Microstrip Line Discontinuities Simulation at Microwave Frequencies

Dr. A.K. Rastogi[1*](FIETE), (MISTE), Munira Bano[1], Manisha Nigam[2]

1. Department of Physics & Electronics, Institute for Excellence in Higher Education, Bhopal, (M.P.), India-462016
2. Govt. MVM, Bhopal, (M.P.), India-462008

*Email:akrastogi_bpl@yahoo.com

Abstract
Microwave and Millimeter wave integrated circuits (MICs) have experienced a tremendous growth over the last 50 years. Microstrip line is one of the popular lines in these MICs. Due to the layout necessities, an electromagnetic wave that propagates down a microstrip line may encounter discontinuities such as T-junctions, Bends and vias. A simulation model is presented here for analysing these discontinuities in microstrips through Sonnet Software. The parameters of microstrip lines are determined from the empirical formulae which are based on full wave analysis. The simulation work has been performed on Alumina substrate. The discontinuities are simulated and compensated which gives important results for designing high frequency microwave circuits.
Key Words: Microwave and millimeter wave integrated circuits (MICs), microstrip line, microstrip line discontinuities, T-junctions, bends, steps in width, full wave analysis, substrate permittivity and sonnet software.

1. Introduction

Monolithic Microwave Integrated Circuits based on Planar Transmission Lines such as microstrip are being considered as viable candidates for microwave communications and other applications. The planar configuration implies that the characteristics of the element can be determined by the dimensions in a single plane. The commonly used different types of printed transmission lines for MICs are microstrip line, strip line, suspended stripline, slotline, coplanar waveguide and finline (Gupta *et al.* 1979). Microstrip line is one of the popular lines in transmission structures, mainly due to the fact that the mode of propagation on microstrip is almost TEM. The microstrip line consists of a single conductor trace on one side of a dielectric substrate and a single ground plane on its opposite side as shown in Figure 1. Since it is an open structure it features the ease of interconnections and adjustments.

Methods of microstrip analysis may be classified into three groups- Quasi Static Methods, Dispersion Methods and Full Wave Analysis. In Quasi Static Methods, the nature of the mode of propagation is considered to be pure TEM, and microstrip characterizations are calculated from the electrostatic capacitance of the structure. It is found from analysis, that this method is adequate for designing circuits at lower frequencies (below X-band) where the strip width and substrate thickness are much smaller than the wavelength in the dielectric material. In the second group, called dispersion models, the deviation from the TEM nature is accounted for quasi empirically. The methods in the third group, take into account the hybrid nature of mode of propagation i.e. quasi TEM mode of propagation (Bhat & Koul 1980; Fooks & Zakarevicius 1990).

2. Microstrip Synthesis

In actual design of microstrip, one wishes to determine the width ‘w’ required to obtain specified characteristic impedance ‘Z_0’ on a substrate of known permittivity ‘ε_r’ and thickness ‘h’. This operation is called synthesis. Various researchers have reported formulas for microstrip calculations (Wheeler 1964; 1965). Owens (1976), carefully investigated the ranges of applicability of many of the expressions given by Wheeler, comparing calculated results with numerical computations. The closed formulas are highly desirable as they are accurate and fast. CAD algorithms can be implemented with these formulas of Edward & Steer.

2.1 Synthesis Formula

For given Z_0 and frequency:
In case of narrow strips i.e. when
$Z_0 > (44 - \varepsilon_r)\ \Omega$

$$\frac{w}{h} = \left[\frac{\exp H'}{8} - \frac{1}{4\exp H'}\right]^{-1} \qquad \text{...... (1)}$$

Where

$$H' = \frac{Z_0\sqrt{2(\varepsilon_r+1)}}{119.9} + \frac{1}{2}\left(\frac{\varepsilon_r-1}{\varepsilon_r+1}\right)\left(\ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}\ln\frac{4}{\pi}\right) \qquad \text{...... (2)}$$

and

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}\left[1 - \frac{1}{2H'}\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\left(\ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}\ln\frac{4}{\pi}\right)\right]^{-2} \quad \ldots\ldots (3)$$

where H' is given by equation (2) or alternatively as a function of $\frac{w}{h}$ from equation (1)

$$H' = \ln\left[4\frac{h}{w} + \sqrt{16\left(\frac{h}{w}\right)^2 + 2}\right] \quad \ldots\ldots (4)$$

For microstrip line on Alumina $(\varepsilon_r = 10)$, this expression appears to be accurate to ± 0.2 % over the impedance range $8 \le Z_0 \le 50\,\Omega$

when $\frac{w}{h}$ and ε_r are given:

$$Z_0 = \frac{119.9}{\sqrt{2(\varepsilon_r + 1)}}\ln\left[4\frac{h}{w} + \sqrt{16\left(\frac{h}{w}\right)^2 + 2}\right] \quad \ldots. (5)$$

3. Microstrip Discontinuities

All practical distributed circuits, whether in waveguides, coaxial lines or any other propagation structure, must inherently contain discontinuities. A straight uninterrupted length of transmission structure would be of little engineering use, and in any case junctions are essential. Although such discontinuities give rise to only very small capacitances and inductances (often <0.1pF and <0.1nH) the reactance of these become particularly significant at the high microwave and millimetre wave frequencies. The performance of amplifiers for example has been shown to be considerably affected by microstrip discontinuity. Many other circuits such as filters, mixers and oscillators involve several discontinuities. All technologies whether based on hybrid MIC or MMIC inherently involves transmission discontinuities (Wheeler 1977). Discontinuity modelling is based upon equivalent capacitances and inductances. Discontinuity capacitance evaluation has been performed by Silvester & Benedek (1973) and discontinuity inductance evaluation has been performed by Gupta & Gopinath (1977). The following are several forms of discontinuities emerging from circuit requirements:

a) Open circuits
b) Series coupling gaps
c) Short circuits through to the ground plane
d) Step width changes
e) T & Cross junctions

3.1 Microstrip Bends

A microstrip bend may be formed by two lines of equal or unequal impedances and is normally used for introducing flexibility in the layout of the circuit design. The equivalent circuit of the microstrip bend with lines of equal impedance is shown in the Figure 2.

In practical circuits, microstrip bends are chamfered to compensate the excess capacitance.

3.2 T-junctions

The T-junctions is perhaps the most important discontinuity in a microstrip as it is found in most circuits such as impedance networks, stub filters and branch line couplers. A microstrip T-junction and its equivalent circuit are shown in the Figure 3. The discontinuity capacitance for this structure has been calculated by Silvester & Benedek (1973).

The T-junction discontinuity compensation is much more difficult than right angled bends and steps in width discontinuity compensation techniques. The T-junctions can be compensated by adjusting the lengths of the three microstrip lines forming the junction.

3.3 Steps in Width

There exists step discontinuity at junctions of two microstrip lines that have different impedances. This type of discontinuity is encountered when designing matching transformers, couplers and filters. The configurations of step discontinuity and its equivalent circuit are shown in the Figure 4. Results for excess capacitance have been given by Farrar & Adams (1971), Benedek & Silvester (1972) and Gupta & Gopinath (1977).

The compensation in this case is done to reduce the effect of discontinuity reactances by chamfering the large width.

4. Results & Discussion

Figure 5. (a) & (b) shows the two and three dimensional model for microstrip bend respectively while the Figure 6. (a) & (b) shows simulation model of T-junctions and Steps in width through Sonnet Software simulation respectively, which is performed on Alumina substrate of substrate permittivity ε_r=9.8 and loss tangent tanδ=0.0002 and substrate thickness h=0.5 mm. The synthesis equation gives the proper width 'w' and effective dielectric constant 'ε_{eff}' required for simulating the microstrip discontinuities.

SONNET Software is commercial Software which provides solutions for high frequency electromagnetic analysis. This **Em** simulation software is used for design and analysis for high frequency microstrip circuits. The analysis engine of Sonnet Suite®, **Em** is appropriate for a wide range of 3D planar structures. The via capabilities allow the analysis of air bridges, wire bonds, spiral inductors, wafer probes, and internal ports as well as for simple grounding.

All the three discontinuities are chamfered in different ways in order to compensate the excess reactance. The discontinuities and their compensated models are analysed which are shown in the Figure 7. (a), (b) and (c). The S-parameters gives us a way of representing a networks transmission and reflection coefficients as they are the only parameters that can be measured at high frequencies.

The results are shown in the Figure 8, 9 and 10 through graphs of the reflection and transmission coefficients.

Figure 8. (a) shows clearly that when the right angled bend is chamfered by changing the angle from 90° to 45°, the transmission is increased through the line and the reflection is decreased which is shown in the Figure 8 (b).

Figure 9. (a) & (b) shows that when the microstrip T-junction discontinuity is compensated by increasing the width of the junction, the transmission and reflection both becomes better.

Figure 10. (a) & (b) shows that compensating the Step in Width by chamfering it, the reflection and transmission are enhanced at the higher frequencies esp. above 10 GHz.

5. Conclusion

Microstrip lines are considered as viable candidates for MMICs. Microstrip due to its various design advantages is particularly very attractive. A straight uninterrupted length of waveguide or transmission line would be of little engineering use. Simulation model is presented in this paper for analysing the general discontinuities in microstrips at higher frequencies. The discontinuities are finely modelled through simulation which shows that the compensated models are better than the uncompensated ones as they increase the transmission and decrease the reflection. The results given here have been applied to most commonly used substrate. The results presented here are useful in the design of MMICs and they form a basis for the improvement of existing CAD models.

References:

Benedek, P. & Silvester, P. (1972), "Equivalent Capacitance for Microstrip Gaps and Steps", *IEEE Trans. Microwave Theory Tech.* **MTT-20**, 729-733.

Bhat, B. & Koul, S.K. (1980), "Stripline-like Transmission Lines for Microwave Integrated Circuits", Wiley Eastern Limited, New-Delhi.

Edwards, T.C. & Steer, M.B. "Foundations of Inter-connect and Microstrip Design", John Wiley & Sons Ltd.

Farrar, A. & Adams, A.T. (1971), "Computation of Lumped Microstrip Capacitances by Matrix Methods: Rectangular Sections and End Effect", *IEEE Trans. Microwave Theory Tech.* **MTT-19**, 495-497.

Fooks, E.H. & Zakarevicius, R.A. (1990), "Microwave Engineering using Microstrip Circuits", Prentice Hall of Australia.

Gupta, K.C., Garg, R. & Bahl, I.J. (1979), "Microstrip Lines and Slot Lines", Artech House Inc., Washington.

Gupta, K.C., & Gopinath, A. (1977), "Equivalent Circuit Capacitance of Microstrip Step Change in Width", *IEEE Trans. Microwave Theory Tech.* **MTT-25**, 819-822.

Owens, R.P. (1976), "Accurate Analytical Determination of Quasi-static Microstrip Line Parameters," *The Radio and Electronic Engineer* **46**, 360-364.

Silvester, P. & Benedek, P. (1973), "Microstrip Discontinuity Capacitances for Right-angle Bends, T-junctions and Crossing", *IEEE Trans. Microwave Theory Tech.* **MTT-21**, 341-346.

Wheeler, H.A. (1964), "Transmission-line Properties of Parallel Wide Strips by a Conformal Mapping Approximation", *IEEE Trans. Microwave Theory and Tech.* **12**, 280-289.

Wheeler, H.A. (1965), "Transmission-line Properties of Parallel Strips separated by a Dielectric Sheet," *IEEE Trans. Microwave Theory and Tech.***13**, 172-185.

Wheeler, H.A. (1977), "Transmission Line Properties of a Strip on a Dielectric Sheet on a plane", *IEEE Trans.* MTT-25, 631-647.

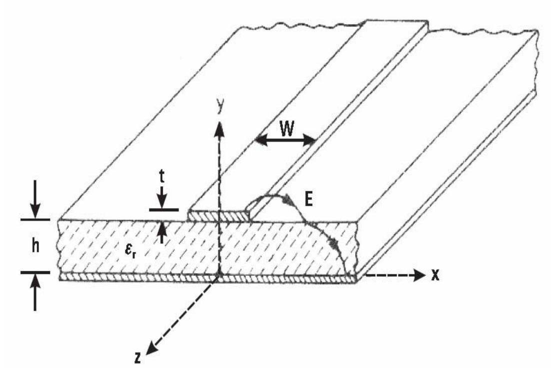

Figure 1. Cross Sectional View of Microstrip line

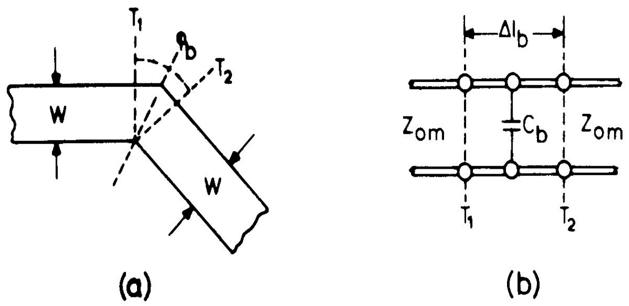

Figure 2. Microstrip Bend Geometry and its Equivalent Circuit

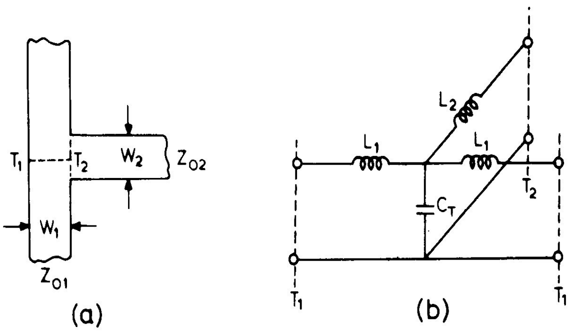

Figure 3. Microstrip T-junction and its Equivalent Circuit

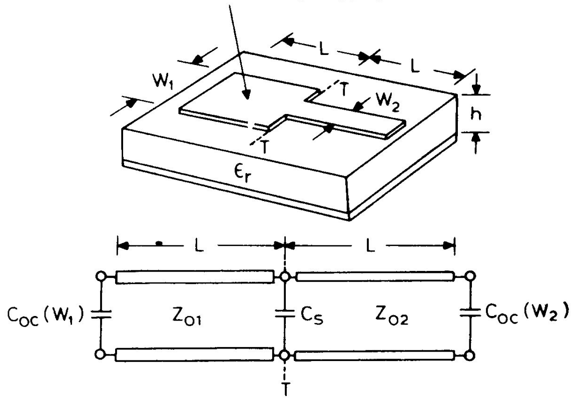

Figure 4. Microstrip Step Discontinuity and its Equivalent Circuit

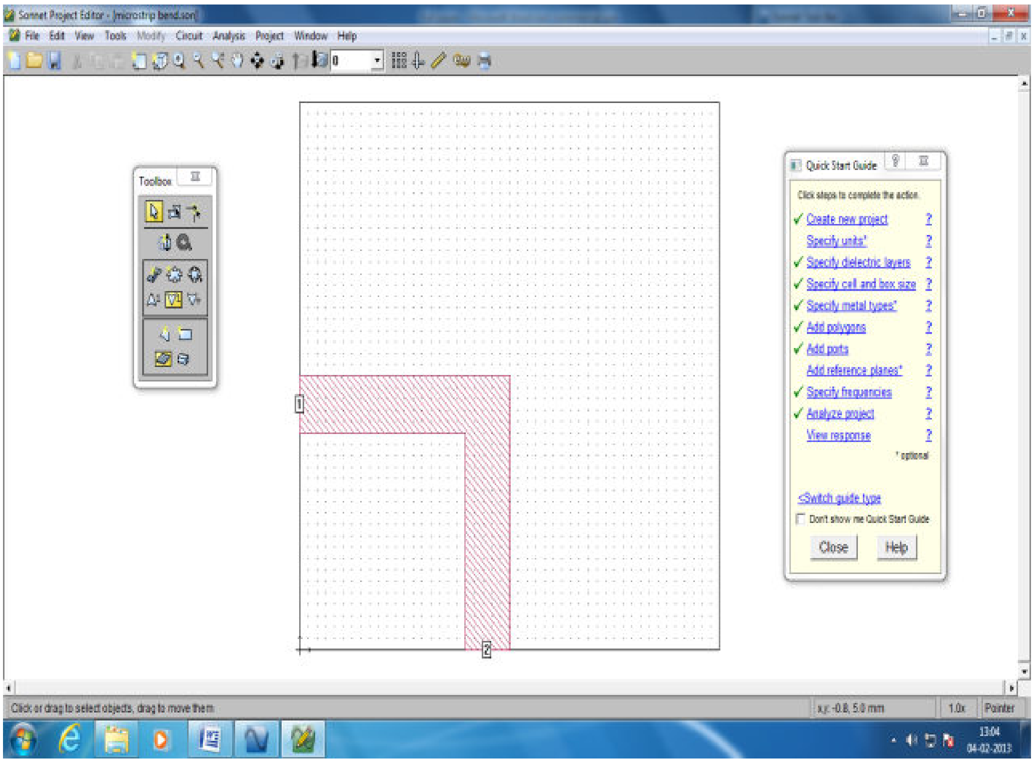

Figure 5(a). Microstrip Bend through Sonnet

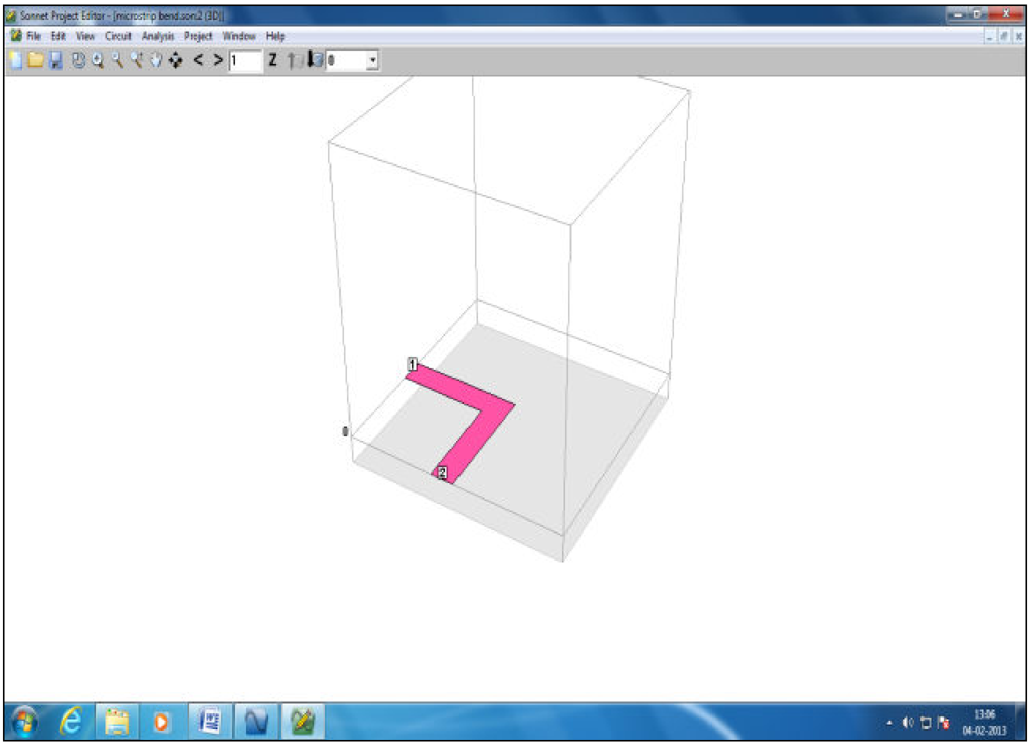

Figure 5(b). 3D Microstrip Bend

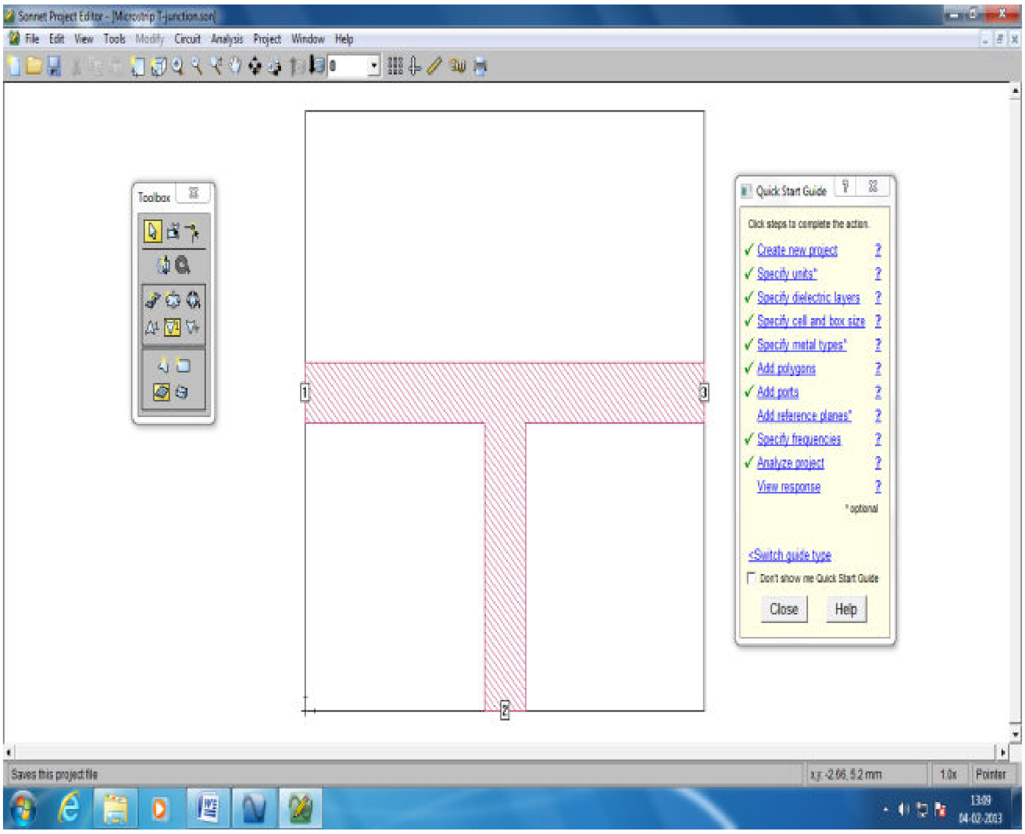

Figure 6(a). Microstrip T-junction through Sonnet

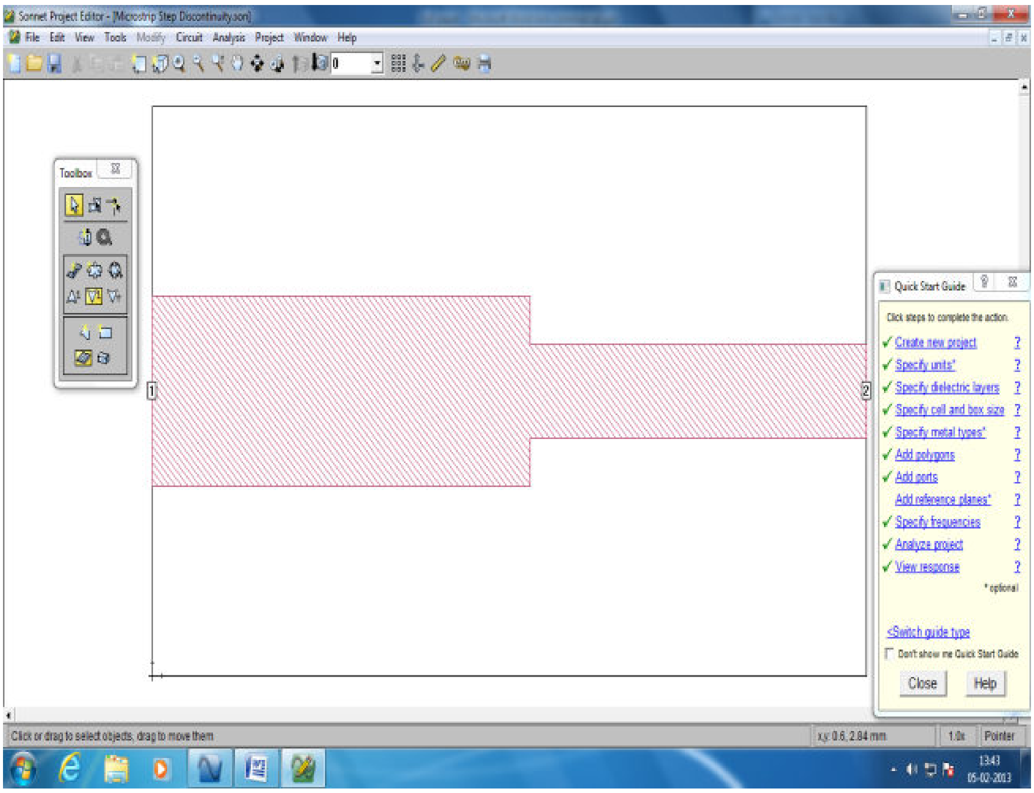

Figure 6 (b). Microstrip Step in Width through Sonnet

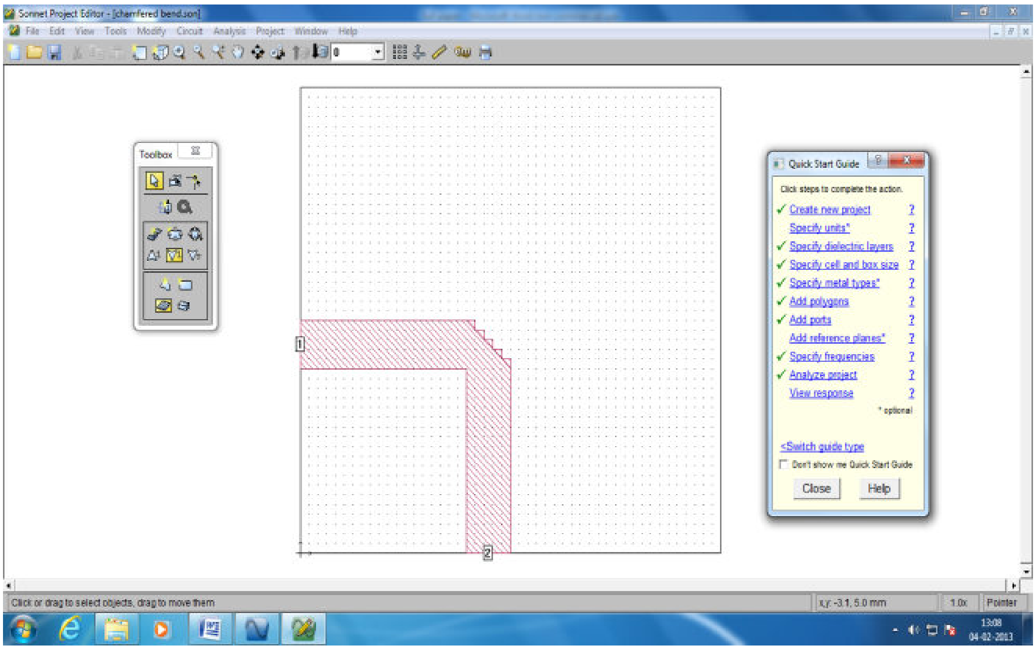

Figure 7(a). Compensated model of Microstrip Bend Discontinuity

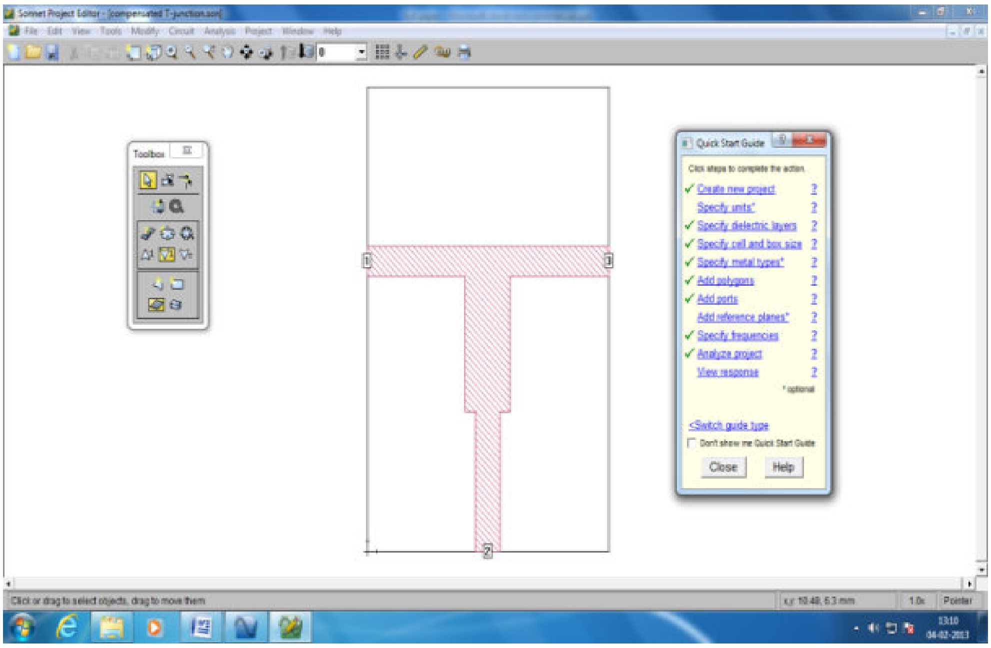

Figure 7(b). Compensated model of Microstrip T-junction Discontinuity

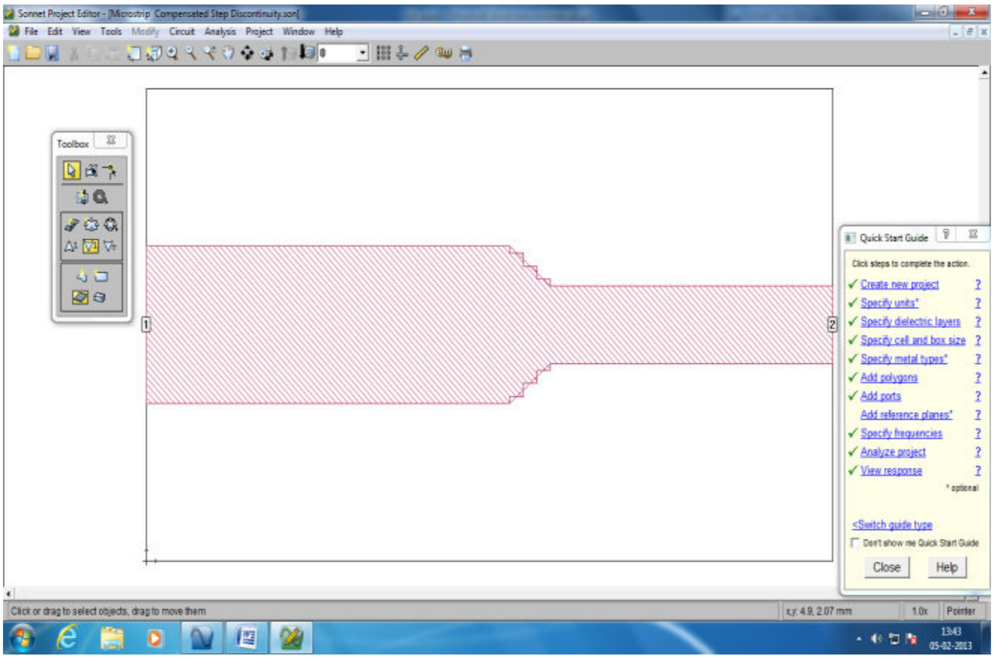

Figure 7(c). Compensated model of Microstrip Step in Width

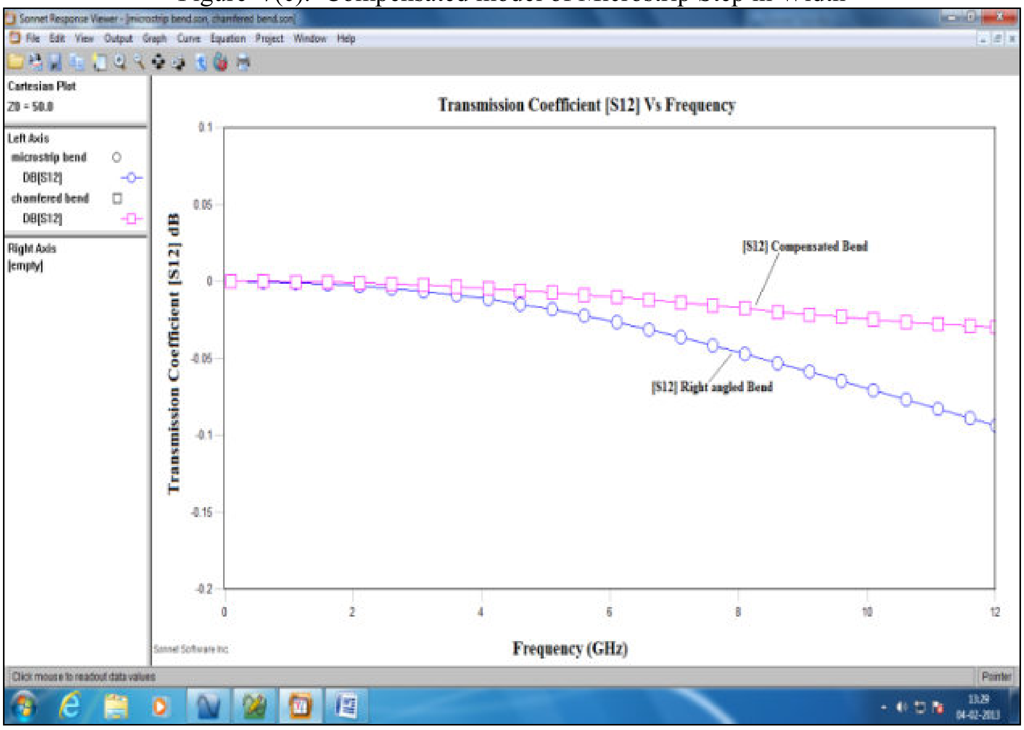

Figure 8(a). Transmission Coefficient Vs Frequency for Microstrip Right angled Bend and Compensated Bend.

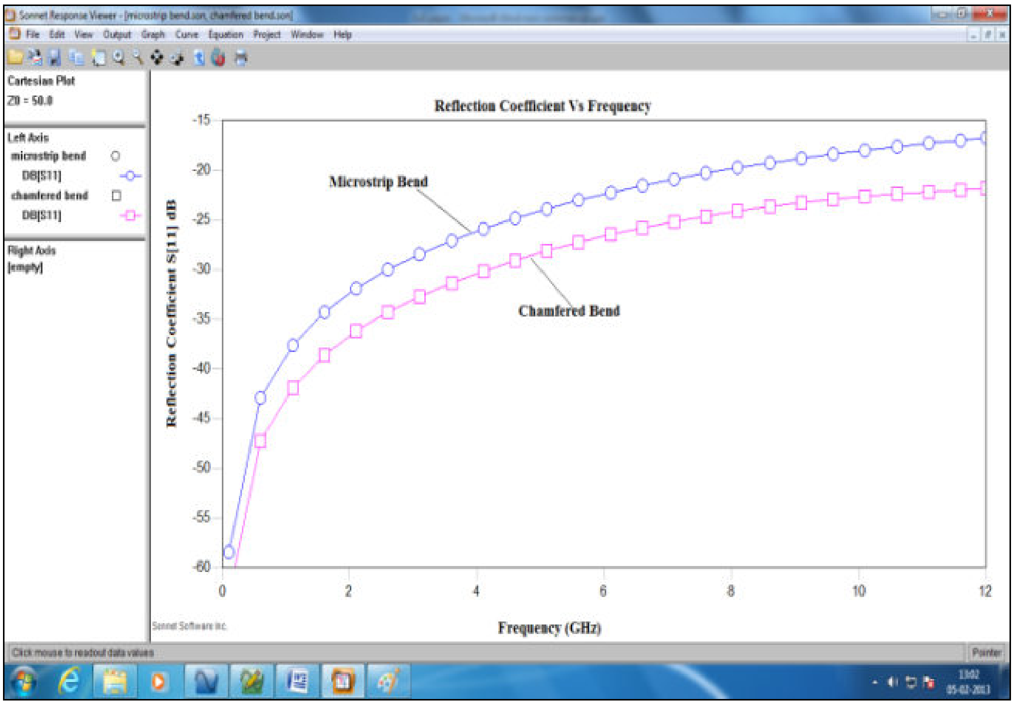

Figure 8(b). Reflection Coefficient Vs Frequency for Microstrip Right angled Bend and Compensated Bend .

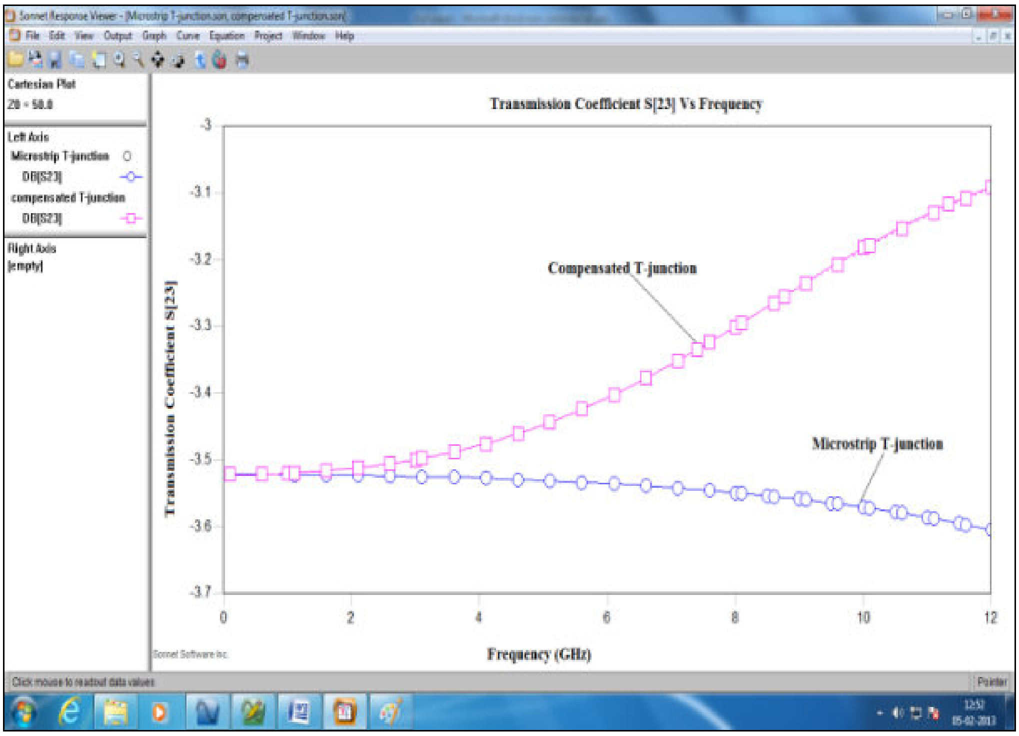

Figure 9(a). Transmission Coefficient Vs Frequency for Microstrip T-junction and Compensated T-junction.

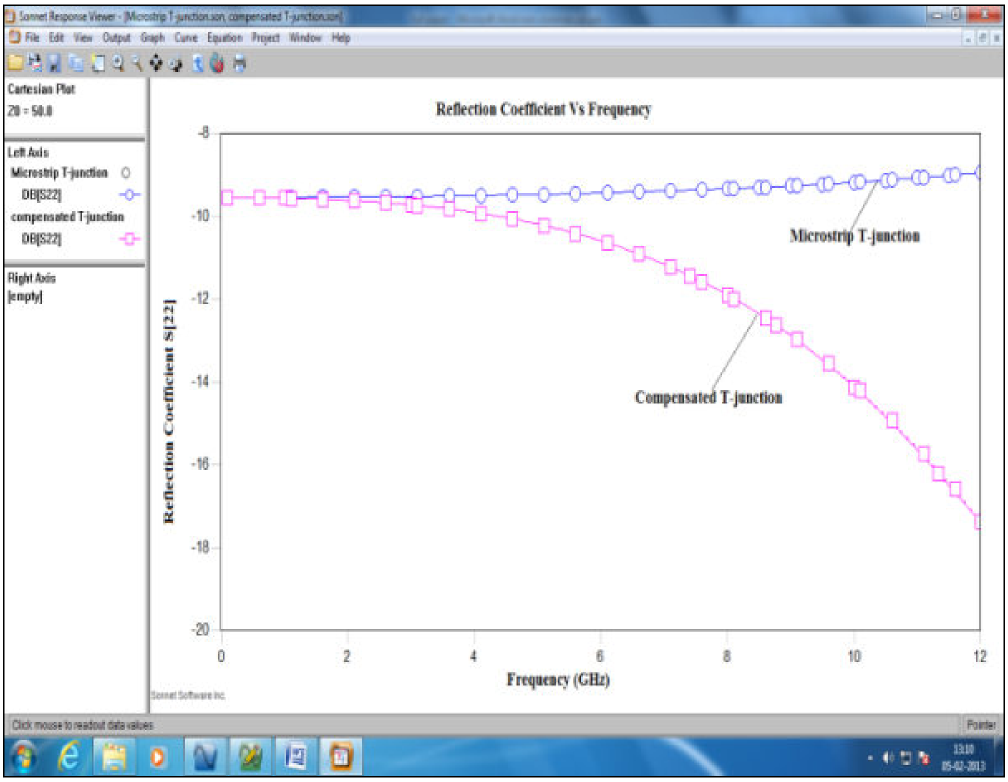

Figure 9(b). Reflection Coefficient Vs Frequency for Microstrip T-junction and Compensated T-junction.

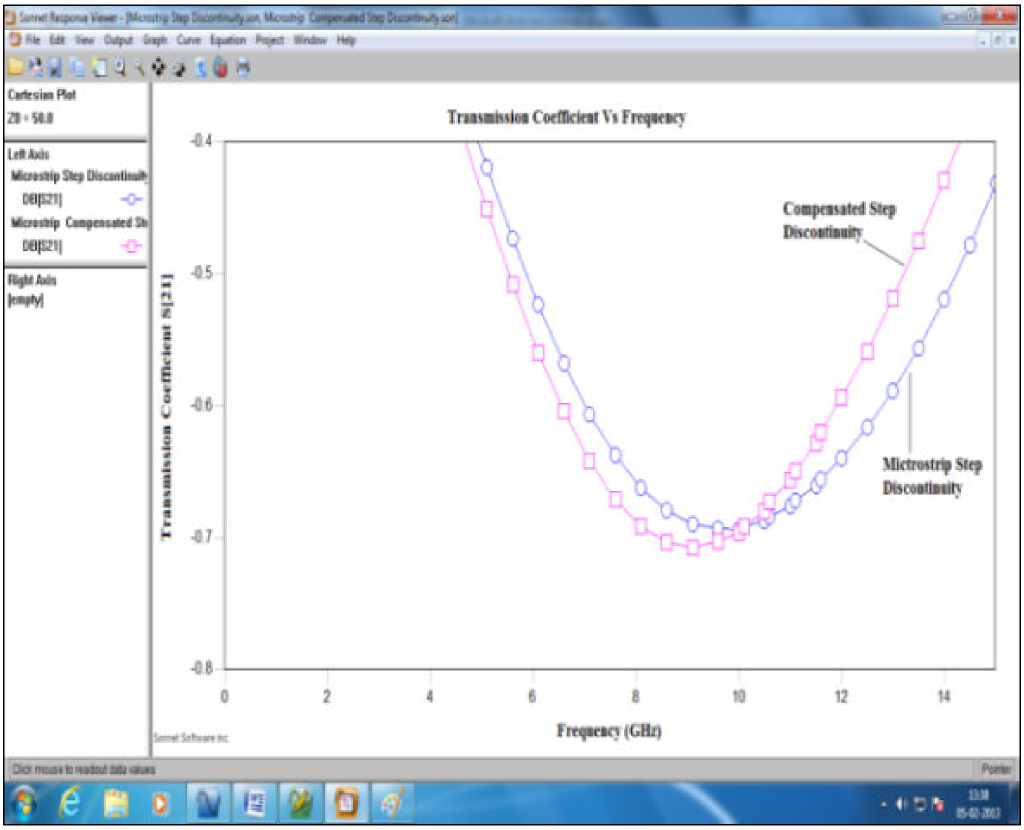

Figure 10(a). Transmission Coefficient Vs Frequency for Microstrip Step Discontinuity and Compensated Step in Width.

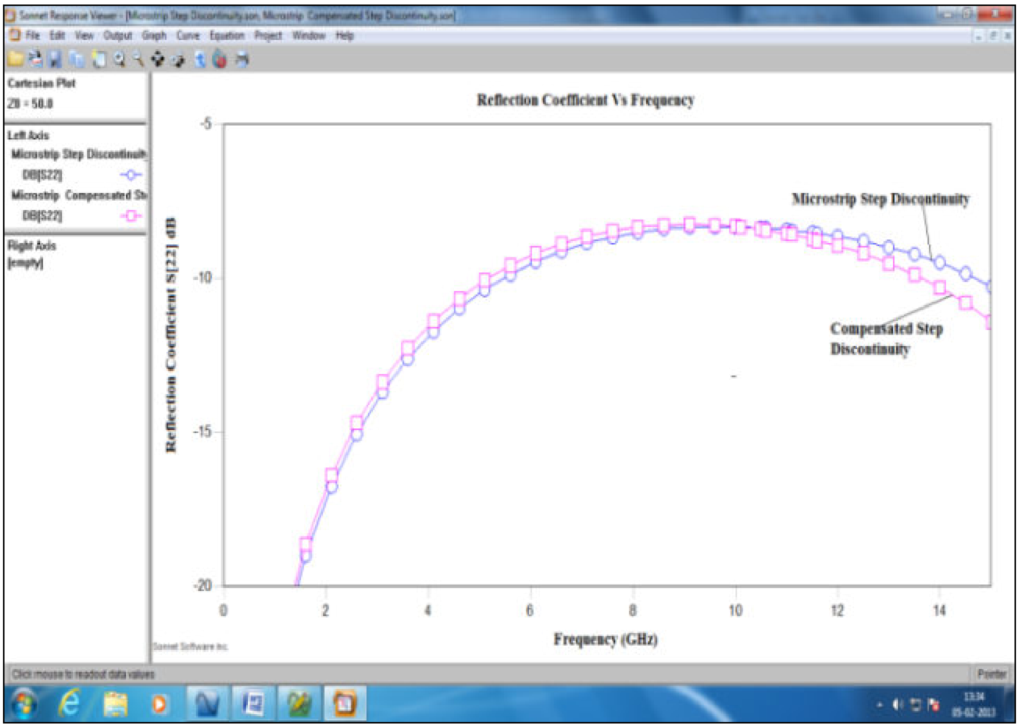

Figure 10(b). Reflection Coefficient Vs Frequency for Microstrip Step Discontinuity and Compensated Step in Width.