I-5. IMPROVED INTERMODULATION REJECTION IN MIXERS

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Intermodulation is one of the most serious forms of spurious response in superheterodyne receivers. This type of interference cannot be completely eliminated by narrow band filters. Major improvements in receiver performance can be made only by improving and making more effective use of the mixing element.

The strongest intermodulation output is generated when one interfering signal frequency is separated from the second harmonic of the other by the tuned frequency of the receiver. Intermodulation rejection is characterized quantitatively by the intermodulation ratio (IMR). The IMR is measured by first measuring the sensitivity of the mixer by recording the tuned frequency input level for a reference output level. The two interfering frequency levels are then adjusted to give the same reference output. The ratio of this input level to the sensitivity is the intermodulation ratio. The experiments described in this paper were performed with a local oscillator (L.O.) frequency of 250 MHz.

An earlier analysis[1] of the mixing process shows that the intermodulation response of exponential diodes is reduced 2 db for each db increase of L.O. power. Unfortunately, the sensitivity of conventional point contact mixer diodes is deteriorated by the use of high L.O. power, due to increased noise. However, hot carrier diodes are considerably quieter at high L.O. levels, and so increased L.O. power is expected on the basis of the theory to improve the rejection of intermodulation with an accompanying increase in dynamic range. This paper reports experimental verification of this theoretical prediction, and shows that the hot carrier diode has a definite advantage over the point contact diode in applications where intermodulation rejection is important.

The prediction of improved I.M. rejection for higher L.O. power was confirmed for powers up to 50 or 100 milliwatts. Above this level, the effect of nonlinear series resistance changes the v-i characteristic of the mixer, as shown in Figure 1, so that the theory is no longer valid. However, this same effect leads to greatly improved performance when the operating point is chosen to minimize higher order terms in the series expansion of the mixer v-i function. Similarly, improved performance was obtained by proper design of another mixing device, the space-charge-limited resistor (SCLR), a device similar to the space-charge-limited diode, which has received extensive treatment in the literature.[2] We have found that the SCLR closely obeys a current function of the form

$$i = k_1 V + k_2 V^2$$

where i and V are the current and voltage, respectively, k_1 and k_2 are constants. A small fourth-order term is also predicted due to nonlinear mobility effects; no third-order term is predicted in the approximate analysis. The theory has been quantitatively verified for devices prepared in this laboratory. The absence of significant high order terms in the current function for the SCLR is mainly responsible for the reduction of intermodulation response that is observed for these devices.

The choice of operating point improves I.M. rejection in this device and in the hot carrier mixer. A bias voltage supply is used for the SCLR, while a resistor controls the bias for the hot carrier.

Intermodulation can be further reduced by the use of the two mixer elements in a balanced mixer arrangement. For hot carrier diodes the measured IMR was about 100 db in this configuration. For preliminary models of the SCLR, the I.M. response to + 5 dbm inputs could be reduced below the noise level. However, the sensitivity of these devices is about 20 db poorer than that of hot carrier diodes. Improved models are expected to close this gap.

In order to explain the fact that balanced mixer operation produces a much larger reduction of I.M. than can be obtained from a single-ended mixer, we must also conjecture that the coefficient of one or more of the expansion terms in question can be reversed in sign, by proper adjustment of the bias on both mixers. This situation produces a cancellation of the corresponding I.M. component in the balanced mixer. In addition, the bias points for the two mixers must each null or minimize another even order term. Figure 2 shows qualitatively how the two lowest order I.M. producing coefficients might vary with bias for these conditions to be met. Referring to Figure 2, bias points V_1, V_2, and V_3 could produce I.M. reduction in single-ended mixer operation, since they all minimize one of the even-order coefficients. In balanced mixer operation, selection of bias points V_1, and V_2 provides both minimization of k_4, the coefficient of the fourth-order term, and cancellation of the I.M. response due to k_6, the coefficient of the sixth-order term. The I.M. response is quite sensitive to bias voltage, so that the adjustment is quite critical.

It will now be shown that some current function f(v) can actually produce the sort of behavior depicted in Figure 2. We could postulate that k_6 is a linear function of bias V. This is the simplest function for k_6 that can satisfy our requirements. However, this choice does not explain the experimental results, and a slightly more complicated form must be used. The choice of a quadratic function for k_6 turns out to be satisfactory. This leads to a function with expansion coefficients which exhibit the desired behavior shown in Figure 2. Figure 3 shows the function compared to an exponential function. The departure from exponential behavior is similar to the departure of the measured current response in Figure 1.

The desired mixer response is mainly determined by the second order coefficient. This coefficient is relatively constant in the function in Figure 3, so that the mixer sensitivity would not be seriously degraded by adjusting bias for optimum I.M. rejection. In practice, the sensitivity was degraded less than 3 db when the bias was adjusted to minimize IMR.

1 L. Becker and R.L. Ernst; Nonlinear Admittance Mixers, RCA Review, December 1964, p. 662.

2 See for example G.T. Wright, Transit Time Effects in the Space-Charge-Limited Silicon Microwave Diode, Solid State Electronics, Vol. 9 No. 1 Jan. 1966, pp 1-6, and references contained therein.

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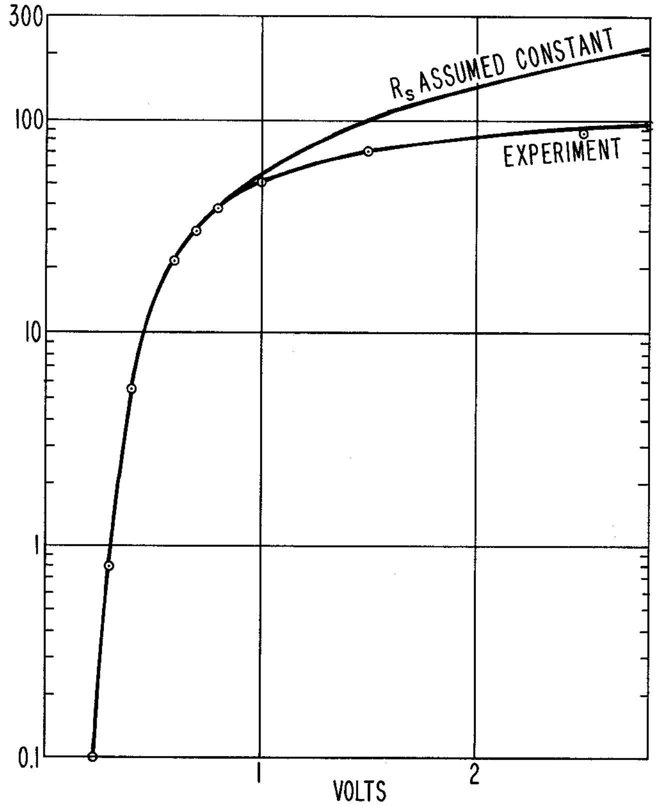

Figure 1. Current response of a Hot Carrier Diode

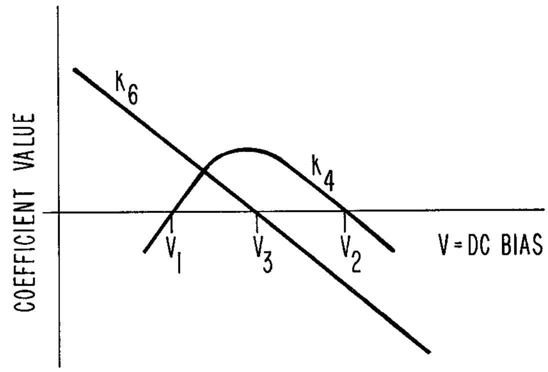

Figure 2. Desired variation of coefficient values with dc bias. This qualitative behavior is necessary to explain the IM reduction in single-ended mixer operation, and IM cancellation and reduction in balanced mixer operation.

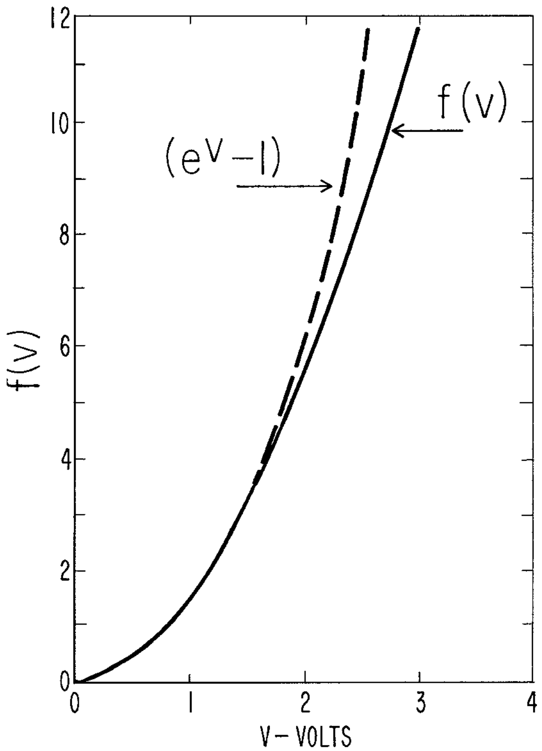

Figure 3. Current function f (V) which gives the desired behavior of coefficients. Exponential current function shown for comparison.