A Dielectric Based Waveguide Integrated in a Multi-layer PCB for Ultra High Speed Communications

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***Abstract*—This paper presents an electromagnetic dielectric wave guiding methodology for ultra-high speed signaling in a multilayer PCB environment. Two dielectric materials, one of which has a higher dielectric constant than the other, are embedded between the two ground planes of an internal PCB layer to enable wave propagation. Different transmission properties can be achieved by varying the dimensions or material properties of the dielectric waveguide. PCB integrated dielectric waveguides can achieve wide operating frequencies in the millimeter wave region of the frequency spectrum thus showing potential to push high speed bus designs to faster data rates than is currently possible.**

Keywords—dielectric waveguide; high speed signaling; printed circuit board (PCB); wave propagation;

I. INTRODUCTION

As the demand for larger data bandwidth and faster clock frequencies in computer server systems and networking devices increases, designing channels for higher speed signaling while maintaining wide band high amplitude signal transmission properties becomes more crucial. Reducing copper surface roughness in the PCB or using ultra low loss dielectrics [1] can provide some signaling attenuation improvements but could result in significant cost increase as well. Also, as the need for technologies that push the clock frequency higher in the millimeter wave spectrum increases, signaling using conventional PCB waveguides such as microstrip and stripline copper traces becomes less feasible due to the large copper losses at higher frequencies. Using optical communication [2] instead of copper is an alternative method to achieve high speed signaling. However, the high cost of optical fibers and their transceivers in addition to the associated complex and sometimes unreliable connectivity motivates the need for an alternative solution in some application areas.

Several studies exist where dielectric waveguides at microwave, millimeter and sub-millimeter wave frequencies have been presented. As presenter in [3] and [4], high dielectric constant ribbon waveguides could be used to guide THz waves when surrounded with a low dielectric constant material. Due to high copper losses at THz frequencies, microstrip lines and striplines are not very useful in most practical implementations which motivated the THz dielectric wave-guiding studies. In such dielectric waveguides, dielectric materials are used to enable wide frequency band and low insertion loss electromagnetic wave transmission. The dielectric materials compose the dielectric waveguide which propagates waves in a quasi-optical way. The main dielectric regions of the waveguide are the narrow core and the cladding with the cladding surrounding the core. The material with the high dielectric constant is the core, while the surrounding is filled with a material having a lower dielectric constant and known as the cladding. A part of the wavefront exists in the cladding; however the wave propagation direction follows the core route. Due to avoiding/minimizing the usage of guiding metals, the loss at high frequency is reduced while a wide operating frequency range can still be obtained. Additionally, the dielectric waveguides have been described to be fabricated at a low cost with the current PCB manufacturing technologies and do not require any additional enabling devices such as electro-optical transceiver which optical fibers used in high speed communication channels require.

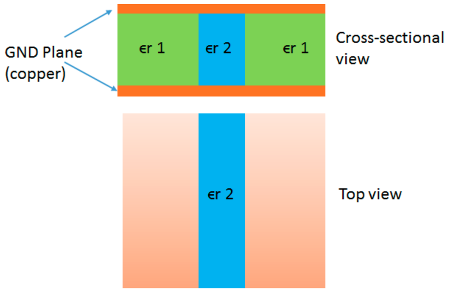

Fig. 1. Top view and cross-sectinal view of the dieletric-based waveguide

For high speed bus computer communication buses, the future need for millimeter wave frequency channels (100 GHz and more) motivates the consideration of using dielectric waveguides. This consideration also makes their implementation and integration in multilayer PCBs a requirement given the present and expected near future manufacturing technology infrastructure. As a result, and while most previous dielectric wave-guiding studies were done with standalone waveguides, this paper aims to ensure their integrability in multilayer PCBs and evaluate their performance in such an environment. In this paper, the basic dielectric waveguide design integrable in a multilayer PCB is presented along with the main design parameters' description. Several simulation studies are also carried out in order to contribute to future PCB integrated dielectric waveguide design guidelines. The simulation studies carried out are wave-guiding sensitivity: to frequency of operation, to bend radius, to different core dielectric constants and to different dielectric thicknesses between the two copper ground planes. The simulation results are presented discussed and discussed in the coming sections.

II. MULTILAYER PCB INTEGRABLE DIELETRIC WAVEGUIDE BASIC DESIGN

To implement the dielectric-based waveguide in a multilayer PCB, two dielectric materials are filled in between the ground planes as shown in Fig. 1. The core material which is located in the center of the waveguide has a relatively higher dielectric constant than the surrounding material (or cladding). No air gap exists between the two materials or between the materials and the ground planes. The best material for the cladding should be chosen to offer a good contrast in the two regions, while also maintaining a relatively low loss in the high frequency range. The core optical width is directly related to how much of the wave-front is contained within the core and how much is within the cladding at a particular frequency. This effect has a direct relationship to how much crosstalk can exist between two neighboring dielectric waveguides and will be addressed in another study.

III. DIELETRIC-BASED WAVEGUIDE SIMULATIONS

In order to investigate the properties of the dielectric-based waveguide implementable in a multilayer PCB environment, sensitivity studies which examine different design parameters of the waveguide were carried out. To provide design flexibility in any future ultra-high-speed communication bus channel, wave guiding must not only be achieved in straight guiding but also in curved guiding. Moreover, curved guiding is more challenging than straight guiding since it is more prone to wave leakage which may greatly reduce the guide's transmission efficiency. Therefore, the sensitivity study was done based on a simple curved guiding structure.

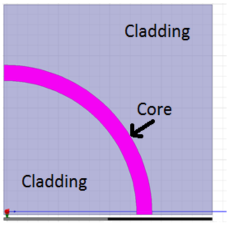

Fig. 2. Arc shaped dielectric waveguide.

The curved guiding structure used in simulation is shown in Fig. 2. Two different dielectric materials were used: one for the core and another for the cladding. In this case, the core route is a quarter of a full circle and it is obvious that the wave propagation guided by this structure will be a 90 degree turn. The dielectrics are sandwiched between two ground planes, each being 1 mil thick. The planar size of the ground planes and cladding region are chosen to be large enough so that the field distribution near the core can be observed. Multiple simulations were carried out using the commercial 3D FEM solver ANSYS HFSS.

To evaluate the sensistivity of the waveguide to the frequency of operation, a core having a 12.5mm long arc with a 1.5 mm width was simulated. The cladding material used air (with an Ɛr=1 and negligible loss at all frequencies) and the core used a Megtron6-like material (with an Ɛr=3.45 and tand=0.0086 at 40GHz). The thickness of the dielectric layer is 10 mils which is comparable to the dielectric thickness between two ground planes in present multi-layer PCBs. The electric field distributions at different frequencies are shown in Fig.3. As can be seen for this design, less leakage exists at higher frequencies. This means that better guiding can be achieved at higher frequencies. This observation can be explained by the fact that the arc curved transition becomes larger with respect to the wavelength leading to better waveguiding. On another note, the leakage translates into waveguide signal loss between the transmitting and the receiving ends.

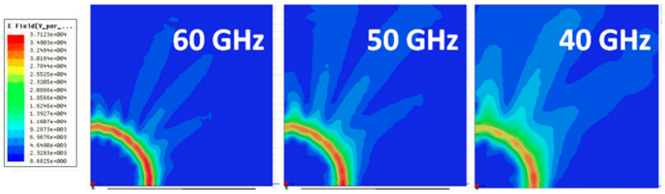

Fig. 3. E-field distribution for a dielectric waveguide having a 12.5mm long arc, air cladding and a Meg6-like core.

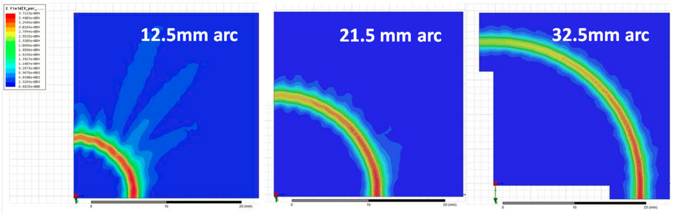

Fig. 4. E-field distribution (at 60GHz) for a channel with air cladding, Meg6-like core, and arc lengths: 32.5mm, 21.5mm and 12.5mm.

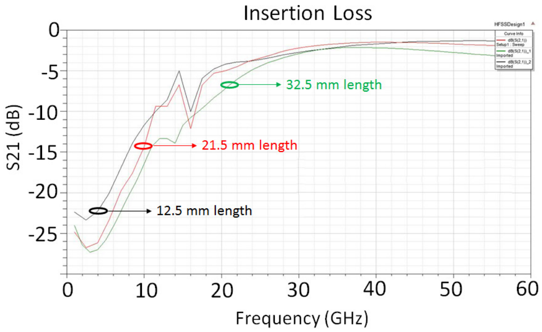

Fig. 5. Insertion losses for channels with air cladding, Meg6 like core, and arc lengths: 32.5mm, 21.5mm and 12.5mm.

A set of simulations with multiple 90 degree arc lengths was also performed to study the sensitivity of the waveguide to different curve transitions as a function of frequency. As shown in Fig.4, wave-guiding structures with 32.5mm and 21.5mm arc lengths are examined in addition to the 12.5mm case previously examined in Fig3. It can be noticed that at 60GHz, the shorter channel has more leakage compared to the longer one. For the channel with 32.5mm arc length, most of the fields are closely confined in and around the core region which indicates a low leakage property. The insertion loss of the three channels is shown in Fig. 5. At low frequencies, all three channels exhibit a high loss property. Up to about 10GHz-15GHz, this high loss is mostly due to the 3D EM solver wave-port cutoff frequency. Between 15GHz and about 25GHz, the high loss property is probably due to sub-optimal guiding characteristics caused in part by the structure being small relative to the wavelength. Above 25GHz, the insertion loss is within the range of -5dB to 0dB for all the waveguides. Note that for the frequency range of 30 to 38GHz, the difference in the insertion loss between all three cases is within 1dB. Moreover, as the frequency increases above 50GHz, the 32.5mm channel starts to show more loss than the other waveguide lengths. From these observations, one can deduce that a shallower curved structure (larger radius arc) has better guiding and less leakage properties while a faster transition curve (smaller radius arc) has worse guiding and more leakage but lower loss due to shorter propagation distance. This behavior means that the best bend (curve) guiding design is one that balances propagation distance and transition shape.

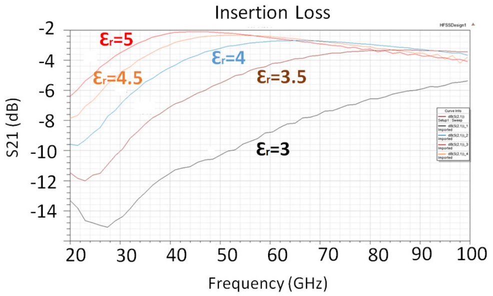

Fig. 6. Insertion loss for a 21.5mm channel with Teflon cladding and various core materials.

Different core materials were also simulated to study the impact of dielectric constant contrasts between the core and the cladding. Fig. 6 shows the simulated insertion loss of a 21.5mm arc length channel with a Teflon-like cladding (with an Ɛr=2.1 and tand=0.001 at 40GHz) and various core materials. The varied core materials have dielectric constants ranging from 3 to 5 with a step of 0.5. The loss tangent of these materials was set to be 0.0086 at 40GHz. It can be seen that the channel with a core material having a larger dielectric constant is able to provide a wider operating frequency range extending into the lower frequencies with less insertion loss. Moreover, it can be seen that the lowest insertion loss encountered by any waveguide at any frequency is that of the highest dielectric contrast between the core and cladding. At frequencies above 80GHz the insertion loss for the core dielectric constants is almost the same except for the Ɛr=3 case. From this observation it can be deduced that even though the higher dielectric constant contrast results in a better guide, the loss encountered by the wave guided by the higher dielectric constant core is more. This means that the best dielectric constant contrast is one that balances between best guiding and lowest loss within the frequency band of interest.

All the simulation results described earlier in this paper are based on a waveguide with a dielectric thickness of 10mils. It is important to investigate the impact of varying the waveguide dielectric thickness on the waveguide transmission. The 21.5mm channel of the previous study for which the results are shown in Fig. 6 with a core dielectric constant of 4.5 was simulated with two additional thicknesses. These are 15mils and 20mils. As shown in Fig.7, the difference in the insertion loss between the three cases was small and the overall trend of the insertion loss is similar. This indicates that the frequency response of the dielectric-based waveguide is not highly sensitive to the PCB dielectric thickness.

IV. CONCLUSION

This work provides a method for high speed signaling using dielectric waveguides in a PCB environment. The traditional copper-based waveguides such as microstrips and striplines are replaced with a dielectric waveguide composed of non-conductive dielectric materials to guide electromagnetic waves. The difference in the dielectric constant between the core and cladding of the dielectric waveguide ensures wave propagation similar to optical fiber wave propagation. Unlike optical fibers which guide optical waves, the proposed dielectric waveguide can guide waves in the millimeter wave frequency spectrum with a large operating frequency range. Sensitivity studies of the dielectric waveguide were carried out to ensure a suitable and expected performance design.

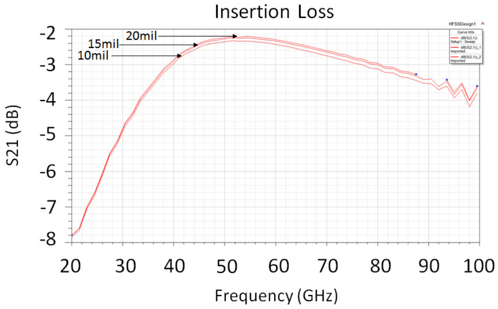

Fig. 7. Insertion loss for a 21.5mm channel with various PCB thicknesses.

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