Timing Skew Enabler Induced by Fiber Weave Effect in High Speed HDMI Channel by Angle Routing Technique in 3DFEM

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Abstract— Fiber skew is one of the most difficult problems to debug. This paper investigates the timing skew problem on high speed, high-definition multimedia interface (HDMI) channel due to the fiber weave effect of Printed circuit board (PCB). This skew causes an asymmetry between the signals in the two lines and converts some of the differential signal into common signal, thereby, distorting the rise time of the differential signal, causing ISI, resulting in the collapse of the eye, and leading to deterministic jitter. In this paper, a method is proposed to minimize intra pair skew and jitter induced by the fiber weave effect. It is a geometry based method to understand the physical degradations in the PCB. The proposed method verified by using the 3DFEM technique in the differential line.

Keywords: Printed circuit board, high-definition multimedia interface, skew and bit-error-rate.

I. INTRODUCTION

PCB substrates or laminates, which are manufactured by impregnating and strengthening a woven fiber glass fabric with an epoxy resin, are not homogeneous materials but are inhomogeneous and anisotropic in nature. Depending on the position, there are local variations of their dielectric characteristics. Typically, the effective permittivity of the glass bundles is ~ 5.0, while that for resin is ~ 3.3. As bit rates are climbing, often going up to 5 GB/s or even beyond, the fiber weave effect is becoming a major challenge in PCBs. The difference in the properties of the glass bundles and resin creates a non-homogenous medium for the signals in the fiberglass weave pattern, causing the signals to propagate at different speeds within a differential pair traces [1]. The difference in speed leads to timing skew and mode conversion at the receiver, resulting in reduced bit-error-rate (BER) performance and increased (electromagnetic interference) EMI radiation [2]. The relative dielectric constant (Dk) surrounding a trace, ultimately determines the propagation delay of signals in the trace [3]. This research work deals with the issue and presents a novel approach to practically establish worst case min/max values for dielectric constant and use these values to model the fiber weave effect using Sigrity 3DFEM modeling software. In the context of the extensive use of HDMI interface in modern medical systems, an HDMI base board case study is used to practically demonstrate the model and to explore the design space.

II. FIBER WEAVE EFFECT MECHANISM IN HIGH SPEED CHANNEL

An increase in data rates can cause an increase in deterministic jitter at low as well as tens of Gbps. An increase in deterministic jitter of tens of Gbps for typical PCB materials can be caused by the fiber-resin dielectric inhomogeneity along the interconnect causing additional signal degradation due to variations in propagation constant and characteristic impedance along the line [4].

For testing purpose, selecting an asymmetric differential stripline for glass type 2116, as shown in figure 1. In differential pair with fiber weave effect, both traces are placed with a specific width and spacing to have the different Dk value. This means that the inter-pair skew in differential pair is effected [5]. At high data rates, the difference in propagation velocities leads to skew between the two traces, which can amount to a substantial fraction of the transmission unit interval, resulting in an increased common mode voltage and a correspondingly degraded differential signal [6].

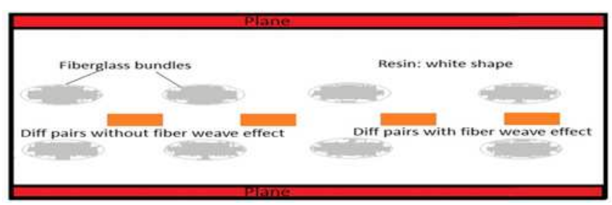

Figure 1: Cross-sectional profile of HDMI transmission line model with/without FWE.

Although, models for transmission lines are usually constructed with either 2D or 3D field solvers, transmission lines with inhomogeneous dielectric may require analysis with a full-wave 3D solver to account for the high-frequency dispersion [7]. Accuracy of solver results depends upon the availability of parameters of dielectric models. Availability of accurate parameters of material models is the most important element of a 3DFEM solver engine. Manufacturers of dielectric laminates usually provide dielectric parameters at 1-3 frequency points in the best cases. Those frequency points may be acceptable to define the wideband Debye model [8]. Wideband Debye (Djordjevic-Sarkar) and multi-pole Debye models are examples of causal dispersive dielectric models suitable for accurate analysis of PCB interconnects.

Wiener upper boundary model (layered dielectric):

$$\varepsilon_{eff,\,max} = \varepsilon_2.\ f.\ \varphi + (1\text{-}\ \varphi.\ f).\ \varepsilon_1 \qquad (1)$$

and lower boundary model (comb-like dielectric):

$$\varepsilon_{eff,\,min} = \ \varepsilon_1.\varepsilon_2/\ \varphi.f.\varepsilon_1.+(1\text{-}\Phi f)\varepsilon_r \qquad (2)$$

where ϕ is the Imbalance Factor. Assuming dielectric 2 is glass with higher DK and lower LT and dielectric 1 is resin with lower DK and higher LT and both simulated with causal models

Further, the investigation of the fiber weave effect on high speed HDMI interface is analyzed by using a board made with FR408HR.

III. METHODOLOGY

Figure 2, shows the HDMI board layout snapshot. Four differential pairs are used to transmit high speed signals and another four pairs are used for receiver.

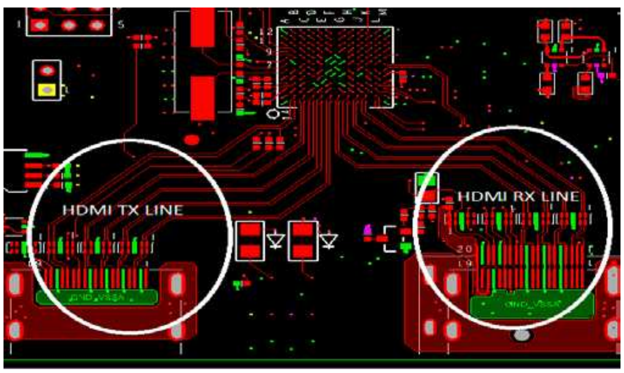

Figure 2: HDMI board layout: four lines for TX and another four for RX

By using the worst case skew by placing the traces with specific width and spacing to have the largest difference in Dk values, where one trace is positioned in the region containing the most glass by volume and the other trace positioned in the region with the most resin. The skew is varied as a function of trace position by maintaining the same differential impedance. To accomplish this, one trace is centered in the maximum resin region while the location of the other trace is shifted. It should be noted that by the differential impedance is kept at a constant value (100 ohms) and the edge coupling between the traces is increased.

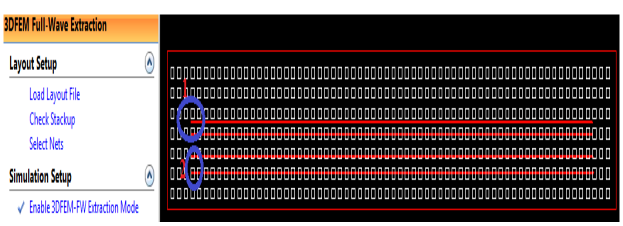

Figure 3: 3D transmission line model in Sigrity 3DFEM tool.

With the 3D transmission line model, the intra-pair time skew has been analyzed using the transient simulation engine in Sigrity 3DFEM as shown in figure 3. In this transient simulation, a step pulse is simulated with differential termination to observe the time skews with respect to transmission line length.

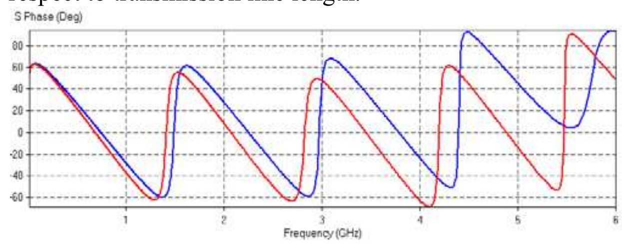

Figure 4: Simulated phase corresponding to each of the traces on asymmetric structure.

Here, figure 4 shows the simulated phase corresponding to each of the traces when both traces run on asymmetric structure. There is an obvious phase difference between the traces owing to the fiber weave effect. First of all, the red line corresponds to the trace running primarily over the glass bundle. The fiber glass bundle has a higher permittivity than resin; therefore, the phase changes more rapidly per unit length of the trace. The red trace runs primarily over the resin, so phase is changed slowly. Because the resin has a lower permittivity than the glass fibers, the phase changes more slowly per unit length of the trace.

The second case when both traces run on symmetric structure is shown by figure 3 mark 2. Also, there is a lesser phase difference between the traces owing to the fiber weave effects because both the lines corresponding to the trace run primarily over the resin bundle.

IV. RESULTS AND DISCUSSION

A solution to mitigate the effects of fiber weaves is proposed. Transmission lines mounted on the PCB are rotated from 0º to 20º to average out the effects of anisotropic. S-parameters are extracted for each angle of rotation and inserted into the board model; the channel performance is checked using Sigrity tool as shown in figure 5. AMI model is assigned to TX and Rx and the eye parameters and BER curve are measured.

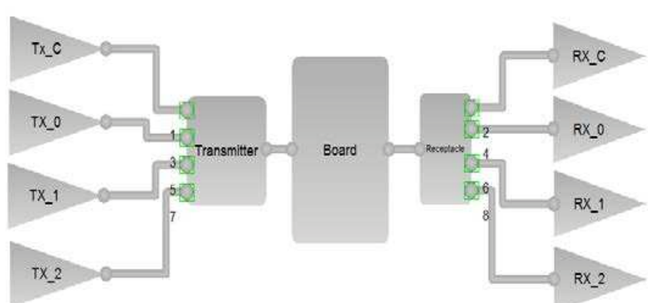

Figure 5: Test bench setup for HDMI channel simulation.

TX and RX lines mounted for four rotations are considered, namely, 0^o 10, 15, and 20. Glass weave induces a skew if location variation in the dielectric constant makes signals in the two lines of a differential pair travel at different speeds. The glass weave with a high dielectric constant bunched into fiber bundles causes a variation in the dielectric constant. Figure 6 shows the 0 and10 rotations. The other rotations, 15 and 20, show similar pattern.

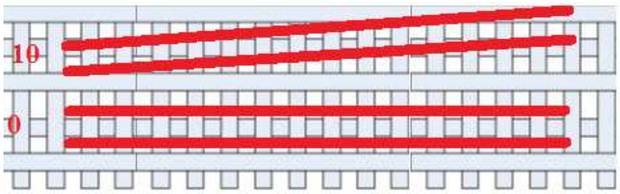

Figure 6: TX lines routed with 0^0 and 10^o rotation on the PCB.

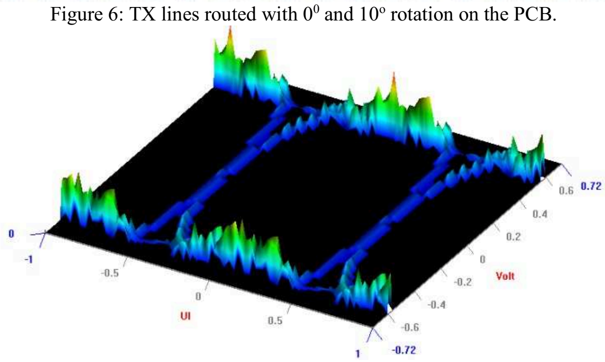

Figure 7(a): Eye diagram, when 0^o rotation routing on the board.

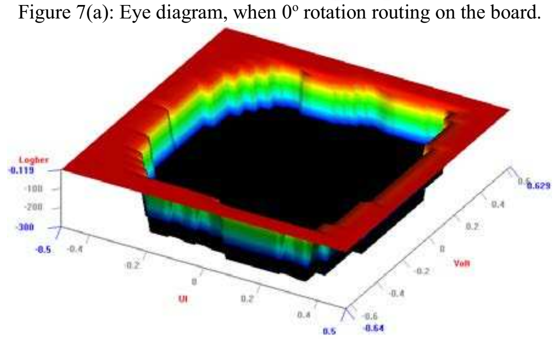

Figure 7(b): Batch tub curve plot, when 0^o rotation routing on the board.

Figure 7 shows the three results, (a) eye diagram, and (b) bathtub curve. The eye height is decreased and jitter increased. Table 1 shows the simulation results, the intra-pair time skew with respect to changes in the rotation angle due to fiber weave effect and table 2 shows the BER measurement parameters for all four cases. The intra-pairs skew is lowest when rotation angle is 10^o, as shown in table 1. Intra-pair timing skew in a differential path causes an increase in the differential insertion loss profile due to timing induced resonances. Increasing the fiber weave effect length, results in a proportional increase in timing skew leading to a decrease in the resonant frequency by the same proportion. Eye width and height is improved when rotation angle is 10^o, as shown in table 2

Table 1: The intra-pair time skew with respect to changes in the rotation angle

Routing Angle	Skew	Eye norm Jitter
0	11.3	0.47
10	2.8	0.17
15	6.195	0.27
20	7.2	0.38

Table 2: Bathtub curve (BER) measurement comparison table

LBER	Eye Width (UI)				Eye Height (mV)			
	10^0	15^0	20^0	0^0	10^0	15^0	20^0	0^0
-16	0.81	0.79	0.80	0.78	1025	1024	1008	855
-15	0.82	0.79	0.81	0.78	1030	1027	1014	859
-14	0.83	0.8	0.81	0.79	1036	1031	1020	863
-13	0.83	0.81	0.79	0.8	1043	1034	1026	867
-12	0.84	0.81	0.82	0.81	1049	1038	1032	872
-11	0.85	0.82	0.82	0.82	1056	1042	1039	877
-10	0.86	0.83	0.83	0.82	1064	1046	1046	882
-9	0.87	0.84	0.85	0.83	1071	1050	1053	887
-8	0.88	0.85	0.84	0.84	1079	1055	1061	892
-7	0.89	0.86	0.85	0.85	1088	1059	1068	898
-6	0.9	0.87	0.86	0.86	1093	1064	1074	904
-5	0.91	0.88	0.86	0.88	1099	1069	1080	909
-4	0.92	0.89	0.88	0.89	1104	1074	1085	923
-3	0.93	0.9	0.9	0.89	1109	1097	1092	945

CONCLUSION

The results demonstrate the fiber weave effect introduces unwanted intra-pair skew on differential signaling, which, if not resolved can lead to failure of high-speed designs. The result of this work is a systematic and practical methodology to identify dielectric models for accurate analysis of above 5 Gbps interconnects HDMI channel. The fiber weave effect must be comprehended and properly accounted for in future high speed bus designs. Table 1 shows when the fiber weave effect requires special accommodations to alleviate its effects and when it can be ignored. Rotating the routing angle by 10 degrees is an extremely effective means of mitigating the negative effects, if necessary.

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