T-6

PREDICTION OF WIDEBAND POWER PERFORMANCE OF MESFET DEVICES USING THE VOLTERRA SERIES REPRESENTATION

C.L. Law and C.S. AITCHISON*

Department of Electronic & Electrical Engineering, King's College(KQC)
Pulton Place, London SW6 5PR, England.
*Now at ERA Technology Ltd, Cleeve Road, Leatherhead, Surrey, England

Abstract

Power performance of a medium power GaAs MESFET is predicted over the frequency range from 2GHz to 16GHz using a non-linear model where the non-linearities represented by power series up to the third order are derived from D.C. and low-frequency measurements. The analysis employs the Volterra series representation up to the third order. Experimental verification is made on a NE9000 medium power MESFET device. The agreement between predicted and measured output power at one dB. gain compression is within ± 0.5dB across the 2-16GHz band.

Introduction

Very wideband solid state GaAs MESFET amplifiers have been developed in the form of Distributed Amplifiers (1). Most of these amplifiers are designed for low noise and for operation in small-signal conditions (2,3). There is a growing need to operate these amplifiers under large signal conditions to give high output power. Kim, Tserng and Shih (4) have designed a Distributed Amplifier with 0.8 W output power at one dB gain compression. Their analysis however did not attempt to tune circuit elements for maximum output power. Such analysis requires a wideband non-linear model of the GaAs MESFET used and an efficient non-linear analysis program.

This paper presents a simplified wideband non-linear model of a MESFET in which the model elements are obtained easily by D.C. measurements, low frequency measurements and optimisation of small-signal scattering parameters at one bias point. The three nonlinear elements considered are gm, gd and Cgs and are represented by power series up to the third order. The non-linear analysis employed is that of the Volterra series representations up to the third order (5). Validity of the model is confirmed by comparing measured and predicted output power of a NE9000 MESFET device embedded between 50 ohms input and output microstrip lines across the 2-16 GHz band for the first time.

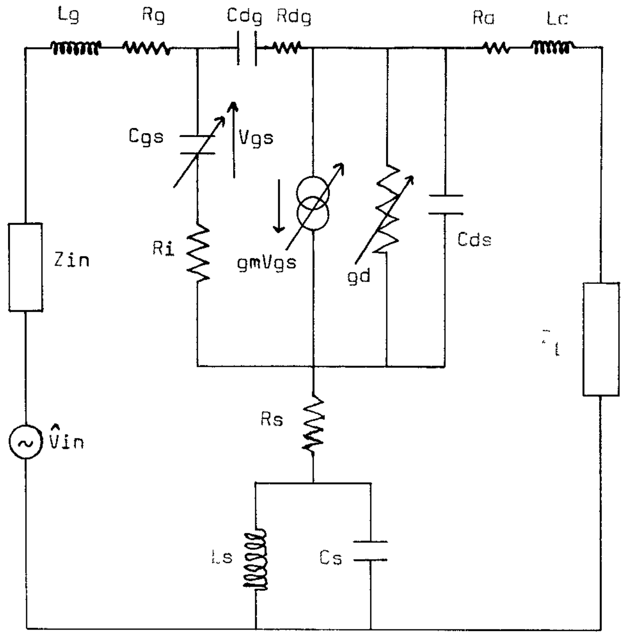

Fig.1 MESFET non-linear equivalent circuit.

Non-linear Analysis

The elements of the non-linear equivalent circuit as shown in Fig. 1 can be divided into two types: Linear elements and non-linear elements. Values of these elements for a medium power device (NE9000) biased at $V_{GS} = -1.0$ and $V_{DS} = 8.0$ are tabulated in table 1. The linear elements are obtained by optimisation of the small signal 's' parameters of the MESFET biased at it's required operating point to give maximum output power.

The three non-linear elements are gm, gd and Cgs. Although gm is a function of V_{GS} and V_{DS},we restrict the non-linearity of gm to be a function of V_{GS} only for simplicity and is expressed as:

$$gm = gmo + gm_1 Vgs + gm_2 Vgs^2 \qquad [1]$$

The coefficients gmo, gm_1 and gm_2 are found by a least-square polynomial curve fitting routine to fit the slope of the measured D.C. curves of I_{DS} versus V_{GS} at the biased V_{DS}. Similarly, gd is a function of V_{GS} and V_{DS}. For simplicity, we restrict the non-linearity of gd to be a function of V_{DS} only, and is expressed as:

$$gd = gdo + gd_1 Vds + gd_2 Vds^2 \qquad [2]$$

Again, the coefficients gdo, gd_1 and gd_2 are found using a least-square polynomial curve fitting routine to fit the measured curve of gd versus Vds at the biased V_{GS} and V_{DS}. The curve of gd versus Vds is measured with a 100 KHz signal using a technique similar to that employed by Mo and Yanai (6). The non-linearity Cgs is approximated by the Schottky-barrier diode capacitance between the gate and the source with Vgs as the sole voltage parameter. The least square polynomial curve fitting routine is again used to fit the calculated values of Cgs from Schottky-barrier theory into a power series of the form:

$$Cgs = Cgso + Cgs_1 Vgs + Cgs_2 Vgs^2 \qquad [3]$$

An efficient method of solving the transfer functions of a system with power series type non-linearity is the non-linear current method described in (5). This method is used to derive the linear transfer function $H_1(W)$, the second order transfer function $H_2(\omega_1,\omega_2)$ and the third order transfer function $H_3(\omega_1,\omega_2,\omega_3)$. The available power gain Gav defined as the ratio of the power dissipated in the optimum load to the available power presented by the source can be expressed as (5):

$$Gav = 4\left|H_1(\omega) + 3/4\ \hat{V}in(\omega_1)\hat{V}in(-\omega_1)H_3(\omega_1,\omega_1,-\omega_1)\right|^2 \qquad [4]$$

From [4], we can see that the gain is made up of two parts. The first is a linear function $H_1(\omega_1)$. The second is proportional to the third order non-linear function, $H_3(\omega_1,\omega_1,-\omega_1)$ and it increases with increasing available power. If we plot Gav versus $P_{in}(\omega_1)$ at 8GHz, we get a curve as shown in Fig. 2. The compression of the gain is due to the third order non-linear transfer function $H_3(\omega_1,\omega_1,-\omega_1)$.

NE9000 V_{DS}=8.0v V_{GS}=-1.0v I_{DS}=50mA		
Lg= 0.46nH.	Cdg= 0.021pF.	$gm=36.5+2.4Vgs-1.0Vgs^2$ (mS)
Rg= 0.5 ohm	Rdg= 29 ohm	
Ri= 5.4 ohm	Cds= 0.06pF.	$gd=1.8-0.2Vds+0.02Vds^2$ (mS)
Rs= 2.0 ohm	Rd= 3.0 ohm	
Ls= 0.1 nH.	Ld= 0.5 nH.	$Cgs=0.55+0.2Vgs+0.06Vgs^2$ (pF.)
Cs= 0.15pF.		

TABLE (1). Values of the non-linear model for a 0.5x400um. MESFET.

Experimental Verification and Discussion

A 0.5x400µm. NEC device was embedded between 50 ohms input and output microstrip lines built on one inch square Alumina substrate. The power performance of the device was measured and predicted across the whole 2-16GHz band. The validity of equation [1] can be checked by plotting the predicted and measured output power at one dB gain compression versus frequency as shown in Fig. 3. We can see that the agreement is within ±0.5 dB from 2 to 16 GHz. The small signal gain of the MESFET across that frequency range is shown in Fig. 4.

It has been pointed out earlier that the gain compression as shown in eqn. [4] is due to the third order non-linear transfer function. We can thus investigate the circuit elements that determine the magnitude of the third order transfer function across the 2-16GHz band. By reducing the magnitude of this function, we can increase the one dB gain compression input power.

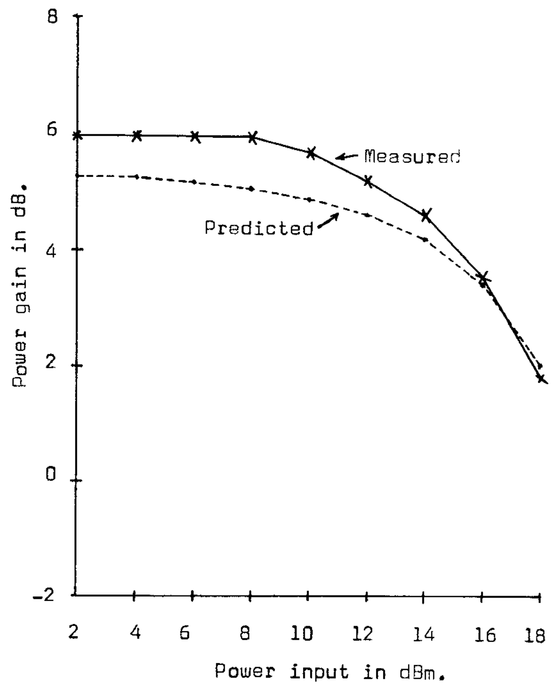

FIG.(2) Graph of predicted and measured power gain versus available input power at 8 GHz. for a 0.5x400um. MESFET.

Conclusion

A wideband non-linear model for GaAs MESFET devices is demonstrated to be valid up to 16 GHz. The efficient method of non-linear analysis in the frequency domain, based on the non-linear current method applied to predict the power performance of the MESFET, can be readily modified to predict power performance of Distributed Amplifiers.

Acknowledgement

We wish to thank O.S.A. Tang and C. Camacho-Penalosa for their helpful discussions. We also wish to thank SERC for supporting this project, and Mike Turner for proof reading.

References

(1) E.L. Ginzton, W.R. Hewlett, J.W. Jasberg and J.D. Noe, "Distributed Amplification", Proc. IRE Vol.36, 1984, pp.956-969.
(2) Y. Ayasli, L.D. Reynolds, J.L. Vorhaus and L.K. Hanes, "2-20 GHz GaAs travelling-wave amplifiers", IEEE. Trans. Microw. Theory Tech., Vol. 32, 1984, pp.71-77.
(3) W. Kennan, T. Andrade and C. Huang, "A miniature 2-18 GHz mondithic GaAs distributed amplifier", IEEE Microwave and Millimeter-Wave Monolithic Circuits Symp. Digest, San Francisco, 1984, pp.41-44.
(4) B. Kim, H.Q. Tsang and H.D. Shih, "High power Distributed Amplifier using MBE Synthesized Material", IEEE Microwave and Millimeter-wave monolithic circuits symp. Digest, St. Louis, 1985, pp.35-37.
(5) J. Bussgang, L. Ehrman and J. Graham, "Analysis of non-linear systems with multiple inputs" Proc. of the IEEE, Vol.62, Aug. 1974, pp.1089-1119.
(6) D.L. Mo and H. Yanai, "Current-Voltage characteristics of the junction-gate field-effect transistor with field dependent mobility", Ibid. ED-17, 1970, pp.577-586.

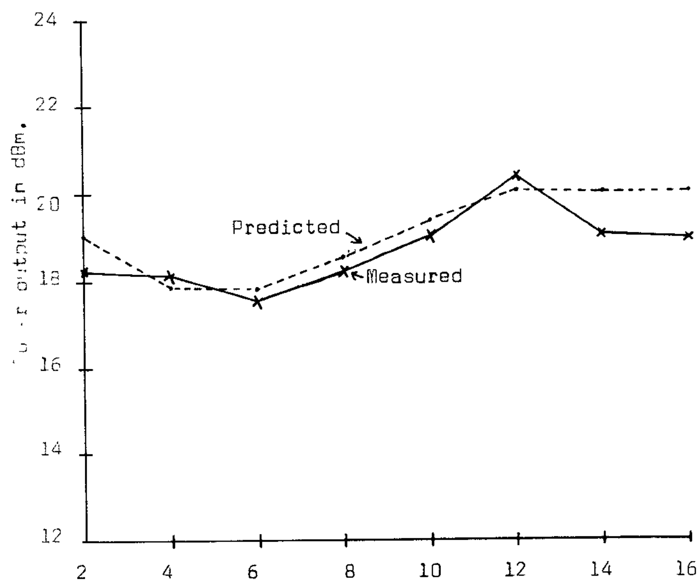

FIG.(3) Predicted and measured output power at one dB. gain compression for a 0.5x400um. MESFET.

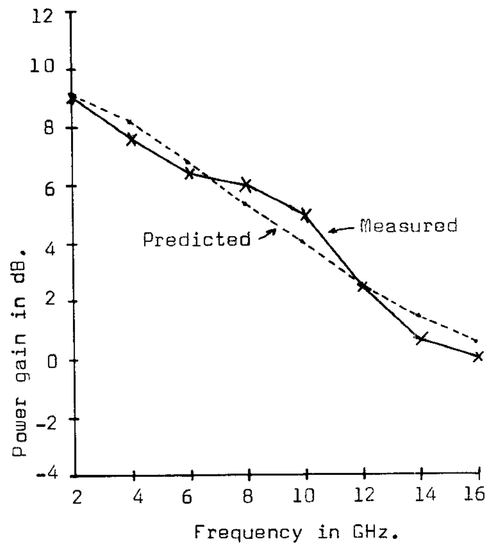

FIG.(4) Predicted and measured small signal gain for a 0.5x400um. MESFET.