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Application of Fem Technique in Realisation of Pin Diode Phase Shifter

Samiran Pramanik*, Bhaswati Seal*, Deepti Thacker*, Nirmalendu Bikas Sinha*

**Department of ECE and EIE,*
College of Engineering & Management, Kolaghat, K.T.P.P Township, Purba- Medinipur, (W.B)., India.

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I. INTRODUCTION

In the design of a Switched line Phase Shifter [4][5], two different lengths of transmission line controlled by switches at input and output is used for obtaining required phase shift. Characteristics impedance of transmission line has a very important role to maintain the impedance matching and phase shift which are vital factor for realization of Switched line Phase Shifter. Hence optimizing widths of such microstrip line sections to obtained suitable characteristics impedance is an important step, generally 50 ohms input and output impedance is used. Although Characteristics impedance of a transmission line can be obtained by closed formation in the literature [1] but to achieve the better accuracy, numerical technique is a handy tool. Numerical techniques are 2D and 3D that are commonly used. Numerical analysis has gained importance recently and is now being used to solve various electromagnetic problems [2] [3].

Here 3D analysis like FEM, which is a boundary value problems to find the characteristics impedance of the microstrip lines is used for designing PIN diode Switched line Phase shifter. Schematic of the PIN diode based Switched line Phase shifter is shown in the fig. 1. And also layout of the switched line phase shifter using 50 ohms microstrip line is shown in fig. 2.

II. FORMULATION OF THE PROBLEM

The structure of the computational domain along with the meshing is shown in Fig. 3. The element shapes are rectangular bricks as shown in Fig. 4 and their basis functions are given by

$$N_1^e = \frac{1}{V^e}\left(x_c^e + \frac{h_x^e}{2} - x\right)\left(y_c^e + \frac{h_y^e}{2} - y\right)\left(z_c^e + \frac{h_z^e}{2} - z\right) \ldots\ldots (1)$$

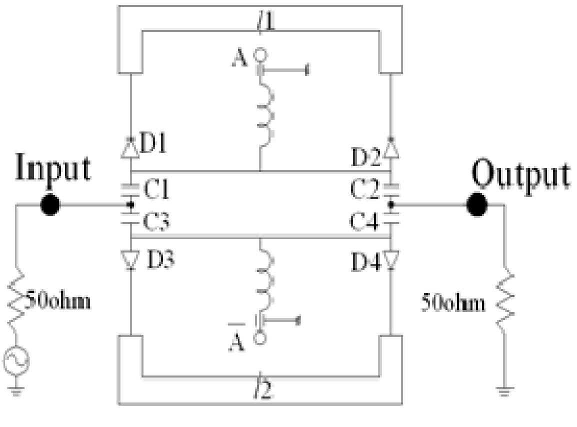

Fig. 1: Schematic diagram of PIN diode Switched line Phase Shifter.

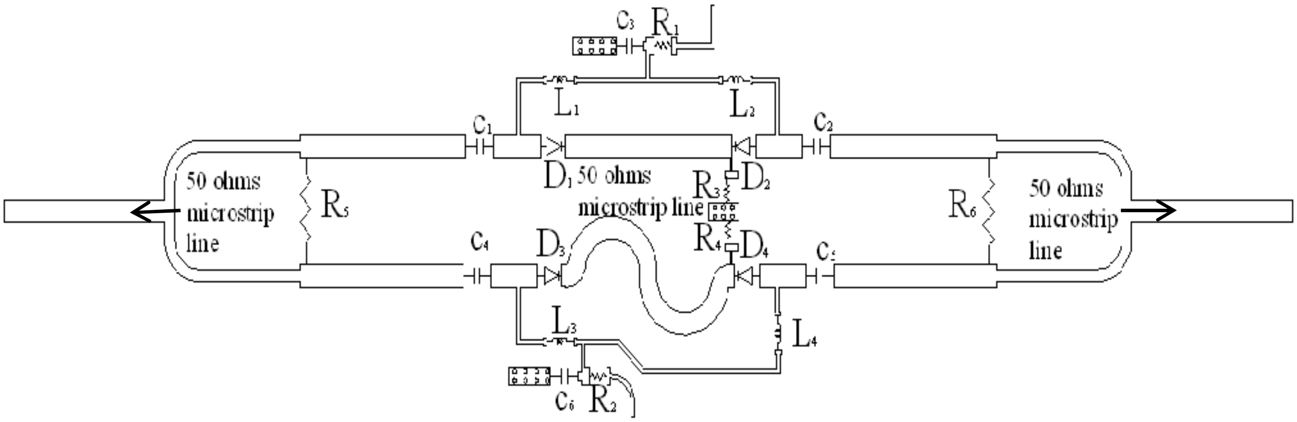

Fig. 2. Layout of the switched phase shifter using 50 ohms microstrip line.

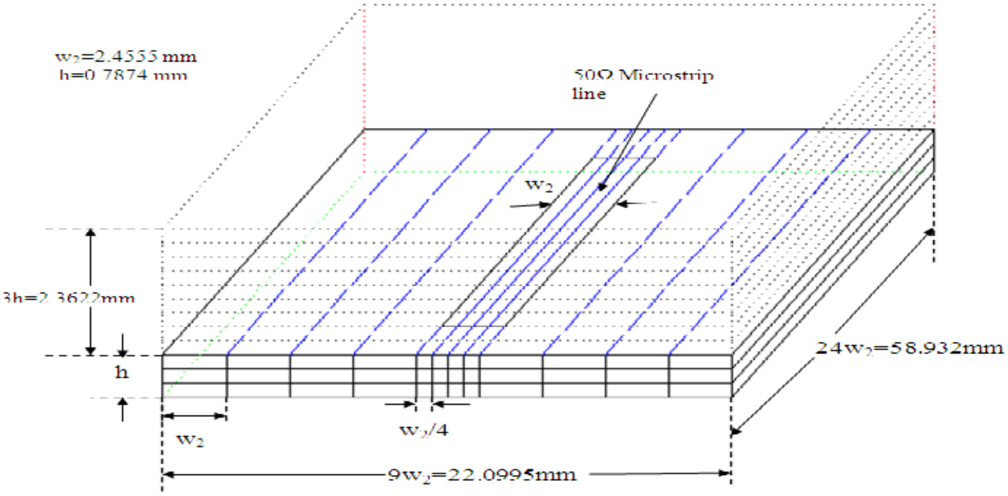

Fig. 3. The geometry of the given problem domain.

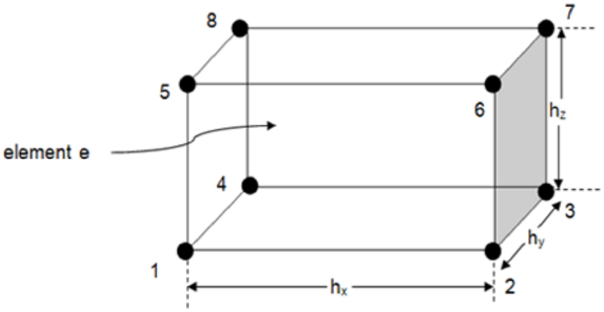

Fig. 4. A rectangular element.

$$N_2^e = \frac{1}{V^e}\left(-x_c^e + \frac{h_x^e}{2} + x\right)\left(y_c^e + \frac{h_y^e}{2} - y\right)\left(z_c^e + \frac{h_z^e}{2} - z\right) \ldots\ldots (2)$$

$$N_3^e = \frac{1}{V^e}\left(-x_c^e + \frac{h_x^e}{2} + x\right)\left(-y_c^e + \frac{h_y^e}{2} + y\right)\left(z_c^e + \frac{h_z^e}{2} - z\right) \ldots (3)$$

$$N_4^e = \frac{1}{V^e}\left(x_c^e + \frac{h_x^e}{2} - x\right)\left(-y_c^e + \frac{h_y^e}{2} + y\right)\left(z_c^e + \frac{h_z^e}{2} - z\right) \ldots\ldots (4)$$

$$N_5^e = \frac{1}{V^e}\left(x_c^e + \frac{h_x^e}{2} - x\right)\left(y_c^e + \frac{h_y^e}{2} - y\right)\left(z_c^e + \frac{h_z^e}{2} + z\right) \ldots\ldots\ldots (5)$$

$$N_6^e = \frac{1}{V^e}\left(-x_c^e + \frac{h_x^e}{2} + x\right)\left(y_c^e + \frac{h_y^e}{2} - y\right)\left(-z_c^e + \frac{h_z^e}{2} + z\right) \ldots\ldots (6)$$

$$N_7^e = \frac{1}{V^e}\left(-x_c^e + \frac{h_x^e}{2} + x\right)\left(-y_c^e + \frac{h_y^e}{2} + y\right)\left(-z_c^e + \frac{h_z^e}{2} + z\right) \ldots\ldots (7)$$

$$N_8^e = \frac{1}{V^e}\left(x_c^e + \frac{h_x^e}{2} + x\right)\left(-y_c^e + \frac{h_y^e}{2} + y\right)\left(-z_c^e + \frac{h_z^e}{2} + z\right) \ldots\ldots (8)$$

Two types of boundary conditions have been used; (i) Dirichlet boundary conditions and (ii) Neumann Boundary Conditions.

If the node voltages be denoted by V_i^e for node i then the following expressions were used

$$V^e = \sum_{i-1}^{8} V_i^e N_i^e \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$W_e = \frac{1}{2}\int \in |E^e|^2 \, . \, dV = \frac{1}{2}\int_v \in |\nabla V^e|^2 \, . \, dV$$

$$= \frac{1}{2} \in \sum_{i-1}^{8}\sum_{j-1}^{8} V_i^e \left[\int_v \nabla N^i \, \nabla N_j . \, dV\right] V_j^e \ldots (10)$$

$$\int_v \nabla N_i^e \, . \, \nabla N_j^e . dV = B^e \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where B^e is the elemental matrix given by

$$B^e = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Now,

$$W = \sum_{e-1}^{1728} W_e = \frac{1}{2} \in [V]^T[A][V] \ldots\ldots (13)$$

Where $[A]$ is the global matrix or sparse matrix. Here 1728 is the number of elements obtained in our problem.

$$\frac{\partial W}{\partial V_1} = \frac{\partial W}{\partial V_2} = \cdots \ldots\ldots\ldots = \frac{\partial W}{\partial V_{2275}} \ldots . (14)$$

Here 2275 is the number of nodes obtained. This gives the values of V_1 through V_{2275}.The characteristic impedance is obtained using the following series of equations

$$Z_c = \frac{1}{v_p c} = \frac{1}{v_{0\sqrt{cc_0}}} \ldots\ldots\ldots\ldots\ldots (15)$$

Where $v_p = v_0\sqrt{\frac{c_0}{c}} = \frac{v_0}{\sqrt{\epsilon_{eff}}} \ldots (16)$

$$\varepsilon_{eff} = \frac{C}{C_0}$$

Where C is the capacitance of the shielded microstrip line with dielectric (RT/Duroid 5880, ε_r = 2.2, tan δ =0.0009) and C_0 is the capacitance of the shielded microstrip line without dielectric.

Again,

$$C = \frac{2Q}{V_0} \ldots\ldots\ldots\ldots(17)$$

$$C_0 = \frac{2Q_0}{V_0} \ldots\ldots(18)$$

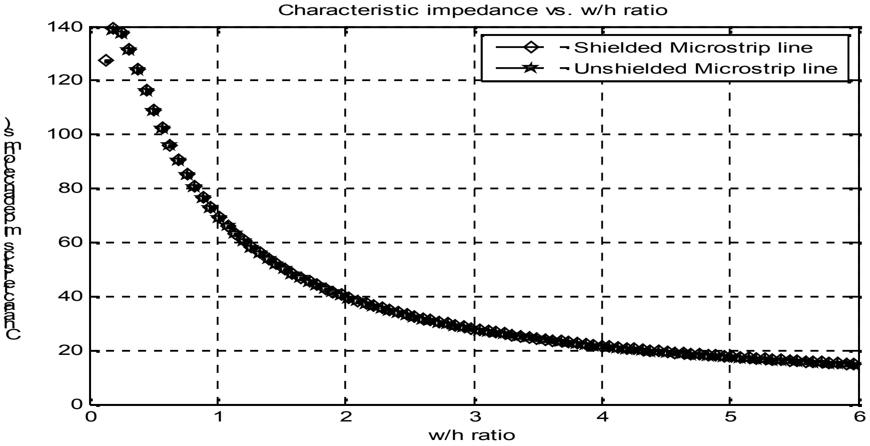

Fig. 5. Plot of Characteristic impedance vs. w/h ratio of a microstrip line.

The factor of 2 appears because Q has been calculated for only half of the problem domain at the plane of symmetry.

Now,

$$Q = \oint_s \vec{D}.\vec{ds} = \oint_s \in \frac{\partial V}{\partial s}.dS \ldots(19)$$

For,

$w/h \geq 1$

$$Z_{c(unshielded)} = Z_{c(shielded)} + M \ldots(20)$$

For,

$w/h \leq 1$

$$Z_{c(unshielded)} = z_{c(shielded)} + M\left\{1 - \tanh\left[\frac{0.48(\frac{w}{h}-1)^{0.5}}{(1+{h^1}/{h})^2}\right]\right\} \ldots\ldots(21)$$

Where, $M = \frac{270}{\sqrt{\in_{eff}}}[1 - \tanh\left(0.28 + 1.2\sqrt{(\frac{h^1}{h}}\right)]$

h^1=3*h=spacing between strip and enclosure above the dielectric as shown in Fig. 3.

$$\in_{eff(unshielded)} = [\in_{eff(shielded)} - \left(\frac{\in_r + 1}{2}\right) \ldots\ldots\ldots(22)$$

Where, $N = \tanh\left[0.18 + 0.235\frac{h^1}{h} - \frac{0.415}{\left({h^1}/{h}\right)^2}\right]$

The code was developed in MATLAB and a plot of characteristic impedance vs. w/h ratio was obtained as shown in Fig. 5.

III. RESULTS

The code is developed in MATLAB and a plot of characteristic impedance vs. w/h ratio was obtained as shown in Fig. 5. From analytical expressions, the w/h ratio for a characteristic impedance of 50Ω and for the given substrate parameters is 1.523. From FEM analysis results, the w/h ratio for the characteristic impedance of 50 Ω obtained is 50.46 for shielded microstrip line and 49.94 for unshielded microstrip line. Hence the percentage error for shielded microstrip line is 0.92% and 0.12% for unshielded microstrip line.

IV. CONCLUSION

FEM analysis has been usedfor designing PIN diode switched line phase shifter to optimize the width of microstrip lines used. The analysis has been developed to obtain the characteristic impedance of shielded microstrip line and closed form expressions are used to convert the characteristic impedance of shielded microstrip line to unshielded microstrip line. The results were compared with the analytical expressions available in the literature and the percentage error obtained was 0.92% for shielded microstrip line and 0.12% for unshielded microstrip line.

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