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# 다양한 매질내의 손실특성 개선을 위한 크로스바 구조의 대칭 결합선로에 대한 해석

( Analysis of Symmetric Coupled Line with Crossbar Embedded Structure for Improved Attenuation Characteristics on the Various Lossy Media )

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## 요 약

일반적으로 MIS(도체-부도체-반도체)의 다층 구조로 이루어진 대칭 결합선로에 대한 해석 절차는 모드(even and odd) 해석에 기초한 특성임피던스와 전파상수를 추출함으로써 단층의 결합선로 해석 절차와 동일하다. 본 논문에서는 손실매질의 다층구조로 이루어진 마이크로 스트립선로의 손실특성의 개선을 위한 새로운 구조를 제안한다. MIS 구조로 된 전송선로의 Si와 SiO<sub>2</sub>층 사이에 0전위를 가진 도체를 일정한 간격의 주기적인 배열로 고안된 새로운 모델의 MIS구조에 대한 유한차분법을 이용한 해석방법이 사용된다. 특히 전송선로에 대한 유전체의 영향을 줄이기 위하여 0전위를 가진 주기적인 결합의 도체로 이루어진 구조가 시간영역의 신호를 통해 시험된다. 다양한 손실률을 가진 불완전 유전체에 따른 주파수 의존적인 추출된 전송선로 파라미터와 등가회로 파라미터가 주파수 함수로서 나타내진다. 특히 본 논문에서 제안한 새로운 구조의 불완전 유전체에 대한 전송선로 파라미터가 주파수 함수로 구해진다.

## Abstract

A characterization procedure for analyzing symmetric coupled MIS(Metal-Insulator-Semiconductor) transmission line is used the same procedure as a general single layer symmetric coupled line with perfect dielectric substrate from the extraction of the characteristic impedance and propagation constant for even- and odd-mode. In this paper, an analysis for a new substrate shielding symmetric coupled MIS structure consisting of grounded crossbar at the interface between Si and SiO<sub>2</sub> layer using the Finite-Difference Time-Domain (FDTD) method is presented. In order to reduce the substrate effects on the transmission line characteristics, a shielding structure consisting of grounded crossbar lines over time-domain signal has been examined. Symmetric coupled MIS transmission line parameters for even- and odd-mode are investigated as the functions of frequency, and the extracted distributed frequency-dependent transmission line parameters and corresponding equivalent circuit parameters as well as quality factor for the new MIS crossbar embedded structure are also presented. It is shown that the quality factor of the symmetric coupled transmission line can be improved without significant change in the characteristic impedance and effective dielectric constant.

**Keywords :** FDTD technique, Embedded and Crossbar Structure, Even- and Odd-mode, Attenuation constant, Characteristic impedance.

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## I. INTRODUCTION

Silicon-based technology is increasingly and widely used for RF and microwave integrated circuits

because of the distinct advantages of low cost and weight, well developed fabrication, easy obtained and integration, small volume, and multi-purpose usage techniques in spite of high attenuation. Interconnects in silicon-based ICs can be classified as Metal-Insulator-Semiconductor (MIS) transmission lines, which consist of metal lines on semiconducting substrates, isolated by a thin  $SiO_2$  oxide layer. As previous work, many researchers have reported the transmission properties of such structures including the analysis based on a parallel-plate waveguide approach of MIS microstrip lines<sup>[1-11]</sup>.

Microstrip structures realized on a  $Si-SiO_2$  substrate are known to be quite sensitive to the conductive properties of  $Si$  because of the particular field configuration. Multi-layer multi-conductor configurations form a part of most of the high-speed circuits. More recently accurate characterization of  $Si$ -based lossy MIS structure including a single microstrip line with crossbars embedded MIS structure and multiple coupled lines on the single and multi-layered dielectric media using the Finite-Difference Time-Domain method has been presented by Kim<sup>[12-15]</sup>.

In this paper, symmetric coupled MIS transmission line structure on  $Si-SiO_2$  substrates as shown in Fig. 1 is analyzed using the FDTD method. Then, a new substrate shielding structure consisting of grounded crossbars is examined, and microstrip characteristics

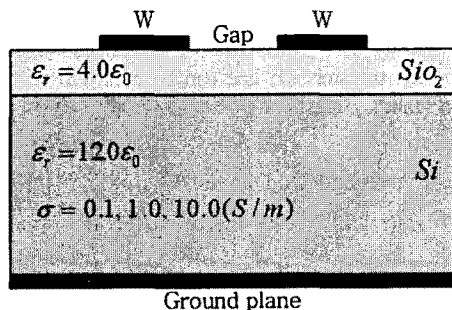


그림 1. 3종류의 다른 도전율을 가진 실리콘에 기초한 MIS 대칭 결합선로

Fig. 1. Symmetric coupled line of Si-based MIS structure with three different substrate conductivities.

for the symmetric coupled line over the crossbar shielding structure is presented. The substrate-shielded microstrip structure is essentially a two-layered microstrip line with a series of crossbar conductors at the interface between  $Si$  and  $SiO_2$  layer.

The crossbar conductors are perpendicular to the main transmission line strip conductors and are assumed to be at ground potential. A full-wave analysis of the crossbar structure is carried out using FDTD. Equivalent circuit parameters are extracted for substrate-shielded microstrip structures from the FDTD simulations, and a comparison is made with the two-layered microstrip structure without substrate shield.

## II. SYMMETRIC COUPLED LINE MIS STRUCTURE

The symmetric coupled microstrip line is very useful for the design of various directional couplers. Basically, there are two fundamental quasi-TEM modes of propagation. The even mode is the mode corresponding to both microstrip conductors being at the same potential  $V$  and having equal currents. The odd mode corresponds to the microstrip conductors being at opposite potentials,  $-V$  and  $V$ , with respect to the ground plane. For the odd mode the currents on the two conductors are also equal in amplitude but of opposite direction.

The important parameters describing the quasi-TEM mode properties of the coupled microstrip line are the even- and odd-mode effective dielectric constants, and the even- and odd-mode characteristic impedances. The line parameters such as effective dielectric constants,  $\epsilon_{effe}(\omega)$  and  $\epsilon_{effo}(\omega)$ , characteristic impedances  $Z_{oe}(\omega)$  and  $Z_{oo}(\omega)$  and propagation constants,  $\gamma_e(\omega)$  and  $\gamma_o(\omega)$  are calculated using equations (1) to (3) of the even- and odd-mode approach for the symmetric coupled line.

$$\gamma(\omega) = \frac{1}{L} \left( \ln \frac{V(z, \omega)}{V(z+L, \omega)} \right) \quad (1)$$

$$Z_0(\omega) = \frac{FFT\left\{\int_d^0 \vec{E} \cdot d\vec{l}\right\}}{FFT\left\{\oint_c \vec{H} \cdot d\vec{l}\right\}} \quad (2)$$

$$\epsilon_{eff}(\omega) = \frac{1}{\omega^2 \mu \epsilon_0} \cdot \left\{ \frac{1}{L} \text{Im} \left[ \ln \left( \frac{V(z, \omega)}{V(z+L, \omega)} \right) \right] \right\}^2 \quad (3)$$

Where L is the length between the two monitored voltage points over the time domain simulations and FFT means the Fast Fourier Transforms,  $\vec{E}$  and  $\vec{H}$  also represent electric and magnetic field intensity, respectively.

Theoretically, the effective dielectric constant for the odd mode is smaller than that for the even mode because a larger percentage of the electric field energy is located in the air region. The capacitance between closely spaced parallel signal conductors at opposite potentials is large, so that the characteristic impedance of the odd mode is smaller than that for the even mode.

The attenuation constant for symmetric coupled microstrip lines is comparable to that for the microstrip line. For closely spaced conductors the increased concentration of the current near the two inner edges for the odd mode, along with the smaller characteristic impedance, increases the attenuation constant of this mode relative to that for the even mode. For the odd mode the attenuation caused by dielectric loss will be less than that for the even mode since the electric field energy is more evenly distributed between the air region and the substrate region for this mode.

Using following equations (4) and (5), the even- and odd-mode parameters for overall capacitances  $C_{e,o}(\omega)$  and inductances  $L_{e,o}(\omega)$  for the symmetric coupled MIS structure can easily be calculated from equations (1) and (2) for each modes. Also the quality factors of symmetric coupled microstrip line for each modes can be calculated from propagation constant  $\gamma_{e,o}(\omega)$  of transmission line shown in equation (6).

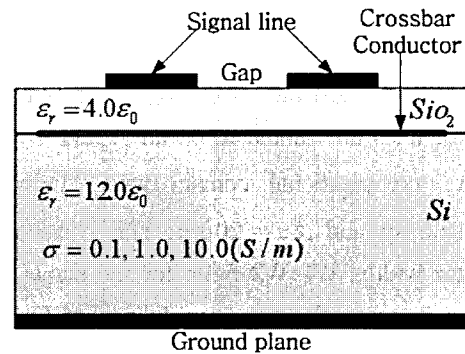
$$\gamma_{e,o}(\omega) Z_{oe,o}(\omega) \equiv R_{e,o}(\omega) + j\omega L_{e,o}(\omega) \quad (4)$$

$$\frac{\gamma_{e,o}(\omega)}{Z_{oe,o}(\omega)} \equiv G_{e,o}(\omega) + j\omega C_{e,o}(\omega) \quad (5)$$

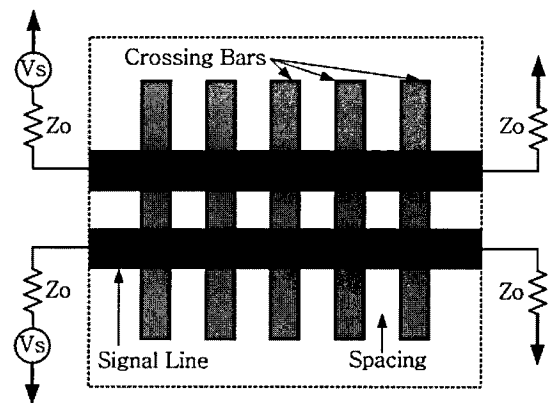
$$Q_{e,o}(\omega) = \frac{\beta_{e,o}(\omega)}{2\alpha_{e,o}(\omega)} \quad (6)$$

### III. SYMMETRIC COUPLED MIS LINES WITH SUBSTRATE SHIELDING

Figures 2 and 3 show side and top view for a symmetric coupled line MIS structure and entire computational domain with embedded grounded



(a)



(b)

그림 2. 0 전위의 크로스바를 가진 MIS 대칭 결합 선로 (a) 옆에서 본 구조 (b) 위에서 본 구조

Fig. 2. (a) Side view and (b) top view of symmetric coupled microstrip MIS line structure with embedded grounded crossbars of zero potential for substrate shielding.

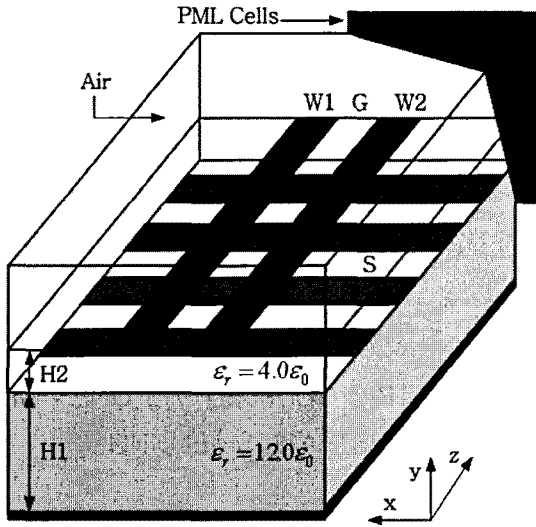


그림 3. 크로스바를 가진 대칭 결합선로 구조의 FDTD 시뮬레이션을 위한 전체 계산영역  
 Fig. 3. Entire computational domain for FDTD simulation of symmetric coupled microstrip MIS lines with the crossbar shielding structure.

crossbars for substrate shielding, respectively. The conductor lines are simulated on an  $N_x \Delta x$  by  $N_y \Delta y$  by  $N_z \Delta z$  computational domain with  $\Delta x = 10 \mu m$ ,  $\Delta y = 12.5 \mu m$  and  $\Delta z = 20 \mu m$ . This corresponds to conductor widths  $W1=W2=5\Delta x$  for the signal lines, a gap size between the two signal lines of  $G=5\Delta x$ , a crossbar conductor width of  $Wc=2\Delta z$ , and spacings  $S=2\Delta z$  between the crossbars, respectively. The substrate heights are  $H1=16\Delta y$  and  $H2=2\Delta y$ .

The entire computational domain including the PML boundary of 8 cells is divided into 78 by 50 by 280 grid cells. In the FDTD simulation, the time step of  $\Delta t = 0.0218 ps$  is used and the total number of time steps is 2700. The input is excited with a Gaussian pulse with  $T = 2.33 ps$  and  $t_0 = 6.98 ps$ .

#### IV. SIMULATION RESULTS FOR THE PROPOSED STRUCTURE

Figures 4 to 7 show the frequency-dependent effective dielectric constant  $\epsilon_{eff}(\omega)$  and characteristic impedance  $Z_0(\omega)$  for the even- and odd-modes for the symmetric coupled lines with the embedded grounded crossbar structure for the three different

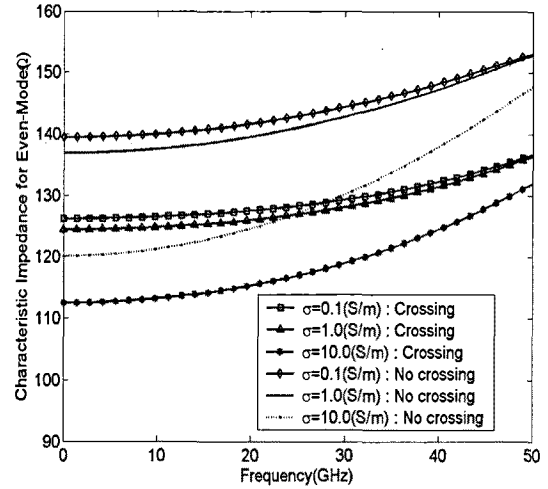


그림 4. 크로스바를 가진 다양한 전도도에 기인한 대칭 MIS 결합선로 구조의 이븐-모드에 대한 특성 임피던스  
 Fig. 4. Characteristic impedances for even-mode of MIS symmetric coupled lines with the crossbar shielding structure.

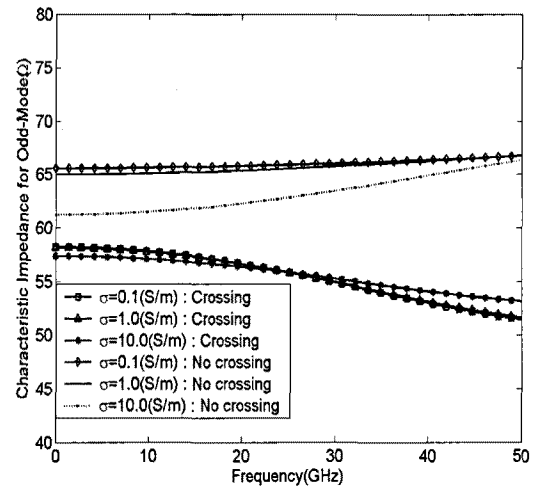


그림 5. 크로스바를 가진 다양한 전도도에 기인한 대칭 MIS 결합선로 구조의 오드-모드에 대한 특성 임피던스  
 Fig. 5. Characteristic impedances for odd-mode of MIS symmetric coupled lines with the crossbar shielding structure.

substrate conductivities,  $\sigma = 0.1, 1.0, 10.0$  (siemens/m). The overall capacitance, inductance, attenuation constant and quality factor for even- and odd-mode are shown in Figures 8 to 11, respectively. It can be seen that as expected, the even mode

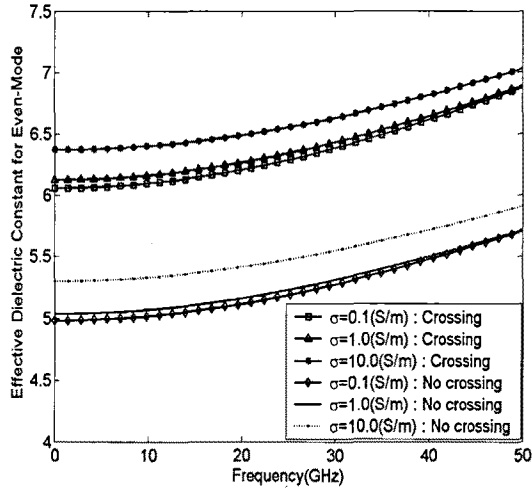


그림 6. 크로스바를 가진 다양한 전도도에 기인한 대칭 MIS 결합선로 구조의 이븐-모드에 대한 유효 유전상수

Fig. 6. Effective dielectric constants for even-mode of MIS symmetric coupled lines with the crossbar shielding structure.

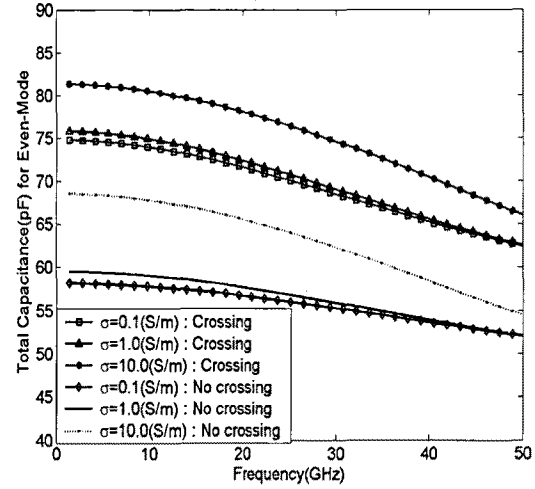


그림 8. 크로스바를 가진 다양한 전도도에 기인한 대칭 MIS 결합선로 구조의 이븐-모드에 대한 전체 커패시턴스

Fig. 8. Total capacitances for even-mode of MIS symmetric coupled lines with the crossbar shielding structure.

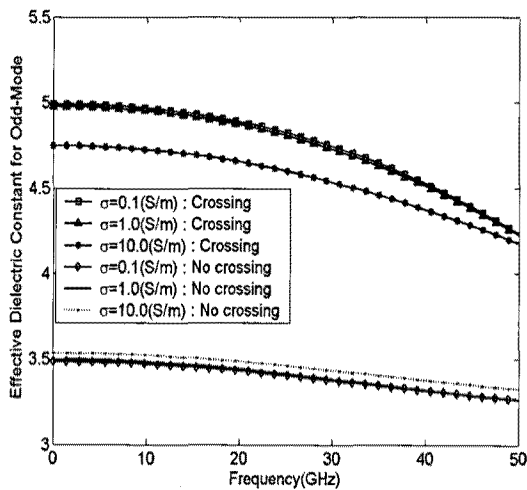


그림 7. 크로스바를 가진 다양한 전도도에 기인한 대칭 MIS 결합선로 구조의 오드-모드에 대한 유효 유전상수

Fig. 7. Effective dielectric constants for odd-mode of MIS symmetric coupled lines with the crossbar shielding structure.

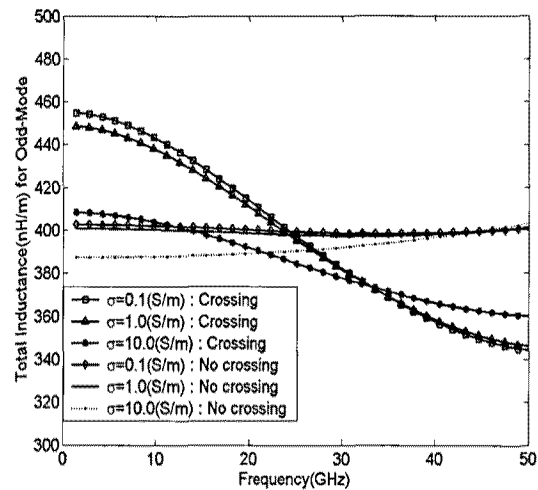


그림 9. 크로스바를 가진 다양한 전도도에 기인한 대칭 MIS 결합선로 구조의 오드-모드에 대한 전체 인덕턴스

Fig. 9. Total inductances for odd-mode of MIS symmetric coupled lines with the crossbar shielding structure.

attenuation characteristic is significantly higher than that for the odd mode due to the stronger field concentration in the substrate for the even mode.

In general, the even mode exhibits stronger frequency dependence. And also, it can be seen that as in the single line case, the crossbar shielding

structure significantly reduces the shunt conductance and attenuation without significantly affecting the characteristic impedance.

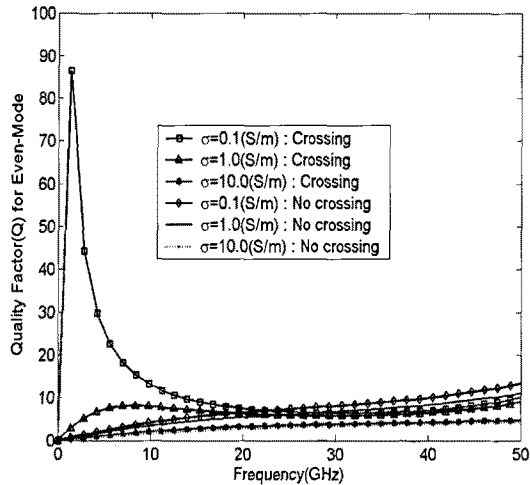


그림 10. 크로스바를 가진 다양한 전도도에 기인한 대칭 MIS 결합선로 구조의 이븐-모드에 대한 Q

Fig. 10. Quality factor for even-mode of MIS symmetric coupled lines with the crossbar shielding structure.

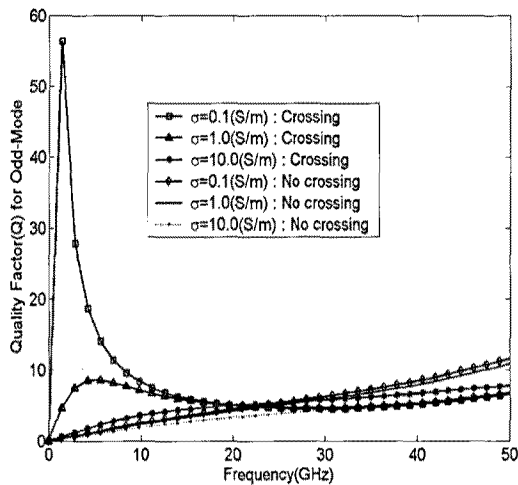


그림 11. 크로스바를 가진 다양한 전도도에 기인한 대칭 MIS 결합선로 구조의 오드-모드에 대한 Q

Fig. 11. Quality factor for odd-mode of MIS symmetric coupled lines with the crossbar shielding structure.

## V. CONCLUDING REMARKS

In this paper, the Finite Difference Time Domain (FDTD) method has been applied to investigate the frequency-dependent propagation characteristics of Si-based multilayer symmetric coupled line MIS structure with crossbar embedded between Si and

SiO<sub>2</sub> layer from the propagation constants and characteristic impedances.

The results show that the transmission line characteristics are strongly influenced by the lossy nature of the silicon substrate. In order to reduce the substrate effects on the transmission line characteristics, a shielding structure consisting of grounded crossbar conductor lines has been examined.

The extracted distributed transmission line parameters and corresponding equivalent circuit parameters as well as quality factor have been examined as a function of frequency. It was found that the quality factor of the symmetric coupled transmission lines can be improved without significant change in the characteristic impedance and effective dielectric constant.

## REFERENCES

- [1] H. Guckel and I. Palocz, "A parallel-plate waveguide approach to micro-miniaturized planar transmission lines for integrated circuits," *IEEE Trans. MTT*, vol. 15, pp. 468-476, Aug. 1967.
- [2] H. Hasegawa and H. Yanai, "Properties of microstrip line on Si-SiO<sub>2</sub> system", *IEEE Trans. MTT*, vol. 19, pp. 869-881, Nov. 1971.
- [3] V. Tripathi and R. Bucolo, "A simple network analog approach for the quasi-static characteristics of general lossy, anisotropic, layered structures," *IEEE Trans. MTT*, vol. 33, pp. 1458-1464, Dec. 1985.
- [4] M. Iskander and T. Lind, "Electromagnetic coupling of coplanar waveguides and microstrip lines to highly lossy dielectric media," *IEEE Trans. MTT*, vol. 37 pp. 1910-1917, Dec. 1989.
- [5] K. Goossen and R. Hammond, "Modeling of picosecond pulse propagation in microstrip interconnections on integrated circuits," *IEEE Trans. MTT*, vol. 37 pp. 469-478, Mar. 1989.
- [6] S. Seki and H. Hasegawa, "Analysis of crosstalk in very high-speed LSI/VLSI's using a coupled multi-conductor MIS microstrip line model," *IEEE Trans. MTT*, vol. 32, pp. 1715-1720, Dec. 1984.
- [7] J. Gilb and C. Balanis, "Asymmetric multiconductor low-coupling structures for

high-speed, high-density digital interconnects,"  
IEEE Trans. MTT, vol.39, pp. 2100-2106, Dec.  
1991.

- [8] V. Tripathi and R. Bucolo, "Analysis and modeling of multilevel parallel and crossing interconnection lines," IEEE Trans. ED, vol. 34, pp. 650-658, Mar. 1987.
- [9] Y. Kim and V.K. Tripathi, "Extraction of multiple coupled line parameters using the FDTD simulation," IEE Proc. Micro. Antennas and Prop., vol. 146, pp. 443-446, Dec. 1999.
- [10] Y. Kim, "Analysis of transmission on Si-based lossy structure using the FDTD method," Journal of KICS. vol. 25, pp. 1527-1533, Sept. 2000.
- [11] Y. Kim, "Characterization of multiple coupled line structures on multi-layered substrate using FDTD technique." Journal of KIMST. vol. 4. pp. 155-163, July, 2000.
- [12] Y. Kim, "Analysis of a new crossbar embedded structure for improved attenuation characteristics on the various lossy media." Journal of the IEEK, vol. 43-TC, pp. 83-88, Dec. 2006.

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