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OVER-HORIZON BUOY COMMUNICATIONS - PARAMETRIC DESIGN GUIDE

15 DECEMBER 1966

Prepared for

DIRECTOR-AIR PROGRAM BRANCH,
NAVAL APPLICATIONS GROUP,
OFFICE OF NAVAL RESEARCH
WASHINGTON, D.C.

Under Contract Number
N-00014-66-C0285

SANDERS ASSOCIATES, INC.
95 Canal Street
Nashua, New Hampshire

VOLUME I

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PREFACE

This study is directed to the specific problems of radio communication between buoys and on-water aircraft. The basic objective is to extract and summarize, from the body of existing communications knowledge, the accepted data and relationships pertinent to the buoy and on-water aircraft environment.

This study document presents the results in a form which simplifies evaluation of the trade-offs available by variation of the external (operational) constraints as well as the communications parameters. The study document will be useful to scientific or technical personnel who have no specific communications training. Typically, utilization of this study document will aid bureau and fleet personnel, who establish operational requirements, to judge whether the communications requirements are practically realizable.

The guidance and many helpful comments of personnel of the ONR Air Programs are gratefully acknowledged, in particular we thank Mr. G. Flohil and Lt. E. Ehlers for their many contributions.

To improve the function of this guide, changes suggested by continued usage will be incorporated. We therefore solicit constructive criticism and comments from any recipients of the guide. Comments may be addressed, attention of the undersigned, to:

Sanders Associates, Inc.
Corporate Systems
95 Canal Street
Nashua, N.H. 03060

Herman Brownstein

Frank P. Cullen

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SECTION 1
INTRODUCTION

The purpose of this study is to provide data and procedures for parametric analysis of radio communications between a dispersed field of ASW buoys and an on-water or airborne aircraft. The analysis procedures also apply to communications links between buoys and a seacraft mother vehicle. In the subject type of weapons system, the communications links rarely exceed a range of 200 miles. Within this range all practical propagation modes and communications variables have been carefully examined and have been consolidated in simplified parametric form.

The basic purpose of this study is to enable optimization of the communications link parameters. In any system evaluation, optimization is accomplished by assessment of trade-offs as the system parameters are varied within the applicable constraints. The situations of desirable optimization fall into three categories:

- Evaluation of proposed systems
- Modification of existing systems
- Design of new systems

The following sections define the optimization categories more completely, introduce and explain the transmission equation, and present a procedural format for parametric optimization.

SECTION 2

TRANSMISSION EQUATION

The parametric relationships of the variables in a communication requirement are best understood by considering the transmission equation. The basics of the transmission equation may be expressed as follows:

$$p_r = p_t g_t g_r l_p l_{ms} \qquad (2\text{-}1)$$

where: *

p_r = received power

p_t = transmitter output power

g_t = transmitter antenna gain

g_r = receiver antenna gain

l_p = propagation loss (expressed as fractional reduction in power)

l_{ms} = miscellaneous system losses such as in a transmission line from the transmitter to its antenna, losses from the receiver antenna to receiver, etc.

This equation (2-1) relates the effects of transmitted power, p_t, antenna gains, g_t and g_r: line losses, l_{ms}; and the propagation loss, l_p, to the received power, p_r. This relationship is shown in Figure 2.1.

---

* Throughout this report lower case letters will be used to denote the numeric ratios, and capital letters will express the corresponding quantities in decibels: e.g., P_r = 10 log p_r. See Norton "Transmission Loss in Radio Propagation" Technical Note #12 U.S. Dept. of Commerce, National Bureau of Standards.

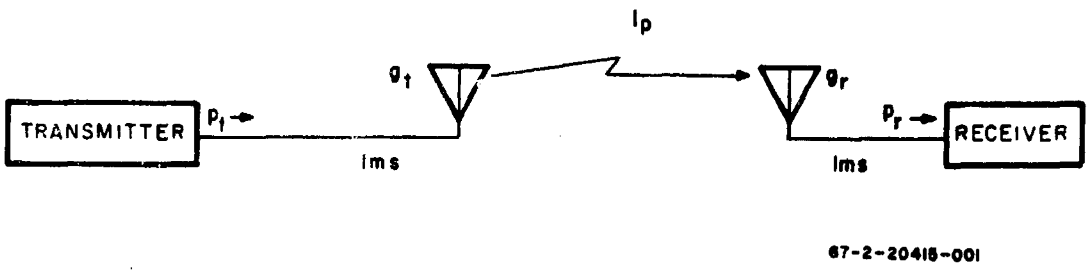

Figure 2-1. Transmission Parameters

The magnitude of received power will depend on antenna gains, line losses, and propagation losses. Line losses and antenna gains are a function of system components.

The propagation loss will depend on the mode of propagation used, i.e., forward scatter, ground wave, reflected wave,(1)(2) range, and frequency.*

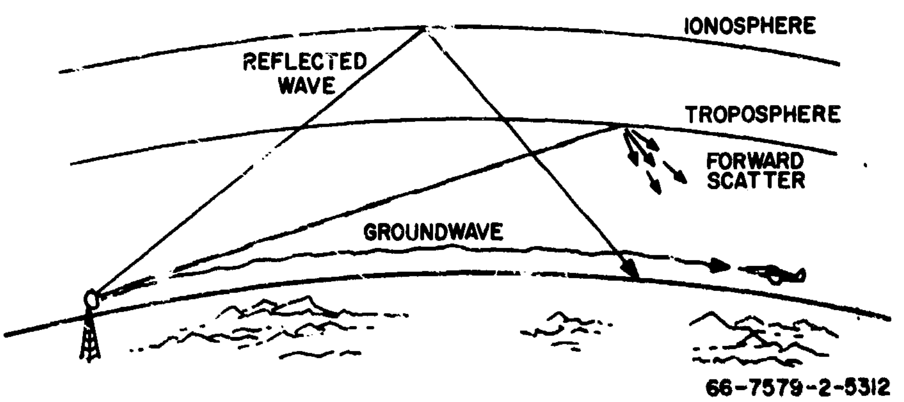

Figure 2-2. Modes of Propagation

The minimum received power necessary to communicate over a communication link will depend on the noise level at the receiver and the signal-to-noise ratio (s/n) required for the particular type of modulation being used.

---

*Throughout this report numbers appearing in parenthesis as a superscript, such as (1) and (2) above, refer to a corresponding number listed in REFERENCES under the corresponding Section .

This signal-to-noise ratio may be further divided into the ideal theoretical signal-to-noise ratio, $(s/n)_{ideal}$, and an additional signal-to-noise margin, $(s/n)_{mar}$, which allows for non-ideal equipment operation, signal fading, and other propagation abnormalities. Therefore, the minimum received power relationship is:

$$p_r = (s/n)_{ideal} (s/n)_{mar} \times \begin{matrix}\text{(operating noise level)} \\ \text{(at receiving terminal)}\end{matrix} \qquad (2\text{-}2)$$

where:

operating noise level = f b k t
at receiving terminal

f = operating noise factor*

b = bandwidth of receiver

k = Boltzmann's constant,[4] 1.380×10^{-28} joules/degree

t = temperature,[4] usually taken at 290°K

therefore

$$p_r = (s/n)_{ideal} (s/n)_{mar} f b k t \qquad (2\text{-}3)$$

Combining equations (2-1) and (2-3)

$$(s/n)_{ideal} (s/n)_{mar} f b k t = p_t g_t g_r l_p l_{ms}$$

Solving for p_t

$$p_t = \frac{(s/n)_{ideal} (s/n)_{mar} f b k t}{g_t g_r l_p l_{ms}} \qquad (2\text{-}4)$$

To facilitate parametric manipulation, it is convenient to transform this equation into a linear additive relationship of the parameters. This transformation is accomplished by taking the logarithm of the terms of the equation. Each term will be expressed in decibels**.

$$P_t = (S/N)_{id} + (S/N)_{mar} - G_t - G_r + L_p + L_{ms} + F + B - 204 \qquad (2\text{-}5)$$

---

*Appendix B

**See Appendix A for discussion of decibel relationship.

Where:

P_t	Transmitter power in dbw (decibels above 1/watt reference)
$(S/N)_{id}$	Ideal (S/N)* ratio, in db, for a given data rate and modulation type
$(S/N)_{mar}$	Added (S/N) ratio, in db, due to inability of the selected modulation to achieve the ideal, added margin for fading in the propagation path, etc.
G_t	Transmitting antenna gain in db
G_r	Receiving antenna gain in db
L_p	Path loss, in db, for selected propagation mode, frequency, and range
L_{ms}	Miscellaneous system losses, in db, due to system components or abnormal antenna inefficiency
F	Operating noise figure at receiving terminal
B	Decibel equivalent in Hz of the effective noise bandwidth in the demodulator
-204	Thermal noise power density. This is the value in dbw of the term, kt, of equation (2-4), i.e., $10 \log (290 \times 1.38 \times 10^{-28})$

*Conforming to common usage, (S/N) is used throughout this report to express 10 log (s/n) and does not imply 10 log s/10 log n; this is an exception to the convention introduced earlier.

SECTION 3
ABBREVIATED DESIGN PROCEDURE

For many purposes a simplified form of the transmission equation can be used to obtain a quick estimate of the communications parameters necessary to satisfy a given requirement. For example, in the initial planning stages of a system, an exact solution is not required and a gross performance calculation is adequate. The abbreviated procedure described in this section provides a quick estimate of power, size, weight, etc. for communication over a given range. Such an estimate offers sufficient insight into the parametric requirements to determine whether the approach is operationally practical. Once the approach has been determined operationally practical, the parameters can be more nearly optimized by the procedures and discussions of Sections 4.1 and 4.3.

Parameters affecting a buoy communications link are related by the transmission equation (2-5):

$$P_t = (S/N)_{id} + (S/N)_{mar} - G_t - G_r + L_p + L_{ms} + F + B - 204$$

using the terms as defined in Section 2. In this equation certain terms such as L_p, and F vary over a wide range as a function of frequency, range, etc., while other terms remain relatively constant.

For the abbreviated equation the more constant terms are assigned reasonable values, and the widely varying terms are incorporated into design curves. The following fixed parameter values are assigned:

G_t = 3 db	These gains are typical of what might be encountered in buoy to on-water operations.
G_r = 3 db	
L_{ms} = 0 db	No additional losses are considered over those incorporated in the power-gain curves.
$(S/N)_{mar}$ = 6 db	This factor is used to account for nominal sea state and propagation conditions.

Parameters included in the design curves:

F	Combined value of atmospheric noise and receiver noise-figure is incorporated into the design curves as a function of frequency.
L_p	Transmission loss which is incorporated into design curves as a function of frequency, range, and propagation mode.
-204 db	This constant is included below in K of equation (3-1) and is incorporated into the design curves.

The resulting simplified transmission equation is:

$$\overline{P} = K + (S/N)_{id} \quad (3\text{-}1)$$

$$P_{tot} = \overline{P} + B \quad (3\text{-}2)$$

where:

$\overline{P}$ is the power in dbw required per cycle of bandwidth,

K is a conversion constant included in the design curves.

B is the bandwidth in Hz expressed in db.

P_{tot} is the total transmitter power, in dbw, for the specified bandwidth.

Having developed a simplified transmission equation, gross performance requirements may be established by means of design curves (Figures 3-1 through 3-11). Prior to using the design curves, a decision must be made on the required range, operating altitude, error rate, and modulation type. The selection of frequency modulation for analog data is recommended and is a reasonable choice for a calculation of this type. For digital data FSK is recommended. The use of the curves is best illustrated by means of three examples, one for digital data and the other two for analog data.

Example 1:

Digital Data

A buoy is required to transmit 1000 bits per second of digital data over a 100 mile range to an aircraft at 500 feet altitude. A 10^{-4} error rate (one error in 10,000 bits of information) is acceptable.

(a) Using Figure 3-1 for FSK modulation

$$(S/N)_{id} = (S/N) = 12.4 \text{ db}$$

(b) Using Figure 3-3 or a receiving altitude of 500 feet (Select Figures 3-2 to 3-8 for other altitudes), set the scale arrow at $(S/N)_{id}$ = 12.4 db and determine $\overline{P}$,

$$\overline{P} = -32 \text{ dbw for a frequency of 8 MHz}$$

Since no frequency was specified in this case, the frequency for the lowest $\overline{P}$ was selected and groundwave propagation chosen. Groundwave curves take line-of-sight propagation into account in the event the receiver is above the horizon.

(c) For digital communications the bandwidth may be considered equal to the data rate.

Bandwidth equals 1000 Hz.

$$B = 10 \log 1000 = 30 \text{ db}$$

(d) Total power required will be:

$$P_{tot} = \overline{P} + B = -32 + 30 = -2 \text{ dbw}$$

$$P_{tot} = \text{antilog } \frac{-2}{10} = 0.65 \text{ watts}$$

(e) An approximate weight and volume can be determined using Figure 3-9.

Assuming 24 hours of total operating time, the buoy transmitter and batteries will weigh about 10 lbs. (limit weight) and have a volume of approximately 0.3 cu. ft.

Example 2:

Analog Data

A buoy is required to transmit analog data over a 100-mile range to an aircraft at 500-foot altitude. A signal-to-noise ratio of 32 db is required[†] to process the data. The highest frequency in the data to be transmitted is 500 Hz; therefore, f_b = 500 Hz.

(a) Using Figure 3-10 for FM modulation, an output S/N ratio $(S/N)_o$ of 32 db intersects the "design line" at an input S/N ratio $(S/N)_i$ of approximately 17 db.* $(S/N)_o$ is the signal-noise-ratio into the demodulator and is therefore equivalent to $(S/N)_{id}$

$$(S/N)_{id} = 17 \text{ db}$$

† Based upon assumed processor characteristics

*The FM improvement in this case is 32 db - 17 db = 15 db. The deviation ratio or modulation index, m, is about 3.5. The "design line" limits the selection of the deviation ratio to the highest recommended value. This is a value yields minimum transmitter power consistent with a reasonable margin above FM threshold.

(b) Using the parametric curves of $\overline{P}$ for a 500 foot altitude, Figure 3-2, set the arrow of the sliding scale at $(S/N)_{id}$ = 17 db and determine $\overline{P}$. Since no radio frequency was specified, we use the frequency which yields minimum $\overline{P}$; this is 8 MHz for groundwave propagation, $\overline{P}$ = -28 dbw

(c) The curves of Figure 3-10 were calculated relative to a bandwidth of twice the highest baseband frequency, f_b, and

$$B = 10 \log (2 f_b)$$
$$B = 10 \log (2 \times 500)$$
$$B = 30 \text{ db}$$

(d) Total power required will be:

$$P_{tot} = \overline{P} + B = -28 + 30 = +2 \text{ dbw}$$
$$P_{tot} = \text{antilog } \frac{2}{10}$$
$$P_{tot} = 1.6 \text{ watts}$$

(e) An approximate weight and volume can be determined from Figure 3-9. Assuming 24 hours of total overating. time, the buoy transmitter and batteries will weigh about 15 pounds and occupy about 0.4 cu. ft.

Example 3:

<u>Analog Data</u>

Assume, in example 2, that we wish to avoid operation at 8 MHz (which is in the HF band and might be subject to considerable interference) and that we decide to operate, if possible, above the HF band (above 30 MHz) and, further, decide that 100 watts is the maximum useable power. What is the highest radio frequency for meeting the requirements of example 2?

For example 2:

h_t = 500 ft

distance = 100 n.m.

f_b = 500 Hz

required $(S/N)_o$ = 32 db

(a) We have decided that P_{tot} = 100 watts, (equivalent to step (d) in the preceding examples 1 and 2). The procedure in this example is the inverse:

P_{tot} = 100 watts

P_{tot} = 10 log 100 = 20 dbw

(b) Find B as in step (c), example 2 and

B = 10 log $(2 f_b)$

B = 10 log (2 x 500)

B = 30 db

(c) Find $\overline{P}$ from $P_{tot} = \overline{P} + B$; solving for $\overline{P} = P_{tot} - B$ we have

P = 20 - 30 dbw

$\overline{P}$ = -10 dbw

(d) As in step (a), example 2, we find from Figure 3-10 that for the required $(S/N)_o$ of 32 db an input (S/N) of 17 db is needed.

$(S/N)_{id}$ = 17 db

(e) Using Figure 3-3 (as in step b, example 2), set the arrow to the sliding scale at 17 db. We have determined in step (c) of this example that a 100 watt transmitter gives a $\overline{P}$ of -10 dbw. On Figure 3-3 find the intersection of the -10 db subordinate with the

100 mile groundwave curve. The intersection is at 40 MHz; this is the maximum operating frequency for the conditions specified.*

It may be noted in this example that the troposcatter curves (dotted lines) in Figure 3-3 show less $\overline{P}$ at 40 MHz for 100 n.m. than groundwave propagation - in fact about 7 db less. One factor which must be taken into account is that troposcatter fades much worse than groundwave propagation. In order to provide the same communication reliability as groundwave*, the troposcatter mode needs additional power for fading margin. See Section 4.1.15 for discussion of this factor. The fading margin is determined using Figure 3-11. A 90% reliability will be provided by a 14 db fading margin. Allowing 14 db for fading margin is equivalent to decreasing the available -10 dbw of power by 14 db. For a -23 dbw power level, troposcatter operation is not possible.

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*Below 30 MHz, signal levels determined using the groundwave curves will provide 90% reliability and at higher frequencies the reliability will be better than 90%.

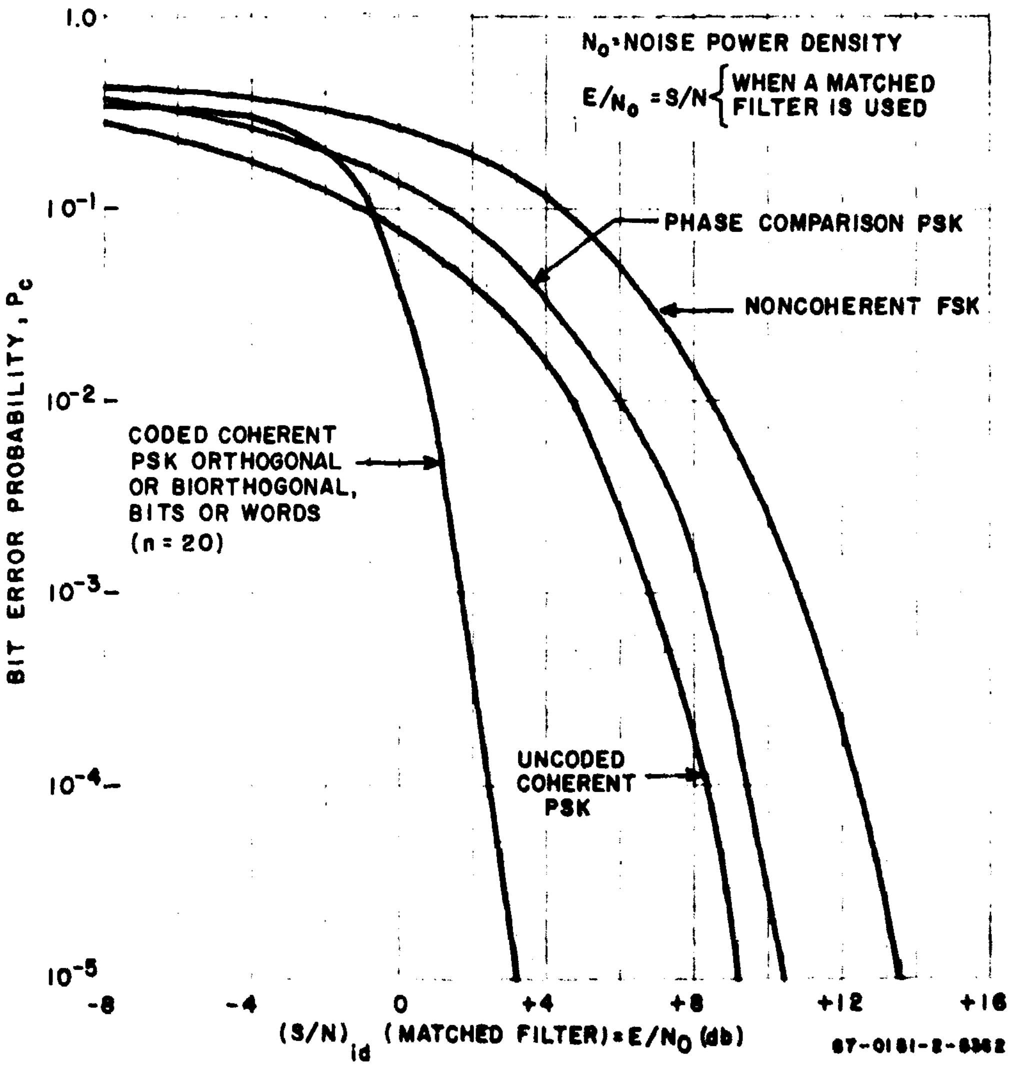
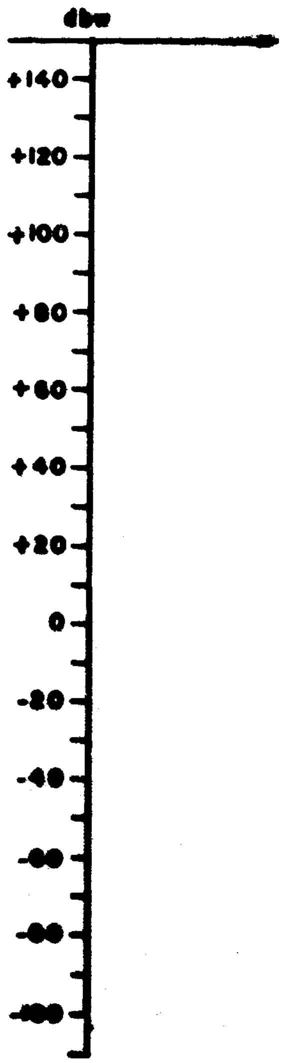


Figure 3-1. Error Rate vs $(S/N)_{id}$


dbw
+140
+120
+100
+80
+60
+40
+20
0
-20
-40

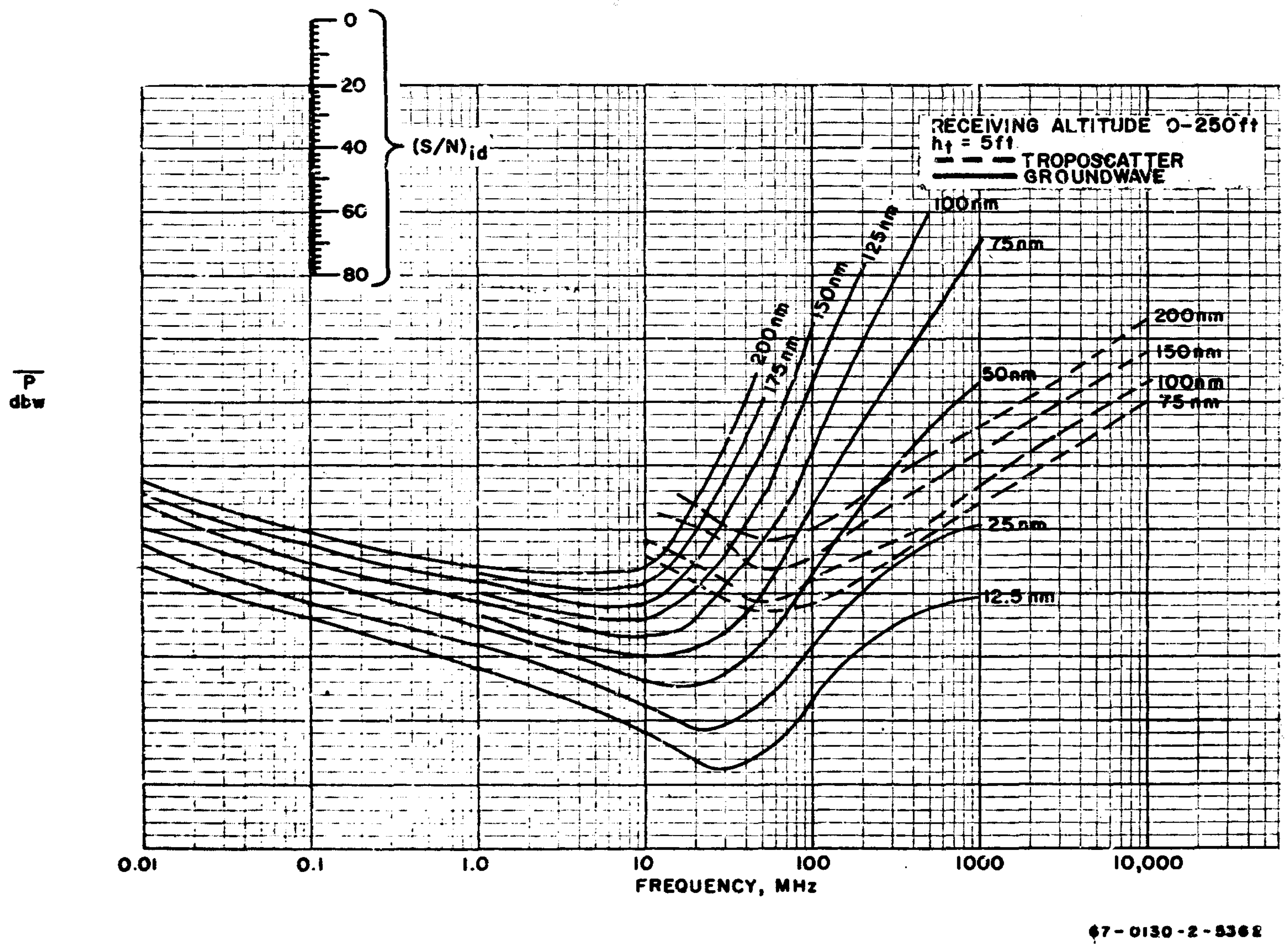


Figure 3-2. Power per Cycle 0-250 ft.

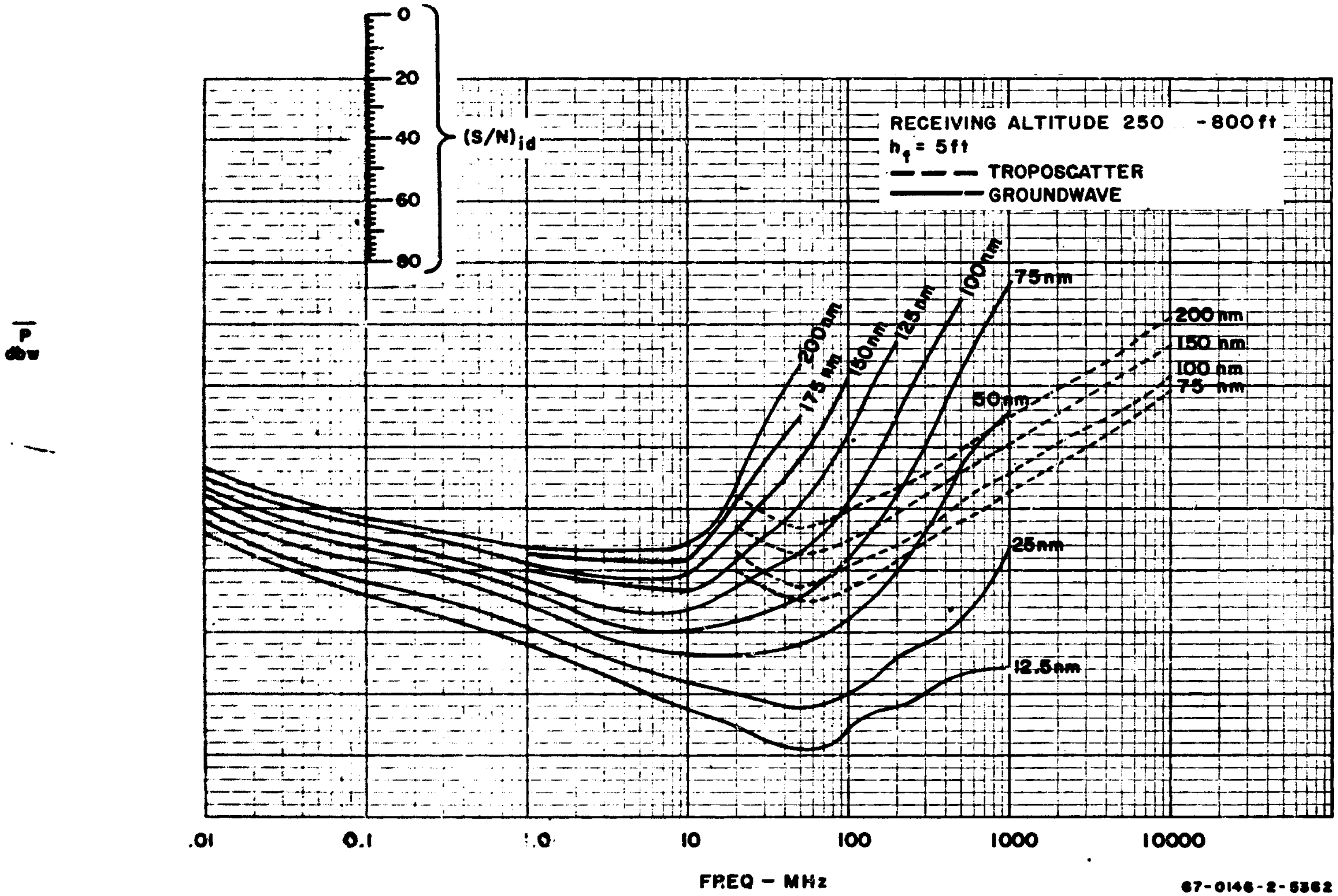


Figure 3-3. Power per Cycle 250-800 ft.

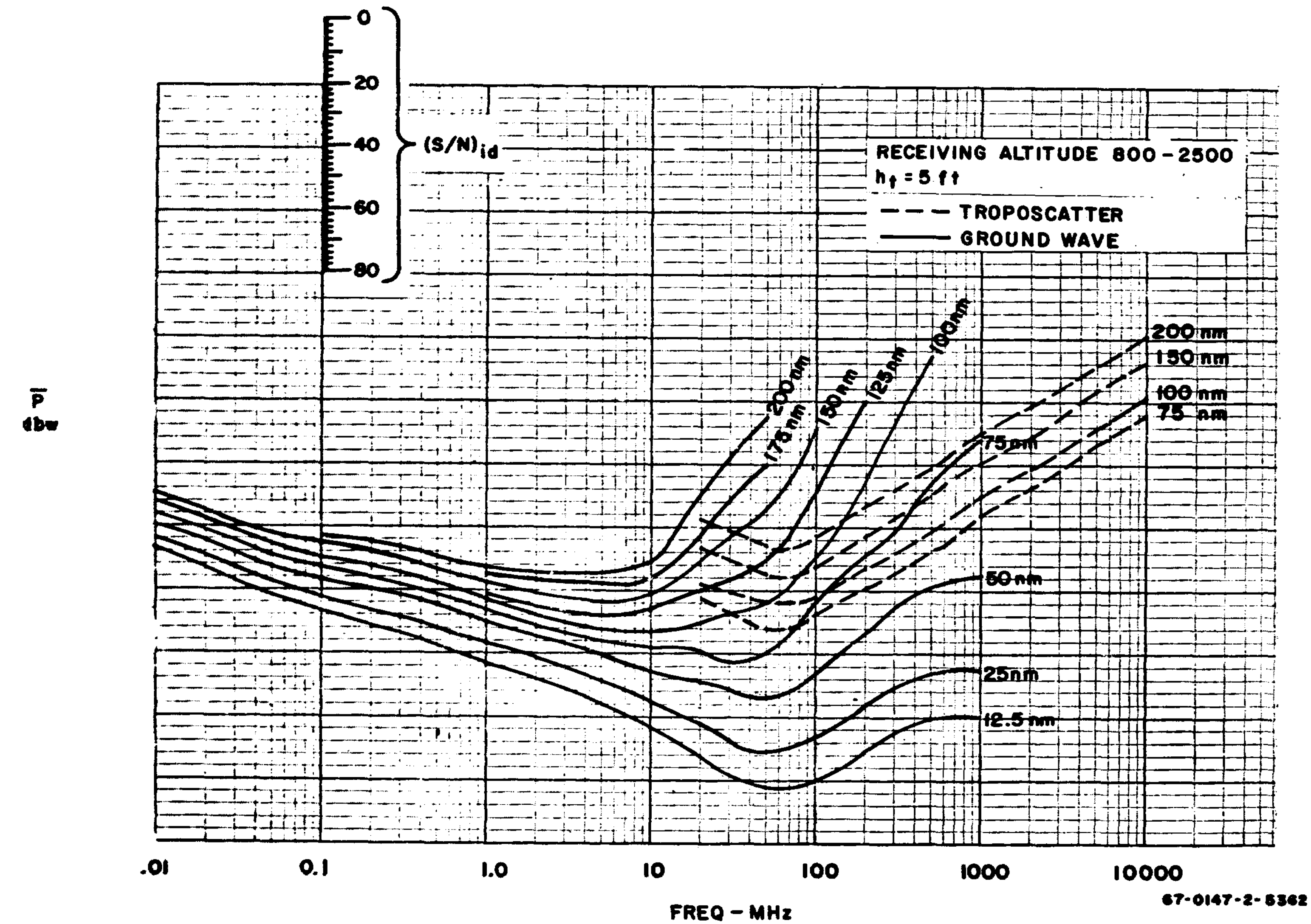


Figure 3-4. Power per Cycle 800-2, 500 ft.

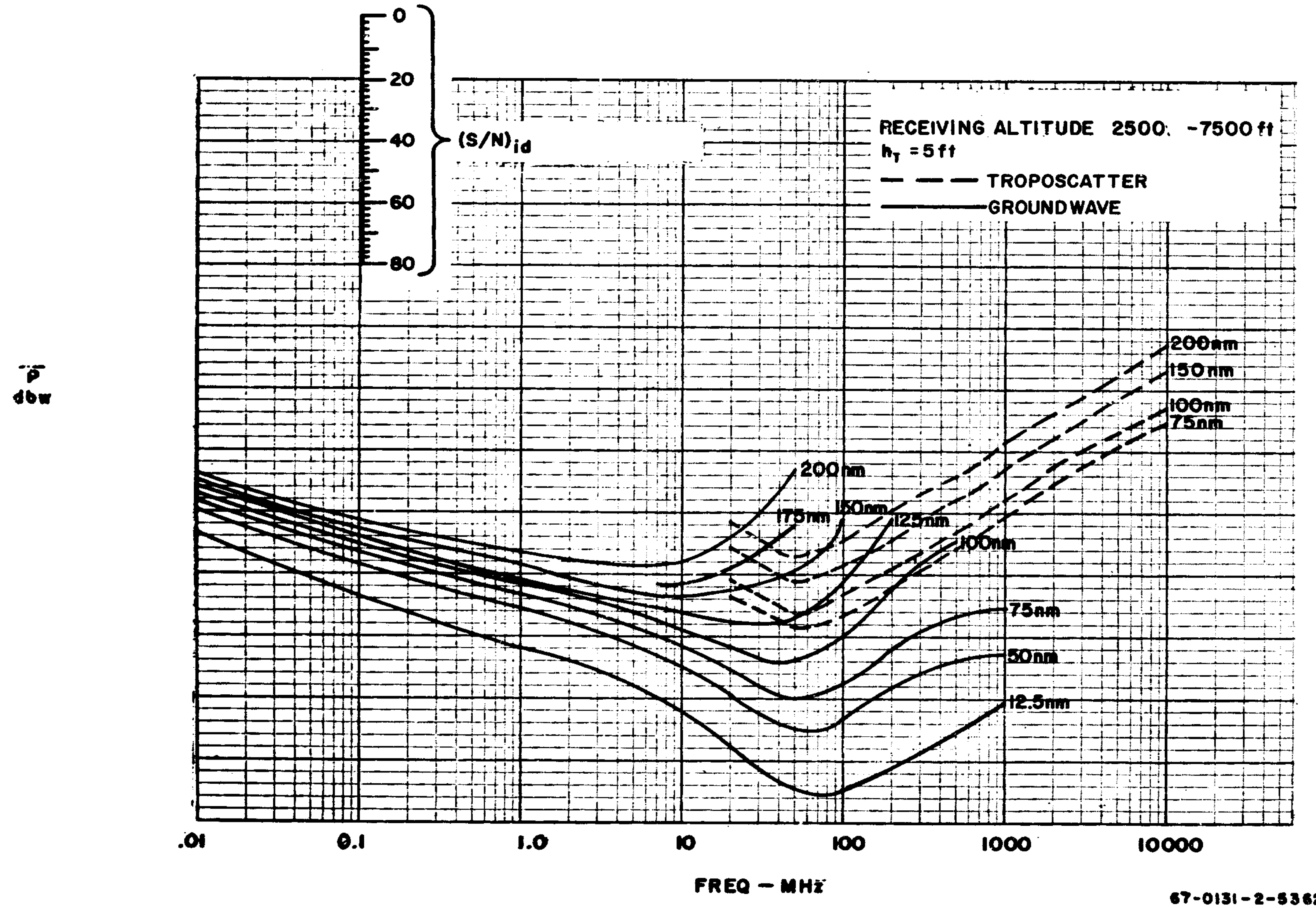


Figure 3-5. Power per Cycle 2,500-7,500 ft.

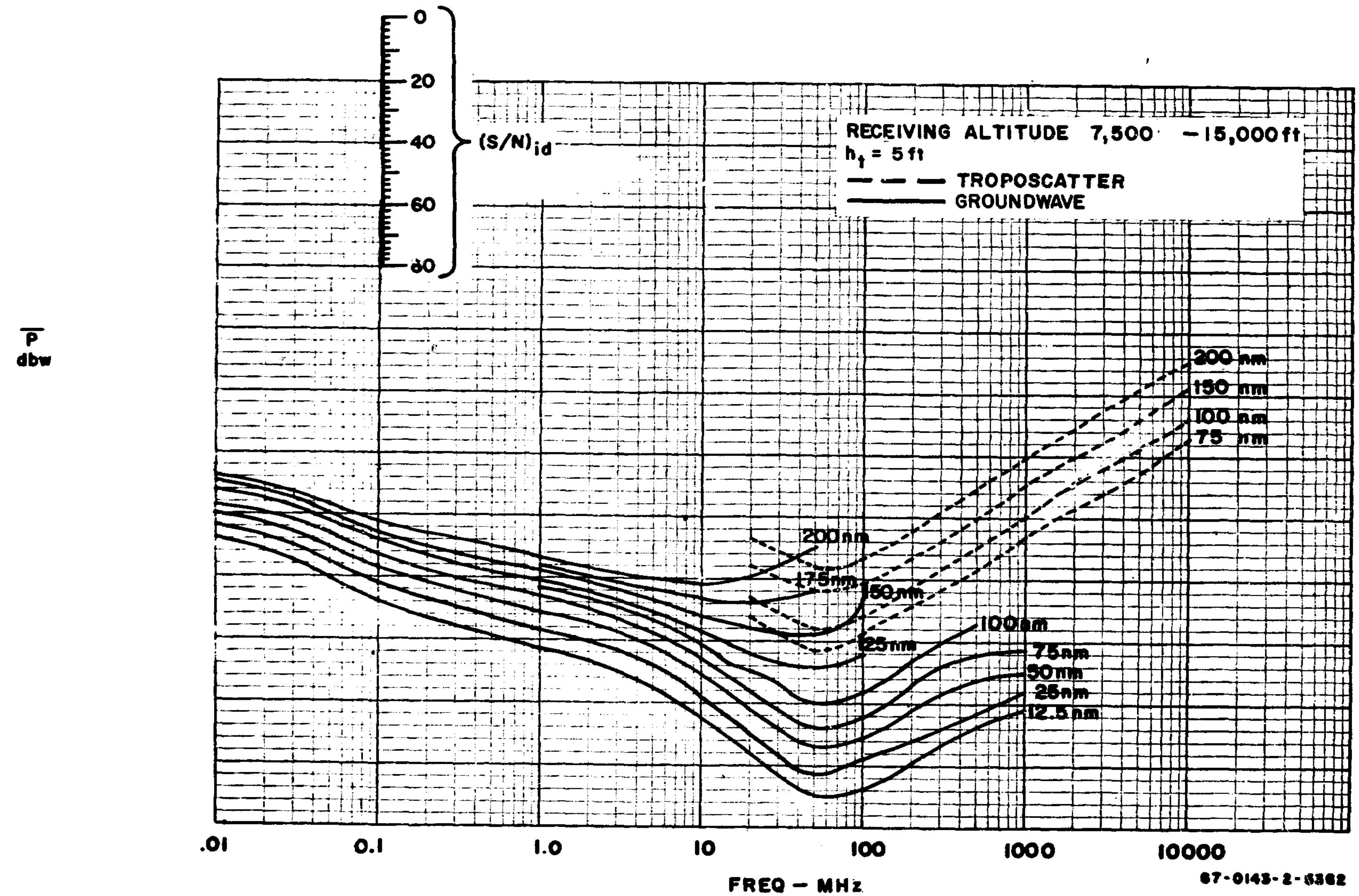


Figure 3-6. Power per Cycle 7,500-15,000 ft.

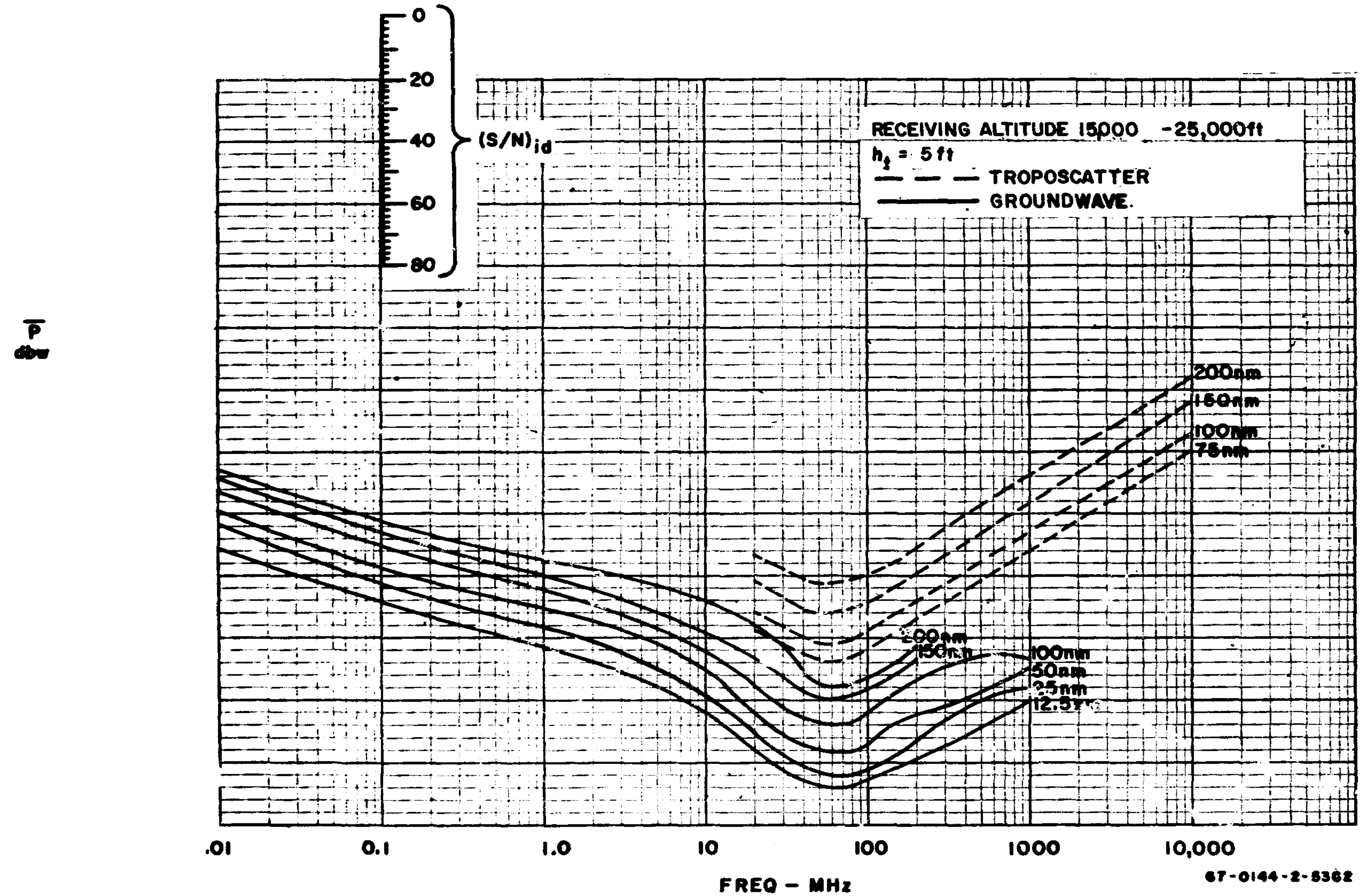


Figure 3-7. Power per Cycle 15,000-25,000 ft.

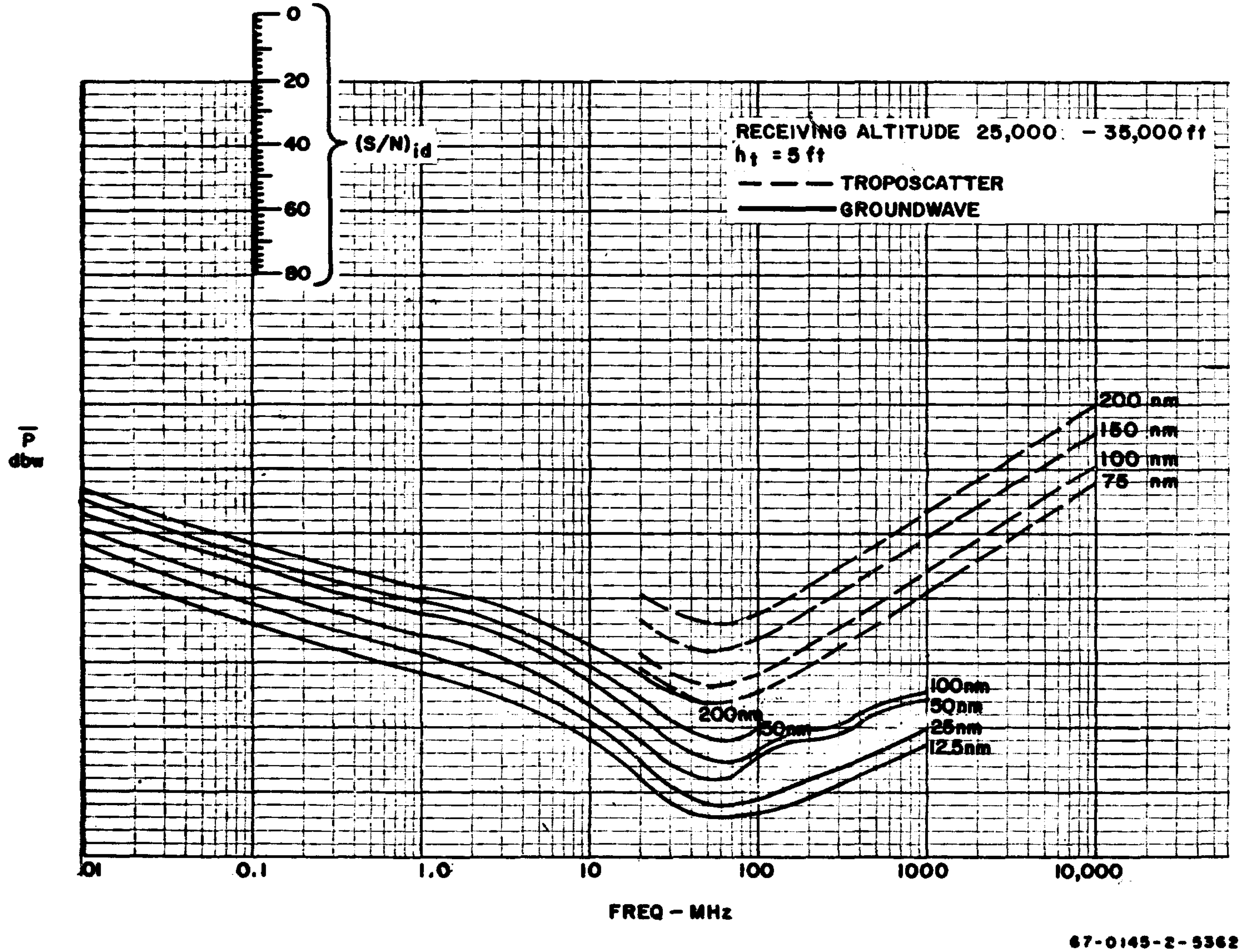


Figure 3-8. Power per Cycle 25,000-35,000 ft.

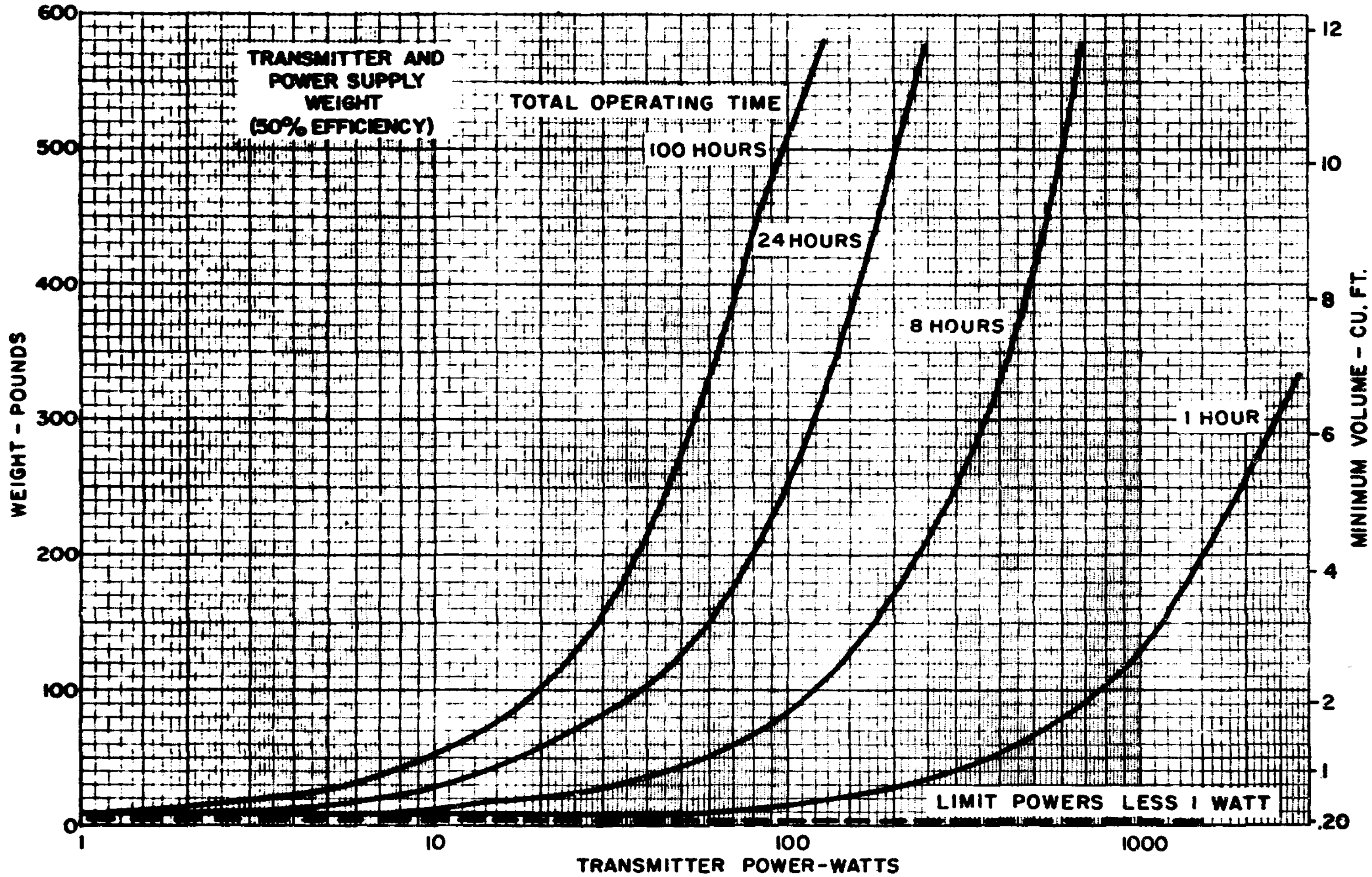


Figure 3-9. Transmitter and Power Supply Weight

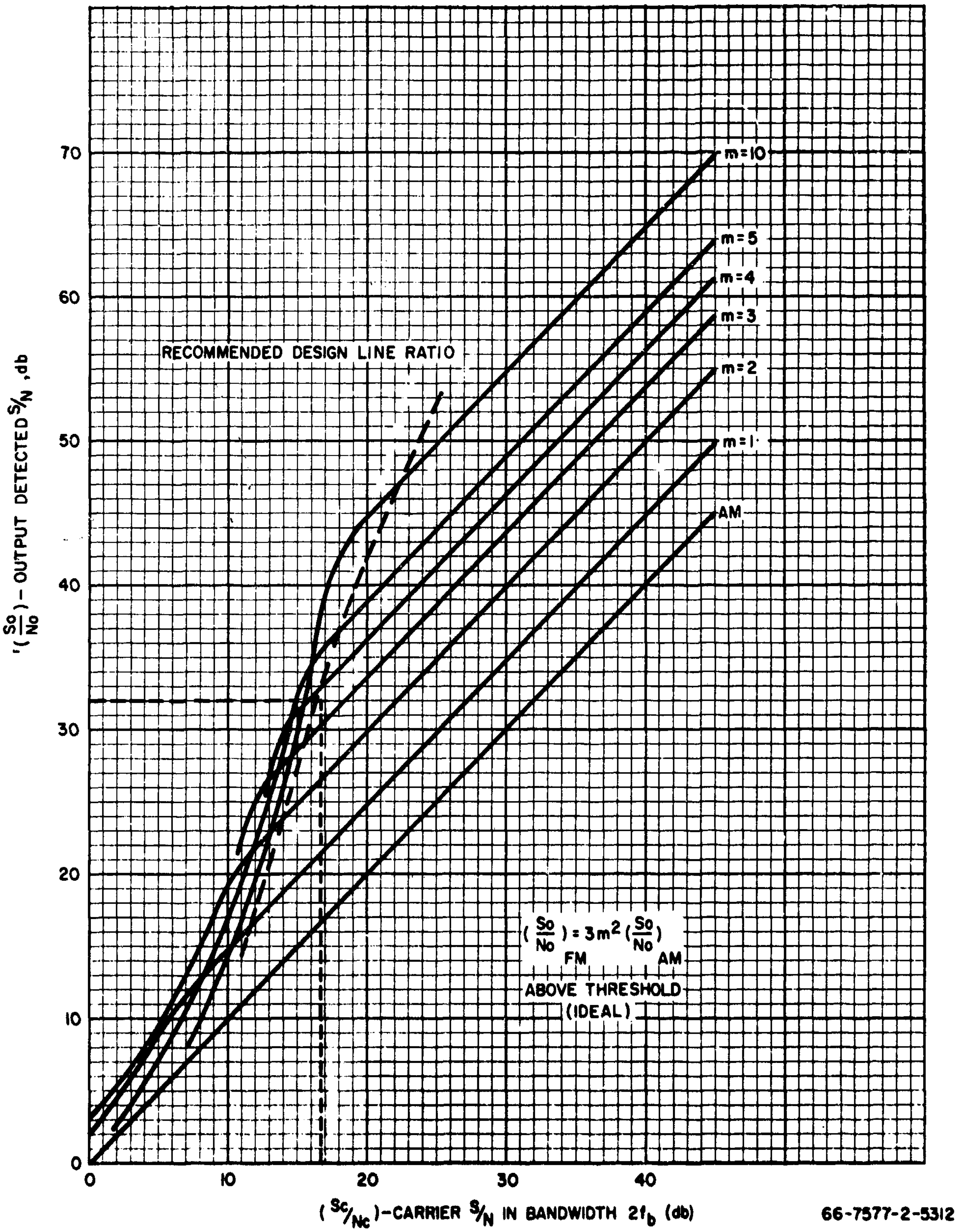


Figure 3-10. FM Improvement Factor

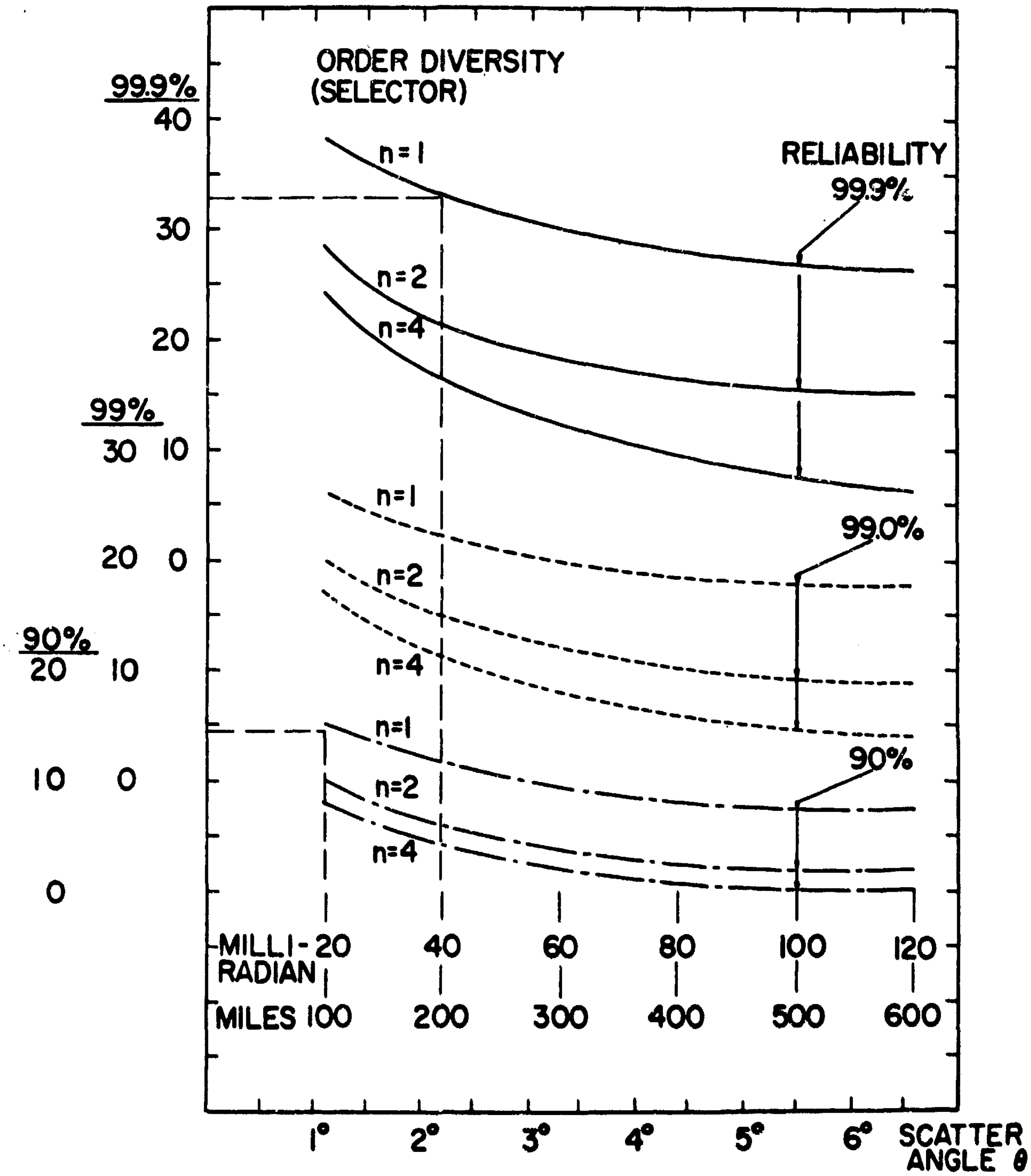


Figure 3-11. Fading Margin with Selector Density

SECTION 4.

PARAMETRIC OPERATIONS

4.1 PROCEDURES

4.1 PARAMETRIC PROCEDURES

The procedures contained in this chapter are intended for application to three operational categories. These are:

- Evaluation of a proposed buoy communications system.
- Modification of an existing buoy communications system.
- Guidance in the design of a new buoy communications system.

A summary list of the procedures normally required and the categories to which they apply are shown in Table 4-1. The detailed procedures follow in Section 4.1.1. Each procedure has the same format.

Format of Procedures

A. Brief Introduction

B. Detailed step by step procedure which identifies the applicable curvies **or** where procedures involve simultaneous options and repetitious processes, a flow chart* is provided

C. Example illustrating the use of the procedure

Where necessary the introduction to the procedure is supplemented by a detailed discussion in Section 4.3 and references in the Index.

The primary parametric relationships are indicated by the transmission equation:

$$P_t = (S/N)_{id} + (S/N)_{mar} - G_t - G_r + L_p + L_{ms} + F + B - 204 \qquad (2\text{-}5)$$

*The flow chart is a graphic aid for illustrating complex procedures, for an example, see Figure 4-1.

The terms in the transmission equation are themselves functions of other factors which we designate as external parameters. The relationships are illustrated in Figure 4-1. The external parameters are indicated by the outer spokes. These outer spokes radiate from the respective primary parameters which they affect.

The example illustrated in Figure 4-1 shows that an increase in antenna size would react on antenna gain by increasing it. The increased gain could be traded-off against any of the other parameters in the transmission equation by passing through the hub of the wheel and out through a chosen external parameter; in the example, range was the external parameter selected. Whether an increase in one parameter requires an increase or decrease in another parameter is covered in the detailed procedures and by the shape of the curves used.

The chart in Figure 4-1 is a generalized form of procedural flow diagrams. We will use a different type of flow chart in this chapter to guide the procedures involving multiple or parallel steps. The symbols used in this type of flow chart and their meaning are illustrated in Figure 4-1A ; one of the simpler flow charts used in Procedure 4.1.8. In this flow chart the range is to be extended. By using the indicated curve, we determine the increased transmission loss (in decibels) that is caused by increased range. The decision block indicates that one of six parameters must be varied to restore the decibel loss due to the added range requirement. For each of these proposed parameter variations, the related curve must be consulted to determine which parameter or combination of parameters will compensate for the range increase.

The degree of adherence to flow chart procedural instructions will depend on the user's level of experience. An experienced user will not need to read the supplemental reference instructions.

Table 4-1. Summary List of Procedures

Procedure	Section	Page	Evaluation	Modification	New Design Guide
Antenna Selection	4.1.1	4-5	x	x	x
Output S/N Ratio	4.1.2	4-6	x		x
Buoy Communication System Design	4.1.3	4-11			x
Coded vs. Uncoded Digital Transmission	4.1.4	4-20	x	x	x
Data Rate Tradeoff	4.1.5	4-22	x	x	x
Diversity Gain	4.1.6	4-23	x	x	
Error Rate Tradeoff	4.1.7	4-26	x	x	
Extended Range	4.1.8	4-27		x	
L_{ms} Term	4.1.9	4-30			x
Modulation Selection	4.1.10	4-32	x	x	x
Power and Range Considerations	4.1.11	4-34	x	x	
Power Supply Considerations	4.1.12	4-35	x	x	x
Propagation Loss - Compensation	4.1.13	4-39	x	x	x
Propagation Mode and Frequency Selection	4.1.14	4-41			x
Signal-to-Noise Margin	4.1.15	4-42			x

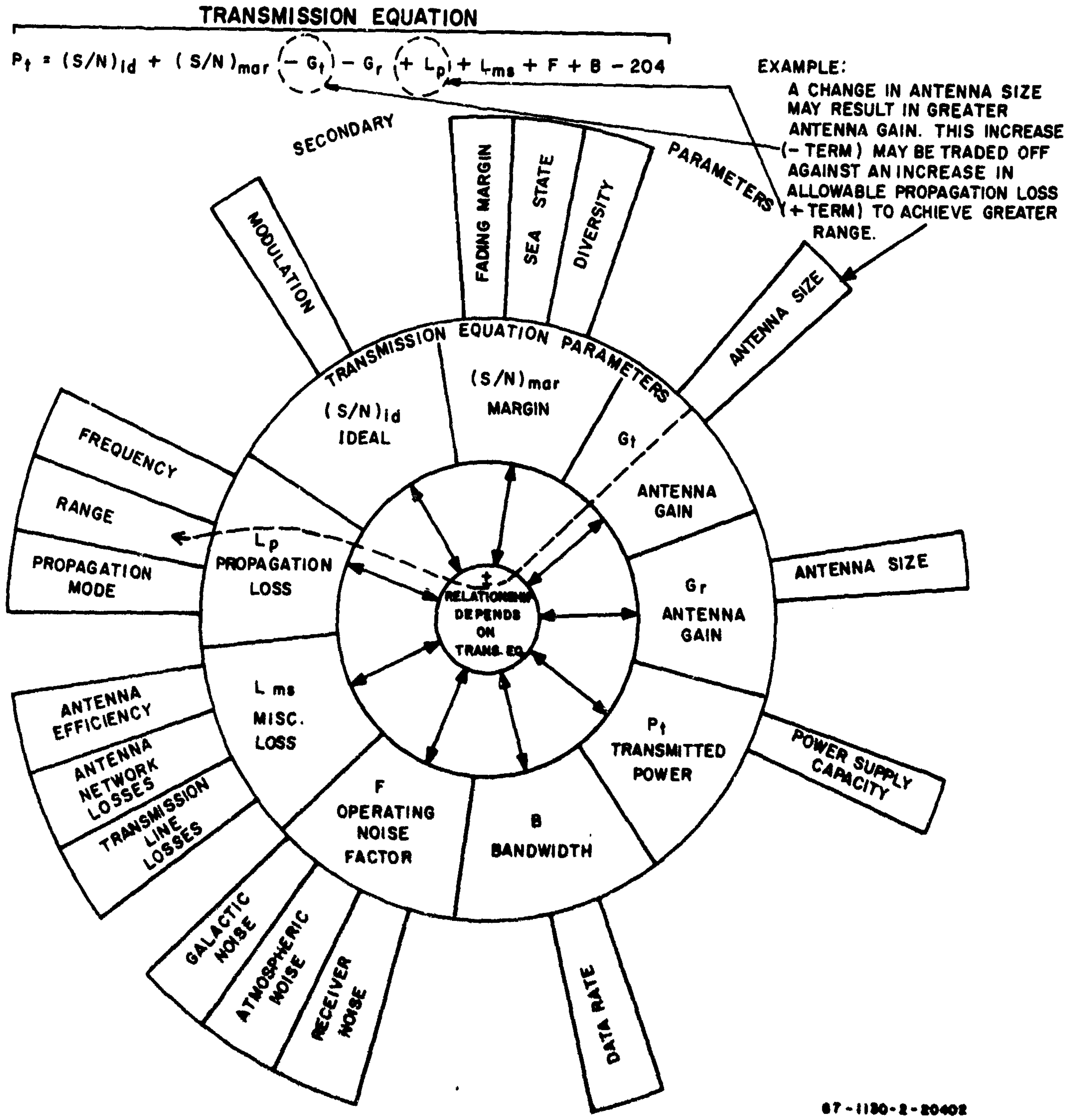
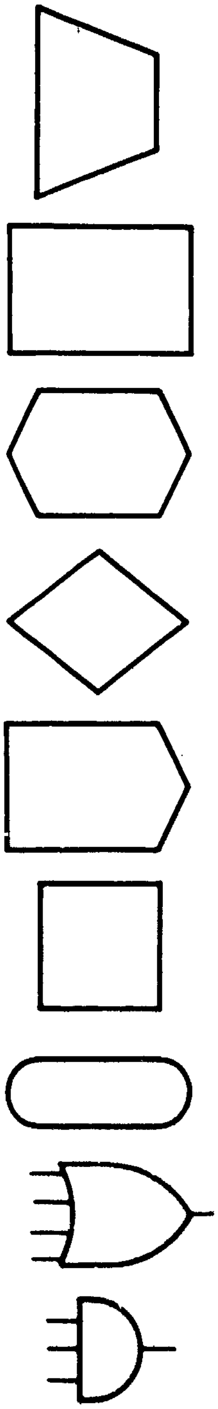


Figure 4-1 Parametric Trade-offs



INPUT / OUTPUT
(DESCRIBES QUANTITATIVE OPERATION OR RESULT)

PROCESS
(ANALYTICAL DETERMINATION)

PARAMETRIC DECISION
BASED ON SYSTEM CONSTRAINTS

PARAMETRIC DECISION
BASED ON OPTIMIZATION CURVES OR TECHNOLOGICAL FACTORS

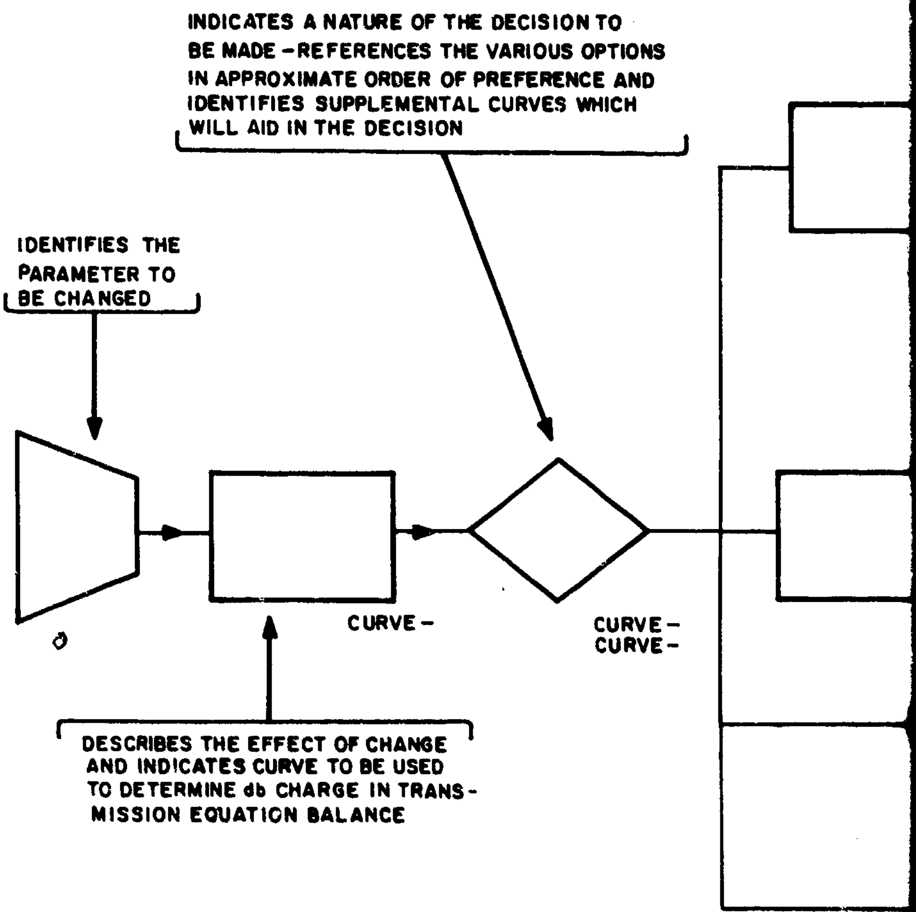
MODIFICATION

OPERATION
(PARAMETRIC VARIATION GUIDED BY OPTIMIZATION CURVES)

TECHNOLOGICAL CONSIDERATION
(FUNCTION SIMILAR TO "OPERATION" BUT LACKING EXPLICIT OPTIMIZATION SELECTION CURVES DUE TO CHANGING TECHNOLOGY)

LOGIC "OR" INDICATING ANY ONE OR COMBINATION OF OPERATIONAL INPUTS WILL DETERMINE OUTPUT SOLUTION

LOGIC "AND" INDICATING THE OPERATIONAL INPUTS REQUIRED TO DETERMINE OUTPUT



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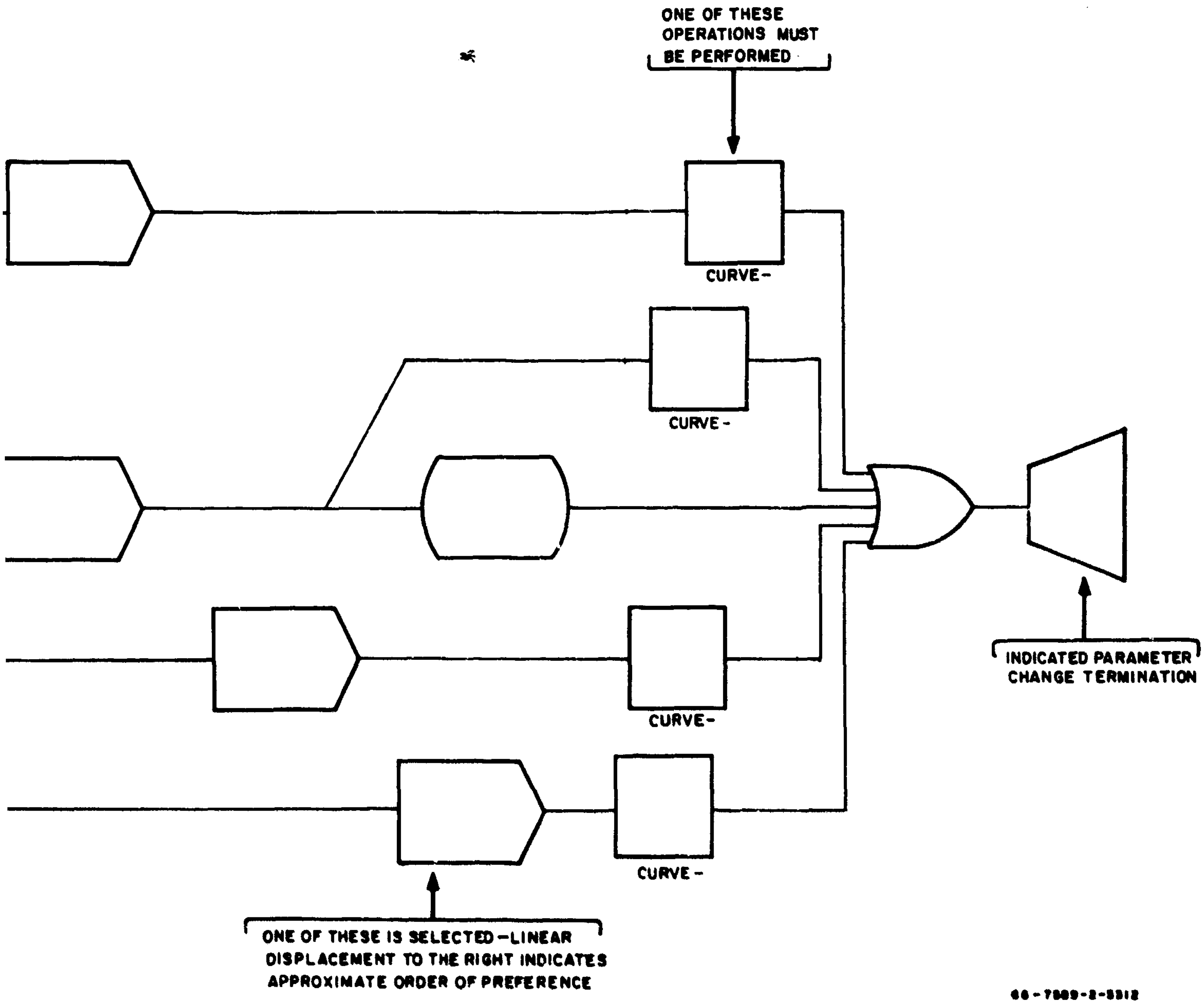

Figure 4-1a Definition of Flow Chart Symbols

The most complex flow chart is that for a buoy communication system design shown in Procedure 4.1.3. This chart, together with the curves of Section 4.2, are used to select parameters for the hypothetical "ONR" Buoy.

4.1.1 ANTENNA SELECTION

Discussion:

For the general case of communication between a multiple buoy field and an on-water/aircraft, several basic conditions relating to antennas will exist. These conditions are:

1. Both buoy and on-water aircraft will require an omnidirectional antenna.
2. The on-water aircraft may use a secondary antenna with directivity at remote locations from the buoy field. The directive antenna pattern will result in a higher gain antenna.
3. The antenna types used will be limited by the size and shape of the buoy or the aerodynamic limitations of the aircraft.
4. Vertical polarization is preferable for operation over sea water because the groundwave propagation attenuation is less than for horizontal polarization.
5. The use of monopole antennas in buoys is common. At frequencies where it is physically difficult to provide antennas with lengths of the order of quarter wavelength or more, loading coils must be used with a resulting efficiency loss.

Charts and curves are referenced by the following Procedure which will aid in antenna selection decisions. These charts do not cover all the variations of antenna types, but are representative [(1)] of what can be achieved.

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(1) Numbers in parentheses are references listed in REFERENCE.

Procedure:

1. Consult chart A-a-1* to determine which antenna types meet the physical configuration limitations of the system. The antenna dimensions are related to wavelength and nomograph A-a-2.

2. Chart A-a-1 indicates the gains which can be expected with the various antennas. In the monopole case a supplemental curve A-a-3 must be used to take into account the coupling efficiency of small (less than one-eighth wavelength) antennas.

3. The intent of the chart is to give some insight into varied antenna configurations. Where more detailed information on the different antenna types is not available, initial systems consideration should assume a monopole antenna will be used.

Example:

Through consideration of antenna characteristics it has been decided that a monopole antenna will meet the physical requirements for mounting on a particular buoy which will transmit at 10 MHz. A gain, G_r, of 4.8 db is indicated on chart A-a-1 for an eighth (1/8 wavelength monopole antenna). Using the nomograph A-a-2, it is determined that the length of an eighth wavelength (H/λ = .125) antenna will be approximately 12 feet. Curve A-a-3 shows that an antenna of this length will operate at about 92% efficiency or 0.5 db loss. The miscellaneous loss term L_m of the transmission equation makes provision for losses of this magnitude.

4.1.2 OUTPUT SIGNAL-TO-NOISE RATIO

Discussion:

Signal-to-noise ratio, (S/N)** is a term which describes the relative signal power to noise power. The ratio of these powers may be expressed in

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*An explanation of curve designations is given in Section 4.2.

**(S/N) is used to designate the power ratio of signal-to-noise in decibels and is equivalent to 10 log (s/n).

various terms such as peak signal-to-rms noise, rms signal-to-rms noise, or peak signal to peak noise. It is common practice to express the signal-to-noise ratio as the ratio of the average signal power to average noise power. This is the practice followed by our report.

The signal-to-noise ratio is indicative of the quality of a received signal. Depending on the type of modulation, certain criteria exist which specify the (S/N) value necessary to receive a signal with given fidelity or error rate. The selection of an appropriate signal-to-noise ratio will differ for analog and digital signals. Typically, the telephone company may qualitatively establish and require that a (S/N) ratio of 35 to 40 db be maintained on its lines for high quality voice communications. A 30 db (S/N) ratio is acceptable for most government and industrial 3 Kc voice channel applications.

For digital data, expressions can be derived which specify for each modulation type, the (S/N) ratio necessary for a given error rate.

Determination of the required (S/N) ratio for digital signals is relatively straightforward. Curves such as A-m-3 may be used and the selection criteria is based on the allowable probability of error.

The range of acceptable error probability for various signal types is discussed in Section 4.3.2.

Determination of the signal-to-noise ratio for analog signals is less exact and is dependent on the nature of the analog data. The analog signals may be broadly classified into two categories:

1. Hydrophone derived signals which have a high noise ambient and are processed by an integration processing procedure
2. Parameter measurement signals such as sea temperature, wind speed, etc. which have a definite precision and are inherently noise free.

For signals in the first category the processing equipment will usually be capable of operating with a low (S/N) ratio as exists when the targets are at maximum ranges. The degree of fidelity or allowable distortion is not too critical since integration tends to reduce the effects. In this situation it is necessary to insure that the thermal noise level of the receiver and processor noise do not further degrade the received signal-to-noise ratio resulting from targets at intermediate ranges. The exact (S/N) ratio often must be qualitatively determined and dependent upon the method of signal processing. The suggested error rates are given in Section 4.3.2 and may be used in conjunction with curve A-e-2 to determine (S/N) ratios.

Signals in the second category usually require relatively high signal-to-noise ratios to maintain accuracy.

The modulation used for signals of this type is principally FM since AM will introduce additional noise. The FM demodulator will have a linearity of 1 to 2% for a deviation of the order of several hundred kilocycles. For smaller deviations the linearity will be better, and the percent of linearity may be considered roughly equivalent to achievable accuracy. The demodulator linearity places an upper limit on the accuracy or resolution of the demodulated signal. This limit is a function of equipment characteristics including the modulator of the transmitter.

A gross figure, representative of the accuracy which may be achieved for a narrow band FM signal, would be 0.1%. Considerably better accuracy can be attained by using digital modulation.

Numerous papers(1), (2), (3) have been written which establish the criteria for operable (S/N) ratios in analog systems. There are many variables involved and the results are mostly applicable to specific modulation types, data rates, and signal waveforms with particular spectral characteristics. Since an objective of this study is to provide generalized parameter selection criteria, set curves have been prepared which will guide in determining the approximate

(S/N) ratio necessary for a given level of resolution of an analog signal. The use of these curves is covered in Procedure.

Procedure:

Digital Data

1. To determine the (S/N) ratio for digital data the modulation type must be known and a reasonable probability of error established.

a. The decision for type of modulation can be made on the basis of the necessity for minimizing (S/N) ratio and allowable equipment complexity. For the three basic types, coherent PSK, differential (phase comparison) PSK, and FSK; the relative (S/N) ratio requirements are shown on curve A-m-3. The representative (S/N) ratios for modulation variations such as multi-phase PSK and orthogonal coding are shown on curves A-m-3, A-m-4 and A-m-5.

The modulator and demodulator required for FSK are the least complex. The equipment complexity increases for differential PSK, coherent PSK, multi-phase PSK, and orthogonal coding in the order listed.

If no prior requirements exist, the selection of coherent PSK will be a good starting point for initial system considerations.

b. For a given system an approximate acceptable error rate is usually known. The error rate discussion, Section 4.3.2, may be helpful in determining a reasonable error rate.

2. Knowing the error rate and modulation type, use curve A-m-3. When orthogonal coding modulation or multi-phase PSK is used, curves A-m-4 and A-m-5 are applicable.

Analog Data

1. To determine the (S/N) ratio for analog data, the required resolution or accuracy must be known. For example, it may be necessary to interpret

the demodulated signal to an accuracy of 5%. This is equivalent to requiring the resolution of the signal into 20 discrete levels.

a. Noise present in the system will affect our ability to resolve the signal into levels. This noise will usually have a gaussian distribution and in some cases impulse type noise may exist. Therefore, there will always be a probability of an error caused by this noise; for measurement type data an acceptable probability of error must be determined. For example, one error per thousand measured values may be acceptable. This is equivalent to a 10^{-3} error probability. Section 4.3.2 may be consulted as a guide in establishing the error probability.

2. For a given error probability and resolution requirement, use of curve A-e-2 will give the (S/N) ratio. The true (S/N) ratio for a specific system will depend on the spectral composition of the input waveform and the filter bandwidths, but the (S/N) ratio determined using this curve will be sufficiently accurate within the intent of this study. For voice communications a (S/N) ratio of 30 db will be acceptable as was discussed previously.

Example:

Analog data

It is required to resolve an analog signal received from a hydrophone into 15 increments. For data of this type an error probability of 5×10^{-2} is reasonable (See Section 4.3.2). Using curve A-e-2, a (S/N) ratio of 30 db is determined.

Digital data

A transmission data rate of 1×10^{3} bits per second is required for a digital signal. Coherent PSK modulation is used and an error rate of 10^{-3} is acceptable. Using curve A-m-3, it is found that an (S/N) ratio of 7 db is required.

4.1.3 BUOY COMMUNICATION SYSTEM DESIGN

This procedure is relatively complex and is supplemented by many of the procedures and discussions. When the required transmitter power, P_t, is not compatible with buoy power supply capacity, space allotted, or current power supply designs; there are a number of alternate feedback paths which are followed to aid in the design correction. These paths are not all inclusive, and other parameter modifications to improve the system may be apparent to the user. The end result is not intended to be a final design, but should allow the user to gain insight into the probable buoy configuration and characteristics.

A flow chart, Figure 4-2 is presented on page 4-47a to guide the design procedure. This flow chart provides a detailed guide to the curves and supplemental discussions necessary to accomplish a buoy communication system design.

The characteristics of a hypothetical buoy are given by following the flow chart. Two design examples are worked using the flow chart as a guide. The steps in each example correspond to the block numbers of the flow chart.

Example:

A communication system will be designed for a hypothetical "ONR" buoy system with the following fixed characteristics:

- buoy operates with an on-water aircraft out to a maximum range of 200 n. mi.
- buoys will be reuseable and deployed for up to 100-hour operating periods.
- data transmitted will be the output of two hydrophones and a buoy heading sensor. Each channel will require a 3 KHz bandwidth.
- spectrum of received data will be visually displayed, and the display will be capable of displaying 15 levels of amplitude.
- buoy is approximately six feet long and two feet in diameter and weighs 1000 pounds.

- buoy antenna will be approximately five feet above sea surface, and the on-water aircraft antenna height will range between 20 to 30 feet above sea surface.
- a transmission reliability of 90% is required.

The flow chart presented in this section, Figure 4-2, will be used to guide the design of the communication system between a hypothetical "ONR" Buoy and an on-water aircraft. An initial assumption is made that no processing will be done in the buoy. Although this assumption leads to impractically large buoy transmitter power (buoy processing will be required), it is instructive to review the analysis procedure. Future work will analyze processing to enable practical buoy transmitter power.

Typical Design Procedure:

The following represents a typical design procedure utilizing the flow chart.

Step	Operation	Required	Result	Remarks
1	decision	Information is data digital or analog?	analog (no buoy processing)	For a first approximation it is decided to transmit analog data. See Discussion 4.3.1.
2	decision	Resolution To what degree must analog levels be resolved?	15 increments	The number of increments depends on the equipment which processes and presents the data. Here it has been assumed that the data display system is capable of displaying 15 increments.
3	procedure	(S/N) Output	30 db	A value of 30 db is obtained by the method of Procedure 4.1.2, Output (S/N) Ratio.
4	decision	Selection of Modulation system	frequency modulation (FM)	It is assumed that bandwidth is not restricted. Where bandwidth is not a limiting factor, frequency modulation is preferable to amplitude modulation.

Step	Operation	Required	Result	Remarks
5	process	Determine carrier (S/N)	16 db	Curve A - m - 2 is useful as a guide in the selection of a deviation ratio. A deviation ratio of 3 is selected. This value gives a reasonable (S/N) improvement while conserving bandwidth. Using curve A - m - 1 for a (S_o/N_o) = 30 db and m = 3, a (S_c/N_c) of 16 db is required.
6	input	Input $(S/N)_{id}$ requirement determined by preceding process	16 db	$(S/N)_{id}$ is equivalent to the carrier (S_c/N_c) ratio.
7	decision	Determine range (miles) of operation	200 nautical miles (n. mi.)	This is a system requirement - max. operational distance for on-water aircraft on surface.
8	decision	Determine altitude	approximate sea level operation. Buoy antenna; h_t = 5 ft. Receiving antenna; h_r = 30 ft.	This is a system condition. The on-water aircraft will operate between sea level and an altitude of several thousand feet. Sea level will be used in system calculation since this is the most severe propagation condition.
9	process	Select frequency and propagation mode Determine $\overline{PG}$ factor*	10 MHz ground-wave -4 dbw	The ground wave mode is selected since it has the lowest $\overline{PG}$ factor as determined using A-p-1 curve for 0-250 ft. altitude. The lowest point occurs at about 5 to 6 MHz. An operating frequency of 10 MHz is selected since it has only

* $\overline{PG}$ factor is a term used to represent the combined P_t, G_t, G_r and B terms of the transmission equation (in decibels)
$\overline{PG} = P_t + G_t + G_r - B$ (power-gain per unit bandwidth)

Step	Operation	Required	Result	Remarks
				a slightly higher $\overline{PG}$ factor and this frequency is less likely to be affected by HF interference. A $(S/N)_{id}$ of 16 db is required (step 5). Use procedures 4.1.15 for $(S/N)_{mar}$ and 4.1.9 for L_{ms}. Allow a $(S/N)_{mar}$ = 3 db and assuming no unusual component losses L_{ms} = 0. This is a total of $(S/N)_{id}$ + $(S/N)_{mar}$ + L_{ms} = 19 db. Set the arrow of the sliding scale to 19 db on curve A-p-1 (0-250 ft.). For an operating frequency of 10 MHz the $\overline{PG}$ factor = -4 dbw.
10	decision	Specify bandwidth	B = 43 db	It is assumed that data from the three data channels is sent simultaneously by frequency division multiplex. Each channel has a bandwidth of 3 kHz and 1 kHz must be allowed for guard bands. Determine the bandwidth (Section 3.3.3). f_b = 10 kHz; m = 3 $m = \frac{\Delta f}{f_b}$ Δf = 30 kHz $B_{IF} = 2\ (\Delta f + f_b)$ B_{IF} = 2 (30 kHz + 10 kHz) = 80 kHz Allow 80 kHz receiver IF bandwidth. Effective noise bandwidth B = 2 (10 kHz) = 20 kHz

Step	Operation	Required	Result	Remarks
				Convert to db $B = 10 \log 20 \times 10^3 = 43$ db
11	decision	Estimate antenna gains	$G_t = 3$ db $G_r = 3$ db	Using nomograph A-a-2 the wavelength of a 10 MHz signal is approximately 100 feet. A half wavelength antenna would be impractical so a monopole antenna with a height of 1/8 wavelength is selected from Chart A-a-1. This is approximately 12 feet and is a reasonable height considering the buoy dimensions. A monopole will be used for both transmitting and receiving.
12	process	Find P_t	$P_t = 33$ dbw $p_t = 2$ kilowatts	$\overline{PG} = P_t + G_t + G_r - B =$ -4 dbw $P_t = -4 - 3 - 3 + 43$ $P_t = 33$ dbw $p_t = \log\text{-}1 \frac{P_t}{10} = 2$ kilowatts
13	technological consideration	Is P_t within buoy constraints	No	This is a technological decision. One check may be made by considering the power supply requirement assuming continuous operation. Use curve A-s-1 and consider the transmitter to be 50% efficient. Selecting a H_2 - O_2 Fuel Cell System for 100 hrs. Operation, power supply capability of 5 watts/lb. should be practical. $\frac{2\text{ kw}}{(0.5 \times 5)} = 800$ lb. The power supply would weigh 80 percent as

Step	Operation	Required	Result	Remarks
				much as the total allowable buoy weight. In order to reduce the required power, the system parameters must be changed. The following blocks on the flow chart indicate procedures which can be followed but deviation from the flow chart should be made whenever knowledge of the particular buoy design indicates certain changes are preferable.

The first design approach is unsatisfactory primarily because of system weight. As indicated on the flow chart several parameter changes must be considered. A first consideration is to reduce the amount of data transmitted and use digital modulation for more efficiency. To reduce the equipment weight a power supply weight limit of about 200 pounds would be reasonable. This weight limit implies the transmitter should be about:

$$\text{wgt. x eff. x watts/lbs} = 200 \times 0.5 \times 5 = 500 \text{ watts}$$

This is about a 6 db decrease in transmitted power and must be compensated by an equivalent change in system parameters such as a reduction bandwidth and $(S/N)_{id}$, or increase in antenna gain.

A variety of system parameter changes are possible, but for illustration purposes the following system changes will be made:

- It is assumed that the data from the buoy channels is slowly varying and can be time division multiplexed.
- Digital modulation will be used.
- A spectrum resolution of 1000 frequency segments will provide sufficient information at the system data display and fifteen levels of amplitude must be transmitted.
- The data in each channel will be transmitted at a rate of five times a minute.

These changes will result in a data rate of: (See Section 4.3.6)

$$\text{Increments per second} = 1000 \text{ increments} \times 5/\text{min.} \times 3 \text{ channels} \times 1 \text{ min}/60 \text{ sec.}$$

$$= 250 \text{ increments/sec.}$$

Fifteen levels of amplitude can be represented by four binary pulses

$$2^4 = 16$$

Data rate = (no. of pulses) (pulse groups/sec.) $\log_2$ (levels/pulse)

$$C = 4 \times 250 \log_2 2 = 1000 \text{ bps}$$

Now the flow chart procedure is followed for a digital design.

Design Procedure for Digital Data:

Step	Operation	Required	Result	Remarks
				The design procedure will be repeated using the changes discussed in the preceding section
1	decision	Information Is data digital or analog?	digital	Processing and multiplexing are being used and digital modulation is better suited for transmission of the data calculated on the preceding page.
2	procedure	Data Rate	1×10^3 bits/second	Refer to the discussion on Information transmission (See section 4.3.6) for additional discussion.
3	decision	Error Rate	10^{-3}	This is a quasi-empirical decision. An error rate of 10^{-3} will result in one bit error per second which should be adequate. This is determined using curve A-e-1.

Step	Operation	Required	Result	Remarks
4	decision	Selection of Modulation System	coherent PSK	Coherent PSK is a commonly used system and is a good selection at least for initial system considerations.
5	process	Determine carrier (S/N)	7 db	This value is obtained from Curve A-m-3 for error rate of 10^{-3} and using coherent PSK modulation.
6	input	$(S/N)_{id}$ result of the previous process.	7 db	$(S/N) = (S/N)_{id}$
7	decision	Determine range (nautical miles) of operation	200 n. m	No change
8	decision	Determine altitude	approximately sea level operation buoy antenna at h_t = 5 ft. and receiving antenna at h_r = 30 ft.	No change
9	process	Select frequency and propagation mode determine $\overline{PG}$ factor	10 MHz groundwave -11 dbw	Same selection of frequency and propagation mode as in the previous step 9. $(S/N)_{mar}$ and L_{ms} are still 3db and 0 db respectively. This is a total of $(S/N)_{id}$ = $(S/N)_{mar} + L_{ms}$ = 7 + 3 + 0 = 10 db Set the arrow on the sliding scale on Curve A-p-1 to 10db. For an operating frequency of 10 MHz. $\overline{PG}$ factor = -11 dbw

Step	Operation	Required	Result	Remarks
10	decision	Specify bandwidth	30 db	For digital modulation a bandwidth equal to the data rate (step 2) is used. $B = 10 \log 1 \times 10^3 = 30$ db
11	decision	Estimate antenna gains	$G_t = 3$ db $G_r = 3$ db	No change
12	process	Find P_t	$P_t = 13$ dbw $P_t = 20$ watts	$P_t + G_t + G_r - B = -11$ $P_t = -11 - 3 - 3 + 30$ $= 13$ dbw $P_t = \log^{-1} \frac{P_t}{10} = 20$ watts
13	technological consideration	Is P_t within buoy constraints	yes	This power requirement is well within the limits.

The system modifications have reduced the required power by over 19 db. Since higher power transmitters are available, there is sufficient margin in the system characteristics to allow further changes on system economy and decreased complexity.

4.1.4 CODED VS UNCODED DIGITAL TRANSMISSION

Discussion:

The use of a coded* binary words will allow system operation at a lower signal-to-noise ratio than in the uncoded case. It allows a lower transmitter power to be used or extends range. Previously the added equipment required for any type of coding other than a simple parity check was prohibitive for many applications. Now that micro-electronic circuits have been developed, the equipment size and cost are greatly reduced and the use of coding may be reasonable in some applications. The curve A-m-3, referenced in the procedure, may be used to determine the approximate signal-to-noise reduction which is realizable by using coding. The signal-to-noise ratios for codes with varied numbers of bits

* Coding discussion, Section 4.3.4 introduces the basic coding concepts.

per word are shown in curve A-m-4 as a function of probability of error. The abscissa of the curve is plotted in terms of the ratio of, E/N_o energy per bit to noise power density. It is reasonable to assume that a matched input filter is used in which case E/N_o will equal the signal-to-noise ratio.

The coded curve shown on curve A-m-3 is representative of the range of improvement expected due to coding. The coding used for this particular curve is either an orthogonal or a biorthogonal code with twenty bits per word (N = 20).

Procedure:

1. To determine the change in signal-to-noise allowable for system operation when a coded modulation is used, see Curve A-m-3 or Curve A-m-4.
2. For the desired system error rate, determine the value of E/N_o for both the coded modulation and the uncoded modulation.
3. The difference in the E/N_o values between the coded modulation and the uncoded modulation will be the change in signal-to-noise ratio. This may be equated to an equivalent power change or to a change in range using Curve A-p-1 for ground wave signals or the corresponding curve for other propagation modes.

Example:

A buoy is operating marginally with PSK modulation at a 10^{-4} error rate. A modulator can be developed to provide a bi-orthogonal coded output with N = 20. This modulator will replace the present modulator and it must be determined if a 3 db improvement in operating margin can be realized.

Using curve A-m-3 at 10^{-4} error rate, E/N_o equals 8.3 db for coherent PSK and E/N_o equals 2.4 db for bi-orthogonal coding. The difference represents approximately 6 db in improving the required (S/N) ratio.

The relative change in E/N_o for other values of N is illustrated in curve A-m-4. To conclude this section on coding, the potential buoy designer is cautioned that any improvement in (S/N) ratio must be balanced against the equipment complexity and cost. It is highly probable that the situation requiring the use of any but the simplest codes will be rarely encountered.

4.1.5 DATA RATE TRADEOFF

Discussion:

Several situations can exist where a change in data rate must be considered. Typically, it may be recognized from the transmission equation that after entering all operating and equipment parameters there is insufficient power to meet the range requirement. The procedure describes the use of the curves to determine the effect of reducing the data rate to overcome this power deficiency. Alternately, it may be recognized that a greater radiated power may be obtained from a buoy transmitter; and it may be desirable to utilize this added power for an increase in the data rate.

Procedure:

1. Data rate is usually given in bps (bits per second). If the data quantity is expressed as number of samples, of pulse groups, use Curve A-d-1 to convert data samples per second and increments per sample or pulses per second into rate of information transmission in bps. (See Discussion 4.3.6).

2. Use Curve A-d-2 to determine the relative change in $\overline{PG}$ factor resulting from the change in data rates.

3. Using Curve A-p-1 for the appropriate altitude, the relative change in $\overline{PG}$ may be translated into an equivalent change in range; or the change in transmitted power may be calculated by the considering of the defining expression for $\overline{PG}$.

$\overline{PG} = P_t + G_r + G_t \quad B$ — Since bandwidth* is proportional to data rate, for a change in data rate:

$\Delta \overline{PG} = \Delta B$ (Δ = change)

$\overline{PG}$ is constant when $\Delta P_t = \Delta B$

* Discussion para. 4.3.3

Example:

Assume a buoy is operational at a 100 mile range. Data is transmitted digitally at 1000 sample per second rate, and each sample is coded as five binary pulses. The present channel capacity is:

$S = n^m = 2^5 = 32$ increments

where m = number of pulses

n = number of levels per pulse

Using curve A-d-1, the data rate, C, may be determined

C = 5000 bps

A decision is made to reduce the number of signal level increments transmitted to 8. This is equivalent to three binary pulses ($2^3 = 8$). The new capacity requirement is:

S = 8

Using curve A-d-1

C = 3000 bps

From curve A-d-2, it is determined that the change in $\overline{PG}$ for the two data rates is 2 db. Assume the operating frequency to be 1 MHz. Using curve A-p-1 (0-250 ft.) with any arbitary scale setting, move along the 1 MHz ordinate line from the intersecting 100 mile range curve. By interpolation it is determined that an equivalent 2 db power change will increase the range by approximately 20 miles. Alternately, the 2 db could be applied to reducing the transmitter power output.

4.1.6 DIVERSITY GAIN

Discussion:

Any communication link operating in a sky-wave or troposcatter propagation mode is subject to variations in propagation loss due to atmospheric turbulence. This variation in propagation loss is called fading. Ground wave propagation is essentially free of major fading effects. Over the ranges considered in this document (to 200 nautical miles), sky-wave propagation would be a disadvantage* because of interference; hence, all subsequent discussion will pertain only to troposcatter. The period of signal fading falls into two categories, rapid fading which has a Raleigh probability distribution and slow fading which has a normal probability distribution. The fading level due to rapid fading changes in a period of seconds to minutes while the slow fading changes occur in periods of minutes to hours.

It is usually the practice to initially design a troposcatter communication link for a 50% reliability.** For operation at greater than 50% reliability, the effects of fading must be compensated by providing an increase in the margin signal-to-noise terms, $(S/N)_{mar}$ of the transmission equation, which is equal to decibel loss variation due to fading. This will result in a corresponding increase in required transmitted power. The range of signal fading may be reduced and consequently power increased by the use of diversity techniques.*** Four types of diversity are used: frequency, space, time, and polarization diversity.

Because of the dimensional constraints of the buoy and on-water aircraft system, frequency and time diversity are most practical for buoy operation.

Three different curve sets which show the improvement realizable due to diversity are included:

- Slow fading margin for reliabilities of 50% to 99.9% as a function of distance. A-t-1.
- Rapid fading margin for reliabilities to 99.99% as a function of the diversity processing system used. A-t-2 to A-t-6.
- This curve specifies the required margin for combined slow and rapid fading for reliabilities of 90% to 99.9%. A-t-7.

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* Discussed in Section 4.3.10

** Reliability of 50% implies the communication link will receive data having the design signal-to-noise ratio or better only 50% of the time when transmitting at the design output power.

*** See Diversity discussion Section 4.3.5 for discussion of diversity techniques and reference (1).

A number of different data transmission requirements may exist where it will be necessary to use one of these curves.

Typically, a voice or discrete data communication link will require a high reliability, 99% to 99.99%, and in this case curve A-t-7 should be used to determine the margin and diversity required. When the data is slowly varying (repetitive momentary fading as characterized by rapid fading may be tolerated), the curve (A-t-1) showing the required margin for slow fading is used. Curves A-t-2 to A-t-6 give the required (S/N) margin against rapid fading conditions and also show the variation in performance of three techniques of three techniques of diversity combining.

The use of these curves will provide a measure of relative system performance improvement which can be realized by the use of diversity. If diversity is to be used in the design of a buoy communication link, consideration must be given to other margin factors. These factors are discussed in the $(S/N)_{mar}$ section, 4.1.15.

Procedure :

1. The required link reliability must be determined. This is an operational decision which depends on the data transmitted, utilization of the data, and its significance. Knowing the link reliability requirement and the type of fading for which compensation is desired, the appropriate curve; A-t-1 for slow fading, A-t-2 for rapid fading, and A-t-7 for combined fading conditions, must be used to determine the margin required.

2. A decision must be made on what type and order of diversity will be used. As indicated in the diversity discussion, either frequency or time diversity are most practical for buoy operation. Also second order (N = 2) diversity is probably the maximum that can be achieved due to equipment size limitations.

3. Diversity curves, A-t-2 to A-t-6, are used to determine the gain resulting from diversity. Any fading margin not compensated for by the selected diversity type gain must be compensated for by an increase in $(S/N)_{mar}$.

Example:

Assume a reliability of 99.9% is required for reception of data from a given buoy which transmits in the troposcatter propagation mode over a 200 miles (173 nautical miles) range. Using curve A-t-7, it is determined that a $(S/N)_{mar}$ of 33 db will be necessary to compensate for the fading variation from the median (0 db reference level) and insure a 99.9% reception probability.

As indicated in the diversity discussion, the buoy and on-water aircraft size will probably restrict the diversity used to frequency or time diversity. For this example second order time diversity will be used. Equal-gain diversity combining is to be used.

From curve A-t-2, it is determined that the diversity gain will be 15 db (28-13 db). This will reduce the required $(S/N)_{mar}$ for fading to 18 db which is equivalent to a 15 db reduction in added power required to achieve this reliability.

4.1.7 ERROR RATE TRADEOFF

The received signal-to-noise level ratio is a guiding criteria in establishing the expected quality of analog or digital communications. A measure of this quality is the probability of an error in interpreting the received signal. Two curves, A-m-3 and A-e-2, are included which relate the probability of error to the required signal-to-noise ratio.

Any change in the signal-to-noise ratio as a result of a change in required error rate may be interpreted as applicable to an equivalent change in the power required. This may be translated to a change in operating range as was illustrated in the data rate tradeoff section.

Curve A-m-3 applies to digital systems using coherent phase shift keying, differential phase shift keying and frequency shift keying. Curve A-e-2 applies to the demodulated signal (output signal) of an analog modulation type system.

Procedure:

1. The decision on how much error can be tolerated will depend on the operational requirements of the system. Curve A-e-1 may be used as a guide to

determine a new acceptable frequency of error. For a given data rate in bits per second (See discussion 4.3.6), a new probability of error may be determined from the curve. This curve may also be used for analog systems by considering the highest modulating frequency as equal to the bit rate.

2. Having determined an acceptable error rate, the appropriate curve is used to determine the required signal to noise ratio:

Curve A-m-3 Digital modulation

Curve A-e-2 Analog modulation

3. The signal to noise ratio change (as a result of selecting a different error rate) is directly equivalent to the allowable power change.

4. This power change may be used to determine the corresponding change in the operating range. Use Curve A-p-1 (select the minimum operating altitude curve) to determine the new range.

Example:

Assume a binary system which operates ground-wave at 1 MHz with a data rate 1000 bps and a error probability of 10^{-5}. From Curve A-e-1 it is determined that this error probability corresponds to about one error every 100 seconds. Assume the system uses an integrating type processor and that an error rate as high as one error per second would not affect the presentation. By means of the curve, it is determined that an error probability of 10^{-3} will meet this requirement.

If frequency shift keying, is used for modulation, it can be determined from Curve A-m-3 that a 3 db change in signal to noise ratio is allowable due to change in error rate. This change may be utilized so that either the transmitter output may be reduced 3 db or the range may be extended. Using Curve A-p-1 and a range of 100 miles, a 3 db change in range along the 1 MHz ordinate line is approximately 30 miles.

4.1.8 EXTENDED RANGE (Figure 4-3)

The range extension of a buoy communication system requires a compensating change in one of the parameters of the transmission equation. Two previous procedures, Data Rate Tradeoff and Error Rate Tradeoff, demonstrated how changes in these parameters affect range. Other parameters or combinations of parameters may be used to accomplish an increase in range. For a given increase in range the decibel change required may be determined by means of Curve A-p-1 or another curve of the A-p series which is closest to the operating altitude of the on-water aircraft. This operation is illustrated by the following flow chart. The converse operation may be applied when it is necessary to determine what decrease range will result from a parameter change.

4.1.8.1 Related Discussion

- Increase Power (D-1)

The capability to increase the buoy transmitted power will depend on the buoy design and technological advances since the design of the buoy. This is a hardware decision and requires a knowledge of the buoy design, component ratings, and power supply capability. See procedure 4.1.11, Power and Range Considerations.

- Increase Antenna Gain (D-2)

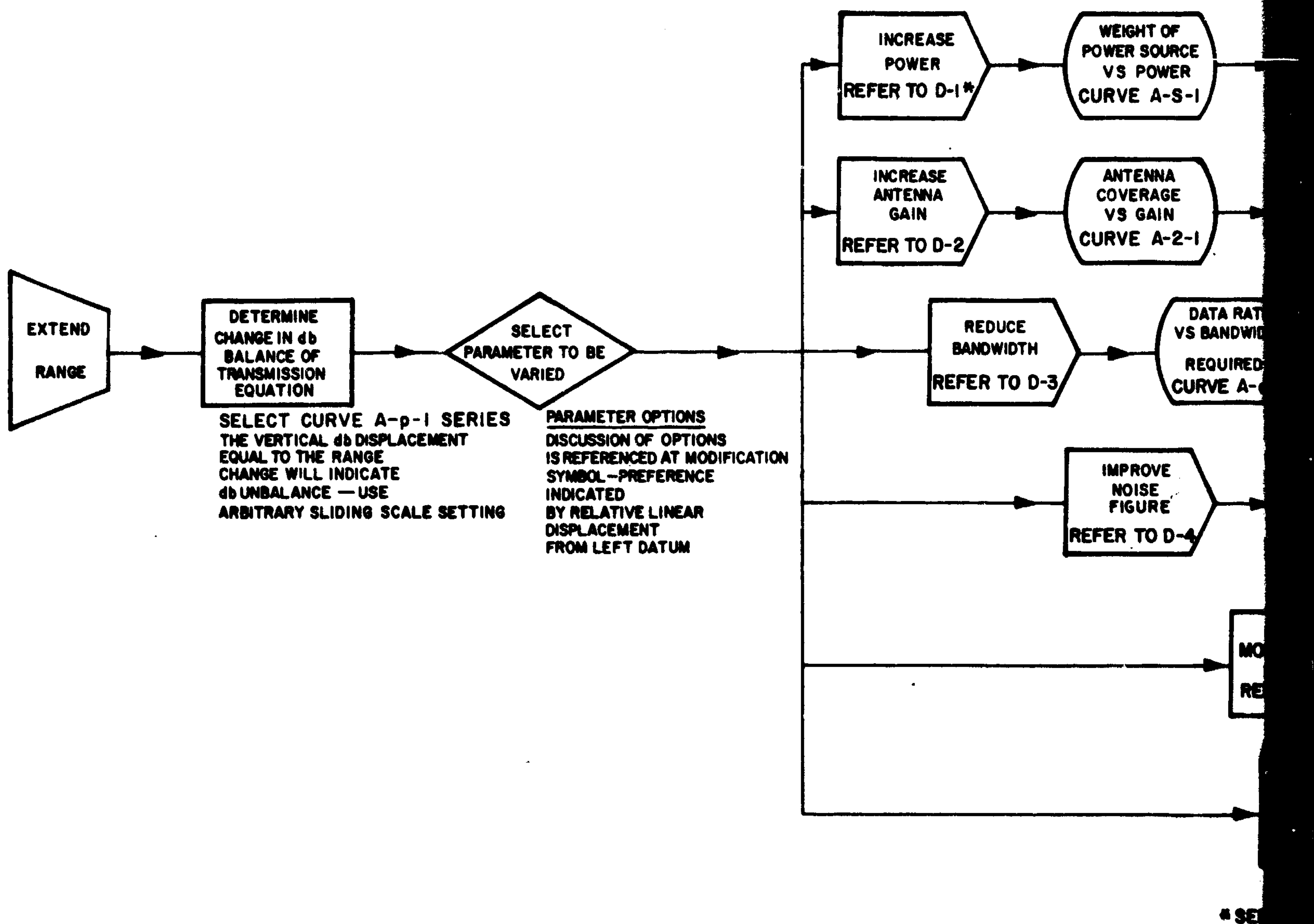
Change in antenna gain is a technological and operational decision. A different antenna design with more gain may be used if consistent with the buoy design, or the antenna coverage requirement may be reduced by allowing for a design variation with a higher antenna gain. See procedure 4.1.1 Antenna Selection.

- Reduce Bandwidth (D-3)

Transmission at a lower data rate will allow a reduction in bandwidth. This is an equipment and operational decision. The complexity of the change depends on the buoy design and the effect of a reduced data rate on system operationl performance. See procedure 4.1.5 Data Rate Tradeoff.

- Improve Noise Figure (D-4)

Improvements in transistor noise figures or the use of parametric amplifiers will often allow an improvement to be made in the system noise figure through substitution of an improved amplifier stage. This decision depends



EXTEND RANGE
DETERMINE CHANGE IN db BALANCE OF TRANSMISSION EQUATION
SELECT CURVE A-p-I SERIES
THE VERTICAL db DISPLACEMENT EQUAL TO THE RANGE CHANGE WILL INDICATE db UNBALANCE — USE ARBITRARY SLIDING SCALE SETTING
SELECT PARAMETER TO BE VARIED
PARAMETER OPTIONS
DISCUSSION OF OPTIONS IS REFERENCED AT MODIFICATION SYMBOL—PREFERENCE INDICATED BY RELATIVE LINEAR DISPLACEMENT FROM LEFT DATUM
INCREASE POWER
REFER TO D-1*
WEIGHT OF POWER SOURCE VS POWER
CURVE A-S-1
INCREASE ANTENNA GAIN
REFER TO D-2
ANTENNA COVERAGE VS GAIN
CURVE A-2-1
REDUCE BANDWIDTH
REFER TO D-3
IMPROVE NOISE FIGURE

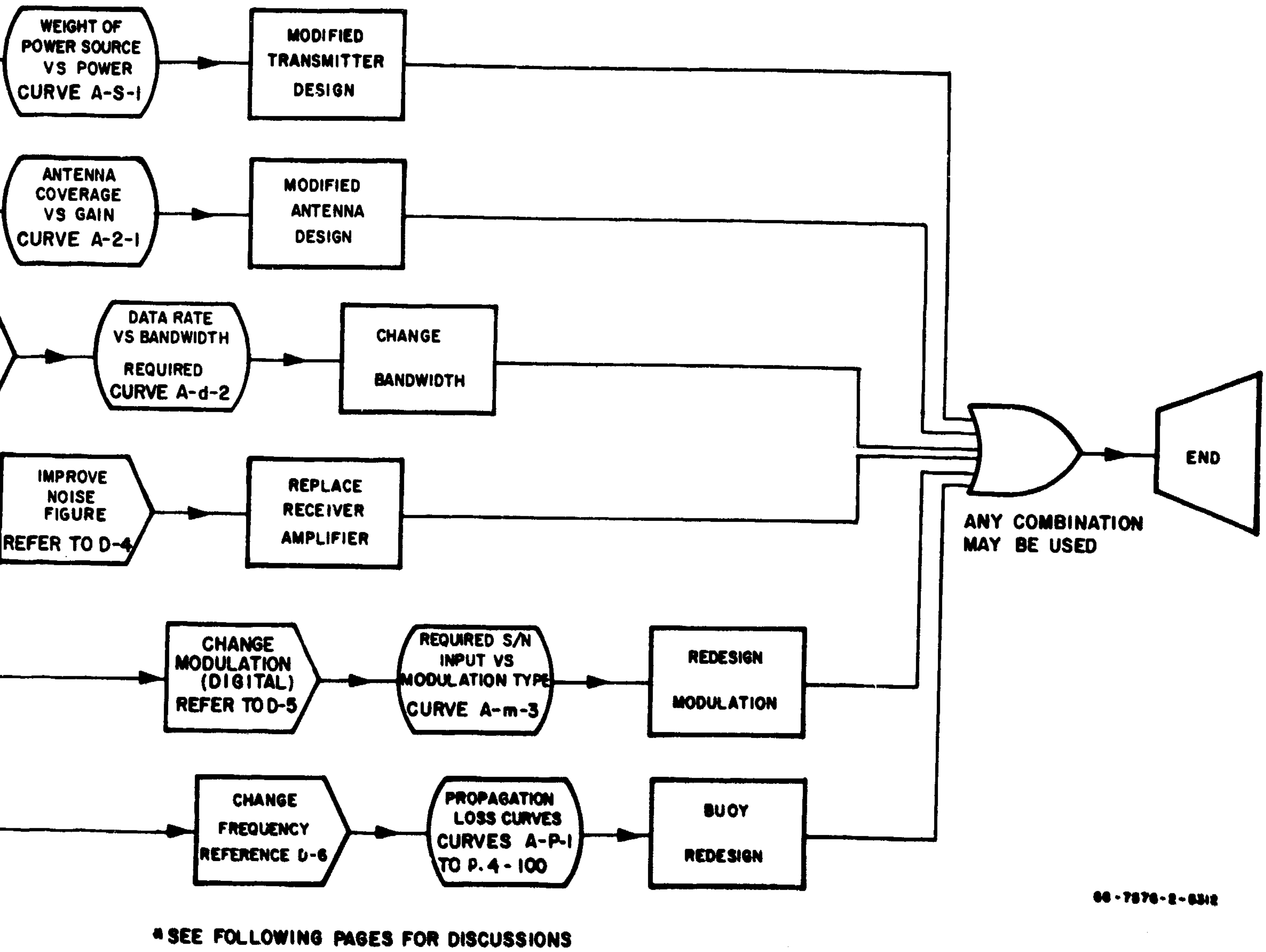


Figure 4-3. Extend Range

2

on the buoy design. See Discussion 4.3.9, Receiver Noise Figure.

- Change Modulation (D-5)

This modification may involve considerable equipment change. Relative reduction in required S/N ratio for various digital modulation types is indicated in Curve (A-m-3). The reduced (S/N) ratio requirement (as a result of selecting a different modulation type) can be traded against the transmission equation unbalance due to the extension in range. See procedure 4.1.10 Modulation Selection.

- Change Frequency (D-6)

This is a drastic modification and represents a major buoy redesign. A change in frequency may result in lower transmission losses either through selection of a more optimum operating frequency or by selection of a frequency which will allow operation in a more favorable propagation mode. See procedure 4.1.13, Propagation Loss-Function of Frequency and Range.

4.1.9 L_{ms} TERM

In the development of the composite noise level curve B-p-1.2, a line loss of 2 db and a 1.5 db component and antenna inefficiency loss have been included. The receiver noise figure has been assumed equal to the transistor diode mixer noise figures shown on the curve. These assumptions are representative of the total losses of this type which might normally be encountered; hence the L_{ms} term may be neglected in many calculations.

The L_{ms} term makes provision for the inclusion of added system losses in the transmission equation. These system losses refer to parameter variations which are different from those nominal values of component loss, antenna efficiency, receiver noise figure, and line loss used to develop the operating noise factor curve B-p-1.2.

$$L_{ms} = \Delta L_1 + \Delta L_c + \Delta N$$

ΔL_1 = line losses both transmitter and receiver in excess of 2 db previously allowed.

ΔL_c = component losses (components prior to amplifier gain stages) and antenna efficiency losses greater than the 1.5 db prevously allowed.

ΔN = variation of receiver noise figure in the range above 50 MHz from the composite noise figure curve of curve B-p-1.3. (this term may be negative).

Example:

Hypothetical buoy - on-water aircraft system operating at 400 MHz

A long transmission line is used between the receiving antenna and the receiver resulting in an overall system line loss of 5 db.

$$\Delta L_1 = 5-2 = 3$$

A power splitter is used prior to the receiver resulting in an added 3 db loss.

$$\Delta L_c = 3 \text{ db}$$

An improved parametric amplifier is used which has a noise figure of 2 db. Using curve B-p-1.2, it is determined that the prevous noise figure was approximately 6 db.

$$\Delta N = 2-6 = -4 \text{ db}$$

The L_{ms} term is equal to:

$$3 + 3 - 4 = 2 \text{ db}$$

$$L_{ms} = 2 \text{ db}$$

4.1.10 MODULATION SELECTION

Modulation* is a secondary parameter related to the transmission equation through the $(S/N)_{id}$ term. This relationship is illustrated in Figure 4-1. For digital data any change in modulation type must result in a corresponding change in error rate or the required effective $(S/N)_{id}$.

The modulation type and required error rate determine the system $(S/N)_{id}$. For digital modulation, a binary word containing a group of information bits may be transmitted as frequency shift or phase shift per information bit. These modulation types are classified as FSK (frequency shift keying), coherent PSK (phase shift keying), and differential PSK (Curve A-m-3 indicates the relative (S/N) required as a function of error probability). Additional signal-to-noise reduction may be obtained by using coding.**

The difference in required (S/N) ratio for various modulation types is illustrated in curve A-m-3[1]. For a fixed bit error probability modulation such as coherent PSK allows operation at a S/N ratio several db lower than FSK modulation. Usually this advantage must be a trade-off against the increased equipment complexity required for coherent PSK. The curve abscissa is given in terms of (E/No), energy per bit to noise power density. Assuming that matched filters will be used, then

$$(E/N_o) = (S/N)$$

where (S/N) is the S/N_{id} of the transmission equation.

For comparison the error probability of an orthogonal coded word is shown on curve A-m-3. A relative comparison of coded words of different length is shown in curve A-m-4[2]. In general, the higher the order of coding used, the greater the complexity required in the coding and demodulating circuits. The relative degree of complexity is a changing technological factor which must be determined individually for each operating situation.

*See reference discussion on modulation 4.3.7.
**See reference discussion on coding 4.3.4.

The PSK mode of modulation is not limited to one or two phases per pulse, but may contain multiple phases. The (S/N) ratio required for multiple phase is shown in curve A-m-5[3]. Since more information is transmitted per pulse, the pulse rate and consequently the bandwidth may be reduced. Curve A-m-6[3] shows the relative (S/N) ratio required for multiple phase modulation, taking the bandwidth reduction into account. Both biphase and quadriphase modulations are essentially equivalent.

Analog information is generally transmitted by either frequency modulation (FM) or single-side band suppressed carrier modulation (SSB). Voice transmission will be by means of SSB whenever the spectrum is crowded and bandwidth must be conserved. The effect of interference and fading will occasionally be severe in this modulation mode, but there is considerable tolerance in understanding voice transmission. In the case of analog data where noise interference can not be tolerated and no level distortion is allowable, FM is the preferred mode of modulation. In addition, FM provides an improvement factor which allows operation at considerably lower input (S/N) ratios than SSB for equivalent output (S/N) ratio requirements. Curve A-m-1[4] illustrates the (S/N) improvement is a function of the deviation ratio*(or modulation index) m.

Procedure:

1. The preceeding discussion has presented curves which can be used to determine the relative differences in the $(S/N)_{id}$ term of the transmission equation when modulation type or error rate requirements are modified. Also these curves may be used in the case of a new design where an initial value of $(S/N)_{id}$ must be determined.

2. As previously indicated an exact choice of modulation type will depend on a detailed analysis of system requirements and is likely to be an iterative process to optimize the modulation characteristics. For initial system design or preliminary evaluation, a reasonable first choice for analog data will be

*Deviation ratio is the ratio of the maximum frequency swing from the mean carrier frequency to the bandwidth of the modulating frequency.

FM with a modulation index of 3 to 5; and for digital data, pulse code modulation (PCM) using coherent PSK.

Example:

Assume a requirement exists to transmit digital data at a 10^{-4} error rate and the $(S/N)_{id}$ required must be determined. Initially, coherent PSK is selected as the modulation type and curve A-m-3 is used to determine the $(S/N)_{id}$ required. For a system using a matched filter [5], (E/N_o) will be equal to $(S/N)_{id}$. A value of $(S/N)_{id}$ equal to 8.5 db is read from the curve. This value is used in the transmission equation along with other parameter values to establish the system characteristics. If system analysis indicates that a lower operating $(S/N)_{id}$ is necessary or less complex modulation circuits must be used, the process is repeated for a new modulation type. Similarly for transmission of analog data, a probability of error must be selected and the corresponding output (S/N) determined. Assume a probability of error equal to 5×10^{-2} is acceptable. Using this value as the probability of error and n = 15, it is determined from Curve A-e-2 that the required output (S/N) (avg. signal power to avg. noise power used for analog levels) is 30.2 db.

For this value of output signal-to-noise ratio and using a deviation ratio of m= 3, it is determined from Curve A-m-1 that the carrier (S/N) required is 16 db. This represents an FM improvement of approximately 14 db. The allowable value of deviation ratio used in the final modulator will depend on the system bandwidth limitations.

4.1.11 POWER AND RANGE CONSIDERATIONS

In the evaluation of a buoy design and operational capability it is desirable to consider the power-range tradeoff. This consideration may allow the user to extend the range by recognizing that new transmitter development will allow greater lower output. In some cases the converse operation may be necessary and it may be desirable to decrease the output power to improve reliability of the transmitter or to prevent mutual interference between buoys.

In any situation of this type, curve A-p-1 will be used to determine power change or the corresponding range modification.

Procedure:

1. The sliding scale for the curve A-p-1 is set at any arbitrary position since only relative change is of interest.

2. To determine the tradeoff of power to range or range to power, select the ordinate line corresponding to the operating frequency.

3. The linear translation along this line due to either power or range change will establish the change in the other variable. This linear translation starts at the intersection of the selected ordinate and the original range point. Interpolate for range points between the range curves.

Example:

Assume a buoy system which operates at 5 MHz and a 75 mile range. A new transistor development will allow replacement of the existing output transistors so that the transmitter power can be increased by 6 db. The power supply has the capacity to handle the power increase. Using curve A-p-1 (0-250 ft.), interpolate to determine the 75 mile point along the 5 MHz ordinate line. A 6 db movement along the line in the direction of increasing range, as a result of this power increase, is interpolated as a 25 nautical mile range change. The new operating range will be 100 nautical miles.

4.1.12 POWER SUPPLY CONSIDERATIONS

Discussion:

For a buoy power supply application, the characteristics of primary interest are capacity, weight, size and environmental tolerance. Power source design is a changing technology and cannot be represented by absolute design criteria. The curves and charts presented with this section are intended to serve only as a guide in the selection of a buoy power source. Power sources such as motor generators, solar cells, and nuclear reactors are not included since their size and power capabilities are not considered consistent with our concept buoys, deployable from an on-water aircraft. Three types of power sources are considered.

- Batteries
- Fuel cells
- Thermoelectric generators

Batteries:

Batteries [1] [2] [3] are divided into two general classifications, primary and secondary cells (See Chart A-s-4). Primary cells must be discarded when the output falls below a usable level, but secondary cells may be recharged.

Primary cells are further subdivided in dry, wet, and reserve cell types. The most common dry cell is the Leclanche' zinc-manganese dioxide type, used in flashlights. A new type of cell made from carbon-magnesium is being developed which has a high watt-hour/pound rating. The primary wet cells of the zinc-cuprice-oxide type do not have as great a capacity as the reserve cells ("sea water battery" type) and are not considered particularly applicable. The reserve cells are assembled in an inactive state and activated prior to use. These cells have a number of advantages over other primary cells. These advantages include a higher energy output per unit of weight and volume, long shelf life, and high overall reliability. The most common reserve type is the water-activated silver chloride cell, and because of the heat generated during discharge these cells may be operated at temperatures to -54°C.

In general, the secondary cells provide high capacity per unit volume and are capable of being recharged. The nickel-cadmium battery is the more commonly used secondary cell.

Although size and weight are important factors when considering the use of primary or secondary cells for a power source, the unit cost and storage requirements must also be considered and may be the determining factors.

Fuel Cells:

The fuel cell [4] [5] is an electrochemical device for converting chemical energy into electrical energy. The fuel cell does not contain its own fuel supply, but receives fuel from an outside source when required. Its use becomes reasonable for operating periods in excess of one day where minimum weight and volume are important.

Thermoelectric Generators:

Thermoelectric generators utilize semiconductor p-n junctions similar to a solar cell to convert heat into electric energy. The source of heat may be either a fossil fuel such as propane gas or a radioisotope. The performance characteristics of thermoelectric generators in a rapidly changing technological area, and only a few performance curves have been plotted for Curve A-s-1. Curves are shown for several SNAP supplies and for a thulium supply. For periods of operation greater than three or four days, the use of such supplies seems reasonable. One drawback may be the lack of facilities for irradiating the radio isotope.

For intermittent high power requirements, consideration should be given to composite supplies such as batteries recharged by an isotope supply.

Procedure:

1. Determine the requirements for the power supply capacity, duty cyle, life, and envoronment. The required power supply capacity will depend on the equipment current and voltage requirements including the transmitter output power as factored by efficiency. The operating requirements will establish the duty cycle and life.

2. Use Curve A-s-1 to select the power supply type. When the life requirements can be met by several supply types, consideration must be given to current manufacturers data on weight, size, availability, and cost.

3. When a battery is selected as the supply, supplemental curves A-s-2 and A-s-3 and Chart A-s-4 should be consulted for additional data on battery characteristics. Chart A-s-6 provides an indication of the present state of fuel cell development, and Chart A-s-7 is indicative of isotope fueled systems.

4. Curve A-s-5 [6] is indicative of the effects of temperature on battery performance. When the battery is expected to operate at temperatures lower than 25°C, allowance should be made for battery degradation.

Example:

Select a power supply for a deployable buoy which must operate for 96 hour periods. The on-board processors and sensors require a continuous 20 watts and the buoy has a 250 watt transmitter which is 50% efficient and operates three minutes in each hour.

Using curve A-s-1, several choices may be made:

A high capacity battery such as a silver-zinc battery may be used for the average load.

A fuel cell such as $H_2 - O_2$ fuel cell may be selected for the average load.

A composite choice can be made; a battery is used for intermittent duty during the transmitting period, and an isotope supply is used for continuous power requirements and recharging the battery.

Estimates of Weight and Volume:

Processors and Sensors: 20 watts x 96 hours = 1920 watt-hours

Intermittent Transmitter Power: $\frac{250 \text{ watts}}{.50} \times \frac{1}{20} \times 96 \text{ hrs.} = \underline{2400}$ watt-hours

4320 watt-hours

average power $\frac{4320}{96} = 45$ watts

Battery Supply

Silver-zinc battery: 59 watt-hours/lb., 4.4 watt-hours/cu. in. (from chart A-s-4)

Required:

$\frac{4320}{59} = \underline{73 \text{ pounds}}$

$\frac{4320}{4.4} = \underline{985 \text{ cu. inch.}}$

or using curve A-s-1, a silver-zinc battery is rated at 0.7 watt/lb. for 96 hours operation

$$\frac{45}{0.7} = 64.3 \text{ pounds}$$

Fuel Cell Supply

$H_2 - O_2$ Fuel Cell

5 watts/lb. Curve A-s-1

.04 watt/cu.in. Chart A-s-6

Estimate based on backpack

Required: $\frac{45}{5} = 9$ lbs. + fuel

$\frac{\text{96 hour}}{\text{14 hr. Operation}}$ x 6 lb. canister = 41.4 lbs/200 w

approximately 10-12 pounds of fuel should be sufficient for 45 watts, a unit weighing 21 pounds will meet the continuous power requirement, but the ability to meet the peak power requirement must be investigated.

Volume: $\frac{45}{.04}$ = 1125 cu. in.

Composite Supply

An isotope supply provides constant watt/lb. rating, but it is mostly effective over longer periods than the 96 hour buoy requirement. Some advantage might be achieved by combining a fuel cell and battery particularly if the fuel cell cannot handle the peak power requirement.

Based on the very tentative data available it may be expected that the fuel cell would weigh about 12 pounds and a silver-zinc battery $\left(\frac{2400}{59}\right)$ about 40 pounds.

No definite conclusions can validly be drawn from these examples. The exercise illustrates how the curves supplied can be used to get an approximation of the power supply weight and volume. Any final design will require consultation with device manufacturers and consideration of cost, operational and logistic requirements.

4.1.13 PROPAGATION LOSS COMPENSATION

Discussion:

In the analysis of a communication link the magnitude of the propagation loss will be a limiting factor. Since the propagation loss is a function of both frequency and range, the allowable loss will determine the range and frequencies which may be used.

From the transmission equation or figure 4.1, it is obvious that any of the other parameters may be changed to compensate for an added propagation loss. Such an increase may be desirable since it will allow a different operating frequency to be used for an increase in range.

When such an operational improvement is required, each of the other system parameters must be examined to determine if new development or techniques will provide a compensating gain. Any proposed parameter change must consider changes in equipment size, power required, reliability, and cost.

One example of parameter change may be the case where an improved modulation technique will allow a 3 db reduction in required (S/N) ratio. It then becomes desirable to determine whether this 3 db (S/N) reduction (traded off against a new operating frequency or an extension in range) will provide a sufficient operational improvement to warrant this change.

Procedure:

1. Determine the decibel change due to new parameter values.

2. This change is directly translatable as a change in allowable propagation loss which may be equated to operation at a new frequency or different range.

3. Depending on the propagation mode and altitude of the receiver, select the appropriate curve:

Groundwave	Curve A-p-1 Series
Forward scatter (Troposcatter)	Curve A-p-1 Series
Skywave - This mode is not considered practical for the prescribed operational conditions (see discussion on Skywave propagation section 4.3.11)	

4. Using the selected curve and starting at the present range curve,* move vertically along the line corresponding to the operating frequency. This vertical displacement, equivalent to the decibel increase or decrease due to the parameter change, will determine the new range.

5. Similarly, lateral movement along a range curve to a point where the change in propagation loss is equivalent to decibel change from parameter variation will determine the new operating frequency.

Example:

Analysis of a hypothetical proposed buoy design indicates that the selected operating frequency of 7 MHz will cause interference with a communication facility. The buoy uses an FSK type modulation. It is desired to change the system parameters so that a different operating frequency may be used. When considering changes in parameters, Figure 4.1 will indicate the various ways in which the transmission equation terms may be interchanged.

For this case it was recognized by use of Curve A-m-3 that a 3 db gain in signal-to-noise ratio could be achieved by changing from FSK to PSK modulation**. Similar parameter changes can be accomplished by considering error rate and data rate modifications. Using Curve A-p-1 (0-250 ft.) and assuming the buoy operates at a maximum 100 mile range, the allowable frequencies can be determined. The 3 db added propagation loss allowable, a result of the change in modulation, will allow use of a frequency as low as 3.5 MHz and as high as 18 MHz. This is determined by laterally moving along the 100 mile range curve in both directions to points which correspond to a 3 db increase over the original propagation loss.

4.1.14 PROPAGATION MODE AND FREQUENCY SELECTION

One of the first decisions in the design of a buoy communication link is the selection of the propagation mode and operating frequency. In some situations the operating frequency will be assigned due to other system considerations. The propagation mode will be determined by the range requirement and the operating

*It may be necessary to interpolate the range curve position

**See modulation discussion 4.3.7.

altitude of the receiver. Factors which influence these decisions are the propagation loss and operating noise level. The effects of these factors have been taken into account in the development of the A-p-1 series of curves. These curves have been prepared for ground-wave and troposcatter modes of propagation and show the magnitude of the power-gain factor,* $\overline{PG}$, as a function of altitude. The curve for the minimum operating altitude is used. The minimum $\overline{PG}$ value is sometimes the preferred operating point, but consideration must be given to possible interference, other users of the frequency, etc.

The flow chart on the following page will serve as a guide to the procedure of selecting a propagation mode and frequency.

4.1.15 SIGNAL-TO-NOISE MARGIN

Discussion:

The signal-to-noise margin term, $(S/N)_{mar}$ is primary parameter of the transmission equation and supplements the ideal signal-to-noise ratio term. This term is used to account for propagation fading conditions and to provide margin requirements for communication link reliability ** of greater than the median (50%).

Ordinarily a communication link is designed to operate between fixed geographic points. Data is available on the median atmospheric noise level during each season and period of the day. Using this data and the other system parameters, it is possible to determine the transmitted power level which will assure a selected (S/N) ratio 50% of the time. If more reliable communication is desired, a power margin related to the reliability required must be provided. For modes

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* $\overline{PG}$ has been defined as the sum of the $P_t + G_t + G_r - B$ terms of the transmission equation.

** A 50% reliability implies that the received (S/N) ratio will be equal to or better than the design value 50% of the time.

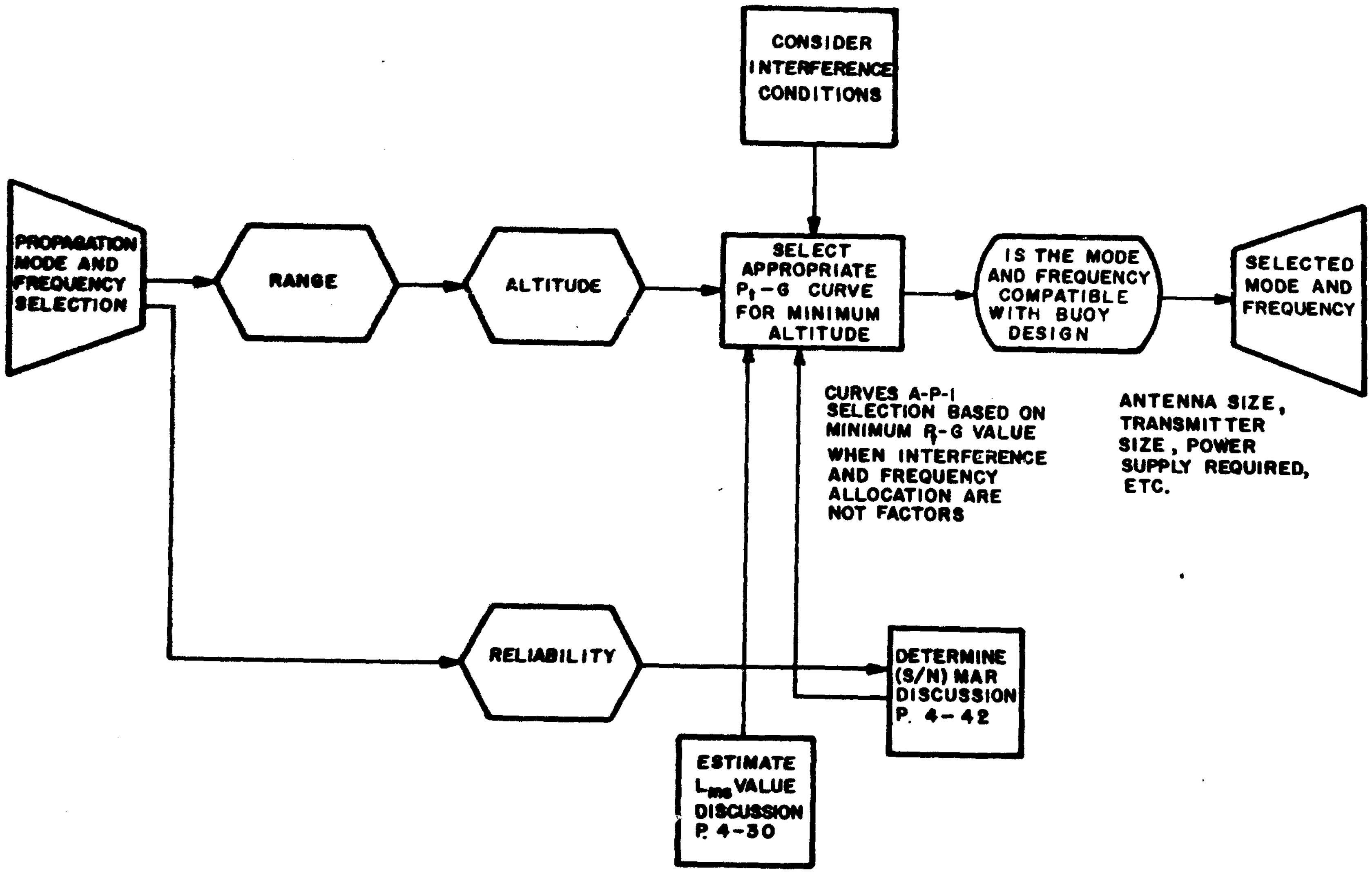


Figure 4-4. Propagation Mode and Frequency Selection

of propagation other than groundwave, such a troposcatter and skywave, an additional margin factor must be included to account for fading. Two types of fading exist. These are rapid fading which varies in level over periods of minutes and slow fading which varies in level over periods of hours.

Since the buoy's geographic location, time of operation, and data reliability are not restricted, it must be assumed that the buoy will operate under the most severe conditions at times. However, the probability that a buoy will operate simultaneously under the worst atmospheric noise conditions, maximum operating ranges and the worst conditions of fading (in the troposcatter mode) is very low. To provide a margin sufficient to cover the worst conditions would impose an unwarranted penalty on the system. Similarly, to provide curves and procedures for calculation of noise and fading conditions for every geographic location and seasonal condition would not be operationally practical. Even if the calculations were made, there is little that could be done to the buoy to compensate for deficiencies, and the only alternate would be to shorten the operating range relative to the buoys. It is the intent of this report to serve as guide to the utilization of a general class of buoys. Therefore, several decisions have been made to simplify the calculations and yet provide valid criteria for practically all operating situations.

The operating noise factor curve, B-p-1.2, is a composite curve which includes atmospheric noise at frequencies below approximately 30 MHz, then galactic and receiver noise at the higher frequencies where they become dominant. The atmospheric noise level used in the highest median atmospheric noise* level for all seasons and geographic locations over the sea. Since operations at this level seldom occur, it is assumed that use of the curve at these levels will assure communication reliability of 90% relative to atmospheric noise interference most of the time even though median noise values are used. Consequently no additional margin is used to compensate for greater than median noise effects when reliability

* The atmospheric noise level with vary about the median level; for greater than 50% communications reliability an additional power margin must be included. This is similar to the troposcatter fading margin.

of 90% or less is required. For higher reliabilities the margin is determined from curve A-p-2. Above 30 MHz, galactic and receiver noise are the major factors. These noise sources are relatively stable and reliability is not a problem.

For the troposcatter mode of transmission the propagation curves have been calculated for operation at a relatively low refractive index of 320. Operation at higher refractive indices will result in a lower transmission loss.

Fading conditions must be taken into consideration since signal strength may vary over a 30 db or larger range due to these fading effects.

A decision must be made on the degree of reliability required in the transmission of data. In general, voice or discrete data will require a high reliability of 99% or better; while data which is repetitive and slowly varying will not usually be disrupted by rapid fading, and a lower reliability is acceptable. In establishing a criteria for a fading margin for both these signal types, it should be remembered that the transmitter and receiver are mobile and that no geographic or environmental limitations have been placed on their sphere of operation. Consequently, the most severe conditions of fading and environmental noise level could exist, but the probability will be low. As in the case of the operating noise factor, provision for the worst case fading margin would place an unreasonable penalty on the system. Some comprise values must be established for the operating conditions which will exist most of the time. The following criteria are recommended:

Voice or Discrete Data

reliability	-	Voice 99% discrete data 99.9%
$(S/N)_{mar}$	-	Use curve A-t-7, N = 1, to determine the margin at the maximum operating range.

Slowly Varying Data

reliability	-	90%
$(S/N)_{mar}$	-	Use curve A-t-1, this curve is for slow fading conditions with the worst time and

season effects [2] occuring simultaneously. This will provide some measure of protection against rapid fading.

Another factor which will affect the transmission loss is due to the movement of the buoy into wave troughs in high sea states. Under sea state 6 conditions the wave heights can be as great as 15 to 20 feet which is sufficient to obscure the antenna of most buoy types. The crest-to-trough change is siting of the transmitting antenna often results in a propagation mode change from line-of-sight communications to a diffraction mode. There is only a limited amount of information available on the loss resulting from this condition. One report [3] considering sonobuoys with small 1 foot antennas estimates a 10 db loss in 5 foot waves, a 12 db loss in 10 foot waves and a 15 db loss in 20 foot waves. However, tests at Sanders Associates with slightly larger antennas under a variety of sea conditions have not indicated that transmission losses are this large.

In lieu of more definite information, a 3 db factor will be included in the $(S/N)_{mar}$ term to cover the effects of sea state conditions.

Procedure:

For ground wave propagation:

1) Fading margin not applicable

2) No margin used for noise above median values when reliability required is 90% or less. For greater reliability, use curve A-p-2. At frequencies higher than 30 MHz, the noise is relatively constant and no margin is necessary for high reliability.

3) Use 3 db margin to cover sea state conditions.
$(S/N)_{mar}$ = 0 (no fading) + 0 (90% reliability or less) + 3 = 3 db

For Troposcatter Propagation:

4) Determine reliability required for type of data transmitted use the recommended criteria of the previous section.

5) Fading margin - for repetitive, slowly varying data use curve A-t-1. For data which will be affected by rapid fading conditions (fade periods of seconds to minutes) use curve A-t-7 which combines both rapid and slow fading.

6) No margin needed for noise variation

7) Use a 3 db margin to cover sea state effects

   $(S/N)_{mar}$ = fading margin + 3 (sea state)

Consideration should be given to the reduction of the $(S/N)_{mar}$ by use of diversity.

Example:

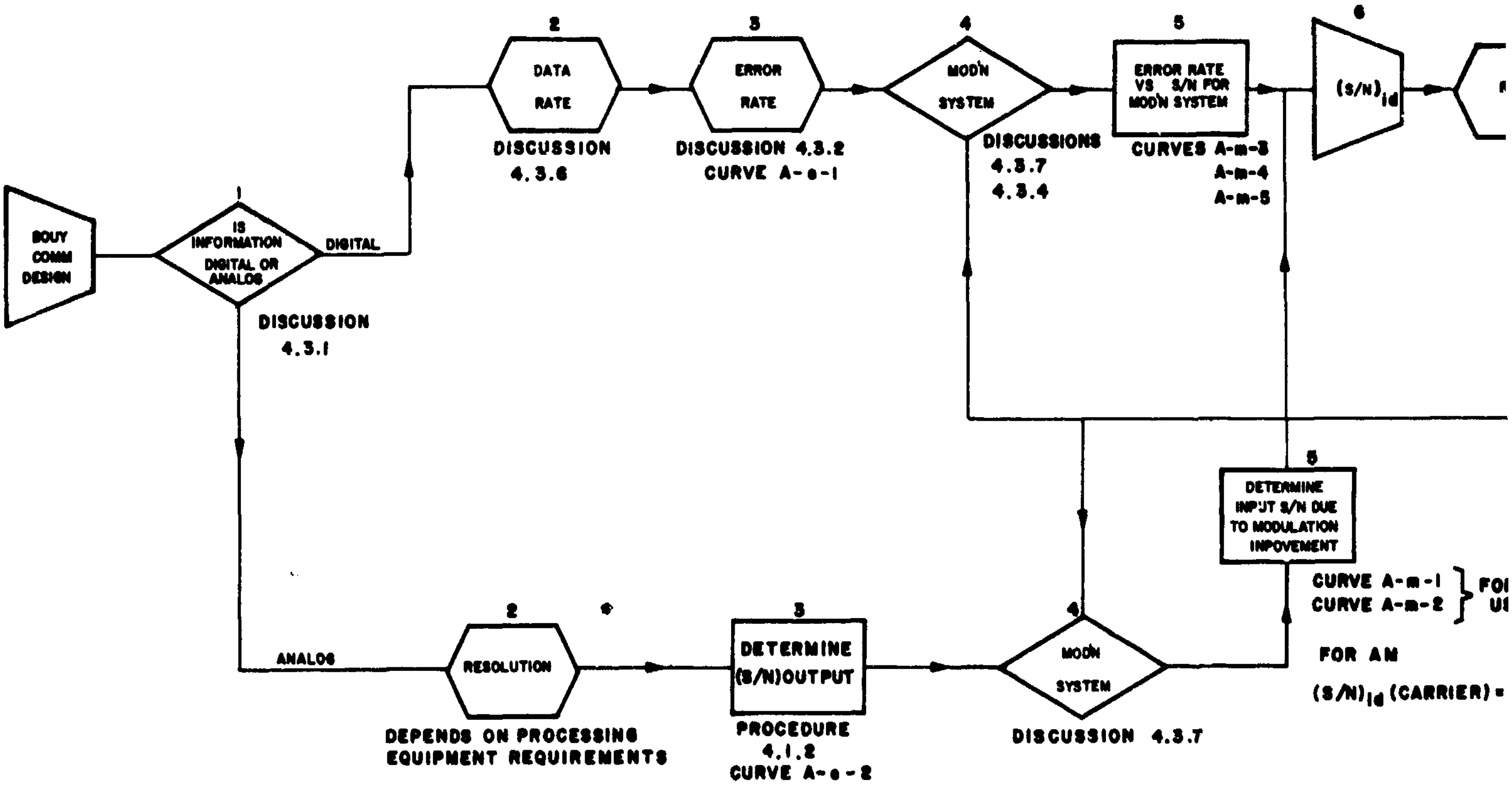
A buoy is operating in the troposcatter propagation mode at a 150 nautical mile maximum range and with a 90% reliability required. Data is repetive and slowly varying so rapid fading will not be considered.

For data of this type 90% reliability will be adequate.

Using curve A-t-1, a slow fading margin of 4.5 db is indicated. Rapid fading effects are not considered for data of this type.

Use 3 db margin for sea conditions

Sum of $(S/N)_{mar}$ components: $(S/N)_{mar} = 4.5 + 3 = 7.5$ db



BOUY COMM DESIGN
1
IS INFORMATION DIGITAL OR ANALOG
DIGITAL
DISCUSSION 4.3.1
2
DATA RATE
DISCUSSION 4.3.6
3
ERROR RATE
DISCUSSION 4.3.2
CURVE A-e-1
4
MOD'N SYSTEM
DISCUSSIONS 4.3.7 4.3.4
5
ERROR RATE VS S/N FOR MOD'N SYSTEM
CURVES A-m-3 A-m-4 A-m-5
6
(S/N)id
ANALOG
2
RESOLUTION
DEPENDS ON PROCESSING EQUIPMENT REQUIREMENTS
3
DETERMINE (S/N)OUTPUT
PROCEDURE 4.1.2
CURVE A-e-2
4
MOD'N SYSTEM
DISCUSSION 4.3.7
5
DETERMINE INPUT S/N DUE TO MODULATION INPOVEMENT
CURVE A-m-1
CURVE A-m-2
FOR AM
(S/N)id (CARRIER) =

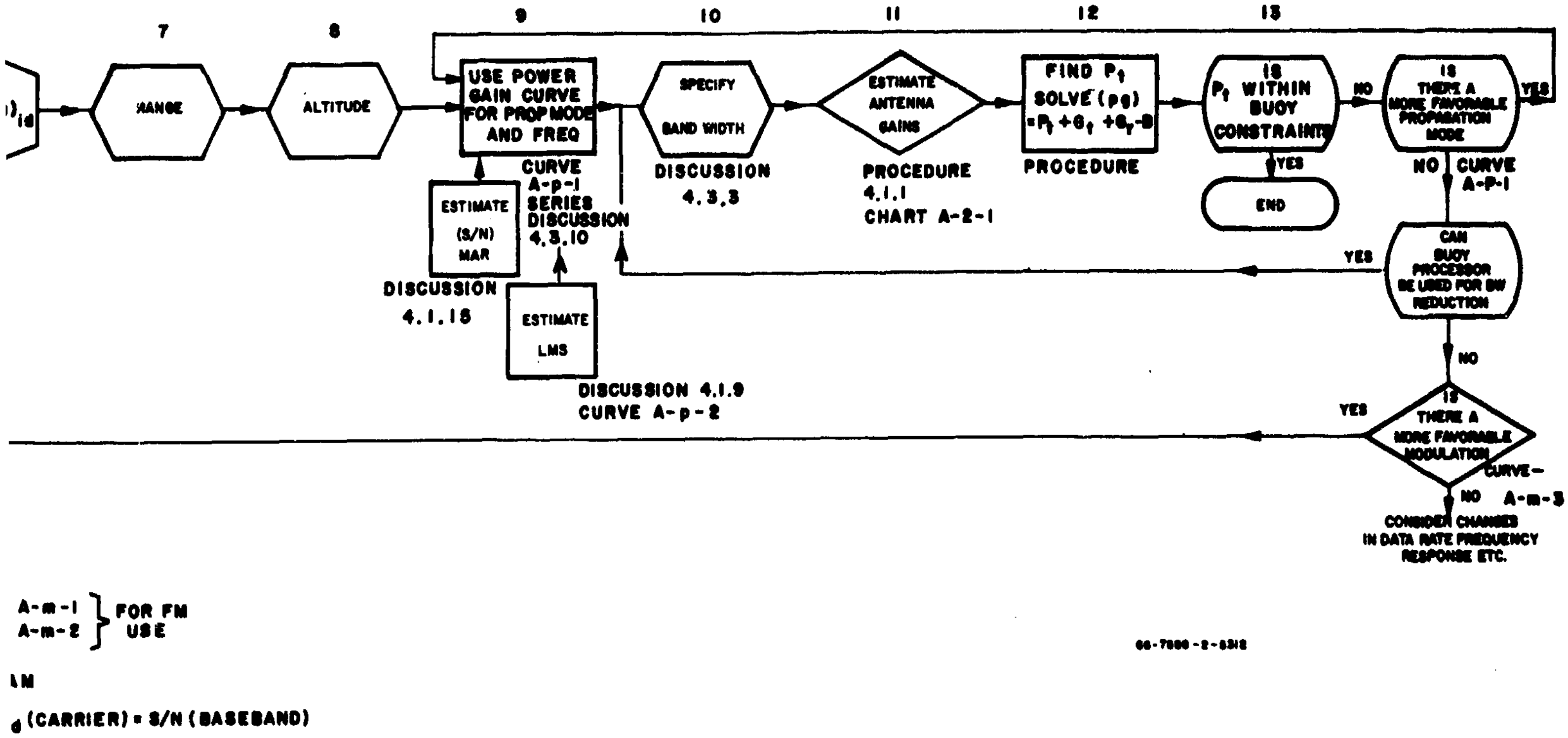


Figure 4-2. Buoy Communication Design

4.2 PARAMETER CURVES

4.2 PARAMETER CURVES

Introduction:

Two classes of curves been included. These classes are primary curves which are directly utilized in the Procedures and flow chart operations and secondary curves which supplement the primary curves. Ordinarily, only the primary curves will be used, but the secondary curves are included to allow the user to investigate second order conditions and effects which are beyond the scope of this study.

To aid in identification and relate the various curves a letter-number designation system will be followed where possible. For example:

<u>Typical Primary Curve Designation</u>

A - m - 6

First letter - indicates level, primary A, secondary B

Second letter - indicates the category, e.g., m - modulation, p - propagation, etc.

Number - indicates the number of the curve

<u>Typical Secondary Curve Designation</u>

B - m - 6.1

This is a secondary curve of A - m - 6 where the 0.1 differentiates it from other secondary curves.

Table 4-2. (A-a-1) Electrically Small Antenna

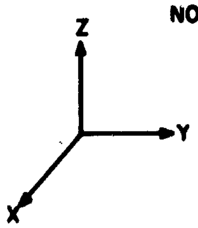
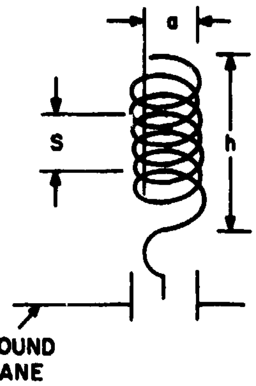
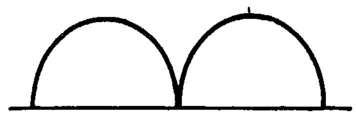
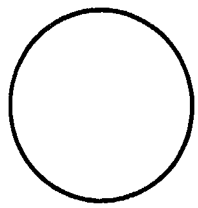
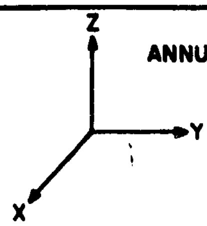
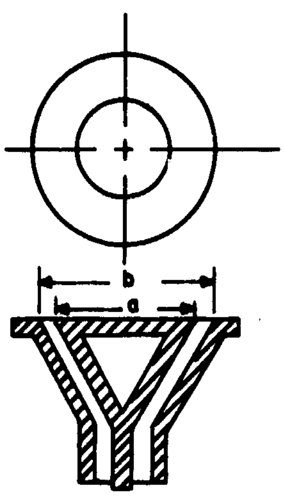
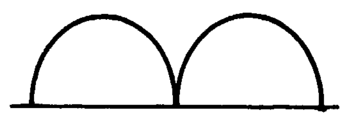
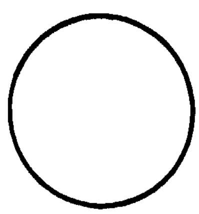
TYPE	RADIATION PATTERN	POLARI-ZATION	REMARKS
NORMAL MODE HELIX   $h < \frac{\lambda}{8}$ $S < 0.05\lambda$ $2a < \frac{\lambda}{10}$ λ = WAVE LENGTH	VERTICAL (Z-Y PLANE)  GROUND PLANE  HORIZONTAL (X-Y PLANE)	ELLIPTICAL AXIAL RATIO $+ = \frac{2S\lambda}{(2\pi a)^2}$ CIRCULAR WHEN $2S\lambda = (2\pi a)^2$	GAIN 4.76 db EASIER TO RESONATE WITH EXTERNAL TUNING THAN A MONOPOLE OF EQUIVALENT HEIGHT
ANNULAR SLOT   λ = WAVELENGTH	VERTICAL (Z-Y PLANE)  GROUND PLANE  HORIZONTAL (X-Y PLANE)	PERPENDICULAR TO PLANE OF SLOT	GAIN APPROXIMATELY 5db MAY BE USEFUL AS RECEIVING ANTENNA FOR THE ON-WATER AIRCRAFT AT UHF AND HIGHER FREQUENCIES

Table 4-2. (A-a-1) Electrically Small Antenna

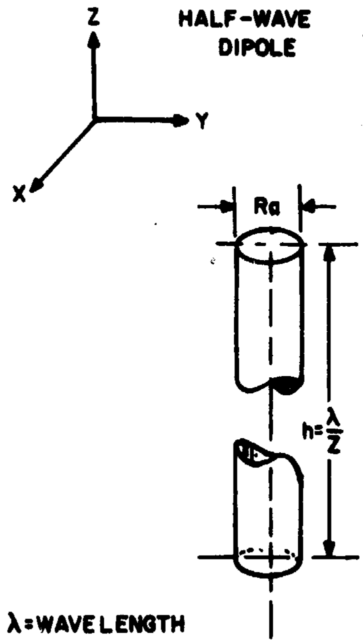
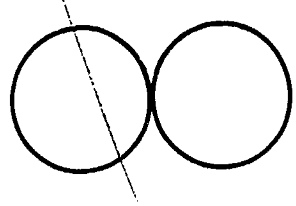
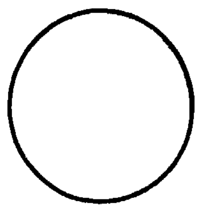
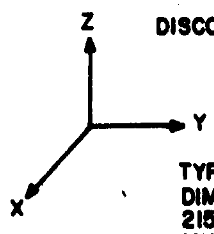
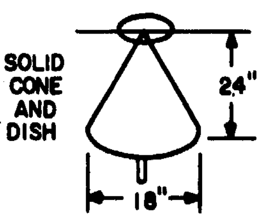
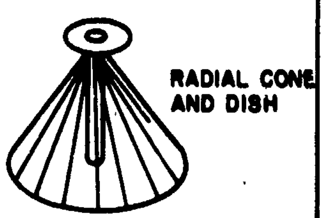
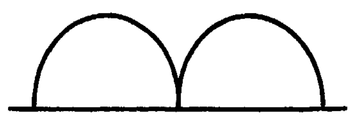
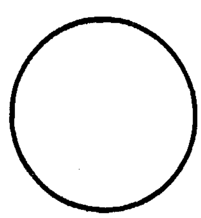
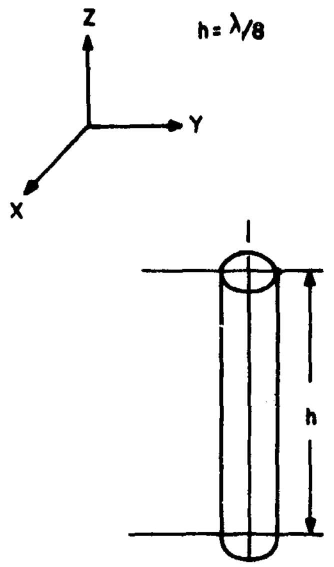
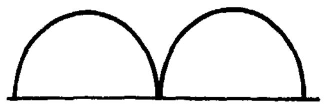
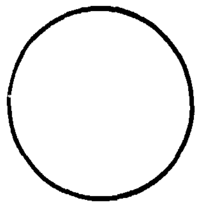
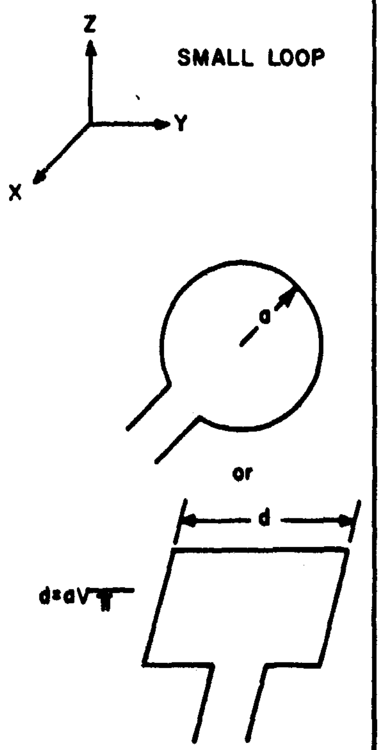
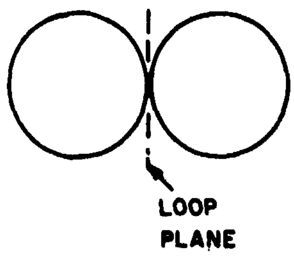
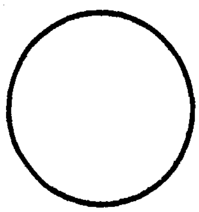
TYPE	RADIATION PATTERN	POLAR-ZATION	GAIN
HALF-WAVE DIPOLE  	VERTICAL (Z-Y PLANE)   HORIZONTAL (X-Y PLANE)	LINEAR VERTICAL	GAIN 2.15 db
DISCONE  TYPICAL DIMENSIONS 215-400 MHZ   	VERTICAL (Z-Y PLANE)   HORIZONTAL (X-Y PLANE)	LINEAR VERTICAL	GAIN 2.15 db EQUIVALENT TO A VERTICAL DIPOLE
SPECIAL ANTENNA TYPES CAN BE DEVELOPED	THESE ANTENNA CAN HAVE RESTRICTED PATTERNS TO IMPROVE GAIN-PARTICULARLY AT UHF(ULTRA HIGH FREQ.) OR HIGHER FREQUENCIES		GAINS OF 6db TO 10 db

Table 4-2. (A-a-1) Electrically Small Antenna (Cont'd)

TYPE	RADIATION PATTERN	POLARIZATION	REMARKS
MONOPOLE  λ = WAVELENGTH	VERTICAL (Z-Y PLANE)  GROUND PLANE  HORIZONTAL (X-Y PLANE)	LINEAR VERTICAL	GAIN 4.8db(IDEAL), USE 3 db FOR OPERATIONAL SITUATION RADIATING EFFICIENCY MUST BE TAKEN INTO ACCOUNT - SEE CURVE A-a-3 ANTENNA WITH λ 4 LENGTH ABOVE PERFECT GROUND HAS 5.15 db GAIN
 	VERTICAL (Z-Y PLANE)   HORIZONTAL (X-Y PLANE)	LINEAR HORIZONTAL (LOOP PLANE HORIZONTAL)	GAIN 1.76 db SMALL ANTENNA WITH PERIMETER $P = 2\pi a < \lambda/8$ MUST BE MATCHED TO IMPROVE EFFICIENCY MATCHING REQUIREMENTS ARE MORE COMPLEX THAN MONOPOLE AND INSTALLATION LOCATION MUST BE CONSIDERED. LOOP HAS NULLS WHEN OPERATED IN VERTICAL POSITION

NOMOGRAPH

ANTENNA HEIGHT - WAVELENGTH RELATIONSHIP

$h = \frac{984}{\text{freq. in MHz}}$

Example A: $\lambda/8 = .125_\lambda$
When f is 10 MHz a $\lambda/8$
antenna would be 12 feet.
$h/_\lambda = .125$

Example B:
When f is 10 mc and
the height is 20 ft. $h/_\lambda$
is .203

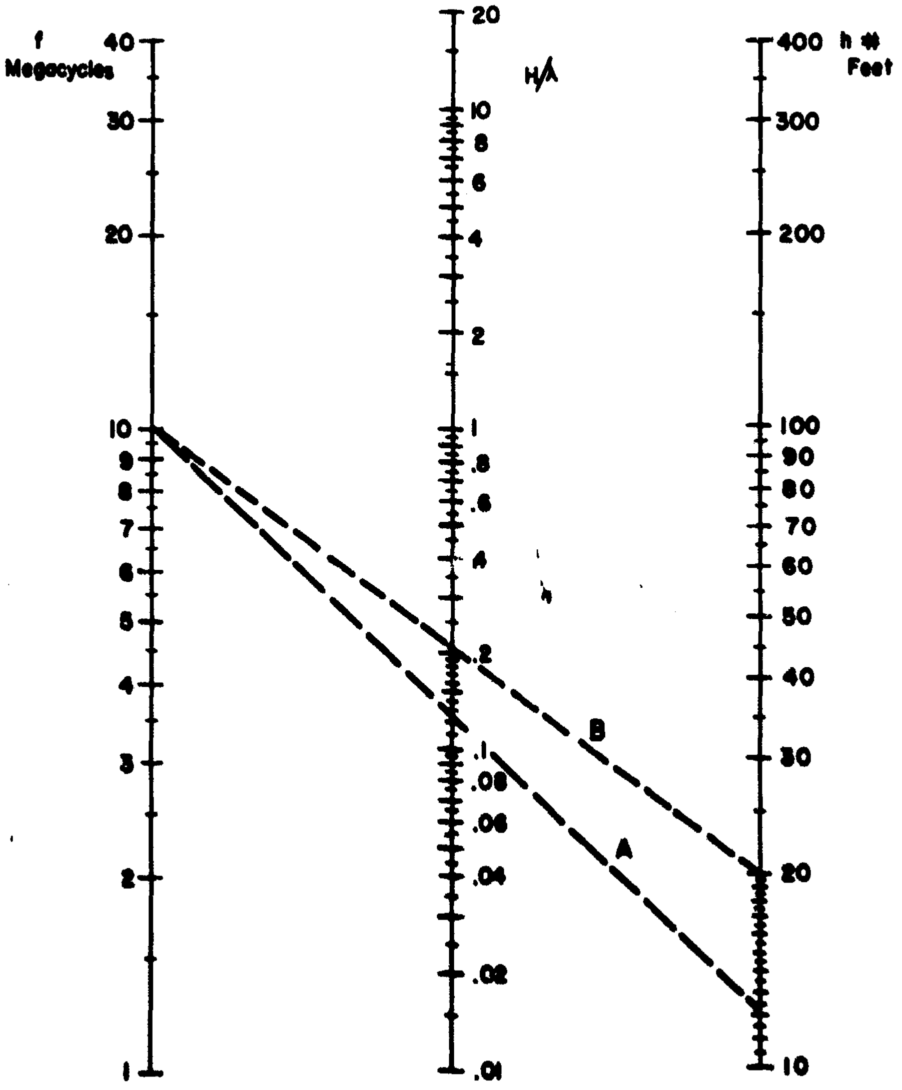


Figure 4-5. Height/Wavelength or Length/Wavelength Nomogram Curve A-a-2.

MONOPOLE ANTENNAS RADIATION EFFICIENCY-VERTICAL POLARIZATION

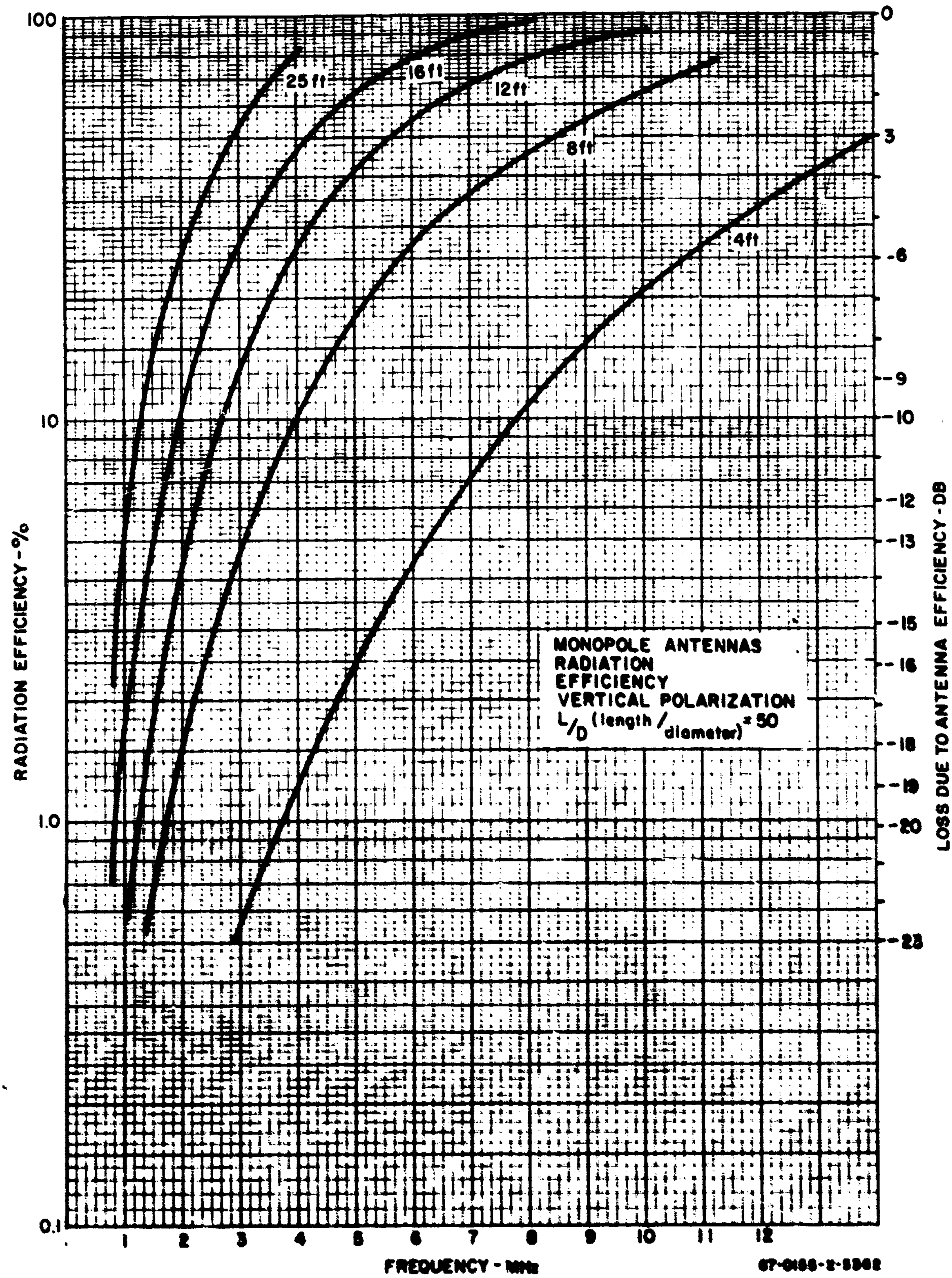


Figure 4-6. Curve A-a-3

DATA RATE

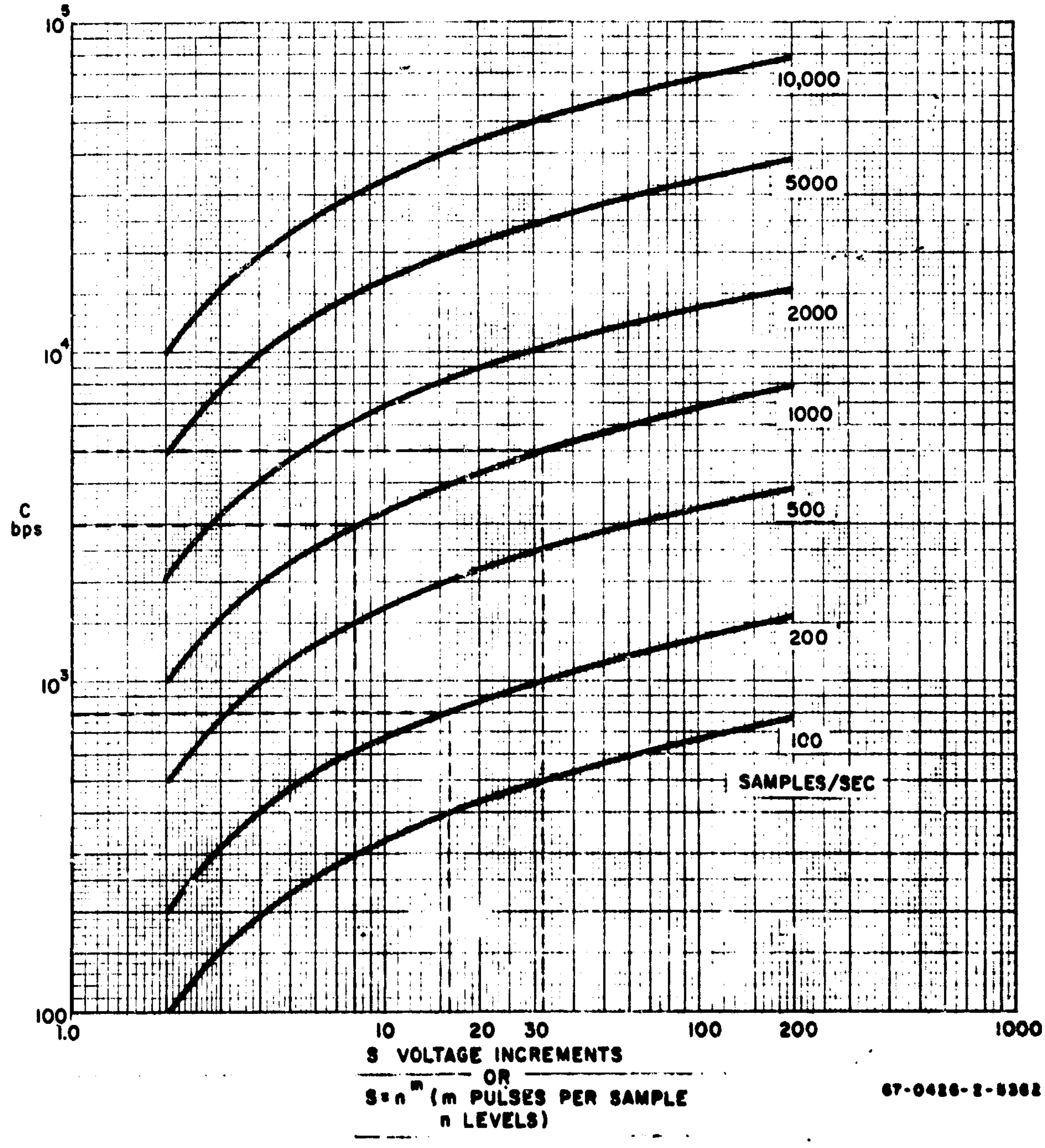


Figure 4-7. Curve A-d-1

Curve A-d-2

Since data rate is directly related to bandwidth, any change in data $\overline{PG}$ rate will cause a corresponding change in the power-gain factor. This curve provides a direct relationship between data rate and a relative power-gain. The change in power-gain factor is determined by the difference in power-gain factors corresponding to the two data rates used in the calculation.

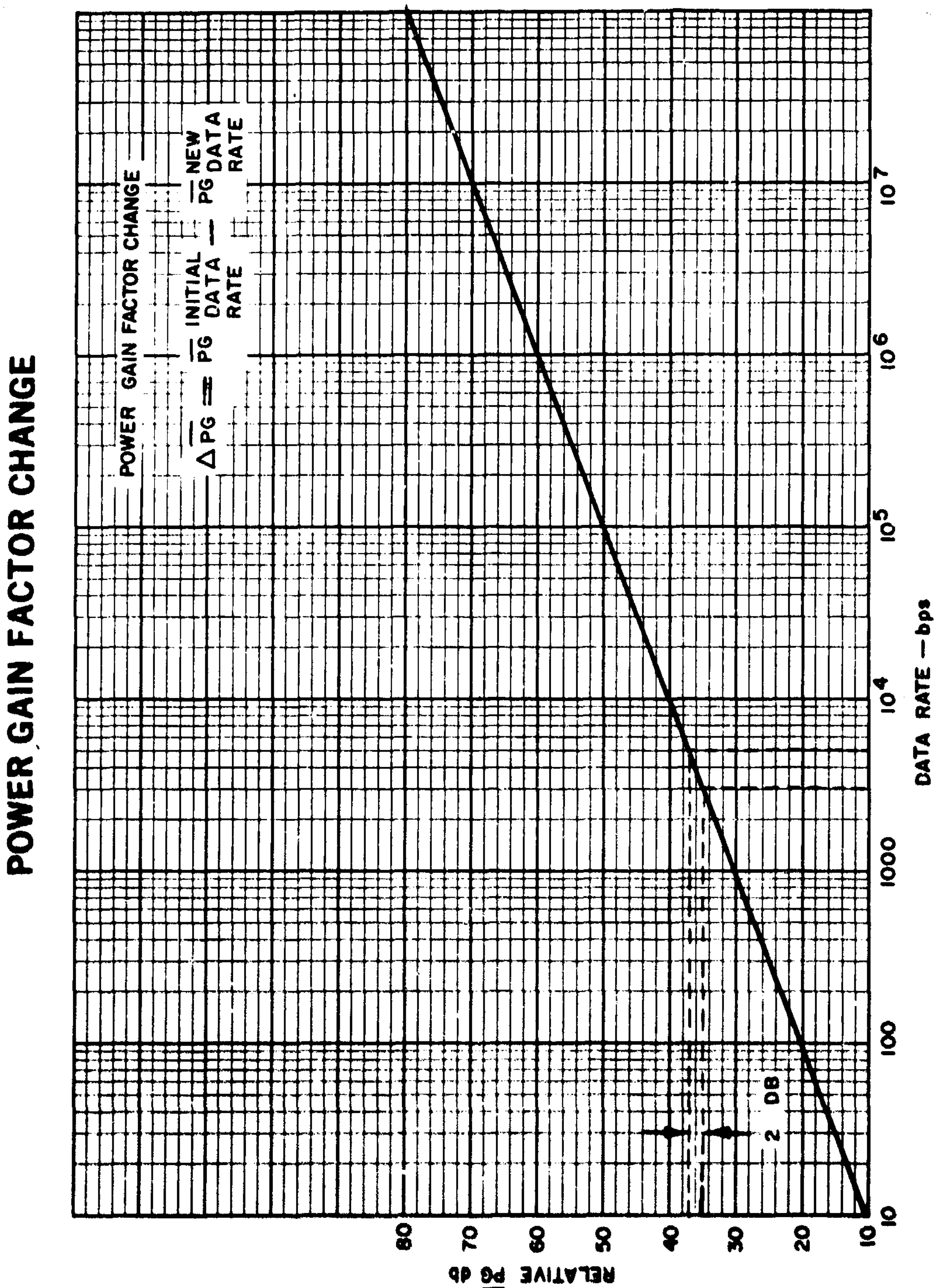


Figure 4-8. Curve A-d-2

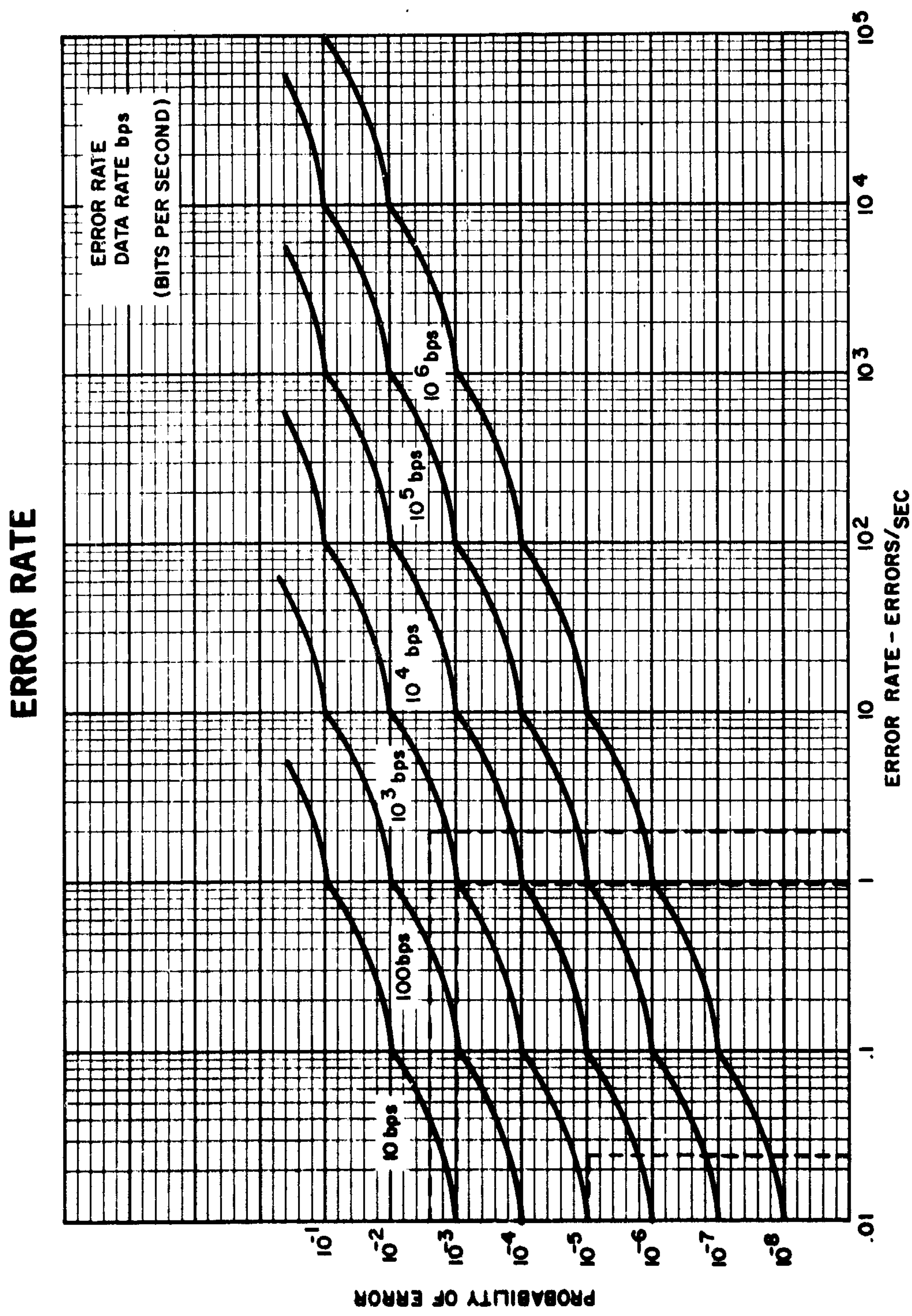


Figure 4-9. Curve A-e-1

ANALOG ERRORS VS. S/N

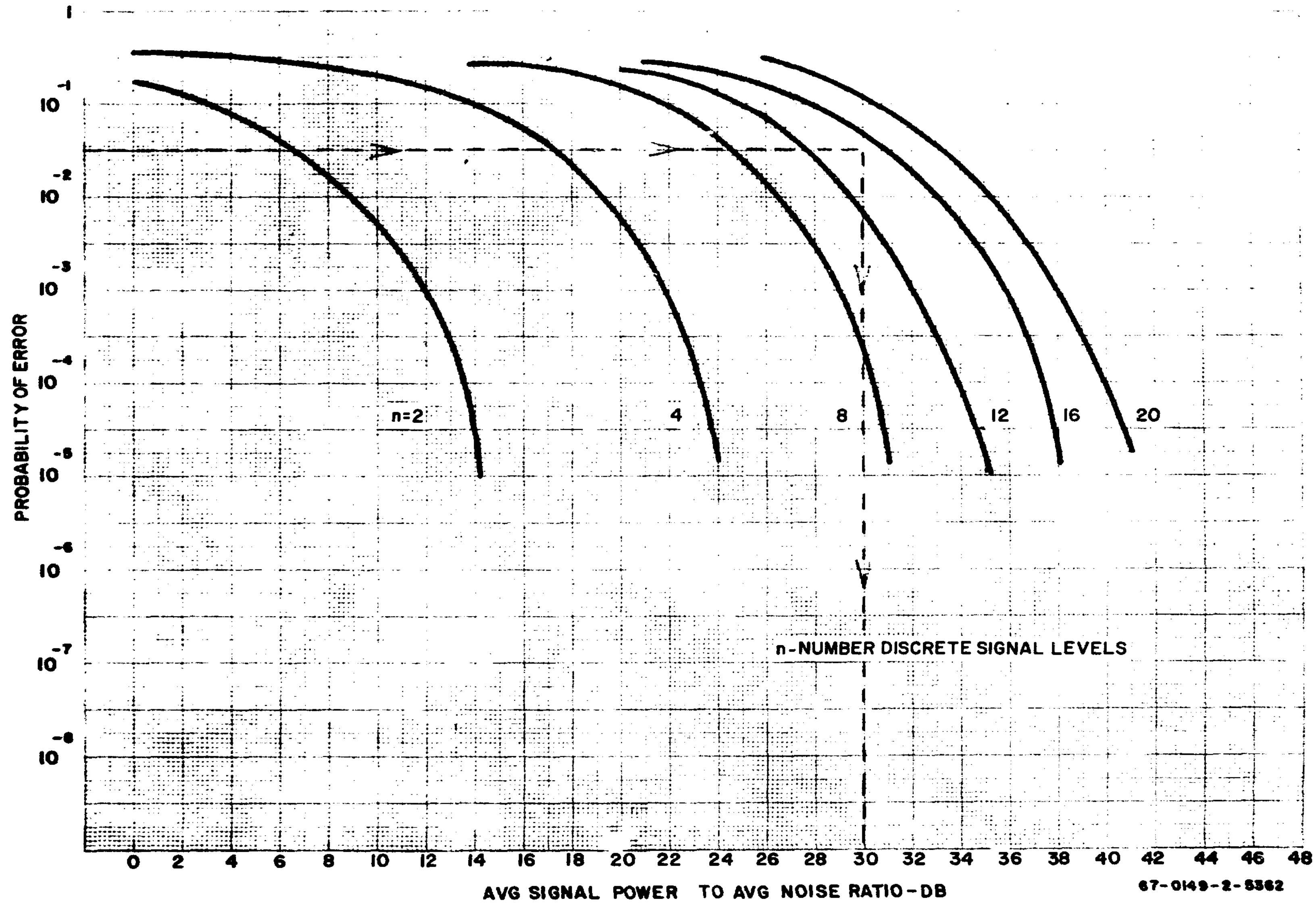


Figure 4-10. Curve A-e-2

RADIO LINE OF SIGHT

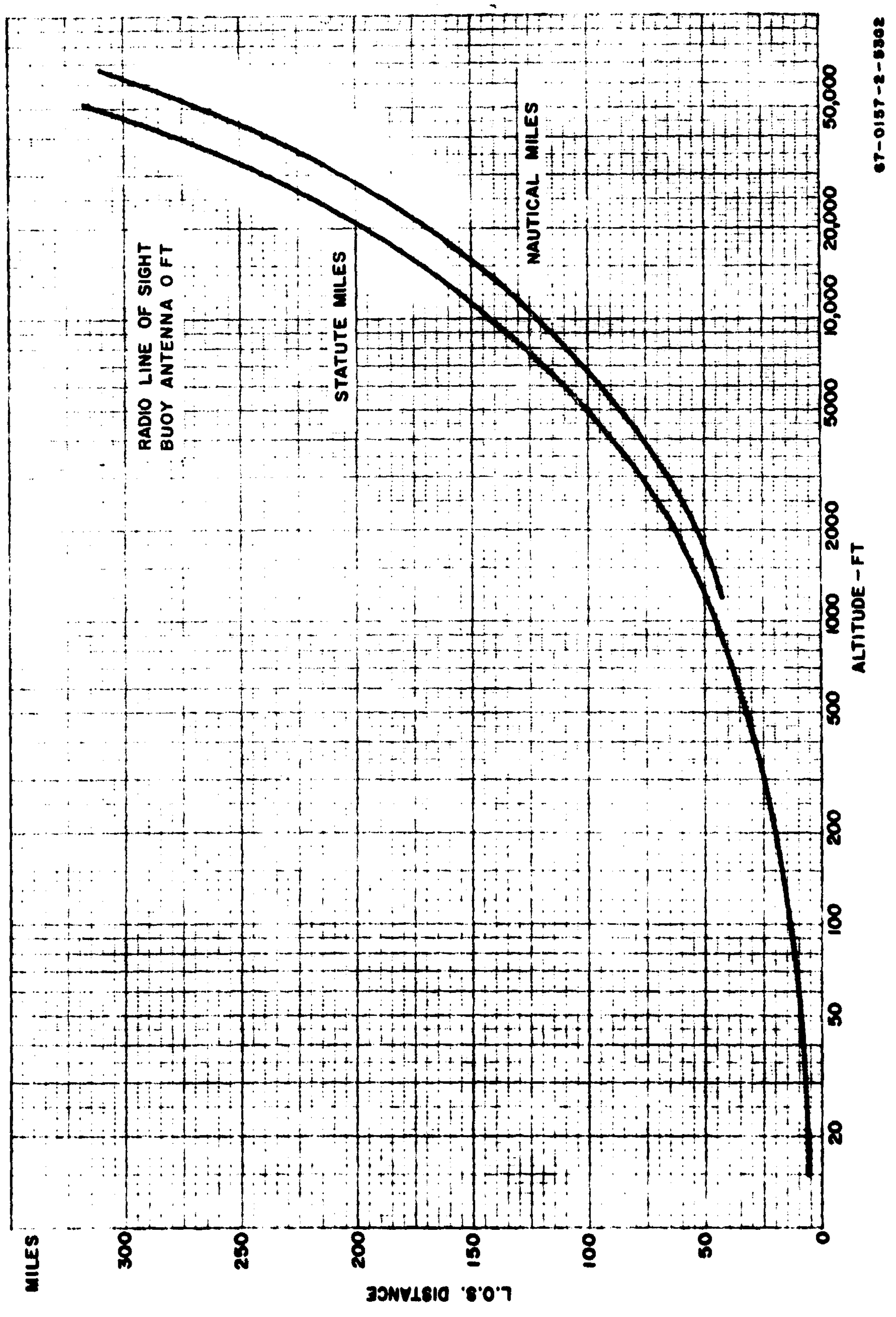


Figure 4-11. Curve A-1-1

Curve A-m-1

This curve shows the (S/N) (signal-to-noise) improvement attainable using frequency modulation (FM) as a function of the deviation ratio (m). The deviation ratio is defined:

$$m = \frac{\Delta f}{f_b} \quad \begin{array}{l}\text{(frequency deviation from carrier frequency)} \\ \text{(frequency of modulation)}\end{array}$$

As illustrated by the curve, a greater frequency deviation results in an improvement in the required S/N input. For example, if an output S_o/N_o of 30 db is required, using a frequency modulation with a deviation ratio of 3 an input S_c/N_c of 16 db is allowable. This is a net 14 db FM improvement.

Curves derived from experimental results [1] are used on the graph and the equation for ideal FM improvement given.

FM improvement is attainable only for input S_c/N_c ratios greater than the threshold level. Threshold levels are given by curve B-m-2.2.

Further signal-to-noise improvement can be achieved through de-emphasis.[2] The signal-to-noise improvement which results from de-emphasis is attained only when the signal has low amplitude high frequency components relative to the low frequencies, and a high output S/N is required. In most cases, the spectral distribution of the buoy modulation does not have this characteristic, and a high S/N ratio is not required from the buoy communication link. Therefore, S/N improvement through de-emphasis and pre-emphasis is not considered. Example: Using a deviation ratio of m = 3, an output (S/N) ratio of 30 db can be obtained with a carrier (S/N) ratio of only 16 db. This represents 14 db of FM improvement.

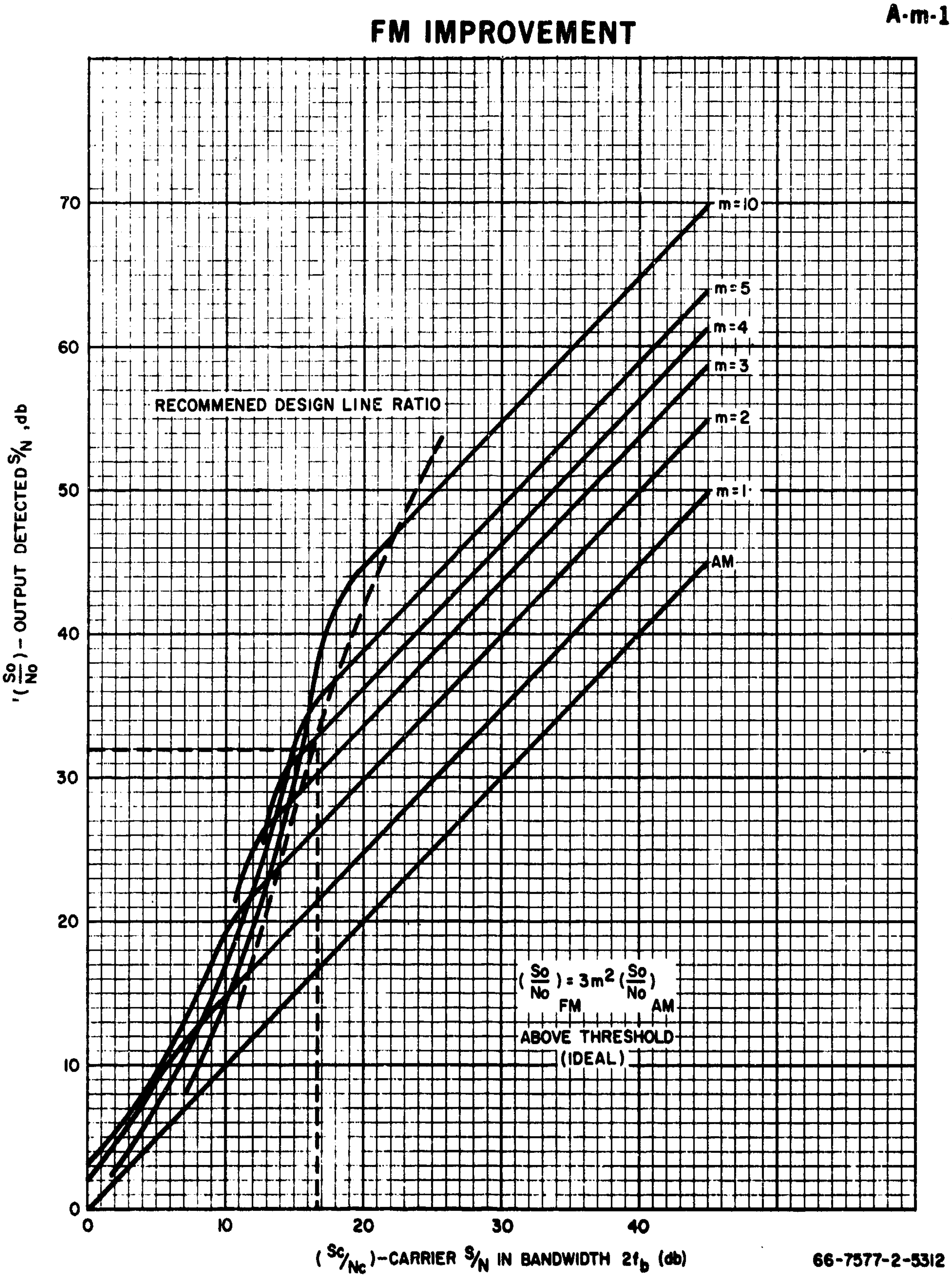


Figure 4-12. Curve A-m-1

Curve A-m-2

This curve was developed from curves A - m - 1 and B - m - 2.2. The curves indicate the approximate optimum deviation ratio for minimum transmitted power and the recommended deviation ratio. The selection of deviation ratios higher than the optimum value on the curve will result in bandwidth increases greater than the gain obtained from the FM improvement factor. For example, selection of an m = 5 for a required output S/N ratio of 30 db will require a larger bandwidth than m = 4, but the FM improvement will be the same.

DEVIATION RATIO FOR MINIMUM TRANSMITTED POWER

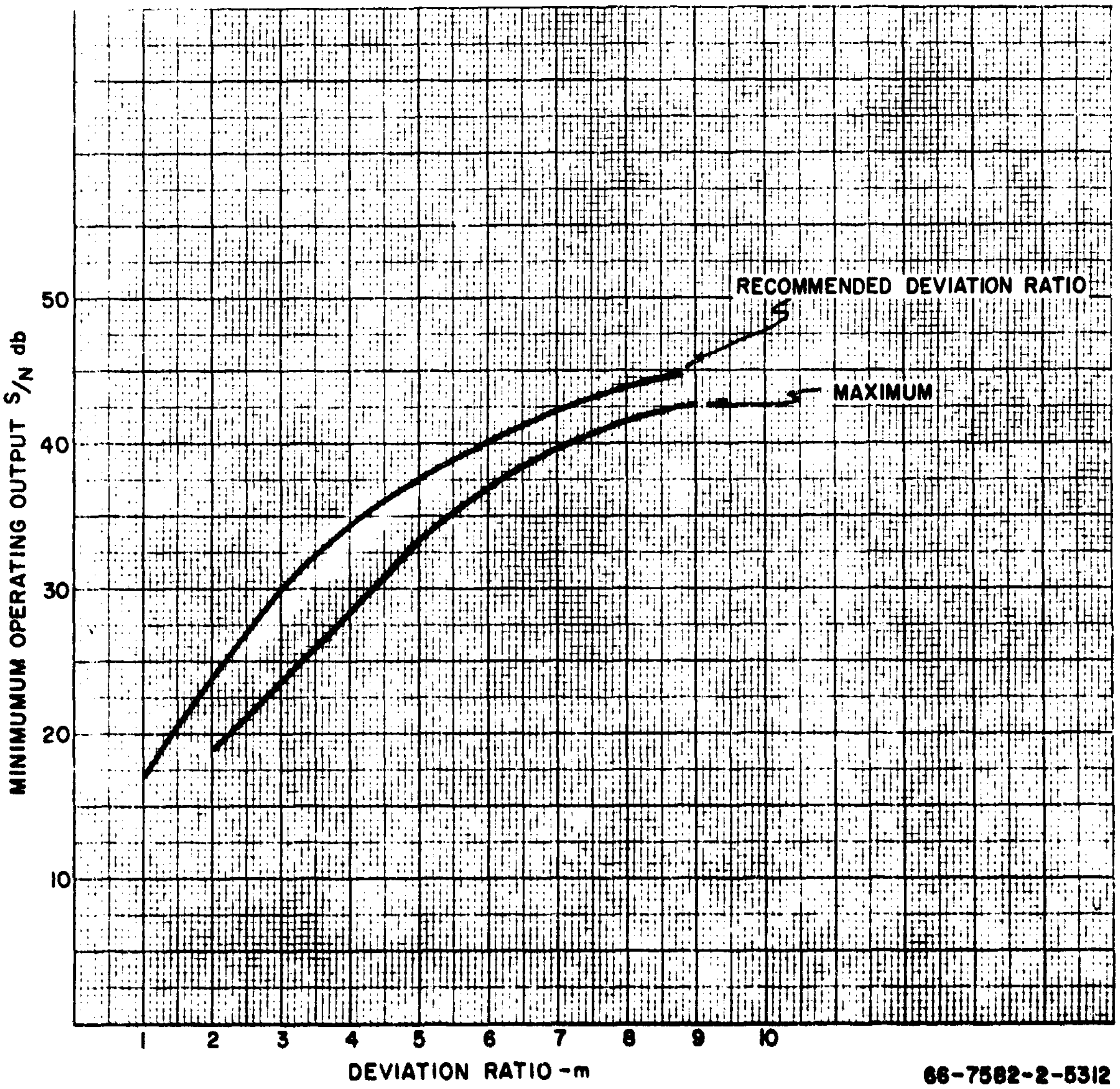


Figure 4-13. Curve A-m-2

Curve A-m-3

This curve relates the (S/N) ratio required for different digital modulation types* as a function of the bit error probability. The modulation types covered are coherent PSK, differential or phase comparison PSK, and non-coherent FSK. A curve showing the (S/N) ratio required for a coded coherent PSK modulation having 20 bits (n = 20) is included to provide a comparison of the (S/N) change obtained by coding. The signal-to-noise ratio is given as E/N_o where E is the energy per bit and N_o is the noise density. For matched filter operation this is equivalent to the $(S/N)_{id}$ term of the transmission equation.

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* J. Lawton, "Comparison of Binary Data Transmission System," Second National Military Electronics Conference Proceedings, 1958.

COMPARISON OF VARIOUS CODED AND UNCODED MODULATION PROCESSES AND VARIATIONS

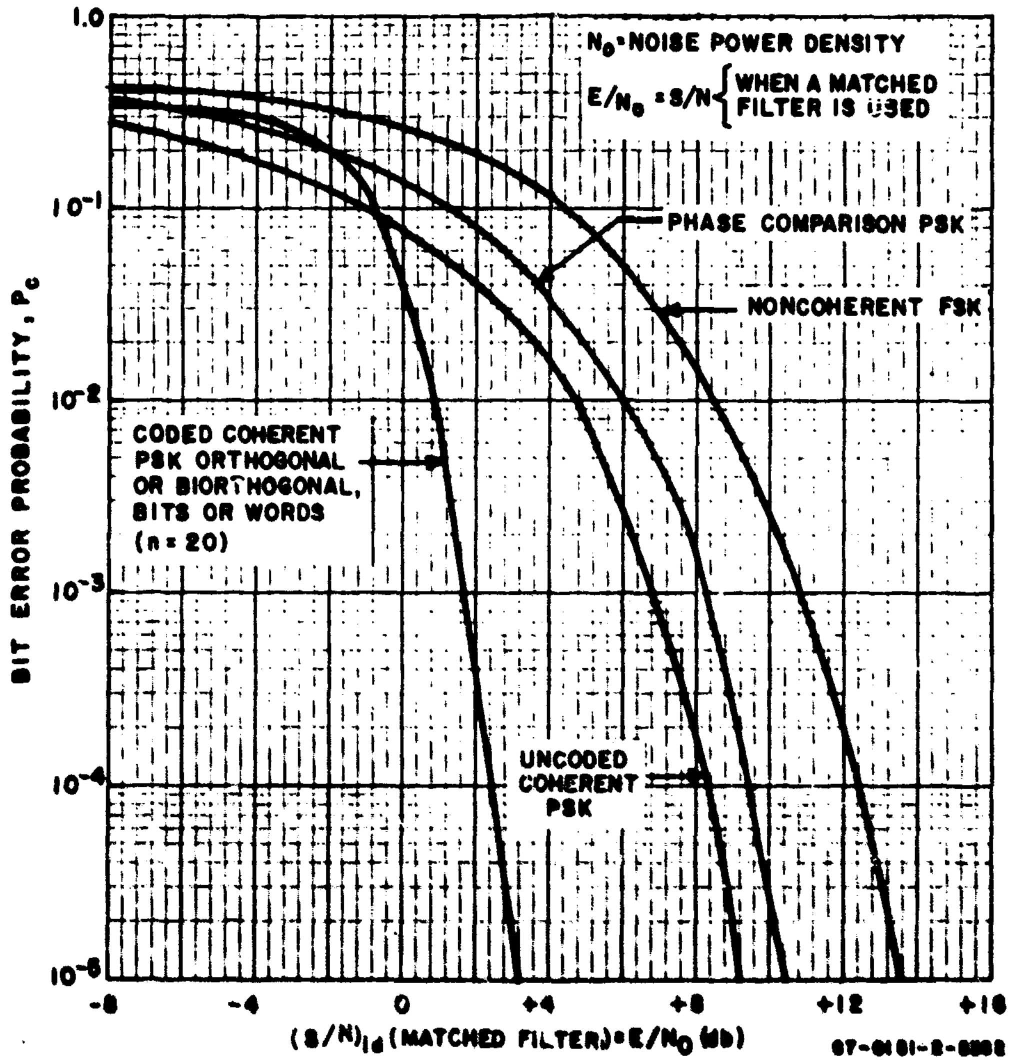


Figure 4-14. Curve A-m-3

BIT ERROR PROBABILITY - BI-ORTHOGONAL CODES

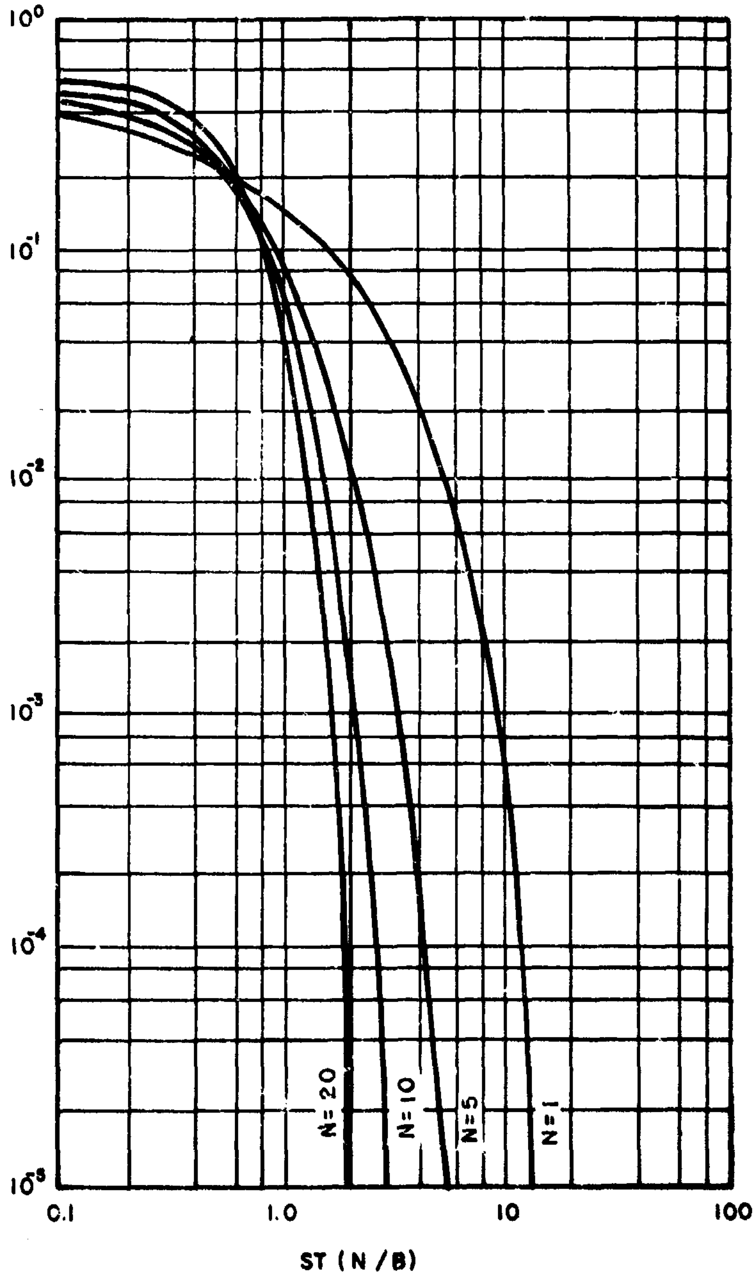
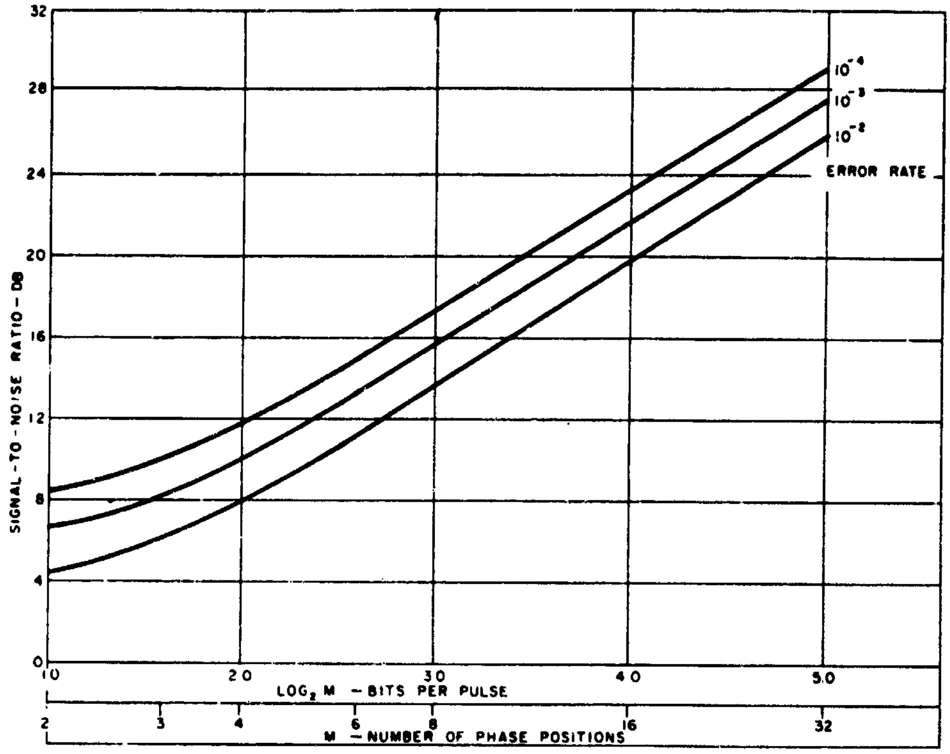
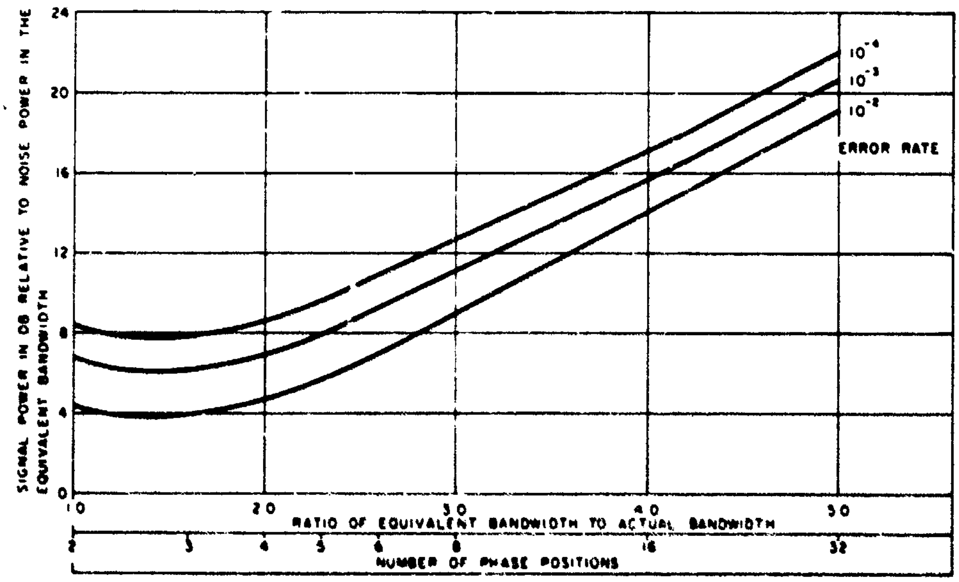


Figure 4-15. Curve A-m-4



A-m-5

SIGNAL-TO-NOISE RATIO REQUIREMENT FOR DIGITAL PHASE MODULATION



A-m-6

RELATIVE POWER REQUIREMENT WITH DIGITAL PHASE MODULATION

Figure 4-16. Curves A-m-5 and A-m-6

A-p-1 Curve Series

This series of curves cover varying altitude from 0-30,000 ft. The noise levels of Curve B-p-1.2 have been added to the transmission loss of Curves B-p-1.1. to develop this series of composite curves which are a function of altitude. curves relate the design parameters (P_t, G_t, G_r and B)* of the transmission equation to the operational and equipment parameters $\left[(S/N)_{id}\ (S/N)_{mar} \text{ and } L_{ms}\right]$ as a function of frequency for fixed operating ranges. The parameters L_p, F and the constant -204 db are accounted for by the curves. The transmitting antenna height is h_t = 5 ft. for all curves.

The curves show the optimum operating frequency for various distances, and a sliding scale is used to provide flexibility in considering parametric variations. In selecting an operating frequency, consideration must be given to possible interference and multimode propagation effects, which may occur at certain frequencies. As a result, the minimum point on a curve is not necessarily the best operating frequency.

An illustration of the use of curves is shown in the following figure. Assume $(S/N)_{id} + (S/N)_{mar} + L_{ms}$ = 22 db at a 100 nautical mile range:

1. Using the curve for 0-250 ft altitude, set the arrow on the sliding scale at 22 db

2. Select 10 MHz as the operating frequency to minimize the power-gain requirement (multipath and multimode propagation effects must be considered in the selection)

3. Read the (PG) factor = -21 db from the scale

---

* These combined parameters are referred to as the $\overline{PG}$ factor.
$\overline{PG} = P_t + G_t + G_r - B$

The $\overline{PG}$ factor read from the curves represents the sum of the transmitter power (P_t), antenna gains ($G_t + G_r$), and bandwidth (a minus value, B) required for operation at a specific frequency, range, and (S/N) ratio. The noise level factored into these curves is the highest median* value for any oceanographic location, season, and time as determined from CCIR report 322.** Since this combination of worst conditions will seldom occur, the $\overline{PG}$ factor obtained from the curves will be sufficient to assume a communication reliability of 90% in most situations. At frequencies above 30 MHz, the noise is relatively constant and will not influence reliability.

The troposcatter propagation mode is subject to signal fading conditions due to atmospheric changes. The $\overline{PG}$ values obtained from the curve are sufficient for 50% communication reliability. When greater reliability is required, a fading margin must be provided in the $(S/N)_{mar}$ term as discussed in Section 4.1.15.

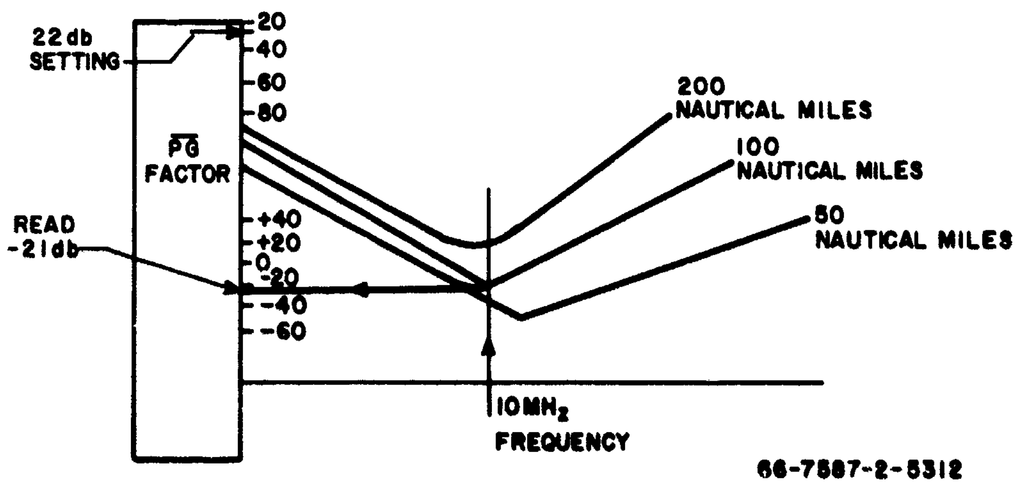
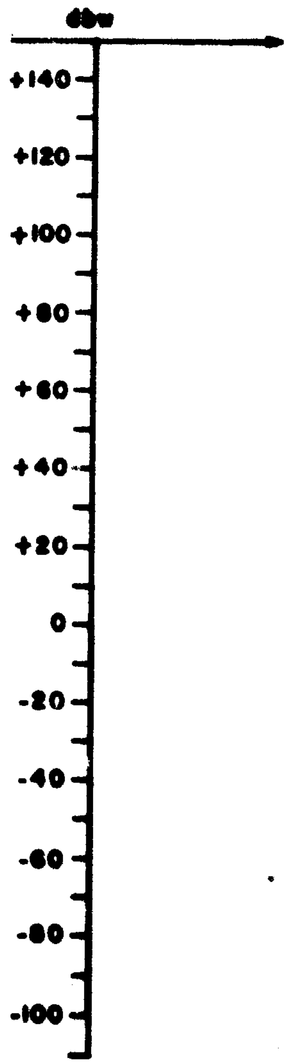
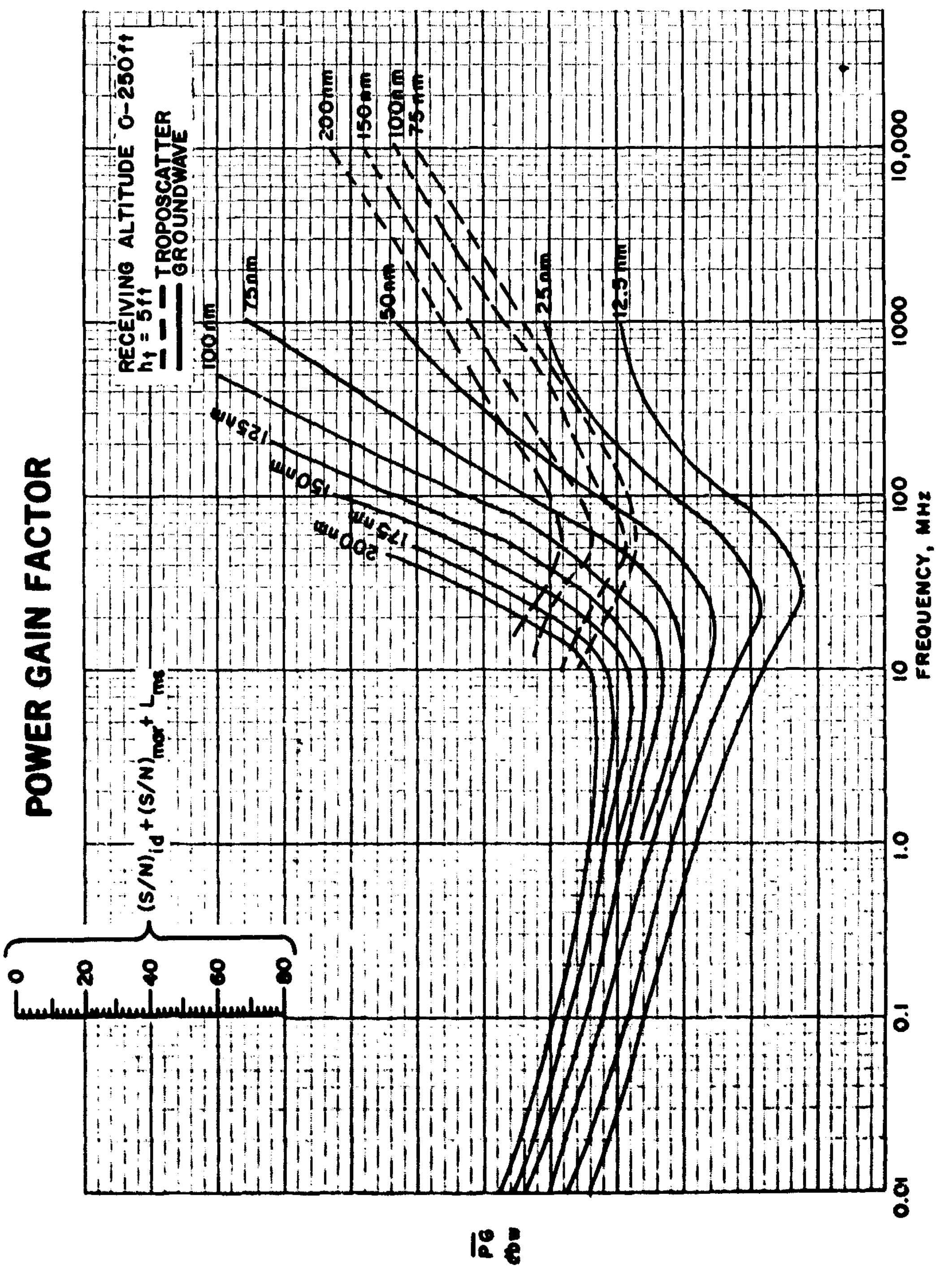


Figure 4-17. Use of Curves

*noise level will be higher 50% of the time and lower 50% of the time.

**see reference (1) of Section 4.1.15


dbw
+140
+120
+100
+80
+60
+40
+20
0
-20
-40
-60
-80
-100



67-0130-2-5362 R1

Figure 4-18. Curve A-p-1

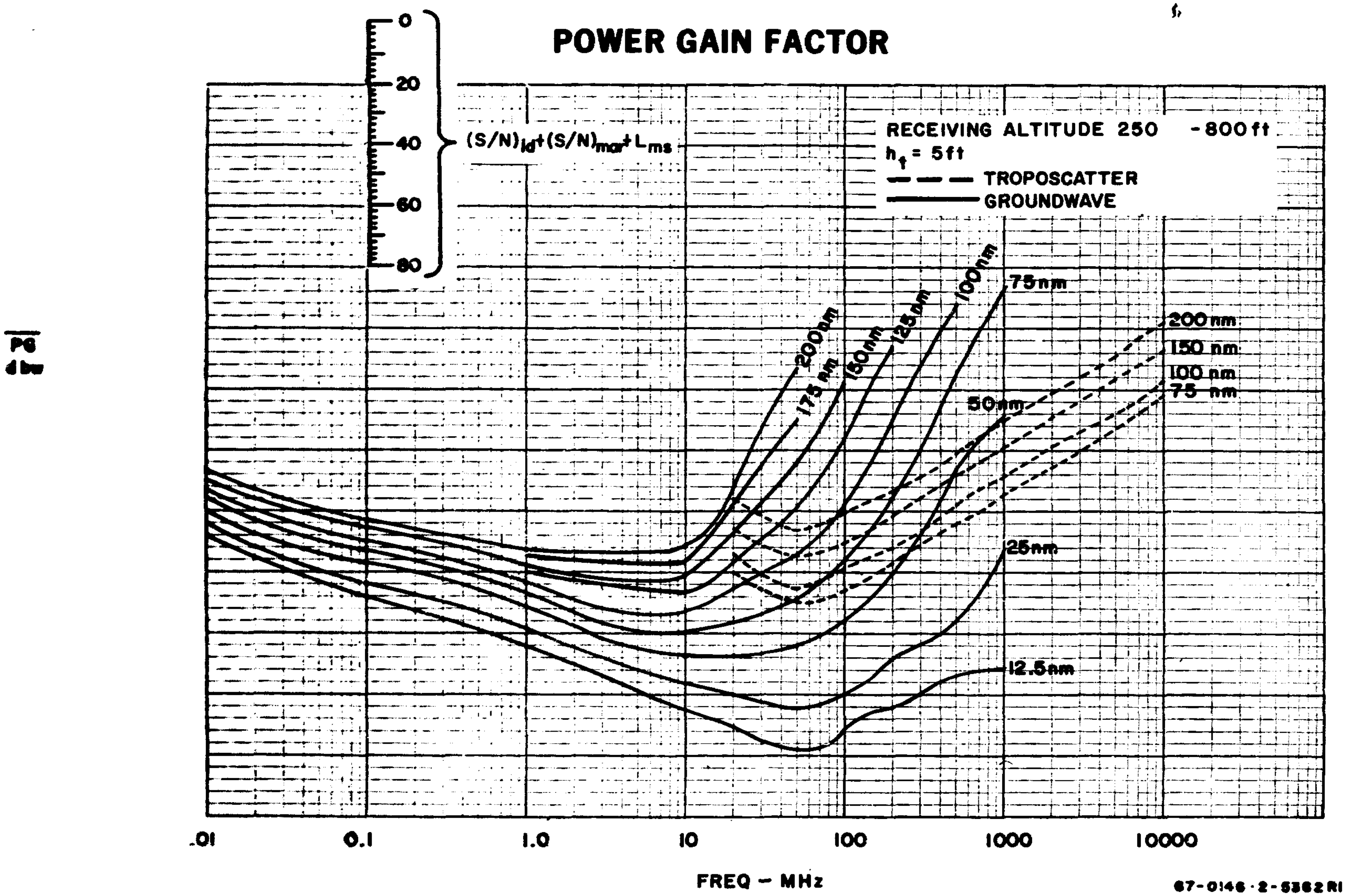


Figure 4-19. Curve A-p-1

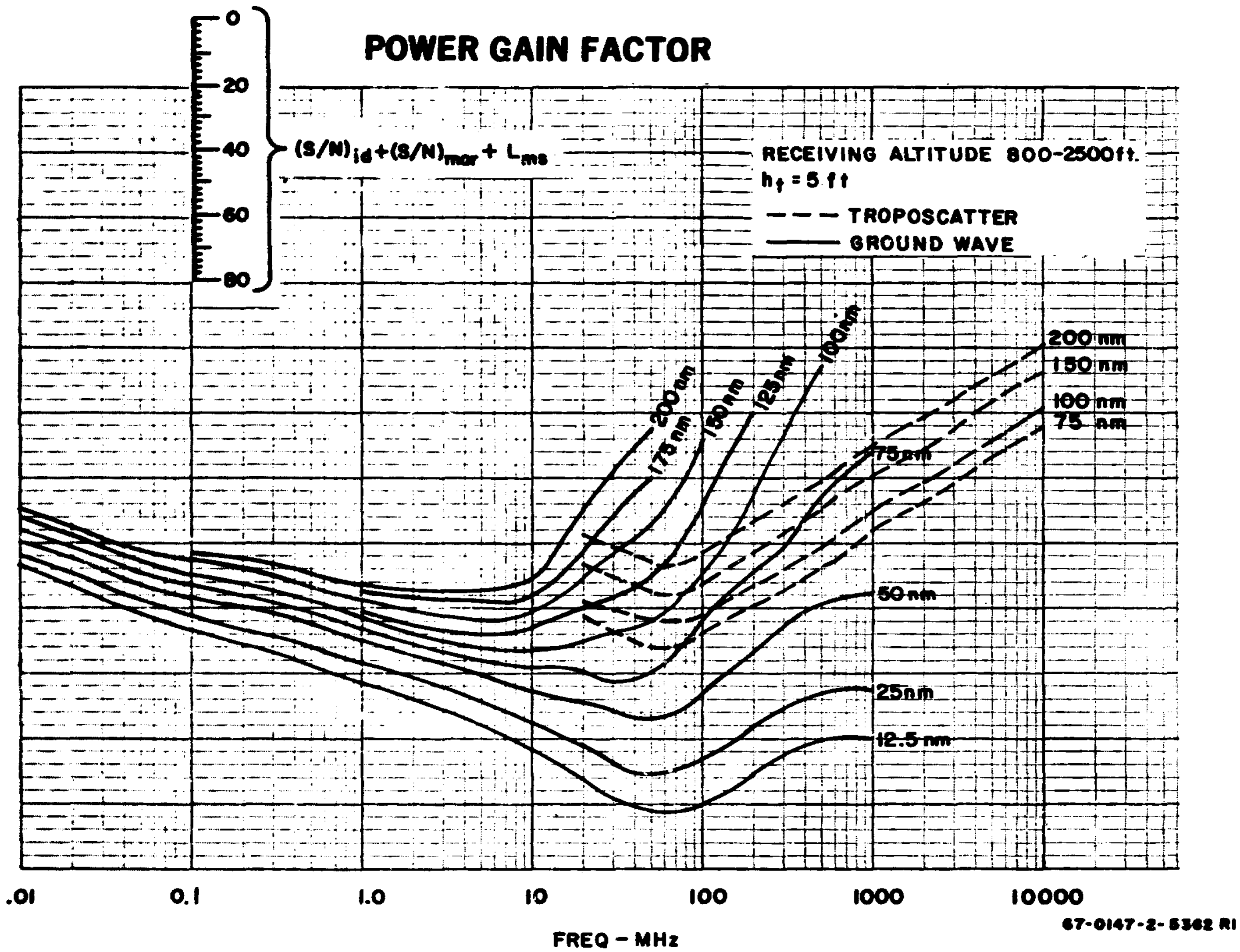


Figure 4-20. Curve A-p-1

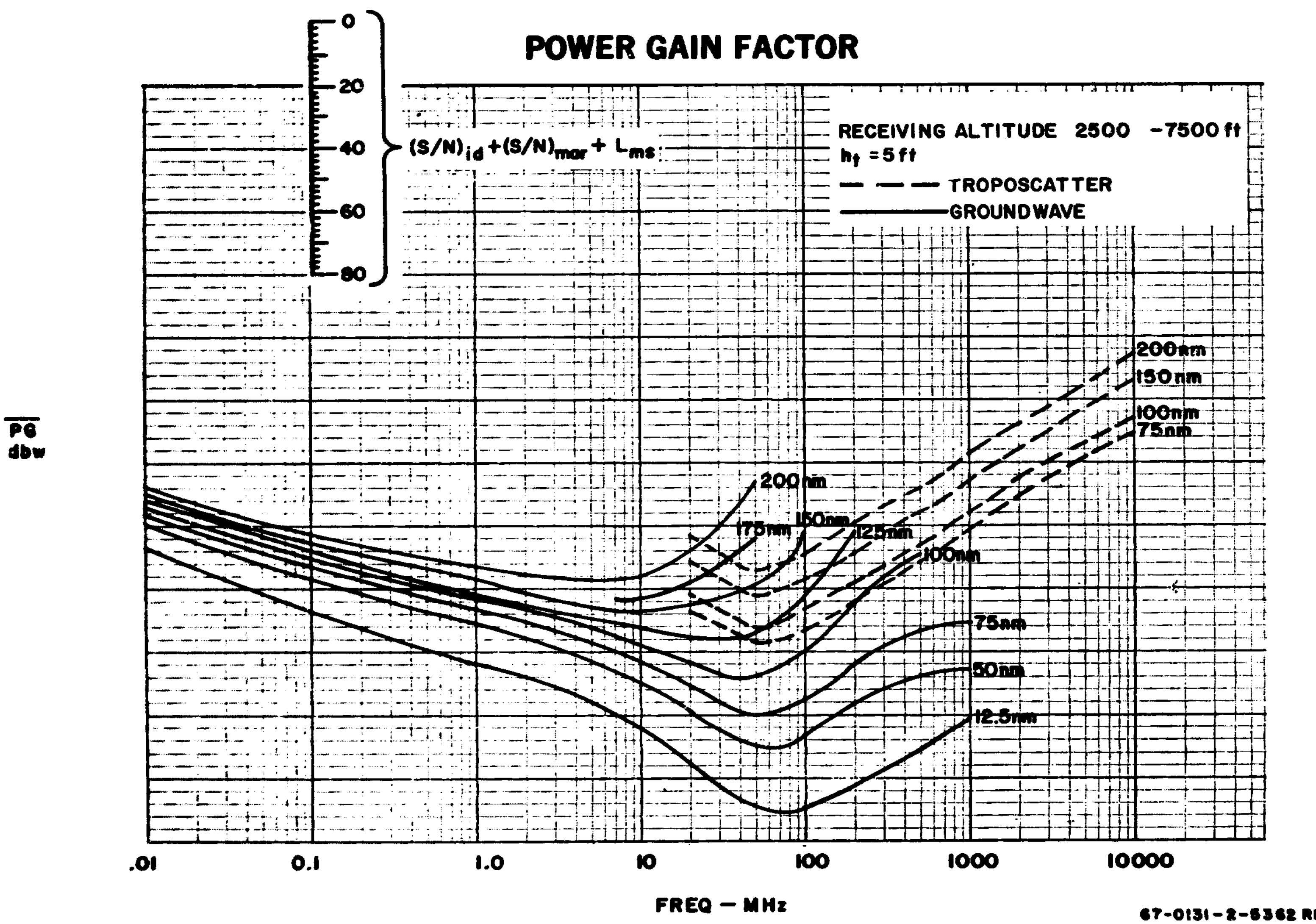


Figure 4-21. Curve A-p-1

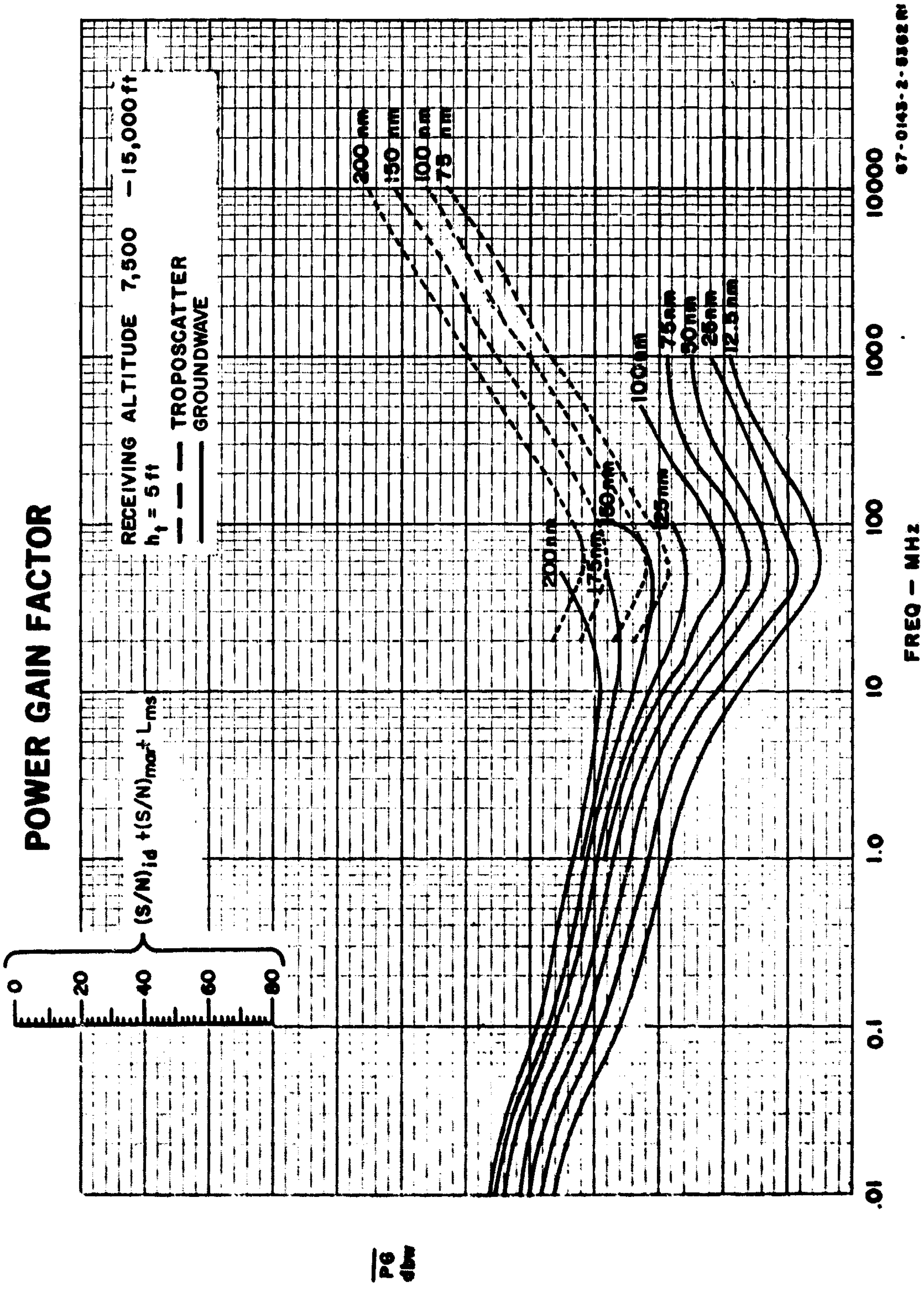


Figure 4-22. Curve A-p-1

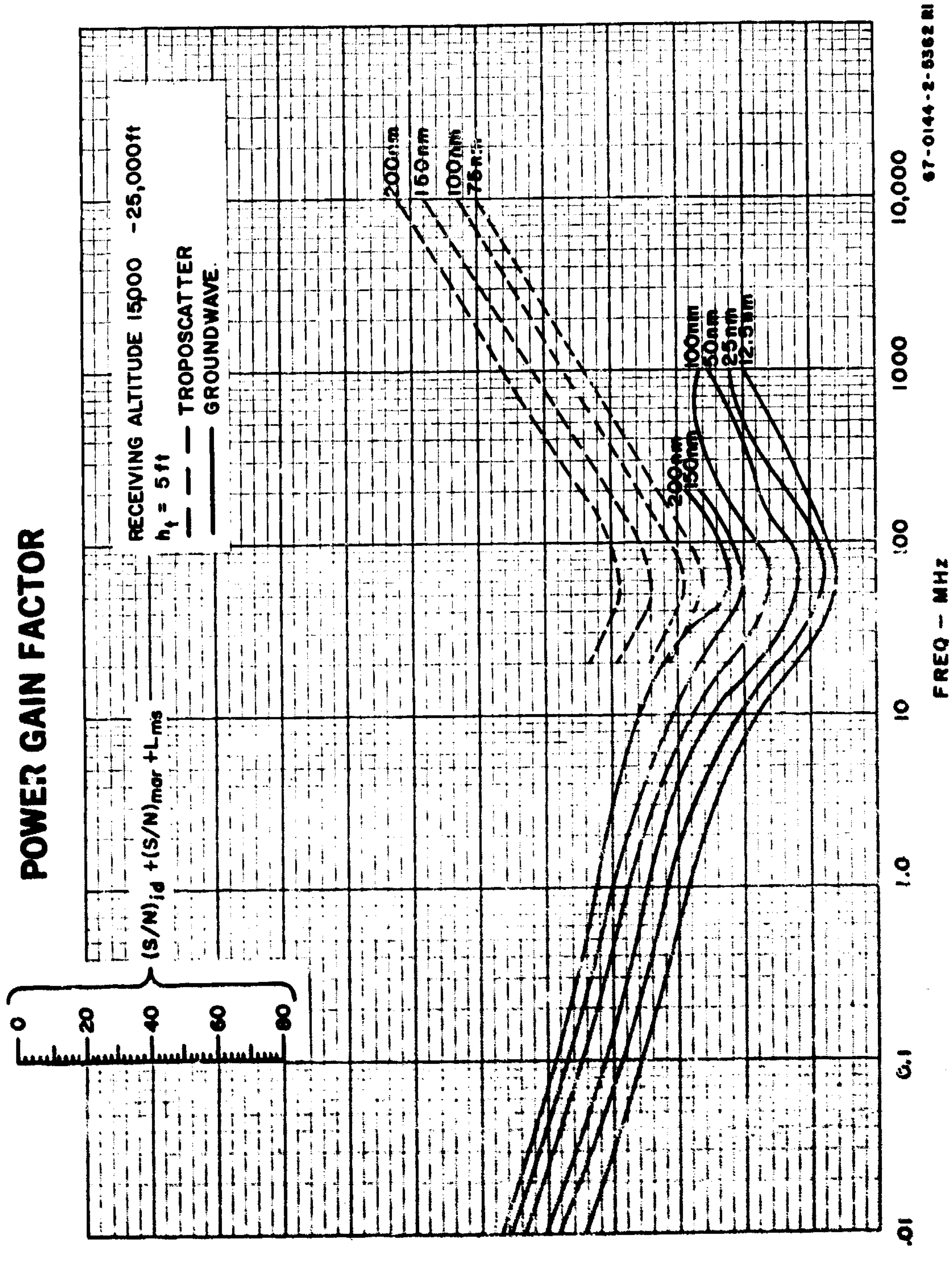


Figure 4-23. Curve A-p-1

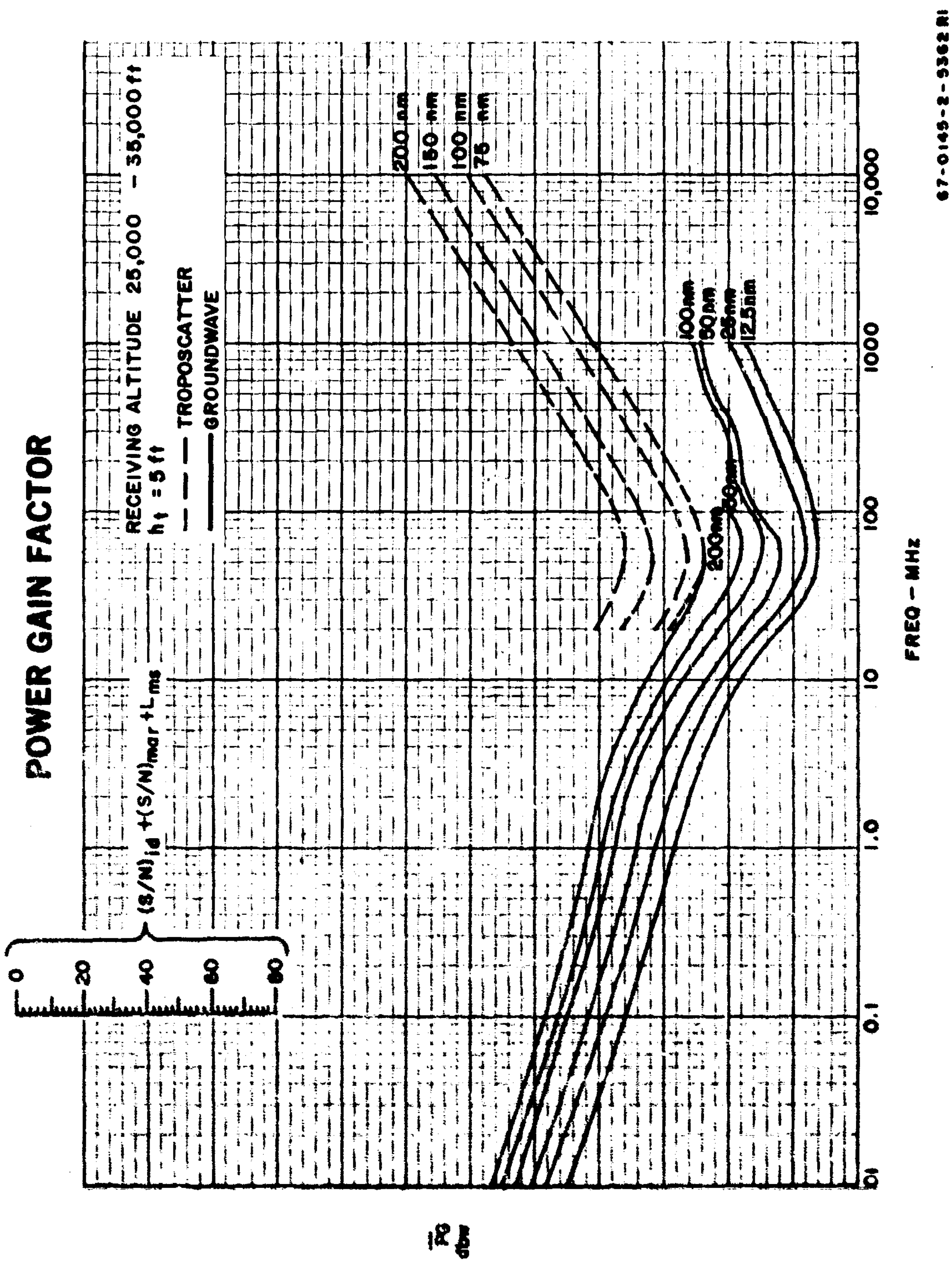


Figure 4-24. Curve A-p-1

RELIABILITY MARGIN

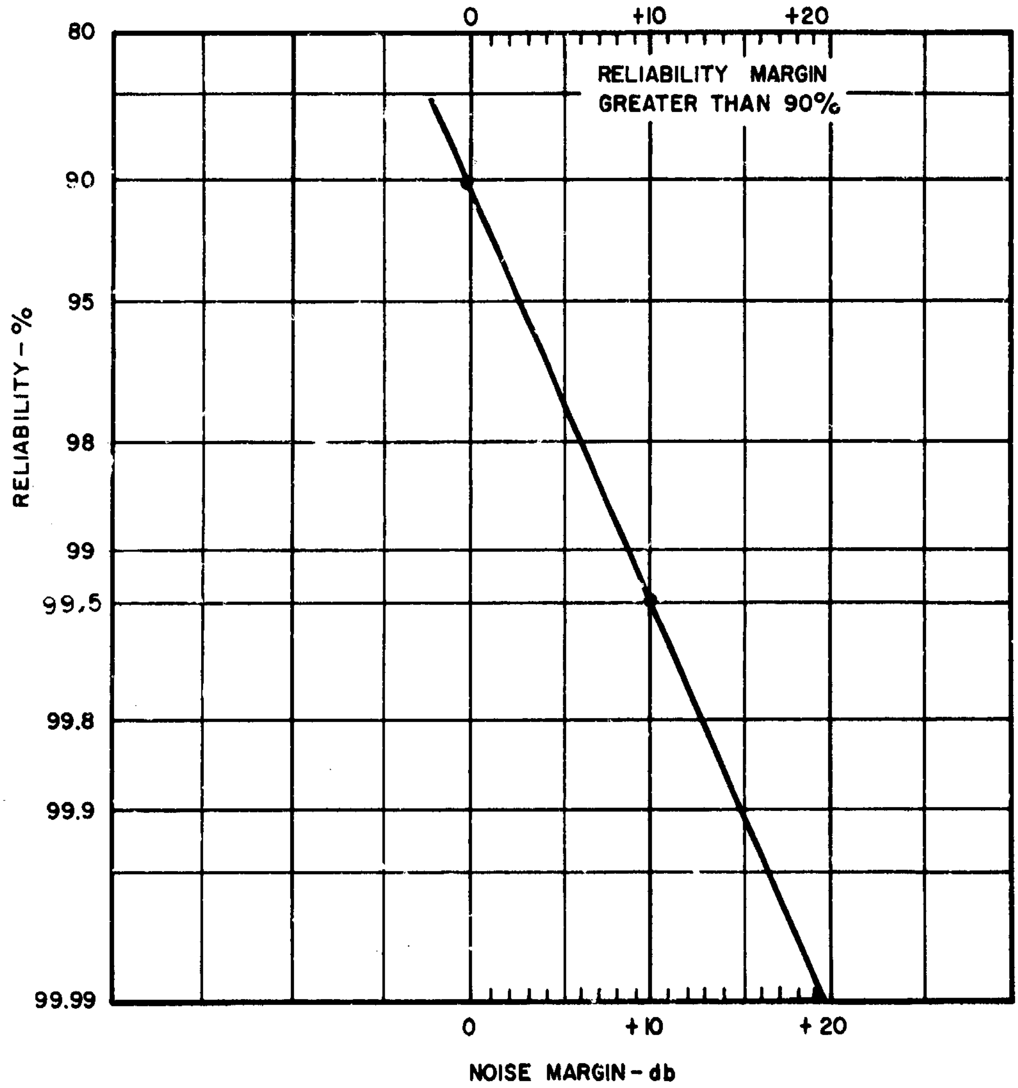


Figure4-25. Curve A-p-2

A-s-l Curve

This curve provides a comparison between various power source types in terms of watts per pound. Operating time is used as a criterion for presenting the relative efficiency. There are several other important criteria which must be considered including size and cost.

Since there are continuing improvements being made in power source design, any selection based on this curve should be checked against the latest technical developments.

TYPES OF BUOY POWER

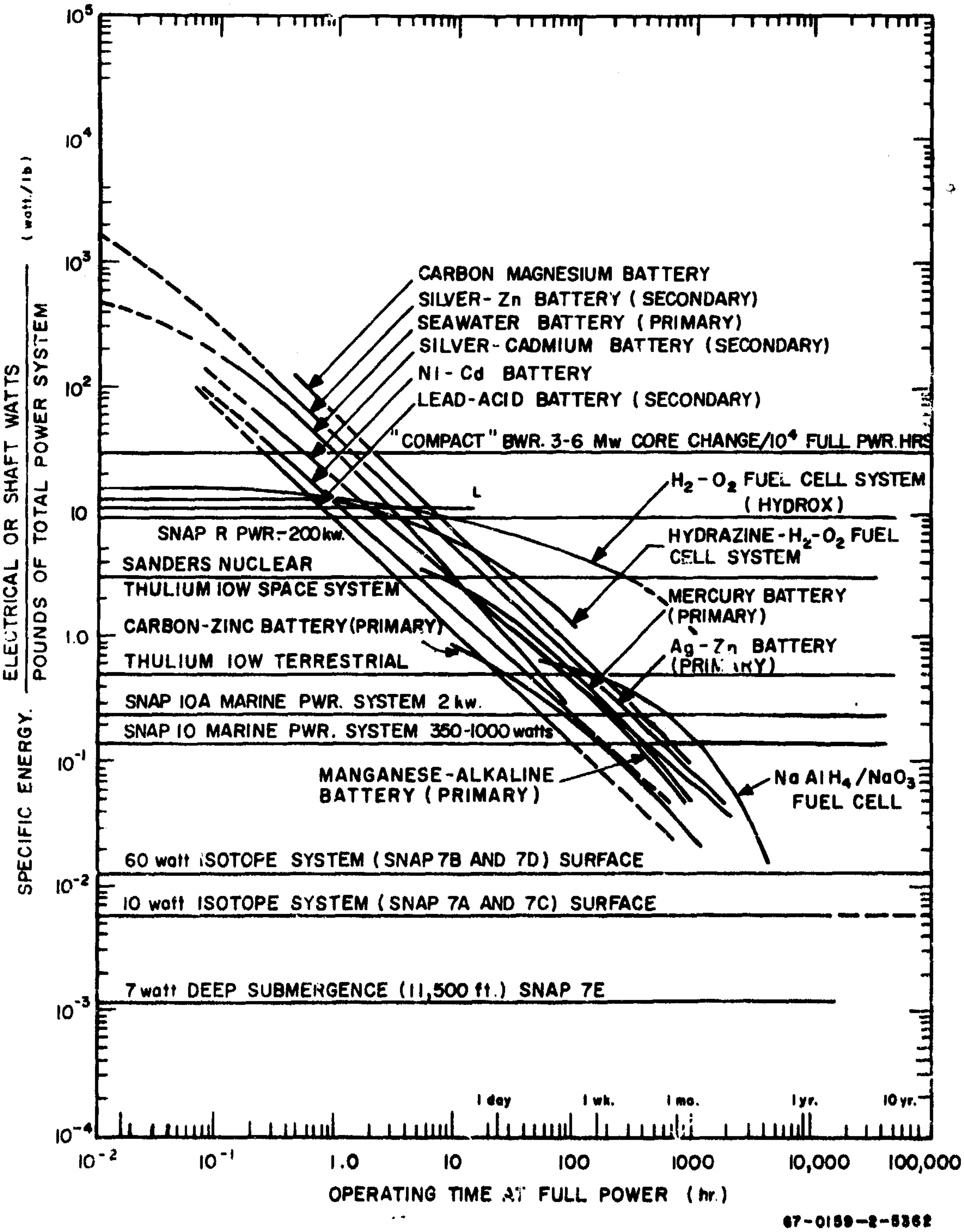


Figure 4-26. Curve A-s-1

TYPICAL ENERGY/VOLUME CURVES FOR SECONDARY BATTERY SYSTEM

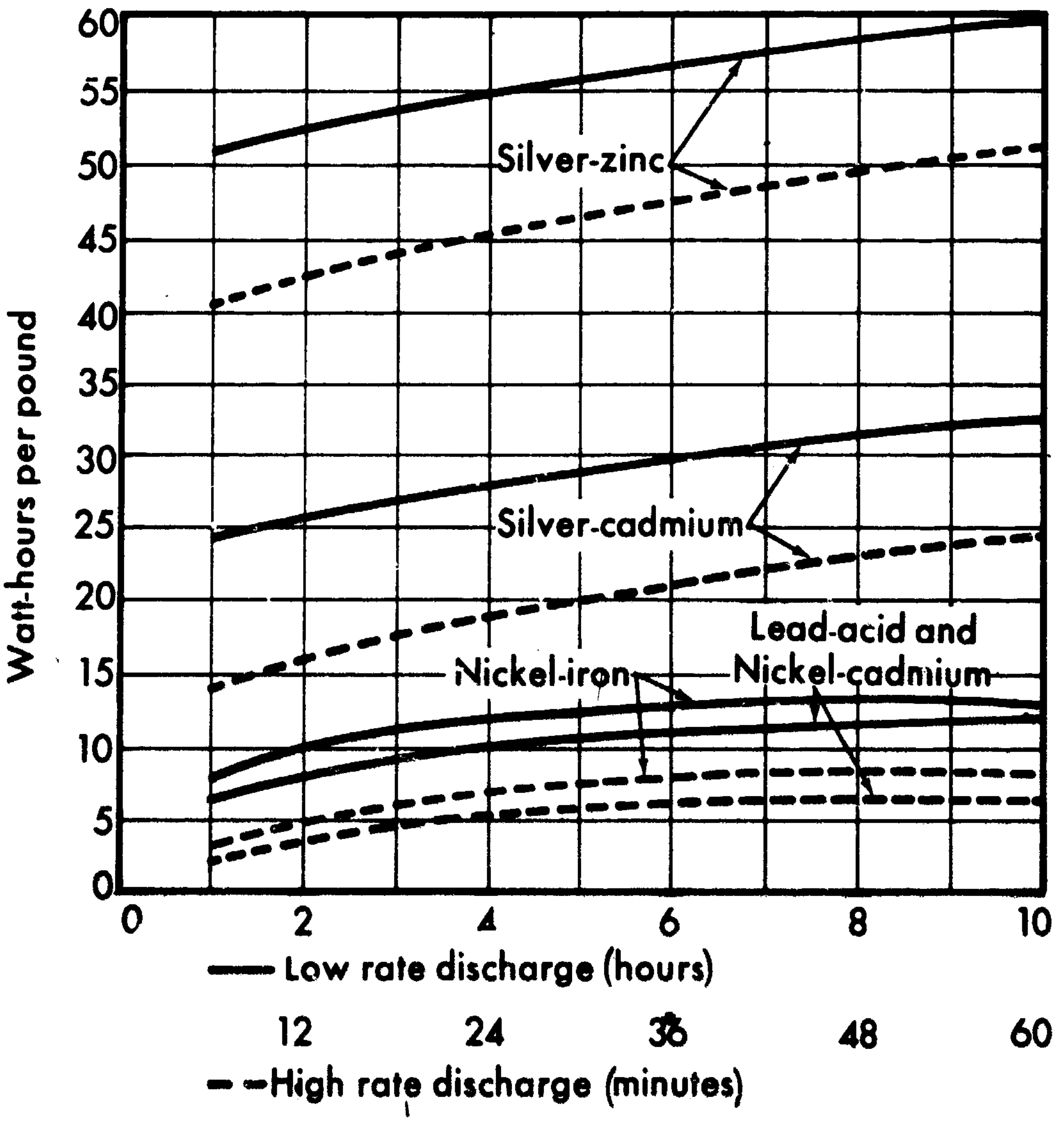


Figure 4-27. Curve A-s-2

TYPICAL ENERGY / WEIGHT CURVES FOR SECONDARY BATTERY SYSTEMS

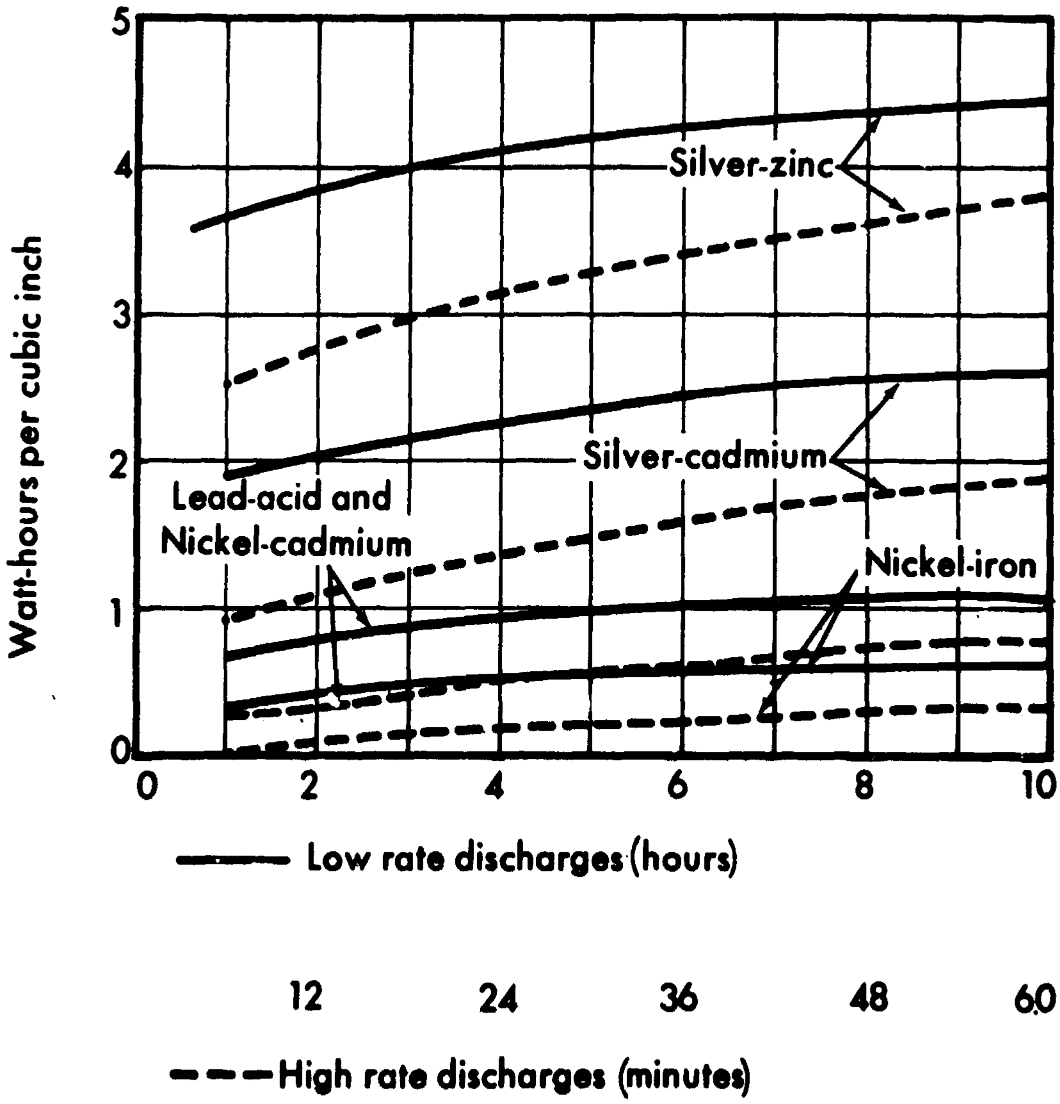


Figure 4-28. Curve A-s-3

Table 4-3. (A-s-4) Types of Primary and Secondary Batteries

		TYPE	ANODE	ELECTROLYTE	CATHODE	WATT-HOURS / LB	WATT-HOURS / CU-IN	SERVICE TEMPERATURE (DRY CELLS)	OPERATIONAL FACTORS
PRIMARY	Ready (dry)	Leclanche	Zn	$ClNH_4$ MnO_2 Cl_2Zn	C	10	1	30 to 90F	
		Mercury	Zn	KOH	HgO C	30	5.0	50 to 160F	
		Alkaline dry cell	Zn	KOH	MnO_2	47	2.2	40 to 90F	
		Magnesium cell	Mg	MgBr	MnO_2	50	3.3		
	Reserve (wet)	Lalande	Zn	NaOH CuO	CuO	20	0.94		
		Air cell	Zn	NaOH O_2-C	CuO	20	2.0		
		Water-activated cuprous-chloride	Mg	Water CuCl	CuCl	21	2.1		
		Water-activated silver-chloride	Mg	Water AgCl	AgCl	47	5.0		
		Silver-zinc	Zn	KOH	AgO	70	5.6		

Table 4-3. (A-s-4) Types of Primary and Secondary Batteries (Cont.)

	TYPE	ANODE	ELECTROLYTE	CATHODE	WATT-HOURS / LB	WATT-HOURS / CU-IN	SERVICE TEMPERATURE (DRY CELLS)	OPERATIONAL FACTORS
SECONDARY	Lead-acid	Pb	H_2SO_4 H_2O	PbO_2	12	1.1		Cannot be hermetically sealed.
	Nickel-iron (Edison)	Fe	KOH	NiO_2	13	0.7		
	Nickel-cadmium (Jungner)	Cd	KOH	NiO_2	12	1.1		Preferred cell for most applications. Good recharge characteristics.
	Silver-zinc	Zn	KOH	AgO	59	4.4		Performance limited by rapid degradation - new developments may improve life.
	Silver-cadmium	Cd	KOH	AgO	32	2.6		Limited ability to accept high charge rates.

Table 4-3.(A-s-4) Types of Primary and Secondary Batteries (Cont.)

	TYPE	ANODE	ELECTROLYTE	CATHODE	WATT-HOURS / LB	WATT-HOURS / CU-IN	SERVICE TEMPERATURE (DRY CELLS)	OPERATIONAL FACTORS
SECONDARY	Lead-acid	Pb	H_2SO_4 H_2O	PbO_2	12	1.1		Cannot be hermetically sealed.
	Nickel-iron (Edison)	Fe	KOH	NiO_2	13	0.7		
	Nickel-cadmium (Jungner)	Cd	KOH	NiO_2	12	1.1		Preferred cell for most applications. Good recharge characteristics.
	Silver-zinc	Zn	KOH	AgO	59	4.4		Performance limited by rapid degradation - new developments may improve life.
	Silver-cadmium	Cd	KOH	AgO	32	2.6		Limited ability to accept high charge rates.

BATTERY PERFORMANCE AT SEA TEMPERATURES

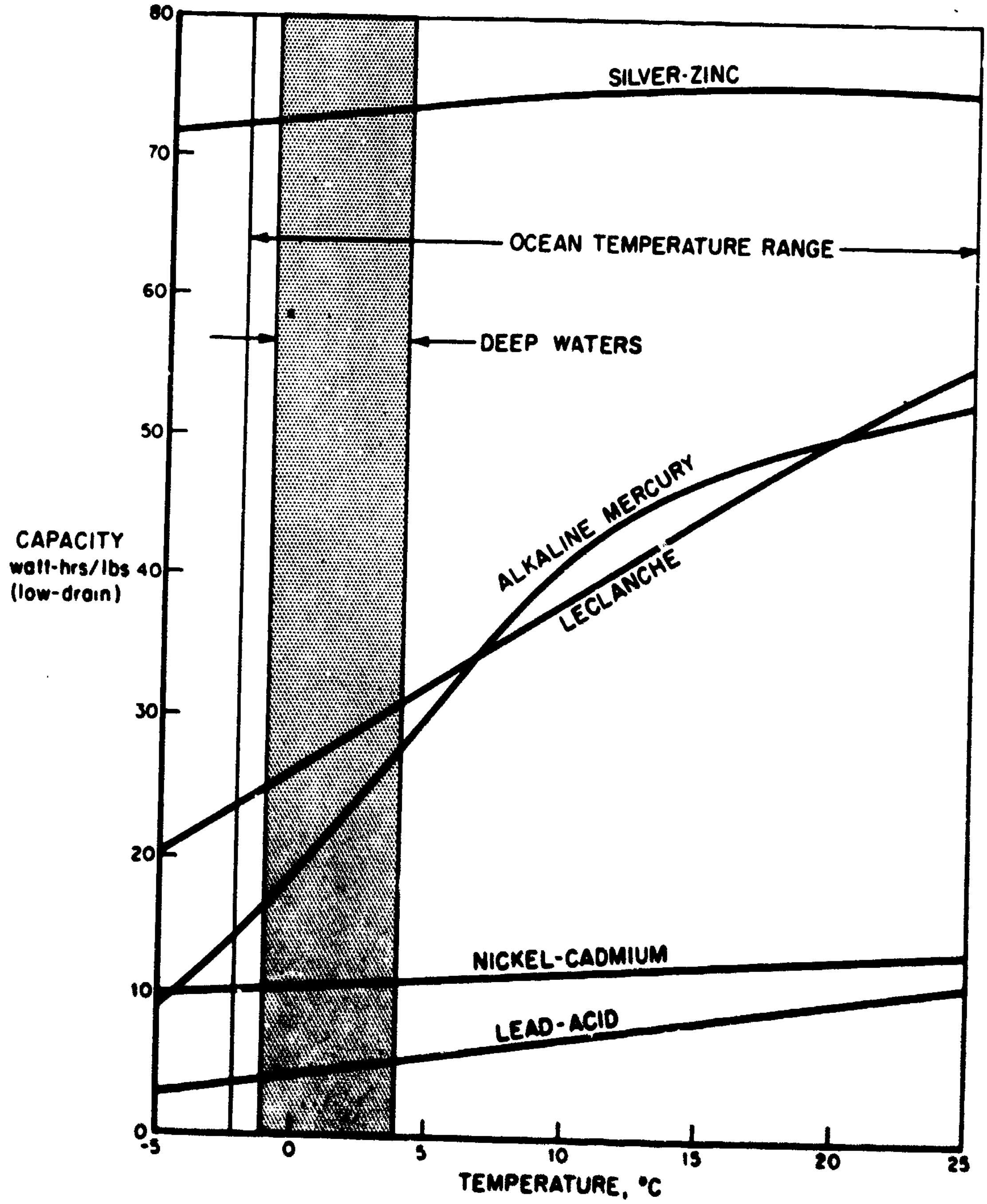


Figure 4-29. Curve A-s-5

Table 4-4 (A-3-6)

Fuel Cells

Type	Manufacturer	lbs/kw	Size	Efficiency
H_2-O_2 Ion-exchange membrane	General Electric	70(lge. cap. units)	Backpack-200W at 24V 30# fuel cell power pack 2.5 cu. ft. / use 6 lb. fuel canister for 14 hours operation	51%
Modified "Bacon"	Pratt & Whitney	150 to 200	--------	61%
Low temperature alkaline	Allis-Chalmers	80 - 90	--------	57%
Na OH	General Electric	250 w.h/#	250 lbs 14.1 cu. ft.	------
Hydrazine NH_4	Monsanto	--------	60 watts 12 pound back-pack .9 cu. ft.	------

Table 4-5 (A-$-7)

Isotope Fueled Systems

Type/Isotope #1 kw	Watts/lb.	Representative Operational Size
Sanders Nuclear Thulium 170 (Terrestrial)	range .5 to 3	10 watts, approximately 1 cu. ft. and 20 pounds 1 year life
Sanders Nuclear STEP II (Space)	3	10 watts, 5 years, 3 pounds
SNAP 7A/7C Strontium 90 (Terrestrial)	.005	10 watts, 20 (dia.) x 21 inches weight 1870 pounds
SNAP 7B/7D Strontium 90 (Terrestrial)	.013	60 watts 22 (dia.) x 34 1/2 inches weight 4600 pounds
SNAP 9A Plutonium -238 (Space)	.92	25 watts 20 (dia.) x 9 1/2 inches weight 27 pounds
SNAP 11 Curium-242 (Space)	.78	21-25 watts 6 (dia.) x 9 inches weight 30 pounds
SNAP 13 Curium-242 (Space)	3	12 watts 2 1/2 (dia.) x 4 inches weight 4 pounds
SNAP 17 Strontium-90 (Space)		25 watts
SNAP 19 Plutonium-238 (Space)		20 watts
SNAP 21 Strontium-90 (Terrestrial)		10 watts

SLOW FADING MARGIN

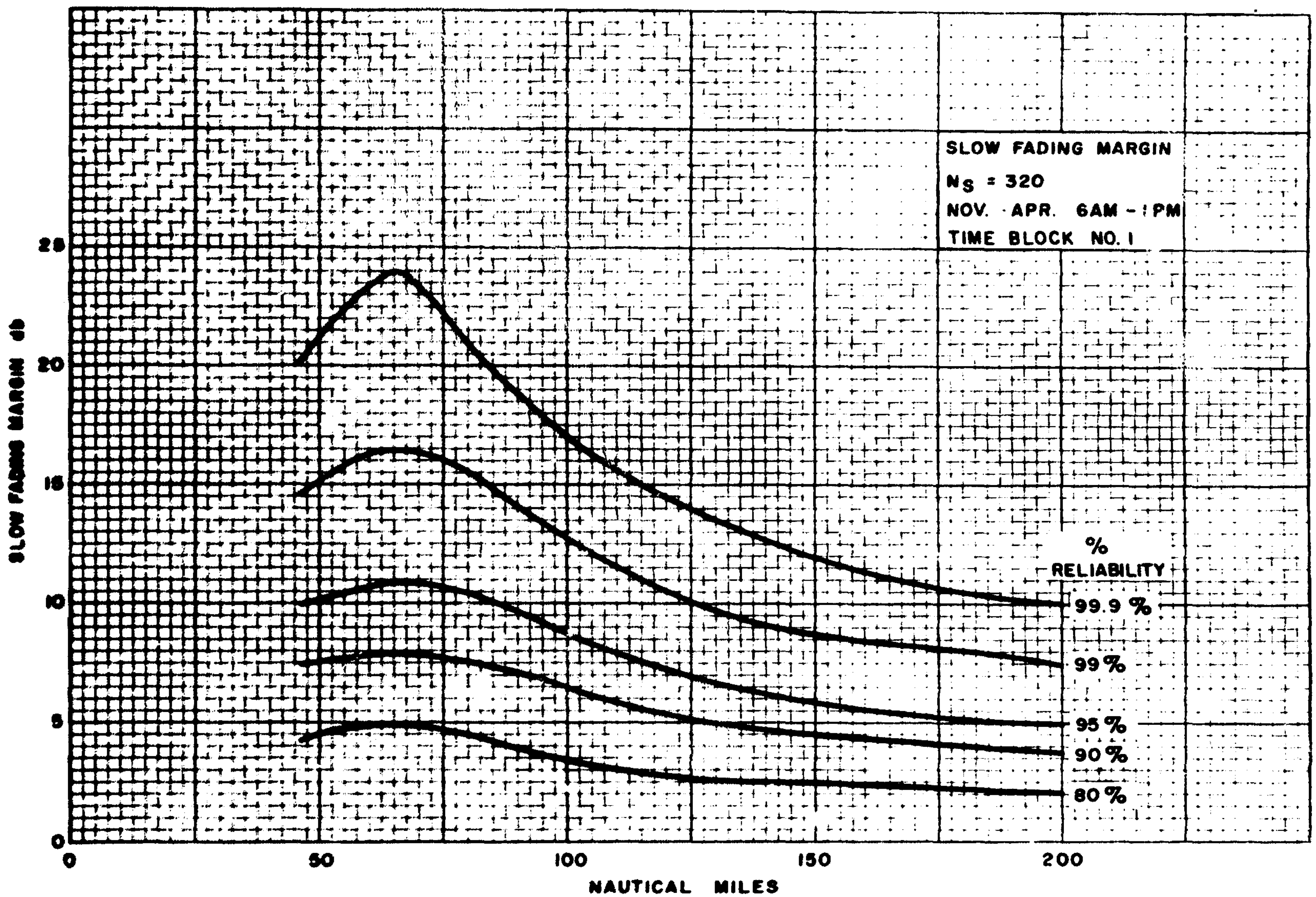


Figure 4-30. Curve A-t-I

DUAL DIVERSITY DISTRIBUTIONS N=2

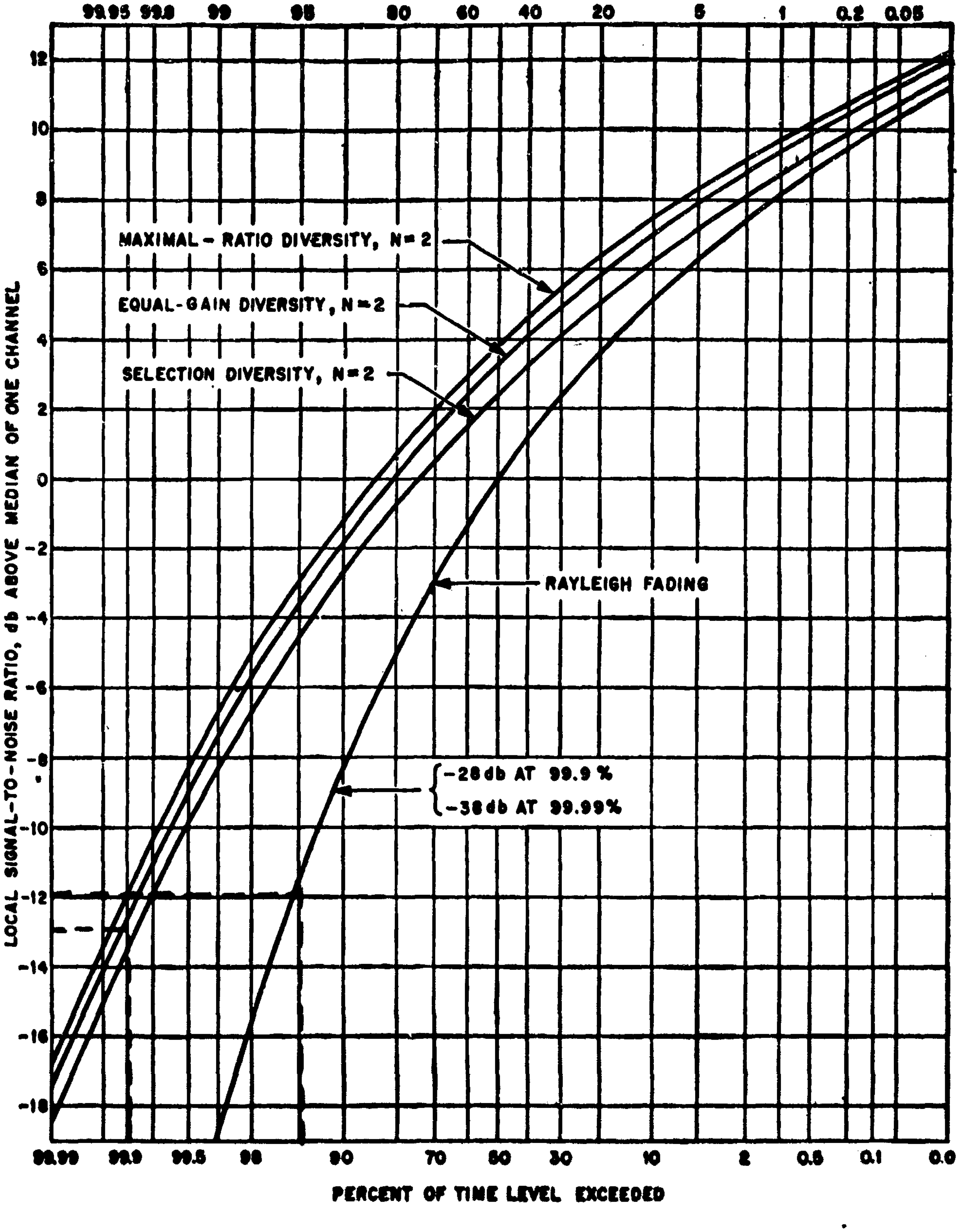


Figure 4-31. Curve A-t-2

DIVERSITY CURVE N=3

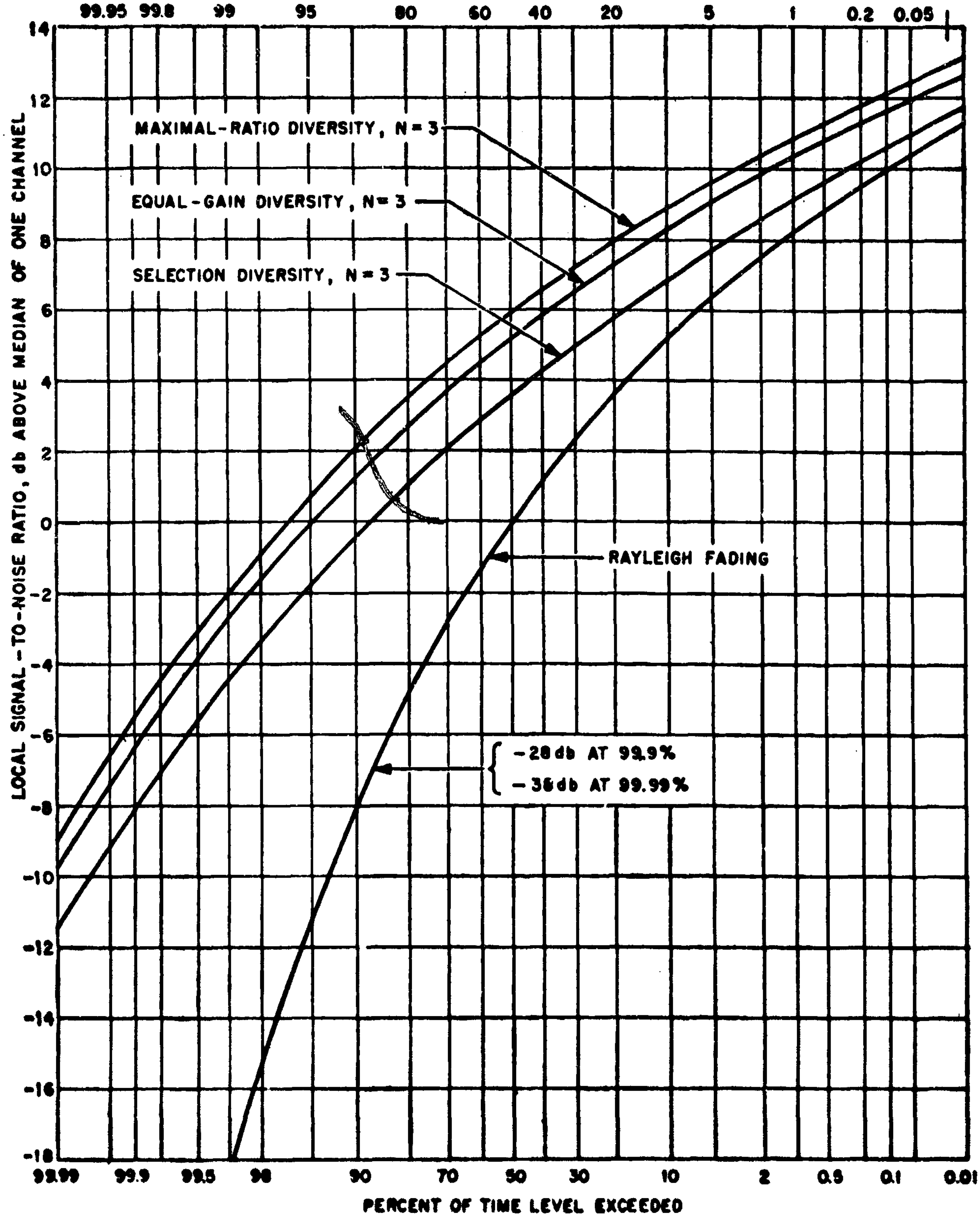


Figure 4-32. Curve A-t-3

DIVERSITY CURVE N=4

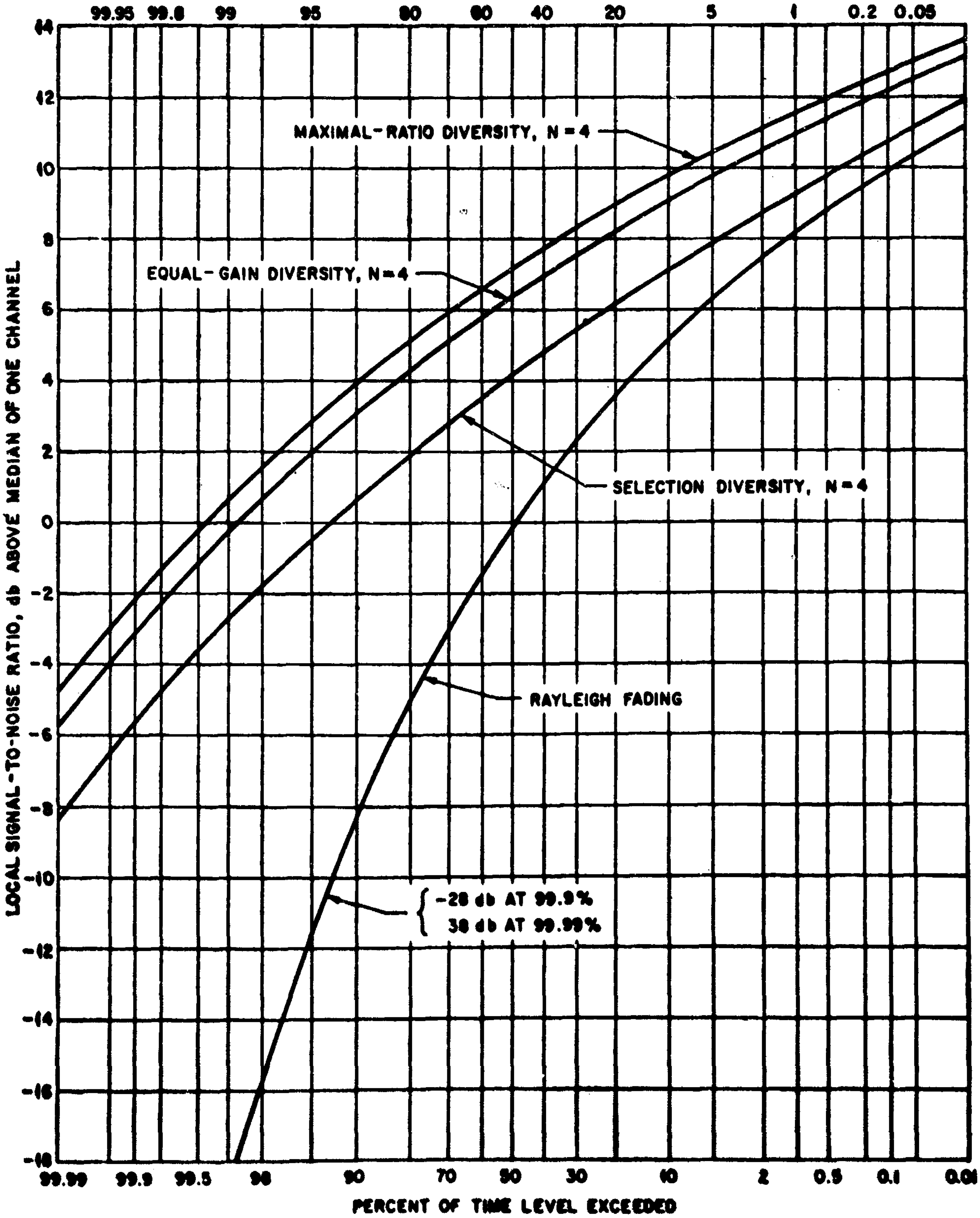


Figure 4-33. Curve A-t-4

DIVERSITY CURVE N=6

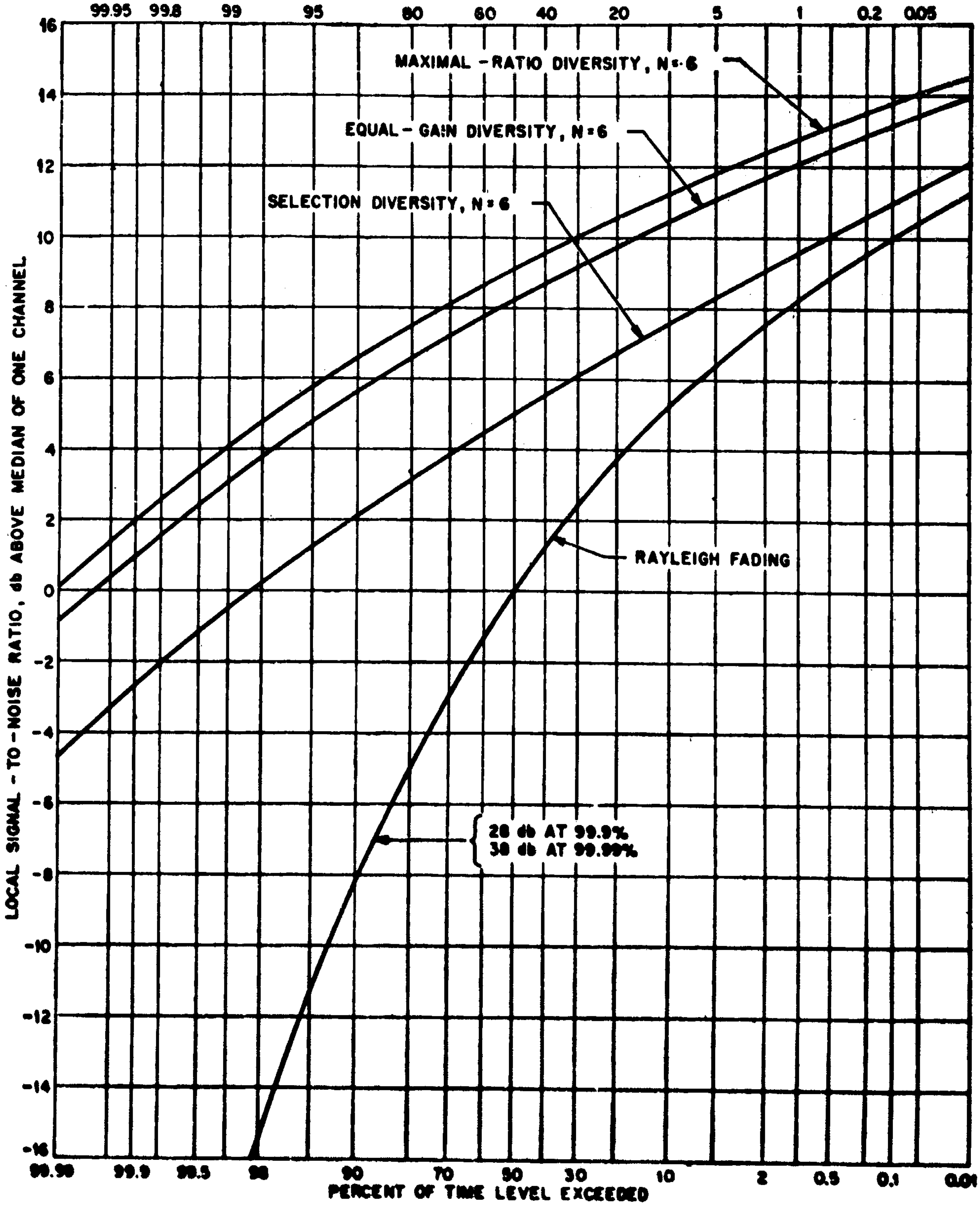


Figure 4-34. Curve A-t-5

DIVERSITY CURVE N=8

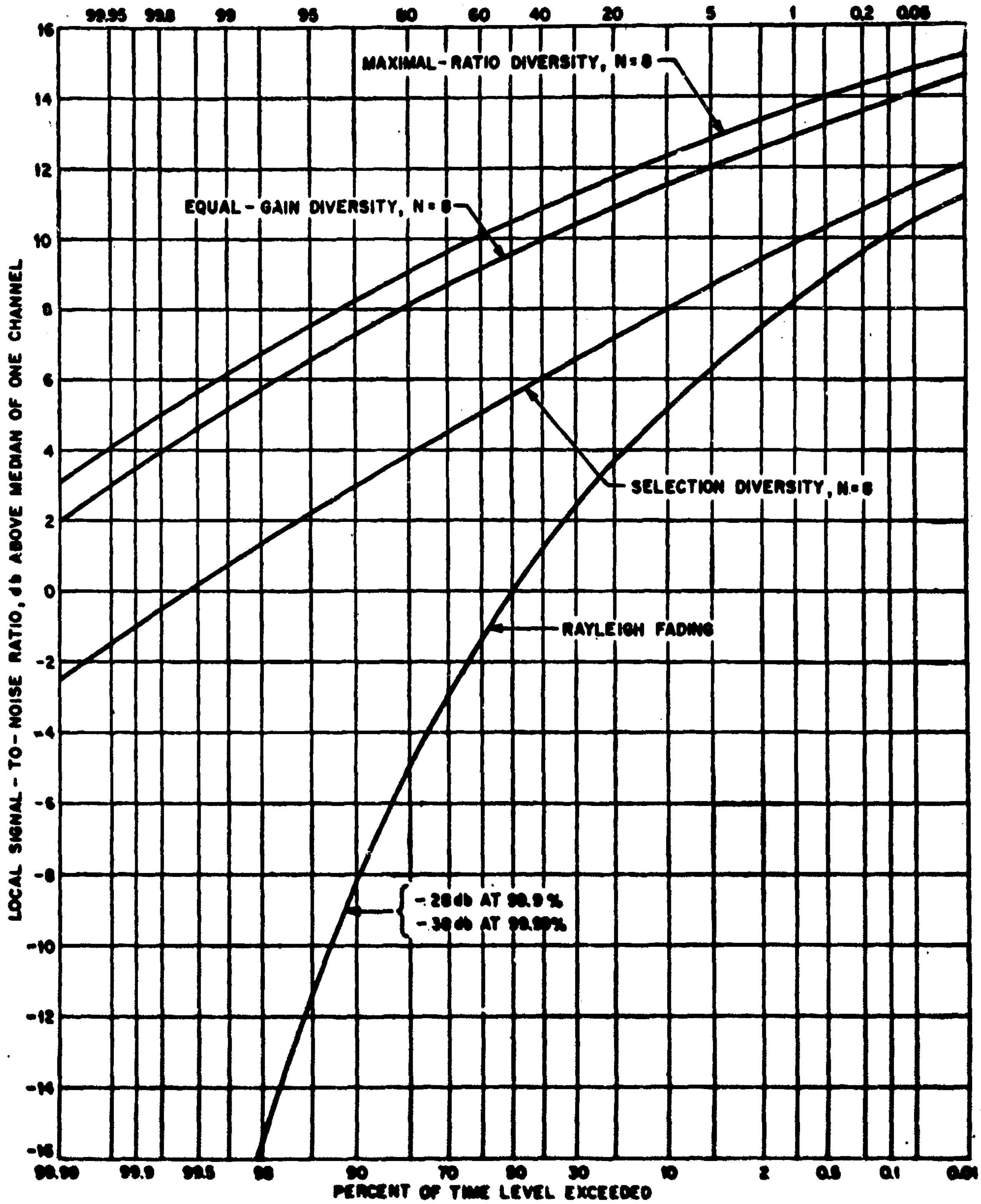


Figure 4-35. Curve A-t-6

FADING MARGIN WITH SELECTOR DIVERSITY

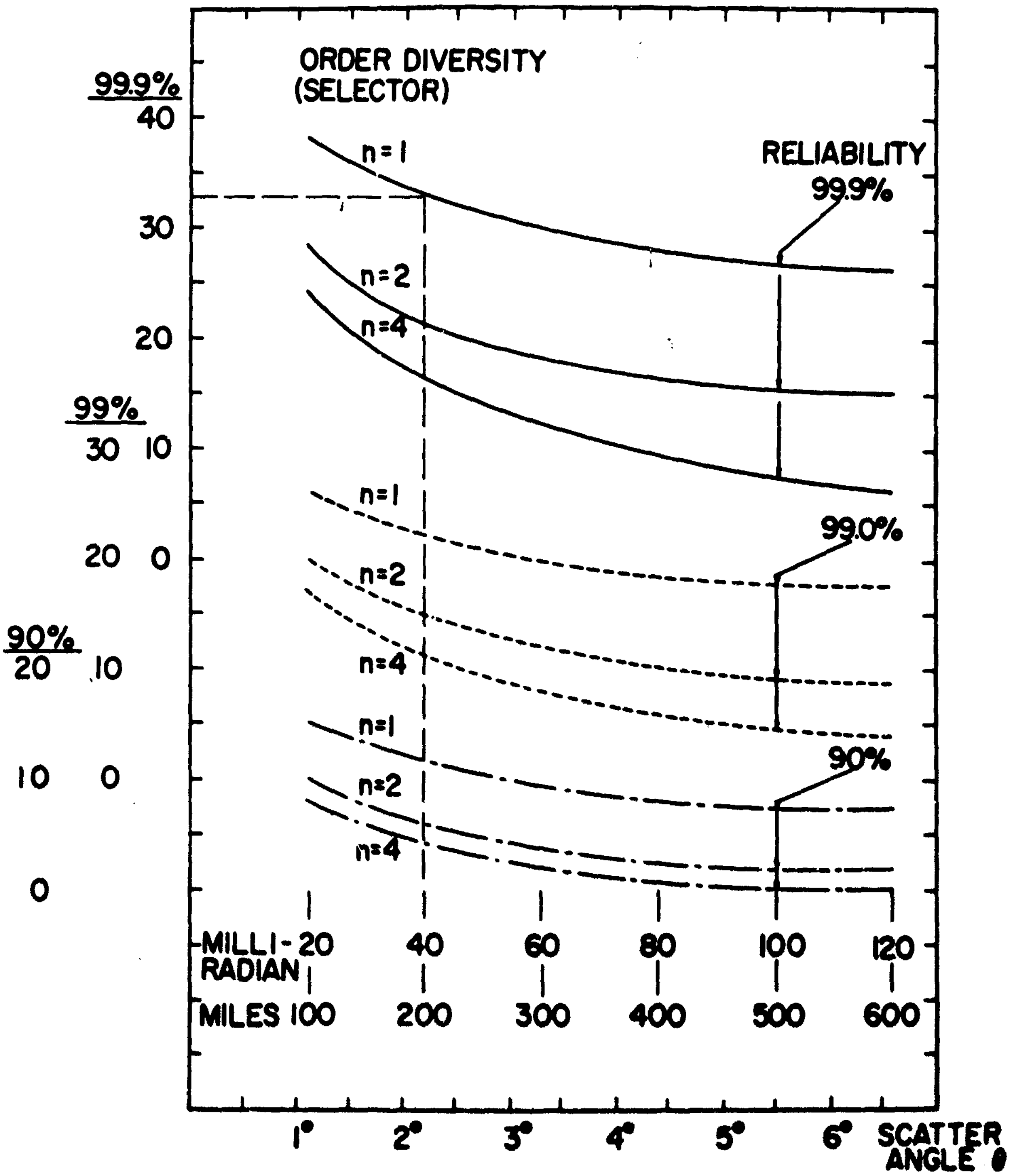


Figure 4-36. Curve A-t-7

Curve B-m-2.1

The relative bandwidth*, $B/\Delta f$, is plotted for different deviation ratios. Since the FM modulation spectrum contains frequency components of varying orders of magnitude, the bandwidth may be defined as containing all frequencies greater than some specified amplitude or as including all components which are greater than a specified power level. For example, a high quality demodulated signal with very low distortion would be obtained from a circuit with a bandwidth which passed all frequencies of the spectrum less than -40 db down from the peak frequencies. This is the basis for curve 3 on the following page.

Other bandwidths may be used based on including all frequencies greater than -30 db., down, curve 2, and -20 db down, curve 1. Curve 1 corresponds to the commonly used expression for FM bandwidth:

$$B_{IF} = 2 f_b (m + 1)$$

f_b - maximum modulation frequency

m - deviation ratio (index of modulation)

* Refers to pre-demodulation or intermediate frequency amplifier bandwidth (See discussion 4.3.3)

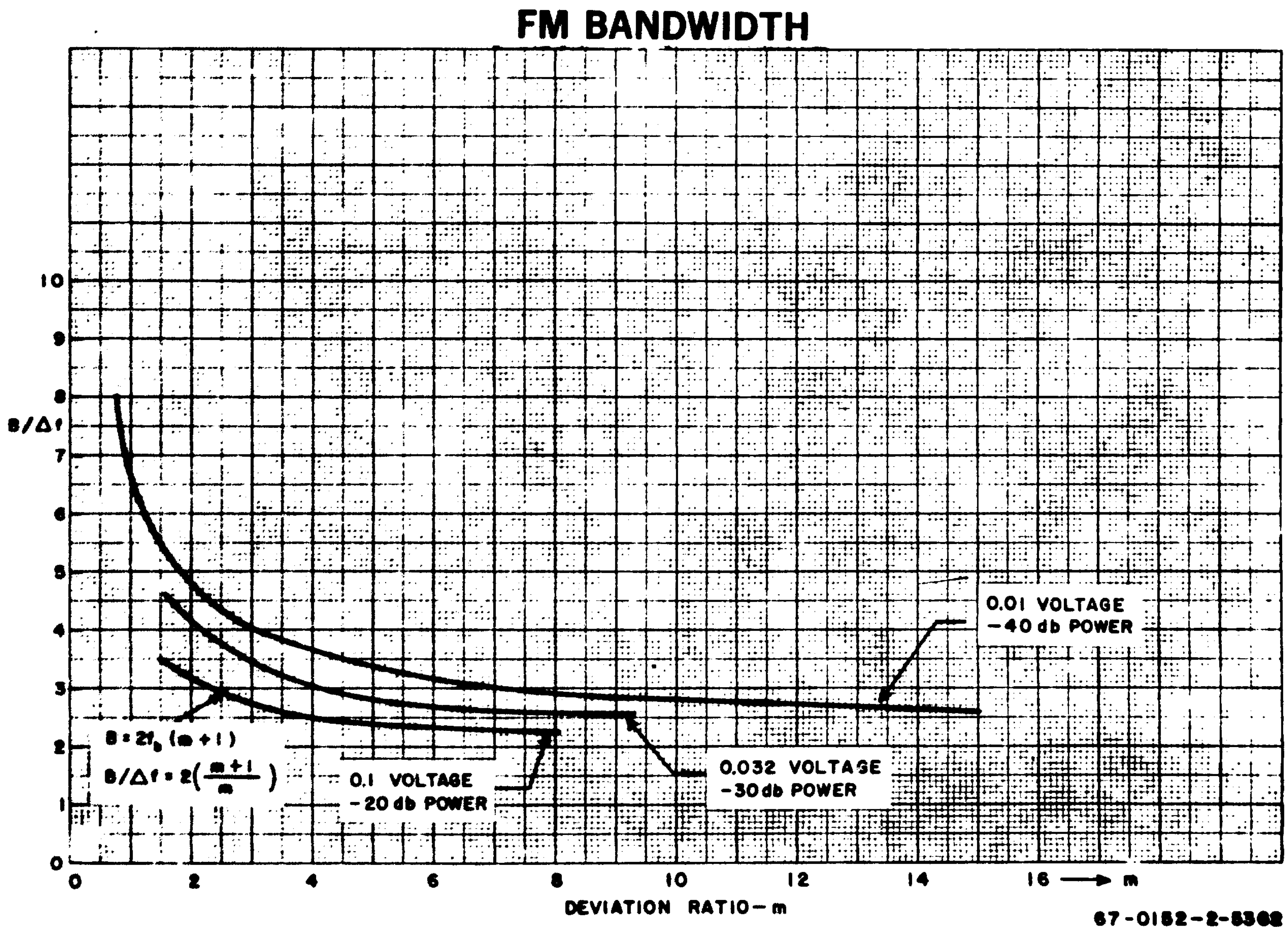


Figure 4-37. Curve B-m-2.1

Curve B-m-2.2

This curve shows the FM threshold for a conventional* FM demodulator. The threshold point is selected at the "knee" of the FM improvement curve (A-m-1). Other types of demodulators are considered by Akima**.

*A conventional FM demodulator uses a limiter and discriminator circuit.

**Akima, H., "Theoretical Studies on the Signal-to-Noise Characteristics of an FM System", IEEE Transactions on Space Electronics and Telemetry, December 1963.

THRESHOLD LEVEL (NOISE IN 2X BASEBAND)

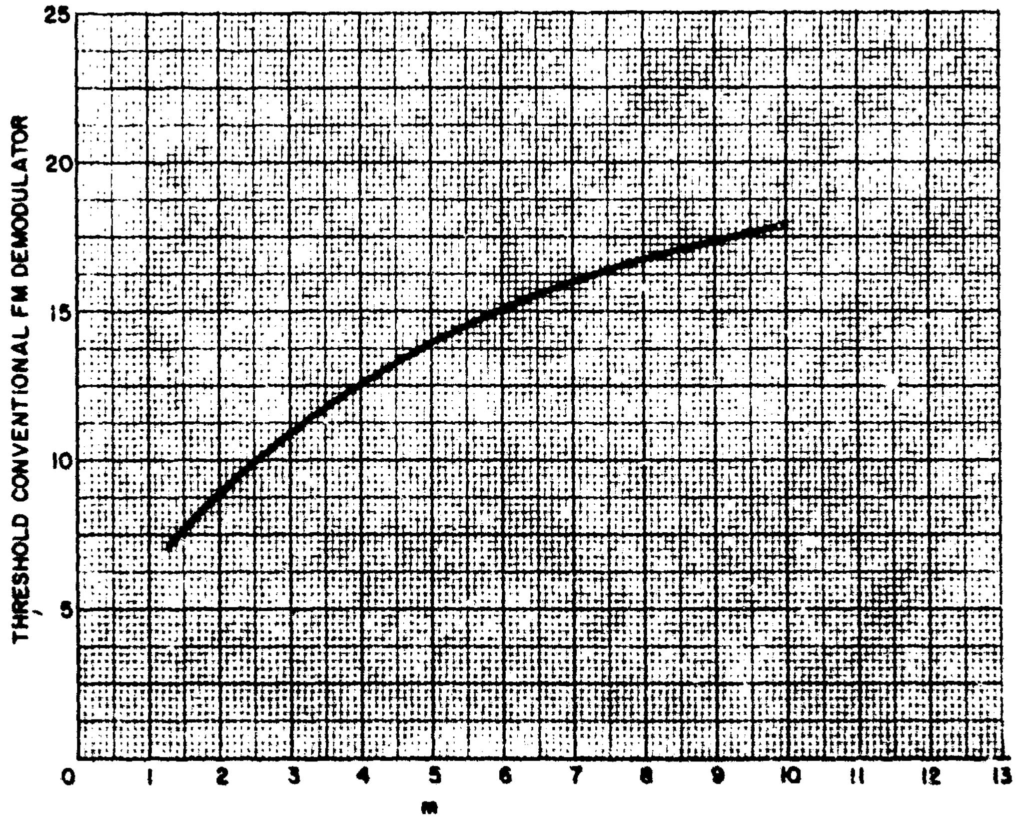


Figure 4-38. Curve B-m-2.2

Curves B-p-1.1

This series of curves gives the propagation loss as a function of frequency and range for seven different altitudes of the receiving antenna. The ground wave mode calculations consider surface wave, direct wave, and reflected wave components. The graph, of free space propagation loss curves, B-p-1.4, for comparison. Ground wave loss was calculated using a computer program* supplied by the National Bureau of Standards.

Troposcatter loss is based on a simplified method of Yeh.** Considering the range and accuracy required for the intended operations of this report, these curves for troposcatter loss are valid.

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*L. Berry and M. Chrisman, "A Fortran Program for Calculations of Ground Wave Propagation over Homogeneous Spherical Earth for Dipole Antennas", NBS Report 9178, National Bureau of Standards, March 1966.

**L. Yeh, "Simple Method for Designing Troposcatter Circuits", IRE Transactions on Communication Systems, September 1960.

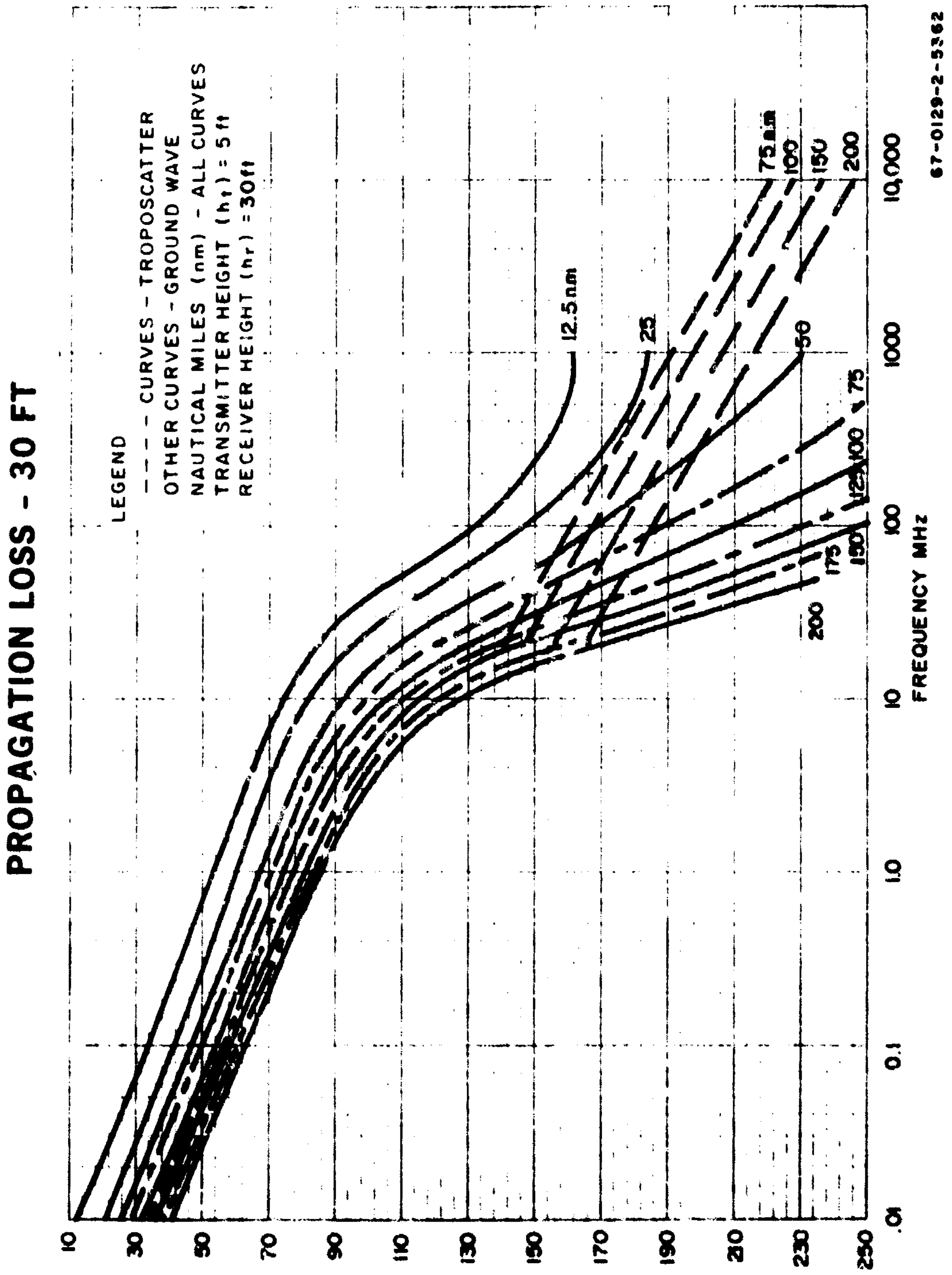

Figure 4-39. Curve B-p-1.1

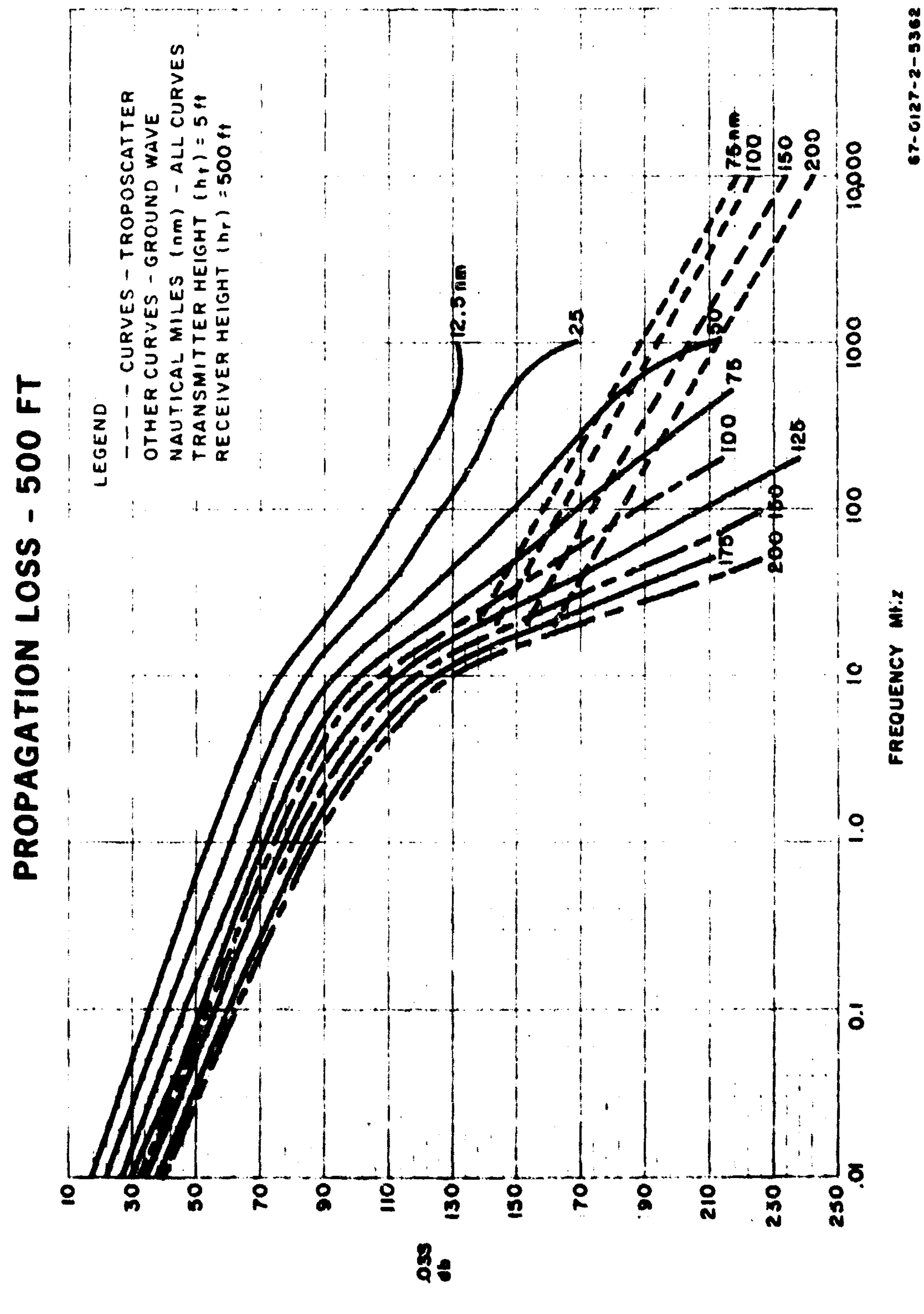

Figure 4-40. Curve B-p-1.1

PROPAGATION LOSS - 5,000 FT

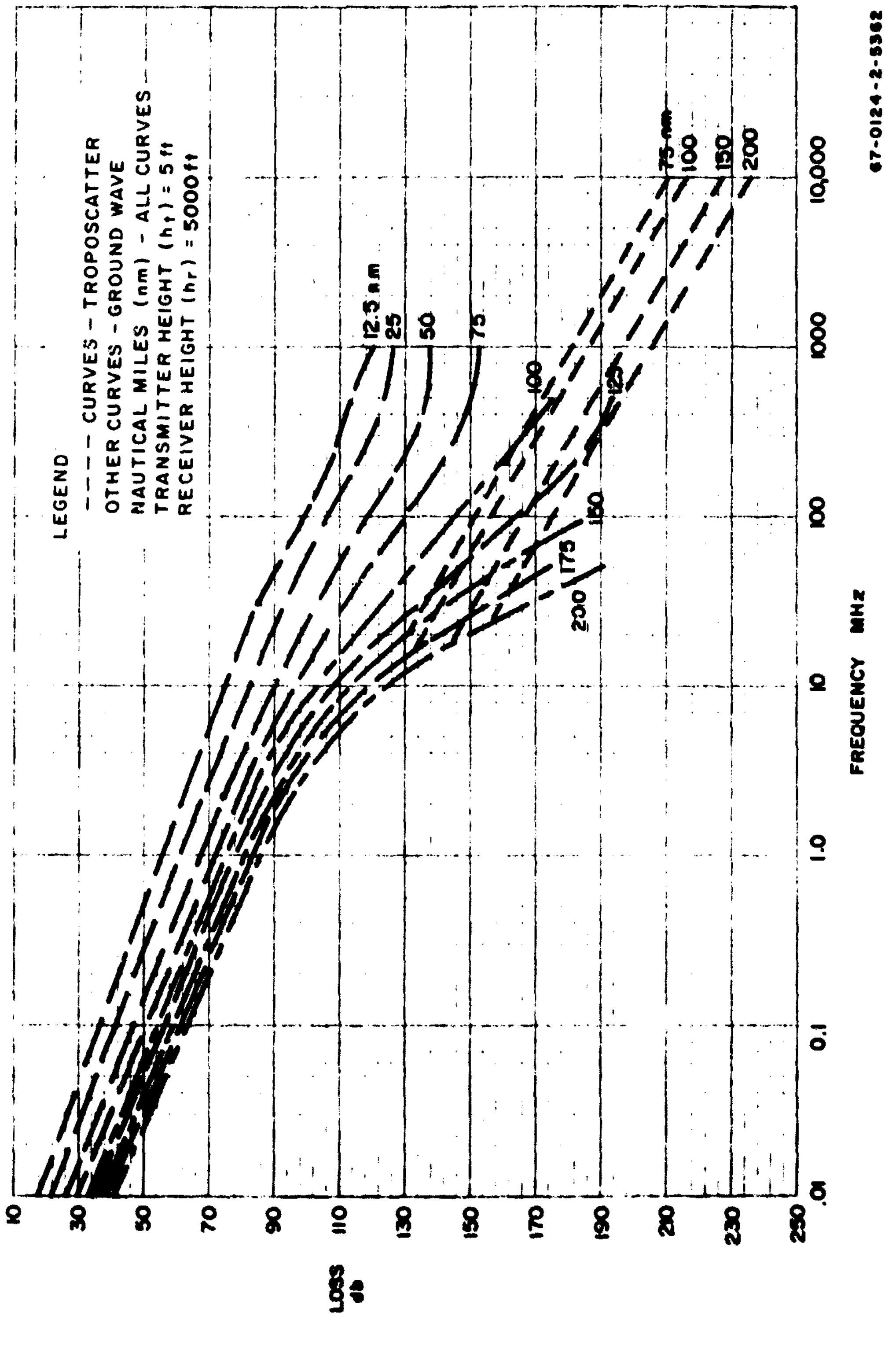

Figure 4-41. Curve B-p-1.1

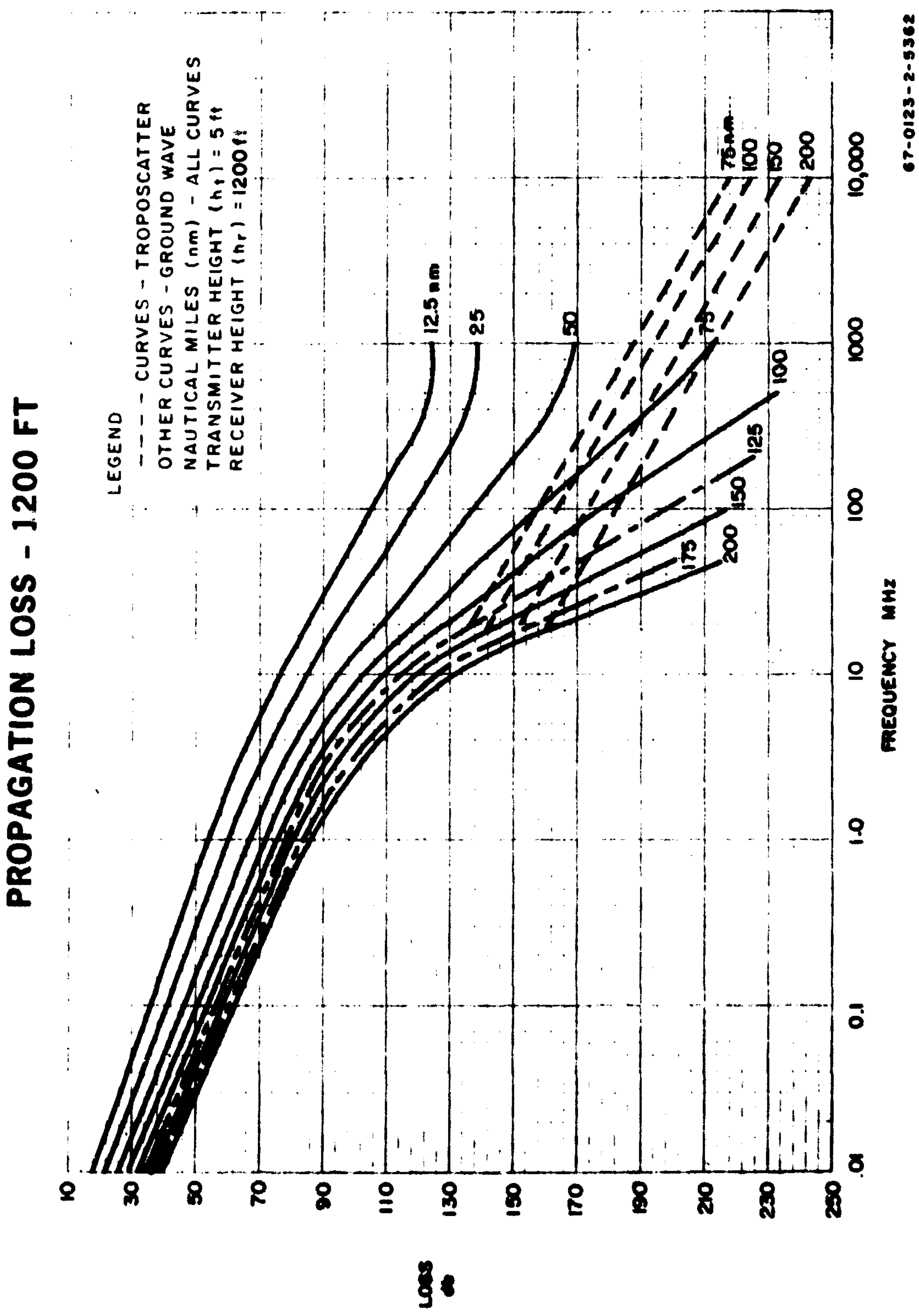

Figure 4-42. Curve B-p-1.1

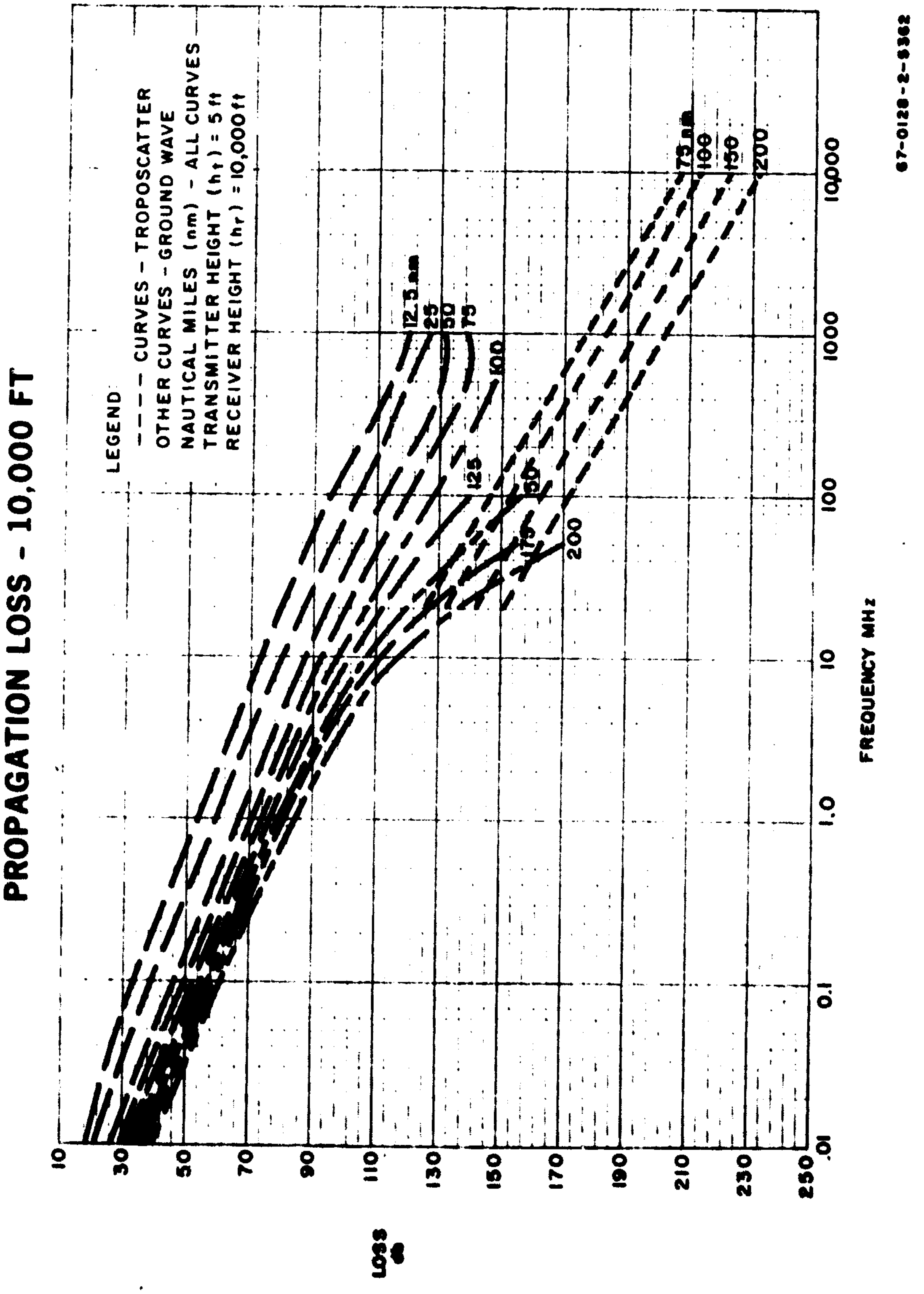

Figure 4-43. Curve B-p-1.1

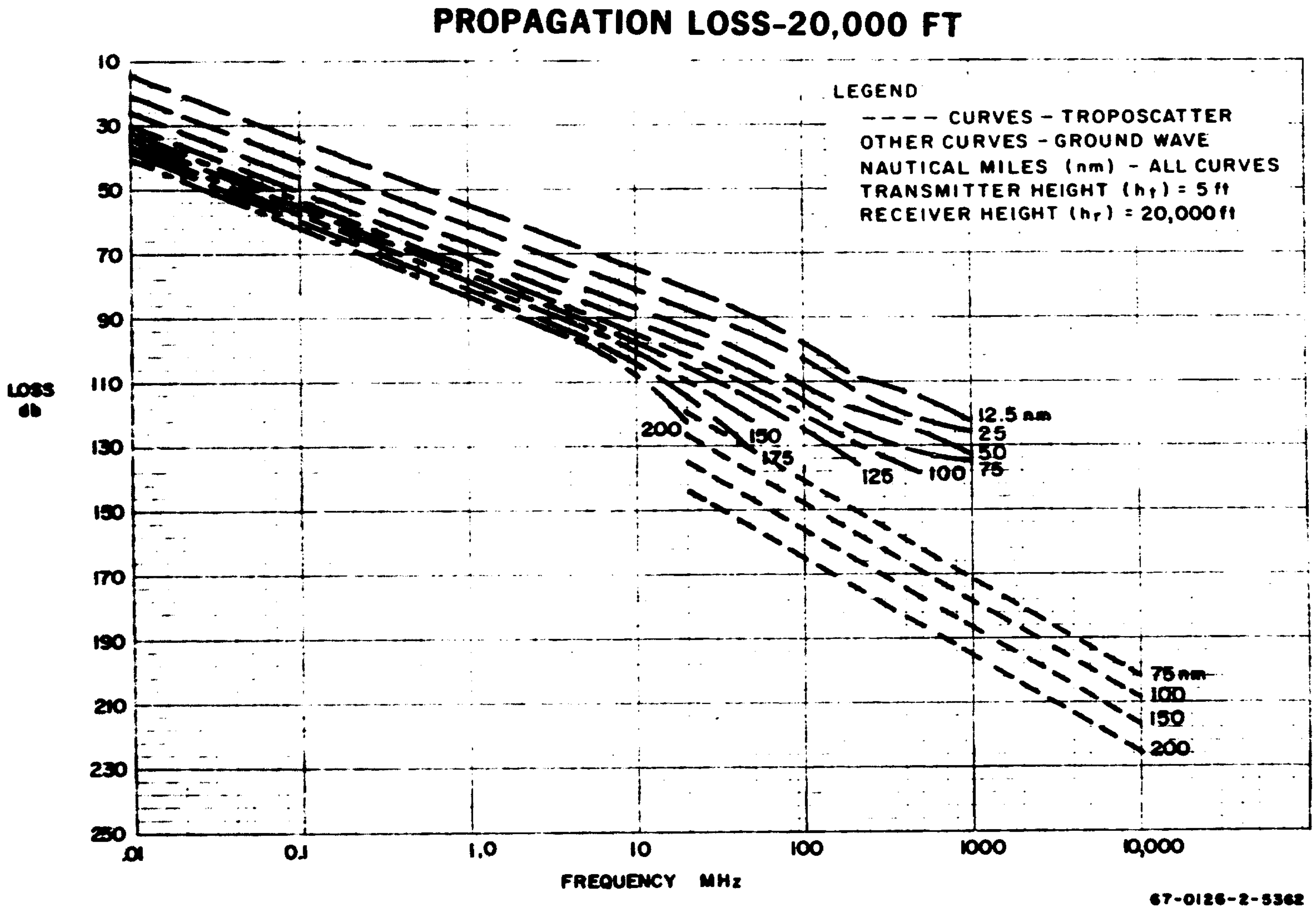

Figure 4-44. Curve B-p-1.1

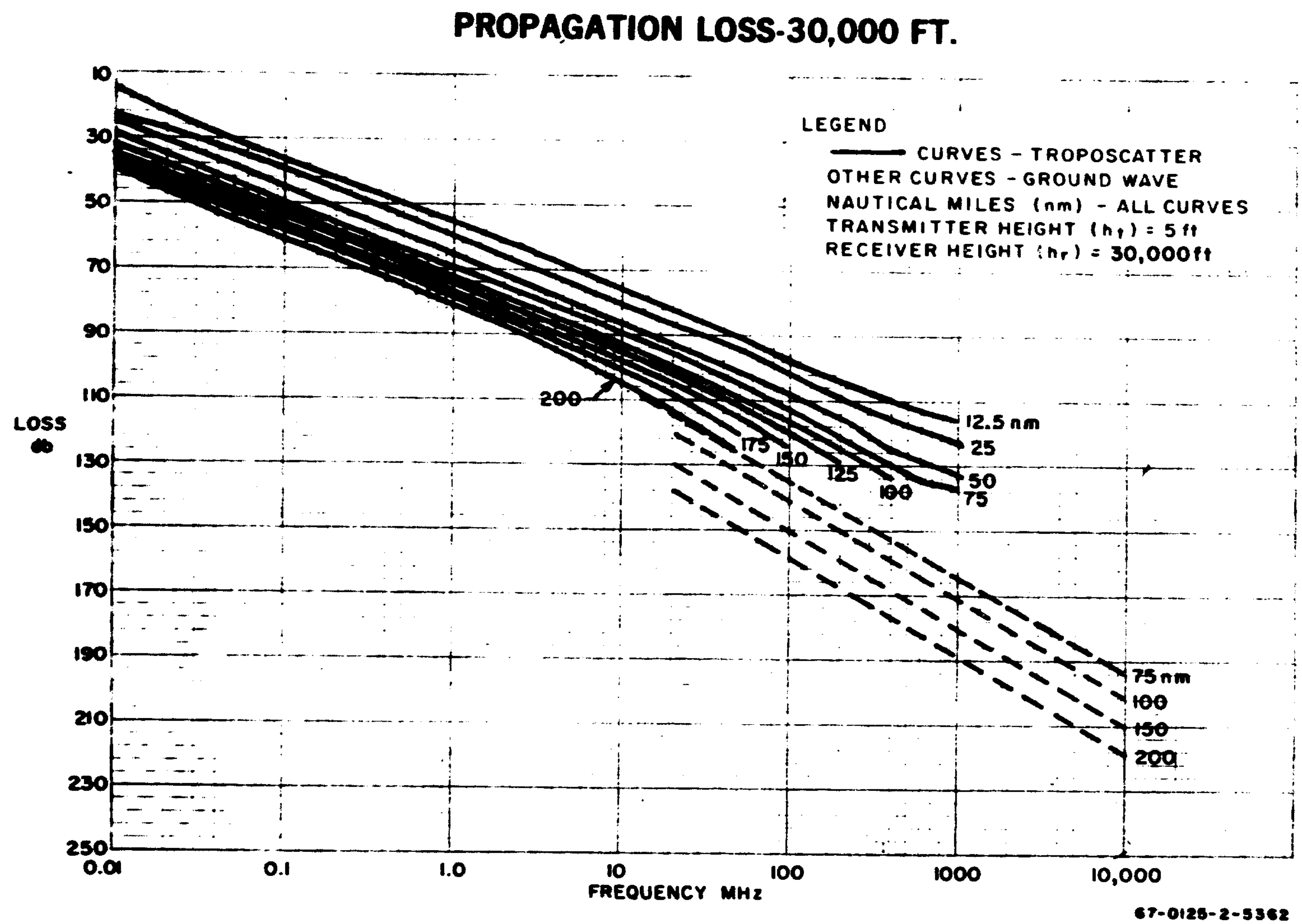

Figure 4-45. Curve B-p-1.1

Curve B-p-1.2

This curve gives the operating noise figure*, F, of the transmission equation and is a composite of the atmospheric, galactic, and receiver noise level over a 0.01 MHz to 10 GHz frequency range. Below approximately 50 MHz, the atmospheric and galactic noise levels are dominant. The levels used in this curve are the upper limits of the median value of the atmospheric noise**. The noise levels which can be expected from current transistors and diode mixers are indicated on the graph. The composite noise level curve is approximately 4 db higher. This is a result of allowing 2 db for line losses and 1.5 db for antenna efficiency in the calculation of the operating noise figure. This level is conservative but is sufficient to account for line losses and component degradation, which might normally be encountered. Atmospheric noise is the dominant component in the operating noise figure at frequencies below 30 MHz. At frequencies above 30 MHz, large variations from the line loss and component degradation values used should be accounted for in the Lms term of the transmission equation. Also receiver noise figures differ considerably from the transistor diode noise figure curve and must be accounted for.

Example: Line Loss

Line losses (both transmitter and receiver) >2 db

add as ΔL_1 term of L_{ms} Component Degradation

Component degradation including antenna efficiency >1.5 db

add as ΔLc term of L_{ms}.

Similarly, variations which differ by more than 1 or 2 db from the transistor and diode mixer noise figure values shown on the graph should be accounted for in the ΔN term of L_{ms}.

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*See section B of appendix for discussion of the operating noise figure.

**CCIR Report #322, World Distribution and Characteristics of Atmospheric Radio Noise.

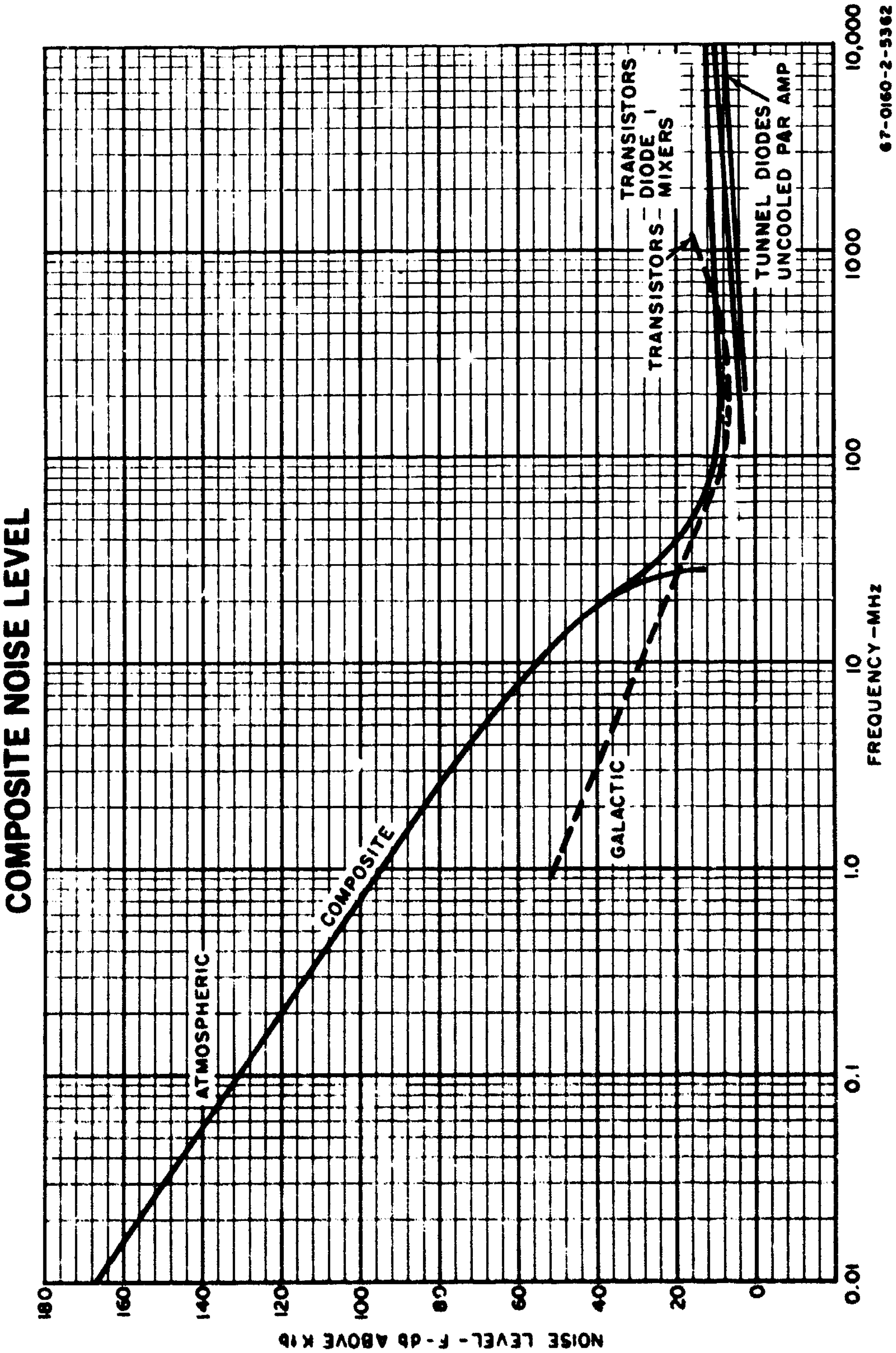


Figure 4-46. Curve B-p-1.2

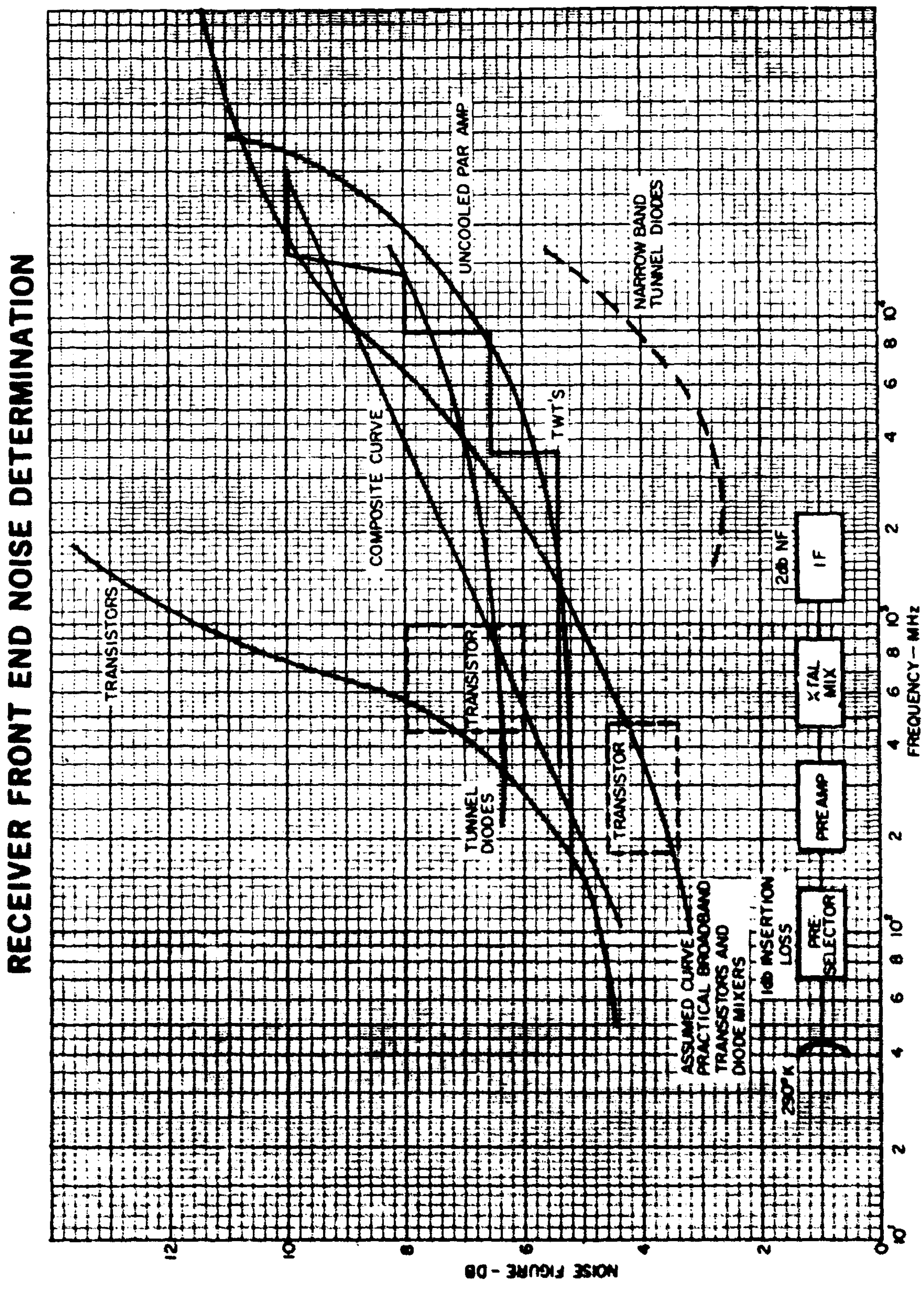


Figure 4-47. Curve B-p-1.3

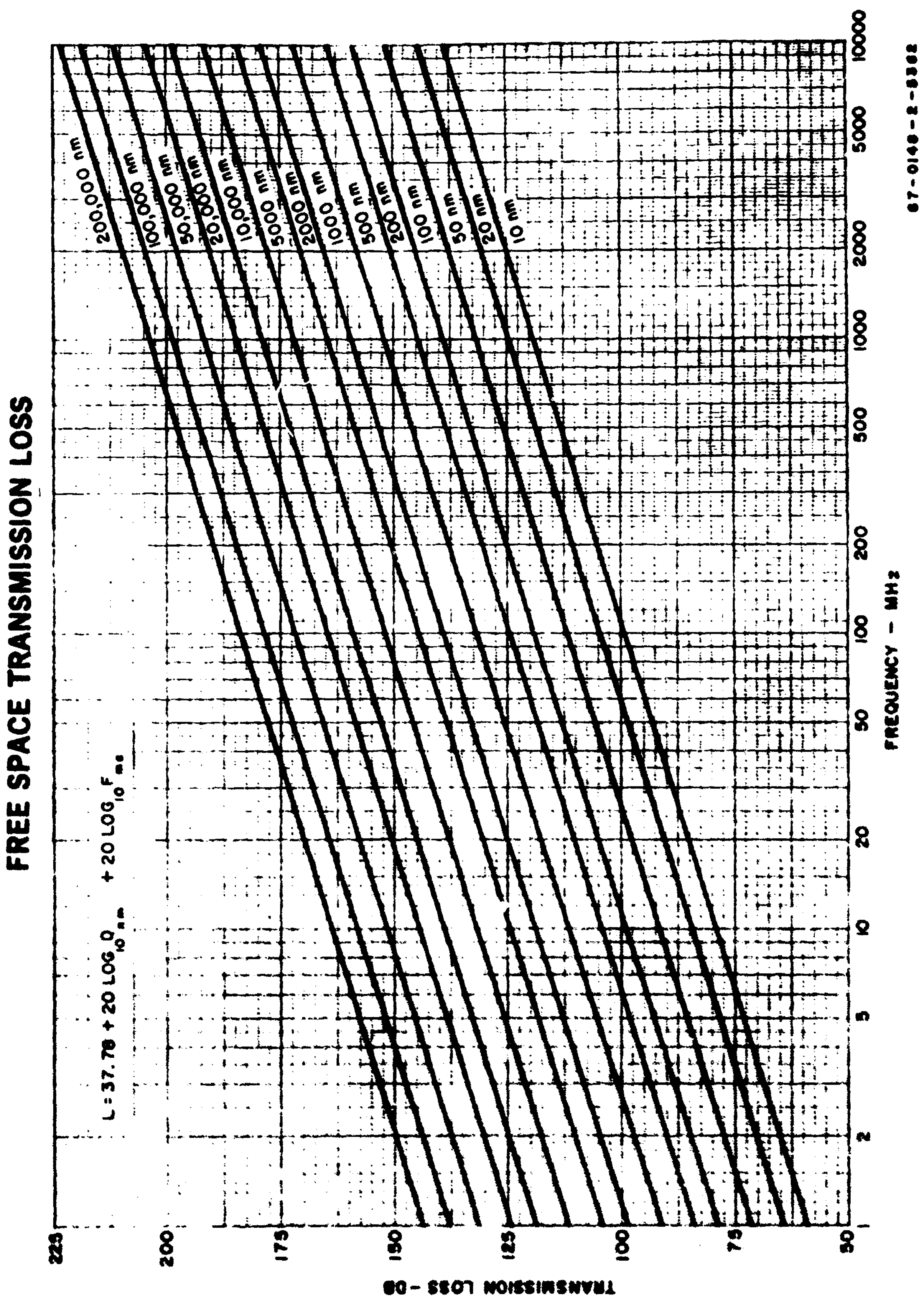


Figure 4-48. Curve B-p-1.4

4.3 DISCUSSIONS

4.3.1 ANALOG VS DIGITAL MODULATION FOR DATA TRANSMISSION

In general, the transmission of data by analog modulation requires less complex equipment, but there are many circumstances where digital modulation must be used.

The following criteria[1] will serve as a guide in deciding between analog or digital data transmission; they are particularly applicable to Analog-FM and Digital-FSK Transmission:

- The analog system is generally simpler.
- At (S/N) ratios higher than 34, there is a power saving by use of digital pulse code modulation.
- The digital signals may be regenerated.
- The digital signal is easier to multiplex.
- Processing of a digital signal is usually easier.
- When the accuracy of the received data must be greater than approximately 0.1%, digital transmission must be used.

4.3.2 ANALOG AND DIGITAL ERROR PROBABILITY

Every communication link will have a variety of noise sources which will result in the addition of a noise voltage component to the demodulated signal. For noise sources having amplitudes with a Gaussian probability distribution such as atmospheric or thermal noise, there will always be a probability of noise amplitude causing an error in the received data. Higher (S/N) ratios will lower the probability of introducing an error. However, increasing the (S/N) ratio means more power is required; and for practical equipment design a compromise must be reached whereby some specific probability of error will be acceptable.

Several approaches to the selection of error probability may be taken. An acceptable error rate may have been previously established through experience with similar systems. Otherwise, two tables, 4.6 and 4.7 are included to guide in the selection of error probability; or Curve A-e-1 may be used as a guide for establishing a reasonable error probability.

Analog Error Probability

Analog data is characterized by a capacity for continuous variation of data magnitude. After reception and demodulation, the analog data will be distorted by noise so that the ability to resolve the analog information level is not infinite, but is a function of noise level. Prior to processing, a minimum acceptable output signal-to-noise ratio must be determined. This determination depends on how many errors in information level are allowable in a time interval and still obtain valid output from the processor. This tolerance to error may be expressed as the maximum acceptable probability of error, or error rate.

The acceptable probability of error will depend on how many levels must be determined and at what rate. Curve A-d-1 is used to express these quantities as an information rate, C, in bits per second (bps). Knowing the information rate and the acceptable interval between errors, Curve A-e-1 may be used to determine the probability of error.

Alternately, knowing the characteristics of the data and its intended usage, the following table, 4-6 , may be used to select an error probability.

Example:

Assume the data processor can tolerate two errors per second and the date consists of 16 distinct levels changing at a sample rate of 200 cycle per second. This is equivalent to 800 bits per second* (bps) as determined by using Curve A-d-1. Having established the information rate, the error rate is determined from Curve A-e-1. The value read from the Curve is 4×10^{-3}.

*See Information Transmission Discussion 4.3.6

Table 4-6 Analog Data Probability of Error

Type	Error Probability	Remarks
Voice	------	(S/N) ratio is usually qualitatively established. Use (S/N) = 30 db for industrial or military use. A high quality circuit may require 35 to 40 db.
Repetitive data - processed by integration	10^{-1} to 10^{-2}	These estimates are intended as a guide. Where more definite information on data characteristics exist, a better error probability can be determined.
Discrete measurements - no relationship to previous data	10^{-4} to 10^{-5}	"
Slowly varying measurements-	10^{-2} to 10^{-3}	"

Table 4-7 Digital Data Probability of Error

Type	Error Probability	Remarks
Repetitive data such as redundant measurements, e.g., sea temperature which changes slightly between measurements and is continuous	10^{-2} to 10^{-3}	Errors range from 1 bit in one hundred to 1 bit in one thousand
Slowly changing continuous data, e.g., digital transmission of hydrophone output where received data is integrated	10^{-1} to 10^{-2}	Errors range from 1 bit in ten to 1 bit in one thousand
Teletype transmission where significant numbers are repeated	5×10^{-2} to 10^{-3}	Errors range from 1 bit in five hundred to 1 bit in one thousand
Rapidly changing data - high accuracy required	10^{-5} to 10^{-6}	Errors range from 1 bit in one hundred thousand to 1 bit in one million

Digital Error Probability

Digital data is characterized by the transmission of a group of pulses for each data increment. For example, successive measurements of relative temperature over a 16 degree range to 1 degree accuracy may be represented by four binary pulses ($S=2^4$). The number of pulses could be reduced by using three or four levels for each pulse, but digital data is usually transmitted by groups of binary pulses.

As in the analog case, the error probability may be established by operational experience with similar systems. Where such criteria isn't available, Table 4-7 or Curve A-e-1 may be used as guides to select a reasonable error probability.

The error probability given in the table and curve is the bit error probability. Since digital transmission is usually by means of pulse groups, it is obvious that there will be higher probability of a pulse group being in error. The expression for the probability of error of a pulse group is:

$$P_e = 1 - (1-p)^n$$

where

P = bit probability of error

n = number of pulses in the group

where p is small, approximately 10^{-3} or less, the series expansion of $(1-p)^n$ will contain two significant terms. Substituting the first two terms of the series expansion:

$$P_e = 1 - (1-np) = np$$

In determining an acceptable digital error probability, the higher group error rate must be considered. This is illustrated in the following example.

Example:

Assume a series of spectral measurements are to be transmitted from a buoy. This data is encoded in groups of five binary pulses per data increment and transmitted at a 2000 bps rate. There will be 3000 data groups per transmission, and one error per transmission is the minimum acceptable performance level. This estimate of acceptable performance must be based on a knowledge of data use and the significance of an error. The following calculation will determine the bit error rate.

Use curve A-d-1:

5 binary pulses $S = n^m = 2^5 = 32$

for $S = 32$ and $C = 2000$ bps

The curve shows that 400 samples (or pulse groups) per second are transmitted. The transmission time for a complete message will be $\frac{3000}{400} = 7.5$ seconds.

Since $P_e = np$

for one error per transmission,

$$P_e = \frac{1}{7.5} = .13 \text{ errors/sec}$$

$$n = 5$$

$$P = \frac{P_e}{n} = \frac{.13}{5} = .026 \text{ errors/sec}$$

Using curve A-e-1:

when $C = 2000$ bps

$P = .026$ errors/sec

The probability of error per bit will be 10^{-5}

4.3.3 BANDWIDTH

The term bandwidth denotes the range of frequency which will be transferred through a particular system component with a specified maximum loss. This range of frequencies is usually defined as the frequencies where the signal will be attenuated by 3 db or less.

The bandwidth will differ in various parts of the communication link. The bandwidth term, B, of the transmission equation refers to the effective noise bandwidth of the demodulator. The bandwidth required to pass any given signal will depend on the fidelity or freedom from distortion which is desired in the demodulated signal. For each modulation type there are criteria which are commonly used to determine the effective noise bandwidth. The following list are the criteria which apply when the bandwidth is selected to match the signal characteristics.

- AM/DSB B = 2 x highest modulating frequency
- AM/SSB B = highest modulating frequency
- FM

For FM modulation, two different bandwidths must be considered in the system design. These are the pre-demodulation or IF* amplifier bandwidth, B_{IF}, and the post-demodulation or output stage bandwidth, B. The IF bandwidth usually is determined:

$$B_{IF} = 2 \text{ (highest modulating frequency) (deviation ratio + 1)}$$

$$B_{IF} = 2 f_b \ (m + 1)$$

This bandwidth includes all frequency components greater than 20 db down from the peak amplitude and establishes a relatively low distortion level. The bandwidth for other level criteria may be determined using Curve B-m-2.1. The significance of this bandwidth is it specifies the frequency spectrum which is occupied by the signal transmission and indicates the required bandwidth of the receiver IF amplifier. The second bandwidth, B, refers to the effective noise bandwidth of the system and is determined by:

$$B = 2 \text{ x highest modulating frequency}$$

$$B = 2 f_b$$

This bandwidth assumes a matched filter is used.

* IF means intermediate frequency referring to these stages of a super heterodyne receiver.

This bandwidth must be used in the transmission equation calculations. The factor 2 results from the effective doubling of noise components due to the summing of upper and lower side-band noise components in the demodulation process.

- DIGITAL B = data rate (bps)

These bandwidths assume the more usual demodulator types are used. Conceivably, for certain types of modulation, modulators may be used which will allow reduced bandwidths.

4.3.4 CODING

A set of data to be transmitted may be represented by a combination of binary pulses or bits. A group of m binary pulses will form 2^m combinations of binary words representing 2^m different quantities.

Example: where m = 3, eight different ($2^3 = 8$) words may be formed:

000	100
001	101
010	110
011	111

By adding an additional pulse to each word so that the total number of "1" is even for all words, errors may be detected whenever any word group differs from the even count. This is known as an even parity error correcting code. Similarly a pulse could be added to each word so that the total number of "1" is odd.

Example: odd parity, last bit position is the parity bit applied to previous 2^m word group:

0001	1000
0010	1011
0100	1100
0111	1110

By adding more redundancy it is possible to correct words as well as detect errors. In the case of even or odd parity error codes, single-error detection is possible because the addition of a parity bit results in all words differing in at least two positions. To correct a single error, the minimum difference between acceptable words must be increased to three positions. The word which results from a single error will then be closer to the original word than to any other word in the alphabet. The difference in the number of position of two binary words is called "Hamming distance" (1).

A variety of error detecting and correcting codes have been developed. (2) These codes fall into two categories: parity checking and majority testing. Among these code variations are:

- Hamming (1) - Uses parity bits to provide a check on interrelated groups of the message bits within a word. The degree of error detection and correction is dependent on the hamming distance.
- Bose-Chandhuri (3) - Generalization of the Hamming code based on a complete mathematical theory allowing systematic word construction.
- Reed-Solomon (4) - Special case of the Bose-Chandhuri code which is useful for correcting multiple bursts of errors.
- Reed-Muller (5) - This is a majority testing type code. The received code is correlated simultaneously with samples of all possible code words. The highest correlation determines the received code word.

The preceeding codes are the block type, where blocks of fixed length are checked independently. Two types of non-block type codes are the Hagelbarger [6] code and a system developed by Wozencraft [7].

The orthogonal and biorthogonal codes which are Reed-Muller types have been used in this report to provide a comparison of the performance which may be obtained by means of coding.

Another variation of coding is the spread spectrum technique [8] [9] [10]. This type of modulation requires a wide bandwidth and is usually implemented by means of frequency hopping or by means of a pseudo-noise generator. The spectrum utilized by both types occupies a wide frequency range. This wide dispersion of frequency components results in transmission of signal levels which are considerably below the noise energy content in the bandwidth occupied by the signal.

As an example, if the spread spectrum signal occupies a bandwidth which is 30 db wider than the bandwidth required using a PSK modulation type, then a processing gain of approximately 30 db can be achieved. A coherent PSK modulated signal would require a signal-to-noise ratio of +8 db for a 10^{-4} error rate. The spread spectrum signal could be detected with a -22 db signal-to-noise ratio for the same error rate.

When considering the use of spread spectrum, several advantages and disadvantages must be considered. A spread spectrum signal is difficult to intercept because of the low signal-to-noise levels of operation. As a result, it provides secure communication. A spread spectrum signal is somewhat resistant to jamming since wide band jammers would be required. However, as might be expected either form of spread spectrum modulation requires considerably more complex equipment and more space than conventional modulation circuits. In addition, synchronization and the time required to synchronize the signal further complicate the operational requirements. Multipath propagation and fading conditions may also limit the amount of processing gain when the communication link is between two ground points.

In general, it is believed that spread spectrum modulation is not practical for buoy to on-water aircraft communication.

4.3.5 DIVERSITY

The value of propagation loss calculated for the troposcatter and skywave propagation modes is the median loss. The actual propagation loss * will exceed the median 50% of the time and be less than the median 50% of the time. For these modes of propagation this loss variation is attributed to a change in the propagation path. This change is called fading and is the result of turbulence in the atmosphere.

To achieve a certain reliability or assurance of communication greater than 50% over a particular communication link a margin signal-to-noise ratio, $(S/N)_{mar}$, must be provided, and consequently the transmitted power must be increased. Diversity is a technique of multichannel communication wherein the effect of fading is reduced, and the increase in $(S/N)_{mar}$ minimized.

The multichannel effect is achieved by one or a combination of diversity techniques; space, time, polarization, and frequency.

Space Diversity - Multiple antennas are used (usually to receive the signal). These antennas are spaced from 10 to 100 wavelengths apart. This spacing depends on the antennas orientation to the signal source. This distance is sufficient to establish multiple signal paths with different fading characteristics.

Time Diversity - Since the signal variations due to rapid fading have periods of the order of seconds to minutes; some type of delay device is used to obtain redundant transmission at intervals longer than the fading period. In this way, there is reasonable assurance that at least one of the signals will be minimally effected by rapid fading.

Polarization Diversity - It has been found that signals of different polarization (vertical and horizontal) traversing the same path are independently affected by fading conditions. By providing dual polarization at the transmitting antenna

* This discussion is primarily applicable to troposcatter propagation.

and a dual polarity receiving antenna, separate channels are established and the effect of rapid fading will be reduced.

Frequency Diversity - As in the case of polarization diversity, the effect of rapid fading will differ with frequency. Frequency differences as small as 1 kHz at VLF (very low frequency) and 20 to 30 kHz at HF (high frequency) are sufficient to achieve a diversity gain.

In all cases the intent of diversity is to reduce the signal variation due to rapid fading and minimize the margin which must be included to obtain a particular level of reliability. The diversity types discussed resulted in dual channels, and this is defined as second order (N = 2) diversity. By increasing the number of spaced antennas, increasing the number of frequencies, or a combination of the several types; higher order diversity will result. The higher diversity gain for higher order diversity systems is shown in the diversity curves (A-t-2 to A-t-6).

The final gain achieved by diversity depends not only on the order, but also on the processing technique. Diversity channels can be processed either predetection or postdetection by using multiple receivers. There are three common types of diversity combining:

- Maximum-Ratio Diversity
- Equal-Gain Diversity
- Selection Diversity

The relative performance of each type is illustrated on the diversity curves. For initial design approximations use equal-gain diversity. A more complete discussion of diversity and combing technique is given in REFERENCES (1) .

In most cases, the use of diversity in a buoy to on-water aircraft communication link will be restricted to either the frequency or time diversity types due to system antenna and spacing constraints.

4.3.6 INFORMATION TRANSMISSION - DATA RATE

Any analog data signal which is to be transmitted digitally must be sampled at the minimum Nyquist rate to avoid ambiguous results after demodulation. This requires that samples be taken at twice the highest frequency of the signal. For a band-limited signal of f_m cps bandwidth, this corresponds to $2 f_m$ samples per second. When each sample is quantized into S discrete voltage levels, the number of bits of information per sample is defined:

$$\text{Information/sample} = \log_2 S \text{ (bits)}$$

The data rate, C, is equal to the product of the number of samples and the number of bits of information.

Then $C = 2 f_m \log_2 S$

C may be determined using Curve A-d-1, where $2 f_m$ equals the samples per second.

Example:

when $f_m = 750$ cps

the sample rate required to reproduce the analog signal

$$2 f_m = 1500 \text{ samples/sec.}$$

eight levels are required

$$S = 8$$

from Curve A-d-1 read

$$C = 4.2 \times 10^3 \text{ bits/sec.}$$

Similarly, it may be required to transmit quantized levels from a transducer as coded pulse groups.

The quantized levels may be encoded into a code group of m pulses of n levels each. In which case:

$S = n^m$ where S is the number of increment levels

$C = N \log_2 n^m$ C is the data rate in bits per second (bps) and N is the number of code groups per second.

$C = m N \log_2 n$

Curve A-d-1 may be used to determine the data rate.

Example:

Each data increment is to be transmitted as a group of four binary pulses at a 200 pulse groups per second rate,

$$\text{then } S = n^m = 2^4 = 16$$

the rate is 200 samples/sec.

$$C = m N \log_2 n$$

or

$$C = N \log_2 S$$

using curve A-d-1

$$C = 800 \text{ bps}$$

The bandwidth normally required to transmit this digital data is equal to the data rate,

$$C \text{ (bits per second)} = B \text{ (cycles per second)}$$

4.3.7 MODULATION

The objective of this study is the investigation of methods and procedures to optimize communications between a buoy and an on-water aircraft. Communication implies the transfer of information which in this case is completed by processing and demodulating a radiated signal from a buoy. At the buoy, the processing of the information to achieve efficient transmission is called the modulation process.

In the selection of the modulation process, several initial determinations must be made:

Data type	-	analog or digital
Data rate	-	
Number of channels	-	time division or frequency division

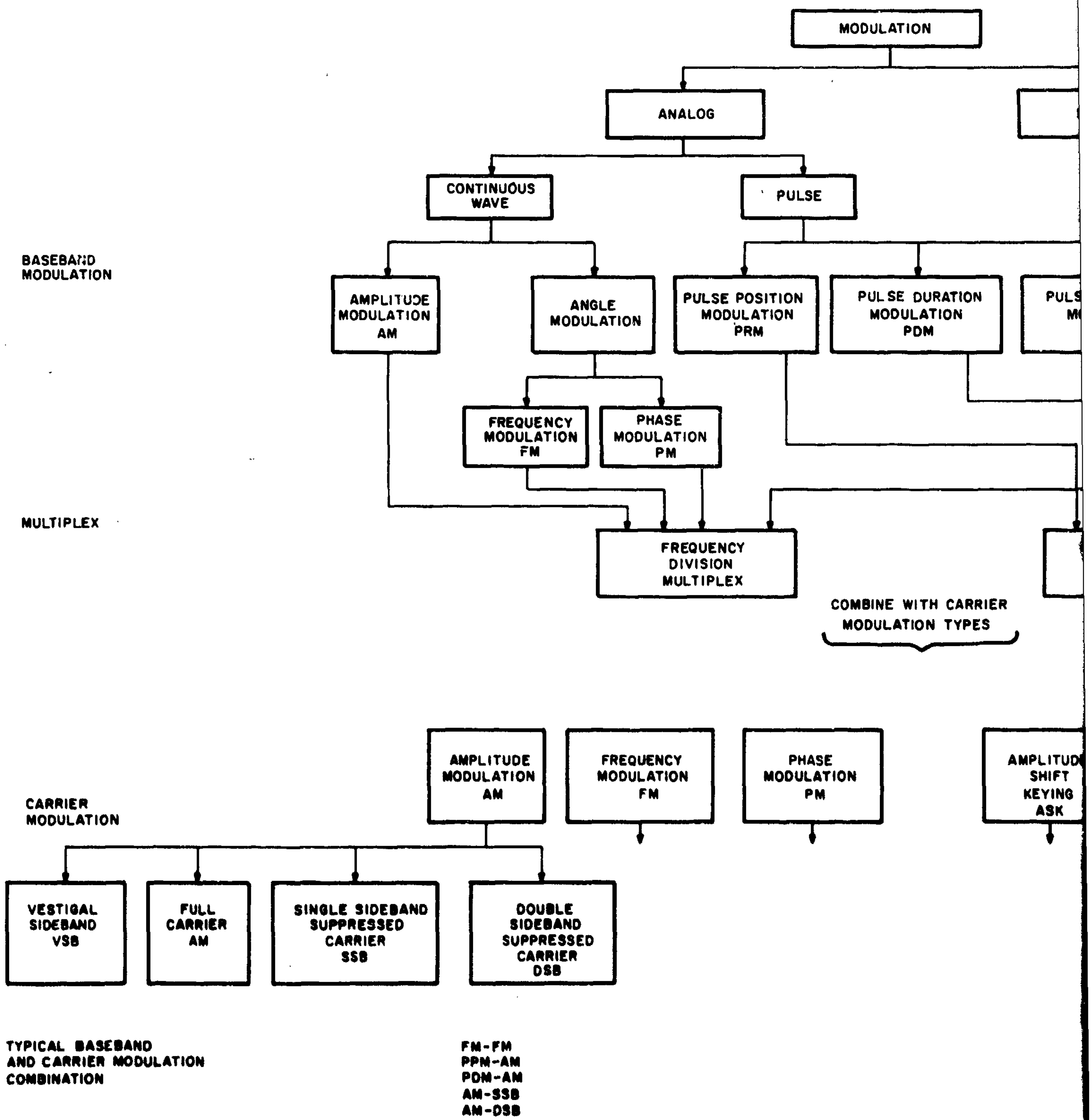
Determination of these parameters is made on the basis of operational requirements such as accuracy, data quantity, and data bandwidth. The selection of the modulation type depends on these operational requirements, the allowable equipment complexity and required reliability of the communication link.

In a multichannel system the information to be transmitted must be processed through several successive stages. First it is necessary to decide whether to transmit the data as successive samples from each channel, i.e., time division multiplex; or the data from each channel may be used to modulate different sub-carrier oscillators, frequency division multiplex. This group of signals is used compositely to modulate either the carrier phase angle or its amplitude.

A chart illustrating the variety of possible modulation techniques is shown in Figure 4-49.

Many of these modulation processes have been used for only special requirements. There have been numerous papers presented which cover the special case where these modulation techniques have been used. Also, detailed analysis has been presented in several texts comparing the different modulation techniques. This report covers only the more usual and operationally practical types of modulation. General recommendations are made and curves provided to guide the user in the selection of these modulation techniques. Where more detailed comparisons of the different modulation types are required, references (2) to (13) may be consulted.

MODULATION TECHNIQUES



MODULATION TECHNIQUES

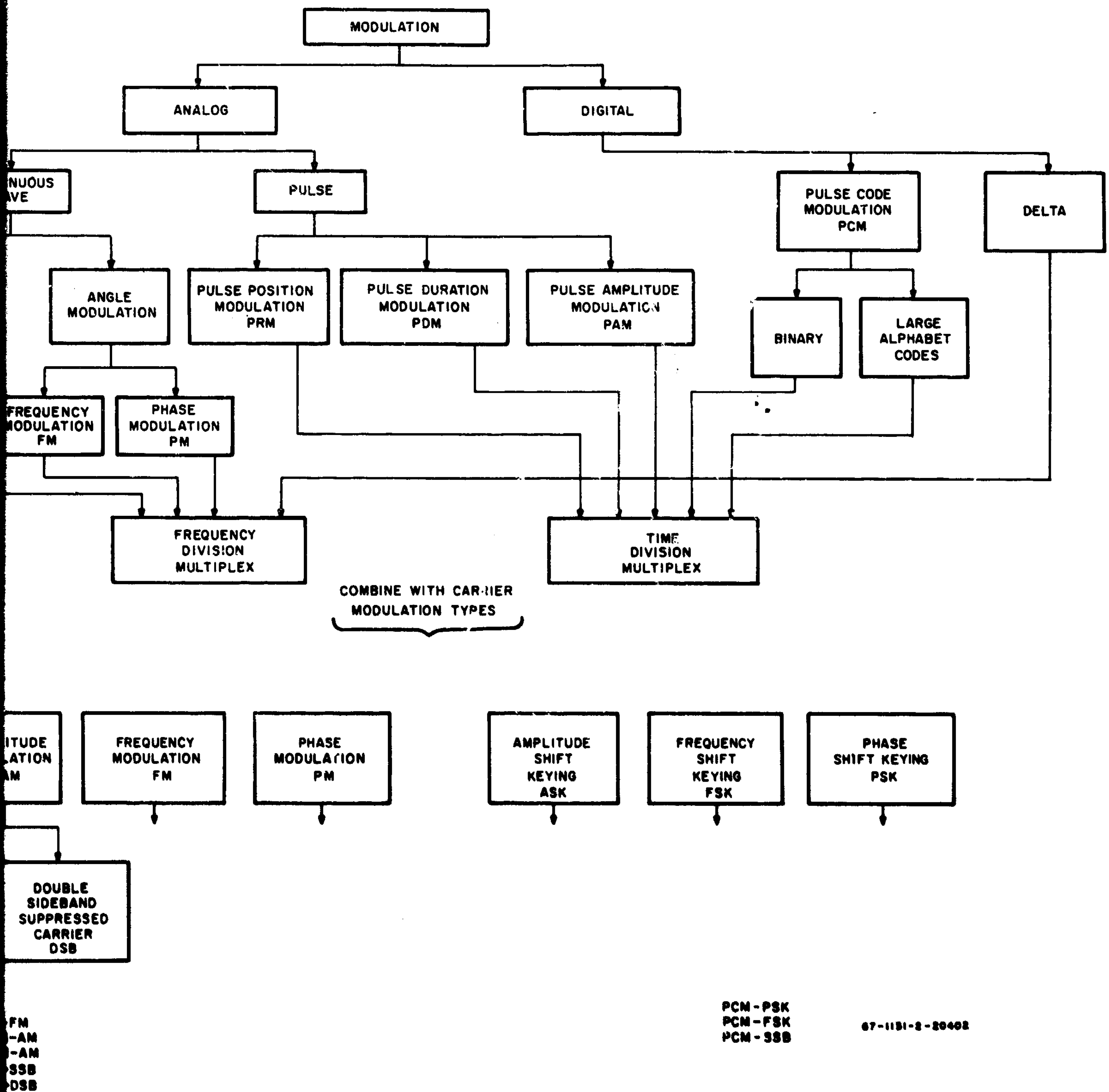


Figure 4-49. Modulation Techniques

For transmission of analog data, only frequency modulation will be considered. The reasons for this decision are:

- Amplitude modulated carriers are subject to interference while frequency modulated carriers are relatively free from interference; and FM exhibits a signal-to-noise improvement [2] after demodulation.
- Some bandwidth saving may be obtained by transmitting an amplitude modulated signal by single sideband, but this is an advantage only where the spectrum is crowded.
- FM requires a S/N threshold of approximately 10 to 13 db, and AM operation below this threshold is possible. However, the dynamic resolution of the AM signal would be limited for a low signal-to-noise ratio, and for most applications a S/N ratio comparable to or greater than that of FM would be necessary.
- Similar objections hold for PAM modulation.
- Other modulation types such as pulse-position and pulse duration modulation exhibit an improvement factor similar to FM. However, they are both special purpose systems and have no advantage over FM for most applications. Similarly delta [13] modulation is somewhat special purpose and is not included.

For transmission of digital data, both PCM (pulse code modulation) and large alphabet coded PCM will be considered. Each binary bit will be transmitted as either a phase shifted signal (PSK - phase shift keying) or a frequency shifted signal (FSK - frequency shift keying).

4.3.8 MODE INTERFERENCE

Interference results from the simultaneous reception of two or more signals having equivalent magnitudes and different phases. This condition may be due to multipath sky-waves, interference between direct and reflected waves of the ground wave mode, ground wave and sky-waves, or between ground wave and troposcatter waves. Ordinarily when the transmitter and receiver sites are fixed, the interference regions can be defined within reasonably narrow limits of frequency. If operation is necessary within these interference frequency limits, a number of steps such as the use of diversity or altering the antenna gain/directivity pattern can be taken to minimize the interference. For mobile installations the problem becomes more severe, and often reduced reliability is accepted as a normal condition of operation.

In general, for the situation of communication between buoys and an on-water aircraft, a constant level of reliability must be maintained. Since there are no geophysical, seasonal, or climatic restrictions on buoy operation, the variety of possible interference conditions is more extensive than in the fixed site case. The nature and type of interference cannot be predicted unless the location, atmospheric conditions, and time of operation are known; but several recommendations can be made:

- Expect ground wave and sky wave interference between frequencies of 1 to 15 MHz. This can be reduced or eliminated if the antenna vertical radiation is kept at low angles - less than 60° and preferably less than 30°.
- At the maximum range of 200 n. mi., ground wave and troposcatter interference will occur at sea level when the frequency is around 40 - 50 MHz. When the on-water aircraft is operating at higher altitudes, the upper interference frequency may extend to several hundred MHz.

Provisions to the buoy design may be necessary to counteract interference,

- Time or frequency diversity may be used.
- A command link between the on-water aircraft and buoy can be used to command the buoy to switch to a second operating frequency or to repeat the previous data.

If the probability of interference is taken into account, the range of interference frequencies may be further reduced. Sky-wave will most likely be troublesome between 2 to 10 MHz, but limiting the transmitting and receiving antenna's vertical pattern will help to control interference in this range. Interference between ground wave and troposcatter waves will probably only be a problem around 48 - 50 MHz since the aircraft can always change altitude to reduce interference at other frequencies. The on-water aircraft also has the capability of achieving an effective space diversity by means of position changes.

4.3.9 RECEIVER NOISE FIGURE

The receiver noise figure is a factor in determining the operating noise figure term, F, of the transmission equation. It has been assumed, in most cases the noise figure of the receiver will be as good as is currently attainable in operational equipment. A variation of ± 1 db in noise figure will have little effect on the overall accuracy of the transmission equation solution. Therefore, a composite noise figure curve based on "state-of-the-art" noise figure studies* has been derived for use in this report, and is incorporated into the operating noise figure, curve B-p-1.2. The composite curve, curve B-p-1.3, extends from 40 MHz to 10000 MHz. Below 40 MHz, the effect of a receiver noise figure on the operating noise figure is negligible because of the large atmospheric noise component.

This approach of using a composite noise figure will simplify the procedure. Whenever the actual receiver noise figure differs from the noise figure curve shown on B-p-1.2 by more than ± 1 db, the variation can be included in ΔN of the Lms term of the transmission equation.

4.3.10 PROPAGATION MODES

Communication between a buoy and an on-water aircraft over ranges up to 200 nautical miles may be maintained by one of three propagation modes:

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* Space Science Corporation report R-4004-2-3 and Sanders Associates study report.

- Ground wave
- Sky-wave
- Troposcatter

The ground wave is composed of three parts; a surface wave, a direct wave, and a wave reflected from the ground. The surface wave is the principle component of the ground wave at frequencies below a few megacycles. The direct and reflected wave contribute to the common "line of sight" communications, as between the ground station and an aircraft. Beyond the line of sight distance the surface wave is the only component of the ground wave. Line of sight distances to a buoy as a function of aircraft altitude are shown in curve A-1-1.

Because of the limited operational range required, sky-wave propagation has a number of unsuitable operational limitations. These limitations on sky-wave propagation for the type of operations considered in this study are discussed in Section 4.3.11.

The troposcatter mode of propagation is effective at frequencies greater than 30 MHz. This mode of propagation occurs due to the forward scattering of the signal field by the turbulent particles within the troposphere region of the atmosphere.

Curve series B-p-1.1, has been prepared for ground wave and troposcatter propagation mode transmission losses (L_p of the transmission equation). The receiving antenna height is varied on successive curves from 30 feet (the equivalent to on-water aircraft operation on the sea surface) to 30,000 feet. The curve for lowest operating altitude of the on-water aircraft should be used for any propagation considerations since this will be the most severe situation.

Troposcatter mode signals are subject to variation as a function of angular distance, time of day, and season of the year. The troposcatter propagation curves give the median transmission loss. Whenever the communication link is operating in the troposcatter mode, an additional factor must be added in the

$(S/N)_{mar}$ term of the transmission equation; this factor accounts for signal variability - see Section 2. The magnitude of the increase in $(S/N)_{mar}$ may be limited by the use of diversity techniques.

4.3.11 SKY-WAVE PROPAGATION

Ions are produced in the earth's atmosphere partly by cosmis rays, but primarily by solar radiation. The region where these ions form is called the ionosphere. Within this region there are three separate levels of ionized particles; defined as the F level at a height of about 175 miles at night, an E level at about 70 miles, and a D level below the E level. During the daytime the F layer splits into two parts, the F_1 and F_2 layers, with average virtual heights of 140 miles and 200 miles respectively.

Below a certain frequency, called the maximum usable frequency (MUF), radio waves incident on these ionospheric layers are refracted and returned to earth. It is propagation of this type which makes use of the ionosphere and is called sky-wave propagation. This mode of propagation allows operation with less transmission loss than ground wave at some frequencies and ranges. This section considers the relative utility of sky-wave propagation for the operational situation of communications between a buoy and an on-water aircraft.

Sky-wave propagation is principally by means of refraction from the E and F layers. Each layer has a different maximum usable frequency above which refraction will not take place. Propagation by means of the F_2 layer also has a lower frequency limit since it must use a frequency which will penetrate the E layer. The D layer attenuates the signal due to its absorption characteristics. The maximum usable frequency on a given ionospheric transmission path is a function of the length of path, its geographic location, the time of day, the season of the year, and the phase of the sunspot cycle. Typically, the maximum usable frequency will vary over a range of 3 to 10 MHz during a 24 hour period for short ranges.

For the operational situation under consideration where the maximum range is 200 nautical miles, the ground-wave signal will be relatively strong compared to sky-wave signals at frequencies less than a few megacycles. This is due to the short operating range and the effect of the D layer absorption on the sky-wave signal. Buoys operating at higher frequencies, 2 to 30 MHz, are capable of transmitting sky-wave signals over a given communications link with a signal strength which will be considerably stronger than ground wave for the same transmitter power. This, however, will not be true for a full 24 hour period. Since the maximum usable frequency (MUF), will change, the higher frequencies cannot be used continuously, and at the lower frequencies the absorption will increase. This poses an operational problem if sky-wave propagation is to be used for buoy communication. Operation at the higher frequencies will require some knowledge of the MUF as a function of geographic location, and time of day. Some provision would have to be made to change frequency during the operating cycles to accommodate the shift in MUF. Use of the lower frequencies only would result in periods where the sky-wave level is considerably below ground wave propagation. The probability also exists, when the signal levels are nearly equal, of a mutual interference condition. Neither of these approaches is consistent with the philosophy of unattended buoys which may be deployed at any oceanographic location for periods of several days.

Whenever the operating range is relatively short, of the order of several hundred nautical miles or less, it is concluded that the sky-wave mode is not suitable. Its use will require added equipment complexity which outweighs any propagation advantage. If ground wave operation is contemplated at frequencies which will support the sky-wave mode, 2 to 30 MHz, the problem of mutual interference must be considered. This situation may be alleviated by shaping the transmitting antenna's vertical pattern to limit the power radiated towards the ionosphere.

REFERENCES

2. Transmission Equation

(1) Norton, K., "The Calculation of Ground-Wave Field Intensity----" Proceedings of IRE, (Dec. 1941).

(2) Bullington, K., "Characteristics of Beyond-the-Horizon Radio Transmission", Proceedings of IRE, (Oct. 1955).

(3) Skolnik, M.I "Introduction to Radar Systems", Mcgraw-Hill (1962), a detailed discussion on p. 361.

4.1.1 Antenna Selection

(1) Lewis, R., "Antenna System Reliability as Related to Radio Frequency Propagation from Ocean Platforms", 1966 Nat. Telemetering Conference Proceedings, Boston, (May 10, 1966).

4.1.2 Output Signal-To-Noise Ratio

(1) Plush, R., et al., "Carries to Noise Requirements for Teletype Communications via Non-Fading or Fading UHF Carriers" U. S. Dept. of Commerce, NBS-5585.

(2) Watt, A., "Performance of Some Radio Systems in the Presence of Thermal and Atmospheric Noise", Proc. IRE, (December 1958).

(3) Whelan, J., "Analog FM vs Digital-PSK Transmission" IEEE Transactions on Communication Theory, Vol. COM-14 No. 3, June 1966.

4.1.6 Diversity Gain

(1) Brennan, D., "Linear Diversity Combining Techniques", Proceedings IRE, (June 1959).

4.1.10 Modulation Selections

(1) Lawton, G., "Comparison of Binary Data Transmission Systems" 2nd. Nat. Military Electronics Conference, (1958).

(2) Viterbi, A., "On Coded Phase - Coherent Communications" IRE Transactions on Space Electronics and Telemetry, (March, 1961).

(3) Cahn, C., "Performance of Digital Phase-Modulation Communication Systems", IRE Transactions on Communications Systems, (May, 1959).

(4) Walsh, C., "Frequency-Modulation Principles", Electro-Technology, (Jan. 1965).

(5) Schwartz, M., et al, "Communication Systems and Techniques", McGraw-Hill, (1966).

4.1.12 Power Supply Considerations

(1) Padwo, S., "The Battery Field, A State-of-the-Art Survey", Electrical Design News, (Jan. 1963).

(2) Morehouse, C., and Thomas, J., "Batteries-Workhorses for Portable Equipment", Electronic Design, (Feb. 15, 1961).

(3) Bernatowicz, D., et al, "Solar and Chemical Power Systems", Space/Aeronautics R & D Issue (1966).

Osmun, W., "Space Nuclear Power: Snap-50/Spur", Space/ Aeronautics, (Dec. 1964).

(4) Stein, B., "Status Report on Fuel Cells", Office of Technical Services Publication PB-151,804, Dept. of Commerce, Washington 25, D.C.

(5) Cohn, E.,"Fuel Cells-Direct Conversion of Chemical to Electrical Energy", Electronic Design, (Feb. 15, 1961).

(6) Horne, R., "Operation of Batteries at Great Ocean Depths", Undersea Technology, (July 1963).

REFERENCES (Continued)

4.1.15 Signal-to-Noise Margin

(1) CCIR Report #322, "World Distribution and Characteristics of Atmospheric Radio Noise".

(2) Rice, P., et al, "Prediction of the Cumulative Distribution with Time of Ground Wave and Tropospheric Wave Transmission Loss", Technical Note #15, National Bureau of Standards, (July 1959).

(3) "Sonobuoy/Destroyer Radio Communication Study", Radio Corp. of America, report CR-63-408-3, (Dec. 1963).

4.3.1 Analog vs. Digital Data Transmission

(1) Whelan, J., "Analog - FM vs. Digital-PSK Transmission", IEEE Transactions on Communication Technology, (June 1966).

4.3.4 Coding

(1) Hamming, R., "Error Detecting and Error Correcting Codes", Bell System Tech. J., vol. 26, pp. 147-160, (April 1950).

(2) Bennett, W., "Data Transmission, pp. 293-299, McGraw-Hill (1965).

(3) Peterson, W., "Encoding and Error Correction Procedure for the Bose-Chaudhuri Codes," IRE Transactions Information Theory, vol. II-6, pp. 459-470, (Sept. 1960).

(4) Reed, I., and Solomon, G., "Polynomial Codes over certain Finite Fields", J. Soc. Ind. Appl. Math., vol. 8, pp. 300-304, (1960).

(5) Reed, I., "A Class of Multiple-Error Correcting Codes and the Decoding Scheme", IRE Transactions Information Theory, vol. II-4, pp. 38-49, (Sept. 1954).

(6) Hagelbarger, D., "Recurrent Codes: Easily Mechanized Burst-correcting Binary Codes", Bell System Tech. J., vol. 38, pp. 969-984, (July 1959).

(7) Wozencraft, J., and Reiffen, B., "Sequencial Decoding", M.I.T. Press, Cambridge, Mass. (1961).

(8) Glenn, A., "Code Division Multiplex System", IEEE Int. Convention Record, Part 6, (1964).

(9) Kepcke, J., "Maximum Spectrum Utilization by Wide Bandwidth Transmission", IEEE Int. Conv. Record, Part 6.

(10) Costas, J., "Poisson, Shannon and the Radio Amateur", Proc. IRE, (Dec. 1959).

4.3.5 Diversity

(1) Brennan, D., "Linear Combining Techniques", Proc. of IRE, (June 1959).

4.3.7 Modulation

(1) "Transmission Systems for Communications", Members of the Technical Staff Bell Telephone Laboratories - discusses frequency division multiplex and time division multiplex.

(2) Schwartz, M., "Information Transmission, Modulation, and Noise", McGraw-Hill, (1959) - Comparative analysis of systems pp. 226-333 - FM improvement factor p. 303.

(3) Slepian, D., "Bounds on Communications", the Bell System Technical Journal, (May 1963).

(4) Viterbi, A., "On Coded Phase-Coherent Communications", IRE Transactions on Space Electronics and Telemetry, (March 1961).

REFERENCES (Continued)

(5) Cahn, C., "Performance of Digital Phase-Modulation Communication Systems", IRE Transactions on Communication Systems, (May 1959).

(6) Lawton, J., "Comparison of Binary Data Transmission Systems", 2nd National Military Electronics Conference (1958).

(7) Whelan, J., "Analog-FM vs. Digital-PSK Transmission", IEEE Transactions on Communication Technology, (June 1966).

(8) Sanders, R., "Communication Efficiency Comparison of Several Communications Systems", Proc. of IRE, (April 1960).

(9) Viterbi, A., "Lower Bounds on Maximum Signal-to-Noise Ratios for Digital Communication Over Gaussian Channel", IEEE Transactions on Communications Systems, (March 1964).

(10) Akima, H., "Theoretical Studies on Signal-to-Noise Characteristics of an FM System", IEEE Transactions on Space Electronics and Telemetry, (Dec. 1963).

(11) Oliver, B., et al, "The Philosophy of PCM", Proc. IRE, vol. 36, (Nov. 1948), pp. 1324-1331.

(12) Helstrom, C., "The Comparison of Digital Communication Systems", Transactions IRE (Communication Systems), vol. CS-8, (Sept. 1960), pp. 141-150.

(13) Panter, P., "Modulation Noise and Spectral Analysis", - Comparative Analysis of Modulation Systems, Chapter 24, - Delta Modulation, McGraw-Hill, (1965), pp. 679-699.

BIBLIOGRAPHICAL REFERENCES

Schwartz, M., "Information Transmission, Modulation, and Noise", McGraw-Hill 1959.

Norton, K., "Transmission Loss in Radio Propagation: II", OTS, Technical Report #12, U.S. Department of Commerce, June 1959.

Signal Corp Radio Propagation Agency. "Ground Wave Field Intensities Including Ground Wave Field Intensities Within the Line of Sight", Technical Report #3, Fort Monmouth, New Jersey, April 1956.

Reed & Russell, "Ultra High Frequency Propagation", Boston Technical Publishers, Inc., 1964.

Baxter, R. et al, "Oceanographic Telemetry for Systems Evaluation", General Dynamics - Contract NOnr-3062 (00) ONR.

CCIR Report #322, World Distribution and Characteristics of Atmospheric Radio Noise.

Propagation

Troposcatter Propagation

Rice, P., et al, "Transmission Loss Predictions for Tropospheric Communication Circuits", Technical Note 101 (revised), National Bureau of Standards.

Yeh, L., "Simple Methods for Designing Troposcatter Circuits", IRE Transactions on Communication Systems, September, 1960.

Groundwave Propagation Curves

Berry, L., and Chrisman, M., "A Fortran Program of Ground Wave Propagation over Homogeneous Spherical Earth for Dipole Antennas", National Bureau of Standards, NBS Report 9178.

BIBLIOGRAPHICAL REFERENCES (Continued)

Power Supplies

"Power from Isotopes", U.S. Atomic Energy Commission.

"Systems for Nuclear Auxiliary Power", TID-20103, U.S. Atomic Energy Commission.

CURVE REFERENCES

A-2-2	Oceanographic Telemetry, General Dynamics/ Convair, ZN495, (November 1960).
A-2-3	Oceanographic Telemetry, General Dynamics/Convair ZN495, (November 1960).
A-m-5 A-m-6	Cahn, C., "Performance of Digital Phase Modulation Communication Systems," IRE Transactions on Communication Systems, (May 1959).
A-s-1	Cohn, P., and Wetch, J., Modification of Curve - Electronic Design, (March 29, 1966).
A-s-2	Padwo, S., "The Battery Field, ...," Electrical Design News, (January 1963).
A-s-3	Padwo, S., "The Battery Field, ...," Electrical Design News, (January 1963).
A-s-5	Horne, R., "The Operation of Batteries at Great Ocean Depths", Undersea Technology, (July 1963).
A-t-2 To A-t-6	Brennan, D., "Linear Diversity, Combining Techniques, Proceedings of IRE's, (June, 1959).
A-t-7	Yeh, L., "Simple Methods of Designing Troposcatter Circuits", IRE Transactions on Communications Systems, (September 1960).
B-p-1.1	Berry, L., and Christman, M., "National Bureau of Standards, Groundwave" program.

APPENDIX A - USE OF DECIBELS

Basic Logarithmic Manipulation

An equation

$$a + b/c = d\ e/f$$

may be expressed as a logarithmic relationship by taking the logarithm of all terms

$$\log a + \log b/c = \log d\ e/f$$

since by definition

$$\log mn = \log m + \log n$$

and

$$\log m/n = \log m - \log n$$

then

$$\log a + \log b - \log c = \log d + \log e - \log f$$

Decibel Definition

By definition

$$A \text{ (decibels)} = 10 \log a$$

where a is a power ratio,

and V (decibels) = 20 log v,

where V is a voltage ratio the equivalency of these definitions is shown:

if $\quad a \text{ (power)} = \frac{v^2}{r} \qquad \text{let } r = 1$

$$10 \log a = 10 \log v^2 = 20 \log v$$

$$A \text{ (decibels)} = V \text{ (decibels)}$$

Decibel Expression for Equation (3-4)

For equation (3-4) all terms are power ratios; therefore, use

$$A \text{ (decibels)} = 10 \log a$$

$$P_t = 10 \log p_t \text{, etc.}$$

The loss terms l_p and l_{ms} are fractions and, since

$$\log 1/a = \log a^{-1} = -\log a$$

L_p and L_{ms} appear as positive terms in the expression.

A chart for transformation of power ratios to decibels is shown in Figure 6-1.

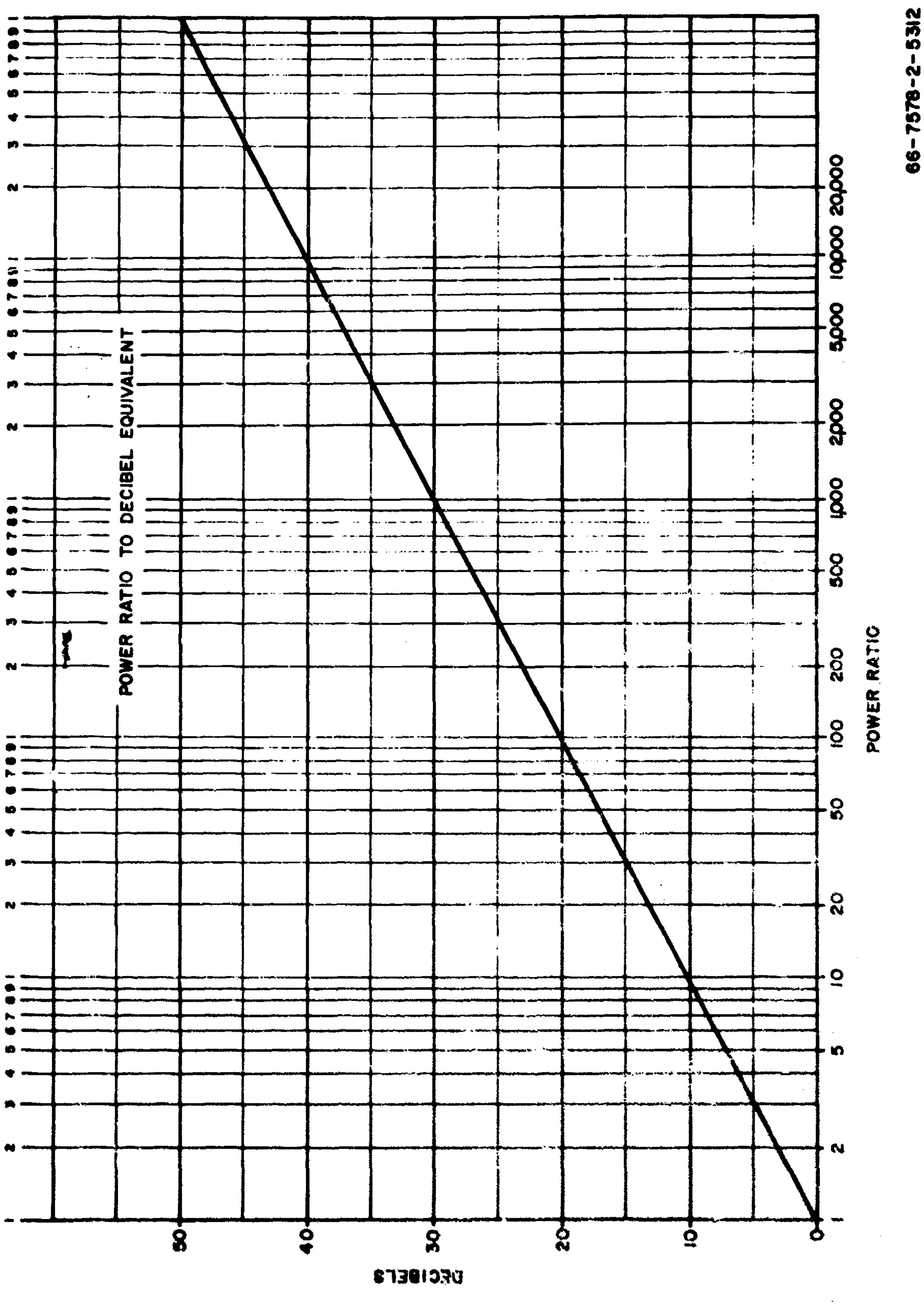

Figure 6-1. Decibel Relationship

APPENDIX B - OPERATING NOISE FACTOR

We now make use of the concept of operating noise factor, f, given in C.C.I.R. Report No. 322.

$$f = f_a - 1 + f_c f_t f_r$$

where

f_c = The noise factor of the antenna circuit (its loss in avail. power)

f_t = The noise factor of the transmission line (its loss in avail. power)

f_r = The noise factor of the receiver

f_a = The ratio of external noise power available from the terminals of an equivalent loss-free antenna to $kt_o b$

k = Boltzmann's constant = 1.38×10^{-23} Joules/^{o}k

t_o = reference temperature (290^{o}k)

b = effective receiver noise bandwidth

The usefulness of the operating noise factor, f, lies in the fact that it defines the relationship between the signal power, p_r, available from a loss-free antenna and the corresponding signal-to-noise ratio, r, at the I.F. output of the receiver, since

$$p_r = f\, r\, kt_o b$$

or

$$r = \frac{p_s}{f\, kt_o b}$$

Note that a given decibel change in the factor, f, will produce an equal decibel change in the output signal-to-noise ratio, r. Where r is equal to the product of the two signal-to-noise terms,

$$r = (s/n)_{ideal} (s/n)_{mar}$$

GLOSSARY

AM/DSB	Amplitude modulation using double sideband
AM/SSB	Amplitude modulation using single sideband
amplitude modulation:	Amplitude modulation is the form of modulation in which the amplitude of the carrier is varied in accordance with the instantaneous value of the modulating signal.
analog signal:	A nominally continuous electrical signal that varies in some direct correlation to a signal impressed on a transducer. The electrical signal may vary its frequency or amplitude; for instance, in response to changes in phenomena or characteristics such as sound, light, heat, position or pressure.
angle modulation:	Modulation in which the angle of a sine-wave carrier is the characteristic varied from its normal value. Phase and frequency modulation are particular forms of angle modulation.
bandwidth:	The difference between the maximum frequency and the minimum frequency required for transmission of a signal. The bandwidth of a television channel is 6 megacycles.
baseband:	In the process of modulation, the frequency band occupied by the aggregate of the transmitted signals when first used to modulate a carrier.
bit:	A contraction of the term binary digit.
bits per second:	Expression of quantity of information.

GLOSSARY (Continued)

capacity: The largest number of digits or characters which may regularly be processed.

channel: A means of one-way transmission. Several channels may share a common path as in carrier systems; in this case each channel is allocated a particular frequency band which is reserved to it.

code: A code is a plan for representing each of a finite number of values, letters or symbols as a particular arrangement or sequency of discrete conditions or events.

coherent phase shift keying: Form of phase shift keying which requires an accuracy reference signal for demodulation of the received signal phase.

delta modulation: Form of digital transmission in which discrete increments relative to previous approximations of signal are transmitted.

demodulation: A process wherein a wave resulting from previous modulation is employed to derive a wave having substantially the characteristics of the original modulating wave.

deviation ratio: In a frequency modulation system, the ratio of the maximum frequency deviation to the maximum modulating frequency of the system. Also called modulation index.

differential phase shift keying:	Form of phase shift keying whereby the phase of the current pulse is compared to the phase of the preceding pulse. Change of phase or absence of change is indicative of information received.
digital signal:	A nominally discontinuous electrical signal that changes from one state to another in discrete steps. The electrical signal could change its amplitude or polarity, for instance, in response to outputs from computers, teletypewriters, etc. Analog signals may be converted to a digital form by quantizing.
diversity:	That method of transmission and/or reception, whereby, in order to reduce the effects of fading, a single received information signal is derived from a combination of, or selection from, a plurality of signals containing the same information. Improvement gained shall be expressed in db.
double sideband:	That method of communication in which the frequencies produced by the process of amplitude modulation are symmetrically spaced both above and below the carrier frequency and are all transmitted; this is conventional AM.
FM:	See frequency modulation.
fading:	Fading is the fluctuation in intensity of any or all components or a received radio signal ue to changes in the characteristics of the propagation path.
fading, rapid:	Short term fading conditions lasting in the order of seconds to minutes.

fading, slow:	Long term fading conditions lasting in the order of minutes to hours.
frequency modulation:	Frequency modulation is modulation in which the instantaneous frequency of a sine wave carrier is caused to depart from the carrier frequency by an amount proportional to the instantaneous value of the modulating wave.
FSK:	See frequency shift keying.
frequency shift keying:	Frequency shift keying is that form of frequency modulation in which the modulating wave shifts the output frequency between predetermined values, and the output wave has no phase discontinuity.
gaussian noise:	Wide frequency spectrum noise having a constant rms amplitude with a gaussian probability distribution of instantaneous frequency amplitude.
guard band:	A guard band is an unused frequency band between two channels to give a margin of safety against mutual interference.
HF	High frequency.
IF	Intermediate frequency amplifier
kHz	Kilohertz - equivalent to kilocycles per second.
matched filter:	Filter with response designed to match the spectrum of the received signal thereby enhancing the received S/N ratio.

MHz	Megahertz - equivalent to megacycles per second
modulation:	Modulation is the process of varying some characteristics of the carrier wave in accordance with the instantaneous value, or samples, of the intelligence to be transmitted.
modulation index:	See deviation ratio.
multiplexing:	The simultaneous transmission of two or more signals within a single channel. The three basic methods of multiplexing involve the separation of signals by time division, frequency division, and phase division.
noise:	Noise is the summation of the unwanted or disturbing power introduced into a communication system from sources such as crosstalk, power induction, atmospheric conditions, electronic circuit components, etc.
PAM :	See pulse amplitude modulation.
PCM :	See pulse code modulation.
PDM :	See pulse duration modulation.
PPM :	See pulse position modulation.
PSK :	See phase shift keying.
parity bit :	A bit added to a binary code group which is used to indicate whether the number of recorded 1 or 0 is even or odd.

$\overline{PG}$ factor: Is equivalent by definition to the combined P_t, G_t, G_r and B terms of the transmission equation expressed in decibels. $(\overline{PG}) = P_t + G_t + G_r - B$ (power gain per unit bandwidth)

phase modulation: Phase modulation is the form of modulation in which the angle relative to the unmodulated carrier angle is varied in accordance with the instantaneous value of the amplitude of the modulating signal.

phase shift keying: Modulation technique whereby information is conveyed by control of the phase of the carrier frequency.

pulse amplitude modulation: Pulse amplitude modulation is the form of modulation in which the amplitude of the pulse carrier is varied in accordance with successive samples of the modulating signal.

pulse code modulation: Pulse code modulation is the form of modulation in which the modulating signal is sampled, and the sample quantized and coded so that each element of information consists of different kinds and/or numbers of pulses and spaces.

pulse duration modulation: See pulse time modulation.

pulse position modulation: See pulse time modulation.

pulse time modulation: Pulse time modulation is the form of modulation in which the time of occurrence of some characteristics of the pulse carrier is varied in accordance with successive samples of the modulating signal. (This includes pulse position and pulse duration or pulse width modulation).

GLOSSARY (Continued)

reliability:	Of a piece of equipment or a system, the probability of specified performance for a given period of time when used in the specified manner.
(S/N)	See signal-to-noise ratio. (S/N) means 10 log (s/n)
signal-to-noise ratio:	A ratio which measures the comprehensibility of a data source or transmission link.
single sideband:	Single sideband transmission is that method of communication in which the frequencies produced by the process of modulation on one side of the carrier.
skywave propagation:	Propagation due to waves reflected from the ionosphere, synonymous to reflected wave propagation.
suppressed carrier transmission:	Suppressed carrier transmission is that method of communication in which the carrier frequency is suppressed either partially or to the maximum degree possible. One or both of the sidebands may be transmitted.
vestigial sideband:	Vestigial sideband transmission is that method of communication in which frequencies of one sideband, the carrier, and only a portion of the other sideband are transmitted.

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PUBLICATIONS NO:

SANDERS DOC. NO: One Contract N-00014-66-CO-285

CLASSIFICATION: UNCLASSIFIED

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13. ABSTRACT

The purpose of this study is to provide data and procedures for parametric analysis of radio communications between a dispersed field of ASW buoys and an on-water or airborne aircraft. The analysis procedures also apply to communications links between buoys and a seacraft mother vehicle. In the subject type of weapons system the communications links rarely exceed a range of 200 miles. Within this range, all practical propagation modes and communications variables have been consolidated in simplified parametric form.

The basic purpose of this study is to enable optimization of the communications link parameters. In any system evaluation or design, optimization is accomplished by assessment of trade-offs as the system parameters are varied within the applicable constraints. The situations where such optimization is desirable fall into three categories: evaluation of proposed systems, modification of existing systems, and design of new systems.

The study defines optimization categories, introduces and explains the transmission equation, and presents a procedural format for parametric optimization.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
ASW Buoys						
Parametric Communications						
Curve						
Transmission Equation						
Ground Wave Propagation						
Sky-wave Propagation						
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