IMPACT OF FIBER WEAVE EFFECT ON HIGH SPEED INTERCONNECTS

PCB dielectric materials are usually woven fiberglass fabrics reinforced with epoxy resin. Both fabric fiber and resin are composite materials with typically different dielectric constant (DK) and loss tangent (DF) properties, presenting a non homogeneous medium for signal propagation. As data rates increase, designers are increasingly moving away from wide parallel buses to serial buses with differential signaling. High-speed serial interfaces such as PCIE, QSFP, SFP, XAUI, uses differential signaling for transmitting and receiving data. Any timing skew between the positive (D+) and negative (D-) data will convert some of the differential signal into a common signal component. Ultimately this results in eye closure at the receiver and contributes to Electro-Magnetic Interference (EMI) radiation. A differential pair routing showing one trace routed over a fiberglass bundle for a portion of its length while the other trace is routed over mostly resin is shown in Figure1. As data rate increases, the fiberglass weave pattern causes signals to propagate at different speeds within differential pair traces, causing timing skew and mode conversion at the receiver, leading to reduced bit-error-rate (BER) performance and increased EMI radiation. This effect can have profound impacts on the effective dielectric constants of printed circuit boards, which can cause unforeseen degradations in signal integrity.

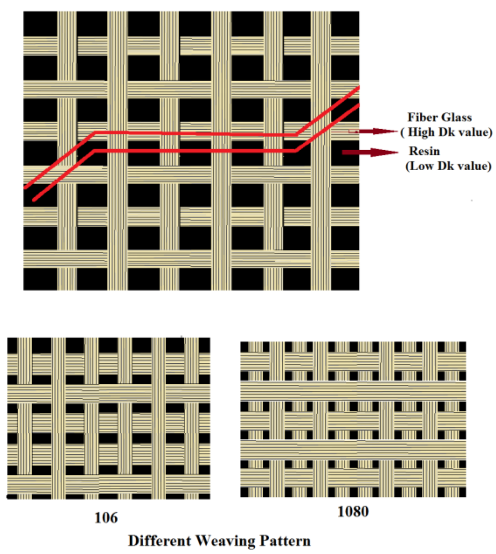

FIGURE 1: Dielectric weave pattern

This article discusses the methods to quantify the impact of fiber weave and the strategies studied to mitigate it. ANSYS Designer software is used to model the circuit to establish worst case min/max values for DK and its effect in high speed interconnects.

FIBER WEAVE EFFECT ANALYSIS

Determining Stack-Up Specific Dk min/max

Our First goal is to quantify the difference in Dk values between the two halves of differential pairs for the typical traces and board materials and to quantify the time skew due to the fiber weave effect.

The appropriate min/max values of *Dk* to use in simulation model can be estimated using the datasheets for the different styles in the family of dielectric material used in the stack-up. For example if the stackup uses ITEQ IT-180A material, we would take the average value Dk of 106 and 7628 styles across the frequency range from the datasheet. Afterwards we can calculate *Dkmin/max* using the following equations.

$Dk_{max} = Dk_{avg\_7628} + Tol$ -----> (1)

$Dk_{min} = Dk_{avg\_106} - Tol$ -----> (2)

Where,

Dkavg_106 = Average Dk of 106 style prepreg

Dkavg_7628 = Average Dk of 7628HR style prepreg

$Tol = (\Delta Dk_{max} - \Delta Dk_{avg}) / 2$

$\Delta Dk_{max} = \Delta Dk_{avg} + (\Delta Dk_{avg} \times \sqrt{((3\sigma_{7628} / Dk_{avg\_7628})^2 + (3\sigma_{106} / Dk_{avg\_106})^2)})$

$\Delta Dk_{avg} = Dk_{avg\_7628} - Dk_{avg\_106}$

σ = Standard Deviation

Example:

We have considered a differential pair with Edge coupled surface Microstrip configuration using ITEQ IT-180A 106 and 7628 style weave patterns having the properties as shown in Figure2.

prepreg IT-180A

Dk

Prepreg	Thickness (in.)	Resin Content	Dk @ 1 MHz	Dk @ 1 GHz	Dk @ 2.0 GHz	Dk @ 5.0 GHz	Dk @ 10.0 GHz
106	2.0	72	4.00	3.90	3.85	3.80	3.60
1067	2.4	71	4.10	3.90	3.90	3.85	3.65
1080	2.8	62	4.15	4.05	3.90	3.85	3.65
1086	3.0	62	4.15	4.05	3.90	3.85	3.65
2113	3.8	56	4.15	4.05	3.95	3.85	3.75
2116	4.6	53	4.20	4.10	4.00	3.90	3.70
1506	6.4	48	4.20	4.10	4.10	3.90	3.80
7628	7.4	43	4.20	4.10	4.00	3.90	3.70
7628HR	8.2	50	4.30	4.20	4.20	4.00	3.90

FIGURE 2: Sheet showing the properties of 106 and 7628 pattern of ITEQ IT-180A

$Dk_{avg\_106} = (4+3.9+3.85+3.8+3.6)/5 = 3.83$

$Dk_{avg\_7628} = (4.3+4.2+4.2+4+3.9)/5 = 4.12$

$\Delta Dk_{avg} = Dk_{avg\_7628} - Dk_{avg\_106} = 4.12 - 3.83 = 0.29$

$\sigma = \sqrt{(\Sigma(x - \bar{x})^2/(N-1))}$

$\sigma_{106} = 0.15$ and $\sigma_{7628} = 0.164$

$$\Delta Dk_{max} = \Delta Dk_{avg} + (\Delta Dk_{avg} \times \sqrt{((3\sigma_{7628} / Dk_{avg\_7628})^2 + (3\sigma_{106} / Dk_{avg\_106})^2)})$$

$\Delta Dk_{max} = 0.338$

$Tol = (\Delta Dk_{max} - \Delta Dk_{avg}) / 2 = \pm 0.024$

$Dk_{max} = Dk_{avg\_7628} + Tol = 4.12 + 0.024$

$Dk_{max} = 4.14$

$Dk_{min} = Dk_{avg\_106} - Tol = 3.83 - 0.028$

$Dk_{min} = 3.806$

Figure 3, shows the stackup considered for pre-layout analysis. The differential pair considered is maintained with the differential impedance of 100 ohm for the nominal case.

Layer	Layer Name	Layer Description	Processed Thickness (mils)
Layer 1	Top	Copper Foil	1.81
		ITEQ IT-180A Prepreg 106	1.9
		ITEQ IT-180A Prepreg 7628	2.891
Layer 2	GND	Plane	1.26

FIGURE 3: Stackup considered for pre-layout analysis

SIMULATION CIRCUIT MODEL

Using ANSYS Designer, we can easily model the circuit. Transmitter parameters were set to 16Gbps with the PRBS Register Length 31. Analysis is done for two different cases.

Case1: Uniform Balanced Transmission line model with the single nominal Dk_{avg_106} value of 3.83 throughout the length of the channel i.e. no fiber weave effect is considered.

Case2: Non-uniform Unbalanced Transmission line model. Two identical multi-layer substrates are defined to model the Fiber Weave effect. One substrate uses the lower *Dk* associated with a high resin area of the material while another substrate uses the higher *Dk* due to the fiberglass weave.

Non-homogeneity between the positive (D+) and negative (D-) is modeled by considering Dk_{max}=4.14 for positive (D+) and Dk_{min} = 3.806 for negative (D-) of the differential pair.

Comparison between the two cases where observed for various trace lengths (4inch, 6inch, 8inch and 10inch). A few observations can be summarized from those responses:

- Response for 4inch differential pair does not see much impact from the fiber weave effect.
- The Eye Height gets smaller as the Trace length increases.
- The higher the bit rate or larger the Dk difference, the faster the decreasing of Eye Height.
- For larger trace length about 10inch, eye closure at receiver end.
- The timing skew between Positive (D+) and Negative (D-) voltage of the differential pair increases with the increase in Trace length and bit rate.

Figure 4 shows the ANSYS Designer simulation results showing the eye diagrams for 4 different fiber lengths (4inch, 6inch, 8inch, 10inch). We can easily observe the Eye height variations (signal degradation) with the increase in fiber length. The fiber Weave is not critical for eye opening until the length is 10" for 16Gbps interface (lossless line). Critical Length will not be same for post layout condition since it includes the parasitic effect of via, EMI of nearest traces and other board parameters.

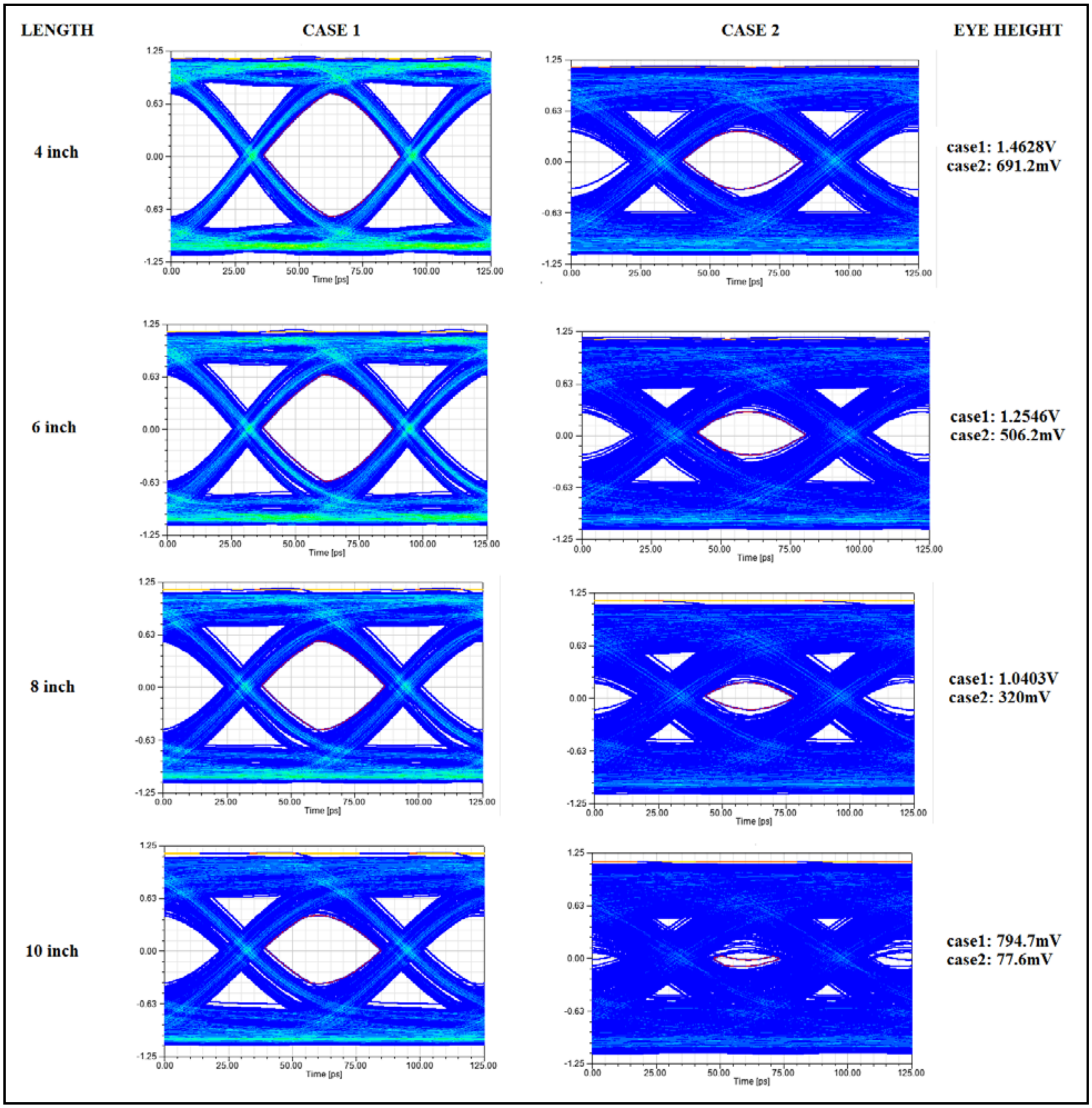

FIGURE 4: Simulated results showing the eye diagrams for 4 different fiber lengths with & without Fiber Weave Effect**.**

Figure 5 shows the ANSYS Designer simulation results showing the Voltage waveforms for 4 different Fiber lengths. We can easily observe the propagation delay between the positive and negative traces of the differential pair, resulting in the signal degradation at the receiver end.

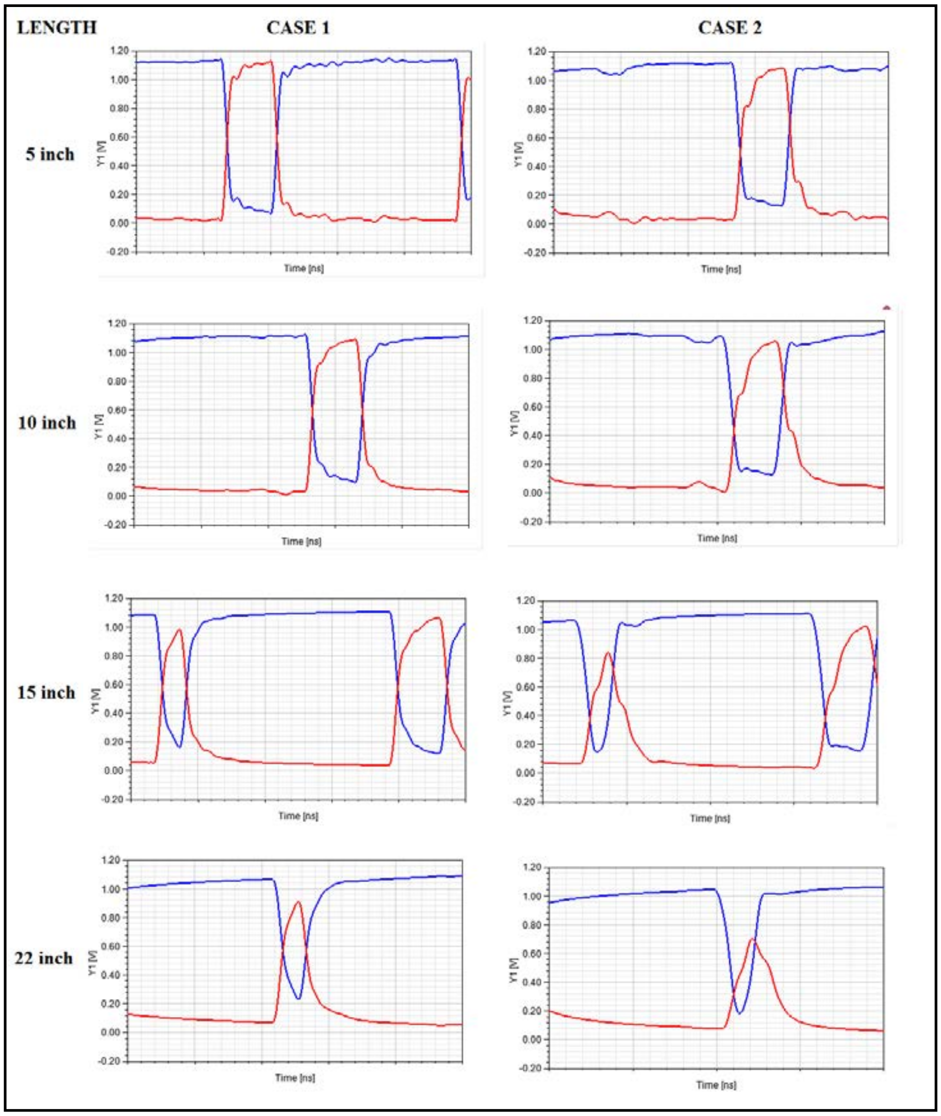

FIGURE 5: Simulation results showing the voltage waveforms for 4 different fiber lengths**.**

The results are re-formatted into an easy look up table. The Table shows the degradation in the Eye Height and Timing skew with the increase in Fiber Length showing the significant fiber weave impact.

Length	4 Inch	6 Inch	8 Inch	10 Inch
Eye Height	691.2mV	506.2mV	320mV	77.6mV

Length	5 Inch	10 Inch	15 Inch	22 Inch
Timing Skew	28.8ps	45.4ps	70.3ps	160.5ps

GUIDELINES TO AVOID FIBER WEAVE EFFECT AT HIGH FREQUENCY:

1. Routing Style:

- Jog the routing per pair spacing at particular interval.
- Zig-zag routing: Angle of zig-zag has to be 10° or more.
- Angled routing: Angle has to be 10° or more.

2. Rotation of Board design/ Material laminate.

- Board manufacture rotates the board on the board panel.
- Designer rotates the board file in CAM or CAD tools.
- Rotate Glass material before cutting it into the board panel.

3. Selection of material

- Select the advance materials like NELCO-SI, materials with less variation between Er (3.2) of epoxy and glass (4.4 instead of 6.6). So that Variation of Dk value will be minimized.
- Select Tighter or course weave materials (Strong binding between resin and glass)
- Pattern less weave material, or pattern that can't align with traces.
- Use glass less materials: Polyimide - Materials without glass reinforcement.

4. Electrical De-skew

- Adjust the skew values in TX and RX (Hardware delay adjustment).

5. Design Floor planning

- Plan the layout (Component Placement), such that routing will automatically ends up with non orthogonal.

References:

[1] Lambert Simonovich,"Practical_Fiber_Weave_Modeling_Iss3_Mar2_12"

[2] Jeff Loyer et al, "Fiber Weave Effect: Practical Impact Analysis and Mitigation Strategies"

[3] Eric Bogatin, https://www.signalintegrityjournal.com, Article:"4103_SIJ_GlassWeave.pdf"

[4] Dielectric material property: ITEQ DK DF 200907 IT180A.pdf