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NOISE SOURCES OF SIGNIFICANCE IN DATA TRANSMISSION

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by

F. B. WOOD

ABSTRACT

An attempt is made to develop preliminary models of the different kinds of noise that are of significance in data transmission. Review of the graphical representation of thermal noise on arithmetic probability paper has led to similar models of other types of noise. The analysis leads to a classification by the number of parameters required to specify an upper bound on the noise distribution and a classification by the type of noise voltage scale needed to make the upper bound distribution gaussian over the significant range. These distributions are: thermal, one parameter, linear; crosstalk, two, linear; impulse, three, logarithmic; and fading, four, log-log. Cut-off noise and interpulse interference (delay distortion) are mentioned for completeness. Appendices are included which compare different assumptions which could alter the nature of these models. For example the choice of counting noise peaks, noise pulses, or actual errors can seriously change the model of impulse noise at this stage of our understanding.

NOTICE

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NOISE SOURCES OF SIGNIFICANCE IN DATA TRANSMISSION

I. Introduction

The objective of this study is to represent in a simplified manner the types of noise and other interference that can cause errors in data transmission. A few years ago P. L. Chessin[1] prepared a bibliography of 601 references on noise. Some selection must be made from the increasing mass of papers on this topic to make the information applicable to data transmission readily accessible. W. R. Bennett prepared an excellent monograph on noise.[2] The illustrations of the basic noise distributions given by Bennett constitute an excellent introduction to or review of noise characteristics.

Earlier analyses of noise were in terms of the influence on voice communication. The literature now includes analyses applicable to radar and to data transmission. However, there is not yet much data available on impulse noise, the type which is the most serious in data transmission. It is assumed that Bell Telephone Laboratories is conducting thorough studies of impulse noise. However, it is important that all divisions of IBM Corp. dealing with data transmission be cognizant of the noise problems even though only approximate analyses are yet available. Therefore the function of this report is to present an outline of the types of noise of significance in data transmission together with whatever empirical data is available. In the case of the well-known thermal noise following a gaussian distribution, the function of this report is to present the probability distribution in a simple graphical way that is simple to use for obtaining the probability of error from the signal-to-noise ratio. It is hoped that the simple graphical presentation will help the engineer to find simple ways of representing other noise distributions.

The first step in reviewing the possible noise sources of significance in data transmission is to plot the probability distributions on as near an equivalent basis as possible as is done in Figure 1-A. The curves in Figure 1-A are based upon data from different sources, some taken by our own tests in IBM Research, some based on data from Bell Telephone Laboratories, Inc. and Airborne Instruments Laboratory, Inc.; and some is estimated from American Telephone and Telegraph Co. practice.

The ordinate (Y) in Figure 1-A is in decibels above one milliwatt (dbm) for curves A40, A60, B, CB, CBC, and CC. A separate ordinate (Y_M) is given on the left of Figure 1-A for curve M in decibels of attenuation. Alternative ways of plotting the equivalent fading noise are discussed in Appendix B. The abscissa, P(X>Y in T), is the probability in per cent that the noise voltage* (X) exceeds the

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*Note: For V_N in peak volts, $X = 20 \log_{10} (V_N/1.4)$ dbm, while for V_N in rms volts, $X = 20 \log_{10} (V_N/1.0)$ dbm. This assumes the characteristic impedance of the channel is 1000 ohms, which is correct for No. 19 AWG cable pairs at 600 cycles/sec or 1200 bits/sec. At 1200 cycles/sec (2400 bits/sec) the same wire pair would have $Z_0 = 700$ ohms.

X = Noise power (dbm; peak or rms as indicated in text)
Y = Reference Power (dbm)
T = Time Interval; 400 μsec in Curve B

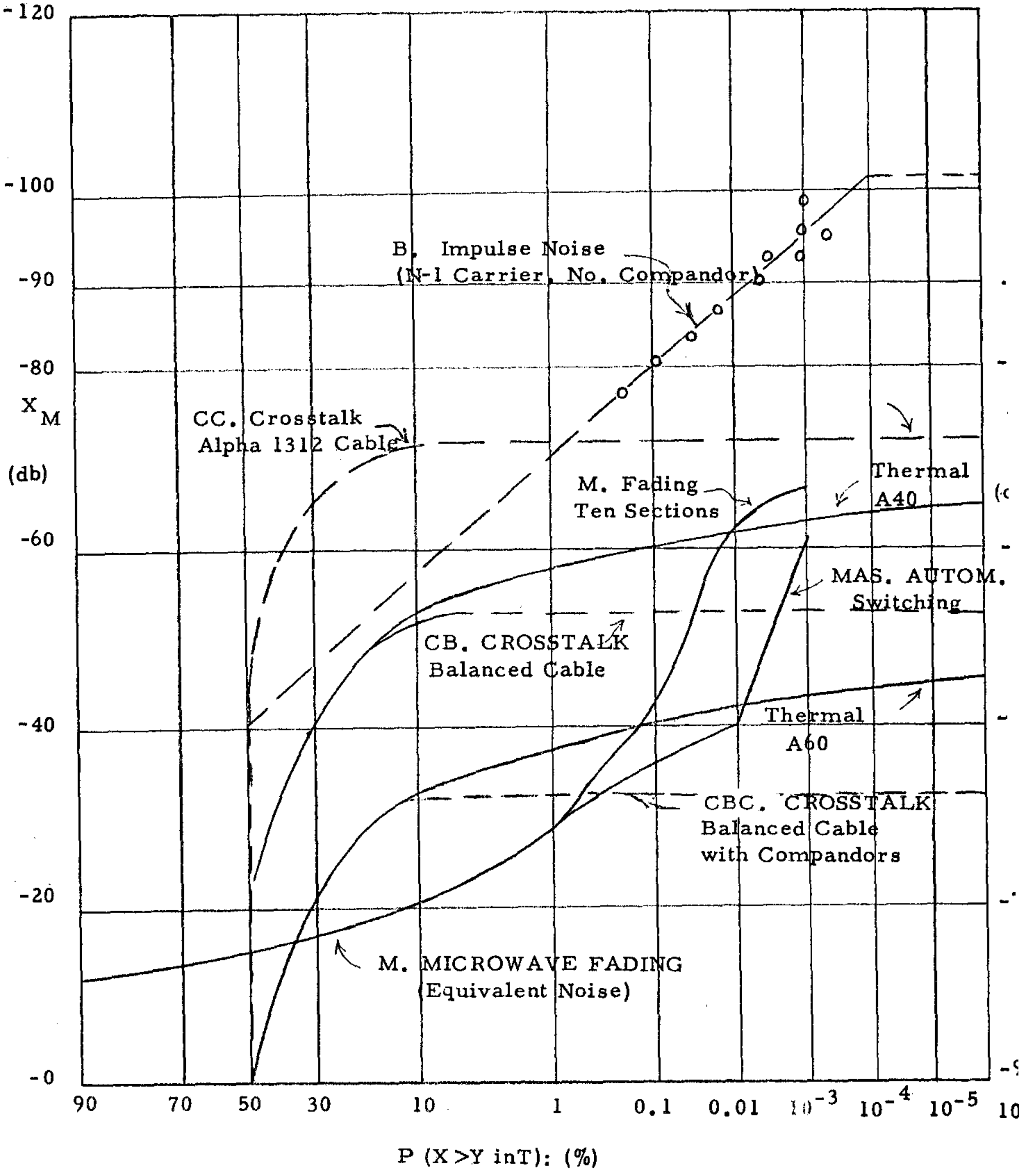


Figure 1A- Principal Types of Noise

reference voltage (Y) in a given time interval (T seconds). With the exception of curve M there is a second half of the curves for negative voltage which is not shown in Figure 1. Curve M is different because fading is equivalent to a multiplicative operation which attenuates the signal as shown in Figure 1-C while the other noise sources shown are algebraically additive to the signal as is shown in Figure 1-B. The period of observation (T) is different for different noise sources, and is further specified in the section of the report dealing with particular noise sources. The well-known mathematical model of gaussian white noise is represented graphically as curves A40 and A60 in Figure 1-A. These particular curves are for signal-to-noise ratios of 40 and 60 decibels, respectively. The length of line between repeaters on voice telephone circuits is chosen so that the lowest signal levels are still well above the gaussian thermal noise.

A second source of noise is "voice crosstalk" which may be due to the carrier crosstalk of carrier channels on adjacent cable pairs or due to the voice signals on adjacent cable pairs. A sample curve is shown as curve CC in Figure 1-A for a particular cable. The telephone companies normally balance the cables so that the crosstalk is 40 db or better as is shown in Curve CB. On an N-1 carrier System, the compandors make another 20 db protection, making curve CBC have a crosstalk of better than 60 db.

The real source of errors in data transmission has been found to be the impulse noise; named "impulse" because it is principally derived from dial pulses and switching transients on adjacent lines and at exchanges through which the channel goes. It is assumed that Bell Telephone Laboratories will complete a thorough study of noise which will give us a good model of impulse noise. In the meantime we are using a tape recording of twenty-five minutes of a "worst line." The experimental points for this N-1 carrier line of one-hundred miles in length are plotted as curve B in Figure 1-A. The data used for this curve is without an equalizer and covers a larger range than that included in the report of Dr. N. Abramson.[3]

A fourth source of interference occurs when microwave links are used, namely fading. Curve M is based upon a Bell Telephone Laboratories report, giving the per cent down time of a channel of ten microwave sections in series.[4-A, 4-B] This curve is not strictly speaking a "noise" probability curve, but a curve of the probability that the attenuation will be less than a given value due to fading. The fading attenuation is included here with noise for comparison so that the problems of maintaining the necessary automatic gain control and automatic switching of channels will be appreciated. The effect of this fading is to lower the carrier power level making the signal more susceptible to interference by gaussian and impulse noise. At present the fading problem can be bypassed by using physical circuits. The curve MAS shows the reduction in down time due to automatic switching to a spare channel when fading is bad.

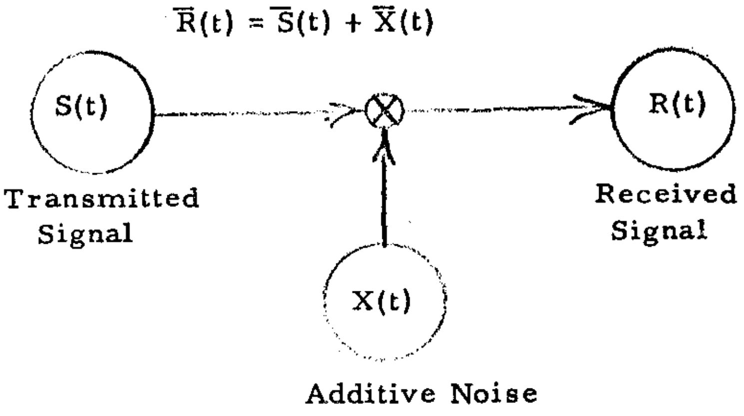


Fig. 1B. Additive Noise Such As: Thermal, Impulse, and Crosstalk

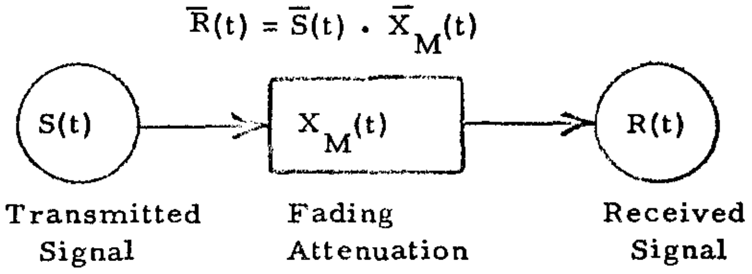
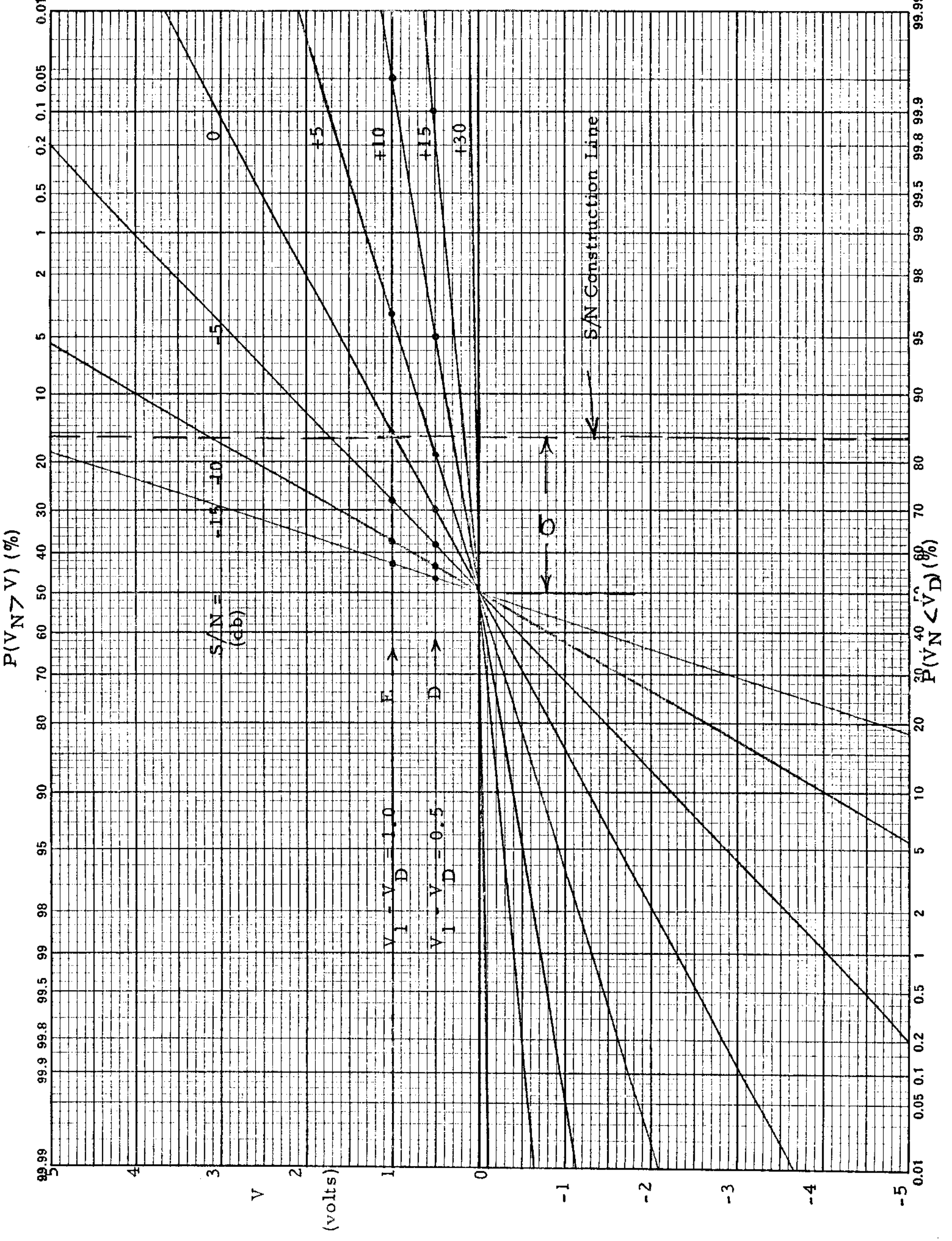


Fig. 1C. Multiplicative Equivalent Noise Such As: Attenuation Due to Multipath Fading.

Figures 1-B and 1-C illustrate the difference between the vectorially additive noises such as thermal noise, impulse noise, and crosstalk and the multiplicative equivalent noise such as the attenuation due to multipath fading. There has been some discussion as to the usefulness in trying to plot both kinds of phenomena on the same scale as in Figure 1-A. Further comments are given in Appendix B.

Another source of interference is the failure of switching circuits and repeaters. These are materially reduced by automatic switching systems developed by Bell Telephone Laboratories.[4-A] Perhaps it is useful to define a "cut off noise" to allow for the complete break of channel when an alternative circuit cannot be found. This possibility of "cut off noise" requires some kind of feedback to acknowledge receipt of messages as discussed in my analysis of optimum block length.[5]

In all of these examples, worst cases are used for illustrations. The objective of this report is to develop some simple approximations by which these noise and attenuation sources can be represented in the analysis of various coding and modulation systems for data transmission.


P(V_N > V) (%)
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
P(V_N < V_D) (%)
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
V
(volts)
5
4
3
2
1
0
-1
-2
-3
-4
-5
S/N =
(db)
0
+5
+10
+15
+30
-5
-10
-15
S/N Construction Line
σ
E
D
V_1 - V_D = 1.0
V_1 - V_D = 0.5

II. Thermal Noise (Gaussian)

Thermal noise from molecular sources in the conductors and amplifiers approaches the normal or gaussian distribution. Discussions of gaussian noise are to be found in various textbooks and handbooks.[6,7] Oscilloscope pictures of this wide-band thermal noise are given by W. R. Bennett. (Ref. 2, Part I, Fig. 1) The formulas are restated here for convenience. The objective of this section is to show the engineer a simple way to use arithmetic probability paper[8] for plotting gaussian noise distributions. The probability density is:

$$P\,(v)\,dv = \{1/\sqrt{2\pi\sigma^2}\}e^{-v^2/2\sigma^2}\,dv, \tag{1}$$

where σ^2 is the variance of the noise distribution and is proportional to the noise power.

The cumulative distribution:

$$P\,(v \leq V) = \int_{-\infty}^{V} P\,(v)\,dv \tag{2}$$

is related to the error function:

$$\operatorname{erf} v = \frac{2}{\sqrt{\pi}} \int_{0}^{v} e^{-t^2}\,dt, \tag{3}$$

$$P(v \leq V) = \frac{1 + \operatorname{erf} v}{2} \tag{4}$$

The square root of the variance is σ, the standard deviation. Graph paper is available for plotting the cumulative gaussian distribution as straight lines. A set of curves of the probability of the noise voltage exceeding V for different values of signal-to-noise ratio (S/N) at one standard deviation is plotted in Figure 2.

The curves of Figure 2 can be used to obtain a probability of error as a function of signal-to-noise ratio for specified detection levels. For example, if a "one" is +1.0 volts and a "zero" is -1.0 volts and we set the detection level at V_D = 0.5 volts, and we assume an equal number of zeros and ones,

$V_R > +0.5$ volts, $S = 1$;

$+0.5 \geq V_R \geq -0.5$ volts, S is indeterminate;

$V_R < -0.5$ volts, $S = 0$.

Drawing the 0.5 volt line (line D) in Figure 2 gives the values in Table I:

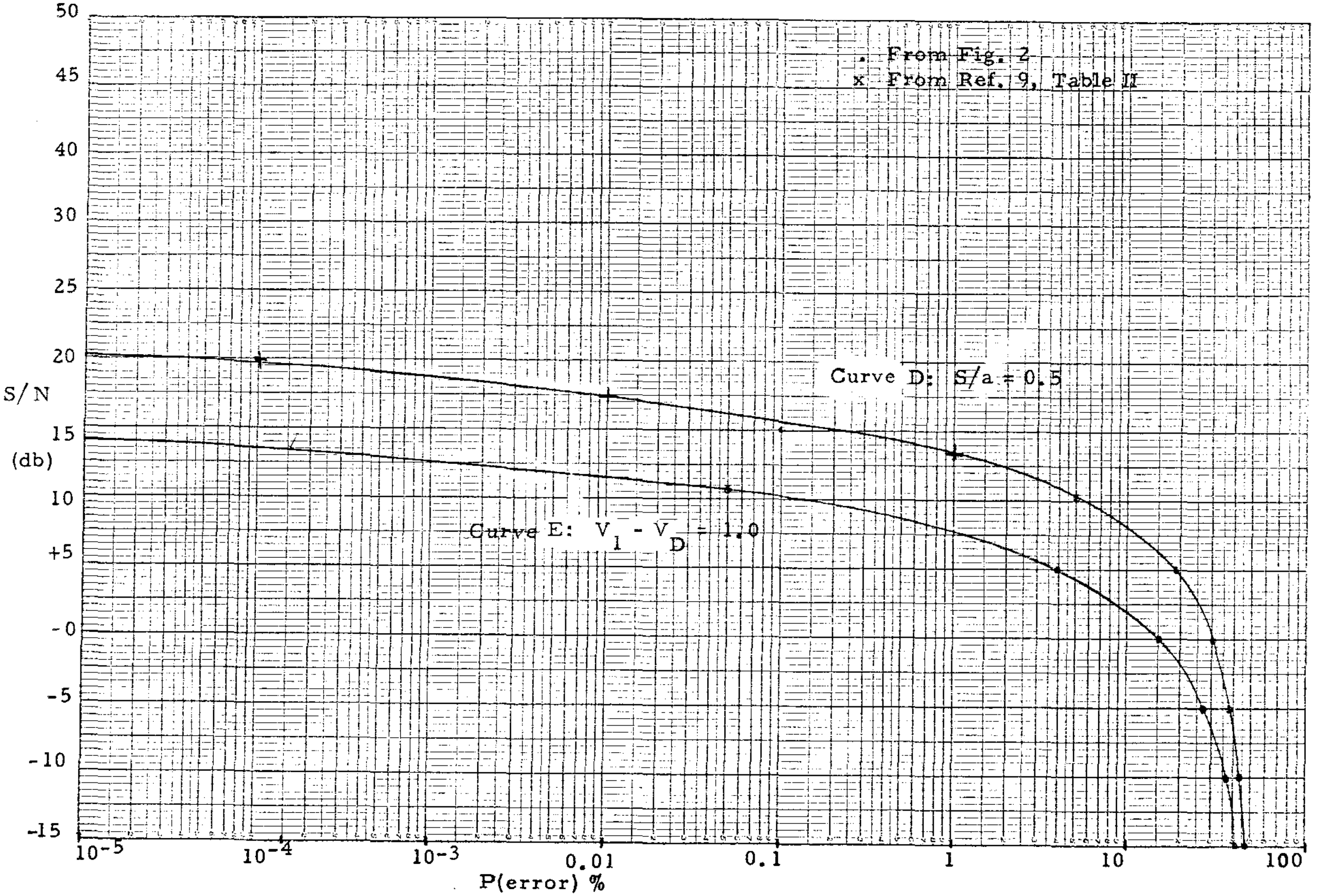


Figure 3 - Probability of Error for Gaussian Additive Noise

S/N (db)	-15	-10	-5	0	+5	+10	+15
P(error) %	46	43	39	30	19	5	0.1

Table I

Sample Calculation; For S/N =-15db:

$$P(\text{error}) = P(s = 1) \cdot P\,(V_N < -0.5) + P(s = 0) \cdot P(V_N > +0.5)$$

$$= 1/2 \times 0.46 + 1/2 \times 0.46 = 0.46 \text{ or } 46\%$$

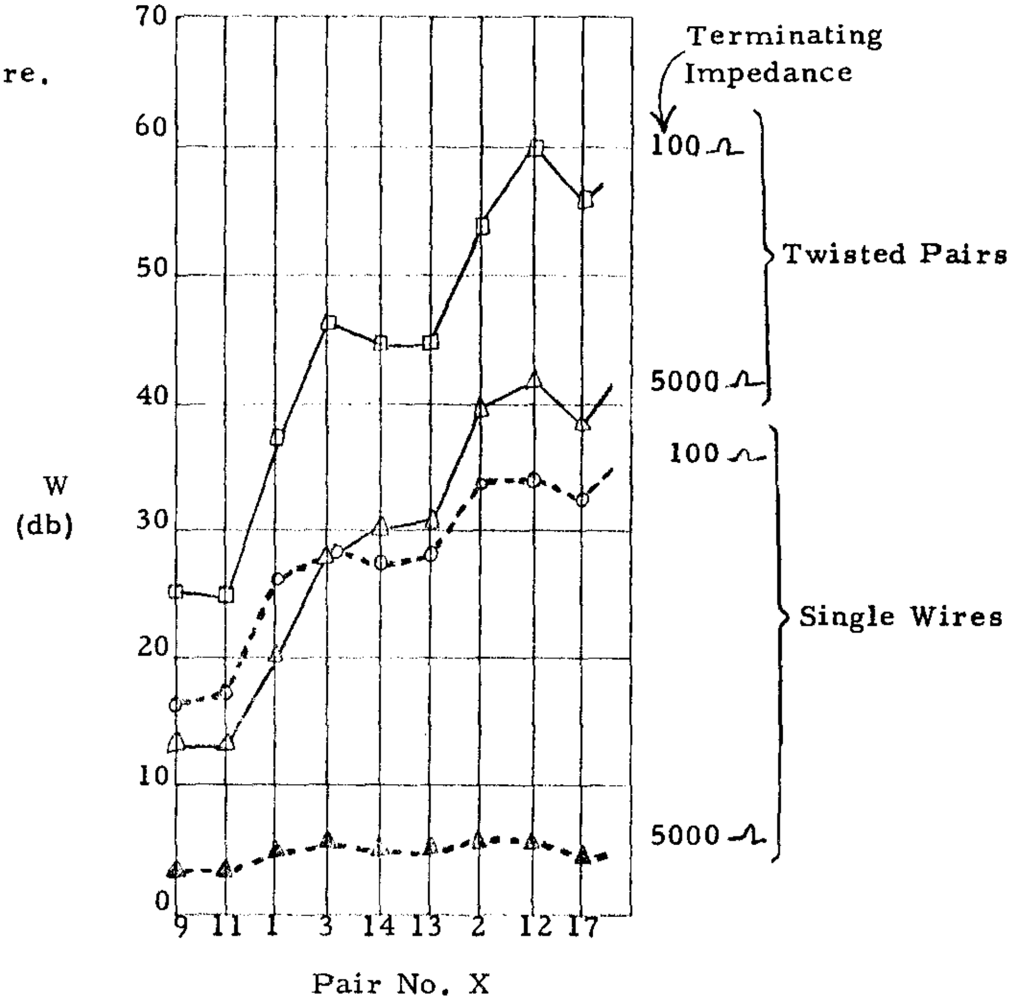
These values are plotted in Figure 3 as curve D. This curve is the same as Table II of Oliver, Pierce, and Shannon.[9]

If the detector does not need the ± 0.5 volt tolerance, we can define:

If $V_R > 0$ volts, $S = 1$

If $V_R < 0$ volts, $S = 0$

which gives Line E in Figure 2. The resultant points are plotted as Curve E in Figure 3. This is the same as the curve given by Mertz in the PIB Symposium.[10] The curves D and E are 6 db apart.



(From Electronics, Feb. 1956, p. 172)

Alpha 1312
cable, 100 ft.
long, 26 pairs,
No. 22 solid wire.

Conditions: 50 volt pulse on pair no. 25, 10μ sec pulses, 1.0μ sec rise time, 1000 pulses/sec.
W = 20 log (50/V), where V is induced voltage in Pair No. X

Figure 4 - Cross-Pulse Pickup in Twisted-Pair Cable

III. Voice-Modulated Carrier Crosstalk Noise

No accurate data is available on this source of noise. The conditions are approximated in the experimental curves of Figure 4 from Stephenson.[11] The high frequency channel of an N1 carrier system is centered at 256 kc/s.[12] The first approximation to the one microsecond rise time of Figure 4 is a 250 kc/s sine wave, which is close to the carrier frequency. Interpolating for a 600 ohm twisted pair in Figure 4 gives about 18 db crosstalk in pair No. 25 from pair No. 9 or No. 11. The pairs numbers used in Figure 4 are for a 100 ft. length of Alpha 1312 cable of 26 pairs of No. 22 solid wire. This estimated "worst" case of 18 db crosstalk is plotted as curve CC in Figure 1.

In Figure 5 the model of voice carrier crosstalk noise proposed here is compared with a curve of gaussian thermal noise. The peak voltage of the crosstalk signal is assumed cut off at the $\sqrt{2}$ times the rms value curve CB40 (curve CB in Figure 1) is for a 40 db crosstalk (rms) signal. Between -0.014 and +0.014 volts the crosstalk voltage is assumed to have a gaussian distribution. This tentative model is based upon the assumption that the crosstalk level is determined primarily by the coupling between cable pairs at the carrier frequencies; for example, the high frequency end of the N-carrier System is 256 kc/s. It is further assumed that the voice signals are limited to not exceed 3 db above the zero dbm level. A sample crosstalk probability curve is shown in Figure 5. Curve CB is for a signal-to-noise ratio of 40 db (or $V_N = 0.01$ volts) at one standard deviation. For comparison, gaussian thermal noise probability curves are shown in Fig. 5 for S/N equals 30 db, 40 db, 45 db, and 71 db, marked as curves A30, A40, A45, and A71.

Normally the operating telephone companies balance the cable pairs in a cable to reduce the effective coupling capacitance which reduces the crosstalk. In the absence of statistical data on the crosstalk coupling, it is here assumed that the balancing will achieve approximately a 20 db improvement for the high frequency end of the N-carrier channels. It is further assumed that the use of the compandors on N-carrier systems can produce an additional 20 db effective reduction in crosstalk.

A sample of the probability density distribution of voice signals is compared with a gaussian distribution in Appendix A to indicate the order of magnitude of the approximation used here.

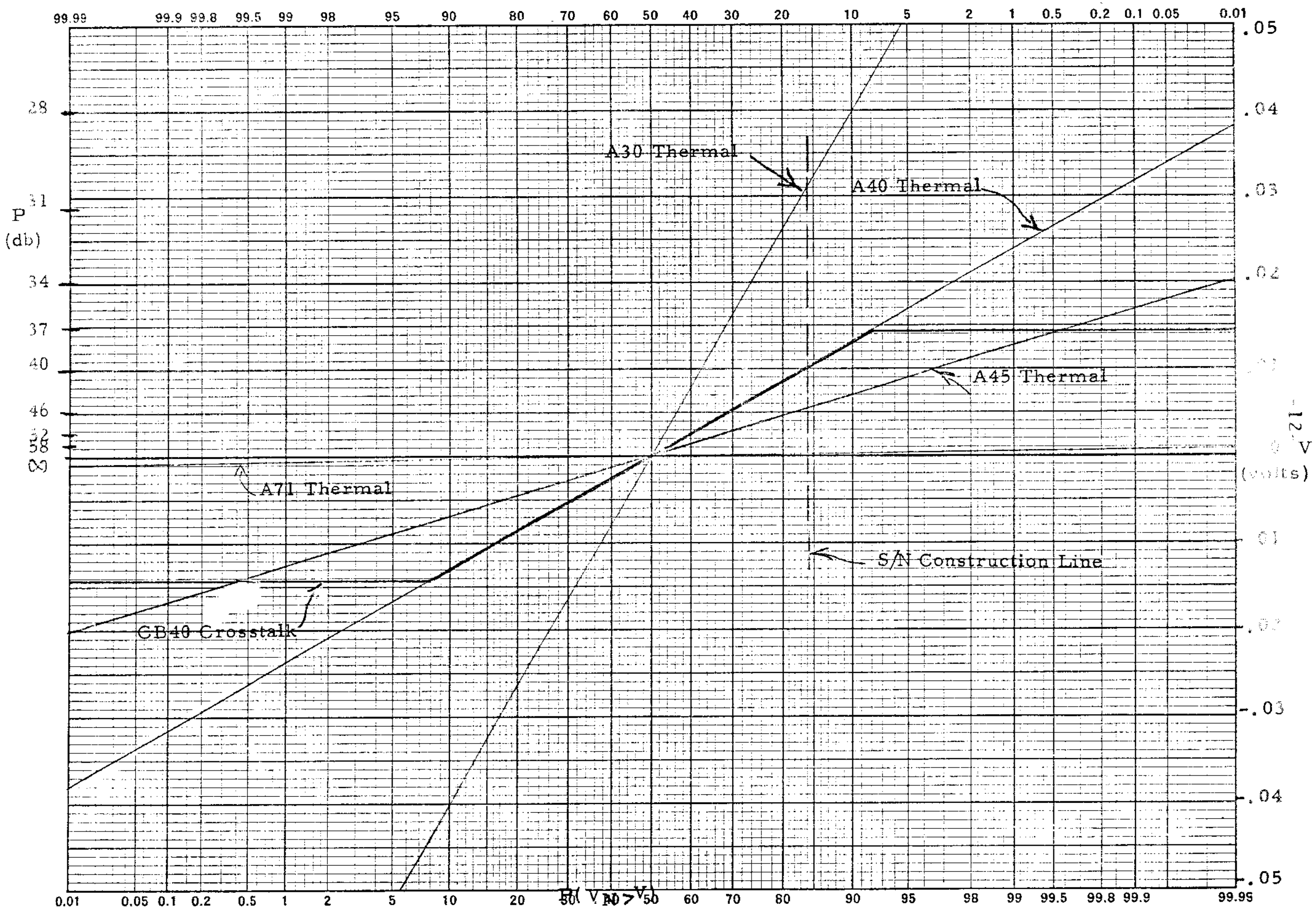


Figure 5 - Thermal Noise and Crosstalk Noise

IV. Impulse Noise

An illustration of how dial pulses and relay transients on an adjacent channel can cause impulse noise is shown in Figure 6. This is more likely to occur at exchanges. Step function S in channel 1 can cause impulse response IR in channel 2 by coupling at any point along the line. For example, the limiting cases are: (1) step function S gives step response SR at end of channel 1 which is differentiated by capacitor C'' and resistor R_o to give impulse response IR at receiver end channel 2, and (2) step function S could cause an impulse I to be coupled into channel 2 through capacitor C' and resistor R_o' which would be transformed to impulse response IR at receiving end of channel 2. Several simplified transforms for transmission lines are given by Sunde.[13] The assumptions used in the over-simplified equivalent circuit of Figure 7 are given by Arguimbau.[14]

The impulse noise of experimental curve B of Figure 1 is replotted on arithmetic probability paper in Figure 8 to illustrate the complete probability curve including impulse noise pulses of negative polarity. A thermal noise curve for a S/N = 30 db is plotted on the same sheet for comparison.

A mathematical representation of the impulse noise distribution is:

$$P\ (U)\ dU = \{1/\sqrt{2\pi\,\sigma^2}\}\ e^{-(U\,-\,U_o)/\,2\sigma^2}\ dU \qquad (5)$$

$$U = 20\ \log_{10} V \qquad (6)$$

U_o is the intersection of the extrapolated probability distribution for positive noise voltage at zero standard deviations. In this example U_o = -50 dbm or 40 dba.

U_c = 10 dbm for T = 0.4×10^{-3} sec.

The noise tape data is replotted another way in Figure 9. Here the impulse noise is defined by the following parameters:

σ = 13 db

U_o = 40 dba or -50 dbm

This gives: $S/N = [(0\ \text{dbm}) - (U_o\,\text{dbm} + \sigma\ \text{db})] = [0 - (-50 + 13)] = +\ 37$ db.

The above S/N = 37 db is the same numerical value of the estimated thermal noise for the tape.

A problem worth considering is: what is the channel capacity (C) as a function of U_o and σ for impulse noise? A set of curves of C/W plotted against $U_o + \sigma$ for different U_o's would be desirable. For example, the curves for thermal noise are given in the ITT Handbook.[15]

It would be desirable to have other sets of data to plot in Figure 9. One curve is available from Bell Telephone Laboratories, but only the σ can be compared with this data.[16] For this data σ is 10 db, but the calibration is uncertain.

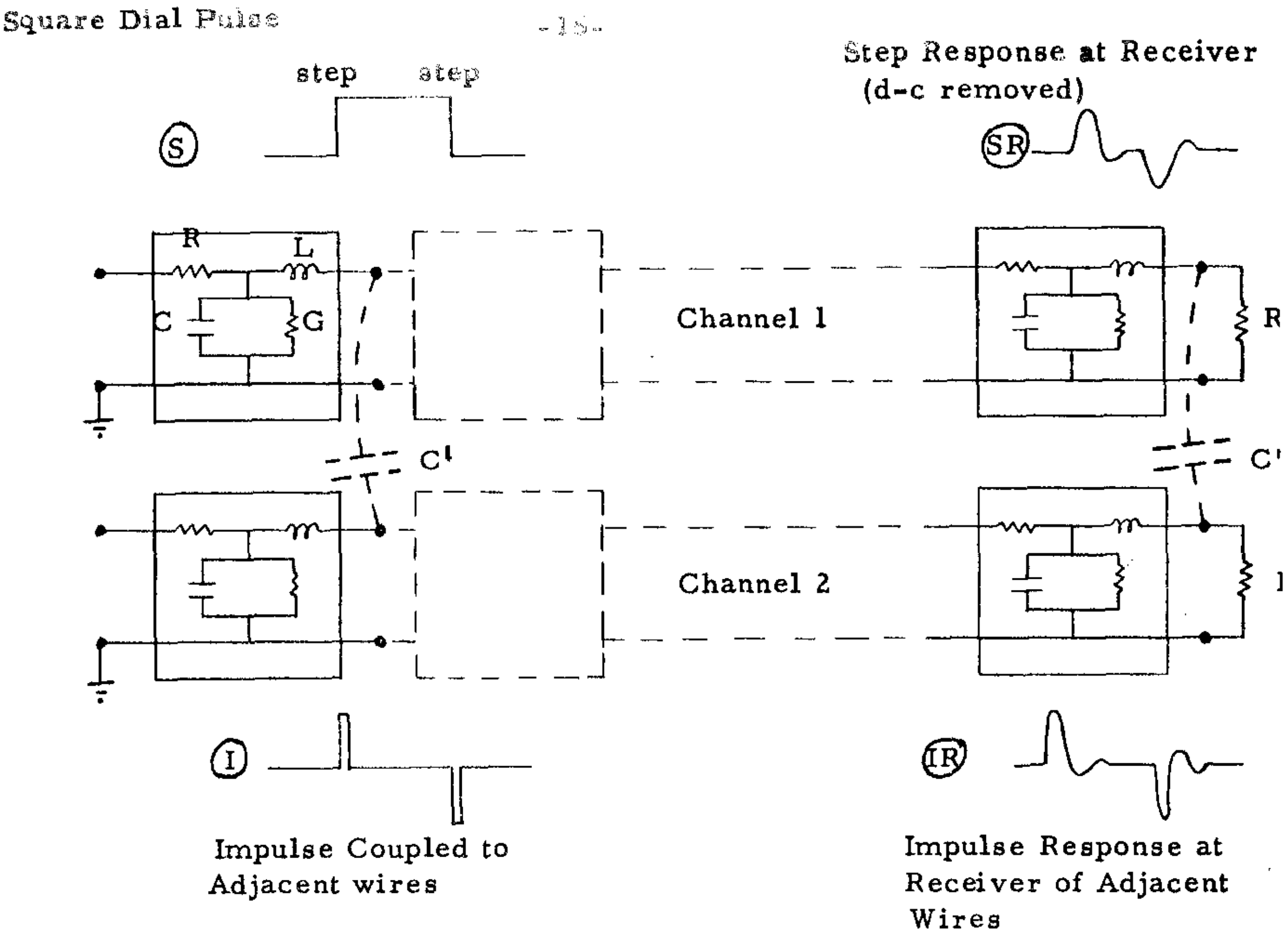
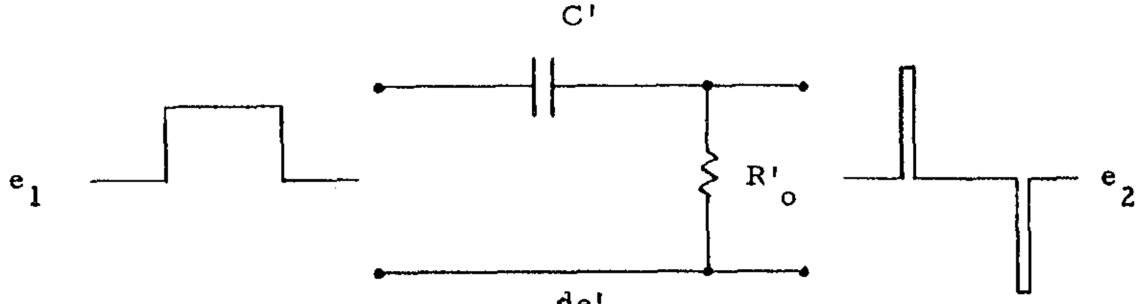


Figure 6 - Impulse Noise Caused by Step Voltage in Nearby Pair of Wires



$$e_2 \sim C' R'_o \frac{de'_1}{dt}$$

Figure 7 - Simplified Representation of Generation of Impulse Noise from Step Voltage

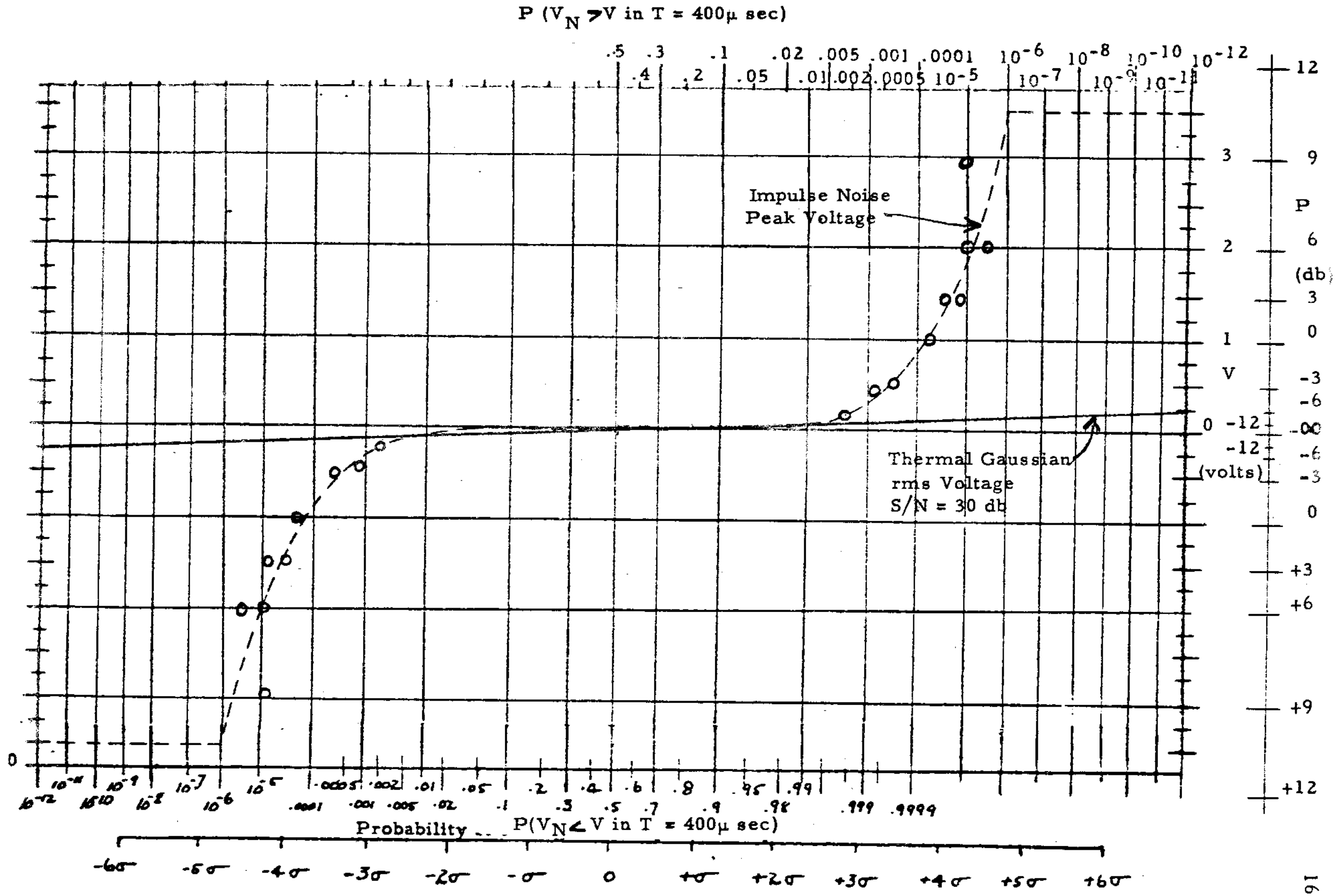


Figure 8 - Impulse Noise and Thermal Noise

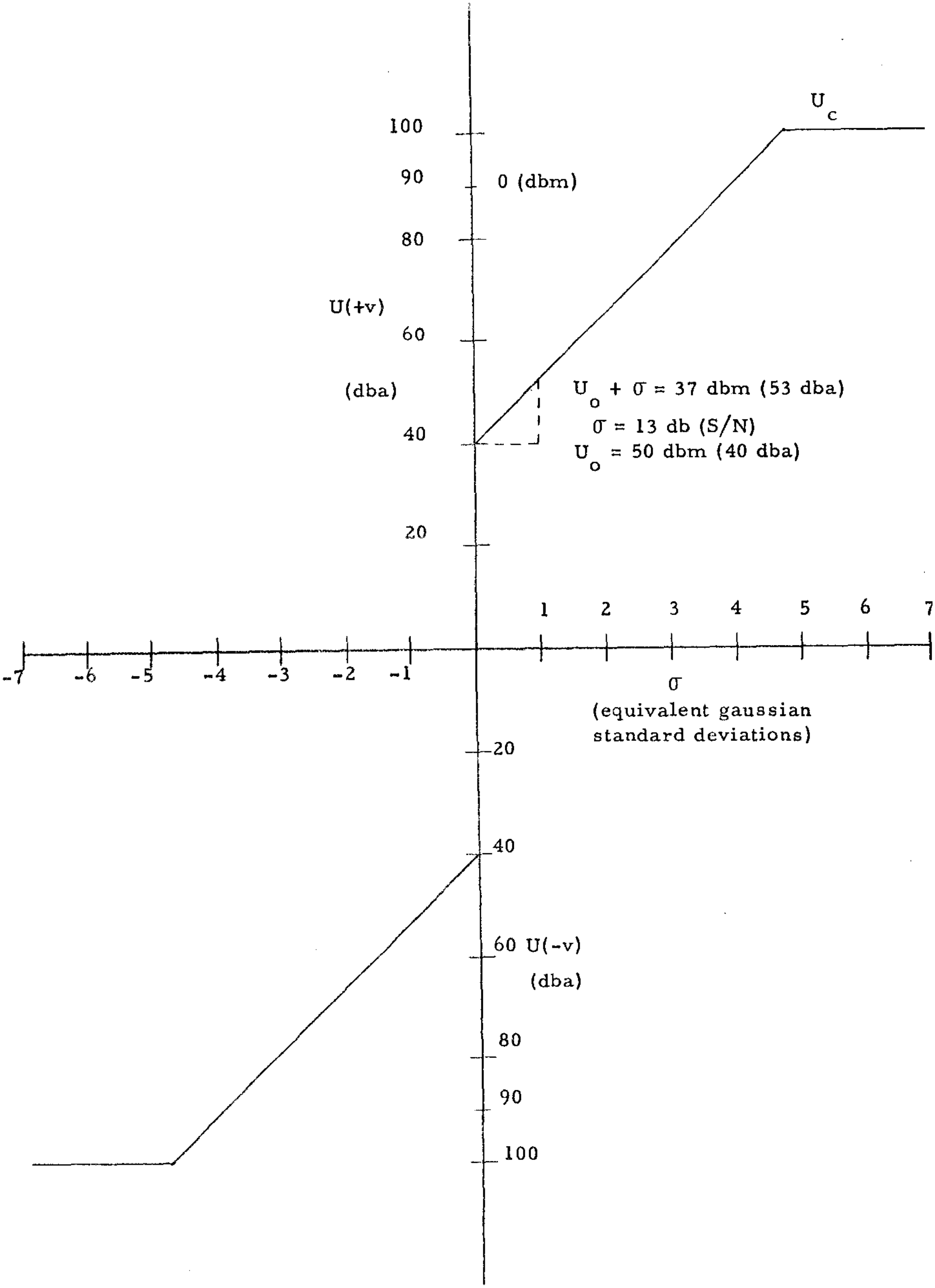


Figure 9 - Simplified Model of Impulse Noise Probability Distribution

V. Cut-Off Noise

A "cut-off noise" is here defined as a cutting of the communication channel through some accident or on microwave channels when the automatic switching cannot find alternate channel. This class of event is here defined as noise to remind us that even though error-correcting was employed, some feedback must be used to insure against the channel being out of commission.

A possible component of this cut-off noise can be extrapolated from the model of fading equivalent noise at the 90 dba level (39 ddba). See W_C in Figure 10. The abbreviation "ddba" used here means decibels of decibels absolute.

VI. Microwave Link Fading

Sample data on microwave TD-2 link fading are given by Bell Telephone Laboratories.[4-A, 4-B] The significance of fading in data transmission is the synchronization problem when the automatic switching system connects a spare channel. The data transmission system must have a suitable error detection code to request repeat of blocks[3] which are mutilated on the deep fades or by the loss of synchronization on switching. Alternatively, "burst-correcting" codes can be used.[17]

To obtain an approximate model of the fading probability, curves M and MAS of Figure 1 are replotted in Figure 10 on "log log gaussian" probability paper. The left vertical scale in W (ddba) is the equivalent noise power of the fade in "decibels of decibels absolute."

Let V = rms equivalent noise voltage;

then $U = 20 \log_{10} V$, and

$$W = 20 \log_{10} U = 20 \log_{10} (10 \log_{10} \{\frac{P}{10^{-12}}\}) \quad (8)$$

where P is the equivalent noise power (watts).

An approximation to the equivalent fading noise is plotted as curve MM in Figure 10.

For $W > 21.5$ ddba, or $U > 11.8$ dba;

$$p(W)\, dW = \{1/\sqrt{2\pi\sigma^2}\}\, e^{-|W-W_o|/2\sigma^2}\, dW \quad (9)$$

For $W \geq 21.5$ ddba, $P(X > 21.5) = 70\%$ (10)

For $W \geq W_1$ ddba;

$$P(X > W) = 70 - \int_{W_1}^{W_0} p(W)\, dW \quad (11)$$

(data based on B.S.T.J. May 1955, p. 480)

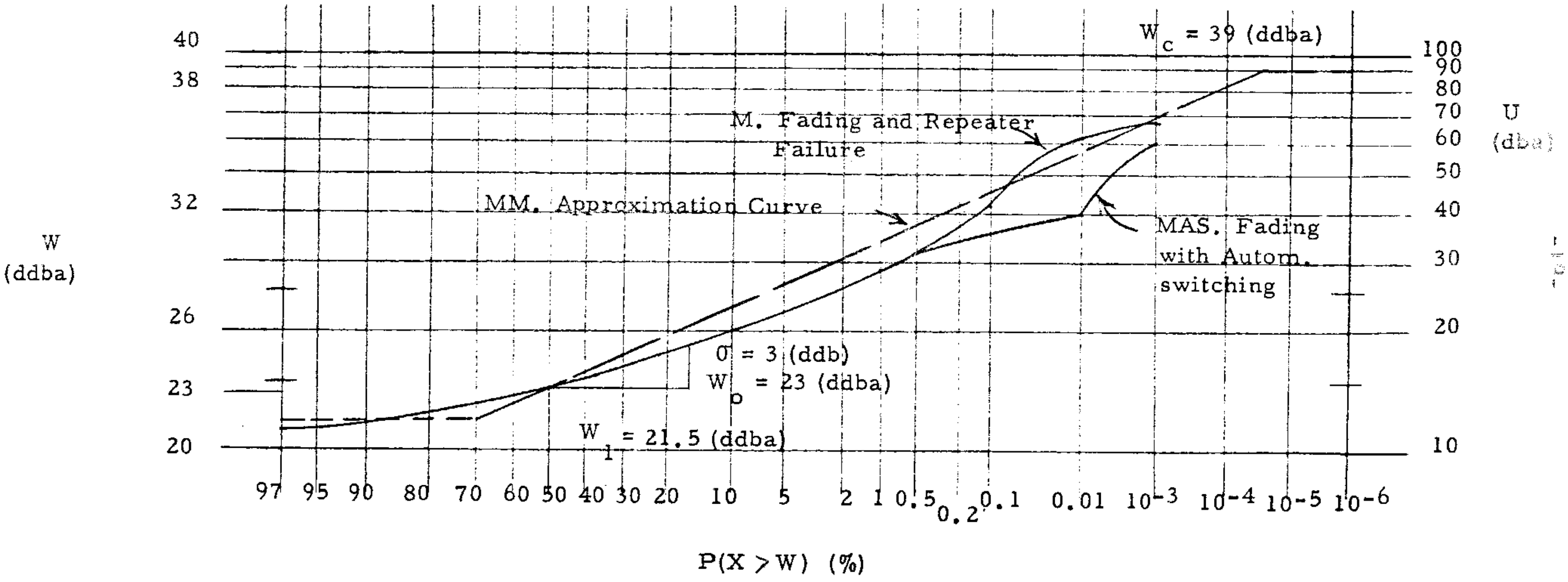


Figure 10 - Equivalent Noise Due to Fading

This curve is plotted as curve MM. It can be seen that it is not an accurate approximation but it gives the following errors in Table II for a sample of heavy summer fading in a link of ten repeater stations. The usefulness of this method of plotting equivalent noise is still debatable. It is equivalent to plotting the fading attenuation of Figure 1-C as if it could be translated into an equivalent additive noise as shown in Figure 1-B for comparison.

This log-log gaussian model of the probability of the equivalent rms fading noise being below a specified level requires the specification of three parameters: (1) W_o, the noise level at 50% probability, (2) σ, the standard deviation for the log-log gaussian region and (3) W_1, the minimum noise level. Another point can be added to this model, namely the 90 dba level (W_c), corresponding to the channel being completely cut off.

A comparison with a Rayleigh probability distribution is given in Appendix B.

TABLE II: P (X > W) FOR FADING

NO SWITCHING

(ddba)	(dba)	P(X > W) Approx. %	P(X > W) Experimental
37	65	.0017	0.0017
34	50	0.03	0.05
32	40	0.22	0.14
30	30	2.0	0.8
26	20	20	20
23	14	50	50
21.5	12	67	85

VII. Conclusions

The different types of noise which can be encountered in data transmission are reviewed in Table III. Thermal white (gaussian) noise is represented graphically on arithmetic probability paper to illustrate the family of probability curves for different signal-to-noise (S/N) ratios. This graphical representation illustrates a simple way of visualizing the construction of error probability curves for thermal noise as a function of S/N. This graphical construction method permits approximate analyses of noise to be developed by graphical means before detailed analytical models are developed.

Similar graphical curves are sought for other noise sources. Insufficient data prevents a definitive model. Since complete impulse noise data is available for only one line, a model for impulse noise at present corresponds to a curve for one principal variable, as one gaussian (thermal) noise curve is valid for one S/N.

For crosstalk noise in terms of peak voltages, the model assumes a gaussian distribution that is limited to some peak value so that two parameters are needed in arithmetic probability coordinates S/N and σ_ℓ . For the present σ_ℓ is assumed to be 3 db.

Impulse noise in terms of peak noise voltages requires three parameters to determine the model in logarithmic probability coordinates: S/N at one standard deviation, σ (standard deviation), U_m (maximum peak).

Fading in terms of equivalent rms noise power requires four parameters for an equivalent gaussian distribution and the second coordinate must be log-log to give a reasonable correspondence.

There is insufficient data available to plot probability distributions of cut-off's of the channel. However, when the fading is extrapolated to 90 dba it is equivalent to a cut off of the line. Interpulse interference due to delay distortion is treated separately for different cases by Abramson[3] and by Sunde.[13]

ACKNOWLEDGMENTS

I wish to acknowledge the assistance of Mr. E. Hopner in discussing the influence of noise on data transmission. Mr. Orman Meyer made the original recording of impulse noise on a tape which made possible a set of points for impulse noise. Mr. John Sutton and Mr. Paul Daher did further experimental work in counting the impulses on the tape.

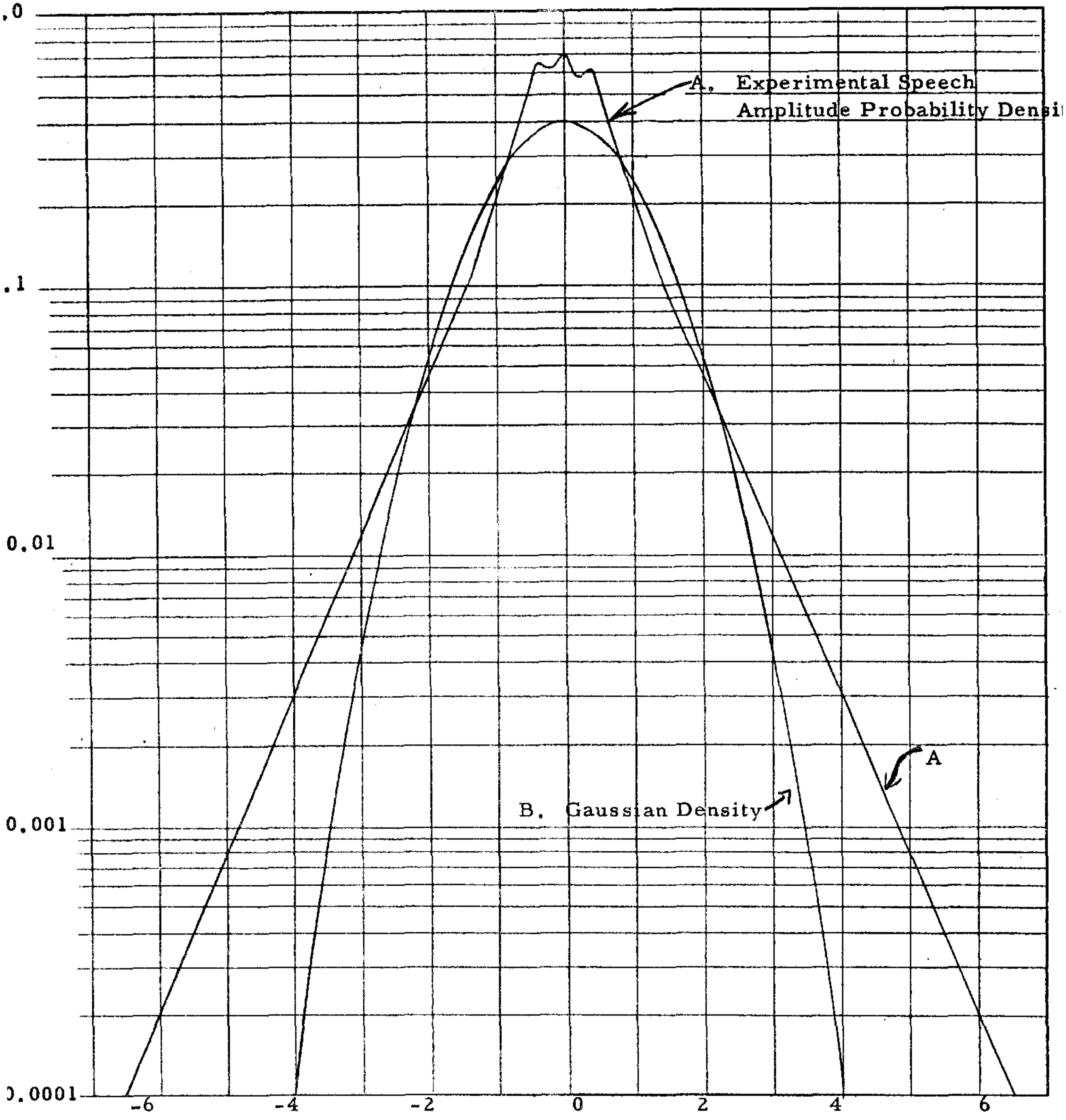
TABLE OF NOISE TYPES

Physical Type	Coordinate for Gaussian	Number of Parameters	Specifications
Thermal	Arithmetic	1	σ (S/N at std. dev.)
Crosstalk	Arithmetic	2	σ (S/N at std. dev.) Δ (limit - S/N)
Impulse	Logarithmic	3	σ (std. dev.) U_o ($\log_{10}$ V at std. dev U_m (limit)
Fading	Log-Log	4	W_o (50% point) σ (std. dev.) W_1 (lower level) W_c (cut off level)
Cutoff	Insufficient data. Partly included in W_c parameter in Fading.		
Distortion	See analyses by: (1) Sunde, Ref. 13 (2) Abramson, Ref. 3		The waveform or distortion of the waveform influences the impulse noise.

TABLE III

APPENDIX A: PROBABILITY DISTRIBUTION OF VOICE SIGNALS

To give an idea of the approximation involved in using a gaussian distribution for the voice-crosstalk noise, the gaussian distribution curve (B) is compared with an experimental curve (A) from W. B. Davenport, Jr.[18]



Standard Deviations, σ

Figure 11 - Speech Signal Amplitude Distribution

APPENDIX B: COMPARISON OF THE FADING DISTRIBUTION WITH A RAYLEIGH DISTRIBUTION

The empirical fading distribution is a composite effect of different physical sources. The Rayleigh distribution is described in several references and handbooks such as Bennett (Ref. 2), ITT (Ref. 7), Grabbe (Ref. 19), and is illustrated in Figure 12. Curves 13A through 13C are fading curves derived from Kaylor (4B) for a single microwave link. A signal level of U = 90 dba is assumed. So P(X>W) means the probability that with fading the effective signal level remains more than W watts. Curve 13B is an integral of the Rayleigh probability density fitted to one set of experimental data. Curve 13E is replotted from Welber (Ref. 4-A) for ten links or sections. Curve 13D was obtained by subtracting curve 13E from 90 dba to show the maximum effective reduction of signal level as a probability distribution. Comparison of curve 13D with the family of curves 13A-13C shows that it is approximately a Rayleigh distribution over the central range.

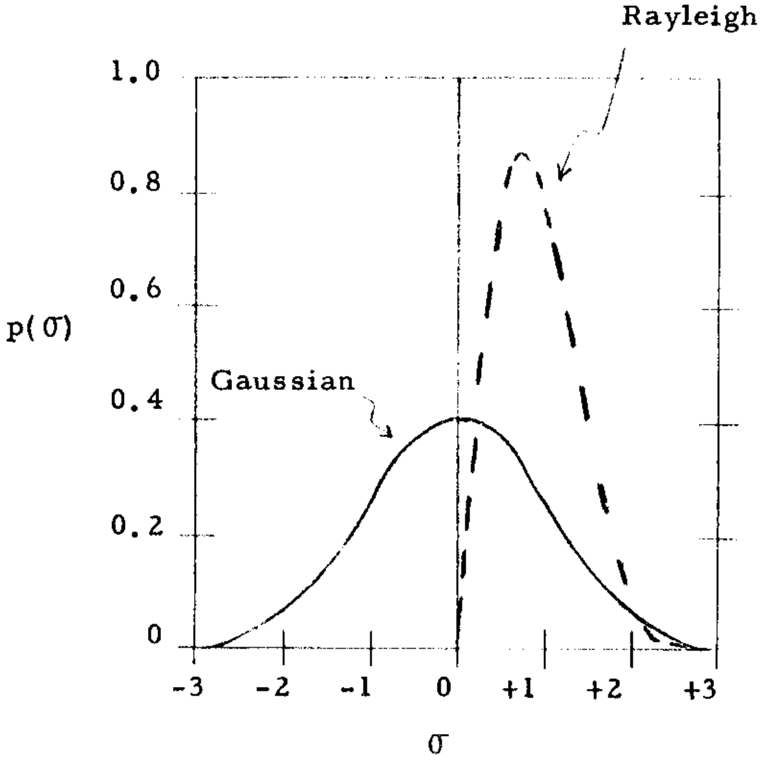


Figure 12 - Comparison of Gaussian White Noise with Rayleigh Noise Distribution

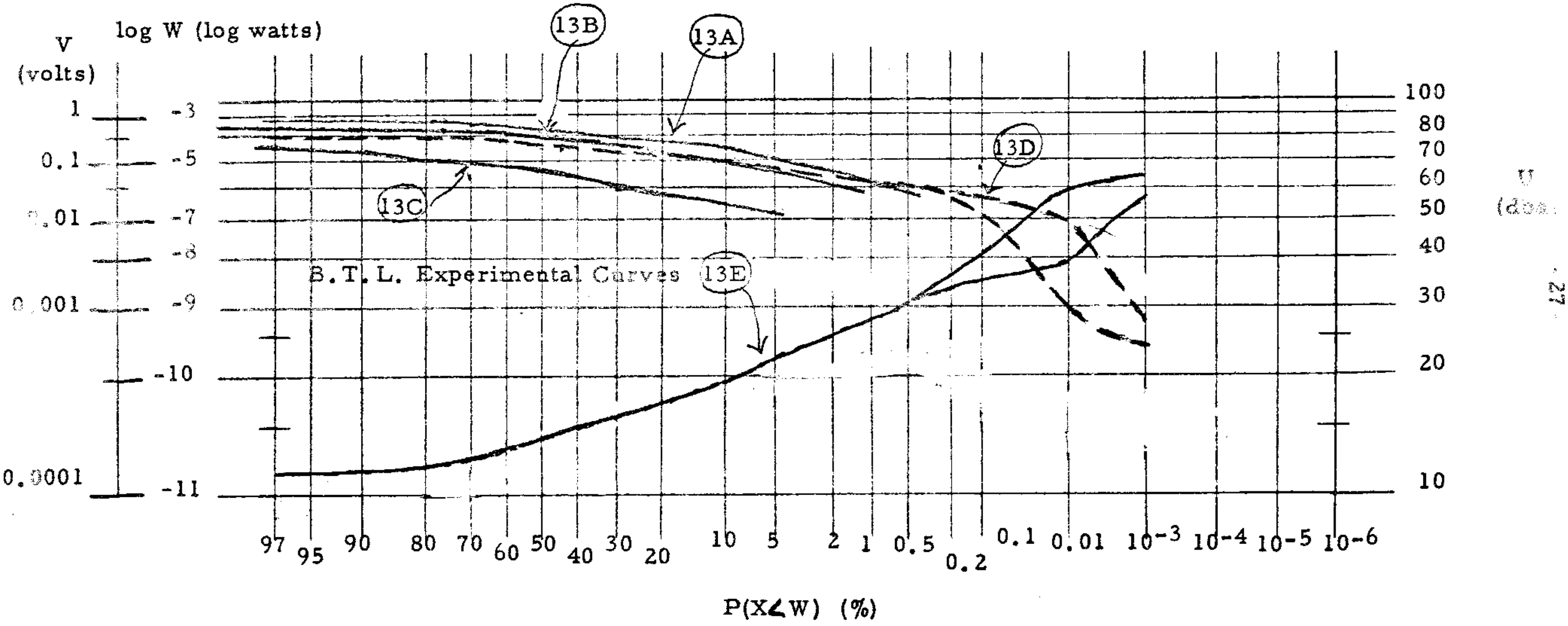
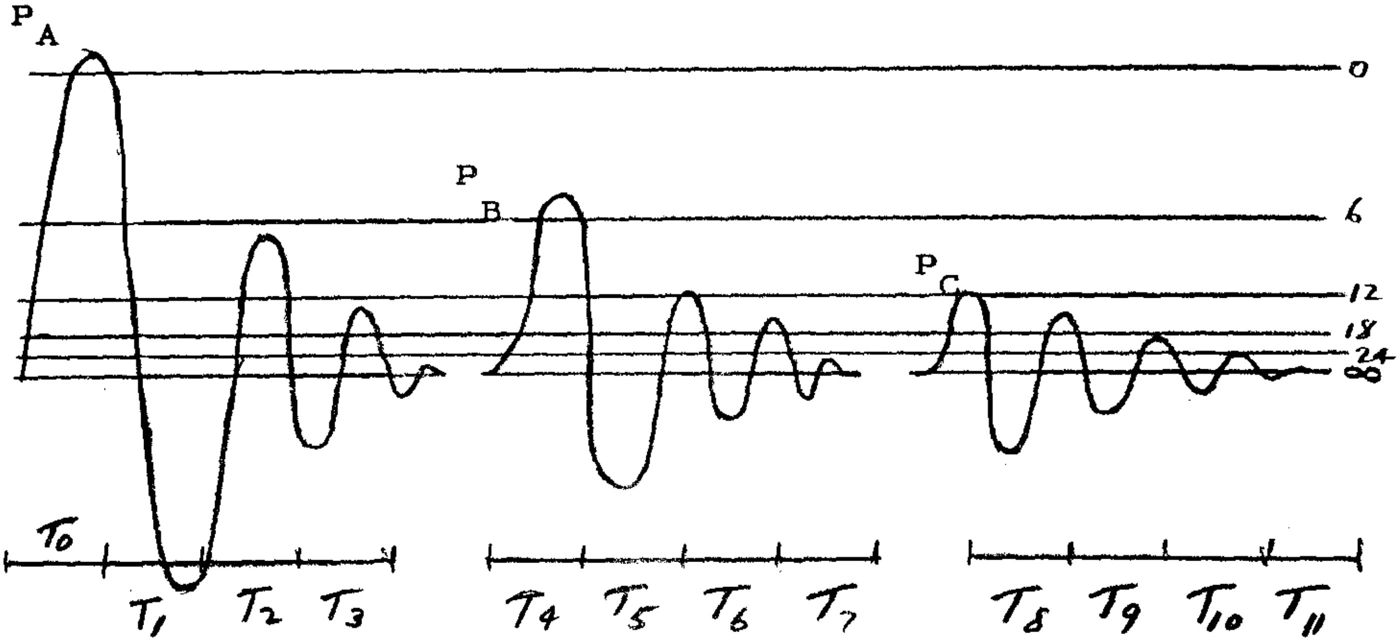


Figure 13 - Comparison of Equivalent Fading Noise and Rayleigh Noise Distribution

APPENDIX C: THE NON-LINEAR RELATION BETWEEN NUMBER OF NOISE PULSES, NOISE PEAKS AND ERRORS

The experiments from which the impulse noise model of Section IV were derived were based on counting of peaks above a specified voltage level. Three noise pulses, P_A, P_B, and P_C are drawn in Fig. 14. The pulse length for signal pulses of a square wave or half-sine wave form is T_0. For a simple integrating detection the maximum number of errors due to the three noise pulses is compared with the number of independent noise pulses detected and the number of peaks which could be detected by the experimental circuit of Section IV.

We see that for a zero db signal level all three counting methods agree. When we set the signal level at - 24 db they are all different i.e.: 3 pulse, 10 peaks, or 7 possible errors. Since the model for the upper bound on impulse noise developed in Section IV is based on counting of noise peaks, it can be seen that the curve of Figure 8 could be different, if pulses or errors were counted instead of peaks. The extensive tests being conducted by Bell Telephone Laboratories and AT&TCo. should give us a more accurate model of impulse noise.



$V = 20 \log_{10}(V_0/V)$	0	6	12	18	24
Pulses	1	2	3	3	3
Peaks	1	2	5	8	10
Max. No. of Errors	1	3	7	6	7

Fig. 14 - A Sample Comparison of Different Ways of Counting Noise Pulses and Errors

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ADDENDUM I - C. C. I. T. T.

In Europe the interconnection of telephone circuits of many countries has led to the establishment of committees of the C.C.I.T.T. to raise questions and to study problems of the defining, measuring, and establishing of specifications for telephone circuits. The following references are added to simplify reference to recent reports of the C.C.I.T.T. (formerly C.C.I.F and C.C.I.T).

20. The International Telephone Consultative Committee (C.C.I.F). XVIIth Plenary Assembly, Geneva, October 1954. Geneva: International Telecommunication Union (Green Book Series). Volume I: (1953) List of Delegates, Minutes of Meeting, Organization of the C.C.I.F., Recommendations on Symbols and Units, Membership of Study Groups, and Chart of Organization of C.C.I.F., 574 pages.

    Page 173: Summary of protection questions including:
    No. 13: Types of unbalance.
    No. 20: Noise due to the electrical protection of cables against corrosion.

    Pages 197-207: Results of measurements of speech power.
    Page 211: Annex: Noise inherent in a telephone system.
    Page 307-309: 3rd S.G. Question, Annex 2, D-F: Proposal for the form of a general noise objective.
    Page 328: Crosstalk.
    Page 337: Summary of transmission questions:
    No. 2: Noise.
    No. 4: Risk of singing in the semi-automatic service.
    No. 5: Reduction in transmission quality due to circuit noise.
    No. 8: Crosstalk.
    No. 23: Admissable variation, as a function of time, of the signal-noise ratio.
    No. 25: Objectionable impulses arising from signalling.
    No. 34: Noise on symmetrical pairs.
    No. 38: Noise on open wire lines.
    No. A: Crosstalk between telephone circuits.
    No. B: Basic noise of a repeater.
    No. I: Cross-talk in cabling of voice frequency repeaters.
    Page 482: Noise which is present for a short time on the switching apparatus.

21. Volume IV (1956) Recommendations and measurements concerning, transmission quality, telephone apparatus, 174 pages.

    1st part: General recommendation on the transmission quality.
    2nd part: Recommendation concerning subscriber station, local lines, etc.
    3rd part: Measuring methods and apparatus.
    Pages 163-170: Bibliography on the subject dealt with in Vol. IV, The Green Book.

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Sec. II: 1 Determination of the curve of noise distribution on a telephone channel is a radio relay system.
Page 10: Sample probability curve.

Sec. III: Influence of noise on telegraphy and telephone signalling.

Sec. IV: Schedule of tests.

25. International Telecommunication Union, Compendium of Technical Recommendations, Issued by C.C.I.F., C.C.I.T and C.C.I.R. Liverpool: Automatic Telephone and Electric Co., Ltd., (Aug. 1956).

Ch. I: Origin and Brief History of the International Telecommunication Union.
Ch. II: Organization.
Ch. III: The C.C.I. Telephonique (C.C.I.E).
Ch. IV: The C.C.I. Telegraphique (C.C.I.T.).
Ch. V: The C.C.I. Radio (C.C.I.R.).
Index of Principal Recommendations of the C.C.I.F.

26. C.C.I.T.T. "Question concerning Telegraph Apparatus entrusted to Study Group 8 in 1957-1960." 17 pages.

Question 1/8 (Former C.C.I.T. Question 34, amended).
Question 2-22/8.
Question 43/8, What general characteristics should be standardized to permit international transmission of metering data? Under comments, the Swedish Administration proposes the question: Transmission over telecommunication circuits of data intended for computing and data-processing machines.

27. Journal UIT (Telecommunication Journal) Volume 24, No. 8, August 1957. Pages 186-189, The First Plenary Assembly of the C.C.I.T.T. (Geneva, 15-20 December 1950). Pages 198-200, Selective List of Publications. Included on list is: "Biblography on Communication Theory, 1953" with Supplements Nos. 1, 2, and 3.

ADDENDUM II: I.P.C.E.A.

Crosstalk noise is restricted by the tolerances on cable manufacture. The effective capacitative unbalance between cable pairs is limited by specifications of the I.P.C.E.A.

28. Insulated Power Cable Engineers Association Standard for Fully Color Coded Polyethylene Insulated Thermoplastic Jockeled Communication Cables Type I, Standard S-51-434.

    Section 14: Limits are given for the average pair-to-pair capacitance unbalance and for the highest value tolerated in any reel. For cables of more than 25 pairs the allowable number of pairs exceeding the unbalance limits are stated. Also average and maximum pair-to-shield capacitance unbalance limits are given.

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