Modeling of Some Coplanar Waveguide Discontinuities

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MODELING OF SOME COPLANAR WAVEGUIDE DISCONTINUITIES

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ABSTRACT

The paper presents lumped equivalent circuit models for several coplanar waveguide discontinuities such as an open circuit, a series gap, and a symmetric step, and their element values as a function of the discontinuity physical dimensions. The model element values are de-embedded from measured S-parameters. The frequency dependence of the effective dielectric constant was measured and compared to computed values.

INTRODUCTION

A coplanar waveguide (CPW) on a dielectric substrate (1) consists of a center strip conductor with semi-infinite ground planes on either sides (Fig. 1). Coplanar waveguide offers several advantages over conventional microstrip line: it facilitates easy shunt as well as series mounting of active and passive devices, it eliminates the need for wrap-around and via-holes, and it has a low radiation loss. These, as well as several other advantages, make CPW ideally suited for microwave integrated circuit applications (2,3). However, very little information is available in the literature on discontinuity models for CPW (4,5). This lack of sufficient discontinuity models for CPW has limited the extent of applications for CPW in microwave circuit design.

This paper presents for the very first time lumped element equivalent circuit models for various discontinuities, together with their element values as a function of the discontinuity physical dimensions. These element values are de-embedded from measured scattering parameters of the discontinuities. The discontinuities characterized in this paper are a series gap in the center conductor, a symmetric step in the center conductor, and an open circuit for two different center conductor widths.

The characteristic impedance for both geometries was 50 Ω. The frequency dependence of the effective dielectric constant, ε(eff), was also measured and is compared to computed values from the literature.
the purpose of de-embedding the discontinuity equivalent circuit parameters, a 1 GHz band centered at 6 GHz was chosen.

EFFECTIVE DIELECTRIC CONSTANT

The \( c_{\text{eff}} \) is determined from the physical length of a pair of series-gap coupled straight resonators which are terminated in a short circuit and the measured resonant frequencies as described in (10). Figures 5(a) and (b) show \( c_{\text{eff}} \) for 50 \( \Omega \) CPW with two different strip widths over the frequency range of 3 to 18 GHz. Also shown in Figs. 5(a) and (b) is \( c_{\text{eff}} \) computed using the expressions in (1), (9), and (11). Good agreement is observed between the measured and computed results above 6 GHz. The \( c_{\text{eff}} \) does not appear to be a strong function of the center strip width for CPW lines of the same impedance.

CPW OPEN CIRCUIT

A CPW open circuit is formed by ending the center strip a short distance before the slot ends, thereby creating a gap, \( g_l \), as shown in Fig. 6. An electric field exists at the open circuit between the terminated center strip and the surrounding ground conductor and hence gives rise to a capacitive reactance. This reactance is seen at a plane coincident with the open end of the center strip. Thus the apparent position of the open circuit is beyond the physical end of the center strip. The open circuit capacitance, \( C_{\text{OC}} \), is a parallel combination of the capacitance due to the fringing fields across the gap, \( g_l \), and those across the slot, \( W \). The gap dependent capacitance varies proportionally as \( 1/g_l \). The slot dependent capacitance is constant. Figure 7 presents the de-embedded open circuit capacitance, \( C_{\text{OC}} \), as obtained from the measured S-parameters.

SERIES GAP IN THE CENTER CONDUCTOR

A series gap of length \( g \) in the center conductor of a CPW is shown in Fig. 6. The gap is modeled as a lumped \( \pi \)-network consisting of a coupling capacitance, \( C_2 \), and two fringing capacitances, \( C_1 \). Analogous to the open circuit, the capacitance across the gap, \( C_2 \), decreases proportionally as \( 1/g \). The fringing capacitance, \( C_1 \), increases from the CPW line capacitance for \( g = 0 \) to the open circuit saturation capacitance for large \( g \). Figure 8 shows the de-embedded capacitances obtained from the measured S-parameters as a function of the gap width \( g \).

STEP CHANGE IN THE WIDTH OF CENTER CONDUCTOR

A step change in width of the center conductor of CPW is shown in Fig. 6. The step discontinuity perturbs the normal CPW electric and magnetic fields which give rise to additional reactances. These additional reactances are assumed to be lumped and located in the plane of the step discontinuity. The modeling experiments show that the reactances can be modeled as a shunt capacitance \( C_s \). The influence of this capacitance is to effectively lengthen the lower impedance CPW line towards the higher impedance CPW line. Figure 9 shows \( C_s \) as a function of the normalized step width. As the normalized step change, \( S_1/S_2 \), increases, \( C_s \) approaches the open circuit saturation capacitance.

DISCUSSIONS

Although the results presented in this paper appear to be self consistent, a mention of the accuracy of the data is required. The two port circuit element models are more accurate than the one port circuit element models. This is because the two port models are based on all four S-parameters versus a single S-parameter for the one port models. Furthermore, the open circuit model is a function of the phase of S11 only. Therefore, the open circuit de-embedded capacitance is sensitive to phase errors. To minimize the phase errors, several precautions were taken. All measurements were made in the frequency range at which the measured propagation constant was close to that used by Touchstone. In addition, the line length from the open circuit to the transition was kept short to minimize the difference in electrical length between the measured and that used by Touchstone.

CONCLUSIONS

The paper presents for the very first time lumped equivalent circuit models for the following CPW discontinuities: an open circuit, a series gap in the center conductor and a symmetric step in the center conductor. The model element values are de-embedded from the measured S-parameters and presented as a function of the discontinuity physical dimensions. The measured frequency dependence of \( c_{\text{eff}} \) is also compared to computed values and found to be in good agreement above 6 GHz.

REFERENCES


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FIGURE 1. - CROSS-SECTION OF THE COPLANAR WAVEGUIDE IN THE TEST FIXTURE.
FIGURE 2. - TRANSITION BETWEEN A 50-OHM CPW AND COAXIAL CONNECTORS USING A LINEAR TAPER TRANSFORMER.

FIGURE 3. - A LUMPED ELEMENT EQUIVALENT CIRCUIT MODEL OF THE TRANSITION BETWEEN THE 50-OHM CPW AND COAXIAL CONNECTOR.
FIGURE 4. - MEASURED (MEASCPW) AND MODELED (MODCPW)
S-PARAMETERS OF THE TRANSITION BETWEEN CPW AND
COAXIAL CONNECTOR.

f_1 = 5.5 GHz
f_2 = 6.3 GHz
**Figure 5.** Measured and computed effective dielectric constant of CPW as a function of frequency.
FIGURE 6. - COPLANAR WAVEGUIDE DISCONTINUITIES AND THEIR LUMPED ELEMENT EQUIVALENT CIRCUIT MODEL.

FIGURE 7. - DE-EMBEDDED LUMPED FRINGING CAPACITANCE FROM MEASURED SCATTERING PARAMETERS AS A FUNCTION OF THE OPEN END GAP WIDTH.
$E_r = 2.2$
$D = 0.125$ in.
$H = 0.72$ in.
$2B = 1.0$ in.
$S/(S + 2W) = 0.9$
$Z_0 = 50$ Ω

$\frac{s_1}{s_1 + 2w} = 0.9$
$z_{01} = 50$ Ω
$S_2 = 2W + S_1$

**Figure 8.** De-embedded lumped fringing and coupling capacitance from measured scattering parameters as a function of gap width.

**Figure 9.** De-embedded lumped shunt capacitance from measured scattering parameters as a function of the normalized step width.
### Model of Some Coplanar Waveguide Discontinuities

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