

MILITARY TECHNICAL COLLEGE
CAIRO-EGYPT



FIRST INTERNATIONAL CONF. ON
ELECTRICAL ENGINEERING

ANALYSIS AND MODELING OF RESONANCE EFFECTS IN A MONOLITHIC MICROWAVE INTEGRATED CIRCUIT PACKAGE

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ABSTRACT

This paper presents analysis and modeling of the resonance effects in a monolithic microwave integrated circuit (MMIC) package using Finite Difference Time Domain method (FDTD). Objectives of the analysis are investigating and evaluating of the resonance effects in a stripline package, and predicting of the resonance parameters which are related to the physical dimensions of the signal line and the discontinuities. A broadband equivalent circuit model of two vias transition in a stripline package including the resonance effects is also developed and presented. Results of the analysis indicate that the package performance is very sensitive to the resonance effects due to the multiple reflections occurred on the signal line. Furthermore, the frequency response of the proposed equivalent circuit model is predicted and compared to the FDTD model of the package discontinuities. Good agreement has been obtained between both models over a wide frequency band. Equivalent circuit model presented in this paper greatly simplifies the analysis and simulation of a complex package including several transition discontinuities, where limits of the resonance effects can be predicted and modeled.

I. INTRODUCTION

Analysis and modeling of the transition interconnects in monolithic microwave integrated circuits (MMIC) packages have been received a great interest over the past few years [1-2]. A typical MMIC package has usually more than one layer of metalization, where different signal lines and ground planes are etched. Transition connects such as via holes or metallic bumps are used to transmit the signal to the other lines and to connect the ground planes at the different layers in the package. In general, resonances in these packages are mainly due to the presence of

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transition discontinuities. These connects cause multiple reflections which interfere with and couple to the signal propagating on the line. Consequently, this has the effect of distorting and degrading the signal which deteriorates the overall package performance. To optimize the overall package performance, resonance effects should be investigated and modeled. Also, limits at which the resonance effects on the package performance become noticeable should be studied.

This paper is mainly concerned with investigation and evaluation of the resonance effects in a stripline package configuration, where only two layers of metalization are considered. The overall resonance effects in a such package is mainly determined by the physical dimensions of the package and the geometries of the transition connects. Also, in microwave circuits applications, an equivalent circuit model of the package discontinuities including the resonance effects can greatly simplify the analysis and simulation of a such complex package. Moreover, using this circuit model, limits of the resonance effects on the package performance can be investigated and modeled. To date, no effort has been reported to develop a such circuit model. A broadband equivalent circuit model of two vies transition has been developed and presented to investigate the limits of the resonance effects on the overall package performance.

A brief summary of FDTD method is presented in section II. Resonance effects on the package performance are investigated and presented in section III. The frequency response of the proposed equivalent circuit model is also computed and compared to the FDTD solution of the package and presented in the same section. Finally, a conclusion is presented in section IV.

II. THEORY

Finite difference time-domain (FDTD) is well known in principle since 1965 [3]. This method has been used for analysis and modeling of several electromagnetic problems [2-5]. The FDTD method can handle a variety of complex geometry including multilayer structures with different electric and magnetic media and transition discontinuities. Recently, FDTD method has been efficiently used to analyze and model the transition discontinuities in a MMIC package including single and multiple layers of metalization [6-8]. In our FDTD analysis, we assume that the media are uniform, isotopic, homogeneous and has no magnetic properties. Also, we assume that the ground and center conductors are perfect conductors (PEC) and have zero thickness. In addition, losses due to conductor and substrate material are neglected in our FDTD model. To excite a MMIC package, a gaussian pulse is used to modulate the transverse spatial distribution of the excitation fields as [9]

$$E_x(x,y) = \psi_x(x,y) \cdot \exp(-(t-t_0)^2/T^2) \quad (1)$$

$$E_y(x,y) = \psi_y(x,y) \cdot \exp(-(t-t_0)^2/T^2) \quad (2)$$

Where,

$\psi_x(x,y)$ The spatial distribution function for x-component of the electric field.

$\psi_y(x,y)$ The spatial distribution function for y-component of the electric field.

t_0 Time center of the pulse.

T Pulse width.

A quasi-static voltage distributions may be used as an initial guess to approximate these functions. However, an error in the computed frequency dependent parameters due to the improper source excitation may be resulted. Therefore, a proper source excitation with accurate spatial distributions of the transverse electric field components is essential for the package analysis. In the analysis, a finite length section of a stripline structure with the same cross section and dielectric material constant as the package is used as reference structure (see fig. 1-a). This reference transmission line is used to determine an accurate and well developed spatial distribution functions using a quasi-static distributions of a gaussian voltage pulse at its output. Using the gaussian pulse, this output is used as the correct spatial distribution functions $\psi_x(x,y)$ and $\psi_y(x,y)$ to excite the MMIC package under investigation. A perfect matched layer boundary condition (PML) is used to truncate the FDTD lattice of the computational domain [11]. Dimensions of the discontinuity are very small compared to the size of the FDTD computational domain required for the analysis. Consequently, using a uniform grid will lead to a huge mesh size which required unrealistic memory. Therefore, we have condensed the mesh only at the region of the discontinuity, where the overall accuracy is improved without significantly sacrificing memory or CPU time. Note that the density of the non uniform mesh has to be gradually varied from low density to high density grids to avoid numerical and dispersion errors [12]. The S-parameters of a package are computed using a modified definition reported in [8] as :

$$S_{ij}(\omega) = \sqrt{\frac{V_i^-(z_i, \omega) \cdot I_i^-(z_i, \omega)}{V_j^+(z_j, \omega) \cdot I_j^+(z_j, \omega)}} \quad (3)$$

Where,

V_i^- denotes the reflected voltage at the port (i).

V_j^+ denotes the incident voltage at the port (j).

I_i^- denotes the reflected current at the port.(i).

I_j^+ denotes the incident current at the port.(j).

ω denotes the angular frequency.

There are two main frequency dependent parameters which are very helpful in developing the equivalent circuit model of the multiple transition discontinuities. These are the characteristic impedance and the propagation constant of the reference structure. These parameters are computed using the FDTD time response as [10]

$$Z_o(\omega, z_i) = \frac{FT[V_{in}^{ref}(z_i, t)] \cdot e^{-k\omega\Delta t / 2}}{\sqrt{FT[I_{in}^{ref}(z_{i-1}, t)] \cdot FT[I_{in}^{ref}(z_i, t)]}} \quad (4)$$

$$\beta(\omega, z_i, z_j) = \frac{1}{(z_j - z_i)} \left\{ \phi_i(\omega, z_i) - \phi_j(\omega, z_j) \right\} \quad (5)$$

Where,

$FT[\cdot]$ denotes the fourier operator.

$V_{in}^{ref}(z_i, t)$ denotes the voltage at the input port (z_i) of the reference structure.

$I_{in}^{ref}(z_i, t)$ denotes the current at the input port (z_i) of the reference structure.

$I_{in}^{ref}(z_{i-1}, t)$ denotes the current at the input port (z_{i-1}) of the reference structure.

k denotes the complex number ($k = \sqrt{-1}$).

Δt denotes the numerical time step to update the FDTD difference equations (sampling interval of the time domain data).

$\phi_i(\omega, z_i)$ denotes the phase of electric (or magnetic) field of the reference structure at the space location z_i .

$\phi_j(\omega, z_j)$ denotes the phase of electric (or magnetic) field of the reference structure at the space location z_j .

The sampling point z_i should be equal to four to five times the line width to minimize the effects of dispersion error on the calculated propagation constant. Also, the difference between the sampling points ($\Delta z = z_j - z_i$) should not be either too small or large. The typical value is between 10 to 15 spatial steps (the spatial step in the direction of propagation). The characteristic impedance given by equation (4) has been found to reduce the numerical error due to the spatial and time offset between the voltage and current calculated using the FDTD method [10].

III. EVALUATION AND MODELING OF RESONANCE EFFECTS IN A STRIPLINE PACKAGE

Consider the geometry and the dimensions of a stripline package shown in fig.1-b, and it is referred to as multiple transitions single line package (MTSL). Resonance effects due to the multiple reflections between two transition discontinuities on the signal line are investigated and presented. The FDTD response of the package are computed for three different distances between the two vies (L_C), and the results are presented in fig.2-a. The reflected electric field due to the discontinuities is computed as the difference between the total incident electric field at the input port of both reference structure and the stripline package. Then, the reflected voltage is computed by integrating this reflected field. As it can be seen from the figure, reflected signals (or voltages) due to the two vies are overlapped when this separation is small. As L_C increases, reflected signals can be separated in the time domain. This indicates that coupling effects between the vies may be neglected if this distance is relatively large. Further discussions will be presented about the effects of this separation on the package performance when equivalent circuit model is analyzed. Also, the S-parameters of the package are computed and compared to the STSL stripline package reported in [8]. Fig. 2-b and fig.2-c show the S-parameters of a MTSL stripline package with $L_C=W_1$ versus STSL package. As it is evident from figures, the presence of more than one via increases the reflection and insertion losses as compared to single transition discontinuity. Also, a resonance on the line has been observed due to the multiple reflections between the vies as shown in fig.2-b and fig.2-c. These resonances are only determined by the length of the transmission line between the vies as will be discussed next.

A general and accurate equivalent circuit model of multiple transition discontinuities has been developed and presented. This circuit model consists of two stages of a STSL equivalent

circuit model which was analyzed and reported in [8] (see fig.3-b). These stages are connected in cascade, and they are separated by a finite length of transmission line as shown in fig.3-c. The length of this line is equal to the physical distance between the inner edges of the vies (not the center). In this circuit model, a simplified three elements circuit model of a single discontinuity is considered. The S-parameters of the equivalent circuit model of a single via transition were computed and compared to the FDTD solution of the package, and reported in [8]. In this analysis, we assumed the same dimensions of the transition discontinuity to use the results of the S-parameters of the circuit model computed in [8]. The following proposed algorithm is used to compute the overall S-parameters of the cascaded equivalent circuit model of the two vies as :

1. Transform the S-parameters computed in [8] into ABCD parameters denoted as $[ABCD]_{ST}$
2. Compute the ABCD parameters of the finite length transmission line denoted as $[ABCD]_{LC}$ using the propagation constant and characteristic impedance of the reference structure.
3. Compute the total ABCD parameters of the cascaded equivalent circuit model as :

$$[ABCD]_{total} = [ABCD]_{ST} \cdot [ABCD]_{LC} \cdot [ABCD]_{ST}$$

4. Transform the total ABCD parameters into S-parameters.
5. Shift the computed S-parameters to the input port of the stripline package by a length C_1 (or C_2) using the propagation constant of the reference structure.

To verify the accuracy of the proposed equivalent circuit, the overall S-parameters of this circuit model are computed using the above algorithm and compared to the FDTD frequency response of the package. Good agreement has been obtained over a wide frequency band between the two models as shown in fig.4. As it is clear from the figure, resonance frequencies of both models are close enough within 2.5% ($F_{FDTD}=39.5$ GHz & $F_{Eq-Cir}=40.5$ GHz). This error may be attributed to the mutual coupling between the vies. To further investigate the coupling effects on the package performance, the S-parameters of the package have been computed for two different separations between the vies. Fig.5 shows the frequency response of the equivalent circuit model as compared to the FDTD solution of the package for $L_c=2W_1$ and $L_c=4W_1$. As L_c increased better agreement is obtained between the two models as shown in figure(5-a). For further increase in this separation, the coupling between the vies decreases, and the frequency response of both models becomes close enough (the difference less than 2%) as shown in fig.5-b. Therefore, coupling effects on the circuit model can be neglected if this

separation is more than twice the line width or via dimensions. On the other hand, due to the multiple reflections on the signal line, resonance effects on the package performance become prominent. However, a typical MMIC package is designed to operate within a narrow band of frequencies to achieve minimum losses. Therefore, the distance between the transition discontinuities " L_c " can be optimized for a given frequency band to achieve minimum losses in the package.

IV. CONCLUSION

Resonance effects in a stripline package have been investigated, evaluated, and presented. Package performance has been found to be very sensitive to the resonance effects. This is mainly due to the effects of the multiple reflections occurred on the signal line. Effects of these resonances on the package performance are determined by the separation between the transition connects. This separation has been found to be more than twice the line width or the via dimensions where, coupling effects can be neglected. Finally, a general and accurate equivalent circuit model of two transition connects in a stripline package has been developed and analyzed in terms of the circuit model of single transition discontinuity. Good agreement has been obtained between the circuit model and the FDTD model over a wide frequency band. The presented circuit model in this paper can greatly simplify the analysis and simulation of a complex MMIC package including several transition discontinuities. Future work will include resonance and coupling effects in a flip chip microstrip-to-coplanar circuit package.

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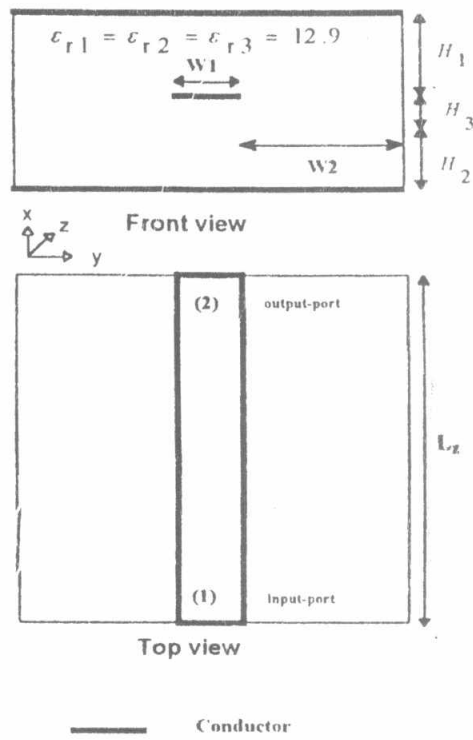


Fig. 1-a Geometry and dimensions of a reference stripline package, $W_1=0.24\text{mm}$
 $H_1=H_2=0.36\text{mm}$, $H_3=0.12\text{mm}$, $L_z=5.76\text{mm}$, $W_2=6W_1=1.44\text{mm}$

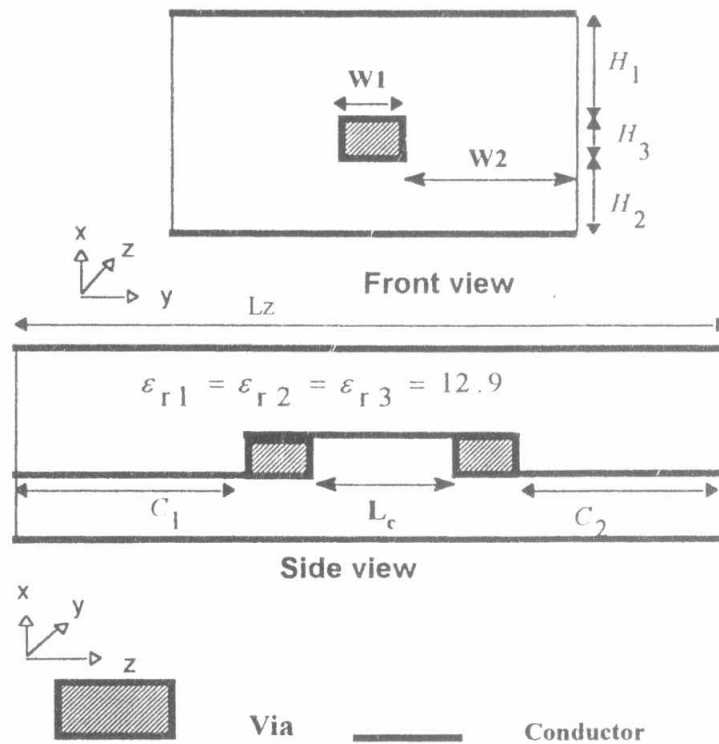


Fig. 1-b Geometry and dimensions of a MTSL stripline package. $W_1=0.24\text{mm}$
 $W_2=6W_1=1.44\text{mm}$, $H_1=H_2=0.36\text{mm}$, $H_3=0.12\text{mm}$, $C_1=C_2=2.76\text{mm}$
 $L_z=5.76\text{mm}$.

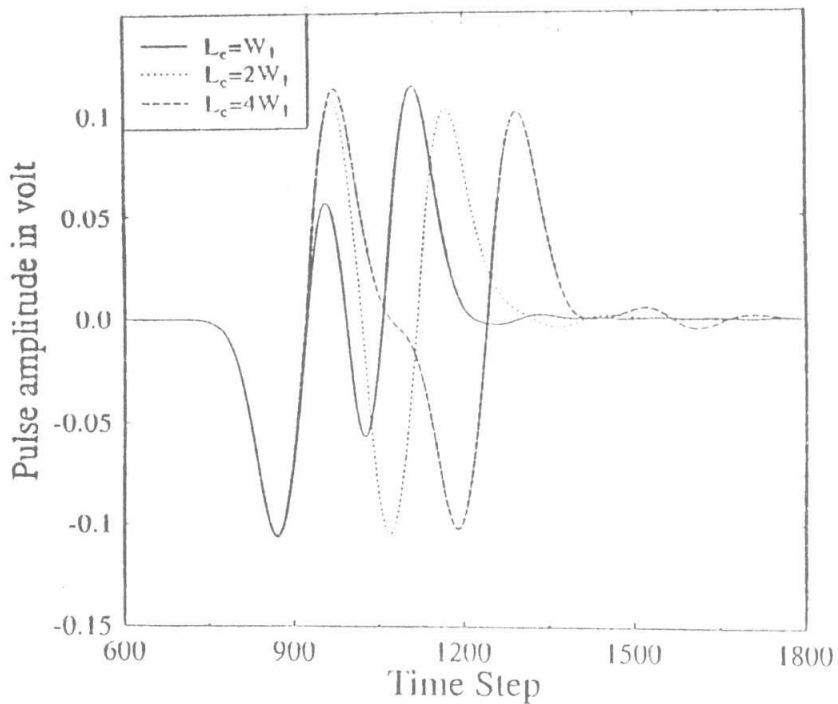


Fig. 2-a Reflected pulse at the input port No. 1 of a MTSL stripline package for three different distance between the transition discontinuities ($L_c = W_1, 2W_1$ and $4W_1$).

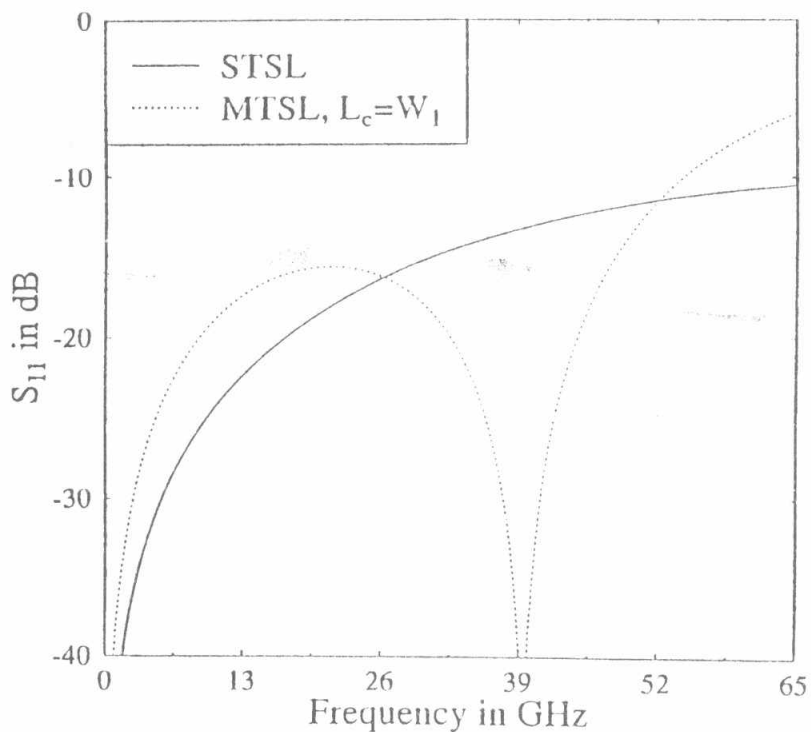


Fig. 2-b S_{11} of STSL versus MTSL of stripline packages.

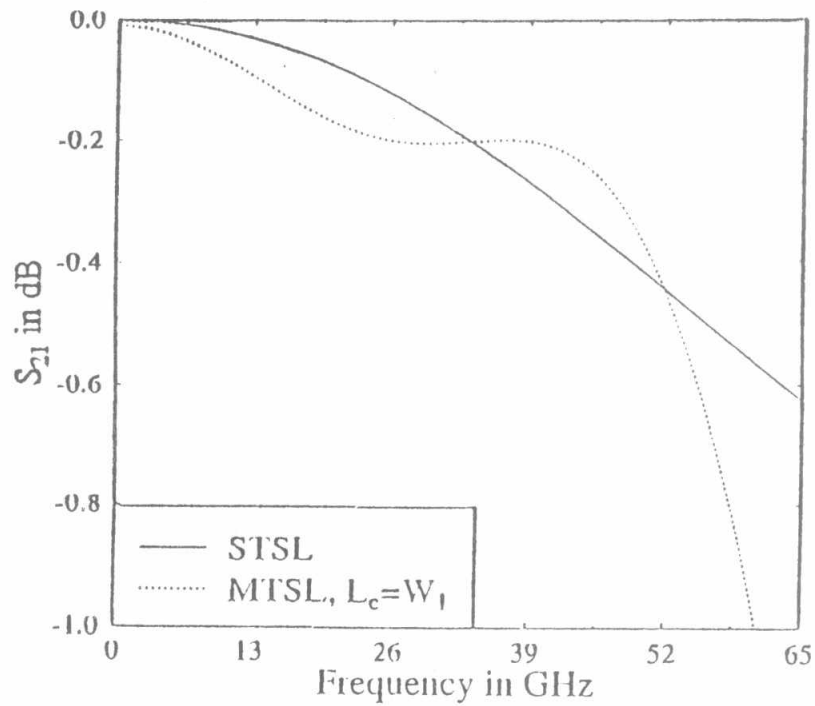


Fig. 2-c S_{21} of STSL versus MTSL of stripline packages.

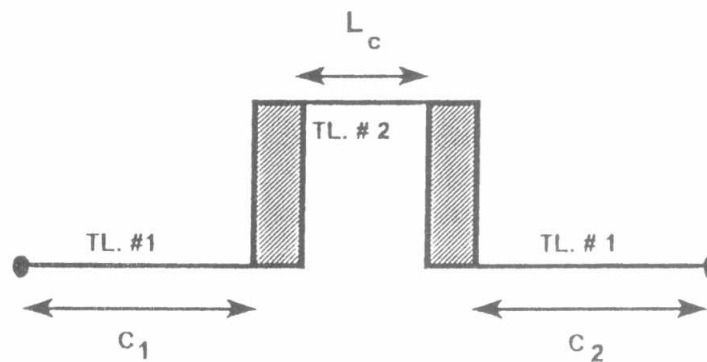
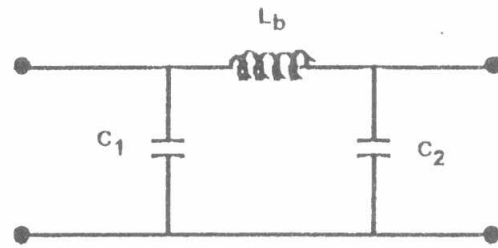
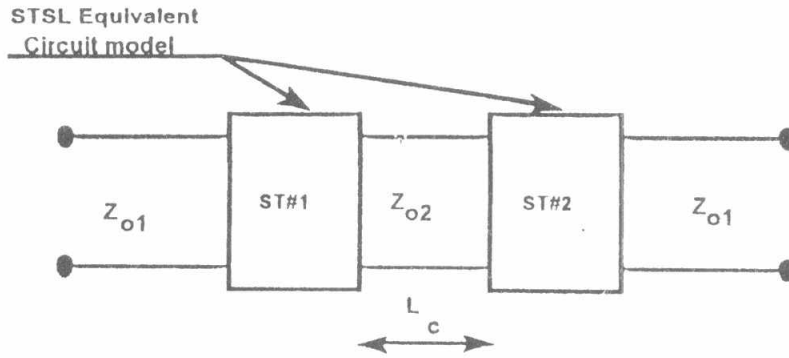


Fig. 3 -a configuration of the discontinuities.



(b)



(c)

Fig. 3. (b) Equivalent circuit model of single via transition in a stripline package (STSL).
 (c) Equivalent circuit model of two vias transitions in a stripline package (MTSL).

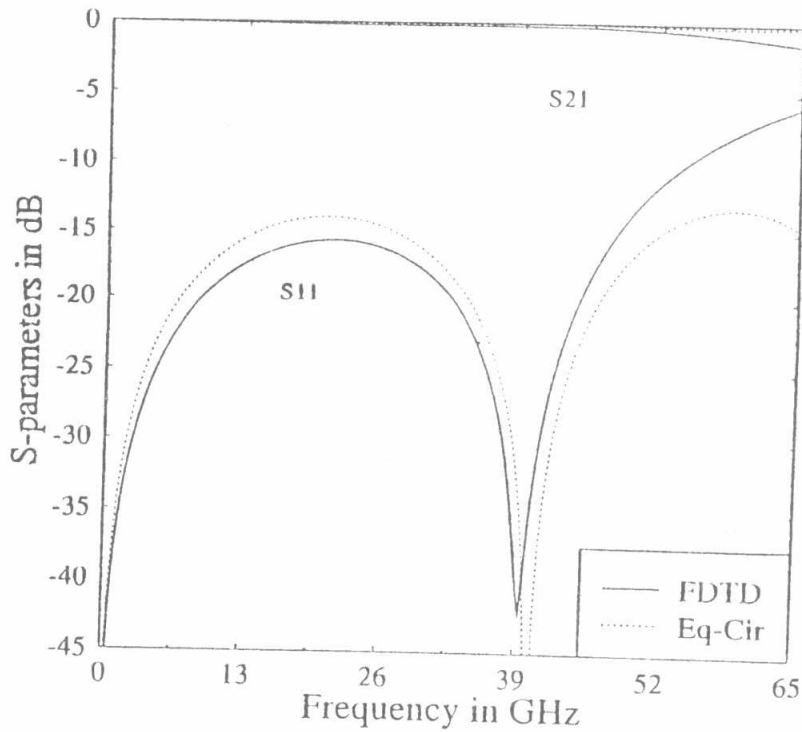


Fig. 4 S-parameters of a MTSL stripline package versus the equivalent circuit model ($L_c=W_1$).

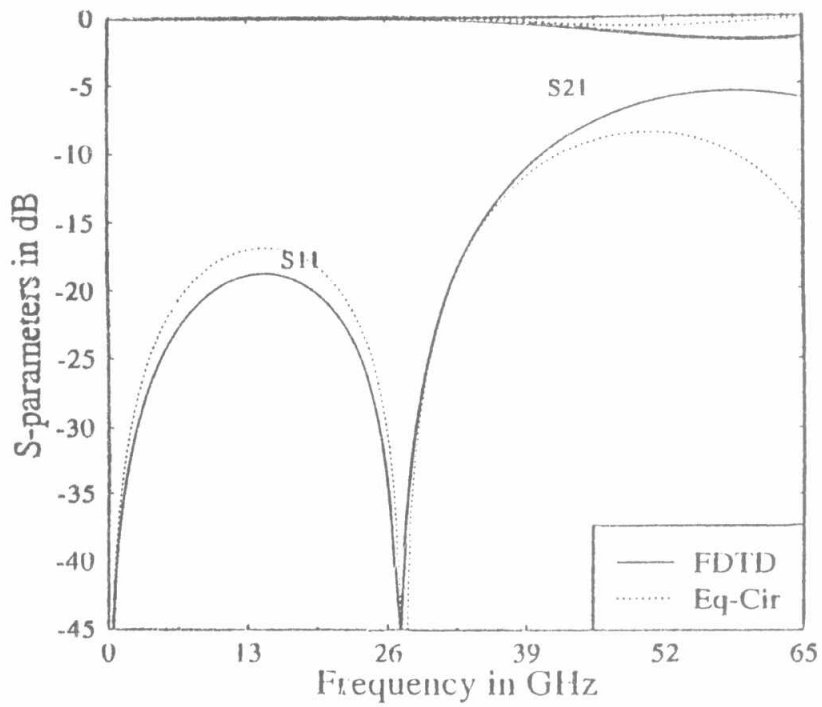


Fig. 5-a S-parameters of a MTSL stripline package versus the equivalent circuit model ($L_c=2W_1$).

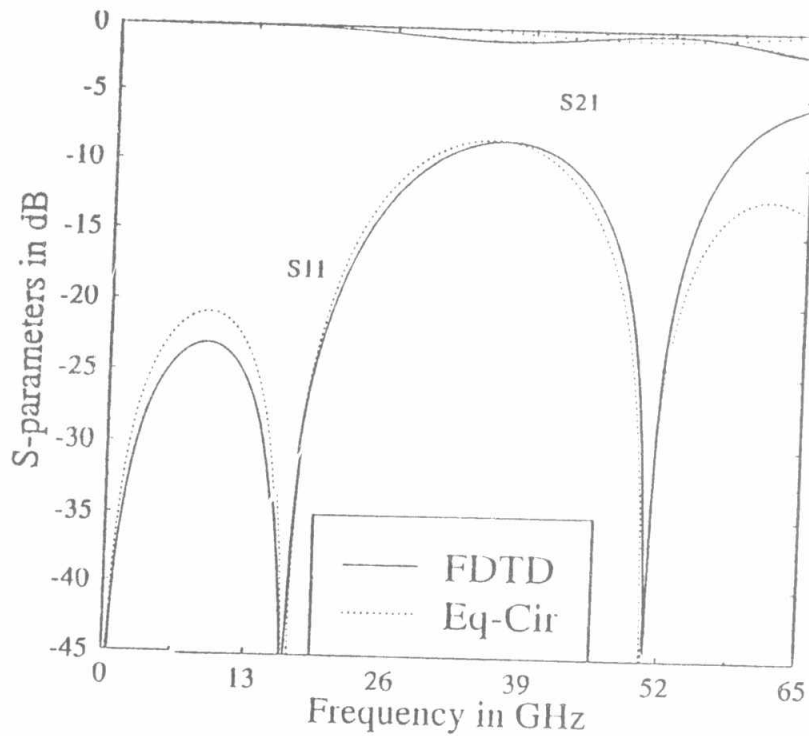


Fig. 5-b S-parameters of a MTSL stripline package versus the equivalent circuit model ($L_c=4W_1$)

