

VI. NOISE IN ELECTRON DEVICES

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A. DETECTION OF LIGHT INTENSITY FLUCTUATIONS THROUGH PHOTO-ELECTRON COUNTS

Measurements on the noise of optical maser oscillators have been in progress for some time.¹ Such measurements can be performed by using spectral methods, that is, by detecting the spectrum of the photomultiplier current,² or they can be made by observing the statistics of the photoelectron count of a photomultiplier illuminated by optical maser light. Measurements of the last kind are reported here.

It was shown previously³ that the correlation functions of the intensity of a light beam may be detected by measurements of the statistics of the photoelectrons in a photomultiplier illuminated by the light. If one observes the number of photoelectrons K in a set of time intervals of fixed length T , one may determine from the observed second factorial moment $\overline{K(K-1)}$ the autocorrelation function of the light intensity. We have³

$$\overline{K(K-1)} = 2a^2 \int_0^T (T-\tau) R(\tau) d\tau. \quad (1)$$

Here, $R(\tau)$ is the autocorrelation function (short-time average) of the light power, and a is a factor related to the photoefficiency, $a = \eta/h\nu$. An optical maser oscillating in a single mode produces at the photomultiplier surface a field amplitude with a time dependence,

$$A(t) = [A_0 + a(t)] \cos [\omega t + \phi(t)] \quad (2)$$

The term A_0 is the steady-state amplitude of the field, $a(t)$ is the small-noise excitation, a quantity with frequency components low compared with the optical frequency. Defining the normalized correlation function of the noise amplitude, we have

$$\rho_a(\tau) = \frac{\overline{a(t) a(t+\tau)}}{a(0)^2}. \quad (3)$$

And the modulation coefficient is

$$m^2 = \frac{\overline{a(0)^2}}{A_0^2}. \quad (4)$$

We then obtain for the autocorrelation function of the power

$$R(t) = \overline{P}^2 [1 + 4m^2 \rho_a(\tau)]. \quad (5)$$

(VI. NOISE IN ELECTRON DEVICES)

Combining these results, we obtain for the mean-square deviation of the photoelectron count

$$\frac{\overline{K^2} - \bar{K}^2}{\bar{K}} = \frac{\delta K^2}{\bar{K}} = 1 + 8 \frac{m^2}{T^2} \bar{K} \int_0^T (T-\tau) \rho_a(\tau) d\tau. \quad (6)$$

If we assume that the autocorrelation function $\rho_a(\tau)$ is of the form

$$\rho_a(\tau) = e^{-\omega_0 |\tau|}, \quad (7)$$

which corresponds to a Lorentzian line shape for the noise, we have

$$\frac{\delta K^2}{\bar{K}} = 1 + 8 \frac{m^2 a}{\omega_0} \left[1 - \frac{1}{\omega_0 T} (1 - e^{-\omega_0 T}) \right], \quad (8)$$

where a is the photoelectron rate, $a = \bar{K}/T$. The bandwidth of the noise expected for a maser oscillating in a single mode will be, in general, narrower than the bandwidth of the optical cavity. The narrowing is due to the negative-resistance effect of the maser material.⁴ Thus the noise bandwidth is, in general, a function of the excitation level of the optical maser. Figure VI-1 shows a set of observed values for the mean-square fluctuation normalized to the photoelectron count. The measurements were taken on a DC excited internal mirror optical maser oscillating at 6328 angstroms.

A thousand samples were taken for each counting interval, T . The deviation of the ideal value from the experimentally determined value, because of the noninfinite number of samples taken, was approximately 5 per cent. Even though the theoretical

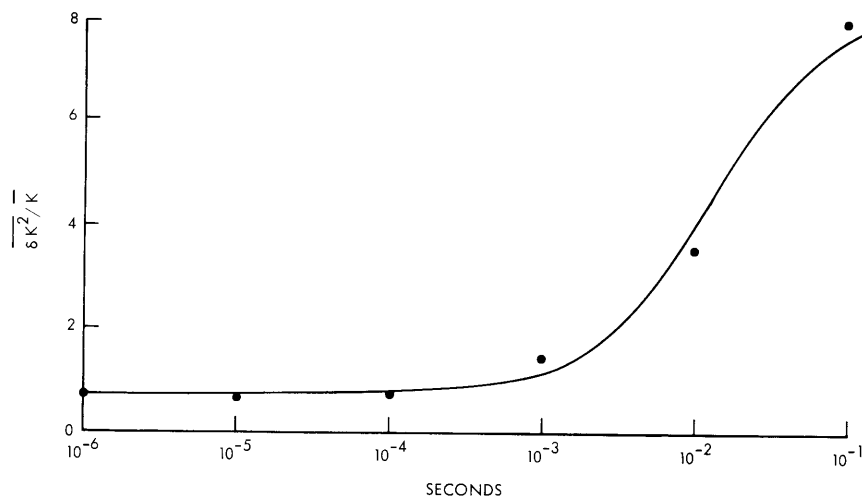


Fig. VI-1. Experimentally determined mean-square deviation.

(VI. NOISE IN ELECTRON DEVICES)

formula predicts that the plot should start out at unity, it was found experimentally that the mean-square fluctuation for short observation times was less than this ideal value. It can be shown that the deviation is due to occurrence of multiple pulses in the resolution time of the counter.

If the light were completely unmodulated, and the photoelectron count were therefore Poisson, the observed mean-square count with an average count of \bar{n} per resolution time would have been

$$\frac{\overline{\delta K^2}}{\bar{K}} = e^{-\bar{n}}. \quad (9)$$

The resolving time of the counter was approximately 20 nanosec, the count was 12.7 million per second; thus $\bar{n} = 0.25$. Therefore, the observed mean-square fluctuations at short observation times can be accounted for theoretically.

The power output of the optical maser was stabilized by an external feedback circuit that kept the fluctuations in the output power to less than one tenth of one per cent. The time constant of the feedback circuit was 1/2 sec, so that rapid fluctuations were not affected by it. In Fig. VI-1 we have fitted a curve to the experimental data under the assumption that the spectrum of the noise amplitude $a(t)$ has bandwidth $\omega_0 = 125$ rad/sec. The corresponding assumed modulation coefficient is $m^2 = 0.9 \times 10^{-5}$. During the counting experiment, the spectrum of the photomultiplier current was monitored. The maser operated quietly and no gas-discharge fluctuations were visible on the spectrum analyzer.

The experiments were performed at Lincoln Laboratory, M. I. T., in cooperation with Mr. C. Freed. Mr. L. R. Cardillo, a candidate for the Bachelor's degree, participated in the measurements.

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References

1. Quarterly Progress Report No. 69, Research Laboratory of Electronics, M. I. T., April 15, 1963, p. 31; No. 70, July 15, 1963, p. 77; No. 71, October 15, 1963, p. 87; No. 72, January 15, 1964, p. 53.
2. Quarterly Progress Report No. 71, loc. cit.
3. Quarterly Progress Report No. 70, loc. cit.
4. Quarterly Progress Report No. 72, loc. cit.

