DISTRIBUTED SMALL SIGNAL MODEL FOR MULTI-FINGERED GaAs PHEMT/MESFET DEVICES

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ABSTRACT

A fully distributed equivalent circuit PHEMT and MESFET model is presented in closed form expressions for single finger end-fed FET geometry. The model includes self and mutual inductances and a new frequency dependent gate resistance. The model was used successfully to model multi-fingered devices which were subjected to equi-phase gate and drain excitations.

Comparisons between measured data and model results are shown to be in excellent agreement for all S-parameters to 50GHz regardless of unit gate width. Scaling issues are also investigated for the new distributed model.

INTRODUCTION

A new distributed model has been developed for a single finger end fed geometry FET. Our model extends previous work done by LaRue [1] for a center fed pi-geometry FET. The new distributed model includes the impedances of the gate and drain electrodes, mutual inductances between the gate and drain electrodes, and a frequency dependent resistance along the gate electrodes. We believe that this is the first introduction of a frequency dependent gate resistance in a small signal model. The single finger gate distributed model can be used to model multi-fingered FET devices provided all fingers are excited in phase. For longer devices, additional elements can be included to compensate for phase variations along the device. Using the new distributed model, excellent agreement between modeled and measured data was obtained for a large variety of unit gate width PHEMT devices from 0 to 50GHz.

The development of a distributed model for multi-fingered FETs was done to obtain a more physical model to account for propagation effects along the gate and drain electrodes. In developing the model we expected to describe FETs more accurately and also to scale devices with periphery more accurately than with the standard lumped element model.

Several PHEMT devices were measured and modeled with our new distributed model. Excellent fit was obtained for all the measured S-parameters of the devices with the noticeable and important exception of the magnitude of S11. Its frequency behavior which could not be accounted for by the conventional lumped element model, could not also be accounted for by our distributed model. Several authors have published work describing skin effect resistance or AC resistance along strips of rectangular conductors [3,4,5]. Taking this under consideration, we have introduced a frequency varying gate resistance into our model and obtained excellent agreement with all S-parameters.

THEORY

The distributed model of the FET was developed from the equations for asymmetric coupled lines in an inhomogeneous medium[2]. Figure 1 shows a schematic diagram of the distributed model with the boundary conditions of zero current along the gate electrode at x = l and zero current along the drain electrode at x = 0. The two port Z parameters were derived from the second order differential equations listed below and the boundary conditions shown in Figure 1.

$$\frac{d^2V_g(x)}{dx^2} = V_g(x)\alpha^2 + V_d(x)\beta^2$$

$$\frac{d^2V_d(x)}{dx^2} = V_g(x)\delta^2 + V_d(x)\gamma^2$$

where the propagation constants are

$$\alpha^2 = Y_{11}Z_g + j\omega MY_{21}, \quad \beta^2 = Y_{12}Z_g + j\omega MY_{22}$$

$$\delta^2 = Y_{21}Z_d + j\omega MY_{11}, \quad \gamma^2 = Y_{22}Z_d + j\omega MY_{12}$$

and $Z_d = R_d + j\omega L_d$, $Z_g = R_g + j\omega L_g$, and M are the per unit width values of the impedances and the mutual inductance associated with the gate and drain electrodes. Y_{ij} are the intrinsic per unit width elements of the Y matrix of the device.

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The propagation parameters above take into account the intrinsic impedances of the gate and drain electrodes (Zg and Zd) and the coupling between the gate and drain electrodes. The inductive mutual coupling M adds additional coupling between the gate and drain electrodes. The main coupling has contributions from the active region of the device and fringing electrode capacitances and is represented by Y_{21} and Y_{12} in the model. The resulting distributed model Z-parameters, presented below, represent a continuous distributed model, not one with a finite number of sections.

$$Z_{11} = \frac{Z_g}{(r^-)^2 - (r^+)^2}\left[\frac{(r^-)^2 - \alpha^2 - \frac{j\omega M\beta^2}{Z_g}}{(r^+)\tanh(r^+ \cdot l)} - \frac{(r^+)^2 - \alpha^2 - \frac{j\omega M\beta^2}{Z_g}}{(r^-)\tanh(r^- \cdot l)}\right]$$

$$Z_{21} = \frac{Z_g\delta^2}{(r^+)^2 - (r^-)^2}\left[\frac{1 - \frac{j\omega M\beta^2}{Z_g\left((r^-)^2 - \alpha^2\right)}}{(r^+)\sinh(r^+ \cdot l)} - \frac{1 - \frac{j\omega M\beta^2}{Z_g\left((r^+)^2 - \alpha^2\right)}}{(r^-)\sinh(r^- \cdot l)}\right]$$

where

$$(r^\pm)^2 = \frac{1}{2}\left[\left(\alpha^2 + \gamma^2\right) \pm \sqrt{\left(\alpha^2 - \gamma^2\right)^2 + 4\beta^2\delta^2}\right]$$

Since the network is symmetric, the expressions for Z22 and Z12 are obtained by replacing Zg with Zd, β^2 with δ^2, δ^2 with β^2, α^2 with γ^2, and r^+ with r^- in the above expressions for Z11 and Z21. In our devices, Ls is not distributed therefore, $j\omega L_s$ should be added to each one of the above Z-parameters to complete the device model.

MEASURED VS. MODELED RESULTS

The new distributed model and the standard lumped element model were compared for a 1.2mm, 6x200µm PHEMT devices fabricated on 2 mil GaAs Substrates with 0.15µm T-gates. Each source finger was grounded through three 25µm square via holes. Small signal measurements were taken for several devices with a drain voltage of 5.0V and a drain current varying from pinch-off to Idss. The PHEMT devices were measured using 0 to 50GHz on-wafer probes on an HP8510 network analyzer. The network analyzer was calibrated to the gate and drain buss bars of the device using standards on GaAs substrates[6].

Measured versus modeled results are shown in Figures 2 and 3 for a bias of Vds = 5.0V, Vgs = -0.1V, and Ids = 159mA. Figure 2 shows the distributed model and standard lumped element model which were optimized to the measured data without using a frequency dependent Rg. It clearly shows that neither of the models accurately represents the measured magnitude of S_{11}.

An empirical formula for a frequency dependent resistance was derived by curve fitting the modeled data with the measured data. The frequency dependence of R_g was found to be the following;

$$R_g(f) = R_g(DC) \cdot \cosh\left(R_{se} \cdot f\right)$$

where $R_g(DC)$ and R_{se} are constants and f is in GHz.

The result of adding the frequency dependent resistance to the models showed a dramatic improvement in the agreement between the modeled versus measured magnitude of S_{11} as shown in Figure 3. The distributed model with $R_g(f)$ was then used to model several devices with unit gate widths of 37.5µm to 200µm very successfully.

MEASURED VS. SCALED MODELED RESULTS

Once excellent agreement between modeled and measured data was obtained with the distributed model, scaling issues were examined by measuring PHEMT devices with a fixed number of gate and drain fingers with different unit gate widths.

Two groups of 600µm and 1.2mm devices were used to investigate the scaling issues. One group used 8x75µm and 8x150µm devices, the other 12x50µm and 12x100µm. Since the two groups behaved similarly, detailed descriptions of the first group only are shown in the following.

S-parameter data of 600µm and 1.2mm devices was taken at Vds = 5V over a range of Ids between 0 and 163mA/mm. The equivalent circuit parameters of the two groups of devices were extracted and compared to each other. Perfect scaling in our distributed model requires equivalency of all the parameters of devices with the same number of fingers. Representative equivalent circuit parameters of 8x75µm (600µm) and 8x150µm (1.2mm) devices are shown in Figures 6 - 12. As can be seen in the figures, the devices do not scale perfectly at any current value. The largest deviation from perfect scaling was observed for R_i which varies between being larger in the shorter unit width devices at low Ids, to being smaller in these devices at high Ids. The discrepancies of the other parameters vary monotonically with drain currents and reach maximum values of 25% at high drain currents. It is interesting to note that the least scaling discrepancy is observed for g_m as shown in Fig. 7.

CONCLUSIONS

The distributed model has been successfully developed for the multi-finger FET geometry. The introduction of a frequency dependent gate resistance showed improved match of measured versus modeled data to 50GHz.

It was also shown that equivalent circuit parameters in the small signal model do not scale perfectly as a function of device periphery and drain current. With further characterization, it may be possible to develop relationships between equivalent circuit parameters as a function of unit gate widths and drain current making it possible to scale the model for different size devices.

ACKNOWLEDMENTS

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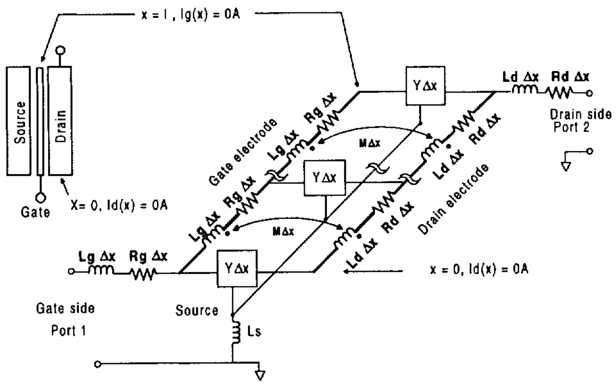


Figure 1(a). Distributed model of single finger FET.

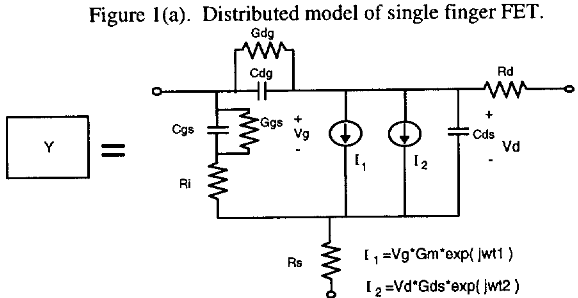
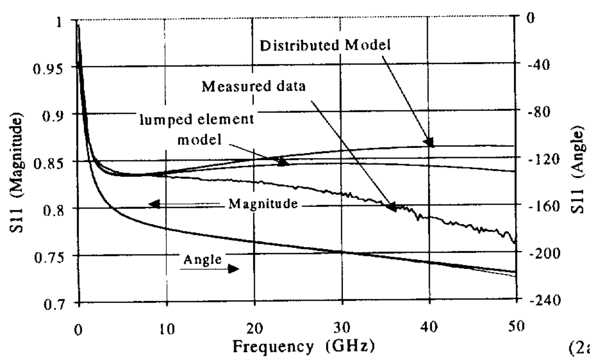
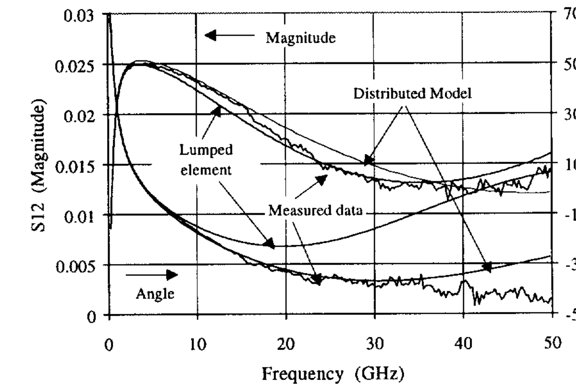


Figure 1(b) Slice model representation of an incremental section of the distributed model.



(2a)



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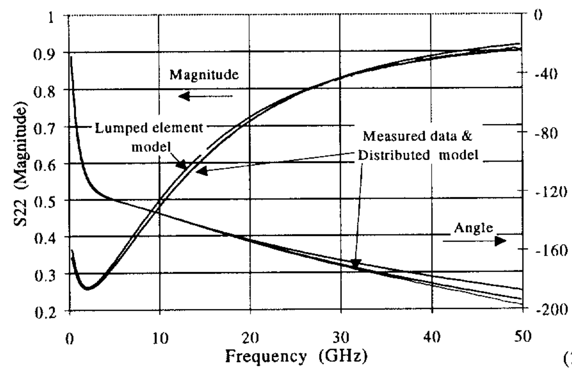
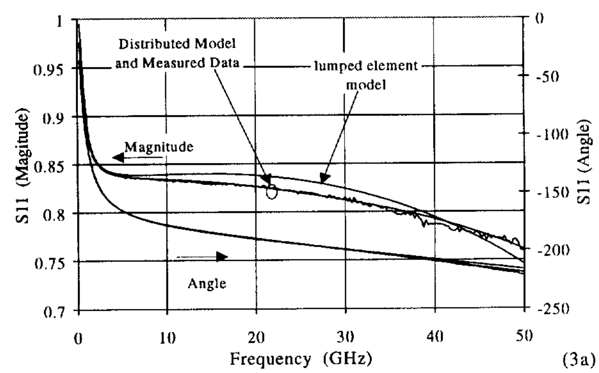
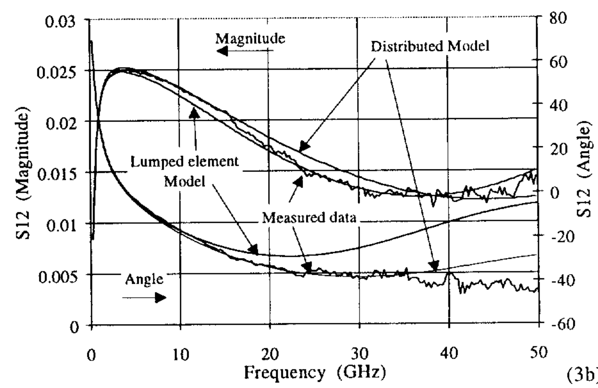


(2c)

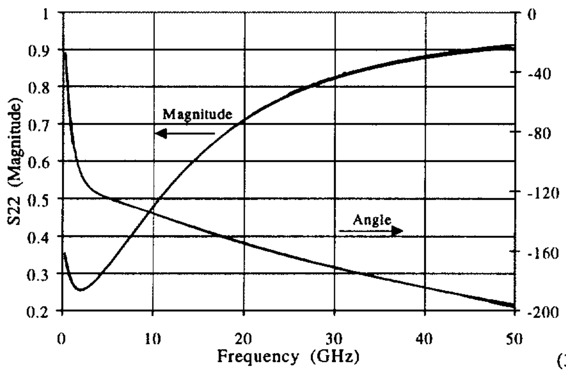
Figures 2a to 2c. Distributed and Lumped element model without frequency dependent gate resistance versus Measured S-parameter data of an 1.2mm (6x200µm) PHEMT device.
Bias: Vds = 5V, Vgs = -0.1V, Ids= 159mA



(3a)



(3b)



(3c)

Figure 3a to 3c. Distributed and Lumped element model with frequency dependent gate resistance versus Measured S-parameter data of an 1.2mm (6x200μm) PHEMT device.
Bias: Vds = 5.0V, Vgs = -0.1V, Ids = 159mA.

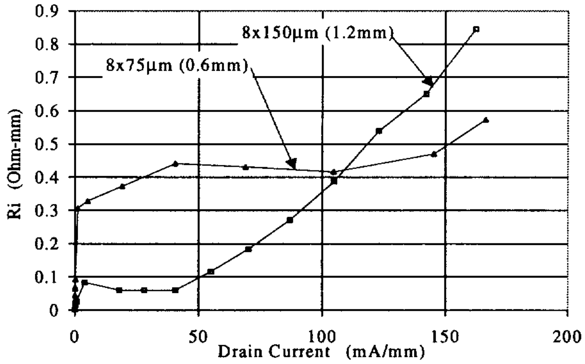


Figure 6. Independently optimized Ri versus drain current (mA/mm)

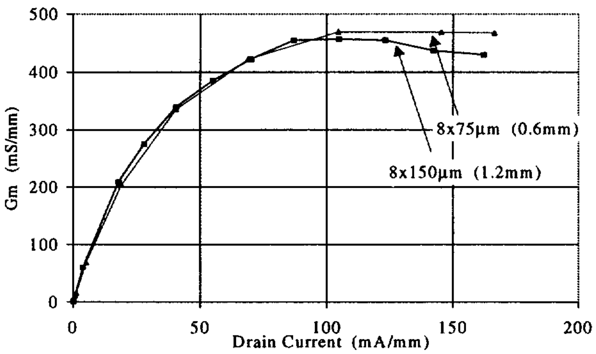


Figure 7. Independently optimized g_m versus drain current (mA/mm).

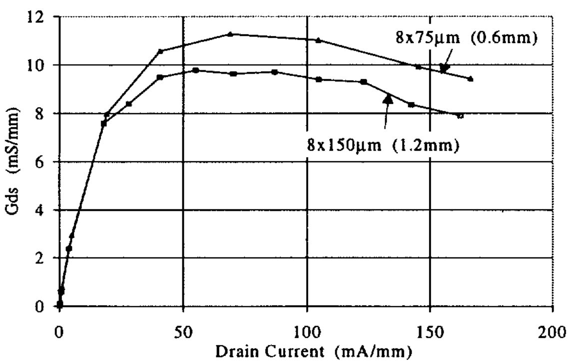


Figure 8. Independently optimized G_{ds} versus drain current (mA/mm).

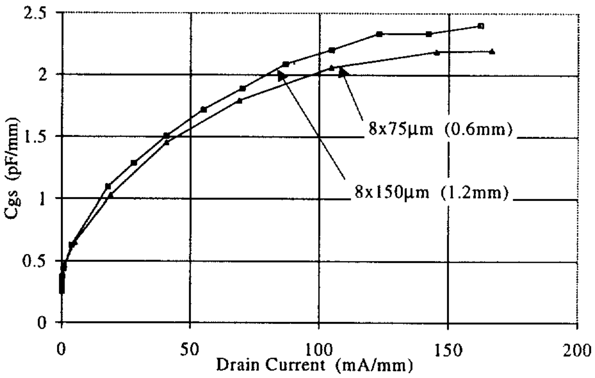


Figure 9. Independently optimized C_{gs} versus drain current (mA/mm).

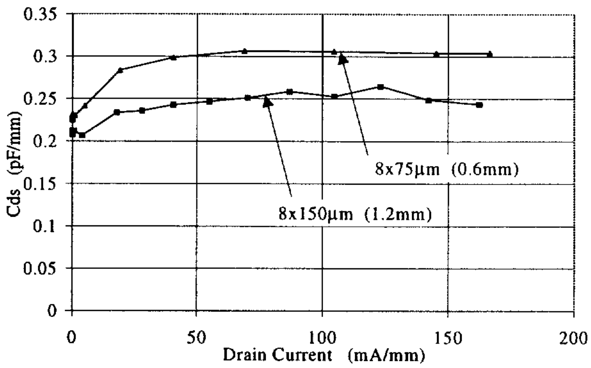


Figure 10. Independently optimized C_{ds} versus drain current (mA/mm).

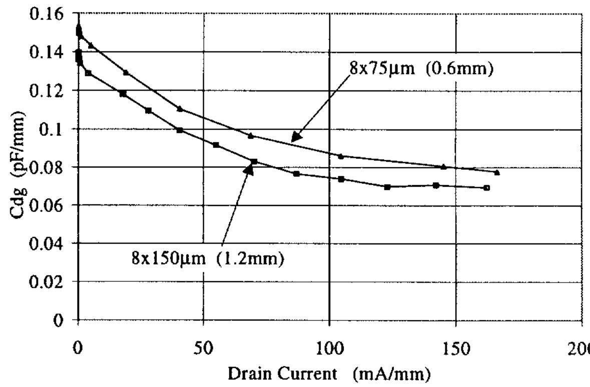


Figure 11. Independently optimized C_{dg} versus drain current (mA/mm).

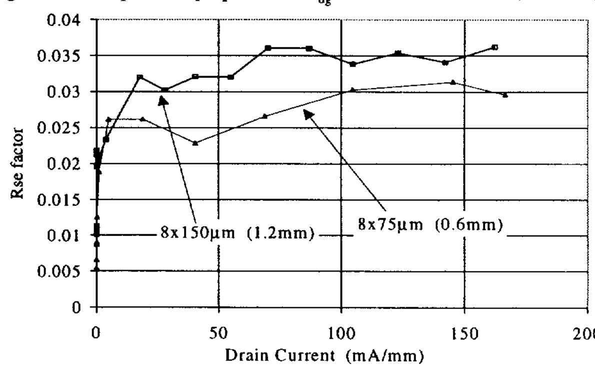


Figure 12. Independently optimized R_{se} versus drain current (mA/mm).