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A New Survey on Comparative Analysis of Discontinuities at Microstrip Lines Using Quasi-Static TLM - SCN

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ABSTRACT

In this paper, a numerical method for full-wave TLM (Transmission Line Matrix) is used for three-dimensional analysis of discontinuities in Microstrip lines and discontinuities parameters-S that has been obtained using the above method. To obtain parameters - S port is required to make the perfect match. Therefore the layers of PML (Perfect Matched Layers) are used for this purpose and PML equations are implemented in the TLM method. **TEM** Also Microstripstructures using the quasi - TEM has also been analyzed. The results of these two methods are compared and shown in the lower microwave frequencies, the curves are overlapped. But with increasing frequency, these figures are far from together and the quasi-TEM approach is no longer valid. TLM used in this paper for the solution of Maxwell's equations SCN (Symmetrical Condensed Node) is.

KEY WORD: TLM, quasi-TEM, FFT, PML, S matrix.

1. INTRODUCTION

In order to analysis of electromagnetic structures, Maxwell equations must be solved exactly. For this purpose these equations must be solved in three dimensions. But this is mostly difficult to solve these equations in three dimensions. To make this work more easier, could be used of approximate followings. These approximates are classified into three categories:

1) Considering one of the components of field as zero, we can solve problem at two dimensions instead of solving at three dimensions. It's clear that discontinuities resulting from corners couldn't be analyzed at transmission lines.

2) We suppose that static mode is current and of waves are propagated as quasi-TEM. Obtained results from this method are just accurate in the case of low frequencies and accuracy of calculations is reduced by increasing frequencies.

3) Eliminating overlaps effect. At some structures like Transmission micro strip lines elimination effect of overlaps and their resulted field, cause decrease in accuracy of structures analysis.

In this paper, using a numerical method for full-wave TLM it's tried to present accurate solution for equations at three dimensions. Also using this method we analyze several kinds of micro strip lines discontinuities.

2. TRANSMISSION LINE MATRIX METHOD (TLM)

TLM method has been presented by Beurle and Johns in 1971 for solving two dimensional problems [1]. This method was developed for solving three dimensional maxwell's equations changed by time quickly [2]. Presented three dimension TLM at [2] was very difficult and with low-benefit calculation. There for, to solve these problems, SCN-TLM method was invented [3] that is used at this paper.TLM method simulate Maxwell equations with three dimensions Mesh from transmission lines. These transmission lines cross each other's in places named node. Number of these nodes depends on intended structure and accuracy. In respect to available between voltages and currents at nodes and Meshs and in addition magnetic and electric fields at intended space on the other hand to solve maxwell equations it's enough to calculate currents and voltages at each node and mesh. Figure1 show a TLM node created by 12 connections of transmission line .dimensions of node are determined at three directions x, y, z with w, v, u respectively.

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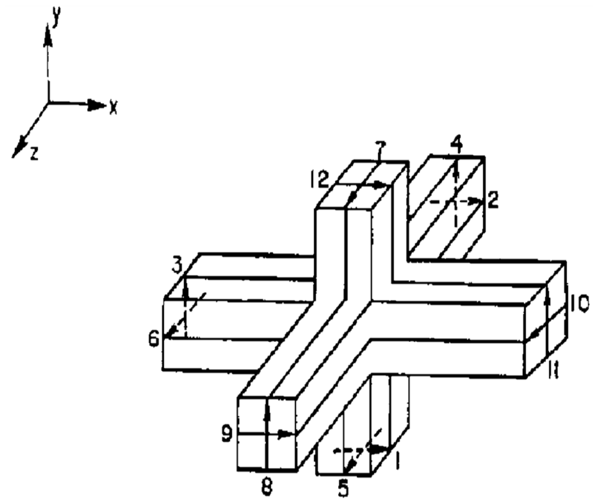


Figure 1- One node from SCN-LTM

2.1. Equations related to TLM method

Differential equations determining manner of currents and voltages at each node [4, 5] are as follows:

$$\begin{aligned}
V\frac{\partial I_Z}{\partial y} - W\frac{\partial I_y}{\partial z} &= 2C_x\frac{\partial V_x}{\partial t}\\
W\frac{\partial I_x}{\partial z} - U\frac{\partial I_Z}{\partial x} &= 2C_y\frac{\partial V_y}{\partial t}\\
U\frac{\partial I_y}{\partial x} - V\frac{\partial I_x}{\partial y} &= 2C_z\frac{\partial V_z}{\partial t}\\
V\frac{\partial V_Z}{\partial y} - W\frac{\partial V_y}{\partial z} &= -2L_x\frac{\partial I_x}{\partial t}\\
W\frac{\partial V_x}{\partial z} - U\frac{\partial V_Z}{\partial x} &= -2L_y\frac{\partial I_y}{\partial t}\\
U\frac{\partial V_y}{\partial x} - U\frac{\partial V_x}{\partial y} &= -2L_z\frac{\partial I_z}{\partial t}
\end{aligned} \qquad (1)$$

That C_z, C_y, C_x, l_z, l_y, l_x inductance sand capacitors of complete transmission line at X, Y, Z directions. I, I,I and V,V,V are total voltages and currents at x, y, z directions.[4]. Now consider following definitions presenting connection between voltage and current with electric and magnetic field:

$$\begin{aligned}
H_X &\equiv I_X/U \quad & E_X &\equiv -V_X/U\\
H_Y &\equiv I_Y/V \quad & E_Y &\equiv -V_Y/V\\
H_X &\equiv I_Z/W \quad & E_Z &\equiv -V_Z/W
\end{aligned} \qquad (2)$$

Relations 1 and 2, relation 3 is obtained:

$$\begin{aligned}
\frac{\partial H_Z}{\partial y} - \frac{\partial H_y}{\partial z} &= C_x\frac{2U}{WV}\frac{\partial V_x}{\partial t}\\
\frac{\partial H_x}{\partial z} - \frac{\partial H_Z}{\partial x} &= C_y\frac{2V}{UW}\frac{\partial V_y}{\partial t}\\
\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} &= C_z\frac{2W}{UV}\frac{\partial V_z}{\partial t}\\
\frac{\partial E_Z}{\partial y} - \frac{\partial E_y}{\partial z} &= -L_x\frac{2U}{WV}\frac{\partial I_x}{\partial t}\\
\frac{\partial E_x}{\partial z} - \frac{\partial E_Z}{\partial x} &= -L_y\frac{2V}{UW}\frac{\partial I_y}{\partial t}\\
\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} &= -L_z\frac{2W}{UV}\frac{\partial I_z}{\partial t}
\end{aligned} \qquad (3)$$

Now consider following definitions:

$$\begin{aligned}
L_X &\equiv \frac{\mu(WV)}{2U} \quad & C_X &\equiv \frac{\varepsilon(WV)}{2U}\\
L_Y &\equiv \frac{\mu(UW)}{2V} \quad & C_Y &\equiv \frac{\varepsilon(UW)}{2V}\\
L_Z &\equiv \frac{\mu(UV)}{2W} \quad & C_Z &\equiv \frac{\varepsilon(UV)}{2W}
\end{aligned} \qquad (4)$$

Replacing Relationships 4 at equations 3, we have:

$$\nabla \times E = -\mu \frac{\partial H}{\partial t}$$
$$\nabla \times H = \varepsilon \frac{\partial E}{\partial t} \quad (5)$$

They are Maxwell's equations. To model materials with different features it's necessary to add capacitors and inductances [5] to nodes. This prevents pulses to reach center of the node simultaneously.

To create at impulses Speed of propagation at all transmission lines must be same and this happen when Ld, Cd of inductance and capacitor distributed at all network transmission lines were same. Then,

$$L_{XS} \equiv \frac{\mu(WV)}{2U} - L_d \quad C_{XS} \equiv \frac{\varepsilon(WV)}{2U} - C_d$$
$$L_{YS} \equiv \frac{\mu(UW)}{2V} - L_d \quad C_{YS} \equiv \frac{\varepsilon(UW)}{2V} - C_d \qquad (6)$$
$$L_{ZS} \equiv \frac{\mu(UV)}{2W} - L_d \quad C_{ZS} \equiv \frac{\varepsilon(UV)}{2W} - C_d$$

These inductances and capacitors are added to center of each node using then Maxwell's equations are modeled with a collection of transmission lines. To performance TLM process, first network is stimulated by impulses of voltage. These initial impulses move at network and when hit the node, they would be returned and distributed. Pulses returned from one node at Time step, K is as follows:

$$V_k^r = \underline{s} V_k^i \quad (7)$$

That V_k^r is vector of returned voltages at Time step, k and V_k^i are vectors of voltageat Time step. $\underline{s}$ is TLM scattering matrix . Relationships at [4] show how to obtain $\underline{s}$ matrix. Pulses returned from one determined node are considered as pulses for next node at next Time Step. This scattering process is continued at different Time Steps until appropriate time for simulation is terminated. Resulted output is a set of impulses that identify a component from field at time area.

3. MAKE PERFECT MATCH ON PORTS

The layer of PML (Perfect Matched Layers) is used for make perfect match on ports.PML rather than to other absorbers like, ABC $_s$, John's matrix, Higdon's etc... has accuracy more than 30dB [6].Each layer of PML is composed from several cells. At of each PML cell Electrical and magnetic conductivity is defined as σ *and* σ°.Now we must write S matrix at TLM equations of each PML cell. Obtained matrix is a 24×24 matrix [7].Used PML have several cells that its electric conductivity at first cell is obtained from formula no.8 [6].

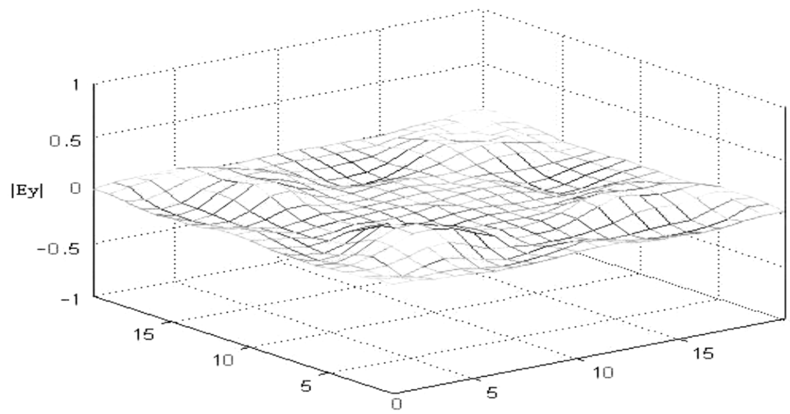
$$\sigma(0) = -\frac{\varepsilon_0 c}{2} \frac{L_n(R)}{\Delta l N^3} \qquad (8)$$

And electric conductivity at next cells is obtained from number (9).

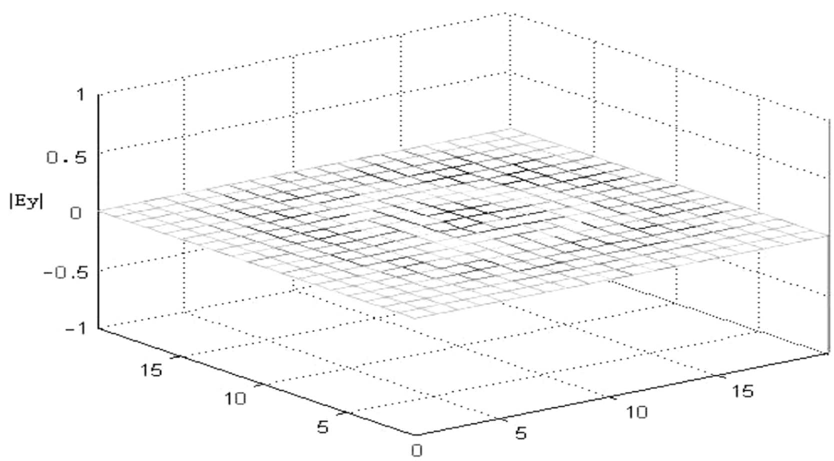
$$\sigma(L) = \sigma(0)[(L+1)^3 - L^3] \quad (9)$$

That, $L = 1,2,\ldots,N-1$

Magnetic conductivity at cells is obtained from relationship $\sigma^{\circ} = \sigma \frac{\mu_0}{\varepsilon_0}$[8]. Each PML cell weaken field several time in such a way that amplitude of returned wave become significantly trivial after passing from four cells. To present PML effect at weaken fields consider cavity with dimensions $20\Delta l \times 20\Delta l \times 20\Delta l$ that $\Delta l = 150\mu m$.we stimulate E_Y field inside cavity. This field returns with opposite phase after that is to cavity walls and this process is continued. We have drawn size of E_Y field after 1000 Time step at figure 2 (A). Now we place PML layer with thickness of four cells at internal metal walls. We stimulate E_Y field again. This field becomes weak after striking to PML layer. Size of this field after passing 1000 Time step is determined at figure 2 (B). As shown at figure 2 (B), E_Y field is completely absorbed by PML layer. We has used from above PML layer to make perfect match on ports.



(A)



(B)

Figure 2 – (A) Size of E_Y field without PML. (B) Size of E_Y field with PML

In addition to E_Y field other fields are also stimulated and it's observed that PML layer is a very good absorber for each six components of electromagnetic field. Now we consider one micro strip line piece with dimensions as$25\Delta l \times 25\Delta l$.Intended micro strip has these specifications as$\Delta l = 150\mu m, w = h = 4\Delta l, \varepsilon_r = 9.8$. we put this piece at a metal box on microstrip piece with specifications of. To prevent effect of metal box on microstrip line we consider height between strip and box. We choose simulation time as $\Delta t = \frac{\Delta l}{2c} = \frac{150\times10^{-6}}{2\times3\times10^{8}} = 0.25\,psec$. We cover internal layer of mental walls with four cells thickness.

4. DETERMINE S-PARAMETERS

We stimulate E_y field at entrance applying Gaussian pulse to ports 3, 4, 8, 11 and save domain of E_y field at entrance and at each Time step as $Eyrec$ at N×1 vector from beginning moment of simulation until is completed and make other row of this vector zero. Here, N determines termination of iteration.We obtain FFT from resulted vector and save it at vector named $fEyrec$. Then we consider $fEyrec$N×1 and make all rows of this vectorzero from beginning of Iteration until that the first returned pulse is received to entrance port and save domain of returned field at each Time step at remained rows. We obtain FFT from resulted vector and save it at $fEyrec$. Then, we can write [9],

$$(S_{11})_i = \frac{(fEyref)_i}{(fEyrec)_i} \qquad (10)$$

That $(fEyref)_i$ at i layer of $fEyref$ vector, $(fEyrec)_i$ at i layer from vector $fEyref$ and $(S_{11})_i$ at i layer from vector S_{11} are at one frequency. On the other hand at output port also we put domain of E_y field at other N×1vector named $fEytrans$. We get FFT from this vector and save results at $fEytrans$ vector. We can write like to relationship (10):

$(S_{21})_i = \frac{(fEytrans)_i}{(fEyinc)_i}$ (11)

Thus, other S-parameters could be obtained for multiport networks types.

5. NUMERICAL RESULTS

At quasi-TEM analysis, we put equivalent circuit of discontinuities of microstrip line [10- 12] and then calculate related S-Parameters at frequency range 1-60GHz. to calculate S-Parameters for T-Junction discontinuities consider figure 3. Presented microstrip piece has dimensions $\frac{w}{h} = 1, L = 25\Delta l, \Delta l = 150\ \mu m$ and Alumina dielectric constant $\varepsilon_{r=9.8}$.

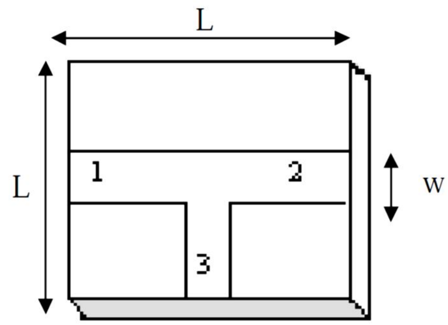


Figure3 - T-Junction discontinuities

Likely, Considerfigure 4 to calculate S-Parameters for Bend discontinuities. Presented microstrip line has dimension $\frac{w}{h} = 2, L = 25\Delta l, h = 4\Delta l, \Delta l = 150\ \mu m$ and Alumina dielectric constant $\varepsilon_{r=9.8}$.

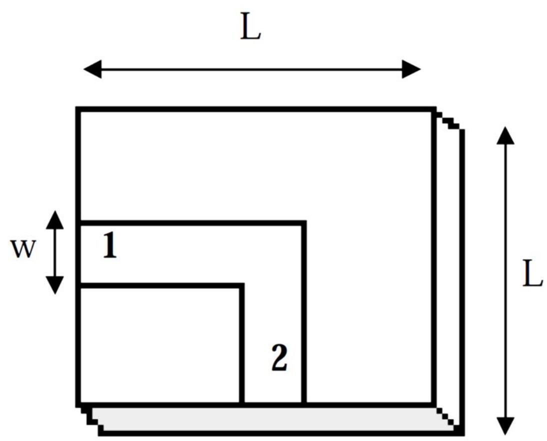


Figure 4 - Bend discontinuities

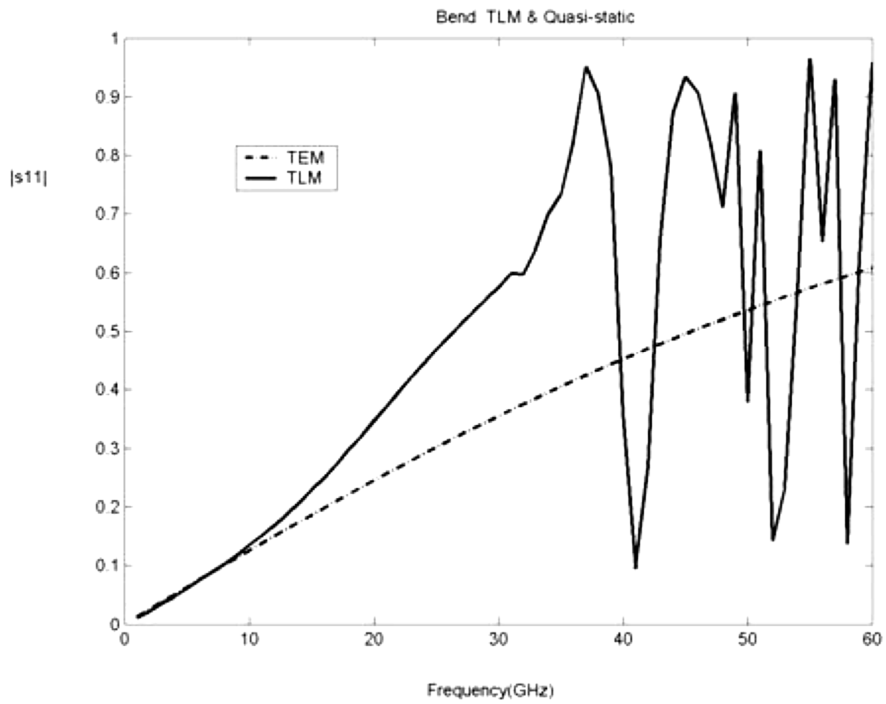
Results obtained from TEM and TLM method are drawn at curvesfigure 5. Infigures5,(A) and (B) are S-Parameters related to Bend discontinuities and (C) to (F) S-Parameters related to T-junction discontinuities. At this figure dotted lines are related to quasi-TEM analysis and continuous line related to TLM analysis. comparison of curves show that at frequencies lower than 10 GHz these curves are matched with each other but they become far from each other when frequency is increased. In fact since line is dispersive, the difference between dynamic methods, TLM with other quasi-static methods is increased to present higher models when frequency is increased. Also, curves obtained from TLM analysis show that at low frequencies curves are relatively soft but with increasing. As mentioned presence of these peaks determines presence of other propagation models along with quasi-TEM mode that TE mode with cutoff frequency $f_{c,TE}$ [13] could be named as one of them.

$f_{c,TE} = \frac{c}{4h\sqrt{\varepsilon_r - 1}}$ (12)

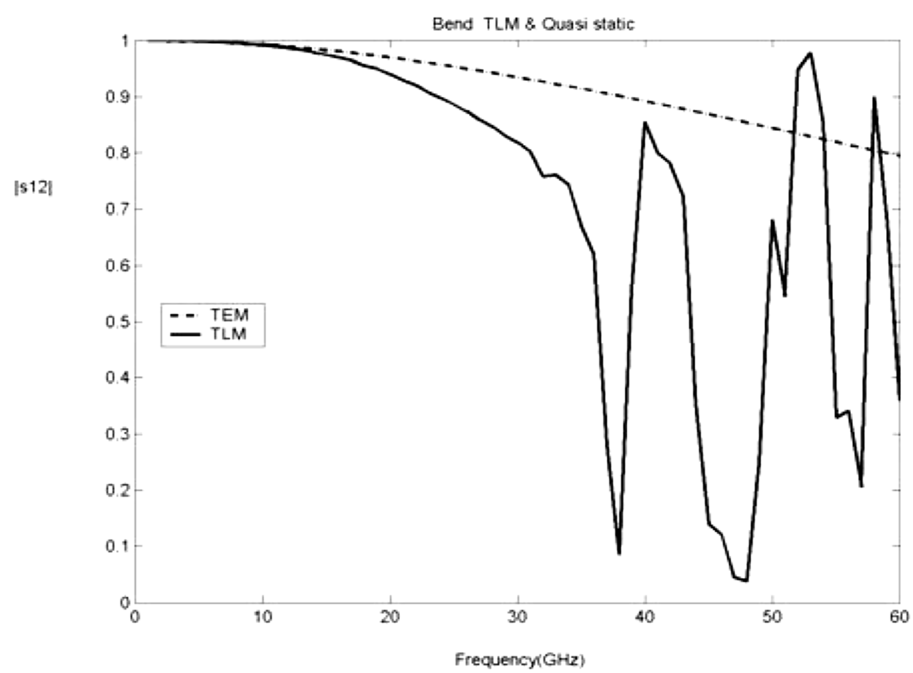
Or coupling from TEM and TM that occurs at f_{TEM1}.

$$f_{TEM1} = \frac{c}{2\sqrt{2}h\sqrt{\varepsilon_r - 1}} \qquad (13)$$

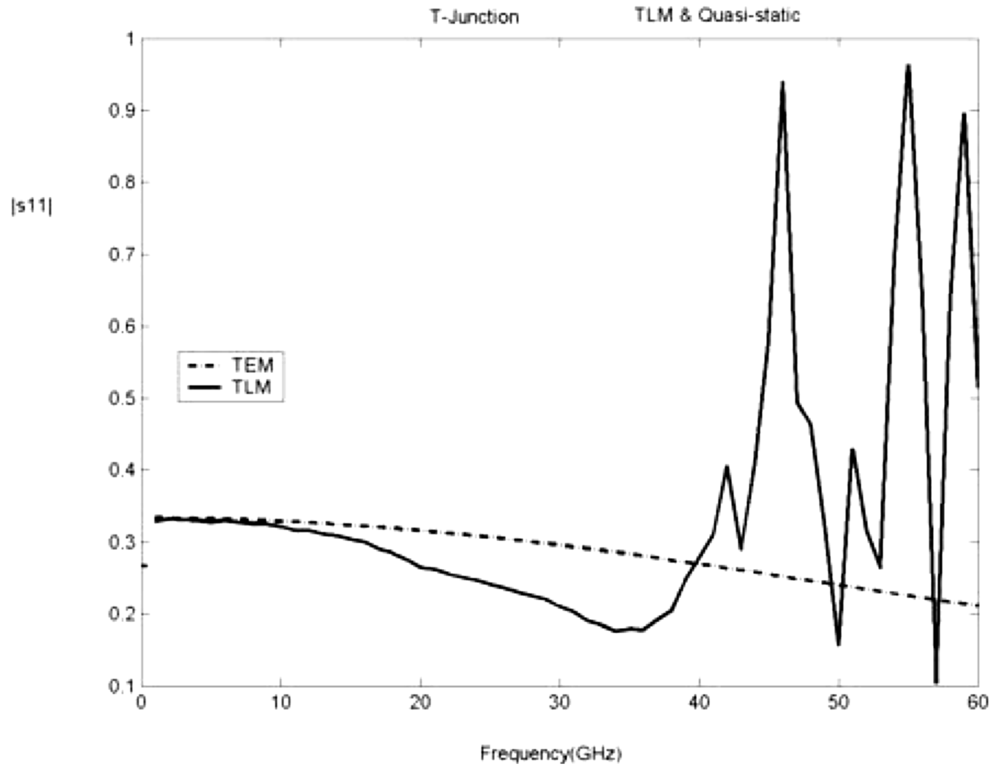
Considering value of $c = 3 \times 10^8, h = 4 \times 150\mu m = 0.6\ mm, \varepsilon_r = 9.8$ is obtained $f_{c,TE} = 1.667\ GHz$ and $f_{TEM1} = 58.529\ GHz$. Effect of these models at higher frequencies makes some peaks on shown curves at cutoff frequencies. It must be noted that obtained above values for $f_{c,TE}$ and f_{TEM1} is appropriate for continuities lines. At result difference between these values and others result related to discontinuities is reasonable. Meanwhile, such peaks are created at circumstances of above frequencies.



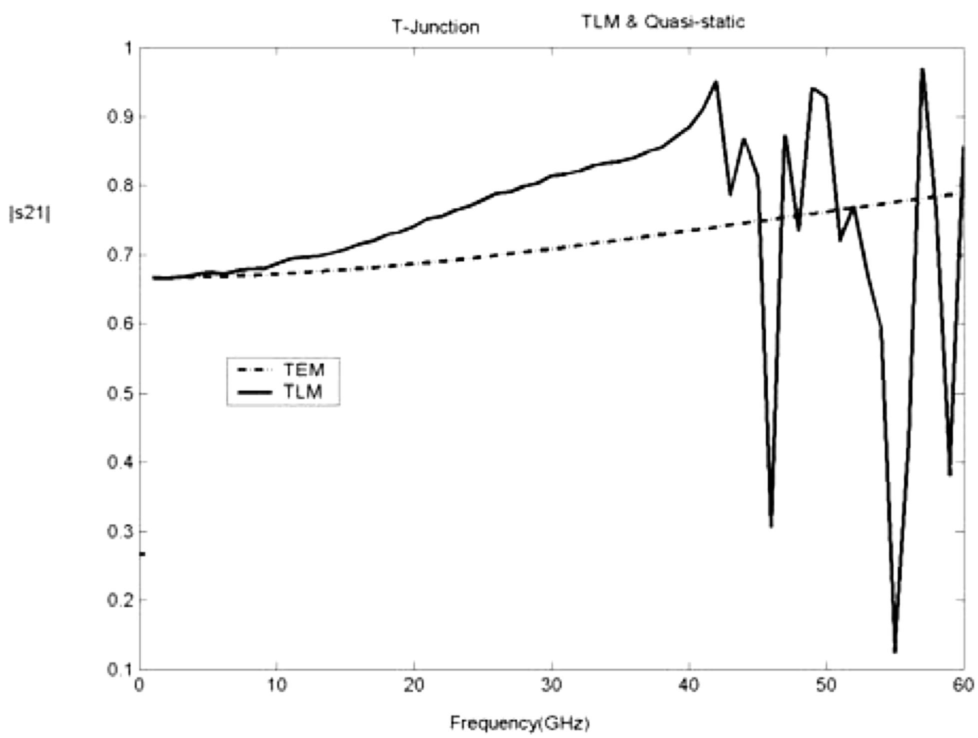
(A)



(B)


T-Junction
TLM & Quasi-static
|s11|
TEM
TLM
Frequency(GHz)

(C)


T-Junction
TLM & Quasi-static
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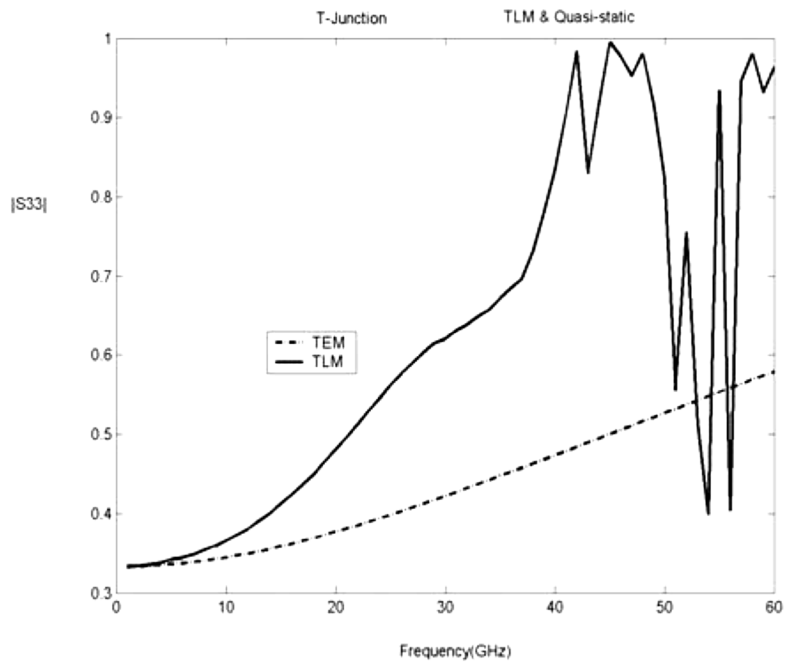
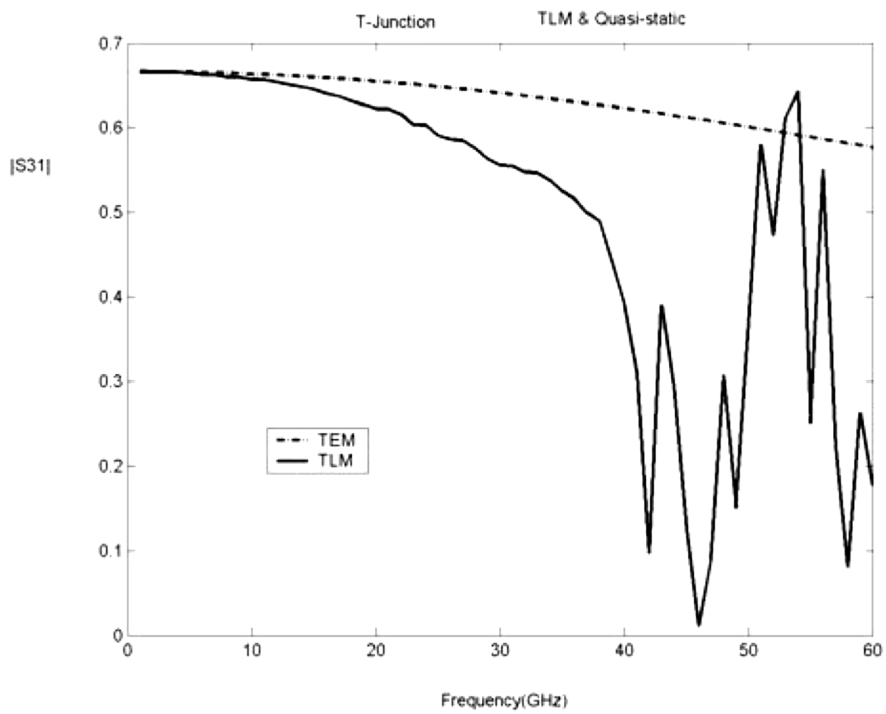
TEM
TLM
Frequency(GHz)

(D)



(E)



(F)

6. CONCLUSION

Quasi-Static methods applied to calculate effect of the discontinuities based on quasi-TEM analysis, develops some relationships that are specially very useful and quick at computer-Aided Design. So, as it's shown at this paper efficiency range of these relationships must be considered. TLM method with respect to ability to analyze different forms of discontinuities is useful mean determining suitable model, frequency limitation and different propagation circumstances that its application to determine frequency range of quasi-Static relationships accuracy at analysis of discontinuities at Microstrip lines is presented at this paper.

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