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THE DEGRADATION OF SIGNAL-TO-NOISE RATIOS IN A CRYSTAL MIXER

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I. INTRODUCTION

In the design of mixer circuits for use in microwave receivers the reduction of mixer noise is of prime importance. Any noise contributed to the incoming signal by the mixer will result in a degradation of the signal-to-noise ratio at the mixer output which will in turn cause an increase in the noise figure of the receiver. Thus, any reduction in the noise figure of the mixer will result in increased usable output from the receiver.

The problem arises as to how much degradation in the signal-to-noise ratio can be expected from passing the signal-to-noise ratio through a mixer. Previous work in this area by S. O. Rice[1] has led to the prediction of theoretical average degradation of the input signal-to-nose ratio of 3 db. Previous work by other investigators[2] has also led to the development of an expression for the minimum noise figure to be expected from mixer circuits employing vacuum diodes. Most diode mixers used in microwave receivers today employ crystals as the nonlinear element rather than vacuum diodes. A study was undertaken by personnel of the Auburn Research Foundation to determine the minimum degradation in the input signal-to-noise ratio to be expected from a

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1. Rice, S. O., "Mathematical Analysis of Random Noise", Part IV <u>Bell System Technical Journal</u>, Vol. 24, 1945.

2. Van Voorhis, S. N., <u>Microwave Receivers</u>, M.I.T. Radiation Laboratory Series, Vol. 23, p. 143.

crystal mixer. The initial object of this study was to obtain a quick estimate of this degradation from a simple measurement. It was later decided, however, to do more extensive research on this subject.

Much of the time spent in this study was devoted to the development of a valid technique for measuring the minimum noise figure of a crystal diode mixer. It was the aim of the investigators that this technique be applicable to any type of crystal mixer and not to just one in particular.

After several months of work it was mutually decided to collect the information obtained from this investigation and submit in report form; the report to contain both positive and negative data.

This report is a discussion of the techniques applied to the solution of the problem.

II. DISCUSSION OF APPROACHES TO THE PROBLEM

Two separate techniques were employed in an effort to obtain experimental data on the noise figure of a crystal mixer. The first technique utilizes a carrier signal modulated with noise while the second utilizes a carrier signal with added noise as the input to the receiver.

A block diagram of the first measurement technique is shown in Figure 1. A 22 kc/s C-W signal is summed with 22 kc/s white noise from a random noise generator. The resultant signal is used to modulate an 18.6 Mc/s r-f carrier signal. This constitutes the signal input to the receiver which consists of the mixer, a high gain i-f amplifier, a detector, a bandpass filter an a true rms voltmeter. The signal input to the mixer S_i, and the noise input to the mixer N_i, are measured. Substitution of these values into the equation

$$\left(\frac{S}{N}\right)_{input} = \frac{S_i}{N_i} \qquad (1)$$

yields the signal-to-noise ratio at the mixer input terminals. In the same manner the signal-to-noise ratio at the output of the receiver is found by using the equation

$$\frac{S}{N}_{output} = \frac{S_o}{N_o} \qquad (2)$$

where S_o and N_o are the respective signal and noise amplitudes at the

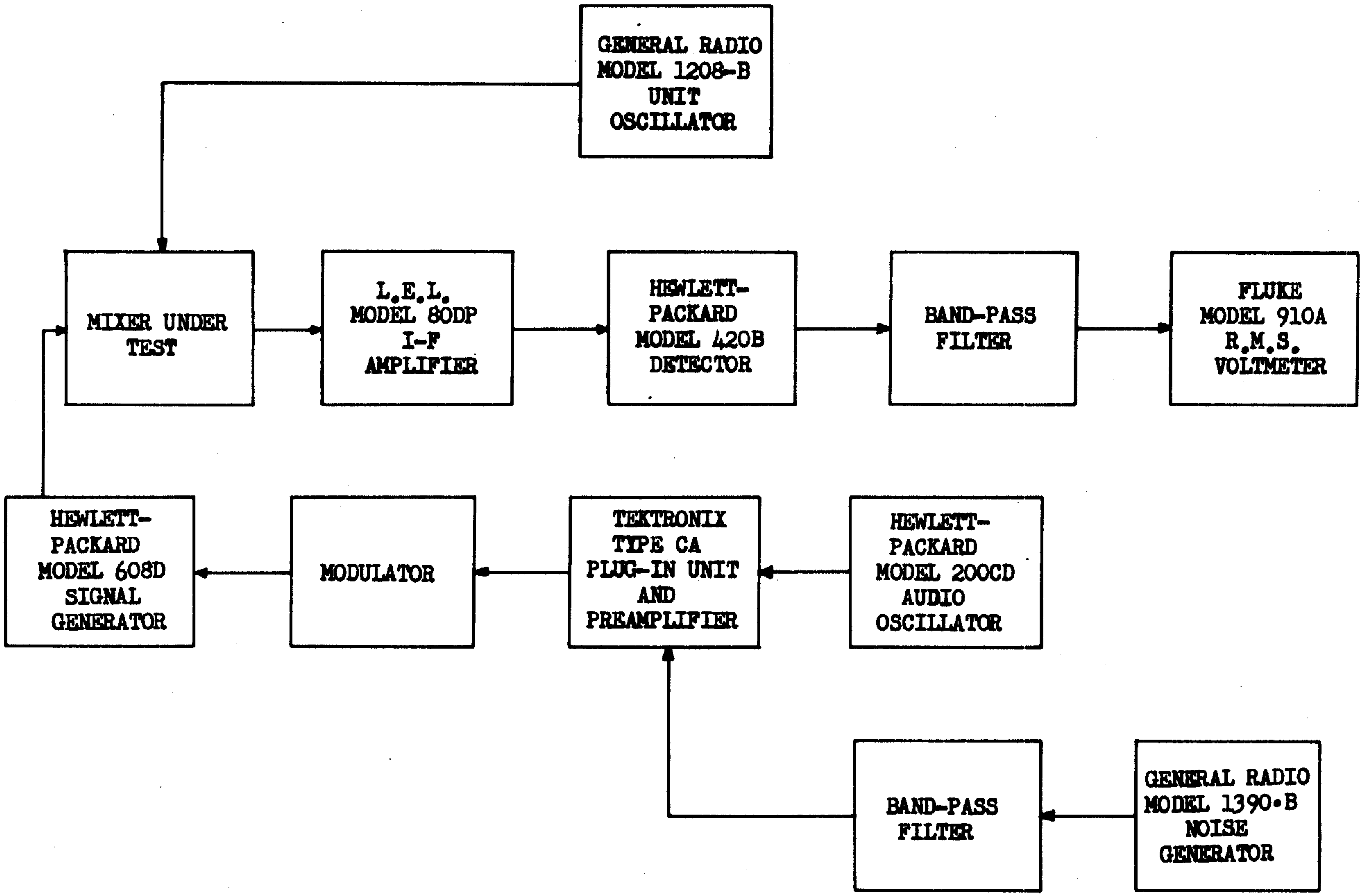

FIGURE 1: MEASURING SYSTEM USED TO DETERMINE NOISE FIGURE OF CRYSTAL MIXER.

output terminals of the receiver. The definition of noise figure together with results of equations (1) and (2) permit determination of the noise figure of the receiver from the relation

$$\text{N.F. receiver} = \frac{(\frac{S}{N})_{\text{input}}}{(\frac{S}{N})_{\text{output}}} . \tag{3}$$

The data thus obtained indicated that there existed either difficulty with the input-output bandwidths or difficulty with matching. This is evidenced by the signal-to-noise ratio at the output being consistantly higher than that at the input.

It was also found that equation (2) does not include the effect of intermodulation products, produced within the mixer as a result of the intermediate frequency beating with the signal noise components. A second technique, which circumvents these difficulties, was then proposed.

A block diagram of the second measurement technique is shown in Figure 2. The receiver consists of the mixer, a high gain i-f amplifier and a true rms voltmeter. The input signal to the receiver is obtained by linearly summing an 18.6 Mc/s C-W signal with band-limited random noise centered about 18.6 Mc/s. To correct the previous bandwidth problem and to avoid bandwidth corrections in the final data, the bandwidths observed at points B and C of Figure 2 are made equal. This is accomplished by connecting a sweep generator to point A of Figure 2 and adjusting the bandwidth observed at point B. The sweep generator is then connected to point B and the output bandwidth observed at point C of Figure 2 is adjusted. Because the input bandwidth has a very limited

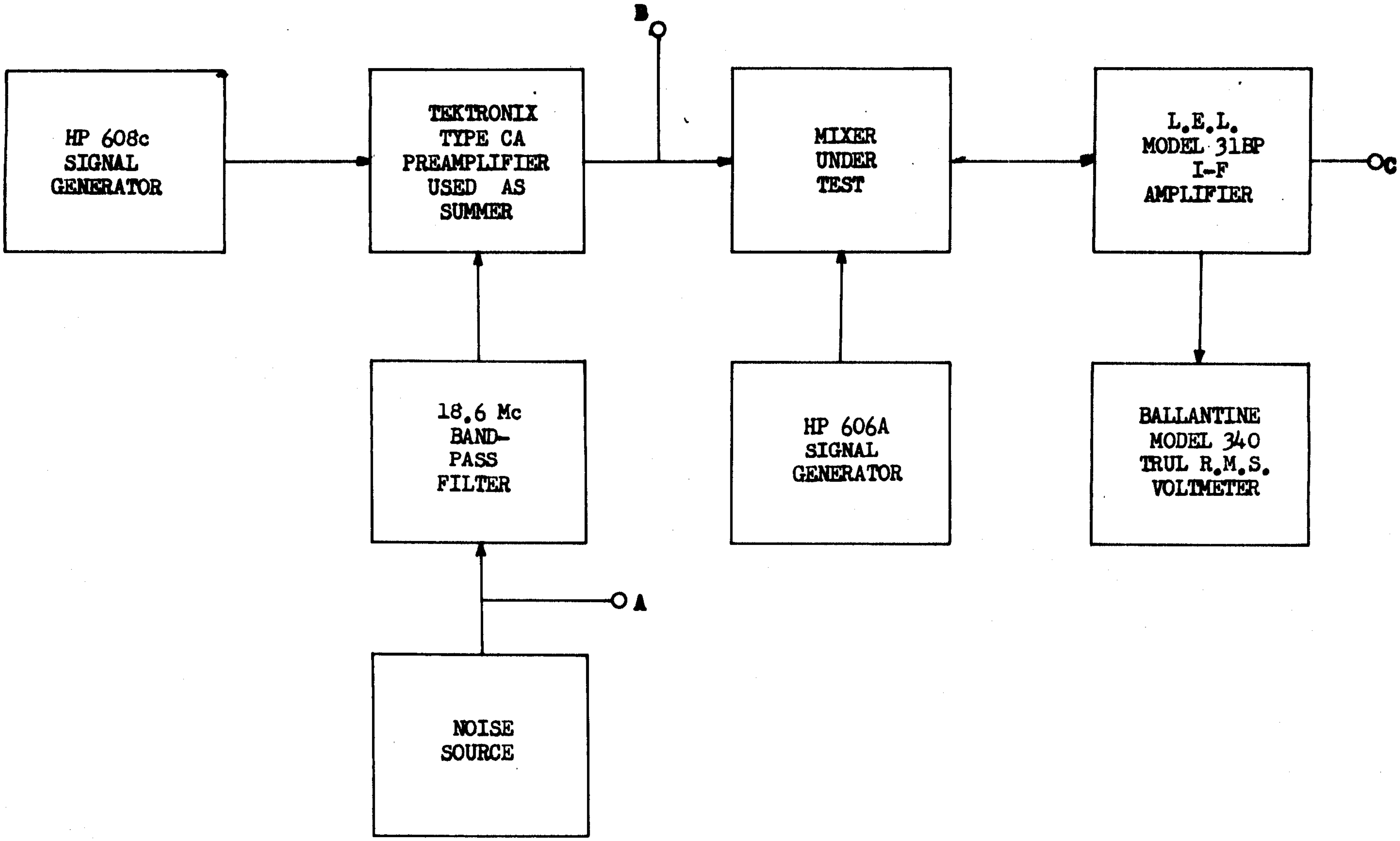

FIGURE 2: REVISED MEASURING SYSTEM USED TO DETERMINE NOISE FIGURE OF CRYSTAL MIXER.

range of adjustment, the output bandwidth is adjusted until it is approximately equal to the input bandwidth as shown in Figures 3 and 4. Each time the sweep generator connections are changed care must be taken to insure that the loading effects on the input and output circuits are not changed. The input signal S_i, and the input signal-plus-noise $(S + N)_i$ are measured. The input signal-to-noise ratio is then calculated from the equation

$$\left(\frac{S}{N}\right)_{input} = \frac{S_i}{(S + N)_i - S_i} \quad . \tag{4}$$

In like manner the output signal S_o, and the output signal-plus-noise $(S + N)_o$ are measured, and the output signal-to-noise ratio is computed from

$$\left(\frac{S}{N}\right)_{output} = \frac{S_o}{(S + N)_o - S_o} \quad . \tag{5}$$

The noise figure of the i-f amplifier is obtained with a Mega-Node Model 403A Noise Diode. In addition, the conversion loss of the mixer is measured under the conditions of operation for use in calculating the mixer noise figure.

The noise figure of the receiver is given by

$$F = F_m + L(F_{if} - 1) \tag{6}$$

where

F = the noise figure of the receiver

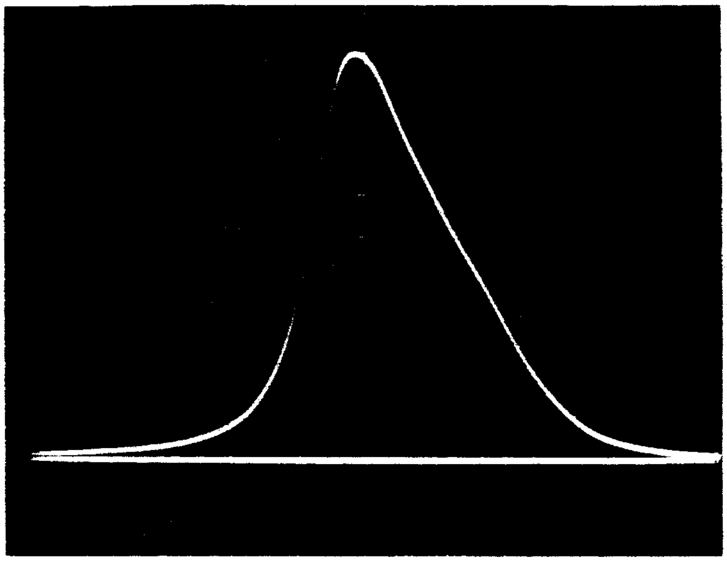

FIGURE 3
INPUT BANDPASS OF THE MEASUREMENT SYSTEM.

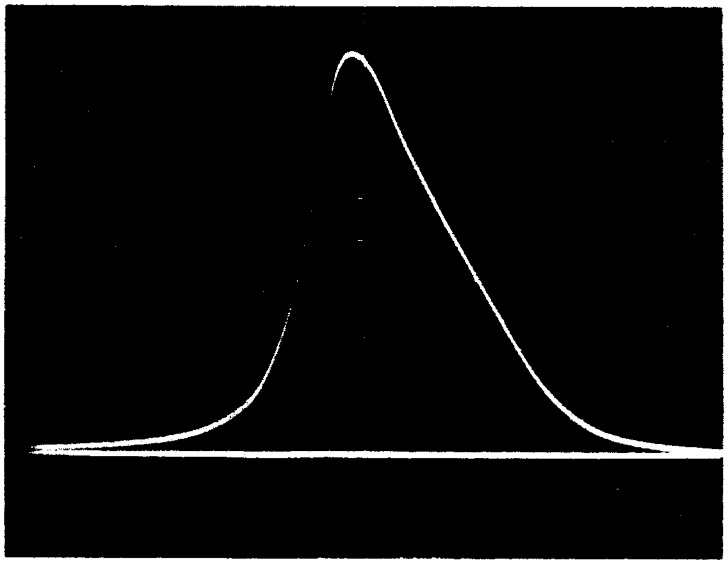

FIGURE 4
OUTPUT BANDPASS OF THE MEASUREMENT SYSTEM.

F_m = the noise figure of the mixer

L = the conversion loss of the mixer, and

F_{if} = the noise figure of the i-f amplifier.

The noise figure, F, of the receiver is obtained from equations (4) and (5); the mixer conversion loss L and amplifier noise figure F_{if} are measured quantities. Thus, from equation (6), the noise figure of the crystal mixer is given by

$$F_m = F - L(F_{if} - 1). \tag{7}$$

The results obtained using this second technique again appeared to be incorrect in that the measured noise figure of the receiver was less than that of various components within the receiver.

The second measurement technique was employed with both a single-ended mixer and a balanced mixer. Under the assumption that the local oscillator signal is noiseless it was found that the balanced mixer offers no imporvement in output signal-to-noise ratio over the single-ended mixer. If, however, the local oscillator is considered noisy, there would be noticeable improvement in the output signal-to-noise ratio from the balanced mixer.

III. CONSLUSION

The results of the mixer noise study are inconclusive. It is beleived, however, that the basic approach to the problem is a sound one involving the measurement of only a few, relatively simple quantities as shown in equation (6). The difficulty appears to be in the measurement of these quantities with sufficient accuracy. No ready solution has been found.

It is recommended that future work in this area be preceeded by an analytical investigation and a thorough study of receiver noise measurement techniques. This knowledge should indicate either a method for perfecting the measurement technique described herein, or another measurement technique having a greater expectation of success.