PCI Express 3.0 De-embedding Method of Implementation Version 1.0

Purpose

This document will provide a step-by-step procedure for extracting the S-parameters from the test channel of the PCI Express Gen 3 so it can be used for the purpose of removing the effects from the transmitter measurements as per the PCI Express Gen 3 requirements.

I. Introduction

PCI Express Generation 3 (PCIe Gen3) moves the signaling speed to 8 Gb/s. At such speed the measurement results are influenced by even a well-designed test fixture, and impact the results of the Transmitter test in particular. The PCIe standard addresses this impairment of the transmitter test with a requirement for de-embedding of the test channel.

Tektronix supports this in the SDLA – Serial Data Link Analysis – toolset, with Option SDLA for Real-time oscilloscopes and Option 80SJNB Advanced for Sampling oscilloscopes. Either of these Tektronix tools supports de-embedding of the test channel (the 'fixture', in the language of the SDLA toolset). This document provides a method of de-embedding with a Real Time Oscilloscope. For de-embedding with Sampling Oscilloscopes please contact Tektronix. Some chipmakers also developed custom fixture de-embedding toolsets.

Regardless of the toolset, the de-embedding process relies on the S-parameters of the circuit, typically in a Touchstone format. This document explains measurement of the minimal required set of the S-parameters for de-embedding as per the PCIe Gen 3 standard, and can also be used as a guide for de-embedding in other similar situations.

II. Assumptions

The test channel is using SMA or SMP connectors at both ends of the lane. It is also assumed that calibration process will set the reference plane to include the SMA or SMP connectors on the test channel.

The measurements are based on the PCI Express Specification and the assumption that the design has followed the guidelines in the specifications. This procedure will generate a S21 as an .s1p Touchstone file. This will be the only required file for the process of de-embedding.

Both instruments in this procedure need to have a standard 20 minute warm up time and need to have a passing compensation status.

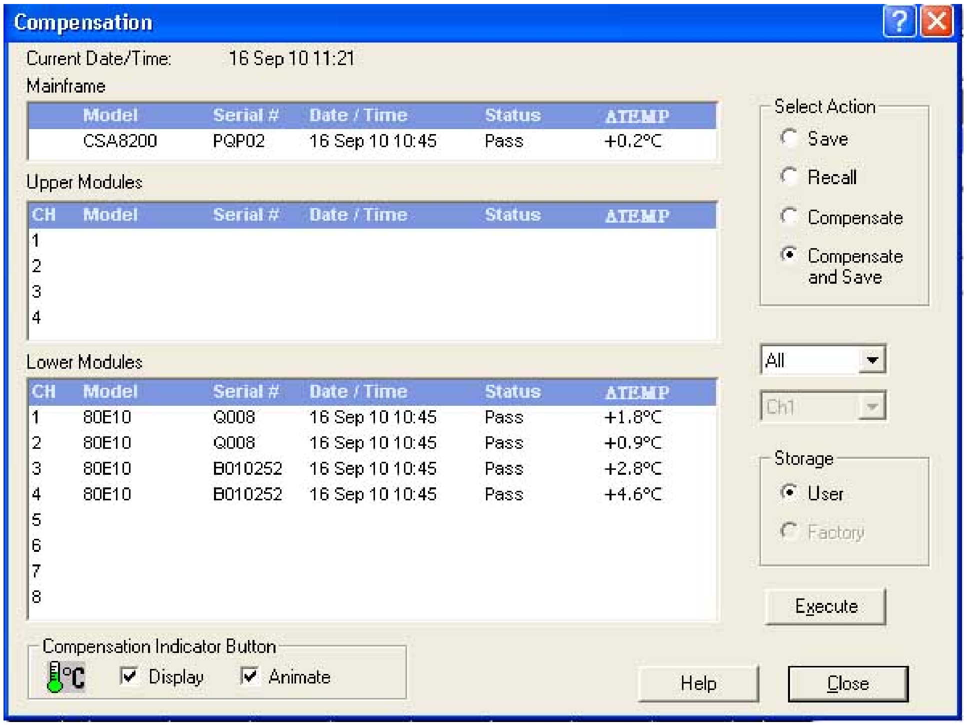


Figure 1 Compensation pane of the DSA8200 Oscilloscope.

III. Equipment Requirements

1. Qty 1 DSA8200 W\External monitor
2. Qty 2 80E08 (TDR Sampling Module) [1,2]
3. IConnect Software [3]
4. Qty 4 6 inch SMA cables (40 GHz)
5. Qty 2 2.92mm female to female adapter (Only required if using fixture with 2.92mm or SMA connectors)
6. Qty 4 2.92mm to SMP Female (40 GHz) (Only needed if using SMP)
7. Qty 2 2.92mm to SMP Male (40 GHz) (Only needed if using SMP)
8. Qty 1 12 GHz (or faster) real-time Oscilloscope (DSA70KB, DPO70KB, MSO70K)
   Options required: DPOJET, SDLA

Refer to Appendix C for Part Numbers

[1] Can be substituted by 80E10

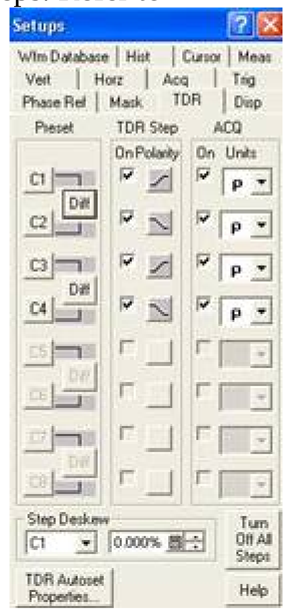
[2] 80E04 can be substituted with a risk of higher error in the de-embedding process

[3] Part number for Iconnect located in appendix C

IV. Measurement of the S-parameters of the Replica Channel

Extracting the S-parameters:

1. Default the oscilloscope setup; connect the External monitor to the video port on the back of the DSA8200 (do not connect the monitor to the “Oscilloscope only VGA” port). Verify that Windows, if not Refer to Appendix D recognize the 2nd monitor.
2. De-skew the Sampling oscilloscope acquisition and TDR steps. Refer to Appendix A.
3. DSA8200 Instrument Configuration:



4. From the Setup->TDR menu select Diff TDR on Ch1 and 2.
5. Apply De-skew values (e.g. as found in Appendix procedure).
6. Select math channels: press Math button on front panel or go to Edit -> Define Math.
7. Set Math 1 to be Ch1-Ch2, and Math 2 to be Ch3-ch4. Press Apply and check box “On” in upper left corner of Math edit window for each math waveform
8. Turn off Ch1 thru Ch4 traces (e.g. on the Front Panel). At this moment the trace M1 will be showing two steps: the first step going from roughly 0 V to about 450 mV; this is the ‘Incident step’; and a somewhat later the voltage increases again from that 450 mV to about 900 mV – the ‘Open’ reflection.
9. Place the orange triangle on the top of the display to the very far left (best to use the mouse for this task).

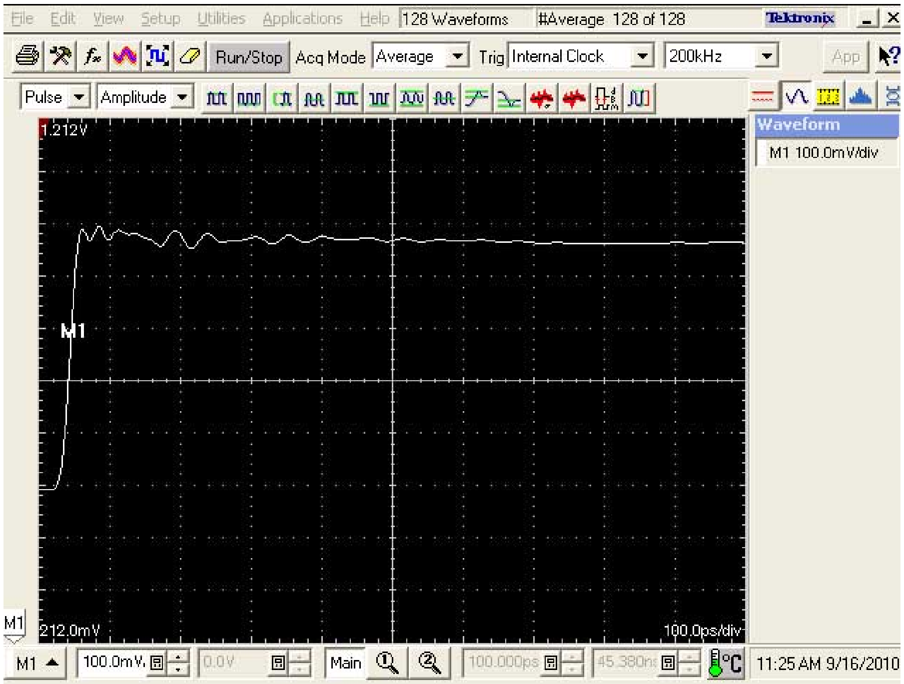


Figure 2

10. Set the Main Time base (MainTB) to 300ps/div (this setting may change based on the length of the reference channel.)
11. In the Setup->Horizontal menu set the record length to 4000 points.

12. Determine the length of test Channel:
    a. Horizontally position the open reflection in the first division to the left of the display. Place the Cursor 1 on the rising edge.
    b. Connect the channels which generate Math 1 to one end of the PCIe replica channel.

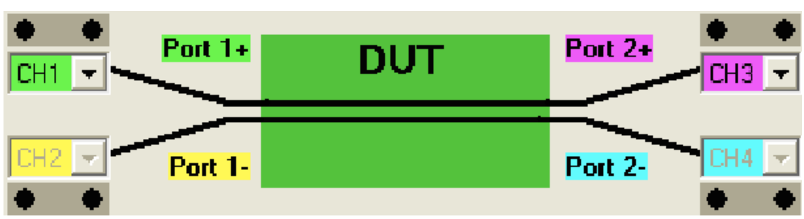


Figure 3

    c. Note that the 'Open' reflection moved to the right; this is the end of the Reference channel. Do not adjust Horizontal Scale or Position.
    If the new 'Open' reflection is not visible (is too far to the right), you can adjust Horizontal Scale to higher time/div (e.g., 1ns) <u>but then disconnect the DUT and return to step a above. This is not necessary if the Horz triangle has been placed correctly.</u>

d. Position the cursor 2 to this new, shifted 'Open' reflection. The delta time is double[4] the propagation delay of the replica channel. Record this value; it will be needed in Step 4 of this MOI.

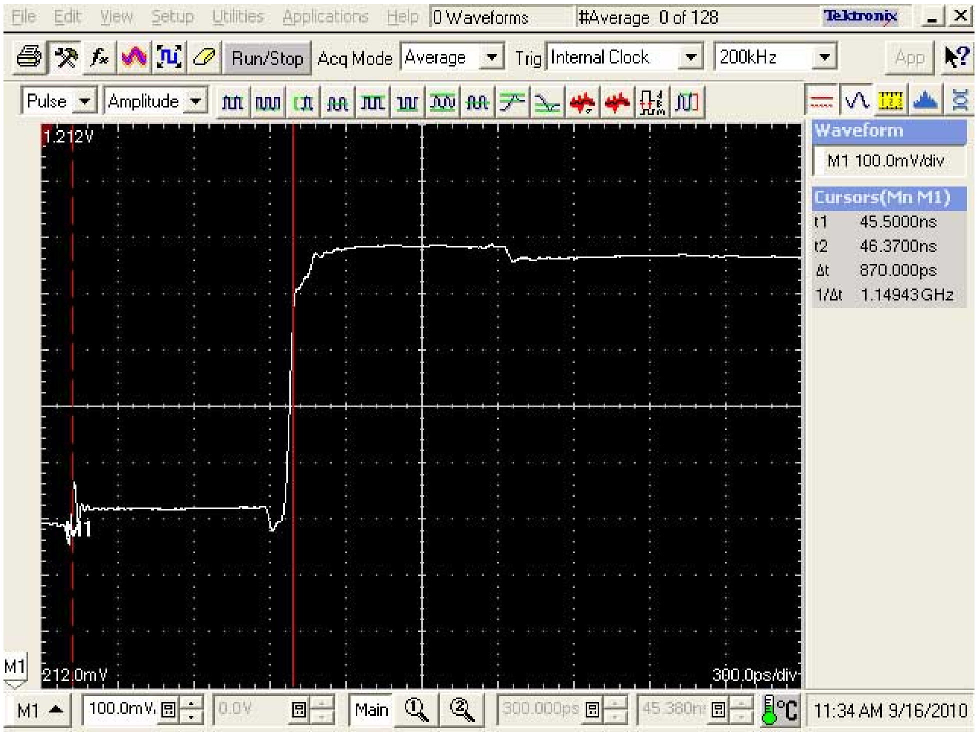


Figure 4

e. Disconnect the replica channel from the TDR.

13. Set Reference plane for Through Calibration

a. Instrument Configuration:

b. Using a through adapter (either 2.92mm or SMP) Connect Ch1 to Ch3 and Ch2 to Ch4.

[4] TDR signal propagates there and back; therefore all propagation delays are doubled.

c. Using the measured double propagation delay value from step 3, set the main time base to be 3 time longer. For example, if the double propagation delay of the replica channel is 1 ns then multiply by 3 and divide by 10 [div/screen] and set the main timebase time/div to that result (300 ps/div).

d. Turn math1 off and math2 on.

   At this point you should see a single rising edge. This is the signal from the TDR sources behind Math1, as it propagated through the cables and the reference through connectors and was acquired by Math2 channels.

e. Using the horizontally position, place the math2 waveform rise so that it is half a division from the left side of the display.

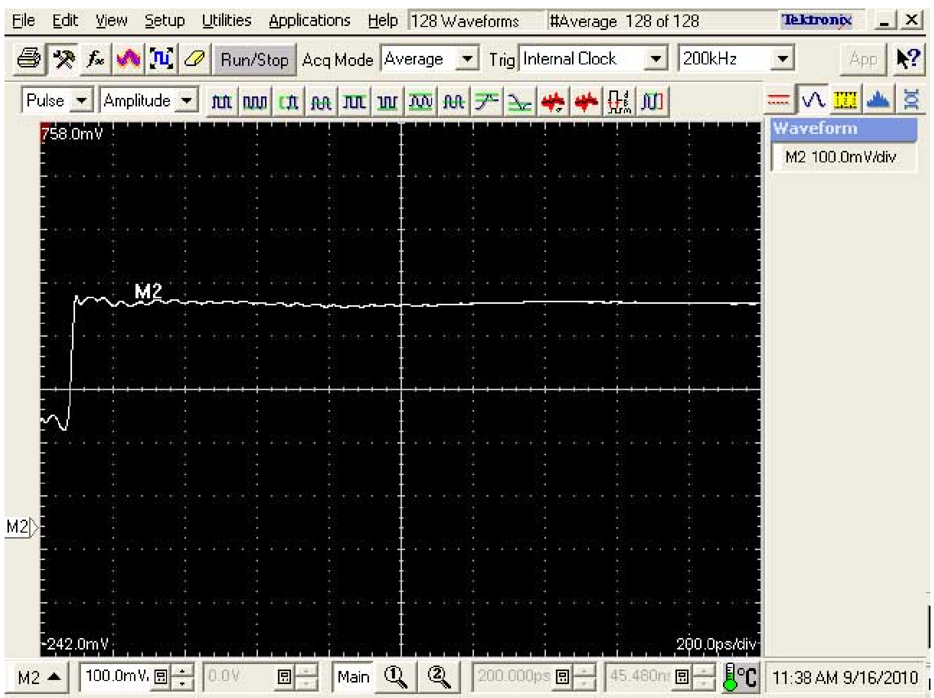


Figure 5

f. In the Setup→Acq menu set the Averages to 128 and select the Stop After 'Condition' button and set the condition for Average Complete.

g. Do not change any Horizontal settings on the oscilloscope after this point. This includes the waveform positioning

14. Capture Through Reference Calibration Waveform

    a. Open IConnect from the oscilloscopes Applications menu. Move the IConnect windows to the external monitor[5].
    In IConnect close all internal windows by clicking on the top-right 'x' button.
    In IConnect, in the 'View' menu select Acquisition Window and Computation Window.
    In IConnect, in the 'Compute' menu select S-parameter.

    b. On the oscilloscope front panel press the clear button followed by the run button.

    c. Once the run button light goes out, move to the IConnect screen.

    d. In Iconnect, in the Acquisition Window (the vertical pane with top-left legend 'Measure') select Refresh then, in the Waveform sub-window highlight the Math2 label then click the Acquire button.

    e. In the legend window double click on the waveform name and re-name it to Thru Ref_TDTdd21.

[5] Note: it is also possible to run IConnect™ on an external Windows PC. The PC then needs to be connected to the Oscilloscope, e.g. via an Ethernet/VISA or via GPIB. Instructions given here assume that IConnect is running on the oscilloscope.

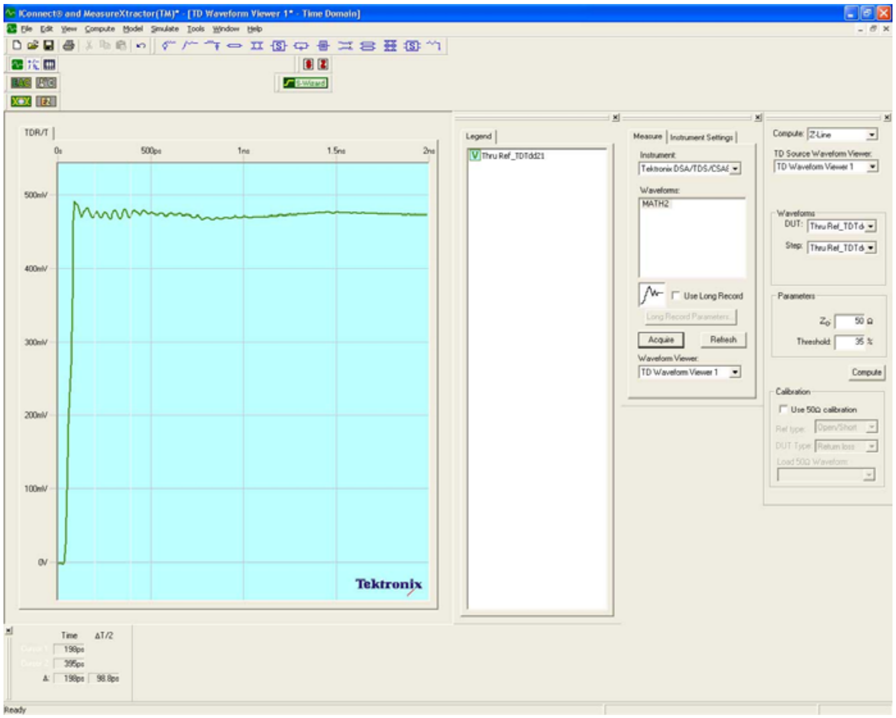


Figure 6

15. Capture TDT waveform

    a. Without changing anything from the previous step: Replace the through adapter that was used for the calibration step with the replica channel (Fixture) that is being measured.

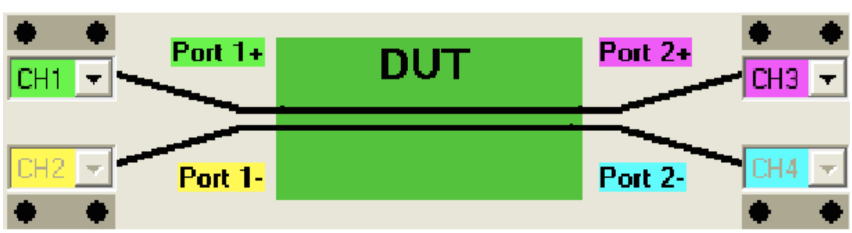


Figure 7

    b. On the oscilloscope front panel press the clear button followed by the run button.
    c. Once the run button light goes out move to the IConnect screen. In IConnect, again in the Acquisition Window (the vertical pane with top-left

legend 'Measure') select Refresh then, in the Waveform sub-window highlight the Math2 label then click the Acquire button and click on the Acquire button.

d. In the legend window double click on the waveform name and re-name the waveform to TDTdd21_replica. (This name can be substituted with any name the user prefers, see Figure 8)

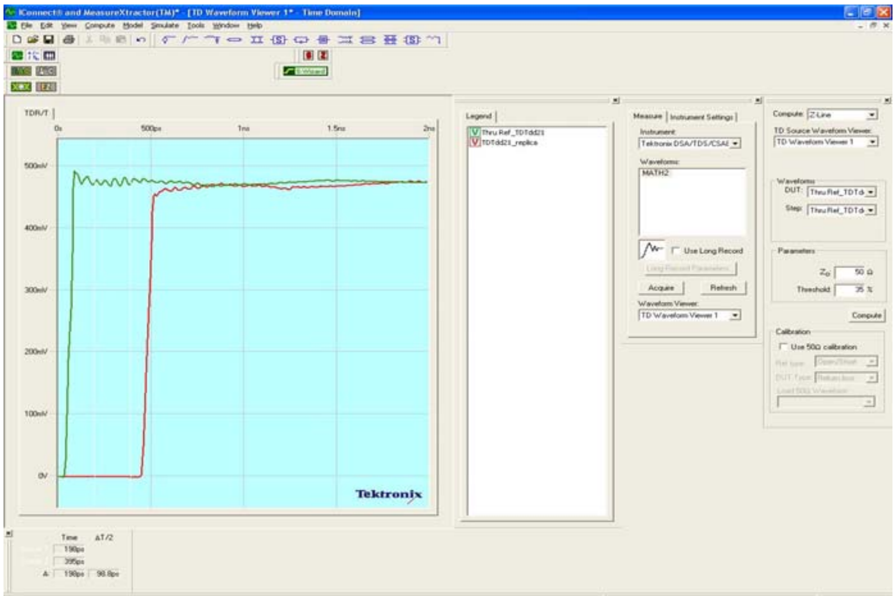


Figure8

16. Compute S21 with IConnect

a. In IConnect select the  button on the tool bar (Figure 9)

b. Still in the Computational window, in the sub-panel labeled Waveforms pull down the selection for DUT. Select the TDTdd21_replica.

c. In the Ref section just below the pull down the Thru Ref_TDTdd21 waveform

d. In the frequency content select manual. Set the delta f to 10M and the f max to 20G.

e. Next press Compute

IConnect generated a new waveform viewer window (within the IConnect) labeled "FD Waveform Viewer 1" with the S21dd curve (magnitude and phase). Verify that the response matches your expectation – typically for a fixture this means a loss of just a fraction of a dB at DC and at 10 MHz, and a gentle roll-off with perhaps 5 to 15 dB loss around 12 GHz (for a 8 Gb/s SerDes measurement).

In the FD Waveform Viewer legend sub-window double click on the waveform name and re-name the waveform to S21dd_replica.

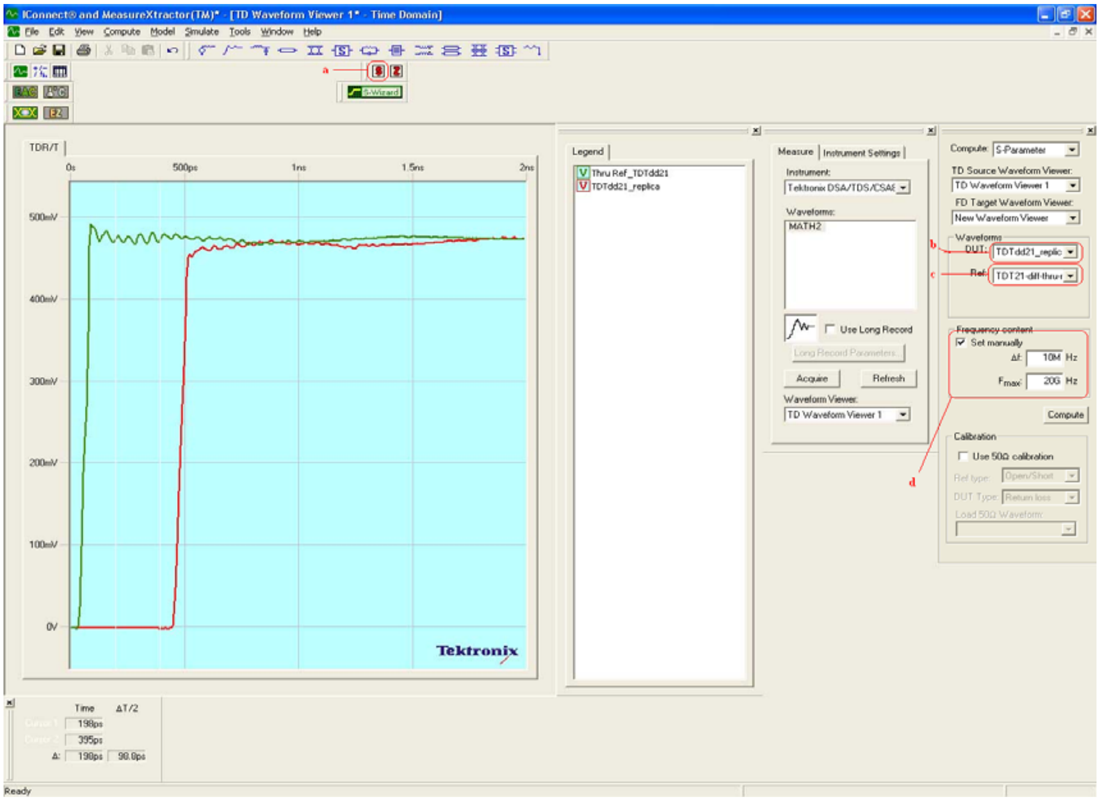


Figure 9

17. Export s1p file

    h. Select the FD waveform viewer to be active (this should be done just clicking on the waveform window)
    i. From the Legend window right click on the S21 waveform that is to be exported. Then click on export to a Touchstone 1 port. This will be used with the Real-time Oscilloscope later in this procedure (will need to transfer to be Real-Time oscilloscope).

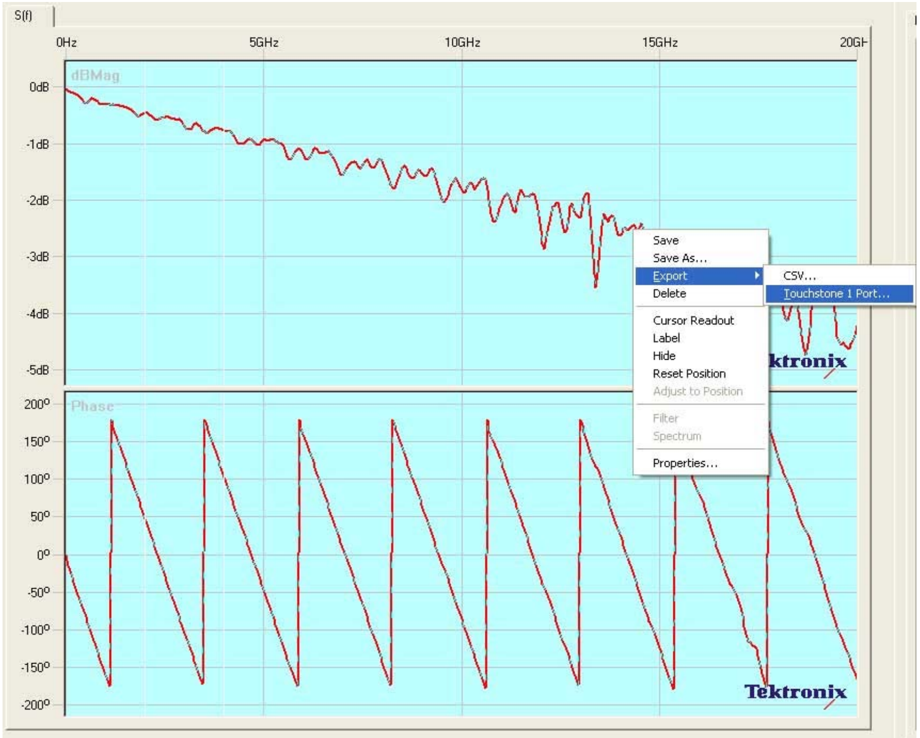


Figure 10

V. Applying the S-parameters

1. Using the Real-time oscilloscope:

   a. Deskew Channels 1 and 2 (Refer to Appendix B)

   b. Connect the Device under test to channel 1 and 2

   c. Configuring the Real-Time Oscilloscope

      i. Turn on Channel 1 and 2

      ii. Adjust the volts/division setting so the signal occupies about 8 vertical divisions

      iii. In the Oscilloscope's Math menu, define Math1 = Ch1-Ch2

      iv. Set Horizontal Scale to 20µs and the Sampling to 50Gs and 20ps/pt. Recommended record length is 10M

      v. Set the trigger on Edge and level to 50% of the vertical scale.

   d. Configuring the Real-time oscilloscope Serial Data Link Analysis.

vi. From the Analysis pull down menu select Serial Data Link Analysis.

vii. Under Oscilloscope source select the channel that is being used M1.

viii. In the Bite Rate (Gb/s) window enter in 8.

ix. Deselect everything except for the Fixture. Clicking on the small radio button in the larger gray button does this. The radio button should be empty.

x. Verify that the TX button in the left top of the window is selected (orange) and the TpA M2 is selected (orange) and everything else is deselected (blue).

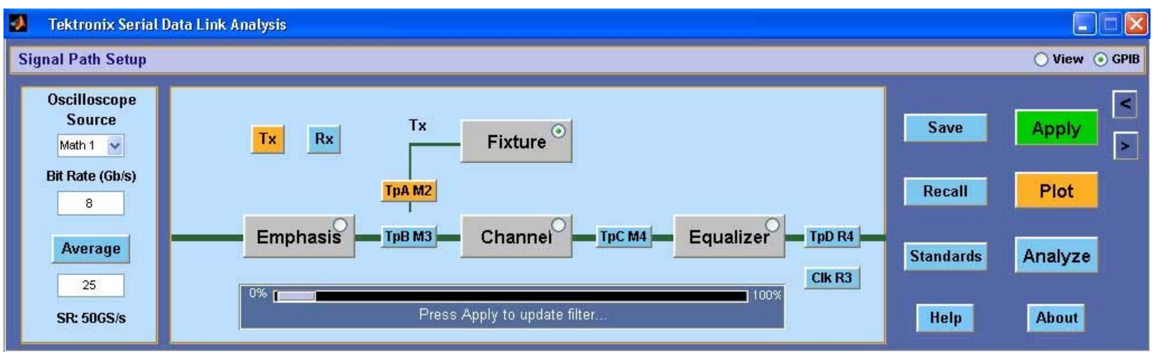


Figure 11

xi. Click on the Fixture button.

xii. Under the Touchstone format select S21.

xiii. Click on the filename Browse button and select the Touchstone file that was created in the previous steps.

xiv. Click on Custom button in the Bandwidth Limit panel, and then click on the filter button.

xv. In the panel that pops up enter 18 in to the BW window. See additional Tektronix Application note on De-embedding for details on this selection.

xvi. Click on the Apply button, then on the Close button.[6]

[6] To export the filter select the export function before closing the custom filter window.

xvii. Click the Ok button.

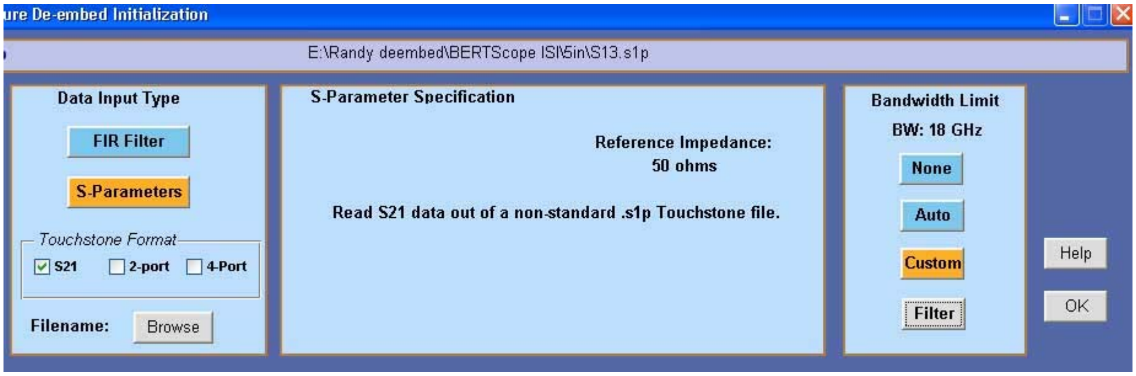


Figure 12

xviii. Click on the Apply Button (Do not click on the analysis button).

IV. Making measurements on the de-embedded Waveform

1. Configuring the DPOJET Real-time Jitter and Eye Analysis:

   a. From the Analysis pull down menu select Jitter and Eye Analysis then click on Select.

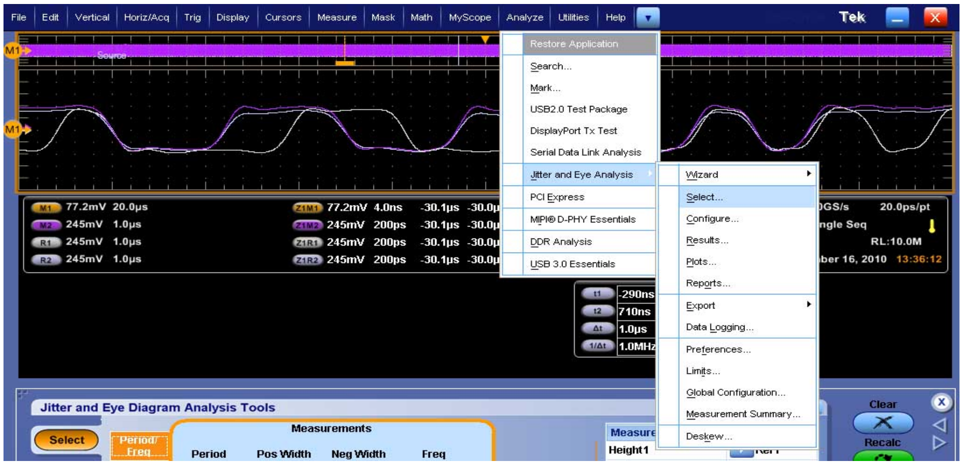


Figure 13

b. Next click on the standards tab.

c. From the pull down in the standard window select PCI Express standard.

d. Select the desired measurements

e. The source should be TpA M2. If not click on the source channel listed beside the measurement. Then select the Math tab in the upper part of the dialog box. Select M2. Next click on Apply all in the right side of the Dialog box.

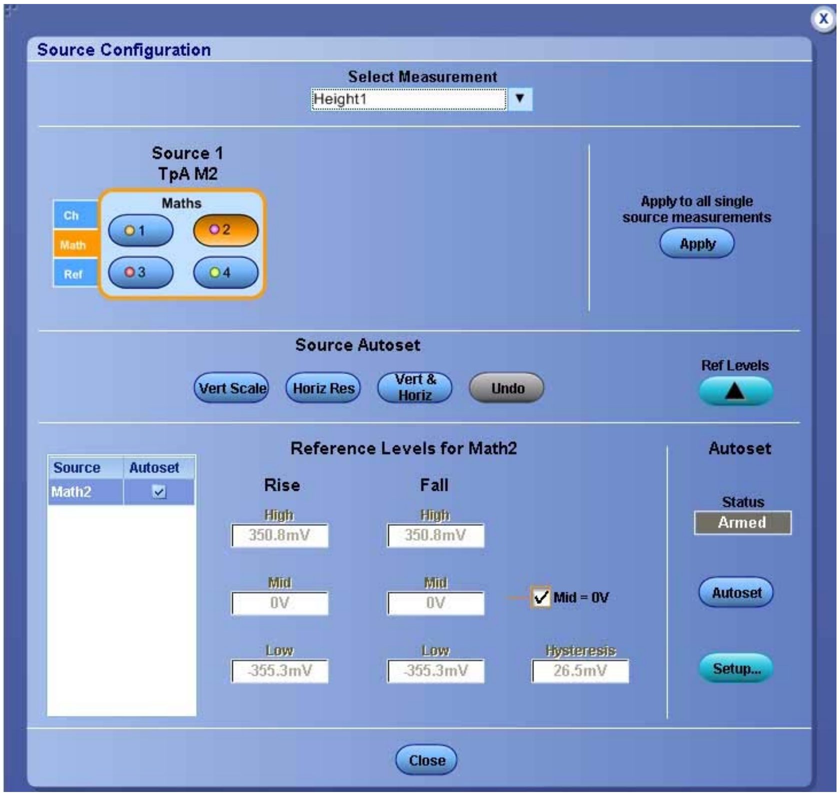


Figure 14

f. Click on the plot tab. High lighting the appropriate measurement then select the desired plot. This can be done for a total of four measurement plots.

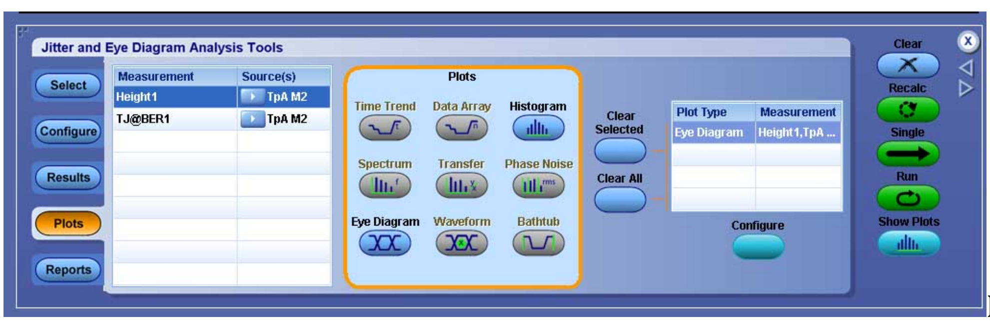


Figure 15

g. Click the Recalc

h. Once this has completed you should have a results table with the associated plots.

i. Click on Report tab on the lower left side of the display (if a report is required).

j. If the waveform data needs to be saved check the box that says save waveform file(s) along with

k. Click on Save As button on the right hand side of the display. In the dialog box that comes up provide the path to the desired folder where the report needs to be saved and the desired name for the file.

1) **Final Measurements Used for Correlation:**

   a) The following measurements results are given as an example of correlation of the de-embedding process with original signal (before fixture) The match in de-embedding will vary depending on several factors, in particular the loss of the fixture being de-embedded, For more details please contact Tektronix.

   The setup of this measurement is listed below.

   i) Rise Time

   ii) Fall Time

   iii) Eye Height

   iv) Eye Width

   v) Jitter

   (1) Rj

   (2) Dj

   (3) TJ@BER

2) **Correlation Data:**

   a) For the purposes of correlation the following patterns were generated from an AWG7122B outputting at an 8GB/s rate.

   i) PRBS9 with no de-emphasis

   ii) CJTPAT with 3dB of de-emphasis.

Measurements	PRBS9 direct out of the signal source	Sig1 PRBS9 after applying De-embed filter[7]	% of Difference
Eye Height	373.49	370.15	-0.89%
Eye Width	92.921	95.034	2.27%
Rise Time	99.085	97.04	-2.06%
Fall Time	103.95	101.3	-2.55%
Rj	0.67238	0.84277	+25.34%
Dj	23.588	21.357	-9.46%
TJ@BER	33.001	33.156	0.47%

[7] Using the S-parameters captured with an 80E10.

Measurements	CJTPAT with 3dB direct out of the signal source	Sig1 CJTPAT with 3dB after applying De-embed filter4	% of Difference
Eye Height	322.1	318.92	-0.99%
Eye Width	104.17	107.26	2.97%
Rise Time	61.184	61.221	0.06%
Fall Time	61.13	60.201	-1.52%
Rj	0.69923	0.68272	-2.36%
Dj	17.922	17.369	-3.09%
TJ@BER	27.292	26.927	-1.34%

Measurement setup:
Signal Source: AWG7122B generating an unimpaired 8 GB/s pattern.

“Direct DUT” measurement: AWG via pair of matched cables, Tek 174-4944-01

Fixture: A replica channel with SMP connectors

Note that the Delta on the Rj measurements may look high based on percentages the actual delta is less than 200fs.

Appendix A: Sampling Oscilloscope Acquisition and TDR Deskew procedure

This deskew procedure utilizes an independent acquisition source and assumes availability of two TDR sampling modules (80E04, 80E08, or 80E10). It can also be used with one TDR (80E04, 80E08, or 80E10), and one dual sampling module (80E03 or 80E09). It aligns both samplers and TDR steps allowing measuring mixed mode S-parameters. The procedure starts with the alignment of the samplers and concludes with alignment of the acquisition channels.

Match samplers to the ends of the cables

The purpose of this step is to set the samplers on each channel so that an input into the open end of each cable arrives at the sample gate at precisely the same time. This step compensates for cable and sampler differences. First stage is alignment of the channels 1-3 using the channel 4 as an independent TDR source, and then aligning acquisition of the channel 4 with respect to already aligned channel 3 using channel one as another independent source.[8] The deskew procedure is to be performed in rho mode.

1. Connect SMA cables to the sampling modules of the oscilloscope. For the best results, it is desired that the SMA cables used in the measurements have approximately the same quality and length (matched within 1ps).
2. Connect channel 1 and channel 4 with SMA barrel[5], activate TDR step on channel 4 and acquisition on channel 1 (see Figure 17).

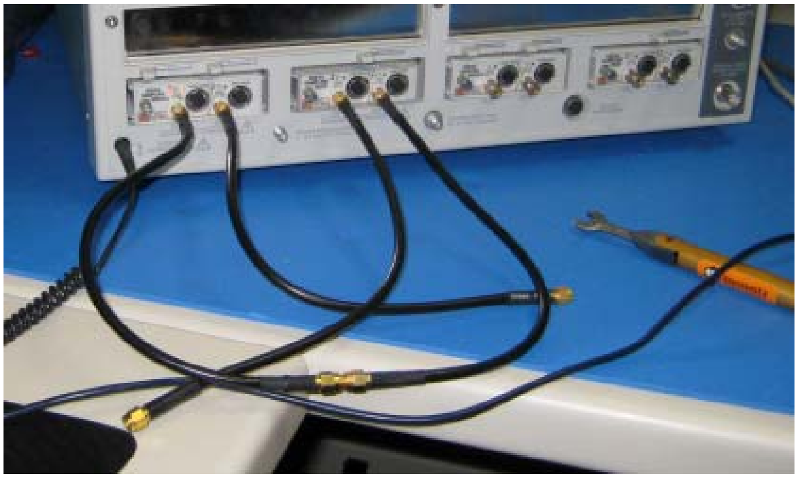


Figure 17 C1 is connected to C4 with SMA barrel. The TDR step is generated on C4 and acquired using C1.

3. Adjust the horizontal position and scale to get the rising edge on screen with good resolution (20ps/div). Record length should have the maximum number of 4000 points.

[8] When only one TDR and one sampling modules are available another TDR channel can be used as an independent TDR source.

4. Save channel one (C1) waveform as a reference trace. Channel 2 and 3 will be aligned with respect to it.
5. Connect channel two (C2) to the channel four (C4) using SMA barrel, and display C2 on the screen.
6. Turn on the delay measurement to measure the time difference between the rising edge on the reference trace and the rising edge of C2 as shown in Figure 18.

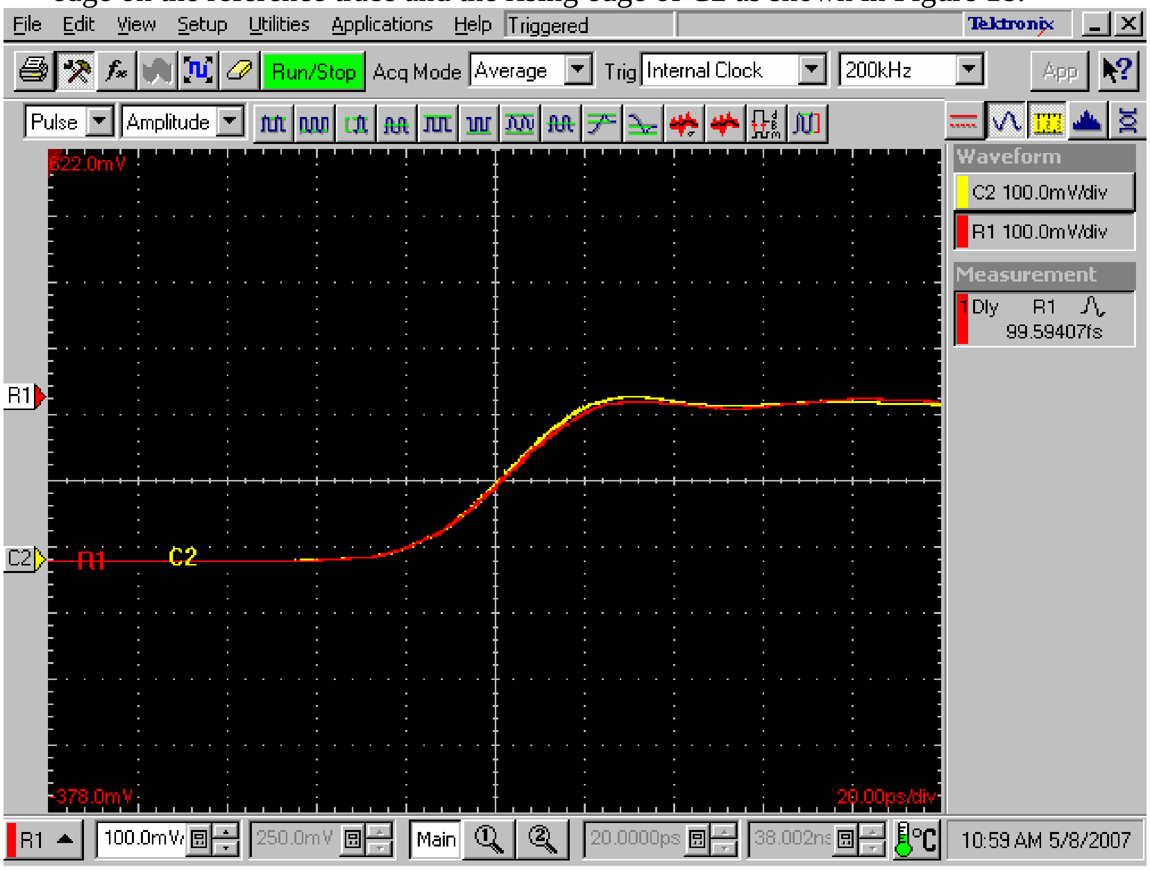


Figure 18 Delay measurements between the reference (R1) acquired from the channel one and the channel two (C2). It has to be the minimum for the best deskew value.

7. Adjust the channel delay[9] value in the Vertical menu of the Setups dialog until a delay value within 1ps is achieved as show
8. Repeat steps 5-7 for the C3.
9. Now, when the acquisition of C1 through C3 is aligned, the same approach can be used to align C4. For this purpose generate a new reference by using the step of C1 and acquiring it on C3. C3 has to be connected to C1 with the SMA barrel.
10. Repeat steps 5-7 for the C4 using acquired reference from C3.
    Now, all four-acquisition channels have been deskewed within 1ps.

[9] When adjusting the samplers on a 80E04 set the Deskew value in place of the Delay value.

Match the TDR pulses to the ends of the cables

The purpose of this step is to adjust the TDR pulses so they arrive at the ends of the cables at precisely the same time. This section describes only odd mode TDR step deskew. The deskew procedure has to be performed in rho mode.

1. Disconnect the SMA barrel[10] and turn on TDR pulses of the appropriate polarity for each channel (C1 and C2, C3 and C4). Use the differential TDR preset selection to activate odd (differential step) mode; we recommend positive step on odd channels, negative step on even numbered channels.
2. Adjust the horizontal position and scale so that the pulses as they arrive at the ends of the cables are visible on screen with good resolution. (Use Average mode and vectored display, a set time scale to 20ps/div).
3. Turn on the delay measurement to measure the time difference between the two pulse edges. The second source will need to represent the channel that is being adjusted.
4. Adjust the Step Deskew in TDR menu to minimize the time difference between the C1, C2 pulses. Independently, minimize the time difference between C3 and C4 pulses. It is not necessary, and in the case of 80E04 it is not even possible, to align the steps from different modules. You might want to activate Fine button to reduce the increment of deskew as shown in

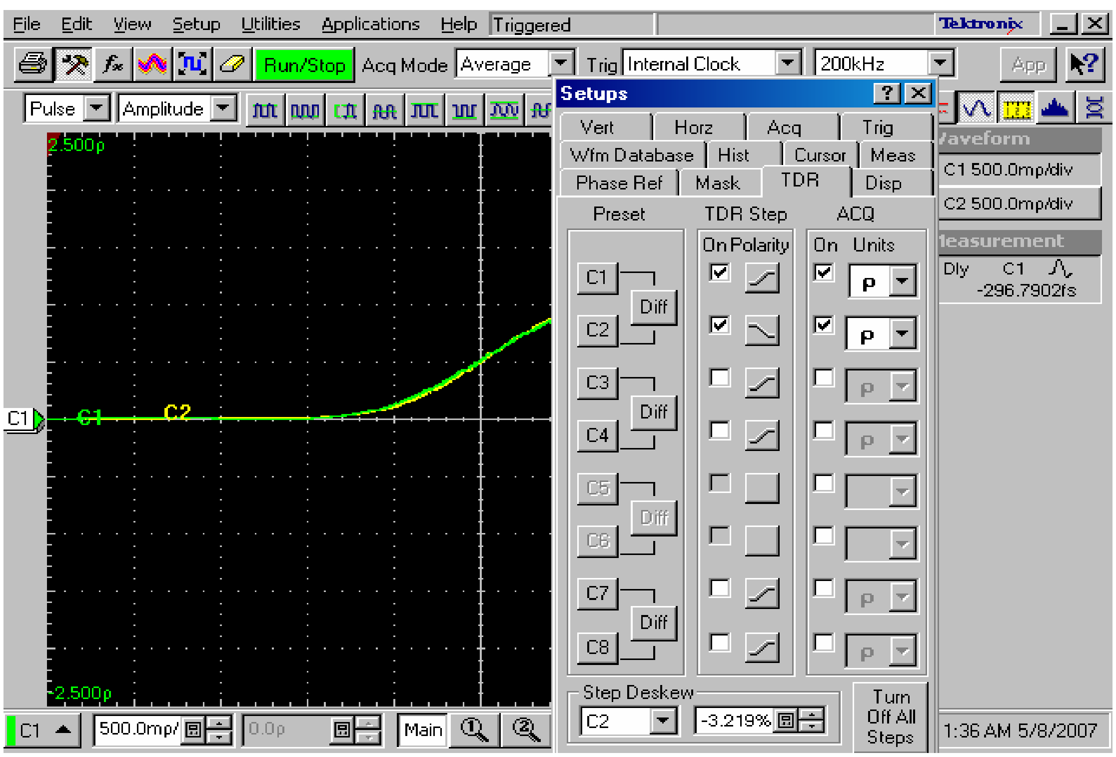


Figure 19 Differential TDR step deskew. The channels C1 and C2 are aligned within ~300fs.

[10] SMA is used only as a reference this can be substituted with an SMP depending on the connector layout of the replica channel.

Appendix B: De-skewing the Acquisition for the Real Time Oscilloscope

Use the following procedure to compensate for timing differences between voltage probes or cables:

1. Set up the instrument to display all of the channels that you want to deskew.
2. Push the instrument Autoset button.
3. Adjust the vertical Scale and Position controls for each channel so that the signals overlap and are centered on the display.
4. Adjust the horizontal Position so that a rising edge is triggered at the center of the display.
5. Adjust the horizontal Scale so that the differences in the channel delays are clearly visible.
6. Adjust the horizontal Position again so that the first rising edge is exactly at the center of the display. The fastest probe is connected to this channel (the fastest probe is usually the one with the shortest cable or with the highest bandwidth).
7. Select Deskew from the Vertical menu to open the Deskew control window.
8. Select one of the slower channels.
9. Adjust the deskew time for the slower channel so that its signal aligns with that of the fastest channel. The deskew adjustment range is ±75 ns.
10. Repeat steps 8 and 9 for each additional channel you want to deskew.
11. Remove the connections from the probe compensation terminals.

Appendix C: Accessories Part Numbers

1. Qty 4 6inh SMA Cables (40GHZ) (Gore Part number TEK40HF06PP)
2. Qty 2 2.92mmfemale to female (40GHz)(Pasternack # PE9438, Only needed if using SMA or 2.92mm connectors)
3. Qty 4 2.92mm to SMP female (40GHz)(Pasternack # PE9779, only needed if using SMP)
4. Qty 2 2.92mm to SMP Male (40GHz)(Pasternack # PE9778, only needed if using SMP)

Appendix D: Connecting an External Monitor to the DSA8200

Connect the Monitor to the VGA output on the back of the instrument. (Do not connect to the Oscilloscope only output)

1. Minimize the DSA8200 oscilloscope application
2. Right Click on the windows Desktop
3. Click on properties
4. In the Display Properties dialog box click on settings
5. In the Display properties dialog box click on Advanced

6. Under the general tab in the Compatibility check Apply the new settings without restarting
7. Click Ok
8. In the Display Properties dialog box click on the display icon with the number 2
9. Check the Extend my Windows desktop onto this monitor
10. Click on apply
11. Click okay.