Electromagnetic Analysis for Microwave FET Modeling

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***Abstract*—This letter presents a technique to analyze complex microwave devices. An electromagnetic three-dimensional (3-D) software is applied to characterize the distributed part of the structure. It is coupled to a circuit simulator to introduce the contribution on the electrical response of the localized passive or active elements contained in the device. The link between the two parts is made thanks to a new type of access, "the localized access."**

We have applied this method to the study of a field effect transistor and good agreements are observed between simulations and measurements from 1 to 30 GHz.

***Index Terms*— FET modeling, finite-element method, hybrid electrical and electromagnetic method.**

I. Introduction

COMPLEX microwave circuits have been until now analyzed applying some commercial simulators. This technique requires the segmentation of the studied structure into simple elements which have responses that are available in a model library. These elements are characterized independently from each other.

Because of the small size and the higher work frequencies of new microwave devices, some indirect electromagnetic couplings can appear between the different parts of the circuits (the distributed ones and the discontinuities between the lines), and also in the passive part of some active elements (the metallization of a field-effect transistor (FET), for example). The segmentation approach cannot permit to take into account these interactions.

With the improvement in computer performance, more rigorous methods have been proposed recently to design complex devices containing both active and passive parts [1]–[3]. We have proposed to couple an electromagnetic simulator, based on the finite-element method (FEM) defined in the frequency domain, and a circuit software [4], [5]. The electromagnetic modeling is applied to the global distributed domain of the circuit. Some localized access are placed inside the meshed volume of analysis to allow a circuit segmentation of the localized passive or active elements. They substitute to the lumped elements, which are not described by their geometrical topologies but by electric relations on their boundaries. So, we can integrate active and/or passive lumped elements or networks in a distributed passive structure. A more developed description and a validation analyzing simple structures have been presented in a previous publication [5].

Our objective is here the characterization of an FET. The global study of this element is divided in two parts. We first analyze the passive domain of the FET, taking into account all its metalizations. The GaAs substrate is in this first approach represented as a dielectric medium. But some localized access is distributed between the source, gate, and drain electrodes. We have then modeled the extrinsic part of the element. This study is presented in Section I. In Section II, an intrinsic circuit model of the real active part of the element is built.

We are then able to give in Section III the response of the whole element, connecting the equivalent scheme of the intrinsic part between the localized access of the distributed domain. The circuit representation is then transferred directly under the electrodes.

Thus, a new model of the FET is established, taking into account all the electromagnetic interactions, not only in the extrinsic part but also between the component and its environment if necessary.

Measurements have been performed and are in good agreements with the theoretical results.

II. Study of the Extrinsic Part of the FET

For this analysis, we used an undoped interdigited FET presented Fig. 1.

So as to reduce the computing time and to let us a greater ease if some dimensional optimizations have to be done, we have segmented the structure in three parts: one (S1) including the gate access and the source contacts, one (S3) including the drain access, and the central one (S2) composed of the different electrodes, where the localized access are integrated.

A modal decomposition is performed in the segmentation planes represented by the dashed lines.

For each segment, we establish a generalized $[S]$ matrix and the different contributions are at last chained to obtain the final $[S]$ matrix between the drain and the gate distributed access. An analysis of the global structure is also performed to validate this segmented approach.

We can verify in Fig. 2 a good agreement between the segmented and global approach and measurements of the undoped FET.

These good results allow us to carry on with the study of the intrinsic part.

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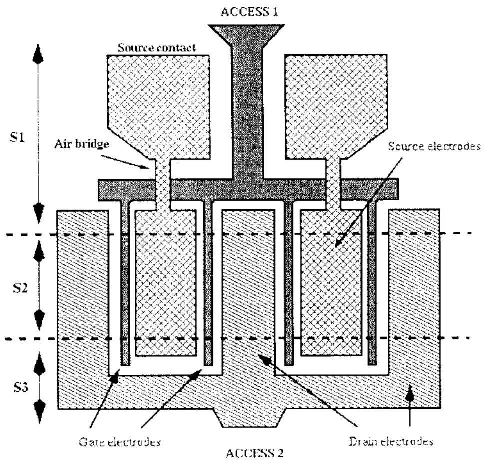

Fig. 1. Distributed passive part of the FET.

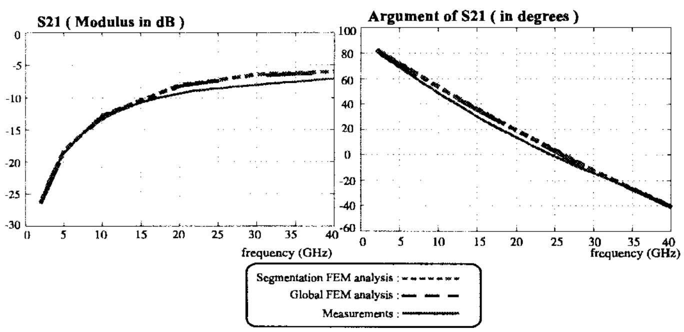

Fig. 2. Comparison between segmented and global FEM analysis and measurements of the undoped FET.

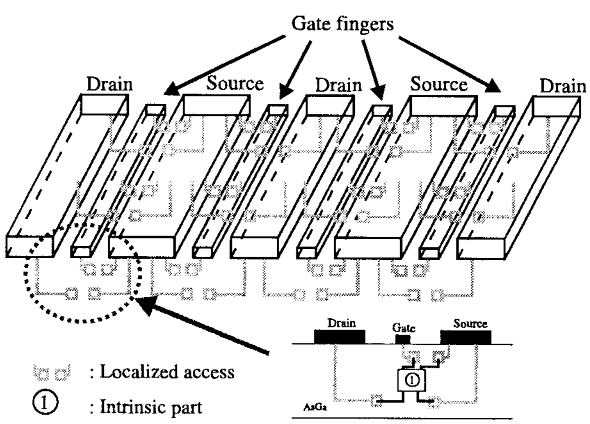

Fig. 3. Distribution of the localized access along the electrodes.

III. Study of the Intrinsic Part of the FET

We performed simultaneously pulsed $I(V)$ and S-parameters measurements of device at different bias conditions. Then, the nonlinear model can be determined using a classical extraction procedure. If we ensure that the transistor is biased at a cold pinchoff regime, we can distinguish the part of capacitances ($C_{\rm gs}$, $C_{\rm gd}$, $C_{\rm ds}$) due to the distributed structure coupling from those corresponding to the depleted area. Thoses coupling capacitances are already

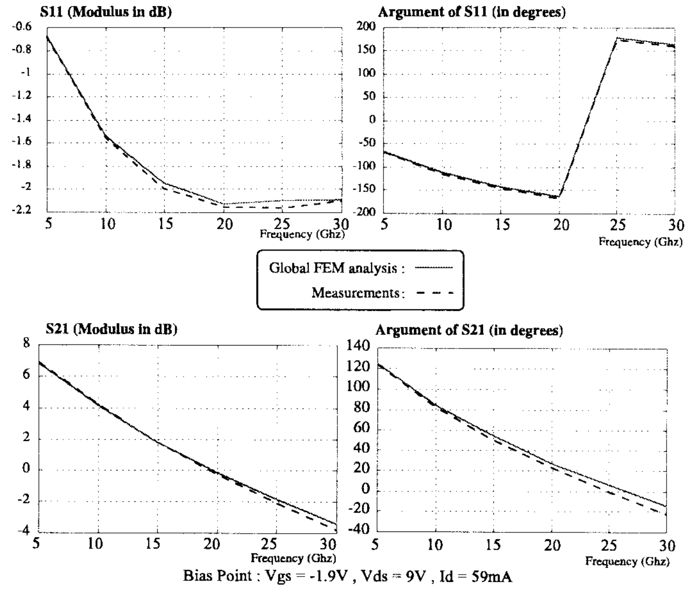

Fig. 4. Global FEM analysis and measurements of the doped FET.

taken into account by the electromagnetic analysis and must be substracted from the final model. In order to validate this characterization, a direct extraction of thoses capacitances has been performed on an undoped FET, and both methods are in good agreement.

We have now an intrinsic model which will be connected between the electrodes of the central part (S2) in Fig. 1.

IV. Global Study of the FET

For this analysis, so as to connect the intrinsic model to the distributed structure, we placed some localized access along the electrodes as seen in Fig. 3.

We chained then between each gate-source and drain-source access a $[S]$ matrix box which characterizes the real active part of the FET.

Fig. 4 presents a good agreement between simulations and measurements until 30 GHz and demonstrates the accuracy of our method.

V. Conclusion

In this paper, the accuracy of a new FET modeling has been demonstrated.

The extrinsic part of the transistor, characterized rigorously by an electromagnetic analysis performed with the three dimensional FEM, is chained with a model of the active part thanks to the localized access concept. Thus we define a more precise model which takes into account of the indirect couplings and enables us an optimization on geometrical dimensions of the FET extrinsic part. It can also be used to perform a better characterization of the couplings between the distributed part of a circuit and the component metallization.

This study has permitted to increase the precision of circuit design step necessary before its realization.

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