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COMPUTER SIMULATION OF ELECTROMAGNETIC COUPLING IN INTERCONNECTS OF A DOUBLE-LAYERED DIELECTRIC PCB: PARALLEL LINES ON OPPOSITE SIDES OF THE LAYER.

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1. Introduction

When increasing of electron device speeds and package density an influence of interconnects on electron circuits performance becomes more significant. Particularly, an electromagnetic interference and radiation from interconnects as well as crosstalk levels caused by an electromagnetic coupling between adjacent interconnects are increasing considerably being by object of steadfast attention of researchers [1,2]. A joint investigation of all these problems is very complex even in quasi-static approximation. A good example of such general approach may be found in paper [3], where starting with calculation of [C] and [L] matrices of general multiconductor configuration by finite element method, a computer model for predicting crosstalk and radiated field of printed circuit board is outlined. A scope of this paper is in calculation of [C] and [L] matrices of interconnects being reference for solving of more general crosstalk reduction problem.

As one of the ways of crosstalk reduction the structure of printed circuit board with two dielectric layers over a ground plane was proposed in paper [4]. Based on classic paper of Yamashita [5] the calculation of propagation characteristics for transmission lines of the board was made in [6]. In paper [7] by means of the variational method calculations an approximate prediction of crosstalk was made. Moreover additional possibilities of crosstalk reduction at the expense of the change of capacitive and inductive coupling relations were shown. Recently the results of calculations of capacitive and inductive matrices for parallel interconnects placed on one side of the dielectric layer are presented for cases of two and five conductors of finite thickness [8].

It should be noted that unlike parallel interconnects on one side of the dielectric layer the parallel interconnects on opposite sides of the layer are not frequently considered in literature. It is caused in part by the assumption that parallel interconnects of adjacent interconnects' layers are decoupled properly, for example, by means of additional grounded layer or if it's absent by sufficient separation of interconnects and minimization of coupling length. However, when high density package of interconnects is necessary the electromagnetic coupling in parallel interconnects of adjacent interconnects' layers may become considerable calling for its quantitative evaluation and additional ways of reduction.

The aim of this paper is to investigate the electromagnetic coupling for two and five parallel interconnects of finite thickness on opposite sides of the dielectric layer.

2. THE METHOD OF CALCULATION

Assume the lines are lossless and without dispersion. Though the lines have nonhomogeneouse filling it is possible to use quasi-static approximation for relatively low frequencies. With these assumptions the electromagnetic coupling in lines under consideration is fully defined by matrices of per unit length capacitive [C] and inductive [L] coefficients.

For calculation of these matrixes the method of moments was used which handles successfully with multiple finite cross section conductors placed arbitraryly in layered dielectric medium above a ground plain [9]. An algorithm of calculations with omitted details consists of the following. After the data entering about quantities and parameters of conductors and dielectric layers all conductor-dielectric and dielectric-dielectric boundaries of structure cross section are discretizied on subintervals and parameters each of them are calculated. Then, the coefficients of a set of linear equations are calculated which is solved N times assuming the N-th conductor to be under the one volt potential and all others grounded. As a result of such solving for given dielectric filling the [C] matrix is obtained but for air filling the [L] matrix is obtained by wellknown formula.

The algorithm was implemented by author in MOM2 program, where some useful possibilities were realized also. In case of partition of dielectric layers by conductors all resulting dielectric intervals are automatically discretizied on subintervals. Few internal circles of calculation for a range of any parameters of structure are possible. An opportunity of graphical presentation of discretizied configuration for preview before calculation is available. An extension of above algorithm for magnetic dielectrics was made also. For more accurate solving of a set of linear equations an algorithm of LU-factorisation with partial choice of a leading element is used. At last, an output one of [C], [C0], [L], [L0] matrixes or all together is possible on screen or to data file.

Table 2.

Ref.	[11]	Our
C11	142.1	143.6
C21	-21.7	-19.8
C31	-0.9	-0.9
C22	93.5	88.6
C32	-18.1	-17.7
C33	88.0	83.1
L11	277.7	279.4
L21	87.8	87.6
L31	36.8	36.5
L22	328.6	330.7
L32	115.8	115.5
L33	338.0	339.0

Table 1.

Ref.	[9]	[10]	Our
C11	91.65	90.73	90.60
C21	-8.22	-8.29	-8.44

To test the algorithm implementation a comparison with published results was made for configurations similar to investigated ones. Comparison with results given by method of moments for case of two coupled microstrip lines is shown in Table1. Comparison with results given by more general integral equation method for more complex case of three coupled lines in double-layered dielectric is shown in Table2.

3. RESULTS OF CALCULATION

To show clearly the electromagnetic coupling features for considered structures having many parameters the calculations are made for the following parameters. Widths of strips are the same. All geometrical parameters of structures are taken relatively to width of strip. The ratio of the second (from a ground plain) dielectric layer height Hd2 to width of strip W is changed from 0.1 to 1.0. The relative dielectric permittivity of the first layer Er1=1,2,3,4 and of the second layer Er2=5. The ratio of thickness of strip T to width of strip W is equal to 0.1. An equidistant discretization is used for all boundaries, where number of subintervals is equal to: 2 on T; 5 on W; 5 on D.

First of all, a case of two coupled lines placed on opposite sides of dielectric layer shown in fig. 1 (a,b,c) is considered. The plots of corresponding normalized capacitive and inductive coefficients versus dielectric parameters are presented in fig.1 (d). Taking into account that a sum of capacitive and inductive couplings is proportional to near end crosstalk but difference of ones is approximately proportional to far end crosstalk, it is seen clearly from this plots how the values may be optimized. The plots permit to predict an electromagnetic coupling and allowable length of coupling between parallel lines of adjacent layers when high density package of interconnects is necessary.

Then, the [C] and [L] matrixes for five strips in staggered arrangement shown in fig.2 (a) are calculated. The configuration is interesting by highest density of parallel strips on two signal layers. The plots of normalized mutual coefficients of these matrixes (in logarithmic scale) versus Hd2/W are presented in fig.2 (b). The contributions of various conductors are seen clearly in these plots. Particularly, unlike the cases considered in [8] when all conductors are placed at the same height from ground plane an influence of not one but two nearest conductors may be dominating for lines of fig. 2 (a). Moreover, the influence of the next conductors may be appreciable for some parameters of configuration. This influence may be quite considerable for characteristics that are critical to relation between integral capacitive and inductive couplings.

It is known that for strict accounting of influence of non neighboring conductors a response of multiconductor transmission lines must be determined. However, the preliminary estimation of [C] and [L] matrices of configuration may simplify the following problem considerably. For example, it may be done by approach [12,13] when influence of all other conductors besides nearest one is assumed negligible and [C] and [L] are assumed tridiagonal and symmetric Toeplitz matrices. However, this approach applied to line from Fig.2 may be incorrect.

4. CONCLUSION

Thus, the results of calculations for wide range of dielectric parameters presented by numerous plots permit to evaluate the capacitive and inductive coupling values and its ratio. Its are useful to predict the possibilities of crosstalk reduction for adjacent interconnects' layers of a double-layered dielectric PCB.

For more complete investigation of electromagnetic coupling in interconnects on opposite sides of dielectric layer a case of orthogonal crossed lines over a ground plane should be considered as well. However, the solving of this problem requires more complex three-dimensional analysis and is a subject of another paper being in preparation.

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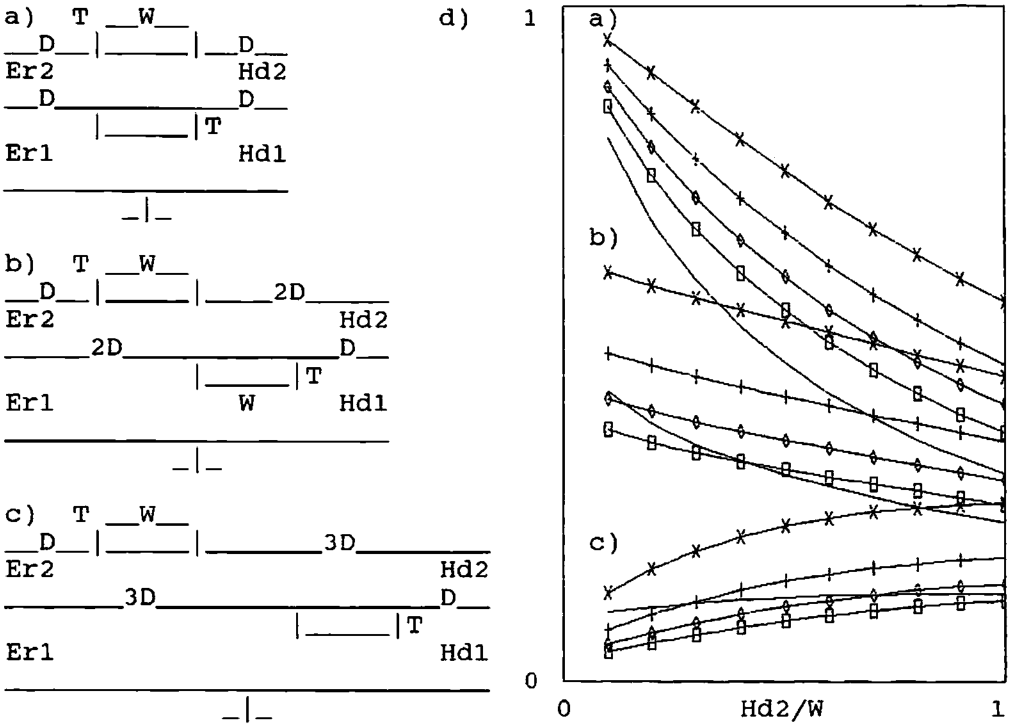
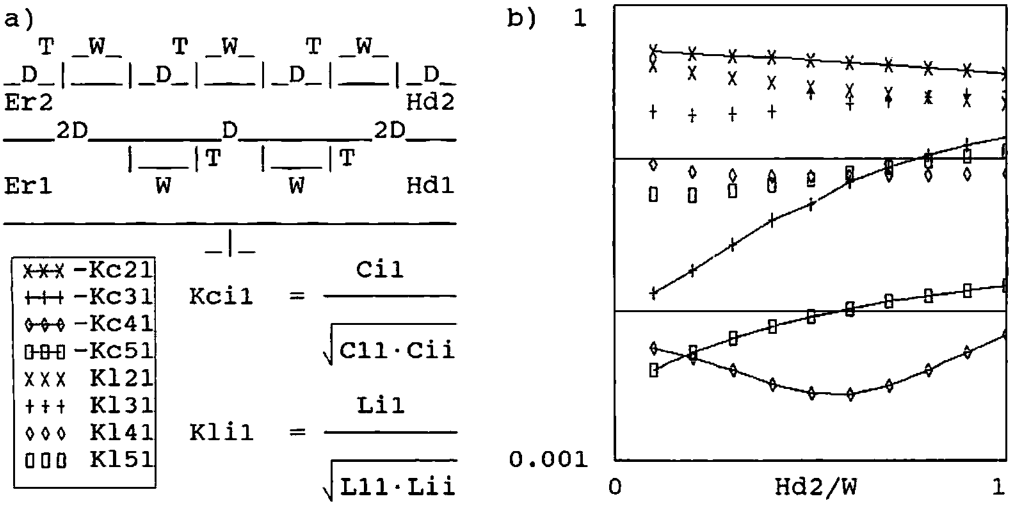


Fig. 1. Two coupled suspended and inverted microstrip lines (a,b,c) and corresponding normalized capacitive and inductive coefficients versus Hd2/W for Er1=1,2,3,4 (d).

xxx -Kc21 for Er1=1
+++ -Kc21 for Er1=2
◊◊◊ -Kc21 for Er1=3
□□□ -Kc21 for Er1=4
— Kl21 (Er1=1-4)

T/W=0.1, Hd1/W=0.5, W=D, Er2=5.

$$Kc21 = \frac{C21}{\sqrt{C11 \cdot C22}} \qquad Kl21 = \frac{L21}{\sqrt{L11 \cdot L22}}$$



xxx -Kc21
+++ -Kc31
◊◊◊ -Kc41
□□□ -Kc51
xxx Kl21
+++ Kl31
◊◊◊ Kl41
□□□ Kl51

$$Kci1 = \frac{Ci1}{\sqrt{C11 \cdot Cii}}$$

$$Kli1 = \frac{Li1}{\sqrt{L11 \cdot Lii}}$$

Fig. 2. Five coupled stagered lines (a) and normalized capacitive and inductive coefficients versus Hd2/W (b). T/W=0.1, Hd1/W=0.5, W=D, Er2=5, Er1=1.