A New Global-Analysis Model for Microwave Circuits with Lumped Elements

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Abstract — **A new global full-wave analysis model by using the gap-current ports to analyze the microwave circuits with linear or nonlinear lumped elements is proposed. Based on this model, all electromagnetic effects due to the distributed parts of circuit structures can be easily characterized. In this study, the proposed model is applied to analyze and design a singly balanced diode mixer circuit using the slotline T-junction as a 180° hybrid.**

I. INTRODUCTION

Simulations of circuit components are essential in predicting the performance of a complex system and in providing an optimum circuit design. Especially in MMIC process, one needs more accurate simulation results because excess tuning after fabrication is difficult. In a conventional design procedure, a circuit is separated into several subcircuits which are then recombined after each subcircuit is simulated individually. This technique may be adequate in providing useful results. However, as the operating frequency of circuits increases, each subcircuit interacts not only through the physical interconnect but also through the electromagnetic (EM) coupling. As the circuit structure becomes more complex and compact, it would be difficult to divide the circuit into several well-defined subcircuits. It is not satisfactory to design each part separately, thus a concurrent analysis is needed.

Global electromagnetic simulators for microwave circuits with lumped elements, such as finite-element method and integral equation method coupled with spectral-domain or space-domain technique [1]-[4], have been developed recently. A common method is based on the field integral equation along with the method of moments, in which the discrete element is inserted in an infinitesimal gap. This introduces a numerical parasitic capacitance that is strongly dependent on the mesh size [3], and can dramatically spoil the results. For this reason, a correction procedure to reduce such a numerical parasitic effect was developed [3].

In this study, a new global full-wave analysis model that uses the gap-current port instead of the port-based model, in which the voltage is regarded as a variable, [4] is proposed. Two major advantages are associated with the gap-current model. First, with the removal of the infinitesimal gap assumption, no additional de-embedding procedure [3] is needed to reduce the numerical parasitic capacitance effect due to the meshing. Second, the gap-current ports may be located at the positions where the lumped elements are inserted, thus this model can naturally take care of the lumped element effect instead of regarding the lumped element as a numerical box. In this study, the problem with a 180° uniplanar singly balanced diode mixer (Fig. 1) is discussed.

II. THEORY

The proposed global full-wave analysis model is based on the mixed-potential integral-equation formulation which uses the method of moment to solve the magnetic current distributions on the apertures and uses the overlapping rooftop basis functions to expand these unknown magnetic currents. Here, one introduces the gap-current port in which the excitation magnetic field is imposed between the two half-rooftop bases as shown in Fig. 2. By using the Galerkin procedure, the inner product of the excitation term can be expressed as the equivalent gap current. Note that these gap currents associated with the excitation ports, where the devices would be located, are retained as variables, and all the other inner product terms are set to zero. Thus the impedance matrix for the integral equation can be simplified, which may characterize the subcircuit from a circuit point of view. Specifically, each excitation is treated as a circuit port, and the port current is regarded as an unknown without additional numerical computation. After the impedance matrix is established, it can be connected to any component by using a circuit-simulation software, which supplies the required tool to simulate the complex system problem or nonlinear circuit.

III. SINGLY BALANCED MIXER

Fig. 1 shows the layout of a 180° singly balanced diode mixer. This uniplanar structure allows for simple

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grounding without via holes and all the components are located on the same substrate side. The proposed circuit is easy to fabricate and has a simple architecture. Here, the slotline T-junction and the twin-spiral coplanar waveguide (CPW)-to-slotline transition [5] are used to replace the traditional 180° hybrid. A series diode pair is mounted across the T-junction of the slotline. In the LO port, matched sections are used to ensure the satisfactory power transfer from LO port to the diode pair. The LO filter is realized by a chip capacitor and the IF lowpass filter by a solenoid inductor.

The twin-spiral transition [5] is adopted due to its wide bandwidth and small size requirement. This transition can achieve a size which is 1/3 that of the conventional CPW-to-slotline transition and has a 2.55:1 bandwidth. Comparing to the ring hybrid or other 180° coupled line circuit, the slotline T-junction splits a signal into two signals of equal amplitudes and 180° out of phases with broad bandwidth and takes up very small area on circuit board. In addition to create 180° out-of-phase RF signal outputs on the series diode pair, the slotline T-junction also guarantees an excellent isolation between the RF/LO and RF/IF ports. By the slotline T-junction, the RF signal, which is associated with the odd CPW mode along the CPW line, would be shorted when it propagates through the junction and meets the first air bridge. The LO signal, carried by the even CPW mode, would meet an opened terminal on the junction. These two modes propagated along the CPW are orthogonal and have very good isolation to each other.

Conventionally, the slotline T-junction in the mixer may be analyzed simply by incorporating the circuit model for diode pair into the transmission-line models for the slot line and CPW line [6]. This equivalent transmission-line circuit model is too simple to take care of the parasitic effects. Especially when the slotline T-junction is more complicated and the diode pair is too close the T-junction, the influence of the parasitic effects, such as the discontinuity effect of the junction as well as the interaction between the junction and the diode pair, would become significant. A method to avoid the interaction effect may be achieved by leaving the diode pair far from the junction [7]. Then the whole circuit can easily be separated into several subcircuits which are easy to analyze.

In order to optimize the performance and to minimize the circuit size, the series diode pair (in Fig. 1) must be located as close to the slotline T-junction as possible. For this circuit, it is not enough to model the slotline T-junction by the conventional equivalent transmission-line circuit model which does not include the discontinuity effect across the junction. In this study, the slotline T-junction and the diode pair combined together are analyzed by the proposed global full-wave analysis model, which combines the gap-current model and the harmonic balanced method for analyzing the nonlinear behavior. In this analysis, the positions of the diodes are replaced by the gap-current ports. Each distributed component can be treated by a four-port subnetwork which is then connected to the gap-current port associated with the diode pair. The diode pair is discussed by the manufacturer's equivalent circuit model. By this model, all the parasitic effects can be naturally handled.

The proposed global analysis model can also be used in the simulation of the LO and IF filters. Their parasitic discontinuity effects are very small, thus the equivalent transmission-line circuit model is also adequate in dealing with the filter circuits.

The length d_2 and bandwidth of the twin-spiral transition are essential in determining the bandwidth of the mixer. Better transfer of RF power into two diodes may be achieved by taking the length d_2 around $\lambda/4$ at the operating frequency.

Shown in Figs. 3(a)-(d) are the simulated and measured results for the diode mixer shown in Fig. 1. The mixer is fabricated on a FR4 substrate with a dielectric constant of 4.3. Here the length d_2 is not exactly $\lambda/4$ at the center frequency 2.5Ghz due to the discontinuity effect. This mixer exhibits a conversion loss of 5-7dB for an LO signal of 2.7dBm when the RF is swept from 2 to 3 GHz, and the best is at 2.4GHz. The conversion loss begins to saturate around 1dBm LO input power and changes very little above 3dBm. Fig. 3(d) shows the LO-to-IF isolation versus LO frequency. All of them are better than 19dB.

IV. CONCLUSIONS

A new global full-wave analysis model by introducing the gap-current ports to analyze the linear and nonlinear circuits has been reported. By this model, all the EM effects and the device nonlinear effects can be included. The design of a uniplanar singly balanced diode mixer illustrates that the proposed model gives results in good agreement with the measurement. The model is easier to apply to the microwave circuits especially with coplanar waveguide structures.

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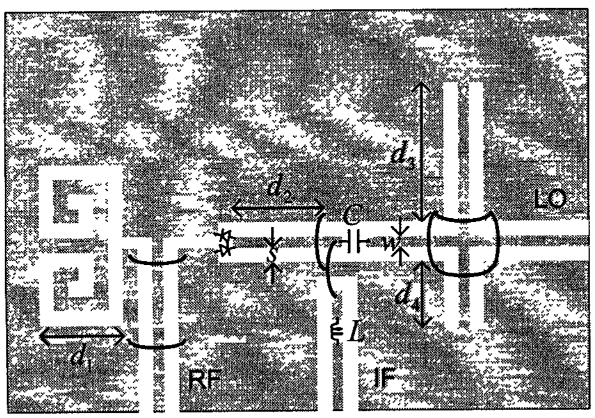

Fig. 1. Geometry of 180° singly balanced diode mixer on a printed circuit board. (s=1.0mm, w=0.75mm, d_1=7mm, d_2=12mm, d_3=25mm, d_4=9.5mm, C=9pF, L=25nH)

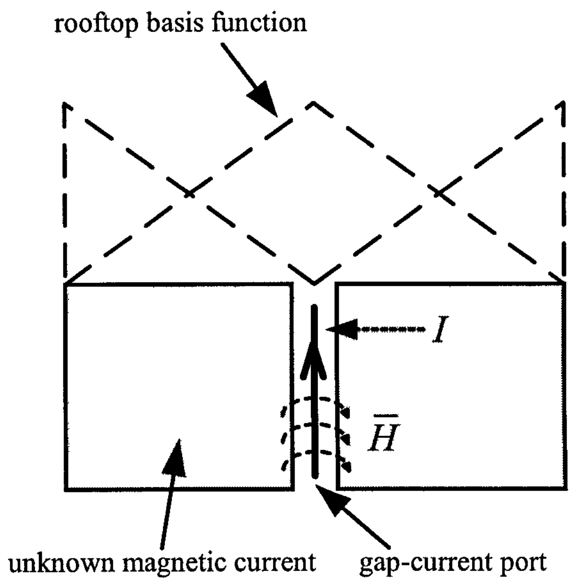

Fig. 2. Configuration of gap-current model.

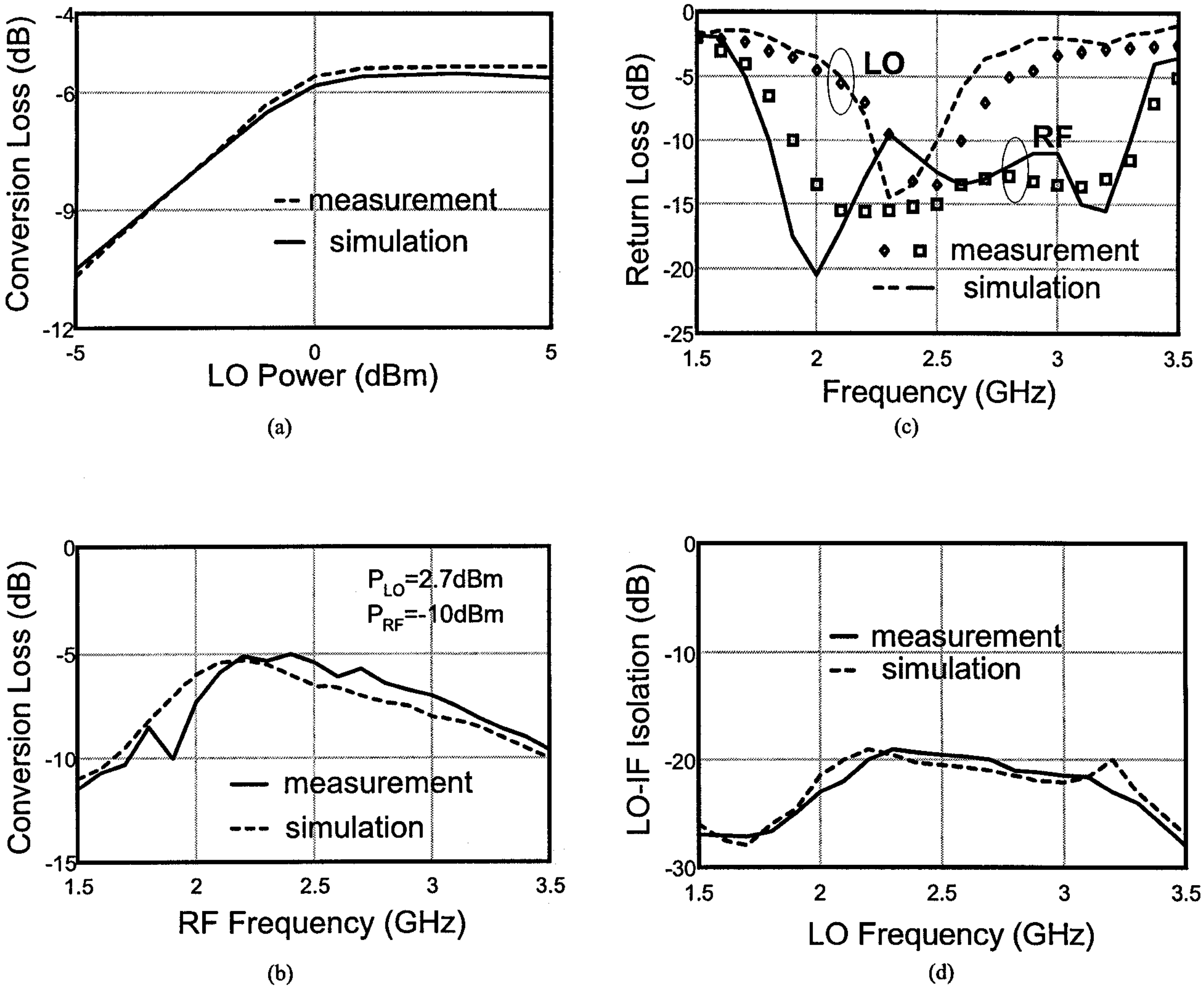

Fig. 3. Simulated and measured results for the mixer (Fig. 1): (a), (b) conversion loss, (c) return loss, and (d) LO-IF isolation.