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Optimized Design of Shielded Microstrip Lines Using Adaptive Finite Element Method

Priyanka Kakria[1], Anupma Marwaha[2] and Manpreet Singh Manna[3]
[1]M.Tech Research Scholar, [2,3]Associate Professor
[1,2]Deptt. of Electronics & Communication Engineering
[3]Deptt. of Electrical & Instrumentation Engineering
Sant Longowal Institute of Engineering & Technology, Longowal, India.
Email: *priyankakakria@rediffmail.com, marwaha_aupma@yahoo.co.in

Abstract: In this paper the attempt has been made to design and analyze single strip shielded microstrip line with capacitive coupling. The objective is to find the capacitance per unit length of shielded microstrip line using Finite Element Technique. The computational and simulation work has been carried out with the help of FEM based COMSOL Multiphysics software. The shielded microstrip line has very significant industrial applications in the variable range of frequencies applied. These are commonly used for high frequency transmission lines also. The adaptive mesh refinement technique is further used to obtain 2D results accurately. Some of these results have been compared and validated with the experimental results.

Keywords: Adaptive Refinement, Coupled Capacitance, Finite Element Method, Shielded Microstripline.

1. Introduction

A new generation of microwave components having much higher degree of miniaturization and integration is presently being conceived through monolithic technology (MMIC)[6]. The main goal of this paper is to perform the comparitive analysis of shielded microstrip line with and without dielectric. A strip conductor, made of copper material is having negligible thickness placed in the isotropic and homogeneous medium. The thickness of the strip conductor has been taken negligible because with small thickness of transmission line the signals can be easily transmitted at high frequencies with low distortion. In this work, modeling of shielded microstrip line, without dielectric and with dielectric, has been done using COMSOL multiphysics package based on finite element method (FEM) [7]. The computation of capacitance for the strip conductor is considered essential in designing microwave and advanced integrated circuits in order to optimize the electrical properties of the integrated circuits. Self and coupling capacitance can also help the designers to optimize the layout of circuit.

2. Method and Simulation Models

FEM is best suitable for the analysis of shielded microstrip lines. This method carries on the processing in three stages: Pre-processing, Processing and Post-processing. In Pre-processing the whole structure is divided into elementary sub domains, which are called finite elements and the field equations are applied to each of them. In processing the FE methods are essentially based on determination of the distribution of electric and magnetic fields in the structures under study, based on the solution of Maxwell's equations. In Post-processing primary simulation results are values for the electric potential and magnetic vector potential and other parameters like flux, flux- density, stored energy forces and torques etc. may be calculated as secondary, post-processing results. The models of shielded microstrip lines are designed under the electrostatics surrounding in COMSOL Multiphysics Inc. (USA) [7]. It is a package for various physics and engineering applications. It facilitates all steps in the modeling process-defining geometry, meshing, specifying physics, solving and then visualizing results.

The characteristics impedance of lossless transmission line is,

$$Z= 1/c\sqrt{CC_0} \qquad .....(1)$$

Z= Characteristics Impedence of line
C= Capacitance per unit length of line when substrate is replaced with air
C_0= Capacitance per unit length of line when substrate is in place

c = Speed of light in vacuum
Velocity of propagation is defined in terms of inductance per unit length and capacitance per unit length.

$$V_p = 1/\sqrt{LC} \quad \text{.....(2)}$$

Now phase velocity for the air dielectric transmission line, where the velocity must be the speed of light. $c = 2.998\times10^8$ m/sec.
By using this value of c in above equation, then equation becomes

$$c = 1/\sqrt{LC_0} \quad \text{.....(3)}$$

If all materials are non magnetic, then

$$L=1/c^2C_0 \quad \text{.....(4)}$$

As we know

$$Z_0=\sqrt{L}/\sqrt{C} \quad \text{.....(5)}$$

Substituting the value of L in eqn. (5)
Then

$$Z_0 = 1/c\sqrt{CC_0} \quad \text{.....(6)}$$

For single strip and coupled pair it is easy to compute these parameters using stand alone 2D field solver. 2D cross-sectional electrostatic solver is used to compute the capacitance [3].

2.1 Analysis of shielded Microstrip line

The strip line used in the model is made by copper material. Here the dielectric material is air, so the value of relative permittivity is 1.[4]

Air:
Relative permittivity (ϵ_r) = 1
Conductivity(s) = 0 S/m

Conductor material:
Relative permittivity (ϵ_r) = 1
Conductivity(s) = 5.8×10^7

These values have been taken for the geometry of single shielded transmission line.
w = width of inner conductor = 1mm
t = thickness of inner conductor = 0.1×10^{-4}mm
a = width of outer conductor = 19mm
b= thickness of outer conductor = 9mm

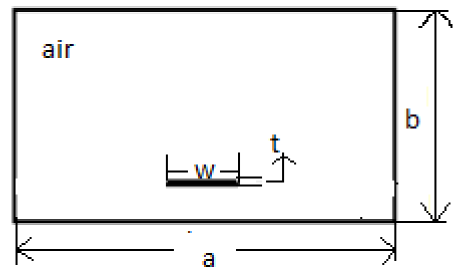

Figure. 1 Shielded microstrip line without dielectric

Fig. 1 shows the design of shielded microstrip line considered for analysis [2]. The geometry of the stripline model has been created in COMSOL using the dimensions mentioned above as shown in fig. 2

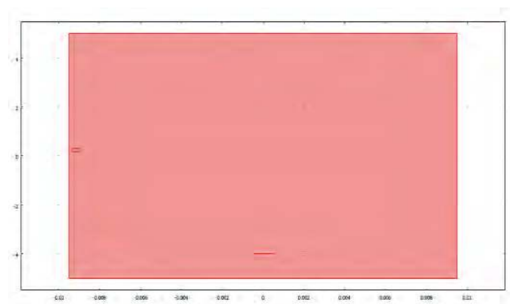

Figure 2. Geometry of shielded microstrip line without dielectric

In the boundary settings, the outer conductor acts as ground and the inner conductor as a port. After applying the boundary conditions, meshing is performed by Adaptive Mesh refinement technique [4].

2.2 Analysis of shielded Microstrip line with dielectric substrate

In this analysis of strip line, dielectric substrate of thickness 1 mm is placed in outer conductor. The values of relative permittivity ϵ_r, is taken as 8.85 and conductivity = 0 S/m [4].

Further, in fig. 3 dielectric substrate of 1 mm height is placed under the inner strip conductor. Width of the dielectric substrate is same as that of the outer conductor.

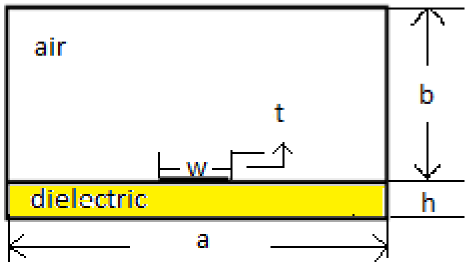

Figure 3. Shielded microstrip line with dielectric substrate.

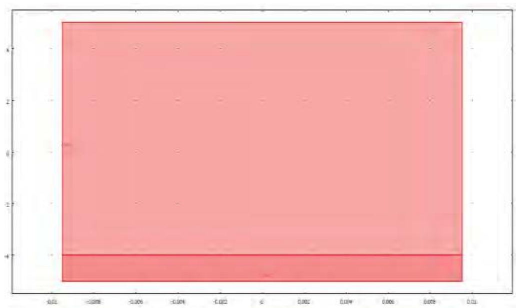

Figure 4. Geometry of shielded microstrip line with dielectric substrate.

Fig. 4 shows the geometry of shielded microtrip line with dielectric substrate. The values taken for this geometry are same as that of shielded microstrip line without dielectric.

3. Adaptive Mesh Refinement Technique

Adaptive meshing includes automatically refine, coarsen or relocate and adjust the basis to achieve a solution having a specified accuracy in an optimal fashion. Adaptive mesh refinement technique has been applied in both the models. After the adaptive refinement, number of mesh points and number of elements got increased as compared to standard meshing statistics.

In Table 1, the values of different items of adaptive meshing are compared.

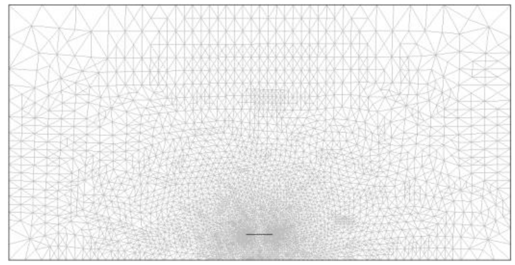

Figure 5. Adaptive meshing refinement of shielded microstrip line

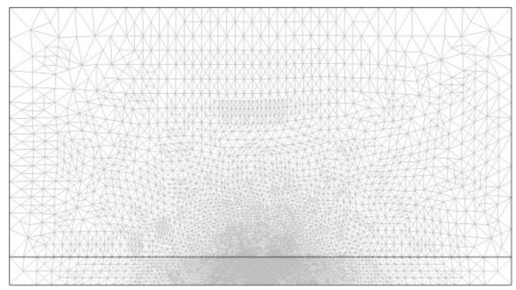

Figure 6. Adaptive meshing refinement of shielded microstrip line with dielectric substrate

Table 1. Adaptive Meshing Refinement Statistics of shielded strip line

Items	Without Dielectric	With dielectric
No of degree of freedom	223697	434590
Total mesh points	56108	108918
Total elements	111481	216754
Triangular elements	111481	216754
Boundary elements	735	1759
vertex elements	8	10

4. Simulation Results

The models generated are executed, and in post processing, potential distribution is obtained. The potential values are used to evaluate the characteristic impedance of shielded microstrip lines.

Capacitance per unit length is,

$C = Q/V_0$

where Q is charge on one conductor in columbs per meter.

V_0 is the potential difference in volts.

Characteristic Impedance is,

$$Z = 1/c\ (CC_0)^{1/2} \qquad \text{.....(7)}$$

Transmission medium is homogenous. So, relative permittivity can be written as,

$$\epsilon_r = C/C_0 \qquad \text{.....(8)}$$

$$C = (\epsilon_r)^{1/2}/cZ_0 \qquad \text{.....(9)}$$

Where, C is the Capacitance per unit length of the shielded strip line [3].

4.1 Surface Potential Distribution

Fig. 7 shows the surface potential distribution within the shielded microstrip lines for the two cases.

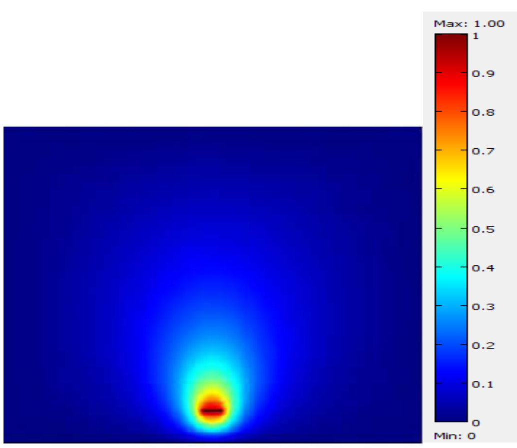

Figure 7. 2D Surface potential distribution of shielded microstrip line

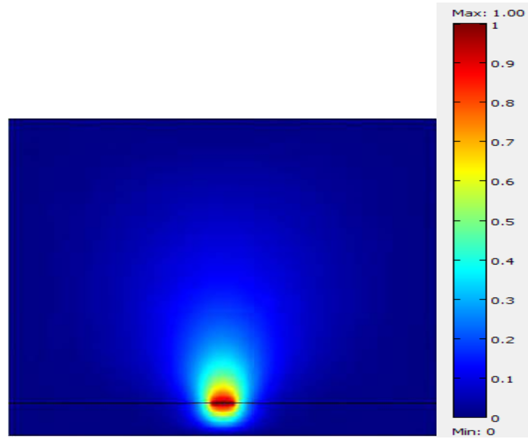

Figure 8. 2D Surface potential distribution of shielded microstrip line with dielectric substrate

The value of capacitance per unit length varies when the dielectric substrate is placed in the outer conductor. The value of capacitance comes out to be approximately 1.59×10^{-11} F/m when the stripline is without dielectric and after adding the dielectric under the inner conductor, the value of capacitance becomes approximately 2.7×10^{-10} F/m.

The electric potential is further plotted as a function of arc-length in figures 9 & 10. It can be observed from fig. 11, that the peak value of electric potential is decreased as the dielectric is placed in the outer conductor.

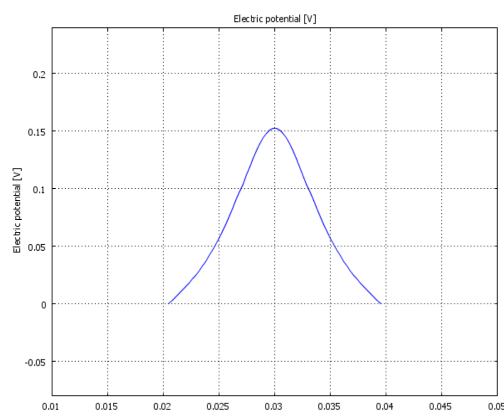

Figure 9. The potential distribution of shielded microstrip line

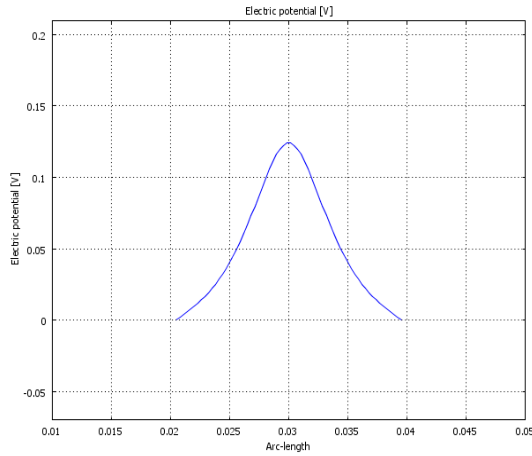

Figure 10. The potential distribution of shielded microstrip line with dielectric substrate

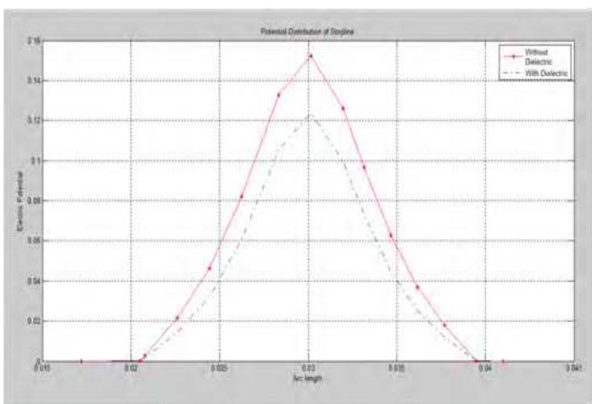

Figure 11. Comparison analysis of potential of shielded microstrip line with and without dielectric substrate

5. Conclusions

In this paper, modeling of two shielded micro-strip lines with and without dielectric are presented. Simulations are performed using COMSOL, a finite element package. Adaptive finite element technique is used for improved refinement. Capacitance and potential distributions of these shielded microstrip lines are compared.

6. References

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