WIDE BAND CAD MODEL FOR COPLANAR WAVEGUIDE USING FDTD TECHNIQUE

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ABSTRACT

The coplanar waveguide (CPW) is one of the most suitable transmission lines for millimeter-wave circuits. This paper presents the development of a very wide band CAD model for the CPW and its discontinuities. The propagation characteristics of CPW and its discontinuities on semiconductor substrates are modeled using the FDTD technique. Empirical equations suitable for implementation in commercial software packages are developed. Several CPW structures were fabricated on GaAs substrates and tested. Very good agreement between the measurement and the model is observed over a wide frequency band, from 1 to 110 GHz.

INTRODUCTION

New commercial market opportunities are emerging for very high frequency technology. Recently FCC allocated 59-64 GHz band for unlicensed commercial applications. In addition, collision avoidance radar, Intelligent Transportation Systems (ITS), Microwave Doppler sensors, Wireless Lan, Cordless telephony, point-to-point communications, electronic toll booths are few of the applications that will require miniaturized circuits at millimeter wave frequencies.

A good passive component model that works well at these frequencies will enable deterministic circuit designs, avoiding the trial and error approach which are quite often used today. Coplanar Waveguide structures are one of the convenient media that can be used for millimeter wave circuits. However accurate wide band width models for the CPW circuits are not commercially available. In this paper we report on the measured and simulated results of CPW structures up to 110 GHz. The measured results are compared with the simulations using the model generated by Finite-Difference Time-Domain (FDTD) technique. The improved model predicts the measured performance from 1 GHz to 110 GHz.

CAD MODEL DEVELOPMENT

A three-dimensional full-wave analysis of the coplanar waveguide using the FDTD technique is performed to obtain the propagation constant and the characteristic impedance. The FDTD technique, developed in our group, directly accounts for both dielectric and conductor losses [1-2]. Details about FDTD technique can be found elsewhere [1,3,4]. The complete analysis procedure is carried out as follows:

1. The propagation constant and the characteristic impedance of every section of the CPW are developed over the desired frequency band. This is achieved by running the FDTD program to obtain the phase constant, attenuation constant, and characteristic impedance of the line as functions of frequency.
2. The structure containing the discontinuity is separately modeled using the FDTD, to obtain its S-parameters. The S-parameters is also developed over the desired frequency band.
3. Based on Steps 1 and 2, an equivalent circuit for the discontinuity is developed. The values of the circuit elements are selected to produce the same S-parameters as obtained in Step 2.
4. Because of the variation of the geometry of the transmission lines, the discontinuity structures, and the substrate materials, Steps 1 through 3 are repeated to develop the equivalent circuit parameters for any combinations needed by the design engineers.

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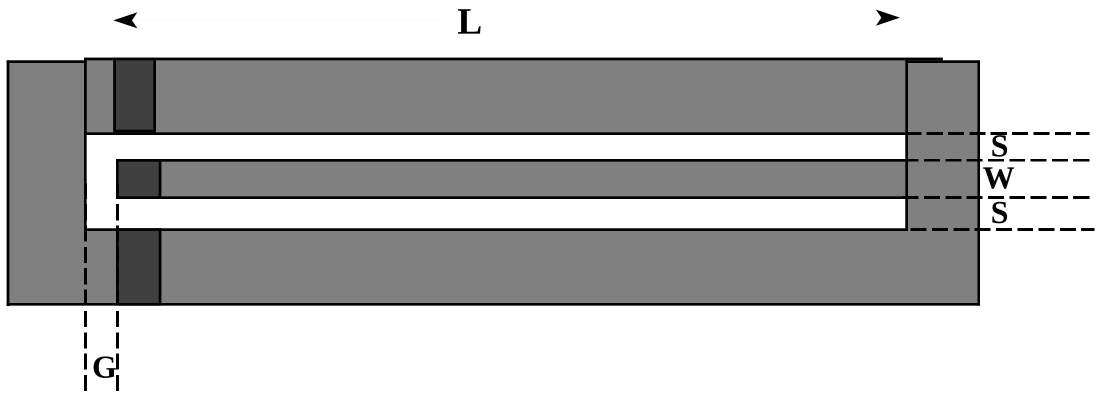

Fig. 1. Layout of the CPW short line.

5. Some discontinuity structures are fabricated and tested to evaluate and validate the equivalent circuit parameters.
6. Empirical expressions for the CPW characteristics and the discontinuity parameters, which are suitable for implementation in commercial CAD design packages, are developed. Several approaches are attempted in developing the empirical expressions. At this stage, piece-wise linear approximations and second-order expressions are found to be adequate.

EXPERIMENTAL VERIFICATIONS

CPW structures such as transmission lines, gaps, steps, airbridges, bends, tees and crosses were fabricated on GaAs substrate with a thickness of 500 μm. In this report, 50 Ω coplanar waveguide structures of transmission line and short line were used to verify the model developed using FDTD technique. The layout of transmission and short line length is 7500 μm (Fig. 1), however, a 50 μm offset was taken into account for each pad in the simulation due to the probe tips positioning. Wrapped around ground connections were used at each port with a 100 μm gap between the end of center line and the ground. This gap is simulated using an end capacitance, 0.01 pF.

RESULTS AND DISCUSSION

The empirical expressions of effective dielectric constant, characteristic impedance, and attenuation constant are given in Eqs. (1), (2), and (3), which were implemented into Libra as variables in the transmission line elements.

$$\varepsilon_{eff} = \varepsilon_1 + \varepsilon_2 f + \varepsilon_3 f^2 \quad (1)$$

$$Z_o = Z_{o1} (\varepsilon_1 / \varepsilon_{eff})^{0.5} \quad (\Omega) \quad (2)$$

$$\alpha = \alpha_1 (1.0 + \alpha_2 f) \qquad f \leq f_1 \quad (3)$$
$$= \alpha_3 + \alpha_4 (f - f_1) \qquad f_1 \leq f \leq f_2$$

where ε_{eff} is the effective dielectric constant, Z_o is the characteristic impedance, α is the attenuation in Np/m, f is the frequency, and ε_1, ε_2, ε_3, Z_{o1}, α_1, α_2, α_3, α_4, f_1 and f_2 are constants depending on the structure geometry, material and loss mechanisms involved. Careful examination of the geometry of the CPW used in this study and the substrate material reveals that many loss mechanisms contribute to the attenuation characteristics over this very wide band. The mechanisms included so far are conductor loss, dielectric loss, and a possible surface-wave excitation at high frequencies. No radiation losses are included in our analysis. One quadratic equation of the form shown in Eq. (1) is sufficient for accurately representing ε_{eff} over the frequency band of interest. However, one equation in the form of Eq. (3) and three equations in the form of Eq. (4) are needed to model the line attenuation over the 110 GHz band. The equations are intentionally developed in this simple, yet accurate form to be compatible with commercially available circuit design packages (e.g., Libra).

S-parameters of the CPWs were measured on wafer using Wiltron 360B Vector Network Analyzer system up to 110 GHz. Open-Short-Load-Through (OSLT) technique was used for calibration. Fig. 2 shows the reflection characteristics of the shorted CPW line (Fig. 1). Very good agreement between the measurement and the model predictions is observed over the wide frequency band. The oscillation feature in magnitude is caused by the gap capacitance, especially at high frequency. The gap capacitance value is determined by fitting the oscillation magnitude at high frequencies. The piece-wise linear attenuation successfully models the roll off in magnitude through the wide band. Excellent agreement in phase between measured and simulated results is also observed, because of the frequency dependent property of the effective dielectric constant is utilized. The phase values cross zero while the integer number of that wavelength is equal to the total transmission length. Fig. 3 shows the transmission characteristics of the CPW transmission line. It can be seen that the model predicts the general trend of the transmission signal. Fig.4 shows the reflection coefficient of the transmission line. At this stage, we believe that a surface wave excitation takes place in this test structure. Further investigation is needed to identify the exact contributions from the various loss mechanisms.

We also developed an equivalent circuit model on a step junction discontinuity structure, following the analysis procedure steps 1 though 3. The gap between the center conductor and the ground plane is fixed to 75 μm for both transmission lines. A single capacitor between the center conductor and the ground was found adequate to represent this step discontinuity. Fig. 5 shows the equivalent capacitance as a function of junction ratio which is defined as the ratio of two center conductor widths. As can be seen, the discontinuity becomes more like a transmission line or an open circuit while the junction ratio approaches 1.

CONCLUSION

The approach to develop and test a very wide band CAD model for CPW line and its discontinuities was presented. The model is based on the FDTD technique. The developed model has been implanted in a commercially available software (i.e., Libra). Very good agreement was obtained between the measurement and the model predictions for frequencies up to 110 GHz.

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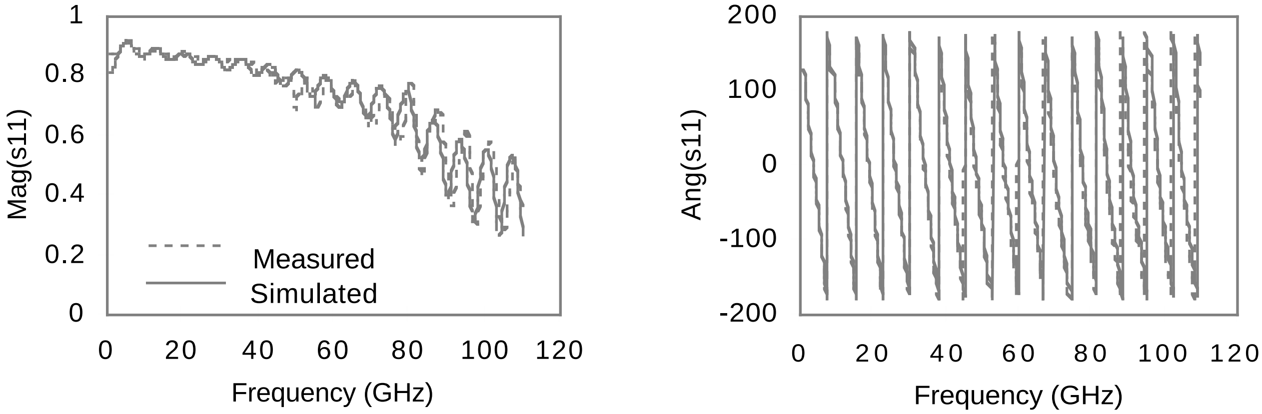

Fig. 2. Reflection characteristics of the short line.

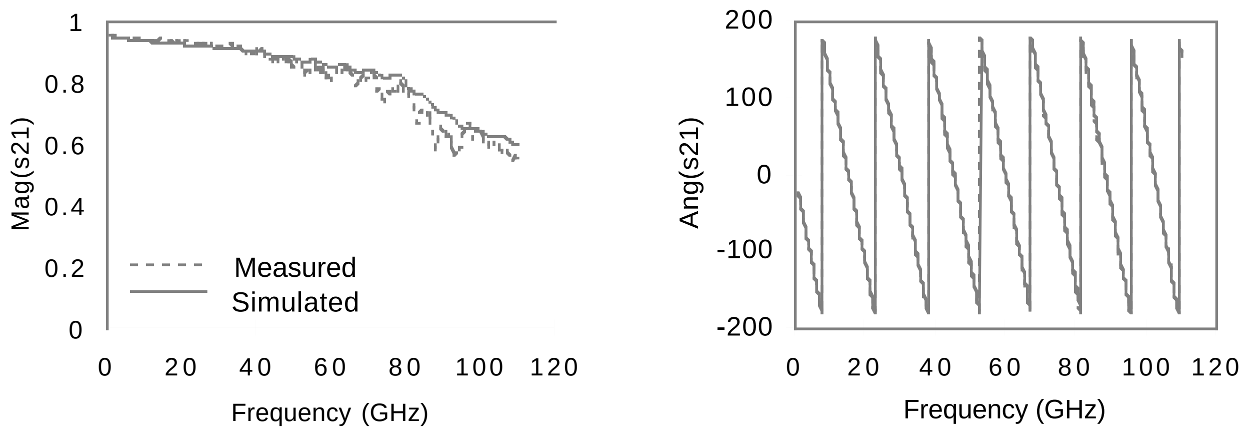

Fig. 3. Transmission characteristics of the transmission line

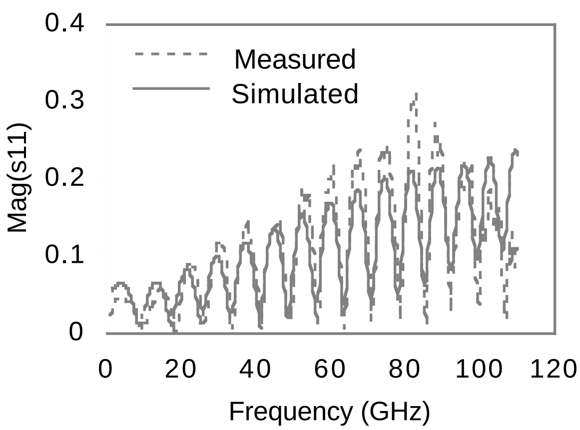

Fig. 4. Reflection characteristics of the transmission line.

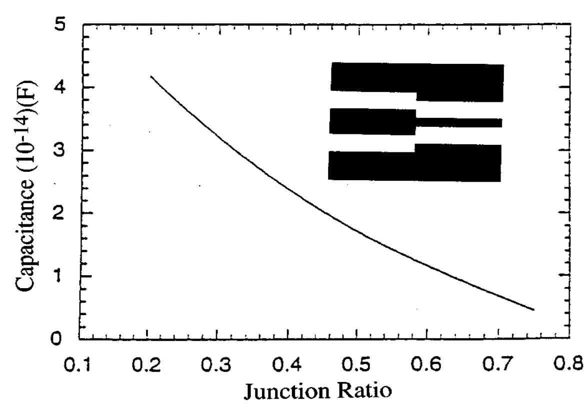

Fig. 5. Step-junction discontinuity capacitance as a function of junction ratio.

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