NONLINEAR ANALYSIS OF A MICROWAVE DIODE MIXER USING THE EXTENDED FDTD

Min Chen, Siou Teck Chew*, and Tatsuo Itoh

Department of Electrical Engineering, University of California, Los Angeles
*Defense Science Organisation, Singapore 118230

ABSTRACT

The application of the extended Finite-Difference Time-Domain (FDTD) method to the analysis of microwave diode mixers is presented in this paper. Using equivalent current-sources and equivalent circuit models, nonlinear active devices can be incorporated into FDTD simulation. An X-band singly balanced diode mixer is analyzed. Good agreement between the experimental and theoretical results verifies the validity of the FDTD algorithm.

INTRODUCTION

Recent development of faster computers and progresses on modeling the original algorithm have made the Finite-Difference Time (FDTD) method attractive to the analyses of microwave circuits, including nonlinear ones. Commercial tools such as Libra possess an extensive library composed of modeling equations for various microwave components. However, chances are that some transmission line structures may not be modeled completely and accurately by the existing equations. Furthermore, the modeling equations cannot predict the mutual couplings between different parts of the circuit. One way to overcome the above-mentioned problems is to apply an electromagnetic solver to create S-parameter circuit blocks for use in a circuit simulator. However, This may be difficult to implement and need a lot of pre-processing. An alternative way is to use the extended FDTD method.

Much effort has been devoted to the extension of the FDTD method to incorporate lumped microwave devices into 3-D full wave analysis. By treating two-terminal lumped elements as distributed elements on the FDTD cells and using equivalent circuit models, an extended FDTD algorithm was employed to analyze microwave systems with passive and active lumped elements [1-3], This approach, however, becomes cumbersome when modeling active devices with complicated equivalent models. A more general approach uses equivalent current sources to grant the direct access to SPICE models for simulation of lumped circuits in FDTD calculations [4]. The simulation of a microwave amplifier was demonstrated [5,6], but only linear behaviors were discussed.

In this paper, the extended FDTD using equivalent current-source technique is applied to analyze a singly balanced diode mixer. The nonlinear characteristics of the mixer are investigated. With the full-wave features of the FDTD algorithm, the entire circuit performance can be visualized and the interaction between components can be taken into account. Comparisons between measured and calculated results are reported for validation of the algorithm.

THEORY

The circuit under consideration is a singly balanced diode mixer consisting of two mixers

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combined by a 90° hybrid coupler [7] as shown in Fig. 1. The inductors L_1 and L_2 realize the IF return by grounding the respective ends of the diodes at the IF frequency and dc. The inductor L_f and capacitor C_f along with the open-circuited microstrip play the role of low-pass filter. The active device is chosen as HP HSMS-8202 Schottky diode pair.

In our approach, the diode device is replaced with the manufacturer's equivalent circuit model which may then be combined with lumped passive elements to form a four-port network as shown in Fig. 2. The employment of horizontal equivalent current-sources at the four interfaces between microstrip and lumped elements allows the interaction between circuit and electromagnetic analysis. The can be seen from the Ampere's current law [6]:

$$C_{eq}\frac{dV}{dt}+I_{eq}(V)=I_t \qquad (1)$$

where C_{eq} is the equivalent capacitance of the FDTD cells and I_{eq} is the equivalent current-source. In each time-marching process, the total current I_t is determined from the integration of H fields, and is then applied to the circuit simulator as excitations. By solving the state equation of the circuit in Fig. 2, the terminal voltages V at the four ports can be obtained and used as feedback to the EM simulator. Because of the nonlinearity due to the diode junction current and capacitance, a nonlinear system is involved. The feedback voltage can be used to update the horizontal E fields of the FDTD cells adjacent to the microstrip end. Note that one end of the equivalent current-sources must be connected to vias as the other end is connected to the microstrip. The sinusoidal excitations of the RF and IF input signals are realized as resistive voltage sources using the same way in [1].

RESULTS

The LO frequency of the mixer in Fig. 1 is designated at 10 GHz. As the RF signal with 10.25 GHz frequency comes in, the output port of the mixer will result in an IF signal with 250 MHz frequency. Fig. 3 shows the resultant field distribution of E_x component just beneath the air-dielectric interface at an instant of time. Using this technique, interesting information, such as propagation, amplitude and phase of the signals can be visualized in the time domin.

In addition to time-domain data, frequency-domain results can also be obtained by conducting the Fourier transform. Fig. 4(a) shows the calculated power spectrum at the output port. In comparison with the simulated results by Libra in Fig. 4(b), fair agreement can be observed for the IF, LO, RF, and image RF signals. Because only four harmonics are used for the Harmonic Balance technique in Libra, the spectrums of the rest harmonics are not available in Fig. 4(b).

Fig 5 shows the plot of IF power versus RF input power for fixed LO power at 4 dBm. Besides the measured and FDTD calculated results, Libra simulation data is also included. As shown in the plot, the curves start from linear section and bend gradually as RF power increases. The important nonlinear parameter, i.e., the 1-dB compression point, can be estimated as 3 dBm. Fixing RF power at -10 dBm, Fig. 6 shows the variation of the conversion loss as the LO power changes from 0 to 10 dBm. Fig. 7 illustrates the comparison of conversion loss versus IF frequency as the LO and RF powers are fixed at 4 dBm and -10 dBm, respectively.

CONCLUSION

In this paper, a microwave diode mixer has been analyzed using the extended FDTD approach. The theoretical predictions are verified by experimental data. However intricate the equivalent circuit model of the linear/nonlinear circuits may be, using the equivalent current-source technique, the FDTD can be extended to analyze various microwave circuits. This approach is particular suited for the active antenna circuits where any part of the circuit is exposed to radiation and can effect the performance of the integrated circuit.

ACKNOWLEDGMENT

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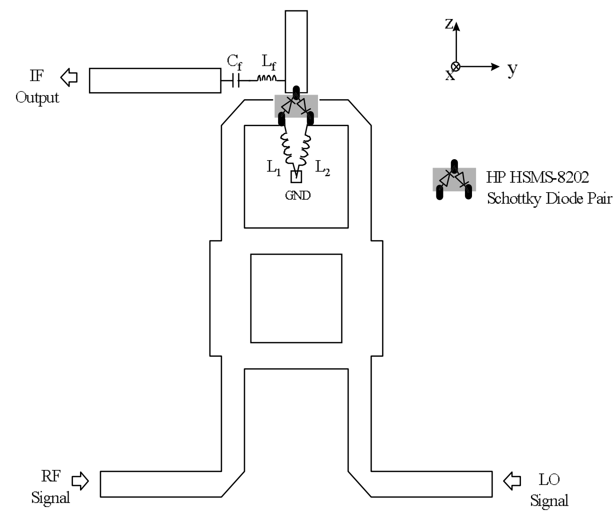

Fig. 1 Layout of a singly balanced diode mixer

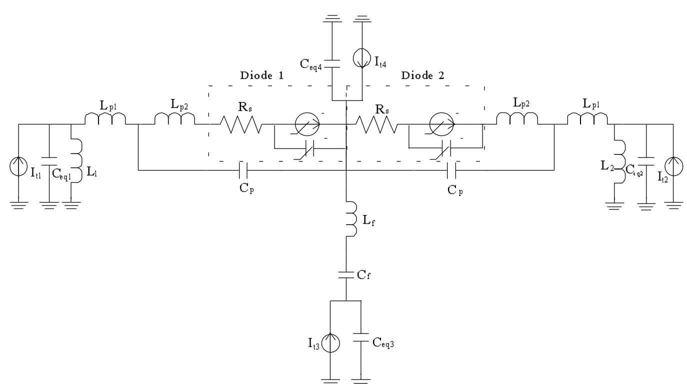

Fig. 2 Equivalent lumped circuit for circuit analysis. L_{p1}, L_{p2}, and C_p represent package parasitics. Junction current I_j, junction capacitor C_j, and linear series resistor R_s constitute the large-signal model of the diode.

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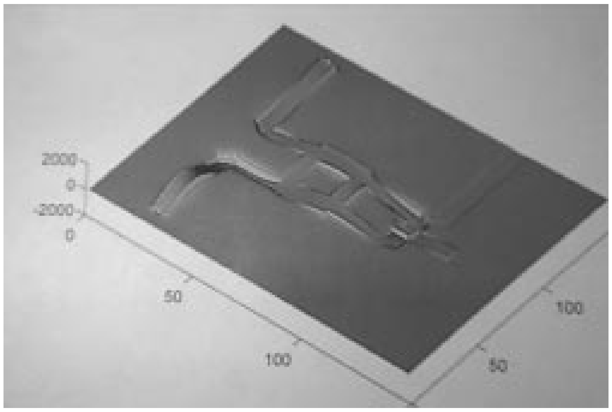
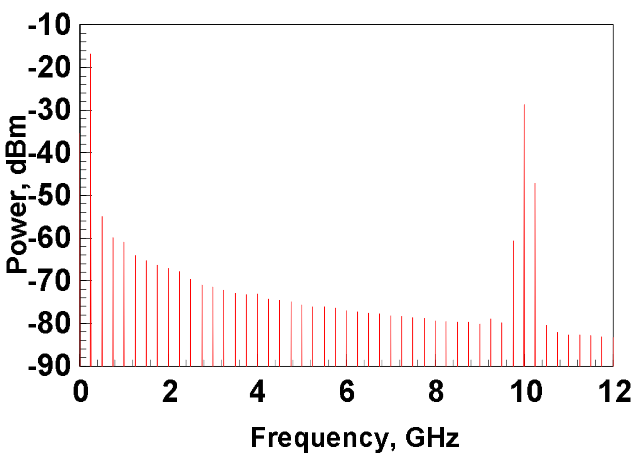
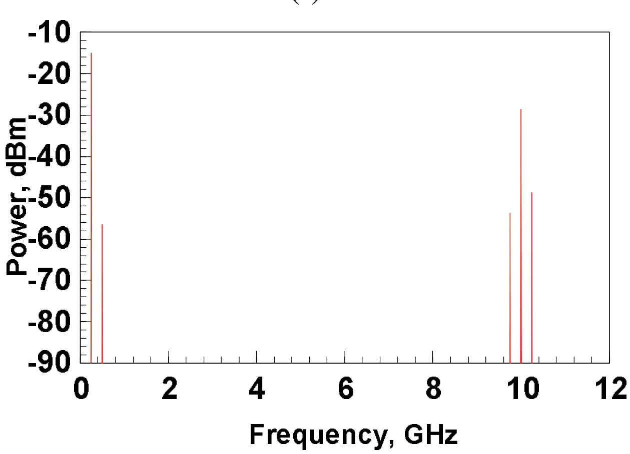


Fig. 3 Field distribution of E_x component beneath the air-dielectric interface at a time instant



(a)



(b)

Fig. 4 Power spectrum at the output for (a)FDTD calculation, (b) Libra simulation.

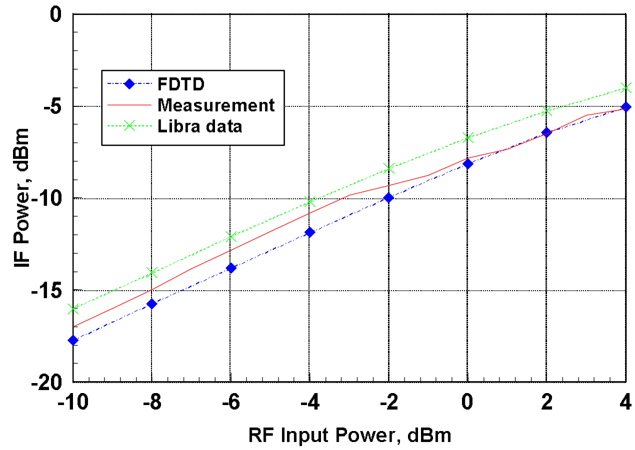


Fig. 5 IF power versus RF input power plot

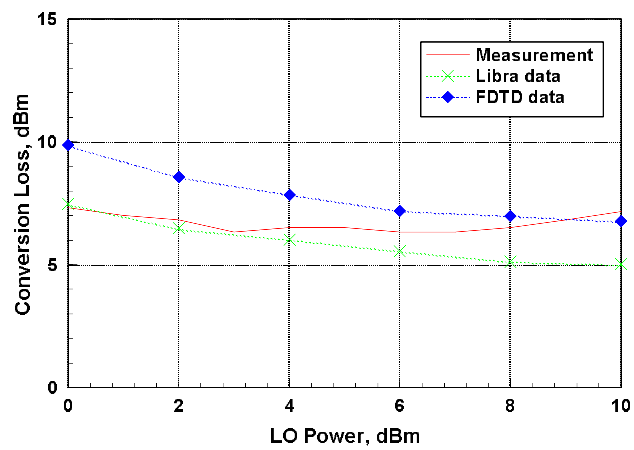


Fig. 6 Variation of conversion loss as a function of LO power

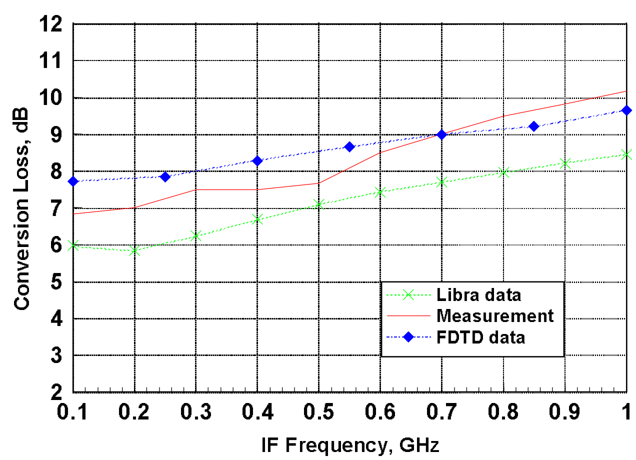


Fig. 7 Variation of conversion loss as a function of IF frequency