II-3. THEORY AND MEASUREMENTS OF NOISE IN VARACTOR HARMONIC GENERATOR SOURCES

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I. Characterization of Noise in RF Sources. Oscillators and harmonic generators are inherently nonlinear. Their responses to noisy perturbations are more characteristic of the modulation process than of linear superposition. It is commonly found that noise is present as modulation sidebands with strong correlation between noise components on opposite sides of the carrier.

Numerous noise measuring techniques and specifications have been devised. Simple spectral distribution measurement in the vicinity of the carrier is a meaningful technique but fails to indicate the phase or amplitude character of the noise modulation. Spectral distributions differ for various types of sources so that a measure of line width has further inadequacies as a complete noise specification. It is now common to specify the noise perturbations of a source by independent determinations of the FM and AM modulation effects without specific determination of any correlation between the presumed AM and FM modulating video functions. Figure 1 shows the fundamental measuring principles in block diagram form and these are explained in the caption. Figures 5 and 6 are typical presentations of data obtained by these techniques.

II. Oscillator Noise. Papers by Edson (1) and Mullen (2) provide a sound basis for analysis of the effects of thermal and shot noise perturbations of oscillators. In the simple model of Figure 2, we have a negative conductance whose effective value varies with the amplitude of oscillation. A steady state is achieved at an amplitude level such that its value is the negative of the load conductance G_L. Perturbation is induced by shot noise current of mean-square value $\gamma^2 2eI_o$ per Hz of bandwidth. (γ^2 is a fudge-factor to allow for unknown smoothing or enhancement effects.) A theoretical relation is given in the figure for AM sideband signal-to-noise ratio for components within a small band ΔB separated from the carrier by the video frequency f_v (or ω_v). The AM spectral distribution is that of a simple resonance. For the optimum load conductance for maximum power $\Delta P/\Delta G_L = 0$, giving $G_1 = 2G_L$. This expression is readily derived from consideration of the rate of decay of an impulsive (shot) disturbance at the peak of the voltage swing which causes an amplitude transient in phase with the steady-state wave. Individual impulsive disturbances in quadrature with the steady-state wave cause phase-steps which may be considered to advance or retard the "setting of the clock". Any single such impulse results in a finite step phase change which persists. Consideration of the statistics of shot noise yields the other equation of Figure 2. The frequency deviation effect of the FM noise sidebands in a small band ΔB is seen to have a white "spectrum" independent of the distance from the carrier.

The equations of Figure 2 apply for the effects of simple shot noise only. Measurements usually show excess AM and FM deviation at slower rates whose sidebands are less than one kc from the carrier. These are believed to arise through other modulation processes; (1) from microphonics, (2) from ac hum and similar interference modulating the effective tank susceptance, and (3) through 1/f or flicker noise which may cause fluctuations in junction capacitances or electronic susceptance effects related to "frequency pushing". These effects have not been analyzed.

III. Amplifier Effects. When a low-level oscillator is used, followed by power amplification, the noise figure of this amplifier is important. Its effects appear in the FM spectrum as a rising characteristic of deviation at increasing distance from the carrier. Analysis here is based upon standard FM theory for a white spectrum of added noise. Figure 4 shows the appropriate equation for this effect. AM noise from the amplifier has an effect as shown in Figure 3.

IV. Frequency Multiplication Effects. FM noise deviation is enhanced in direct proportion to the frequency multiplication involved. This degrades the signal-to-noise ratio for FM sidebands in the factor N^2.

V. Effects of Compression and Expansion. Amplitude nonlinearity is common in power amplification and frequency multiplication. The factor K_e may be defined as $K_e = (dP_o/dP_i)/(P_o/P_i)$ where P_o and P_i are the input and output powers of the networks involved. Its effects on AM noise are included in Figure 3.

VI. Reduction of FM Noise in Crystal Oscillators. A technique has been found for improving crystal oscillator FM noise by using a quartz crystal with an external shunt inductor which resonates with the wafer capacitance. In the video range of 1 kc/s to 10 kc/s, FM noise deviation at X-band has been reduced to < 0.2 c/s rms in a 100 c/s bandwidth "window".

VII. Experimental Results. Measurements of the AM noise spectra of some typical X-band sources are shown in Figure 5. At video frequencies below approximately 10 kc, all of these exhibit behavior approximating a 1/f character. The noise spectra of a Microwave Associates' magnetron (stabilized with an external passive cavity) and that of a Varian klystron have also been measured and are plotted for purposes of comparison.

Measurements of the rms FM noise deviation spectra taken on the same sources are shown in Figure 6. Here again, the spectra show behavior which is approximately 1/f at low video frequencies. It is believed that the noise in the solid-state source below 5 kc/s arises in the oscillator. The minimum value has the same order of magnitude which we can expect from shot noise contributions indicated by the equations of Figure 2. Below 5 kc/s, 1/f "frequency pushing" effects are evident. Above 5 kc/s, the noise levels approximate the expected behavior from additive "white" noise arising in the low-level amplifier stage. This rising characteristic with frequency is expected from standard FM theory.

References.

1. Edson, W. A., "Noise in Oscillators", Proc. IRE, V48, No. 8, p. 1454, August 1960.
2. Mullen, J. A., "Background Noise in Nonlinear Oscillators", Proc. IRE, V48, No. 8, p. 1467, August 1960.

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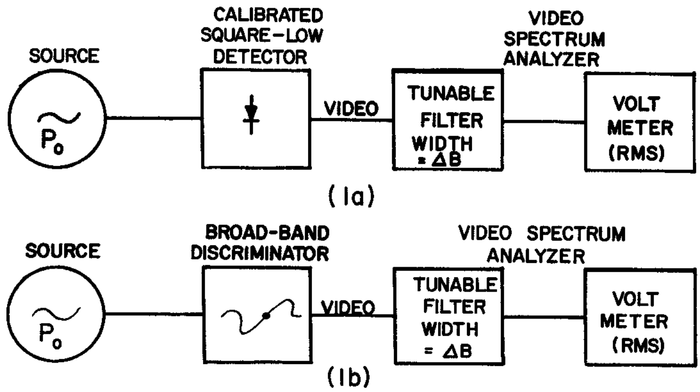
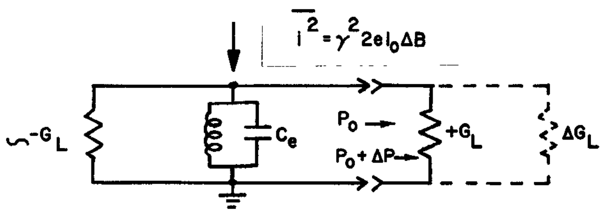


Figure 1. Block diagrams illustrating the basic noise measuring techniques for AM and FM fluctuations of oscillators and other sources. The modulation is detected and converted to video signals and their spectra are measured with a wave analyzer.



$$G_l = \frac{2G_L}{1 - \frac{\Delta P}{\Delta G_L}\frac{G_L}{P_0}}$$

$$\frac{(P_N)_{AM}}{P_0} = \frac{\gamma^2 2eI_0\Delta B}{2P_0G_L\left[\left(\frac{G_l}{G_L}\right)^2 + \left(\frac{2C_e\omega_v}{G_L}\right)^2\right]}$$

$$\overline{(DEV)^2} = \frac{\gamma^2 2eI_0\Delta B G_L}{16\pi^2 P_0 C_e^2}\ (cps)^2$$

Figure 2. Theoretical noise parameters for a simple negative-conductance oscillator perturbed by shot noise. The conductance G_l is determined by nonlinear saturation effects and is equal to $2G_L$ for optimum power loading. Theoretically, the frequency deviation shows a white video spectrum when detected with a wideband discriminator.

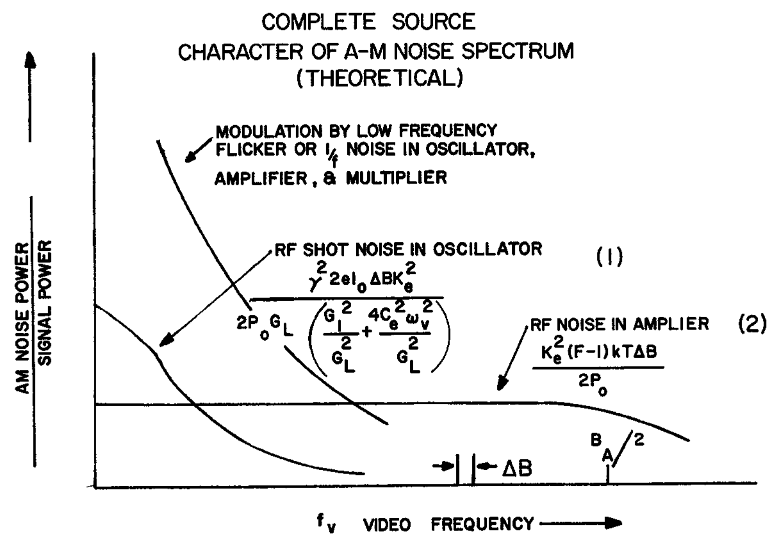


Figure 3. Curves showing the contributions to the AM noise expected from various noise sources in a harmonic generator device which includes a low-level oscillator, a power amplifier, and a varactor chain. Theoretical expressions are given for the oscillator and amplifier contributions due to shot noise. 1/f modulation effects are not analyzed but normally dominate.

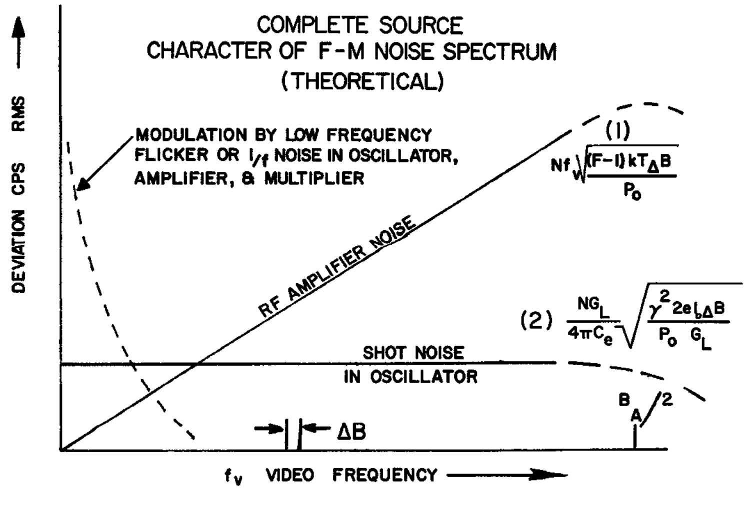


Figure 4. Curves showing the contributions to FM noise fluctuations to be expected from various noise sources in a varactor harmonic generator source. The 1/f characteristic at low video frequencies has not been analyzed.

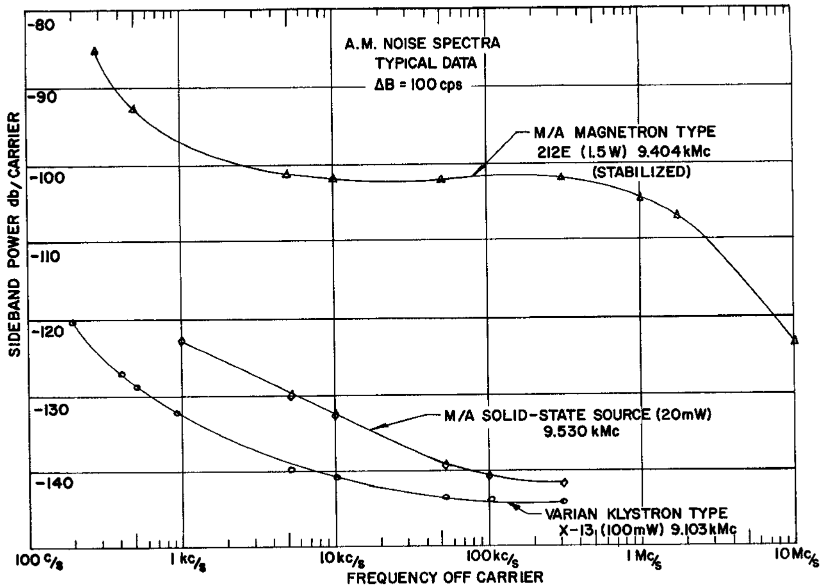


Figure 5. Some typical measurements of AM noise in various types of microwave sources.

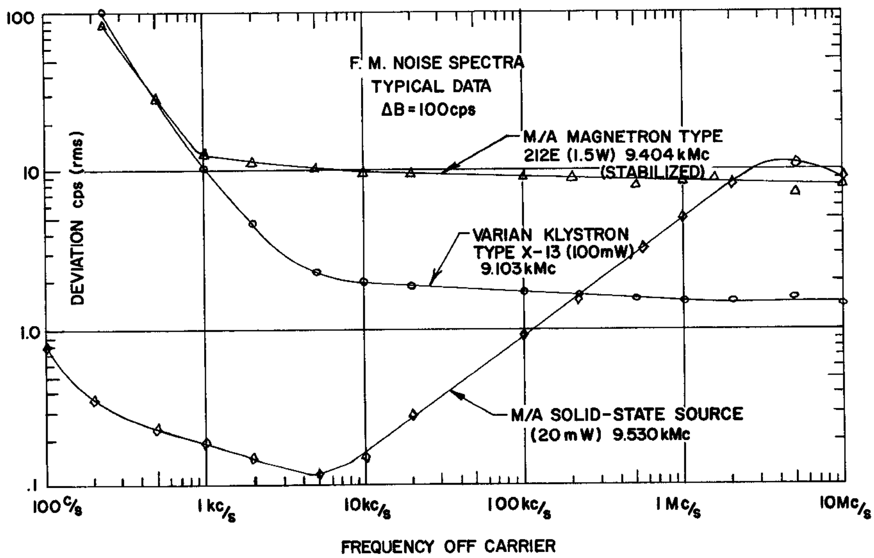


Figure 6. Some typical measurements of FM noise deviation in several types of sources.