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AN EXTENDED SHORT-OPEN CALIBRATION TECHNIQUE FOR MULTIMODE ANALYSIS OF ASYMMETRIC COPLANAR-WAVEGUIDE DISCONTINUITIES

Chi-Hsueh Wang, Huei Wang, and Chun Hsiung Chen
Department of Electrical Engineering and Graduate Institute of Communication Engineering,
National Taiwan University, Taipei 106, Taiwan, R.O.C.
Tel: 886-2-23635251-221, FAX: 886-2-23638247
E-mail: chchen@ew.ee.ntu.edu.tw

This paper presents an extended short-open calibration (SOC) technique to handle the multimode conversion phenomenon associated with the asymmetric coplanar-waveguide (CPW) discontinuities. Specifically, two CPW asymmetric discontinuity structures are analyzed by this technique and their simulated results are tested by the ones using the matrix-pencil de-embedding technique.

1 Introduction

With increased operating frequency and higher performance requirements, the equivalent-circuit models based on a quasi-static assumption are not accurate enough in characterizing a complex circuit. The fullwave analysis is required in order to include more electromagnetic effects such as dispersion, radiation, and mode coupling into consideration. Specifically the multimode-coupling phenomenon associated with an asymmetric coplanar waveguide (CPW) structure may create the power loss due to the conversion between even CPW mode and odd CPW (or coupled-slotline) mode. Thus an analysis of this multimode-coupling problem is essential in improving the circuit performance with asymmetric CPW discontinuity structures.

A fullwave algorithm has been developed to analyze the mode-conversion phenomenon in a CPW bend discontinuity [1]. Based on the mixed-potential integral-equation (MPIE) formulation, the magnetic current distributions over the apertures can be determined, from which the scattering parameters associated with the even and odd CPW modes excited by the discontinuity may be extracted by the matrix pencil approach. However, in order to compensate for the effects of open and short circuit terminations and to get stable results, a long calibration line is needed in the simulation. Generally, the discontinuity is smaller in comparison with the wavelength, but the calibration line is usually about one or two wavelengths. The simulation with longer calibration line is a highly time consuming process and needs tremendous computer resources.

A matched load simulation technique is an alternative approach to extract the multimode S-parameters [2], [3]. But it must include the modal guided wavelengths and the port characteristic impedance which are simulated by another numerical algorithm.

Recently, a newly de-embedding scheme called the short-open calibration (SOC) technique was developed [4]. This technique can get acceptable results by using a shorter calibration line which is even shorter than a quarter wavelength. Furthermore, it can determine the S-parameters without the need of either defining the port characteristic impedance or normalization with respect to a specified value.

In this study, an extended algorithm based on the SOC technique is developed to handle the multimode-coupling problem associated with the CPW circuit. Specifically, two asymmetric CPW structures are handled by the extended SOC algorithm, and the simulated results are compared with the simulated ones by the matrix-pencil method [1].

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2 Formulation

Fig. 1(a) shows the configuration of a simple asymmetric CPW discontinuity structure. The ground plane and dielectric substrate (dielectric constant ε_r=4.3 and thickness h=1.54mm) are extended to infinity. The reference plane is placed at a distance g from the discontinuity. For excitation, two source currents I_1 and I_2 are placed at the end of the uniform feed line. By the MPIE formulation for this multimode problem, one can get a 2*2 admittance matrix for the mode-conversion mechanism between even CPW mode and odd CPW mode

$$\begin{bmatrix} Y_{ee} & Y_{eo} \\ Y_{oe} & Y_{oo} \end{bmatrix} \cdot \begin{bmatrix} V_e \\ V_o \end{bmatrix} = \begin{bmatrix} I_e \\ I_o \end{bmatrix}. \tag{1}$$

Here, V_e, V_o, I_e, and I_o are the voltage and current terms associated with the even mode and odd mode, respectively. The subscript ee (or eo) describes the effect on the propagated even mode due to the excited even (or odd) mode.

The mode voltages and currents V_e, V_o, I_e, and I_o are related to the ones V_1, V_2, I_1, and I_2 at the excitation ports by

$$V_e = \frac{V_1 - V_2}{2},\ I_e = I_1 - I_2,\ V_o = V_1 + V_2,\ I_o = \frac{I_1 + I_2}{2}. \tag{2}$$

Here, the matrix in (1) includes both the effect of discontinuities at the excitations and that of the phase delay along the uniform feed CPW line. They can be eliminated by applying the SOC technique [4].

By the SOC procedure, the structure in Fig. 1(a) may be decomposed into two distinct parts: the error box for the CPW feed line and the core circuit box for the asymmetric CPW discontinuity, which is at the right side of the reference plane. Based on the network topologies of the open and short standards with the even mode excitation as represented by Fig. 2(a) and Fig. 2(b), three equations for calculating the ABCD matrix could be established when V_e^{O2}, V_e^{O1}, I_e^{O1}, V_e^{S1}, I_e^{S1}, and V_e^{S2} are given. For the open-end standard with even-mode excitation (Fig. 2(a)), V_e^{O2} is the voltage at the open-end, V_e^{O1} is the port voltage, and I_e^{O1} is the port current, respectively. For the short-end standard with even-mode excitation (Fig. 2(b)), V_e^{S1}, I_e^{S1}, and V_e^{S2} are the port voltage, port current, and the voltage at the short end, respectively. By coupling these three equations together with the reciprocity relation, the ABCD matrix of the error box for the even mode can be established. Similarly, the error box for the odd mode, represented by Fig. 2(c) and Fig. 2(d), can also be obtained.

After the error boxes having been established, the S-parameters of the core circuit box can be deduced by connecting the inverse matrices for the error boxes to the whole circuit matrix in (1). Fig. 3 shows the equivalent-circuit representation of the asymmetric CPW discontinuity structure based on the extended SOC de-embedding technique. In this technique, the mode-coupling phenomenon between the error boxes for even mode and odd mode is neglected.

3 Results

For validation, two simulations for the asymmetric CPW discontinuity problem (Fig. 1(a)) are conducted. The first one is based on the proposed extended SOC procedure and the second one is based on the matrix-pencil technique for de-embedding. Fig. 1(b) shows the corresponding simulated results for the asymmetric CPW discontinuity problem in Fig. 1(a). Here, Γ_{ee} is the reflection coefficient for the even mode due to an incident even mode, and Γ_{eo} is the one for the even mode due to an incident odd mode. Note that the mode conversion occurs when Γ_{eo} and Γ_{oe} are close to 0dB.

The extended SOC technique is also employed to study the CPW right-angle bend (Fig. 4(a)). In Fig. 4(b), two simulated results based on extended SOC technique and matrix-pencil method [1] are included for comparison. T_{ee} is the transmission coefficient for the even mode due to an incident even mode, and T_{eo} is the one for the even mode due to an incident odd mode. Mode conversion phenomenon occurs around 12 GHz. Good agreement between two simulated rersults supports the accuracy of both techniques.

4 Conclusion

In this study, an extended SOC de-embedding procedure has been presented to handle the multimode coupling problem associated with the asymmetric CPW discontinuities. By this procedure, all the parasitic effects from feed lines and excitation ports can be removed. Thus, the whole circuit can be analyzed by fewer computer resources owing to the use of shorter calibration lines which are even shorter than a quarter wavelength. Furthermore, the S-parameters may be determined without additional numerical calculation of the port characteristic impedance or normalization with a specified value.

Acknowledgment

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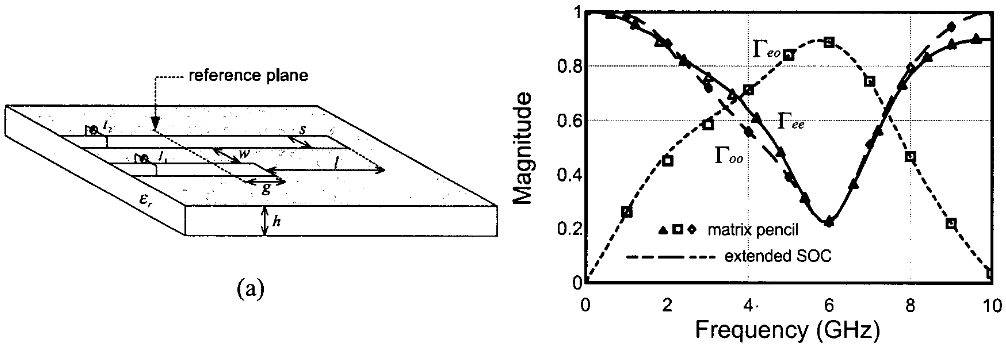
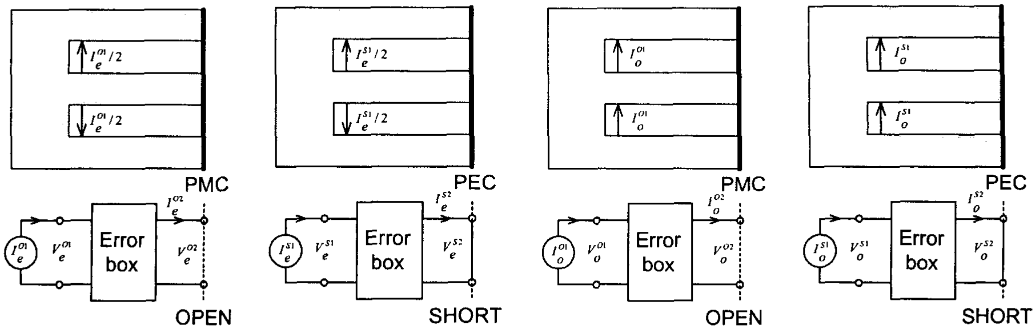


(a)

(b)

Fig. 1 (a) Configuration of asymmetric CPW discontinuity structure (s=1.0mm, w=0.75mm, l=10mm, g=5mm, h=1.54mm, ε_r=4.3), and (b) its simulated reflection coefficients.



(a) (b) (c) (d)

Fig. 2 Configurations and equivalent-circuit representations for the standard calibration elements in the extended SOC procedure: (a) open-end with even-mode excitation, (b) short-end with even-mode excitation, (c) open-end with odd-mode excitation, (d) short-end with odd-mode excitation.

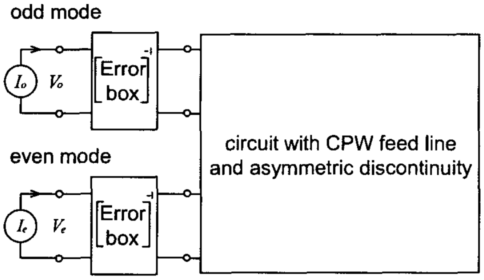
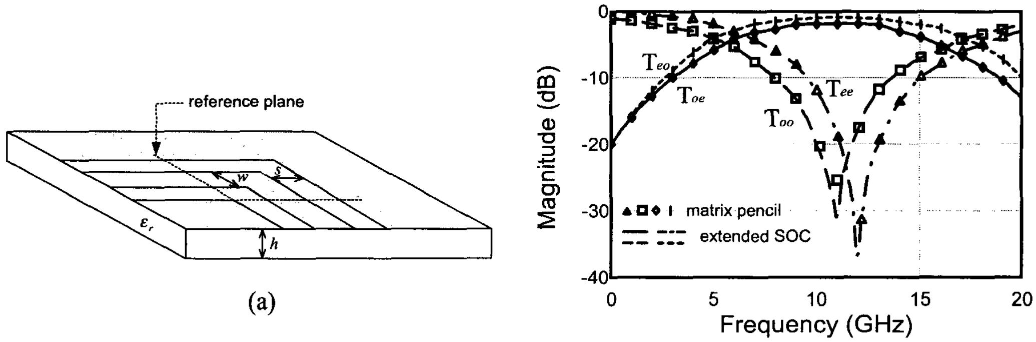


Fig. 3 Equivalent-circuit representation of the asymmetric CPW discontinuity structure (Fig. 1(a)) based on the extended SOC de-embedding procedure.



(a) (b)

Fig. 4 (a) Configuration of CPW right-angle bend (s=0.3mm, w=5mm, h=1.58mm, ε_r=2.33), and (b) its simulated transmission coefficients.