SIMULATION OF HIGH FREQUENCY DISPERSION PHENOMENA IN EQUIVALENT CIRCUITS FOR MICROWAVE FET-TYPE DEVICES

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ABSTRACT

Two different mechanisms are proposed to explain and simulate the high frequency dispersion phenomena in equivalent circuits for microwave FET-type devices: a) transversal propagation along the metallizations of the device, and b) limitations in the intrinsic equivalent circuit. The first mechanism is accounted for by using a distributed equivalent circuit, while the second one is modelled by means of a modified intrinsic equivalent circuit.

Keywords: FET-type device equivalent circuits, high frequency dispersion, microwave and millimeter wave CAD.

1. INTRODUCTION

Equivalent circuits are an essential tool in the CAD of microwave and millimeter wave applications of FET-type devices like MESFETs and HEMTs. However, when extracted from S-parameters, the elements of these equivalent circuits show an important frequency dependence above 10 GHz [1]. These phenomena, named 'high frequency dispersion phenomena', reduce the usefulness of the equivalent circuits in the extrapolation of the behaviour of the device outside the measurement frequency range, and suggest the existence of frequency limits for the modelling.

A FET-type device is really a 3D device where the width of the gate is an important parameter. The importance of this parameter increases with the frequency since the device can be considered as a coupled transmission line structure where modes can propagate along the metallizations. Therefore transversal propagation effects must be incorporated into HEMT or MESFET models when the simulation or their behaviour at millimeter wave frequencies is required [2].

However, this mechanism is not sufficient to explain high frequency dispersion phenomena. If transversal propagation is removed by resorting to 2D physical simulations, the derived intrinsic Y-parameters can not be modelled by the most commonly used intrinsic equivalent circuits ('intrinsic high frequency dispersion phenomena'). Since no transversal propagation effects can be claimed in this case, futher modifications must be introduced in the intrinsic circuit.

In this paper, an equivalent circuit which incorporates both mechanism is presented. Its ability to simulate the high frequency dispersion phenomena is shown using a Fujitsu MESFET device.

2. THE EQUIVALENT CIRCUIT

The equivalent circuit proposed to simulate high frequency dispersion phenomena is shown in Fig. 1, where transversal propagation effects can be accounted for by using a distributed equivalent circuit. In this distributed circuit, Rtg, Rtd, Ltg, Ltd and Mt are introduced in order to build, in conjunction with a certain number of intrinsic cells, a coupled transmission line that models the distributed nature of the device metallizations. This distributed circuit with one of its terminations open-circuited and excited through the other termination is used to simulate the behaviour of the intrinsic device.

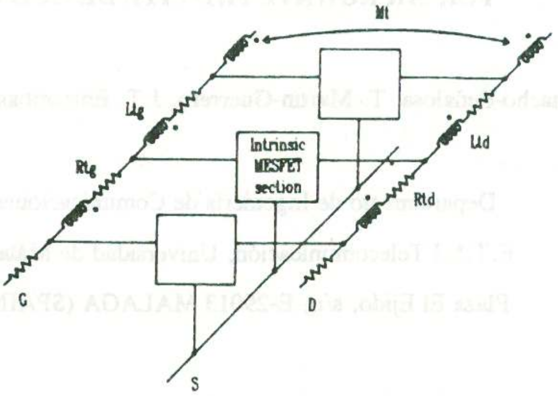

Figure 1: *Equivalent circuit for the simulation of transversal propagation effects (intrinsic MESFET).*

It is clear that the simulation of the intrinsic high frequency dispersion phenomena has to be performed by the equivalent circuit corresponding to the intrinsic MESFET section. The modification proposed in this paper can be seen in Fig. 2, where a resistance Rdd has been introduced in a previously developed model [3].

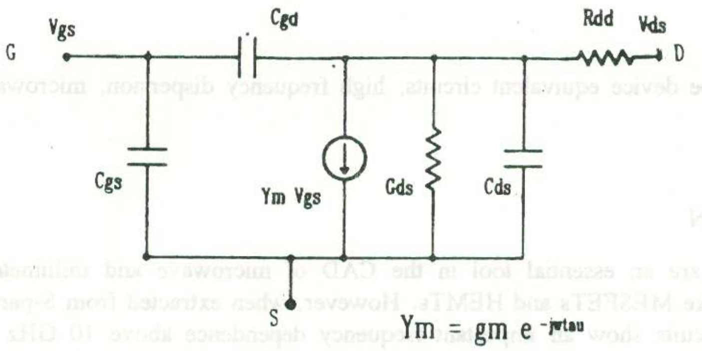

Figure 2: *Equivalent circuit for the simulation of intrinsic high frequency dispersion (intrinsic MESFET section).*

Eight extrinsic elements (Lg, Rg, Cpg, Ld, Rd, Cpd, Rs and Ls) have been added to the circuit to take into account the effect of bond wires, bonding pads and source via holes, as shown in Fig. 3.

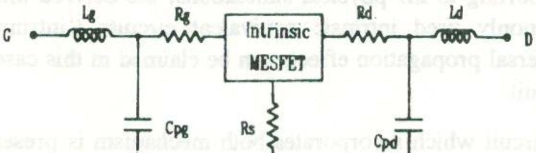

Figure 3: *Extrinsic elements in the complete equivalent circuit.*

3. RESULTS

In order to check the capabilities of the proposed model, a MESFET device from Fujitsu (power FET chip FLK022XV) has been used. The values of the elements of the equivalent circuit have been obtained by fitting the simulated S-parameters to the mesured ones by means of an in-house optimization computer code. The results corresponding to the bias condition defined by Vgs=-0.64V and Vds=5V are presented in Table I (20 intrinsic cells were used in the computations). Fig. 4 shows the good simulation provided by the proposed model.

Gme (mS)	Cme (pF)	Gds (mS)	Cds (pF)	Cgd (pF)	Cgs (pF)	Rdd (ohm)
59.3	-0.24	4.85	0.12	0.035	0.62	2.1

Table I (a) *: Intrinsic MESFET section elements.*

Rtg (ohm)	Ltg (ohm)	Rtd (ohm)	Ltd (ohm)	Mt (pH)
7.0	0.20	6.5	0.47	5.2

Table I (b) *Propagation elements.*

Rd (ohm)	Ld (nH)	Rg (ohm)	Lg (nh)	Rs (ohm)	Ls (pH)	Cpg (pF)	Cpd (pF)
0.62	0.11	0.17	0.13	2.3	1.1	0.022	0.073

Table I (c) *: Extrinsic elements.*

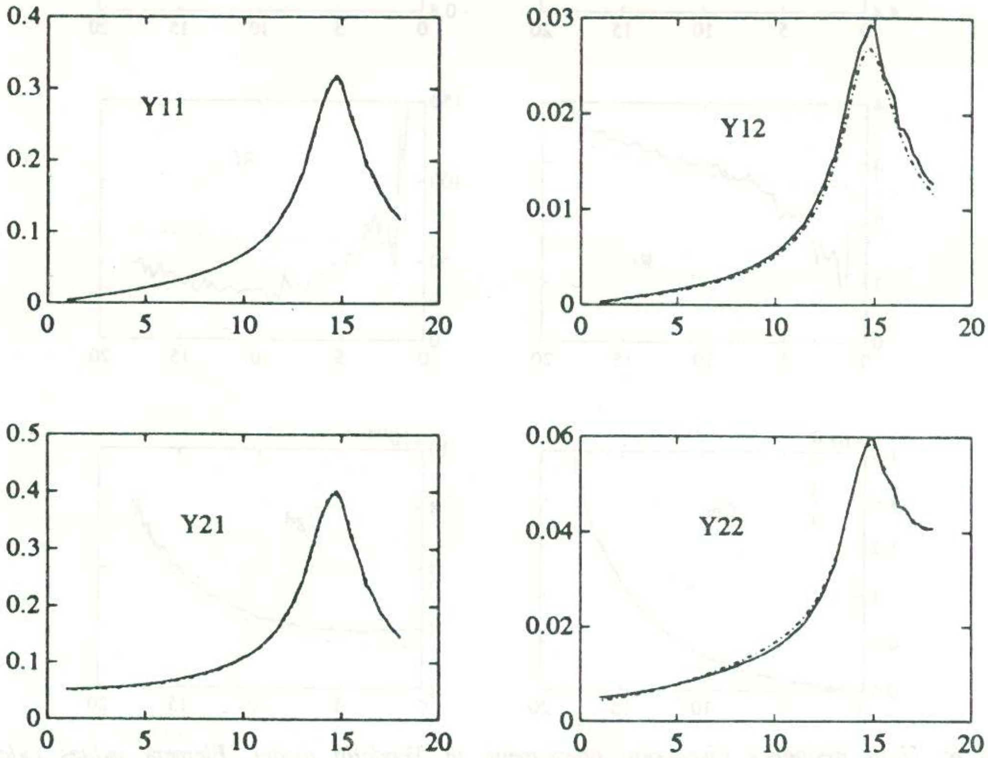

Figure 4: *Calculated (dashed lines) and measured (solid lines) Y-parameters (magnitude, S) for the Fujitsu MESFET (frequency range 0-20 GHz).*

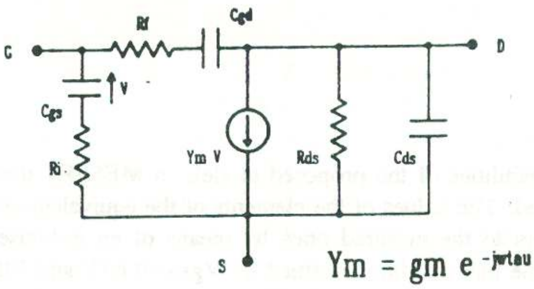

Figure 5: *Vendelin model*

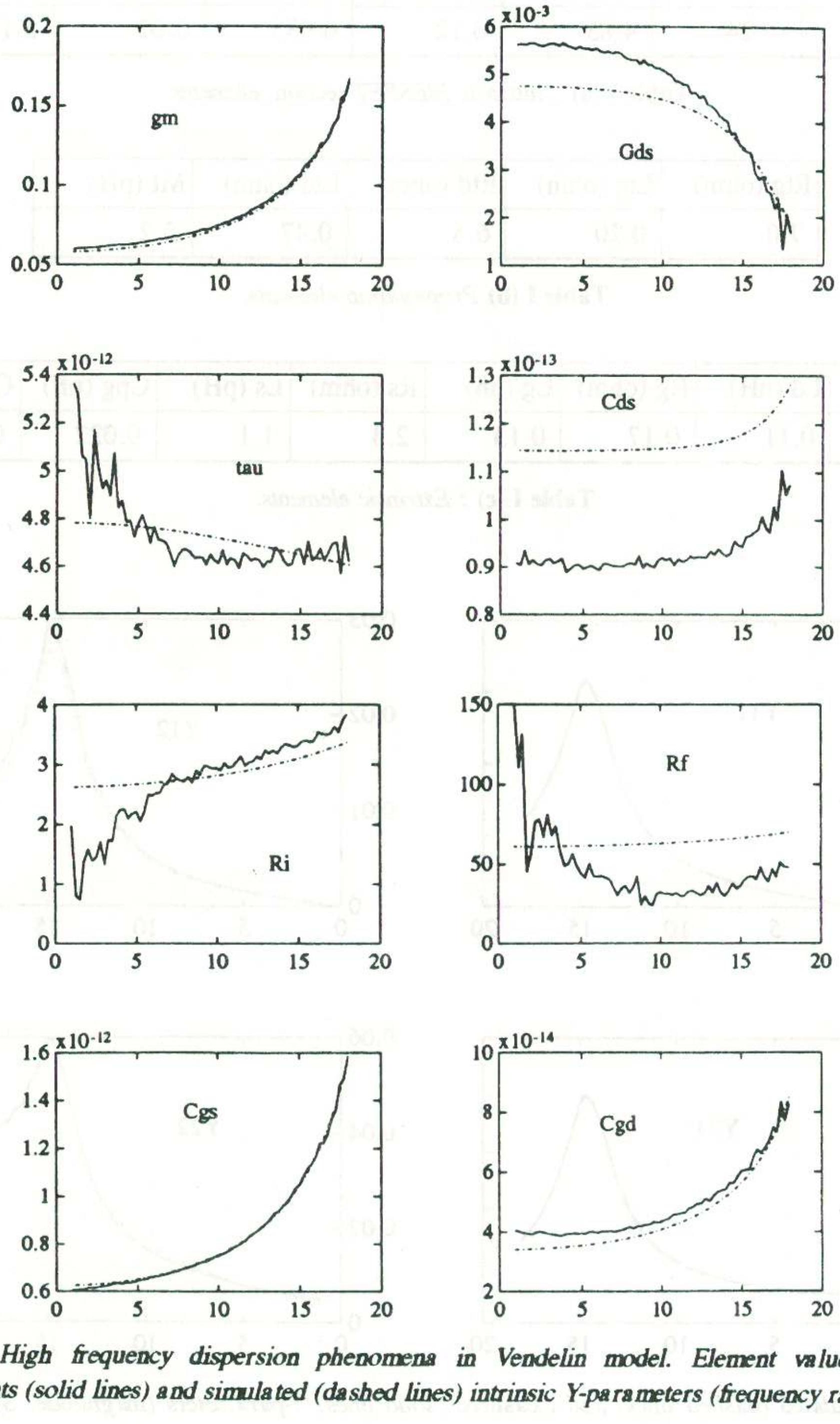

Figure 6: *High frequency dispersion phenomena in Vendelin model. Element values calculated from measurements (solid lines) and simulated (dashed lines) intrinsic Y-parameters (frequency range 0-20 GHz).*

In order to study the ability of the proposed model to predict the high frequency dispersion phenomena, a commonly used equivalent circuit, the Vendelin model [4] (see Fig. 5) has been utilized. To perform this study, the element values of Vendelin model have been calculated from the measured intrinsic Y-parameters (after extracting the extrinsic elements) up to 18 GHz. The results are shown in Fig. 6 It is evident from this figure that a very strong frequency dependence ('high frequency dispersion') exists in this equivalent circuit and that, therefore, any extrapolation of the performance of the device by using this model would not be very reliable. On the contrary, the dashed lines also shown in this figure, and corresponding to the simulated intrinsic Y-parameters, suggest that the proposed equivalent circuit is able to simulate very closely these high frequency dispersion phenomena. It should be emphasized that this model can simulate this dispersive behaviour with elements that are frequency-independent.

In the case of the so called 'intrinsic high frequency dispersion' a comparison between measured and simulated results is not possible since any real device is always tridimensional. Nevertheless it is possible to get some information about the frequency behaviour of the 2D intrinsic cell by simulating the Y-parameters of the overall intrinsic cell shown in Fig. 2 with the element values presented in Table I. Fig. 7 shows the frequency behaviour of the Vendelin elements (normalized) when used to simulate this '2D intrinsic cell'. It transpires from this figure that the Vendelin model has some inherent ability to simulate the intrinsic high frequency dispersion since many of its elements are almost frequency-independent.

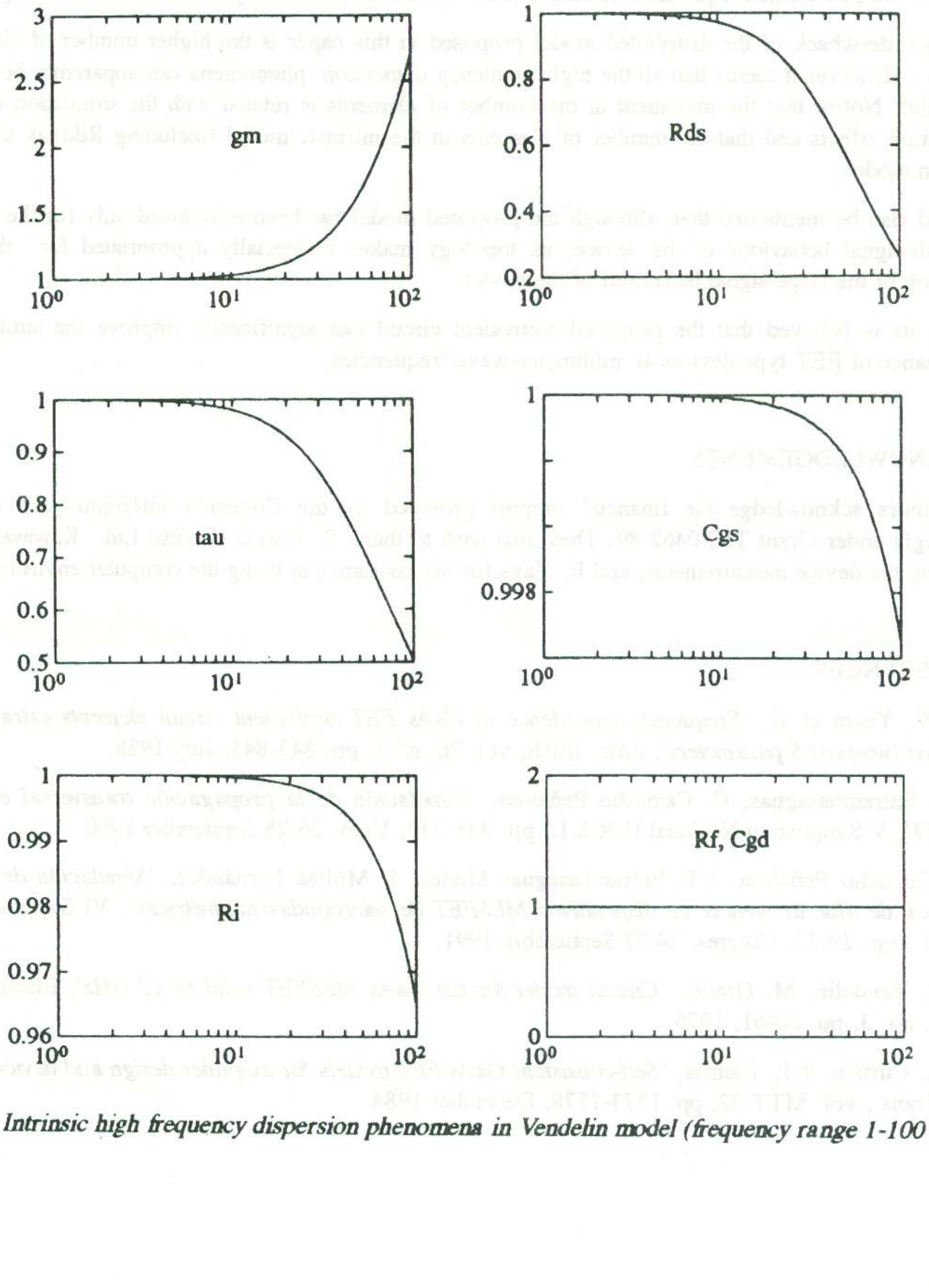

Figure 7: *Intrinsic high frequency dispersion phenomena in Vendelin model (frequency range 1-100 GHz).*

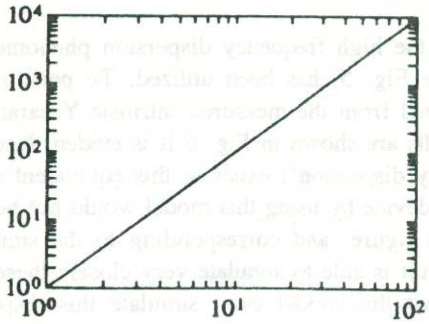

Figure 8: *Normalized real part of Y12 parameter simulated by the proposed intrinsic model.*

The circuit shown in Fig. 2 is the result of adding a resistance Rdd to a very simple equivalent circuit that has no conductance elements between gate and source or gate and drain, and that therefore is unable to simulate any dispersion phenomena in the intrinsic cell. The introduction of this new resistance modifies significantly the frequency behaviour of the intrinsic elements. In particular, the real part of the resulting Y12 is proportional to the square of the frequency (Fig. 8), which is consistent with the results obtained by 2D physical simulations [5].

4. CONCLUSIONS

A model has been proposed that is able to simulate with great accuracy the high frequency dispersion phenomena. The main advantage of this model is that it can provide some physical explanation to the observed frequency behaviour in the elements of commonly used equivalent circuits. In particular, the obtained results suggest that transversal propagation effects are extremely important at this frequency range. This means that the use of lumped-element equivalent circuits must be questioned since they can lead to misleading conclusions.

The major drawback of the distributed model proposed in this paper is the higher number of elements that it includes . However it seems that all the high frequency dispersion phenomena can apparently be simulated by this model. Notice that the increment in the number of elements is related with the simulation of transversal propagation effects and that the number of elements in the intrinsic model (including Rdd) is smaller than in Vendelin model.

It should also be mentioned that, although the proposed model has been introduced only for the simulation of the small-signal behaviour of the device, its topology makes it specially appropriated for the efficient simulation of the large-signal behaviour of the device.

Finally, its is believed that the proposed equivalent circuit can significantly improve the simulation of the performance of FET-type devices at millimeter-wave frequencies.

5. ACKNOWLEDGEMENTS

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