INTERMODULATION DISTORTION BEHAVIOR OF GaAs POWER FETS

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ABSTRACT

The 4 GHz intermodulation distortion (IMD) behavior of several power GaAs FETs from different manufacturers is studied. The two-tone IMD and AM to PM conversion is a function of the source and load impedances. The IMD is not "well-behaved" in general (3:1 IMD slope), and therefore the third-order intercept point is not valid in characterizing tnese power FET's. This data was applied in the design of a 2 watt 3.7-4.2 GHz linear amplifier. Its linearity performance is compared to that of a 2 GHz linear bipolar amplifier.

Introduction

Very little data is currently available on the linearity behavior of power GaAs FETs. Initial tests revealed several peculiarities of power FETs:

1. The IMD levels are sensitive to tuning.
2. The IMD is not "well-behaved"; i.e., for a 1 dB increase in input power the third order IMD does not, in general, increase 3 dB but may change from -5 to 15 dB.
3. Gain expansion is common and dependent on tuning.

These necessitate measurement of the gain and IMD levels as a function of output power level to accurately characterize device behavior.

Power amplifier linearity is often a major limiting factor in the design of radio systems that require linear amplitude response. The deviaton of power GaAs FETs from the "well behaved" IMD response has generated the need for accurate characterization of the linear properties of power GaAs FETs. Therefore a study was undertaken to characterise and compare some commercially available devices.

Device Distortion Measurements

Power FETs supplied by five manufacturers were analyzed under various tuning and bias conditions for IMD characteristics, AM-PM conversion, and gain saturation. The test setups use slide-screw tuners for tuning the device input and output, and all biasing was done with constant voltages on the drain and gate. All tests were done at 4.0 GHz. IMD tests were done with a variable power two-tone input signal having IMD lower than -60 dB; AM-PM conversion tests were done with the same setup except a network analyzer sampled the input and output phase, using a CW signal.

The gate tuning has little effect on the IMD or power characteristics, but the drain tuning can be optimized for maximum small signal gain (SSG), maximum large-signal gain (LSG), or a compromise of gain for improved IMD performance (G+I). Moving the load impedance from the optimum power point toward IMD optima on the constant power contours results in various compromises between gain and IMD [1]. Note that this tuning sensitivity makes consistent IMD vs power over a frequency band difficult to achieve. Figure 1 shows the source and load impedances for the three tuning conditions for a typical case. The "G+I" tuning is not unique, but rather one possible compromise of gain for improved IMD. Tuning the drain for maximum power or best IMD seems to adjust one non-linearity of the device to cancel another. The cancellation is greatest near one powerlevel, then quickly deteriorates

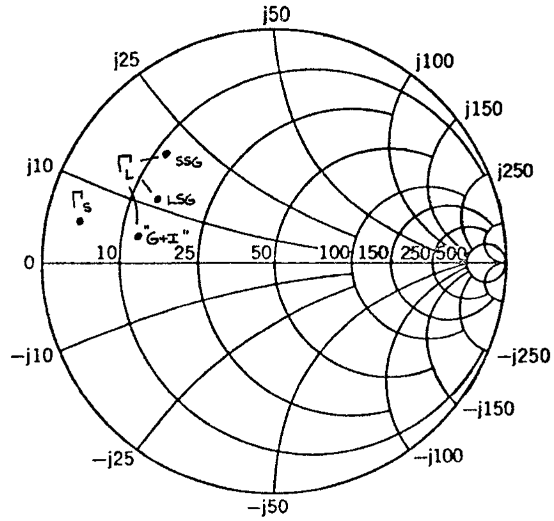

Figure 1: Source and Load Impedances of a Typical Device for Maximum Small Signal Gain, Large-Signal Gain, and Gain-IMD Compromise

at higher powers. In figure 2 the two-tone output power, third- and fifth-order IMD, AM-PM conversion, and drain current are plotted as a function of input power for a typical case. The IMD is of course dependent on biasing, and the cases shown here use the manufacturers' recommended drain voltages at about .5 Idss. With constant-voltage biasing the drain current changes with input power and tuning (Figure 2 is a typical case). The optimum IMD tuning usually has the worst efficiency for a given gain. Other interesting IMD characteristics are possible with different biasing, such as a constant third-order IMD at -26 dB from +26 to +31 dBm output. No IMD dependence on the frequency separation of the two test tones was observed for tone separations between 10 kHz and 20 MHz. A test for sensitivity to harmonic impedances was done with a line stretcher and fundamental filter. No measurable effect was seen at power levels up to about 1 dB compressed. Figure 3 compares the performance of FETs from the different manufacturers with each device tuned for maximum large-signal gain. Plotting the IMD as a function of output power eases comparison at a given output power.

Figure 2 is the normal plot of IMD levels vs input power which is used to graphically predict the third-order intercept point. For the third-order intercept to have any meaning, the IMD power must rise as the cube of the input power (3:1 on a dB scale) for powers less than the 1 dB gain compression power. The IMD vs power of smaller FET's (less than about 100 mW)

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often follows this 3:1 slope closely. Clearly the third-order intercept point is of dubious value in characterizing these power FET's or amplifiers built with these devices. The concept of a third-order intercept point derives from the modeling of the non-linearity as a power series or Volterra series of only three terms, which implies that the third-order distortion power will always rise as the cube of the input power [2,3,4]. If higher-order terms are included in the series, the behavior of these devices can be modeled. However, the complexity necessary in such a model probably wouldn't contribute either to intuitive grasp or to simple numbers like an intercept point for specifying linearity. The 1 dB gain compression point (GCP) with a two-tone signal was about 1.6 dB lower than with a CW signal for all the devices when tuned for maximum power. All the devices tested exhibited gain expansion to some degree, though usually only when tuned near the region where gain is being traded for better IMD. The typical expansion is .2 dB, though as much as 1.2 db of expansion was observed. For such a device or amplifier, the 1 dB GCP is a similarly ill-suited specification.

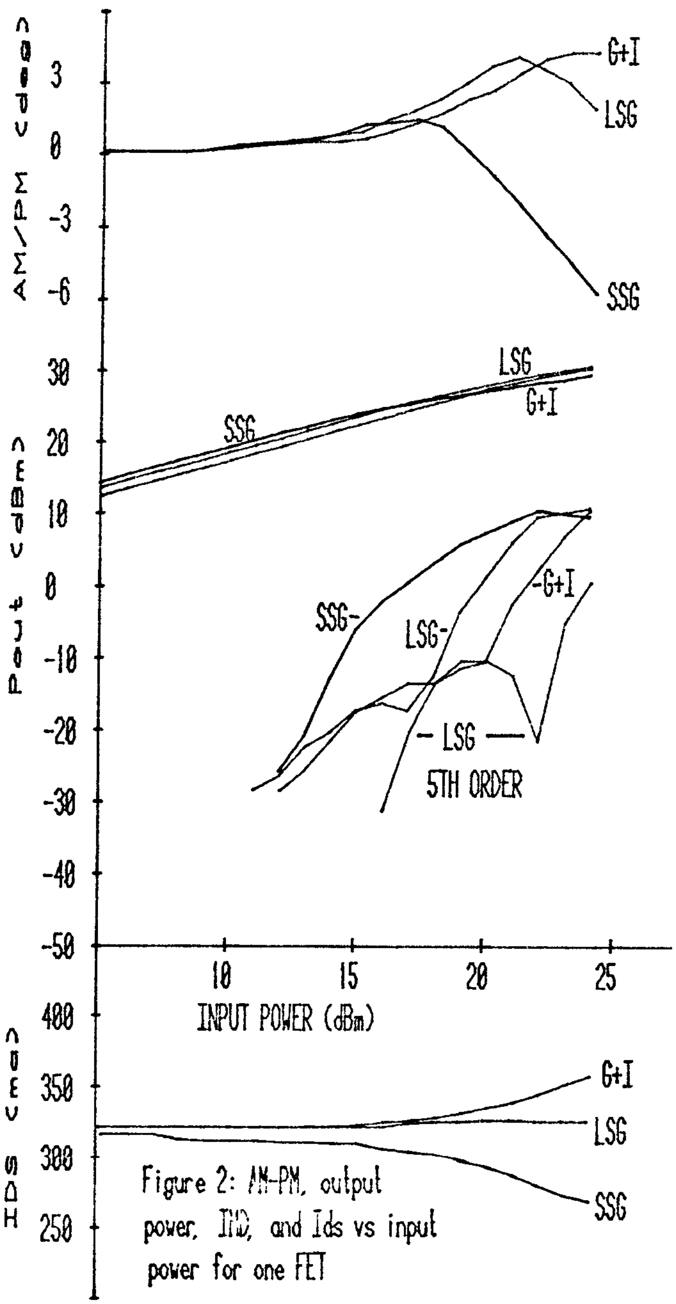

Figure 2: AM-PM, output power, IMD, and Ids vs input power for one FET

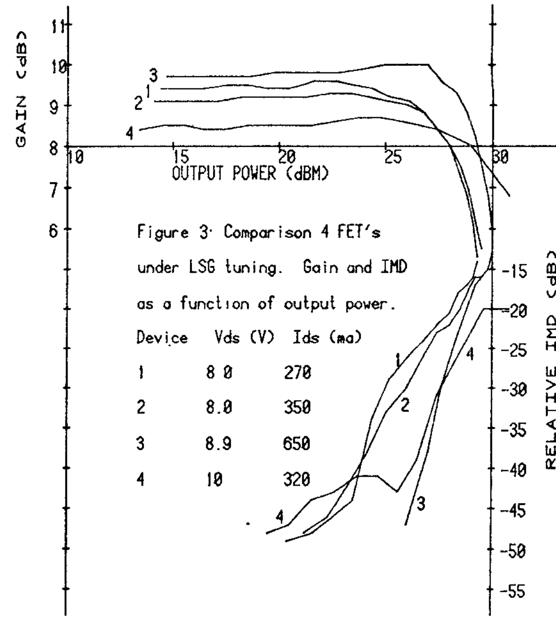

Figure 3· Comparison 4 FET's under LSG tuning. Gain and IMD as a function of output power.

Device	Vds (V)	Ids (ma)
1	8 0	270
2	8.0	350
3	8.9	650
4	10	320

Cascaded FET Distortion

The CW saturation and AM/PM conversion of a non-linearity at a given frequency determine its IMD behavior, and these could be used in principle to predict the IMD of cascaded stages. In practice, however, small non-linearities are more accurately measured by IMD tests, which tell only the magnitude of the distortion and not its phase. A worst case of IMD contribution is the in-phase addition of the IMD voltages of each stage. This was tested on some typical power FET amplifier stages, and Figure 4 shows that this is a reasonable approximation. The performance of the 3-stage FET amplifier in Figure 7 agrees well with this also.

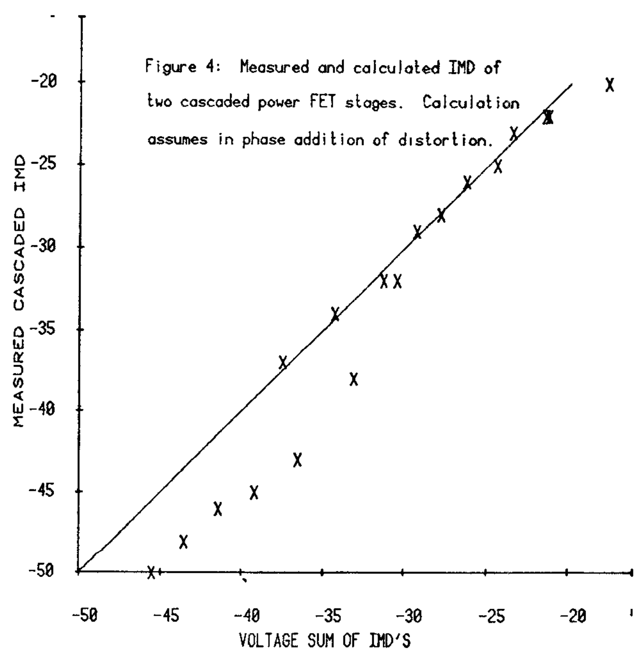

Figure 4: Measured and calculated IMD of two cascaded power FET stages. Calculation assumes in phase addition of distortion.

Amplifier Linearity Effects on Radio System Performance.

In a QAM digital radio system the system bit error rate (BER) floor is directly related to the third order IMD slope of the linear power amplifier. Figure 5 illustrates the different BER floors of a digital radio system using two different amplifiers. The two bipolar amplifiers have the same saturated output power and the same third order IMD level at the output operating power level (Po=2 W;IMD=-30 dB). The subtle difference between their performances is in the third-order IMD slopes between the operating power level and the saturated output power, due to different output devices. Amplifier 1 has a break in the IMD slope from 3:1 to 4:1 at the output power level, while amplifier 2 does not change IMD slope until it is almost fully saturated (see figure 6).

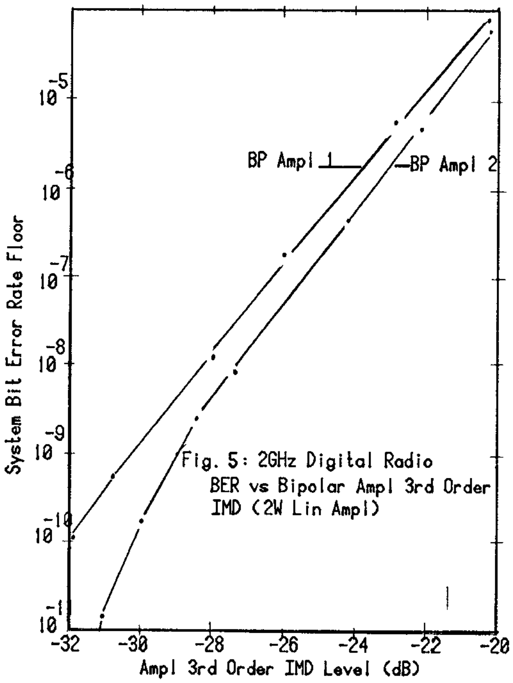

Fig. 5: 2GHz Digital Radio BER vs Bipolar Ampl 3rd Order IMD (2W Lin Ampl)

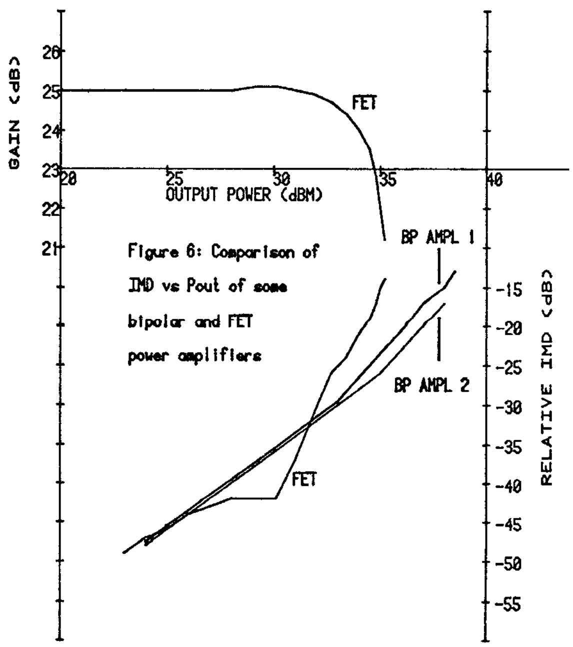

Figure 6: Comparison of IMD vs Pout of some bipolar and FET power amplifiers

A 2-watt 3.7-4.2 GHz GaAs FET power amplifier was developed using single and cascaded device data discussed above. Its gain and IMD as a function of output power at different frequencies is shown in figure 7, and its IMD behavior is compared to that of the bipolar amplifiers in figure 6. System BER measurements have not been completed with the 4 GHz FET amplifier, but the radical IMD behavior of the GaAs FET amplifier from the bipolar amplifier IMD response will require a different output power/IMD operating point. Possibly the most critical application will develop in AM/SSB systems requiring an extremely linear system.

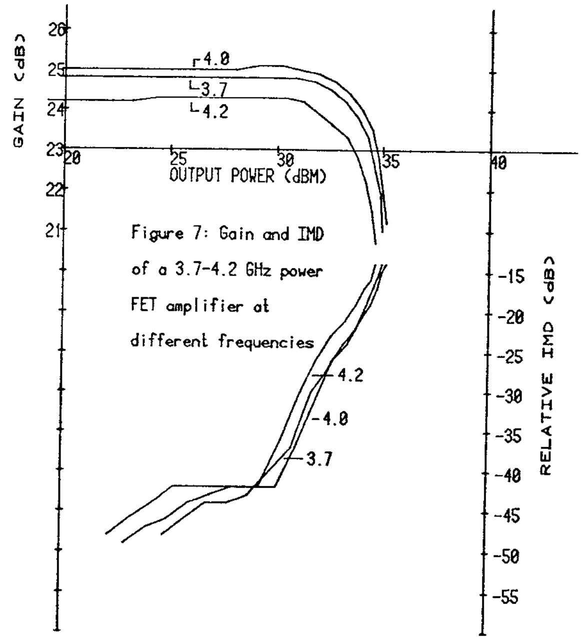

Figure 7: Gain and IMD of a 3.7-4.2 GHz power FET amplifier at different frequencies

CONCLUSION

The IMD vs power of typical GaAs power FET's is so irregular that the only reasonable specification of IMD is a graph of IMD over the power ranges of interest. The third-order intercept point is not suited for the linearity specification. A graph of typical device performance should show the gain and IMD when the FET is tuned for maximum power and biased for best IMD. The IMD of a cascade of power FET's can be reasonably approximated as the in-phase addition of the seperate IMD voltages. The IMD characteristics of a 2-watt linear power FET amplifier were presented. Finally, it was shown that even subtle differences between IMD behaviors can have important effects on system performance. The authors wish to acknowledge the helpful suggestions of Dr. Chi Hsieh in this study.

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