RADIO ENGINEERING
MICROWAVE RADIO
NOISE
GENERAL

CONTENTS PAGE

1. GENERAL

1.01 This section covers the necessary procedures for calculating the free space propagation noise performance of various microwave radio relay systems. The computation methods discussed in Parts 3, 5, 6, 7 and 8 are applicable to frequency, phase and amplitude modulation radio equipments only. A brief summary of the contents follows.

1.02 Part 2 shows the method to be used in arriving at the carrier-to-noise ratio at the radio receiver input. This is the first step in computing the expected noise performance for all microwave systems carrying either message or television services.

1.03 Part 3 shows the method of adjusting the carrier-to-noise ratio for the various types of multiplexing equipment to obtain the actual noise power in dba on the individual message channels.

1.04 Parts 4 and 5 cover additional correction factors for use with compandors and baseband equalization (use of pre-emphasis and de-emphasis networks).

1.05 Part 6 contains information for deriving the video peak-to-peak signal to rms noise ratio in television systems.

1.06 Part 7 includes additional considerations necessary for the computation of multihop system performance.

1.07 Part 8 contains the mathematical derivations associated with some of the computations used in the preceding parts.

1.08 Part 9 contains drawings associated with this section and references to other sources containing information on these and similar subjects.

2. CARRIER-TO-NOISE RATIO AT THE RADIO RECEIVER INPUT

(A) General

2.01 The path loss level diagram shown below is typical for a single hop microwave system. By following certain procedures, to be covered, it will be shown that the radio carrier-to-noise ratio for such a system can be calculated providing certain basic system parameters are known. These parameters relate to the radio transmission facility and are as follows:

P_t = Transmitter power output in dbm.

G_t = Transmitting antenna gain in db above a half-wave dipole.

G_r = Receiving antenna gain in db above a half-wave dipole.

L_{rt} = Miscellaneous filter, waveguide, coax., etc, losses expressed in db.

a = Transmission path loss expressed in db relative to half-wave dipoles.

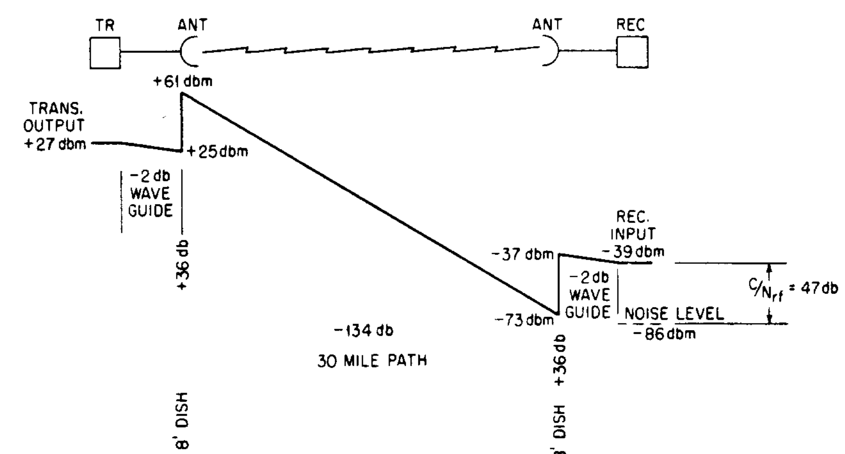
N_r = Equivalent receiver and antenna noise at the receiver input (expressed in dbm).

P_t, L_{rt}, and N_r are properties of the equipment and should be determined from the specifications for the equipment in question.

G_t and G_r for simple parabolic antennas may be found from Fig. 1, Part 9.

When the path length is known, values of "a" may be taken from Fig. 2, Part 9.

TD-2 PATH LOSS LEVEL DIAGRAM



2.02 The noise power (N_r) accounts for the noise generators (vacuum tubes, etc) inherent within the receiver and thermal noise from the antenna. The sum of these noise components produces a noise power which at frequencies above about 500 megacycles becomes the controlling source of noise. It is this noise which determines how small the incoming desired signal can be before it is masked and no longer usable. The noise power is usually expressed in dbm at the input of the receiver in the bandwidth of the if. amplifier. This power is the noise at the receiver input which is equivalent to the sum of all the noise components mentioned above. The noise figure of a receiver is defined as the ratio (expressed in decibels) between the noise power output of the receiver and the noise power output of a hypothetical perfect receiver of the same bandwidth and measured at equal level points.

(B) Method of Computation

2.03 The thermal noise power present at the input of a perfect receiver (NP) is given by:

$$NP\ (\text{dbm}) = -174 + 10 \log \text{(bandwidth in cycles)*} \quad (1)$$

2.04 The receiver noise figure, noise power, and noise power in a perfect receiver, are related as follows:

$$N_r = NP + N_f \text{ (all expressed in decibels)} \quad (2)$$

Where N_r equals the equivalent noise power generated within the receiver in question.

NP equals the noise power in a theoretically perfect receiver of the same bandwidth.

N_f equals the noise figure of the receiver in question.

2.05 The preceding values of P_t, G_t, G_r, L_{rt}, and "a" may be combined to produce the received carrier power which is defined as P_r.

$$P_r = P_t + G_t + G_r - L_{rt} - a \text{ (expressed in dbm)} \quad (3)$$

* Where the bandwidth refers to that in which the noise power is measured or computed.

2.06 The value for P_r (the received carrier power) is now compared with the noise power at the receiver input to give the carrier-to-noise ratio at the input to the receiver C/N_{rf}.

$$C/N_{rf} = P_r - N_r \text{ (where } P_r \text{ and } N_r \text{ are expressed in dbm)} \quad (4)$$

2.07 Combining the two preceding equations

$$C/N_{rf}\ (\text{db}) = P_t + G_t + G_r - L_{rt} - a - N_r \quad (5)$$

2.08 For convenience in computing the channel noise (multiplex) and the video noise (television), the above ratio will be reduced to the carrier-to-noise ratio per cycle of bandwidth C/N_c by dividing N_{rf} by B_{rf} where the bandwidth B_{rf} refers to the passband in which the noise power (N_{rf}) was measured. When such information is lacking, a usable approximation may be had by noting the bandwidth between the -2 db points on the if. bandpass characteristic.

$$C/N_c = \frac{C}{\frac{N_{rf}}{B_{rf}}} = \frac{CB_{rf}}{N_{rf}} \quad (6)$$

$$C/N_c\ (\text{db}) = C/N_{rf}\ (\text{db}) + 10 \log B_{rf} \quad (7)$$

3. VOICE CHANNEL NOISE LEVEL COMPUTATION FOR MULTICHANNEL MULTIPLEX APPLICATIONS

(A) General

3.01 In order to compute the noise level for a single voice channel the following microwave and multiplex parameters are required.**

- d_{rf} The Maximum Deviation of the Radio Transmitter.
- n Number of Voice Channels.
- B_m Frequency Band Occupied by the Multiplex Channels.
- M_1 Multiplex Loading Factor.
- M_c The Multiplex Conversion Factor.
- S_o The Power at the Switchboard Level Point Corresponding to Full Modulation.

** This computation is applicable to frequency, phase and amplitude modulation only.

3.02 "d_{rf}," the Maximum Deviation, is the recommended peak swing of the radio frequency carrier when frequency or phase modulation is employed. For the case of amplitude modulation, $d_{rf} = 0$.

3.03 "n," the Number of Voice Channels, is usually established by the type of multiplex and the circuit requirements.

3.04 "B_m," the Frequency Spectrum, is the band occupied by the output frequencies of the multiplex. For example, a 24-channel N carrier system occupies the spectrum from 40 to 260 kilocycles.

3.05 "M_1," the Multiplex Loading Factor, relates the loading of a carrier system when one channel is transmitted to the loading when all channels are transmitted. If the permissible peak modulation is not to be exceeded as increasing numbers of channels are transmitted, the level per channel must be reduced. The degree of such reduction is determined by the type of multiplexing used.

3.06 "M_c," the Multiplex Conversion Factor, relates to the noise reduction efficiencies of the various multiplexing techniques. This value involves, for example, the subcarrier deviation ratio in the case of FM multiplex.

3.07 "S_o" is the Switchboard Level, required to produce full modulation of the multiplex equipment. Under "Bull" talker conditions, the speech peaks will exceed this level only a very small part of the time. So-called "Normal" and "Quiet" talkers may be as much as 30 to 40 db below this full modulation level; however, present transmission objectives have been established recognizing that adequate transmission performance must be provided for talkers within such a wide range of levels.

(B) Method of Computation

Demodulation Process

3.08 Starting with the radio frequency carrier-to-noise ratio per cycle of bandwidth (C/N_c as previously derived in Paragraph 2.08), we will modify this value to show the effects of detection to produce the signal-to-noise ratio per cycle of bandwidth in the baseband.

3.09 A fully amplitude modulated signal is composed of the carrier and upper and lower sidebands. The peak power in such a signal is divided with one-half in the carrier and one-quarter in each sideband. During demodulation, the upper and lower sidebands are combined in phase to produce the desired output signal. As a result of this in-phase addition of the sidebands, the peak signal power is equal to the peak carrier power.

$$C = S \tag{1}$$

3.10 Following similar reasoning, the noise power in the post detection bandwidth will be found to be equal to that in the predetection bandwidth (assuming unity gain). However, since the sideband noise powers are combined at random into a noise signal occupying only one-half of the predetection bandwidth, the noise power per cycle has doubled.

3.11 The noise power per cycle after detection is, therefore, three decibels higher in level than the noise power per cycle prior to detection.

3.12 Collecting the foregoing, the signal-to-noise ratio per cycle after detection for the case of full modulation is equal to:

$$S_d/N_c = C/N_c - 3 \text{ (db)} \tag{2}$$

3.13 The above expression (2) for the post detection signal-to-noise ratio per cycle was derived by consideration of a fully amplitude modulated carrier. Our next concern will be the improvement obtained when such a carrier is frequency or phase modulated. The Improvement Factor will account for such improvements.

Improvement Factor

3.14 When frequency or phase modulation is employed, large improvements in the signal-to-noise ratio are possible due to the effectively wider band occupied by the signal voltage as compared with the narrower band occupied by the detected noise. Such "improvements" are restricted by the threshold* effects and the intermodulation and crosstalk performance desired. In some extreme cases, such as television transmission, where wideband modulating voltages are employed, degradation in the signal-to-noise ratio results if comparatively small "swings" are employed.

* For the purpose of this computation, it is assumed that the carrier-to-noise ratio at the input to the receiver (C/N_{rf}) is sufficient to produce the full frequency or phase modulation improvement. This value is approximately 10 db (6 to 14 depending upon the type of multiplex employed). The computation of system

operation below the threshold point is extremely difficult involving many assumptions and in most instances, the resulting fading margins and channel noise levels would be far short of established objectives.

3.15 The Improvement Factor for the more typical cases is presented below:

Improvement Factor = 20 log D (3)

Where D equals

Frequency or Phase Modulation - - - - -

$\frac{d_{rf}}{F_{tc}}$ See Note 1, below.

and

d_{rf} is the maximum deviation specified for the frequency or phase modulated rf carrier.

F_{tc} is the top frequency of the baseband occupied by the multiplex.

Note 1: The Improvement Factor definition, 20 log D, is equally applicable to frequency or phase modulation at the top frequency of the baseband. However, where a single channel is transmitted with frequency modulation and the greater portion of the baseband is occupied, the improvement for the band as a whole becomes 5 + 20 log D. An example of this is the transmission of television signals. See Part 8.

3.16 The factor $\frac{d_{rf}}{F_{tc}}$ is referred to as the Deviation Ratio (D) and a plot of the Improvement Factor for various values of d_{rf} and F_{tc} is shown in Fig. 3. From Equation (2) the post detection signal-to-noise ratio at the top frequency in the baseband is:

Post Detection Signal-to-Noise Ratio		RF Carrier-to-Noise Ratio per Cycle of Bandwidth		Detection Factor		Improvement Factor
S_d/N_c	=	C/N_c	-	3	+	20 log D (4)

Multiplex Loading Factor

3.17 At this point in the transmission computations under discussion, the baseband signal-to-noise per cycle will be corrected to include the reduction in subcarrier level which must be accepted when more than one carrier is to be transmitted simultaneously over the system. The previous discussion assumed that the modulating signal was a single carrier voltage; however, when multichannel multiplexing is proposed, this is not the case.

3.18 As the number of channels multiplexed is increased (system loading), the in-phase addition of the individual channel voltages can be very high as compared to the average value of the complex wave. When this peak-to-average ratio is large, and individual channel components exist a substantial part of the time (such as when transmitting carriers), the average level of modulation must be lowered to protect the system from overload when high peaks are present. The exact value of such reductions will be dependent upon the degree of overload to be tolerated, the portion of the total time that such overload can be accepted, and the intermodulation noise objectives to be met for the particular service involved.

3.19 Some typical multiplex arrangements and the value of the Multiplex Loading Factor (M_1) for each is shown in Table I.

Table I

Type of Multiplex	Number of Channels n	Type of Modulation	M_1 (db)*
Motorola	6	FM	-16
Motorola	12	FM	-22
Motorola	24	FM	-28
N Carrier	12	AM	-25
N Carrier	24	AM	-31
ON Carrier	20	SSB	-26
ON Carrier	40	SSB	-32
Lenkurt 45BX	24	SSBSC	- 5**
Lenkurt 45BX	48	SSBSC	- 6**
L Carrier (Lenkurt 45D)	60	SSBSC	- 7**
L Carrier (Lenkurt 45D)	96	SSBSC	- 8**
L Carrier (Lenkurt 45D)	120	SSBSC	- 9**

SSB = Single Sideband

SSBSC = Single Sideband Suppressed Carrier

* See Part 8 for qualifications and derivations.

** If the use of compandors is assumed for these applications, the values shown for M_1 must be further reduced 4 db to compensate for the resulting effectively higher channel loading - i.e.,

Lenkurt 45BX (Compandors)	24	SSBSC	-9

3.20 The equation for the single channel signal-to-noise ratio per cycle at the top of the baseband, has now become:

$$S_c/N_c = C/N_c - 3 + 20 \log D + M_1$$

Only two steps need now be taken to derive the voice channel signal-to-noise (S_{vc}/N) ratio at the output of the multiplex equipment for the condition of full modulation.

Bandwidth Factor

3.21 The first of these converts the noise level per cycle of bandwidth to the noise level in the bandwidth of the voice channel. As was previously discussed, the detection process (if double sideband) effectively doubles the noise per cycle, consequently the signal-to-noise per cycle must be corrected by:

$$-(3 + 10 \log B_{vc}) \qquad (6)$$

Where B_{vc} = Bandwidth of the voice channel.
Combining this with Equation (5),

$$S_c/N = C/N_c - 3 + 20 \log D + M_1 - 3 - 10 \log B_{vc} \qquad (7)$$

In most cases, this bandwidth may be taken as 3,000 cycles which nets a correction of 35 + 3 or 38 decibels, thus

$$S_c/N = C/N_c - 41 + 20 \log D + M_1 \qquad (8)$$

Multiplex Conversion Factor

3.22 The second of these corrections (M_c) accounts for the various efficiencies of the multiplex techniques as applied to the individual voice channels rather than the baseband as a whole. This correction in a sense relates the ratio of the efficiency of the multiplexing technique used to that of a fully amplitude modulated subcarrier.

3.23 The Multiplex Conversion Factors as these corrections are called, are presented in Table II.

Table II

Multiplex	M_c*
Frequency Modulation Motorola	+11 db
Double Sideband AM Type N	0 db
Single Sideband AM Types ON, L or Lenkurt	+ 3 db

* The derivation of the values may be found in Part 8.

3.24 The top voice channel signal-to-noise ratio for all cases is

Voice Channel Signal-to-Noise		RF Carrier-to-Noise Per Cycle of Bandwidth		Detection and Bandwidth Factor		Improvement Factor		Multiplex Loading Factor		Multiplex Conversion Factor	
S_{vc}/N	=	C/N_c	-	41	+	20 log D	+	M_1	+	M_c	(9)

It should be kept in mind that this expression gives the voice channel signal-to-noise ratio for the condition of full modulation.

Voice Channel Noise Power in DBM and DBA

3.25 This last equation (9) provides the ratio we have been looking for but does not establish the absolute channel noise level. This can be done readily for any point in the system if the signal power at that point corresponding to full modulation is known. It is convenient to refer to the channel noise power in terms of the equivalent noise at the zero level toll line position (OTLP). To determine this we need to know the corresponding signal power at this position which will produce full modulation of the multiplex channel unit.

3.26 Talker volumes at the toll switchboard range through wide limits. It is desirable to employ as high a degree of modulation as practicable in order to obtain as favorable a signal-to-noise ratio as possible. At the same time it is necessary to avoid excessive overloading due to the peak levels of "bull talkers." The adjustment of the input to the multiplex system, therefore, represents an operating compromise between the channel limiting characteristic, the statistical possibility of overload, and the channel noise performance under conditions of other than full modulation.

3.27 For most present types of multiplex equipments the normal adjustment is such that full modulation is exceeded only in the case of peak signals from a negligible number of "bull talkers." For such systems, therefore, the signal power at the zero level toll line position (OTLP) corresponding to full modulation is the peak signal power of the "bull talker." It has been determined that with plant of present design the signal power of a single tone equivalent to the normal peaks* of such a "bull talker" is approximately 8 dbm. For such multiplex systems 8 dbm is, therefore, the value that should be used for signal power in computing the absolute voice channel noise power from equation (9).

3.28 The Motorola equipment differs from most present multiplex equipments in that it employs frequency modulation and has substantially different overload characteristics. With this equipment an input adjustment may be employed permitting the peaks of "bull talkers" generally to overload considerably without resulting in serious distortion. In practice, the adjustment may be such that full modulation will occur when speech having a peak power equivalent to a single tone of +4 dbm is applied at the zero level toll line position (OTLP). Consequently, the speech power into the multiplex equipment is 4 db higher with the resulting transmission improvement. In this case, therefore, a value of 4 dbm should be employed in calculating the voice channel noise power from equation (9).

* This peak value would be expected to be exceeded by the loudest 2% of the talkers and then by only about 2% of their peaks.

3.29 In Table III values are given of S_o (the single tone switchboard power which would produce full modulation) for a number of multiplex systems of current design. New multiplex equipments may require different adjustments resulting in different values for S_o. Moreover, any future changes which affect the level of speech at the switchboard will also result in changes in the value of S_o.

Table III

Multiplex	S_o (OTLP)*
N Carrier	+8 dbm
ON Carrier	+8 dbm
L Carrier	+8 dbm
Lenkurt 45BX	+8 dbm
Lenkurt 45D	+8 dbm
Motorola	+4 dbm

* The values shown can not be transmitted by the multiplex equipment on a continuous basis without serious overload and should not be construed as the test tone levels which will normally be somewhat below those shown.

3.30 The flat noise power at the channel output for the highest channel in the transmitted band is as follows:

$$N_{dbm} \text{ (at OTLP)} = S_o - S_{vc}/N \qquad (10)$$

To correct this level to dba, a correction of 82 db is applied.

$$N_{dba} \text{ (at OTLP)} = S_o - S_{vc}/N + 82 \qquad (11)$$

3.31 This is the noise power which will be measured by a noise set (F1A weighting) when fluctuation noise is controlling. Such additional contributing factors introduced by compandors, equalization, and multihop systems are discussed in Parts 4, 5 and 7, respectively.

(C) Examples

3.32 In the following paragraphs, two typical combinations of radio and multiplex equipments are considered together with the computations for Radio Frequency Carrier-to-Noise Ratio (C/N_{rf}) and Noise Level in dba (N_{dba}) in the top channel of the multiplex equipment. Other similar examples will be found in Parts 4, 6, and 7. The noise performance of any proposed system can ordinarily be computed from the examples by substitution of the appropriate values.

3.33 Example 1 - Lenkurt 72B FM Radio (900 Megacycles) with Lenkurt 45BX Multiplex

Radio Equipment

Symbol	Definition	Data
P_t	Transmitter Output Power 5 Watts (Equip. Spec.)	+ 37 dbm
G_t	Transmitting Antenna Gain 10' Dish (Fig. 1)	25 db
G_r	Receiving Antenna Gain 10' Dish (Fig. 1)	25 db
L_{rt}	Misc. Losses (Coaxial Cable - Diplexer, Etc) (Equip. Spec.)	6 db
a	Path Loss 30 Miles (Fig. 2)	121 db
N_r	Receiver Noise Level (Equip. Spec.)	- 96 dbm

$$P_r = P_t + G_t + G_r - L_{rt} - a$$

$$= 37 + 25 + 25 - 6 - 121$$

$$= -40 \text{ dbm}$$

$$C/N_{rf} = P_r - N_r = -40 - (-96)$$

$$= 56 \text{ db}$$

B_{rf} = 1.5 megacycles (Normally the if. passband between the -2 db points)

$$C/N_c = C/N_{rf} + 10 \log B_{rf}$$

$$= 56 + 10 \log 1{,}500{,}000$$

$$= 56 + 62$$

$$= 118 \text{ db}$$

Multiplex Equipment

Symbol	Definition	Data
d_{rf}	Maximum Deviation (RF)	500 kc
n	Number of Channels	24
B_m	Frequency Spectrum Occupied	40 to 140 kc
M_l	Multiplex Loading Factor (Table I)	-5 db
M_c	Multiplex Conversion Factor (Table II)	+3 db
S_o	Switchboard Level (Table III)	+8 dbm

As shown by Equation (9)

Voice Channel Signal-to-Noise		RF Carrier-to-Noise Per Cycle of Bandwidth		Detection and Bandwidth Factor		Improvement Factor		Multiplex Loading Factor		Multiplex Conversion Factor
S_{vc}/N	=	C/N_c	-	41	+	$20 \log D$	+	M_l	+	M_c

Equation (3) shows Improvement Factor = 20 log D

Where $D = \frac{d_{rf}}{F_{tc}}$ d_{rf} = 500 kcs, F_{tc} = 140 kcs

The value for the Improvement Factor may be read from Fig. 3 to be 11 db.

$S_{vc}/N = 118 - 41 + 11 - 5 + 3$

$= 86$

$N_{dba} = S_o - S_{vc}/N + 82$

$= 8 - 86 + 82$

= 4 dba* at the zero level point

3.34 Example 2 - Motorola FM Radio (6000 Megacycles) with Motorola Multiplex

Radio Equipment

Symbol	Definition	Data
P_t	Transmitter Output Power 0.1 Watt (Equip. Spec.)	+ 20 dbm
G_t	Transmitting Antenna Gain 40" Dish (Fig. 1)	33 db**
G_r	Receiving Antenna Gain 40" Dish (Fig. 1)	33 db**
L_{rt}	Misc. Losses (Rec. Filter) (Equip. Spec.)	2 db
a	Path Loss 20 Miles (Fig. 2)	134 db
N_r	Receiver Noise Level (Equip. Spec.)	- 85 dbm

* As the noise level within the multiplex terminals is of about the same magnitude, computed values below 10 dba may not be realized. However, if the actual measurement showed the noise to be 10 dba, normal signal variations of two or three db caused by minor fading, would produce no noticeable change in this value. An additional improvement is available from the equalization network incorporated in the Lenkurt 42B radio equipment. See Part 5.

** These values are not necessarily applicable where a reflector is used in conjunction with the dish.

$P_r = P_t + G_t + G_r - L_{rt} - a$

$= 20 + 33 + 33 - 2 - 134$

$= -50$ dbm

$C/N_{rf} = P_r - N_r = -50 - (-85)$

$= 35$ db

B_{rf} = 12 megacycles (Normally the if. passband between the -2 db points)

$C/N_c = C/N_{rf} + 10 \log B_{rf}$

$= 35 + 10 \log 12{,}000{,}000$

$= 35 + 71$

$= 106$ db

Multiplex Equipment

Symbol	Definition	Data
d_{rf}	Maximum Deviation (RF)	5 Megacycles
n	Number of Channels	24
B_m	Frequency Spectrum Occupied	400 to 800 kc
M_l	Multiplex Loading Factor (Table I)	-28 db
M_c	Multiplex Conversion Factor (Table II)	+11 db
S_o	Switchboard Level (Table III)	+ 4 dbm

As shown by Equation (9)

Voice Channel Signal-to-Noise		RF Carrier-to-Noise Per Cycle of Bandwidth		Detection and Bandwidth Factor		Improvement Factor		Multiplex Loading Factor		Multiplex Conversion Factor
S_{vc}/N	=	C/N_c	-	41	+	20 log D	+	M_l	+	M_c

Equation (3) shows Improvement Factor = 20 log D

Where $D = \frac{d_{rf}}{F_{tc}}$ d_{rf} = 5 megacycles, F_{tc} = 800 kc

The value for the Improvement Factor may be read from Fig. 3 to be 16 db.

$$S_{vc}/N = 106 - 41 + 16 - 28 + 11$$

$$= 64 \text{ db}$$

$$N_{dba} = S_o - S_{vc}/N + 82$$

$$= 4 - 64 + 82$$

= 22 dba at the zero level point

4. COMPANDOR ADVANTAGE

(A) Channel Noise Improvement by Use of Compandors

4.01 Certain types of multiplex equipments (N, O, etc) have compandors incorporated while other varieties allow an option on such usage (Lenkurt 45 type, etc).

4.02 The compandor basically consists of two units, a compressor and an expandor. No attempt will be made here to show all the advantages of these units, however, the net effect upon the listener is an effective reduction* by some 23 db of the output noise of the multiplex equipment. Three limits must be placed upon the advantages of such units.

(1) When the noise level of the system without compandors approaches the level of the modulation, the compandor fails to distinguish between noise and speech and its advantage is reduced. This effect is not normally reached in the operation of a microwave system.

(2) When the noise level of the system is so low that noise within the expandor is controlling. This level is about 5 dba (OTLP).

(3) If compandors are used with single sideband suppressed carrier channelizing equipment (L, 45BX, 45D, etc), a 4 db reduction in the Loading Factor (M_l) must be applied to compensate for the resulting effectively higher channel loading.

4.03 Some general rules are:

If the noise level of the multiplex (N_{dba}) is within the range 28 to 59 dba at zero level, the full 23 db improvement factor may be taken.

If the noise level is less than 28 dba at zero level, use 5 dba.

* Although the effective improvement by use of the compandor is 23 db, the value as measured on a 2-type noise set is 28 db. This latter value does not recognize an impairment resulting from the so-called "hush-hush" effect. This effect is caused by compressor "attack" and expandor "hangover" characteristics which, during speech transmission, acts to reduce the over-all improvement by about 5 db.

(B) Example

4.04 Motorola FM Radio (6000 Megacycles) with ON Carrier

Radio Equipment

Symbol	Definition	Data
P_t	Transmitter Power Output 0.1 Watt (Equip. Spec.)	+ 20 dbm
G_t	Transmitting Antenna Gain (See Note 1, Par. 4.06) (Fig. 1)	38 db
G_r	Receiving Antenna Gain (See Note 2, Par. 4.06) (Fig. 1)	41 db
L_{rt}	Misc. Losses (Rec. Filter) (Equip. Spec.)	2 db
a	Path Loss 50 Miles (Fig. 2)	142 db
N_r	Receiver Noise Level (Equip. Spec.)	- 85 dbm

$$P_r = P_t + G_t + G_r - L_{rt} - a$$
$$= 20 + 38 + 41 - 2 - 142$$
$$= -45 \text{ dbm}$$

$$C/N_{rf} = P_r - N_r = -45 \text{ dbm} - (-85 \text{ dbm})$$
$$= 40 \text{ db}$$

B_{rf} = 12 megacycles (Normally the if. passband between the -2 db points)

$$C/N_c = C/N_{rf} + 10 \log B_{rf}$$
$$= 40 + 10 \log 12{,}000{,}000$$
$$= 40 + 71$$
$$= 111 \text{ db}$$

Multiplex Equipment

Symbol	Definition	Data
d_{rf}	Maximum Deviation (See Note 3, Par. 4.06)	2.5 Megacycles
n	Number of Channels	40
B_m	Frequency Spectrum Occupied	40 to 260 kcs
M_l	Multiplex Loading Factor	-32 db
M_c	Multiplex Conversion Factor	+ 3 db
S_o	Switchboard Level	+ 8 dbm

As shown by Equation (9)

Voice Channel Signal-to-Noise		RF Carrier-to-Noise Per Cycle of Bandwidth		Detection and Bandwidth Factor		Improvement Factor		Multiplex Loading Factor		Multiplex Conversion Factor
S_{vc}/N	=	C/N_c	-	41	+	20 log D	+	M_l	+	M_c

Equation (3) shows Improvement Factor = 20 log D

Where $D = \frac{d_{rf}}{F_{tc}}$ d_{rf} = 2.5 megacycles (See Note (3))

F_{tc} = 260 kcs

The value for the Improvement Factor may be read from Fig. 3 to be 20 db.

$$S_{vc}/N = 111 - 41 + 20 - 32 + 3$$
$$= 61 \text{ db}$$

$$N_{dba} = S_o - S_{vc}/N + 82$$
$$= 8 - 61 + 82$$
$$= 29 \text{ dba}$$

4.05 Applying an effective noise reduction of 23 db for the compandor advantage the resulting channel noise becomes:

N_{dba} (with compandor) = 6 dba

4.06 Notes

(1) Transmitting antenna assumed to be a tower mounted 8 by 12 curved reflector at a separation of 135 feet from a 40-inch parabola. (150-foot tower)

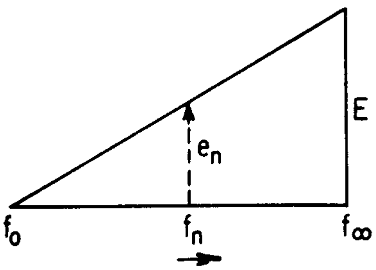
(2) Receiving antenna assumed to be a 10-foot parabola. No reflector required.

(3) The full deviation of 5 megacycles available with Motorola equipment while producing a high signal-to-fluctuation noise ratio, may in some cases result in a lower than desirable signal-to-intermodulation noise ratio. Multiplex equipments which occupy more than one octave in the baseband are more susceptible to modulation products than are those utilizing one octave or less; consequently, a somewhat reduced deviation is recommended. The 2.5-megacycle swing shown represents a balance between fluctuation and intermodulation noise performance.

5. BASEBAND EQUALIZATION

(A) General

5.01 The output noise amplitude spectrum of a frequency modulated receiver is triangular, that is, it varies directly with increasing frequency at a rate of six decibels per octave. This triangular noise spectrum is produced by the discriminator characteristic. The higher the frequency of the noise energy impressed upon the discriminator, the greater the corresponding output noise voltage.



5.02 All previous computations of channel noise were referenced to the top channel to be transmitted, which, in an FM* system will be the poorest channel with regard to noise performance. By placing a network, whose amplitude transmission is proportional to frequency, ahead of the transmitter, the output signal voltage will also be triangular.

5.03 By passing the discriminator output voltage through a reciprocal network the signal-to-noise ratio at the output of the receiver can be reduced to a constant, independent of frequency.

* When an FM system is completely equalized it becomes a phase modulated system. In such instances all channels would provide equal noise performance. The improvement in the noise performance in the top channel for this case is 5 db.

5.04 Usually networks of less than 6 db per octave slope are used as the peak modulation requirements become rather severe as complete equalization is approached. For example, with a multiplex terminal which has an output some seven octaves wide (2.5 kc to 320 kc), the input equalization required is 42 db for equal top and bottom channel noise performance. In practice, such networks would be designed to produce an acceptable top channel if possible, but not one completely equalized.

5.05 The REL-Lenkurt equipments make use of such compromise networks which result in about 3 db improvement in the top channel noise performance. Rather than present a lengthy discussion as to the method of design of such networks, they are more properly handled by Laboratories Personnel for individual cases.

5.06 Suffice to say that the practical improvement resulting from complete equalization is about 5 db.

6. TELEVISION PERFORMANCE COMPUTATION

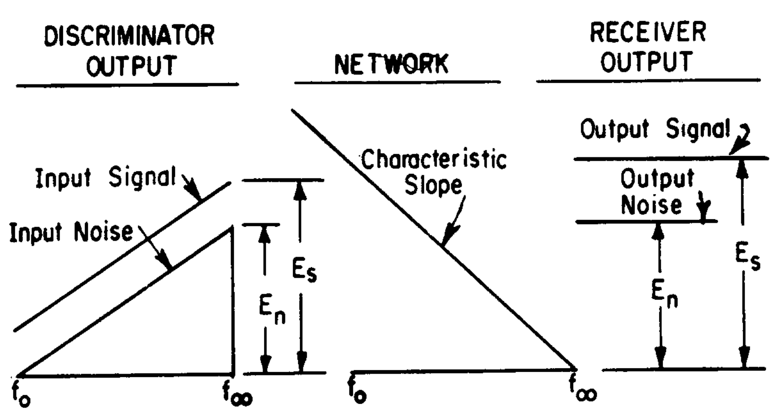
(A) General

6.01 A method of deriving the peak-to-peak signal-to-rms fluctuation noise ratio when television transmission is contemplated will be presented. As a starting point, the rf carrier-to-noise ratio per cycle of bandwidth C/N_c (db) [See Equation (7), Part 2] is required.

6.02 As was discussed in Part 3 (Paragraphs 3.08 to 3.12), the full modulation post detection signal-to-noise ratio per cycle of bandwidth after detection is:

$$S_d/N_c = C/N_c - 3 \text{ (db)} \qquad (1)$$

6.03 The foregoing has assumed a fully amplitude modulated carrier. When frequency modulation is employed, an increase in



signal-to-noise ratio is possible (see Paragraphs 3.14 and 3.15, Part 3) with the resulting improvement as shown below:

$$\text{Improvement Factor} = 20 \log D \text{ (db)} \qquad (2)$$

$$\text{Where } D = \frac{d_{rf}}{F_{tc}}$$

d_{rf} is the maximum deviation specified for the frequency modulated carrier.

F_{tc} is the top frequency of the baseband occupied by the video signal - for standard television signals (monochrome or color) this value may be taken as 4.3 megacycles.

6.04 The post detection signal-to-noise per cycle of bandwidth at the top frequency of the baseband becomes:

$$S_d/N_c = C/N_c - 3 + 20 \log D \text{ (db)} \qquad (3)$$

6.05 If the baseband is assumed to contain flat noise weighting, the foregoing noise in the bandwidth of one cycle can now be corrected to show the noise existing in the bandwidth of the baseband. As the baseband is expanded from one cycle to the required bandwidth, the baseband rms signal-to-rms noise ratio becomes:

$$S_d/N_b = C/N_c - 3 + 20 \log D + 10 \log B_{tv} \text{ (db)} \qquad (4)$$

Where B_{tv} equals the bandwidth of the video signal - in the common case B_{tv} is 4.3 megacycles.

For the general case, Equation (4) simplifies to:

$$S_d/N_b = C/N_c + 20 \log D - 69 \text{ (db)} \qquad (5)$$

6.06 When frequency modulation is employed, the baseband noise has triangular rather than flat weighting as previously assumed. (See Part 8B.) The net effect is a reduction in the wideband noise power of approximately five decibels. Applying this noise reduction factor to Equation (5), the output baseband rms signal-to-rms noise ratio becomes:

$$S_c/N_b = C/N_c + 20 \log D - 64 \text{ (db)} \qquad (6)$$

6.07 Recognizing the difficulty of accurately determining the rms value of a video signal, all objectives and measurements as used within the Bell System are based on peak-to-peak signal levels. Such levels are easily determined by use of wideband oscilloscopes.

6.08 When substituting the peak-to-peak signal level for the previously considered rms signal level, a nine decibel correction in the ratio is necessary. This final step produces the desired result, namely the video-(peak-to-peak) to-noise (rms) ratio.

Peak-to-Peak Signal-to-RMS Noise Ratio		RF Carrier-to-Noise Per Cycle of Bandwidth	Improvement Factor	Miscellaneous Collected Factors	
S_{pp}/N	=	C/N_c	+ 20 log D	- 55	(db)

(7)

6.09 Examples of the computations for typical cases are discussed in Part B.

6.10 Where more than one hop is contemplated, Part 7 shows the necessary steps for adjusting the foregoing single hop results to multiple hop performance.

(B) Examples

6.11 Example 1 - Western Electric TE Microwave System (4000 Megacycles)

Symbol	Definition	Data
P_t	Transmitter Power Output 400 mw (Equip. Spec.)	+ 26 dbm
G_t	Transmitting Antenna Gain 57" dish (Equip. Spec.)	31 db
G_r	Receiving Antenna Gain 57" dish (Equip. Spec.)	31 db
L_{rt}	Misc. Losses	0
a	Path Loss 20 miles (Fig. 2)	131 db
N_r	Receiver Noise Level (Equip. Spec.)	- 85 dbm

$$P_r = P_t + G_t + G_r - L_{rt} - a$$
$$= 26 + 31 + 31 - 0 - 131$$
$$= -43 \text{ dbm}$$

$$C/N_{rf} = P_r - N_r = -43 \text{ dbm} - (-85 \text{ dbm})$$
$$= 42 \text{ db}$$

B_{rf} = 16 megacycles (Normally the if. passband between the -2 db points)

$$C/N_c = C/N_{rf} + 10 \log B_{rf}$$
$$= 42 + 10 \log 16{,}000{,}000$$
$$= 42 + 72$$
$$= 114 \text{ db}$$

6.12 When used for television transmission, the maximum deviation (d_{rf}) of the TE equipment is 2 megacycles and the top frequency of the baseband (F_{tc}) is 4.3 megacycles.

Therefore:

$$\text{Improvement Factor} = 20 \log D = 20 \log \frac{2}{4.3}$$

Improvement Factor = -7 db

The peak-to-peak signal-to-rms noise at the output of the system can now be derived by use of Equation (7):

Peak-to-Peak Signal-to-RMS Noise Ratio		RF Carrier-to-Noise Per Cycle of Bandwidth		Improvement Factor		Miscellaneous Collected Factors
S_{pp}/N	=	C/N_c	+	20 log D	-	55
	=	114	+	(-7)	-	55
	=	52 db				

6.13 Example 2 - Western Electric TD2 Microwave System (4000 Megacycles)

Symbol	Definition	Data
P_t	Transmitter Power Output 500 mw (Equip. Spec.)	+ 27 dbm
G_t	Transmitting Antenna Gain 10 by 10 Lens Antenna (Equip. Spec.)	37 db
G_r	Receiving Antenna Gain 10 by 10 Lens Antenna (Equip. Spec.)	37 db
L_{rt}	Misc. Losses (200' of Waveguide)	3 db
a	Path Loss 33 Miles (Fig. 2)	135 db
N_r	Receiver Noise Level (Equip. Spec.)	- 86 db

$$P_r = P_t + G_t + G_r - L_{rt} - a$$

$$= 27 + 37 + 37 - 3 - 135$$

$$= -37 \text{ dbm}$$

$$C/N_{rf} = P_r - N_r = -37 \text{ dbm} - (-86 \text{ dbm})$$

$$= 49 \text{ db}$$

B_{rf} - 25 megacycles

$$C/N_c = C/N_{rf} + 10 \log B_{rf}$$

$$= 49 + 10 \log 25{,}000{,}000$$

$$= 49 + 74$$

$$= 123 \text{ db}$$

6.14 The maximum deviation (d_{rf}) employed on TD2 for television transmission is 4 megacycles and the top frequency of the baseband (F_{tc}) is 4.3 megacycles. Therefore:

$$\text{Improvement Factor} = 20 \log D = 20 \log \frac{4}{4.3}$$

Improvement Factor = -1 db

Incorporating the foregoing into Equation (7):

Peak-to-Peak Signal-to-RMS Noise Ratio		RF Carrier-to-Noise Per Cycle of Bandwidth		Improvement Factor		Miscellaneous Collected Factors
S_{pp}/N	=	C/N_c	+	20 log D	-	55
	=	123	+	(-1)	-	55
	=	67 db				

7. MULTIHOP CONSIDERATIONS

(A) General

7.01 If the particular microwave system being considered is of more than one section, the results obtained must be corrected for the effects of the additional sections. This correction may be applied in two ways:

(1) The C/N_{rf} may be computed for each section and the values obtained added on a reciprocal power basis, to form an effective C'/N_{rf} for the entire system. This value is then used in the final channel noise computation.

(2) The channel noise may be computed for each section and the values obtained added on a power basis.

An example of each type of computation follows.

(B) Examples

Systems with No Channel Dropping

7.02 A four section system with hops of 22, 31, 26 and 45 miles each using Lenkurt (900 megacycles) equipment is to be considered. It is proposed that six-foot parabolas will be used on the three shorter sections and 10-foot parabolas on the last. Computation required is the effective C'/N_{rf}.

Symbol	Definition	Data			
	Path Length (Miles	22	31	26	45
P_t	Power Output (5 Watts)	+ 37 dbm	+ 37 dbm	+ 37 dbm	+ 37 dbm
G_t	Transmitting Antenna Gain	20 db	20 db	20 db	25 db
G_r	Receiving Antenna Gain	20 db	20 db	20 db	25 db
a	Path Loss	118 db	121 db	120 db	125 db
L_{rt}	Misc. Losses (Coaxial Cable)	3 db	3 db	3 db	3 db
N_r	Receiver Noise Level	- 96 dbm	- 96 dbm	- 96 dbm	- 96 dbm
C/N_{rf}	Carrier-to-Noise At the Receiver Input	52 db	49 db	50 db	55 db

Combining the above on a power basis:

$$-52 = 10 \log X_1 \qquad X_1 = 63 \times 10^{-7}$$

$$-49 = 10 \log X_2 \qquad X_2 = 126 \times 10^{-7}$$

$$-50 = 10 \log X_3 \qquad X_3 = 100 \times 10^{-7}$$

$$-55 = 10 \log X_4 \qquad X_4 = 25 \times 10^{-7}$$

$$X = 314 \times 10^{-7}$$

$$C'/N_{rf} = 10 \log 10^7 - 10 \log 314 = 70 - 25$$

$$= 45 \text{ db}$$

7.03 This result is now used to compute the channel noise of the entire system. This method of computation assumes that all sections utilize the same types of microwave equipment, and that all units are adjusted to produce the same operating characteristics (equal deviation ratios, channel loading, etc).

Systems Employing Channel Dropping

7.04 The second method of computation is especially suitable where the type of microwave equipment, number of channels, deviation ratio, etc, is not uniform throughout the length of the system. Under these conditions, the channel noise is computed for each section independently as shown under "Voice Channel Noise Level Computation." Be sure to include such items as a reduction in the channel loading if channels are dropped at repeaters, and increases in the deviation ratio if the band occupied by the multiplex is reduced at an intermediate repeater.

7.05 As an example, consider a three section system as follows:

Microwave Equipment	Motorola FM Radio (6000 Megacycles)
Multiplex Equipment	ON Carrier

Two sections have 40 channels and the last has 20 channels. Computation required is the channel noise for the through 20 channels and the same for the short haul 20 channels. This example will assume that no equalization networks have been supplied.

Symbol	Definition	Data		
	Length of Path (Miles)	18	28	45
P_t	Transmitter Power Output (.1 Watt)	20 dbm	20 dbm	20 dbm
G_t	Transmitting Antenna Gain (Note 1)	36 db	38 db	38 db
G_r	Receiving Antenna Gain (Note 1)	36 db	38 db	38 db
a	Path Loss	134 db	137 db	141 db
L_{rt}	Misc. Filter Losses	2 db	2 db	2 db
N_r	Receiver Noise Level	- 85 dbm	- 85 dbm	- 85 dbm
B_{rf}	Bandwidth of Radio Channel	12 megacycles	12 megacycles	12 megacycles
C/N_{rf}	Carrier-to-Noise Ratio at Receiver Input	41 db	42 db	38 db
C/N_c =	$C/N_{rf} + 10 \log B_{rf}$	112 db	113 db	109 db

Note 1: These gain figures contemplate the use of curved reflector and 40" dish combinations as follows:

Gain	Reflector Size	Dish-Reflector Spacing
36 db	6' x 8'	105'
38 db	8' x 12'	185'

Multiplex Equipment

Symbol	Definition	Data		
	Length of Path	18	28	45
n	Number of Voice Channels	40	40	20
B_m	Frequency Spectrum Occupied	40 to 264 kc	40 to 264 kc	40 to 140 kc
M_l	Multiplex Loading Factor	- 32	- 32	- 26
M_c	Multiplex Conversion Factor	3 db	3 db	3 db
S_o	Switchboard Level	+ 8 dbm	+ 8 dbm	+ 8 dbm
d_{rf}	Maximum Deviation of the Radio Transmitter	2.5 megacycles	2.5 megacycles	2.5 megacycles

Computation of Channel Noise per Section

Symbol	Definition	Data		
	Length of Path Miles	18	28	45
C/N_c	Carrier-to-Noise per Cycle	112 db	113 db	109 db
Improvement Factor	$= 20 \log \frac{d_{rf}}{F_{tc}}$	19 db	19 db	25 db
M_1		- 32 db	- 32 db	- 26 db
M_c		+ 3 db	+ 3 db	+ 3 db
S_c/N	$= C/N_c - 41 + 20 \log D + M_1 + M_c$	61 db	62 db	70 db
S_o		+ 8 dbm	+ 8 dbm	+ 8 dbm
N_{dba}	$= S_o - S_c/N + 82$	29 dba	28 dba	20 dba

Combining these values for all sections, and two sections, respectively.

29 dba = 10 log X_1	X_1 = 794	X_1 = 794
28 dba = 10 log X_2	X_2 = 631	X_2 = 631
20 dba = 10 log X_3	X_3 = 100	
	X' = 1525	X" = 1425

10 log 1525 = 32 dba*

10 log 1425 = 32 dba*

* Values shown are to the nearest db.

7.06 The 32 dba approximates the noise in the top channel of both the through 20 channels as well as the short haul 20 channels. As was shown, the noise contribution from the last section is insignificant when compared with the noise level in the two previous sections.

7.07 This 32 dba figure does not yet include the effect of the compandors. As was previously discussed, whenever the computed noise without compandors is found to be in the range 28 to 59 dba the full compandor advantage of 23 db is available.

7.08 Consequently, the circuit noise level under nonfading conditions will be 9 dba (32 - 23).

8. MATHEMATICAL DERIVATIONS

(A) General

8.01 The values for the multiplex equipment shown in Tables I and II for the Multiplex Loading Factor M_1 and the Multiplex Conversion Factor M_c (Section 3) were based on the following assumptions:

(a) If the multiplexing technique requires the transmission of comparatively high level carriers, then such voice modulation as may exist will cause no appreciable increase in the system loading over that of the carriers alone. This is true for N, ON, and Motorola multiplex.

(b) When signaling tones are transmitted over the system and contribute to the system loading, such loading will be considered as being in addition to that in subparagraph a. This is true for N and ON where the signaling tones are derived from a single source and, consequently, are in phase, and are transmitted at levels corresponding to 0 dbm at the toll line position.

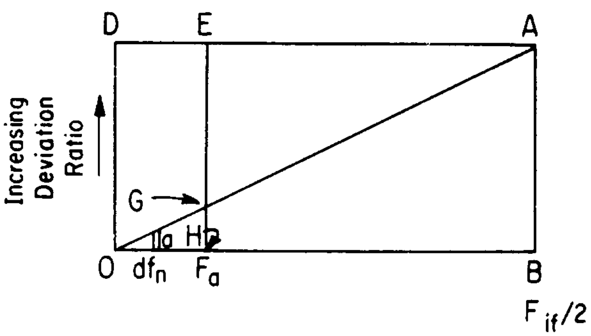
Note: It must be recognized that the values computed for M_1 by this method are conservative. It is expected that in many cases the individual channel carrier levels can be increased, however, as the modulation characteristics of the radio equipment are not precisely known, a conservative approach is recommended. Once the particular system has been placed in operation it will be possible to determine what increases in levels are possible and still meet intermodulation and distortion objectives.

8.02 All derivations will make use of the following definitions:

- E_o = The single frequency voltage required at the input of the radio frequency equipment to produce peak modulation of the rf equipment.
- E_n = Level of a single subcarrier.
- $E_{sb\ 1}$ = Peak level of upper sideband energy.
- $E_{sb\ 2}$ = Peak level of lower sideband energy.
- n = Number of voice channels transmitted.
- M_1 = Ratio between E_o and the peak level produced by a single modulated subcarrier.

(B) Frequency Modulation Noise Advantage

8.03 The derivation of the output signal-to-noise ratio of a frequency modulated carrier to that of an equal amplitude modulated carrier when modulated by a single frequency may be approached as follows. Equal full modulation signal outputs and perfect limiting are assumed.



f_n = frequency of the noise component

F_a = audio channel width

F_{if} = peak-to-peak swing

$D = \frac{F_{if}}{2F_a}$ = deviation ratio

P_a = Noise Power in Amplitude Modulated Channel

P_f = Noise Power in Frequency Modulated Channel

8.04 It can be shown that:

$$\frac{P_a}{P_f} = \frac{\text{Area (ODEH) (ordinates)}^2}{\text{Area (OGH) (ordinates)}^2}$$

$$= \frac{(OD)^2 F_a}{\int_o^{F_a} (a)^2 \, df_n}$$

Solving for "a" in terms of f_n:

$$\frac{a}{f_n} = \frac{(OD)}{F_{if}/2}$$

Substituting $a = \frac{2 f_n (CD)}{F_{if}}$

$$\frac{P_a}{P_f} = \frac{(OD)^2 F_a}{\int_o^{F_a} \left(\frac{2 f_n (OD)}{F_{if}}\right)^2 df_n} = \frac{(OD)^2 F_a}{\frac{4 (OD)^2}{F_{if}^2} \int_o^{F_a} f_n^2 \, df_n}$$

$$= \frac{(OD)^2 F_a}{\frac{4 (OD)^2}{F_{if}^2} \times \frac{F_a^3}{3}} = 3 \frac{(F_{if})^2}{(2 F_a)^2} = 3 D^2$$

If N_a = Amplitude Modulation Noise Voltage

N_f = Frequency Modulation Noise Voltage

$$\frac{N_a}{N_f} = \sqrt{\frac{P_a}{P_f}} = \sqrt{3} \frac{F_{if}}{2 F_a} = 3 D$$

S_a = Signal Level Input for Amplitude Modulation

S_f = Signal Level Input for Frequency Modulation

If $S_a = S_f$

then

$$\frac{\frac{S_a}{N_a}}{\frac{S_f}{N_f}} = \frac{\sqrt{\frac{1}{3 D}}}{\frac{1}{1}} = \frac{1}{\sqrt{3} D} = -5 - 20 \log D$$

$$\frac{\frac{S_f}{N_f}}{\frac{S_a}{N_a}} = 5 + 20 \log D*$$

* It can be shown that at the top edge of the modulation band, the noise power density improvement is just 20 log D.

(C) Motorola Multiplex

8.05 This type of multiplex operates under the following conditions:

(a) All subcarriers are transmitted continuously.

(b) The peak frequency modulation of the subcarriers is $\pm$ 6 kc when full modulation is applied.

(c) Signaling is accomplished by shifting the subcarrier transmitter center frequency with no change in carrier level.

8.06 The peak radio frequency swing will be observed when all the subcarrier signals are added in phase. Therefore:

$$E_n = \frac{E_o}{n}$$

$$\frac{E_n}{E_o} = \frac{1}{n} = M_1$$

$$\therefore M_1 = -20 \log n \text{ (db)}$$

Example: For n equals 24 channels of Motorola multiplex, $M_1 = -20 \log 24 = -28$ db.

8.07 In Motorola multiplex equipment, the peak-to-peak swing is $\pm$ 6 kc (12 kc) and the audio bandwidth = 3 kc. Therefore:

$$D = \frac{6}{3} = 2$$

and

$$\frac{\frac{S_f}{N_f}}{\frac{S_a}{N_a}} = 5 + 20 \log 2 = 5 + 6 = 11 \text{ db } (M_c)$$

(D) N Carrier Multiplexing with Signaling

8.08 During signaling periods, the sideband energies are in phase and approximately 15 db below the carrier level. If the carrier level (E_n) is assumed to be unity, then each sideband level at peak equals 0.178 E_n. The peak swing occurs when the input voltage is E_{peak}.

$$E_{peak} = E_n + E_{sb\ 1} + E_{sb\ 2}$$

$$= E_n + .178\ E_n + .178\ E_n$$

$$= 1.36\ E_n$$

Consequently, $\frac{E_o}{1.36\ E_n}$ is the ratio between the peak single channel modulating voltage and a single tone which produces the same peak modulation of the transmitter. For any number of channels (n), this relation becomes:

$$\frac{E_o}{1.36\ E_n\ (n)}$$

$$\therefore M_1 = \frac{E_n}{E_o} = \frac{1}{1.36\ (n)} = -20 \log 1.36 \quad n$$

$$= -20 \log n - 3 \text{ db}$$

8.09 Example:

Find M_1 for n equals 24 N Carrier Channels

$$M_1 = -20 \log 24 - 3 \text{ db}$$

$$= -28 - 3$$

$$= -31 \text{ db}$$

For other values of n, M_1 may be computed accordingly.

8.10 M_c = 0 as N Carrier is double sideband amplitude modulation.

(E) ON Carrier Multiplexing with Signaling

8.11 During signaling periods, the sideband energies are in phase and approximately 6 db below the carrier level. If the carrier level (E_n) is assumed to be unity, then each sideband level at peak equals 0.5 E_n. The peak swing occurs when the input voltage is E_{peak}.

$$E_{peak} = E_n + E_{sb\,1} + E_{sb\,2}$$

$$\approx E_n + 0.5\,E_n + 0.5\,E_n$$

$$= 2.0\,E_n$$

Consequently, $\frac{E_o}{2\,E_n}$ is the ratio between the peak modulating voltage (per two channels) and a single tone which produces the same peak modulation of the transmitter. For any number of channels (n), this relation becomes:

$$\frac{E_o}{2\,E_n \frac{(n)}{(2)}}$$

$$M_1 = \frac{E_n}{E_o} = \frac{2}{2\,n} = -20 \log n$$

8.12 Example:

Find M_1 for n equals 40 ON Carrier Channels

$$M_1 = -20 \log n$$

$$= -20 \log 40$$

$$= -32 \text{ db}$$

For other values of n, M_1 may be computed accordingly.

8.13 Derivation of M_c for ON Carrier Multiplex - As the ON equipment derives the individual channels by single sideband techniques, the noise level per channel is 3 decibels less than that for similar double sideband systems. This represents an over-all 3-decibel improvement in the signal-to-noise ratio, consequently,

$$M_c = +3 \text{ db}$$

(F) Single Sideband Suppressed Carrier Multiplexing

8.14 A consideration of the loading effects of Single Sideband Suppressed Carrier is considerably beyond the scope of this discussion; however, for a complete treatment of the subject, the following reference is recommended:

Holbrook and Dixon, Load Rating Theory for Multichannel Amplifiers, Bell System Technical Journal, October, 1939, Pages 622 to 644.

8.15 Normal signaling levels over such channels are so low as to reduce their effects to that similar to speech loading. Consequently, signaling tones are not considered as being in addition to speech loading, but rather equivalent to it.

8.16 The value of M_c is +3 decibels using the same approach as described under ON Carrier Multiplexing.

9. DRAWINGS AND REFERENCES

(A) Drawings

(B) References

Proceedings of the IRE, May 1935	The Detection of Frequency Modulated Waves - by J. G. Chaffee
Proceedings of the IRE, April 1937	Frequency Modulation Noise Characteristics - by M. G. Crosby
Proceedings of the IRE, Sept. 1951	Radio Relay System Design 60 to 600 Megacycles - by R. Guenther
Proceedings of the IRE, Jan. 1953	UHF Radio Relay System Engineering - by J. J. Egli

Bell System Light Route Microwave Radio Conference Notes, May 26 to 29, 1952

Modulation Theory -	H. S. Black - Van Nostrand and Company

Bell System Technical Journal, Oct. 1939 — Load Rating Theory for Multichannel Amplifiers by B. D. Holbrook and J. T. Dixon

Electronics - June 1946 — Theoretical Signal-to-Noise Ratios by J. Ernest Smith

Bell Laboratories Record - Aug. 1953 — A Speech Volume Survey on Telephone Message Circuits - V. Subrizi

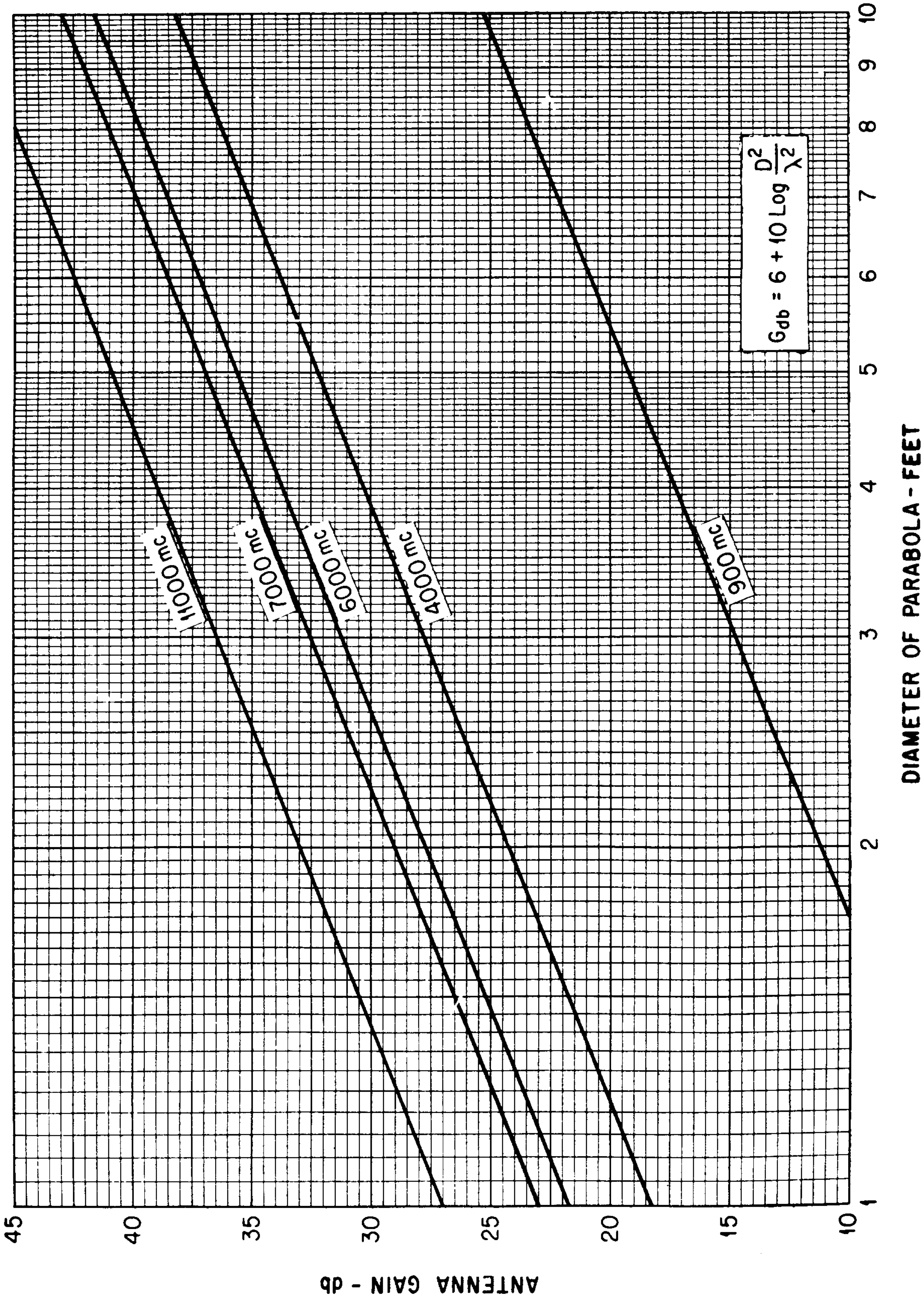


Fig. 1 — Gain of a Parabolic Antenna Relative to a Half-Wave Dipole

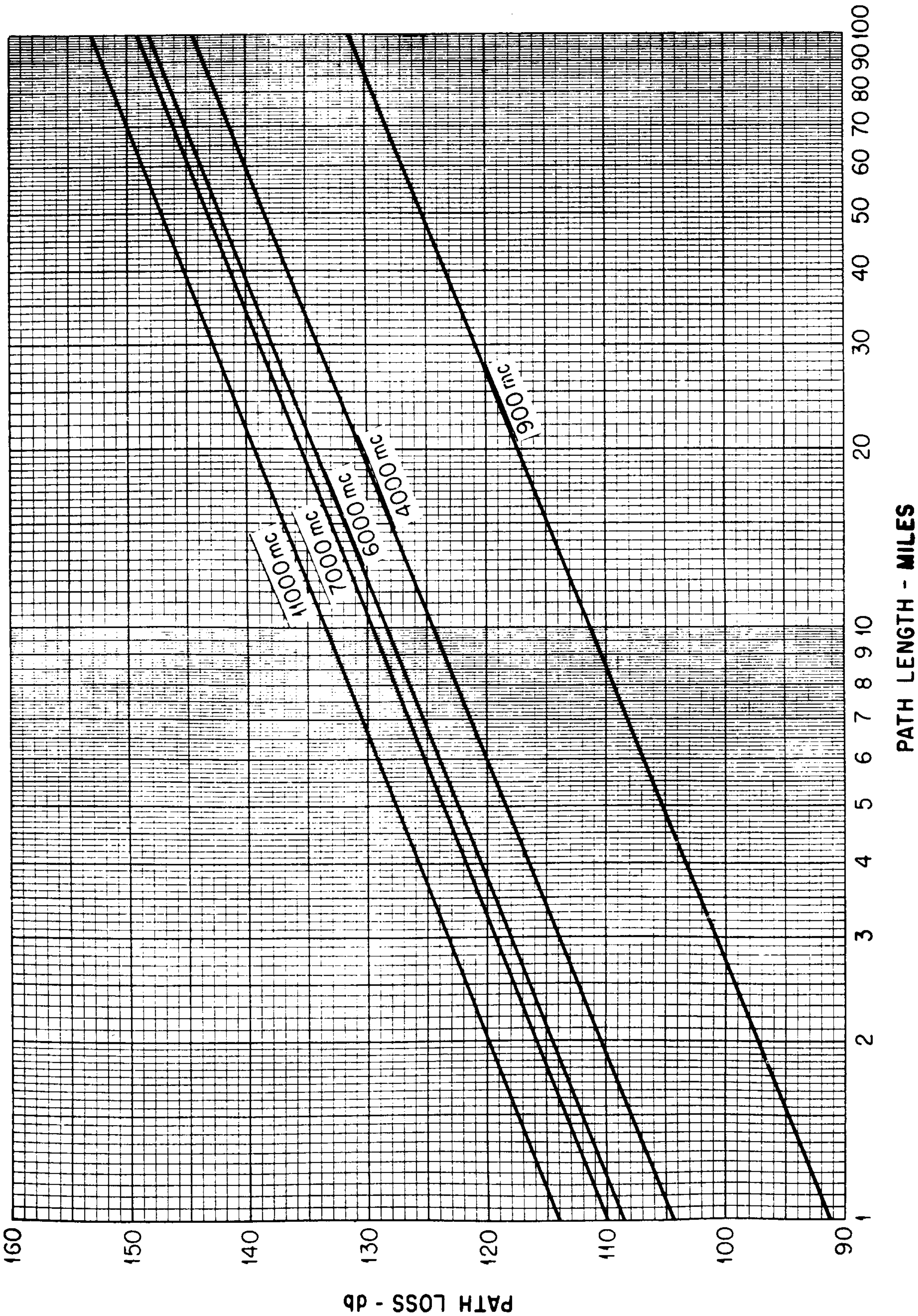
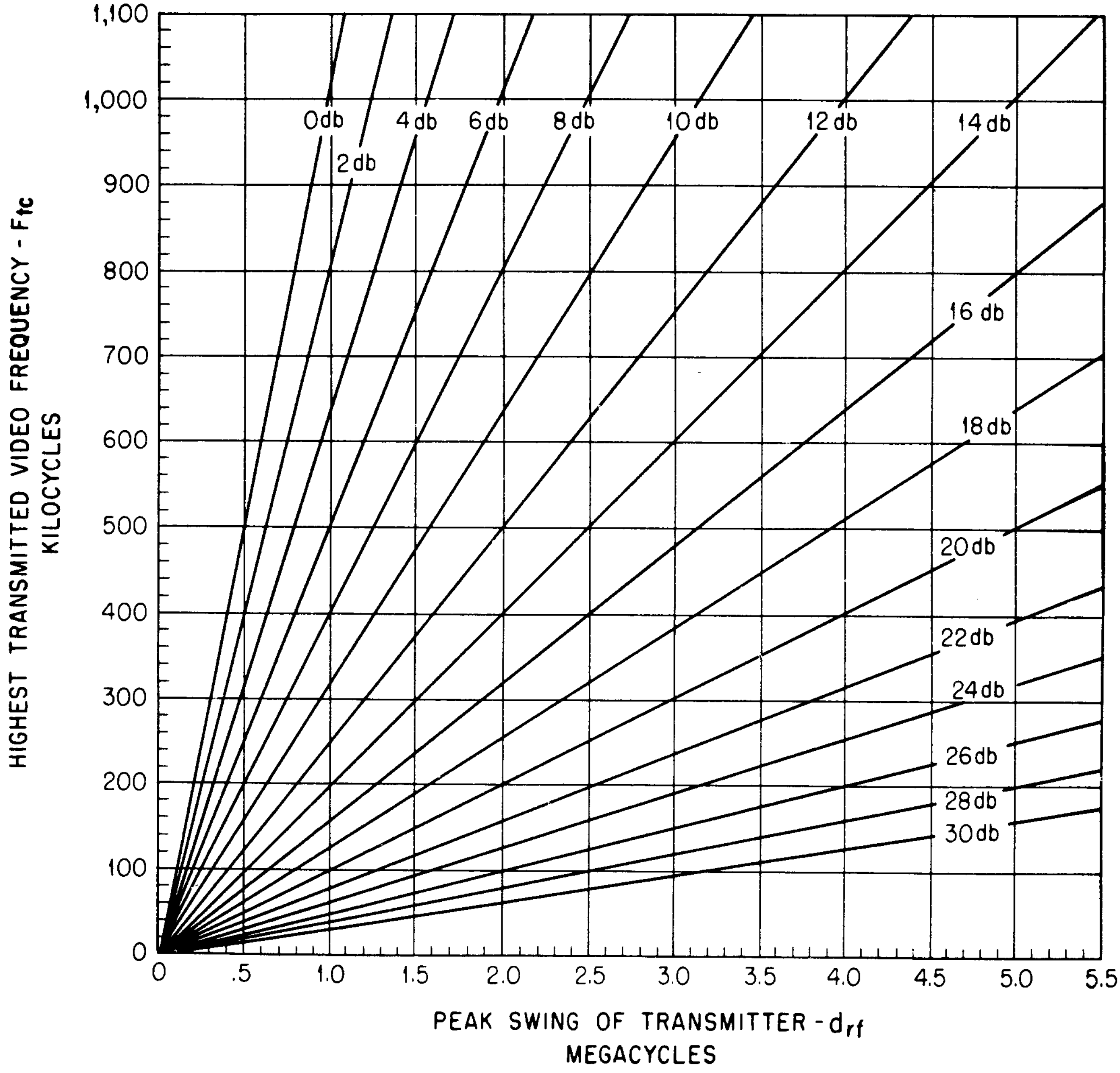
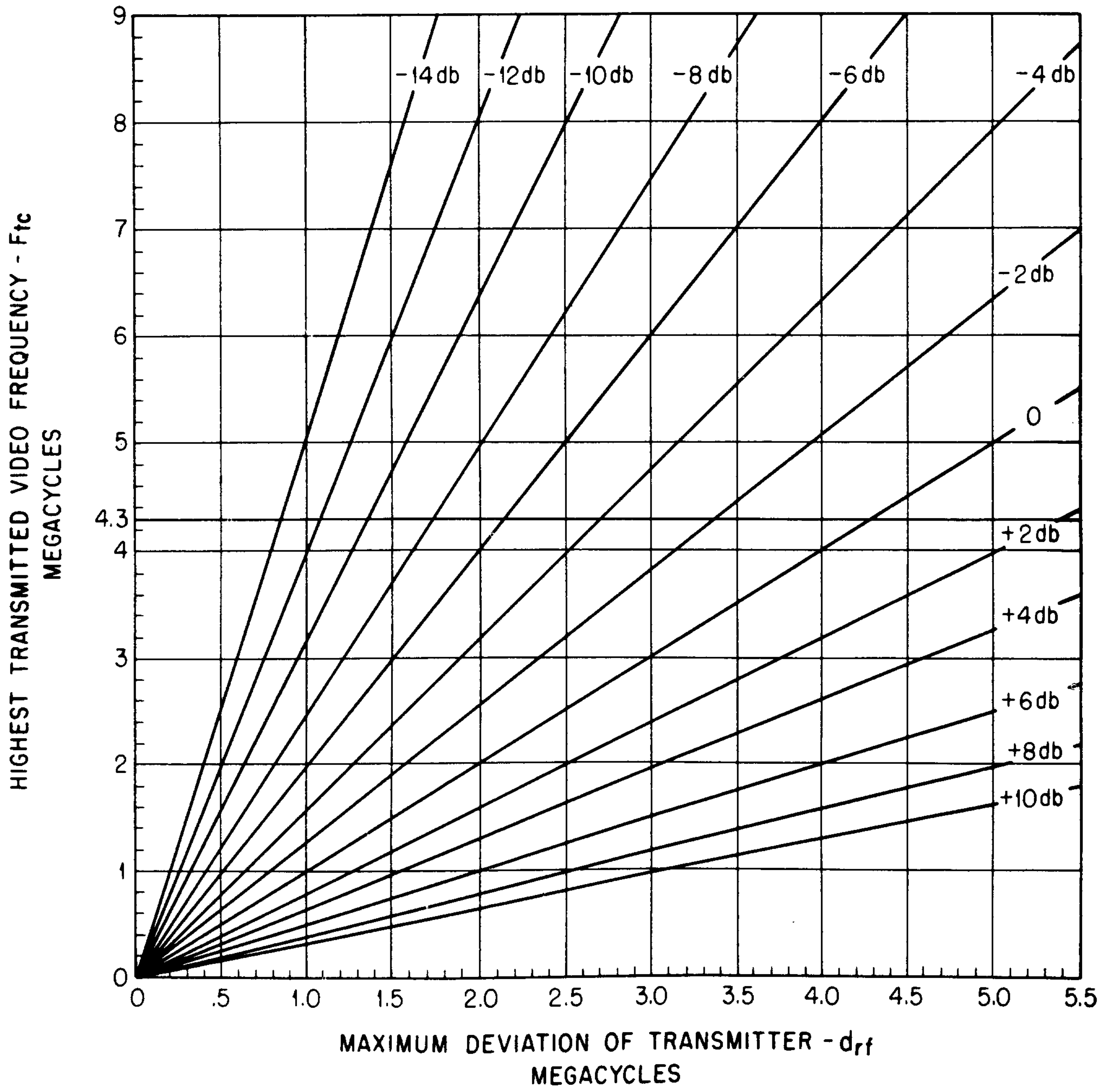


Fig. 2 – Free Space Loss Between Half-Wave Dipoles



Improvement Factor = $20 \text{ Log } \frac{d_{rf}}{F_{tc}}$

Fig. 3 – Chart for Determination of Improvement Factor for Multichannel Telephone Transmission



Improvement Factor = $20 \text{ Log } \frac{d_{rf}}{F_{tc}}$

Fig. 4 – Chart for Determination of Improvement Factor for Television Transmission