Analysis of Microstrip Transmission-Line on an Anisotropic Substrate

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Abstract— **This paper addresses simple and straight solution of anisotropy. Dispersion & Characteristic Impedance play the vital role in modeling the circuit characteristics. For anisotropy, Equivalent isotropic relative permittivity $\varepsilon_{\mathrm{r,iso}}^{\mathrm{eq}}$ is the function of the physical dimension (w/h) of the Microstrip line. Several investigators have used different rigorous numerical solutions as Transmission-Line Matrix, Method of Moment, Fourier Series Techniques and SDA etc. to obtain expressions for the medium transformation. The proposed solution can be employed to compute the propagation characteristics of microstrip line at every anisotropic substrate materials. Two closed form models are valid for all practical and theoretical anisotropic materials ($0.01 \le w/h \le 15$) with high frequency.**

Key words: - **Anisotropic substrate, Characteristic Impedance, Equivalent relative permittivity, Isotropic medium, Microstrip line.**

I. INTRODUCTION

DIELECTRIC constitutes an important design complication into the quasi-static characteristics of single Microstrip transmission lines on anisotropic substrate. Effort has been made by several investigators to account for the effect of anisotropy on the effective relative permittivity and characteristic impedance of a microstrip line [1-5]-[7-8].The closed-form expressions are reported that converts the anisotropic substrate to the equivalent isotropic substrate with equivalent substrate thickness without any consideration of w/h-ratio of the microstrip line [1, 7]. We must take into account the effect of w/h-ratio of the microstrip for accurate computation of the equivalent isotropic relative permittivity. Edward et al. have used the finite-difference method with an analytical formula to achieve this end [1, 2]. Fritsch and Wolff have used the full-wave method for this purpose [8]. Edward et al. have also given the closed-form expression, applicable only to the Sapphire substrate to get an equivalent isotropic relative permittivity [2].

The models are valid over the wide range of parameters. The accuracy of the models are tested against available experimental and numerical results and also against the results obtained from the commercial software Empire [6]. In this paper reports two w/h-ratio dependent closed – form models to compute the equivalent isotropic relative permittivity of a microstrip line without using the finite difference or the full-wave method.

II. DISCUSSION OF MODELS

MODEL # 1 The process of getting w/h dependent equivalent isotropic relative permittivity $\varepsilon_{\mathrm{r,iso}}^{\mathrm{eq}}$ of the anisotropic substrate involves two steps- (i) getting the equivalent isotropic substrate $\varepsilon_{\mathrm{r,eq}}$ and equivalent substrate thickness h_{eq} the without consideration of w/h-ratio[7], (ii) getting the w/h dependent equivalent isotropic relative permittivity $\varepsilon_{\mathrm{r,iso}}^{\mathrm{eq}}$ with original substrate thickness h by the method of partial capacitance.

The method of partial capacitance provides the w/h dependent equivalent isotropic relative permittivity $\varepsilon_{r,iso}^{eq}$ of the substrate with original width w and thickness h. There is an extension in width of the microstrip to $w+\Delta w$ due to the fringe capacitance. We assume that the main central parallel plate capacitance is caused by the component $\varepsilon_{\mathrm{ryy}}$. Thus the total line capacitance *p.u.l.* on the equivalent isotropic substrate could be written as a combination of the fringe capacitance and the central capacitance.

$$\frac{\varepsilon_0\, \varepsilon_{r,iso}^{eq}\,(w+\Delta w)}{h} = \frac{\varepsilon_0\, \varepsilon_{r,eq}\Delta w}{h} + \frac{\varepsilon_0\, \varepsilon_{r,yy} w}{h}$$
$$\Rightarrow \varepsilon_{r,iso}^{eq} = \varepsilon_{r,eq}\,\frac{\Delta w}{w+\Delta w} + \varepsilon_{r,yy}\,\frac{w}{w+\Delta w} \tag{1}$$

However, as the line capacitance *p.u.l.* is proportional to the width of the strip conductor, i.e. fringe capacitance $C_f \propto \Delta w$, central parallel plate capacitance $C_p \propto w$ and the total line capacitance $C_t \propto (w+\Delta w)$,

$$\varepsilon_{r,iso}^{eq} = \frac{\varepsilon_{r,eq}C_f + \varepsilon_{r,yy}C_p}{C_t} = \frac{\varepsilon_{r,eq}C_t + (\varepsilon_{r,yy} - \varepsilon_{r,eq})C_p}{C_t} \tag{2}$$

where, $C_t = C_p + C_f$.

The total line capacitance *p.u.l.* of a microstrip on the equivalent isotropic substrate is obtained from steps- (i) and the central parallel plate line capacitance *p.u.l.* is obtained from the $\varepsilon_{\mathrm{ryy}}$ component of the anisotropic substrate.

$$C_t = \frac{\varepsilon_{r\,eff}(w, h_{eq}, \varepsilon_{req})}{v\; Z_0(w, h_{eq}, \varepsilon_{req}=1)} \quad (a) \qquad C_p = \varepsilon_{ryy}\,\varepsilon_0\,\frac{w}{h} \quad (b) \tag{3}$$

where, v is velocity of EM-wave in the free-space.

We can use the relative permittivity $\varepsilon_{\mathrm{r,iso}}^{\mathrm{eq}}$ with substrate thickness h and strip width w to compute the correct static effective relative permittivity and characteristic impedance of the original microstrip on the anisotropic substrate.

MODEL # 2 Simple and accurate closed- form model to compute the w/h dependent equivalent isotropic relative permittivity $\varepsilon_{\mathrm{r,iso}}^{\mathrm{eq}}$ of an anisotropic substrate by curve-fitting the numerical data. The expressions are given below

$$\varepsilon_{r,iso}^{eq} = K.Y.\varepsilon_{ryy} \tag{4}$$

where,

$$Y = -7.0\times10^{-5}(w/h)^4 + 0.0017(w/h)^3 - 0.0149(w/h)^2 + 0.0568(w/h) + 0.9099$$

$$K = \begin{cases} 1.1256\sqrt{\dfrac{\varepsilon_{rxx}}{\varepsilon_{ryy}}} - 0.0151 & 0 < w/h \le 1 \\ 1 & w/h > 1 \end{cases}$$

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III. RESULTS

The w/h dependent equivalent isotropic relative permittivity $\varepsilon_{r,iso}^{eq}$ of an anisotropic substrate has been obtained by Edward by using the finite difference method also by using the empirical method that is applicable only to Sapphire substrate [1, 2]. Fig.1 compares the model #1 and model #2 against results of Edward on Sapphire substrate. The maximum deviation 1.3% and 1.2% for the model #1 and model #2 respectively occurs for the narrow width microstrip line. The W/h ratio has significant effect on equivalent isotropic relative permittivity.

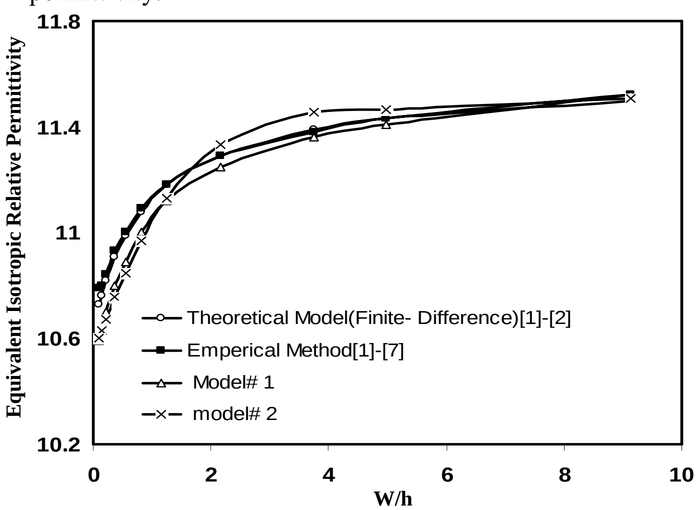

Fig.1: Comparison of both models against the finite difference method.

We have further compared model #1 to compute the effective relative permittivity and characteristic impedance over wide range of anisotropic ratio $n = \sqrt{\varepsilon_{rxx}/\varepsilon_{ryy}}$ on substrate with $\varepsilon_{ry} = 2.55, 4.5, 9.9$ [3]against the results obtained from the commercial software- Empire [6].We have also compared the results of Alexopoulos and Krowne [3] obtained by numerical methods against same software. Fig.2 shows these comparisons in respect of the characteristic impedance for W/h=0.1, 1.0, and 10.0 It is apparent that the model # 1 has less deviation.

The numerical method of Alexopoulos and Krowne has average deviation up to 13.59% for the effective relative permittivity and 9.11% for the characteristic impedance; whereas the model #1 has these deviations only 5.3% and 1.78%. The model #2 has identical results. Finally the model #1 has been used along with the dispersion model to compute the dispersion in microstrip line on Sapphire substrate [1, 2]. Fig.3 compare against the experimental results. The maximum deviation is within 1% that is within the accuracy limit of Jensen dispersion model[5] for the isotropic substrate.

V. CONCLUSION

This paper presented closed-form models to obtain the equivalent relative permittivity of the microstrip line on the anisotropic substrate for $0 < w/h \le 10$, anisotropic ratio $0.5 \le n \le 3$ for both low and high permittivity substrates. The model has accuracy 0.5% against the full-wave method. The models are used to compute effective relative permittivity and characteristic impedance with 5.3% and 1.78% respectively against the commercial software Empire. Thus the proposed models could be incorporated in the CAD for development of the components on the anisotropic substrates.

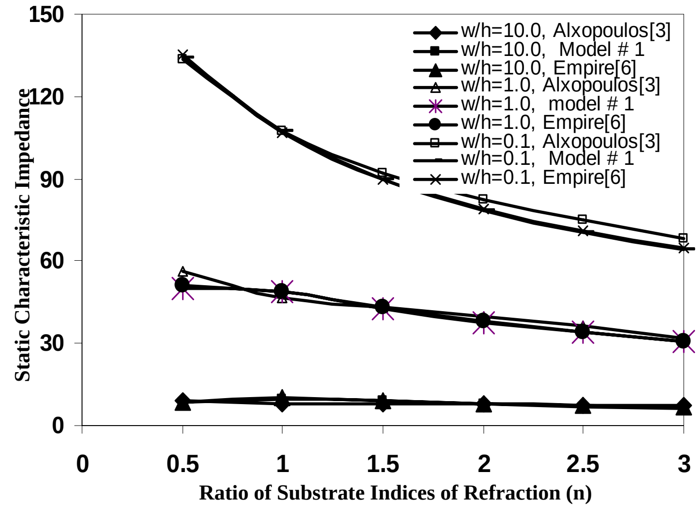

Fig. 2: Static Characteristic Impedance against Imst Empire (ε_{ry} =9.9).

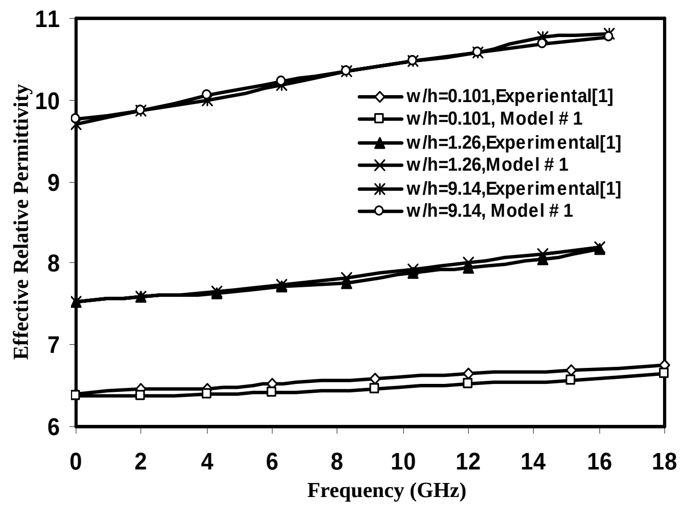

Fig.3 frequency dependent effective elative Permittivity of model # 1 against experimental results on Sapphire.

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