MODELING AND ANALYSIS OF GaAs MESFETs CONSIDERING THE WAVE PROPAGATION EFFECT

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ABSTRACT

The effect of wave propagation along the electrodes of a GaAs MESFET is studied using distributed circuit analysis technique. Each distributed device element is considered as a combination of two pair of coupled coplanar strips and a conventional GaAs MESFET. The distributed equivalent circuit is then analyzed using SUPER-COMPACT. The maximum available power gain (MAG) or the maximum stable power gain (MSG) of the device is calculated as a function of device width. The results show, for single gate MESFETs over 100 µm wide, the transmission line properties of the electrodes have a significant effect on the transistor performance. The power gain also depends on where the input signal is fed and where the output signal is extracted.

INTRODUCTION

As operating frequencies of microwave GaAs MESFETs increase to the millimeter wave range, the dimensions of the electrodes become comparable to the wavelength. The transmission line properties of the electrodes need to be considered in order for the device parameters extracted at low fequencies to be applied to broad band circuit analysis at microwave and millimeter frequencies.

Recently, Heinrich and Hartnagel [1] reported on their numerical study of the problem using the full wave analysis technique and concluded that the distributed nature of the electrodes becomes significant when the frequency is above 20 GHz. Heinrich [2] also proposed a distributed equivalent circuit model which takes less computer time in doing device analysis.

In this paper, a similar study is presented using a new distributed equivalent circuit model which can be integrated into a circuit simulator as a preprocessor. In the analysis, a microwave GaAs MESFET is subdivided into many small unit device elements. Each element is represented by a 4-port equivalent circuit as shown in Fig. 1, which combines a conventional MESFET small signal circuit model and ten other circuit elements to account for the coupled transmission line effect of the electrode structure. The parameters in the MESFET model circuit are obtained from DC and low frequency measurements. The ten extra circuit elements need to be calculated from the geometry and material constants of the electrodes using the formulation derived for coplanar waveguides and coplanar strips.

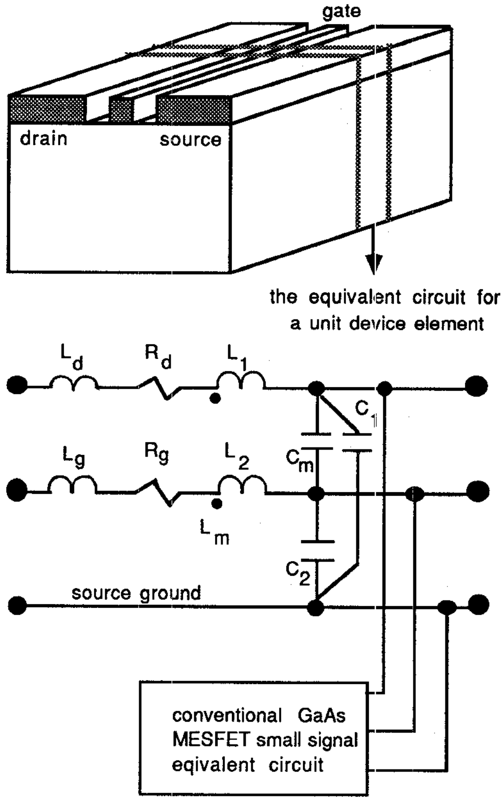

Fig. 1. The equivalent circuit of a unit GaAs MESFET device element in the distributed circuit model.

TRANSMISSION LINE PROPERTY OF THE ELECTRODES OF A GaAs MESFET

Assuming the source electrode of the unit GaAs MESFET element is grounded, the transmission line effect of a unit length of the drain electrode is modeled by L_1 and C_1 and a unit length of the gate electrode is

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modeled by L_2 and C_2. The coupling effect between the two electrodes is modeled by L_m and C_m. The internal inductance and resistance due to the skin effect are frequency dependent and are modeled by L_d, R_d, L_g, and R_g.

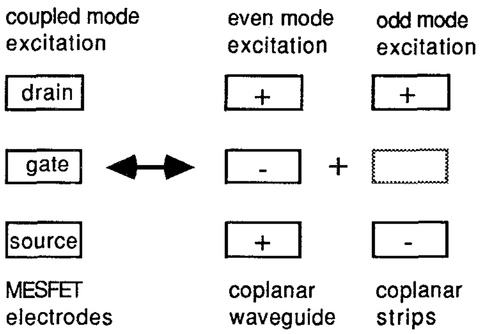

Fig. 2. The coupled excitation on the electrodes of a MESFET is decomposed into even mode and odd mode excitations, which are analogous to wave propagation on coplanar waveguide and strips.

These parameters are obtained from the geometry and material constants of the electrodes. This is a symmetrical device, i.e. the gate-source and gate-drain spacings are equal. It will also support TEM mode wave propagation of energy that can be decomposed into an even and odd mode of excitation as shown in Fig. 2. The even mode wave transmission is analogous to excitation of a coplanar waveguide [3, p.260] and the odd mode wave transmission is analogous to excitation of a pair of coplanar strips [3, p.266] each with equal circuit dimensions. The equivalent circuit elements for the electrodes in a unit device element (L_1, L_2, L_m, C_1, C_2, and C_m) are thus related to the coplanar waveguide equivalent circuit elements (L_{cpw} and C_{cpw}) and coplanar strip equivalent circuit elements (L_{cps} and C_{cps}) by

$$L_1 = L_{cps} \qquad (1)$$

$$L_2 = L_{cpw} + \frac{1}{4} L_{cps} \qquad (2)$$

$$L_m = \frac{1}{2} L_{cps} \qquad (3)$$

$$C_1 = \frac{1}{2} C_{cpw} \qquad (4)$$

$$C_2 = C_{cps} - \frac{1}{4} C_{cpw} \qquad (5)$$

$$C_m = \frac{1}{2} C_{cpw} \qquad (6)$$

The detailed analysis is given by Chang [4]. The values of L_{cpw}, C_{cpw}, L_{cps}, and C_{cps} can be calculated from the dielectric constants of GaAs and air and the characteristic impedances of the coplanar waveguide and coplanar strips [3,5] of same dimension as shown in Fig. 3.

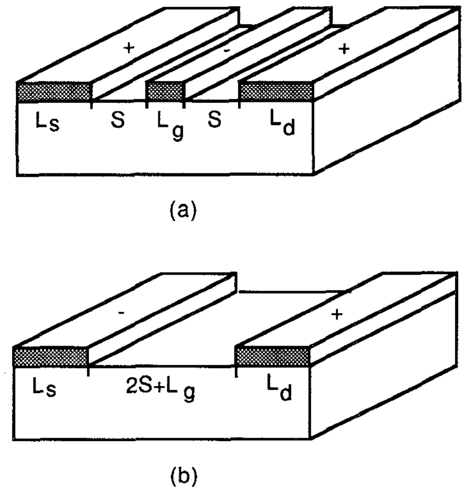

Fig. 3. A coplanar waveguide (a) and coplanar strips (b) of same dimension as the MESFET under consideration.

The internal inductance and resistance per unit length of an electrode are obtained from [6,7],

$$L = \frac{1}{a} Re[Z_{int} Coth(\Upsilon b)] \qquad (7)$$

$$R = \frac{1}{\omega a} Im[Z_{int} Coth(\Upsilon b)] \qquad (8)$$

Here, Z_{int} is the internal impedence of the electrode, a is the longer side and b is the shorter side of the crosssection of the electrode, respectively, ω is the angular frequency, and Υ is a propagation constant which is a function of skin depth δ.

$$\Upsilon = \frac{1+j}{\delta} \qquad (9)$$

Assuming all electrodes are made of gold 1 μm thick on a GaAs substrate of 100 μm thick as shown in Fig. 4. The device is assumed to be such that the gate length is 0.5 μm and the drain length is 50 μm. For various electrode spacings S, the calculated values of L_1, L_2, L_m, C_1, C_2, and C_m are tabulated in Table 1. The skin resistance, R_g and R_d, and internal inductance, L_g and L_d, of the gate and drain electrodes, respectively, are not dependent on the electrode spacing and are tabulated versus frequency in Table 2.

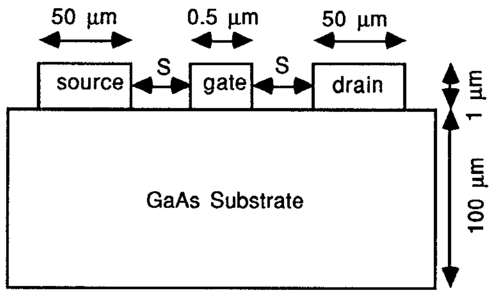

Fig. 4. Cross-sectional view of a unit GaAs MESFET device element under consideration.

TABLE 1

Model parameters in the equivalent circuit of a unit length coupled transmission lines as shown in Fig. 4.

Spacing S	1.0µm	1.5µm	2.0µm	2.5µm
L_1(pH/µm)	.387	.413	.436	.455
L_2(pH/µm)	.694	.769	.825	.870
L_m(pH/µm)	.194	.207	.218	.227
C_1(fF/µm)	.164	.154	.147	.141
C_2(fF/µm)	.065	.058	.054	.051
C_m(fF/µm)	.065	.058	.054	.051

TABLE 2

The skin resistance and internal inductance of the gate (0.5µm) and the drain (50µm) electrodes at various frequencies. The thickness of the electrodes is 1 µm.

Freq f (GHz)	R_g (Ω/µm)	L_g (pH/µm)	R_d (mΩ/µm)	L_d (fH/µm)
1	.044	.209	0.44	8.37
10	.045	.208	0.55	7.77
20	.047	.205	0.78	6.57
40	.055	.194	1.18	4.75
60	.066	.180	1.45	3.84
80	.078	.164	1.67	3.31
100	.090	.150	1.86	2.96

RESULTS

The circuit parameters illustrated in the previous section and the device parameters for the half micron gate length TI-TGF1350 commercial GaAs MESFETs were used in the SUPER-COMPACT simulations. The analysis was done by dividing the device into many unit device elements. Each element was modeled by the 4-port equivalent circuit shown in Fig. 1 and the resultant distributed equivalent circuit was analyzed for a 50 Ω characteristic impedance line.

If the device was unconditionally stable, the maximum available power gain (MAG) was calculated. If the device was conditionally stable, i.e., with a stability factor of less then one, the maximum stable power gain (MSG) was calculated instead. The results show that MAG/MSG varies with the device width in different ways at different frequencies. The transistor gain also depends on where the input signal is fed and where the output signal is extracted. A GaAs MESFET with both input and output nodes connected to the mid point of the gate and drain electrodes, as shown in Fig. 5, will provide a higher gain compared to devices of other input-output schemes, such as those shown in Figs. 6 and 7. For all practical purposes, a MESFET should have the width of a single gate limited to within 100 µm from feed point to end point for optimum power gain. Should higher current be required, a complex interdigitated gate electrode structure or a manifold cascade device structure should be used.

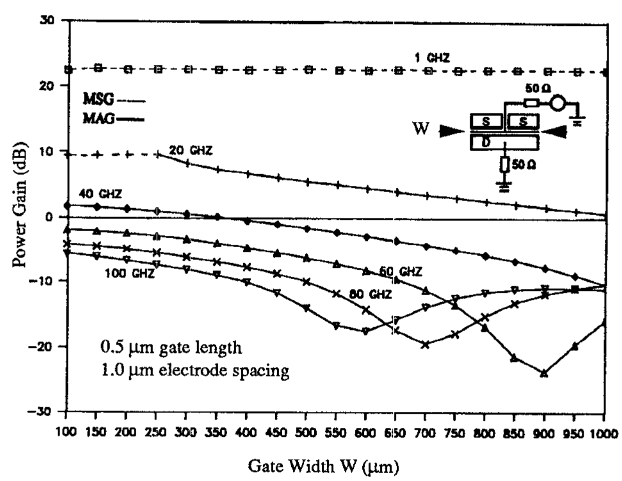

Fig. 5. The power gain of a GaAs MESFET with the inserted I/O scheme plotted as a function of gate width for various frequencies.

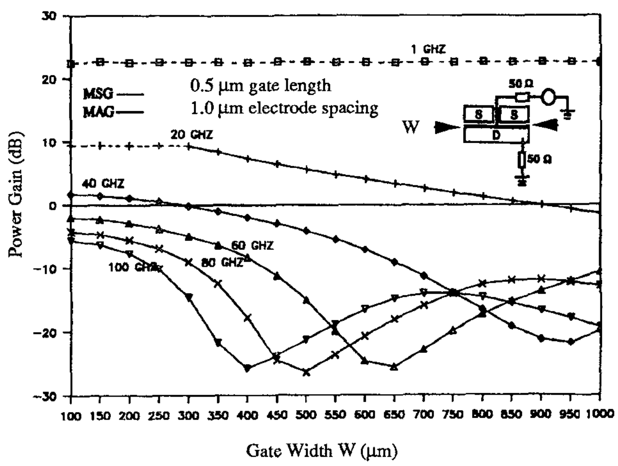

Fig. 6. The power gain of a GaAs MESFET with the inserted I/O scheme plotted as a function of gate width for various frequencies.

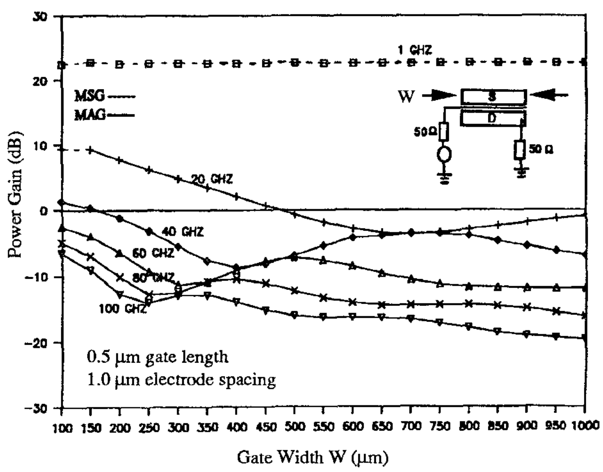

Fig. 7. The power gain of a GaAs MESFET with the inserted I/O scheme plotted as a function of gate width for various frequencies.

CONCLUSIONS

A distributed GaAs MESFET model is presented which takes into account the wave propagation effect on the electrodes. Each unit equivalent circuit consists of two sub-equivalent circuits: one to model the transmission line properties of the coupled gate and drain electrodes, and the other represents the traditional GaAs MESFET small signal model. The circuit elements in the first sub-equivalent circuit are calculated from the material constants and geometry of the electrodes. The parameters in the traditional GaAs MESFET model are obtained from DC and low frequency measurements. A preprocessor to a microwave circuit simulator is under development to take the device parameters from low frequency measurements and use the distributed equivalent circuit model presented here to calculate the high frequency device model parameters for more accurate microwave and millimeter wave circuit modeling.

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REFERENCES

1. W. Heinrich and H. L. Hartnagel, " Wave Propagation on MESFET Electrodes and Its Influence on Transistor Gain," IEEE Trans. Microwave Theory and Tech., MTT-35, p.1, 1987.

2. W. Heinrich, "Distributed Equivalent-Circuit Model for Traveling Wave FET Design," IEEE Trans. Microwave Theory and Tech., MTT-35, p.487, 1987.

3. K. C. Gupta, R. Gary, and I. J. Bahl, Microstrip Lines and Slot Lines, Artech House, 1979.

4. R. J. Chang, Modeling and Analysis of a GaAs MESFET Considering Wave Propagation Effect on the Electrodes, M.S. Thesis, the University of Texas at Arlington, 1988.

5. G. Ghione and C. Naldi, "Analytical Formulas for Coplanar Lines in Hybrid and Monolithic MICs," Electron Letters, vol.20, p.179, 1984.

6. H. Guckel, P. A. Brennan, and I. Palocz, "A Parallel Plate Waveguide Approach to Microminiaturized Planar Transmission Lines for Integrated Circuits," IEEE Trans. Microwave Theory and Tech., MTT-15, p.468, 1967.

7. D. Jager, "Slow Wave Propagation Along Variable Schottky Contact Microstrip Lines," IEEE Trans. Microwave Theory and Tech. MTT-24, p.566, 1976.