Propagation Characteristics of Slot-line in Lossy Media with Conductor Thickness

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Abstract **– In this paper the CAD oriented closed-form model is presented to compute frequency dependent effective relative permittivity and characteristic impedance of a slot-line with finite conductor thickness in the range $3\mu m - 50\mu m$. The model has average accuracy of about 2% against the full-wave results from different sources in the frequency range 2GHz–60GHz,** $2.22 \le \varepsilon_r \le 20$, $0.02 \le w/h \le 1.0$, $0.01 \le h/\lambda_0 \le 0.25/\sqrt{(\varepsilon_r - 1)}$**. The dielectric loss and conductor loss for slot lines have been computed using the closed-form model. The results have been verified and are found to be in excellent agreement with the practical and theoretical data available in the literature.**

Key words: *Microwave/millimeter-wave technology; Slot-line; Conductor thickness based propagation characteristics; Dielectric loss; Conductor loss*

1. Introduction

The usefulness of slot lines is increasing at higher microwave and millimeter-wave frequencies. The dispersion characteristics of slot line have been investigated by several authors [5]-[8], which have been computed by the Spectral Domain Analysis (SDA). However, the available models do not take into account the effect of finite conductor thickness on the line parameters and the SDA is not suitable for the CAD purpose. This communication suggests empirical models to account the effect of the conductor thickness on the $\varepsilon_{reff}(f)$ and $Z_0(f)$ and closed –form expressions for the computation of the dielectric loss and the conductor loss of the slot-line. The validity of the proposed models is tested in the frequency range 2GHz – 60GHz and conductor thickness $3\mu m - 50\mu m$. The results for losses have been verified in the frequency range 2GHz – 18GHz.

2. Conductor Thickness based Effective Relative Permittivity and Characteristic Impedance

The accuracy of all three closed-form models with conductor thickness has been compared against the full-wave results of Kitazawa et al. [1]. The % deviations of all three models between 0 – 50 μm are shown in Fig.1 for $\varepsilon_r = 20, w/h = 0.5$. Garg-Gupta [5] and Janaswamy and Schaubert [6] have been selected as a combined model to incorporate the effect of conductor thickness on $\varepsilon_{\mathrm{reff}}(\mathrm{f})$ and $\mathrm{Z}_0(\mathrm{f})$ of a slot-line as they have the least % deviation for both parameters.

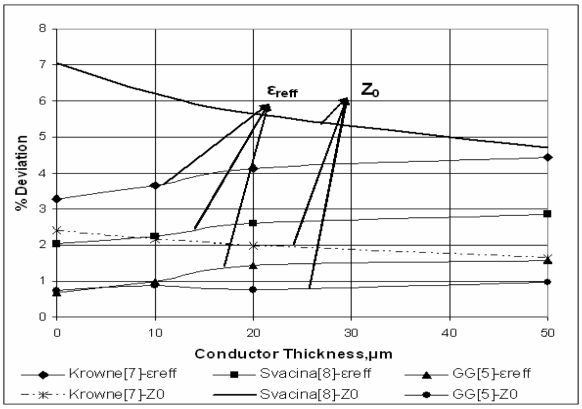


Fig. 1: % Deviation of three closed –form for characteristic impedance and effective relative permittivity against results of SDA [1].

2.1 Effective Relative Permittivity

The closed-form model for the effective relative permittivity of a slot-line with zero conductor thickness could be written in the parametric form,

$$\lambda_g / \lambda_0 = 1/\sqrt{\varepsilon_{reff}(f,t=0)} = f_1(\varepsilon_r, w/h, h/\lambda_0, t=0) \qquad (1)$$

The expressions for the function f_1 are obtained from [5, 6]. The effect of conductor thickness on $\varepsilon_{reff}(f,t)$ is accounted in model 1 given below, that was suggested for the microstrip line [10]. However, for the slot-line case, it degrades at high frequency. We suggest the introduction of an empirical correction factor $(t/\lambda_0)^p$ in the model.

Model 1:

$$\varepsilon_{reff}(f,t) = \varepsilon_{reff}(f,t=0) - \left\{ \left(\frac{\varepsilon_r - 1}{4.6} \frac{t/h}{\sqrt{w/h}} \right) - \left(\frac{t}{\lambda_0} \right)^p \right\} \qquad (2a)$$

$$p = 0.0006 f^2 - 0.0369 f + 0.7714 \qquad (2b)$$

where, f is frequency in GHz; t, h, λ_0, λ_g, ε_r are conductor thickness, substrate thickness, slot-width, free-space wavelength, guided wavelength and relative permittivity of substrate respectively. The conductor thickness decreases the effective relative permittivity. Fig. 2(a) compares the model at frequency 2GHz and 10GHz for the slot-line on substrate having ε_r = 2.5, 9.8 and 20, $w/h = 0.5$ against the conductor thickness 0 - 90 μm. The model 1 has average deviation 2.16% and maximum deviation 9.96 % for $t = 0 - 50$ μm; ε_r = 9.7 - 20; w/h = 0.2 – 1.

2.2 Characteristic Impedance

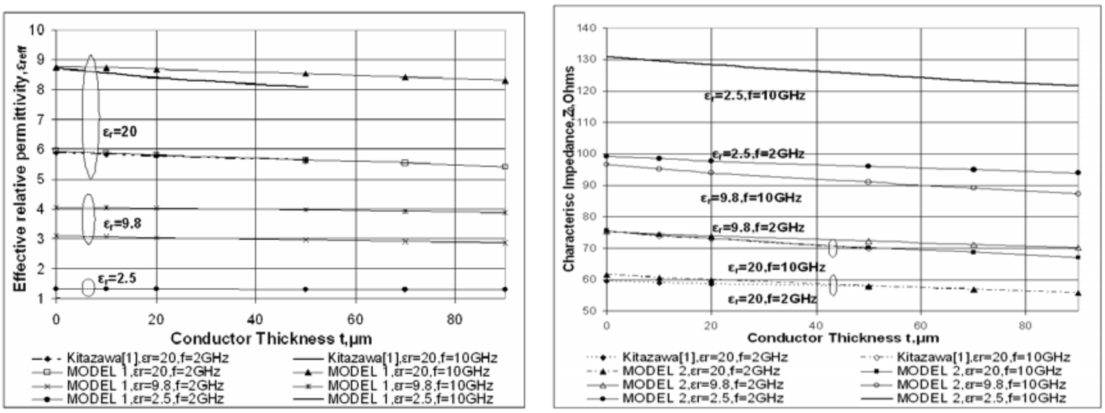
The dispersive characteristic impedance of a slot-line with zero conductor thickness can be computed from the closed-form model that can be expressed in the functional form as

$$Z_0(f,t=0) = f_2(\varepsilon_r, w/h, h/\lambda_0, t=0) \qquad (3)$$

The full expressions for the function f_2 can be obtained from [5, 6]. The strip conductor thickness t alters the slot-width. Thus, to account the effect of the conductor thickness t on the characteristic impedance, the physical slot-width w in above expression can be replaced by the equivalent slot-width: $w_{eq} = w - \Delta w$. The incremental slot-width Δw can be computed from the following expression, primarily used with microstrip line [11]

Model 2:

$$\Delta w = \frac{t}{\pi}\left[1 + \ln(4) - 0.5 \ln\left(\left[\frac{t}{h}\right]^2 + \left[\frac{t}{\pi w}\right]^2 \right) \right] \qquad (4)$$



(a) (b)

Fig. 2: Comparison against SDA results [1] of ε_r=2.5, 9.8 and 20 for w/h=0.5 at f=2 and 10GHz for (a) Effective relative permittivity and (b) Characteristic impedance.

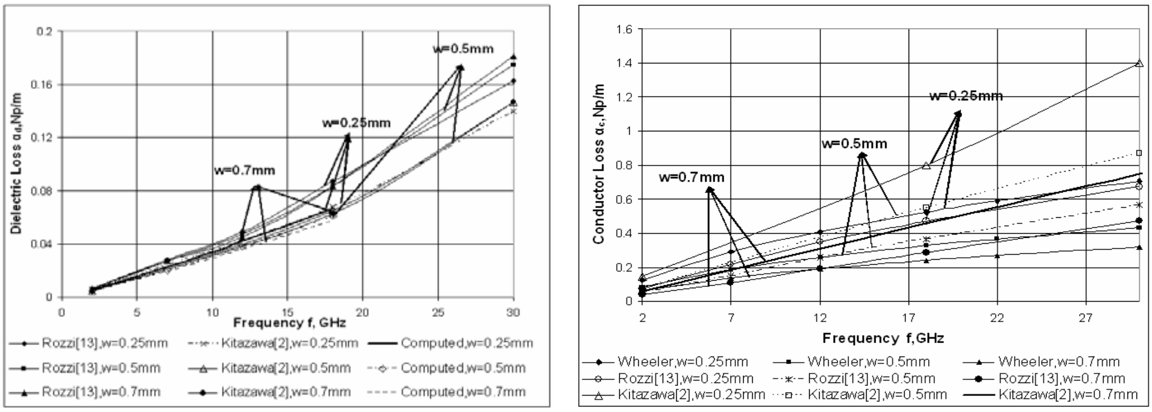
The characteristic impedance also decreases with increase in the conductor thickness. The computed characteristic impedance of slot-line using closed-form model 2 is compared against the SDA results in Fig. 2(b) at frequency 2GHz and 10GHz for the slot-line on substrate having $\varepsilon_r =$ 2.5, 9.8 and 20, $w/h = 0.5$ against the conductor thickness 0 - 90 μm. The maximum deviation of 10% occurs only at 2GHz where waveguide model based closed-form is not accurate due to the unrealistic cut-off behavior [4]. On average, the model 2 follows the SDA results within 2% deviation.

3. **Losses**

Fig. 3(a) and (b) show the dielectric losses and the conductor losses for slot line together with the published data [2], [13]. The dielectric losses α_d, results obtained are lesser than those in [13] but are in closer approximation with [2]. The Wheeler incremental inductance formulation has been used for computing the conductor losses in slot lines. The conductor loss α_c, values are larger than those in [13] but are slightly comparable to those in [2]. The results have been verified against the SDA results in 2GHz – 18GHz for the conductor thickness 6μm, $\varepsilon_r = 9.8$, $h = 0.635mm$, $0.1 \le w/h \le 1.0$, $0.01 \le h/\lambda_0 \le 0.25/\sqrt{(\varepsilon_r - 1)}$.

4. Conclusion

The closed-form dispersion models are presented to compute effective relative permittivity and characteristic impedance of a slot-line with finite conductor thickness. The models have average accuracy of about 2% against the SDA results in 2GHz– 60GHz for the conductor thickness 3μm-50μm, $2.22 \le \varepsilon_r \le 20$, $0.02 \le w/h \le 1.0$, $0.01 \le h/\lambda_0 \le 0.25/\sqrt{(\varepsilon_r - 1)}$. The dielectric losses and conductor losses for slot lines have been computed using the closed-form models in 2GHz – 18GHz, which are in close agreement with the experimental results.



(a) (b)

Fig. 3: (a) Dielectric losses, and (b) Conductor losses of slot line for ε_r=9.8, t=6μm, h=0.635mm.

Acknowledgement

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