FDTD SIMULATION OF A MICROWAVE AMPLIFIER

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ABSTRACT

This paper presents the application of the Finite-Difference Time-Domain (FDTD) method to microwave circuits. An amplifier with a three-terminal active device is analyzed. The active device is replaced with equivalent current sources to integrate with FDTD simulation. The simulation results are compared with measured data and show good agreement.

I. INTRODUCTION

The Finite-Difference Time-Domain (FDTD) method has been widely used to analyze electromagnetics problems. Recently, it is extended and applied to microwave circuits. Reports have shown that two-terminal passive and active elements are treated as distributed elements in the FDTD algorithm [1, 2]. For three-terminal devices, the SPICE lumped circuit model has been employed to couple into FDTD calculations, and the time response is verified with SPICE simulator [3]. However, to the best of the authors' knowledge of these papers, only [2] has compared the results with measured data.

In this paper, the FDTD method is used to analyze a microwave amplifier. This amplifier is a complete circuit, which includes DC block capacitors, input/output matching circuits, and a three-terminal FET. The FDTD method provides the full-wave analysis of the whole circuit. A lumped equivalent circuit of the active device is used to characterize the voltage-current relationship of the device.

II. THEORETICAL MODEL

The critical consideration in this simulation lies on the modeling of the interaction between the active device and electromagnetic fields. Conventionally, the active device is characterized by its S parameters, or its lumped equivalent circuit. Here, to integrate into the FDTD algorithm, the gate and the drain ports are replaced with equivalent current sources at respective positions. These sources represent the voltage-current relationship, which is the input impedance as well as the mutual coupling between the two ports. Thus, signal gain/loss transfer is accounted for.

These current sources are time-varying and dependent on the node voltages. The values of these current are determined from the lumped equivalent circuit. Since these current sources satisfies the S parameters, the device is well characterized.

The integration of the equivalent current with FDTD method is governed by Ampere's current law [3],

$$\nabla\times H=\varepsilon\frac{\partial E}{\partial t}+J_{Device}\ , \qquad (1)$$

where J_{Device} is the equivalent current source. The circuit theory is used to determine the node voltage of the active device by solving the state equation of the equivalent circuit at each time step [4]. Then the voltage is fed back into FDTD simulation via the current sources. The backward finite difference scheme is used here to solve the state equation.

To account for the physical direction of current flow, the equivalent currents are placed horizontally on the air-dielectric interface and distributed uniformly across the microstrip line to reduce additional discontinuity of the connection. The structure and position of the current source is shown in Fig. 1. One end of the source is connected to the microstrip line. The other end is connected to the ground plane using vias. This placement provides a voltage reference point, as well as a model of the vias from the source pad to the ground plane. The significance of this placement is that the sources physically behave in agreement with the device. It also avoids the unphysical and numerically unstable coupling between the gate and the drain.

III. RESULTS

A microwave amplifier is designed at 6 GHz to have 9 dB gain. The active device is a GaAs MESFET, NEC72084, biased at $V_D = 3$ V and $I_{DS} = 30$ mA. The small signal equivalent circuit for this bias condition is shown as Fig. 2. The element values optimize the measured device S parameters.

In FDTD simulation, a modulated Gaussian pulse is excited. The observing plane is placed at some distance before input matching circuit and after output matching circuit. These planes are used as the reference planes for S parameters. For AC simulation, the DC solder pad are connected to the ground plane through vias. The packaged FET occupies 8 cells in the longitudinal direction. The equivalent current sources are placed in one cell only, and distribute uniformly across the microstrip line.

The E_y field distribution beneath the air-dielectric interface at one instant in time is shown in Fig. 3. By taking Fourier transform of the time response at the reference planes, the S parameter is shown in Fig. 4. The Touchstone simulated data are plotted together. The measured data is shown in Fig. 5. The calculated gain and return loss of FDTD at 6 GHz are 9.3 dB and 10.46 dB, respectively. FDTD simulations show good agreement with measured results. The results also features those out-of-band dips due to DC bias circuits near 1 GHz and 11 GHz.

IV. CONCLUSION

An equivalent current source approach is applied to electromagnetic simulation of microwave circuits with active devices. The extended FDTD simulations of a microwave amplifier have good agreement with measured data. The advantages of time domain simulations are not only to provide the transient response of microwave circuits, but also to visualize the field distribution and to have full understanding of the field behavior. In general, this approach can be applied to simulate those circuits with multi-terminal active devices.

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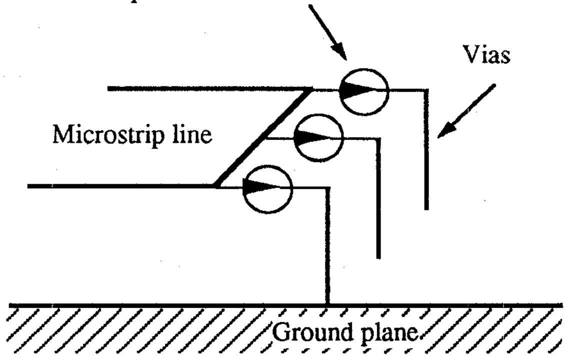


Fig. 1. The implementation of the equivalent current sources.

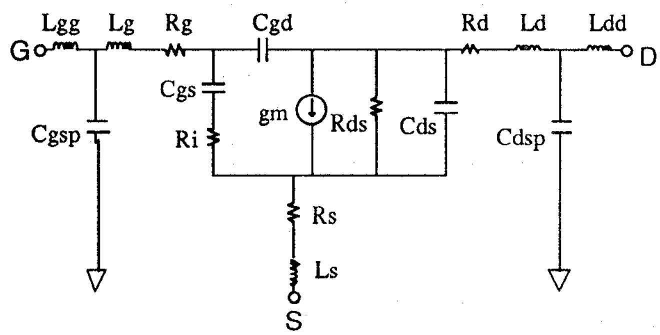


Fig. 2. The small signal equivalent circuit of MESFET. The element values optimize the measured device S parameters.

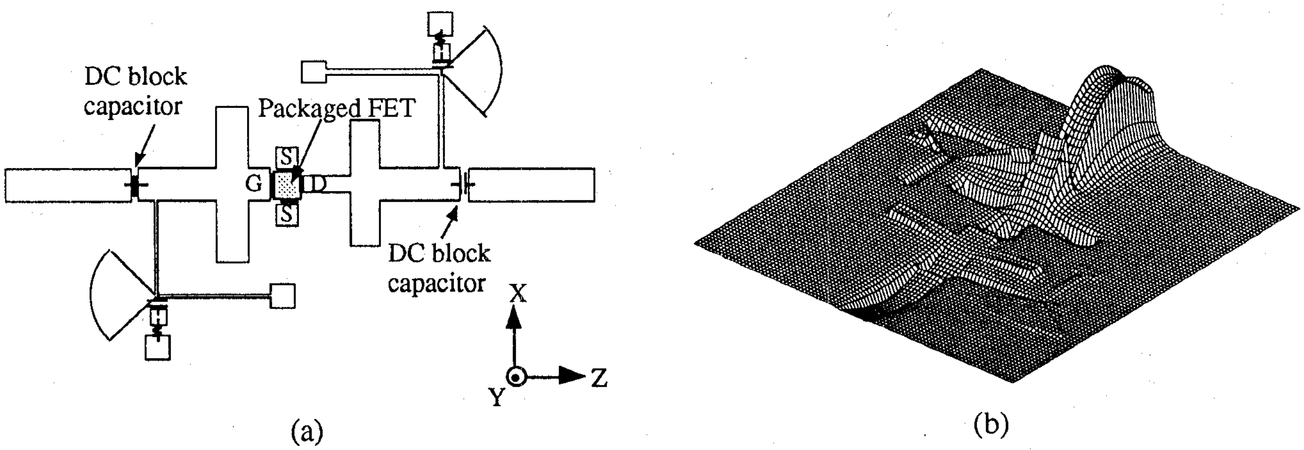
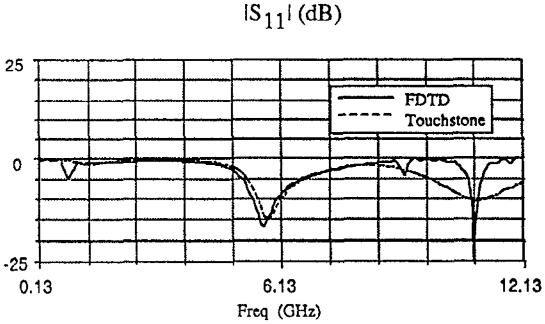
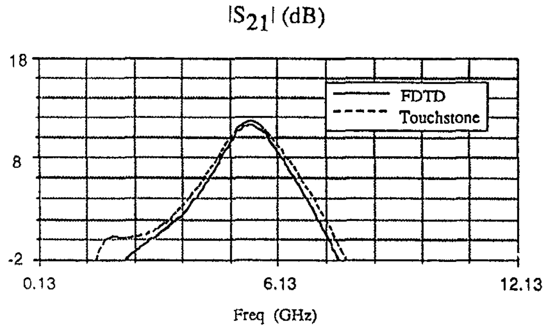


Fig. 3. Simulation of the microwave amplifier, (a) The layout of the microwave amplifier, and (b) the field distribution of Ey component beneath the air-dielectric interface at a time instant when the pulse has traveled through the circuit.

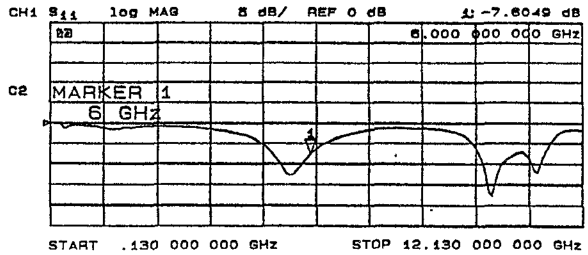


(a)

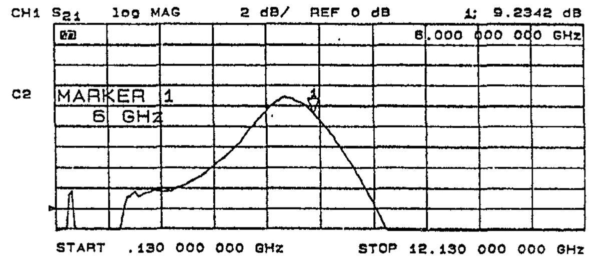


(b)

Fig. 4. The simulated S parameters of FDTD and Touchstone, (a) $|S_{11}|$, (b) $|S_{21}|$. The gain and return loss at 6 GHz obtained by FDTD are 9.3 dB and 10.46 dB, respectively, which are very close to measured data in Fig. 5.



(a)



(b)

Fig. 5. The S parameters of measured data, (a) $|S_{11}|$, and (b) $|S_{21}|$