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ANALYSIS AND MODELING OF CROSSTALK IN DIFFERENT HIGH SPEED PLANAR STRUCTURE USING ADVANCED DESIGN SYSTEM

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ABSTRACT

This work deals with the analytical method for estimating coupling between arbitrarily directed multiple finite-length lines with different line lengths and heights. Coupling or crosstalk analysis is performed by developing an expanded circuit-concept approach based on PEEC Method. An electric image method using the quasi-static terms of the accurate Green's function is used to estimate the electromagnetic fields in an inhomogeneous medium such as a printed circuit board. The approach is applied to the analysis of parallel and nonparallel or bent micro strip models, and embedded-line models in which one line is embedded and the other is on the surface layer. To verify the proposed approach, we conducted some experiments and compared the results of our approach with the results of measurements and a commercial electromagnetic solver.

Keyword: PEEC method, bent line, crosstalk, expanded circuit concept, modified telegrapher's equations, multiconductor transmission lines (MTL) theory, multilayer, quasi-dynamic images method.

1. INTRODUCTION

Modern mobile communication handsets, computer motherboards, graphics cards circuit boards, and PCI interconnects all utilize of parallel transmission lines that transmit digital signals between components. For transmission lines carrying different information electromagnetic coupling between these lines is of a destructive nature. All devices suffer reduced signal integrity because of this coupling. This corruption is due to capacitive and/or inductive coupling which was studied extensively. Some researchers have studied crosstalk in microstrip using even and odd mode analysis [1, 7], others have analyzed the mutual inductances and capacitances. Zhou cited Leone stating that certain approximations and assumptions were made that ignore the line width and field distribution it is difficult to obtain solution with both simplicity and Abbosh [10] confirms by stating, "Analytical studies result in closed-form expressions which are suitable for analysis and design, but the accuracies depend to a large extent on the involved approximations." Abbosh goes on to say that numerical methods conducted by [10] are accurate but do not yield practical algorithms for design optimization. Integral equations utilizing image theory were performed by Hellman and Palocz, and they pointed out that conformal mapping was performed on a single microstrip and the resulting integral cannot be evaluated in closed form when applied to multiple microstrip lines.

Higher data transmissions and circuit densities have been the trend in the electronic circuit design of gigabit digital printed circuit boards (PCBs). However, unexpected electromagnetic (EM) coupling problems, such as crosstalk, that can cause timing violations, false clocking, and intermittent data faults, have frequently been observed. The problem is directly associated with the effect of multiconductor transmission lines (MTLs) because PCB traces are the largest or longest components amongst all the devices on a PCB.

In general, a typical crosstalk model includes parallel transmission lines, or MTLs. Crosstalk analysis of parallel MTLs has been studied using network functions based on the telegrapher's equations under the assumption of transverse electromagnetic (TEM) mode propagation or at least quasi-TEM mode propagation [1], [2]. However, MTLs in PCBs are not always parallel and of the same length, and may contain some discontinuities such as vias and bends. These discontinuity effects as well as nearby parallel lines will cause crosstalk, but are not taken into account in an ordinary transmission line theory. Typical MTL theory uses per-unit-length parameter matrices of the cross-sectional dimension. Using the similarity transformation, natural modes are decomposed into orthogonal modes, and the PEEC equations for each orthogonal mode can then be easily solved. Generally, for discontinuities such as nonparallel lines, the perunit-length parameter matrices cannot be obtained. Thus, it is also difficult to obtain orthogonal modes using the similarity transformation in ordinary MTL equations. A transmission line generates EM fields, and these affect neighboring lines, causing induced currents in the lines. This concept corresponds to crosstalk or coupling in the EM field theory. In the circuit theory, the phenomenon is expressed in terms of mutual capacitance and mutual inductance, which is a basic concept of the telegrapher's equations for the MTL theory. These findings suggest that a method of dealing with crosstalk between various types of lines with discontinuities may succeed in combining both concepts.

2. THEORY AND DEVELOPMENT

Coupled planar transmission line structures

Planar transmission lines such as stripline and microstrip have the ability to propagate transverse electromagnetic (TEM) waves and quasi TEM waves, respectively. The solutions to the line parameters are nontrivial and the procedure of obtaining the line parameters involves the application of partial differential equations which yield solutions that involve infinite summations for the capacitance [7] within the dielectric medium separating the conductive planes and strips. The focus of this research is not on the analysis of a single line which was done in [11], but on the analysis of 2 and 3 narrow side coupled lines in stripline, microstrip and microstrip with a dielectric overlay.

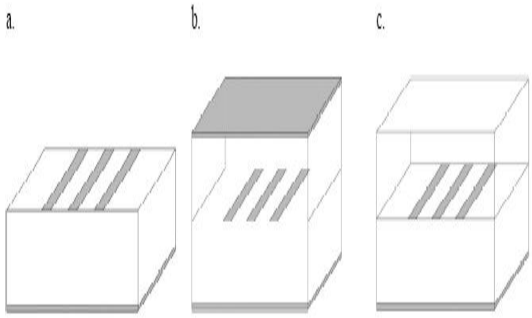

Figure-1. Microstrip (a), Stripline (b), and Microstrip with dielectric overlay (c).

The analysis of coupled lines is logically more complex than that of a single line. Many engineers and scientists have developed different methods to analyze N-coupled transmission line structures but the route to a nominal solution for all of these methods is through numerical techniques where certain simplifications have been made [3,4] due to mathematical complexity.

2.1 Field visualization

To establish a simplified concept of the coupling mechanisms involved for the different propagation modes of three coupled transmission lines begin by finding find orthogonal components of fields at different points of the cross sectional structure. This implies that we are assuming a TEM propagation mode for all 3 modes. For a three coupled line structure there are three modes of propagation that we define as the side active odd mode, center active odd mode, and the even mode. Even mode propagation is defined as all three signals propagating in the same direction. The center active odd mode is defined as the center conducting strip propagating in the ±z-direction and the outer strips propagating signals in the ∓z-direction. The side active odd mode is defined as either the left or right strip propagating in the ±z-direction and the center and right or left in the ∓z-directions.

2.2 Even mode field analysis

Assume a signal with amplitude V(z)=+V0e-jβz is applied to all lines in the microstrip geometry shown in the figure(2) below and that the lines are terminated with matched loads to eliminate reflected waves. The potential distribution in the x-direction at y=b is given by the curve below along the potential distribution in the y-direction under each strip.

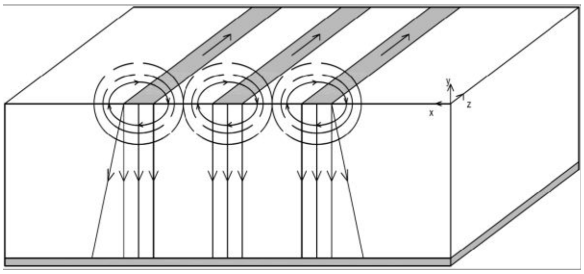

Figure-2. Even mode field distribution.

The x-component of the magnetic field under each line is in the same direction and thus they add to each other. Combining these results with those of the y-component of the magnetic field clearly shows that there is a net magnetic field encircling all 3 transmission lines.

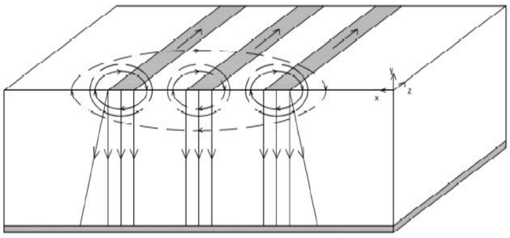

Figure-3. Effective field distribution for even mode.

2.3 Center active odd mode field analysis

The center active odd mode has the two side transmission lines propagating in the direction opposite to that of the center transmission line. In contrast to the even mode, capacitive coupling will be dominant due to the potential difference between the conducting strips. The continuous electric field lines from the center conductor to the side conductors imply that the vector sum of the magnetic fields between the lines equals zero because of the opposing propagation directions.

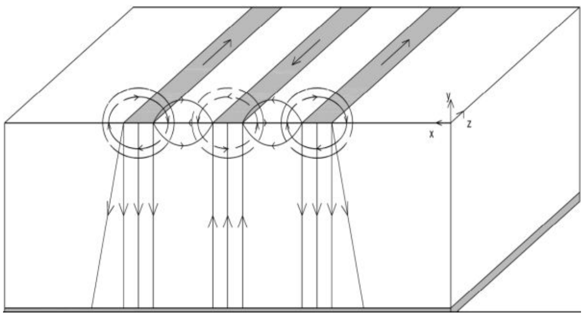

Figure-4. Center active odd mode field distribution.

The center conductor has a signal propagating in the +z-direction and the outer conductors in the –z direction. By a similar analysis we can approximate the potential distributions in the x and y directions and follow the same procedure that will lead to the determination of the directions of electromagnetic fields.

2.4 Side active odd mode field analysis

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For the final mode of propagation we will assume that the leftmost strip conductor is propagating a TEM wave in the +z-direction and the center and right conductors are propagating a signal in the –z-direction. The potential distribution in the parameter for y=b is shown below.

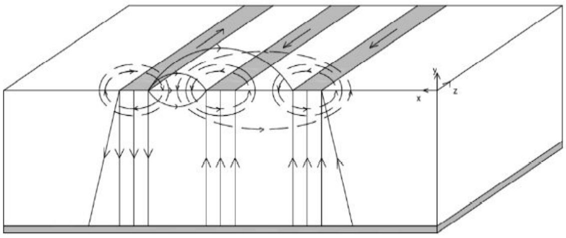

Figure-5. Side active odd mode field distribution.

2.5 Quantitative analysis

Some researchers have studied crosstalk in microstrip using even and odd mode analysis [**1**,**7**], others have analyzed the mutual inductances and capacitances [**2**,**6**]. There are certain approximations and assumptions were made that ignore the line width and field distribution, not because he was inadequate but because, "It is difficult to obtain solution with both simplicity and accuracy if one just studies the coupling in a direct way [**2**]." Abbosh [**10**] confirms by stating, "Analytical studies result in closed-form expressions which are suitable for analysis and design, but the accuracies depend to a large extent on the involved approximations."

3. ENHANCING NOISE IMMUNITY

One proposed solution to reduce electromagnetic coupling between parallel lines is to have a grounded conducting strip between the transmitting lines. This grounded center strip is terminated into a matched load on both ends, and has periodically spaced of vias along the length of the conductor. The purpose of these vias along with the center conductor is to capture radiated electric fields and create a closed surface for magnetic fields to permeate and cancel based of the principle of Faraday's Law. This work will examine the even and odd propagating modes in this structure give a qualitative analysis of the field behavior of this structure and explain how it acts to reduce the coupling between lines.

3.1 Odd mode propagation

Capacitive coupling is the dominant mechanism that leads to signal degradation for signals propagating in opposite directions. The insertion of a grounded strip conductor with periodic short circuit through holes allows parasitic electric fields to couple to this conductor and dissipate into the ground plane. For two signals propagating in opposite directions with their voltage maximums 180o out of phase, their electric fields are such that they couple to the center conductor and the vias. The electric fields couple to the center conductor and cancel due to induced surface charge. Recalling the potential distributions in the x-direction for the center active odd mode it is easy to see that there is a potential gradient which induces an electric field inversely proportional to the spacing of the lines and directly proportional to the potential difference between the lines. Grounding the center conductor allows the potential distribution in the x-direction to have a smaller slope for the same spacing. This smaller slope means a lower magnitude x-oriented electric field. The fact that the coupling is now with a grounded conductor ensures that there is less re-radiation. This in turn reduces
the corruption from the signal on its neighboring transmission line. The grounded conductor serves as a channel for the radiated energy.

3.2 Even mode propagation

The even mode propagation for the shielded lines has a similar mechanism to enhance noise immunity with the exception being that it comes from magnetic fields. Again for TEM wave propagation we will have magnetic fields permeating the surfaces of the loops created in the center conductor and through hole shorts. These magnetic fields, according to Faraday's Law will induce eddy currents into these loops. The time derivative can be moved into the integrand because the area of the surface is not changing in time. Utilizing Kirchoff's Current Law, we can see that the currents will sum in such a way as to not cancel each other. These induced currents will in turn generate magnetic fields to oppose the magnetic fields penetrating the closed surface of the loop thus enhancing the noise immunity of one line from the other. In order for induced magnetic field to cancel the incident magnetic field, the self-inductance of the shield line must be as high as possible and the resistance of the line as low as possible so that the phase difference between the induced voltage and induced current approaches ninety degrees. One such method to ensure that line inductance is sufficiently high is to make sure that the vias are made with the smallest diameter to height ratio possible.

4. CIRCUIT MODEL FOR TWO-BENT TRANSMISSION LINES

We consider a model of two bent lines as shown in Figure-6. Each bent line consists of two straight-line sections. In the figure, we set a different coordinate system for each line section, *xi–yi–zi* coordinates. The four line sections are of different length *li* in the *xi* directions and of the same line height, *yi* = *h*, above a ground plane. Here, we assume the characteristic impedance of each line section is approximated to that of the isolated line because the line arrangement in many cases, except for the purpose of coupling, is for weak coupling. We consider the bent line consisting of line sections 1 and 2 shown in Fig. 3 and discuss the expression for the terminal voltage and current, *V*1(0) and *I*1(0).

$$\begin{bmatrix} V_1(0) \\ I_1(0) \end{bmatrix} = F(l_1) \begin{bmatrix} V_1(l_1) \\ I_1(l_1) \end{bmatrix} + \sum_{i=1}^{4} \hat{F'}_{1i} \begin{bmatrix} V_i(l_i) \\ I_i(l_i) \end{bmatrix}$$

For i = 1 in this case, the EM fields due to the $x1$ -axis-line current are taken into account in the expression for the matrix of the $x1$ -axis line itself. Therefore, only the riser effect, ***A*** (0, Ay 1,1 , 0), should be taken into account in calculating the second term on the right side .

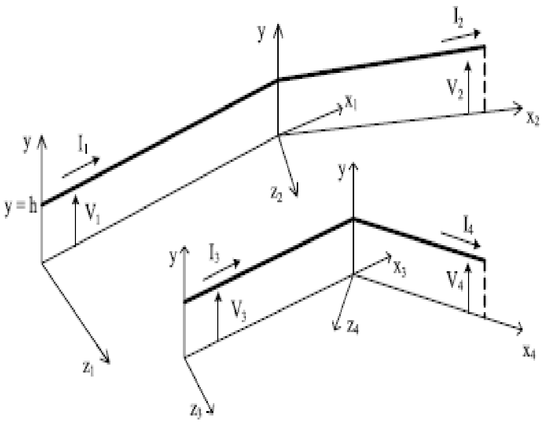

Figure-6. Model for two-bent lines consisting of two straight-line sections and their coordinate system.

5. VALIDATION

5.1 ADS simulation

To discuss whether the proposed approach is effective, we considered various models. Some models were fabricated and their frequency responses were measured with a vector network analyzer, while the others were calculated using ADS.

5.2 Parallel and nonparallel microstrip-line models

First, we consider two parallel microstrip lines in discussing the better validity of the quasi-dynamic images model over the effective dielectric model for estimating EM fields. In this study, we use a fixed value for the dielectric constant in all frequency bands. The results calculated by the aforementioned two methods are compared with those obtained by a commercial solver (ADS). The PCB models have two parallel 1-mm-wide microstrips on a substrate of a relative dielectric constant of 4.5. In Fig. 9(a), the two 15-cm-long lines are 2 cm apart in the longitudinal direction. The separation between lines is 1 mm and the substrate is 1.6-mm thick. $Z0$ of the isolated line is about 85 Ω and _eff is about 3.14.

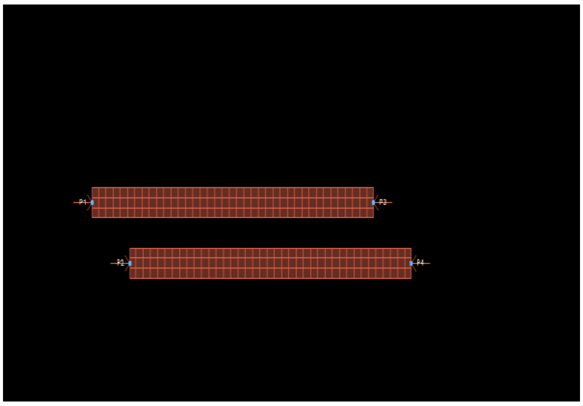

Figure-7. Simple models: (a) parallel microstrip lines with a closed separation on a thick substrate

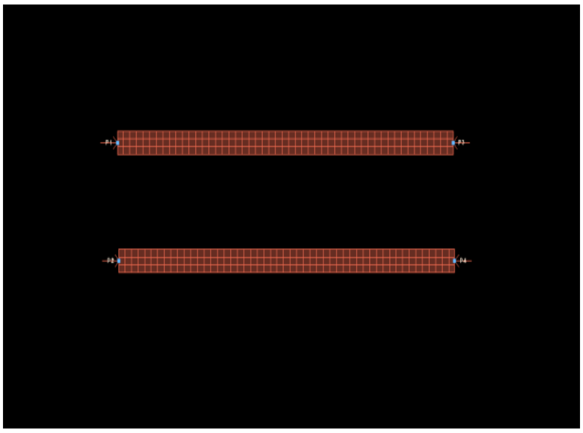

Figure-8. Parallel microstrip lines with a wide separation on a thin substrate.

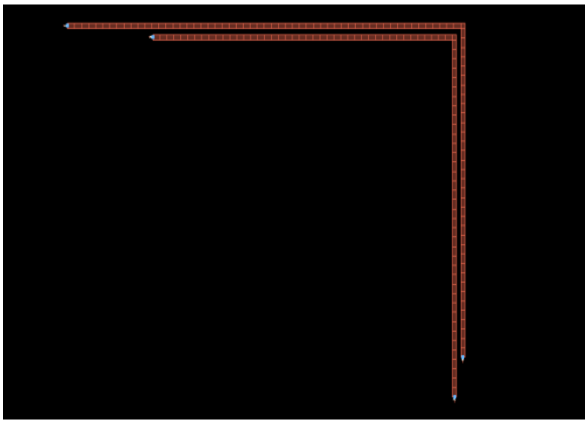

Figure-9. Parallel microstrip lines with a sharp bent on a thin substrate: Type –A.

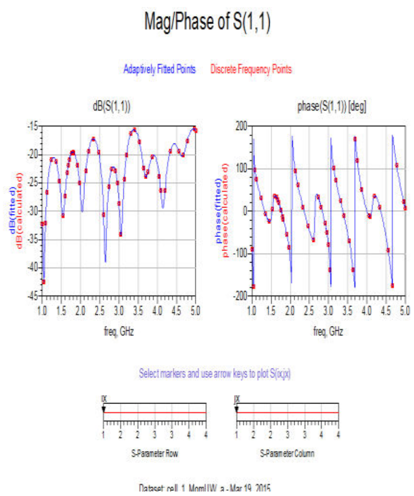

Figure-10. Insertion loss calculation for parallel microstrip lines with a sharp bent on a thin substrate: Type A.

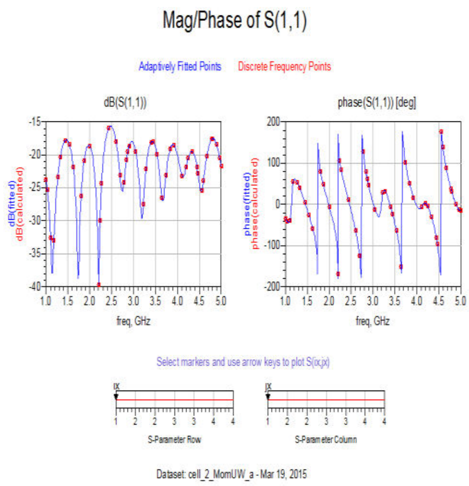

Figure-13. Insertion loss calculation for parallel microstrip lines with a curved bent on a thin substrate: Type B.

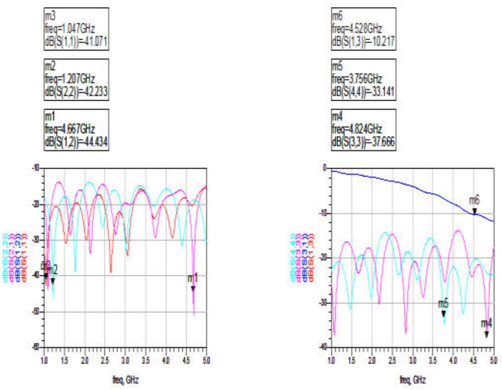

Figure-11. S Parameters of parallel microstrip lines with a sharp bent on a thin substrate: Type A.

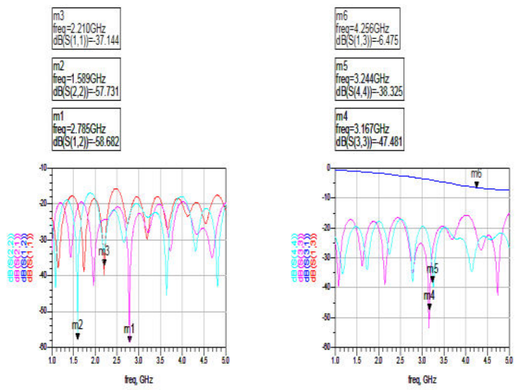

Figure-14. S Parameters of parallel microstrip lines with a curved bent on a thin substrate: Type B.

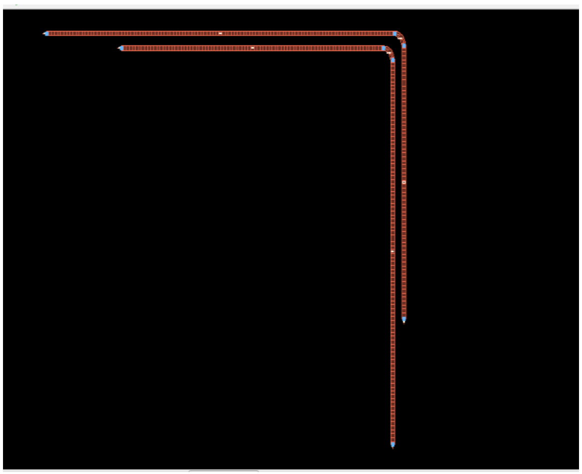

Figure-12. Parallel microstrip lines with a curved bent on a thin substrate: Type B.

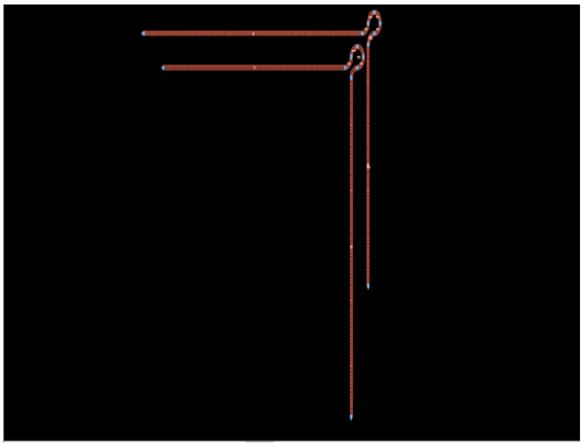

Figure-15. Parallel microstrip lines with a bubbled bent on a thin substrate: Type C.

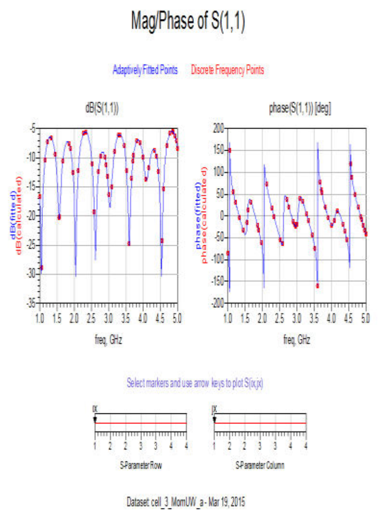

Figure-16. Insertion loss calculation for parallel microstrip lines with a bubbled bent on a thin substrate: Type C.

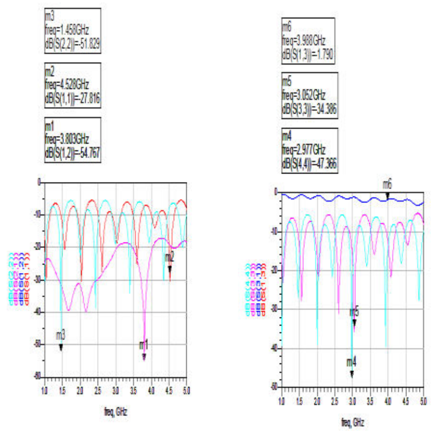

Figure-17. S parameters of parallel microstrip lines with a bubbled bent on a thin substrate: Type C.

6. CONCLUSIONS

We have proposed the expanded circuit-concept approach based on the PEEC Method formulation to analyze crosstalk of a complex configuration of trace lines on a PCB. The quasi-dynamic images method has been applied to the proposed approach for the estimation of EM fields in an inhomogeneous medium. A variety of models were studied to verify the effectiveness of our approach. The results were confirmed by comparing them with those of measurement and simulation (ADS). The proposed approach satisfactorily predicts the crosstalk for a microstrip-line model and an embedded-line model on a PCB as well as a transmission-line model in a homogeneous medium for complex-layout traces. We found that the approach using the quasi-dynamic images model has a more accurate solution than the approach using the effective dielectric model when the separation was wide and the substrate was thin.

Table-1. Parameter descriptions.

Structure	L	H	W	R
Type-A 1st cond	93mm	57mm	1mm	2.5mm
2nd cond	70mm	80mm	1mm	2.5mm
Type-B 1st cond	93mm	57mm	1mm	2.5mm
2nd cond	70mm	80mm	1mm	2.5mm
3rd cond	47mm	103mm	1mm	2.5mm
Type-C 1st cond	93mm	57mm	1mm	2.5mm
2nd cond	70mm	80mm	1mm	2.5mm

L-length, H-height, W-width, R-radius

Table-2. Measurement results.

Structure	Insertion loss	Return loss
Type-A	-2.759	-40.128
Type-B	-2.766	-48.363
Type-C	-3.035	-54.366

Charaistics impedence (z_0)=75Ω.

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