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A CAD Oriented Model of Elevated Coplanar Waveguide for Millimeter Wave Applications

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Abstract : - In this paper the closed form analysis of Computer Aided Design oriented model for the characteristic impedance (z_0) and the effective dielectric constant (ε_{reff}) of Elevated Coplanar Waveguide structures are obtained and performances are predicted using theoretical analysis. Numerically efficient and accurate formulae based on the conformal mapping method for the analysis of elevated coplanar waveguide structures are presented. Accurate closed form analysis formulas for Elevated Coplanar Waveguides are derived and verified with Matlab (7.0). These results have been compared with low loss MMIC rate race hybrid using Elevated Coplanar Waveguides.

***Keywords*: - Coplanar Waveguide, Elevated Coplanar Waveguide, Conformal Mapping Method.**

I. INTRODUCTION

Recent progresses in High Temperature Super-Conductor (HTSC) Microwave devices, integrated optical Travelling Wave Modulators (TWM) and optically controlled Microwave devices has necessitated the extensive analysis and simulation models for Coplanar Waveguide (CPW) structure and its variants [2]. Coplanar Waveguide (CPW) was first proposed as an MIC transmission medium by Wen [1] at the David Samoff Research Center in 1969. CPW has several advantages over Microstrip including:
Lower dispersion, less radiation loss, easy grounding of shunt-mounted components, lower fabrication cost since via-holes are eliminated, closed-form expressions for the characteristic impedance, higher directivity couplers due to near equality of even and effective dielectric constant and odd mode propagation constants. This fact, together with the absence at that time of any CAD data for discontinuities, undoubtedly hindered the widespread application of CPW despite its advantages.

The quasi-static modeling of ECPW structure and its variants using Finite Element Method (FEM) has been reported [3]-[4]. Numerical procedures are time consuming and also accuracy of simulation models is proportional to computation time. Closed form model gives a convenient way to design the required design specification [5], and they have potential application in simulation that requires successful first pass design with desired accuracy. To achieve this, compact Computer Aided Design (CAD) simulation model either in quasi-static limit or in full-wave is needed to characterize the transmission lines. Full-Wave analysis model provides precision characterization at wider frequency range, but becomes quite complex in the multilayer environment. On the other hand, quasi-static analysis provides good accuracy with Full-Wave analysis models [11] and is suitable for CAD software package for frequencies up to 20 GHz. Conformal Mapping Method has been reported as a versatile tool for providing closed form models for CAD environment. Erli Chen et al. has successfully implemented Conformal Mapping Method for Multilayer CPW [6] and Jiri Svacina for Multilayer Microstrip line [7]. The past researchers have not reported the closed form expression for ECPW of quasi-static limit in CAD environment.

II. ELEVATED COPLANAR WAVEGUIDE

In today's scenario, the use of an Elevated Coplanar Waveguide (ECPW) has been proposed to increase the bandwidth of sampling circuits. One of the variant structures of CPW is Elevated Coplanar Waveguide shown in Fig.1, which provides compact and reliable circuit in Microwave and Millimeter Wave frequencies. The objective is to obtain a closed form analysis model for Elevated Coplanar Waveguide using Conformal Mapping Method and is based on the partial capacitance technique using Schwarz-Christoffel transformation for mapping technique. Elevated CPW lines have been used to reduce the losses. For the designed Elevated Coplanar Waveguides, it has been shown that a low loss transmission line is obtainable compared to the conventional CPW and a very low effective dielectric constant close to 2 could be realized by confining most of the electromagnetic fields in the lossless air layer [13] and useful in high speed digital interconnects [14].

III. METHOD OF ANALYSIS

Simple analytical formulas for the quasi-TEM parameters obtained from either exact or approximate conformal mapping techniques are proposed. Schwarz-Christoffel conformal transformation from Z-plane to T-plane is given by [9]. The equation for mapping is as follows,

$$\frac{dZ}{dT} = F'(T) = A\prod_{i=1}^{N}(T - r_i)^{-\alpha_i} \qquad (1)$$

Where A is a constant, r_i is the co-ordinate in T plane and α_i is the angle made by the polygon with the real axis.

To calculate the quasi-static line parameters namely the line impedance and line effective dielectric constant, one needs to find the line capacitance. The line capacitance of ECPW structure shown in Fig.1 and is calculated using the method of superposition of partial capacitance [4], as given in the following steps.

Step: 1

The structure is assumed to be transfer symmetric so that one half of the plane that is the right hand side of Fig.2 is taken for analysis is shown in Fig.3a. The enclosed dielectric is assumed to be of finite thickness and infinitely wide.

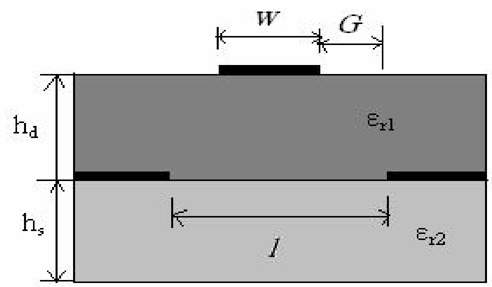

Fig.1 Cross Sectional view of an ECPW with two substrates

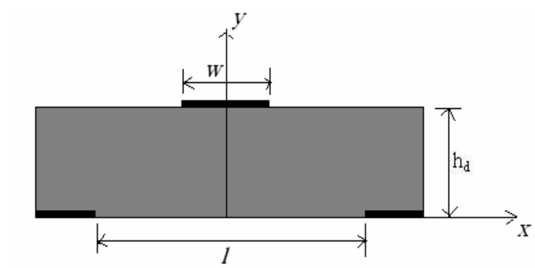

Fig.2 The Cross Sectional view of an ECPW with a single structure

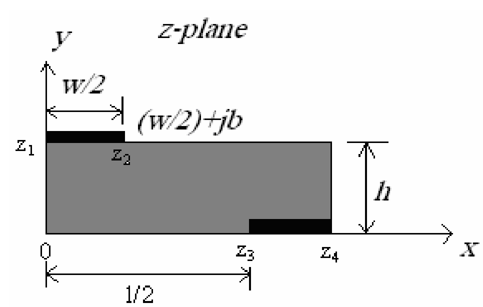

Fig. 3 a

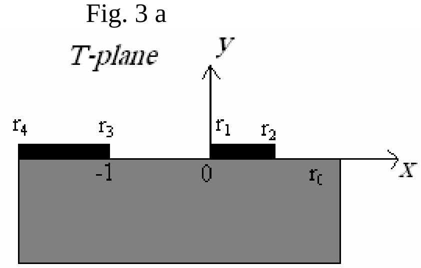

Fig.3 b

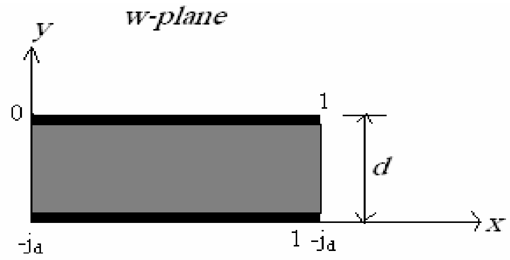

Fig.3 c

Fig. 3 Capacitance configurations of an ECPW

Step: 2

The structure taken for analysis is transformed into T-plane so that the conducting strip and the ground plane lie in the real axis [8]. The co-ordinates in the T-plane are chosen such that, $r_1 < r_2 < r_0$ as shown in Fig.3b. The structure in T-plane is transformed into W-plane as shown in Fig.3c and the mapping uses the equation (1).

Step: 3

The total line capacitance of ECPW structure (C_{ECPW}), as shown in Fig.2, is given by,

$$C_{ECPW} = C_0 + C_1 + C_2 + C_3 \qquad (2)$$

Where C_0 is the line capacitance of an ECPW with dielectrics replaced by air. Upon solving boundary condition problem using conformal mapping technique the line capacitance C_0 is given by,

$$C_0 = 4\,\varepsilon_0\, K(k_0^1) / K(k_0) \qquad (3)$$

C_1 is the line capacitance calculated for the structure with the presence of the inserted dielectric layer having thickness h_d where the electric field exists and the relative dielectric constant of (ε_{r1}-1). Using conformal mapping method the line capacitance C_1 is given by,

$$C_1 = 2\varepsilon_0 (\varepsilon_{r1}-1) K(k_1^1) / K(k_1) \qquad (4)$$

The line capacitance C_2 derived for the structure with the presence of the substrate having the electric field concentration in the thickness h_s and the relative dielectric constant (ε_{r2} -1).
Hence,

$$C_2 = 2\,\varepsilon_0\,(\varepsilon_{r2} - 1)\,K(k_2^1) / K(k_2) \qquad (5)$$

Similarly, the capacitance C_3 is calculated for the structure with the inserted dielectric layer thickness h_d if $h_d > h_s$ or the substrate thickness h_s if $h_s > h_d$ and relative dielectric constant ($\varepsilon_{r1} - \varepsilon_{r2}$) if $\varepsilon_{r1} > \varepsilon_{r2}$ or ($\varepsilon_{r2} - \varepsilon_{r1}$) if $\varepsilon_{r2} > \varepsilon_{r1}$. Then,

$$C_3 = 2\,\varepsilon_0\,(\varepsilon_{r1} - \varepsilon_{r2})\,K(k_3^{'}) / K(k_3) \qquad (6)$$

Where $K(k_i)$ is the complete elliptical integral of the first kind, with i = 0 to 3

$$k_i = \frac{1}{\sqrt{-r_{0i}}} \quad \text{and} \quad k_i^1 = \sqrt{1 - k_i^2} \qquad (7)$$

Where,

$$r_{0i} = \sinh^2 \left[\frac{w\pi}{4\left(-h - j\dfrac{l}{2}\right)} \right] \qquad (8)$$

and h represents the height of the inserted dielectric (h_d) or the substrate thickness (h_s) as the case may be, w is the strip width and l is the line width.

(2)

Using equations (2) to (8), the effective dielectric constant (ε_{reff}) and characteristic impedance (Z_0) are calculated as,

$$\varepsilon_{reff} = C_{ECPW} / C_0 \,,$$

(3)

$$\varepsilon_{reff} = 1 + \frac{(\varepsilon_{r1} - 1) K(k_1) K(k_0)}{K(k_1) K(k_0^1)} + \frac{1}{2} \frac{(\varepsilon_{r2} - 1) K(k_2^1) K(k_0)}{K(k_2) K(k_0^1)}$$

$$+ \frac{1}{2} \frac{(\varepsilon_{r1} - \varepsilon_{r2}) K(k_3^1) K(k_0)}{K(k_3) K(k_0^1)} \qquad (9)$$

$$V_{ph} = \frac{v_0}{\sqrt{\varepsilon_{reff}}} \qquad (10)$$

Where v_0 is the velocity of the electromagnetic wave in free space and V_{ph} is the phase velocity. The expression of characteristic impedance in lossless TEM case [11]:

$$Z_0 = \sqrt{\frac{L}{C}} \qquad (11)$$

Where C and L is capacitance and inductance respectively.

Characteristic impedance of an ECPW is given by,

$$Z_0 = \frac{1}{C_{ECPW} V_{ph}} = \frac{60}{\sqrt{\varepsilon_{reff}}} \frac{K(k_0)}{K\left(k_0'\right)} \Omega \qquad (12)$$

IV. NUMERICAL RESULTS AND DISCUSSION

Thus, the structure of the closed form analysis of ECPW is modelled and the parameters are derived. The characteristic impedance (Z_0) and effective dielectric constant (ε_{eff}) of the closed form analysis model of ECPW structure has been obtained using Conformal Mapping Method (CMM). The characteristic impedance of CPW's are determined mainly by W/G ratio (W is the center conductor width, G is the gap width).Therefore, to increase the CPW characteristic impedance, G must be expand and W reduced. Obviously, this results in a wide circuit and increases insertion loss. The ECPW can overcome these problems. The performance of the structure is shown by characteristic impedance (Ω) versus line width L (L=W+2G) and also the performance is shown by effective dielectric constant (ε_{reff}) versus line width (L) for various strip elevations (h_d) in Fig.4 and Fig.5. For example, a 145 Ω characteristic impedance is obtained at a line width L of 40 μm, at an h = 10 μm, while a very large L over 120 μm is required for conventional "planar" CPW's (h = 0). Therefore, the size of high impedance CPW's is reduced using elevated CPW's without reducing the conductor width W.

To prove the validity of the developed analysis models, Z_0 is calculated for ECPW structure under CPW limit by removing the inserted dielectric layer (ε_{r1}) and reducing the strip elevation to zero (h_d =0) [8]. The results are verified for various elevations with the results presented by H.Kamitsuna [3]. In this case, the percentage of error varies between 0.01% to 0.015% in the chosen limit of the line width, which shows the accuracy of the proposed model. Comparison of the ECPW characteristic impedance and the effective dielectric constant including the case of h = 0 is shown in table 1.

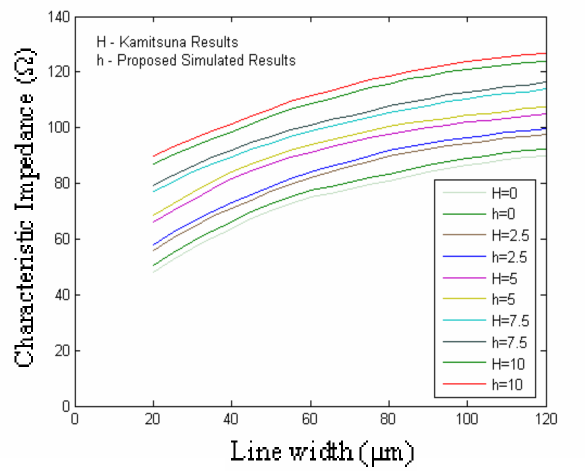

Fig.4 Comparison of characteristic impedance of an ECPW with Kamitsuna for ε_{r1} = 3.3 and ε_{r2} = 12.9 and h represents the height of the inserted dielectric layer (h_d) same as substrate thickness (h_s).

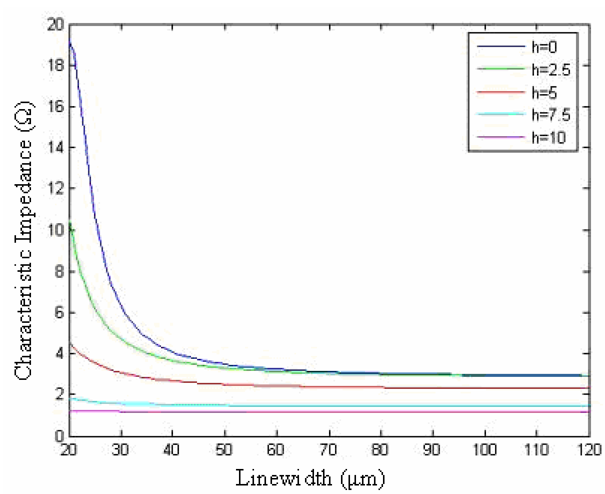

Fig.5 Effective dielectric constant (ε_{reff}) vs. linewidth (μm) of an ECPW for ε_{r1} = 3.3 and ε_{r2} = 12.9.

Table:1 Comparison of an ECPW characteristic impedance and the effective dielectric constant including the case of h = 0

Thickness h (μm)	Line Width (μm)	Characteristic impedance Z_0 (Ω)	Effective dielectric constant (ε_{reff})
h = 0	20	50.5000	12.9
	30	59.0000	9.3
	40	66.0000	4.9
	50	72.8000	4.5
	60	77.5000	4.3
h = 2.5	20	58.0000	9.9
	30	66.0000	5.2
	40	73.0000	4.4
	50	79.0000	3.9
	60	84.0000	3.8
h = 5.0	20	68.6000	4.3
	30	76.6000	3.8
	40	84.1000	3.5
	50	89.6000	3.3
	60	93.8000	3.4
h = 7.5	20	79.3000	1.9
	30	86.3000	1.8
	40	91.8000	1.75
	50	96.8000	1.7
	60	101.0000	1.65
h = 10	20	89.8000	1.4
	30	95.8000	1.35
	40	101.3000	1.3
	50	106.8000	1.2
	60	111.4000	1.1

V. CONCLUSION

The characteristic impedance and the effective dielectric permittivity of ECPW are calculated using the Conformal Mapping Method and presented. The performance measured is compared with Kamitsuna model and the percentage of error varies in the chosen limit of the line width and found to be effective when the width is low. This model would be more advantageous and compatible for Computer Aided Design of Microwave and Millimeter wave components using an ECPW structure. An obvious direction for future research work is expanding both width and depth in the closed form analysis of ECPW. The proposed model can be used to model different structures with multiple number of layers in order to further reduce the percentage of errors. The performance can be measured and is more useful in the field of Microwave and Millimeter wave components using ECPW structures.

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