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Design Synthesis of a Microstripline Coupler

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ABSTRACT

Several authors have developed various methods for the study of characteristics of single & coupled microstriplines. This paper deals with the analytical studies of the design synthesis of microstripline couplers and their variation with geometry and frequency using Alumina substrates for the design synthesis of the microstripline coupler which is the aim of the present work. All the parallel line couplers, whether mode of propagation is true TEM or not, have the even and odd-mode property which always results in even- mode characteristic impedance (Z_{oe}) and odd-mode characteristic impedance (Z_{oo}).

Keywords : Microstripline, Couplers, Antenna, Characteristics Impedance.

I. INTRODUCTION

For the study of the characteristic impedance of the microstripline coupler we develop the mathematical formula for even and odd-mode and then we will calculate the results. With the help of these results design synthesis technique is used to obtain the geometrical parameters of a coupler of given parameters. The mathematical formulation is based on the conformal transformation technique developed by H.A. Wheeler and Calculation is based on the computer programming developed by S. K. Kaul using closed form formula of Schwarzmann. This technique is too much popular now-a-days and provides an easy approach for the analysis and synthesis of single and coupled microstriplines and other structures useful in MIC's.

II. METHODS AND MATERIAL

Parallel plate striplines support pure TEM mode of propagation but microstrip cannot support pure TEM mode as it is an inhomogeneous structure and it supports quasi-TEM mode [1-5]. However, at low frequency the mode of propagation closely resembles the TEM mode. Wheeler calculated capacitances, phase velocities and impedances of single and coupled strips. Following these various approximate methods have been adopted by Crystal, H. Howe, MAR Gunston, Policky and Stover etc. Bryant and Weis used Green's function technique and calculated the even- and odd- mode impedances of the coupled microstrip lines. S. Akhatarzad, Thomas R. Rowbotham and Peter B. Johns, M.K. Krage and G.I. Haddad also calculated the even- and odd- mode characteristic impedances of coupled microstrip using different techniques. E. Yamashita and R. Mitra presented an analysis based on variation principle. These results were found in reasonable agreement amongst themselves. Banmali, Rawat and Babu using methods of images calculated the characteristic parameters and founded them in close agreement with each other. The results obtained by image method were intermediate between Wheeler's two results for wide and narrow strips [6-10].

The present paper involves the problems in quasi-static limit in lower giga hertz range of frequency. This leads to very useful design criteria especially at lower frequencies. The quasi-TEM allows the magnetic and electric fields to be considered, separately. When only the magnetic field is considered, the dilelectric inhomogeneity is ignored, since the dielectric medium is treated as free space. But when considering the electric field, the inhomogeneity must be taken into account since the normal component of electric field is discontinuous at the dielectric interface.

III. RESULTS AND DISCUSSION

1.1 Formulation of the problem for even and odd-modes characteristic impedances of a microstripline coupler

The study of microstripline coupler involves the analysis of even- and odd- modes of propagation. In the even-mode, energy traveling down, one microstrip line is coupled into a parallel line and travels in the same direction, where as in the odd-mode energy travels in the reverse direction after coupling.

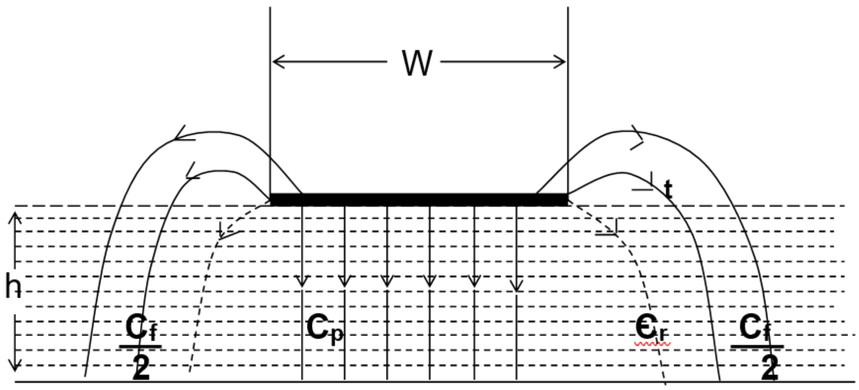

Fig.1: **Electric field configuration in a microstrip (Isolated)**

$$Z = \frac{n}{\sqrt{\epsilon_{re}}} \cdot \frac{1}{w/h + 2w/3h\sqrt{\epsilon_{re}} + 2.7/\log 4h/t}$$

Where, n=377Ω = free space impedance, w= strip width, h= substrate height, t= strip thickness, and ϵ_{re}= effective relative permittivity.

The derivation of the equation for the modes begins with the consideration of a basic single microstrip conductor shown in Fig (1). The characteristic impedance can be calculated with the help of elementary transmission line equation expressed as [11]

$$Z_o = 1/V_P C_P \qquad \text{---------------} \qquad 1$$

Where, V_P = phase velocity of the wave traveling along the microstrip line.

C_P = capacitance per unit length of the line.

The capacitance of the line is the result of the combination of different components indicated in fig (1). These are:

C_{PP} = parallel plate capacitance between lower surface of the microstrip and the ground plane and is given by

$C_{PP} = [€_{reff}/c.\eta].(w/h)$ --------------- 2

C_{PPU} = capacitance between the upper surface of the microstrip and the ground plane which is expressed as

$C_{PPU} = (2/3)[€_{reff}/c.\eta].(w/h)$ --------------- 3

C_F = the fringing capacitance at the edges of the microstrip and is expressed

$C_F = [€_{reff}/ c.\eta].(2.7/Log4h/t)$ --------------- 4

Where,

w = microstrip width

$€_{reff}$ = the effective dielectric constant of the medium

h = height of the substrate

η = free space impedance = 377 Ω

c = the velocity of light in free space

= $3.0 X 10^8$ m/sec.

t = microstrip thickness.

Thus, the total capacitance (C_P) of the isolated microstrip structure is expressed as

$C_P = C_{PP} + C_{PPU} + C_F$

or $C_p = (€_{reff} / c.\eta)(w/h) + (2/3)(€_{reff} / c.\eta)(w/h)(€_{reff} / c.\eta).(2.7/Log4h/t)$

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This is the expression of the capacitance of the microstrip structure in terms of its geometric parameters.

The phase velocity V_P can be calculated by the formula

$V_P = c / €_{reff}$ --------------- 6

For wide strip, $€_{reff}$, $€_r$, and

For narrow strip, $€_{reff}$ $(€_r + 1) / 2$

Where,

$€_r$ = relative dielectric constant.

From equations 1, 5, and 6, we get

$Z_o = (€/€_{reff}).[1/[(w/h) + (2w/3h) + (2.7/Log4h/t)]]$ ------------ 7

The calculations made on the basis of this expression give the characteristics impedance, the propagation constant and other transmission parameters of a single microstrip structure.

When the second conductor is introduced close to the first one, the field distribution gets altered. In even-mode the electric field lines follow the pattern fairly similar to that of the isolated conductor. In case of odd-mode, the two conductors are linked by the electric field lines.

The form of equation 6 obtained for the isolated microstrip line are also useful in calculating the characteristic impedance of microstrip coupler in even- and odd- modes. In the even-mode C_P is replaced by C_{PO} and in the odd-mode by C_{PO}. Since the electric field lines are distributed in air and below the conductor in the dielectric substrate, the dielectric medium now becomes inhomogeneous. Due to inhomogeneity the phase velocity (V_P) for the isolated case is replaced by V_{PO} for the even- mode and V_{PO} for the odd- mode. Further in place of $€_{reff}$ the effective dielectric constants $(€_{reff})_e$ and $(€_{reff})_o$ are to be used for even- and odd- modes separately. Similarly Z_{oe} and Z_{oo} represent the characteristic impedances for even-and odd- modes respectively.

3.2. Even mode characteristics impedance (Z_{oe})

The total capacitance is constituted by the following components:

C_{PPE} = parallel plate capacitance as equation 4.2.2 for even mode.

C_{PPU} = capacitance between upper surface of the conductor and ground plane as equation (4.2.3)

C'_{PPU} = capacitance between strip conductor and ground plane enclosed between two striplines.

$= (2Є_{reff} / 3\ c.η).\ (w/h).\ (1/\ [(w/s) + 1]]$ --------------- 8

C_F = Fringe capacitance at the edge of the striplines as equation 4.

C'_F = Fringe capacitance between two edges of the microstripline.

$= (Є_r / c.η)\ (2.7/\log(4h/t))\ .\ (1/[(w/s) + 1]]$ --------------- 9

Thus the total capacitance for even-mode coupled lines is expressed as

$C_{PE} = C_{PPE}+(1/2)C_{PPU}+ (1/2)C_F + (1/2)C'_{PPU} + (1/2)C'_F$ ------------ 10

Now we can write the characteristic impedance for even-mode configuration as

$Z_{oe} = (η /\sqrt{Є_{reff}}).\ [1/\ [(w/h) + (w/3h) + (1.35/\log(4h/t))+ (w/3h).(1/((w/s)+1)) + (1.35/\log (4h/t)).\ (1/\ ((w/s) + 1))]]$ --------------- 11

and for t = 0

$Z_{oe} = (η /\sqrt{Є_{reff}}).\ [1/\ \{(w/h)\ [1+ (1/3\sqrt{Є_{reff}})] + (1/3\sqrt{Є_{reff}}).\ (w/h)\ (1/\ (w/s) + 1)\}]$

$= (η/\sqrt{Є_{reff}}).\ [1/\ \{(w/h)\ [1+ (1/3/\sqrt{Є_{reff}})] + (1/3\sqrt{Є_{reff}})\ (1/(w/s)+1)\}$ ---- 12

3.3 Odd-mode characteristic impedance (Z_{oo})

In the case of odd- mode coupled lines, the total capacitance (C_{PO}) is determined in terms of the following components:

C''_{PPU} = capacitance between strip conductor and the ground plane spaces enclosed between the two microstrip lines.

$= (8/3).\ (€_{reff} / c.η)$ --------------- 13

C''_F = Fringe capacitance between edges of the microstrip lines and is given as

$= (€_{reff} / c.η)\ [2.7 / \log (4stan (4h/s)/ t)]$ --------------- 14

The total capacitance of the odd-mode coupled lines is thus expressed as

$C_{PO} = C_{PP}+ (1/2)C_{PPU}+ (1/2)\ C''_{PPU} + (1/2)C_F + (1/2)C''_F$ ---------------- 15

And the odd-mode characteristic impedance (Z_{oo}) is given as

$Z_{oo} =(η/€_{reff}).[1/\{(w/h)+(w/3h€_{reff})+(1.35/\log(4h/t))(4/3€_{reff}).(1/((s/w)+1)) + (1.35/\log (4stan (4h/s)/ t)\}]$ --------------- 16

When, t = 0

$Z_{oo} = (η/€_{reff}).\ [1/\ \{(w/h)\ [1+ (1/3€_{reff}) + (4/3€_{reff})\ (1/(s/w) +1)\}]$ - 17

Table – 1: Dependence of characteristic impedance of coupled microstripline for even & odd-modes on strip width

h = 100 mils, t = 0.01 mils, f = 2 GHz, $\epsilon_r = 9.6$,

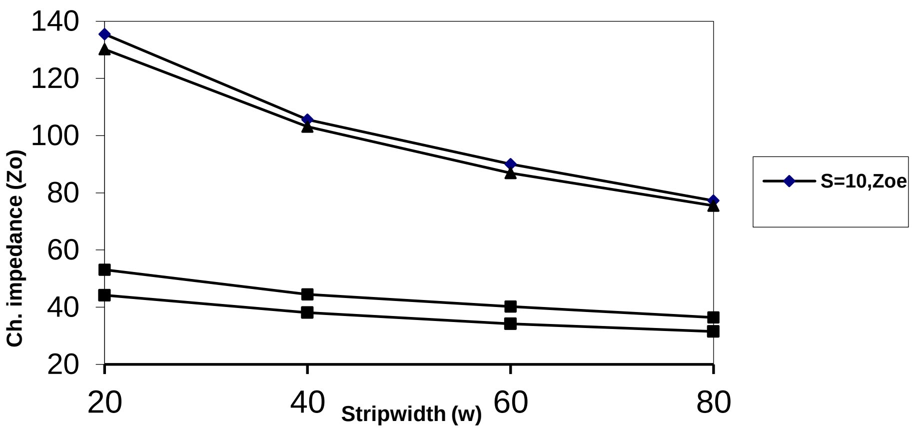
1 mils = 10^{-3} inch = 2.54 μm

Stripwidth	S=10mils				S=20mils			
W (mils)	Z_{oe} Ω	Z_{oo} Ω	$(\epsilon_{reff})_e$	$(\epsilon_{reff})_o$	Z_{oe} Ω	Z_{oo} Ω	$(\epsilon_{reff})_e$	$(\epsilon_{reff})_o$
20	135.50	44.20	6.52	5.42	130.20	53.10	6.65	5.40
40	105.60	38.12	6.80	5.40	103.12	44.50	6.92	5.35
60	90.10	34.20	7.12	5.39	86.90	40.20	7.15	5.32
80	77.25	31.50	7.28	5.35	75.50	36.40	7.35	5.28

Graph – 1: Dependence of characteristic impedance of coupled microstripline for even & odd-modes on strip width

h = 100 mils, t = 0.01 mils, f = 2 GHz, $\epsilon_r = 9.6$

1 mils = 10^{-3} inch = 2.54 μm



3.4 Design synthesis of microstripline coupler

The coupling coefficient (C) at mid band frequency has been expressed in equation 17. The feed line characteristic impedance is given by

$$Z_o = [Z_{oe} \times Z_{oo}]^{1/2} \quad \text{-------------} \quad 18$$

Now for the design of a microstripline directional coupler of given coupling coefficient and feed line characteristic impedance we calculate even and odd-modes characteristic impedances using equations

$$Z_{oe} = Z_o [(1 + C) / (1 - C)]^{1/2} \quad \text{--------------} \quad 19$$

$$Z_{oo} = Z_o [(1 - C) / (1 + C)]^{1/2} \quad \text{--------------} \quad 20$$

Again using these values of characteristic impedances shape ratio for Alumina dielectric substrate ($\epsilon_r = 9.6$) is expressed as

$$W/h = 20.37 [4/ Z_{oe} + 1/ Z_{oo}] \quad \text{---------------} \quad 21$$

And approximate value space ratio is given by

$$s/h = 377\ (4\ Z_{oo} + Z_{oe}) / (3 + 5\sqrt{\epsilon_r})\ Z_o^2 \quad \text{----------------} \quad 22$$

Using these equations stripwidth and spacing between two striplines have been calculated for given coupling. Again these values of shape ratio and space ratio are used to calculate Z_{oo} and Z_{oe} and results obtained are compared for conformity as Z_{oe} = 86.6 Ω and Z_{oo} = 28.8 Ω for w = 18.8 mils and s = 15 mils. Here 1 mil stand for 10^{-3} inch.

IV. CONCLUSION

From the study of dependence of characteristic impedance of the microstripline directional coupler for even and odd-modes with strip width, spacing between two striplines and height of the dielectric substrates and also from the study of variation of guide wavelength for even and odd-modes with stripwidth, spacing and height of the substrate we draw useful information for design of directional couplers of different coupling coefficient and feed line characteristic impedance. These results obtained in the synthesis process are also reasonable agreement with those obtained in analysis process. So, this provides an important and necessary tool for the designer to fabricate directional coupler of desired coupling coefficient and directivity. This also provides scope for future work.

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