DESIGN TECHNIQUES FOR LINEAR REQUIREMENTS FOR MMIC POWER AMPLIFIERS

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ABSTRACT

Measurements and simulations on MESFET's and GaAs HBT's shows that intermodulation suppression and efficiency can be greatly improved by applying the correct loads not only to the fundamental but also to at least the first two harmonics and the low frequency mixing term.
At 40 dBc IM3 the efficiency for the MESFET is increased from 20 to 30 % and in the case of the GaAs HBT the improvement is from 10 to 17 %.

INTRODUCTION

Mobile phone systems and WLAN applications are increasing the demand for highly linear power amplifiers as the modulation schemes changes. In addition to high linearity there is also a need for high efficiency which contradicts the linearity requirement.
Different techniques can be used to improve linearity such as feedforward or predistortion, but in all cases the basic amplifier should be as linear as possible to enhance the total performance of the linearized amplifier.

Before the design starts of an amplifier with linearity and efficiency requirements, a semiconductor technology is choosen to give good linearity. However, it is as important to use the correct loading on all harmonics as to choose a specific technology. Described below are some results on modeling a MESFET and terminating harmonics for enhancing linearity and efficiency. A brief comparison with a GaAs HBT and a SiGe HBT is also included.

DEVICE MODELING

The device used is a MESFET from the TriQuint HiP process. A TOM2 model has been modified with new equations to curve fit both Cgs and gm (Ids vs Vgs) to measurements. The agreement is very good as can be seen in figure 1 (Cgs).
To show the importance of the Cgs function when simulating nonlinearities, a simulation of third order intermodulation suppression is shown in figure 2 for the modified TOM2 model together with a simulation using the same model except for changing the Cgs function to a constant. The difference in IM3 suppression for low levels is 20 dB. The same type of simulation have been performed for the gm function but showing that this is a second order effect on nonlinearities.

LOAD-PULL FOR EFFICIENCY AND LINEARITY

A large number of load-pull measurements for IM3 suppression, efficiency and output power have been performed on a 4.6 mm device which is capable of delivering slightly more than 1W when tuned for maximum power. In the intended application it will be used at approximately 6 dB backoff due to peak envelope reasons. Therefore load-pull have been performed at both maximum power and at 25 dBm output power.

Tuning for PAE in compression shows an efficiency maximum of 61.4% as shown in figure 3. Searching for maximum IM3 suppression at a constant output power of 25 dBm is shown in figure 4. As can bee seen in the two plots, the load for max compressed PAE and max IM3 suppression are almost identical. A power sweep versus PAE, IM3, gain and output power is shown in figure 5. The plot shows that -40 dBc IM3 is reached for 5.75 dB backoff from 1 dB compression which is 25 dBm. At this point the PAE is 20% which is good but must still be improved. This can be done by optimizing the harmonic loads.

OPTIMUM HARMONIC LOADING

For finding the optimum harmonic loading on a 2 mm device, a simulation was set up where the phase of the harmonic load for the first and second harmonic were swept from –180 to 180 degrees while keeping the magnitude to 1, i.e a purely reactive load. The same technique was also used for the load at the low frequency mixing term in the IM simulation. The results for the first harmonic can be seen in figures 6 and 7, where the IM suppression changes approximately 10 dB due to the phase angle. The change in PAE is not as significant but it is important to note that the optimum is found for the same phase as for optimum IM.
Once the optimum phases for the loads at first and second harmonic as well as the loading of the difference frequency is found and applied to the device, the bias is reoptimized to get the best efficiency and linearity trade-off. In the case of this MESFET the PAE at 40 dBc IM3 suppression was enhanced from 20 to 30 %.

LOAD-PULL ON SiGe HBT

Load-pull measurements have been performed on a SiGe HBT to find the optimum load for PAE as well as for linearity. The measurement was performed at 2 GHz and the collector voltage is 3.2 V. The result for searching max PAE can be seen in figure 8. The optimum load including bondwire is at 128.6-j35.5 ohms, giving 45.3 % PAE. The plot in figure 9 shows contours for output power and PAE at 40 dBc of IM3 suppression.
As in the case of the MESFET, the optimum load impedance with respect to efficiency for 40 dBc IM3 suppression is the same as for maximum PAE in compression.

HARMONIC TERMINATIONS ON A GaAs HBT

Simulations have been performed on a GaAs HBT to investigate the influence of harmonic terminations on IM3 suppression versus efficiency of the device.
Efficiency and IM3 suppression are shown in figures 10 and 11 for optimum load at the fundamental, 2 GHz. Maximum PAE is 54 %. At 40 dBc of IM3 suppression the efficiency is 10 %.
When the optimum loads for the harmonics are applied to the device, the maximum efficiency is increased to 74 %. In this case the efficiency at 40 dBc of IM3 suppression is increased to 17 %. This can be seen in figures 12 and 13.

CONCLUSIONS

In the MESFET model it is shown that the main contribution to nonlinearities at low levels is due to Cgs and therefore it is very important to model this behaviour correct in order to predict IM3.
It is shown that the efficiency for a given IM3 suppression is increased from 20 to 30 % by terminating harmonics and low frequency signals with the optimum loads.
Measurements indicates that optimum load for IM3 suppression in back-off is the same as the optimum load for maximum PAE and not for maximum output power.

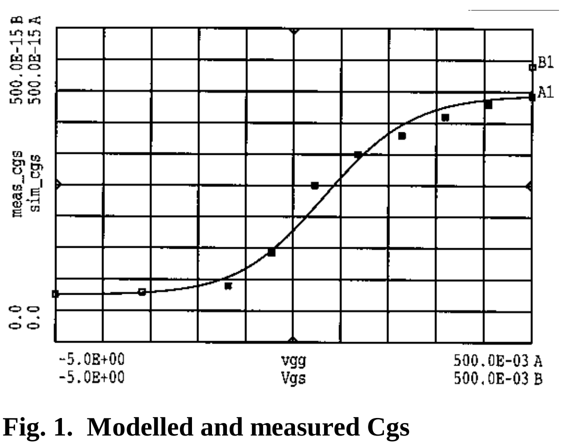


Fig. 1. Modelled and measured Cgs

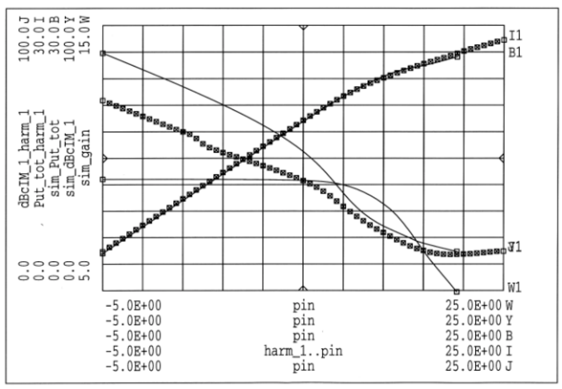


Fig. 2. IM3 with constant Cgs (thin line)

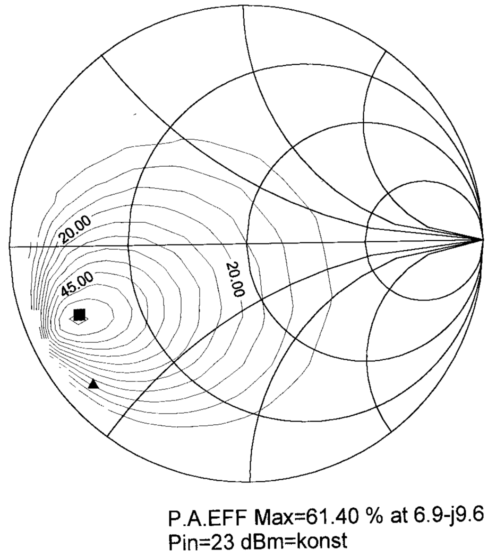


Fig. 3. Load-Pull for max PAE

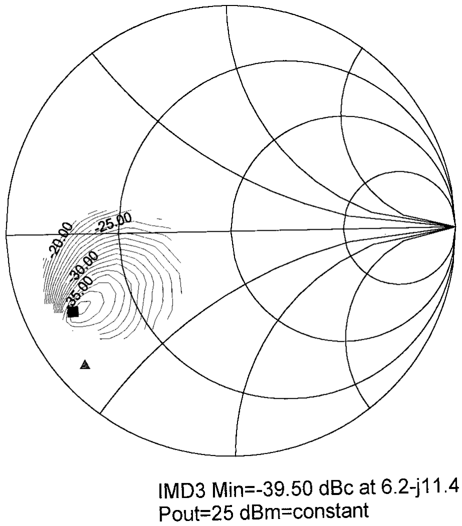


Fig. 4. IM3 contours at 25 dBm output power.

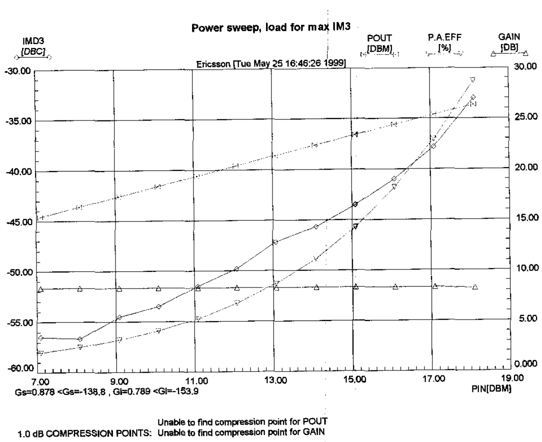


Fig. 5. Power sweep for optimum IM load at 25 dBm.

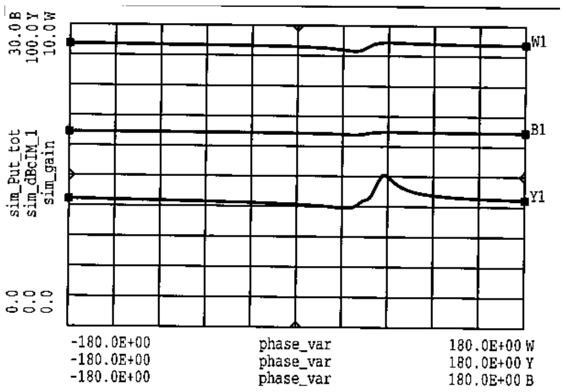


Fig. 6. Sweeping the phase of the load at the first harmonic. IM3 lower curve, 10 dB/div

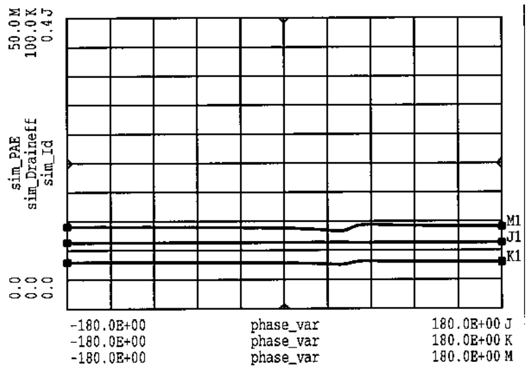


Fig. 7. Sweeping the phase of the load at the first harmonic. PAE upper curve, 5%/div

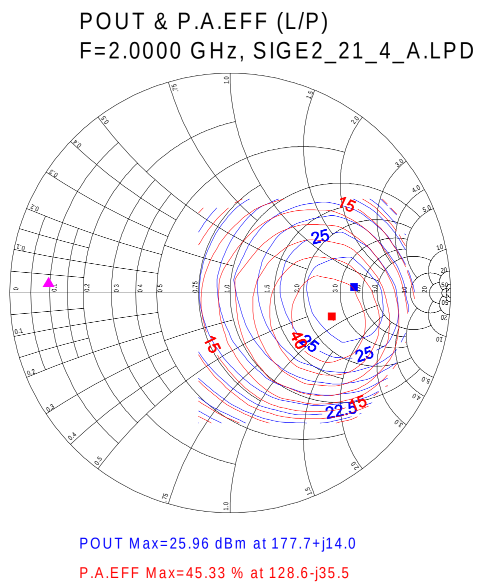


Fig. 8. Power and PAE contours for the SiGe HBT

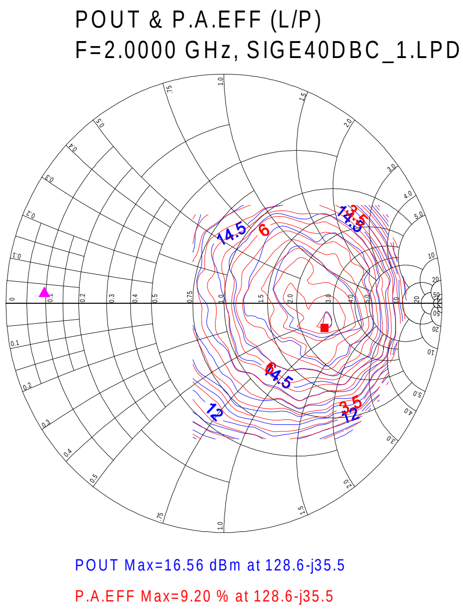


Fig. 9. Power and PAE contours for 40 dBc of IM3 suppression

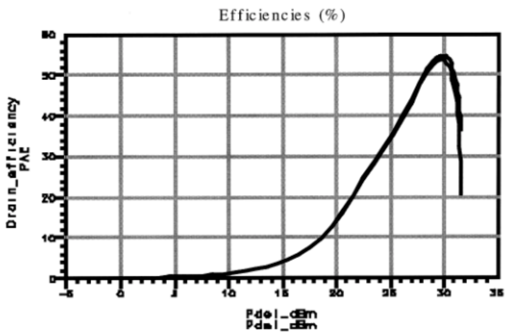
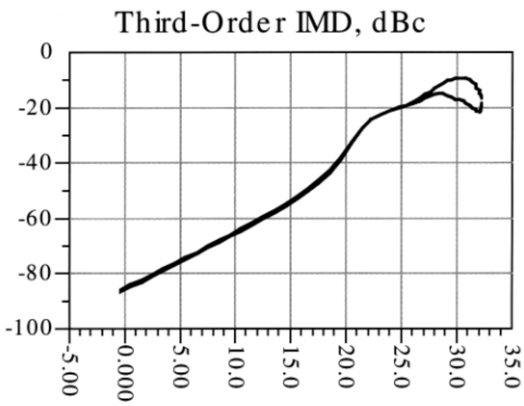


Fig. 10. Efficiency of GaAs HBT without harmonic tuning



. Fig. 11. IM3 suppression of GaAs HBT without harmonic tuning

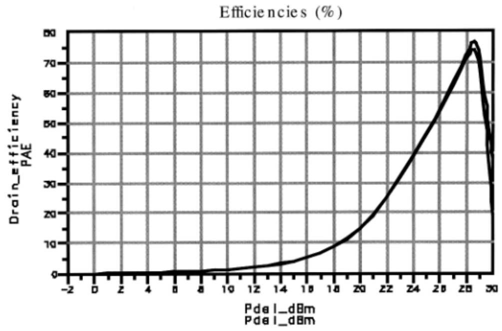


Fig. 12. Efficiency of GaAs HBT with harmonic tuning

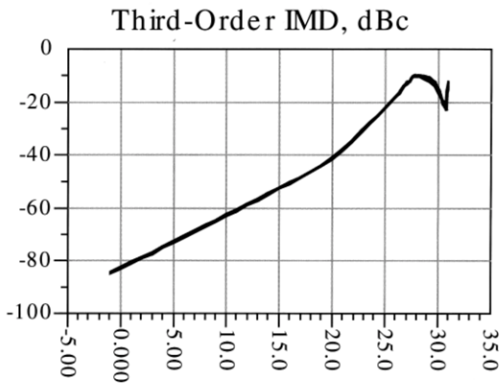


Fig. 13. IM3 suppression of GaAs HBT with harmonic tuning