Dispersion and Characterization of Coplanar Waveguide Based On Conformal Mapping Technique

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Abstract

In this paper we proposed the estimation of the characteristic impedance, effect of dispersion, and the effective dielectric constant of Coplanar Waveguide (CPW) using conformal mapping theory and performances are analyzed. Numerically efficient and accurate formulae based on the conformal mapping method for the analysis of coplanar waveguide structures are presented. The analysis formulas for Coplanar Waveguides are derived and verified with Matlab. The Characteristic Impedance of CPW for different dielectric material using finite substrate as well as for infinite thickness of the substrate material and peering effect of dispersion is under consideration in this work. With the help of CPW transmission techniques, substantial amount of efficiency has been achieved. The design equation obtained by conformal mapping technique which is the simplest and most often used quasi-static method consists of complete elliptical integral.

Keywords: — *CPW, microstrip, fringing field, conformal mapping, Transmission line, Quasi-TEM.*

I.   INTRODUCTION

The coplanar waveguide (CPW) is an alternative to microstrip and strip line that place both, the signal and ground current on the same layer [5]. Since 1969 it has rapidly gained widespread use of RF and Microwave integrated circuits due to its many attractive features such as active device can be mounted on top of circuit, elimination of via holes in connecting circuit elements to ground, it has very high frequency response, immediate access to adjust power plane, low radiation and dispersion loss, continuous, lower cross talk as well as CPW design technique allows to reduce the circuit size by about 30% [1], it facilitates easy shunt as well as series surface mounting of active and passive devices, ease in realizing compact balanced circuits, easy integration with solid-state devices and ease the fabrications too with respect to other conventional transmission lines or devices [5]. The coplanar technology provides the possibility to design highly condensed microwave integrated circuits, especially if additional use is made of a lumped element technique. Very small circuit layouts can be made up to highest frequencies. Because the fundamental coplanar waveguide does not use a conducting ground plane on the backside of the substrate material, the parasitic capacitances of the lumped circuit components like spiral inductors or inter-digital capacitors are small compared to the microstrip case. This results in a much higher first resonant frequency of these components so that even at millimetre-wave frequencies (e.g., 40–60 GHz) a lumped element technique can be used in coplanar monolithic integrated circuits.

II.   STRUCTURE AND DESIGN

Coplanar waveguides can be broadly classified as the conventional CPW, conductor-backed CPW and the micromachined CPW. In a conventional CPW, the ground planes are of semi-infinite extent on either side. However, in a practical circuit the ground planes are made of finite extent. Then conductor-backed CPW has an additional ground plane at the bottom surface of the substrate. This lower ground plane not only provides mechanical support to the substrate but also acts as a heat sink for circuits with active devices. The micromachined CPWs are of two types, namely, the microshield line [7] and the CPW suspended by a silicon dioxide membrane above a micromachined groove [8].

But basically in coplanar waveguide (CPW) structure the conductor formed a centre strip separated by a narrow gap from two ground plane on either side. The gap in the coplanar waveguide is usually very small and supports electric fields primarily concentrated in the dielectric [6].

There exist two main types of coplanar lines: the first, called coplanar waveguide (CPW), is composed of a median metallic strip separated by two narrow slits from a infinite ground plane, which is shown in the figure 1.
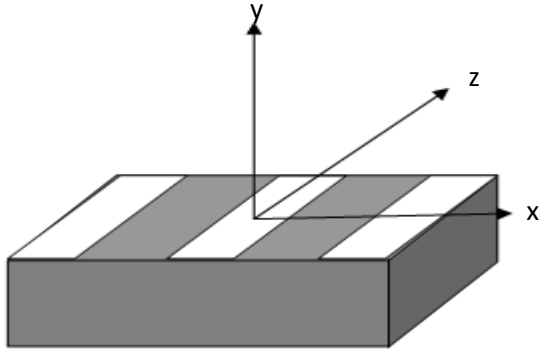
Fig:1 coplanar waveguide line

The characteristic dimensions of a CPW are the central strip width and the width of the slots . The structure is obviously symmetrical along a vertical plane running in the middle of the central strip and z is the direction of propagation of wave. The other coplanar line; called a coplanar slot (CPS) is the complementary of that topology, consisting of two strips running side by side, which is shown in the figure 2.
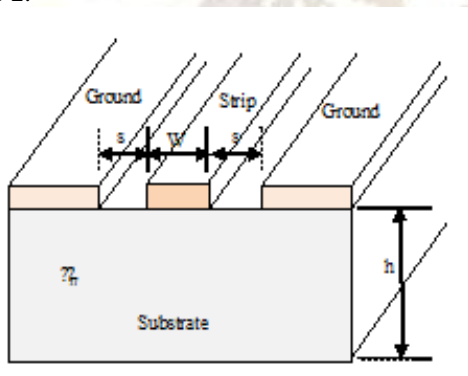

Fig. 2 coplanar waveguide of finite substrate (slot line).

III.   CHARACTERISTIC FEATURES

a) Since the number of the electric and magnetic field lines in the air is higher than the number of the same lines in case of microstrip, the effective dielectric constant (ε_{eff}) of coplanar waveguide is typically lower than the effective dielectric constant (ε_{eff}) for microstrip, so the maximum characteristics impedance value are higher than the microstrip value [4].

b) In case of coplanar waveguide the actual dimensions of the centre-strip, the separation, the thickness and permittivity of dielectric substrate determined the effective dielectric constant, attenuation and the characteristics impedance of the line.

c) We can minimize the radiation in case of coplanar waveguide and to concentrate the fields in the substrate area by the help of making dielectric substrate thickness equal to about twice the gap width.

d) As the coplanar waveguide has two ground planes, so the ease in maintaining at the same potential to prevent unwanted modes from propagating.

e) It is well studied that a coplanar waveguide containing little fringing field in the air space, so the coplanar waveguide (CPW) exhibits low dispersion.

f) Frequency dispersion in the case of coplanar waveguide is generally small, but there is a slight dependence on line dimensions, and narrow lines are less frequency dispersive than the wide lines [3].

g) The grounded coplanar waveguide (GCPW) is used on printed circuit boards as an alternative choice of microstrip line. With vias connecting the ground planes, the grounded coplanar waveguide is less possibility to radiate and has higher isolation than microstrip. There is always a ground plane exists between any two adjacent lines, hence cross talk effects between adjacent lines are very week [2]. So regarding these facts coplanar waveguide circuits can be made denser than conventional microstrip circuits.

IV.   QUASI-STATIC ANALYSIS BY CONFORMAL MAPPINGS IN CASE OF PLANAR CPW

A CPW is an appropriate transmission line and has ability to generate elliptical polarized magnetic fields with two modes of propagation namely quasi- TEM and non-TEM mode for CPW, closed form design equation obtained by conformal mapping method which is the simplest and most often used quasi-static method consist of complete elliptic integral which are difficult to calculate even with computers, hence approximate formulas are proposed for the calculation of elliptical integral by conformal mapping [1]. A CPW can be quasi-statically analyzed by the use of conformal mappings which consists in transforming the geometry of the PCB into another conformation, whose properties make the computations straightforward [4].
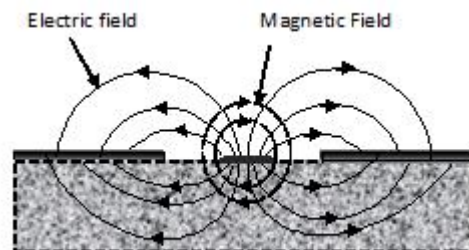

Fig:3 Electric and Magnetic field distribution of even mode

The CPW of negligible thickness located on top of an infinitely deep substrate, as shown on the left of the figure below, can be mapped into a parallel

plate capacitor filled with dielectric ABCD using the conformal function:

$$w = \int_{z0}^{z} \frac{dz}{\sqrt{\left(z - \frac{W}{2}\right)\left(z - \frac{W}{2} - s\right)}} \quad \text{………………} (1)$$
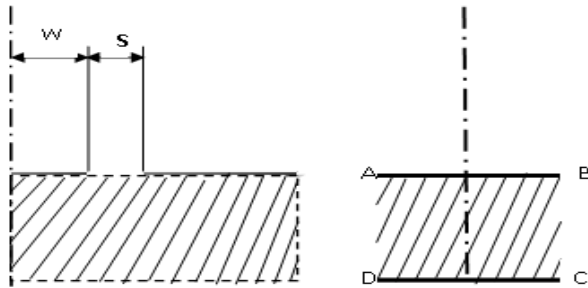

Fig:4 Infinitely deep substrate of CPW and Parallel plate capacitor filled with dielectric substrate.

To further simplify the analysis, the original dielectric boundary is assumed to constitute a magnetic wall, so that BC and AD become magnetic walls too and there is no resulting fringing field in the resulting capacitor. With that assumption, the capacitance per unit length is merely the sum of the top (air filled) and bottom (dielectric filled) partial capacitances. The latter is given by:

$$Z = \frac{30\pi}{\sqrt{\varepsilon_{re}}} \cdot \frac{K'(k_1)}{K(k_1)} \quad \text{……………………………} (2)$$

In practical cases, the substrate has a finite thickness h. To carry out the analysis of this conformation, a preliminary conformal mapping transforms the finite thickness dielectric into an infinite thickness one. Only the effective permittivity is altered; it becomes:

$$\varepsilon_{re} = 1 + \frac{\varepsilon_r - 1}{2} \cdot \frac{K(k_2)}{K'(k_2)} \cdot \frac{K'(k_1)}{K(k_1)} \quad \text{………………} (3)$$

a. EFFECT OF DISPERSION

The coplanar waveguide (CPW) structure is subdivided into five classes based on substrate thickness, backside metallization, and ground plane width. Radiation and guided modes are studied in each class, and their effects on loss and dispersion are described. For coplanar waveguides, dispersion due to interaction with surface wave parallel-plate modes in the substrate strongly depends on the ground-to-ground spacing (W+2G). If this spacing is small compared to dielectric wavelength and substrate thickness, both dispersion and radiation losses are minimized. In finite ground plane cases, small ground-to-ground spacing compared to substrate thickness is necessary to avoid the excitation of the microstrip mode and to minimize the deviation of the CPW mode from the odd mode of the ideal line. Limitations on the reduction of (W+2G) come from conductor loss, which imposes a minimum width requirement on the center conductor. If substrate thickness is to be kept large compared with this dimension, it is inescapable that, at high frequencies, the operation of the CPW will not be below the cut off frequency of surface wave modes. However, the interaction of the CPW mode with surface wave modes is negligible for integrated circuit applications when ground-to-ground spacing is small compared with dielectric wavelength. The effects of dispersion in CPW are similar to those encountered in the microstrip lines, though the net effect on impedance is likely different [5]. The closed form expression to compute $\varepsilon_{re}(f)$ from its quasi-static value:

$$\sqrt{\varepsilon_{re}(f)} = \sqrt{\varepsilon_{re}(0)} + \frac{\sqrt{\varepsilon_r} - \sqrt{\varepsilon_{re}(0)}}{1 + G.\left(\frac{f}{f_{TE}}\right)^{-1.8}} \quad \text{……………} (4)$$

Where

$$G = e^u. ln\left(\frac{W}{s}\right) + v$$
$$u = o.54 - 0.64p + 0.015p^2$$
$$v = 0.43 - 0.86p + 0.54p^2$$

$$p = ln\left(\frac{W}{h}\right)$$

Where f_{TE} is the cut-off frequency of the TE_0 mode, defined by:-[6]

$$f_{TE} = \frac{c}{4h.\sqrt{\varepsilon_r - 1}}$$

V.   RESULT AND ANALYSIS
CHARACTERISTICS   IMPEDANCE   Vs NORMALISED STRIP WIDTH FOR VARIOUS MODES OF COPLANAR WAVEGUIDE USING DIFFERENT DIELECTRIC MATERIALS:

6.1 For Finite Substrate Thickness

It is observed that as we increasing the normalised strip width of CPW, the characteristics impedance decreases but it is slightly increases at 7.9433 value point. This verification is done on putting the conductor width constant.
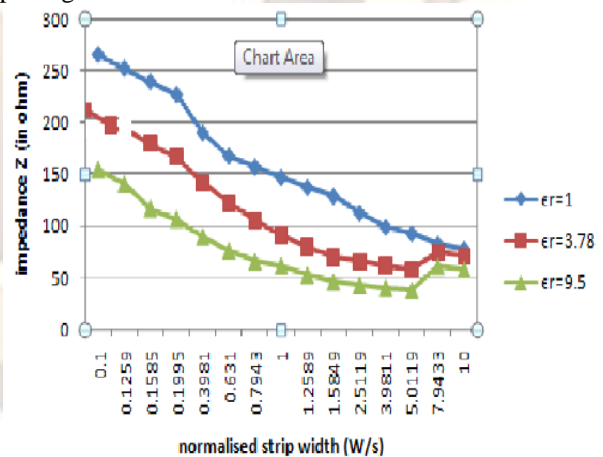

Fig:5 Characteristics impedance Vs Normalised strip width (in mm)

6.2 For Infinite Substrate Thickness

It is observed that as we increasing the normalised strip width of CPW, the characteristics impedance decreases continuously. This is done by varying slot width.
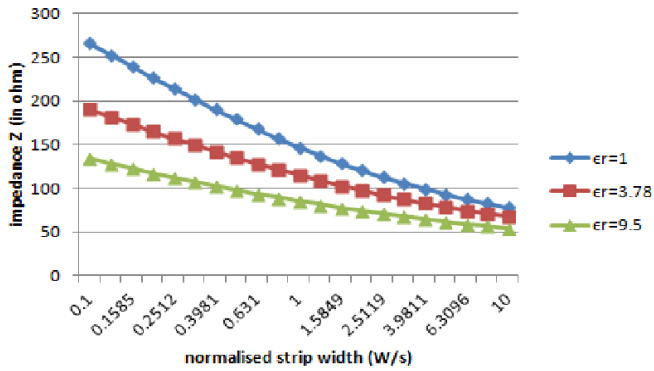
Fig:6 Characteristics impedance Vs Normalised strip width (in mm)

6.3 Effect of Dispersion on Finite Substrate Thickness

The characteristic impedance is more prominantly decreases with increasing the normalised strip width in the case of effect of dispersion.
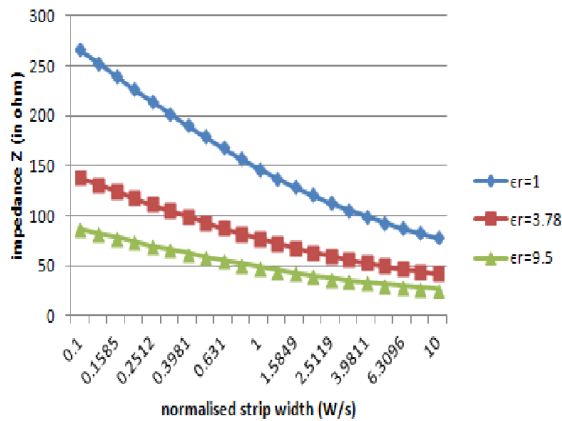

Fig:7 Characteristics impedance Vs Normalised strip width (in mm

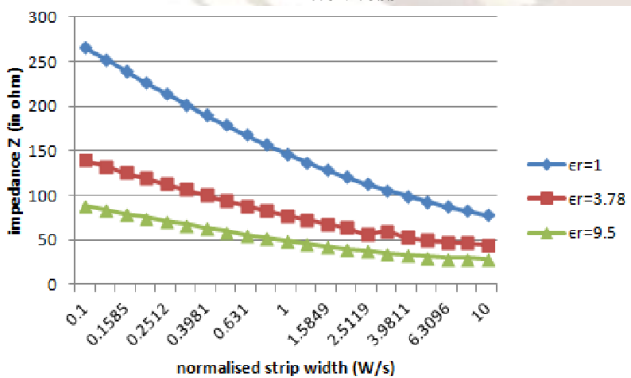### 6.4 Effect of Dispersion on Infinite Substrate Thickness

Fig:8 Characteristics impedance Vs Normalised strip width (in mm)

In all cases of CPW which I have been mentioned, the Characteristics impedance decreases with increase in normalised strip width but in the case of dispersion when alumina is used as dielectric material whose relative permittivity is equal to 9.5 for infinite thickness, finite thickness of CPW, the electric field between central strip line and ground plane becomes more and more dominant as compared to dielectric material with lower permittivity, which means there will be an increase in displacement current also called leakage current from central strip to ground plane. With large leakage current, conductance increases which eventually corresponds into a large decrement of characteristic impedance.

It is also observed that in the entire above figure, if the slot width or spacing between the ground plane and conductor plane increases than normalized strip width ultimately renumerated. It is cleared that that the characteristic impedance of CPW strongly decreases as re-reduce the strip width which is due to strong electric field between central strip and ground.

VI.   CONCLUSION

The work shows the effectiveness of CPW and overcastting the advantages of propagation of energy from one point to another point. The evaluation of characteristic impedance of CPW has been done with the help of conformal mapping methodology. Variation of characteristic impedance with normalized strip width due to change in different substrate thickness, different dielectric materials and effect of dispersion is also represented. It has been observed that characteristic impedance decreases with advancement of normalized strip width and increases for increasing dielectric substrate thickness but in case of dispersion the effective permittivity decreases which adversely affect the characteristic impedance also to decrease more. In this observation of coplanar waveguide the actual dimensions of the centre-strip, the separation, the thickness and permittivity of dielectric substrate determines the effective dielectric constant, attenuation and the characteristics impedance of the line. The characteristics can be applied in microwave devices circuits and integrated circuits to design different antenna models, amplifiers, active combiners, frequency doublers, mixer and switches for different purposes.

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