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Coupling Performance Analysis of a Buried Meshed-Ground in a Multi-layered Structure

Myoung-Sub Joung*, Jun-Seok Park†, Hyeong-Seok Kim, Jae-Bong Lim* and Hong-Goo Cho***

Abstract - Since the manufacturing process in the LTCC process does not allow solid ground planes between ceramic layers to isolate the signal lines, the buried ground should be realized as a meshed ground plane. Both characteristic impedances of the signal lines and couplings between different signal layers are influenced by the properties of these meshed planes. In this paper, we propose a new analysis method for coupling behavior between internal transmission lines, which are isolated by the buried meshed-ground planes. The coupling behavior between layers isolated by meshed-ground planes is investigated by the coupled-transmission line model for the isolated layers. The coupling factors between isolated lines with the meshed-ground are extracted by 2-D FEM calculations.

Keywords: buried meshed-ground, LTCC

1. Introduction

Increasing the speed of signals for a variety of applications in the mobile communications and computer fields has focused an increasing amount of attention on the coupling mechanisms within interconnection structures. Ceramic-based multilayer circuits and modules composed of High Temperature Cofired Ceramics (HTCC) or Low Temperature Cofired Ceramics (LTCC) provide the excellent electrical properties of ceramics at high frequencies with precise control of the layer thickness to various applications. According to the lower process temperature (< 900C°), LTCC has the added advantage of making use of low resistive conductor systems such as Ag or Au. Since LTCC contains a large amount of glass, which lowers the relative permittivity of the material, the velocity of the propagated signals is increased compared to HTCC circuits. The design of such a multilayer circuit requires the designer to consider a set of electrical and technological constraints for fabrications or ceramic processes. One essential modification of ideal conditions is necessary for the buried ground/power planes, which are implemented by meshed configurations as shown in Fig. 1. The reasons to avoid complete ground areas are attributed mainly to the ceramic fabrication technology. According to tape manufacturers, the metallized area should be below 50%. On one hand, this constraint is necessary to maintain sufficient tape-to-tape contact during lamination to achieve a good bond between adjacent layers. On the other hand, this limit is required to control the shrinkage of the substrate. LTCC tapes shrink laterally during firing by approximately 12 to 15%. Due to the different shrinkage and expansion behavior of grass and metal during firing and cooling, an excessively high content of silver paste could force the substrate to shrink even more. This fact leads either to deformation of the circuit carrier or to positioning problems in the mounting process of ICs and other additional components [1]. In this paper, in order to achieve the optimum design of the buried meshed-ground plane, we newly propose an analysis and modeling method for the coupling estimation of buried transmission lines in different layers due to the imperfect isolation of the meshed-ground plane. The ground plane pattern influences both the characteristic impedance of the transmission lines and the coupling between lines. Coupling is now possible for parallel lines in one layer with the edge coupling scheme and between different signal layers through the ground plane with edge or broad side couplings. This paper focuses only on the analysis and estimation of the nominal coupling amounts, which might be occurred, between different signal-layers based on the coupled-transmission line model. We have simulated several coupled-lines with a buried meshed-ground plane to show the validity of this paper.

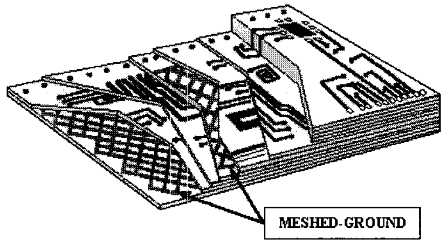

Fig. 1 Schematic of the buried mashed-ground in a LTCC multilayer module.

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† Corresponding Author: School of Electrical Engineering, Kookmin University, Seoul, 136-702, Korea. (jspark@kookmin.ac.kr)

* School of Electrical Engineering, Kookmin University, Seoul, 136-702, Korea.

** Dept. of Electrical and Electronics Engineering, Chungang University, Seoul, 156-756, Korea. (kimcaf2@cau.ac.kr)

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2. Modeling of a Meshed-Ground Plane Based on Coupled-line Theory

The evaluation and estimation of the coupling between isolated lines by a buried meshed-ground plane has been made possible only by practical tests with useful designs or by sophisticated electrical field simulations [1]. However, in this paper, we have analyzed the coupling characteristics between isolated lines by a buried meshed-ground plane by using parallel coupled-transmission modeling. The couplings between lines are evaluated by calculating the coupling parameters such as even-mode and odd-mode impedances of the coupled lines through the meshed-ground plane unit. The coupling parameters, which are even- and odd-mode capacitances, can be calculated by using the following formula [2].

$$C_e = C_{11} = C_{22} \qquad (1)$$

$$C_o = C_{11} + 2C_{12} \qquad (2)$$

$$Z_{0e} = \frac{1}{\upsilon C_e} \qquad (3)$$

$$Z_{0o} = \frac{1}{\upsilon C_o} \qquad (4)$$

Once the coupling parameters are extracted for a given dimension, then the coupling values are evaluated by well-known relations.

$$C = \frac{Z_{0e} - Z_{0o}}{Z_{0e} + Z_{0o}} \qquad (5)$$

$$\text{Coupling Constant} = 20\log\frac{jC\tan\theta}{\sqrt{1-C^2}+j\tan\theta} \qquad (6)$$

where θ means the coupling electrical length, which can be calculated for a given structure by solving the eigenvalue. Fig. 2 indicates a coupled-line with the unit cell of the buried meshed-ground plane where the unit cell is divided by one section of the metal eliminated segment and two solid ground segments at both ends of the signal line. In order to calculate the coupling of the coupled-line section with the meshed-ground unit, the coupling parameters and eigenvalues for each basic segment should be extracted. For the ideal solid ground segments, couplings between coupled-lines never occur. Thus, for those cases, coupling parameter means the characteristic impedances of each transmission line. Fig. 3 indicates the cross-sectional view of a coupled-line with the meshed-ground plane unit at the reference plane A-A'. The material for the simulations was a Dupont 943, which has the best loss characteristic. DP943 green tape is one of the most popular materials for LTCC. Dielectric constant of the substrate was chosen to be 7.8, which is that of DP943.

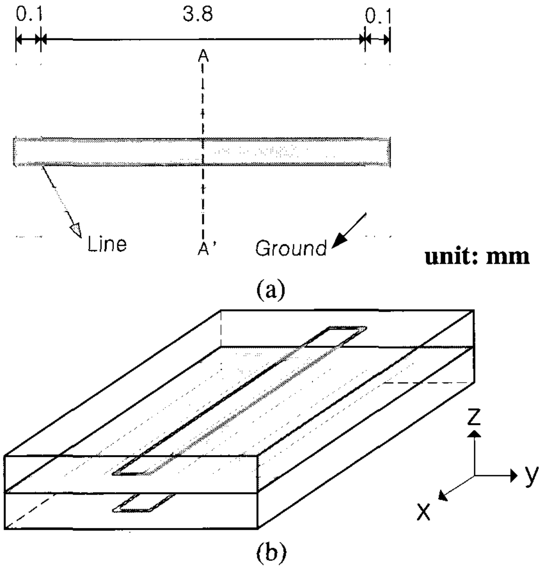


Fig. 2 Coupled-line with unit-cell of the buried meshed-ground plane. (a) Top view. (b) 3-dimensional view.

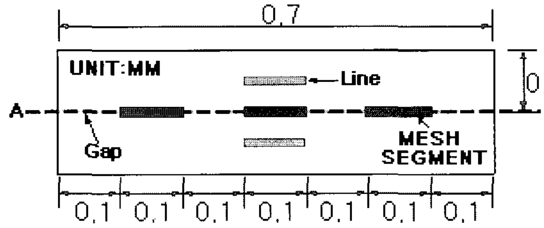


Fig. 3 Cross-sectional view of coupled-line section with the buried meshed-ground plane unit for the extraction of coupling parameters.

Fig. 4 shows the simulations for calculating the coupling parameters and propagation constants of each mode by using the 2-D FEM algorithm. By calculating the capacitances of each mode, we can calculate the even- and odd-mode impedances for a given dimension, which determine the coupling value of the coupled-line section. Furthermore, by solving the eigenvalue with how to extract Z_{oe} and Z_{oo} from obtained β_e and β_o, we can extract the propagation constants to calculate the corresponding electrical length of the coupled-line section.

From the extracted coupling parameters, we can establish the equivalent circuit for the coupled-line section with the unit-cell of the buried meshed ground plane. The cases considered in this paper are symmetric meshed-ground planes. However, the method presented in this paper could be applicable to asymmetric cases.

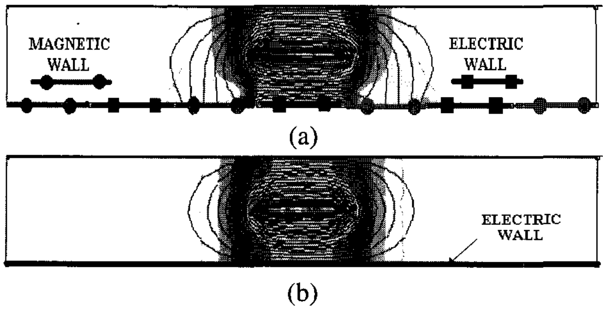


Fig. 4 2-D FEM calculations for the extraction of coupling parameters. (a) Even mode case. (b) Odd mode case.

3. Simulations on Coupled-line with a Buried Meshed Ground Plane

Fig. 5 indicates the equivalent circuit model for the coupled-line section with the unit-cell of the buried meshed ground plane shown in Fig. 2, which is composed of the meshed-ground and solid-ground sections. Coupling parameters and electrical lengths for each coupled-line in the equivalent circuit have been computed by using 2-D FEM calculations after placing the E-wall and M-wall to extract Z_{0e} and Z_{0o} as illustrated in Fig. 4. For the solid-ground section, the even- and odd-mode impedance is identical because there is no coupling behavior. With this equivalent circuit, a direct comparison was then made between 3-D EM simulation on the coupled-line with the meshed-ground unit and circuit simulation on its coupled-line equivalent model. Fig. 6 presents the result of comparison between the EM-simulation on the physical coupled-lines isolated by meshed-ground and the circuit simulation on its equivalent model. The circuit simulation had tighter coupling than the EM simulation and the compared result shows some difference in high frequency band.

For more general cases, a coupled-line with twenty meshed-ground unit segments, having unit-cell dimension as shown in Fig. 2 has been analyzed. Fig. 7 and Fig. 8 indicate an example model and corresponding equivalent circuit model, respectively. Comparison of simulations on the example of Fig. 7 is demonstrated in Fig. 9. The coupling difference is indicated much like the result of Fig. 6 and the difference error generated is greater than that of Fig. 6 because of combination unit-cells.

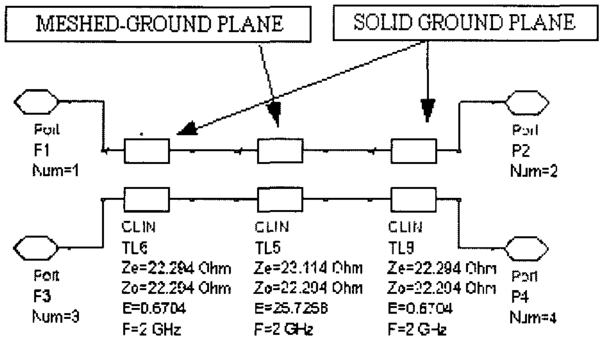


Fig. 5 Equivalent schematic model for the unit-cell of the buried meshed-ground plane shown in Fig. 2.

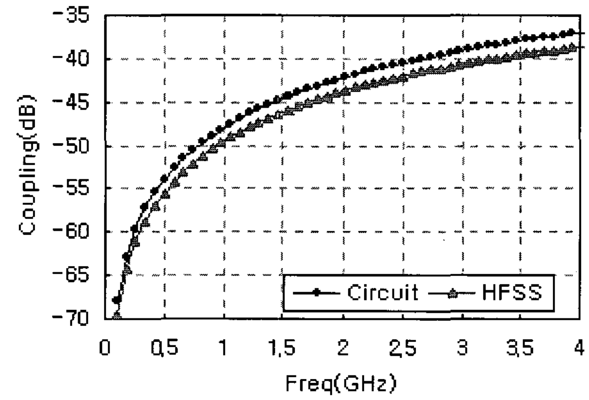


Fig. 6 Comparison between the 3-D EM simulation on the coupled-line with the meshed-ground unit shown in Fig. 2 and the circuit simulation on its coupled-line equivalent model depicted in Fig. 5.

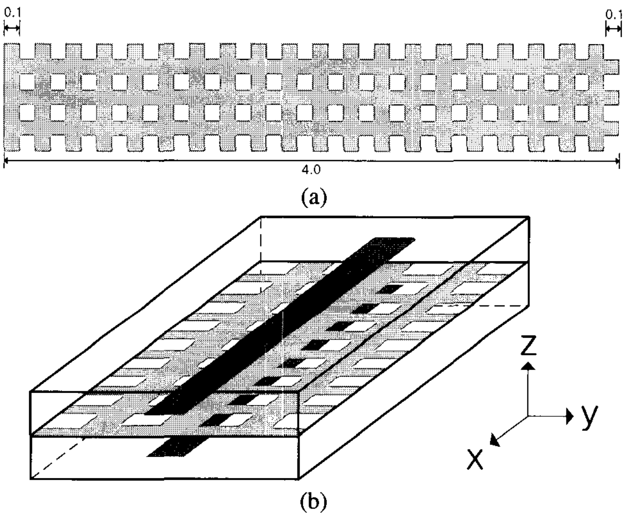


Fig. 7 Coupled-line with the buried meshed-ground plane. (a) Meshed-ground dimension. (b) 3-dimensional view.

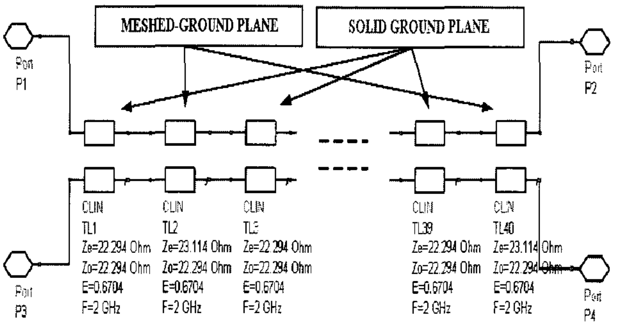


Fig. 8 Equivalent schematic model for a coupled-line with the buried meshed-ground plane shown in Fig. 7.

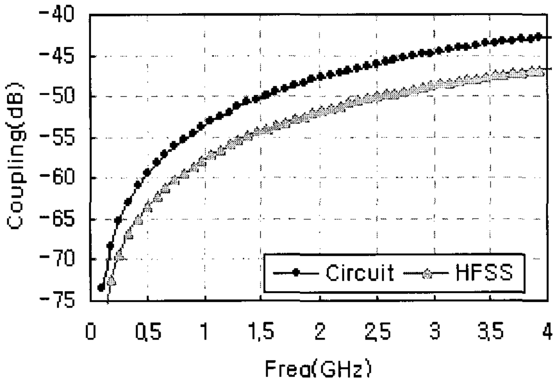


Fig. 9 Comparison between 3-D EM simulation on coupled-line with the meshed-ground shown in Fig. 7 and circuit simulation on its coupled-line equivalent model shown in Fig. 8.

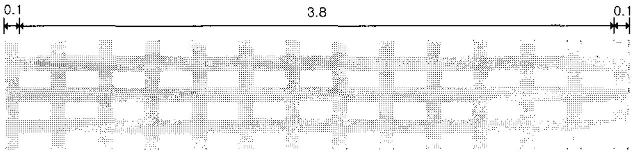


Fig. 10 A buried meshed-ground plane with changing grid pitch value for a coupled-line.

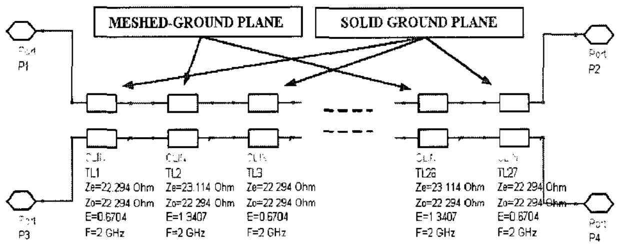


Fig. 11 Equivalent schematic model for a coupled-line of the buried meshed-ground plane shown in Fig. 10.

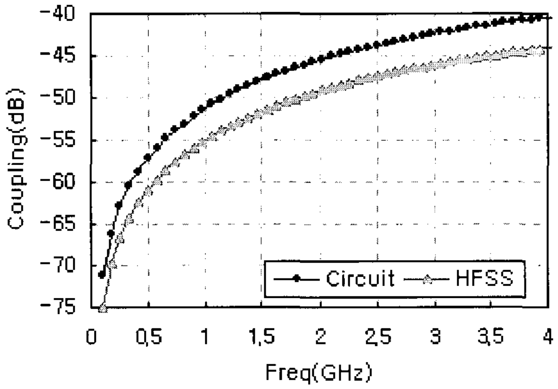


Fig. 12 Comparison between the 3-D EM simulation on coupled-line with the meshed-ground shown in Fig. 10 and the circuit simulation on its coupled-line equivalent model shown in Fig. 11.

In order to investigate the influence of the unit-cell dimension, we have taken another example with fluctuation in the longitudinal dimension of the coupled-line sections as shown in Fig. 10. Fig. 11 and Fig. 12 represent corresponding equivalent circuit and comparing simulation results, respectively. For all examples, good agreements between EM- and circuit simulations were achieved. Furthermore, at this time fabrications for measurements are being processed with LTCC technology. It is noticeable that there are differences of frequency shift in all comparisons due to the junction capacitances of the step discontinuities.

4. Compensation of the junction capacitor

A step discontinuity in transmission lines generates a capacitance at the junction of the discontinuity as indicated in Fig. 13 (a). Due to this junction capacitance the characteristic impedance of the transmission line becomes slightly smaller than the original value and the electrical length of the line θ decreases [3, 4]. Thus, the operating frequency goes up as shown in a comparison of the simulations.

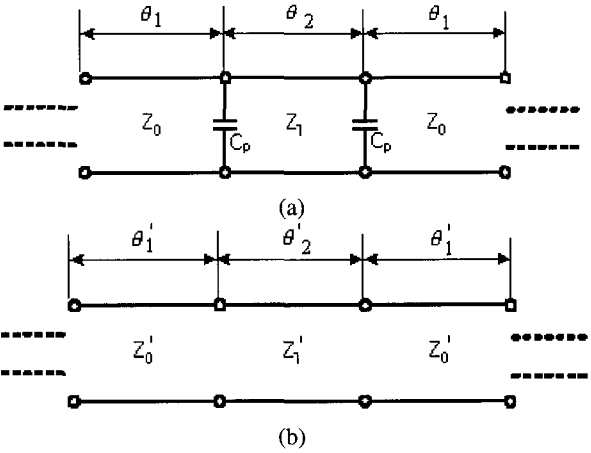
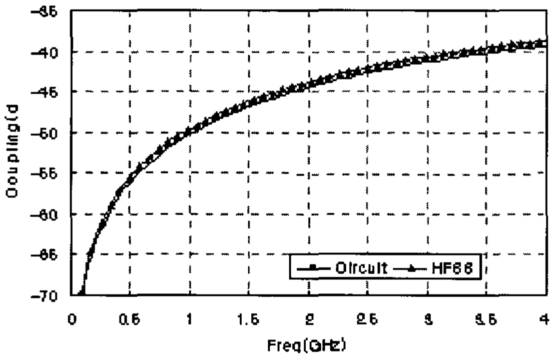
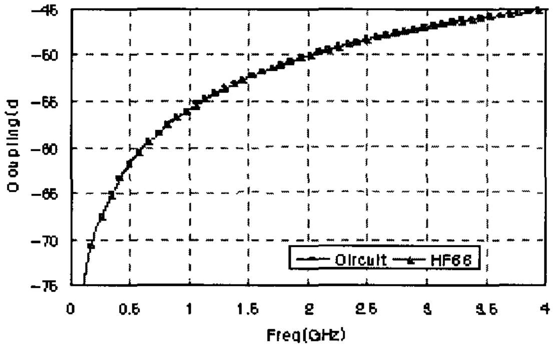


Fig. 13 Equivalence between transmission line step with (a) junction capacitances and (b) no junction capacitance.

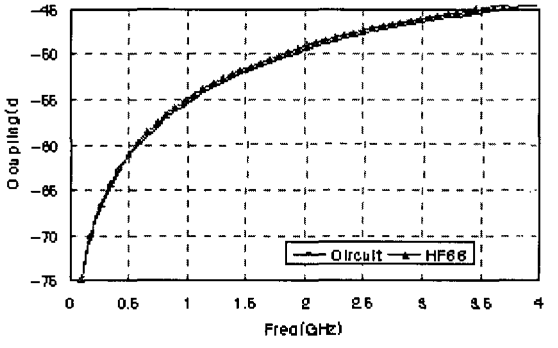
In order to consider the effects of the junction capacitance, the line lengths and impedance should be decreased. In this paper, we have considered only the phase variation due to the junction capacitance, which has been calculated by using conformal mapping formula. The used method is as follows. Firstly, characteristic impedance, Z_1 and Z_0, are fixed and the junction capacitor C_p, and phase θ_1, θ_2 is extracted. Next, after obtained C_p is added to characteristic impedance, the compensated impedances and phases are re-extracted. Fig. 14 shows comparisons between the 3-D EM simulations and corresponding circuit simulations with compensation of the junction capacitances By considering the effect of the junction capacitance, which is due to the junction step discontinuity, the frequency shift shown in the simple model without the step capacitances disappears as demonstrated in Fig. 14. These results of the comparisons provide a very accurate estimation of the coupling between lines isolated by meshed-ground plane.



(a) Example of Fig. 2



(b) Example of Fig. 7



(c) Example of Fig. 10

Fig. 14 Comparisons between the 3-D EM simulations on coupled-lines using meshed-ground and the circuit simulations on corresponding coupled-line equivalent models with compensation of the junction capacitances.

5. Conclusion

In this paper, we have proposed an analysis and modeling method for the coupling estimation of buried transmission lines in different layers due to the imperfect isolation of the meshed-ground plane. Good agreements between 3-D EM simulations on coupled-lines with the meshed-ground and circuit simulations on corresponding equivalent models pertinently demonstrate the validity of the method presented in this paper. Moreover, we have investigated the influence of the junction capacitance due to the step discontinuity. Additional research for the rotated lines with arbitrary angles isolated with buried meshed-ground plain might be required in the application to practical cases. Furthermore, in the general cases such as asymmetrical cases, 3D calculation rather than 2D calculation can be applied.

Acknowledgements

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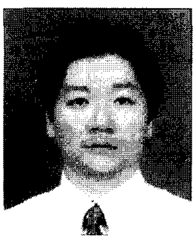
References

[1] H. Thust et al, “Coupling behavior between transmission lines with meshed ground planes in LTCC-MCMs,” *Microwave Journal*, vol.41, no.11, pp.70-79, Nov. 1998.

[2] David M. Pozar, *Microwave Engineering*, John Wiley & Sons, Inc, 1998.

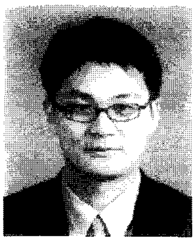
[3] R. Levy, “A Generalized Design Technique for Practical Distributed Reciprocal Ladder Network,” *IEEE Trans. Microwave Theory tech.*, vol. MTT-21, no.8, pp519-526, Aug. 1973.

[4] R. Levy, “Tapered corrugated waveguide low-pass filter,” IEEE *Transaction on. Microwave Theory and tech.* vol. MTT-21, no.8, pp526-532, Aug. 1973.



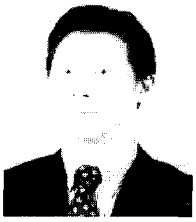
Myoung-Sub Joung

He received his B.S. degree in Electrical-Control Engineering from Hongik University, Seoul, Korea, in 1996 and his M.S. degree in Electrical Engineering from Kookmin University, Seoul, Korea, in 2000. From 1999 to 2002, he was a System Development Engineer at Hyun-kwang Co. He is currently working toward a Ph.D. degree at Kookmin University. His research interests are RF and microwave hybrid module design using MMIC technology.



Jun-Seok Park

He received his B.S. and M.S. degrees in Electronic Engineering and his Ph.D. degree in Radio Frequency and Monolithic Microwave and Integrated Circuits from Kookmin University, Seoul, Korea, in 1991, 1993 and 1996, respectively. In 1997, he joined the Department of Electrical Engineering at the University of California in Los Angeles as a Postdoctoral Researcher. From 1998 to 2002, he joined the Division of Information Technology Engineering, Soonchunhyang University, Asan, Korea, where he was an Assistant Professor and Director of the Super-Module Research Laboratories. He is currently an Assistant Professor at Kookmin University, Seoul, Korea. He is also the Technical Advisor of several RF/microwave component and system companies such as Wavics Inc. and Flambda Inc. His current research involves RF and microwave hybrid module design using low-temperature co-fired ceramic techniques and RF integrated circuit (RFIC) design. His group has developed several novel components with a DGS. His group has also worked extensively in the area of various RF and microwave components with a novel configuration and design method.

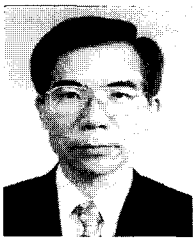


Hyeong-Seok Kim

He was born in Seoul, Korea, on October 9, 1962. He received his B.S. and M.S. degrees in Electrical Engineering from Seoul National University, Seoul, Korea, in 1985 and 1987, respectively. In 1990, he received his Ph.D. degree from Seoul National University. From 1990 to 2002, he was with the Department of Electrical Eng. at Soonchunhyang University, where he was a Professor in the Division of Information and Technology Engineering. He was also a Visiting Professor at the Rensselaer Polytechnic University from 1997 to 1998. In 1998, he was Chief of CEDOS, Soonchunhyang University. At present, he is the Director of ITFE (Information and Telecommunication Facilities Engineering) and Edit Committee of the KIEE (Korea Institute of Electrical Engineering). Since 2002, he has been with the Department of Electrical and Electronics Engineering at Chungang University. His research interests include electromagnetic field simulation, microwave device analysis and design as well as electromagnetic education.

Jae-Bong Lim

He received his B.S., M.S. and Ph.D degrees in Electrical Engineering in 1974, 1976, and 1987, respectively, from Seoul National University, Seoul, Korea. He was an Assistant Professor at Chungnam National University, Daejeon, Korea and a Visiting Professor at Texas University, USA. Since 1982, he has been a Professor in the School of Electrical Engineering, Kookmin University, Seoul, Korea. As well, he has worked as the Technical Advisor of SKT, Hung-chang, and Samsung Electronics. He is currently Technical Advisor of the Netel Corporation and the A-telsys Corporation. His areas of research involve the commercial application of the GPS system and the optic-repeater designs for cellular/ IMT-2000.



Hong-Goo Cho

He received his B.S., M.S. and Ph.D. degrees in Electronics Engineering from Seoul National University, Korea in 1972, 1979, and 1987, respectively. In September 1980, he joined Kookmin University, Korea, and is currently a Professor in the School of Electrical Engineering. He was also a Visiting Professor at Colorado University and Syracuse University in 1988 and 2001, respectively. His areas of research include electromagnetic numerical analysis, antenna analysis and design. His current research involves RF and microwave hybrid module design using low-temperature co-fired ceramic techniques and RF integrated circuit (RFIC) design.