XIII. SEMICONDUCTOR NOISE

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A. PROBLEMS IN THE MEASUREMENT OF NOISE AMPLITUDE PROBABILITIES

Since the report of January 15, 1954, our attention has been focused primarily upon finding a convenient method of characterizing nongaussian noises.

From a practical point of view, the precision of an amplitude probability distribution determined from experiment is bound to be limited, especially in the low-probability regions. Moreover, unless the noise being studied is radically nongaussian, mere visual comparisons of its amplitude distributions with those of gaussian noise are likely to be unsatisfactory. The most difficult cases will, of course, be those with almost gaussian distributions. Consequently, the description of nongaussian noises in terms of the moments of their amplitude probability distributions appears particularly attractive from the standpoint of evaluating experimental results. It is, however, also attractive for the theoretical questions with which we are immediately concerned. For example, the moment description appears to furnish the key to a rather simple demonstration that the first amplitude probability distribution of the output of a sufficiently narrow-band linear filter is always gaussian, regardless of the type of noise input. The details of this demonstration are not yet sufficiently complete to warrant presentation here, but the possibility of actually determining how (in terms of its moments) the output distribution deviates from gaussian as the filter bandwidth increases, looks quite promising at the moment.

J. Hilibrand

B. NOISE AND CHANNEL EFFECT IN P-N JUNCTIONS

As reported in the Quarterly Progress Report of January 15, 1954, preliminary measurements on reverse-biased p-n junctions indicated that the presence of a water-vapor induced n-type surface conductivity layer, or "channel," on the p-side produced a large increase in the noise current. Without a more detailed model of the channel and more careful control of the experimental variables, however, it was impossible to establish definitely the correlation between the noise and the channel, or to get at the actual noise mechanism. Accordingly, a fairly detailed study of channels in grown germanium p-n junctions was undertaken, in cooperation with R. H. Kingston of Lincoln Laboratory. Using an optical technique to measure the length of the channel (1) and aqueous salt solutions to provide the desired humidity, it was found that (a) no channel was formed on a freshly CP4-etched surface, and (b) for well-oxidized surfaces, large excess reverse currents occurred which were directly proportional to the length of the channel for all

measured values of applied voltage and humidity. By combining this observation with the known behavior of the channel conductivity with humidity and voltage (2), a formula for the excess current as a function of the applied bias was derived, which in spite of several oversimplifications in the model agrees reasonably well with the experimental results. This phase of the work has now been completed and the results submitted for publication.

With this knowledge of the channel behavior to guide the experiments, the original investigation of the correlation between the 1/f noise and the channel is being resumed, using the recently completed noise analyzer (see section XIII-D) for the measurements.

A. L. McWhorter

References

1. H. Christensen, American Physical Society Meeting, Minneapolis, June 28-30, 1954; also to be published in Proc. I.R.E.

2. R. H. Kingston, Phys. Rev. 93, 346 (1954).

C. MODULATION NOISE IN SEMICONDUCTOR DEVICES

The experiment described in the Quarterly Progress Report of January 15, 1954, has been continued. Several 1N38 diodes have been back-biased and at the same time fed a 10 kc/sec signal current. The amplitude-modulation noise and the low-frequency noise have been recorded simultaneously and compared.

The results indicate that the nonlinearity of the diode is insufficient to account for the observed depth of noise modulation, which is an order of magnitude larger than that expected from a mixing of signal and noise. These results seem to justify the assumed model for the noisy diode in terms of a fluctuating volt-ampere characteristic (Quarterly Progress Report, July 15, 1953).

The present bridge circuit, used for boosting the exceedingly small noise modulation depths (several per thousand) to values suitable for linear amplification and detection, is subject to error in calibration. Further work will seek to improve the accuracy of the method, and to determine the relation between the fluctuation in the static and the dynamic resistances of the diode.

J. Gross

D. NOISE ANALYZER

Construction and preliminary testing have been completed on the recording noise analyzer for which tentative specifications were listed in the Quarterly Progress Report of January 15, 1954.
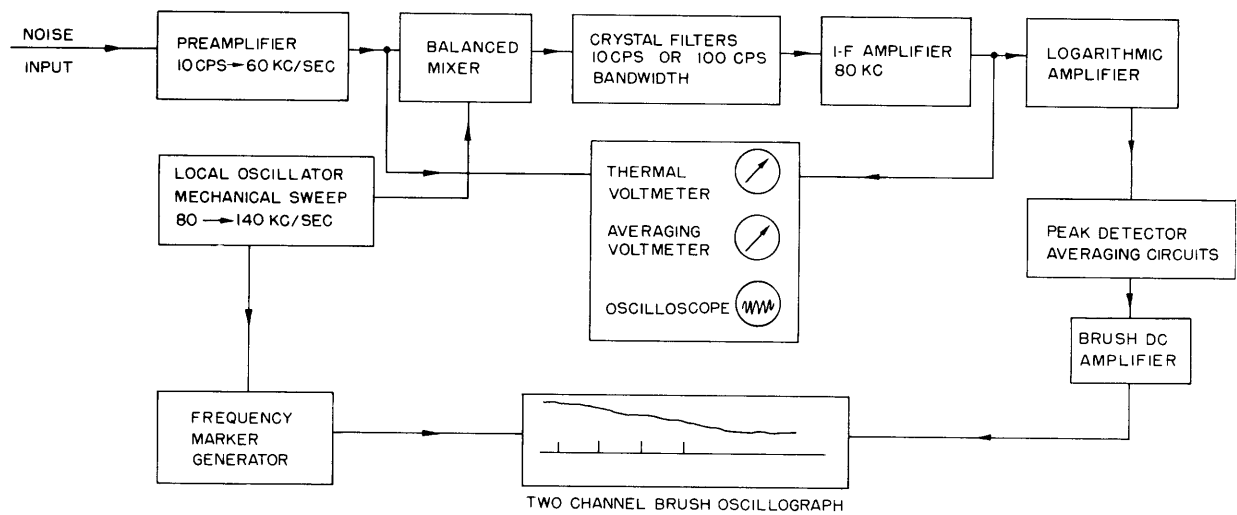
Fig. XIII-1

Block diagram of recording noise analyzer.

Figure XIII-1 shows a block diagram of the analyzer. The input to the Brush oscillo-graph is a dc voltage proportional to the logarithm of the rms value of the noise voltage at the analyzer input, in a bandwidth determined by the selected crystal filter and at a center frequency determined by that of the local oscillator. The analyzer thus yields a noise voltage vs frequency spectrum which is direct-reading and linear in decibels.

That the logarithm of the rms noise voltage is actually measured by the analyzer requires justification. Assume that the analyzer input noise is gaussian. The output of the 80-kc, i-f amplifier (see Fig. XIII-1) will then be narrow-band gaussian noise, whose envelope has a Rayleigh (1) probability density distribution given by

$$W_1(E) = \begin{cases} \left[E/\sigma^2(x)\right] \exp\left[-E^2/2\sigma^2(x)\right] & E \geqslant 0 \\ 0 & E \leqslant 0 \end{cases} \tag{1}$$

where E is the envelope amplitude and $\sigma(x)$ is the rms value of narrow-band noise. The amplitude $Y(t)$ of the output of the logarithmic amplifier is related to its input amplitude $X(t)$ by the relation

$$Y(t) = K \log X(t) \tag{2}$$

where K is a constant, and $\log = \log_{10}$.

The circuitry following the logarithmic amplifier yields the average value of the envelope of the output of that amplifier. It therefore follows that the system output $\overline{Y}$ is the average value of the logarithm of a random variable with a Rayleigh probability distribution

$$Y = \int_{-\infty}^{\infty} (K \log E)\, W_1(E)\, dE = \frac{K}{\sigma^2(x)} \int_0^{\infty} E(\log E) \exp\left[-E^2/2\sigma^2(x)\right] dE \qquad (3)$$

This integral is easily handled by the substitution

$$y = \frac{E}{2^{1/2}\sigma} \qquad (4)$$

which yields

$$\overline{Y} = 2K\left[\log 2^{1/2} + \log \sigma\right] \int_0^{\infty} y \exp(-y^2)\, dy + 2K \int_0^{\infty} y(\log y) \exp(-y^2)\, dy \qquad (5)$$

Since

$$\int_0^{\infty} y \exp(-y^2)\, dy = \frac{1}{2} \qquad (6)$$

and

$$\int_0^{\infty} y(\log y) \exp(-y^2)\, dy = \frac{0.434}{4} \int_0^{\infty} (\log_e x) \exp(-x)\, dx = -0.1255 \qquad (7)$$

therefore

$$\overline{Y} = K(\log 2^{1/2} - 0.1255) + K \log \sigma(x) \qquad (8)$$

A similar analysis of the system response to a sinusoid of rms value σ shows that the dc output in that case is given by

$$\overline{Y}_{sin} = K \log 2^{1/2} + K \log \sigma(x) \qquad (9)$$

The following important results are obtained by examining Eqs. 8 and 9: (a) By adjusting the gain of the Brush (dc) amplifier to make $K = 20$, the system reads directly and linearly in decibels. (b) Calibration by sinusoidal input is made possible by observing that when $K = 20$, the difference between the system outputs for sinusoidal and random inputs of the same rms value is $20 \times 0.1255 = 2.51$ db.

The validity of both results has been verified experimentally with thermal noise inputs.

D. I. Kosowsky

References

1. W. B. Davenport, Notes on an Introduction to Noise Theory, M.I.T., 1952, Chap. IX (class notes).