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NON LINEAR EQUIVALENT CIRCUIT FOR BROADBAND GaAs MESFET POWER AMPLIFIER DESIGN

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ABSTRACT

A non-linear equivalent circuit is developped to model the fundamental frequency r.f. performance of a 1 µm x 800 µm GaAs MESFET, based on two-port large-signal amplifier measurements between 6-8 GHz. Potentially large-band, the circuit accurately predicts in-band AM/PM conversion and saturation of the device with arbitrary terminal loads.

INTRODUCTION

The modelling of the performance of power GaAs MESFETs is based either on analytical time-domain models (1), or on fundamental frequency equivalent circuit models using data obtained by load pull measurement (2) or by 50 Ohms S-parameter measurement (3). However for typical class A-B amplifiers, the performance obtained from the GaAs FET is dependent on the terminal loads presented to both ports (4). Fundamental frequency equivalent circuits based on load pull or on 50 Ω S-parameters lack the information necessary for accurate broadband frequency design of GaAs MESFET power amplifiers, particularly with regard to the reverse feedback between the output and the input of the device.

This paper presents a non-linear equivalent circuit model of a medium power GaAs MESFET, obtained using data from two-port large-signal measurements at 6-8 GHz, with the device embedded in an optimum output power matching environment. An equivalent circuit is fitted to the device parameter variation with signal drive level. Next the variation of the selected non-linear elements of the equivalent circuit with respect to voltages across their terminals is established. Finally the equivalent circuit, now independent of frequency and applied loads can be used to predict fundamental frequency performance of the transistor under any loading conditions and at frequencies in or around the measurement band. An example of AM/PM distortion, predicted and measured, is supplied.

LARGE SIGNAL MEASUREMENTS

A medium power 1 µm x 800 µm GaAs MESFET † is matched at its input and output ports to give an acceptable output power/gain performance. The full two-port parameters of the amplifier are then measured in the manner described in reference 4, for discrete input signal drive levels, P_i, from small-signal (P_i = 5 mW) to well into gain compression (P_i = 60 mW), at 6, 7 and 8 GHz. The terminal loads are characterised separately, and by a process of de-embedding the transistor two-port parameters are obtained at each frequency and for each signal drive level.

In order to be able to exploit this information, it is necessary to fit a large-signal equivalent circuit of the transistor to the two-port data at successive drive levels and for each frequency. Next by characterising each non-linear element as a function of the voltage across its terminals or, in the case of the transconductance gm, a voltage across the terminals of a specific element, one may obtain a non-linear model independent of frequency or of load terminations.

† THOMSON-CSF experimental transistor.

LARGE SIGNAL EQUIVALENT CIRCUIT MODEL

The equivalent circuit used is given in Figure 1, the non-linear elements being : device input capacitance C_i, gate-to-drain feedback capacitance C_{gd}, transconductance gm and output conductance g_d. This equivalent circuit is initially fitted to the measured small-signal S-parameters of the GaAs MESFET across the frequency range 0.5-8.5 GHz using an in-house optimisation program, the

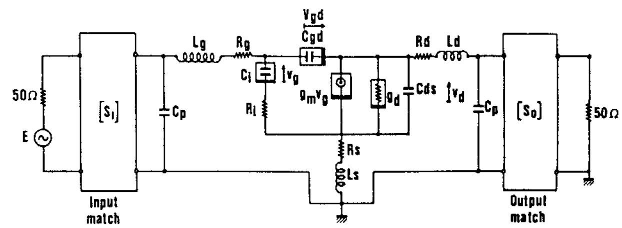

Figure 1 - Power MESFET non-linear equivalent circuit

initial values of certain elements (R_g, R_s, Rd and gm) being obtained by static and low-frequency measurements. The fit obtained is shown in figure 2 : the non-varying equivalent circuit elements are now set up as are the low-signal values of the 4 non-linear elements.

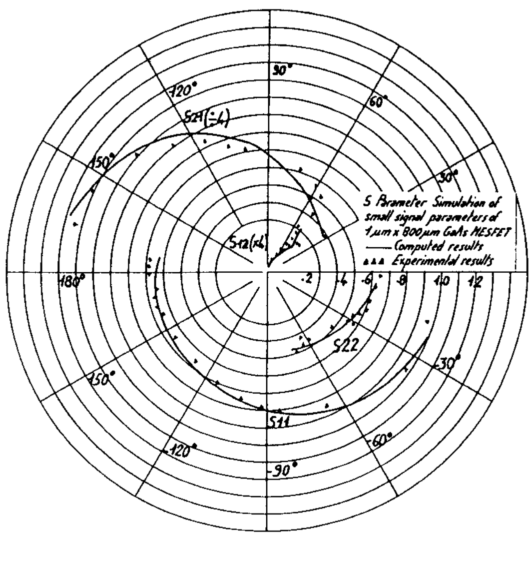

Figure 2 - Small-signal S-parameter simulation 0.5 - 8.5 GHz

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These 4 equivalent circuit elements are now "optimised" to give best fit to the transistor large-signal data at each drive level. Finally a nodal analysis program, SIDERAL 2, is used to obtain the distribution of currents and voltages in the equivalent circuit. By this means the variation of a non-linear element can be related to specific current or voltage level.

NON-LINEAR ELEMENT BEHAVIOUR

The most striking features of the variation of large-signal S-parameters with input signal drive (4) concerns $|S_{22}|$ which drops rapidly before stabilising, $|S_{21}|$ which falls off progressively and $|S_{12}|$ which rises dramatically (by a factor of 2 or 3).

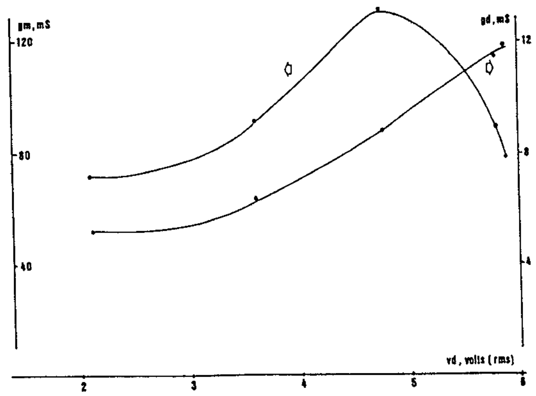

Figure 3 - Variation of gm and gd with output voltage, vd

gd and gm

Corresponding to $|S_{22}|$, in figure 3 one observes a rise in g_d, output conductance, with respect to the r.m.s. output voltage, vd, across its terminals, tailing off with the onset of saturation. The transconductance, gm, rises sharply to a peak of amost twice its linear value before dropping sharply as saturation approaches. This is in marked contrast with $|S_{21}|$ which falls off steadily after a slight gain expansion (0.1 dB) about Pi = 30 mW (vd = 3.6 V r.m.s.). This is due to $|S_{21}|$ being a function of gd and C_i as well as gm. The ratio of C_i to R_i, R_s and L_s determine, to a first approximation, the reference voltage v_g, and g_d defines the power available from the device. Thus $|S_{21}|$ remains constant upto 30 mW because the increase in g_m is offset by the rise in C_i and g_d.

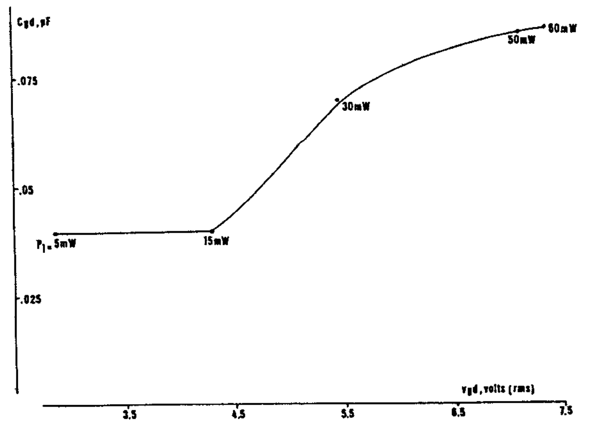

Figure 4 - Variation of feedback capacitance C_{gd} with terminal voltage vgd

Cgd

The rise in $|S_{12}|$ can be traced to an increase in the feedback capacitance, C_{gd}, figure 4, but also to variations in C_i, g_m and g_d. This is again because the value of C_i sets up the reference voltage, v_g, and subsequently gm and gd determine the current that will flow through the common series feedback element, $R_s + j\omega L_s$.

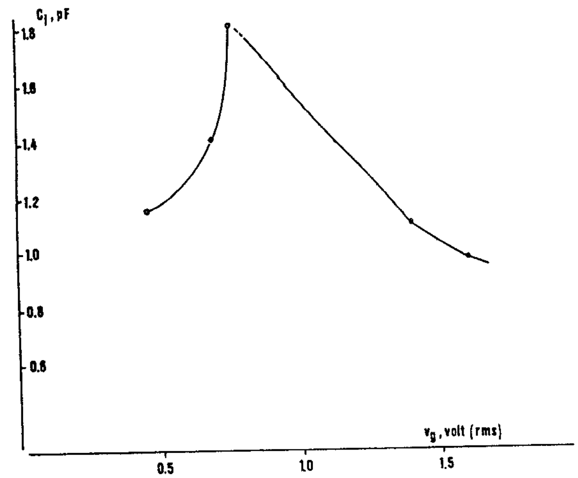

Figure 5 - Variation of input capacitance C_i with terminal voltage vg.

Ci

The peaking and subsequent tailing off of C_i with increased drive level is difficult to understand. It is observed that variations of this element have, paradoxically, a more important effect on the transistor output (because of the corresponding variation in vg), than on the input, as evidenced by the fact that S_{11} remains relatively constant with signal drive (4).

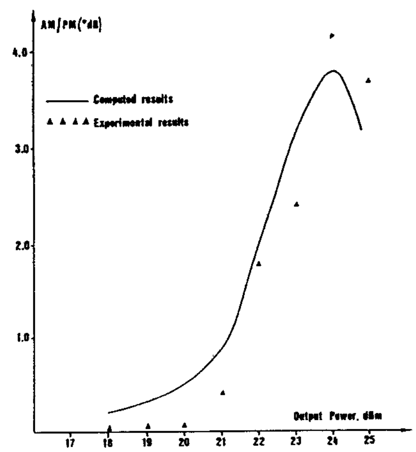

Figure 6 - Predicted and measured AM/PM conversion for power MESFET amplifier.

The large-signal equivalent circuit was used to predict the r.f. performance of the GaAs MESFET with respect to gain saturation and AM/PM conversion in the band 6-8 GHz fairly accurately. An example of the good agreement between measured and predicted results of AM/PM conversion at 6 GHz is given in figure 6. Similar results were obtained at other frequencies. This model can be extended to cover a larger frequency range, and gain and saturation performance of the device can be predicted for any arbitrary terminal loads.

CONCLUSION

A non-linear equivalent circuit model of the large-signal behaviour of a power GaAs MESFET has been developped over the frequency range 6-8 GHz. This model has been derived by fitting an electrical equivalent circuit incorporating 4 non-linear elements to two-port large-signal parameters of the transistors embedded in an amplifier configuration. The non-linear equivalent circuit enables fundamental frequency r.f. performance of the transistor to be accurately predicted.

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