Analysis of HEMT Harmonic Generation using a Vector Nonlinear Measurement System

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Abstract

A study of HEMT harmonic generation was carried out using a Vector Nonlinear Measurement System to measure drain and gate waveforms. The cause of second and third harmonic nulls with increasing input power, and their direct relation to the output IV characteristics is shown. The effect of DC drain current variation with increasing input drive level is also explained. The results indicate the potential for exploiting harmonic nulling behaviour in circuit applications. Analysis of second harmonic dependency on quiescent operating point shows a doubling mode with intrinsic suppression of unwanted third harmonic.

Introduction

The main aim of this work is to analyse the nonlinear effects of harmonic nulling and bias movement of the HEMT under increasing RF input drive level. Four mechanisms were proposed as possible causes of the effects namely: i) Output IV nonlinearity, ii) Gate resistive nonlinearity, iii) Capacitive nonlinearity and iv) Interaction between bias movement and i), ii) or iii).

A second aim was to assess the application of the HEMT as an active doubler by carrying out harmonic measurements while sweeping the static dc operating voltages.

The new insights into harmonic generation, given by these measurements, are useful in understanding device behaviour and exploiting it in nonlinear circuit design.

The Microwave Transition Analyser based Vector Nonlinear Measurement System has the facility of harmonic and waveform measurements. Traditional spectrum analyser measurements provide magnitude of harmonic components only. Since the MTA captures phase of harmonic components this can be used in vector calibration of the system, enabling an error correction of the full series (up to the 9th harmonic) to the device planes. These in turn can be transformed to time domain voltage and current waveforms. This is useful in that the actual large

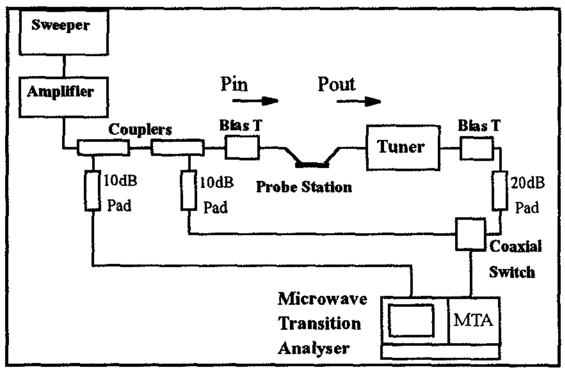

Figure 1 The Vector Nonlinear Measurement System

signal output RF trajectory in the I-V plane can be measured rather than deduced from dc, pulsed or small-signal measurements.

The Vector Nonlinear Measurement System

The MTA based nonlinear measurement system has been described previously in the literature [1-6] and consists of a single tone high power input source,

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two input couplers and bias tees as in Figure 1. A switch allows all the measurement quantities to be captured by the 2 channels of the MTA which has a 40GHz bandwidth. A vector calibration routine has been implemented [4] which enables the MTA to perform the calibration measurements itself. The accuracy of the system depends primarily on the MTA and is typically best for the fundamental signal and at higher power levels. Uncertainty levels are typically less than 1dB and 5 degrees phase for the fundamental signal, decreasing gradually towards the limit of dynamic range which is about 70dB.

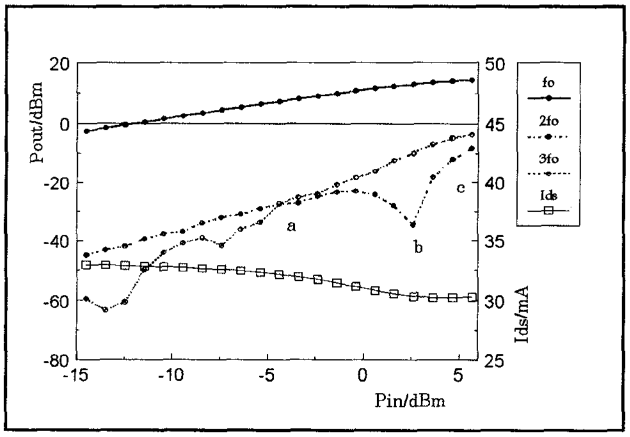

Figure 2 Harmonic Ouptut and Ids vs Input Power showing 2nd harmonic null point at point b.

Power Sweep Characteristics

A 2x60um gate width, 0.25um HEMT has been used for this study, with all measurements at a 2 GHz input frequency and with nominal 50ohm RF and DC load. Measurement of output harmonics with swept input power for a Class A bias point gives rise to characteristics such as that in Figure 2. The fundamental signal rises linearly until rolling off into saturation. Second and third harmonics tend to rise initially at the rate of the fundamental signal. In this case, the second harmonic subsequently exhibits a null point or drop-out at 3dBm input power. In fact any of the harmonics may have one or more null points depending on bias, and the effect is noted with both FET and Bipolar devices.

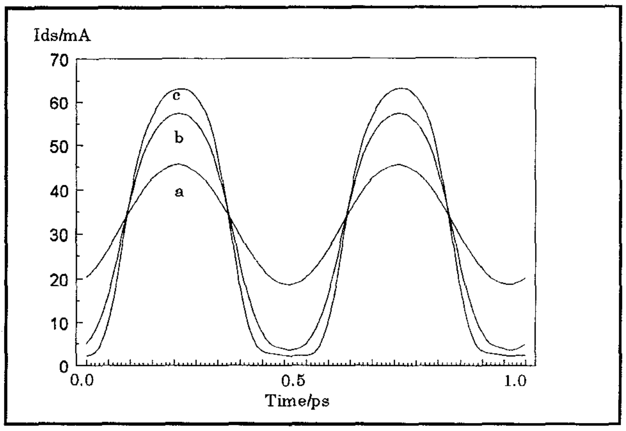

Figure 3 Drain current waveforms at points a, b and c in the power sweep

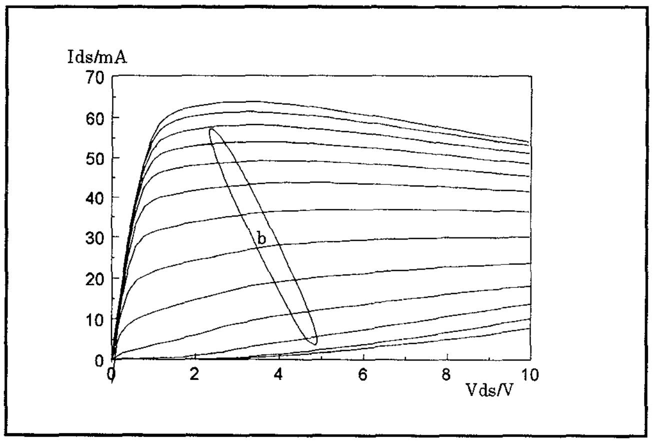

Figure 4 Hemt dc IV characteristics and dynamic load line at the null point

The Second Harmonic Null

The waveforms and dynamic load-line captured at specific points in the power sweep can be used to explain this effect. Figure 3 shows the Ids waveforms at three points, a) small signal b) At the drop-out and c) After drop-out. Additionally the dynamic load-line is plotted for the drop-out point in Figure 4. At low drive levels the waveforms are nearly sinusoidal with some even and odd order distortion giving rise to a small harmonic content. At the drop-out point the Ids waveform is compressed at both ends of the waveform by a similar amount. This is consistent with a mostly odd order fourier series and explains the reduction in second and increase in third harmonic at the null point. Increasing the drive further we observe the waveform compresses much faster at the lower end of current swing due to pinch-off, hence increasing the even harmonic content once again. The effect of second harmonic drop-out is thus caused by a bias point in the middle of the characteristics which initially allows symmetrical waveform clipping to occur. Subsequently one side is compressed more

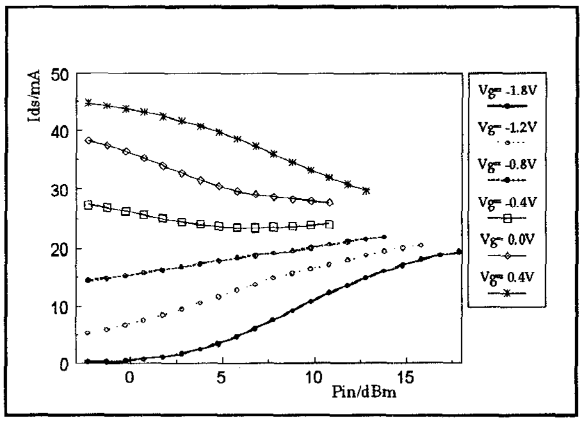

Figure 5 DC Drain Current versus Input Power for various Vgs.

sharply. A similar mechanism can be shown to cause third harmonic drop out.

Bias Movement with Input Drive

The interesting effect of drain current movement or 'self-biasing' is illustrated in Figure 5, (Ids versus input power for various Vgs, Vds=3V) and again may be described in terms of the output waveforms in the I-V plane and starting bias. Initial bias points close to pinch off show increasing current with drive level, whereas bias points close to the maximum current limit show decreasing current with drive level. In fact the final current at high drive levels converges to the mid point of the Ids range (irrespective of starting current). The reason is that premature clipping at one side or the other naturally results in the average dc value of the waveform moving away from this point (as in a half rectified sinewave).

The HEMT as an Active Doubler

We investigated the second harmonic generation of the HEMT for doubler applications. The conventional approach to doubler design is to resonate the second harmonic output, while selecting the bias point which gives the required conduction angle and gain.[7] We investigated the practical behaviour of the device used above with bias point (in pinch-off mode) , Vds=3V and with a nominal 50ohm load.

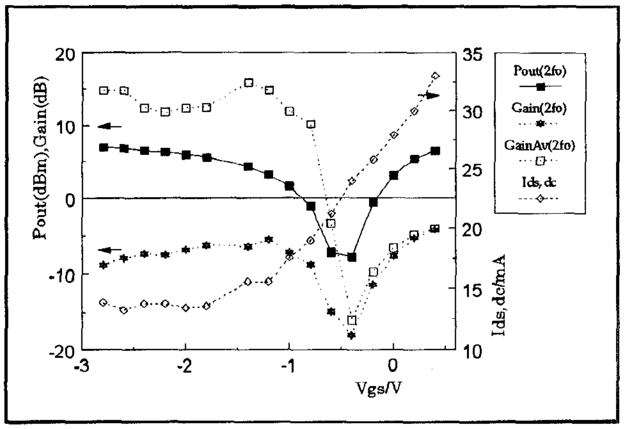

Figure 6 2nd Harmonic Ouput Power and Conversion Gain vs Vgs

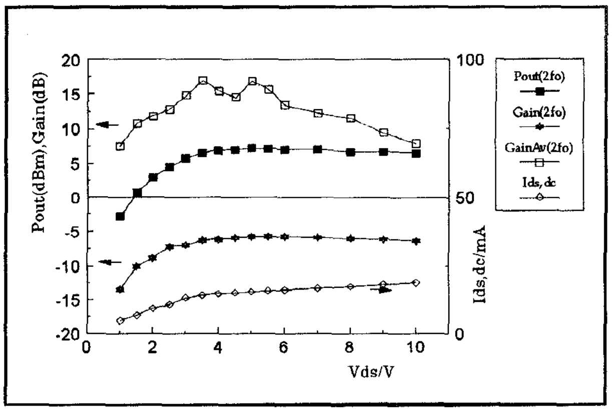

Figure 7 2nd Harmonic Ouptut Power and Conversion Gain versus Vds Bias

Vgs and Vds Dependency

Figure 6 shows the variation of maximum first harmonic output power obtained for power sweeps at different values of gate voltage Vgs. The available conversion gain, actual conversion gain and drain current are also plotted. While the second harmonic output power is high at low Vgs and high Vgs, the available gain is high only at low Vgs voltages. The reason for gain reduction at high Vgs is due to the losses in gate conduction. This plot shows the trade off between power out and gain below Vt (-1.2V), while the available gain holds up well. A good compromise appears to be 2xVt. High Vgs values exhibit poor conversion gain but may be useful if fundamental gain is required at quiescent (eg. for doubling oscillator applications).

Figure 7 shows the variation of maximum output power at 2fo with Vds. The main effect is the maximum current limit permitted by the I-V characteristics and RF load resistance (50ohm) causing saturation of these curves. This confirms that harmonic load resistance must be chosen to maximise I-V excursion for the rectified waveform. In order to obtain higher harmonic output, devices with greater gate width and higher current limit could be used.

Output Power Flatness and Harmonic Rejection

Second harmonic output against input power Pin for various Vgs values is shown in Figure 8. Choice of input power and bias allows the output power flatness to be controlled. The curve for Vgs=-1.4V shows that the flatness of output power is quite good at 3dB for 12dB change in input power, and 1dB for 5dB change in input power. These figures worsen slightly as Vgs is decreased.

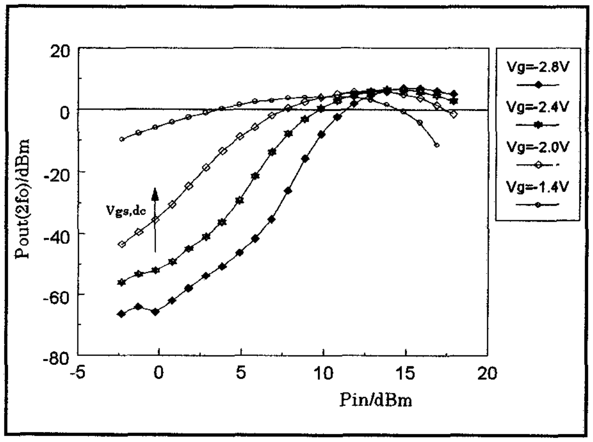

Figure 8 2nd Harmonic Output Power vs Input Power for various Vgs below pinch-off.

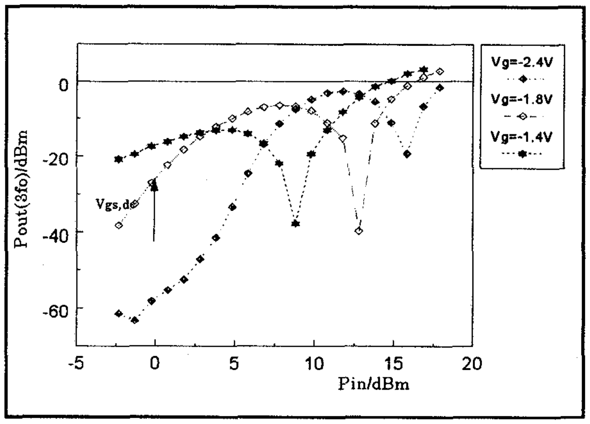

Figure 9 3rd harmonic Ouptut Power vs Input Power for Vgs

Third harmonic nulling may be exploited as shown in Figure 9 which plots the third harmonic output power versus input power for different values of Vgs. The null is a clear function of Vgs and input power. Selecting Vgs and input power range will allow intrinsic suppression of third harmonic to be achieved. Vds has a relatively small effect on the null point.

Conclusions

The reasons for bias movement and harmonic drop-outs on sweeping input power have been shown to be primarily due to the RF drain current-voltage trajectory superimposed on the nonlinearity of the I-V output characteristics. Gate conduction is important at the high Vgs bias points which have lower available gain. The effect of bias point on doubling action has been presented and gives a practical indication of the gain vs output power trade-off as initial bias is varied. A method of setting the HEMT operating point to achieve good harmonic output power flatness with input power and increased third harmonic suppression has been demonstrated.

References

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