Modelling of 3D Multilayer Coplanar Waveguide Structure with Incorporated Wideband Vertical Interconnection

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Abstract **- The characteristics of three-dimensional (3D) multilayer coplanar waveguide (CPW) lines incorporating a 90^o vertical interconnection structure have been investigated using a full wave analysis. Possible coupling effects between CPW lines in different layers have been taken into account, with results showing that such effects could be very strong if the adjacent CPW lines are too close. As the distance between the adjacent lines increases, the coupling effects become weak; nevertheless it is not completely negligible for many practical applications. Equivalent circuits including such weak coupling effects which comprises of mixed lumped components and transmission lines have been developed. A good agreement with the full wave analysed results over k_u, k and k_a bands has been achieved. In addition to fundamental propagation mode, higher order mode effects have also been examined. The simulation results indicate that the second or third order modes might become dominant propagation mode at higher frequency depending upon the CPW structure and its layer distance.**

I. INTRODUCTION

The trend of minimisation in size, weight and cost for use in commercial wireless communication systems has resulted in an increasing demand for highly integrated system-on-chip solutions. As conventional two-dimensional integrated circuits are almost squeezed to their limits, three-dimensional integrated circuits are starting to take over, as they provide an additional dimension in terms of compactness and efficient integration.

The CPW lines with 90^o vertical interconnect between stacked circuits have been demonstrated in [1]-[2] to offer many advantages in integrated active antenna applications. The stacking of microwave circuits and the physical implementation of the vertical interconnections are achievable by using the "MultiChip Module Vertical" (MCM-V) technology [3]. However, designing a multilayered circuit incorporating a wideband vertical interconnection is quite a task, and few publications have put forward working models that can be put into use. This paper investigates wideband multilayer CPW lines with a 90^o vertical interconnection using full wave analysis.

Equivalent circuit models based on this full wave analysis are then presented, such that lumped components and transmission line models can represent the multilayered CPW designs. The main reason for developing such circuit models is the timesaving factor associated with it; however, it should be pointed out that such circuit models are only valid within a certain frequency range.

Higher order propagation modes that exist with fundamental mode have profound effects on the transmission line performance. At lower frequencies higher order propagation modes are negligible. The signal energy will not be lost to mode energy inter-exchanges. However, at higher frequencies, higher order propagation modes deteriorates the transmission quality, as some of the signal energy will be converted from fundamental mode to higher order modes. This energy inter-exchange between modes can be severe for 3D structure CPW such that the transmission line frequency application range is limited.

II. PROPOSED DESIGNS

Two basic structures of 90^o vertical interconnection on CPW lines are shown in Figure 1 and 2. The silicon substrate is of 400 μm thick with ε_{rs} of 11.9, and dielectric layer is of ε_{rd} = 2.1. The length of CPW line on each layer is 300μm; the metallic thickness is 1μm, and both the top and bottom CPW lines are designed using HP ADS Momentum such that their characteristic impedance is 50Ω. The choice of silicon as the main dielectric substrate for the structure is mainly due to the fact that silicon is easily obtainable and comparatively cheap compared to other dielectric substrates. Also, for simulation simplicity, the metal and the dielectrics used are assumed to be ideal.

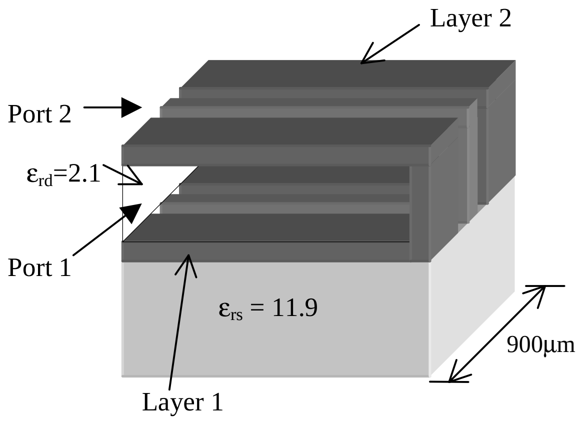

Fig. 1: A 3D multilayer CPW structure (Structure 1)

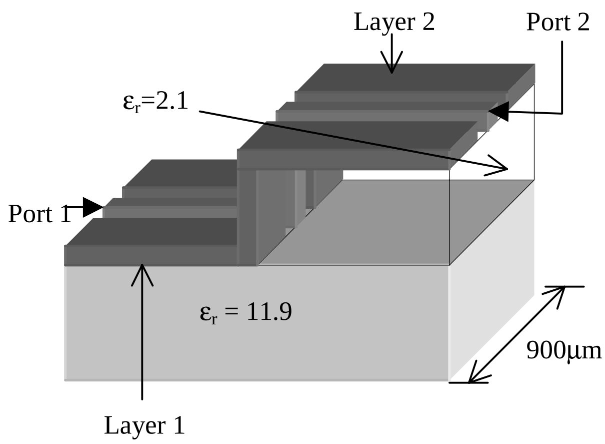

Fig. 2: A 3D multilayer CPW structure (Structure 2)

The model is then simulated using HP HFSS for frequencies from k_u to k_a bands. Figures 3 and 4 show the reflection coefficients of Structure 1 and 2 versus frequencies with various dielectric layer thicknesses. It can be seen that Structure 1 is very dispersive with thinner layers due to strong coupling effects between two adjacent CPW lines, which cause more electric fields being restricted within the layer. In comparison with Structure 2, which is free of any coupling effect due to the separation of two CPW lines, Structure 1 exhibits low dispersion behaviour only if the distance between the adjacent CPW lines is greater than about 50 µm for the dimension indicated in Figure 1. As the distance is further increased to 250µm, the dispersion behaviour does not improve significantly.

III. EQUIVALENT CIRCUITS

Equivalent circuits for both structures are developed using a combination of lumped components and transmission line models in HP ADS, based on full wave analysis, as shown in Figures 5 and 6. Simple

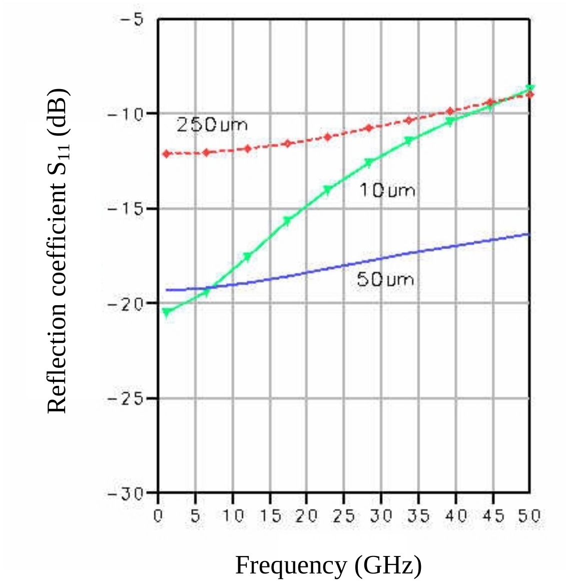

Fig. 3 :S_{11} for Structure 1 with varying top substrate height

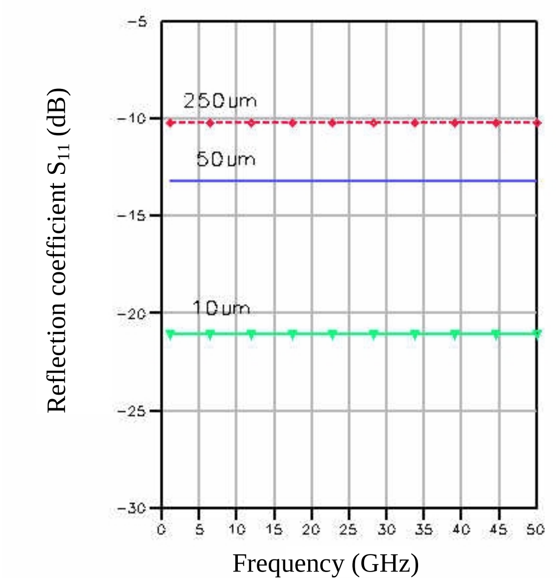

Fig. 4: S_{11} for Structure 2 with varying top substrate height

CPW models (labelled as CPW1 and CPW2 in Figures 5 and 6 respectively) represent the top CPW and the bottom CPW in Structure 1 and 2. The 90^o vertical interconnection in both structures is represented by another CPW model (labelled CPW3 in Figures 5 and 6). The weak coupling effects for Structure 1 is represented by the capacitance C3, while the discontinuities between the top CPW, the vertical interconnection and the bottom CPW are represented by capacitances C2 and C1 and inductances L1 and L2 respectively. For Structure 2, the same equivalent circuit applies, but without the coupling capacitance C3.

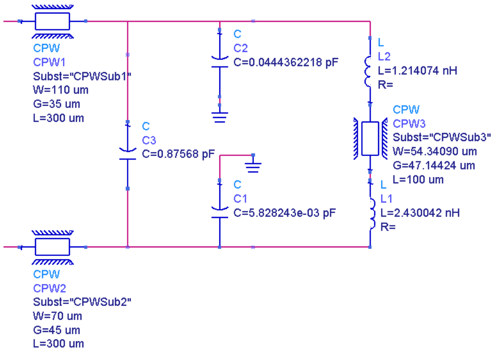

Fig. 5 : Equivalent circuit for Structure 1

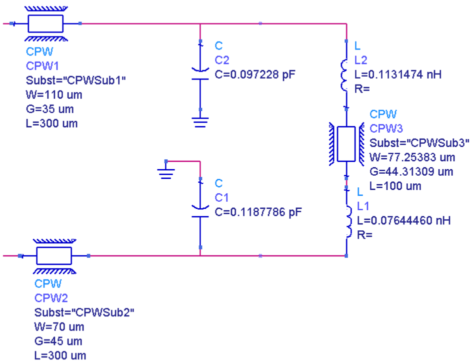

Fig. 6 : Equivalent circuit for Structure 2

The equivalent circuit results are shown in Figures 7 and 8. It can be seen that the equivalent circuits are found to be a valid approximation of the multilayer CPW lines with the vertical interconnection from 15 GHz to 40 GHz of frequency range.

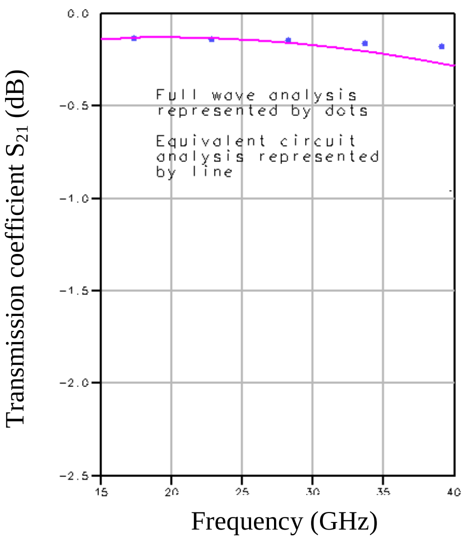

Fig. 7: Comparisons of S_{21} from full wave analysis and circuit model for Structure 1

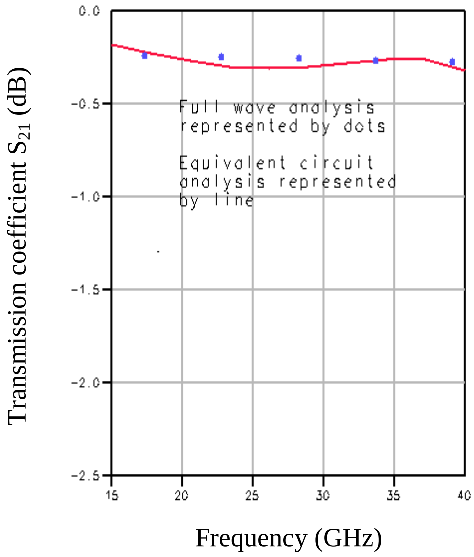

Fig. 8: Comparisons of S_{21} from full wave analysis and circuit model for Structure 2

IV. HIGHER ORDER MODES

Higher order mode effects for both structures have been studied. Figures 9 and 10 show the S_{11} and S_{22} of the fundamental, second and third order modes of Structure 1 with the distance between the two layers of 50µm. As shown in the figures, the second order mode increases from –78 dBm at 1 GHz to –23 dBm at 50 GHz for S_{11}, while the third order mode climbs from –71 dBm at 1GHz to –31 dBm at 50GHz for S_{22}. Note that the second order mode is much higher than the third order mode for S_{11}; however, the third order mode is the dominant higher order mode for S_{22}. This is due to the specific layer structure of Structure 1 where the metal layer 2 is covered by air while the metal layer 1 is based on a silicon substrate.

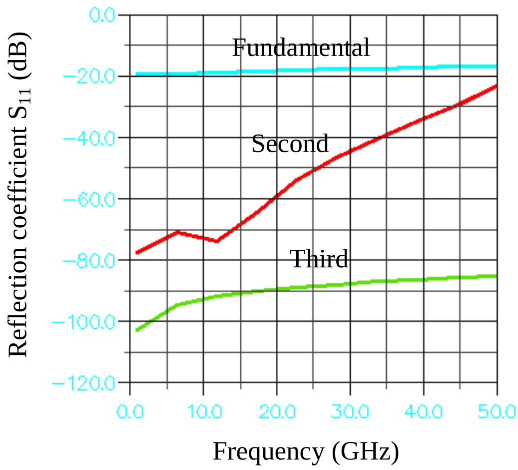

Fig. 9: S_{11} for Structure 1 with layer distance of 50µm

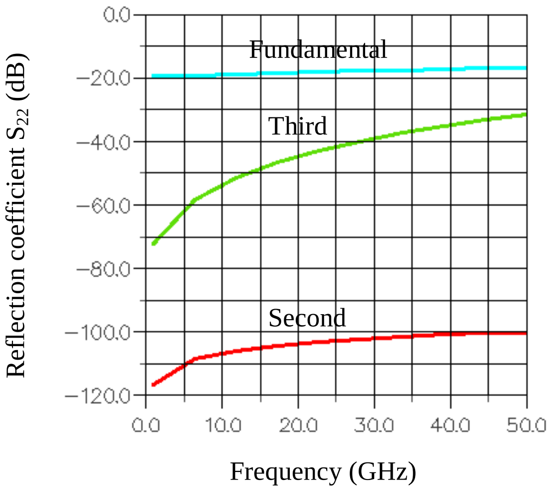

Fig. 10: S_{22} for Structure 1 with layer distance of 50µm

Figures 11 and 12 illustrate the S_{11} and S_{22} of the fundamental, second and third modes of Structure 2 with the layer distance of 5µm. It is evident that the third order mode overtakes the fundamental mode and becomes the dominant propagation mode at about 40 GHz. With this layer distance, Structure 2 can only be used as a proper transmission line below 30 GHz.

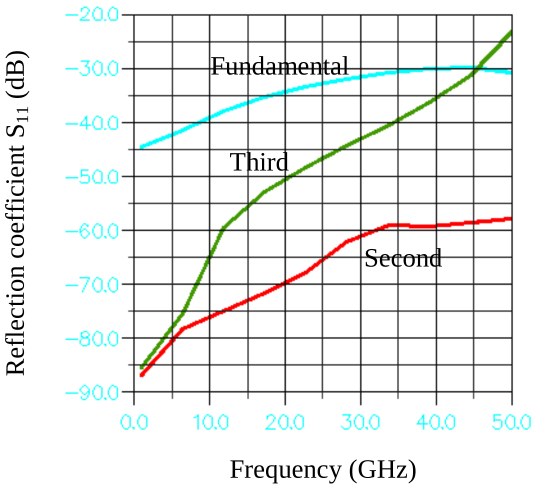

Fig. 11: S_{11} of Structure 2 with layer distance of 5µm

V. CONCLUSIONS

Three-dimensional multilayer coplanar waveguide structures with a wideband 90^{o} vertical interconnection have been investigated using full wave analyses. The values obtained indicated that good transmission characteristics of Structure 1 can only be achieved with a thick layer in between two adjacent CPW lines. The dispersion could be severe if the two adjacent layers are to close. Structure 2, however, may have shown very low dispersive characteristics, but its application would be limited due to higher order mode effects at relatively lower frequency range. Also, the equivalent circuits for

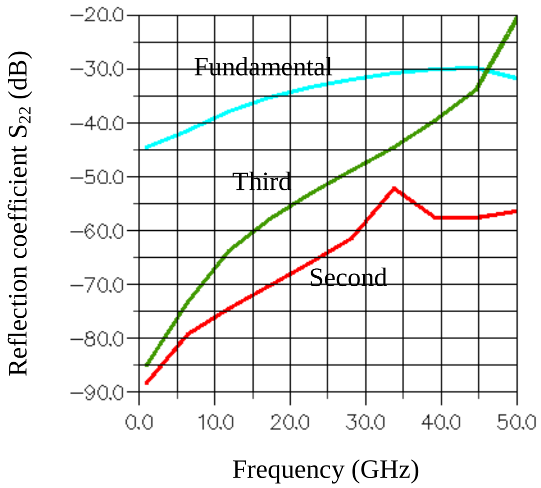

Fig. 12: S_{22} for Structure 2 with layer distance of 5µm

both structures have been developed, which show a good agreement with full wave results from HP HFSS. The models can be very useful in 3D microwave circuit designs.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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