# Conductor Loss Computataion of Suspended Asymmetric Coplanar Waveguide

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***Abstract*—In this paper the conductor loss computation of suspended asymmetric coplanar waveguide (ACPW) is presented using quasi static spectral domain approach (SDA) method that incorporates the two layer conductor model of conductor and finite conductivity. The results of present method is compared with EM simulator- HFSS and CST in the frequency range 1-100 GHz. The average deviation in effective dielectric constant and conductor loss is about 1.27% and 11.0% respectively.**

**Keywords-Quasi static spectral domain approach (SDA); suspended asymmetric coplanar waveguide; single layer reduction (SLR) method; conductor loss.**

## I. INTRODUCTION

The coplanar waveguide (CPW) have several advantage over microstrip line and widely used in MIC and MMICs applications. The asymmetric coplanar waveguide (ACPW) provides additional degree of freedom in controlling the line parameters- effective relative permittivity and characteristic impedance. Presence of coplanar ground conductor gives ease of connectivity of components, as compared to a microstrip line. Different cpw structures have been investigated, both on isotropic and anisotropic substrates, single layer and multilayer, with finite conductor thickness etc. by conformal mapping, quasi static method and full wave method [1-5]. The full-wave methods are time consuming and not CAD oriented. The closed-form model is reported for the single layer substrate symmetrical CPW that has been extended to the ACPW [4]. Thus a faster computation method is needed to compute the dispersive line parameters of the ACPW on multilayer and suspended dielectric substrate without using the full-wave methods.

In the present work, we reformulate Galerkin's method based spectral domain approach (SDA) for multilayer ACPW with finite strip thickness and finite conductivity. The two-layer conductor model [6], reported for the microstrip, is used for the ACPW line. We introduced the concept of effective inductance to account for the effect of finite strip conductivity on the low frequency dispersion. We further introduce the concept of equivalent symmetrical gap – width [4] that converts the ACPW to the symmetrical CPW. The single layer reduction (SLR) [7] method is used to convert the multilayer ACPW to equivalent single layer substrate. Incorporating these concepts with the static SDA formulation and using available dispersion model for the symmetrical CPW, we get the dispersion results of the suspended ACPW. Results of the present method are compared against two EM simulators Ansoft HFSS and CST Microwave Studio [8, 9].

## II. ANALYSIS OF SUSPENDED ACPW

Fig. 1 shows the shielded isotropic multilayer ACPW. The standard symmetrical CPW is obtained for $G_1=G_2$ and $S_1=S_2$.

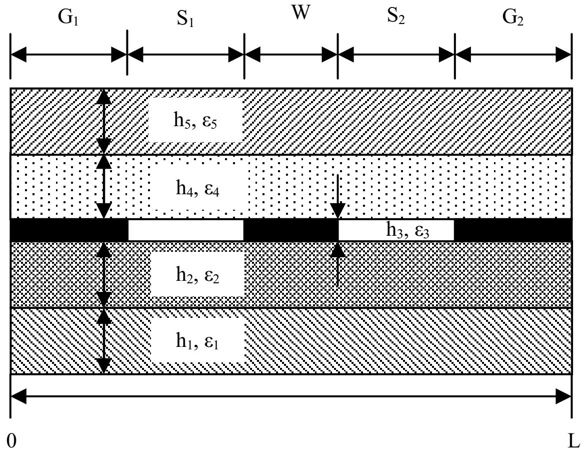

Figure 1. Multilayer asymmetric coplanar waveguide

The finite thickness of strip conductor is accounted by the *two-layer conductor model* that considers the strip as two conducting surfaces- surface-1 and surface-2, separated by thickness $h_3$. In the discrete Fourier domain, the dyadic Green's function of the ACPW with two-layer conductor model can be written as follows [6, 10]:

$$\begin{bmatrix} \tilde{G}_{11}(\beta_n) & \tilde{G}_{12}(\beta_n) \\ \tilde{G}_{21}(\beta_n) & \tilde{G}_{22}(\beta_n) \end{bmatrix} \times \begin{bmatrix} \sum_{i=1}^{N_1} a_i^1 \tilde{\rho}_{s1i}(\beta_n) + \sum_{i=1}^{N_1} b_i^1 \tilde{\rho}_{s2i}(\beta_n) + \sum_{i=1}^{N_1} c_i^1 \tilde{\rho}_{s3i}(\beta_n) \\ \sum_{i=1}^{N_1} a_i^2 \tilde{\rho}_{s1i}(\beta_n) + \sum_{i=1}^{N_1} b_i^2 \tilde{\rho}_{s2i}(\beta_n) + \sum_{i=1}^{N_1} c_i^2 \tilde{\rho}_{s3i}(\beta_n) \end{bmatrix} = \begin{bmatrix} \tilde{V}_c^1(\beta_n) + \tilde{V}_d^1(\beta_n) \\ \tilde{V}_c^2(\beta_n) + \tilde{V}_d^2(\beta_n) \end{bmatrix} \quad (1)$$

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The components of the dyadic Green's function are obtained by using the transverse transmission line (TTL) technique in the Fourier domain. The coefficients $a_i^p, b_i^p, c_i^p; p = 1, 2$, associated with expansions of charge distribution functions used in (1), are determined by taking the inner products with six testing functions. Resulting six equations are solved with the help of Parseval's identity to get distribution expansion coefficients $a_i^1$ and $a_i^2$ on the central strip. We compute the line capacitance of a multilayer ACPW with finite strip thickness by [10]:

$$\frac{C}{\varepsilon_o} = \sum_{i=1}^{N_1} \left( a_i^1 Q_i + a_i^2 Q_i \right) \tag{2}$$

Finally the effective dielectric constant $(\varepsilon_{reff})$ and characteristic impedance $(Z_o)$ of multilayer ACPW are obtained as follows:

$$\varepsilon_{reff} = \frac{C_d(\varepsilon_r)}{C_a(\varepsilon_r = 1)} \quad (a) \quad Z_0 = \frac{1}{c\sqrt{C_d(\varepsilon_r)\, C_a(\varepsilon_r = 1)}} \quad (b) \tag{3}$$

where c is velocity of the EM-wave in the free-space. The line capacitance $C_d(\varepsilon_r)$ is on the dielectric layers and $C_a(\varepsilon_r = 1)$ is on the air-substrate

The single layer reduction (SLR) is used to convert the multilayer ACPW to the ACPW on the single equivalent dielectric with $\varepsilon_r = \varepsilon_{req}$ and $h_{eq}=h_1+h_2$ [7]. Now we convert the ACPW to the symmetrical CPW with slot-gap width $S_{eq}$, using the concept of *weighting factors*:

$$S_{eq} = WF_1 \times S_1 + WF_2 \times S_2 \tag{4}$$

where the weighting factors $WF_i\,(i = 1,2)$ corresponding to slot –gap $S_1$ and $S_2$ are [4]

$$WF_1 = \frac{M_1 D_1}{M_1 D_1 + M_2 D_2} \quad (a-1) \qquad WF_2 = \frac{M_2 D_2}{M_1 D_1 + M_2 D_2} \quad (a-2)$$

$$M_1 = 0.15A(1 - A) + 0.5 \quad (b-1)$$
$$M_2 = -0.15A(1 - A) + 0.5 \quad (b-2)$$

$$D_1 = 4\varepsilon_o \frac{K(k_1)}{K(k_1')} + 2\varepsilon_o \frac{h_3}{S_1} \quad (c-1)$$
$$D_2 = 4\varepsilon_o \frac{K(k_2)}{K(k_2')} + 2\varepsilon_o \frac{h_3}{S_2} \quad (c-2) \tag{5}$$

$$k_1 = \frac{W}{W + 2S_1}, k_2 = \frac{W}{W + 2S_2} \quad (a)$$
$$\text{The aspect-ratio of slot-gap: } A = \sqrt{\frac{S_1}{S_2}} \quad (b) \tag{6}$$

## III. COMPUTATION OF DISPERSION

The dispersive effective relative permittivity and characteristic impedance of the multilayer ACPW are computed on the equivalent single layer substrate by the following expression that also incorporates effect of finite conductor thickness and finite strip conductivity:

$$\varepsilon_{reff}(f, \delta_s) = \left[ \sqrt{\mu_{eff}(f)\ \varepsilon_{reff}(f = 0)} + \frac{\sqrt{\varepsilon_{req}} - \sqrt{K\,\varepsilon_{reff}(f = 0)}}{\left(1 + a\,F^{-b}\right)} \right]^2 \tag{7}$$

where $F = \frac{f}{f_{TE}}$ and $f_{TE} = \frac{c_o}{4h_{eq}\sqrt{\varepsilon_{req} - 1}}$ is the cutoff frequency of the $TE_1$ mode, $b = 1.8$ and

$$\log(a) = u \log\left(\frac{W}{S_{eq}}\right) + v \quad (a)$$
$$u = 0.54 - 0.64\,q + 0.015\,q^2, \quad v = 0.43 - 0.86\,q + 0.540\,q^2$$
$$q = \log\left(\frac{W}{h_{eq}}\right) \quad (b) \tag{8}$$

$$Z_0(f, \varepsilon_{req}, h_{eq}) = Z_0(f = 0, \varepsilon_{req} = 1, h_{eq}) \times \sqrt{\frac{\mu_{eff}(f)}{\varepsilon_{reff}(f, \mu_{eff}(f) = 1)}} \tag{9}$$

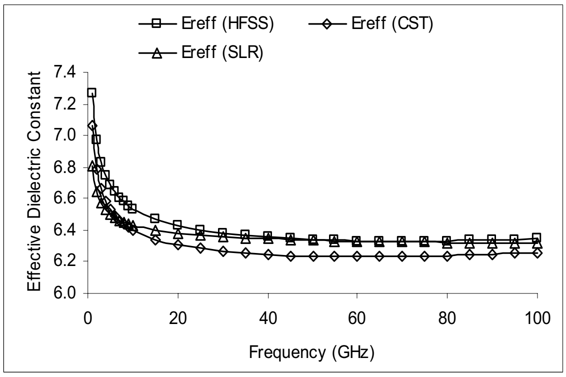
$$\mu_{eff}(f) = \frac{C(\delta_s = 0, \varepsilon_r = 1)}{C(\delta_s, \varepsilon_r = 1)} \tag{10}$$

where $C(\delta_s = 0, \varepsilon_r = 1)$ is the capacitance of ACPW without taking skin depth and $C(\delta_s, \varepsilon_r = 1)$ is capacitance of ACPW with skin depth of strip conductor. The conductor loss of suspended ACPW is computed by incremental inductance method [11].

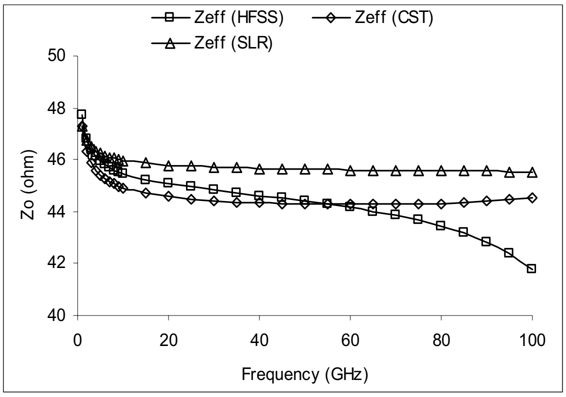
$$\alpha_c = \frac{\pi}{\lambda_0}\sqrt{\varepsilon_{reff}'}\frac{\Delta Z}{Z(\varepsilon_{r1} = \varepsilon_{r1} = \ldots = 1, h, W, \delta_s, h_3)}$$
$$\Delta Z = Z(\varepsilon_{r1} = \varepsilon_{r2} \ldots = 1, W - \delta_s, S_1 + \delta_s, S_2 + \delta_s, h_3 - \delta_s) - Z(\varepsilon_{r1} = \varepsilon_{r2} = \ldots = 1, W, S_1, S_2, h_3) \tag{11}$$

## IV. RESULTS

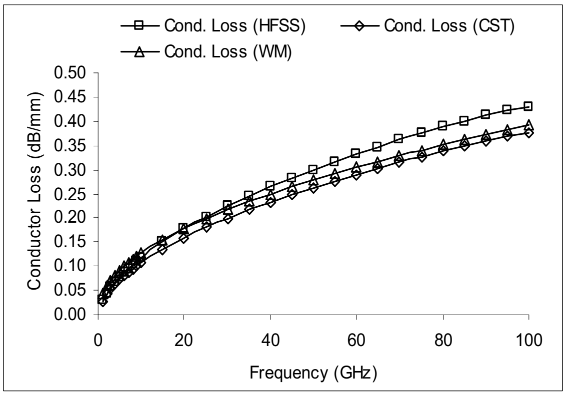
We have compared accuracy of the present model (PM) for the suspended asymmetric coplanar waveguide on substrate- $\varepsilon_1 = 1$, $\varepsilon_2 = 12.9$, $h_1 = 127\mu m$, $h_2 = 254\mu m$, $h_4 = 0$, $h_5 = 10H$, $H = h_1 + h_2$, $\sigma = 4.1 \times 10^7 S/m$, $W = 24\mu m$, $S_1 = 9\mu m$, $S_2 = 27\mu m$ against the results of two EM simulators – the Ansoft HFSS and CST Microwave Studio. The conductor thickness $h_3$ is $3\mu m$.



(a) Effective Dielectric Constant

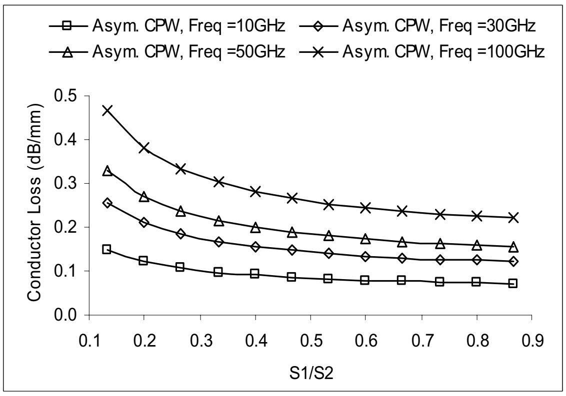


(b) Impedance



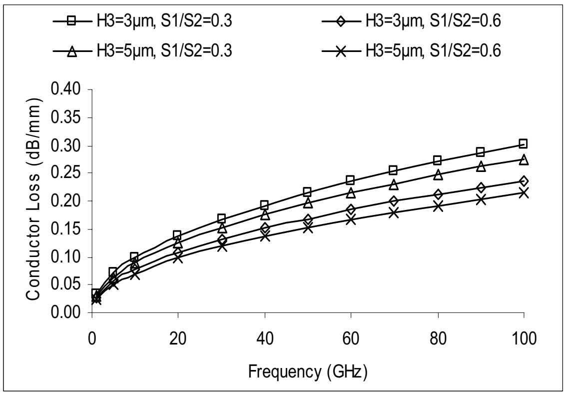
(c) Conductor Loss

Figure 2. Variation of Effective Dielectric Constant, impedance and conductor loss with frequency of Suspended ACPW.



(a) Conductor Loss for different asymmetric aspect ratio $S_1/S_2$

Fig. 2 show the results of the frequency dependent effective dielectric constant, impedance and conductor loss in the frequency range 1-100 GHz for the suspended ACPW line.



(b) Conductor Loss for different conductor thickness

Figure 3. Variation of Conductor loss for Suspended ACPW.

Fig. 3 shows the variation of conductor loss for different conductor thickness and slot gap aspect ratio. The results of the present model (PM) and EM simulators agree well in the entire frequency range.

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