A NON-LINEAR DESIGN AND OPTIMIZATION PROCEDURE FOR GaAs MESFET OSCILLATORS

T.J. Brazil and J.O. Scanlan

Department of Electronic Engineering
University College Dublin
Ireland

Abstract

An approximate but successful non-linear design/optimisation procedure is described for a GaAs MESFET oscillator, based on initial availability of an appropriate device model and a large-signal simulation analysis tool. A number of variations of the design procedure are compared, and each is checked against a full self-consistent solution for the optimized oscillator.

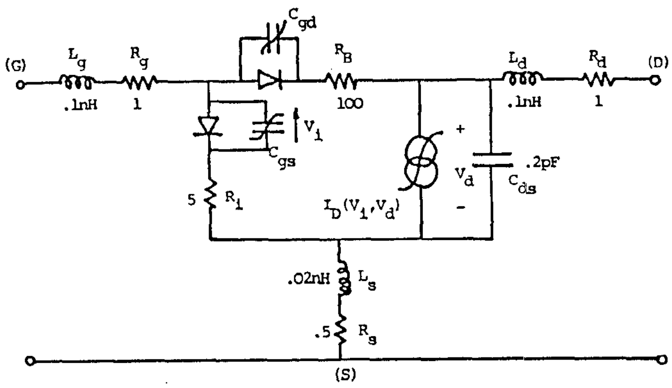
Introduction

Available CAD tools for non-linear MESFET applications such as oscillators are essentially restricted to the analysis problem: that is, given a device and circuit with specified bias conditions, it is possible to use the computer to simulate for the expected microwave performance. In practice, the design/optimization problem is frequently of much greater interest, whereby, for example, a non-linear CAD tool would predict the circuit conditions required to obtain optimum output power from an oscillator over a specified range of frequencies. This second kind of CAD usage is, of course, well-established in linear or small-signal MESFET applications.

The purpose of this contribution is to show how an approximate but successful non-linear design/optimization procedure can be developed for a MESFET oscillator, provided an appropriate device model and large-signal computer analysis tool are initially available. The output of the design procedure is verified by running the analysis program using this output data, and checking that the predicted performance is indeed achieved. The present work is an extension of previous work (1) which dealt exclusively with power amplifiers using MESFETS.

Device Characterisation

It is convenient to illustrate the method with a specific example. Figure 1(a) shows the assumed non-linear model of the GaAs MESFET and the bias conditions chosen are indicated on the D.C. characteristics of Fig.1(b). The large-signal analysis program used in the present work is a modified version of SPICE2, in which the circuit of Fig.1(a) is built up as a subcircuit. The form of current source indicated in the model was introduced into SPICE2 by editing the source code to replace the existing level 1 MOSFET model in SPICE, which is contained in the subroutine MOSEQ1.



$C_{gso} = 2.5pF$; $C_{gdo} = .03pF$; $V_{Bgd} = 14V$; $\phi = .7V$

$I_D = .075.\left[|V_i + 2.8|^{1.5} + .05V_d\right].\tanh(V_d)$ (A)

(a) : Non-Linear MESFET Equivalent Circuit

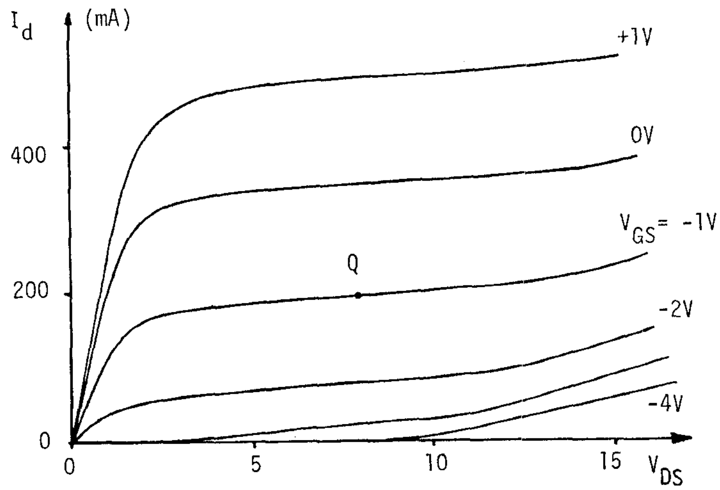


Fig. 1 (b) DC Characteristics and Q-Point

0149-645X/87/0000-0907$01.00 © 1987 IEEE

It is assumed that the active device is to be used in an oscillator circuit as shown in Fig.2, and that the circuit element values are required which will provide maximum power in the load at a specified frequency (10 GHz).

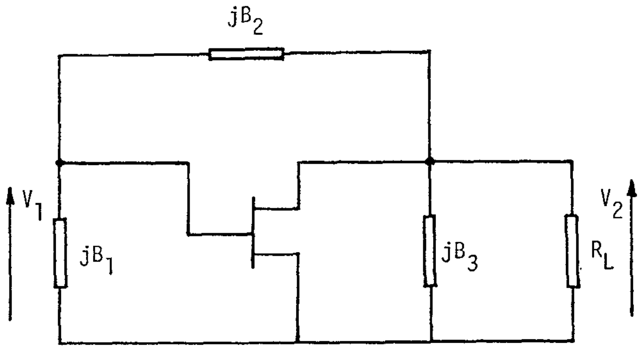


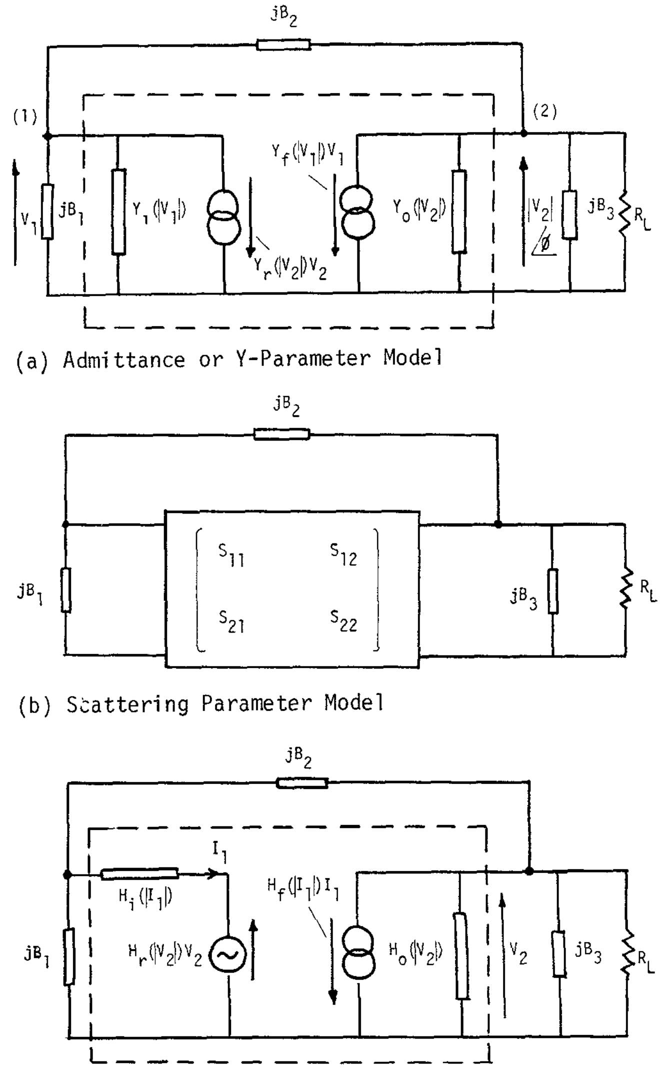
Fig. 2 : MESFET Oscillator Configuration

A key preliminary step in the design procedure is to use the analysis program to develop a non-linear "functional" equivalent circuit of the device at the bias conditions and frequency of interest. In fact, three possible forms of this large-signal equivalent circuit are indicated in Fig.3, namely, an admittance model, a scattering-parameter model and a hybrid model.

There are approximations inherent in this form of large-signal modelling - for example, the decomposition into separate elements shown in Fig.3 is not strictly valid under large-signal conditions. In addition, each model imposes specific constraints on the external circuit at the input and output. The Y-parameter model, for instance, is based on the assumption of sinusoidal terminal voltages (although the associated currents may be quite non-sinusoidal). Similarly, the hybrid model assumes both a sinusoidal current at the gate and a sinusoidal drain voltage. These conditions may be secured in principle to any arbitrary degree by the inclusion of appropriate filters in the external circuit (1).

Strictly, the large-signal S-parameter model requires both voltage and current to be sinusoidal at input and output, and, therefore, its meaningfulness is doubtful under large-signal conditions, although this approach is commonly used in the literature (2), (3).

It is quite straight-forward to determine the values of the elements shown in Fig. 3 at a number of specific amplitudes by means of the large-signal analysis program (for example, Y_f in Fig.3(a) may be determined as the ratio of the short-circuit output current to the input drive voltage V_1, etc.). Using numerical interpolation, this data then serves to characterise the non-linear behaviour of the active device at



(a) Admittance or Y-Parameter Model

(b) Scattering Parameter Model

(c) Hybrid Parameter Model

Fig.3: Large-Signal MESFET Equivalent Circuit Models at Design Frequency

the design frequency. Although the discussion here has been in terms of an equivalent-circuit device characterisation, the data could be equally well produced by a non-linear simulator based on device physical behaviour.

Oscillator Design

The design procedure is outlined in the case of the Y-parameter model : the other cases may be treated similarly. Suppose an oscillation has been established at the required frequency and that the voltage V_1 (= $|V_1|.\angle 0°$) is known in Fig. 3(a). Two node equations may then be written as follows:

$$j.B_2(V_2 - V_1) = \left[jB_1 + Y_i(|V_1|)\right].V_1 + Y_r(|V_2|).V_2 \quad ....(1)$$

$$j.B_2(V_1 - V_2) = Y_f(|V_1|).V_1 + \left[Y_o(|V_2|) + B_3 + G_L\right].V_2 \quad ....(2)$$

The unknown parameters are $|V_2|$, ϕ, B_1, B_2, B_3 and a solution of these two equations in real and imaginary form will yield four values, so the system is underdetermined. An assumption such as $B_1 = B_3$, or B_3 set equal to a fixed value, may be made to produce a determined system.

The procedure is then to assume trial values of B_1, B_2 and to consider the magnitude form of equation (1) as defining a non-linear equation in $|V_2|$ which may be solved numerically. Application of equation (1) in complex form will then provide the phase of V_2. Using a root-finding procedure for systems of non-linear equations, the initial trial values of B_1, B_2, B_3 are iteratively adjusted until the node equation at (2) is satisfied. If no oscillation is possible, then no roots will be obtained. This procedure has been found in practice to be extremely fast, convenient and reliable. In order to obtain the maximum output power, the voltage $|V_1|$ is stepped systematically until a maximum occurs in $|V_2|$.

Results and Conclusions

An example of the computed variation in oscillator drain voltage with gate voltage amplitude is given in Fig. 4, using the Y- parameter model (solid line). In order to check the design data generated, the large-signal analysis tool (SPICE2) may be run at each design point, with the device now characterised by its full equivalent circuit (Fig.1(a)). When the time-domain solution is continued until a steady-state oscillation is obtained, and the drain voltage waveform is Fourier Analysed, the plot shown as a dashed line in Fig.4 is obtained.

In view of the approximations inherent in the method described, the agreement shown in Fig.4 is quite good. An example of the gate and drain voltage waveforms obtained from SPICE2 at the maximum power point is shown in Fig.5. Similar exercises to the above have been carried out in the case of the S - model and the H - model, and the data for all three at the maximum power point is summarised in Table (1).

Overall it is seen that the mutual agreement between the various modelling approaches is quite good. The Y - model produces a design yielding slightly higher output power than the others, however, the H - model more nearly predicts the

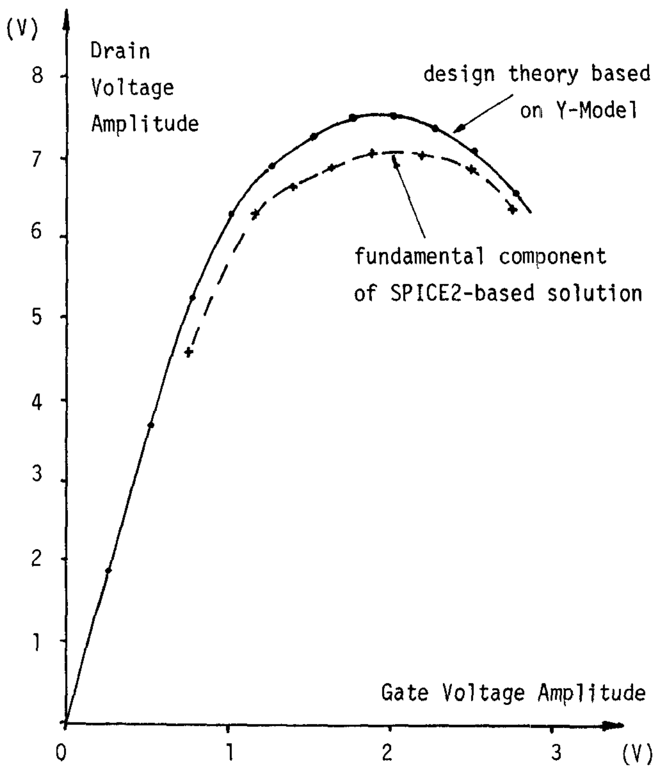


Fig. 4 : Comparison of Y-Parameter Oscillator Designs with Time-Domain Simulation Results.

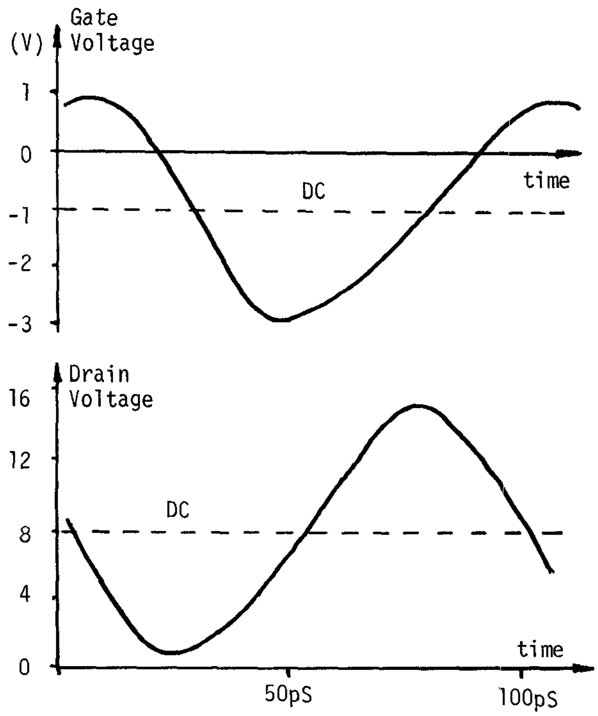


Fig. 5 : Oscillator Waveforms at Maximum Power From Time-Domain Analysis

TABLE (1)

SUMMARY OF RESULTS AT MAXIMUM

OSCILLATOR POWER

Model		Input Voltage/ Current	Output Voltage Amplitude(V)	Phase Shift (Degrees)	Power Output (mW)	Frequency (GHz)
Y-Model	Predicted	2.0V	7.553	96.09	570	10.0
	Obtained	1.878V	7.048	93.08	496	9.98
S-Model	Predicted	2.25V	7.332	91.77	537	10.0
	Obtained	2.121V	6.983	92.34	488	9.97
H-Model	Predicted	0.225A	7.075	78.11	501	10.0
	Obtained	0.210A	6.914	77.67	479	9.97

(Note: all voltage and current values refer to signal amplitudes at the fundamental frequency.)

actual power obtained from self-consistent solution. The S - model appears to be the least effective. In all cases the operating frequency obtained was particularly close to the design value.

In conclusion, it is believed that a useful design methodology has been presented and evaluated which permits efficient and quite accurate optimization to be carried out for MESFET oscillator applications.

References

(1) Brazil T., "Evaluation of non-linear functional equivalent circuit models for a GaAs MESFET and their application to optimum power amplifier design," 16th European Microwave Conference, Dublin, pp.195-200 Sept. 1986.

(2) Johnson, K.M., "Large-Signal GaAs MESFET oscillator design," IEEE Trans. Microwave Theory Tech., vol. MTT-27, pp. 217-227, March 1979.

(3) Gilmore R.J., and Rosenbaum F.J., "An analytic approach to optimum oscillator design using S-parameters," IEEE Trans. Microwave Theory Tech., Vol. MTT-31, pp. 633-639, August 1983.