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STUDIES OF RANDOM NOISE: AN ANNOTATED BIBLIOGRAPHY

by

Herbert P. Eckstein

December 1966

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ABSTRACT

This bibliography contains a selection of papers, most of them annotated, on noise and the effects of noise on signals. Consequently, several surveys of information theory and papers dealing with interdependent aspects are included. Sources of the contemplated noise were either environmental or inherent in the equipment, which includes effects of both the atmosphere and other transmitters. Accordingly, several studies include non-Gaussian as well as Gaussian noise.

FOREWORD

This bibliography was compiled in response to a request by the Instrumentation and Communication Division, Marshall Space Flight Center. The area of interest is in the useful application of noise, properly so called; hence, no studies on noise elimination are included, but studies on overcoming the effects of noise are presented because of the import on communication.

A number of titles of pertinent papers was furnished by Messrs. Mixon and Saunders of the Instrumentation and Communication Division; others were located in the open literature, mainly by searching in

1) Science Abstracts Section B (Telecommunications),
2) Bulletin Signaletique des Telecommunications,
3) IEEE and IRE Transactions,
4) Proceedings of the IEEE and IRE.

Several reports located during a search of the Technical Abstract Bulletin of DDC and of the Scientific and Technical Aerospace Abstracts of NASA were found to have been published in the open literature also; wherever possible the AD number of essays published in the open literature is identified.

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Section I. INTRODUCTION

The need for transfer of information is probably as basic in both aspects, transmitting and receiving, as are the fundamental drives for self-preservation and its group-oriented form: preservation of the species. Transfer of information takes widely varying forms, from the dance of the bees to the trumpeting of the elephant, from a glance or gesture to the profound thesis written on an electric typewriter by a typist listening to an electronic recording device, etc.

Disregarding form and content of the information, it consists of two elements, signals and noise. Signals arise either from determinate processes, for which the future course and events at a time, t, can be predicted as in the case of harmonic oscillation, or from indeterminate (also called stochastic or statistical) processes, for which future values are not known. Only signals of this second group convey true information, that is, by definition, information not known to the receiver in advance. This information is not necessarily meaningful like a sequence of letters or numbers, which was, however, unknown to the recipient of the message; it may consist of mere noise, such as thermal and/or shot noise in electrical applications or of random pressure fluctuations and thermal motion of gas or liquid molecules (Maxwell-Boltzmann statistics and Brownian motion).

If the number of mutually independent particles causing the noise is large, their chance or random motion can be characterized by Gaussian statistics, and Gaussian noise is the probability distribution of the instantaneous value $n(t)$ of a random voltage, current, pressure, velocity, or other time function. The variance σ^2 is the only significant statistic and is equal to the ensemble mean-squared value n, if the average value of the probability distribution is zero.

If the spectral density of the noise (when generated) is constant for all frequencies, the noise is "white;" although it is physically not strictly admissible because of the implied infinite power, it is a good approximation if the spectral density may be assumed constant over the contemplated range of frequencies.

The following bibliography contains a representative collection of reports dealing primarily with the mathematical aspects of retrieving from noise signals information that they contain in the form of stationary (time-independent) elements, the statistical average values of which are known in advance; such values are, for instance, the bandwidth and the effective value. This problem of communication is not confined to radar, radio, and television; it occurs equally in every field of the exact sciences, and a few papers out of the domains of acoustics and optics are included for this reason. The total number of studies in this field is far too great to allow comprehensiveness, but it is believed that this collection provides sufficient information about the state-of-the-art.

Section II. BIBLIOGRAPHY

1. Abend, Kenneth,
SOME COMBINATIONS OF NOISE SIGNALS, Proceedings of the IRE, Vol. 50, No. 12, December 1962, pp. 2518-2519.

Not abstracted.

2. Atherton, D. P.,
THE EVALUATION OF THE RESPONSE OF SINGLE-VALUED NON-LINEARITIES TO SEVERAL INPUTS, Proceedings of the IEE, Vol. 109, Part CO, No. 15, March 1962, pp. 146-157.

The transform method for evaluating the coefficients of the various terms in the output autocorrelation function of a nonlinearity with an input consisting of a sinusoidal signal and Gaussian noise is considered. Solutions, all of which involve confluent hypergeometric functions, are given for a few analytically defined nonlinear characteristics. A short table of these functions is also given to facilitate computation. A new expression for evaluating the coefficients, a double integral involving the nonlinear characteristic and the moments of the sinusoidal and Gaussian input signals, is derived. A graphical method of solution applicable to any single-valued nonlinearity is given and a comparison made with experimental and theoretical results. Extension of the technique to several uncorrelated input signals of any known amplitude probability density distribution is shown to be possible.

3. Aubrun, J.-N., Veillet, P., and Van Hiep, Tran,
EXTRACTION OF PERIODIC SIGNALS FROM NOISE, Proceedings of the Twelfth Colloque Ampere, Bordeaux, 1963, Electronic Magnetic Resonance and Solid Dielectrics (In French), Amsterdam, North-Holland Publishing Company, 1964, pp. 534-548, QC762 C714.

Resonance lines are often produced by a spectrograph as periodic signals with a poor signal/noise ratio. This ratio can be remarkably improved when one realizes the mean value of the signal, point after point, by sampling. This system makes possible, simultaneously, a direct observation of the initial signal on an oscilloscope and a continuous recording of the improved signal. The authors describe here the principle and the effective realization of this kind of sampling system and expound the theory of noise transmission by periodic gain systems of which this sampling system and the lock-in amplifier are special cases. This theory enables these two systems to be compared. The experimental study is in good agreement.

4. Balakrishnan, A. V., ON A CLASS OF NONLINEAR ESTIMATION PROBLEMS, IEEE Transactions, Vol. IT-10, No. 4, October 1964, pp. 314-320.

The 'noise-in-noise' problem is viewed as an estimation problem rather than a detection problem. Specifically, this is the problem of estimating the random scale parameter 'a' from observations x(t), where $x(t) = \alpha S(t) + N(t) \quad 0 \leq t \leq T < \infty$. Here, S(t) and N(t) are Gaussian processes with known covariances. The optimal mean-square estimator is nonlinear, and the bulk of the paper is concerned with methods for determining it. In particular, a computer algorithm based on steepest decent is developed. Also, the relationship to the detection problem, particularly the so-called singular cases, is examined.

5. Bello, P. and Higgins, W., EFFECT OF HARD-LIMITING ON THE PROBABILITIES OF INCORRECT DISMISSAL AND FALSE ALARM AT THE OUTPUT OF AN ENVELOPE DETECTOR, IRE Transactions, Vol. IT-7, No. 2, April 1961, pp. 60-66.

This paper is concerned with the effect of hard-limiting on the signal detectability of a system consisting of a limiter, narrow-band filter, and envelope detector in cascade. The input to the system is a pulsed IF signal immersed in noise whose power spectrum is uniform over a band of width W cycles.

Assuming that the noise bandwidth W is much larger than the bandwidth of the narrow-band filter, the probability distribution of the output of the filter will approach Gaussian. A bivariate Edgeworth series approximation is necessary to handle the narrow-band-filter output since the "in-phase" and "quadrature" components of the narrow-band-filter output are statistically dependent random variables. An expression is derived for the probability of incorrect dismissal that requires the numerical evaluation of single integrals only. From the same bivariate Edgeworth series, an expression is derived for the probability-density function of the output of the envelope detector for the zero-input-signal case. Subsequent integration leads to the probability of false alarm.

6. Bennett, W. R.,
METHODS OF SOLVING NOISE PROBLEMS, Proceedings of the IRE, Vol. 44, No. 5, May 1956, pp. 609-638.

A tutorial exposition is given of various analytical concepts and techniques of proved value in calculating the response of electrical systems to noise waves. The relevant probability theory is reviewed with illustrative examples. Topics from statistics discussed include probability density, moments, stationary and ergodic processes, characteristic functions, semi-invariants, the central limit theorem, the Gaussian process, correlation, and power spectra. It is shown how the theory can be applied to cases of noise and signal subjected to such operations as filtering, rectification, periodic sampling, envelope detection, phase detection, and frequency detection.

7. Bevensee, R. M.,
THE FUNDAMENTAL NOISE LIMIT OF LINEAR AMPLIFIERS, Proceedings of the IEEE, Vol. 51, No. 1, January 1963, p. 245.

Not abstracted; see also Heffner.

8. Blachman, Nelson M.,
FM RECEPTION AND THE ZEROS OF NARROW-BAND GAUSSIAN NOISE, IEEE Transactions, Vol. IT-10, No. 3, July 1964, pp. 235-241.

If $x(t)$ and $y(t)$ are statistically independent stationary Gaussian random processes, each having correlation function $\psi(\tau)$, mean squared value $\delta^2 = \psi(0)$, and spectral density $\Psi(f)$, then $u(t) = x(t) \cos 2\pi Ft - y(t) \sin 2\pi Ft$ is a stationary Gaussian random process with correlation function $\psi(\tau) \cos 2\pi F\tau$ and with spectral density $\frac{1}{2}\Psi(f - F) + \frac{1}{2}\Psi(f + F)$, symmetric about F for large F. From this representation of $u(t)$ it is shown that the variance of the number of zeros of $u(t)$ in the interval $(0, T)$ is, for integral 2FT,

$$\text{var } Z = \frac{1}{4} - \frac{1}{\pi^2} \arcsin^2 \frac{\psi(T)}{\sigma^2} + \frac{2}{\pi^2}\int_0^T \frac{(T - \tau)\psi'^2(\tau)}{\sigma^4 - \psi^2(\tau)}\, d\tau + O(1/F).$$

This result complements that of Steinberg et al., giving var Z for wide-band Gaussian noise. The limit of (var Z)/T as $T \to \infty$ is evaluated for several spectra, and expressions are found for the variance of the number of zeros of the sum of the foregoing narrow-band noise plus a sinusoid of frequency F.

From these results the low-frequency output spectral density of an FM receiver is obtained. Below the threshold, the output signal-to-noise ratio is found to be

$$\frac{\pi^2 (1 - \exp - A^2/2\sigma^2)^2 D_{rms}^2}{W \int_0^\infty \frac{\psi'^2(\tau)}{\sigma^4 - \psi^2(\tau)} \exp - \frac{A^2}{\sigma^2 - \psi(\tau)} \, d\tau},$$

where $A^2/2\delta^2$ is the input signal-to-noise ratio, D_{rms} is the rms frequency deviation, assumed small enough not to affect the output noise, and W is the output bandwidth, assumed small compared to the input bandwidth. By the addition of the well known "triangular" noise, this expression is made valid through and above the threshold, thus unifying various results of Rice. The quieting of a wide-band FM receiver by a signal is also considered.

9. Blasbalg, H., Freeman, D., and Keeler, R., RANDOM-ACCESS COMMUNICATIONS USING FREQUENCY-SHIFTED PN (PSEUDO-NOISE) SIGNALS, <u>IEEE International Convention Record</u>, Vol 12, Part 6, 1964, pp. 192-216.TK6540I59.

In this paper the basic principles of random-access communications techniques using frequency-shifted pseudo-noise (PN) signal addresses are discussed. The mathematical expression for the clutter generated by mutually interfering signals is obtained and shown to be the well known ambiguity function. It is shown that the delay resolution property of these signals provides a simple communications technique for encoding the voice signal into higher-order alphabets. In the absence of thermal noise, higher-order alphabets prove to be the key to efficient communications over a common channel system in the presence of a mixture of both equal power and extremely strong talkers.

Simplified block diagrams of random-access communcation techniques are discussed. An approximation to the error probability as a function of the channel parameters is presented along with curves.

Digital computer simulation for FSK, PN-signal address communication is discussed and measurements of some of the important characteristics which govern the behavior of such systems are presented. Computer printouts showing the matched filter output in response to a mixture of desired signal with and without limiting are shown. Printouts of the cross-sections through the frequency axis of the ambiguity function for a 127-bit maximum length sequence are presented.

Finally, a schematic diagram of a digital matched filter designed, constructed, and demonstrated at the IBM Communications Systems Department is briefly discussed.

10. Blokh, E. L. and Kharkevich, A. A., PARASITIC MODULATION CAUSED BY SMALL ADDITIVE NOISE, Telecommunications and Radio Engineering, Part 2: Radio Engineering (Translation of Radiotekhnika), Vol. 17, No. 11, November 1962, pp. 3-13.

General relations are derived for the signal/noise ratio when a carrier is acted on by small additive noise. A geometric interpretation of the problem is given. As an example, a carrier in the form of a sequence of trapezoidal pulses is examined. The possibility of compensating the parasitic modulation by variation of unmodulated parameters of the carrier is discussed.

11. Blotekjaer, Kjell, AN EXPERIMENTAL INVESTIGATION OF SOME PROPERTIES OF BAND-PASS LIMITED GAUSSIAN NOISE, IRE Transactions, Vol. IT-4, No. 3, September 1958, pp. 100-102.

The probability distribution of time intervals between successive zero crossings of band-pass limited Gaussian noise is determined experimentally for a number of different filters having nearly rectangular frequency characteristics. For one particular filter, the distribution of time intervals between crossings of levels different from zero is also found.

12. Blotekjaer, Kjell, ON THE POSTDETECTION CORRELATION BETWEEN TWO SINUSOIDAL SIGNALS WITH SUPERIMPOSED CORRELATED NOISE, IRE Transactions, Vol. IT-7, No. 4, October 1961, pp. 271-272.

Not abstracted.

13. Bol'shakov, I. A. and Latysh, V. G.,
SEPARATING AN UNKNOWN NUMBER OF FLUCTUATING SIGNALS FROM NOISE ON THE BASIS OF THE THEORY OF RANDOM POINTS, Radiotekhnika i Elektronika, Vol. 9, No. 3, March 1964, pp. 408-417. Translated into English from Russian in Radio Engineering and Electronic Physics, Vol. 9, No. 3, March 1964, pp. 326-334.

A statistical study is made of a system of n-fluctuating impulsive signals depending on a parameter. With the aid of the theory of random points, operators are found for the formulation of the a posteriori probability density of an indeterminate number of indicated parameters depending on a posteriori data and the obtained sample of a mixture of signals and noise.

14. Bosch, B. G. and Gambling, W. A.,
TECHNIQUES OF MICROWAVE NOISE MEASUREMENT, Journal of the British Institution of Radio Engineers, Vol. 21, No. 6, June 1961, pp. 503-515.

After a brief outline of some aspects of microwave oscillator noise, the paper describes various techniques of noise measurement. The latter include AM and FM direct detection and superheterodyne methods as well as systems for the measurement of correlation.

15. Brown, J. L., Jr.,
GENERATING UNCORRELATED RANDOM OUTPUTS BY NONLINEAR PROCESSING OF A SINGLE NOISE SOURCE, IEEE Transactions on Applications and Industry, Vol. 83, No. 75, November 1964, pp. 408-410.

It is shown that, for a single Gaussian noise source, an arbitrary number of mutually uncorrelated outputs can be produced by passing the noise through a parallel cascade of zero-memory nonlinear filters, where the output of the kth filter is related to its input by a kth-degree Hermite polynomial. This generalizes a recent finding in which four noncorrelated outputs were produced from a Gaussian source by nonlinear processing; extensions of this method to certain non-Gaussian noise sources are also indicated. The noncorrelation between Gaussian input and distortion terms in the equivalent gain representation of an instantaneous nonlinearity is shown to hold for any separable random process.

16. Brown University, Division of Applied Mathematics, Providence, Rhode Island,

AN APPROXIMATE METHOD IN SIGNAL DETECTION by Walter F. Freiberger, January 1962, Technical Report No. 12, AD 274 202, Contract DA 36-039SC-78130

A theorem from the theory of Toeplitz forms is applied to the problem of estimating the best test statistic for the detection of Gaussian signals in Gaussian noise.

17. Brown, William M.,

TIME STATISTICS OF NOISE, IRE Transactions, Vol. IT-4, No. 4, December 1958, pp. 137-144.

The object of this paper is to develop the theory of time statistics and to give methods for calculating them. For the most part, the time statistics are formulated in terms of ensemble statistics which are usually provided by statistical mechanics.

If a process consists of, e.g., all physically realizable models of a system containing noisy resistors, there is no practical way to identify which model one has available for "testing." Thus, a time statistic measured with the available model will not be predictable unless this statistic is the same for almost all the models; when this is the case, the process is called uniform for this statistic. A dual property is in common use for ensemble statistics. The process is called stationary for an ensemble statistic, provided it is the same at all times. Though some discussion of stationarity is given in this paper, the emphasis is on not requiring stationarity. In particular, special attention is given to nonstationarity introduced by determinate signals. While stationarity plays only a minor role in the theory of the time statistics of noise, uniformity plays a crucial role. Given only uniformity, Theorem 1 formulates time statistics as the time average of the corresponding ensemble statistics. The additional condition of stationarity merely simplifies the calculation by rendering the "ergodic hypothesis" satisfied, i.e., by rendering equality of time and ensemble statistics.

With Theorem 1 as a nucleus, the remainder of the paper attempts to develop an understanding of what makes a process uniform.

18. Clarke, K. K. and Cohn, J.,
CARRIER-TO-NOISE STATISTICS FOR VARIOUS CARRIER AND INTERFERENCE CHARACTERISTICS, Proceedings of the IRE, Vol. 46, May 1958, pp. 889-895.

Techniques are presented for the calculation of the statistical properties of the resultant carrier-to-noise ratios of systems subject to both additive and multiplicative noise. The cases considered are those in which the desired signal is either steady or exhibits Rayleigh fading while the interference consists of receiver noise plus an interfering signal which may be steady, Rayleigh fading, Gaussian fading, or Rayleigh fast fading with slow Gaussian fading of the median of the Rayleigh distribution. The results of the indicated calculations are presented graphically. A simple process is outlined for converting the data presented for use with any other signal strength.

The utility of the data is demonstrated by a sample calculation, the results of which are presented graphically. This calculation derives threshold data for the system as a function of desired signal power with the percentage of time that it operates in one of its two possible modes (fading or nonfading) as a parameter.

Attention is called to the technique demonstrated in the Appendix. This result appears quite useful in many joint or combination probability problems, especially those requiring numerical solutions.

Although this paper stemmed from work on line-of-sight microwave links, the results may be useful in other applications in the HF, VHF, and UHF regions.

19. Collins, C. A. and Williams, A. D.,
NOISE AND INTERMODULATION PROBLEMS IN MULTI-CHANNEL CLOSED-CIRCUIT TELEVISION SYSTEMS, AIEE Transactions on Communications and Electronics, Vol. 80, No. 57, November 1961, pp. 486-491.

This paper describes methods for evaluating the performance of RF closed-circuit TV systems with respect to interferences caused by amplifier thermal noise and nonlinear response. The methods are applicable to any system in which amplifier parameters are known and in which operating-signal magnitudes have been specified.

The methods discussed also have a use in system design. The last part of the paper points out how the application of these methods of analysis leads to the conclusion that system noise and nonlinearity performance can be improved by reducing amplifier spacing. As noted, the limit to this reduction in spacing occurs with amplifiers spaced 8.7 db apart.

20. Cooke, Harry F.,
ON THE TWO-GENERATOR METHOD (e_n, i_n) OF NOISE CHARACTERIZATION, Proceedings of the IRE, Vol. 50, No. 12, December 1962, pp. 2520-2521.

Not abstracted.

21. Cooley Electronics Laboratory, The University of Michigan, Ann Arbor, Michigan,
A COMPUTER-AUGMENTED TECHNIQUE FOR THE DESIGN OF LIKELIHOOD-RATIO RECEIVERS by T. G. Birdsall and L. W. Nolte, October 1962, Technical Report No. 130, AD 292 161, Contract Nonr-1224(36).

Standard approximation methods of design of detection receivers are reviewed, and a method based on fitting curves calculated on a high-speed computer is presented. This computer-augmented technique is applied to the design problem of a signal distorted by a sign-preserving, rapidly varying transmission gain.

22. The G. C. Dewey Corporation, New York, New York,
A STUDY OF CORRELATOR BEHAVIOR USING "NON-STATIONARY" SIGNALS: PART I by W. G. Chesnut, June 1963, Report R-127-1, AD 411 249

This report develops the expected correlation behavior of analog and clipper correlators processing nonstationary signals and noise. It is shown that nonstationary signals (multiplicative noise) may result in slightly degraded correlator performance though the degradation is the same for the two correlators. Nonstationary noise may degrade analog processing gain, whereas it appears to improve the processing by the clipper correlator. The development is restricted to the case of small signals buried in noise. A companion article presents the results of an experimental investigation designed to evaluate the developments in this report and to investigate correlator behavior for the case of large signals.

23. The G. C. Dewey Corporation, New York, New York, A STUDY OF CORRELATOR BEHAVIOR USING "NON-STATIONARY" SIGNALS: PART II by W. G. Chesnut, June 1963, Report R-127-1, AD 412 534 (Unclassified).

An experimental investigation of the cross-correlation gains of an analog and a clipper correlator has been carried out. The signals and noise used in this study we have characterized as being non-stationary. An attempt has been made to compare experimentally determined gains for the case of small signals buried in noise with those predicted theoretically. Generally speaking, these results agree with the predictions which are presented in a companion paper.

24. Doyle, W., BAND-PASS LIMITERS AND RANDOM WALKS, IRE Transactions, Vol. IT-8, No. 6, October 1962, pp. 380-381.

Not abstracted.

25. Doyle, W. and Reed, I. S., APPROXIMATE BAND-PASS LIMITER ENVELOPE DISTRIBUTIONS, IEEE Transactions, Vol. IT-10, No. 3, July 1964, pp. 180-185.

An approximate distribution is computed for the envelope of sine wave plus noise after passage through a wide-band filter, limiter, and narrow-band filter. It is shown that as the input bandwidth to the limiter increases, the output envelope distribution converges to the usual sine wave in noise envelope distribution, without limiting, but with a definite 1.04 db loss. First-order correction terms are supplied which make it possible to compute first-order statistics for the output envelope when the output signal-to-noise ratio is on the order of one.

26. Fisher, Sydney T., A COMPLETELY CONSISTENT DEFINITION OF TEMPERATURE SENSITIVITY INCLUDING NEGATIVE CONDUCTANCE DEVICES, Proceedings of the IRE, Vol. 50, February 1962, p. 204.

Not abstracted.

27. Galejs, Janis,
SIGNAL-TO-NOISE RATIOS IN SMOOTH LIMITERS, IRE Transactions, Vol. IT-5, No. 2, June 1959, pp. 79-85.

Signal-to-noise ratios associated with smooth band-pass limiting and subsequent narrow-band filtering of a periodic signal and random noise are computed. Observed changes in signal-to-noise ratios may be used to estimate detectability losses. The error function is used to represent the limiter characteristic at various degrees of limiting. First-order corrections with an increasing input signal to the signal-to-noise ratios, which are based on the small signal theory, are computed for limiter input noise with sin x/x, Gaussian, and exponential correlation functions.

28. Galejs, Janis,
FREQUENCY DIFFERENCES BETWEEN TWO PARTIALLY CORRELATED NOISE CHANNELS, IRE Transactions, Vol. IT-7, No. 2, April 1961, pp. 72-81.

Approximate probability distributions of the difference frequency between two noise channels which contain dissimilar Gaussian, rectangular or triple-tuned RLC band-pass filters are calculated. For noise channels that differ only in time delay, a proportionality between rate of change of instantaneous frequency and the difference frequency is assumed. For dissimilar filters, an approximately equivalent single filter-time delay process is defined. The single filter is determined from the moment averages of the two dissimilar filters, while the equivalent time delay is computed by equating the magnitude of the correlation function in the two processes.

29. Gerrish, A. M. and Schultheiss, P. M.,
INFORMATION RATES OF NON-GAUSSIAN PROCESSES, IEEE Transactions, Vol. IT-10, No. 4, October 1964, pp. 265-271.

The rate distortion function R(D) of an information source was introduced by Shannon to specify the channel capacity required on transmitting information from the source with an average distortion not exceeding D. Exact rates have been calculated for Gaussian sources under a mean-square error criterion. For non-Gaussian continuous sources, Shannon has given upper and lower bounds on R(D). In specific cases, the difference between these two bounds may not be sufficiently small to provide a useful estimate of R(D).

The present paper is concerned with improving estimates of information rates of non-Gaussian sources under a mean-square error criterion. The sources considered are ergodic, and their statistical properties are characterized by a bounded and continuous n-dimensional probability density function. The paper gives a set of necessary and sufficient conditions for R(D) to equal Shannon's lower bound. For sources satisfying these conditions, exact rate calculations are possible. For sources that do not satisfy the required conditions, an improved upper bound is obtained that never exceeds Shannon's upper bound. Under rather general conditions, the new upper bound approaches Shannon's lower bound for small values of distortion, so that the true value of R(D) can be estimated very accurately for small D.

30. Grignetti, Mario,
PROBABILITY DENSITY FOR CORRELATORS, IRE Transactions, Vol. IT-8, No. 6, October 1962, pp. 383-384.

Not abstracted.

31. Halsted, Leonard R.,
ON BINARY DATA TRANSMISSION ERROR RATES DUE TO COMBINATIONS OF GAUSSIAN AND IMPULSE NOISE, IEEE Transactions, Vol. CS-11, No. 3, September 1963, pp. 428-435.

Error rates are computed for a binary data transmission system subject to both Gaussian and impulse noise. The rates are displayed as a function of λT, where T is the signal duration and λ^{-1} is the average time between noise pulses. Poisson-distributed impulse noise and periodically recurring noise pulse clusters are considered. Error rates are computed for cases in which 2, 5, 10, 30, 50, and 100 percent of the total noise power is impulse noise power, and for signal-to-noise ratios that would give error rates of 10^{-4}, 10^{-5}, 10^{-6}, and 10^{-7} if the noise were 100 percent Gaussian. A linear receiver and correlator are assumed, and the assumption about the distribution of the correlator output caused by impulse noise is varied to illustrate how this assumption affects the error rate. Stretch transformations are used to modify the error rate curves presented according to system and noise pulse-width parameters. Simple graphical techniques are described for the construction of approximate error rate curves.

The computed error rates illustrate, for data transmission systems subject to impulsive interference, the reduction in error rate that can be realized by increasing the signal duration. The simultaneous transmission of orthogonal signals is discussed. This makes it possible to use signals having a long duration without reducing the data rate or causing intersignal interference; this can be done without requiring additional bandwidth.

32. Heffner, H.,
THE FUNDAMENTAL NOISE LIMIT OF LINEAR AMPLIFIERS, Proceedings of the IRE, Vol. 50, July 1962, pp. 1604-1608.

If the uncertainty principle of quantum mechanics is applied to the process of signal measurement, two theorems relating to amplifier noise performance can be deduced. First, it can be shown that it is impossible to construct a linear noiseless amplifier. Second, if the amplifier is characterized as having additive white Gaussian noise, it can be shown that the minimum possible noise temperature of any linear amplifier is

$$T_n = \left[\ln \frac{2 - \frac{1}{G}}{1 - \frac{1}{G}} \right]^{-1} \frac{h\nu}{k} \ .$$

In the limit of high gain G this expression reduces to that previously derived for the ideal maser and parametric amplifier. It is shown that the minimum noise amplifier does not degrade the signal but rather allows the use of an inaccurate detector to make measurements on an incoming signal to the greatest accuracy consistent with the uncertainty principle.

33. Heffner, H.,
AUTHOR'S COMMENTS, Proceedings of the IEEE, Vol. 51, No. 1, January 1963, p. 246.

Not abstracted. See also Bevensee, R. M.

34. Huang, R. Y., and Johnson, R. A.,
INFORMATION TRANSMISSION WITH TIME-CONTINUOUS RANDOM PROCESSES, IEEE Transactions, Vol. IT-9, No. 2, April 1963, pp. 84-94.

Shannon's definition for the information content of a Gaussian, time-continuous process in Gaussian noise is extended to the case where the observation interval is finite, and where the processes may be nonstationary, in a straightforward way. The extension is based on a generalization of the Karhunen-Loeve Expansion, which allows both the signal and noise processes to be expanded in the same set of functions, with uncorrelated coefficients. The resultant definition is consistent with that of Gel'fand and Yaglom, and avoids the difficulties posed by Good and Doog to Shannon's original definition.

This definition is shown to be useful by applying it to the calculation of the information content of some cases of stationary signals in stationary noise, with different spectra, and to one case where both are nonstationary. Limiting relations are derived to show that this reduces to previously established results in some cases and to enable one to obtain rule-of-thumb estimates in others. In addition, both the matched filter and the Wiener filter are related to the information, the matched filter in a very direct way in that it converts a time-continuous process to a set of random variables while conserving the information.

35. Huttly, N. A., THE EFFECT OF MIXING TWO NOISY SIGNALS, The Marconi Review, Vol 23, No. 139, 1960, pp. 153-169.

The general analytical expression was obtained for the effect of mixing two signals when each has noise with it, but in order to proceed from this it was necessary to deal with less general cases, and even in these cases various assumptions had to be made regarding the bandwidth of the input and output signals and mid-band frequency of the output. The actual cases chosen were those which were most likely to occur in practice. The forms of the expressions resulting from the choice of the impulse response and autocorrelation in most cases would be intractable mathematically, and any attempt at a solution would involve the use of electronic computers.

36. Institute of Science and Technology, The University of Michigan, EFFECTIVE ANTENNA TEMPERATURE FROM TERRESTRIAL AND COSMIC NOISE IN THE 0.1- TO 40.0-Gc BAND by A. Naparstek, March 1963, Rep. 4515-20-T, Contract No. AF 33(616)-8244, AD 406 215

This report presents a derivation of an expression for the effective antenna temperature for an antenna viewing a multitude of discrete and distributed radio-frequency noise sources. The presentation makes use of concepts, parameters, and units that have been introduced in radio astronomy for the purpose of describing measurements of radio-frequency radiation of extraterrestrial origin.

The report also presents a comprehensive review and analysis of current knowledge of and available data on radio-frequency noise of terrestrial and extraterrestrial origin in the 0.1 to 40.0 Gc frequency band. These data, together with the derived equation for the effective antenna temperature, will enable one to calculate the effective antenna temperature for any antenna located on the earth's surface, provided the normalized power pattern, the directivity, and the efficiency of the antenna are known. The report also shows how to determine realistic bounds for the effective antenna temperature of antennas located in aerospace.

Analysis of the data on the various noise sources shows that, even for some presently available receiving systems (which use masers as preamplifiers), the external noise will exceed the internally generated noise (referred to the receiver input terminals) of the receiver for certain orientations of the antenna. From the standpoint of external noise considerations only, the optimum frequency band lies between 2 and 8 Gc.

37. Jet Propulsion Laboratory,
DETECTION OF UNKNOWN SIGNALS IN STRONG NOISE, Research Summary No. 36-7, Vol. 1, February 1961, pp. 53-54.

Not abstracted.

38. Jet Propulsion Laboratory,
PHASE MODULATION THROUGH A LIMITER, Research Summary No. 36-7, Vol. 1, February 1961, pp. 54-60.

Not abstracted.

39. Jones, J. J.,
HARD-LIMITING OF TWO SIGNALS IN RANDOM NOISE, IEEE Transactions, Vol. IT-9, No. 1, January 1963, pp. 34-42.

Two sinusoidal signals and Gaussian noise lying in a narrow band are passed through an ideal band-pass limiter that confines the output spectrum to the vicinity of the input frequencies. The output spectrum, consisting of both discrete and continuous components, is studied in terms of its corresponding auto-correlation function. The discrete output components are identified with the output signals and intermodulation products due to interference between the two input signals. The continuous part of the spectrum is associated with the output noise. The effects of limiting are expressed by ratios among the average powers of the output spectral components. Performance curves are given that show signal suppression, the ratio of output to input SNR's, and the relative strength of the intermodulation terms.

40. Kaufman, H. and Roberts, G. E., CORRELATION FUNCTION AT THE OUTPUT OF AN ERROR FUNCTION LIMITER, Journal of Electronics and Control, Vol. 15, August 1963, pp. 165-170.

The correlation function at the output of a half-wave limiter is obtained in the form of a doubly infinite series where the limiter characteristic is described by an error function. The input to the limiter is assumed to be Gaussian noise. The results also display the particular term previously obtained by Baum for the corresponding full-wave (odd) limiter.

41. Keilson, J., Mermin, N. D., and Bello, P., A THEOREM ON CROSS CORRELATION BETWEEN NOISY CHANNELS, IRE Transactions, Vol. IT-5, No. 2, June 1959, pp. 77-79.

Two channels carry noise waveforms, $N_0(t) + N_1(t)$ and $N_0(t) + N_2(t)$, where $N_0(t)$ is a common narrow-band Gaussian noise and $N_1(t)$ and $N_2(t)$ are independent narrow-band Gaussian noises associated with each channel. The outputs of each channel are sent through detectors whose outputs, $F(x, y)$, are identical homogeneous functions of the components, x and y, of their inputs N, where $N(t) = x(t) \cos \omega_0 t + y(t) \sin \omega_0 t$. Let $R_{12}(\tau)$ be the normalized cross-correlation function of the two detector outputs. It is shown that to determine $R_{12}(\tau)$ it suffices to know the normalized autocorrelation function $R_0(\tau)$ of the output of a single such detector when the input is $N_0(t)$; i.e., if $R_0(\tau) = G(\sigma_0^2, \rho(\tau))$ where $\rho(\tau)$ and σ_0 are the normalized autocorrelation function and rms of either component of N_0, then it is shown that $R_{12}(\tau) = G(\sigma_0^2, Z\rho(\tau))$ where $Z = \left\{\left[1 + (\sigma_1^2/\sigma_0^2)\right] \left[(1 + (\sigma_2^2/\sigma_0^2)\right]\right\}^{-1/2}$.

42. Khurgin, Ya. I.,
CERTAIN PROPERTIES OF RANDOM PULSE PROCESSES, Trudy Vsesoyuznogo soveshchaniya, pp. 72-78, Yerevan, AN Arm. SSR, 1960. Translated into English from Russian by Air Force Systems Command, Translation FTD-TT-62-1147, AD 423 603.

Attention is given to the properties of random pulse processes which are encountered in many radio-engineering problems. Pulse self-oscillations were used as an example taking into account fluctuation processes in circuits and tubes, or the sequence of spikes above a certain defined level of random noise. In general, attention was directed toward a single class of such processes which is reasonably descriptive of many practical interesting cases. Consideration was given in greater detail to the simplest class of random pulse processes in which the sequence interval between the moments of pulse appearances is a sequence of positive, independent, identically distributed random variables having probability density.

43. Kirshner, J. M.,
SIGNAL SPACE, MODULATION, AND BAND WIDTH, Conference Proceedings, 6th National Convention on Military Electronics, June 1962, pp. 149-153, UG485 N277.

This paper begins by defining signal space and showing how it enables one to determine the degree to which two different signals approximate each other. Shannon's theorem on channel capacity is then heuristically derived in terms of the ability to discriminate between signals in the presence of noise. It is shown that as the communication systems bandwidth is allowed to increase, the ability to recognize a given signal is not impaired. Having concluded that a given communication channel is less subject to information loss if its bandwidth is made as wide as practically feasible, the paper then considers the fact that many channels of communication are in general required to be situated in a given region of the spectrum. Since it is desirable that each channel use the entire available spectrum, it is necessary to investigate the possiblity of assigning channels by some method other than narrow bands. It is shown that in principle it is possible to obtain exactly the same number of noninterfering channels, each using the entire spectrum, as can be obtained by use of narrow bands.

The result is obtained that in a many-dimensional space two vectors randomly chosen have a high probability of being at an angle close to 90 degrees. The concept of signal space allows this fact to be used to show the extent of interference to be expected from two noise waves of a given bandwidth and duration.

The possibility of increasing the number of available channels in a given bandwidth by allowing mutual interference is examined, and it is shown that there is no way that this can be done such that the amount of interference of each station with every other station is the same. On the other hand, it is possible to choose the channels in such a way that the average interference caused to any one channel by all the others combined is the same. This latter criterion is met by a set of randomly chosen noise waves. It is shown that the interference is approximately proportional to the number of channels in operation (all stations being of equal power).

44. Kozma, Adam and Kelly, David Lee,
SPATIAL FILTERING FOR DETECTION OF SIGNALS SUBMERGED IN NOISE, Applied Optics, Vol 4, No. 4, April 1965, pp. 387-392.

Matched filtering is described as a spatial filtering operation. A technique for producing a matched filter, wherein the filter transfer function is modulated onto a spatial carrier and the resulting function is hard-clipped allowing a filter construction of completely opaque and transparent lines, is given. The effect of this nonlinearity on the S/N is shown to be small. The effects of extraneous frequencies in the filter is shown to be negligible if the spatial carrier is sufficiently high. Experimental results are presented showing the detectability of the signal in the presence of various levels of additive noise.

45. Kulikov, Ye. I.,
ESTIMATION OF THE PARAMETERS OF RADIO SIGNALS ON A BACKGROUND OF GAUSSIAN NOISE, Radiotekhnika, Vol. 19, No. 9, September 1964, pp. 41-46, Translated into English from Russian in Telecommunications and Radio Engineering, Part 2, Vol. 19, No. 9, September 1964, pp. 94-98.

An approximate method for calculating the variance of time-varying signal-parameter estimates in the reception of a sequence of radio pulses on a background of additive Gaussian noise is considered.

46. Leipnik, Roy,
THE EFFECT OF INSTANTANEOUS NONLINEAR DEVICES ON CROSS-CORRELATION, <u>IRE Transactions</u>, Vol. IT-4, June 1958, pp. 73-76.

If $X_1(t)$, $X_2(t)$ are two noises (stochastic processes) and f and g are functions describing the action of two instantaneous nonlinear devices, we say that the (m, n) cross-correlation property holds in case the cross-correlation of $f(X_1(t_1))$ with $g(X_2(t_2))$ is proportional to the cross-correlation of $X_1(t_2)$ with $X_2(t_2)$, whenever f and g are polynomials of degrees not exceeding m and n, respectively. We take $m = \infty$ or $n = \infty$ to mean that f or g is any continuous function.

The Barrett-Lampard expansion of the second-order joint density of $X_1(t_1)$ and $X_2(t_2)$ is used to derive an expression for the cross-correlation of $f(X_1(t_1))$ and $g(X_2(t_2))$. This expression yields necessary and sufficient conditions for the validity of the cross-correlation property in three cases: $X_1(t)$ and $X_2(t)$ stationary, m, n unrestricted; $X_1(t)$ stationary, m, n unrestricted; $X_1(t)$ stationary, $n = 1$.

Examples are constructed with the help of special orthonormal polynomials illustrating the necessity and sufficiency of the conditions.

47. Levin, Morris J.,
ESTIMATION OF A SYSTEM PULSE TRANSFER FUNCTION IN THE PRESENCE OF NOISE, <u>IEEE Transactions</u>, Vol. AC-9, No. 3, July 1964, pp. 229-235, AD 453 555.

Statistical estimation theory is applied to derive effective techniques for measurement of the pulse transfer function of a linear system from normal operating records obscured by additive noise. It is shown that the problem is equivalent to that of fitting a hyperplane to a set of observed points with random errors in certain coordinates. A method of Kiipmans is applied to obtain generalized least squares estimates which are also maximum likelihood estimates when the noise is white and Gaussian. The estimates of the coefficients are obtained as the components of the eigenvector corresponding to the smallest eigenvalue of a matrix equation involving the sample auto- and cross-correlation functions of the input and output records and the covariance matrix of the corresponding noise components. Expressions for the sampling variances and biases are given. The properties of the simpler standard least squares estimates are also considered. The appropriate modifications for nonwhite noise are described.

48. Lincoln Laboratory, MIT, Lexington, Massachusetts, CONFIDENCE INTERVALS AND SAMPLE SIZES IN THE MEASUREMENT OF SIGNAL AND NOISE POWERS, SIGNAL-TO-NOISE RATIOS, AND PROBABILITY OF ERROR by Jerry Holsinger, January 1963, Report 34-G-9, AD 295 133

This report considers the estimation errors involved in both discrete and continuous estimates of certain parameters of a Gaussian random process. For discrete estimates, the confidence interval concept is used to obtain probabilistic bounds on the estimation errors. Roughly analogous results are also obtained for continuous estimates. The bounds obtained are useful for a) determining the accuracy of an estimate given the value of the estimate and the number of samples used (or for the continuous case the effective TW_s) and b) for determining roughly the number of samples required (or the effective TW_s) to provide an estimate of a specified accuracy. The bounds are presented graphically and examples of their use are given.

A second result is the derivation of an approximate, but convenient and reasonably accurate, method for evaluating the non-central t-distribution by means of tables of the normal distribution. This allows certain calculations to be made that are not now possible with existing tables.

49. Loeb, Julien, A PHYSICAL INTERPRETATION OF SHANNON'S AMBIGUITY, Annales de telecommunication, Vol. 13, March-April 1958, pp. 78-82 (In French).

An element of a noisy circuit can generally be represented by a series of probabilities of transition, in other words, probabilities a_{ki} that each transmitted symbol S_k is (falsely) received as symbol S_i. From these probabilities a matrix is formed in such a manner that the statistical properties of the circuit elements in series can be calculated by means of multiplication of the matrices. When there are numerous symbols and the noise is additive (amplitude or similar types of modulation), the matrices become "grills", and the result is much simpler because these "grills" can be multiplied in the same manner as are the simple algebraic polynomials. We obtain in this case the physical interpretation of Shannon's "ambiguity". The mathematical instrument that has been developed can be applied to more complicated problems, such as nonlinear circuit elements, non-Gaussian noises, or coders.

50. McDonald, R. A. and Schultheiss, P. M.,
EFFECTIVE BANDLIMITS OF GAUSSIAN PROCESSES UNDER A MEAN-SQUARE CRITERION, Proceedings of the IEEE, Vol. 52, No. 9, September 1964, pp. 1080-1081.

To simplify the analysis of communication systems, it is convenient to assign a "bandlimit" even to those signals whose spectrum extends to infinite frequencies. The effective bandwidth proposed for such signals is defined in terms of the permissible mean-square error D. It is the highest frequency f_0 of intersection of the signal power spectrum curve with the noise power spectrum curve, where the area under the latter is equal to D. As an application to sampling theory, it is argued that there is no theoretical reason for sampling at a rate higher than $2f_0$ samples per second.

51. McFadden, J. A.,
ON THE LENGTHS OF INTERVALS IN A STATIONARY POINT PROCESS, Journal of the Royal Statistical Society, Series B (Methodological), Vol. 24, No. 2, 1962, pp. 264-382.

The paper is concerned with the lengths of intervals in a stationary point process. Relations are given between the various probability functions, and moments are considered. Two different random variables are introduced for the lengths of intervals, according to whether the measurement is made from an arbitrary event or beginning at an arbitrary time, and their properties are compared. In particular, new properties are derived for the correlation coefficients between the lengths of successive intervals. Examples are given. A theorem is proved, giving conditions under which two independent stationary point processes with independent intervals may be superposed, giving a new point process which also has independent intervals. Mention is made of the application to the theory of binary random processes and to the zeros of a Gaussian process.

52. McMillan, B. and Slepian, D.,
INFORMATION THEORY, Proceedings of the IRE, Vol. 50, May 1962, pp. 1151-1157.

During the last 20 years, three theories dealing with the interaction of signals and noise in communication systems have come into being: the detection theory, the statistical theory of filtering and prediction, and Shannon's information theory. They have developed rapidly and now play a key role in the communication engineer's understanding of his field. This paper presents a brief description of the central concepts of each of these theories, discusses their differences and common parts, and attempts to point out their successes and shortcomings.

53. Medvedev, V. I.,
INVESTIGATION OF A METHOD OF PHASE MEASUREMENTS IN THE CASE OF NON-COHERENT SIGNALS, Vestnik moskovskogo universiteta, seriya III, fizika, astronomiya, No. 6, 1963, pp. 77-84, Translated into English from Russian by Air Force System Command, Translation FTD-TT-64-1173, AD 609 149.

A method for measuring the change in phase difference between frequency-stable noncoherent signals with a significant frequency difference is considered and demonstrated. Experimental results verify the possiblity of making phase measurements between noncoherent signals by this method.

54. The MITRE Corporation, Bedford, Massachusetts,
PHASE AND ENVELOPE OF LINEAR FM PULSE-COMPRESSION SIGNALS FROM HIGH VELOCITY TARGETS by M. H. Ueberschaer, November 1964, Technical Documentary Report No. ESD-TDR-64-128, AD 608 056, Contract AF 19(628)-2390

Equations for the phase and envelope of the output signal from a linear filter, matched to the transmitted signal, are derived. The transmitted signal is assumed to have a flat band-limited amplitude spectrum and a linear group delay. The input to the "matched filter" is the radar echo returned from a moving target whose velocity is essentially constant during the illumination time. It is shown that the returned signal is related to the transmitted signal by a time dilation. The resulting expressions for the phase and envelope are functions which involve Fresnel integrals. Approximations for these expressions are worked out. They are shown to be similar in form to those which are obtained when the returned signal is assumed to be related to the transmitted signal by a Doppler shift.

55. Morozov, V. A.,
A METHOD OF DETECTION OF WEAK NOISE SIGNALS, Radiotekhnika i Elektronika, Vol. 9, No. 3, March 1964, pp. 439-448, Translated into English from Russian in Radio Engineering and Electronic Physics, Vol. 9, No. 3, March 1964, pp. 352-360.

The detection of weak noise signals is examined by a binary-storing method differing from the conventional method by the fact that a narrow-band low-pass filter is inserted in front of the binary storing device (consisting of a comparator and a pulse counter). With such a receiver design, the requirements toward the speed of the binary storing device, which are normally determined by the frequency band of the received signal, can be considerably reduced.

It is shown that with regard to the detection of a weak noise signal stored over a prolonged period, the system of matched filter, linear detector, narrow-band low-pass filter, and binary storing device is practically equivalent to an optimum receiver which forms the likelihood ratio.

56. New York University, College of Engineering, New York, New York,
NOISE AND RANDOM PROCESSES by John R. Ragazzini and S. S. L. Chang, October 1961, AFOSR Report 1533, Technical Report 400-40, AD 269 567 (Unclassified).

This report is the original version of a review paper written at the invitation of the Institute of Radio Engineers for the 50th Anniversary Issue of the Proceedings. See item 62.

57. North, Dwight O.,
ANALYSIS OF THE FACTORS WHICH DETERMINE SIGNAL/NOISE DISCRIMINATION IN PULSED-CARRIER SYSTEMS, Proceedings of the IEEE, Vol. 51, No. 7, July 1963, pp. 1016-1027.

The smallest signal discernible through background noise is formulated in terms of the pulse energy, its repetition rate, the receiver design, and the choice of integrating and indicating means.

The smallest signal visible on a Type-A scan can be improved upon by the use of electromechanical integrators. Integration before detection is, in theory, ultimately the most effective, but runs into serious practical difficulties. These are avoided when the integration is performed after detection. Optimum predetector selectivity is formulated. The optimum detector

(square law) is found, and other detectors compared. A transmitter criterion provides a basis for comparing the effectiveness of transmitters, and shows how, at the expense of range resolution, longer pulses can increase visibility.

58. Pierce, John W.,
A MARKOFF ENVELOPE PROCESS, IRE Transactions, Vol. IT-4, No. 4, December 1958, pp. 163-166.

It is shown that the envelope of a narrow-band Gaussian noise constitutes a first-order Markoff process if the power spectrum of the noise is the same as would be obtained from a singly tuned RLC filter with white noise at the input.

59. Price, Robert,
A USEFUL THEOREM FOR NONLINEAR DEVICES HAVING GAUSSIAN INPUTS, IRE Transactions, Vol. IT-4, No. 2, June 1958, pp. 69-72.

If and only if the inputs to a set of nonlinear, zero-memory devices are variates drawn from a Gaussian random process, a useful general relationship may be found between certain input and output statistics of the set. This relationship equates partial derivatives of the (high-order) output correlation coefficient taken with respect to the input correlation coefficients, to the output correlation coefficient of a new set of nonlinear devices bearing a simple derivative relation to the original set. Application is made to the interesting special cases of conventional cross-correlation and autocorrelation functions, and Bussgang's theorem is easily proved. As examples, the output autocorrelation functions are simply obtained for a hard limiter, linear detector, clipper, and smooth limiter.

60. Price, Robert,
COMMENT ON: "A USEFUL THEOREM FOR NONLINEAR DEVICES HAVING GAUSSIAN INPUTS," IEEE Transactions, Vol. IT-10, No. 2, April 1964, p. 171.

The utility of the proposed theorem is enhanced by specified modifications. Errors and omissions are corrected.

61. Queen's University, New York,
A NOTE ON POWER-LAW DEVICES AND THEIR EFFECT ON SIGNAL-TO-NOISE RATIO by C. M. Berglund, Department of Electrical Engineering, December 1962, Research Report 62-3, AD 291 427.

The effect of power-law devices, used as either band-pass nonlinear amplifiers or envelope detectors, on the signal-to-noise ratio is determined for both limiting cases of very large and very small input signal-to-noise ratios. Expressions are derived for the degradation in signal-to-noise ratio in terms of the envelopes and phases of the signal and noise. The results are general, applying to Gaussian and non-Gaussian noises and modulated and unmodulated signals, and allow important conclusions to be reached concerning the value of power-law devices in communication systems in various signal and noise environments.

It is found that, in general, band-pass nonlinear amplifiers can be chosen to improve the signal-to-noise ratio if the input signal-to-noise ratio is small and the noise is non-Gaussian. Envelope detectors usually degrade the signal-to-noise ratio since they exhibit a "small-signal suppression" effect in all noise environments except for the special case of unmodulated sine-wave interference.

62. Ragazzini, John R. and Chang, S. S. L.,
NOISE AND RANDOM PROCESSES, Proceedings of the IRE, Vol. 50, May 1962, pp. 1146-1151.

Early investigators in the field of communications first realized that the presence of unwanted random noise was an important factor following the discovery that the maximum gain of an amplifier was limited by the discrete nature of currents in electron tubes. Called shot effect, this was first explained by W. Schottky and later by many other investigators. Much research on this problem during the second and third decades of the twentieth century finally led to the rigorous formulation of the phenomenon by B. J. Thompson and others in 1940. Concurrently, the problem of spontaneous thermal noise effects in conductors was studied and formulated. By 1940, the situation was developed to an extent that the application of mathematical statistics to explain and solve broader noise problems in systems was inevitable. About this time, the basic contributions of N. Wiener led to an understanding of the optimum linear filtration of signals imbedded in random noise. His work influenced the entire course of development of theory on the optimization of filters designed to abstract a signal out of its noisy environment.

63. Reiffen, Barney,
A NOTE ON "VERY NOISY" CHANNELS, Information and Control, Vol. 6, June 1963, pp. 126-130, DDC Reprint: AD 416 195.

A "very noisy" channel is defined. This definition corresponds to many physical channels operating at low signal-to-noise ratio. For "very noisy" discrete input memoryless channels, the computation cutoff rate for sequential decoding, R_{comp}, is shown to be one-half the capacity, C. Furthermore, that choice of input probabilities which achieves C also maximizes R_{comp}, and vice versa.

64. Rensselaer Polytechnic Institute, Department of Mathematics, Troy, New York,
THE OUTPUT PROBABILITY DISTRIBUTION OF A CORRELATION DETECTOR WITH SIGNAL PLUS NOISE INPUTS by Melvin J. Jacobson, 1 June 1962, Report RPI Math Rep No. 55, AD 276 364, Contract No. Nonr-591(09)

In this paper a study is made of the problem of determining the probability density function of the output of a correlation detector whose two inputs consist of correlated signal corrupted by uncorrelated noise. The inputs are stationary and Gaussian, one having the characteristics of white noise and the other being RC-filtered white noise. The postmultiplier averager is also an RC filter. The general case of signal plus noise inputs is investigated, and the special cases of signal-only and noise-only inputs are also considered. Detailed results are presented when the ratio of the time-constant of the postmultiplier filter to that of the premultiplier filter is one-half and also, in the practical case, when this ratio is large. With the probability distribution determined, a statistical theory of signal detection is applied, a major result being the determination of the relationship between detection probability and the classical detection measure, output signal-to-noise ratio.

65. Rice, S. O., Bell Telephone Laboratories, Murry Hill, New Jersey,
MATHEMATICAL ANALYSIS OF RANDOM NOISE, Bell System Tech. J., Vol. 23, No. 3, July 1944, pp. 282-332, Vol. 24, No. 1, January 1945, pp. 46-156.

This paper deals with the mathematical analysis of noise obtained by passing random noise through physical devices. The random noise considered is that which arises from shot effect in vacuum tubes or from thermal agitation of electrons in resistors. Our main interest is in the statistical properties of such noise and we leave to one side many physical results of which Nyquist's law may be given as an example.

The paper consists of four main parts. The first part is concerned with shot effect. The shot effect is important not only in its own right but also because it is a typical source of noise. The Fourier series representation of a noise current, which is used extensively in the following parts, may be obtained from the relatively simple concepts inherent in the shot effect.

The second part is devoted principally to the fundamental result that the power spectrum of a noise current is the Fourier transform of its correlation function. This result is used again in Parts III and IV.

A rather thorough discussion of the statistics of random noise currents is given in Part III. Probability distributions associated with the maxima of the current and the maxima of its envelope are developed. Formulas for the expected number of zeros and maxima per second are given, and a start is made toward obtaining the probability distribution of the zeros.

When a noise voltage or a noise voltage plus a signal is applied to a nonlinear device, such as a square-law or linear rectifier, the output will also contain noise. The methods which are available for computing the amount of noise and its spectral distribution are discussed in Part IV.

66. Richard, R. H. and Gore, C. W., A NONLINEAR FILTER FOR NON-GAUSSIAN INTERFERENCE, IEEE Transactions, Vol. CS-11, No. 3, December 1963, pp. 436-443.

A nonlinear filter is investigated, and its effectiveness in improving signal detectability in the presence of certain types of non-Gaussian noise is determined. The filter consists of a zero-memory nonlinear device followed by a low-pass filter, the non-linear device being designed on the basis of only the first-order statistics of the interfering noise and of the sum of signal and noise.

The class of noise used in the study is that obtained by passing Gaussian noise through a zero-memory nonlinear element. Because of this, the non-Gaussian process can still be characterized by relatively few parameters.

The results of the study indicate that, when the noise probability density function is sufficiently different from

Gaussian, a considerable improvement in detection reliability can be obtained. When the noise is Gaussian, the filter reduces to a linear one.

67. Rihaczek, A. W.,
RADAR RESOLUTION PROPERTIES OF PULSE TRAINS, Proceedings of the IEEE, Vol. 52, February 1964, pp. 153-164.

The concept of pulse compression has stimulated interest in the range and Doppler resolution properties of radar signals, but most of the theoretical investigations to date have been concerned with single pulse signals. The properties of coherent pulse trains, a practically important class of radar signals, have not received adequate treatment in the literature. Little information appears to be available on pulse trains using pulse-to-pulse waveform coding, frequency shifting, or repetition period staggering. This paper attempts to fill a gap in the radar literature by analyzing the resolution potential of pulse trains. The treatment is limited to the practical class of pulse trains where all component pulses have identical envelopes and bandwidths, but the waveforms under these envelopes, frequency bands, and repetition interval are left arbitrary. The results of the study convey an understanding of the effects of pulse train coding and thus give a clear indication of both the potential and the limitations of pulse trains in radar applications.

68. Roberts, G. E. and Kaufman, H.,
CORRELATION FUNCTION AT THE OUTPUT OF A NON-LINEAR DEVICE, IRE Transactions, Vol. IT-8, No. 4, July 1962, pp. 322-323.

Not abstracted.

69. Rubin, Milton D.,
COMPARISON OF SIGNAL AND NOISE IN FULL-WAVE AND HALF-WAVE RECTIFIERS, IRE Transactions, Vol. IT-8, No. 6, October 1962, pp. 379-380.

Not abstracted.

70. Ruchkin, D. S.,
RECONSTRUCTION ERROR AND DELAY FOR AMPLITUDE-SAMPLED WHITE NOISE, Proceedings of the IRE, Vol. 49, September 1961, p. 1436.

Not abstracted.

71. Scheftelowitz, Henry,
NOISE IN A PCM TRANSMISSION SYSTEM, Research Department, Telefonaktiebolaget L. M. Ericsson, Stockholm, Ericsson Technics, Vol. 16, No. 2, 1960, pp. 207-244.

The different noise sources in a PCM transmission system have been evaluated and their impact on the overall signal-to-noise ratio calculated. Furthermore, formulae are given which show the signal-to-noise ratio in relation to repeater spacing.

72. Selin, Ivan,
THE SEQUENTIAL ESTIMATION AND DETECTION OF SIGNALS IN NORMAL NOISE, PART I, Information and Control, Vol. 7, No. 4, December 1964, pp. 512-534.

This paper discusses the sequential detection of signals in stationary, normal, colored noise. Two classes of signals are considered: signals which are known exactly, and signals known except for a finite number of parameters.

This basic study in the statistics of detection prepares mathematical and statistical foundations for further study of sequential estimation and detection.

73. Selin, Ivan,
THE SEQUENTIAL ESTIMATION AND DETECTION OF SIGNALS IN NORMAL NOISE, PART II, Information and Control, Vol 8, No. 1, February 1965, pp. 1-35.

The object of this paper is to present results on the sequential detection of known signals, and of signals known except for unknown parameters, when Gaussian noise is present. The principal analytical tool for the study is the Karhunen-Loève expansion of a random process in terms of the characteristic functions of the covariance kernel. If the process is continuous in the mean, the expansion converges in mean square to the original process over the interval of definition (the observation interval). The well-known results on this expansion all relate

to a fixed observation interval. When the length of the observation interval is allowed to vary, as in the case of sequential analysis, some further properties of the expansion must be derived as a preliminary to an attack on the statistical problems. These properties, which might be considered as results in probability theory, are presented in Part I, along with a statement of the problems to be studied in a form suitable for the sequel. Part II presents more special results of a statistical nature.

74. Shutterly, H. B.,
GENERAL RESULTS IN THE MATHEMATICAL THEORY OF RANDOM SIGNALS AND NOISE IN NONLINEAR DEVICES, IEEE Transactions, Vol. IT-9, No. 2, April 1963, pp. 74-84.

An analysis is made of the output resulting from passing signals and noise through general zero memory nonlinear devices. New expressions are derived for the output time function and autocorrelation function in terms of weighted averages of the nonlinear characteristic and its derivatives. These expressions are not restricted to Gaussian noise and apply to any nonlinearity having no more than a finite number of discontinuities. The method of analysis used is heuristic.

75. Skolnik, M. I.,
RELAXATION OSCILLATIONS AND NOISE FROM LOW-CURRENT ARC DISCHARGES, Journal of Applied Physics, Vol. 26, No. 1, January 1955, pp. 74-79.

Under certain conditions the usual gas-discharge circuit was found to give rise to relaxation oscillations. The relaxation oscillations produce a series of very narrow pulses with random pulse repetition interval, which appear as noise. The amount of noise was found to depend upon the gas, the cathode electrode material, the power supply voltage, and the external circuit configuration. It seems that this mechanism may be responsible for most of the high level noise usually reported from gas discharges. The pulsed nature of the apparently continuous discharge appears to be a fundamental property of the low-current, cold-cathode arc which has not been considered previously.

76. Slepian, D.,
NOISE OUTPUT OF BALANCED FREQUENCY DISCRIMINATOR, Proceedings of the IRE, Vol. 46, March 1958, p. 614.

Not abstracted.

77. Smith, M. W. and Lambert, R. F.,
PROPAGATION OF BAND-LIMITED NOISE, The Journal of the Acoustical Society of America, Vol. 32, April 1960, pp. 512-514.

Theoretical and experimental work on the propagation of band limited noise in a plane wave tube are here reported. Characteristics of the spatial crosscorrelation curve are controlled by the arithmetic mean frequency of the band and the bandwidth of the noise. The amplitude of the correlation function for zero spatial separation is directly proportional to the total power Ak_b where A is the density of the cross power spectra and k_b is the bandwidth in wave number. Agreement between theory and experiment is quite good for relatively small spatial separations.

78. Stanford University, Stanford Electronics Laboratories, Stanford, California,
COMMUNICATION IN RANDOM OR UNKNOWN CHANNELS by C. K. Rushforth, July 1962, Technical Report No. 2004-6, NR 373 360, SEL-62-086, AD 283 083

This paper deals with the problem of communicating in the presence of random or unknown multiplicative disturbances. The main contributions of this work are in the areas of signal selection and the design and evaluation of the associated receiver.

It is shown that the optimum signals for a known channel can be the worst possible signals for the unknown or random channel. Physical reasoning leads us to choose the signals (s', s') and (s', -s') -- the first is associated with channel measurement, the second with the transmission of information. The optimum receiver for this set of signals when the channel output is white noise is shown to cross-correlate the perturbed reference with the perturbed message. This is the so-called transmitted-reference system.

Evaluation of the error probability for the transmitted-reference system for various situations indicates that, for a fixed signal-to-noise ratio, the error probability increases as the time-bandwidth product increases. It is also shown that, when the additive noise powers associated with the reference and message signals are different, the error probability can be reduced by putting more of the available energy in the noisier signal. A simplified criterion for this energy division is obtained.

When the channel outputs are correlated from one observation to the next, it is shown that the transmitted-reference system can easily be modified to adapt itself to the channel. Finally, the performance of the transmitted-reference system is compared with that of a Bayes receiver using on-off signaling. It is shown that if the a priori uncertainty about the channel is large, the transmitted-reference system will exhibit superior performance.

79. Stanford University, Systems Techniques Laboratory, Stanford, California,
NOISE FIGURES, NOISE TEMPERATURES, AND SYSTEM SENSITIVITY by Philipp H. Enslow, July 1961, Technical Report No. 516-2, AD 265 552.

This report presents the definitions of terms used in systems noise work as well as the general techniques of describing noise power resulting from both the source and the excess noise added by the network under consideration. A unique feature of this report is a unified development of seven "noise temperatures" encountered in this field with tables showing the relationships among them and their uses. A general technique for calculating the sensitivity of a receiver is presented and three examples are treated in detail: the simple crystal-video system, the crystal-video receiver with RF preamplification, and the superheterodyne system. All systems are divided into two classes for which the calculations are similar: receivers having only a simple detector and those having some form of linear amplification preceding the detector. The final analysis of the noise performance of the system requires a comparison of the predetection and postdetection excess noise. This comparison is performed by referring all excess noise power to the detector input and classifying the system according to whether (a) the predetection noise predominates, (b) the postdetection noise predominates, or (c) the predetection noise and the postdetection noise are comparable in magnitude.

The appendices cover several topics of interest, such as image response and the special problems encountered with a panoramic receiver.

80. Stull, Keefer S., Jr.,
RECTIFICATION OF NARROW-BAND NOISE, <u>Electronic Industries</u>, Vol. 19, No. 5, May 1960, p. 103.

Not abstracted.

81. Tatarinov, A. B.,
ESTIMATION OF THE CONSTANT COMPONENT OF A DETECTED PERIODIC SIGNAL MIXED WITH ADDITIVE GAUSSIAN NOISE USING A SEGMENT OF A SINGLE SAMPLE OF FINITE DURATION, Telecommunications and Radio Engineering, Part 2: Radio Engineering (Translation of Radiotekhnika), Vol. 18, No. 6, June 1963, pp. 5-14.

Using a single sample of finite duration, the problem of estimation of the mean value of a detected harmonic signal on a background of additive Gaussian noise, mixing with the signal before the detection process, is considered. For linear and square-law detectors, equations are derived for the relative bias of the estimate and the coefficient of variation due to noise and the relation of connecting these quantities to the value of the signal-to-noise ratio and the duration of the analyzed sample. Some of the results are presented graphically.

82. Terpugov, A. F.,
DETECTION OF SIGNALS IN NOISE IN THE PRESENCE OF UNKNOWN PARAMETERS, Radiotekhnika i Elektronika, Vol. 9, No. 1, January 1964, Translated into English from Russian in Radio Engineering and Electronic Physics, Vol. 9, No. 1, January 1964, pp. 48-52.

Two approaches to the problem of detecting a signal in noise in the presence of unknown parameters, similar to the approach to games, are considered. The first approach, in combination with a set of axioms, leads to known results. The second approach gives a new criterion of gain, which is applied to the solution of the posed problem.

83. Thaler, S. and Meltzer, S. A.,
THE AMPLITUDE DISTRIBUTION AND FALSE ALARM RATE OF NOISE AFTER POST-DETECTION FILTERING, Proceedings of the IRE, Vol. 49, No. 2, February 1961, pp. 479-485.

A digital computer has been used to simulate the passage of white Gaussian noise through a narrow-band filter, followed by a detector and a postdetection filter. The amplitude distribution of the output of the postdetection filter has been obtained for several different detectors. In addition, the variation of false alarm rates with detector law, postdetection filtering, time constants, and threshold setting has been investigated. Not only the numerical results but also the approach and the new detectors described are believed of interest.

84. Thomasian, A. J.,
FOUNDATIONS OF INFORMATION THEORY, IEEE Transactions, Vol. IT-9, No. 4, October 1963, pp. 221-223; Also Available as Report No. 64-38, AD 609 362, Contract Nonr-222(53).

This is a selective survey, mainly restricted to extensions of Shannon's original results to communication models which incorporate new phenomena. Some attention is also given to generalizations of the Shannon-McMillan theorem and to finite-state channels.

85. TRG, Incorporated, Melville, Long Island, New York,
RANGE AND ANGLE ERRORS FOR TIME-DEPENDENT SIGNALS WITH A RECTANGULAR FREQUENCY SPECTRUM by Visvaldis Mangulis, November 1964, Report TRG-023-TN-64-1, AD 454 737, Contract NObsr-93023

The signal amplitude is assumed to be of the form $\sin\sigma t/\sigma t$, where t is the time and 2σ the bandwidth. The signal is incident at an angle on a line receiver; the time required to traverse the receiver can be greater or less than the effective pulse length of the signal. It is shown that the error in the time of arrival of the peak signal (which is proportional to an error in the range to a target) is inversely proportional to the bandwidth in the limit of very small or very large bandwidths, and it has some additional dependence on σ between these extreme limits. The error in the angle of the signal arrival is inversely proportional to the center frequency for small bandwidths, and it is inversely proportional to the bandwidth for large bandwidths.

86. University of Dayton, Dayton, Ohio, 45409,
NOISE POWER SPECTRUM ANALYSIS STUDIES by Richard R. Hazen, December 1964, Final Scientific Report No. 2, AD 460 854, Contract No. AF 33(657)-10385

This technical report discusses the problems related to performance capabilities of experimental type high-power, wide-band RF noise generators and noise distribution measurement techniques.

The object of the program was to determine by a research study effort the inherent characteristics of two types of noise sources, to study noise distribution instrumentation methods, and to investigate solid state noise sources and amplifier feasibility up to one GC.

The experimental devices under study were the CSF (Warnecke) crossed-field RW-628 and the Hughes high-power plasma microwave noise source SAP 1/13, 3/4, and 4/6.

87. University of Dayton, Dayton, Ohio 45409,
NOISE POWER SPECTRUM ANALYSIS STUDIES AND KLYSTRON POWER MEASUREMENTS by Richard R. Hazen, May 1963, Report ASD-TDR-63-435, AD 412 359L, Contract No. AF 33(616)-7718

This technical report discusses the problems related to measurement techniques and the performance capabilities of experimental type wide-band RF noise generators and power oscillators built under Air Force sponsored programs, devices of which were investigated by the University of Dayton.

The object of the program was to determine by a research study effort the inherent characteristics of three types of noise generators and the power output of a supported drift tube klystron. Noise generation in the Burrough's AF-12 experimental noise source tube was also to be studied.

The experimental devices under study were the Hughes High Power Plasma Microwave Noise Source, SAP-1, the Burroughs BX-3000, the Watkins-Johnson WJ-218 noise generator, and the Eimac supported drift tube klystron.

88. U. S. Army Electronics Laboratories, U. S. Army Electronics Command, Fort Monmouth, New Jersey,
HIGH RANGE RESOLUTION COHERENT RADAR by Samuel E. Craig, June 1964, Technical Report 2496, AD 608 038

An experimental coherent radar was assembled to investigate the value of high range resolution, without comparable azimuthal resolution, in differentiating between natural targets and man-made targets. A pulsed varactor diode in a microwave switch was used to modulate the output of a CW klystron. The peak power output was about 100 milliwatts. The best range resolution obtained was about three feet. Since the system used coherent detection, any target motion appeared quite clearly on the A-scope presentation. A distinct difference could be seen between the return from a steadily moving target, such as a vehicle, and the return from an irregularly moving target, such as a tree branch or foliage swaying in the wind. A range resolution of 15 feet was found to be insufficient to show any clear differences between a walking man and a moving vehicle. With a six-foot range resolution, however, the return from a moving vehicle began to show more than one peak. With the three-foot resolution, a vehicle might show as many as four or five peaks. An intensity-modulated raster display was used for part of the tests. This type of display, which presented the relative phases of the separate returns from a target where the resolution was fine enough to produce more than one return, also indicated the possibility of showing whether a slowly moving target was approaching or receding. The use of different types of vehicles at varying aspects is recommended for further evaluation of the high range resolution technique. Reduction in equipment size and weight to provide portability is also recommended.

89. U. S. Naval Research Laboratory,
ANTENNA AND RECEIVING-SYSTEM NOISE-TEMPERATURE CALCULATION by L. V. Blake, 1961, NRL Report 5668, AD 265 414

This report is basically oriented to the problem of radar maximum range calculation, but has application to radio receiving systems in general.

In Part I, a calculated curve representing the noise temperature of a typical directive antenna in the frequency range 100 to 10, 000 megacycles is presented, together with the method and details of calculation. This curve may be used as an approximation for any directive antenna in this frequency range, and its values may be readily modified for other assumed or actual conditions.

Part II presents a methodology for utilizing this antenna noise temperature in calculation of a receiving-system noise temperature from which the total system noise power output and the signal-to-noise power ratio may conveniently be computed. Basic concepts and definitions are first reviewed and then applied to development of equations for the noise temperatures of system components and an overall system of cascaded components referred to an arbitrary point within the system.

The need for definition of both the spot (frequency-dependent) noise temperature and the average temperature over a passband is pointed out, and also the need for definition of a transducer noise temperature that represents only the intrinsic transducer noise. The IRE-defined input noise temperature of a twoport transducer is interpreted for the case of a multiple-input-response transducer. For the purposes of this report, a quantity called "principal-response effective input noise temperature" is defined. It is equivalent to the IRE-defined temperature with the contribution of the input termination (via the spurious responses) deleted.

The use of system noise temperature for comparing the low-noise merit of different systems is discussed. For this purpose the system temperature must be referred to the system input terminals, and these terminals must be defined to precede all system elements that result in dissipative loss, including loss that may occur in the antenna structure. Moreover, if the antenna is included as part of a system being thus rated, some standard or convention as to the noise environment (such as the assumptions made in calculating the curve in Part I) is needed.

The calculation of received signal power for various types of systems (one-way radio, monostatic and bistatic radar, satellite-reflection communication) is briefly reviewed, to show how the system noise temperature may be used for signal-to-noise-ratio calculation. The case in which signal power may be simultaneously received via more than one input response channel of a multiple-response receiver (as in radiometry) is briefly considered.

90. Varshamov, R. R. and Megrelishvili, R. P., ESTIMATION OF SIGNAL NUMBER IN A CLASS OF CORRECTING CODES, Avtomatika i Telemekhanika, Vol. 25, No. 7, July 1964, pp. 1101-1103, Translated into English from Russian in Automation and Remote Control, Vol. 25, No. 7, July 1964, pp. 987-989.

A class of correcting codes is examined, which is capable of counteracting interferences of a special type, namely, those having the form of "packets." The necessary and sufficient condition for the existence of such codes for a given source intensity of the interference is established.

91. Velichkin, A. I. and Ponomareva, V. D., EXPERIMENTAL INVESTIGATION OF THE DURATION OF NOISE PEAKS, Radiotekhnika, Vol. 15, No. 10, October 1960, pp. 21-26, Translated into English from Russian in Radio Engineering, Vol. 15, No. 10, October 1960, pp. 28-35.

Note: Pages 30 and 31 of the translation are missing, apparently because of an error in printing.

The probability density of the duration of peak periods and intervals between peaks is experimentally determined at different levels of Gaussian noise and Rayleigh noise.

92. Wierwille, W. W.,
A NEW APPROACH TO THE SPECTRUM ANALYSIS OF NON-STATIONARY SIGNALS, IEEE Paper 63-63, <u>IEEE Transactions on Applications and Industry</u>, Vol. 82, November 1963, pp. 322-327.

A new approach is presented which allows proper spectral measurements of time-nonstationary signals. The power spectrum is defined on the basis of ensemble averages and, therefore, contains a time variation when the signals are non-stationary. It is shown that a spectrum analyzer can be designed which measures these time-varying spectra in a nearly optimum manner. Design equations are given, and practical considerations are discussed.

93. Zabronsky, H.,
STATISTICAL PROPERTIES OF M-ARY FREQUENCY-SHIFT-KEYED AND PHASE-SHIFT-KEYED MODULATION CARRIERS, <u>RCA Review</u>, Vol. 22, No. 3, September 1961, pp. 431-460.

This paper presents methods for determining the statistical properties of frequency-shift-keyed and phase-shift-keyed modulated carriers through a limiter plus other devices in the presence of white Gaussian noise. Closed form expressions are obtained for the transition probabilities in mistaking one signal for another.

A nonlinear element such as a limiter offers ususual analytic difficulties. It is hoped that the methods presented in this paper will be useful in the solution of other problems involving signals plus noise through nonlinear devices.

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13. ABSTRACT

This bibliography contains a selection of papers, most of them annotated, on noise and the effects of noise on signals. Consequently, several surveys of information theory and papers dealing with interdependent aspects are included. Sources of the contemplated noise were either environmental or inherent in the equipment, which includes effects of both the atmosphere and other transmitters. Accordingly, several studies include non-Gaussian as well as Gaussian noise.

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