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CROSSTALK REDUCTION USING STEP SHAPED TRANSMISSION LINE

A. R. Mallahzadeh, A. H. Ghasemi, S. Akhlaghi, B. Rahmati and R. Bayderkhani

Faculty of Engineering
Shahed University
Tehran, Iran

Abstract—In this paper, a novel method for crosstalk reduction is proposed. This is achieved through using the step shaped transmission line, which basically attempts to create steps along the transmission lines to decrease the crosstalk, while having negligible variation in return loss. To this end, various simulations are carried out to get an intuition regarding the underlying processes conducted to the far-end crosstalk, thereby enabling to optimize the far-end crosstalk, and simultaneously to yield a small variation in the return loss. Accordingly, a conventional coupled transmission line is employed as a benchmark, enabling to have an idea regarding the impact of the proposed method in terms of the ability to decrease the far-end cross talk. Furthermore, the proposed transmission line and the benchmark structure are fabricated and then evaluated to verify the experimental results to that of the simulation. In addition, comprehensive parametric studies have been carried out to get insight on the effect of various adjustable parameters over the crosstalk. The obtained results show that the crosstalk is decreased more than 4 dB over the entire operating bandwidth. Some advantages such as ease of design and fabrication have made the proposed technique an advisable method when dealing with low crosstalk.

1. INTRODUCTION

The problem of crosstalk reduction has been regarded as one of the most important challenges when dealing with EMC in VLSI applications, thereby is an integral part of development of high-speed and high-density digital electronic equipment. Particularly, the

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Corresponding author: A. R. Mallahzadeh (mallahzadeh@shahed.ac.ir).

problem becomes more conspicuous for long coupled multi-conductor transmission lines [1].

In the last decades, major advances have undergone to investigate the source of crosstalk, properly. For instance, the problem of crosstalk between multiple transmission lines has been investigated in [2], where an analytical result is proposed for some parallel and equal length transmission lines. In [3, 4], the crosstalk between two conductors with finite lengths and arbitrary directions is analyzed by using the circuit-concept approach. Moreover, for some kinds of interconnects cross-sections, in [1] a method for measuring the far end crosstalk is proposed using the so called equalization of modal propagation delays or that of capacitive and inductive couplings.

On the other hand, there have been some efforts to reduce the effect of crosstalk. Specifically, to alleviate the far-end crosstalk on the nearby transmission lines, several approaches have been proposed. In [1], a new method based on periodical coupling and loading for crosstalk reduction is proposed, wherein the effect of crosstalk is analytically investigated and then empirically evaluated. In [7], the effect of crosstalk is deducted through investigating a proper air gap between two suspended transmission lines. Moreover, the effect of crosstalk can be decreased by using either isotropic or anisotropic multilayer structures [8, 9]. Also, the crosstalk between parallel coupled lines on the PCBs can be reduced by inserting an additional trace with the metal filled via hole fence between the interfering lines [10]. In [11], an elegant crosstalk as well as signal reflection reduction technique through the use of nonlinear transmission lines (NLTLs) for high-speed VLSI application is deduced. Also, in [12] it is demonstrated that the crosstalk can be reduced by changing the distance of the desired lines. Finally, in [13] a serpentine guard trace is employed to reduce the far-end crosstalk arising between two nearby transmission lines.

All of the aforementioned methods are identified for a particular circuit and cannot be extended to more general cases, as they heavily rely on the underlying structure. Moreover, they possess some difficulties ahead of fabrication process which increases the ultimate cost and time of release.

Motivated by the aforementioned issues, we propose using a unified approach which can be used in large variety of applications with reasonable complexity. This is achieved through using different couplings along two nearby transmission lines which basically attempts to make a balance between inductive and capacitive couplings, thereby alleviate the effect of crosstalk. To this end, some steps with various widths along each nearby transmission lines are provided which aim at making different couplings along transmission lines. From now on, we call this structure as Step-shaped transmission line. Furthermore, a comprehensive parametric study has been carried out to investigate the effect of various parameters on the performance criterion, thereby enabling to optimize the crosstalk. Accordingly, through simulation and measurement, various measurements including the return loss, the insertion loss, and the crosstalk of the proposed method are compared to that of the conventional nearby transmission lines which is served as a benchmark. Simulation results indicate that there is a close agreement between the measurement results to that of the simulations.

The rest of paper is organized as follows: Section 2 first motivates and then formalizes the problem. Section 3 presents the proposed method in details. Also, the simulation results for comprehensive parametric studies, followed by some measurement results to confirm the simulations, are presented in this section. Finally, Section 4 concludes the paper and highlights the future works.

2. TRANSMISSION LINE MODELING AND COMPENSATION OF FAR-END CROSSTALK

We consider two parallel transmission lines which are placed on the same side of a substrate and at a certain distance away. This section aims to briefly discuss the source of crosstalk arising for two parallel transmission lines and then studies its relation to transmission line parameters. Then, a unique technique is going to be used to compensate the far-end crosstalk.

The n coupled lossless transmission lines can be modeled as Fig. 1, where in the network of n coupled transmission lines can be thought as n uncoupled lines followed by two coupling transformation network

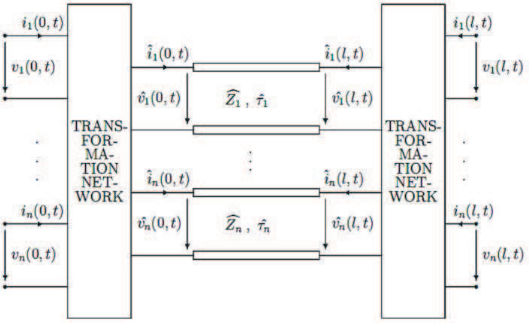

Figure 1. Transmission line model for the n coupled line system.

banks placed at the input and the output ports. Moreover, it is assumed that the TEM mode is the only propagation mode in the lines.

As a result, the voltages and currents on a lossless n-line system are given by the generalized telegrapher's equations as follows:

$$\begin{pmatrix} v^z(z,t) \\ i^z(z,t) \end{pmatrix} = -\begin{pmatrix} 0 & L \\ C & L \end{pmatrix} \begin{pmatrix} v^t(z,t) \\ i^t(z,t) \end{pmatrix} \tag{1}$$

where, L and C are, respectively, the inductance and the capacitance matrices whose elements represent self and mutual parameters per unit length of the lines. Matrix C is symmetric and is given by:

$$C = \begin{bmatrix} C_{1,1} & -C_{1,2} & \dots & -C_{1,n} \\ \vdots & \vdots & \vdots & \vdots \\ -C_{n,1} & -C_{n,2} & \dots & -C_{n,n} \end{bmatrix} \tag{2}$$

with diagonal entries as follows:

$$C_{i,i} = C_{i,0} + \sum_{j=1, j\neq i}^{n} C_{ij} \tag{3}$$

for structures of interest, with either a single or multilayered dielectric medium whose magnetic properties are the same as those of free space, we have:

$$L = L_0 = \mu_0 \varepsilon_0 C_0^{-1} \tag{4}$$

where C_0 is the capacitance matrix of the same set of transmission lines with the dielectric replaced by air.

The capacitive coupling factor, K_c, and inductive coupling factor, K_l, for two transmission lines are defined as:

$$K_c = -C_{2,1}/C_{1,1} \tag{5}$$

$$K_l = -L_{2,1}/L_{1,1} \tag{6}$$

The capacitive coupling of nearby transmission lines may be more than, less than or equal to the inductive coupling in accordance with the line parameters. Therefore, the far-end crosstalk of one section is approximately proportional to the difference of capacitive and inductive couplings of this section, and hence, may have either positive or negative polarity depending on the width of section, line parameters and type of transmission lines. For general case of cascaded sections of coupled transmission lines, in order to decrease the crosstalk, one should rely on the following rule:

If the sign of calculated crosstalk of some sections are positive and that of the rest are negative, the partial or complete compensation of far-end crosstalk is possible. The quantitative expression of the aforementioned condition representing approximately the accurate condition may be written as [10]:

$$\sum_{i=1}^{n} (K_{C_i} - K_{L_i}) \cdot \tau_{0_i} \cdot \ell_i = 0 \tag{7}$$

where n is total number of cascaded sections of coupled lines; $K_{C_i} - K_{L_i}$ is difference of capacitive and inductive couplings in the i'th section; τ_{0_i} is the average of the per unit length propagation delays of the lines of the i'th section; ℓ_i is length of i'th section.

Motivated by the aforementioned issues, two nearby transmission lines can be divided into multiple sections, each of different width and length. However, in this work, all sections are assumed to have a same length. This is achieved through replacing each of parallel coupled transmission lines by multiple cascaded sections with the same length. The impedance characteristics of the first and the last sections are restricted to conform to the impedance matching, that is 50 ohm, while the impedance characteristic of middle sections are optimized to reduce the crosstalk. In other words, dividing the transmission lines into some sections renders capacitance and inductance matrices to vary, thereby changing the coupling factors of each section. As a result, one may optimize the width of each section to reduce far-end crosstalk, while having a reasonable insertion loss and return loss.

3. TRANSMISSION LINES DESIGN AND RESULTS

In this section to verify the accuracy of the aforementioned method, two types of transmission lines are considered: (i) The ordinary transmission line which serves as a benchmark and (ii) the stepped transmission line. The simulation and experimental results of the two types of transmission lines are also presented. To emphasize the accuracy of the simulation results, two commercially available software packages, the HFSS and the Microwave Office, have been used. Comparison results show that there is a close agreement between them, confirming the simulation results are reasonably accurate. In order to validate the simulation results, the designed transmission lines are also fabricated on Teflon substrate ($\varepsilon_r = 2.1$, $\tan\delta = 0.001$) with thickness $h = 1.6\,\text{mm}$, and further compared with the simulation results. Fig. 2 shows the photograph of the fabricated transmission lines. All dimensions after some initial calculations are optimized using HFSS and Microwave Office (M.O.) to yield the minimum far-end crosstalk and the minimum return loss, while having the reasonable insertion loss.

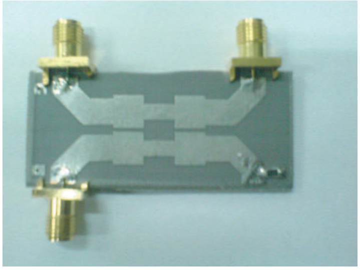

Figure 2. The photograph of the fabricated step-shaped transmission lines.

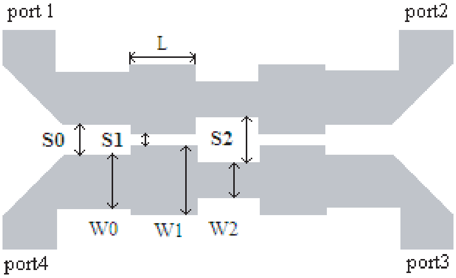

Figure 3. The geometry of the stepped-shaped transmission line.

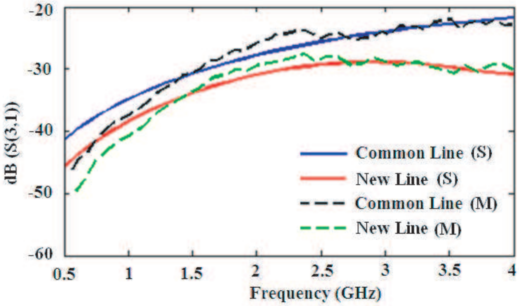

Figure 4. Simulated (S) and measured (M) crosstalk, S_{31}, of the common lines and stepped transmission lines.

Figure 3 shows the configuration of the proposed transmission lines. The dimensions of the ordinary transmission lines are as follow: $L = 30\,\mathrm{mm}$, $W = 5\,\mathrm{mm}$ with $s = 2\,\mathrm{mm}$ as spacing. The dimensions of the stepped transmission lines are: $L = 6\,\mathrm{mm}$ (the length of sections are the same), $W_0 = 5\,\mathrm{mm}$, $S_0 = 2\,\mathrm{mm}$, $W_1 = 6.3\,\mathrm{mm}$, $S_1 = 0.7\,\mathrm{mm}$, $W_2 = 3\,\mathrm{mm}$, and $S_2 = 4\,\mathrm{mm}$ with line spacing similar to the ordinary transmission lines.

The simulated and measured far-end crosstalk, of the ordinary and the stepped transmission lines are shown in Fig. 4. The results show that the far-end crosstalk is improved more than 4 dB for the entire operating bandwidth of 3.5 GHz without any marginal changing in return loss and also insertion loss, Figs. 8 and 6 respectively. To the best of authors' knowledge, the current work is completely different to what is done in other works in terms of the operating wideband [1, 2]. This is due to the fact that despite of other works, the current structure can be easily extended to reduce the crosstalk for wideband applications with reasonable complexity. It is worth mentioning that

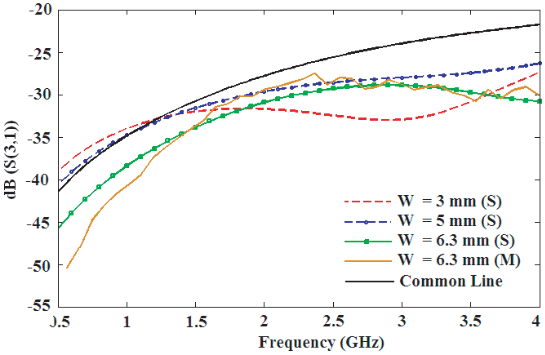

Figure 5. Simulated (S) and measured (M) crosstalk, S_{31}, of the common lines and stepped transmission lines for various first step widths W_1. ($W_0 = 5\,\text{mm}$, $W_2 = 3\,\text{mm}$, $L = 6\,\text{mm}$).

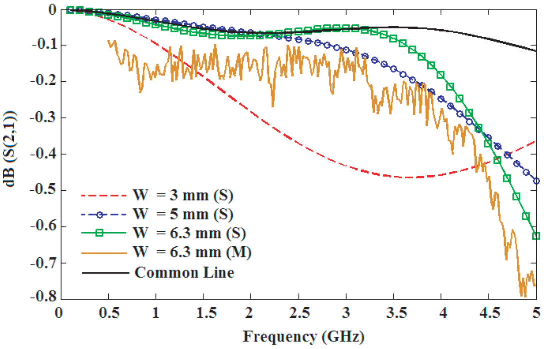

Figure 6. Simulated (S) and measured (M) insertion loss, S_{21}, of the common lines and stepped transmission lines for various first step widths W_1. ($W_0 = 5\,\text{mm}$, $W_2 = 3\,\text{mm}$, $L = 6\,\text{mm}$).

the resulting bandwidth and the crosstalk reduction due to using our proposed method are, respectively, 3 times and 2.5 dB smaller than that of the method given in [10].

The simulation results show that increasing the number of sections can improve the bandwidth of the far end cross talk cancelation in the expense of deterioration of insertion loss and increasing the complexity of final design which possess some difficulties ahead of fabrication process and increases the ultimate cost and time of release. In other words, there is a tradeoff between ease of design in terms of having a reasonable complexity and the desired features such as crosstalk, insertion loss, return loss, and the operating bandwidth.

To better understand the impact of each parameter on the crosstalk, insertion loss, etc, the effect of various parameters is investigated, showing some of them have a large impact on these features. For instance, design parameters such as W_1, W_2, W_3, s, ε_r directly affect the far-end crosstalk, insertion loss, and also return loss of the stepped-shape transmission line. This enables to find out which parameters are involved in the mutual coupling between ports, thereby drawing a path regarding further steps to alleviate this problem.

Nothing to mention that there is a direct relation between increasing line spacing and the final crosstalk. Increasing the line spacing, renders the mutual coupling to decrease. However, due to the lack of space, this is not applicable in most scenarios.

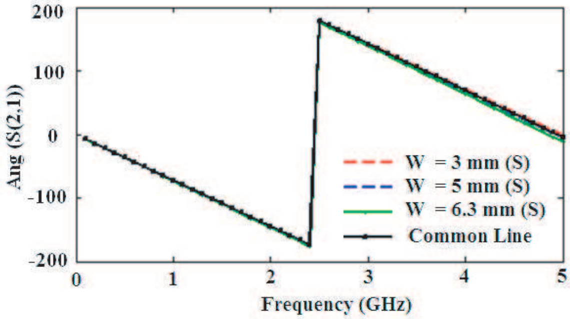

Figure 7. Simulate through line phase for the common lines and new stepped transmission lines for various first step width W_1. ($W_0 = 5\,\mathrm{mm}$, $W_2 = 3\,\mathrm{mm}$, $L = 6\,\mathrm{mm}$).

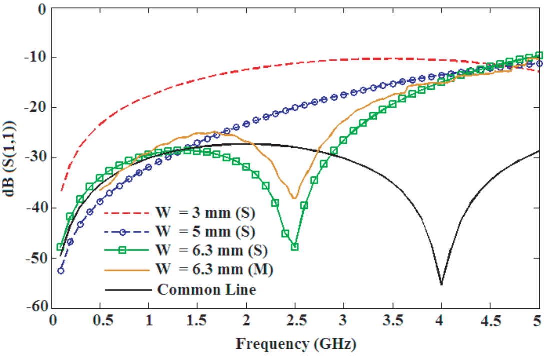

Figure 8. Simulate (S) and measured (M) Return loss, S_{11}, of a common line and new coupled line for various first step width W_1. ($W_0 = 5\,\mathrm{mm}$, $W_2 = 3\,\mathrm{mm}$, $L = 6\,\mathrm{mm}$).

The important parameters that affect the crosstalk, S_{31}, insertion loss, S_{21}, and return loss, S_{11}, are W_1, W_2. So these parameters are studied in more details as follows.

Figure 5 shows the effect of first section's width, W_1, on the crosstalk. As W_1 increases, while W_2 and the length L of sections are kept unchanged, the crosstalk decreases, however, at the expense of degradation in the return and the insertion loss. Specifically, this is more conspicuous at higher frequency bands. Figs. 6 and 7 illustrate the effect of first section's width, W_1, on the magnitude and the phase of the insertion loss, S_{21}. The results show that by increasing W_1 and fixing the other parameters, there is a minor change in the phase and the magnitude of insertion loss. Moreover, referring to Fig. 8, W_1 can affect the return loss S_{11}. This figure shows that as W_1 increases, the resulting S_{11} decreases. Accordingly, it is observed that the effect of W_2 on the return loss, insertion loss, and far-end crosstalk is similar to W_1. As a result, one can optimize the aforementioned parameters to make a balance between desired criteria of reasonable insertion loss, low crosstalk, etc.

4. CONCLUSION

This paper aims to introduce a novel method for crosstalk reduction using the so called stepped transmission lines. Although, extensive reaches are carried out in this area, fewer efforts are devoted to explore methods which simultaneously make a balance between ease of design, the time of fabrication process, operating bandwidth. Noting above together with the fact that our proposed method can be easily adopted in wide variety of applications, the authors believe that this alludes to some practical implications which interests both practitioners and researchers. In addition to this, the presented method can to be easily extended to multiple coupled transmission lines. Also, the proposed method can decrease the far-end crosstalk in wide bandwidth. Noting above, the proposed method can be useful for large scale high-speed and high-density digital electronic equipment.

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