Analysis of Coupling Characteristics between Transmission Lines with a Buried Meshed-Ground in LTCC–MCMs

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Abstract — **Since the manufacturing 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 plane is investigated by the coupled-transmission lines model for the isolated layers. The coupling factors between isolated lines with the meshed-ground are extracted by 2-D FEM calculations.**

I. INTRODUCTION

Increasing speed of signals for a variety of applications in the mobile communications and computer fields make a growing attention to coupling mechanisms inside 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 enough 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, we newly propose analysis and modeling method for the coupling estimation of a buried transmission lines in different layers due to the imperfect isolation of 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 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. Also, at this time fabrication for measurements is being on process.

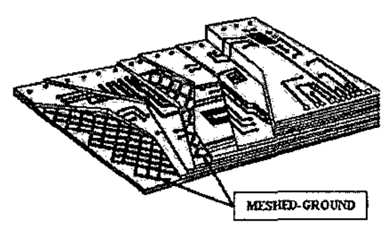

Fig. 1. Schematic of the buried mashed-ground in a LTCC multilayer module.

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II. MODELING OF COUPLED-LINE WITH A MESHED-GROUND PLANE

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 the parallel coupled-transmission modeling. The couplings between lines are evaluated by calculating the coupling parameters such as even-and odd-mode impedances of the coupled-lines through the meshed-ground plane unit. The coupling parameters can be calculated by using following formula. [2]

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

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

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

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

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

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

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

where θ means the coupling electrical length, which can be calculated for a given structure by solving the eigenvalue. Fig.2 shows a coupled-line with the unit cell of the buried meshed-ground plane where the unit cell is divided by one section of the mesh-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 segments should be extracted. For the ideal solid ground segments, couplings between coupled-lines are never occurred. Thus, for those cases, coupling parameter means the characteristic impedances of each transmission line. Fig.3 shows the cross-sectional view of 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 most good loss characteristic. DP943 green tape is one of most popular material for LTCC. Dielectric constant of substrate was chosen to be 7.8, which is that of DP943.

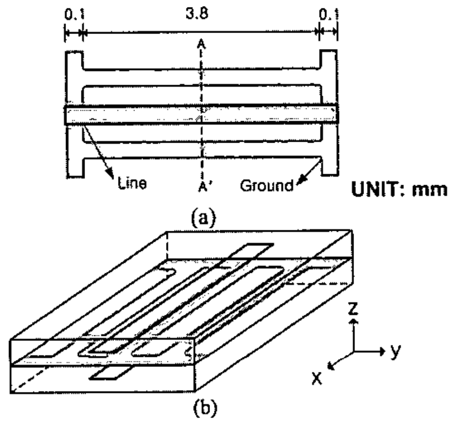

Fig. 2. Coupled-line with unit-cell of the buried meshed-ground plane. (a) Top view. (b) 3-dimensional view.

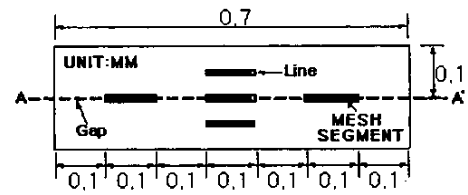

Fig. 3. Cross-sectional view of coupled-line section with the buried meshed-ground plane unit for the extraction of coupling parameters.

Fig.4 shows the simulations for calculating the coupling parameters and propagation constants of each mode by using 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 coupled-line section. Furthermore, by solving the eigenvalue, we can extract the propagation constants to calculate the corresponding electrical length of the coupled-line section.

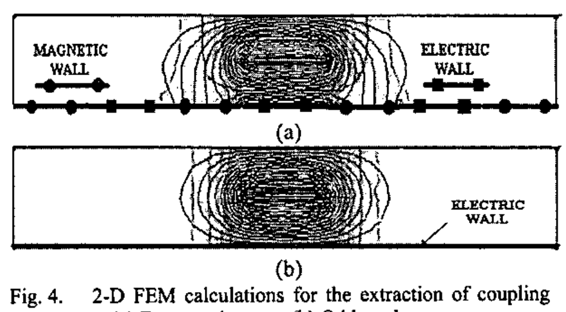

Fig. 4. 2-D FEM calculations for the extraction of coupling parameters. (a) Even mode case. (b) Odd mode case.

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

III. SIMULATIONS ON COUPLED-LINE WITH A BURIED MESHED GROUND PLANE

Fig.5 shows the equivalent circuit model for the coupled-line section with unit-cell of the buried meshed ground plane shown in Fig.2, which is composed of the meshed-ground section 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. For the solid-ground section, the even- and odd-mode impedance is identical because that 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 show the result of comparison.

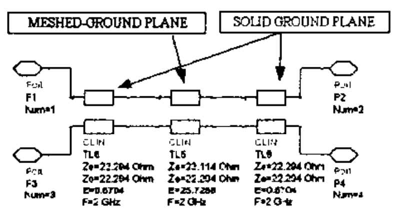

Fig. 5. Equivalent schematic model for the unit-cell of the buried meshed-ground plane shown in Fig.2.

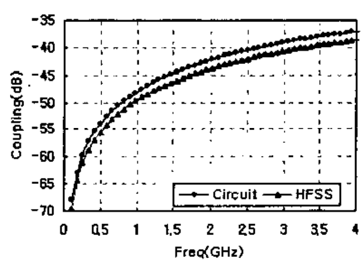

Fig. 6. Comparison between the 3-D EM simulation on coupled-line with the meshed-ground unit shown in Fig.2 and the circuit simulation on its coupled-line equivalent model shown in Fig.5.

For more general case, more complex example has been analyzed a coupled-line with twenty meshed-ground unit segments, which have dimension of unit-cell shown in Fig.2. Fig.7 and Fig.8 show an example model and corresponding equivalent circuit, respectively. Comparison of simulations on the example of Fig.7 is demonstrated in Fig.9.

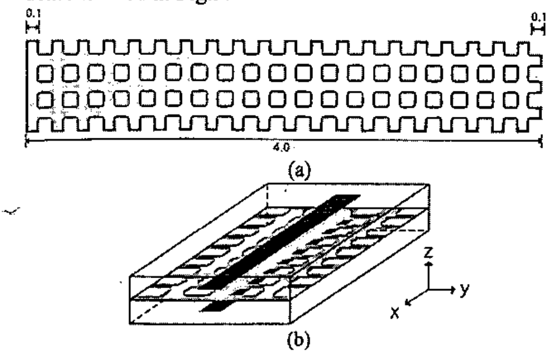

Fig. 7. Coupled-line with the buried meshed-ground plane. (a) Meshed-ground dimension. (b) 3-dimensional view.

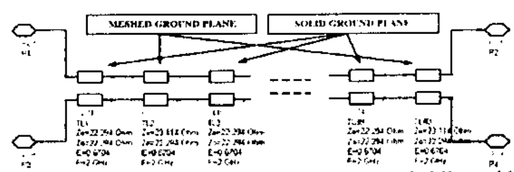

Fig. 8. Equivalent schematic model for a coupled-line with the buried meshed-ground plane shown in Fig.7.

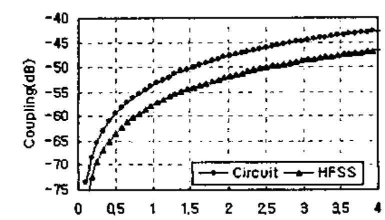

Fig. 9. Comparison between 3-D EM simulation on coupled-line with the meshed-ground shown in Fig.7 and circuit simulation on its coupled-line equivalent model shown in Fig.8.

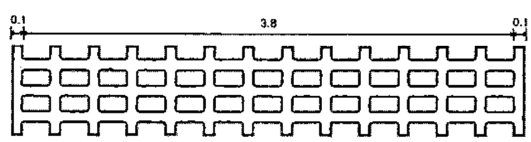

Fig.10. A buried meshed-ground plane with changing the grid pitch value for a coupled-line.

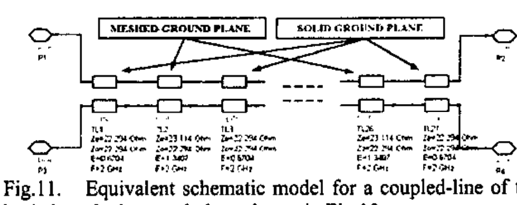

Fig.11. Equivalent schematic model for a coupled-line of the buried meshed-ground plane shown in Fig.10.

In order to investigate the influence of the unit-cell dimension, we have taken another example with changing in longitudinal dimension of the coupled-line sections as shown in Fig.10. Fig.11 and Fig.12 show 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 processing with LTCC technology. It is noticeable that there are differences of frequency shifting in all comparisons due to the junction capacitances of the step discontinuities.

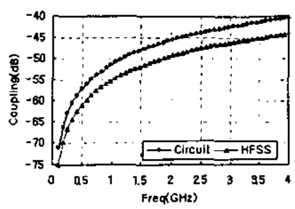

Fig. 12. Comparison between the 3-D EM simulation on coupled-line with the meshed-ground shown in Fig.10 and the circuit simulation on its coupled-line equivalent model shown in Fig.11

IV. Compensation of The Junction Capacitance

A step discontinuity in transmission lines generates a capacitance at the junction of the discontinuity as shown 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 to as shown in comparing simulations.

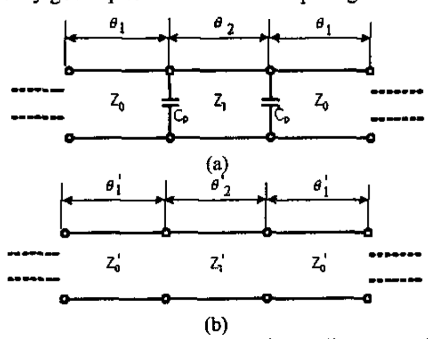

Fig.13. Equivalence between transmission line step with (a) junction capacitances and (b) no junction capacitance.

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. Fig.14 shows comparisons between the 3-D EM simulations and corresponding circuit simulations with compensation of the junction capacitances.

IV. Conclusion

In this paper, we have proposed an analysis and modeling method for the coupling estimation of a buried transmission lines in different layers due to the imperfect isolation of 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 show the validity of presented method in this paper. Moreover, we have investigated the influence of the junction capacitance due to the step discontinuity. Further, at this time the devices for measurements are being fabricated with LTCC process.

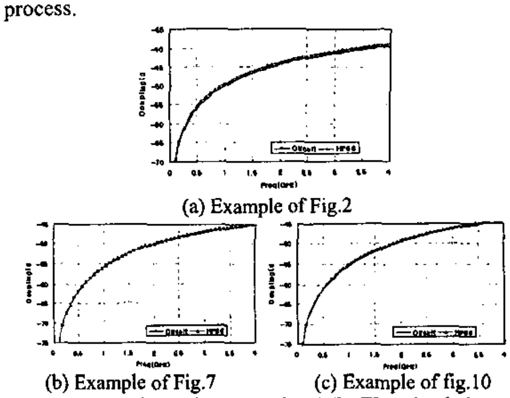

Fig.14. Comparisons between the 3-D EM simulations on coupled-lines with the meshed-ground and the circuit simulations on corresponding coupled-line equivalent models with compensation of the junction capacitances.

Acknowledgement

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