Application Note

Differential Interconnect Analysis Using Probing Techniques and the LeCroy WaveExpert 100H

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100 ohm differential impedance interconnect systems as shown in Figure 1 are increasingly used in back planes, chip to chip, cable, connector and package designs to:

- Minimize the input voltage requirement
- Resistive to common noise
- Resistive to electromagnetic interference

A differential system that depends on low voltage signaling like LVDS (low-voltage differential signaling) must be designed with minimal impedance discontinuities and skin effect frequency loss which cause an imbalance between two voltages and signal loss. These factors are also important if the interconnect link is to support other serial differential standards (Gigabit Ethernet, Serial ATA, Firewire, etc.). When active components are assembled on an interconnect system, it is worthwhile to verify the interconnect bandwidth performance so there is a high probability that a design will pass its functional G/Bit compliance standard at this point in the design process. Validating the interconnect bandwidth performance early in the design stage will save engineering time later if have to troubleshoot an active design that is failing due to the interconnect bandwidth was is inadequate for the serial standard making it nearly impossible to locate the source of the design flaw.

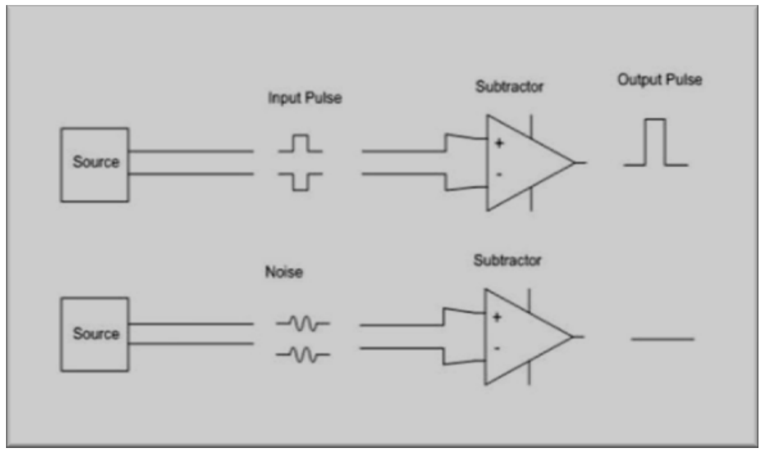


Fig 1) Differential transmission line

This paper illustrates the effect of imbalanced differential interconnect systems due to long lossy interconnects and short L/C discontinuities on eye diagrams running G/bit compliance patterns. The paper demonstrates the need for measuring interconnects in both time (impedance) and frequency (s-parameters) domains. The LeCroy WaveExpert 100H TDR system is used to measure a differential Test Coupon interconnect as a Test Case to show how to measure differential impedance and S-parameters (return and insertion loss) to determine the differential Test Coupon interconnect bandwidth (BW=.35/*rt).*

Is an Impedance Measurement Enough to Determine Bandwidth?

Measuring the differential impedance (a time domain value) of an interconnect system alone does not provide enough signal integrity information to determine if transmission lines have enough bandwidth to meet specific serial differential standards because the frequency component is not quantified in the time domain. For example, if the differential transmission line measures 100 ohms +/- 10% impedance it is a good indication there is little reflection. However, the impedance measurement provides no information how the interconnect behaves at different frequencies over which the serial standard must function (i.e. 6.25G/bits).

If the rise time of the device, as measured from 10% and 90% of the step height of the device output voltage is faster than the time needed to support the 5th harmonic, the interconnect system (T_{ro}= $\sqrt{Trs^2 + Tr1^2 + \ldots.Trn^2}$) should be designed such that the system interconnect for the step response to have sharp corners on rise and fall of the eye diagram so the signal goes from rail to rail as shown in Figure 2. **Effects of a short L/C discontinuity**

Figure 2 shows the same 100ps rise time 6.25G/bit eye diagram taken from the same device and test board. The measurements were taken with the device installed in two different test sockets containing different interposer types. High frequency components of the left eye diagram were attenuated to create a nonsymmetrical eye diagram. The first socket used to test the device contained a pogo-pin interposer that had adequate bandwidth as measured by the insertion loss (S21) but had a large L/C discontinuity impedance value resulting in a slower rise and fall time outlined by red circles in the eye diagram. This discontinuity adversely effects the return loss (S11) S-parameters bandwidth which is often overlooked when selecting test sockets and connectors. The right eye diagram used the same device and compliance pattern and was tested using a second socket with a 40 GHz bandwidth conductive diamond Pin-Less Interposer™. The Pin-Less Interposer™ has almost no L/C discontinuity so in comparison with the pogo-pin interposer it minimizes the S11 return loss S-parameters and reduces the high frequency roll off so the eye diagram maintains its symmetrical shape. Measuring the impedance waveform alone would not reveal this problem but evidence of bandwidth roll off would show up in the interconnect frequency domain S-parameters and during Functional Compliance Testing.

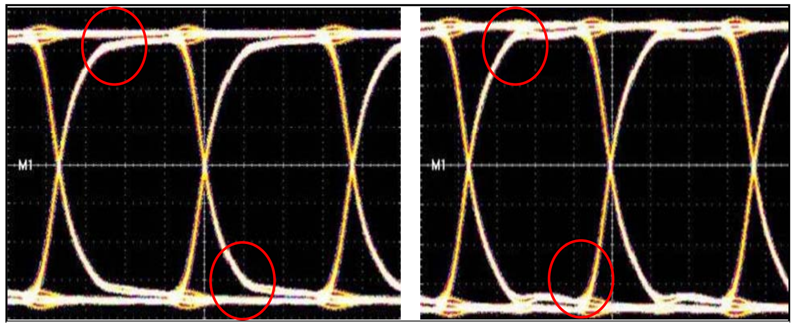


Fig.2) Eye diagram on left device tested in Socket using a pogo-pin interposer, eye diagram on right device tested in Pin-Less Interposer™ socket

Measuring the Effect of a Long Interconnect

A simple experiment to measure the interconnect system bandwidth is to inject a TDR pulse using the WaveExpert 100H TDR module and a TDR probe into the Tx or the near end differential line with no active components attached and measure the rise time at the unterminated far end (Rx) as demonstrated in Figure 3.

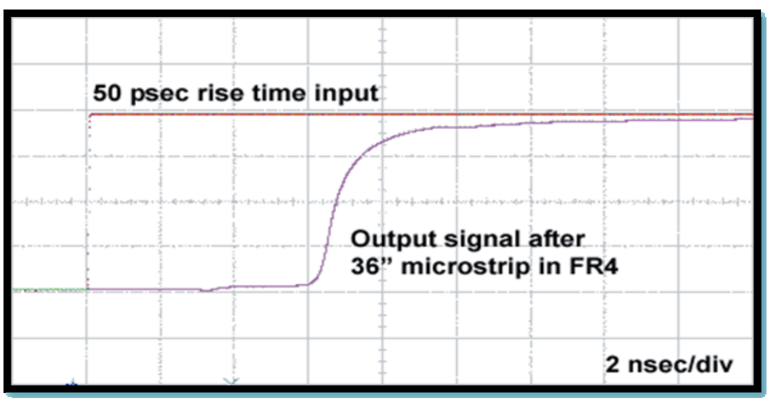
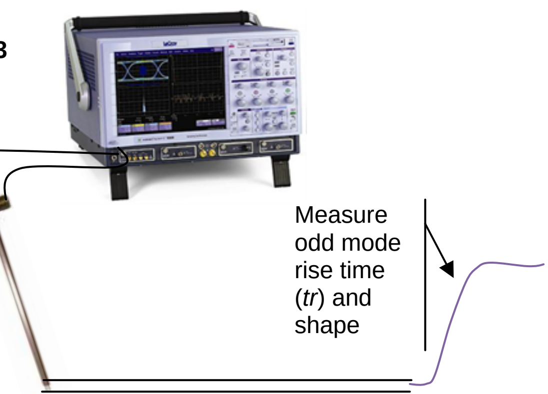
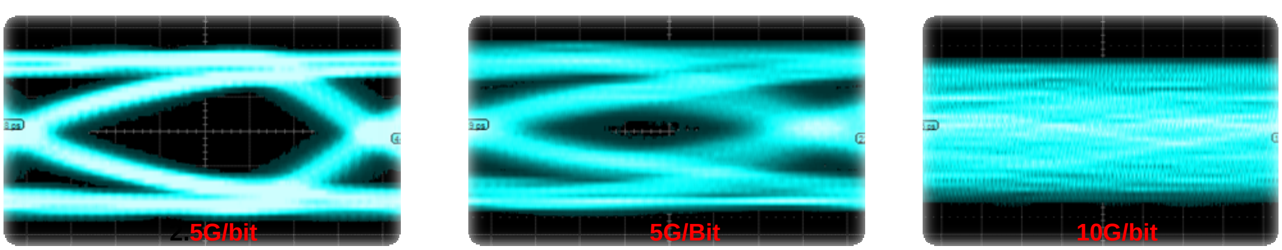


Fig. 3



Use the instrument rise time parametric function to measure the odd TDR voltage rise time at the far open end of the transmission line. Plug in the rise time value in the formula (BW=.35/rt) to determine the interconnect bandwidth (subtract the TDR and cable loss for a precise measurement). In figure 3, note the significant signal rise time roll off after traveling the through 36" micro-strip compared to the input rise time of 50ps. The loss of high frequency harmonic components when attenuated contributes to eye diagram closure. This is very clear as demonstrated in Figure 4 when a pseudo random bit pattern is increased through an interconnect system without improving the interconnect bandwidth performance, the eye diagram rise and fall times roll off to the point there is no eye left.

Fig. 4



TEST CASE

Measuring Differential Interconnect Signal Integrity using the LeCroy WaveExpert 100H

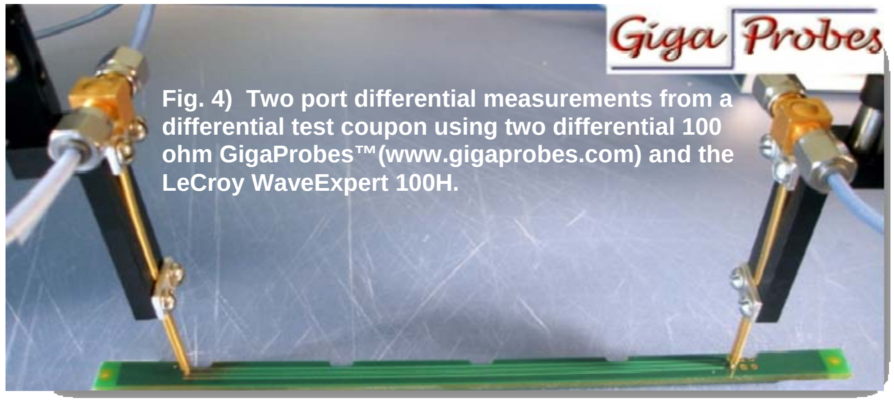


Fig. 4) Two port differential measurements from a differential test coupon using two differential 100 ohm GigaProbes™(www.gigaprobes.com) and the LeCroy WaveExpert 100H.

Measuring impedance and S-parameters of the differential interconnect system is easy with the LeCroy WaveExpert 100H. It is the scope of this paper to demonstrate how this is done and will use a PCB differential test coupon to extract the differential impedance and the S-parameters and calculate the bandwidth. In Figure 4, the GigaProbes™ are placed on the near end and on the far end of the differential test coupon. Differential TDR (Time-domain reflectometry) and TDT (Time Domain Transmission) waveforms will be measured. Using the signal integrity functions of the LeCroy WaveExpert 100H the return loss (SDD11) is generated from the TDR waveform and the insertion loss (SDD21) is extracted from the TDT waveforms.

Figure 5 shows the instrument components and setup for making a two port differential impedance and S-parameter measurement on the differential test coupon. Each sampling head uses module extenders (Part number ME-15) to connect them to the WaveExpert 100H making it possible to move them closer to the probes. This allows for using shorter, less expensive, less lossy SMA cables to sustain the TDR rise time to maintain interconnect impedance resolution and extend the S-parameters bandwidth. This is evident in Fig 3 above where the long trace degraded the TDR pulse. The same result would occur if long SMA cables were used. The relationship between TDR rise times and resolving impedance discontinuities is explained in Fig 6.

Using the Cascade Ez probe holder arm (or equivalent) to hold the probe in place provides a stable measurement and a hands free environment to operate the LeCroy WaveExpert 100H. The test coupon is affixed to a grounded static-free mat using earthquake putty to prevent any movement during the measurement.

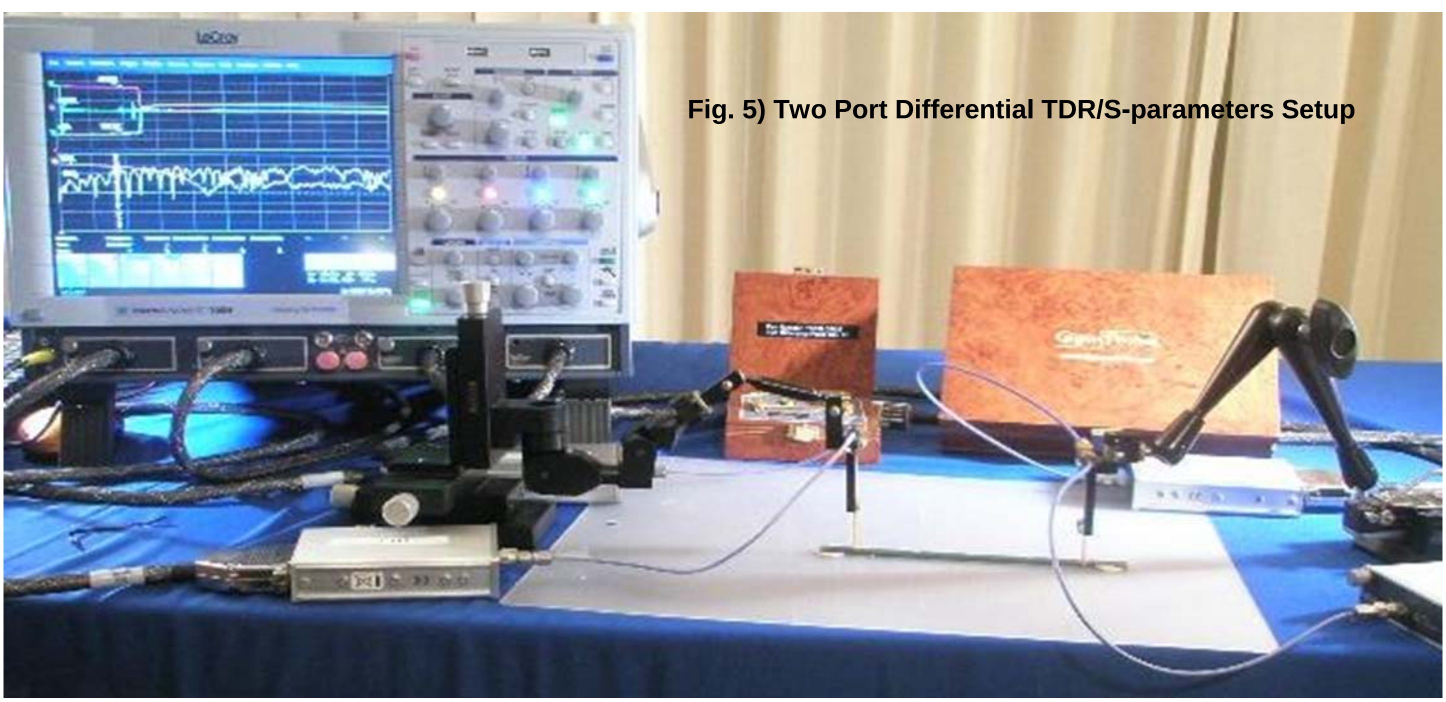


Fig. 5) Two Port Differential TDR/S-parameters Setup

After performing a two port SOLT calibration routine on the WaveExpert 100H TDR using the end of the SMA cable as the calibration reference point, the GigaProbes™ are attached to the SMA cables. Each GigaProbe is mounted to the GPMMA (GigaProbes Micromanipulator Adapter) and attached to the end of each Articulating Probe Arm. One probe is set down on the test coupon near end and the other probe on the far end of the test coupon. Figure 6 is a printout of the waveforms that are displayed on the Wave Expert

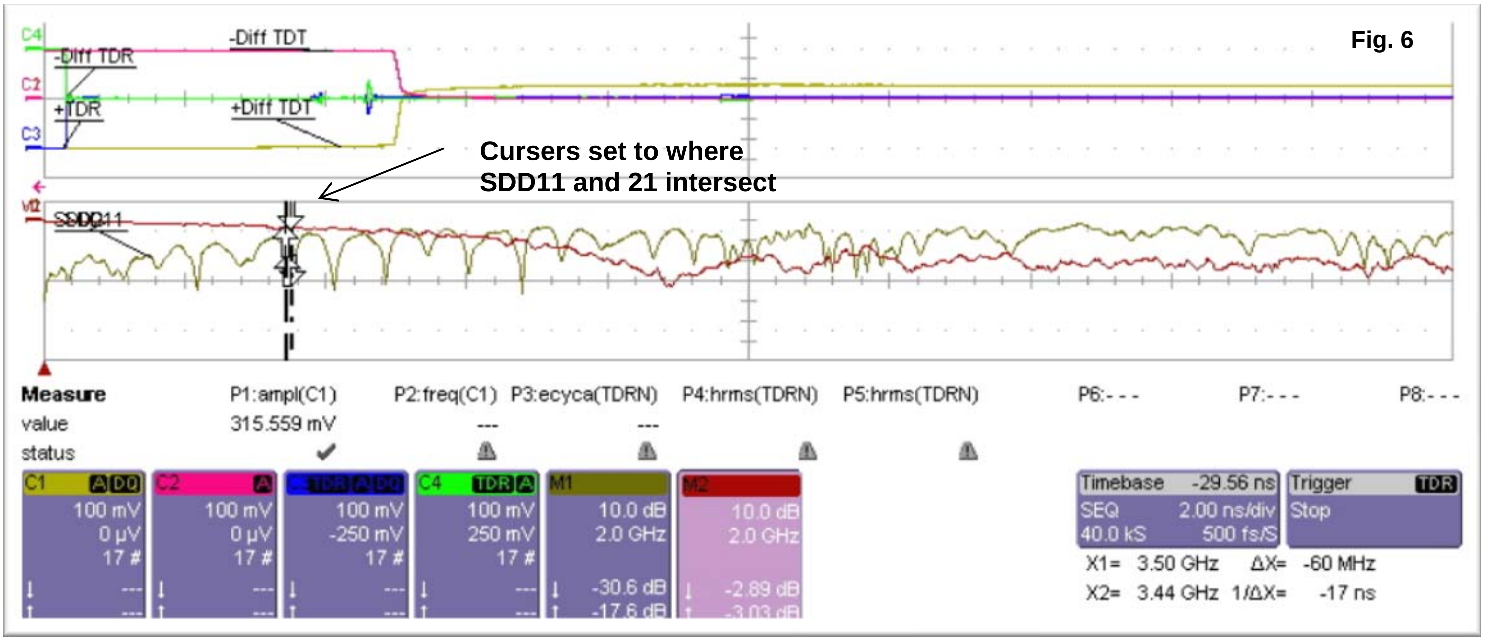


Fig. 6

100H once the measurements are completed. The printout can be used in a lab report to document engineering test results. The length and time base may be different due to the interconnect length to be measured. The odd mode differential voltages are: - TDR (even) blue, +TDR (odd) green, +TDT (odd) red and – TDT even (olive). Select the SDD11 function and it will display the data and store it in a memory and then recall it to the display. Next, select the SDD21 function and store it in a memory location and recall it to the display. Set the waveform display for two graticles. Using a mouse, click and Move all the TDR and TDT waveforms to the top graticle and the S-parameters to the bottom gratical. It should be similar to the display seen in Figure 6.

Measuring Differential Bandwidth

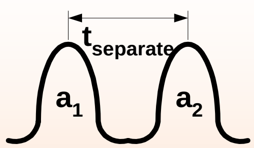
Turn the curser display function on and attach to the SDD11 return loss s-parameter plot which is derived from the differential TDR waveforms. The reflected signal should be less than 10% the incident signal. Move the cursor to -20dB, this is a common specification for a return loss of up to the full bandwidth of the application. Set the second waveform curser on the SDD 21 insertion loss s-parameter plot where it measures -3dB. The SDD21 or insertion plot is derived from the differential TDT waveforms. As an accepted rule, the amplitude of the signal transmitted through an interconnect must be at least 70% the amplitude going in through the interconnect to be large enough to be useful. Transmitted amplitude of 70% is –3 dB. Use the frequency at which the magnitude of SDD21 has dropped to below – 3 dB as a measure of the interconnect bandwidth and refer to this as the “-3 dB bandwidth.” The return loss waveform should be at least -20db and the insertion loss -3db. By placing cursers on the S-parameters the frequency vs. db values can be read to determine if the design meets expected or simulated bandwidth requirements.

Two 50 ohm terminators attached to one GigaProbes™ create a 100 ohm differential termination. When used for creating return loss S-parameter from TDR measurements.

TIP

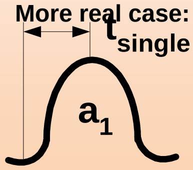
To make accurate S-parameter measurements, the far end of the transmission line must be terminated. To create a terminated transmission line connect the far end probe to sampling module via SMA connector(s) or attach a 50 ohm SMA terminator to the connector end of probe as seen on the left. This creates a short 500ps loss less far end 100 ohm or 50 ohm terminator.

Fig. 6 **Accepted Rules for Resolving Discontinuities using TDR**



To resolve a_1 and a_2 as separate discontinuities:
$t_{separate} > t_{TDR\_risetime}$ /2

More real case: resolving a single discontinuity



a_1 is not resolved if $t_{single} << t_{TDR\_risetime}$

Two discontinuities will be observed as two separate ones if the distance between them is at least half the TDR rise time. There is no similar rule for how small a single discontinuity can be, but such discontinuity cannot be much smaller than half the TDR rise time until it can no longer be resolved. Nonetheless, smaller discontinuities can be analyzed and electrically characterized, but will need relative or comparative TDR measurements to be performed.

Two Port Differential TDR/S-parameters Instrument Component List

Qty	**Product Description**
1	LeCroy WaveExpert 100H
4	20 GHz Electrical Sampling Module with TDR ST-20
4	1.5 Meter Module Extender Cable ME-15
1	DVT30-1MM 30GHz GigaProbes(tm) A TDR/TDT Interconnect Analysis Kit (contains two 30Ghz TDR probes)
4	DVT24GHZ-12 Twelve inch 24GHz Ultra-Flex SMA Cables
2	Cascade Ez-Probe or equivalent probe holders

Web Site Resources

LeCroy WaveExpert: http://www.lecroy.com/tm/products/Scopes/WaveExpert/default.asp

GigaProbes™: http://www.gigaprobes.com/instrumentcompatibility/lecroy.html

Free TDR/S-parameters Seminar: http://www.gigaprobes.com/freetdrspramseminar.html

GCI Pin-Less Interposer™ 40GHz/14ps rise time test sockets: http://www.gigaconnections.com/