II. SOLID-STATE MICROWAVE ELECTRONICS*

Academic and Research Staff

Prof. P. L. Penfield, Jr.
Prof. D. H. Steinbrecher

Graduate Students

E. L. Caples
A. Chu
R. H. S. Kwong
D. F. Peterson
H. Po

A. INTERMODULATION DISTORTION IN AVALANCHE DIODE AMPLIFIERS

1. Introduction

One method of obtaining information about nonlinearities in an amplifier is through intermodulation distortion analysis. A two-tone signal is applied to the amplifier and mixes in the nonlinearity to produce odd-order distortion terms in the output spectrum. The manner in which these distortion products depend on the input signal strength gives information about the nature and degree of the nonlinearity.

In treating the avalanche diode amplifier we first present odd-order distortion data taken on an actual amplifier using a diode whose incremental impedance is known from measurements. Then, using a proposed nonlinear model for the diode, the distortion products are calculated and compared with the measured products.

2. Experimental Determination of Intercepts and Gain Compression

a. Experiment

The odd-order intermodulation distortion products were measured with the use of the test arrangement shown in Fig. II-1. The broadband balanced mixer was used to convert the signals down to around 50 mHz where they could be closely resolved on a low-frequency spectrum analyzer. The frequency difference of the input signals was kept between 1 mHz and 2 mHz to make sure the frequencies of the odd-order distortion products were well within the bandwidth of the amplifier.

b. Measured Distortion and Gain Compression

Data taken on an amplifier with the following parameters is shown in Fig. II-2: amplifier gain 13.6 dB; amplifier bandwidth 125 mHz; center frequency 9.67 GHz; and DC bias current 23A. The gain compression curve in Fig. II-2 was measured at

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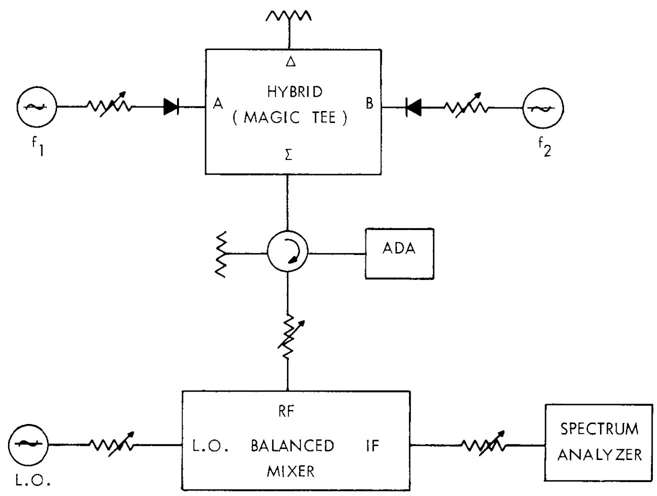

Fig. II-1. Test arrangement for measuring intermodulation distortion.

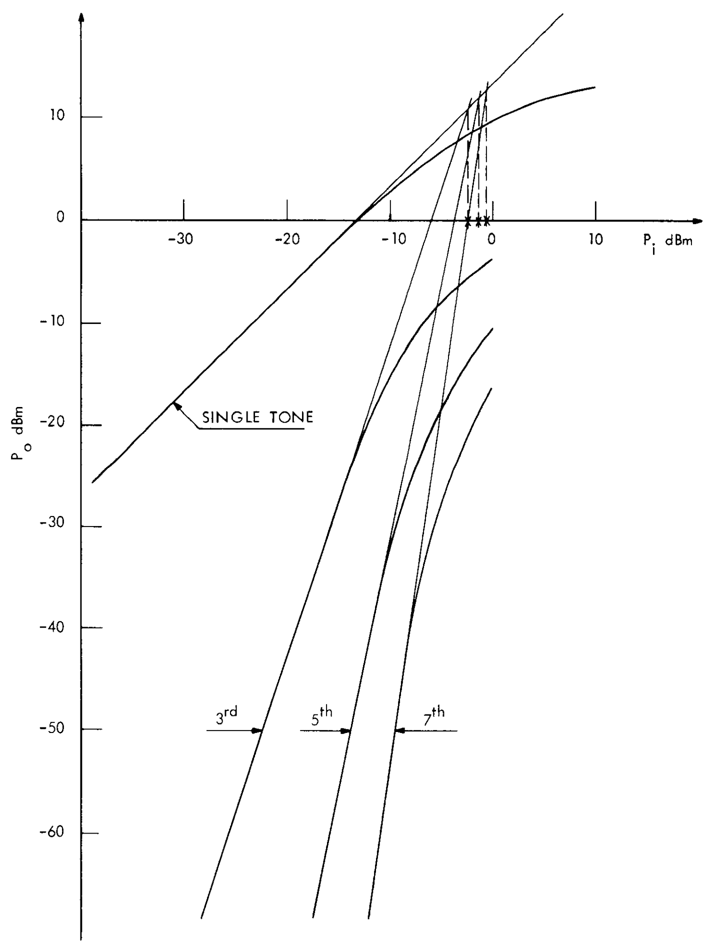

Fig. II-2. Measured intermodulation distortion products and gain compression of the amplifier.

9.67 GHz using a single signal.

The n^{th} odd-order intercept at the input of the amplifier is defined as that value of input power at which the power in the n^{th} order distortion products at the output is equal to the power in the two-tone at the output if these powers were to continue to increase at their low-level rate. In Fig. II-2 these intercepts are found graphically by extending the behavior of the distortion products at low input power. For this amplifier, the first three intercepts are $I_3 = -2.5$ dBm, $I_5 = -1.5$ dBm, and $I_7 = -0.75$ dBm.

The slopes of the $P_3(P_i)$ and $P_5(P_i)$ curves are very close to 3 and 5, respectively, where P_3 and P_5 are the powers in the third- and fifth-order products. The slope of the $P_7(P_i)$ curve was drawn at 7, but only a few data points were available.

These measured intercepts will be compared with those calculated for the same amplifier.

3. Calculation of Intercepts and Gain Compression

a. Nonlinear Model for the Avalanche Diode

The calculations are based on the circuit shown in Fig. II-3, where the parasitic series resistance is included. The inductive nonlinearity can be obtained theoretically[1] or semiempirically by extending measured results that show that the incremental inductance is inversely proportional to the DC current I_o.[2] The controlled current source, i_G, is caused physically by carrier drift in the diode and can be approximated incrementally by a negative conductance, $-G$, which is proportional to carrier drift

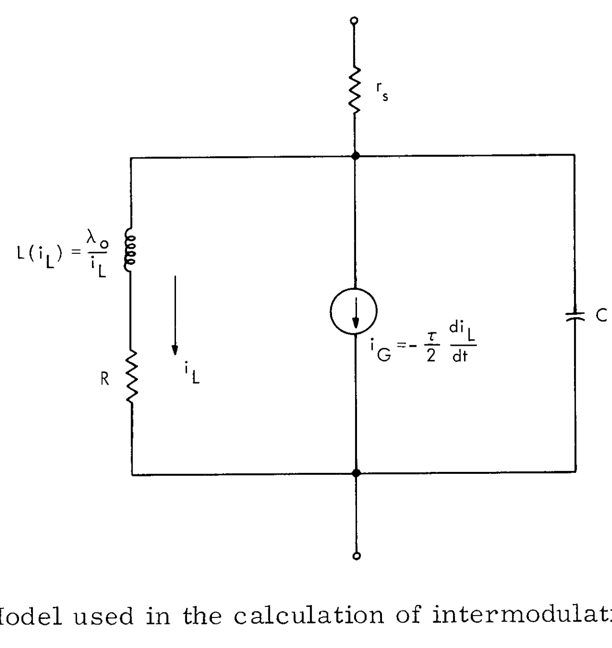

Fig. II-3. Model used in the calculation of intermodulation distortion.

time τ, as $G = \tau I_o/2\lambda_o$. Since this conductance is the quantity available from incremental measurements, we have for i_G in terms of measured parameters,

$$i_G = -LG \frac{di_L}{dt}, \tag{1}$$

where $L = \lambda_o/I_o$.

b. Intercept and Gain Compression Formulas in Terms of Diode Parameters

Using the circuit model of Fig. II-3, the n^{th} odd-order intercept at the input of the amplifier is calculated to be

$$I_{ni} = \frac{I_o^2}{4} \left[\frac{2G_d\left|R+j\omega_1L+\beta r_s\right|^2}{\rho^2 - 1}\right]^{\frac{n+1}{n-1}} \left[\frac{\rho}{\omega_1 L a_n \alpha}\right]^{\frac{2}{n-1}} \qquad n \text{ odd} \neq 1, \tag{2}$$

where $\rho > 1$ is the magnitude of the amplifier reflection coefficient, G_d is the small-signal diode (including r_s) conductance, and

$$\beta = 1 - j\omega LG + j\omega c(R+j\omega L) \tag{3}$$

$$\alpha = \left|1-j\omega LG\right| \tag{4}$$

$$a_n = \frac{(n-1)!}{2^{n-1}\left(\frac{n+1}{2}\right)!\left(\frac{n-1}{2}\right)!} \qquad n \text{ odd} \neq 1. \tag{5}$$

Equation 2 was derived under the assumption that the frequency difference $\omega_2 - \omega_1 = \Delta\omega$ is such that

$$n\Delta\omega \ll \omega_1 \text{ or } \omega_2, \text{ n odd;} \tag{6}$$

consequently, $m\omega_1 - n\omega_2$, $|n-m| = 1$ was replaced by ω_1. The amplifier is also assumed to be "tuned" at ω_1.

Gain compression, which was calculated using a single-frequency input, can be expressed as

$$P_{in} = \frac{4\left|R+j\omega_1L+\beta r_s\right|^2 I_o^2 G_d}{(\rho_o-1)^2 (\rho(P_{in})+1)^2} (\rho_o-\rho(P_{in})), \tag{7}$$

where $\rho(P_{in})$ is the magnitude of the reflection coefficient as a function of P_{in}, and ρ_o is its small-signal value ($P_{in} \to 0$). Equation 7 is valid for values of ρ such that

$$\rho_o > \rho > \frac{3\rho_o + 1}{\rho_o + 3}. \tag{8}$$

c. Calculations for the Diode Used in the Measurements

The measured small-signal parameters of the diode used in the intermod measurements are the following.

$\lambda_o = 1.04 \times 10^{-10}$ A-H

$R = 14.6\ \Omega$

$G = 0.065\ I_o\ \mho$

$C = 0.75$ pF

$r_s = 0.58\ \Omega$.

The first three intercepts calculated by using (2) with these parameters at frequency 9.67 GHz, bias $I_o = 23$ mA, and gain 4.8 of the experiment are then $I_{3i} = -3.46$ dBm,

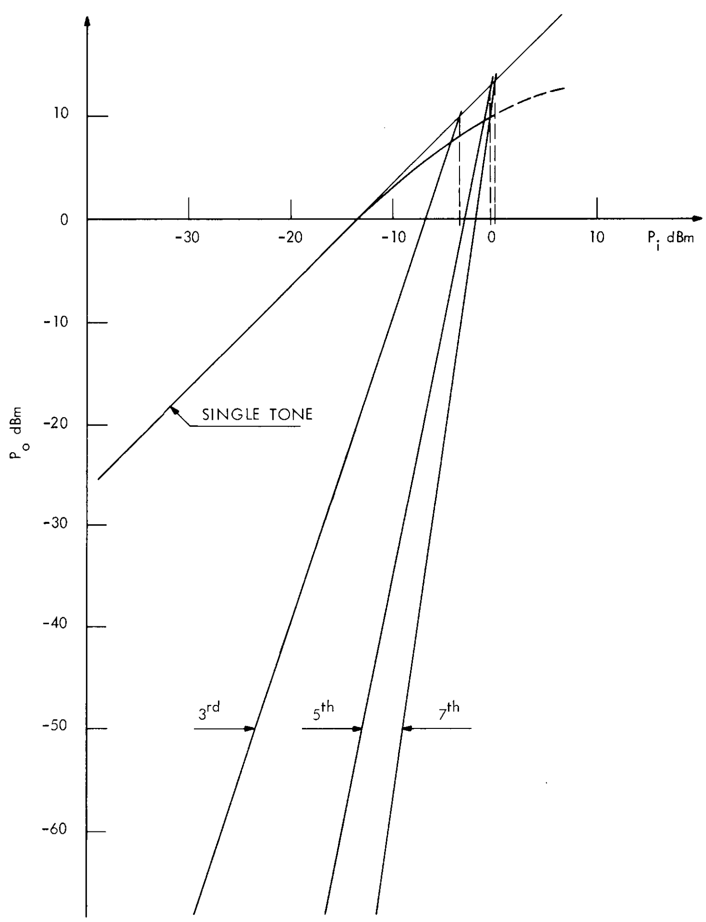

Fig. II-4. Calculated intermodulation distortion products and gain compression of the amplifier.

I_{5i} = -0.47 dBm, and I_{7i} = +0.017 dBm. These values are in good agreement with the measured values presented above.

The gain compression calculated from (7) is shown in Fig. II-4 for the given amplifier. The value of input power at which the power gain is compressed by 1 dB is calculated to be -7.1 dBm. This also compares well with the measured 1-dB compression point at -6.8 dBm.

The agreement between the measured and computed results indicates that the model used in the calculations is useful for predicting intermodulation distortion, and that the odd-order intercepts are available from the small-signal parameters of the diode.

D. F. Peterson

References

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2. D. H. Steinbrecher and D. F. Peterson, "Small-Signal Model with Frequency-Independent Elements for the Avalanche Region of a Microwave Negative-Resistance Diode," IEEE Trans., Vol. ED-17, No. 10, pp. 883-891, October 1970.