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Noise measurement techniques

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NOISE MEASUREMEMT TECHNIQUES

MEASUREMENT TECHNIQUES

The noise measurement techniques employed before the 1960's and in use today incorporate four basic elements: an antenna, receiver, detector, and metering device. The antenna is a "standard" antenna or the antenna of an operational system; the receiver is a type consistent with the existing state-of-the-art tuned radio frequency heterodyne, or, in the early 1930's, a superheterodyne. An electro-mechanical or vacuum tube voltmeter has been used as the metering device. The detector chosen has been the one that gave the desired statistical parameter-peak voltage, quasi-peak voltage, square law (voltage squared or calorimetric), or average voltage. The performance, and especially differences in performance of these diverse detectors, is understood and has been discussed extensively (Geselowitz, 1961). For single frequency, continuous-wave inputs, the four detectors, suitably calibrated, give comparable readings. In all other cases, it is difficult or impossible to correlate readings from the several diverse detectors unless there is a priori independent knowledge of the waveform of the received noise. A recent extensive discussion of this has been given by Magrab and Blomquist (1971). The units for reporting the results of noise measurements made with these various detectors are discussed further in Appendix C.

It is common practice for many commercial detectors to use scales that are calibrated to read rms voltage of a sine wave. Magrab and Blomquist (1971) depict what the peak, average, and rms meter will read when calibrated in rms for a sine wave, and what the error in dB is compared to the true rms reading. Table shows results for signals whose waveforms are known in detail. (For the case of white Gaussian noise shown, p(x) is known, so that average voltage and rms voltage can be calculated.) In the case of man-made noise, because the process is random (waveform unknowable), the proper detector must be used because it is impossible to convert from one detector reading to another; i.e., an rms measurement requires an rms detector, etc. In addition, the dynamic range capabilities of the detector must be adequate. For man-made noise, this generally means that large dynamic range requirements need to be met. Matheson (1970) has an excellent discussion of this problem.

Table . Peak, Average, and RMS Detector Readings when Calibrated to Read RMS Voltage of a Sine Wave (Magrab and Blomquist, 1971)

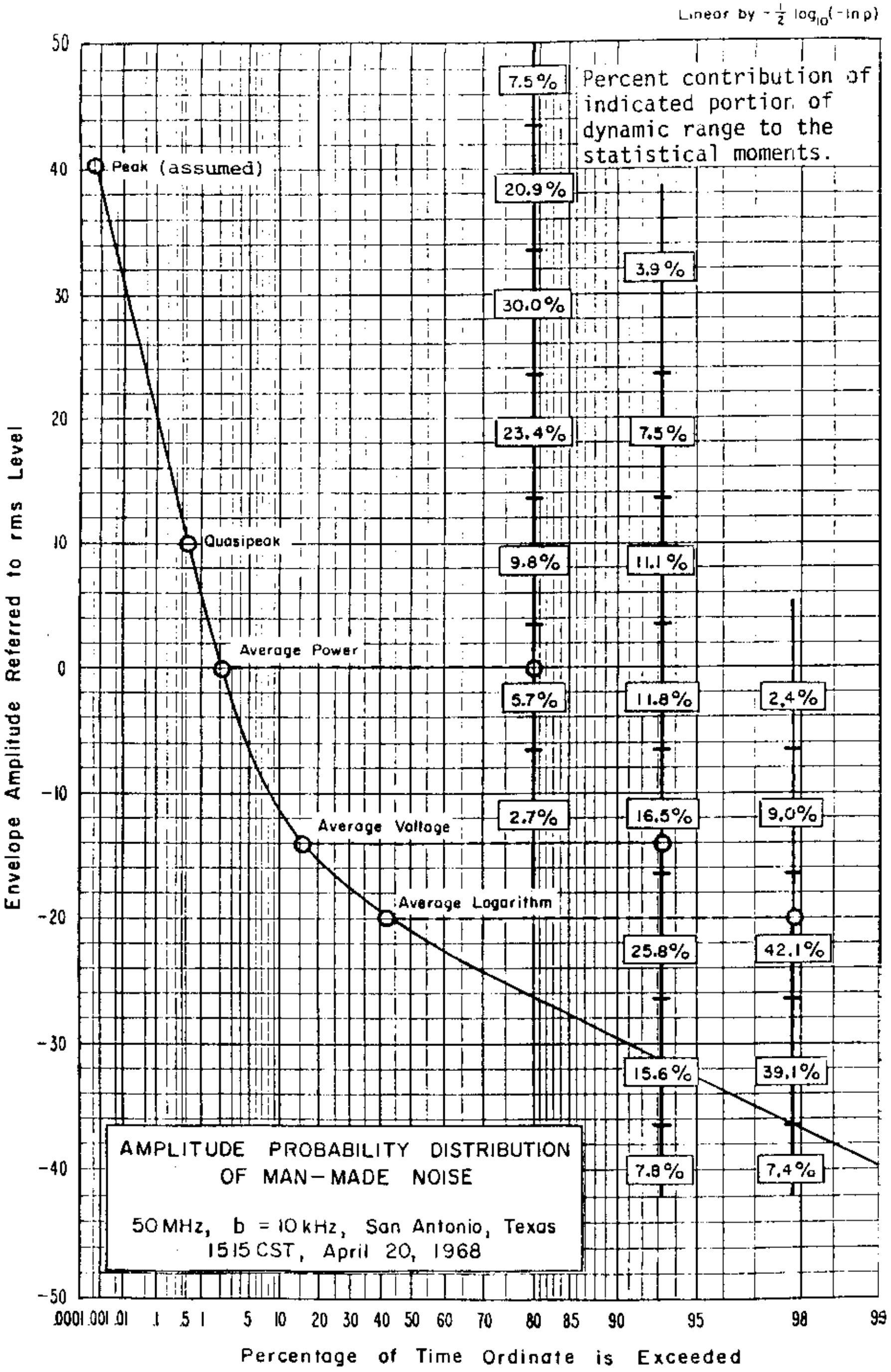
Wave Form	Rms Meter Indicates	Rectified Average Meter Indicates (Calibrated in Rms)	Peak Meter Indicates (Calibrated in Rms)	Error (dB) $[20 \log_{10}(E/E_{rms})]$ Average	Peak
Sine wave	0.707	0.707	0.707	0	0
Sine wave Plus 100% Third harmonic					
In phase	1.000	0.944	1.09	-0.50	0.748
Out of phase	1.000	0.472	0.382	-6.52	-8.36
Square wave	1.000	1.111	0.707	+0.91	-3.00
Gaussian noise	1.000	0.887	---	-1.04	---
Pulse train					
D = 0.1	0.318	0.111	0.707	-9.14	+6.10
D = 0.01	0.10	0.011	0.707	-19.17	+16.99

D = duty cycle

As an example, figure shows a typical man-made noise distribution measured in a 10 kHz bandwidth. The dynamic range (difference between value exceeded 0.0001% of the time and value exceeded 99% of the time) of this sample of noise is approximately 85 dB. The figure shows the measured rms voltage, average voltage, and average log voltage moments, along with the percentage each portion of the dynamic range contributes to these moments. Figure 4.10 also shows the measured quasi-peak voltage with detector charge and discharge time constants of 1 ms and 600 ms respectively. Note that since the quasi-peak voltage depends on the time structure of the noise as well as the amplitude structure (APD), no indication is given on figure 4.10 as to which portion of the dynamic range contributes to the quasi-peak voltage. To measure the rms voltage to within 1/2 dB accuracy would require an instantaneous dynamic range of 50 dB (actually 100 dB due to the required squaring operation). If the measuring equipment saturates and clips the upper portions of the APD, that amount of power is lost and would represent a measurement error. Thus an rms detector having a 14 dB (5:1) crest factor (i.e., a detector which saturates 14 dB above the rms voltage) would miss 82% of the noise power (resulting in a reading too low by 7.2 dB).

The root-mean-square method of detection has a growing utility in problems of current interest and has low implementation cost, large dynamic range, and wide frequency-band response. Of course, rms detection is required to measure the basic noise parameter, mean power. Commercial rms detectors are available with sufficient dynamic range for the measurement of man-made impulsive noise (e.g., Singer NM 26T, see Microwaves, Nov., 1974). In the past five years, several commercial products have been marketed that use rms detectors to measure the power in pulses as short as 100 ns and frequencies as high as 18 GHz (e.g., Pacific Measurements, Inc., Palo Alto; and Hewlett-Packard Co., Palo Alto, California). There are unsolved problems in measuring impulsive interference when it is extremely infrequent, of extremely short duration, or swept in frequency. Recourse to transient instruments (i.e., broadband oscillographs, storage or sampling oscilloscopes, tape loop recorders, etc.) with wide dynamic response system capability is necessary to investigate the man-made transient interference often encountered in present-day systems (Ellison, 1968; Herzog, 1973).

Magrab and Blomquist (1971, sec. 7-13) introduce the problem of measuring signals of low duty cycle and single transients with durations below



A typical man-made noise amplitude probability distribution.

1 µs. Further information on this problem can be gleaned from the developments recently made in the measurement of acoustical transients (Magrab and Blomquist, 1971; Wahrmann, 1969).

For analysis and/or design of communication systems, greater knowledge of the received noise process is generally required than that given by the above detector outputs (average, rms, etc.). Techniques for measurements of these more detailed statistics (e.g., probability density functions, autocorrelation, etc.) vary greatly and range from the analog recording — A to D conversion — large scale computer analysis technique to those using specialized electronic circuitry. Techniques for making detailed statistical measurements are discussed and summarized by Bendat and Piersol (1971). Until recently, the capability to make such detailed statistical measurements has resided in a few Government and private research laboratories using specially developed equipment. Commercial equipment is now available for detailed statistical measurements of impulsive noise.

REFERENCES

Bendat, J. S., and A. G. Piersol (1971), Random Data; Analysis and Measurement Procedures (Wiley-Interscience, New York).

Ellison, R. W. (1968), Transients in an electronics manufacturing facility, Proc. of 1971 Mountain-West Conf. on Electromagnetic Compatibility, Tucson, November 11-12; also in Proc. 1969 Southeastern Conf. in EMC, Atlanta, November. Three volumes of data on industrial transients are given in R. Loveland, C. Bond, and R. Ellison, Electronics Manufacturing Facility - EMC Test Report, TM-0495-8, -8A, -8C, Martin Marietta Corporation, Denver, 1968/9. (Available from author).

Geselowitz, D. B. (1961), Response of ideal radio noise meter to continuous sine wave, recurrent impulses, and random noise, IRE Trans. RFI, May, 2-10.

Herzog, R. (1973), How to catch a transient, Machine Design, March 22, 170-175.

Magrab, E. B., and D. S. Blomquist (1971), The Measurement of Time Varying Phenomena (Wiley-Interscience). See also J. J. Davidson, Average vs. RMS meters for measuring noise, IRE Trnas., Audio, July-August, 1961, 108-111.

Matheson, R. J. (1970), Instrumentation problems encountered making man-made electromagnetic noise measurements for predicting communication system performance, IEEE Trans. EMC, EMC-12, No. 4. Also R. J. Matheson, High impedance driver boosts detector's dynamic range, Electronics Survey, October 25, 1971.

Wahrmann, C. G. (1969), Impulse noise measurements, B&K Tech. Rev., 1, 7-18, Magrab & Blomquist, loc. cit. section 4, 7.