

New PCB Materials for Low Skew Close Phase Matching in 10Gbps Differential System Designs

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A new process to weave, flatten and spread the glass reinforcement material has been developed to be used in high performance differentially routed printed circuit boards (PCB's). In conventionally reinforced materials a granularity of dielectric constant is caused by the higher dielectric constant of the reinforcing glass fibers and the surrounding matrix of resin. These granularities are of the same order of magnitude as the differential trace parameters in terms of line spacing, trace width and trace pair separation. Consequently, one trace of the differential pair will have a different propagation velocity causing the different arrival times of the differential signal components. This asymmetry leads to common mode conversion of the signals and EMI as well as receiver detection difficulties. This paper describes the features and benefits of low cost processes for the modification of conventional PCB glass cloth reinforcing glass strands which mitigates the serious effects of intra-pair skew especially for 5, 6.25 and 10 Gigabit per second differential PCB trace designs.

Introduction

Publications recently released by Intel [1-2] and Teraspeed Consulting Group LLC [2] and others at recent DesignCon meetings [3-5] and patent submissions [6, 7] point out the need for trace pair parameters which do not vary with respect to the position of the PCB traces above (below) the warp and weft strands of the reinforcing glass cloth. These publications all point out the use of rotated artwork to reduce the effects of the granularity of the underlying glass reinforcement. However, during the fabrication process, rotation of the artwork is limited by the size of the design, producibility rules and inspection requirements as well as the finite probability that one or more high speed traces will be aligned with the reinforcing fibers.

This paper reports the dielectric constant measurements and analysis of the six Microstrip Asahi Test Boards with respect to dielectric constant as a function of position and direction.

Measurement of Propagation Delay

The work depends on the accurate determination of the propagation delay and effective dielectric constant of PCB materials when transmitting digital signals with risetimes ≤ 50 ps. Time domain methodologies lend themselves to this type of propagation delay characterization. The two time domain methodologies used to infer the dielectric constant are summarized below:

1. The first method called "Time Domain Reflection (TDR) Methodology" utilizes a one port open circuit reflection measurement based on the two-way propagation delay between a well matched source and the open circuited far end of the transmission line.
2. The second method called "Time Domain Transmission (TDT) Methodology" utilizes a two-port direct propagation delay measurement between a well matched source and a well matched load at the end of the transmission line.

These two methods are summarized in reference [8].

The TDR method depends on time it takes from the launch of a step voltage signal from a source point, propagation down the interconnect, reflection back from the far end of an interconnect and propagation back through interconnect. The far end is either short or open circuited which, in either case, causes a total reflection. The source time is usually set by establishment of an open circuit at the signal source point. The interconnect propagation delay is half the time it takes for the signal travel from the source to when it is reflected back at the source. The higher the bandwidth of the interconnect, the more the reflected signal retains its risetime and the more accurate is the propagation delay measurement.

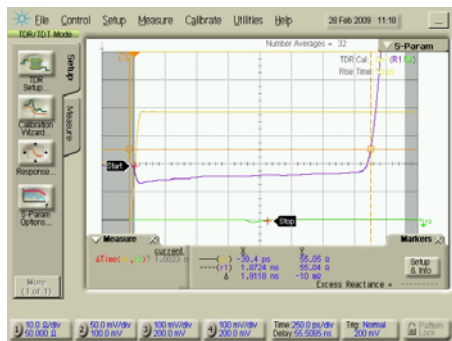
The source reference plane is simple to establish when using probes. For the TDR method, the probe is lifted and the $\tau_d=0$

reference plane is noted and stored. When the TDR measurement is performed, the far end of the interconnect is most easily an open circuit and the time t_L to the open circuit is noted, and the unit propagation delay is approximated by:

$$\tau_{pd} = \frac{0.5 * t_L}{L}$$

where : L = Interconnect Length

Typical TDR data is shown in Figure 1 below. An open circuit TDR at the source is stored in the scope memory together with time scale and amplitude. The scope probe is lowered onto the test trace and the far end of the trace is maintained as an open circuit. The time between cursors is t_L noted above.



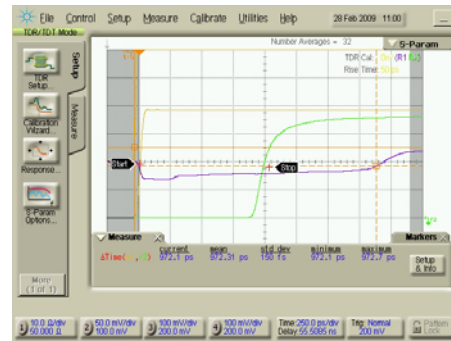
TDR Propagation Delay Measurement
Figure 1

The TDT method depends on the difference between the time the signal passes the 50% voltage excursion point at the source reference plane ($\tau_d=0$) and the 50% signal excursion time point at the end of the interconnect ($\tau_d=t_L$). The TDT method will include risetime loss effects due to dispersive losses from skin effects, dielectric losses and surface roughness.

When measurements are made using the TDT method, the zero reference time is established by using a zero length conductor (usually on the probe impedance calibration reference). The two probes are positioned on the calibration conductor face-to-face and the step voltage time delay through the measurement apparatus at the 50% risetime point is noted. When the measurement probe is set at L , the end of the interconnect, this time is also noted at the 50% risetime point. The difference in time delay between the probe signals is the propagation delay ΔT of the interconnect and the unit time delay is given by,

$$\tau_{pd} = \frac{\Delta T}{L}$$

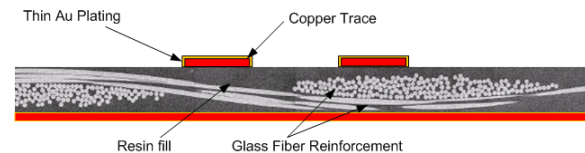
Typical TDT measurement data is shown in Figure 2 below. A zero length reference is established between the source and destination probes and stored in the scope's memory. The probes are then moved to the source and destination footprints and lowered onto the footprints. The TDT waveform is seen on the right (along with the TDR waveform). The scope has a Δt measurement function based on the 50% crossing of each waveform. The result is noted and recorded.



TDT Propagation Delay Measurement
Figure 2

Determining the Dielectric Constant: ϵ_r

The relationship between the propagation delay and dielectric constant is simple for TEM structures such as coaxial cables and stripline PCB designs. The relationship between propagation delay and dielectric constant is more involved for quasi-TEM structures such as the microstrip structures being used in this program.



Microstrip Test Structure
Figure 3

The propagation delay to dielectric constant relationship in microstrip is given in [9] as:

$$\tau_{pd} = 2.3 * (\epsilon_r + 1.41)$$

$$\text{where } \tau_{pd} = ns / m$$

$$2 < \epsilon_r < 15$$

$$0.1 < W/H < 3.0$$

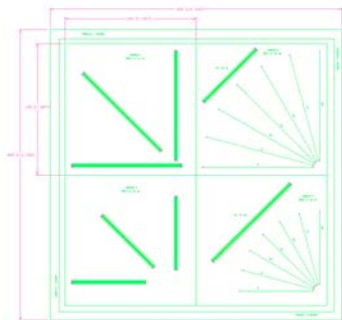
Note that the propagation delay does not involve the dimensions of the interconnect structure.

PCB Material Test Boards

Six (6) microstrip PCB material test cards have been designed and fabricated to facilitate the comparison of the new modified glass reinforcement samples with conventional 106 reinforced FR-4 and PPE PCBs (Samples 1 & 2).

- Sample 1: FR-4 Resin with open weave 106 Fiber Glass Reinforcement
- Sample 2: PPE Resin with open weave 106 Fiber Glass Reinforcement
- Sample 3: PPE Resin with 1067 Glass Fiber woven, flattened and spread
- Sample 4: PPE Resin with 6048 Glass fiber double knit weave
- Sample 5: PPE Resin with 1037 Glass weave flattened and spread
- Sample 6: PPE Resin with E-Glass filler with 1037 Glass weave flattened and spread

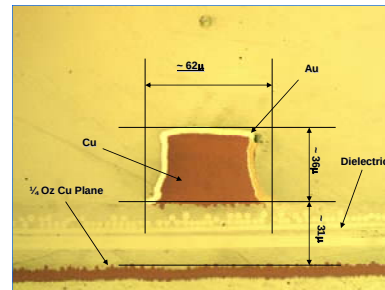
The overall size of the test boards is 400mm x 400mm [~15.75" x ~15.75"]. There are four (4) individual test areas, 180mm x 180mm [~7.087" x 7.087"]. In two of the test areas there are three groups of ten (10) parallel traces. In each group of test traces are either 10cm or 15cm in length.



Test Article Design
Figure 4

The grouped traces are arrayed at 0°, 45° and 90° to horizontal. There are two other test groups where there is an isolated group of 10 traces at 135° as well as a fan of traces at various angles. All traces have a fabricated width of 0.075mm [2.925mils]. Each trace is terminated at each end with a ground-signal-ground pad structure with 350 micron ground to signal pad centerline spacing. The copper traces were plated with hard gold and no solder mask was applied. A typical cross-section of a trace is shown in Figure 3.

The trace cross-section shows that the width to dielectric height ratio, (W/H) ~ 2, well within the range of the validity of the propagation delay to dielectric constant formula previously given.

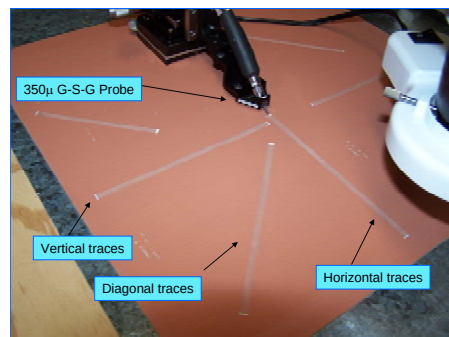


Test Article Trace Cross-section
Figure 5

The cross-section photos show that the finished trace width was 0.062mm, slightly below the design width. This had the positive effect of raising the impedance of the design resulting in better matched measurements.

Measurement of the Test Articles

Measurements were made utilizing 40 GHz microwave wedge probes in a 350 µm G-S-G tip configuration. The probe dual grounds minimize launch reflections and maximize signal launch risetime. A complementary footprint was designed to land the probes.

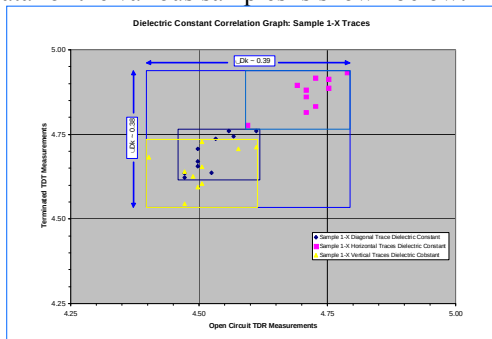


Probe in TDR Measurement Configuration
Figure 6

The measurement instrumentation used was an Agilent Infinium DCA 86100C Time Domain and Frequency Domain scope with a Time Domain Reflectometer and differential receiver modules. This instrument permits the measurement of differential impedance, crosstalk, Time Domain Transmission (TDT) and propagation time over a wide dynamic range. Through the use of hard wired logic in the Agilent 86100C scope, the interconnect S-Parameters are available for viewing and Touchstone file format storage through a drop-down menu.

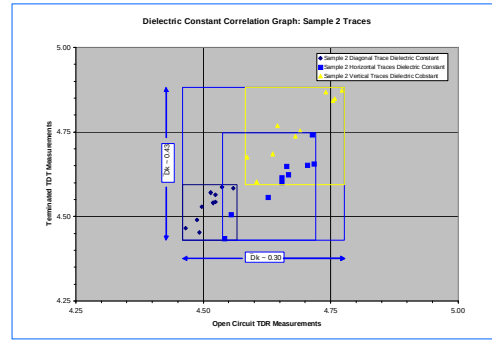
Measurements were principally confined to the 15 cm samples to average out minor longitudinal variations in trace width due to the etching process. Typical TDR and TDT propagation delay data has been shown in Figures 1 and 2. A sample board was selected from the list of test articles. The characteristics of the board reinforcing glass fibers were not known prior to the measurements. The measurements were conducted as “double blind” studies.

Each group of ten (10) Horizontal, Vertical and Diagonal traces was measured by the TDR and TDT methodologies. The data was recorded and entered into spread sheets for post-measurement analysis. Dielectric constants were determined from the two methodologies using the propagation delay delays extracted from the recorded measurements and the microstrip to dielectric constant formula. The post-processed data for the various samples is shown below:



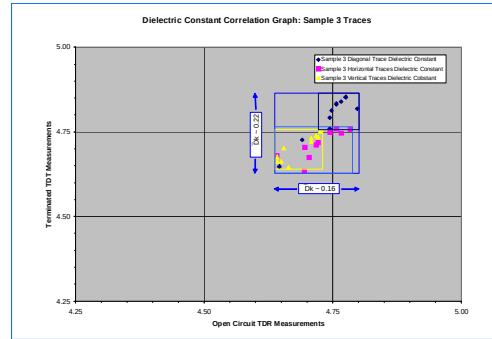
Dk Distribution for Sample 1: 106 FR-4
Figure 7

Although the individual dielectric constants for a given direction are closely distributed, there is significant dispersion when considered as a single group.



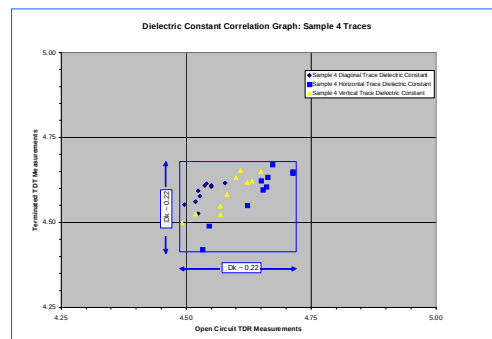
Dk Distribution for Sample 2: 106 PPE
Figure 8

Note the distribution of Dk in Sample 2 is somewhat less extensive than Sample 1, there is still considerable dispersion and lack of correlation between the various trace directions.



Dk Distribution for Sample 3: 1067 PPE
Figure 9

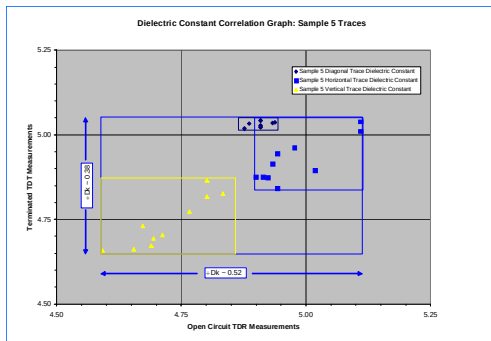
Sample 3 shows a high level of Dk correlation between the horizontal and vertical dielectric constant. The diagonal results show a slight elevation of Dk as would be expected from the double thickness of glass fibers in the diagonal direction. The level of overall Dk correlation is significantly better than either of the preceding samples.



Dk Distribution for Sample 4: 6048 Double Knit PPE

Figure 10

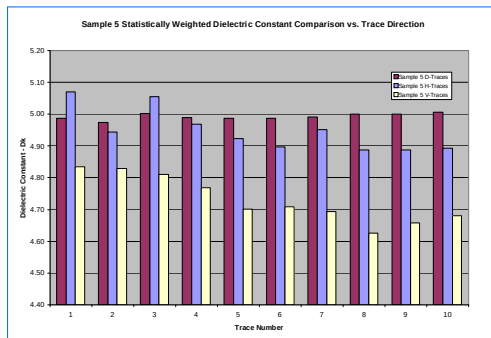
The Dk results for the double knit Sample 4 show very high correlation in all directions. This is an expected result since the density of double knit fiber is more or less independent of direction. The overall distribution is slightly worse than Sample 3 but significantly better than Samples 1 and 2.



Dk Distribution for Sample 5: 1037 Spread, PPE

Figure 11

Sample 5 shows an unexpectedly wide distribution of Dk, although the glass fibers have been flattened and spread. However, a cross-sectional analysis showed that the openings in the basket weave were more pronounced than expected. There is poor correlation between the Horizontal Dk and vertical Dk. The Diagonal Dks are in general higher than either Horizontal or vertical with a few exceptions. The Diagonal Dk's are more closely correlated with the Horizontal Dk's. This more clearly shown in the figure shown below:

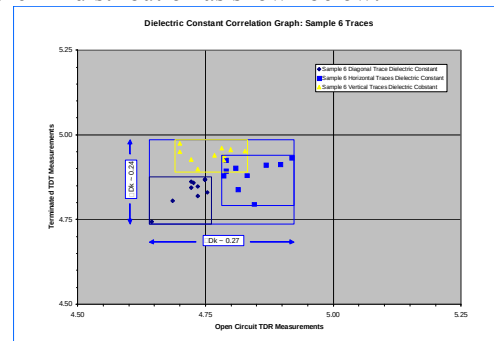


Sample 5 Dk Distribution vs. Direction

Figure 12

Note the correlation between Horizontal and Diagonal Dk's.

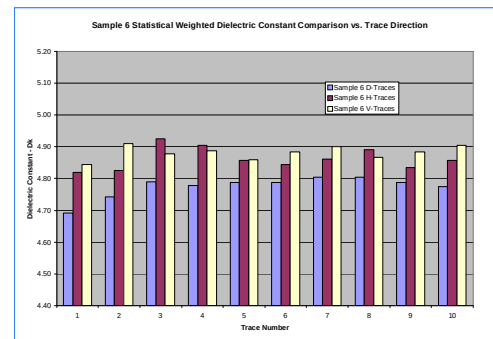
Sample 6 is truly unique in its characteristics. Sample 6 is constructed from the same glass fibers as Sample 5 and one might expect similar poor correlation between directional Dk's. However, glass fill has been added to the resin mixture which has a most advantageous effect on the Dk distribution as shown below:



Dk Distribution for Sample 5: 1037 Spread with glass filled PPE resin

Figure 13

The results show considerable improvement in the Dk correlations vs. direction. The results are very close to those exhibited by Sample 3 with 1067 flattened and spread glass reinforcement. The addition of glass fill has resulted in a minor rise in the dielectric constant of approximately 5%. The high degree of directional correlation is seen in Figure 14 below.



Sample 6 Dk Distribution vs. Direction

Figure 14

Summary & Conclusions

The project has demonstrated that the use of a cost effective process of flattening and spreading of conventional glass reinforcing fiber strands results in the significantly reduced spatial and directional dielectric constant variations in multi-Gigabit differential systems. The addition of glass filler in the resin system to loosely woven glass reinforcement has been shown to be very effective in improving the uniformity of the Dk of the material vs. direction.

Additionally, a set of repeatable time domain test methodologies has been developed which are strongly predictive with respect to dielectric constant characterization.

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