Investigation of Microstrip Dispersions and Bend Discontinuities

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Abstract- This paper presents an EM analysis of dispersions & discontinuities in a microstrip transmission lines. Dispersion characteristics of a microstrip lines are investigated by the existing models for study of microstrip lines and then compare the results with Software Simulation. Dispersions on microstrip lines with characteristics impedance 50Ω are investigated for the frequency range 1 to 18 GHz for Alumina substrate and 1 to 3 GHz for FR4. The frequency dependent characteristics of microstrip dispersions and discontinuities were analyzed by MoM based Sonnet Software Simulation. This paper discusses two issues concerning the dispersions and bend discontinuity for Alumina and FR4. The CAD analyses for compensated and non-compensated discontinuities are simulated & compared. The Sonnet Software is used for the analysis of variations in effective dielectric constant, scattering parameters & current densities at various frequency range. The work is of practical significance for microwave researchers and engineers.

Keywords – Microwave integrated circuits, Microstrip lines, Dispersions, Discontinuities, Scattering parameters, Effective dielectric constant, method of moments and EM simulations.

I. INTRODUCTION

MICs or MMICs based on the planar transmission line techniques has an important role in advancing the radio and microwave frequency communication technologies. The building blocks for MICs are planar transmission lines, such as microstrip, coupled microstrip line, coplanar waveguide, slotline and finline. Microstrip is a very attractive and essential part of microwave integrated circuit, from which modern microwave components are made. The transmission line that is used in 90% of the circuits is the microstrip line. It consists of dielectric substrate of height h, dielectric constant ε_r, metal or conducting material on its back side. On top of the substrate a metallic strip of width w and metallization thickness t is the waveguide design. An open microstrip line structure is shown in Fig. 1. The mode of propagation in a microstrip is almost TEM and mainly it is an open structure, so microstrip line has easy of fabrication and also features ease of interconnections and adjustments. Practical Microstrip line is shown in Fig. 2. For accurate circuit design, it is essential to have sufficient knowledge of the dispersions characteristics, phase velocity, characteristics impedance, losses and scattering parameters for both straight and microstrip lines with discontinuities. Initially the microstrip was regarded as a quasi TEM mode transmission line for a frequency up to few GHz, and the parameters phase velocity, characteristics impedance and effective dielectric constant are independent of frequency. In quasi static analysis microstrip support pure TEM mode, and can be described in terms of static capacitance and inductances only. At higher frequencies mode of propagation is not pure TEM mode due to dielectric interface and little components of both electric and magnetic fields exits. Fullwave analysis is carried out to study time-varying electric and magnetic fields in terms of S-parameters in a microstrip lines at higher frequencies [1], [2].
II. DISPERSIONS AND DISCONTINUITIES

The frequency dependence of wave velocity in a transmission line is known as dispersion property and is required for microstrip circuit design. CAD requires accurate and reliable information on the dispersion behaviour of microstrip line. All microstrip lines are dispersive and the accurate relationship between wavelength and frequency is very problematical. This dynamic or dispersive mechanism is due to hybrid mode of propagation along microstrip line and is responsible for variation in current and charge distributions in both strip and ground plane as the frequency increases. The dispersions or effective dielectric constant $\varepsilon_{\text{eff}}(f)$ increases with frequency. The dispersion properties have been studied analytically and mathematically by a number of researchers and many approximate dispersion formulas were proposed to provide information on the dispersion behaviors of microstrip [3], [4]. The significant dispersions model given by, Getsinger [5], Edwards and Owens [6], Yamashita et al. [7], Kirschning and Jensen [8], Kobayashi [9], and many others.
The microstrip dispersions $\varepsilon_{\text{eff}}(f)$ always increases with frequency, as frequency tends to 0 $\varepsilon_{\text{eff}}(f) = \varepsilon_{\text{eff}}$ and as frequency tends to infinity $\varepsilon_{\text{eff}} = \varepsilon_r$ [1], [10]. The frequency dependent effective permittivity is a function of frequency, substrate height, substrate relative permittivity and $Z_0$ as follows:

$$\varepsilon_{\text{eff}}(f, h, \varepsilon_r, \varepsilon_{\text{eff}}, Z_0)$$

Microstrip discontinuities are the basic elements of Microstrip Integrated Circuits. Microstrip discontinuities such as open ends, gaps, step impedance, bends, T-junctions and crossings are elements of many complex microstrip circuits like filters, couplers, impedance transformers and patch antenna. These discontinuities may cause disturbances in the electric and magnetic fields which affect the signal. To manage these disturbances the PCB designers have to make CAD capabilities prior to the engineering process. A variety of approaches have been made to work out on the equivalent circuit for these discontinuities. The capacitances of microstrip discontinuities have been calculated by Silvester & Benedek and inductance elements of the equivalent circuits is computed by Gopinath, Silvester, Easter and Thomson [10]–[14]. At lower frequencies these static characteristics i.e. capacitances and inductances are sufficient. At higher frequencies to analyze discontinuities the S-parameters has to be investigated. The S-parameters is a way of representing a network’s transmission and reflection coefficients, and the only the parameters that can be measured at higher frequencies. The fullwave analysis of a microstrip discontinuities have been reported mainly by Menzel, Chadha, Gupta, Wolff, Jansen and Koster [15]–[17]. The microstrip bend discontinuities and its various compensations like chamfered bend, single step bend and double step bend are shown in Fig. 4.

![Figure 4. Microstrip bend discontinuities](image_url)

(a) 90° bend (b) Chamfered 90° bend (c) One Step 90° bend (d) double step 90° bend
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III. ELECTROMAGNETIC SIMULATION AND ANALYSIS

The EM simulations for dispersion and discontinuities were performed on Alumina substrates for the frequency up to 18 GHz and for FR4 substrates up to 3 GHz. Analysis of microstrip dispersions and its bend discontinuities using Sonnet EM Simulations are as follows:

i. Comparisons of dispersion models with EM simulator software for Alumina and FR4 substrates are shown in Fig. 5 and Fig. 6. From figure it is clear that for high dielectric constant the dispersions given by sonnet software, MoM based EM simulator, is very near to Yamashita dispersion models, but for low dielectric substrate effective dielectric variations are less.

ii. Variations of $\varepsilon_{\text{eff}}(f)$ with frequency for Alumina substrate for different w/h are shown in Fig. 7. Graphs show that as w/h increases the effective dielectric constant also increases. Variations of $\varepsilon_{\text{eff}}(f)$ with frequency for FR4 substrate for different $Z_0$ are shown in Fig. 8.

iii. Microstrip bend discontinuities and its various compensations implementation for Alumina and FR4, at junctions were investigated. Scattering Parameters were analyzed for bend discontinuities and three different types of compensations. The variations of reflection coefficient $S_{11}$(dB) with frequency for Alumina and FR4 are shown in Fig. 9 and Fig. 10. The reflection coefficients $S_{11}$(dB) for chamfered and double step bend are less as compared to 90° bend and single step bend. The appropriate removal of copper at a junction to implement compensation provides better results as compared to 90° bend. The variations of transmission coefficient $S_{21}$(dB) with frequency for Alumina and FR4 are shown in Fig.11 and Fig.12. The transmission coefficients $S_{21}$(dB) for chamfered and double step bend are more as compared to 90° bend and single step bend.

Figure 5. Variations of $\varepsilon_{\text{eff}}$ (Alumina) with frequency for different dispersion formulas & MoM Sonnet Software Simulations
Figure 6. Variations of $\varepsilon_{\text{eff}}$ (FR4) with frequency for different dispersion formulas & MoM Sonnet Software Simulations

Figure 7. Variations of $\varepsilon_{\text{eff}}$ (Alumina) with frequency for different w/h
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Figure 8. Variations of $\varepsilon_{\text{eff}}$ (FR4) with frequency for different Characteristics Impedance

Figure 9. $S$-parameters $S_{11}$ (dB) for the uncompensated and compensated bend discontinuities for Alumina
Figure 10. S-parameters $S_{11}$ (dB) for the uncompensated and compensated bend discontinuities for FR4.

Figure 11. S-parameters $S_{21}$ (dB) for the uncompensated and compensated bend discontinuities for Alumina.
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IV. CONCLUSION

A simulation results for the microstrip dispersions and its bend discontinuity characterization of microstrip transmission lines for Alumina and FR4 substrates were presented. The dispersions were investigated for various dispersion models and its comparisons with MoM based software. S parameters for a microstrip bend junctions and its three different types of compensations were studied and analyzed. As w/h increases the effective dielectric constant for Alumina substrate increases. As characteristics impedance decreases the effective dielectric constant for FR4 substrate increases. The transmission coefficient increases & reflection coefficient decreases for chamfered and double step bend discontinuities. The EM simulation modeling approach is useful for a design of a complete microwave circuits prior to fabrications. The work is of practical relevance for RF designers.

REFERENCE