NEW DISPERSION MODELS FOR OPEN SUSPENDED SUBSTRATE MICROSTRIPS

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Abstract

New dispersion models for the effective dielectric constant and impedance of open suspended substrate microstrips are presented. For frequencies above 20 GHz, the accuracy of these models (in reproducing the exact fullwave data) is better than 1 percent for the effective dielectric constant and mostly better than 2.5 percent for the impedance.

Introduction

Suspended substrate microstrips (SSM's) are emerging as very popular transmission media for millimeter-wave applications. These lines, in their unshielded form, can be of two types, namely, suspended and inverted structures. The cross-sections of the suspended and inverted microstrip structure are shown in Fig. 1, with various dimensions and parameters defined therein. The main advantages of SSM's over the conventional microstrip as well as over structures like the finline are low-loss, low-dispersion, and relaxed dimensional tolerances.

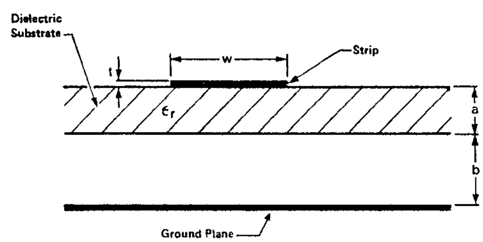

Figure 1 (a) Suspended Microstrip

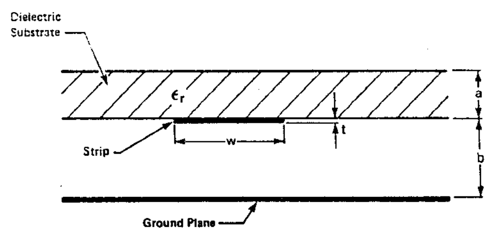

Figure 1 (b) Inverted Microstrip

The dispersion in SSM's, although characteristically low, is not altogether negligible. In fact, the dispersion effects in these lines become increasingly important as the substrate dielectric constant increases [1] - [3]. Keeping this in mind, the present authors have been working on modeling the dispersion effects in SSM's. In an earlier work [4], the well-known Getsinger model [5] was modified for the frequency-dependent effective dielectric constant of the suspended microstrip (SMS). The present paper further refines the model and also extends it to the inverted microstrip (IMS). A model for the frequency-dependent value of the impedance (power-current definition), valid for both suspended and inverted structures, is also derived.

The modeling results reported in this paper are based on the exact fullwave data generated by authors at the University of Ottawa (using spectral-domain approach). Four very commonly used substrate materials, namely RT-duroid (dielectric constant 2.22), fused quartz (dielectric constant 3.78), Alumina (dielectric constant 9.8), and Gallium Arsenide (dielectric constant 12.9), are considered.

It should be pointed out that although a lot of quasistatic research on SSM's has been and is being done (see, e.g., [6] - [12]), accurate results including dispersion effects in these lines are still scarce. In fact, the present author's efforts in formulating the dispersion effects in SSM's through closed-form equations seem to be completely original.

The work reported in this paper will be of great practical interest to the millimeter-wave circuit designer. The results will significantly advance the state-of-the-art on accurate CAD modeling of suspended substrate microstrips.

DISPERSION MODEL FOR EFFECTIVE DIELECTRIC CONSTANT

The frequency-dependent value of the effective dielectric constant is given by

$$\varepsilon_{re}(f) = \frac{\varepsilon_{re}(0) + K_\varepsilon \, \varepsilon_r}{1 + K_\varepsilon} \qquad (1)$$

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Where $\varepsilon_{re}(0)$ is the quasistatic value of the effective dielectric constant (calculable from either [10] or [12]), ε_r is the substrate dielectric constant, and

$$K_\varepsilon = \sum_{i=0}^{4} \left\{ c_i \ (\varepsilon_r, \ a/b, W/b) \right\} (f/f_p)^i \qquad (2)$$

In (2), f is the operating frequency and f_p is defined by

$$f_p = \frac{Z_o}{2\mu_o \ (a + b)} \ \frac{a}{0.064} \qquad (3)$$

Where Z_o is the quasistatic value of the impedance (calculable from either [10] or [12]), $\mu_o = 4\pi \times 10^{-9}$ H/cm, and a and b are measured in cm (see Figure 1).

Various c's in (2) are known in terms of ε_r, a/b and W/b.

The model represented by the above equations is valid for both suspended and inverted structures.

DISPERSION MODEL FOR IMPEDANCE

The frequency-dependent value of impedance is given by

$$Z(f) = \frac{120\pi \ (a + b)}{W_e(f)\sqrt{\varepsilon_{re}(f)}} \ \frac{a}{0.074} \qquad (4)$$

Where $\varepsilon_{re}(f)$ is known from Equation (1), a and b are again in cm, and $W_e(f)$ is the width of the equivalent planar waveguide (in cm).

$W_e(f)$ can be shown to be a solution of

$$\sum_{i=0}^{4} F_i \left\{ W_e(f)/\lambda \right\}^i = 0 \qquad (5)$$

Where λ is the free-space wavelength in cm and various F's are given by

$$F_o = d_o \ W/\lambda \qquad (6a)$$

$$F_1 = -d_o - 2\left(\frac{W_e(0)}{\lambda} - d_1 \ \frac{W}{\lambda}\right)\sqrt{\varepsilon_{re}(f)} \qquad (6b)$$

$$F_2 = 2 \ (1-d_1)\sqrt{\varepsilon_{re}(f)} \ + 4 \ d_2 \frac{W}{\lambda} \ \varepsilon_{re}(f) \qquad (6c)$$

$$F_3 = -4\left\{d_2 \ - \ 2d_3 \ \frac{W}{\lambda} \ \sqrt{\varepsilon_{re}(f)}\right\}\varepsilon_{re}(f) \qquad (6d)$$

$$F_4 = \ -8 \ d_3 \ \varepsilon_{re}(f) \ \sqrt{\varepsilon_{re}(f)} \qquad (6e)$$

In (6), $W_e(0)$ is the quasistatic value of $W_e(f)$ and is given by

$$W_e(0) = \frac{120\pi \ (a + b)}{Z_o \ \sqrt{\varepsilon_{re}(0)}} \ \frac{a}{0.064} \qquad (7)$$

Moreover, d_o, d_1, d_2 and d_3 are known functions of ε_r a/b and W/b.

The model presented in this section is valid for both suspended and inverted microstrips.

RESULTS AND DISCUSSION

Equations (1) and (4) were used to compute the effective dielectric constant and impedance of both suspended and inverted microstrips (with Coefficients c and d appropriately selected). Two representative comparisons between the modeled and exact data are shown in Figures 2 and 3, respectively. Figure 2 is for a suspended microstrip on GaAs substrate (a/b = 0.6, W/b = 4) and Figure 3 is for an inverted microstrip on RT-duroid substrate (a/b = 0.6, W/b = 4). The agreement between modeled and exact data is quite good for most of the frequency range. For the practical range f>20 GHz, the effective dielectric constant model is found to be accurate to within 1 percent and the impedance model to mostly within 2.5 percent.

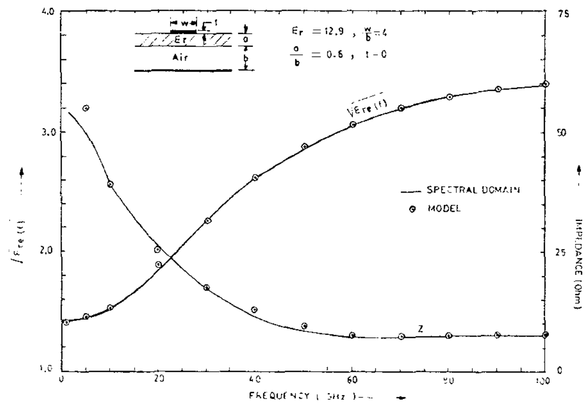

Figure 2

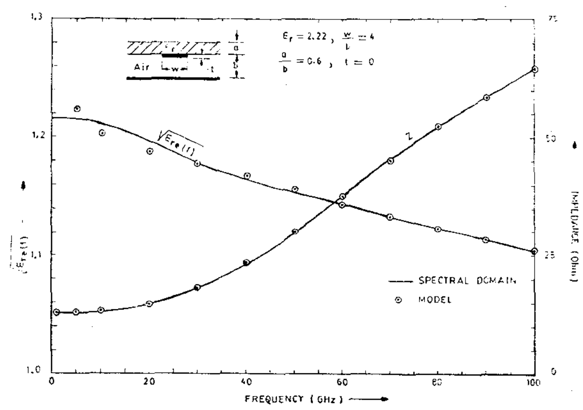

Figure 3

CONCLUSIONS

New dispersion models for open suspended and inverted microstrips are reported. The models are sufficiently accurate for all practical purposes and will be a very useful addition to the millimeter-wave circuit designer's library.

LIST OF FIGURES

Figure 1. Cross-sections of suspended substrate microstrips.

(a) Suspended (b) Inverted

Figure 2. A comparison between modeled and exact data (suspended microstrip).

Figure 3. A comparison between modeled and exact data (inverted microstrip).

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