PCI Express Specification Revision 3.0

Keysight Method of Implementation (MOI) for PCIe 3.0 Transmitter/Receiver Impedance/Return Loss Tests Using Keysight E5071C ENA Option TDR

Table of Contents

1. Modification Record

Revision	Comments	Issue Date
01.00	Initial Release.	Jun. 05, 2015

2. Purpose

This test procedure was written to explain how to use the Keysight ENA Option TDR to make the transmitter/receiver output/input impedance & return loss measurements per PCIe BASE Specification Revision 3.0.

3. References

➢ BASE Specification Revision 3.0 (November 10, 2010)

4. Required Equipment

Description	Test Equipment	QTY

Network Analyzer	Keysight E5071C ENA Series Network Analyzer
	➢ Option 440/445/460/465/480/485/4D5/4K5 (one of port/freq. options)
	➢ Option TDR (Enhanced time domain analysis)
	Note: Ensure that
	  - E5071C firmware revision A.11.31 or above (Windows XP), or B.13.01 or above (Windows 7) is installed
	  - E5071C-TDR application software revision A.01.57 or above (Windows XP), or B.02.02.00.00 or above (Windows 7) is installed
		1 ea.

4-port ECal	Keysight N4431B (E5071C-44x/46x/48x) Keysight N4433A (E5071C-4D5/4K5)	1 ea.
Adapter	1250-1744 3.5 mm(f)-Type N(m) adapter (E5071C-44x/46x/48x) or 83059B coaxial adapter (E5071C-4D5/4K5) for E5071C ports	4 ea.
RF cable	3.5 mm or SMA cables of 4 GHz bandwidth or more.	4 ea.

5. Test Procedure

5.1. Outline of Test Procedure

1. **Setup**
   - ➢ Automatic setup by recalling a state file or manual setup
2. **Calibration**
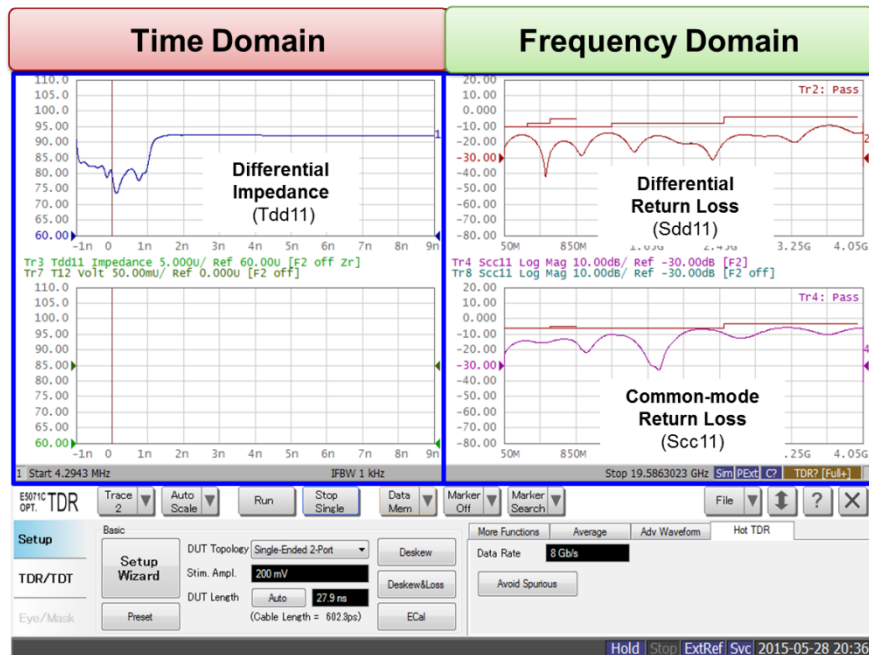   - ➢ ECal Calibration and De-embedding
3. **Measurements**
   ### 4-1. Time-domain Measurements
   Tx/Rx Impedance
   ### 4-2. Frequency-domain Measurements
   Tx/Rx Differential/Common-mode Return Loss

Note: Hard keys (Keys on the E5071C's front panel) are displayed in Blue color and **Bold**.
(Example: **Avg**, **Analysis**)
Note: Soft keys (Keys on the E5071C's screen) are displayed in **Bold**.
(Example: **S11**, **Real**, **Transform**)
Note: Buttons of the TDR software are displayed in Green color and **Bold**.
(Example: **Trace**, **Rise Time**)
Note: Tabs of the TDR software are displayed in Brown color and **Bold**.
(Example: **Setup**, **Trace Control**)

5.2. Setup

5.2.1. Recalling a State File

This section describes how to recall a state file of the E5071C that includes all the measurement settings for PCIe 3.0 transmitter/receiver output/input impedance & return loss tests. The state file can be downloaded at:

http://www.keysight.com/find/ena-tdr_compliance

Copy the state file into the E5071C's directory via USB mass storage device and recall the state file using the TDR software. Necessary parameters for testing are automatically set up in the E5071C. Refer to Appendix for the details about manual setup. If TDR setup wizard is shown, click **Close** button in the TDR setup wizard main window.

1. Open **Setup** tab.
2. Click **Advanced Mode** to show the dialog box.
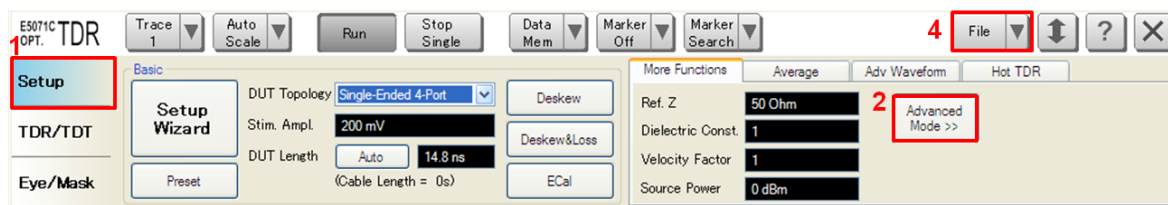
3. A dialog box appears requesting for confirmation. Then click **Yes**. (Uncheck "Use Advanced Calibration Methods")
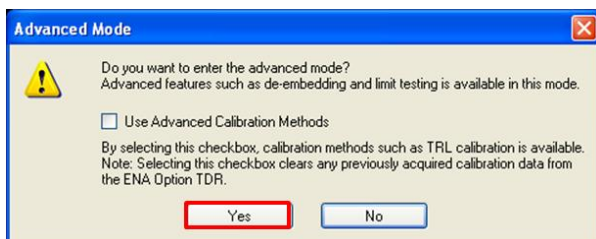

4. Click **File** and select **Recall State**.
5. Specify a folder and a file name, and click **Open**.

The E5071C's channel 1 is used for both time-domain and frequency-domain measurements by using the TDR software displayed at the bottom of the E5071C's screen.

5.2.2. Saving a State File

All the measurement settings including calibration information can be saved in a state file (*.tdr). After performing calibration, all necessary calibration coefficients are saved in a state file and can be recalled for the next measurements.

1. Press **Save/Recall** > **Save Type** and select **State & Cal** as a state file type.
2. Click **File** of the TDR software and select **Save State**.
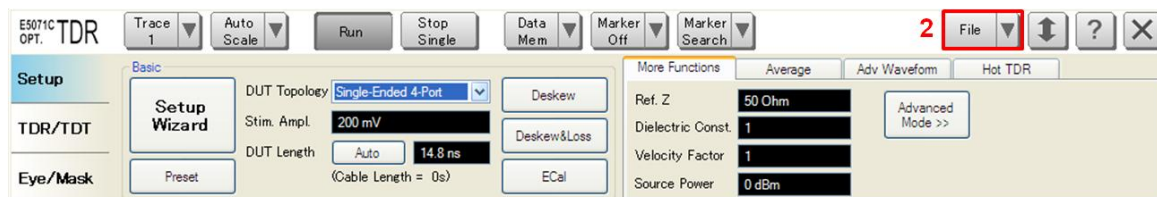
3. Enter file name and save the state file with calibration information.

5.3. Calibration

The purpose of this step is to calibrate the RF effects such as delay, loss or mismatch of RF cables and breakout channel traces before measurements. In order to remove the breakout channel trace effect, ECal calibration & de-embedding are available with the E5071C firmware.

Tx/Rx return loss measurements are specified in the PCIe 3.0 BASE Specification so the measurements are defined to be performed at the device's pin. Specifically, Tx/Rx return loss measurements are made at the end of the respective breakout channels and require that the breakout channel's contribution to RL be de-embedded, thereby associating the return loss with the Tx or Rx pin. The replica channel reproduces the electrical characteristics of the breakout channel as closely as possible, matching its length, layer transitions, etc, making it possible to de-embed measurements to the pin of the DUT.
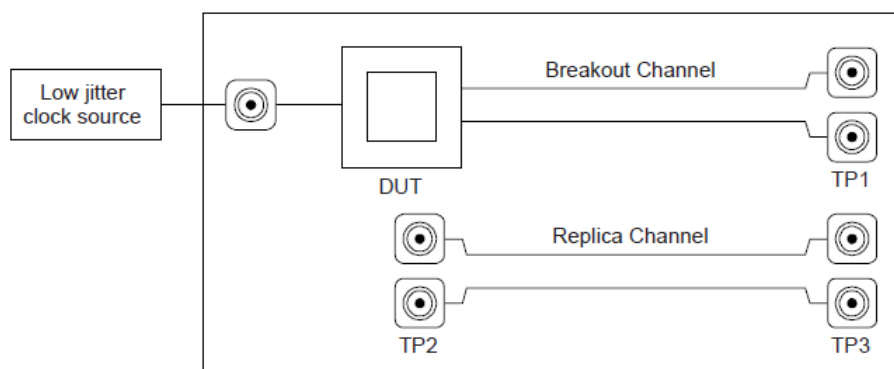

Tx Test Board Example

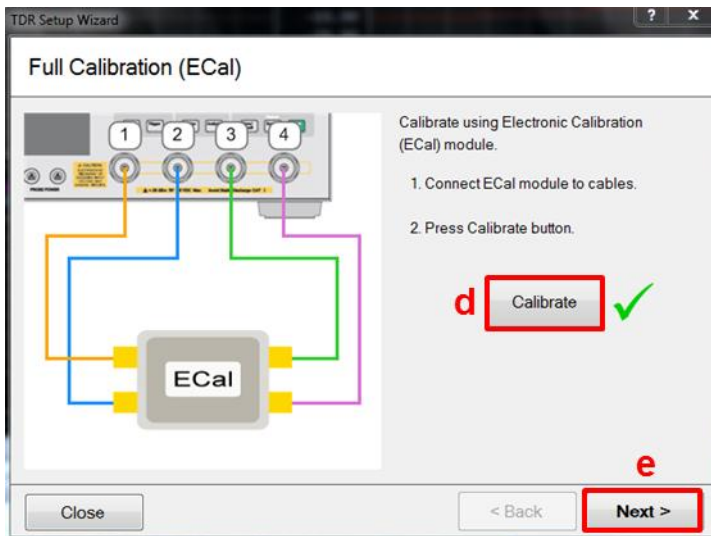## 5.3.1. ECal Calibration and De-embedding

Full calibration is performed by using the 4-port ECal Module (i.e. N4433A) at the end of RF cables connected to the E5071C's test ports. The effect of the breakout channel is removed by de-embedding the breakout channel traces with S-parameter Touchstone files. Refer to Appendix for the details about de-embedding file creation.
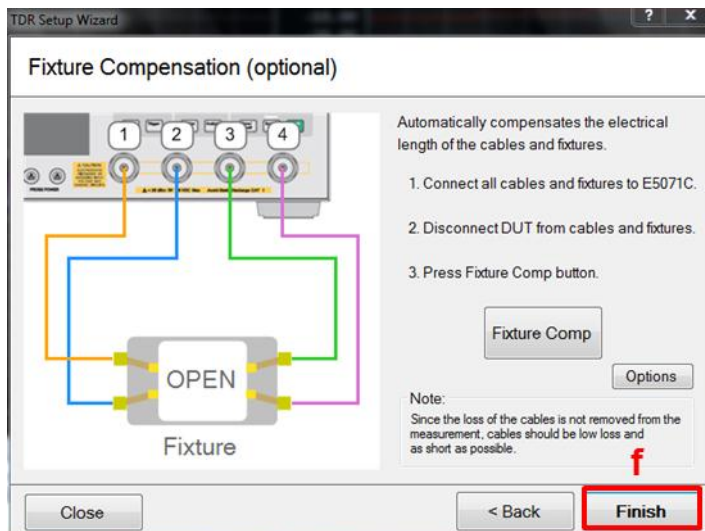
1. ECal Calibration
   a) Click **Setup** tab.
   b) Click **ECal** to launch the TDR Setup Wizard.
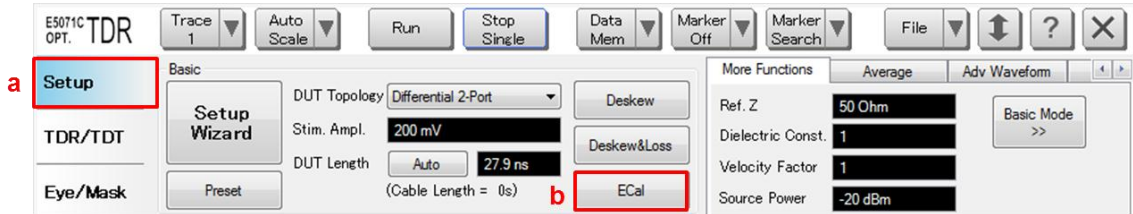
   c) Connect the E5071C ports (port 1 to 4) to the ECal module with RF cables.
   d) Click **Calibrate** to perform ECal calibration.
   e) Click **Next >**.
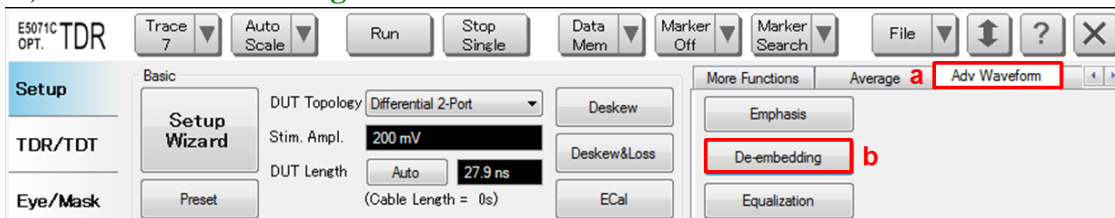

   f) Click **Finish** to complete ECal calibration.

2. De-embedding
   a) Click **Adv Waveform** tab
   b) Click **De-embedding** to launch Advanced Waveform wizard.

   c) Click De-embedding box to set the Touchstone file. 2-port files (*.s2p) for single-ended lines (Port 1, Port 2) or 4-port files (*.s4p) for differential lines (Diff Port 1) can be selected for the de-embedding function.
   d) Load the Touchstone file.
   e) Enable the de-embedding function.
   f) Click **OK**.
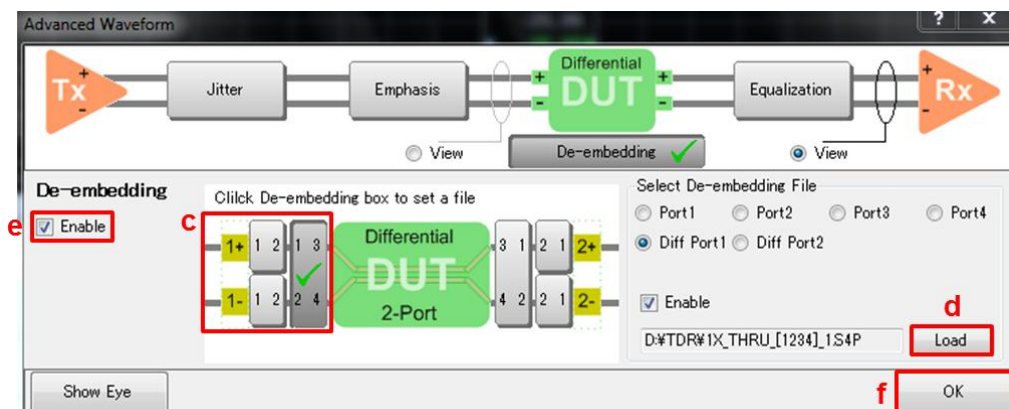
5.4. Measurement

Tx/Rx return loss measurements are made for both common mode and differential return loss. In addition to the return loss, the impedance measurements also can be performed.

The DUT must be powered up and DC isolated, and its data+/data- outputs/inputs must be in the low-Z state at a static value. Also, make sure that Spread Spectrum Clocking (SSC) is turned off.

5.4.1. Tx Output Impedance & Differential/Common-mode Return Loss

The Tx output impedance & differential/common-mode return loss measurements insure the transmitter has the proper output impedance under the actual operating condition.

1. Connect the E5071C ports (port 1 to 2) to the breakout channel with RF cables.
   Note: Unused pots should be terminated with 50 ohm terminators.

2. Press **Trace Max** to maximize the selected trace on the screen.
3. Select **Trace 1 (Tdd11)**.
4. Click **Run**.
5. Power up and place the DUT (Tx) data+/data- outputs in the low-Z state at a static value under the actual operating condition.
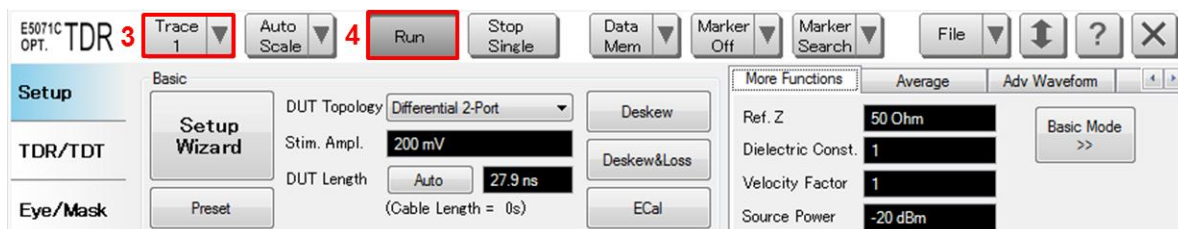
6. Confirm the measured output impedance is within the tolerance.
7. Select **Trace 2 (Sdd11)**.
8. Open **TDR/TDT** tab.
9. Input horizontal scale (400 MHz/div) and horizontal position (50 MHz).
10. Confirm the measured return loss is within the limit shown below.
11. Select **Trace 4 (Scc11)**.
12. Input horizontal scale (400 MHz/div) and horizontal position (50 MHz).
13. Confirm the measured return loss is within the limit shown below.

Return Loss	2.5 GT/s	5 GT/s	8 GT/s	Note
Tx differential return loss	-10 dB	-8 dB	-4 dB	Tr2
Tx common-mode return loss	-6 dB	-6 dB	-3 dB	Tr4

5.4.2. Rx Input Impedance & Differential/Common-mode Return Loss

The Rx input impedance & differential/common-mode return loss measurements insure the receiver has the proper input impedance under the actual operating condition.

1. Connect the E5071C ports (port 1 to 2) to the breakout channel with RF cables.
   Note: Unused fixture pots should be terminated with 50 ohm terminators.
2. Press **Trace Max** to maximize the selected trace on the screen.
3. Select **Trace 1 (Tdd11)**.
4. Click **Run**.
5. Power up and place the DUT (Rx) data+/data- inputs in the low-Z state at a static value under the actual operating condition.
6. Confirm the measured input impedance is within the tolerance.
7. Select **Trace 6 (Sdd11)**.
8. Open **TDR/TDT** tab.
9. Input horizontal scale (400 MHz/div) and horizontal position (50 MHz).

10. Confirm the measured return loss is within the limit shown below.
11. Select **Trace 8 (Scc11)**.
12. Input horizontal scale (400 MHz/div) and horizontal position (50 MHz).
13. Confirm the measured return loss is within the limit shown below.

| Return Loss	2.5 GT/s	5 GT/s	8 GT/s	Note
Rx differential return loss	-10 dB	-8 dB	-5 dB	Tr6
Rx common-mode return loss	-6 dB	-6 dB	-5 dB	Tr8

6. [Appendix] Manual Setup

The procedures of manual setup for time-domain and frequency domain measurements are introduced in the section. All the following parameters are saved in the E5071C's state file, which is available at: www.keysight.com/find/ena-tdr_pcie-txrx

6.1.Channel & Trace Setup

If TDR setup wizard is shown when launching the TDR software, click **Close** button in the TDR setup wizard main window.

1. Open **Setup** tab in the TDR software.
2. Click **Preset** to preset the instrument. Click **OK** in a dialog box to continue.
3. Set **DUT Topology** to "Differential 2-Port". Click **OK** in a dialog box.
4. Input DUT Length (27.9 ns).
5. Open **More Functions** tab.
6. Input Source Power (-20 dBm).
7. Click **Advanced Mode>>**.
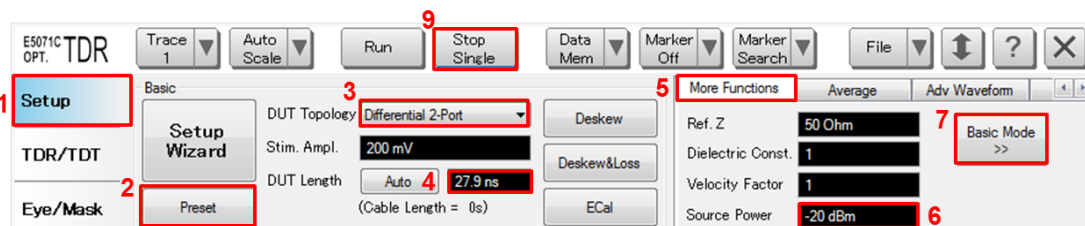
8. A dialog box appears requesting for confirmation. Then click **Yes**. (Clear the check box for "Use Advanced Calibration Methods")
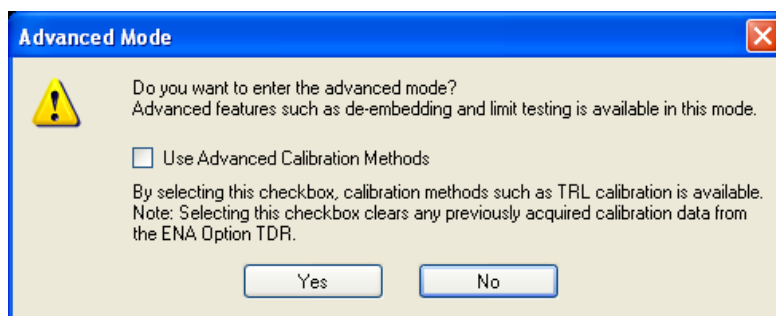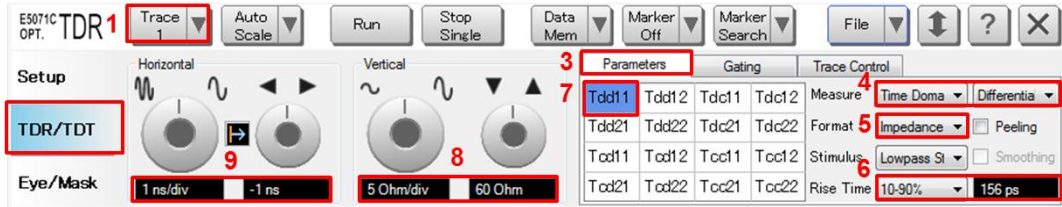

9. Click **Stop Single**.

6.2.Impedance

1. Select **Trace 1**.
2. Open **TDR/TDT** tab.
3. Open **Parameters** tab.
4. Select "Time Domain' and "Differential" for Measure.
5. Select Format to "Impedance"

6. Select **Rise Time** to 10-90% and input value (156 ps).
7. Click **Tdd11**.
8. Input vertical scale (5 Ohm/div) and vertical position (60 Ohm).
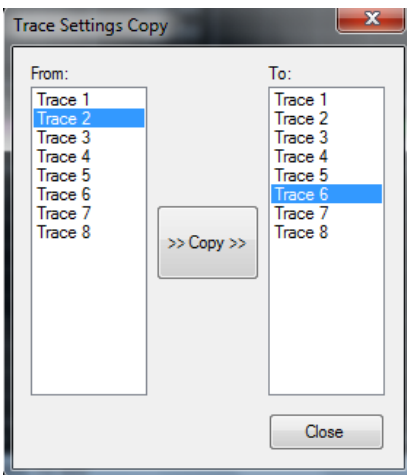9. Input horizontal scale (1 ns/div) and horizontal position (-1 ns).

6.3. Differential Return Loss

1. Select **Trace 2**.
2. Open **Parameters** tab.
3. Select "S-Parameter' and "Differential" for Measure.
4. Select Format to "Log Mag"
5. Select **Rise Time** to 10-90% and input value (156 ps).
6. Click **Sdd11**.
7. Input vertical scale (10 dB/div) and vertical position (-30 dB).
8. Open **Trace Control** tab.
9. Click **Trace Settings Copy** to launch trace copy dialog box.
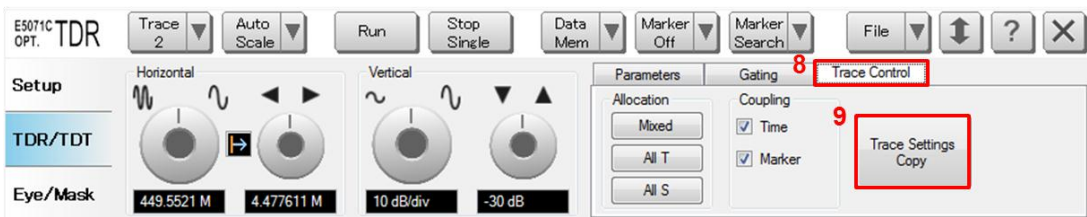
10. Select the Trace 2 in the From list.
11. Select the Trace 6 in the To list.
12. Click **Copy**.
13. Click **Close**.

6.4. Common-mode Return Loss

1. Select **Trace 4**.
2. Open **Parameters** tab.
3. Select "S-Parameter' and "Differential" for Measure.
4. Select Format to "Log Mag"
5. Select **Rise Time** to 10-90% and input value (156 ps).
6. Click **Scc11**.
7. Input vertical scale (10 dB/div) and vertical position (-30 dB).
8. Open **Trace Control** tab.
9. Click **Trace Settings Copy** to launch trace copy dialog box.
10. Select the Trace 4 in the From list.
11. Select the Trace 8 in the To list.
12. Click **Copy**.
13. Click **Close**.

6.5. Defining Limit Line Tables

1. Press **Trace Next** to select trace to set the limit line table.
2. Press **Analysis** > **Limit Test > Limit Line** and turn it **ON** to display limit lines.
3. Press **Analysis** > **Limit Test > Edit Limit Line** to edit the limit line table.

	Type	Begin Stimulus	End Stimulus	Begin Response	End Response
1	MAX	0 s	600 ps	105 U	105 U
2	MIN	0 s	600 ps	75 U	75 U
3					

4. Press **Analysis** > **Limit Test > Limit Test** and turn it **ON**.
5. Press **Analysis** > **Limit Test** > **Fail Sign** to switch the fail sign ON/OFF. When turned on, the Fail sign is displayed on the E5071C's screen, if one or more failed traces are within the channel.
6. Press **System** > **Misc Setup** > **Beeper** > **Beep Warning** to turn ON/OFF the warning beeper.

7. [Appendix] De-embedding File Creation using ENA

Direct probing at pins is not generally feasible, so data is instead measured at the end of the breakout channel. By means of the replica channel it is possible to determine the loss vs. frequency characteristics of the breakout channel and de-embed this channel. The loss effects of the breakout channel may be minimized by means of de-embedding.

The procedure to create the de-embedding file using ENA and replica channel is introduced in the section.

7.1. De-embedding File for Replica Channel

1. Recall the state file as described in 5.2.1. Recalling a State File.
2. Perform the calibration using ECal as described in 5.3.1 ECal Calibration and De-embedding > 1. ECal Calibration.
3. Press **Trace Max** to maximize the selected trace on the screen.
4. Select **Trace 2**.
5. Open **TDR/TDT** tab.
6. Open **Parameters** tab.
7. Click **Sdd21**.
8. Connect the E5071C ports (port 1 to 4) to replica channel with RF cables as shown below (1, 2, 3, 4 are E5071C port numbers).
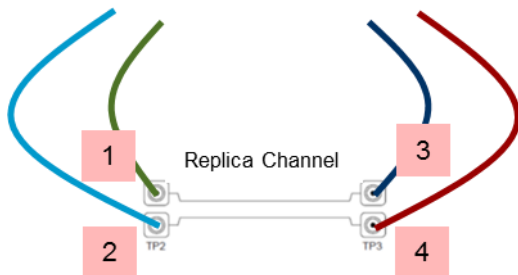

9. Click **Stop Single**.
10. Click **File** and select **Save Touchstone**.
11. Specify a folder and a file name, and click **Save** (*.s4p).
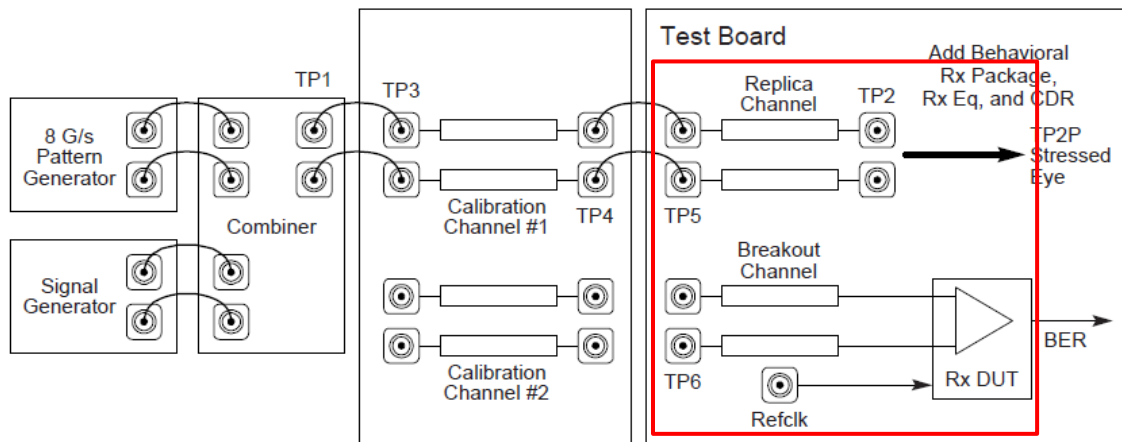12. Click **Sdd11**.

Break-out channels should be designed to have an insertion loss of less than 2 dB and a return loss of greater than 15 dB at 4 GHz, which may require use of low loss dielectric, wide signal traces and back-drilling of break-out vias or use of micro-via technology.

The impedance targets for the breakout channel are 100 ohm differential and 50 ohm single-ended. For best accuracy the actual breakout channel impedance should be within ±10% of these values. For larger deviations a more complex de-embedding technique may be required.
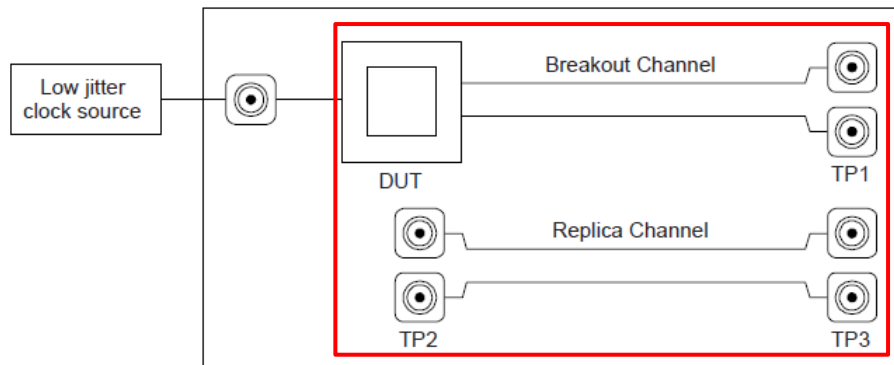
Tx Test Board Example

Rx Test Board Example