

De-embedding Gigaprobes[®] Using Time Domain Gating with the LeCroy SPARQ

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Summary

Differential S-parameters can be measured using the Gigaprobe[®] DVT30-1mm differential TDR probe using the LeCroy SPARQ[®] Signal Integrity Network Analyzer. This application note describes a method for de-embedding the Gigaprobes from the measured S-parameters using the SPARQ application's time domain gating feature. Other differential TDR probes, as well as structures like adapters and launches can also be de-embedded using this feature.



Figure 1: Two Gigaprobe DVT30-1mm differential TDR probes, the LeCroy SPARQ-4004E Signal Integrity Network Analyzer.

DVT30-1mm Gigaprobe

The DVT30-1mm Gigaprobe from DVT Solutions is a 30 GHz, 100 ohm differential probe designed for making TDR measurements on differential structures. It features an adjustable probe pitch, from 0.25 mm to 2 mm, and utilizes gold-plated conductive diamond tips to ensure a good connection to the probed surface. The probe includes two SMA connectors that connect to the SPARQ via the SPARQ's port cables and routes signals through a "sheath" (see the rightmost image in Figure 2) to the diamond tips. Internally, it is structured like a twinaxial cable: the two signal lines contained within a single ground shield. The DVT30-1mm does not include a probe tip for the ground connection, so when used with a network analyzer, only differential mode S-parameters can be measured: common signal is not passed from one probe to another when making 4-port measurements.

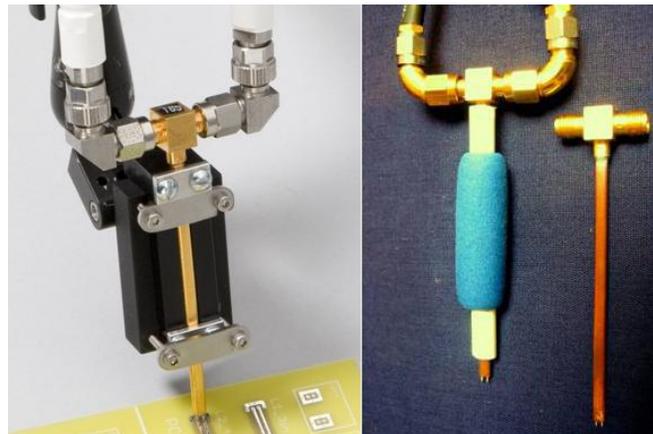


Figure 2: Left side – Gigaprobe mounted on the EZ-Probe positioner. Right-side image shows Gigaprobes within a blue foam cushion for hand-held use, and without being mounted or sheathed.

Configuring the SPARQ for the S-parameter Measurement

The SPARQ uses TDR/T as the method to characterize a device under test. For more information about how the SPARQ makes S-parameter measurements, see the application note [SPARQ S-parameter Measurement Methodology](#).

Basic SPARQ setup

The LeCroy SPARQ setup screen is most easily invoked by clicking the **Setup** button at the top of the application window. Settings for **End Frequency**, **Num Points**, **DUT length**, and **Accuracy** are entered on this screen. Configuring to make a measurement is straightforward; the settings in Figure 3 are typical.

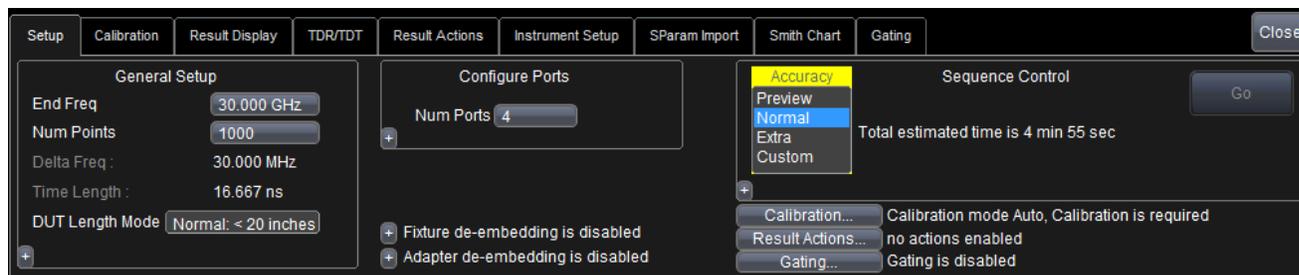


Figure 3: Setup dialog for configuring S-parameter measurements (basic view)

Configuring the SPARQ for Differential S-parameters

The SPARQ includes a configuration screen for mixed-mode measurements. To access this screen, click the **Configure** button in the extended view of the setup dialog (not shown). The configuration shown in Figure 4 defines two differential ports; differential port 1, which uses SPARQ ports 1 & 2, and differential port 2, which uses SPARQ ports 3 & 4. Click **Apply**, and then close the dialog. The SPARQ will now return mixed-mode S-parameters, with the differential-to-differential elements in the upper-left quadrant.

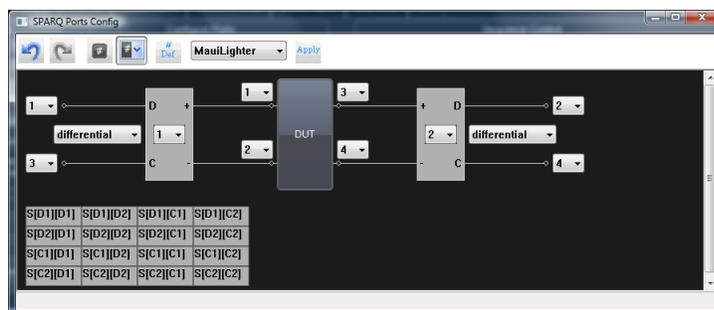


Figure 4: SPARQ Port Config dialog for configuring mixed-mode s-parameters

The common signal S-parameters are currently selected to be included in the measurement, but can be excluded such that only a 2-port Touchstone file is output. This is accomplished by choosing “X” for the outermost selectors that are currently set for 3 & 4.

Connection & Performing the Measurement

Two Gigaprobes were placed on either ends of the 3” differential lane on a CCN demo board shown in Figure 5. The left-side probe was connected to SPARQ ports 1 & 2, and the right-side probe to ports 3 & 4, such that ports 1 and 3 are at either ends of one net, and 2 and 4 of the other. Figure 2 shows the cables (with white shrouds) connected to elbow connectors, which are connected to the Gigaprobe.

We then proceed with calibration and the DUT measurement. Like all network analyzers, the SPARQ requires calibration prior to measurement. For the SPARQ, this is a “hands-off” and automatic process. The “E” model SPARQs contains a built-in OSLT calibration kit that is used to calibrate the SPARQ automatically without need to connect/disconnect calibration constants. When the user clicks **Go** the SPARQ first performs the calibration by routing the TDR

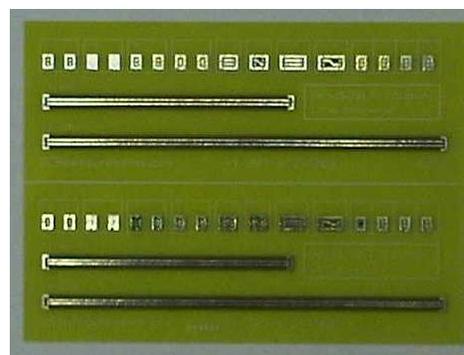


Figure 5: Probing demo board, courtesy of CCN, www.pcbmeasurements.com

combination pulser/sampler and TDT sampler to the internal OSLT calibration kit, and then to pairs of front-panel ports for the measurement of the DUT. (Successive measurements do not require the calibration step). After the calibration and DUT measurement steps, the SPARQ calculates the S-parameters. Results shown in this application note are from measurements taken using a 100mil structure (for calibrating loss) and a 3" differential structure shown in Figure 5.

TDR and TDT Waveforms

Figure 6 shows the TDR waveform when issuing pulses from SPARQ port 1, and the corresponding TDT waveforms for ports 2, 3, and 4. (Recall that ports 1 & 2 connect to one probe, and 3 & 4 to the other.) Viewing the TDR and TDT waveforms is useful both for understanding device behavior as described below, but also for ensuring that the connections to the the DUT are solid. Positioning probes can be difficult, and a time domain view of the connections is indispensable.

The TDR and TDT waveforms give clear indication that the common signal is not transmitted. The TDR waveform includes a second step in the third horizontal division, which implies that the net initially looks like an open circuit. If there was a shared ground for ports 1 & 3, then the TDR trace would not show the second step. The edges in the 3rd division in the TDT waveforms for ports 2 & 4 are evidence that these ports are acting as a return path. These ports are not directly coupled to port 1, so one would not expect such a well-defined edge on these ports.

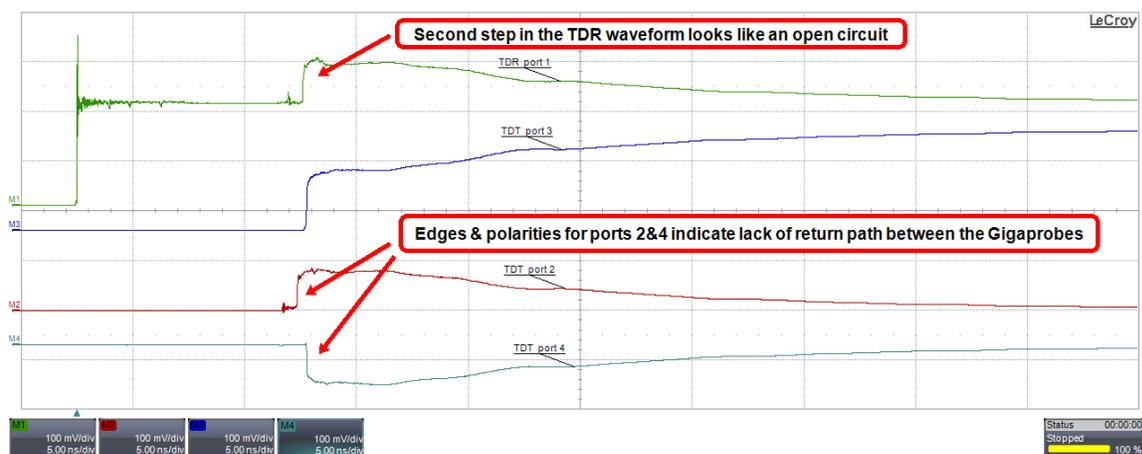


Figure 6: TDR and TDT waveforms when issuing TDR pulses into port 1. Waveforms show the lack of the common signal connection. Note the coupling to port 2 (red trace), and the apparent transmission of an inverse polarity pulse through to port 4.

Initial Results

The figures below show S-parameter results for the 3-inch trace prior to performing any de-embedding of the probes. Figure 7 shows the mixed-mode results, Figure 8 shows single-ended. (Switching between single-ended and mixed mode configurations can be done without re-measuring the DUT; all that's required is to "recalculate".) Figure 9 the impedance profiles calculated from the differential return loss measurements SDD11, SDD22, SCC11 and SCC22. We will be using the SPARQ's impedance profile (Z) "time domain result" when determining where to apply time domain gating, but we will use a 100mil trace for this purpose rather than the 3-inch trace.

It is quickly inferred from the screenshots below that common signal is not getting through the DUT. In Figure 7 the common signal return loss is near unity, while the common signal insertion loss is high, especially compared to the differential-mode insertion loss. The single-ended results shown below in Figure 8 also show evidence that we are probing with the DVT30-1mm. For example, the insertion loss in the lower-left grid drops immediately after DC. Figure 9 directly shows the effect of the lack of a ground:

the common signal to common signal impedance profile in the lower grids look very much like open circuits.

Saving the Measurement

Users should save a “.cal” file to allow re-analysis of all calculated results. This is done via the calibration dialog. The .cal file is a **calibration and measurement file** that contains the TDR and TDT waveforms taken when measuring both the internal calibration standards and the DUT. We will later recall this file, and recalculate the S-parameters with gating enabled. If a .cal file is saved, users can subsequently load the file, and change configurations that can modify the calculated S-parameters, including gating settings, end frequency, number of points, to name a few. Users can also save a Touchstone file via the Result Actions tab. The format of the S-parameters saved (i.e. single-ended or mixed-mode) will match the configuration of what is displayed.

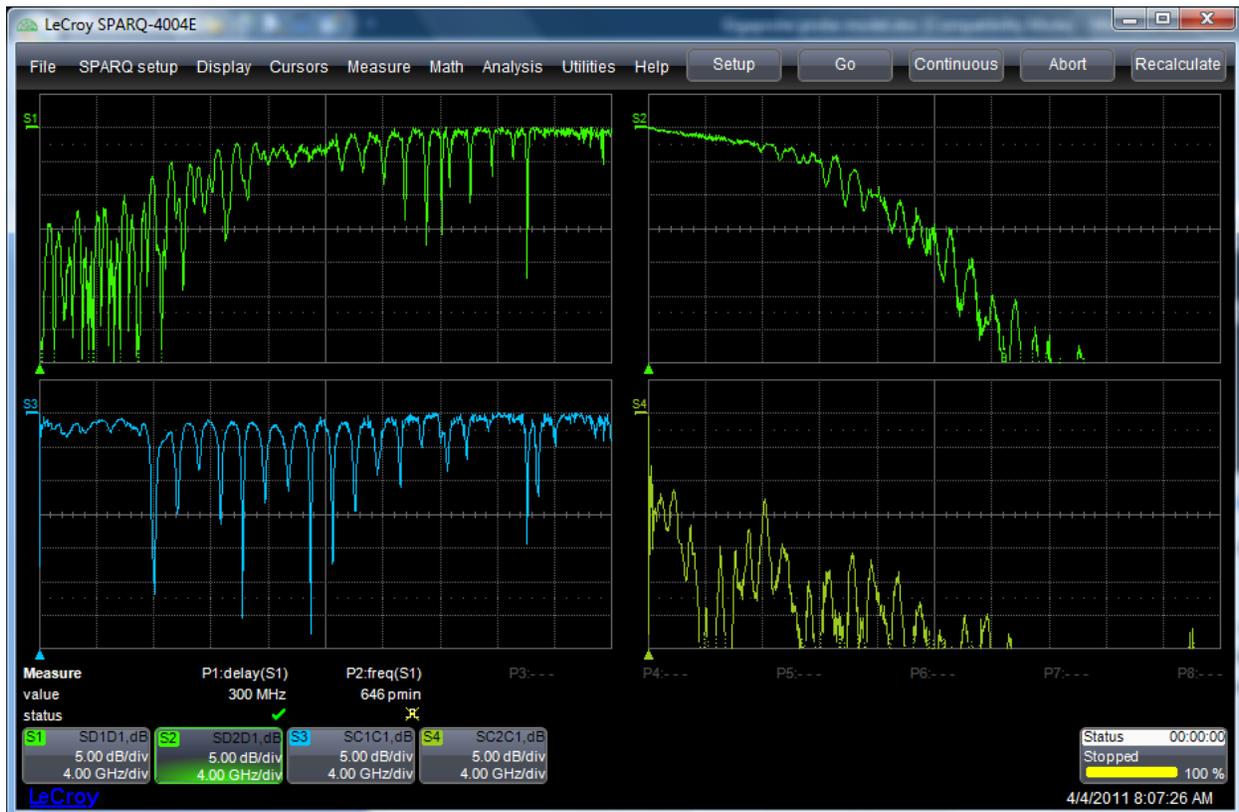


Figure 7: Mixed-Mode S-parameters of the diff probe + 3" differential structure. Traces are, beginning with upper left, going clockwise: SDD11, SDD21, SCC11, SCC21. The differential mode results look typical for a differential channel, and it is clear that the probes do not pass the common signal. The scales for the traces are shown in the rectangles in the lower left; 5db/div vertically, 4GHz/div horizontally.

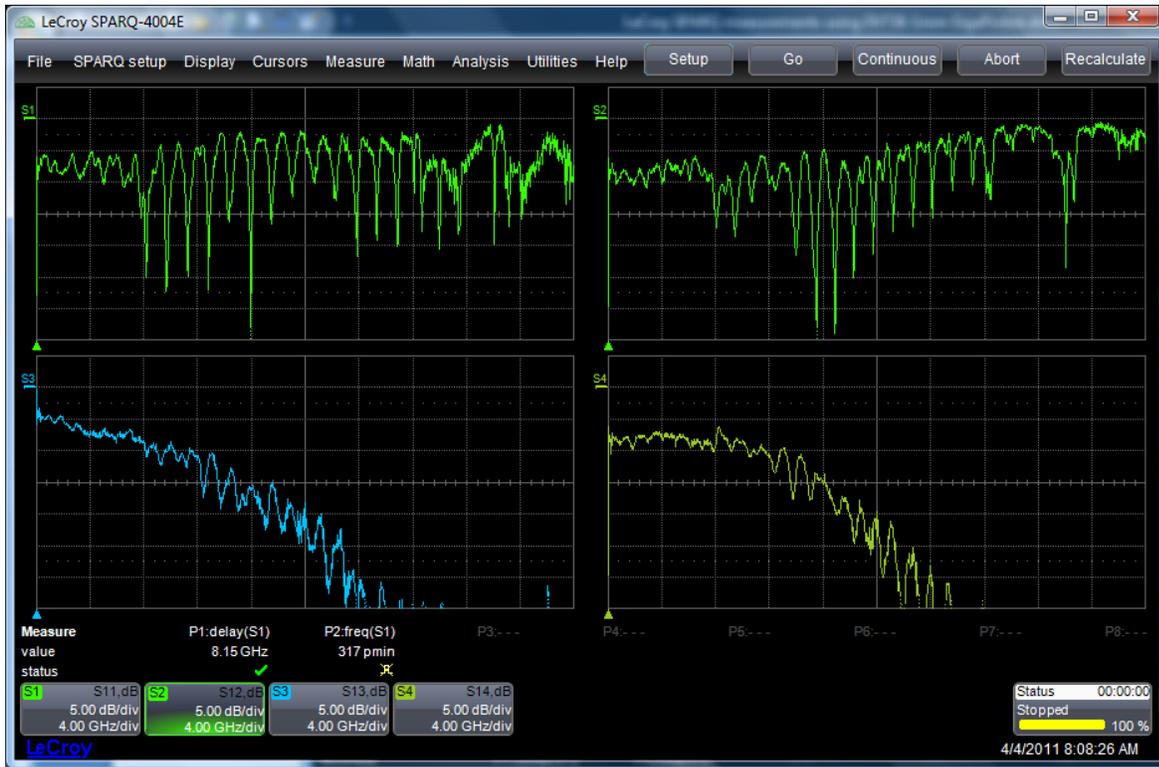


Figure 8: S-parameters when configured for single-ended results.



Figure 9: Differential and common signal impedance profiles looking into differential port 1.

SPARQ De-embedding Capabilities

The SPARQ includes the capability to de-embed user's cables, adapters and fixture in order to move the reference plane to the desired location via *S-parameter de-embedding*.

Figure 10 shows a diagram of this process. The port cables and adapters are de-embedded via an algorithm that uses

S-parameter measurement, and thus the S-parameters for these components must be known prior to the time of measurement. For the port cables, this is not an issue; a standard SPARQ includes both the port cables and touchstone files for the cables. The SPARQ application automatically reads these files from the SPARQs SD card, and enters the filenames into the GUI. For adapters and the fixture, the user selects the Touchstone files to use. Cable de-embedding is configured in the **Instrument Setup** dialog, and adapter and fixture de-embedding is on the extended view of the **Setup** dialog. (Cable de-embedding is configured by default.)

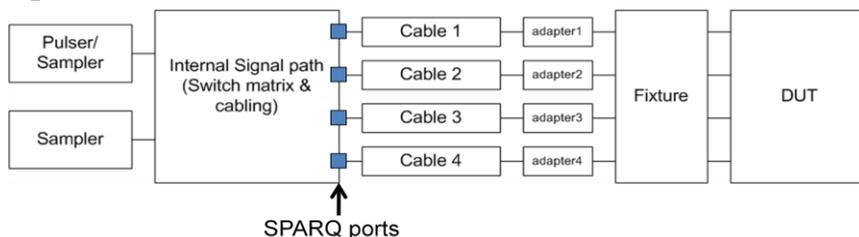


Figure 10: SPARQ reference plane map for S-parameter de-embedding

In order to de-embed the DVT30-1mm quickly and easily, the best approach is to use the SPARQ's **time domain gating**.

Time Domain Gating Feature

Gating was added to the SPARQ software in version 6.5.0.5. With time-domain gating, users can move the reference plane by a configurable delay for each user port. (User ports are what are in an S-parameter matrix, and can be single-ended or differential. They need not be the SPARQ front panel ports.)

This feature works in two ways:

- Port extension, in which the reference plane is moved to a position determined by a user-defined delay, characteristic impedance and a loss value.
- Impedance peeling, in which the reference plane is moved by analyzing the measured impedance profile and by incorporating the specified delay and loss value.

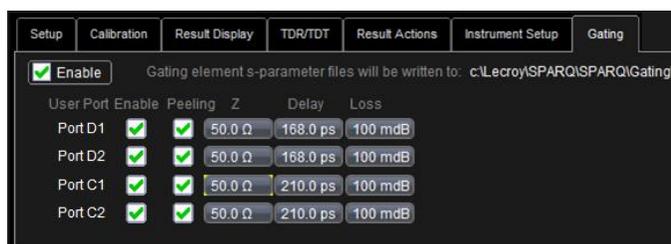


Figure 11: Gating with mixed-mode port configuration

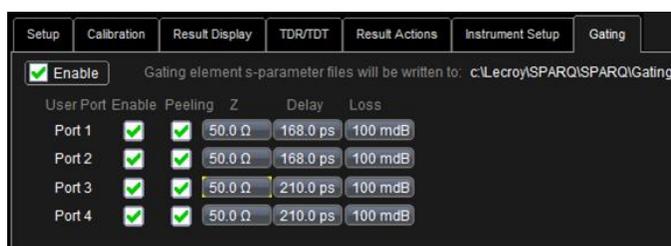


Figure 12: Gating in a single-ended configuration.

Each port can be gated independently, using either single-ended or mixed-mode port configuration. Figure 11 and Figure 12 show the gating dialogs for each scenario. After the gating is applied, the de-embedded portions – the **gating elements** – are saved as S2P files and are available for future use in the path C:\LeCroy\SPARQ\SPARQ\Gating.

When gating is enabled, the SPARQ software first calculates the S-parameters without any gating in order to determine the S-parameters of the DUT to the reference plane determined by the setup in Figure 10. Then, for ports enabled for gating with peeling, the impedance profiles are calculated from the

appropriate S-parameter (e.g. SDD11 for differential port 1), and truncated to the delay time selected by the user. The profile and loss characteristic is then input to a peeling algorithm that determines the S-parameters of the gating element that properly accounts for multiple reflections caused by any impedance discontinuities. When peeling is not checked, a model for a transmission line with the selected impedance, length and loss is created, and the corresponding S2P generated. Finally, the S2P created for each enabled port is de-embedded from the full S-parameter measurement using the same de-embedding algorithm that is used to de-embedded cables and adapters.

Determining Gate Positions

The values to use for **Delay** and **Loss** can be determined during a calibration phase in which we place the probes on a trace that serves as a calibration standard. Figure 13 shows a measurement of the 100 mil trace on the CCN demo board, with the SPARQ configured to display the step response for the SDD11 and SDD22 S-parameters. The traces show good alignment with each other, as well as symmetry, such that it is easy to identify the location of the probe tips and the center of the DUT. The cursor is positioned at the center of the DUT, with the time = **~486 ps**. Using this as the time to configure for the delay setting allows us to establish a new reference plane that is 50 mil into the trace. By moving the reference plane to this position rather than to the probe tips, we establish the plane a short distance away from the tips and from any varying impedance discontinuities due to the way in which the probe is positioned on the board. Alternatively, the peak times to the left of the cursor could have been used to de-embed to the probe tips.

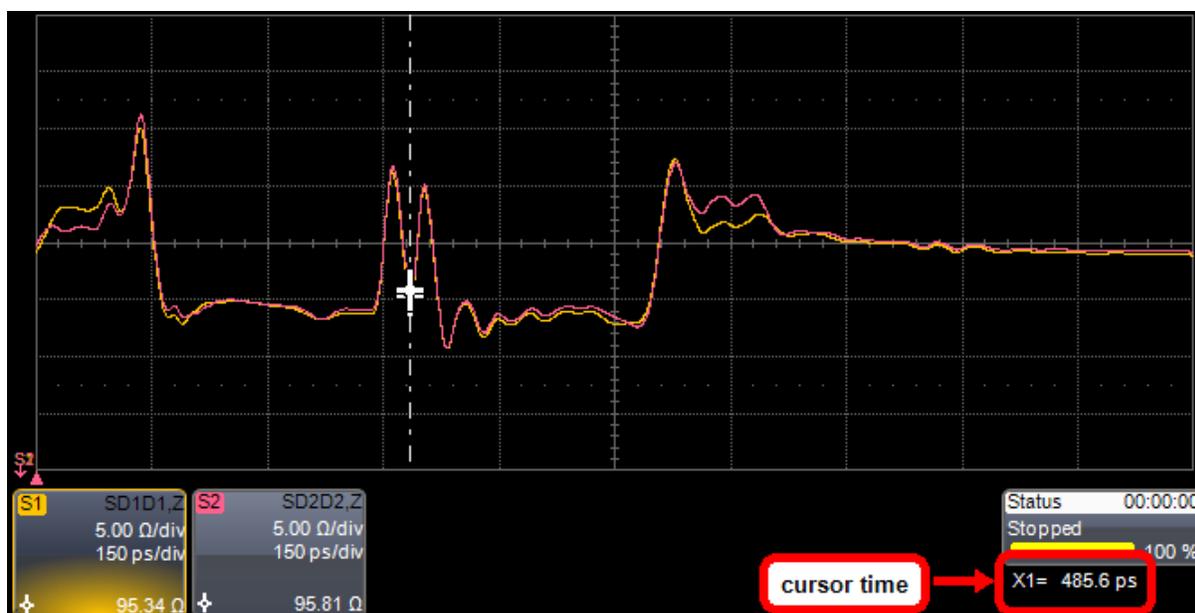


Figure 13: Differential Impedance profiles for the 100mil differential structure.

Determining Loss

The next step is to determine a value to use for **Loss** to use in the gating dialog. In applications where the gating elements have a known loss per GHz per ns, users can simply enter in the known value, but when loss is not a known quantity, other techniques must be employed. We will determine the loss to use by using the gating feature to establish a reference plane that results in a DUT that is zero-length. This can be done by placing the probes tip-to-tip, but for this application note, we gate to the center of the 100 mil structure as described above. A zero-length DUT would have no insertion loss, and since we have gated out all other structures, no return loss as well. Any loss seen is due to inaccuracies of the approach, as well as loss that should be attributed to the gating elements. Figure 14 shows the SDD12 result after gating is applied, with traces shown for loss characteristic set for 0, 0.05 and 0.08 dB/GHz/ns. As the specified loss is increased, insertion loss is moved out of the S-parameters of the zero-length DUT, and into the gating elements. The ideal would be a flat line at zero dB; we see that a value of about 80mdB/GHz/ns gives the best result, with the conclusion that the algorithm has a “bandwidth” for this application of about 12 GHz.

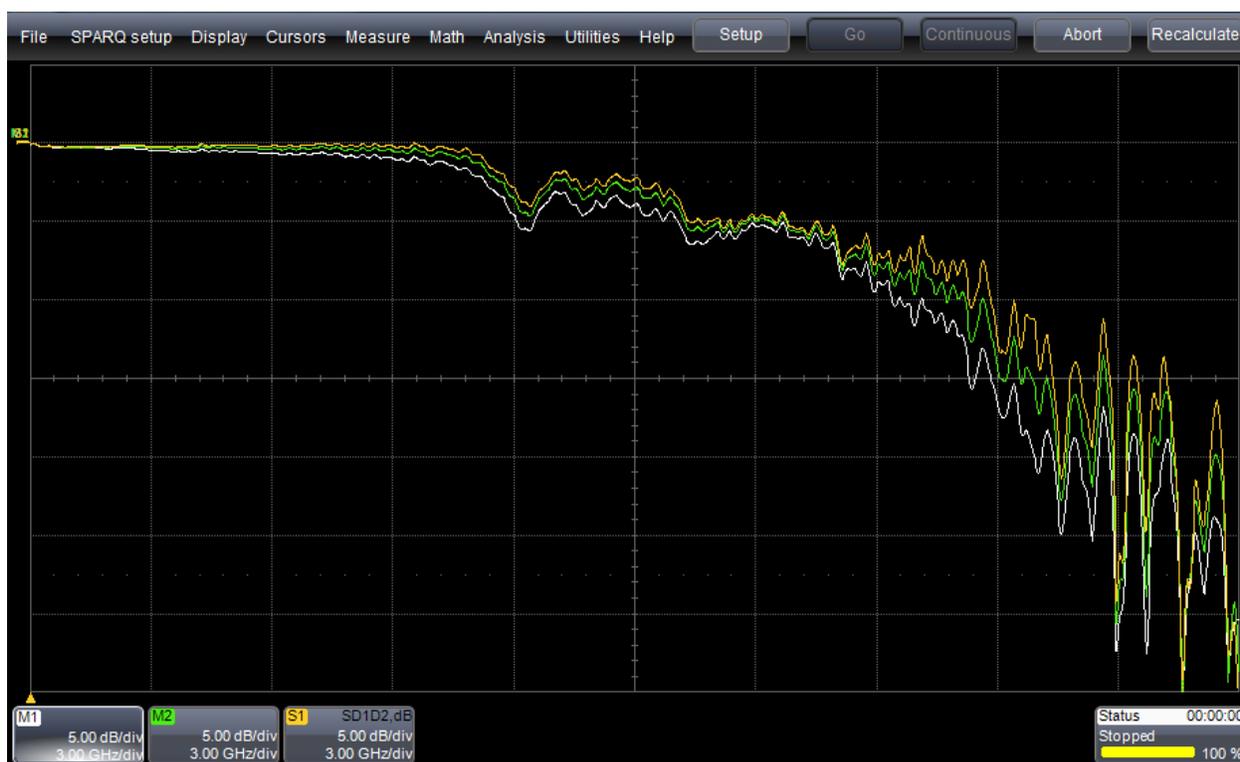


Figure 14: SDD12. White: gating with 0dB/GHz/ns selected, green: 0.05 dB, orange 0.08 dB.

Final Measurements of the 3" Structure

Now we can apply the gating feature, with the previously measured delay and loss values of 486 ps and 80mdB/GHz/ns. Since we saved the “.cal” file, we can easily recall the previous measurement and recalculate new results. Figure 15 shows the ungated impedance profile (white traces), the profile with gating enabled (pink), and the profile of the gating element (green). To display the S-parameters of the gating element, the **SParam Import** feature is used, via the dialog of the same name. The lower grid shows a zoom of gated result.

The upper grid in Figure 15 shows a good match between the gating element and the ungated result, from which we can conclude that we generated a workable model of the differential characteristics of the Gigaprobe. The ability to view the S-parameters and impedance profile of the gating elements allows users to understand exactly what has been de-embedded in both the frequency and time domains. This gives users a complete picture of the de-embedding process. The middle grid shows the S-parameters after gating, where we can see that effect of the interface between the probe tip and board has been removed.

In Figure 16, the final S-parameters after gating are shown, and the SPARQ software option **Signal Integrity Studio** is used to return an eye diagram using the measured S-parameters. The full S-parameter matrix can be saved via the Result Actions tab.



Figure 15: Upper grid: Comparison of ungated result (white) to the gating element (green). Middle grid: comparison of ungated result to gated result (pink). The lower grid shows a zoom of the pink trace, and is the de-embedded measurement of the DUT.

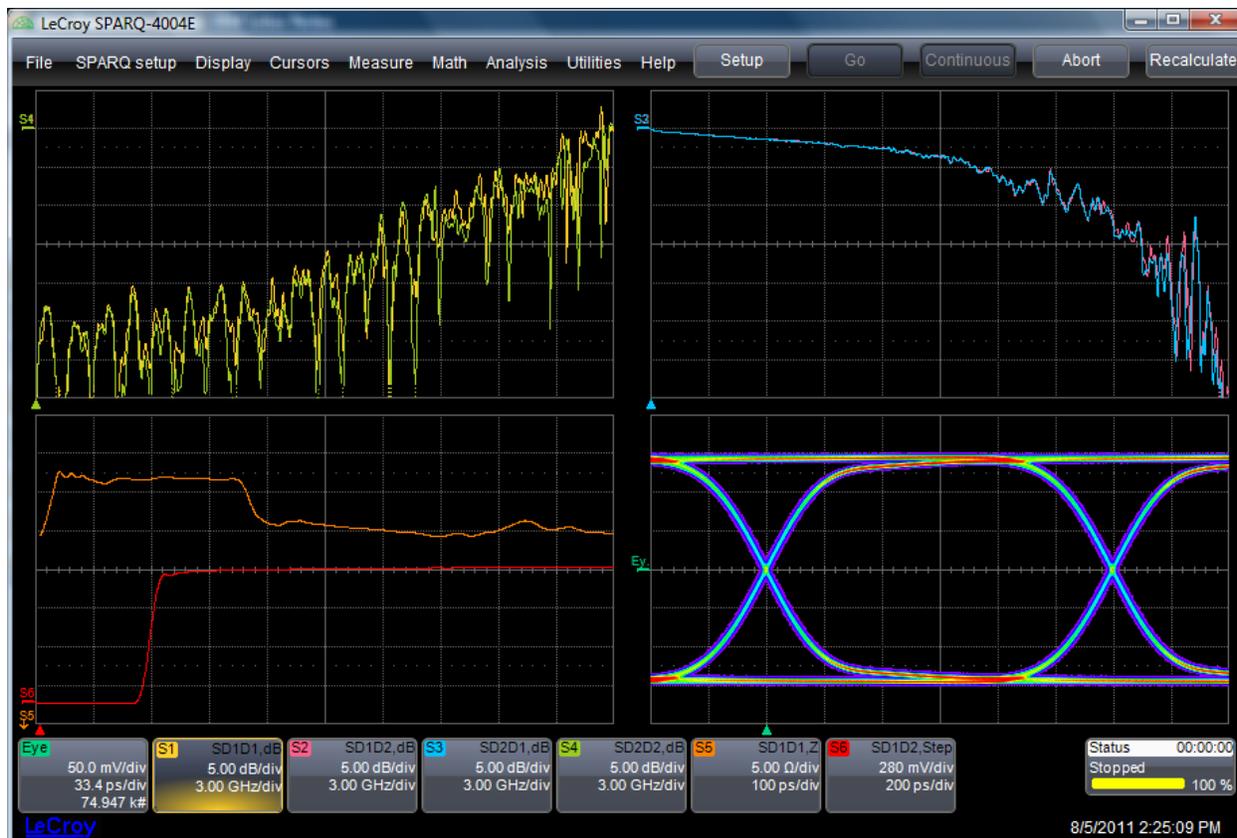


Figure 16: Final results for the 3-inch structure after gating. The eye diagram is generated using the Signal Integrity Studio option for SPARQ.

Using the GatingElement_n Touchstone Files

Two-port Touchstone files for each port that is enabled for gating are output to the path C:\LeCroy\SPARQ\SPARQ\Gating. These files can be copied and/or renamed as desired when users wish to use the gating elements in other simulations or models. They can also be used in the SPARQ's adapter de-embedding feature, but, as described above, it is recommended that users employ the time domain gating feature to de-embed the DVT30-1mm at the time of measurement rather than by using a static S-parameter model, as would be the case when seeking to re-use the gating elements.

Benefits of Time domain Gating for Gigaprobe De-embedding

Measurements that utilize probes can vary due to variability in the probe-DUT connection. Changing the angle of attack and connection pressure will change the electrical behavior of the interface. Coupling to adjacent nets and to the operator holding the probe can also change the probe's behavior. The consequence is that using a static S-parameter model for the probe will result in measurement error. The better solution for modeling the probe behavior is characterize the probes at the time of measurement, and then to de-embed their effects. This is accomplished quickly and accurately by using the time domain gating of the SPARQ application. The implementation of gating on the SPARQ returns both the full S-parameter matrix after gating, along with the S-parameters of the gated elements.