A Ku-BAND IMPATT AMPLIFIER WITH IMPROVED INTERMODULATION PRODUCTS

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Abstract

More than 40 dB 3rd order intermodulation product has been achieved in a 13 GHz band 2-stage IMPATT amplifier with 21 dBm output level and 11 dB gain, using diode bias current compensation and phase predistortion techniques. Theoretical calculations also verified the experimental data.

Introduction

Recently, IMPATT reflection type amplifiers have been put in practical applications such as in FM[1] or PCM communication and radar systems. But in the application to amplitude modulation systems such as TV or SSB-AM transmission systems[2], the intermodulation product is particularly important factor. Several authors reported[3] in detail the measured intermodulation products produced in an X-band IMPATT linear amplifier. The 3rd order IMP. commonly observed at high level operation in these IMPATT amplifiers is about 10 ~ 20 dB, which does not meet with the required specification for those AM systems.

In this paper, a new technique to improve the Intermodulation Products (IMP) produced in IMPATT amplifier is described, which utilizes a diode bias current compensation according to the signal input level of the amplifier.

A 13 GHz band IMPATT amplifier (small signal Gain= 7 dB) using this technique showed the 3rd order IMP of more than 35 dB within the input level up to 17 dBm (sum of the two equal amplitude input signal levels). In addition to this technique, a phase predistortion technique was applied to the UHF signal (which is up-converted to 13 GHz band) and more than 40 dB of 3rd IMP. was obtained, which enabled the amplifier to be used in TV transmission microwave systems.

Evaluation of Intermodulation Products

The amplifier mount has a coaxial-waveguide configuration[1]. A packaged Si-IMPATT diode is mounted on the center conductor of a coaxial line which is passed through the reduced height WR-62 waveguide. The breakdown voltage of the diode is about 62 volts and typical oscillating power is 600mW. Figure 1 shows typical characteristics of the 13 GHz band IMPATT amplifier, as a parameter of bias current Iop. At the 110mA and 77 volts-operating bias condition, this amplifier has a small signal gain of 8 dB, 1 dB gain compression output level of 22.5 dBm, 8 degree-relative phase shift at this output level and about 500 MHz 3 dB-bandwidth at 15 dBm-input level.

To obtain the intermodulation products produced in this IMPATT amplifier, the r.f. voltage dependency of the electronic admittance $\overline{Y}_D = -\overline{G}_D + j\overline{B}_D$ of the device were measured by the following simple procedure, where $\overline{B}_D$ includes the susceptance B_L of the load admittance Y_L (= $G_L + jB_L$), looking from the diode wafer. The normalized electronic admittance $\overline{y}_D$ (= $-\overline{g}_D + \overline{b}_D$) is denoted using a quadratic equation of $|u|$ as follows

$$\begin{aligned} \overline{g}_D &= \overline{G}_D/G_L = g_0 - g_1|u| - g_2|u|^2 \\ \overline{b}_D &= \overline{B}_D/B_L = b_0 + b_1|u| + b_2|u|^2 \\ u &= \sqrt{G_L}\, V_{rf}\, e^{j(\omega t+\varphi)} \end{aligned} \tag{1}$$

where u is instantaneous amplitude parameter, Vrf is the amplitude of the r.f. voltage applied to the device and g_0, g_1, g_2, b_0, b_1 and b_2 are the constant parameters of the equations at a fixed bias current.

The bias current dependencies of parameters g_0, g_1, g_2, b_0, b_1 and b_2 are shown in Figs. 2(a) and (b). These values are derived from both the measured linearity and phase shift characteristics of the amplifier.

The intermodulation products (IMPs.) can be calculated using $\overline{y}_D$, input level P_{in} and u as follows. When two signals (f_1 and f_2) are put into the amplifier, the envelope of input signals is slowly varying with the beat frequency $\Delta f = f_1 \sim f_2$. Therefore the r.f. amplitude $|u|$ at the device is also varied with the same beat frequency. When the beat frequency is much smaller than the bandwidth of the amplifier, then the instantaneous value of $|u|$ is calculated from the assumed sinusoidal input signal with the same amplitude as the input signals-envelope. And the relative phase difference between u and input signal is also determined with the same manner. The spectrum intensity of output signal is calculated from instantaneous value of u. The calculated results of the 3rd and 5th order IMPs are shown in Fig. 3 as a parameter of operating current, as well as the measured those values of this amplifier under the operating condition shown in Fig. 1.

In this case, two equal amplitude signals f_1 and f_2 ($\Delta f = f_1 \sim f_2$ = 5 MHz) are supplied to the input of the amplifier. The calculated IMPs closely coincided with the measured ones. But these values of the IMP. are too poor for AM transmission systems use.

The electronic admittance of IMPATT diode varies by the change of bias current as follows; the electronic conductance increases and susceptance decreases with the increase of the bias current as shown in Figs. 2. On the other hand, r.f. voltage dependencies of the electronic admittance have opposite tendencies. Therefore, by controlling bias current according to the input signal level, the variation of the electronic admittance due to the variation of r.f. input level can be compensated. Now the electronic admittance is approximated as the function of $|u|$ and bias current I_b. It fits our purpose of decreasing the intermodulation products to use the time dependent bias current as shown in eq. 3.

$$\begin{aligned} I_b &= I_{op} + k\sqrt{P_{in}}\cos 2pt \\ \overline{y}_D &= \overline{y}_D(|u|, I_b) \end{aligned} \tag{3}$$

where k is the positive constant to show the rate of compensation and $p = (\omega_2 - \omega_1)/2$.

The calculation of intermodulation products is done in the similar way as discussed above except using the time dependent electronic admittance $\overline{y}_D[|u|, I_b(t_o)]$ as shown in Fig. 4. 3rd order intermodulation products are decreased to 40 dB at 10 dBm input level with the compensation current amplitude of 8 mA for this input level.

Experimental Results of Bias Current Compensation

Figure 5 shows the basic block diagram of the bias current compensation circuit applied to the IMPATT amplifier. Very small amount of power of both input signals (f_1 and f_2) is taken out through a directional coupler and the envelope of the two signal waveform is detected by a diode detector. Then the detected signal is amplified by a video amplifier with a proper gain to give an optimum compensating bias current which is superposed on the fixed bias current of the IMPATT diode.

Experimental results of this bias current compensation applied to the 13 GHz IMPATT amplifier are shown in Fig. 6, as a parameter of the compensation current. The IMPATT amplifier has a small signal gain of 7 dB and −1 dB compression output level of 20 dBm. The frequency difference between the two signals with equal amplitude $\Delta f = f_1 \sim f_2$ is 1 MHz. In this experiment, input level of the detector and gain of the video amplifier were adjusted to give an optimum compensation at 17 dBm input level of the IMPATT amplifier. So, at the input level of 17 dBm, the improvement in the 3rd IMP attains to as much as 22 dB, but, at lower input level below 5 dBm, the improvement is very small because of the dynamic range limitation of the detector, if the gain of the video amplifier maintains constant. The compensation current was measured at the D. C. bias terminal of the IMPATT diode and represented by the peak to peak value of the detected current envelope of 1 MHz beat frequency.

In the application to Multi-channel TV transmission microwave system, the 3rd order IMP of more than 40 dB is required for the IMPATT amplifier. So, in addition to this bias current compensation technique, the phase predistortion circuit was applied to the UHF signal which is up-converted to 13 GHz band. To meet with this system requirement of the output power, 2-stage IMPATT amplifier was necessary to provide the output power of more than 21 dBm with the total gain of 11 dB. Resultant 3rd IMP of this system including the up-converter was more than 40 dB, that satisfied the specification of the TV transmission system.

Conclusion

Bias current compensation technique is suitable for improving the intermodulation products produced in IMPATT linear amplifiers. These amplifier will find further application fields in the amplitude modulation transmission systems.

Reference

1) H. Komizo, Y. Ito, H. Ashida and M. Shinoda, "A 0.5-W CW IMPATT Diode Amplifier for High-Capacity 11-GHz FM Radio-Relay Equipment", '72 ISSCC Digest of Technical Paper pp 36-37.

2) F. Ivanek, "Single-Sideband Amplitude Modulation in Microwave Transmission Systems", The Microwave Journal, April '72 pp 27-36.

3) R. J. Trew, N. A. Masnari and G. I. Haddad,"Intermodulation Characteristics of X-Band IMPATT Amplifiers", '72 G-MTT. pp 182-184.

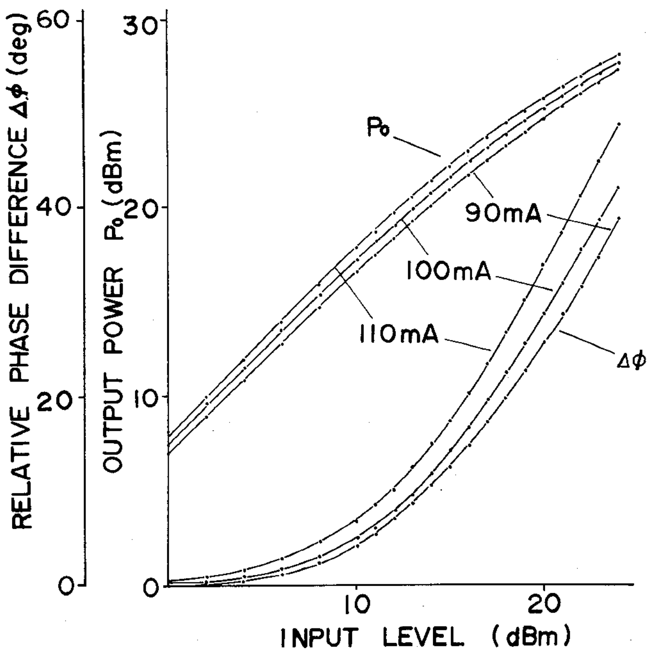

FIG. 1 TYPICAL CHARACTERISTICS OF OUTPUT POWER Po AND RELATIVE PHASE DIFFERENCE Δφ BETWEEN THE INPUT AND OUTPUT SIGNAL VS. INPUT LEVEL OF THE SINGLE STAGE AMPLIFIER AS A PARAMETER OF BIAS CURRENT Iop.

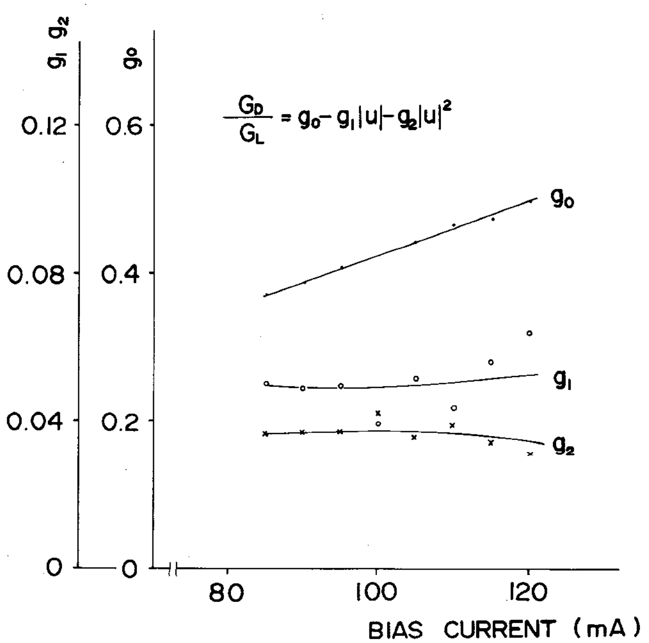

FIG. 2(a) BIAS CURRENT DEPENDENCY OF ELECTRONIC CONDUCTANCE

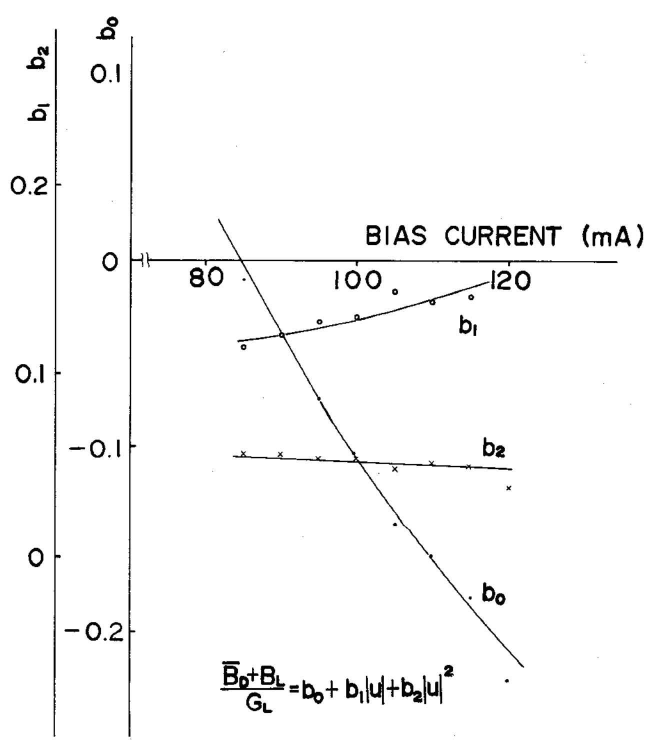

FIG. 2(b) BIAS CURRENT DEPENDENCY OF ELECTRONIC SUSCEPTANCE

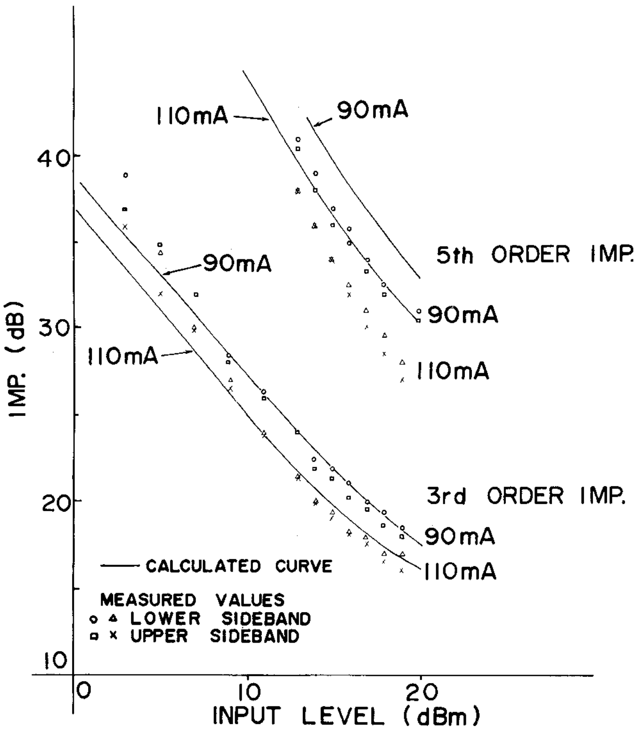

FIG. 3 MEASURED AND CALCULATED VALUES OF THE 3RD AND 5TH ORDER INTERMODULATION PRODUCTS IN THE SINGLE STAGE IMPATT AMPLIFIER. FIGURES SHOW BIAS CURRENT.

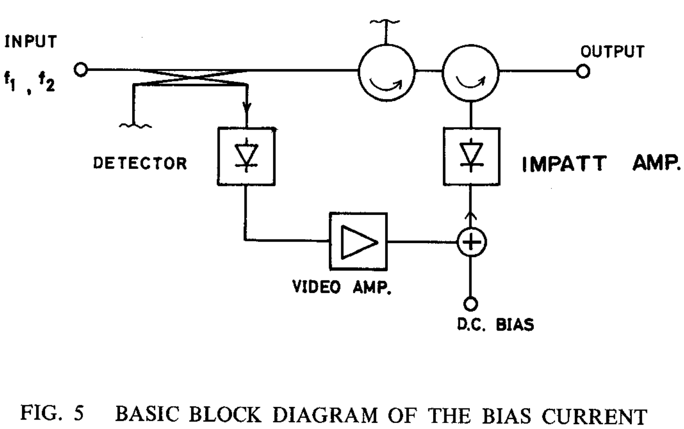

FIG. 5 BASIC BLOCK DIAGRAM OF THE BIAS CURRENT COMPENSATION CIRCUIT APPLIED TO THE IMPATT DIODE AMPLIFIER

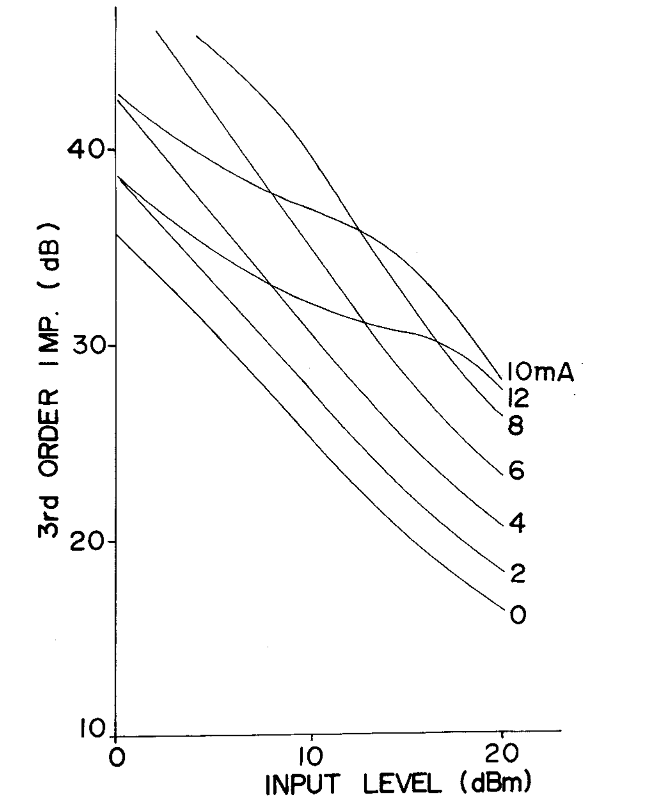

FIG. 4 CALCULATED 3RD ORDER INTERMODULATION PRODUCTS OF THE IMPATT AMPLIFIER USING THE BIAS CURRENT COMPENSATION, AS A PARAMETER OF THE COMPENSATION CURRENT. (FIGURES SHOW THE COMPENSATION CURRENT OF INPUT POWER = 10 dBm.)

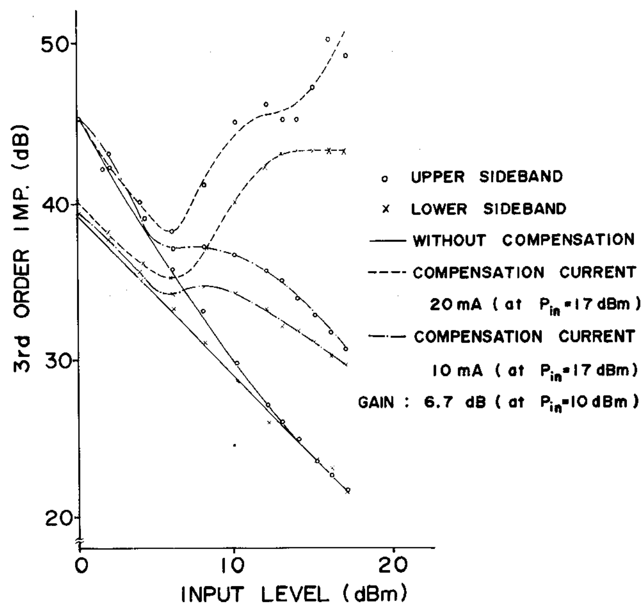

FIG. 6 MEASURED 3RD ORDER INTERMODULATION PRODUCTS OF THE SINGLE STAGE IMPATT AMPLIFIER USING THE BIAS CURRENT COMPENSATION, AS A PARAMETER OF THE COMPENSATION CURRENT.