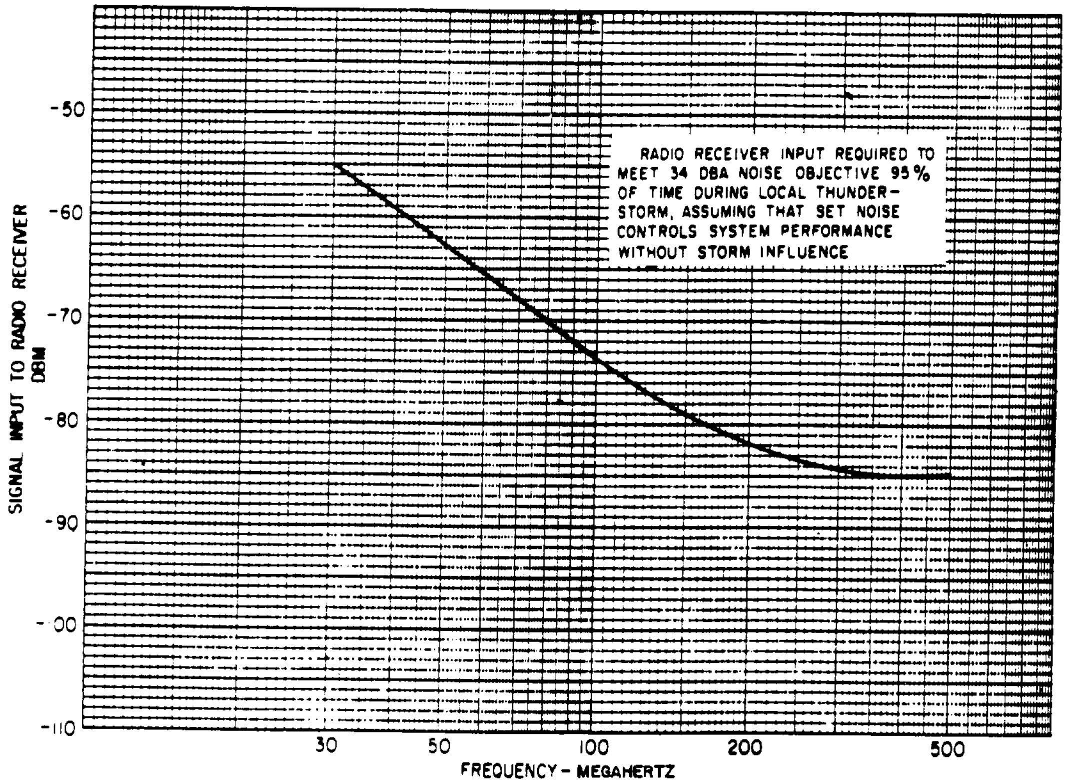


Fig. 16 — Radio Receiver Input Required to Meet 34 dBa Noise Objective 95 Percent of Time during Local Thunderstorms

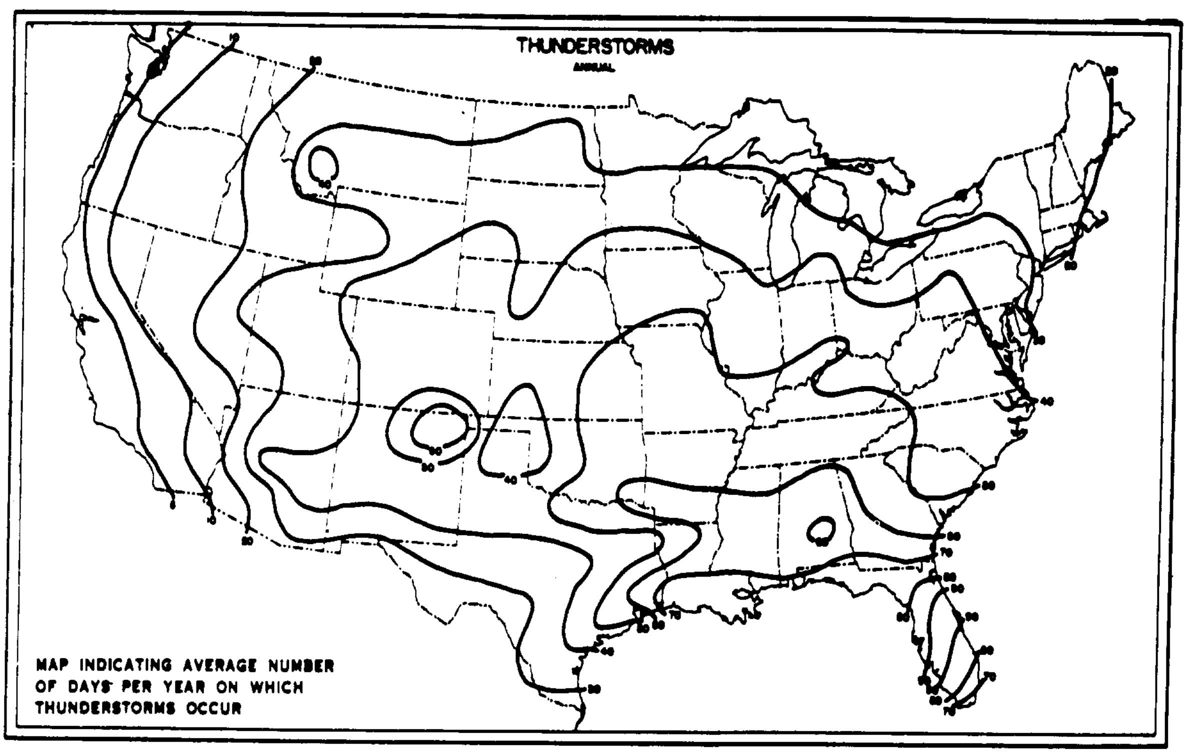


Fig. 17 — Frequency of Thunderstorms in United States

and, when demodulated, gives a hissing sound. Its value has been measured as being some 10 to 15 dB higher than thermal noise at frequencies near 30 megahertz, dropping with increasing frequency and approaching thermal noise intensity at about 300 megahertz. Its effect on point-to-point radio installations is generally reduced by the use of directional antennas, which tend to discriminate against noises coming from above the horizon, and by the fact that, even with antennas aimed over paths which will intersect the Milky Way, the duration of coincidence will be relatively short.

D. Control of Site Noise

6.11 Radio noises may be coupled to the receiver input in several ways:

(a) By space transmission (radiation, electric, or magnetic induction) to the antenna.

(b) By conduction along the power or telephone service lines to the receiver.

(c) Through an impedance common to the noise source and the receiver antenna circuit.

6.12 Most well designed receivers will include adequate filtering and shielding to protect not only against noise access via the service lines, but also by radiation into set wiring.

6.13 A short low-impedance ground at the radio receiver will do much to reduce the possibilities of coupling noise to the system through impedances common to the receiver input and the noise source. Where it is not possible to obtain a low-impedance ground, it may be necessary to use separate ground leads for radio and other equipment to obtain satisfactory noise performance and to connect these leads to a common point. To minimize noise coupling between such separate ground leads, it is necessary to maintain a reasonable separation between the several wires. Care should also be taken to avoid coupling between wiring of the radio antenna circuit and disturbing circuits such as those feeding or grounding elevator machinery, light flasher, and telegraph or dial switching units. Such coupling may result from the practice of "bunching" wires, either in a wiring form in a raceway or in a "ring lead." The effect of the coupling may be increased by incidental resonances and standing waves in the wiring, and may be extended through coupling at separate localities between wires nominally carrying only ac or dc and wiring of the disturbing circuit and of the radio receiver circuits.

6.14 Noise entering a radio receiver antenna is subject to reduction in two general ways, either through suppression at the source or by reducing the coupling between the noise field and the receiver input.

6.15 Suppression at the source may be effective if the controlling noise sources can be identified through the use of arrangements such as are described in Bell System Practice, Section 940-250-101 or by other means appropriate to the problem, and can be suppressed by such devices as spark suppression networks, power line filters, shields, or combinations of these. Such suppression methods can not generally be relied upon to provide permanent noise protection since changes made at the noise source often reduce the effectiveness of the suppressive devices after initial installation. This requires that the Telephone Company maintain continuing surveillance over the interfering device if noise suppression at the source is to be relied upon.

6.16 Space coupling between the noise source and the antenna is subject to a degree of control in several ways, including site selection, increased separation, shielding of secondary noise sources, choice of polarization, and choice of antenna.

6.17 Since propagation of radio noise follows the same laws as apply to desired signals, it is often possible to decrease the coupling to the noise source by relocating the antenna with relation to a fixed noise source. Maximum noise attenuation will occur within the first few wave lengths; each doubling of the distance beyond this "near field" will add about 6 dB of noise path loss and if the increased separation is obtained by increasing the antenna height, the signal-to-noise ratio will be further improved by the increase in strength of the desired signal. This device may prove useful when antennas are to be located near dial telephone offices in suburban areas where the telephone equipment represents the principal noise source and is relatively concentrated. In such cases, significant noise reduction may be effected through rather small changes in antenna height. In the case illustrated in Figure 18, a change in antenna supporting structure of only 15 feet might result in a noise reduction approaching 6 dB at the antenna and would be accompanied by a signal increase that might reach 3 dB. This would provide an effective S/N improvement near 9 dB.

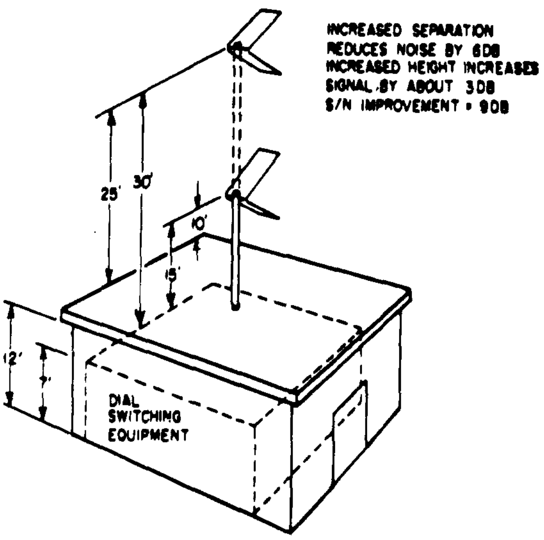


Fig. 18 — Effect of Antenna Location on Coupling to Noise Sources

6.18 Where fixed radio stations are located in rural areas, away from highways, telephone offices, and other real or potential noise sources, the aerial telephone and power wire plant feeding the installation may act as a noise transmission medium or as a secondary noise source and may transmit the controlling radio noise to the receiver input. In such cases, it is possible to reduce the noise level materially by burying the service leads for a distance of 300 to 500 feet from the antenna location. The shielding achieved in this manner will increase the effective separation between the receiving antenna and the noise source and thus reduce their coupling. In some cases, it might also be feasible to introduce filter networks into power and telephone lines a similar distance from the receiving site with the same result. The amount of isolation from noise sources which is needed to achieve optimum performance will vary with the height of the antenna, the pattern of the antenna, and the relation of noise sources to the receiving site. The use of a 300-foot buried entrance section appears satisfactory where antenna heights are under about 60 feet. Greater antenna heights expose the antenna to noise sources in a greater area and thus may require a longer buried service entrance.

6.19 When the electric field of a radio wave is in a plane parallel to the earth's surface, the wave is considered to have horizontal polarization; if the electric field is perpendicular to the surface of the earth, the polarization is considered to be vertical. Most short-haul toll radio installations will share frequencies with urban mobile systems employing vertical polarization; in situations where potential interference exists between point-to-point installations and mobile systems or where point-to-point installations share antenna supports with mobile systems, some additional protection against mutual interference may be gained by the use of horizontal polarization; further, many antennas available for point-to-point applications are physically better designed for horizontal than for vertical installation. Horizontal polarization results from horizontal orientation of the radiating elements of the antenna. It should also be noted that the selection of antenna type and the manner in which the antenna is used may influence signal-to-noise ratio performance of a system, both by increasing the received signal and by decreasing the effective noise. These effects are discussed in Part 7 of this section.

7. ANTENNAS AND ANTENNA ARRANGEMENTS

A. General

7.01 The selection of antennas for VHF point-to-point installations and the physical and electrical arrangement in which they are used will vary with type of service and method of operation. Within limitations imposed by service requirements, other factors including the type of antenna, required antenna height, and available space along with the various items of paragraph 7.07 will influence the particular arrangement chosen. Service requirements, from the point of view of antenna arrangements, may be separated into cases involving single or two-frequency switched carrier operation, those requiring simultaneous transmission and reception, and those in which simultaneous operation of several transmitters or receivers is required at one location. The requirements of each of these services will be discussed separately.

B. Types of Antennas

7.02 The design of point-to-point VHF or UHF radio systems will usually include the use of directional or "gain" type antennas. These consist of several elements arranged mechanically and electrically in such a manner as to cause them, when used for transmitting, to concentrate the radiated energy in a "beam" rather than to radiate it uniformly in all directions. This results in a greater field strength in the direction of the beam rather than in other directions and thus in an effective power gain in that direction (and by an accompanying reduction of power radiated in other directions). The ratio of the power received by an antenna at a given distance from a half-wave reference dipole, excited by a transmitter of known power, to that received by the same antenna from the directional antenna (in its favored direction), when it is excited by the same transmitter power, is the power gain of the antenna. This is usually expressed in decibels. It can be shown by the principle of reciprocity that the same gain and directivity, which are obtained when an antenna is used for transmitting, are also realized when the antenna is used for receiving. Also, the transmitting loss in directions away from the main lobe is realized when the antenna is used for receiving and provides discrimination against signals and noise from those directions.

7.03 It can be seen that very real benefits in the operation of radio systems may result from the reduction in the area of potential interference which is obtained when a directive antenna is used at the transmitter; also, the discrimination against unwanted signals and noise which may accompany the use of directional antennas in the receiving direction is of real value. This last benefit may sometimes permit the achievement of an effective signal-to-noise ratio improvement equal to several times the antenna gain. This occurs in cases where noise sources are so located in azimuth with respect to the receiver as to permit taking advantage of the "front-to-back" ratio of the antenna. The effect extends to include discrimination against noises originating at positions on the sides of the antenna, and also, because of the narrowing of the vertical angle which generally occurs when horizontal directivity is increased may also result in discrimination against noise sources close to the receiving antenna and directly in the path to the transmitter.

7.04 Horizontally polarized corner reflector antennas provide satisfactory characteristics for most point-to-point installations. Typical corner-reflector antennas operating between 150 and 160 megahertz may be expected to give gains of about 7.5 dB compared to a dipole, with a front-to-back ratio of about 15 dB, while a similar antenna for 450-megahertz operation can be expected to provide about 8 dB gain with a front-to-back ratio near 25 dB.

7.05 In some cases, transmitting or receiving gains which are greater than can be obtained using a single corner reflector antenna may be needed. Such a situation may occur if a noise source is near one terminal of a system and on the line to the transmitter. In this case, it would be desirable to increase the effective radiated power. This may be done by stacking two antennas, thus doubling the number of elements and providing a gain about 3 dB greater than would be obtained from a single antenna. If the stacking is done in such a way as to narrow the vertical pattern, additional gain may also be obtained from the receiving antenna with accompanying improvement of the desired signal and discrimination against the undesired noise.

7.06 In addition to corner reflector antennas, directional antennas for VHF service may include Yagi arrays and, particularly at frequencies near 450 megahertz, parabolic reflectors. The 10-foot parabola has an effective gain relative to a dipole of 18 dB at 450 megahertz. If situations are encountered where greater gains than this are needed to provide a reliable facility, parabolic reflectors 28 feet and 60 feet in diameter are available. Their gain at 450 megahertz is about 27 dB and 34 dB, respectively, but because of their cost, their use will probably be limited to very rare situations. Special situations may also arise in which the use of other types of antennas, rhombic, V, helical, etc, may warrant consideration.

C. Choice of Antenna Arrangements

7.07 After the choice of a suitable antenna for a system has been made and such factors as antenna height, type of antenna support, location, etc, are known, the engineer will want to determine if the installation can best be served by the use of separate transmitting and receiving antennas or if a common antenna with suitable filters is to be preferred. Principal factors which may influence his choice of antenna arrangements to meet a particular service requirement will include the following:

(a) The relative ease and cost of placing two antennas and transmission lines as compared to the cost of a single antenna and line with any necessary additional filters.

(b) The relative ease of maintenance of two antennas and lines as compared to a single antenna and line.

(c) The relative height of antenna supporting structure required for a single antenna installation versus that required for dual installation. (Where it is desirable to separate two antennas vertically rather than horizontally in order to simplify structural arrangements or to provide greater ease of maintenance, the height of the antenna support must generally be increased to maintain satisfactory transmission. The cost of such additional height may tend to favor choice of a single antenna installation.)

(d) The possible effect of increased wind loading of two antennas on the size and type of antenna support required.

(e) The effect of filter insertion loss on circuit transmission performance. (In some cases where other factors favor single antenna installations, it may be desirable to use better transmission lines than would otherwise be chosen to compensate wholly or in part for this loss.)

One- or Two-Frequency Switched Carrier Terminals

7.08 Installations using only one frequency for two-way service with manual or voice-operated carrier control are sometimes used in conjunction with mobile systems or for private line services. Such installations can be operated with a single antenna at each end, normally connected to the receiver, but switched by means of a relay when required for transmitting. Two-frequency switched carrier systems can operate in the same way since the separation between transmitting and receiving frequencies will usually be only a few megahertz, permitting the use of the same antenna for both purposes without excessive loss at either frequency. Switching can be done by the antenna relay provided in most radio transmitters. (See Fig. 19A.)

7.09 Two-frequency push-to-talk installations used to control base stations in the mobile service require that the control terminal maintain control of the remote base transmitter. This can not be accomplished unless the receiver of the point-to-point radio link associated with the base station remains active at all times, and it is therefore necessary to arrange for simultaneous transmission and reception at this type of terminal in the same manner as in systems using two-frequency continuous carrier. (See Fig. 19B.)

Two-Frequency Terminals — Continuous Carrier

7.10 Simultaneous transmission and reception at one location on frequencies separated by only a few percent requires that sufficient loss is provided between transmitter output and receiver input to avoid receiver desensitization. Such desensitization will occur whenever the radio frequency input to the receiver is great enough to overload any of the early receiver stages (as evidenced by grid current on positive peaks), thus causing them to act as limiters. A further limitation on system performance may be imposed by "extraband" radiation of the local transmitter, consisting of noise or of spurious frequencies originating within the transmitter and falling in the frequency band used for reception of signals from the distant terminal. The presence of such spurious radiation will effectively add to the site noise and may, if of sufficient magnitude, seriously limit performance.

7.11 Practical installations may achieve the necessary decoupling of transmitter output and receiver input through the use of separate antennas with suitable physical separation or, where a common antenna is used for both transmitting and receiving, through the use of filter networks. Because rather large separations between antennas may be needed to provide the required space attenuation, a third arrangement using separate antennas with reasonable separation to secure part of the attenuation and with filters providing the remainder may be attractive in some instances. These arrangements are indicated in Fig. 19C and D.

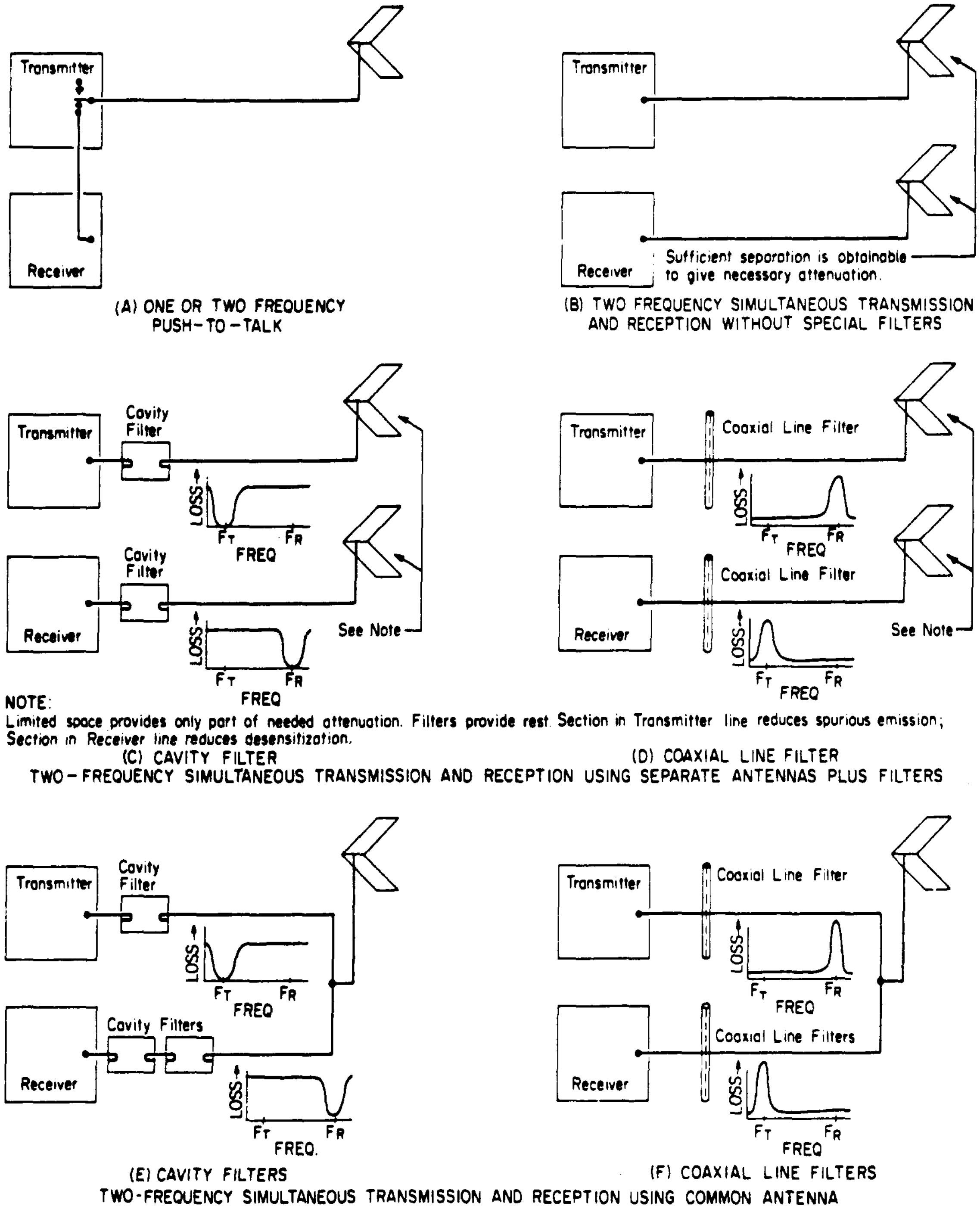


Fig. 19 — Antenna Arrangements for Fixed Stations

7.12 The absolute value of undesired signal at the input to a receiver which will cause a given amount of desensitization depends upon the characteristics of the receiver and upon the frequency separation between the desired and the undesired signal. This is true because the selectivity of the input circuit of the receiver effectively supplements other loss ahead of the first grid circuit to control the signal voltage applied at that point. Also, where the frequency separation between signals is small, the loss of the first interstage coupling device at the transmitter frequency may be less than the gain of the first tube; where this is the case, the voltage applied to the grid of the second tube becomes controlling in determining the isolation needed at the transmitting frequency. From the foregoing, it will be seen that, while desensitization is related to receiver selectivity, it is affected only by the receiver radio frequency selectivity, and is independent of the receiver intermediate frequency characteristics. With systems operating at frequencies near 150 megahertz and with 5-megahertz frequency separation, using receivers having high mu radio frequency pentode amplifiers with only one tuned circuit ahead of the first grid, the overload point appears to be near −10 dBm. Figure 20 shows the estimated limiting values of undesired signal levels which can be tolerated by such receivers plotted as a function of frequency separation at 150 and 450 megahertz. It will be noted that requirements at 450 megahertz are somewhat more rigorous than at 150 megahertz, since the percentage separation of transmitting and receiving frequencies is smaller while the selectivity of receiver circuits at the same time may be somewhat less. Partial compensation for these more severe requirements may result in systems using separate transmitting and receiving antennas due to the greater space attenuation provided by a given separation at 450 megahertz as compared to 150 megahertz. Where filters are required to avoid receiver desensitization, they will be inserted in the receiver antenna circuit and will be arranged to discriminate against the near-end transmitting frequency. (See Fig. 19C, D, E, and F.)

7.13 Radio transmitters in general will produce, in addition to the desired carrier plus its modulation, some undesired signals at other frequencies. The undesired output divides

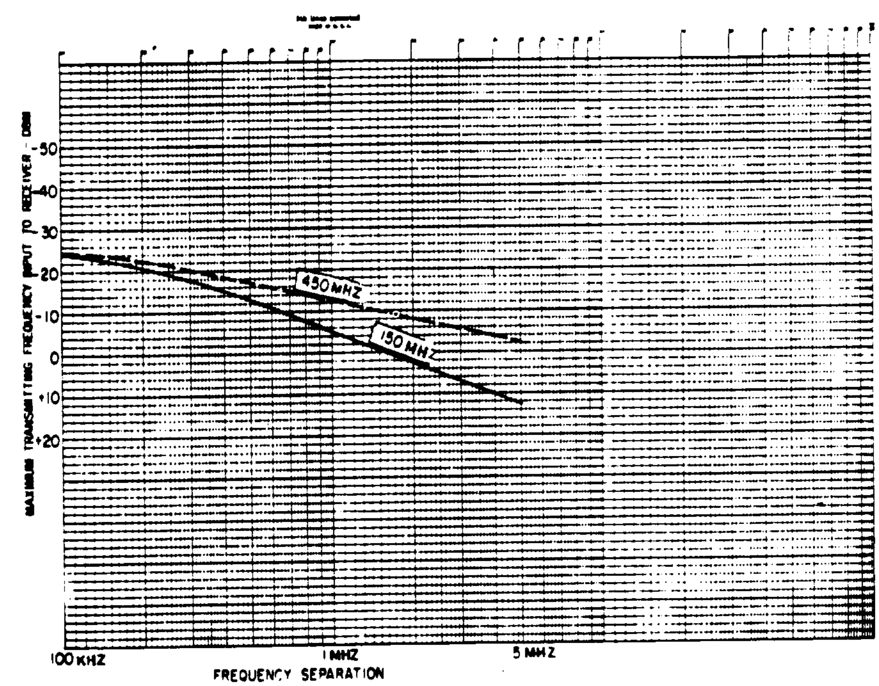


Fig. 20 — Maximum Off–Channel Input Which Can be Tolerated by Typical Receivers with Negligible Loss of Sensitivity

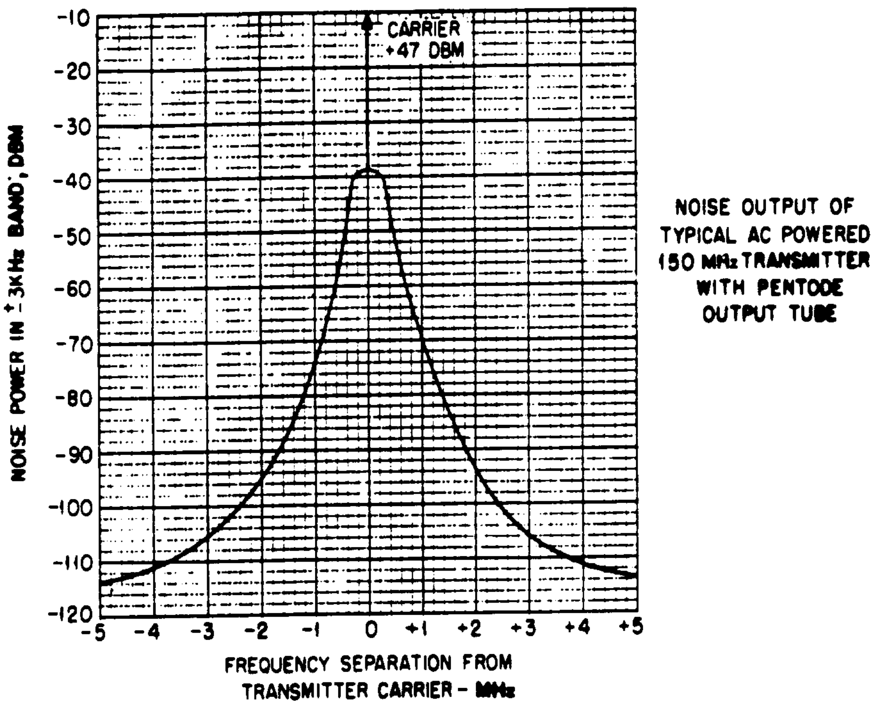
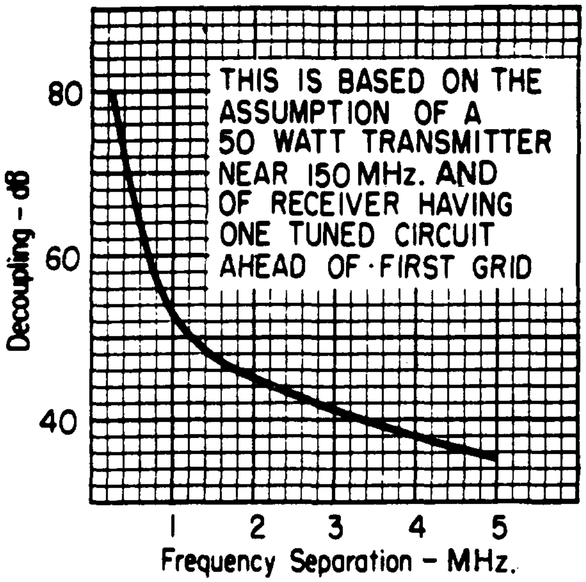


Fig. 21 — Noise Spectrum of Typical 150–Megahertz Radio Transmitter

into two components, noise and spurious signals. In well designed 150-megahertz equipment, the noise component may be expected to have a value 75 to 85 dB below the carrier at frequencies only a few hundred kilohertz from the carrier, becoming lower as the frequency separation is increased. Figure 21 shows approximate values of noise which may be expected at the output of a typical 150-megahertz 60-watt transmitter using pentode or tetrode output tubes. Noise emission from 450-megahertz equipment can be expected to be perhaps 6 dB higher for frequencies separated from the carrier by the same percentage.

7.14 Transmitter extraband noise within the passband of the near-end receiver effectively adds to site noise and thus, may limit system performance. This requires, in addition to the isolation needed between the transmitter and receiver to prevent desensitization, suppression of spurious products falling on the receiving frequency. This can be provided by filters in the transmitter output, by increased antenna directivity, or by increased separation between the transmitting and receiving antennas. In some cases a combination of these arrangements may be used. The filters included in the transmitting legs of Fig. 19C, D, E, and F satisfy this requirement. At frequency separations of 5 megahertz near 150 megahertz and with 50- to 60-watt transmitters, 25 dB of loss at the receiving frequency will be adequate and should result in sufficient suppression of transmitter extraband radiation to assure only a negligible circuit noise contribution (about 0.5 dB) under conditions of no site noise. At smaller frequency separations or with higher transmitter power, sufficient attenuation must be provided to reduce transmitter noise below the value which will degrade the circuit performance. The curve of Fig. 22 provides data which may be used in determining the required filtering or suppression by other means, assuming a 50-watt transmitter having a tetrode or pentode output stage. The values of suppression taken from this figure are the total required. Where filters are used to provide all or part of the loss between transmitter and receiver, the loss required at transmitting and receiving frequencies can be estimated by reference to Fig. 20 and 21. Figure 21 is based on the effective noise which would occur in a demodulated 3000-hertz band. This compares to the expected noise power of −128 dBm at the receiver input in the same bandwidth as developed in paragraph 5.13.



Decoupling required between transmitter and receiver to result in negligible circuit impairment. Includes allowances for transmitter extraband radiation and receiver desensitization.

Fig. 22 — Required Decoupling between 50-Watt Transmitter and Receiver Related to Frequency Separation

7.15 Spurious emissions, as contrasted to transmitter noise, occur at fixed frequencies. They may be harmonics of the operating frequency or may be due to "leak-through" to the antenna of power at the various multiples of the transmitter crystal frequency. Their level will be within the limits specified by the manufacturer and will rarely be higher than 75 dB below carrier power. The ease of predicting the frequencies at which the more significant spurious emissions will fall makes it possible to avoid a choice of equipment and frequency which will result in a spurious emission at the receiving frequency. Similarly, where point-to-point installations operate with mobile radio systems, precautions should be taken to assure that mutual interference does not occur from such spurious emissions. The 150-megahertz transmitters commonly include a filter network designed to reduce the level of emissions at frequencies higher than the carrier to a level sufficiently low that they should rarely cause interference to other services. Where emissions at frequencies lower than the fundamental cause interference to other services, they may be attenuated by the use of a transmission line filter in the transmitting antenna feed line tuned to the frequency of the interfering spurious emission (see Fig. 19D) or by the use of a band-pass cavity filter in the transmitting antenna feed line (see Fig. 19E). Some situations may require the use of additional "[illegible]" sections, tuned to the interfering frequency and inserted in the transmitter antenna line. Similar solutions would be used in those cases where separate transmitting and receiving antennas are used. In such cases, the necessity for providing additional filter sections may make it worthwhile to consider the use of single antenna installations rather than of separate antennas since the filters which are required to suppress spurious emissions will frequently provide sufficient transmitter-receiver isolation to permit such operation.

7.16 Superheterodyne receivers may have several spurious responses, ie, frequencies other than the desired frequency at which a signal can be received. Sensitivity at these spurious frequencies will usually be markedly lower than at the operating frequency, but if one should coincide with the near-end transmitting frequency or the frequency of a spurious emission from the local transmitter, serious system degradation might result. Prediction of receiver spurious response frequencies is complicated by the number of factors which combine to cause them. The probability of trouble from this source is small; thus it would appear that if trouble is experienced in a particular application, the receiver should be tested for spurious responses. If spurious responses are found to cause difficulty, they may be shifted in frequency by shifting the frequency of one or both of the receiver oscillators by a few kilocycles, compensating for this by shifting the appropriate intermediate frequency by the same amount. This will maintain the same operating frequency but will detune the spurious response.

7.17 Radio frequency filters mentioned in the preceding paragraphs are discussed in Bell System Practice, Section 402-307-100. They may be bandpass cavity filters used in conjunction with transformer sections of transmission line, or they may consist of "traps" and complementary "compensating stubs" made of transmission line and tuned to the required frequency. The Western Electric 552A filter operating near 150 megahertz will provide about 25 dB of attenuation per cavity at frequencies 5 megahertz apart with an insertion loss of less than 1 dB over a 600-kilohertz band. Commercial types of cavities can provide higher isolation but have narrower bandwidth and greater insertion loss. In the application of filters of any type, the various cables connecting the sections and equipment act as transmission line transformers and consequently, are critical in length.

D. Coupling between Antennas

7.18 Coupling between antennas depends upon several factors, including their physical spacing, radiation patterns, mutual coupling to other objects, and separation from objects in the foreground which may reflect energy from the transmitting to the receiving antenna. Figure 23 shows the estimated coupling loss between two Andrew type 3605 corner reflector antennas operating in the frequency range 152 to 172 megahertz, as a function of their separation. Data are presented for both co-linear and co-planer orientation.

7.19 Where it is necessary to estimate the coupling between antennas other than those covered by Fig. 23, this can be done if the dimensions of the antenna and its radiation pattern are known. The coupling (C) expressed in dB is given by the formula:

$$C = G_t + G_r - 20\,\text{LOG.}\frac{4\pi D}{\lambda}$$

Where G_t and G_r are the gains (see Note) of the transmitting and receiving antennas in the direction of coupling, expressed in dB, referred to an isotropic radiator, D is the distance between centers of the radiating elements measured through the effective antenna aperture, as shown in Fig. 24, and both D and λ are expressed in a common unit.

> *Note:* In practical cases the antenna gains G_t and G_r in the direction of coupling will normally have negative values.

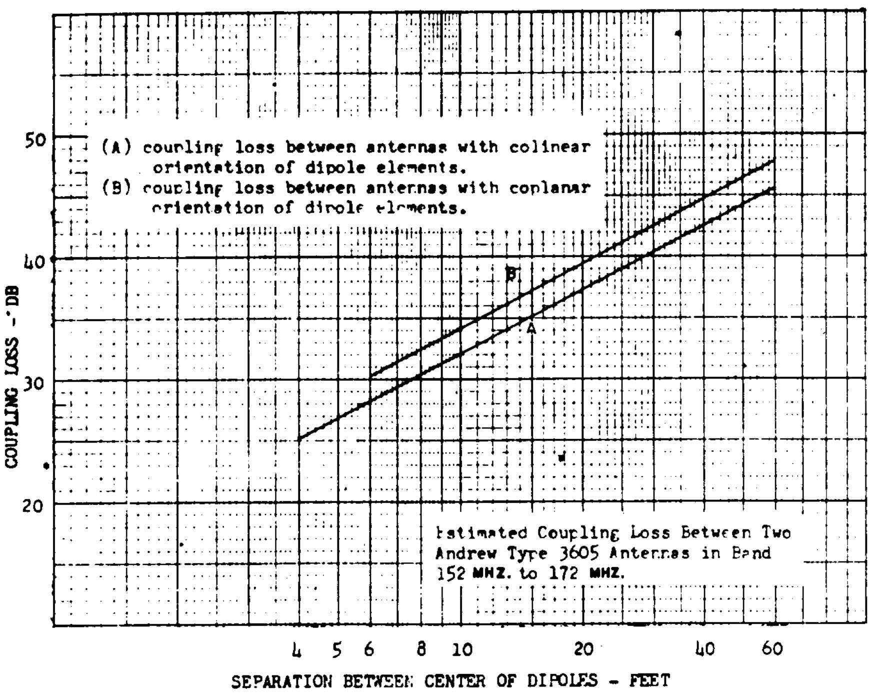


Fig. 23 — Estimated Coupling between Corner Reflector Antennas

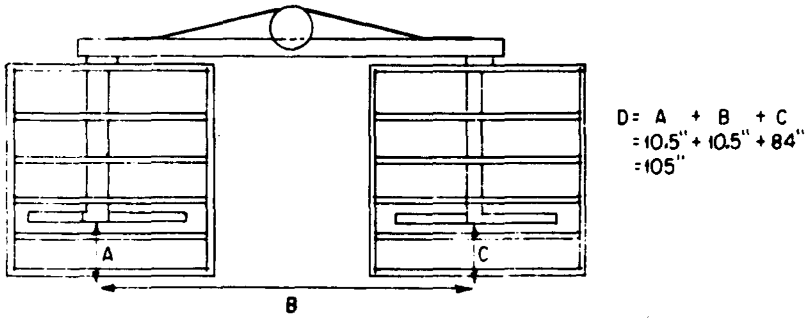


Fig. 24 — Method of Measuring Coupling Path Length between Corner Reflector Antennas

7.20 If two corner reflector antennas having characteristics in the "E" plane at the operating frequency as shown in Fig. 25 are arranged for horizontal polarization and are mounted at the ends of a crossarm as indicated in Fig. 24, their coupling may be computed as follows:

$G_r = G_t$

$= 9.6$ dB (the gain in the forward lobe referred to an isotropic radiator)*

-15.5 dB (the value of the envelope of the antenna pattern in the direction of coupling referred to the main lobe)

$= -5.9$ dB (the gain in the direction of coupling referred to an isotropic radiator)

* The antenna gain used in this computation is related to an isotropic radiator. This is a theoretical source of energy which radiates in all directions. The characteristics of a half-wave dipole result in an increased radiation efficiency of 2.15 dB in the direction of maximum radiation and it is customary for manufacturers to rate gain antennas in terms of gain referred to a half-wave dipole. Since the quantity we seek in this case is the absolute coupling between transmitter and receiver, we must include all antenna gain in our computation. This requires that we add the gain of the reference dipole over the isotropic radiator (+2.15 dB) to the gain of the subject antenna

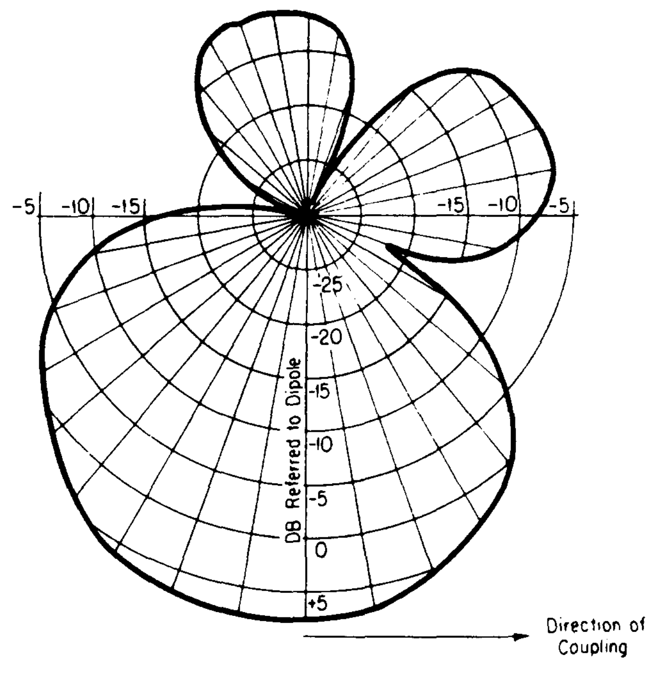


Fig. 25 — Typical Radiation Pattern for Corner Reflector Antenna

as taken from the manufacturer's data, thus the value 9.6 dB for G_t and G_r rather than 7.5 dB.

λ at 155 MHz = 76.0 in.

D = 105 in (See Fig. 24)

$$C = -5.9 \text{ dB} - 5.9 \text{ dB} - 20\text{LOG.}\frac{4\ \pi\ 105}{76.0}$$

$$= -11.8 \text{ dB} - 20\text{LOG.}(17.40)$$

$= -11.8 \text{ dB} \quad -24.8 \text{ dB}$

$= -36.6 \text{ dB}$

7.21 It should be noted that radiation patterns of commercial antennas are not necessarily symmetrical and, unless it is possible to determine accurately the direction of minimum radiation, the more pessimistic choice should be made as was done in this case. (−8 dB referred to a dipole rather than −15.5 dB.)

E. Simultaneous Operation of Transmitters

7.22 Operation of several transmitters at one location requires caution to assure that spurious emissions are not produced through intermodulation. Where antennas of several transmitters are coupled, energy from any transmitter will be fed into the nonlinear plate circuit of the others and, where this occurs, intermodulation products are generated. Where these products are at frequencies which are not largely attenuated by the transmitter output circuit and by the antenna, they are re-radiated and may cause interference. Since the interference occurs on the frequency to which affected receivers are tuned, it is not possible to reduce its effect at the receiver. Thus, if required, suppression must be applied at the transmitter. If P and Q are taken to represent the frequencies of two adjacent transmitters, it can be shown that principal intermodulation products will have frequencies of (2P − Q) and of (2Q − P); other products will be generated but their frequency will be so far removed from the operating frequency, or their level will be so low after third order products are suppressed, they will not be important. In the same manner, operation of three transmitters at one site may cause generation of another family of third order products similar in magnitude to the (2P − Q) and (2Q − P) products mentioned. These are generated in the same manner and have frequencies of (P + Q − R), (P + R − Q), and (Q + R − P), where P, Q, and R are the individual transmitter frequencies. Higher order products of lower magnitude are also generated but will rarely cause trouble.

7.23 The FCC regulations specify the maximum power which will be permitted in spurious and other undesired emissions from radio transmitters. These are stated in the regulations governing the various radio services and must be met in all cases. Interference to other services may require even greater suppression of intermodulation products than is required by law. The method of estimating the amount of suppression which is necessary for a particular situation and the methods which may be used to obtain this suppression will be treated in subsequent paragraphs.

7.24 With transmitters of equal power, the level of intermodulation products is equal to the transmitted power minus the sum of the coupling loss between antennas, the conversion loss in the transmitter, and any additional filter loss which may be provided. Where transmitters of different powers are involved, the power level of intermodulation products will depend upon the lowest powered source. Conversion loss where third order products (2P − Q) and (2Q − P) are involved may be taken to be 10 dB, while in the case of fifth order products (3P − 2Q) and (3Q − 2P), near 25 dB. On this basis, it is possible to determine the required coupling loss between antennas to meet a particular requirement. For example, we may consider the case of a 50-watt transmitter operating with its antenna separated by a distance which results in a coupling loss of 40 dB from the antenna of a 250-watt transmitter and with the need to suppress intermodulation products to a level 70 dB below the 50-watt carrier. Requirements would be as follows:

Space attenuation between antennas	40 dB
Conversion loss (third order products)	10 dB
Total loss	50 dB
Required suppression	70 dB
Additional loss needed	20 dB*
Safety factor	5 dB
Total loss to be provided	25 dB*

* These values are the sum of the filter losses at the frequency of the other transmitters whose

output enters into the intermodulation process and at the frequency of the modulation product which is to be suppressed.

7.25 Because the frequencies requiring suppression usually lie close to the transmitter fundamental frequency, it is necessary to use filters having a very narrow passband and a steep characteristic curve. It is desirable to limit this requirement to a minimum since the insertion loss of the filter tends to increase as its bandwidth decreases. It should be noted that the selection of a cavity filter to be used in the transmitting output circuit must be based not only upon its filter characteristics but also, upon its ability to dissipate power. For example, a cavity having a 3-dB insertion loss at the operating frequency would, when connected in the output circuit of a 50-watt radio transmitter, be called upon to dissipate 25 watts of power. Unless the cavity is designed to do this without the generation of excessive heat and without detuning, it may be necessary to provide cooling blowers or to use several cavities, each having a lower loss rather than one cavity providing all of the required filtering. Filters will, of course, be required in the output of each transmitter. Bell System Practice, Section 402-307-100 will give information which will aid in the selection of the particular cavity for each application and will assist in determining the type and length of critical cables.

7.26 The preceding discussion assumes that all energy coupled mutually between transmitters is coupled between their antenna circuits. Ideally this could be true but in practical applications, other paths such as power lines, telephone lines, and equipment cabinets may contribute undesirable coupling. Coupling resulting from leaks such as are described may, under some conditions, result from 15 to 20 dB of additional spurious radiation. Installation of suitable low-pass filters, adequately shielded, in power and telephone lines will do much to eliminate these paths. Good design will generally require that transmitters which are to operate simultaneously will be separated by a few feet; where this is not possible, common impedances resulting from cabinets in contact, etc, should be kept to a minimum. Additional shielding, application of contact "finger stock" to doors, and other similar devices may be necessary where large amounts of suppression are required.

7.27 Cases will occur in which suppression of intermodulation products at the transmitter input is not effective in eliminating interference to other services. This is possible since transmitter plate circuits are only one of several points at which intermodulation may occur. The input circuit of the receiver experiencing interference is the most probable of these locations while nonlinear elements external to both the transmitter and receiver may cause difficulty under some conditions.

7.28 Receiver susceptibility to such intermodulation varies with receiver design and is dependent on radio frequency selectivity, the type of input tube, and its operating parameters. Intermodulation may occur whenever the input stage is operating in a nonlinear manner and will frequently occur at levels well below those causing receiver desensitization. Elimination of such intermodulation can generally be accomplished by the addition of filters to the receiver input circuit. These are designed to reduce the magnitude of the interfering signal. They may be bandpass cavities or transmission line "traps" as appropriate but must have characteristics which will attenuate one or both of the undesired signals while passing the desired signal.

7.29 Nonlinear elements external to both the radio transmitter and receiver may, when in strong radio frequency fields, act as a mixer to produce various intermodulation products. These modulation products may be radiated and cause interference in nearby receivers. Since the signals which are being mixed can not be reduced and since the signal entering the receiver is on the receiving frequency, filtering is not possible and it becomes necessary to locate and eliminate the cause of trouble. Common sources of external modulation are contacts between dissimilar metals of various sorts or poor contacts between corroded pieces of similar metal. Such items as loose tower parts, poor contacts between copper transmission lines and galvanized towers, and similar conditions may all cause trouble in this manner. Correction of such conditions will, of course, require the location of the nonlinear element and the installation of a low-resistance bond across it.

F. Simultaneous Operation of Receivers

7.30 Under some conditions, it may be desirable to operate several receivers from one antenna, securing the necessary attenuation of transmitter frequencies by one of the arrangements discussed earlier in this Part. Bell System Practice, Section 402-100-100 provides data on networks for 150-megahertz operation which may be fabricated of coaxial transmission line and which will provide optimum performance. It should be pointed out that these arrangements will result in a bridging loss of 3 dB at each frequency for the first receiver bridge, 4.8 dB where three receivers are in use, and 6 dB for four receivers. This may be of consequence at very quiet receiving locations but will be less serious at most receiving sites since the loss affects both signal and noise equally and will, accordingly, have little effect on the circuit performance. An alternative arrangement which is useful at frequencies in the 30- to 50-megahertz range particularly involves the use of an "antenna matching unit." This is essentially a broadband amplifier with a cathode follower output for each receiver which is to be connected. Where such a device is to be used in installations using simultaneous transmission and reception, filtering necessary to avoid first stage overload must be inserted ahead of the coupling unit and further caution must be taken to assure that early receiver stages are protected.

8. DETERMINATION OF SYSTEM MODULATION LEVELS

A. General

8.01 The relation between speech power and full transmitter deviation is, along with site noise and radio receiver input signal, one of the principal factors determining the channel noise performance of a radio system. The lowest signal-to-noise ratio, of course, occurs when the transmitter is fully modulated. This condition rarely occurs since the range of volume levels encountered in speech transmission (between the 1 percent weak talker and the 1 percent "bull" talker) is approximately 25 VU, while occasional speech peaks for a particular talker may rise 17 dB above his own average (98 percent of the peaks will be 10 dB or less above the average).

8.02 Levels proposed in this section are chosen to provide a satisfactory transmission margin, assuming average talker volume distribution. For special cases, where volume levels are higher or lower than the average, where special talker distribution occurs (military service, private mobile systems, etc) or where requirements of distortion differ from the normal toll objective, the load capacity allowances proposed may be adjusted to meet specific needs. In discussing system loading, we will first consider the volume levels applicable for a single-channel system, then, with that discussion as background will consider the multichannel case.

B. Requirements (Single Channel)

8.03 In single-channel systems, the requirements limiting the highest level at which speech may be applied to the radio transmitter are:

(a) Control of transmitter deviation within suitable limits.

(b) Avoidance of serious peak distortion effects.

The highest permissible transmitter deviation is fixed by the radio station license and by the characteristics of the radio transmitter and receiver. System loading which results in high average deviation will, as has been said, provide the most satisfactory noise performance for the average or weak talker but, because of the wide range of talker volumes encountered, care must be taken to maintain good transmission quality for the "bull" talker. By way of illustration, if we assume system adjustments which result in full modulation (usually ±15 kilohertz) under the influence of the speech peaks of the 1 percent "bull" talker, the average deviation for the 50 percent or average talker would be near ±0.6 kilohertz. Such low average deviation would severely penalize the weak or average talker in order to provide optimum performance, even at speech peaks, for a small number of "bull" talkers. In order to avoid the inefficiency of such operation, it is necessary to strive for an operating compromise which will permit satisfactory service for the large majority of the talkers.

8.04 The objective of high average modulation is more easily attained if radio transmitters employed for single-channel systems are equipped with peak deviation limiters. Such limiters control modulator performance by acting as fixed gain amplifiers for inputs below a predetermined level; above that input level, their output is sharply limited. This characteristic prevents overdeviation of the transmitter, making possible higher average modulation than might otherwise be achieved. The process of peak limiting, however, is accomplished by rapid increases in the level of distortion products. Because of this, it is necessary to assign system levels on the basis of the highest average deviation consistent with holding to a very small percentage of the total, the time during which the signal level and the distortion are excessive. For the purpose of very light route end links, single-frequency distortion not in excess of 5 percent (−26 dB) is considered acceptable.

C. Levels for the Single-Channel Uncompandored System

8.05 Single-channel systems with phase modulation and peak limiting will meet distortion objectives during a very large part of the time if the transmitter deviation is adjusted to ±15 kilohertz with a 1000-Hz tone of +9 dBm applied at the 0TLP. This deviation on a continuing basis would, of course, result in excessive distortion; however, since signals having a level of +9 dBm or higher occur only very rarely as speech peaks of short duration, the transmission degradation which results will not be objectionable. As a practical matter, system lineup will usually be specified on the basis that 0 dBm of 1000-hertz tone at the 0TLP should produce ±5.3-kilohertz deviation. This provides the desired result (assuming that deviation is directly proportional to modulating voltage) and, at the same time, avoids undesirable operating conditions.

8.06 The equivalent single-frequency power level which is required to produce ***full*** modulation is known as the channel load capacity. Its value is a quantitative measure of the system power handling margin available for protection against excessive distortion under peak conditions. Tables 2 and 3 have been prepared to show the relation between talker volume, transmitter deviation, and distortion for a single channel phase-modulated system operating with a 9-dB load capacity allowance (based on 1000-Hz test tone). It will be seen that this results in satisfactory distortion performance for all talkers on an rms or average basis, with excessive distortion occurring only on peaks of the highest level "bull" talker. These occur not more than 2 percent of the time for any particular talker and thus, it is felt the distortion penalty is not too severe since it is accompanied by relatively high average deviation. The conclusion that the 9-dB channel load capacity allowance chosen is optimum can be borne out as follows:

(a) Increasing the channel levels by as little as 3 dB will result in excessive distortion of the 1 percent talker on even an rms basis and in very high distortion on peaks for a considerable number of talkers.

(b) A 3-dB reduction in level, on the other hand, would reduce peak distortion for the 1 percent "bull" talker only slightly; it would add 3 dB to channel noise for all talkers.

D. Levels for the Single-Channel Compandored System

8.07 The use of the channel compandors to improve system performance is discussed in Section 940-250-101. As part of that discussion, it is shown that the compandor action results in raising the average levels at the transmitter input and in higher average deviation. Reference to Fig. 2 of Bell System Practice, Section 940-250-101, will show that the action of the compressor on a steady tone at a level of 0 dBm will raise the relative level of the tone at the transmitter input to +2.5 dBm, while a tone having a level of +10 dBm would be reduced to a relative value of +7.5 dBm by the compressor. Speech peaks, having a duration shorter than the "attack" time of the compressor, are not affected by the compressor action to the same degree as is a steady tone. Satisfactory operation will, however, be obtained if the system deviation is established on the same basis as it was without the compandor, ie, if 0 dBm of 1000-hertz tone (at the equivalent of 0TLP) at the compandor ***input*** is allowed to produce ±5.3 kilohertz of transmitter deviation (9 dB below ±15 kilo-

TABLE 2

RELATION BETWEEN TEST POWER OR TALKER VOLUME, DEVIATION, AND DISTORTION IN A SINGLE CHANNEL PHASE–MODULATED RADIO SYSTEM

TALKER DISTRIBUTION	TEST POWER DBM OR TALKER VOLUME VU AT OTLP	EQUIVALENT RMS POWER DBM AT OTLP (Note 1) (Note 2)	DEVIATION KHZ (Note 6)		DISTORTION PERCENTAGE (Note 5)	
			RMS	PEAK (Note 4)	RMS	PEAK
Test Power	0 dBm, 1000 Hz	0 dBm, 1000 Hz	±5.3	±5.3	<3.0	< 3.0
50%	–14.2 VU	–15.6 (1500 Hz)	±1.33	±4.2	<3.5	< 3.0
16%	– 9.2 VU	–10.6 (1500 Hz)	±2.36	±7.45	<3.0	< 5.0
1%	– 2.5 VU	– 3.9 (1500 Hz)	±5.1	±16.3	<3.0	>20.0

TABLE 3

RELATION BETWEEN TEST POWER OR TALKER VOLUME, DEVIATION, AND DISTORTION IN A SINGLE CHANNEL PHASE-MODULATED SYSTEM EQUIPPED WITH COMPANDOR

TALKER DISTRIBUTION	TEST POWER DBM OR TALKER VOLUME VU AT OTLP	EQUIVALENT RMS POWER AT OTLP DBM (Note 1) (Note 2)	EQUIVALENT RMS POWER AT COMPANDOR OUTPUT (Note 3)	DEVIATION KHZ (Note 6)		DISTORTION PERCENTAGE (Note 5)	
				RMS	PEAK (Note 4)	RMS	PEAK
Test Power	0 dBm, 1000 Hz	0 dBm, 1000 Hz	+2.5 dBm, 1000 Hz	±5.3	± 5.3	<3.0	< 3.0
50%	–14.2 VU	–15.6 (1500 Hz)	–5.3 dBm (1500 Hz)	±3.18	±10.1	<3.0	< 4.0
16%	– 9.2 VU	–10.6 (1500 Hz)	–2.8 dBm (1500 Hz)	±4.33	±13.7	<3.0	< 8.0
1%	– 2.5 VU	– 3.9 (1500 Hz)	+0.5 dBm (1500 Hz)	±6.34	±20.0	<4.0	>20.0

Note 1: Test results have shown that speech volume in VU may be related to the equivalent rms power level in dBm by the conversion factor, –1.4. That is:

$$\text{dBm} = \text{VU} - 1.4$$

Note 2: Analysis indicates that the average effect of speech in modulating a ***phase-modulated*** radio transmitter is approximately equal to the effect of a 1500-hertz sine wave having the same rms power level.

Note 3: This assumes a compandor having characteristics similar to that discussed in Section 940-250-101.

Note 4: Peak values taken here are 10 dB higher than the rms. For any particular talker volume, 98 percent of all power levels will be equal to or lower than this. The remaining 2 percent of the power levels will reach values more than 10 dB above the rms and some peaks may be as much as 17 dB above the rms for that talker volume.

Note 5: Distortion values chosen here are felt to be representative of those which will be encountered using commercial mobile radio base station equipment with deviation limiters set to limit deviation to ±15 kHz.

Note 6: Deviation shown in this column is that which would occur in the absence of peak deviation limiting.

hertz full deviation). This same 9 dB (below full modulation) load capacity allowance will be satisfactory for systems employing other maximum deviations. Table 3 provides an analysis of compandored system results.

8.08 In the event that frequency-modulated radio equipment rather than phase-modulated equipment is to be used in single channel service, the load capacity allowance may be adjusted downward. This is possible because the effect of speech is approximately equal to the effect of 1500 Hz sine-wave power in modulating a phase-modulated transmitter. Since a frequency-modulated transmitter is not sensitive to the frequency of the modulating signal, a correction of 3.5 dB (20 LOG. $\frac{1500}{1000}$ may be applied. This will result in a load capacity allowance of 5.5 dB. Restating this, a tone (regardless of frequency) at a level of +5.5 dBm at the 0TLP would fully modulate the frequency-modulated transmitter, while 0 dBm at the same point would produce ±8.0 kilohertz of deviation.

E. Levels for Three-Channel Compandored System with FM Radio

8.09 Channel levels in 3-channel radio systems are governed by the same general requirements (transmitter modulation and intrachannel distortion) that direct the choice of levels in single channel systems. In addition, the problem of intermodulation, which may in some cases contribute the limiting channel noise, must also be considered in establishing system operating conditions (this will be discussed in later paragraphs). Since the computation of levels for any given application is a complex process, this section will discuss the principal factors to be considered and will provide recommended operating levels for two practical combinations of equipment, but it will not attempt a complete analysis of the methods whereby recommended levels have been chosen.

8.10 When more than one voltage is applied to the input of a transmitter modulator, the deviation resulting is proportional to the instantaneous sum of the applied voltages. Consideration of this alone might lead to the conclusion that system load capacity allowances must be based upon peak addition of the channel signals; however, where more than a few channels are to be transmitted by a common medium, it is possible to apply statistical methods to the determination of the total power which is to be expected from the channel group during the busy hour. By these methods, it is possible to develop a value which includes allowances for such factors as the ratio of busy to idle circuits, the ratio of talking to listening users, the statistical talker distribution, the amount of overload which can be tolerated, and other similar factors. This allowance can be used for determining the system load capacity for any particular situation. The amount by which the single-channel load capacity allowance must be increased in order to meet these additional requirements which accompany multichannel operation (assuming SSBSC operation) will range from a low value (2 to 3 dB) for a small number of circuits to perhaps 10 dB or more for cases involving a few hundred channels.

8.11 The system load capacity required depends upon those factors considered above, along with the speech power delivered to the system by the individual active channel. This will, in most multiplex equipments in use today and for most talker volumes, be directly related to the speech power which has been applied to the channel. It is true, however, that carrier system modulator characteristics are not always entirely linear and above a certain overload point, they will act as voltage limiters. This, of course, will result in establishing a certain maximum signal level which the multiplex unit can deliver to the radio system. This is desirable for our purpose as it provides a definite limitation on the power which will be contributed by any single channel. The characteristics of the copper-oxide modulators used in the Western Electric H1 carrier and in the Lenkurt 33-type units are approximately those shown in Fig. 26. The modulator characteristics of other carrier systems may vary materially from this, and these variations must be taken into consideration if the levels proposed in this section are used in assemblies containing other types of multiplex equipment. In general, intrachannel distortion performance will be dependent upon channel modulator characteristics and will have satisfactorily

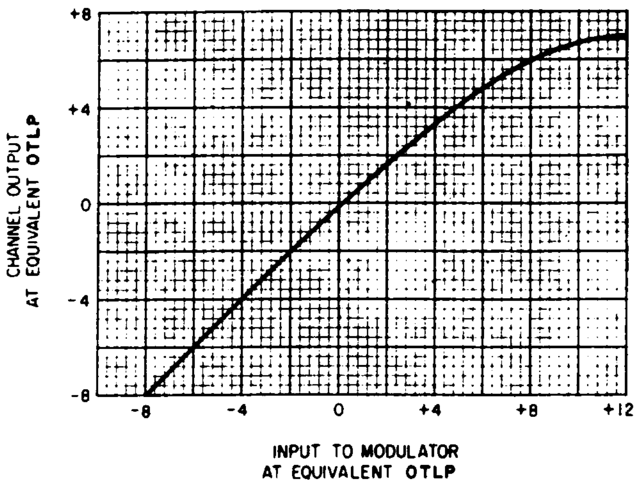


Fig. 26 — Characteristics of Modulators of H1 and Lenkurt 33B Carrier Systems

low values if multiplex equipment is operated at specified input levels.

8.12 The presence of nonlinear elements in any part of a transmission system will result in distortion and will cause the generation, during transmission, of frequencies which were not present at the system input. The percentage of distortion in any particular system will tend to rise as the signal level applied to the system is increased (and thus, as the frequency deviation is increased). When several signals are introduced into a radio system simultaneously, both the transmitter deviation and the distortion are determined by the combined levels of the several signals in peak addition. For a typical radio unit, meeting requirements as outlined in paragraph 8.06, distortion values of 0.1 percent to 4 percent (distortion products from 28 to 60 dB below the fundamental) can be expected at levels causing a deviation of less than about ±10 kilohertz. The distortion percentage may rise to a value as high as 20 percent (products 14 dB below the fundamental) when the deviation reaches ±15 kilohertz.

8.13 Distortion products resulting from the intermodulation of several single-frequency signaling tones or carriers can usually be held to satisfactorily low levels by controlling the relative level at which the signaling is applied to the radio system. This will also limit the level of intermodulation noise resulting from the presence of signaling tones and one or more talkers; it will not affect the level of intermodulation noise occurring as the result of simultaneous high level speech in two or more channels. Such modulation noise may appear as high level bursts in another channel and, since these occur at a syllabic rate, they will be particularly annoying to the listener even though they are not intelligible. The nature of this noise is such that it can not be tolerated for more than a small part of the total time. The interference caused by this effect may actually be of greater consequence in the operation of a system with only a few channels than in a system having a greater number of channels. In the latter case where the number of active channels can be expected to be quite large, the noise loses its syllabic nature and becomes random in character.

8.14 Since the distortion characteristics of the modified mobile radio base station equipment contemplated for point-to-point service represents a compromise between performance which is satisfactory for the mobile services and costs, it is not likely that improved intermodulation performance can be obtained. Also, while it might be possible to obtain satisfactory intermodulation performance by a reduction of channel level at the radio equipment input, this improvement would be obtained at the expense of much lower deviation, poorer channel noise performance, and reduced range by comparison with a system having optimum modulation levels (disregarding intermodulation noise).

8.15 The use of compandors in VHF applications offers the opportunity to obtain a marked improvement (as much as 23 dB) in the channel noise performance. The same improvement will assist in the reduction of modulation noise in multichannel systems and, as a practical matter, it appears to offer the only satisfactory solution to this problem in the very light route service. Consequently, the use of compandors in multichannel systems of the type discussed is essential, if good service is to be provided.

8.16 The foregoing discussion has been based upon the premise that all channel signals are to be applied to the radio system at the same level. Where this is done in a system using frequency modulation, the channel noise performance of the top channel, because of the "triangular" noise spectrum, will control system performance (Fig. 27) and may be as much (in a three-channel case) as 20 dB poorer than the voice-frequency channel. Because of this, it is desirable to apply equalization or pre-emphasis to the system, thus obtaining substantially equal noise performance on all channels. If such equalization is carried out completely, the system is converted to a phase-modulated characteristic with a "flat" noise spectrum (Fig. 28). The maximum theoretical noise improvement which can be obtained by pre-emphasis is 4.8 dB and no real advantage will be realized if pre-emphasis is carried beyond this point. Because of low-frequency noise which may be present in the voice-frequency band, intermodulation bursts, etc, it may be desirable to operate the voice channel at levels somewhat higher than the foregoing would indicate. This will result in an effective system modulation characteristic between frequency modulation and phase modulation as indicated in Fig. 29.

8.17 Table 4 has been prepared to show levels proposed for three-channel operation and the relation between transmitter deviation and channel levels for various talker conditions which can be expected. The values chosen are

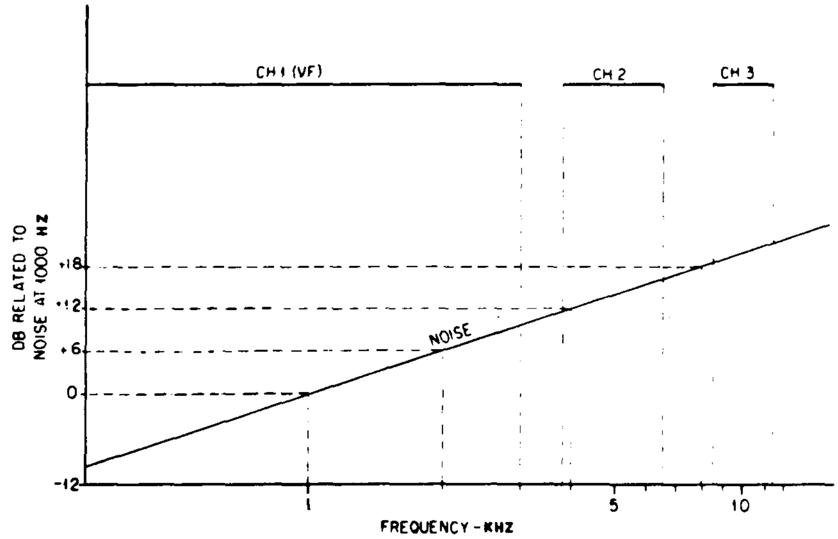


Fig. 27 — Relation of Signal to Noise in a Frequency–Modulated System

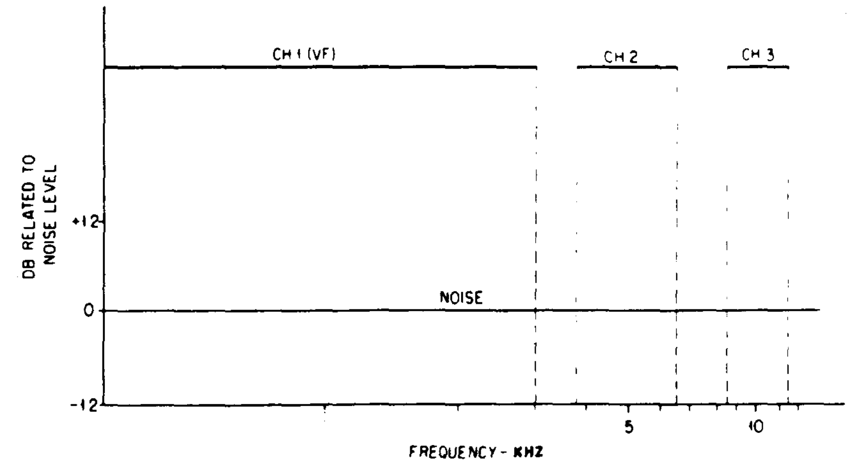


Fig. 28 — Relation of Signal to "Flat" Noise

TABLE 4

RELATION BETWEEN TEST POWER, TALKER VOLUME, AND DEVIATION FOR THREE–CHANNEL COMPANDORED VHF RADIO SYSTEM WITH FREQUENCY MODULATION

TALKER DISTRIBUTION	POWER — DBM OR TALKER VOLUME VU AT OTLP	(NOTE 1) EQUIVALENT RMS POWER AT OTLP	(NOTE 2) TRANSMITTER INPUT RELATIVE TO ±15 KHZ DEVIATION			TRANSMITTER DEVIATION KHZ						
						RMS			PEAK (NOTE 3)			
			V	C1	C2	V	C1	C2	V	C1	C2	
Test Tone	0 dBm, 1000 Hz	0 dBm, 1000 Hz	—13.5	— 7.5	— 3.5	3.2	6.3	10.0	3.2	6.3	10.0	
50%	—14.2	—15.6	—21.3	—15.3	—11.3	1.3	2.6	4.1	4.1	8.2	12.9	
16%	— 9.2	—10.6	—18.8	—12.8	— 8.8	1.7	3.4	5.4	5.5	10.9	15.1	
1%	— 2.5	— 3.9	—15.5	— 9.5	— 5.5	2.5	5.0	8.0	7.8	11.2	17.8	(Note 4)
Signaling Tone			—30	—30	—30	0.5	0.5	0.5	0.5	0.5	0.5	

Note 1: Test results have shown that speech volume in VU may be related to the equivalent rms power level in dBm by the conversion factor, —1.4. That is:

$$\text{dBm} = \text{VU} - 1.4$$

Note 2: V refers to the voice-frequency channel; C1 and C2 refer to the low- and high-frequency derived channels, respectively.

Note 3: Peak values taken here are 10 dB higher than the rms. For any particular talker volume, 98 percent of all power levels will be equal to or lower than this. The remaining 2 percent of the power levels will reach values more than 10 dB above the rms and some peaks may be as much as 17 dB above the rms for that talker volume. Peak deviation indicated is adjusted to include the effect of the channel modulators for channels C1 and C2.

Note 4: This is a theoretical value which will not ordinarily be reached in practice because of the overload characteristics of the system components.

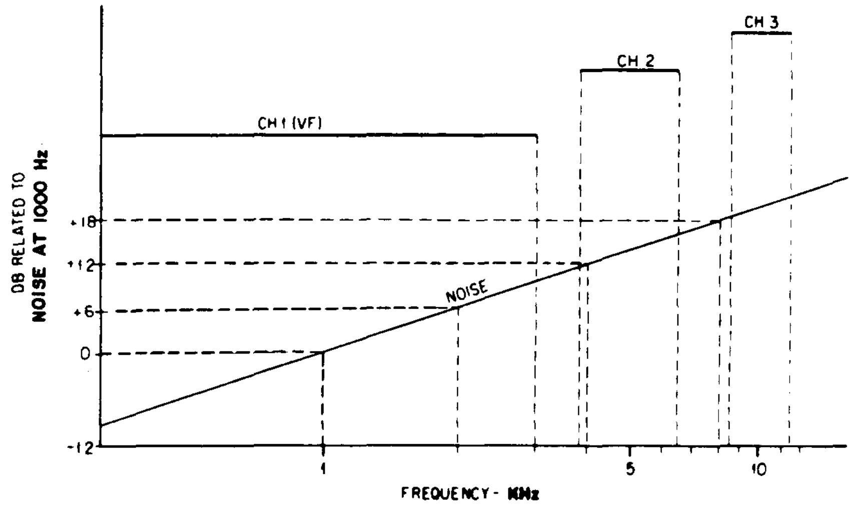


Fig. 29 — Relation of Signal to Noise with Partial Pre–emphasis

based upon the use of multiplex equipment occupying the spectrum between about 3500 Hz and 11000 Hz and thus, they will be satisfactory for use with Western Electric H1 carrier and single sideband suppressed carrier and other systems with similar channel assignments.

F. Levels for Three-Channel System with Phase-Modulated Radio Equipment

8.18 Situations in which multiplex equipment is to be used with phase-modulated radio equipment (such as the Western Electric 542A transmitter modified for broadband operation) require somewhat different treatment than that indicated in Table 4. In systems using H1 carrier multiplex, transmitter modulation performance similar to that shown in Table 4 will be obtained if channel output levels with 0 dBm of 1000-Hz tone applied to the compressor input are as follows:

TABLE 5

CHANNEL	CARRIER FREQUENCY RESULTING FROM 1000-HZ TONE AT CHANNEL INPUT	TRANSMITTER INPUT LEVEL RELATIVE TO LEVEL OF 1000-HZ TONE REQUIRED TO PRODUCE DEVIATION OF ±15 KHZ
V	1000	—17.0 dB
C1	6150	—23.0 dB
C2	8150	—23.0 dB

Similarly, if Lenkurt 33-type carrier or other equipment with a similar channel assignment is to be used with a phase-modulated radio system, levels as indicated below would be used for performance similar to that shown in Table 4.

TABLE 6

CHANNEL	CARRIER FREQUENCY RESULTING FROM 1000-HZ TONE AT CHANNEL INPUT	TRANSMITTER INPUT LEVEL RELATIVE TO LEVEL OF 1000-HZ TONE REQUIRED TO PRODUCE DEVIATION OF ±15 KHZ
V	1000	—17.0 dB
C1	4500	—21.5 dB
C2	10500	—25.0 dB

9. NOISE PERFORMANCE OF RADIO SYSTEMS

A. General

9.01 Part 5 of this section discussed the theoretical considerations influencing channel noise performance while the various aspects of site noise and its control are covered in Part 6 of this section. Bell System Practice, Section 940-250-102 provides a means of determining the effective magnitude of site noise at a particular location.

9.02 Figure 30 provides data concerning the noise performance of typical systems adjusted in accordance with this section, relating the receiver RF input to the noise at the 0TLP

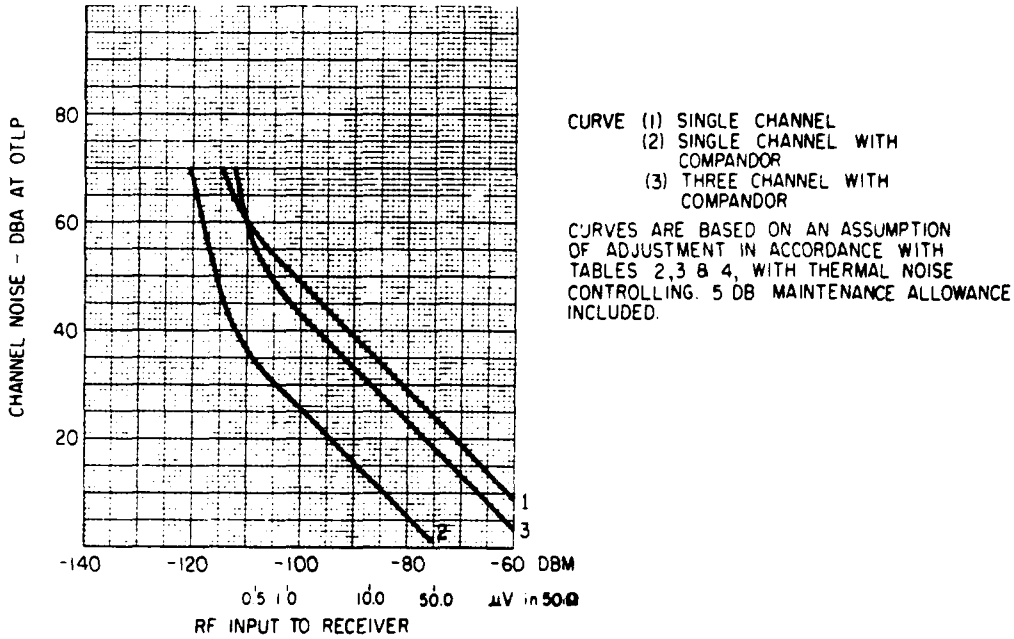


Fig. 30 — Channel Noise Versus RF Input to Receiver

of the *worst* channel (top carrier channel). In each case appropriate allowances have been made for channel and system load capacity, receiver noise figure, and such maintenance conditions as misalignment, tube aging, etc. These curves are based upon the assumption that thermal noise controls system performance.

9.03 Computation of noise in channels other than the top channel of multichannel systems using frequency-modulated radio may be based upon an assumption that the effect of the noise weighting network upon triangular noise (referred to the 1000-hertz point of the channel) results in approximately the same effective noise power as would result were the baseband noise flat. On this basis, three-channel systems adjusted in accordance with Table 4 will have top channel noise performance in accordance with Fig. 29. Low carrier channel performance will be 4 dB better than this with voice-frequency channel performance about 10 dB better than top channel. This assumes that radio noise controls system performance in all channels. This will rarely be true insofar as the voice-frequency channel is concerned since equipment noise, hum, etc, may contribute substantial additional channel noise.

10. WIRE EXTENSIONS TO RADIO FACILITIES

10.01 Where radio transmission requirements dictate the installation of radio equipment at locations away from the terminating central office and it is feasible to extend voice-frequency drops on a 2- or 4-wire basis, no unusual problems are to be expected. Levels and losses permissible will be in accordance with the limits established in the AB Series of Practices with standard design of the wire extensions. Channel performance objectives will, of course, apply to the combined wire and radio facilities, and design of the radio section must be such that its performance will not result in failure of the combined facility to meet objectives.

10.02 Situations requiring the installation of the radio equipment portion of multichannel systems at locations away from the terminating central office may be satisfied by voice-frequency wire extensions or by extensions of the high-frequency line. The latter arrangement will usually be more economical but may result in some problems. The principal factors requiring consideration will usually be slope and crosstalk.

10.03 Where slope of the wire facility used to extend the high-frequency line of radio systems results in unsatisfactory channel-frequency characteristics, slope equalization of the type employed in program transmission circuits may be useful. The gain required to compensate for the equalization loss will usually be available in the carrier terminal receiving equipment. If additional gain is needed, various types of program amplifiers may be employed.

10.04 If we assume the use of three-channel compandored systems of the type discussed in this section, operating with wire extensions at both ends of the radio path, satisfactory operation from the standpoint of crosstalk between opposite directions of transmission in the wire facilities may be expected if the following conditions are met:

(a) Transmitting levels in high- and low-frequency channels should be the same in both directions.

(b) Near-end crosstalk coupling between pairs chosen for use should not exceed 40 dB plus the high-frequency loss (near-end).

10.05 General rules for pair selection can not easily be given and in most situations it will be desirable to perform measurements of near-end crosstalk at several frequencies in the band.

11. TYPICAL SYSTEM DESIGNS (EXAMPLES)

A. General

11.01 This part of this practice provides examples of the overall design of typical 150-megahertz VHF radio systems showing the application of the information which has been presented earlier. Figure 31 shows the relative signal and noise levels at various points within a typical single-channel compandored system. This diagram assumes a median path loss of about 123 dB, noise at the receiving site typical of a suburban area (medium site noise), and system adjustment in accordance with Part 9 of this section. In the preparation of the level diagram, signal levels are shown at various points, with gains and losses due to each circuit element appearing directly below the element. The difference between carrier-to-noise ratios at the receiver input and the signal-to-noise ratio at the receiver output and at the expandor output (points A, B, and C) are due to the effect of the frequency-modulated improvement and the expandor noise advantage, respectively. Figure 32 is included to permit a ready estimate of the median 150-megahertz radio path loss between antennas at various effective heights over a smooth earth path. As an aid to the understanding of VHF systems design, Subparts B and C will tabulate the principal design factors considered, evaluate their effects upon system performance, and indicate the source of information by appropriate references.

B. Single-Channel Plans

11.02 Given the need for a single voice-frequency channel connecting two central offices located in suburban communities about 22 miles apart, the engineer might consider several alternative plans including, in a typical case, arrangements as follows:

(a) Radio terminals located at the central office buildings, antennas supported on existing buildings or by the use of 45-foot wood poles to provide effective antenna elevation of 40 feet; 50-watt transmitters operating near 150 megahertz, Andrew type 3605 antennas; and channel compandors.

(b) Radio terminals located at the central office buildings, 50-watt transmitters without compandors; antennas as above elevated to provide the required reduction in path loss.

(c) Radio terminals located in quiet locations; 50-watt transmitters, no compandors; antennas as above, supported on wood poles of the minimum height necessary to provide the required path loss.

11.03 Table 7 tabulates the principal design features of these three plans and compares them feature by feature.

11.04 Having set forth the features of the various plans, an evaluation of their relative merits is in order. Some factors to be considered

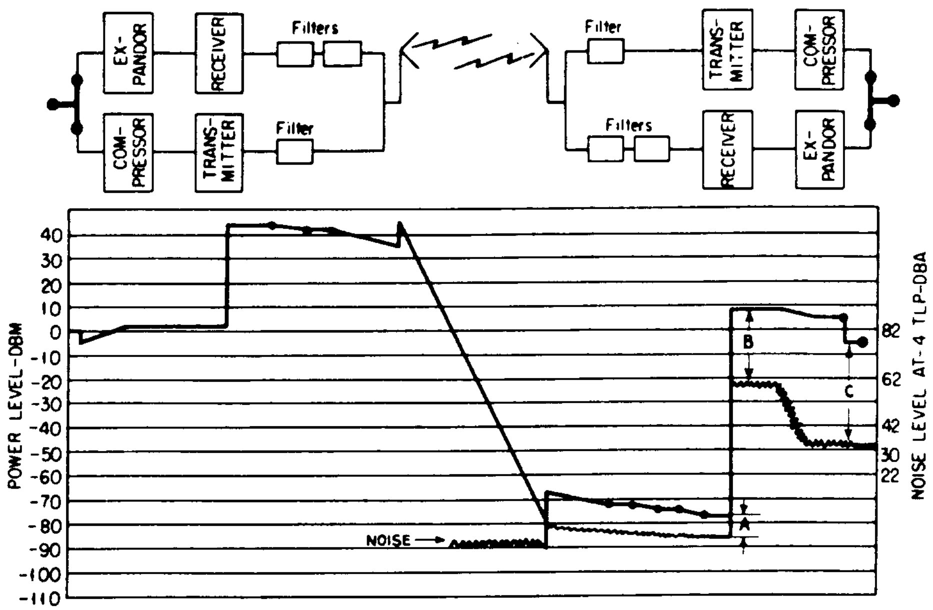


Fig. 31 — Signal and Noise Levels in Typical Single-Channel 150-Megahertz Radio System with Compandors

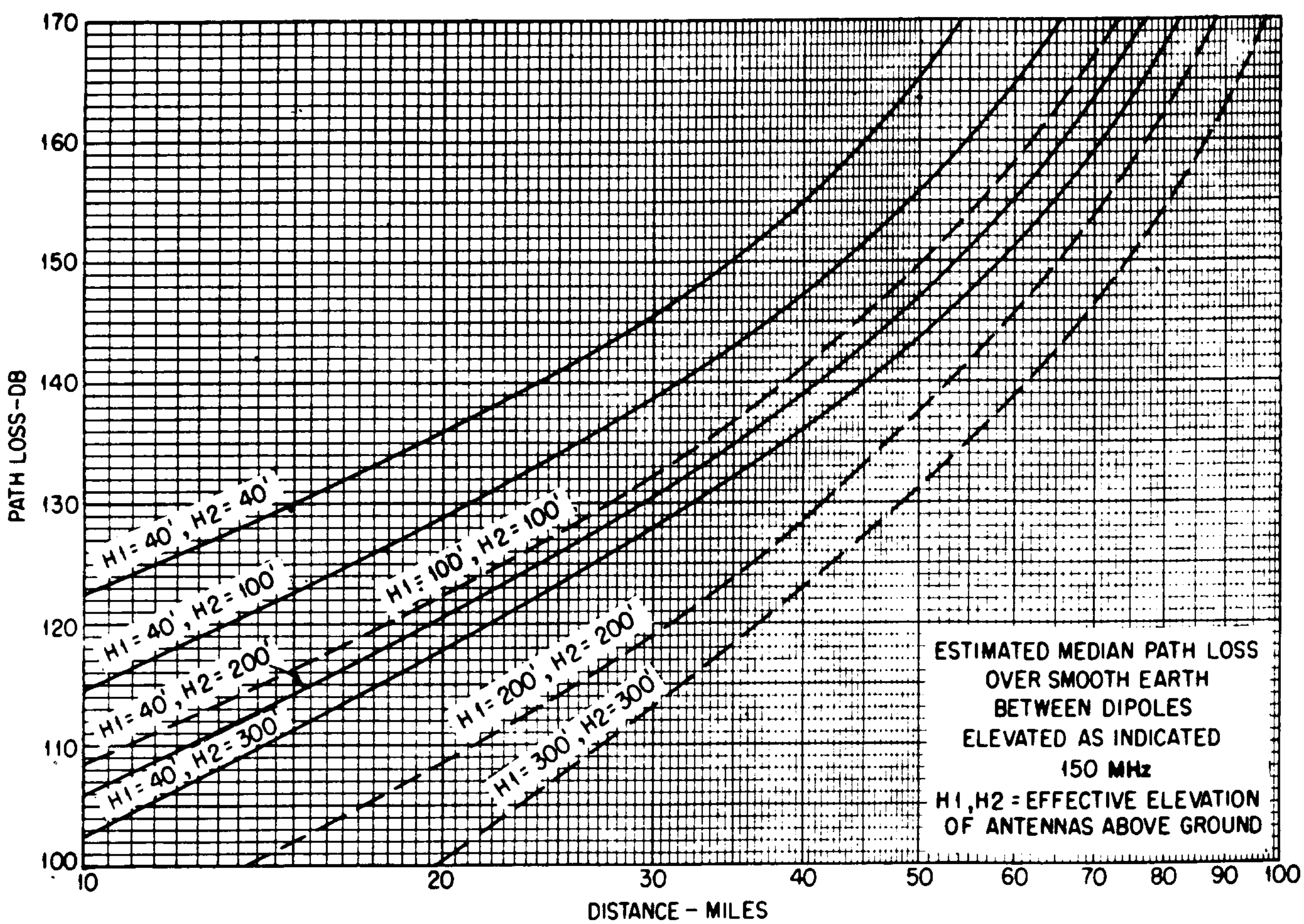


Fig. 32 — Estimated Path Loss over Smooth Earth at 150 Megahertz

TABLE 7

ITEM	REFERENCE	PLAN A	PLAN B	PLAN C
(1) Channel Noise Objective	Par. 4.02	34 dBa at 0TLP	34 dBA at 0TLP	34 dBa at 0TLP
(2) Distance to be Spanned	Given	22 mi	22 mi	22 mi
(3) Site	Table 1, Part 5	Suburban	Suburban	Rural
(4) Required RF Input to Receiver	Table 1, Part 5 or Test per 940-250-102	−78 dBm	−55 dBm	−83 dBm
PLUS FACTORS				
(5) Transmitter Power	Assume 50 watts	+47 dBm	+47 dBm	+47 dBm
(6) Total Antenna Gain (T + R)	Assume Andrew 3605	+15 dB	+15 dB	+15 dB
(7) Sum of Plus Factors	Line (5) + (6)	+62 dBm	+62 dBm	+62 dBm
PERMISSIBLE LOSS				
(8)	From Lines (4) and (7)	140 dB	117 dB	145 dB
MINUS FACTORS				
(9) Transmission Line (Transmitting)	Fig. 5 of 940-250-101	80 Ft RG 8A/U = −1.9 dB	270 Ft 7/8-in Styroflex = −1.5 dB	80 Ft RG 8A/U = −1.9 dB
(10) Transmission Line (Receiving)	Fig. 5 of 940-250-101	See Note	See Note	−1.9 dB
(11) Filter Insertion Loss (Transmitting Leg)	Par. 7.17 and 402-307-100	−1.0 dB	−1.0 dB	−1.0 dB
(12) Filter Insertion Loss (Receiving Leg)	Par. 7.17 and 402-307-100	See Note	See Note	−2.0 dB
(13) Sum of Minus Factors	Line (9) + (10) + (11) + (12)	−2.9 dB	−2.5 dB	−6.8 dB
(14) Maximum Permissible Path Loss	From Lines (8) and (13)	137.1 dB	114.5 dB	138.2 dB
Required Effective Antenna Height	By Extrapolation from Fig. 32	40 ft each end	175 ft each end	40 ft each end

Note: In situations involving practical radio receiver power input levels and with site noise more than about 10 dB above thermal, it is permissible to disregard the insertion loss of filters and transmission line in the receiver antenna circuit. This is true because both noise and signal are affected equally by this loss and thus the carrier to noise ratio, as well as the signal to noise ratio, are the same with or without the common loss. At locations having a very low site noise contribution, on the other hand, the loss in the receiving antenna circuit must be considered since the principal source of noise is within the receiver. Where this is true, the reduction in signal input is accompanied by a reduction in signal to noise ratio. Assuming that noise tests were made using an antenna similar to that proposed for the service, and properly oriented, it is proper, however, to include the antenna gain in the computation since the weighting effect of the antenna was reflected in the noise measurement.

in evaluating these plans are tabulated in Table 8. Because of the wide variety of conditions which will be encountered in practical cases, no values are assigned; however, if we take Plan A as our reference, we may indicate the more favorable factors by (+), unfavorable by (—), and factors which are equivalent in all cases, or which are neutral, by (X). Thus, in the Cost columns, a (+) will usually indicate lower first cost than for Plan A, a (—) higher first cost; in the Maintenance column, (+) may indicate lower cost but may also indicate greater convenience or better circuit reliability, both factors of importance in system design.

C. Three-Channel Plans

11.05 Given a need for three-message channels to provide service between two small towns separated by about 38 miles over relatively smooth earth with site noise at the worst location, as determined by tests, 15 dB above thermal, the engineer might consider the use of several plans, finally reducing the group from which his choice is to be made to two plans, (Table 9) as follows:

(a) A three-channel system equipped with channel compandors; terminal and radio equipment to be located at the central offices; antennas supported at the minimum elevations required to provide the desired path loss.

(b) Three single-channel systems equipped with compandors; with terminal and radio equipment located at the central offices; and with antennas supported at minimum elevations required to provide the desired path loss.

TABLE 8

ITEM	PLAN A		PLAN B		PLAN C	
	COST	MAINTENANCE	COST	MAINTENANCE	COST	MAINTENANCE
Land and Buildings	X	X	X	X	—	—
Antenna Support	X	X	—	—	X	X
Power Supply (Regular and Emergency)	X	X	X	X	—	—
Connecting Wire Facilities	X	X	X	X	—	—
Antennas	X	X	X	—	X	X
Transmission Line	X	X	—	—	X	X
Radio Equipment	X	X	X	X	X	—
Terminal Equipment	X	X	+	+	+	+
Test Equipment	X	X	X	X	—	—

TABLE 9

ITEM	REFERENCE	PLAN A	PLAN B
(1) Channel Noise Objective	Par. 4.02	34 dBa	34 dBa
(2) Distance to be Spanned	Given	38 mi	38 mi
(3) Site Noise	Assume Determined by Test per 940-250-102	15 dB above thermal	15 dB above thermal
(4) Required RF Input to Receiver	Part 5 or Test Results	—76 dBm	—93 dBm
PLUS FACTORS			
(5) Transmitting Power	Assume 50 Watts	+47 dBm	+47 dBm
(6) Total Ant. Gain	Andrew 3605	+15 dB	+15 dB
(7) Sum of Plus Factors	Line (5) + (6)	+62 dBm	+62 dBm
(8) Permissible Loss	From Lines (4) and (7)	138 dB	155 dB
MINUS FACTORS			
(9) Transmission Line (Transmitting)	Fig. 5 of 940-250-101	170 Ft RG 17A/U —1.9 dB	80 Ft RG 8A/U —1.9 dB
(10) Transmission Line (Receiving)	See Note of Table 7	—	—
(11) Filter Insertion Loss (Transmitting)	Par. 7.17 and 402-307-100	—1.0 dB	—1.0 dB
(12) Filter Insertion Loss (Receiving)	See Note of Table 7	—	—
(13) Sum of Minus Factors	Line (9) + (10) + (11) + (12)	—2.9 dB	—2.9 dB
(14) Maximum Permissible Path Loss	From Lines (8) and (13)	135.1 dB	152.1 dB
(15) Effective Antenna Height Required	By Extrapolation from Fig. 32	140 Ft Each End	40 Ft Each End

11.06 If we consider the two plans for obtaining three-message channels in the same way as we did the alternative plans for single-channel installation, with Table 9, Plan A as our reference we may prepare tabulations as follows:

TABLE 10

ITEM	PLAN A		PLAN B	
Land and Buildings	X	X	X	X
Antenna Support	X	X	+	+
Power Supply (Regular and Emergency)	X	X	X	X
Connecting Wire Facilities	X	X	X	X
Antennas	X	X	X	X
Transmission Line	X	X	+	+
Radio Equipment	X	X	–	–
Terminal Equipment	X	X	+	+
Test Equipment	X	X	X	X

It is not possible to assign absolute values to the various factors measured above on a broad basis, but consideration in a particular case should result in determination of the preferred means of obtaining the required facility. In evaluating these plans, certain secondary considerations must be given weight along with the major items. In this particular case, the most important of these might be the effective service protection offered by the three single-channel installations. This apparent advantage might be balanced in part, however, by the problem of intermodulation resulting from the operation of several transmitters at one location and the problem of supporting three separate antennas at each terminal.

D. Summary

11.07 Consideration of the foregoing material and of the material in other parts of this section will reveal that system transmission design will frequently require compromises between various factors if optimum results are to be accomplished. Assuming that a certain performance objective is to be met and that the distance to be spanned is also fixed, other features of the system design which might be varied would include:

(a) Transmitter power.

(b) Antenna gains.

(c) Antenna height.

(d) Location (to control site noise or effective antenna height).

(e) Radio system bandwidth (single channel versus three channel).

(f) Use of compandors.

(g) Frequency (150 megahertz versus 450 megahertz, for example).

In special cases particularly in private systems where connection to the general telephone network is not involved, it may be possible to modify the system adjustments proposed in Part 8 either as the result of a smaller range of talker volumes or because of a willingness to relax distortion requirements. Such system readjustments might result in an improvement of a few dB in S/N, thus permitting some economies in systems serving selected talker groups, such as users of a private radio system, military groups, etc. Alternatively in special cases, it might be desirable to relax channel noise performance requirements by a few dB, thus effecting some first cost economies.