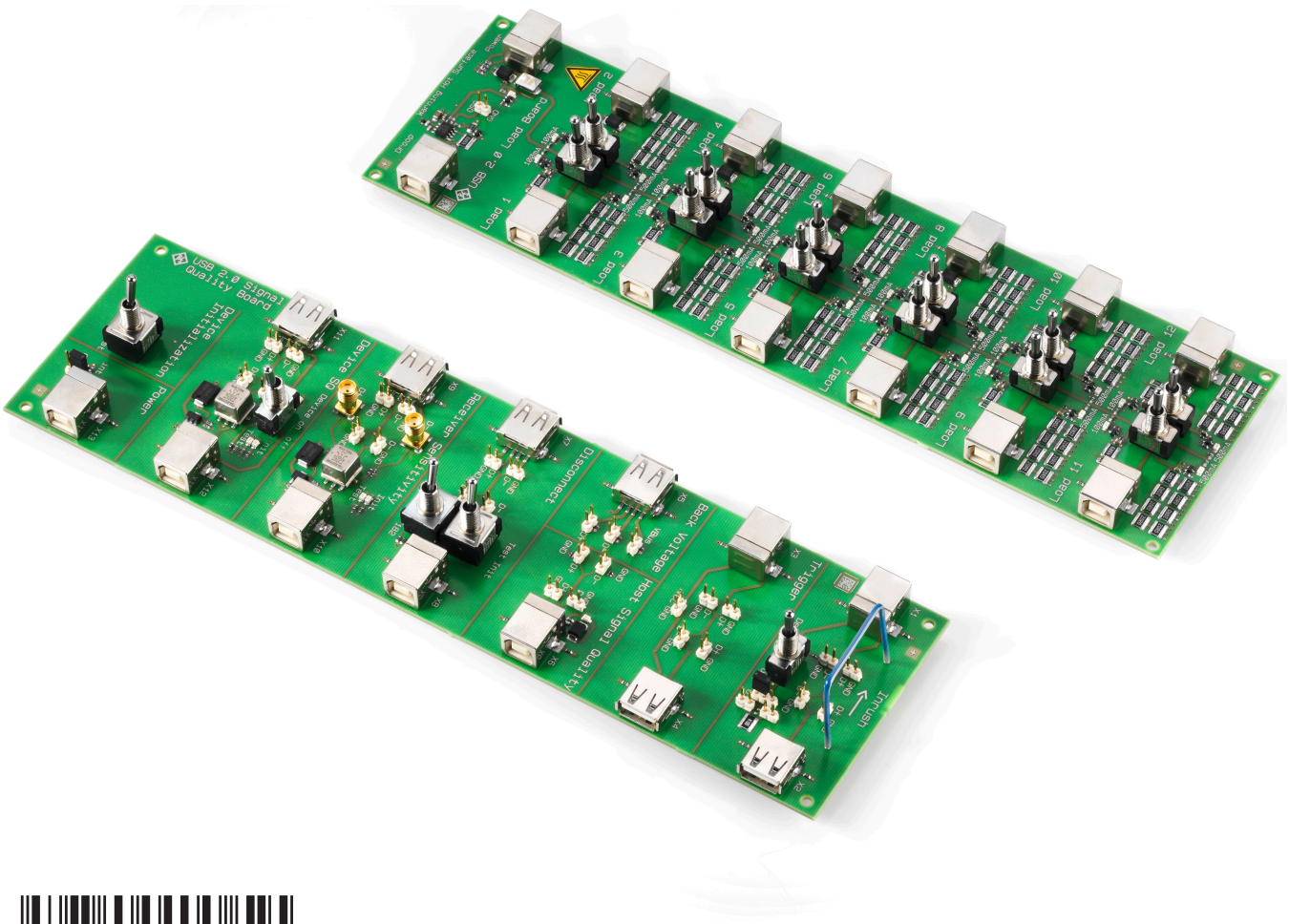
R&S®RTO-K21
USB 2.0 Compliance Test
Test Procedures



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Test & Measurement

Test Procedures

ROHDE&SCHWARZ

This manual describes the USB 2.0 Compliance Test Procedures with option R&S®RTO-K21 (1317.4103.02). The tests require the R&S®RT-ZF01 Test Fixture Set (1317.3420.02) and the R&S ScopeSuite software.

The software contained in this product makes use of several valuable open source software packages. For information, see the "Open Source Acknowledgement" document, which is available for download from the R&S RTO product page at http://www.rohde-schwarz.com/product/rto.html > "Software".
Rohde & Schwarz would like to thank the open source community for their valuable contribution to embedded computing.

Revision History

Rev	Date	Chapter	Comments
01	Dec-10-2012	all	Edit for final release
0101	Feb-12-2013	3.1; 4.1 and 5.1	Update of model numbers
02	Apr-05-2013	1.1 1.2; 1.4; 3.1.7 2.2 3.1.6, 4.1.5	Update of requirements New Update of report formats Added the arbitrary waveform generator
03	Dec-05-2013	all	Update incorporates MOI review and changes in R&S ScopeSuite version 2.0
04	Feb-19-2014	1.5 3.1.1, 4.1.1, 4.1.2 all test case chapters 3.1.5 Annex	Test configuration for USB DUTs New equipment for Signal Quality Tests (USB-IF USB 2.0 hi-speed test fixture + pair of SMA cables) Added info on connecting DUT to test fixture and/or test bed computer Edited test procedure J/K, SE0_NAK New chapter: Ordering information
05	Mar-17-2014	1.5 3.1.4 4.1.3 3.1.5, 4.1.11, 5.1.5	New configuration for DC voltage measurement Improved measurement description Added info on USB-IF host test fixture connection Added info on ProbeMeter usage
06	Feb-19-2016	all 1, 2.1, 2.7, 3.1, 3.2	Update to current R&S ScopeSuite version. New chapters

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The following abbreviations are used throughout this manual: R&S®RTO is abbreviated as R&S RTO, and R&S®ScopeSuite is abbreviated as R&S ScopeSuite.

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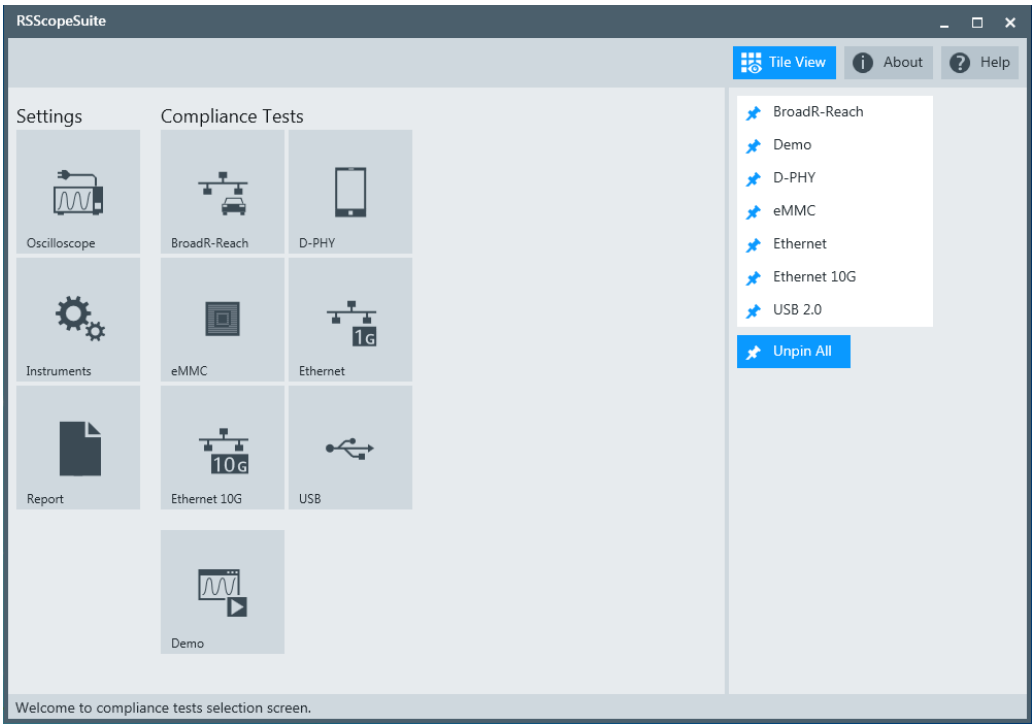
1 R&S ScopeSuite Overview

The R&S ScopeSuite software is used with R&S RTO oscilloscopes. It can be installed on a test computer or directly on the R&S RTO if the instrument has the Windows 7 operating system.



The R&S ScopeSuite main panel has several areas:

- "Settings": connection settings to oscilloscope and other instruments as well as default report settings
- "Compliance Tests": selection of the compliance test
- "Demo": accesses demo test cases that can be used for trying out the software without having a connection to an oscilloscope
- "Help": opens the help file, conatining information about the R&S ScopeSuite configuration
- "About": gives information about the R&S ScopeSuite software
- "Tile View": allows a personalization of the compliance test selection
  You can configure which tests are visible in the compliance test section and which are hidden, so that only the ones you use are displayed.

► To hide a test from the "Compliance Tests" view do one of the following:

a) Right-click on the compliance test you want to hide.
The icon of the test changes, see Figure 1-1. Now with a left click you can hide the test

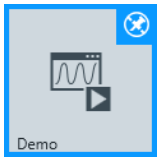


Figure 1-1: Unpin icon

b) Click on "Title View" to show a list of the available test cases. By clicking on a test case in the show list you can pin/unpin it from the main panel.

2 Preparing the Measurements

2.1 Test Equipment

For USB 2.0 compliance tests, the following test equipment is recommended:

- R&S RTO oscilloscope with 4 channels and at least 2 GHz bandwidth.
  For full speed and low speed compliance tests, a 4-channel R&S RTO with less than 2 GHz bandwidth is sufficient.
- R&S RT-ZF1 USB 2.0 compliance test fixture set, which consists of the load board and the signal quality board.
- Probes:
  - 2x single-ended active probes with at least 2 GHz bandwidth
  - 2x differential active probe with at least 2 GHz bandwidth
- Tabor WX2182B/WX2182C 2.3 GS/s dual channel arbitrary waveform generator for receiver sensitivity tests
- R&S ScopeSuite software, which can be installed on a computer or directly on the R&S RTO.
- R&S RTO-K21 USB 2.0 compliance test option (required option, installed on the R&S RTO)
- Make sure that you use the latest version of the USBHSET tool. Check the following websites for downloads:
  - USB 3.0 host: www.usb.org/developers/tools/
  - USB 2.0 host: www.usb.org/developers/tools/usb20_tools/

  Regularly check the USB-IF website compliance.usb.org/index.asp?UpdateFile=Electrical&Format=Standard for USB-IF compliance updates.

2.2 Installing Software and License

The preparation steps have to be performed only once for each computer and instrument that are used for testing.

NOTICE

Uninstall older versions of the R&S ScopeSuite

If an older version of the R&S ScopeSuite is installed, make sure to uninstall the old version before you install the new one. You can find the version number of the current installation in "Help" menu > "About". To uninstall the R&S ScopeSuite, use the Windows Control Panel > "Programs".

To install the R&S ScopeSuite

1. Download the R&S ScopeSuite software from the "Software" section on the Rohde & Schwarz R&S RTO website: www.rohde-schwarz.com/product/rto.html.
2. Install the R&S ScopeSuite software:
   - Either on the computer that is used for testing,
   - or on the R&S RTO if the instrument has a Windows 7 operating system.

To install the license key on the R&S RTO

► When you got the license key of the compliance test option, enable it on the R&S RTO using SETUP > "SW Options".
For a detailed description, refer to the R&S RTO User Manual, chapter "Installing Options", or to the online help on the instrument.

To install USBHSET on the USB host

1. Download the USBHSET tool kit (HS Electrical Test Tool):
   - USB 3.0 host: www.usb.org/developers/tools/
   - USB 2.0 host: www.usb.org/developers/tools/usb20_tools/
2. Install USBHSET on the USB host.

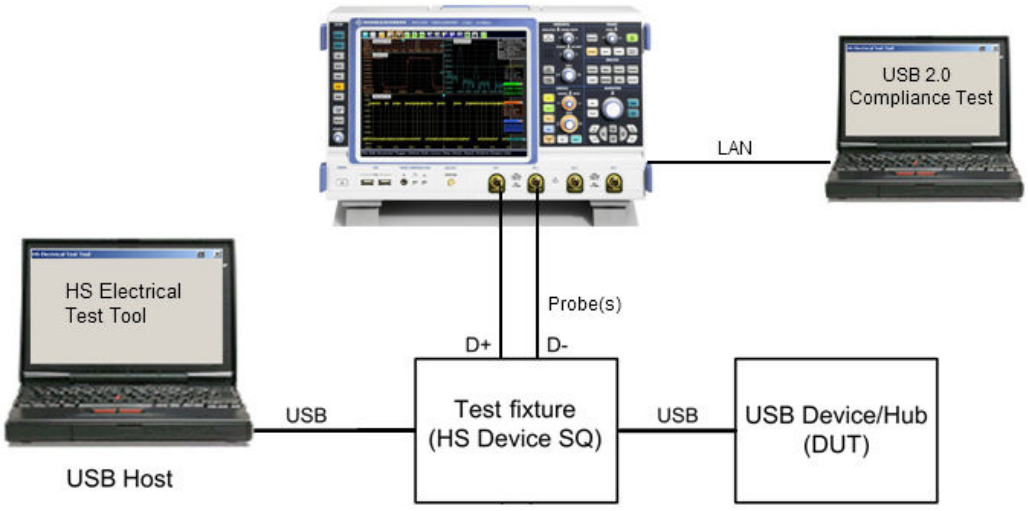


Figure 2-1: Test setup for USB device tests

2.3 Setting Up the Network

If the R&S ScopeSuite software runs on a test computer, the computer and the testing R&S RTO require a LAN connection.

There are two ways of connection:

- LAN (local area network): It is recommended that you connect to a LAN with DHCP server. This server uses the Dynamic Host Configuration Protocol (DHCP) to assign all address information automatically.
  If no DHCP server is available, or if the Tabor WX2182B is used for automatic testing, assign fixed IP adresses to all devices.
- Direct connection of the instruments and the computer or connection to a switch using LAN cables: Assign fixed IP addresses to the computer and the instruments and reboot all devices.

To set up and test the LAN connection

1. Connect the computer and the instruments to the same LAN.
2. Start all devices.
3. If no DHCP server is available, assign fixed IP addresses to all devices.
4. Ping the instruments to make sure that the connection has been established.
5. If VISA is installed, check if VISA can access the instruments.
   a) Start VISA on the test computer.
   b) Validate the VISA address string of each device.

See also:

- Chapter 2.5, "Connecting the R&S RTO", on page 9
- Chapter 2.6, "Connecting the Arbitrary Waveform Generator", on page 11

2.4 Starting the R&S ScopeSuite

To start the R&S ScopeSuite on the test computer or on the oscilloscope:

► Double-click the R&S ScopeSuite program icon.

To start the R&S ScopeSuite on the instrument, in the R&S RTO firmware:

► On the "Analysis" menu, tap "Start Compliance Test".

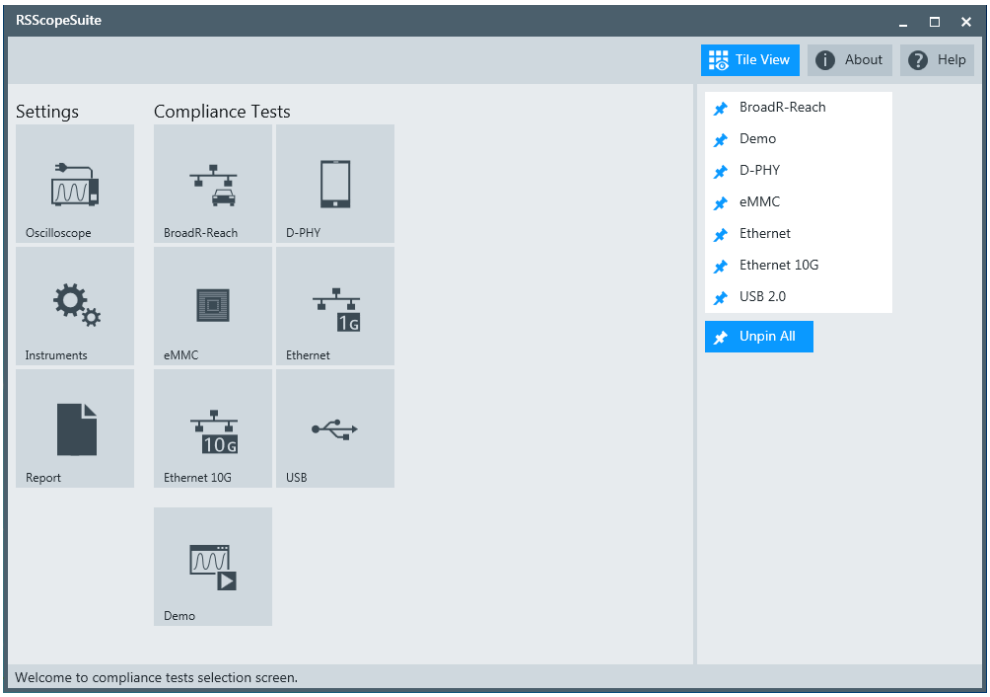
2.5 Connecting the R&S RTO

If the R&S ScopeSuite is installed directly on the instrument, the software detects the R&S RTO firmware automatically, and the "Oscilloscope" button is not available in the R&S ScopeSuite.

If the R&S ScopeSuite software runs on a test computer, the computer and the testing R&S RTO require a LAN connection, see Chapter 2.3, "Setting Up the Network",

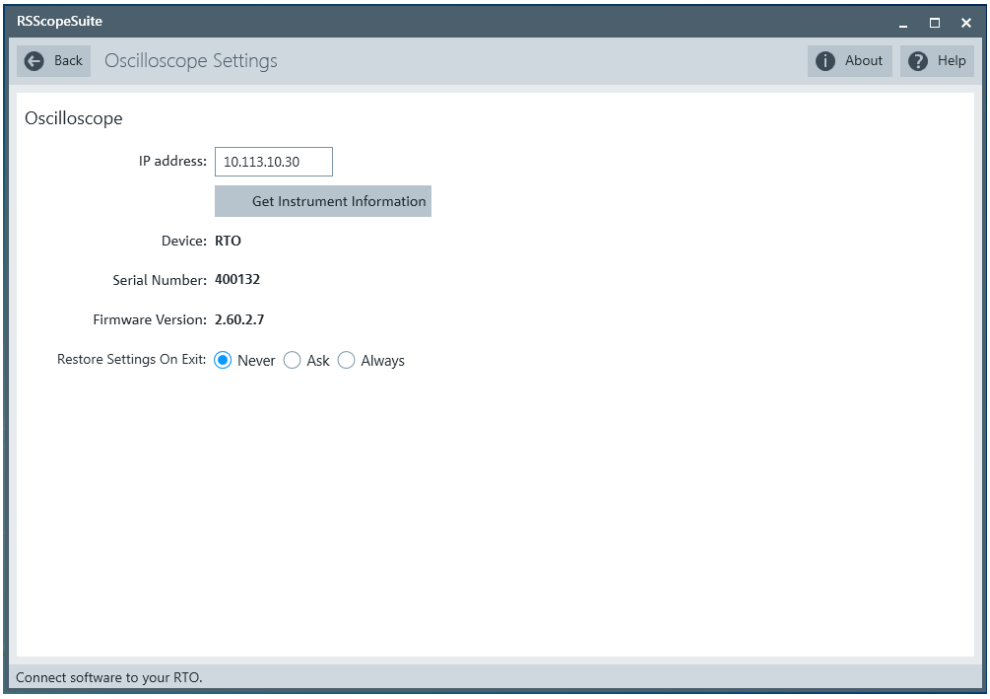
on page 8. The R&S ScopeSuite software needs the IP address of the R&S RTO to establish connection.

1. Start the R&S RTO.
2. Start the R&S ScopeSuite software.
3. Click "Settings" > "Osilloscope".



4. Enter the IP address of the R&S RTO.
   To obtain the IP address: Press the SETUP key on the instrument and tap the "System" tab.
5. Click "Get Instrument Information".

   The computer connects with the instrument and gets the instrument data.



If the connection fails, an error message is shown.

2.6 Connecting the Arbitrary Waveform Generator

For USB receiver sensitivity tests, an arbitrary waveform generator (AWG) is required. The tests can be performed manually or automatically, depending on the the available AWG.

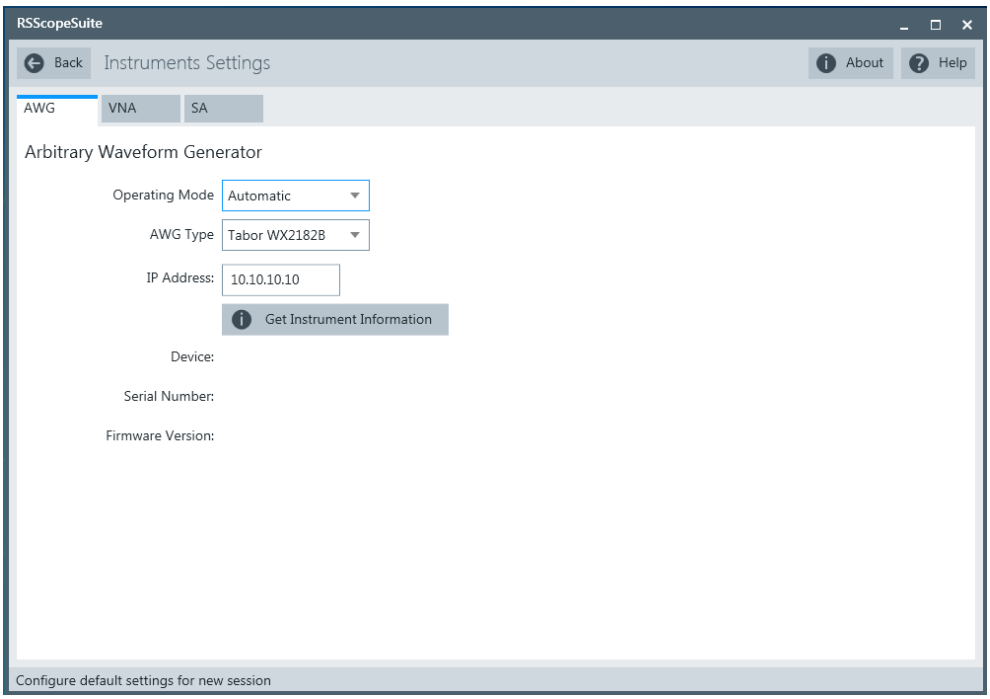
Automatic test execution is possible with all instruments that are listed in the dialog box. In automatic mode, the R&S ScopeSuite configures the instrument and ensures that the AWG sends the required waveforms. Automatic mode requires a LAN connection and the installation of a VISA implementation (NI-VISA, Agilent-VISA, Tektronic-VISA 4.0 and above) on the computer that is running the R&S ScopeSuite. If the R&S ScopeSuite is installed on the R&S RTO, no installation is needed because VISA is already installed on the instrument. If the Tabor WX2182B is used for automatic testing, fixed IP addresses are required.

For manual test execution it is recommended to use one of the listed AWGs. Moreover, any AWG can be used that has a sampling rate above 1.44 GSa/sec. In manual mode, you connect the AWG to the test board and configure the instrument manually. VISA is not required. The R&S ScopeSuite uses VISA if it is installed, otherwise it uses the VXI-11 protocol.

To configure the arbitrary waveform generator for automatic testing

1. Connect the computer and the AWG and set up the LAN connection, see Chapter 2.3, "Setting Up the Network", on page 8.

2. In the R&S ScopeSuite, click "Instruments".
3. Click the "AWG" tab.
4. Select the "Automatic" operating mode.
5. Select the "AWG Type" and enter its IP address.



6. Click "Get Instrument Information".

   The computer or R&S RTO connects with the instrument and retrieves the instrument data.

7. If the connection to the Tabor arbitrary waveform generator failed, check on the instrument and if the IP address is assigned correctly.

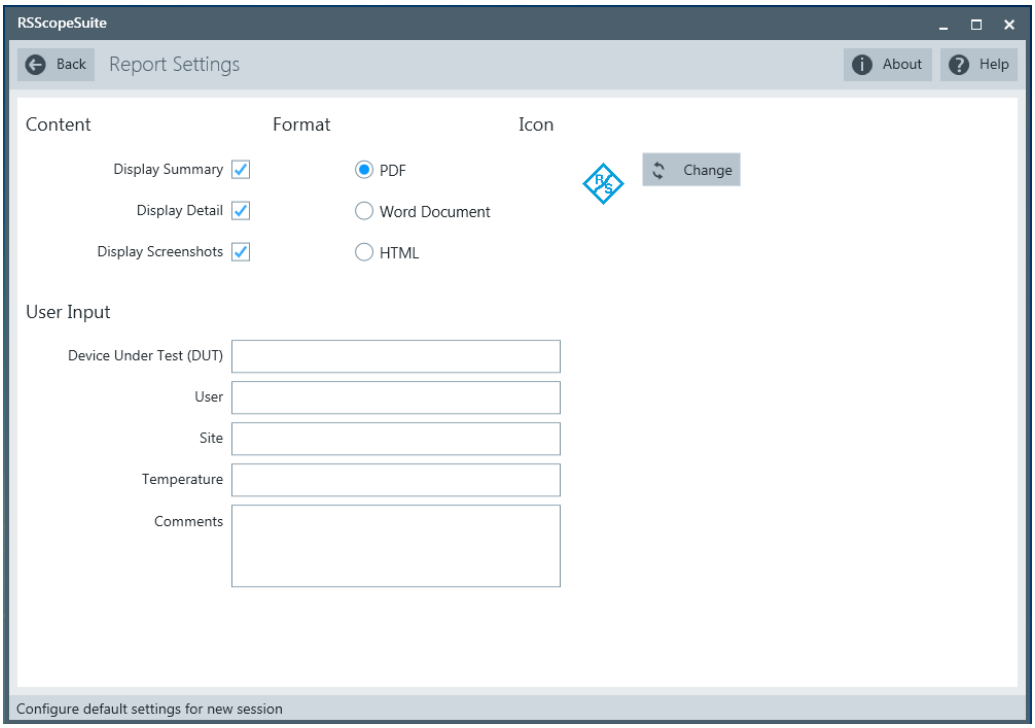
To configure the AWG for manual testing

1. In the "AWG" tab, enable the "Manual" operating mode.
2. Connect the AWG to the test fixture as described in the test wizard. To create the test waveforms, use the files `MIN_ADD1.txt` and `IN_ADD1.txt`, which are provided in the installation directory of the R&S ScopeSuite.

2.7 Report Configuration

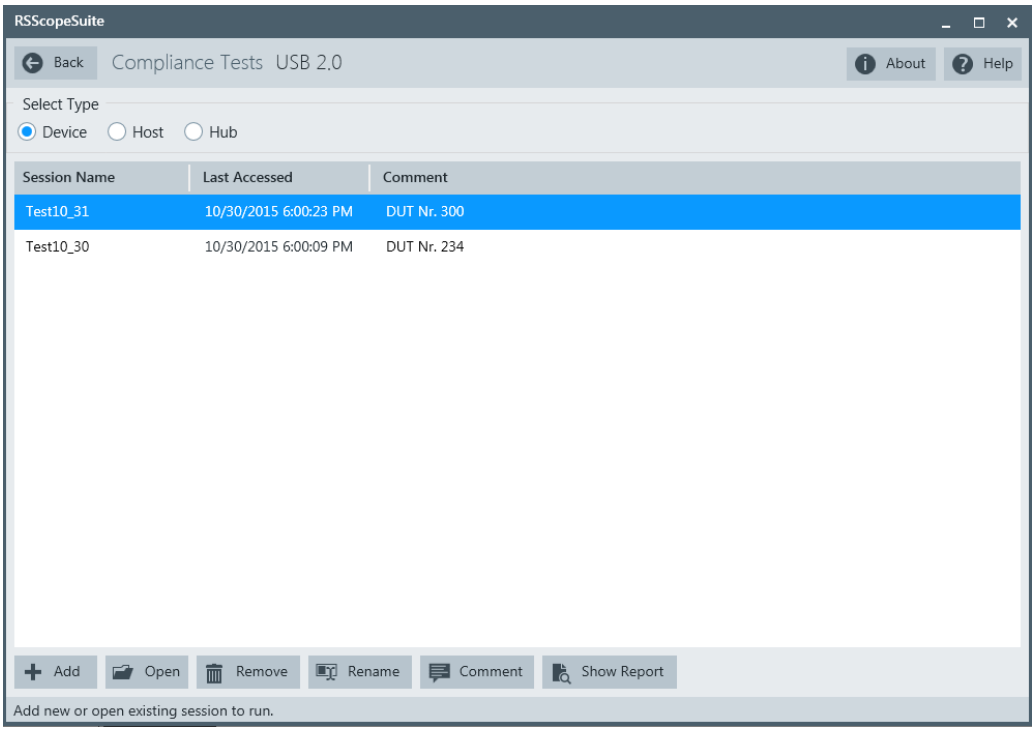
In the "Report Configuration" menu, you can select the format of the report and the details to be included in the report. You can also select an icon that will be displayed in the upper left corner of the report.

Additionally, you can enter common information on the test that will be written in the "General Information" section of the test report.



3 Performing Tests

3.1 Starting a Test Session



After you open a compliance test the "Session Selection" dialog appears. In this dialog you can create new sessions, open or view existing report.

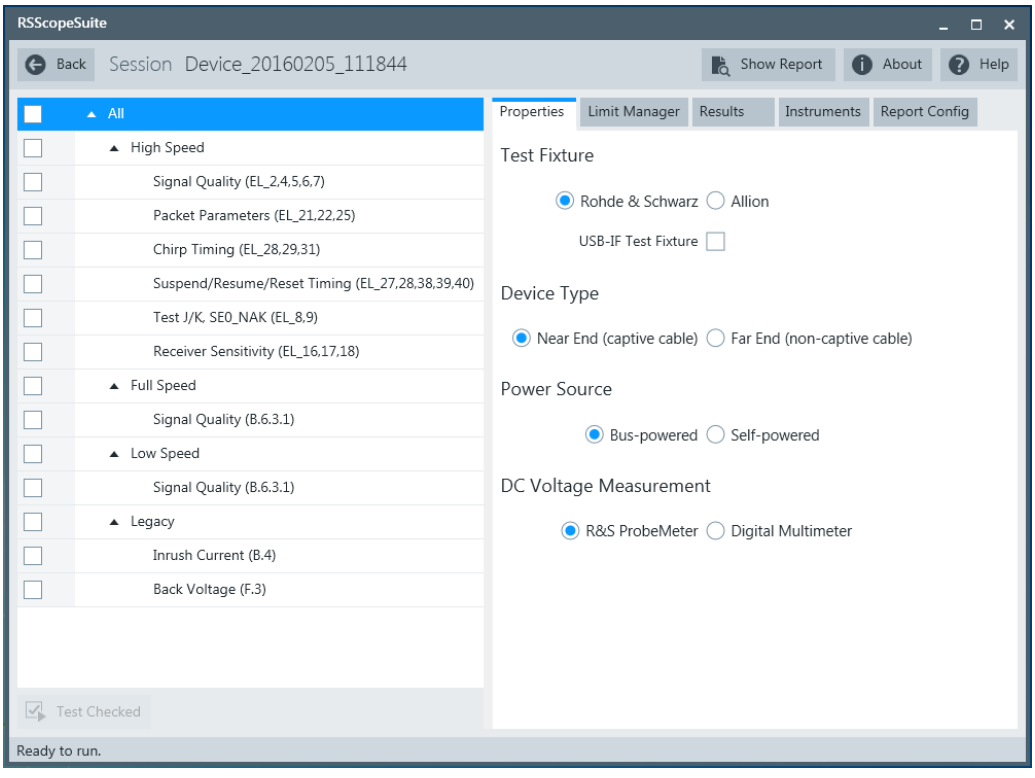
The following functions are available for handling test sessions:

Function	Description
"Add"	Adds a new session
"Open"	Opens the selected session
"Remove"	Removes the selected session
"Rename"	Changes the "Session Name"
"Comment"	Adds a comment
"Show report"	Generates a report for the selected session

3.2 Configuring the Test

1. In the R&S ScopeSuite window, select the compliance test to be performed:
   - "USB 2.0"
2. Open a test session, see Chapter 3.1, "Starting a Test Session", on page 14.
3. Adjust the "Properties" settings for the test cases you want to perform.
4. Click "Limit Manager" and edit the limit criterias, see Chapter 3.2.1.1, "Limit Manager", on page 16.
5. If you want to use special report settings the "Report Config" tab to define the format and contents of the report. Otherwise the settings defined in "RSScopeSuite" > "Settings" > "Report" will be used. See Chapter 2.7, "Report Configuration", on page 12.
6. Click "Test Checked"/"Test Single" and proceed as descibed in the relevant test case chapter.

3.2.1 General Test Settings



Each session dialog is divided into several sections:

- "Properties": shows the settings that can be made for the test case selected on the left side of the dialog. You can differentiate between the "All" and the sub test properties
  In the "All" > "Properties" tab you can configure the settings for all test cases in the current session. Once you change and save a setting in this tab the changes will be done for all test in the sessions. At the same time there will be a special marking for the functions that have different settings for different sub tests.
- "Limit Manager": sets the measurement limits that are used for compliance testing, see Chapter 3.2.1.1, "Limit Manager", on page 16.
- "Results": shows an overview of the available test results for this session.
- "Instruments": defines instruments settings for connecting to external devices, that are specific for this t est session.
  When a session is first created the global settings ("RSScopeSuite" > "Settings" > "Instruments") are copied to the session. This "Instruments" tab can be used to change those copied defaults.
- "Report Config": defines the format and contents of the report for this session.
  When a session is first created the global settings ("RSScopeSuite" > "Settings" > "Report") are copied to the session. This "Report Config" tab can be used to change those copied defaults.
- "Test Checked"/ "Test Single": starts the selected test group.

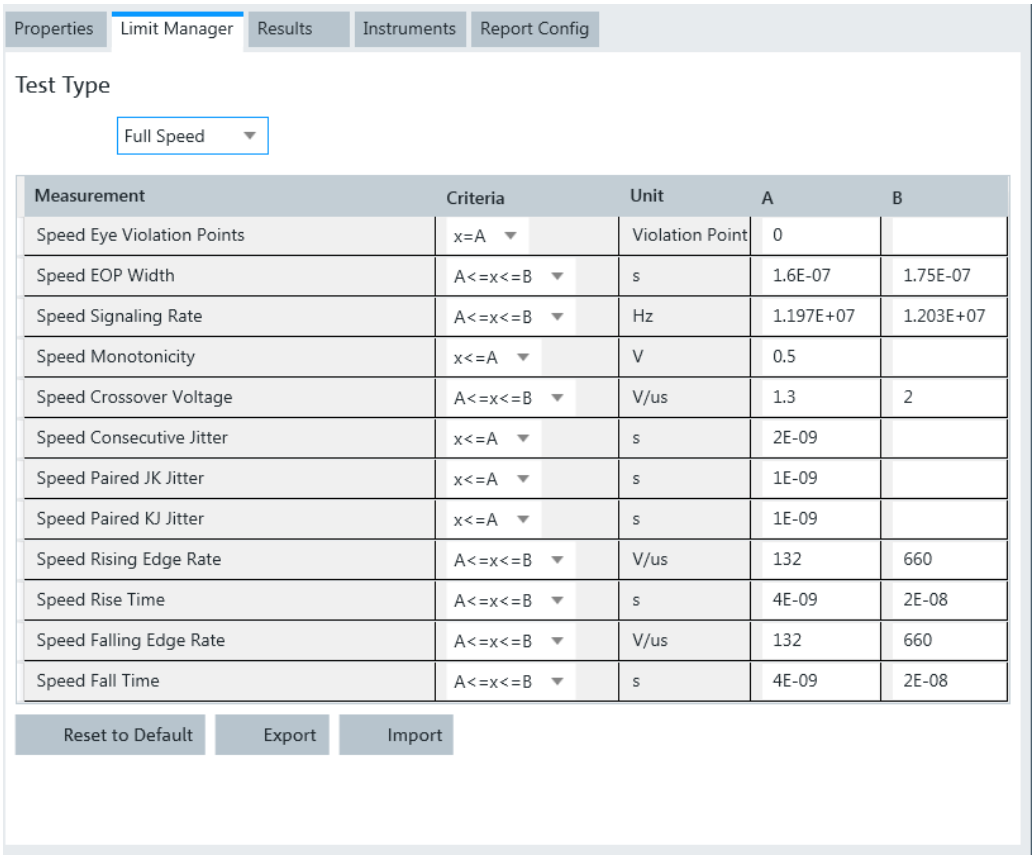
3.2.1.1 Limit Manager

The "Limit Manager" shows the measurement limits that are used for compliance testing.

Each limit comprises the comparison criterion, the unit, the limit value A, and a second limit value B if the criterion requires two limits.

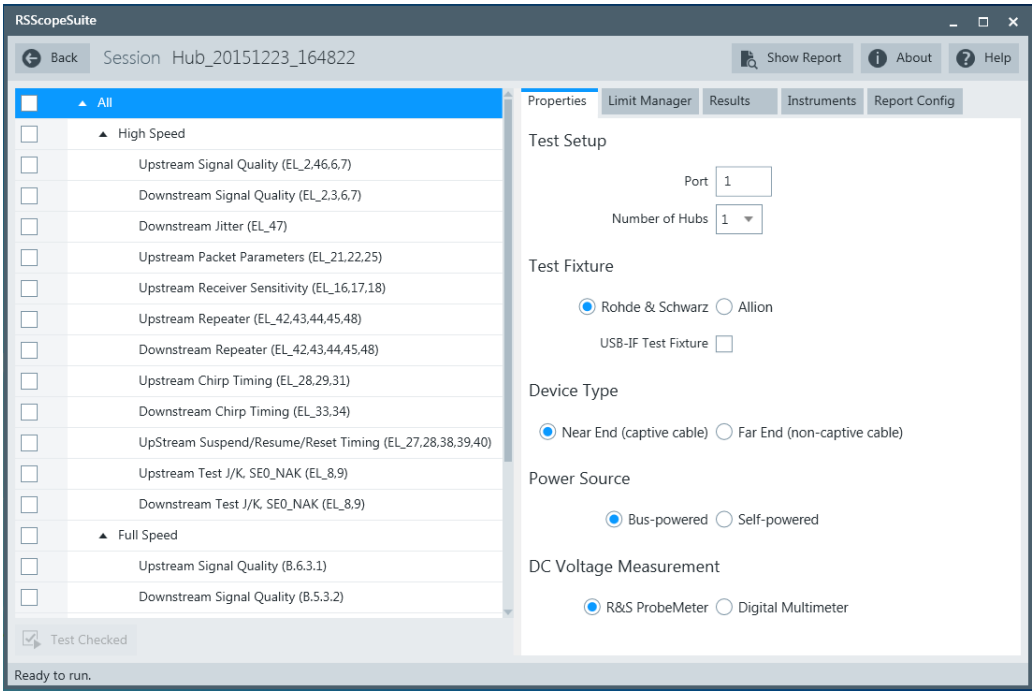
You can set the values to defaults, change the values in the table, export the table in xml format, or import xml files with limit settings.

1. Select the "Test Type".
2. Check and adjust the measurement limits.



3.2.2 Test Configuration for USB 2.0

The test configuration consists of some USB 2.0-specific configuration settings that depend on the selected DUT type - "Device", "Host" or "Hub".



Test Fixture

The R&S RTO-K21 supports three sets of test fixtures:

- R&S RT-ZF1: this set consists of a signal quality board and a load board. They can be used to run all tests that are required for USB high speed, full speed and low speed. For more information, refer to www.scope-of-the-art.com/en/oscilloscopes/RTO-|-Ordering_Information-|-14-|-5430.html.
  To use this set of test fixtures, select "Rohde & Schwarz" under "Test Fixture".
- Allion USB-TF-FXS-1: this set consists of 8 pieces which can be bought together or separately from Allion. For more information, refer to www.allion.com/test_tool_usb.html.
  If you want to use this set of test fixtures, select Allion.
- USB-IF USB2.0 Hi-Speed Signal Quality Test Fixtures – this set consists of a device test fixture and a host test fixture. It is the only set of test fixtures approved by USB-IF and covers USB high speed signal quality tests and hub downstream jitter test. These fixtures are connected to the oscilloscope using a pair of SMA cables instead a differential probe. For more information, refer to compliance.usb.org/index.asp?UpdateFile=Electrical&Format=Standard#86.
  If you want to use this set of fixtures, enable "USB-IF Test Fixture for High Speed Signal Quality Test".
  You can select the USB-IF USB2.0 test fixture set in addition to one of the other test fixture sets. The R&S ScopeSuite guides you to use the USB-IF fixtures for high speed signal quality tests. For all other tests, it guides you to use the selected Allion or R&S RT-ZF1 test fixture set. If "USB-IF Test Fixture for High Speed Signal Quality Test" is disabled, the application guides you to use the selected test fixture set for all tests.

Device Type
If the DUT is a *device or hub (upstream port) without a captive cable*: enable "Near End (non-captive cable)".

If the DUT is a *device or hub (upstream port) with a captive cable*, enable "Far End (captive cable)".

By definition, a captive cable has a type A connector on one end and any connector other than type B on the other end (including soldered cable), see www.usb.org/developers/compliance/cable for details. Also refer to compliance.usb.org/index.asp?UpdateFile=Electrical#8 for further clarifications on "Near End" and "Far End".

Power Source
If the DUT is a *bus powered device or hub (upstream port)*: enable "Bus-powered".

If the DUT is a *self-powered device or hub (upstream port)*, enable "Self-powered".

OTG or Embedded Host
If the DUT is a USB On-The-Go (OTG) or embedded host, enable this setting

Host or Hub Port Number
If the DUT is a *host or a hub (downstream ports)*: enter the port number of the downstream port under test.

Note that only one port number can be entered at one time. If you plan to test multiple downstream ports, remember to update this field before every test cycle.

DC Voltage Measurement
The probes at least 2 GHz bandwidth and at least 2 GHz bandwidth contain a built-in digital voltmeter known as R&S ProbeMeter. It allows DC voltage measurements to be carried out automatically.

If you want to use the R&S ProbeMeter for DC voltage measurement, enable "R&S ProbeMeter".

If you want to use an external voltmeter for DC voltage measurement, enable "Digital Multimeter".

3.3 Initiating the Test

To perform compliance tests, the device under test is connected to the test board in a test-specific way. Using a probe, the test board is connected with the R&S RTO. The probe connections are test-specific. The R&S ScopeSuite guides you step-by-step through the connection setup and the test sequence.

1. Set the test fixture on a nonconductive, static-approved work surface.
2. In the R&S ScopeSuite window, select the compliance test.
3. In the "Session Selection" dialog, select the DUT type.
4. Open a test session, see Chapter 3.1, "Starting a Test Session", on page 14.

5. Check the test configuration settings and adjust, if neccessary. See: Chapter 3.2, "Configuring the Test", on page 15.
6. Click "Test Checked" for starting all checked test cases or "Test Single" for starting only the selected test case.

   The R&S ScopeSuite test wizard explains the following individual setup steps. A detailed test description can be found in the following chapters:
   - Chapter 4, "Device Tests", on page 21
   - Chapter 6, "Host Tests", on page 116
   - Chapter 5, "Hub Tests", on page 79

3.4 Getting Test Results

For each test, the test data - report, diagrams and waveform files - is saved in the following folder:
`%ProgramData%\Rohde-Schwarz\RSScopeSuite\3.0\Sessions\USB\<DUT_Types>\<Session_Name>`

If you resume an existing session, new measurements are appended to the report, new diagrams and waveform files are added to the session folder. Existing files are not deleted or replaced. Sessions data remain until you delete them in the "Results" tab of the session.

The report format can be defined in "RSScopeSuite" > "Settings" > "Report" for all compliance tests (see also Chapter 2.7, "Report Configuration", on page 12). If you want to use special report settings for a session, you can define the format and contents of the report in the "Report Config" tab of the session.

All test results are listed in the "Results" tab. Reports can be provided in PDF, MSWord, or HTML format. To view and print PDF reports, you need a PDF viewer, for example, the Acrobat Reader.

The test report file can be created at the end of the test, or later in the "Session Selection" dialog.

To show a test report

1. In the R&S ScopeSuite window, select the compliance test to be performed.
2. Select the session name in the "Session Selection" dialog and click "Show report".

   The report opens in a separate application window, depending on the file format. You can check the test results and print the report.

To delete the results, diagrams and waveform files of a session

1. In the "Session Selection" dialog select the session and open it.
2. In the "Results" tab, select the result to be deleted.
3. Click "Remove".

4 Device Tests

4.1 High-Speed Device Tests

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- Packet Parameters....29
- Chirp Timing....36
- Suspend/Resume/Reset Timing....41
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4.1.1 Signal Quality

Table 4-1: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the device you want to test	1
Signal quality board, "Device SQ" section or USB-IF USB2.0 hi-speed signal quality device test fixture	R&S RT-ZF1	1
Differential probe or a pair of SMA cables if USB-IF device test fixture is used	differential probe with at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

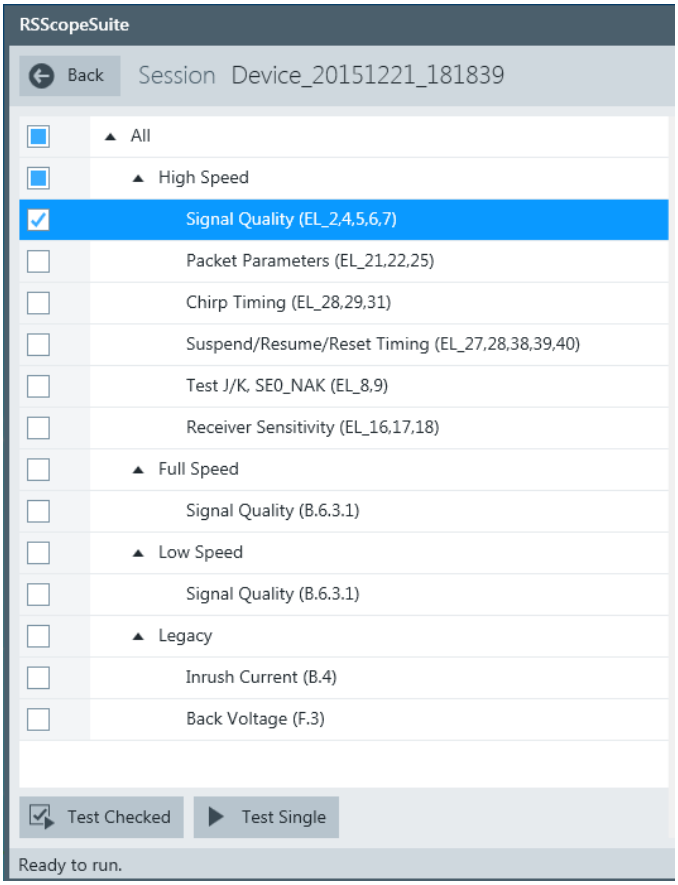
Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Device"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Signal Quality (EL_2,4,5,6,7)" test case and click "Start".



2. Connect the DUT to the test fixture as shown in the picture.

Figure 4-1: R&S RT-ZF1: connection to DUT

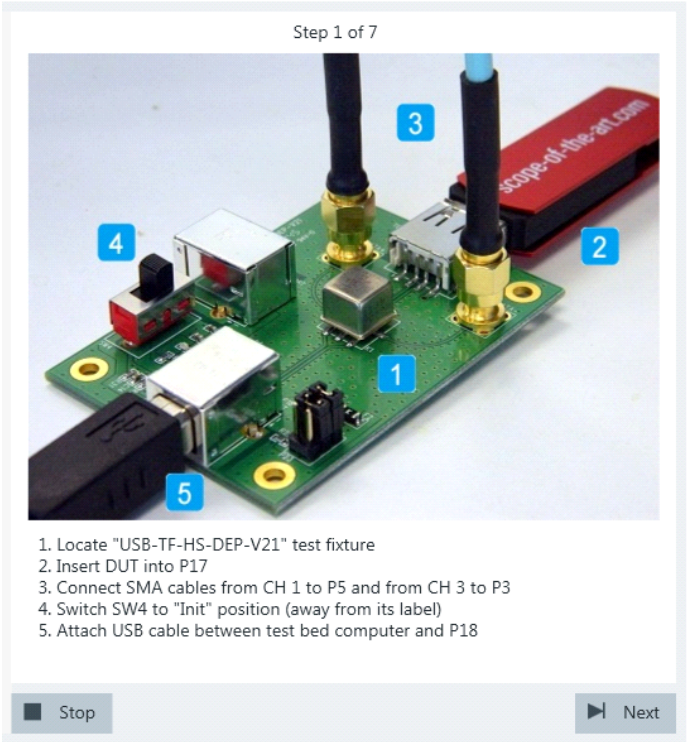
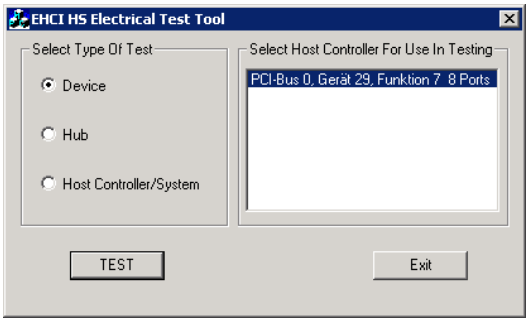


Figure 4-2: USB-IF USB2.0 Hi-Speed Signal Quality device test fixture: connection to DUT

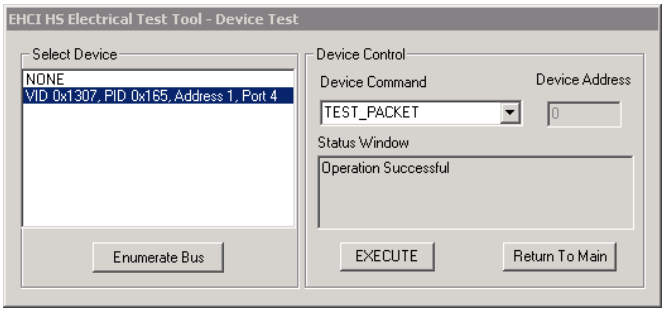
If the DUT has a type A connector attached, plug it into the test fixture directly. Otherwise, connect the DUT to the test fixture using a 4-inch cable.
Use a 1-meter non-captive cable to connect the test bed computer to the test fixture.

Note: Make sure the "Device Type" setting in the "Test Configuration" is enabled correctly according to compliance.usb.org/index.asp?UpdateFile=Electrical#8 (see Chapter 3.2, "Configuring the Test", on page 15).

3. Click "Next".
4. Start the HS Electrical Test Tool on the test bed computer.
5. Select "Device" on the left side, and the host controller to which the DUT is connected on the right side.
   Note: the values in the list may vary.



6. Click "TEST".
7. Select "TEST_PACKET" from the "Device Command" list.



8. Click "EXECUTE" and wait until "Operation Successful" is shown under "Status Window".
9. On the test fixture, switch to "Test" position as shown in the picture.

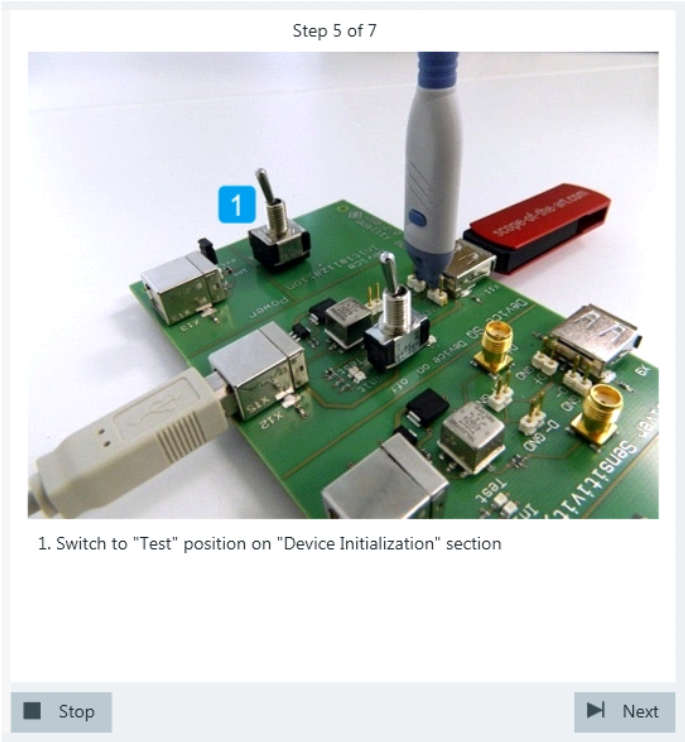


Figure 4-3: R&S RT-ZF1: "Test" position

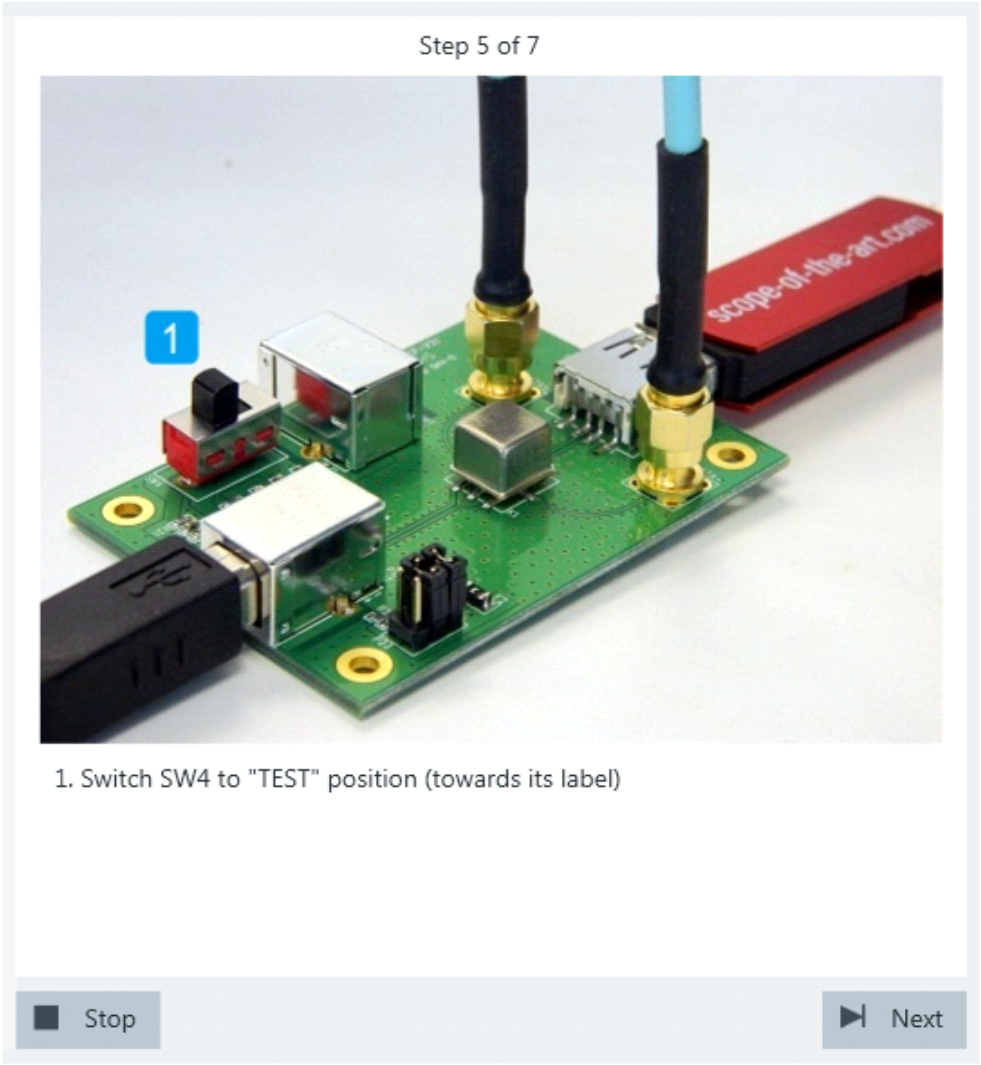
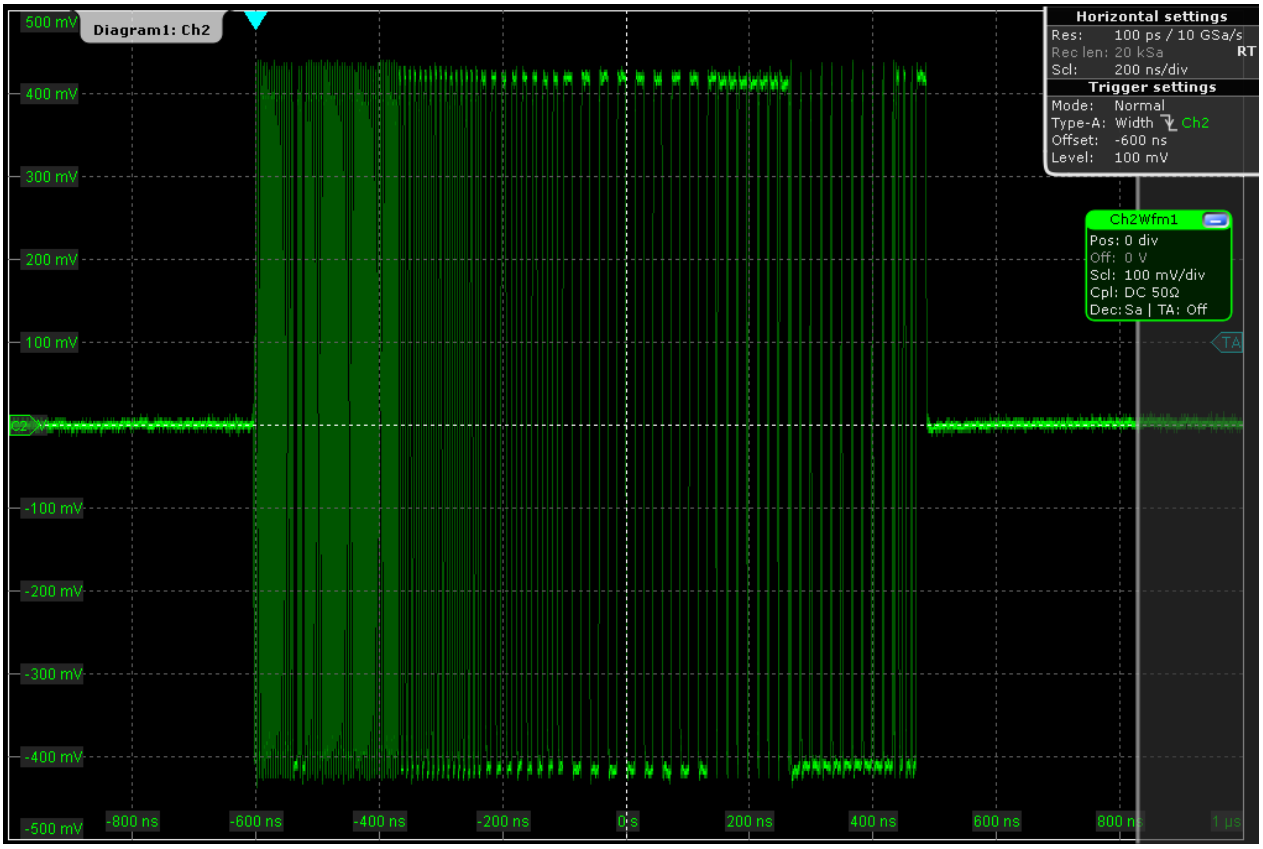


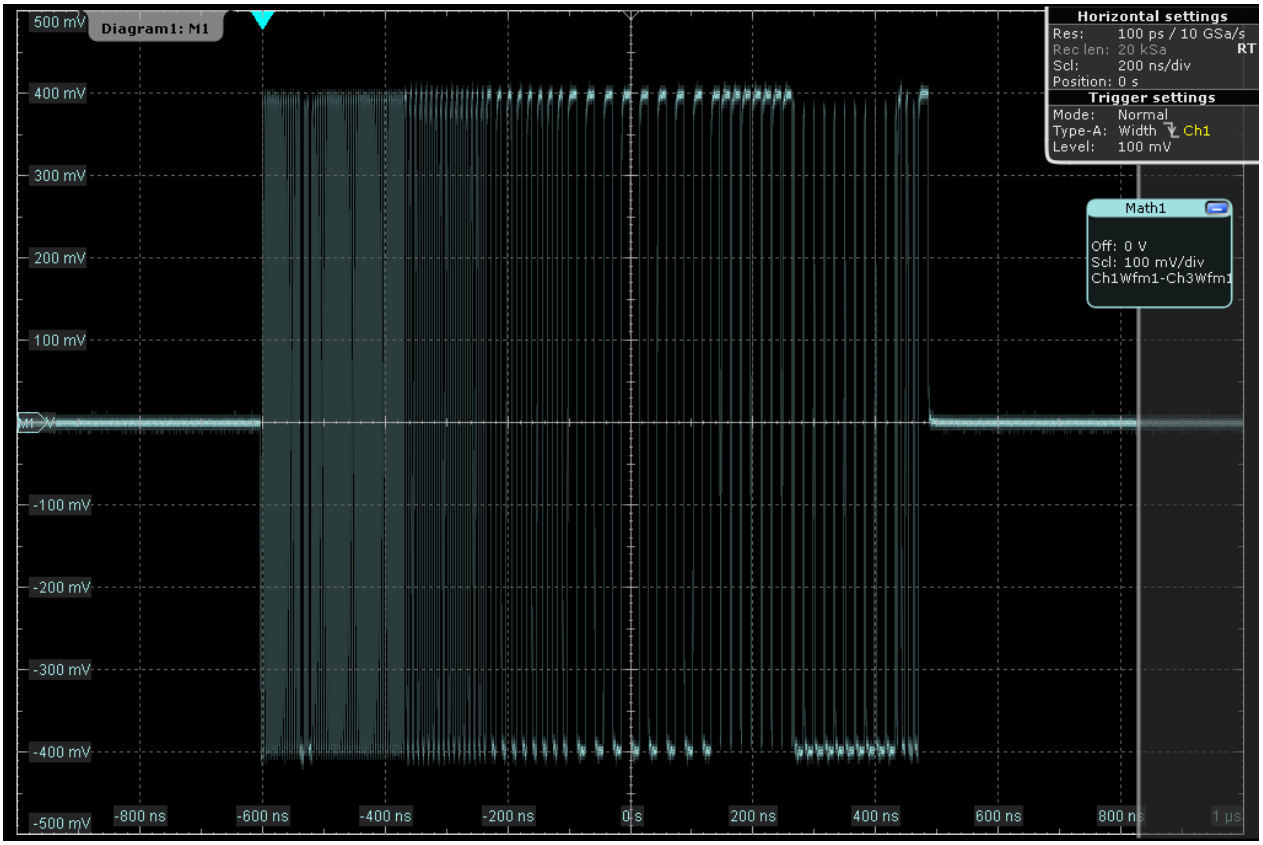
Figure 4-4: USB-IF USB 2.0 hi-speed signal quality device test fixture: "Test" position

10. Click Next.

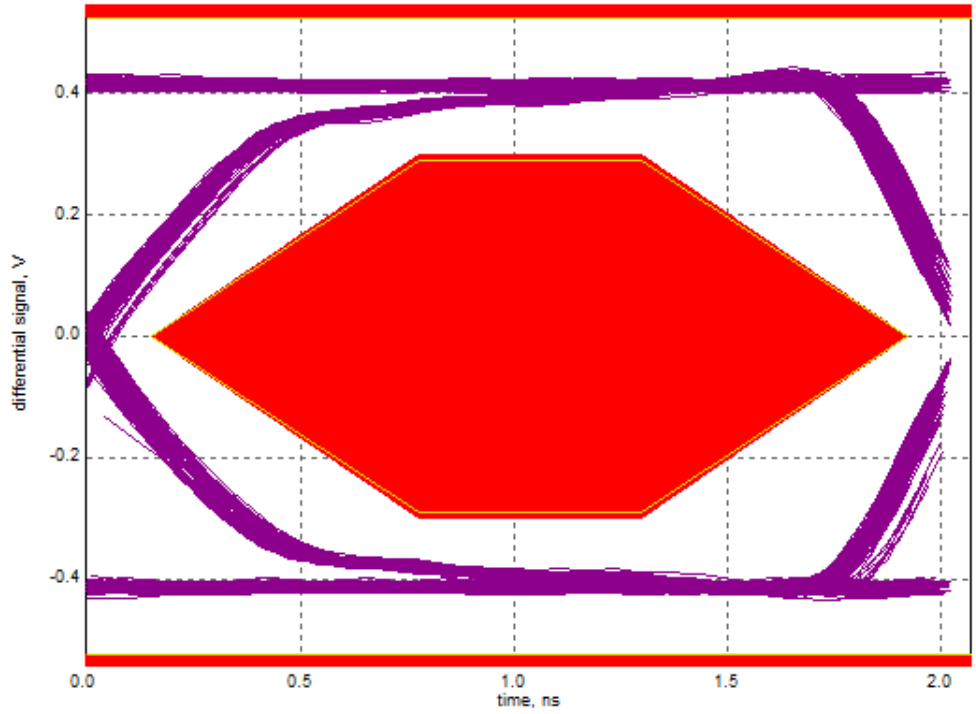
    The DUT sends test packets that look like this:



If USB-IF USB2.0 Hi-Speed Signal Quality device test fixture is used, the application uses the built-in math function to create the differential signal of D+ and D-. The waveform will look like this:



11. These packages are analyzed in an eye diagram.



The results are saved and can be viewed in the report.

4.1.2 Packet Parameters

Table 4-2: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the device you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

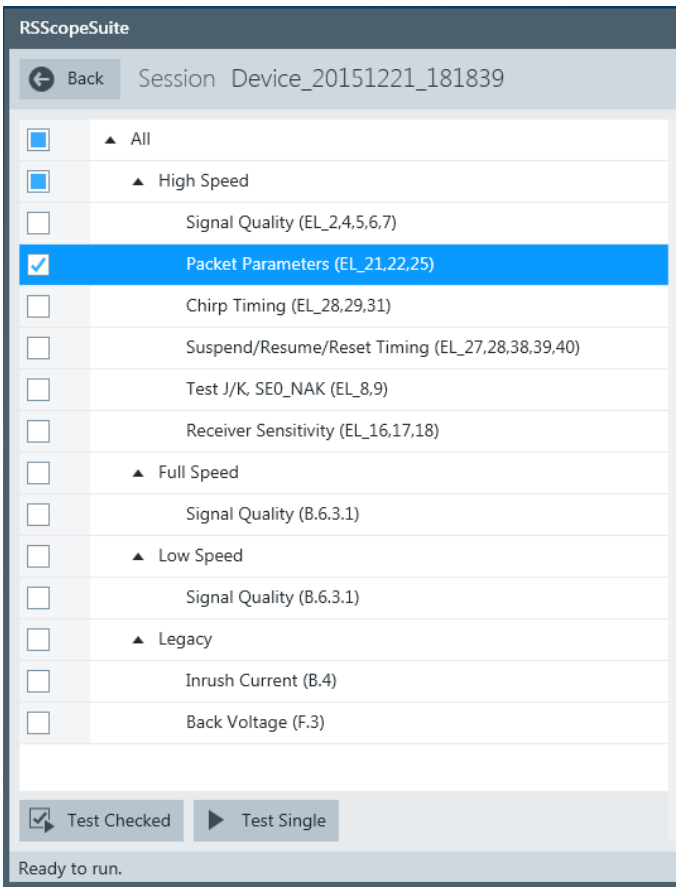
Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9

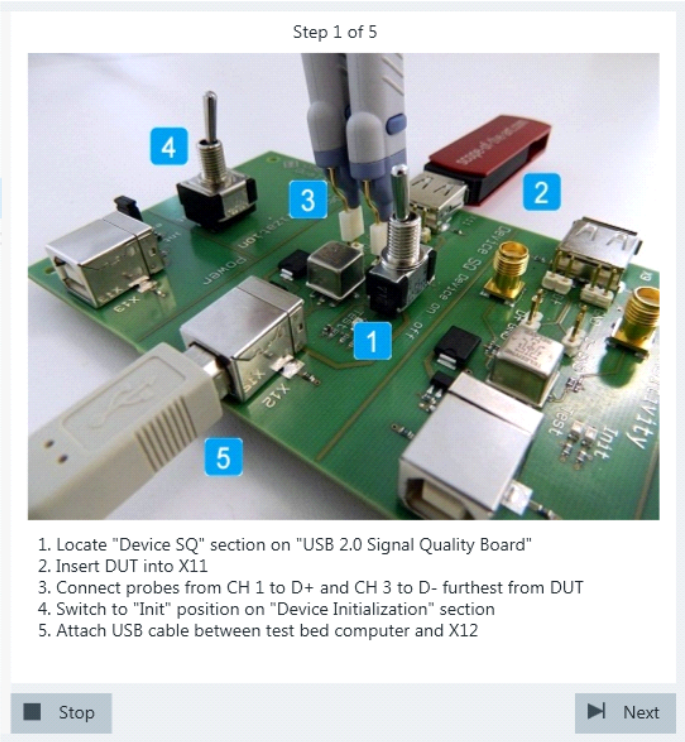
- Configure and initiate the test with DUT type = **"Device"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Packet Parameters (EL_21,22,25)" test case and click "Test Single".

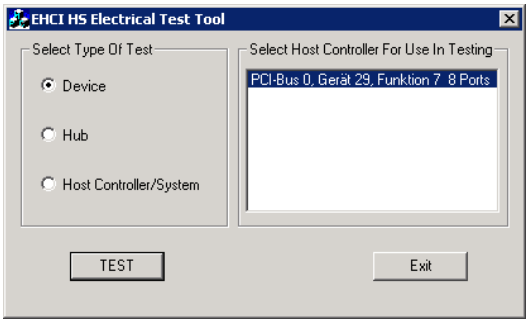


2. Connect the DUT to the test fixture as shown in the picture.

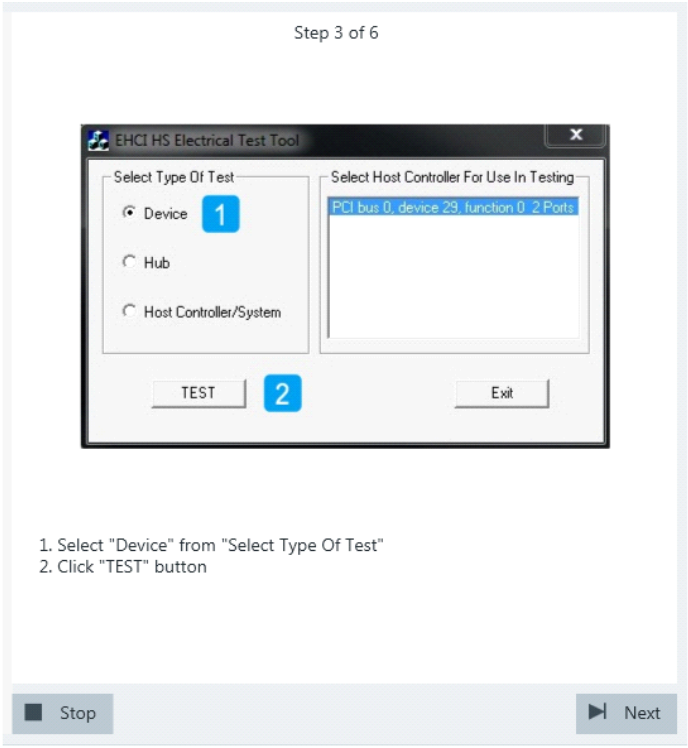


If the DUT has a type A connector attached, plug it into the test fixture directly. Otherwise, connect the DUT to the test fixture using a 4-inch cable.
Use a 1-meter non-captive cable to connect the test bed computer to the test fixture.

3. Click "Next".
4. Start the HS Electrical Test Tool on the test bed computer.
5. Select "Device" on the left side, and the host controller to which the DUT is connected on the right side.
   Note: the values in the list may vary.

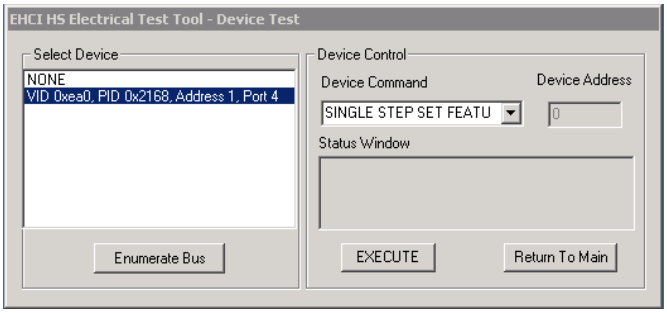


6. Click "TEST".
7. Click "Next" in the R&S ScopeSuite.



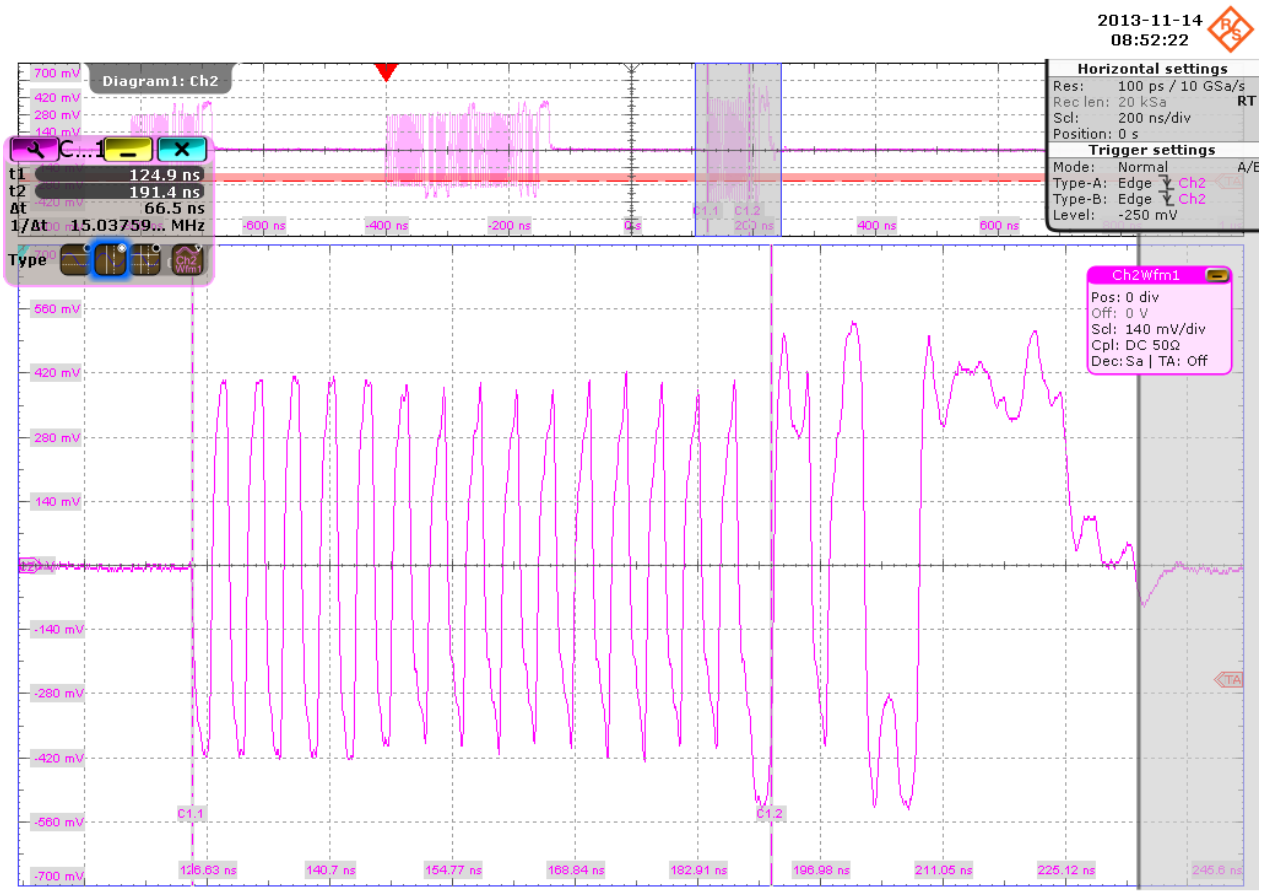
The RTO is set to trigger on the packets sent between host (Set_Feature Packet) and device.

8. Select "SINGLE STEP SET FEATURE" on the "Device Command" list.

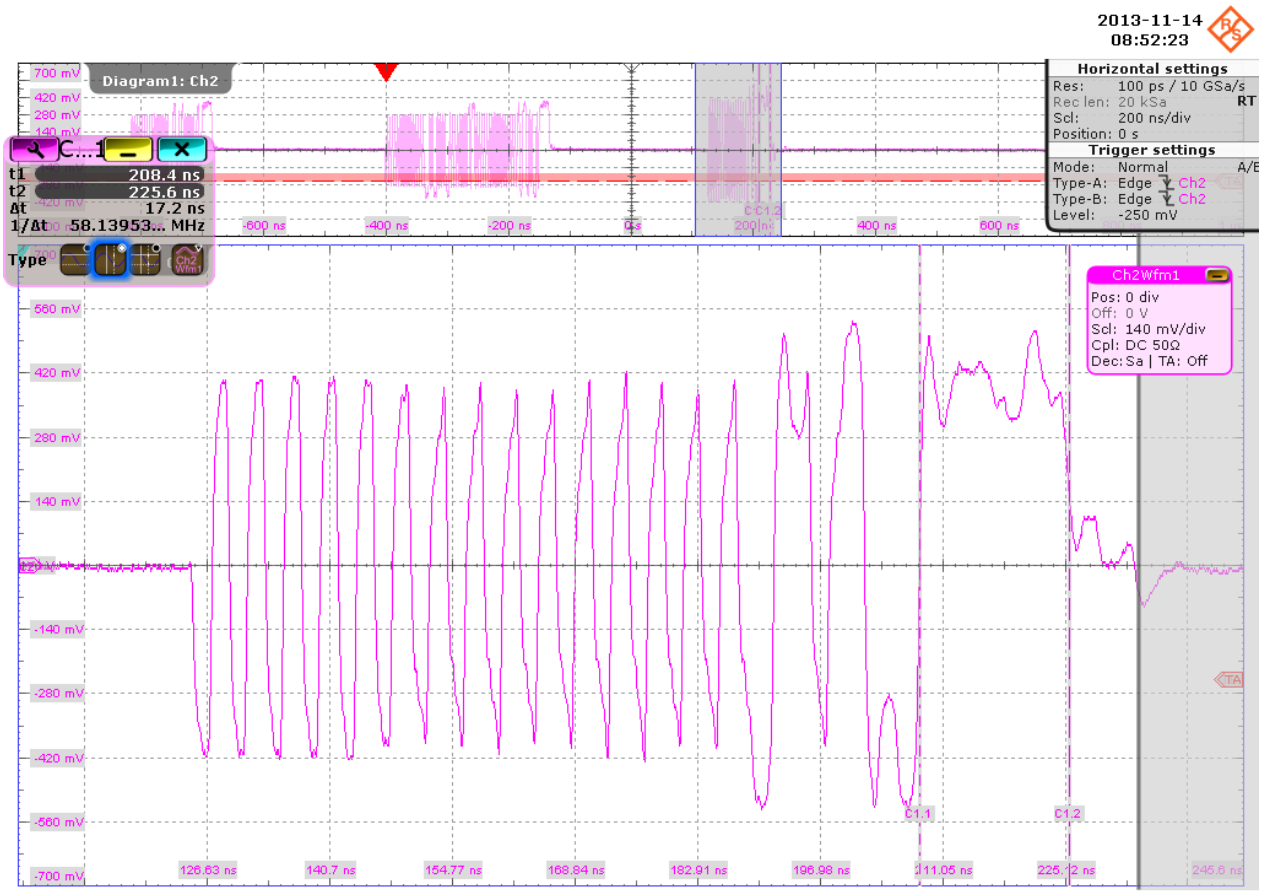


9. Click "EXECUTE" and wait for its change to "Step".

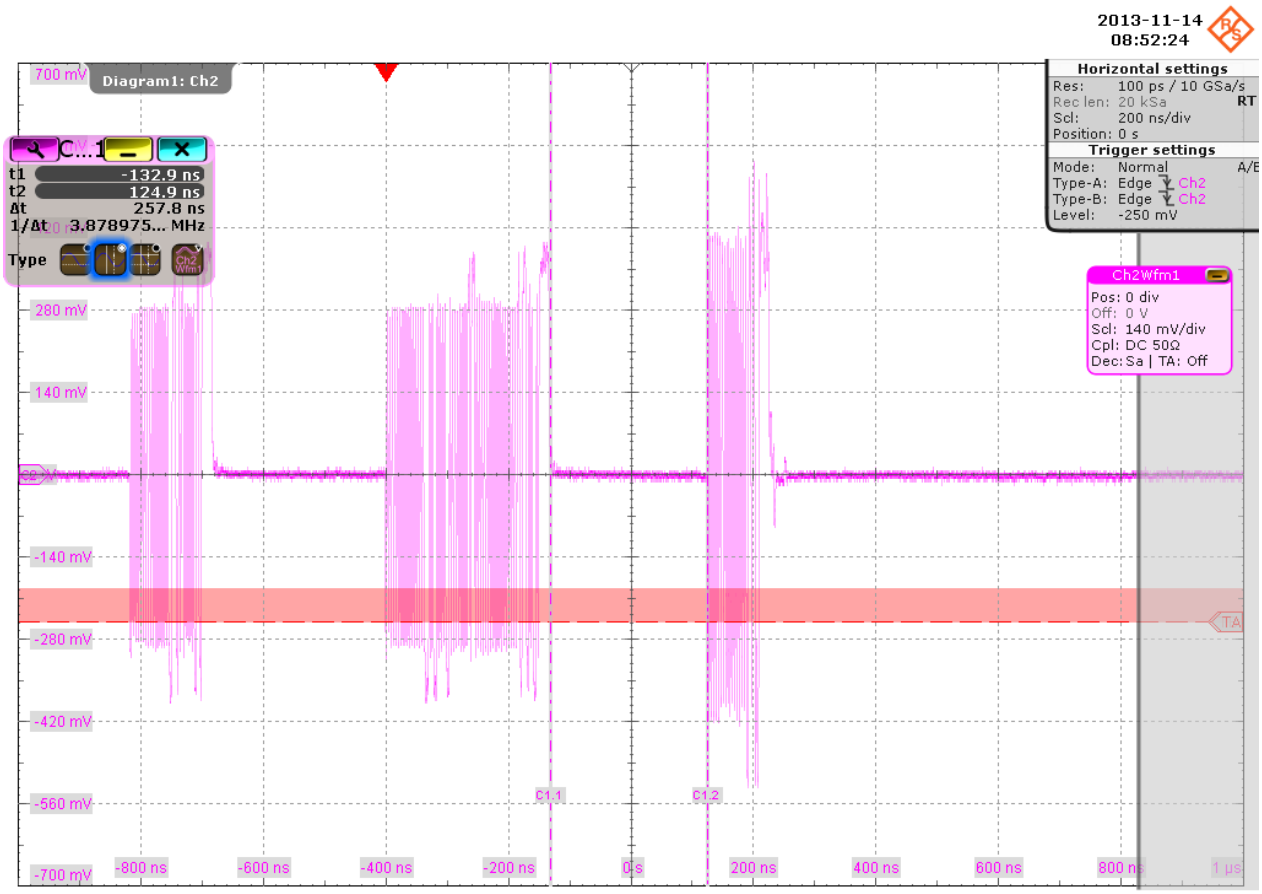
   A waveform is captured as pictured below.



The first packet on the left is an "IN" packet sent by the test bed computer. It is followed by a "Set Feature" packet (middle) also sent from the test bed computer. On the right you can see the answer from the DUT with higher amplitude than the packets from the test bed computer.
The application counts the number of bits in the DUT packet SYNC field by measuring the duration of the first 31 pulses. This is EL_21.

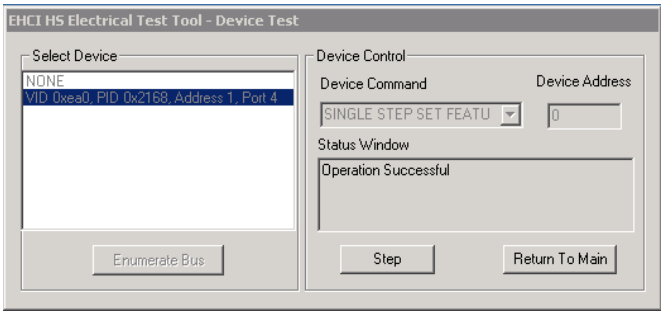


The application counts the number of bits in the DUT packet EOP field by measuring the duration of the widest pulse. This is EL_25.

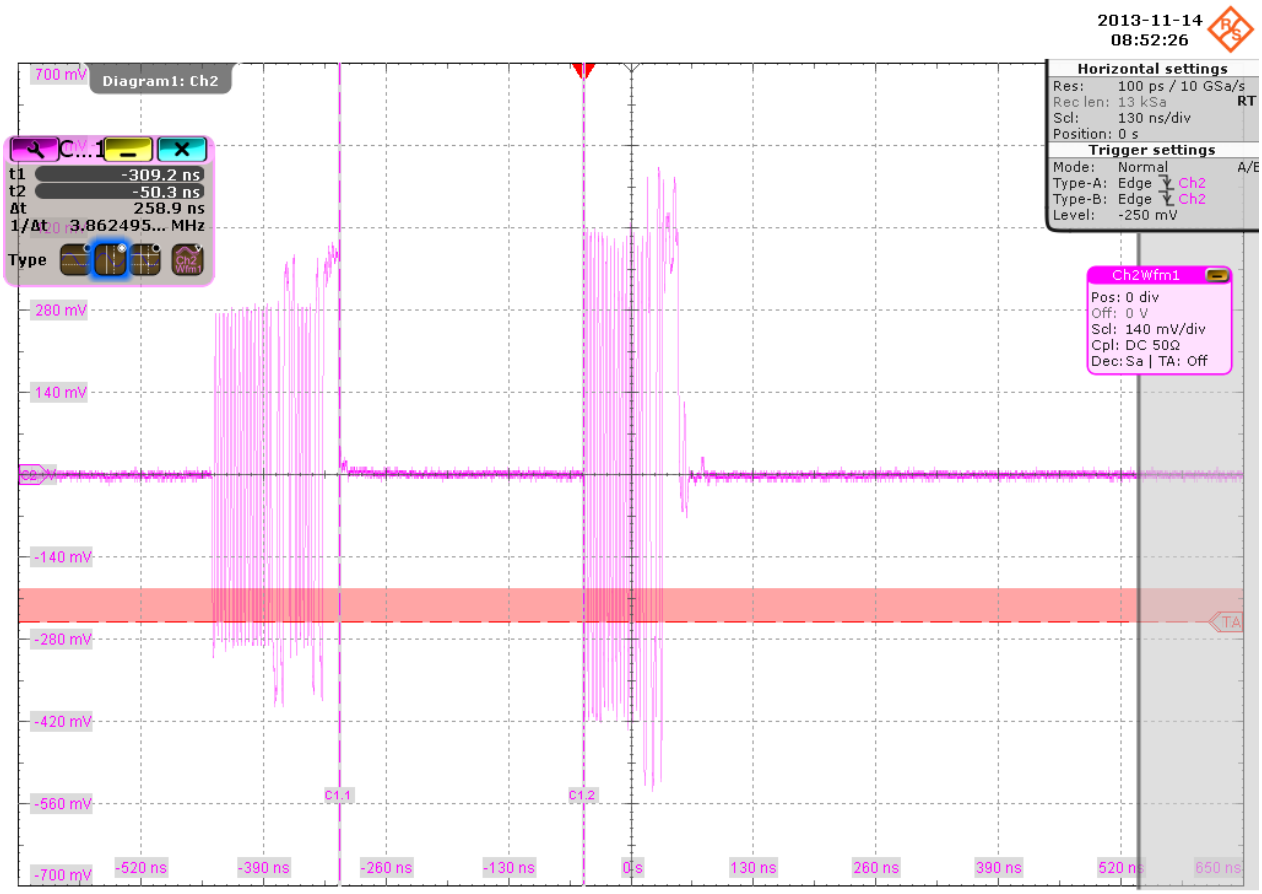


The application measures the time between the “Set Feature” packet and DUT packet. This is EL_22.

10. Click "Step" and wait until "Operation Successful" is shown under "Status Window".



A waveform is captured as pictured below.



The first packet (left) is an "IN Packet" sent by the host. The second packet with higher amplitude is the answer from the device. The application measures the time between the two packets. This is EL_22.

The results are saved and can be viewed in the report.

4.1.3 Chirp Timing

Table 4-3: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the device you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Single-ended probe	at least 2 GHz bandwidth	2
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

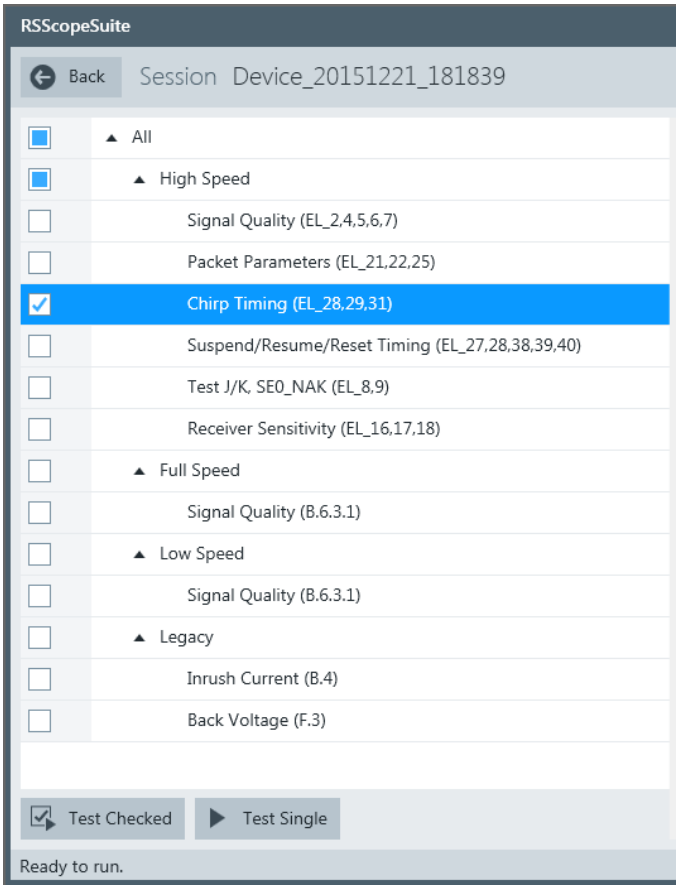
Test preparation

Before you run the test, complete the following actions:

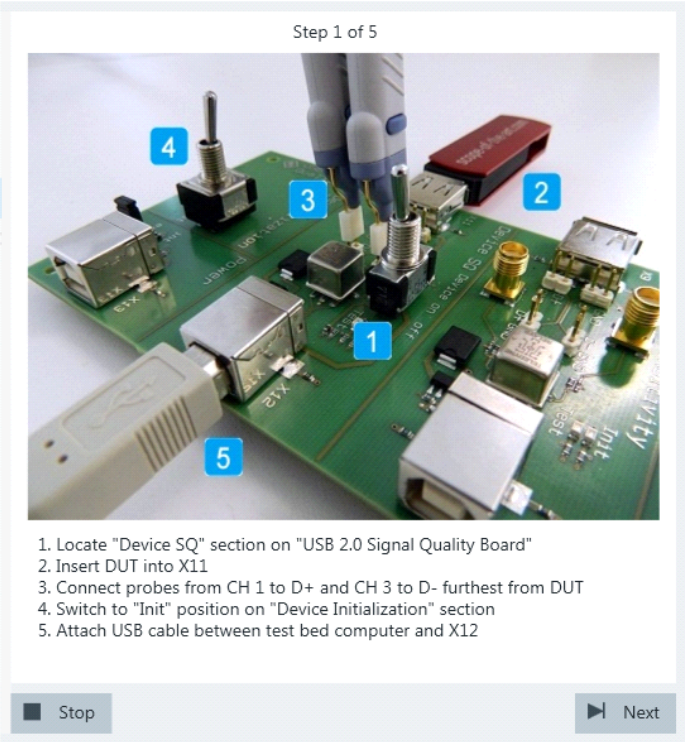
- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Device"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Chirp Timing (EL_28,29,31)" test case and click "Test Single".

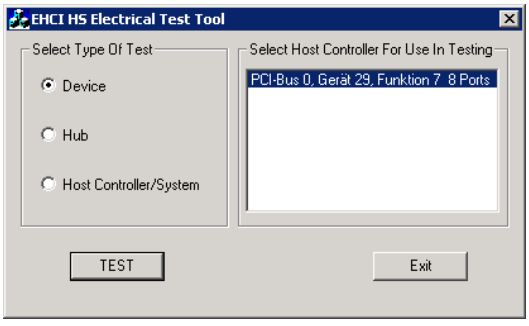


2. Connect the DUT to the test fixture as shown in the picture.

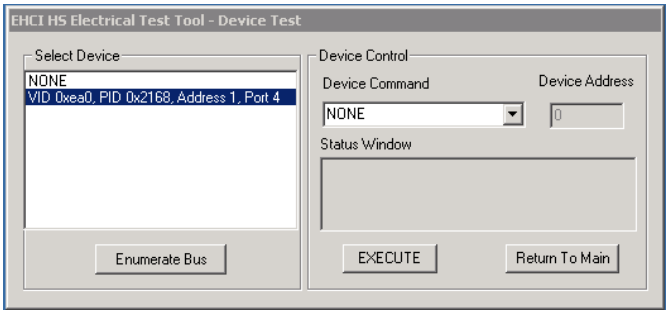


If the DUT has a type A connector attached, plug it into the test fixture directly. Otherwise, connect the DUT to the test fixture using a 4-inch cable.
Use a 1-meter non-captive cable to connect the test bed computer to the test fixture.

3. Click "Next".
4. Start the HS Electrical Test Tool on the test bed computer.
5. Select "Device" on the left side, and the host controller to which the DUT is connected on the right side.
Note: the values in the list may vary.



6. Click "TEST".
7. Click"Enumerate Bus" in the HS Electrical Test Tool.



8. Click "Next" in the R&S ScopeSuite.

   The Figure 4-5 shows an overview over D+/D- when a host is negotiating high-speed with the device.

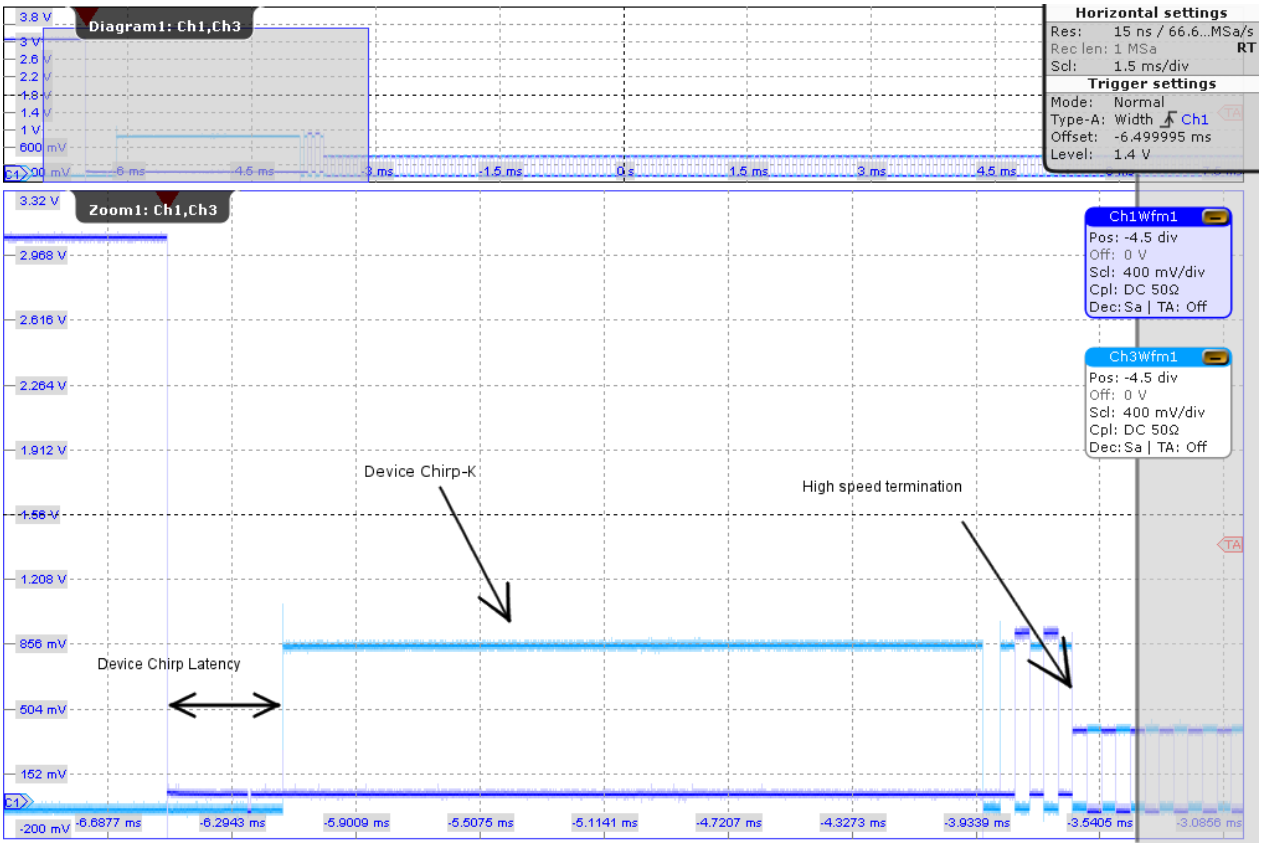


Figure 4-5: High-speed communication of host and device

To start a communication with a device, the host pulls down both data lines to low levels. Big drop of D+ (Ch1Wfm1) is shown on the right side. The device has now 2.5us seconds to respond with a rise of D-. We call this Chirp K Latency and the EL_28 measurement has to be in the range from 2.5us to 6ms. The host sees this Device Chirp-K (800mV on D-) and has to respond to it within 1ms and latest within 7ms. The answer is a series of K-J chirp pairs. The length of the Device Chirp-K time corresponds to the EL_29 measurement. After at least 3 K-J chirp pairs the device can assume that the host is high speed capable. When sure, the device applies the 45 Ohm terminations and by this pulls down the voltage of the chirps to 400mV. This drop can be seen in more detail in Figure 4-6. The time from the third Chirp till the drop has to be in the range from 0s to 500us. We store this measurement under EL_31 High Speed Termination After Chirp.

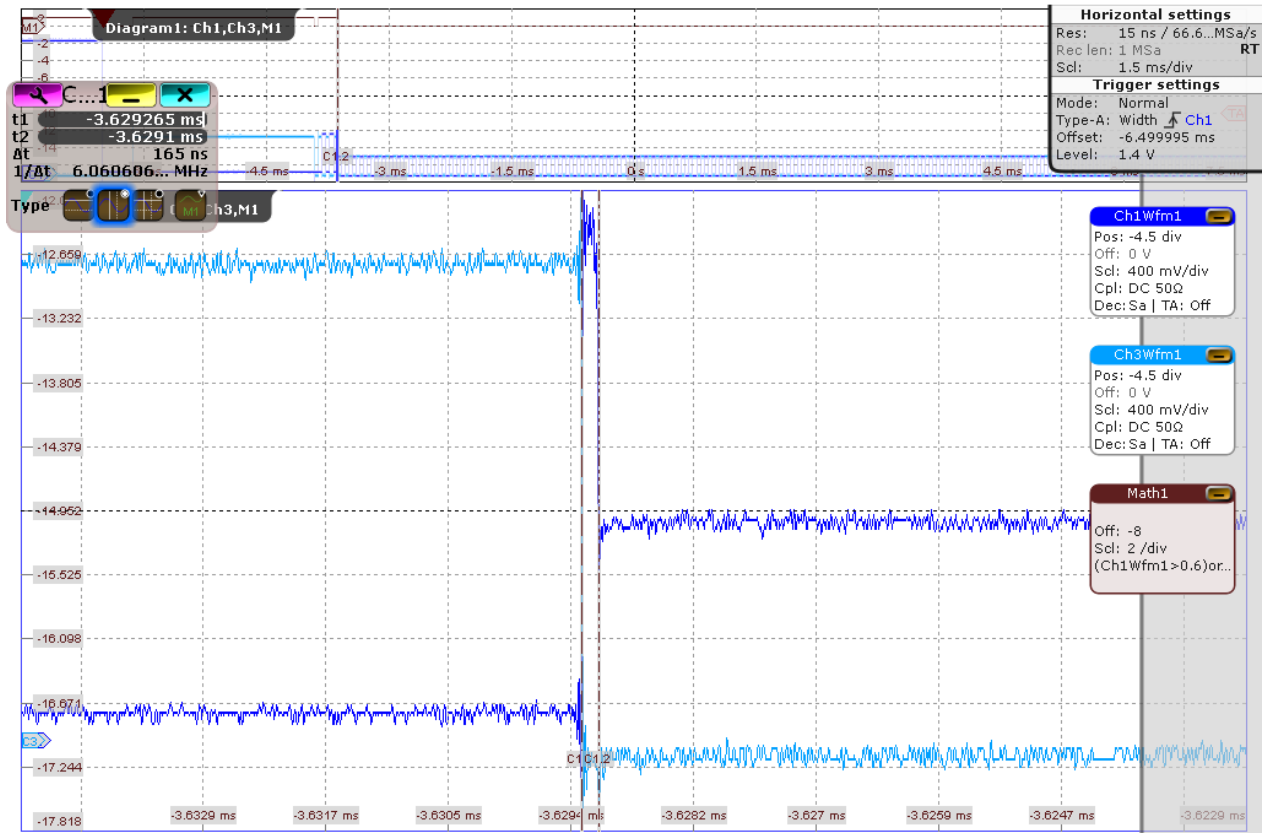


Figure 4-6: EL_31 chirp drop

The results are saved and can be viewed in the report.

4.1.4 Suspend/Resume/Reset Timing

Table 4-4: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the device you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Single-ended probe	at least 2 GHz bandwidth	2
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

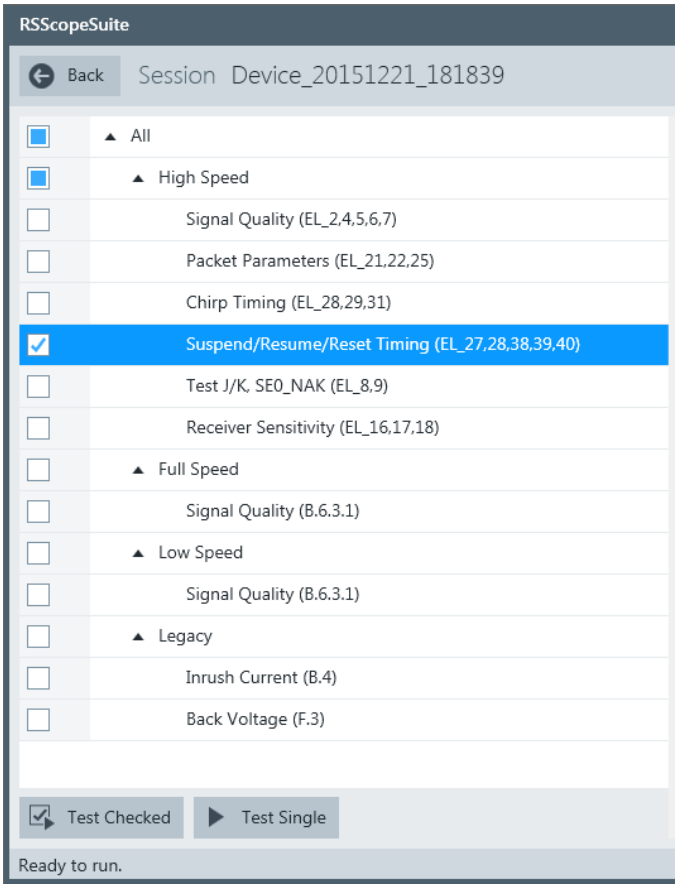
Test preparation

Before you run the test, complete the following actions:

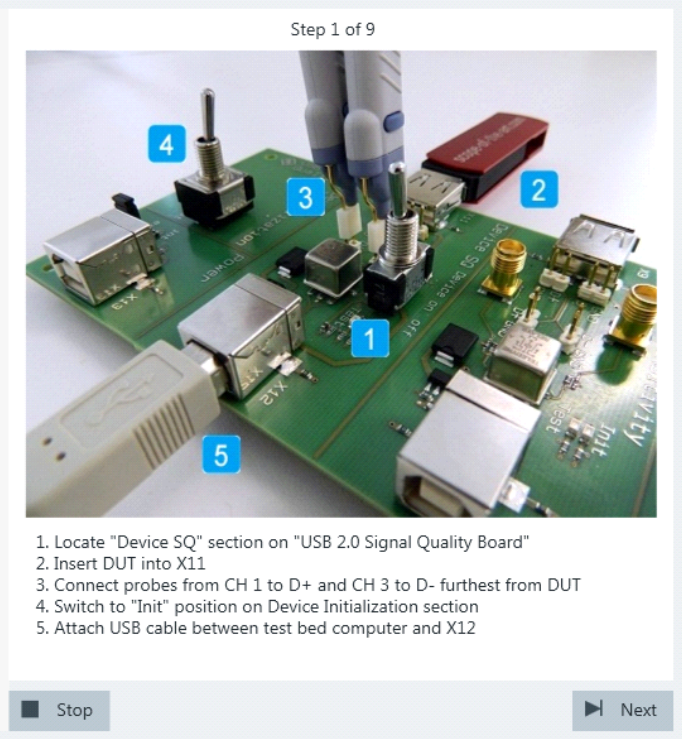
- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Device"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Suspend/Resume/Reset Timing (EL_27,28,38,39,40)" test case and click "Test Single".

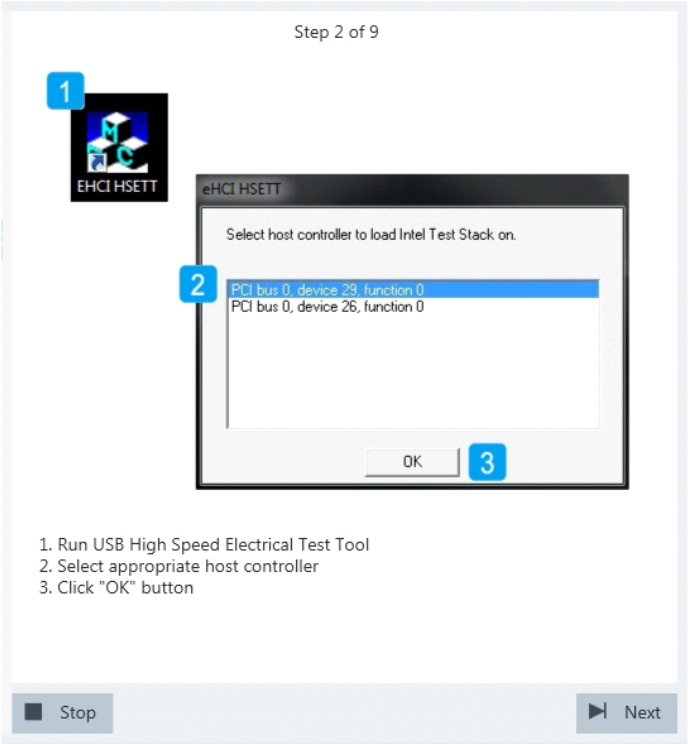


2. Connect the DUT to the test fixture as shown in the picture.

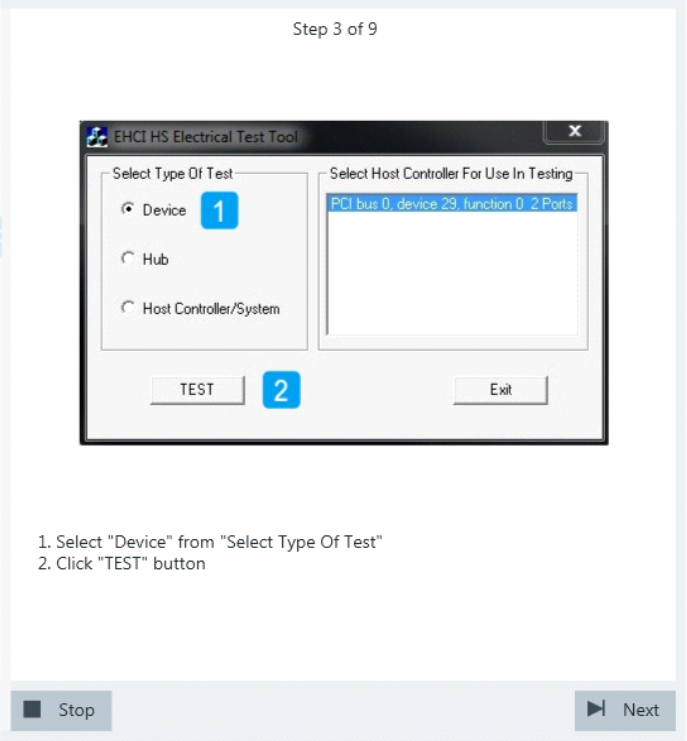


If the DUT has a type A connector attached, plug it into the test fixture directly. Otherwise, connect the DUT to the test fixture using a 4-inch cable.
Use a 1-meter non-captive cable to connect the test bed computer to the test fixture.

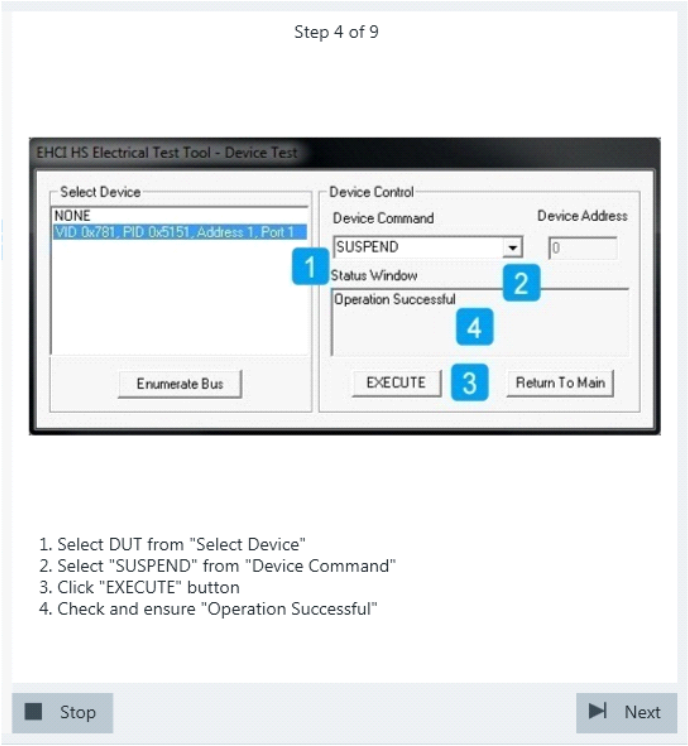
3. Click "Next".
4. Start the HS Electrical Test Tool on the test bed computer.
5. Select the host controller to which the DUT is connected and click OK.
   Note: the values in the list may vary.
   Click "Next" in the R&S ScopeSuite.



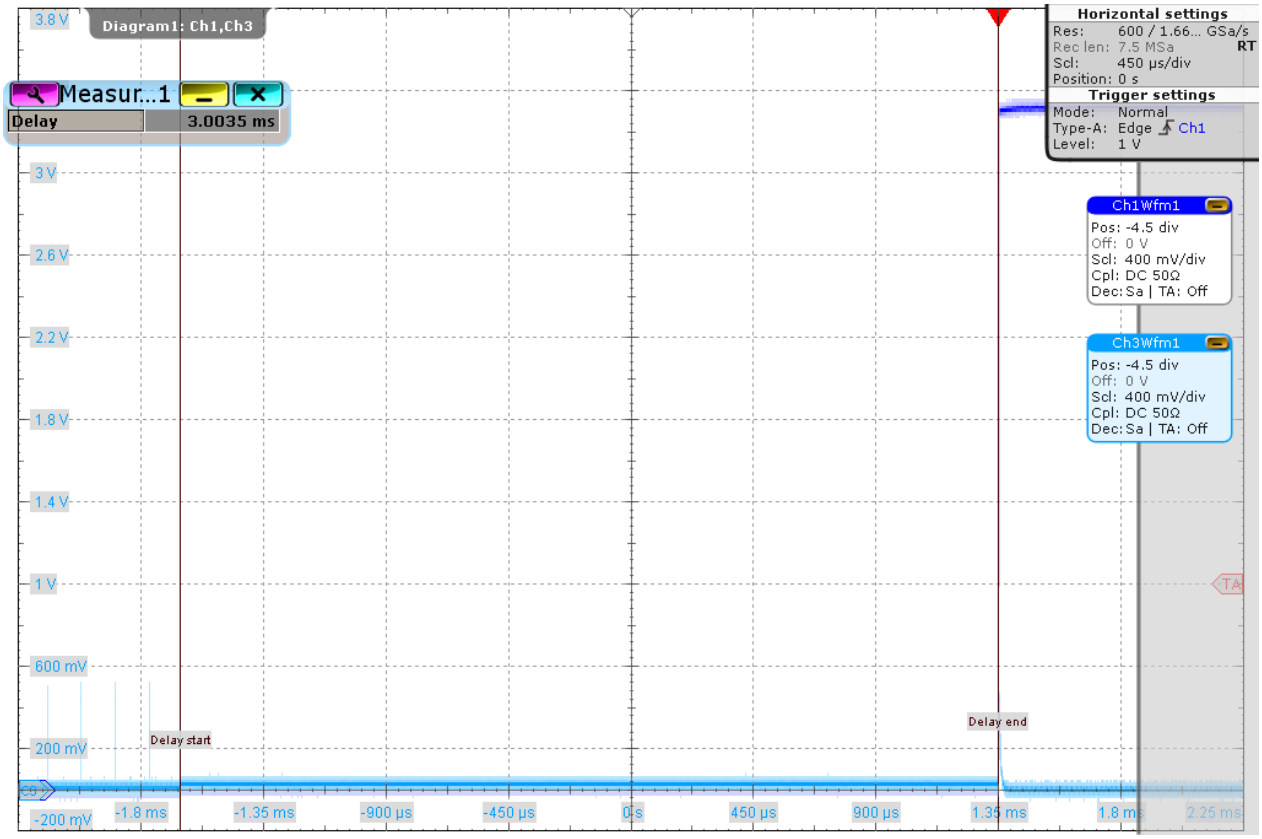
6. Select "Device" on the left side, and click "TEST"



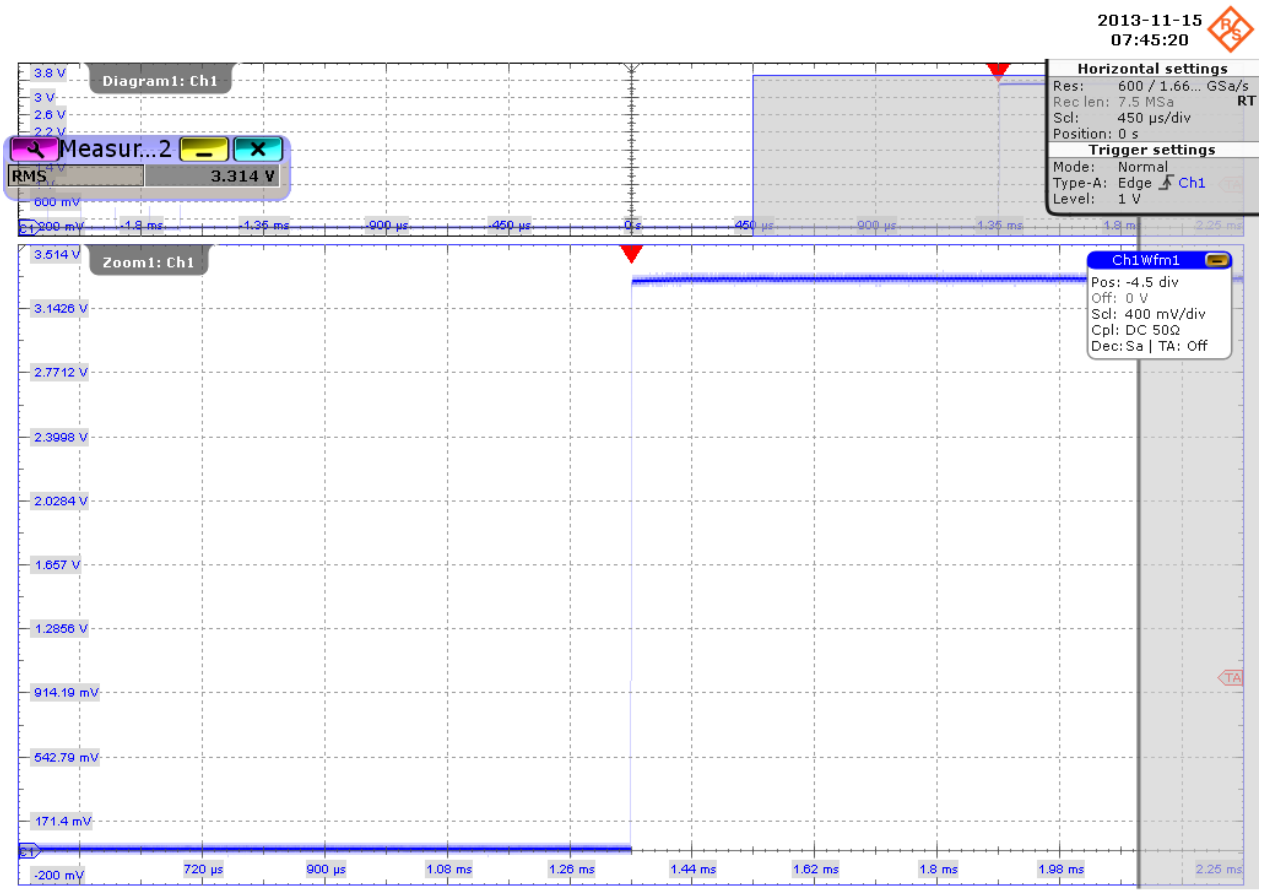
7. Configure the HS Electrical Test Tool as shown in the picture.



Waveforms are captured as pictured below.



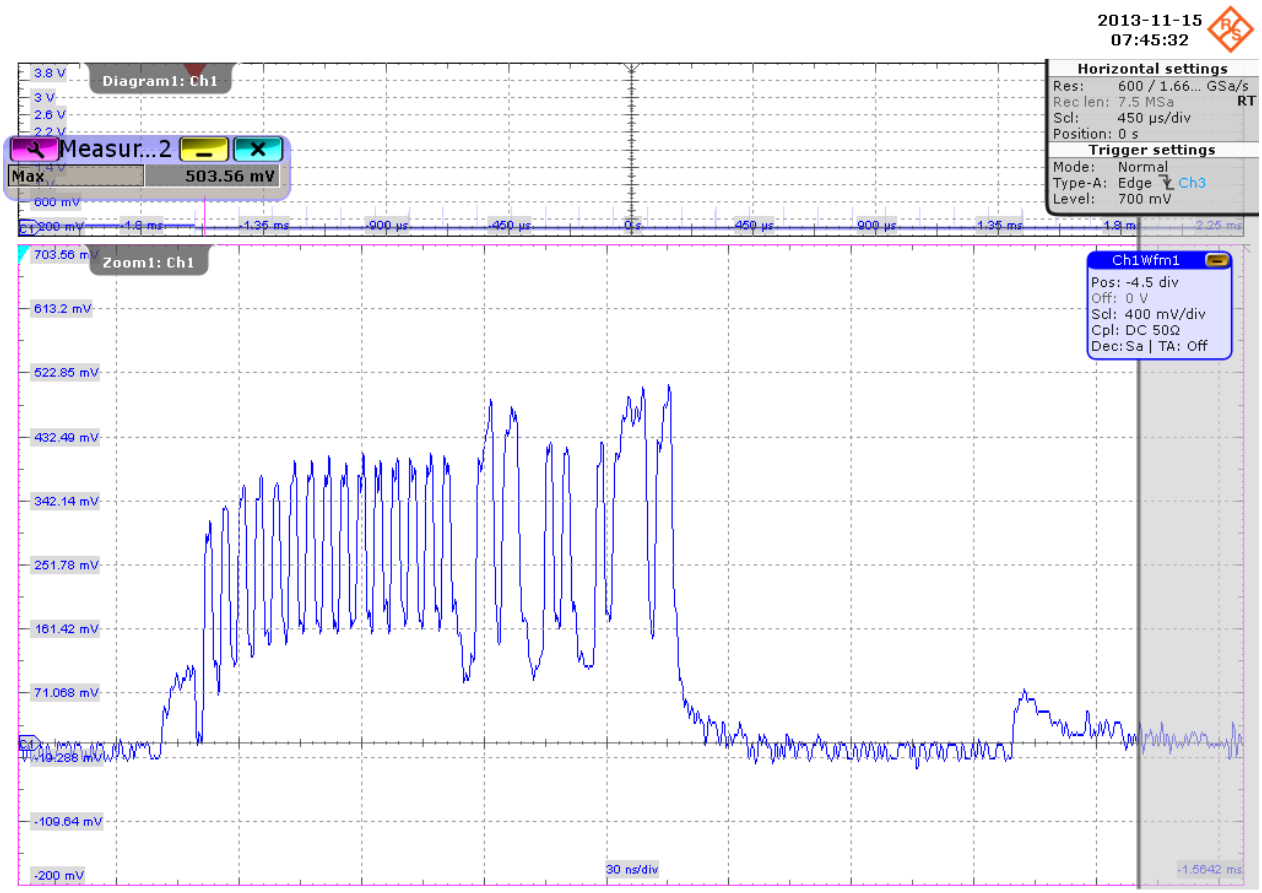
The application measures the time between the last falling edge of the last “Start of Frame” packet and the start of the suspended state. This is EL_38.

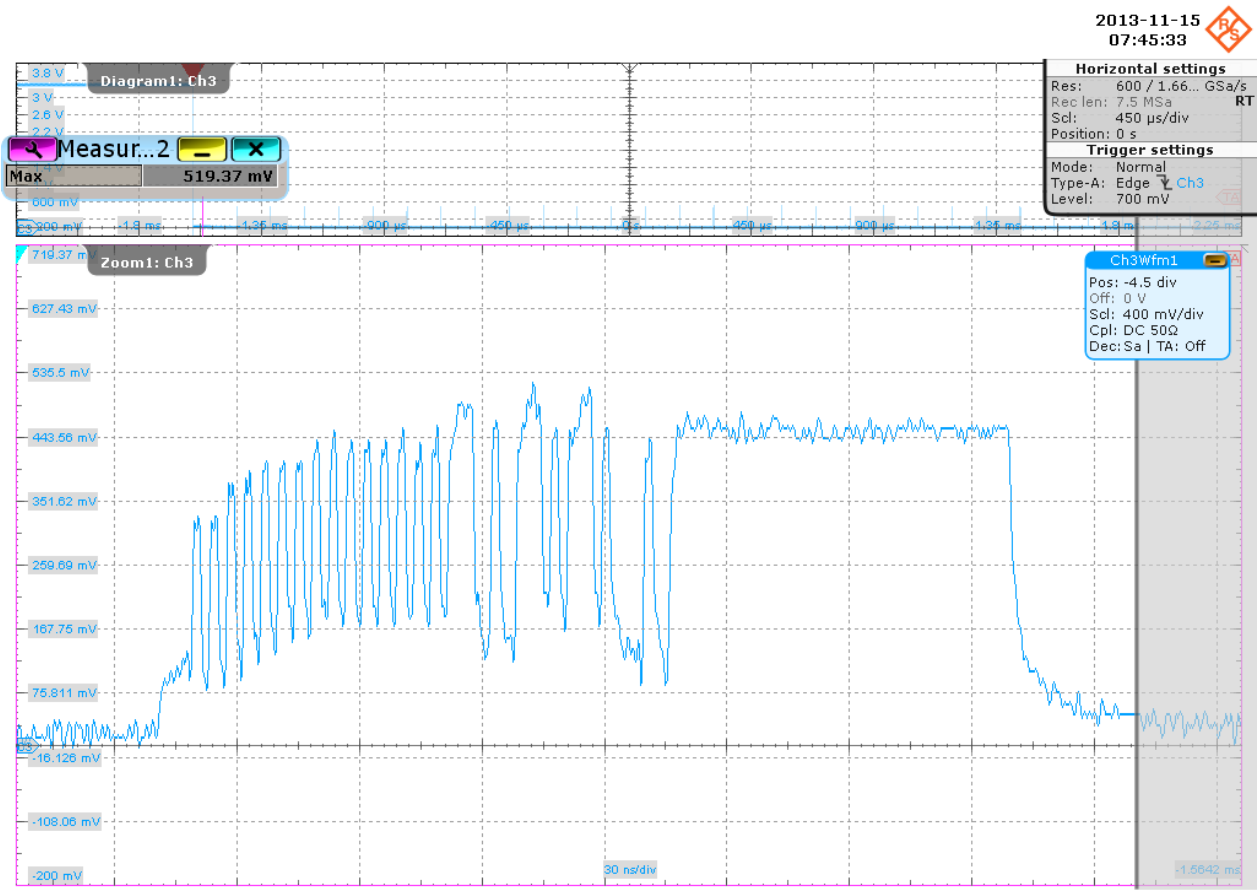


When entering the suspended state, DUT pulls D+ from ~0 V to ~3 V (as shown in the picture above) and D- remains in ~0 V. The application zooms into the suspended state and measures the voltage of D+/-. This is EL_39.

8. Proceed in the HS Electrical Test Tool as shown in the picture.

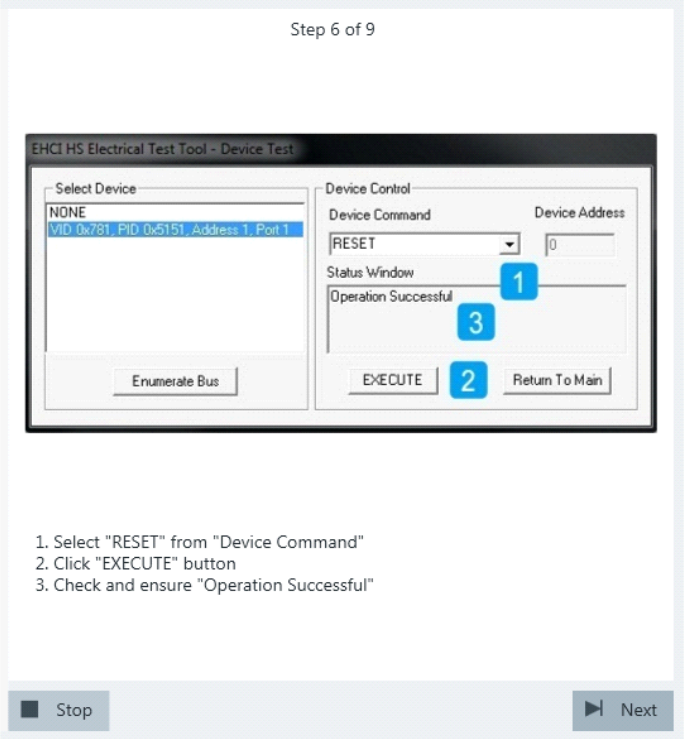
Waveforms are captured as pictured below.


2013-11-15
07:45:32
Diagram1: Ch1
Measur...2
Max
503.56 mV
Horizontal settings
Res: 600 / 1.66... GSa/s
Rec len: 7.5 MSa
RT
Scl: 450 µs/div
Position: 0 s
Trigger settings
Mode: Normal
Type-A: Edge Ch3
Level: 700 mV
Zoom1: Ch1
Ch1Wfm1
Pos: -4.5 div
Off: 0 V
Scl: 400 mV/div
Cpl: DC 50Ω
Dec: Sa | TA: Off
703.56 mV
613.2 mV
522.85 mV
432.49 mV
342.14 mV
251.78 mV
161.42 mV
71.068 mV
-19.288 mV
-109.64 mV
-200 mV
30 ns/div
-1.5642 ms

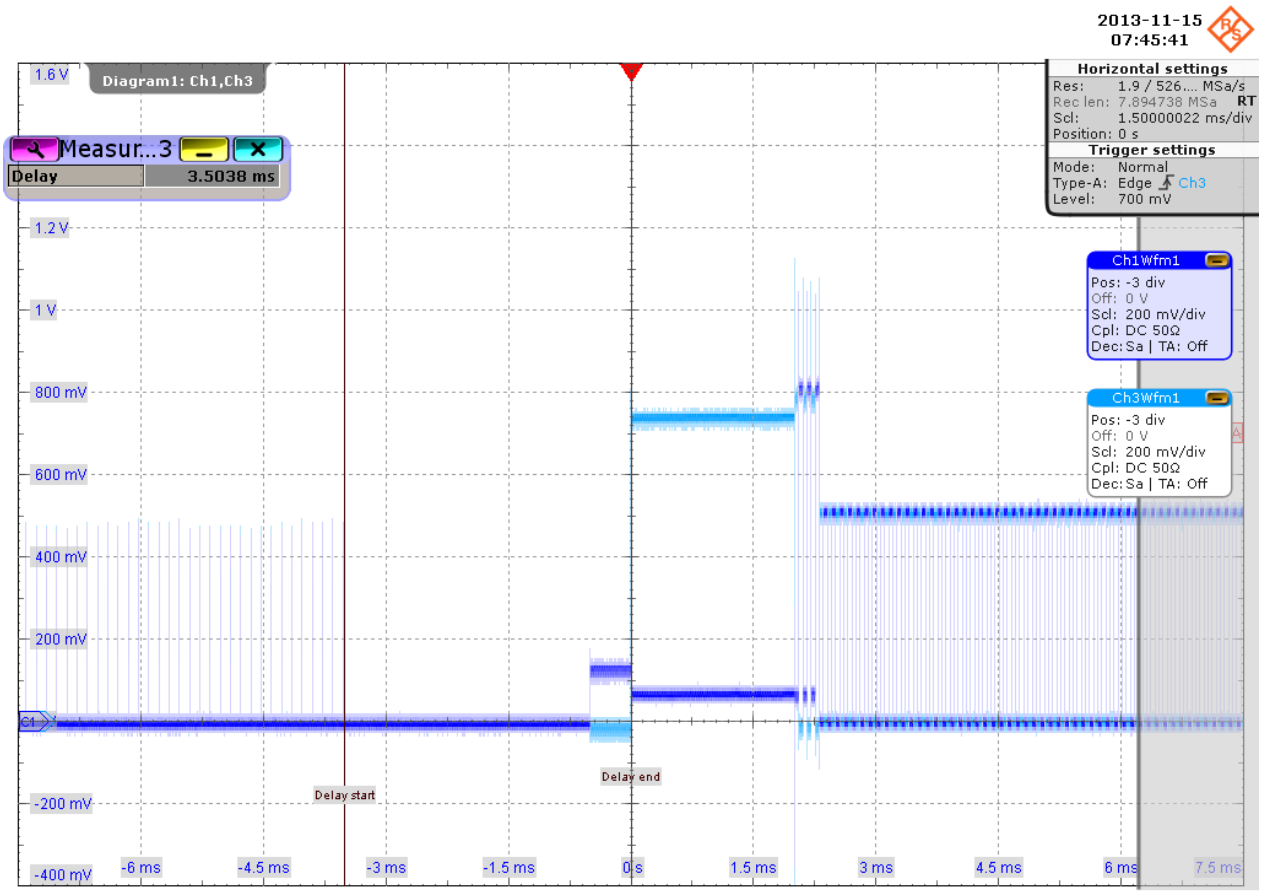


The application zooms into the first “Start of Frame” packet and measures the maximum voltage of D+ and D-. This is EL_40.

9. Proceed in the HS Electrical Test Tool as shown in the picture.



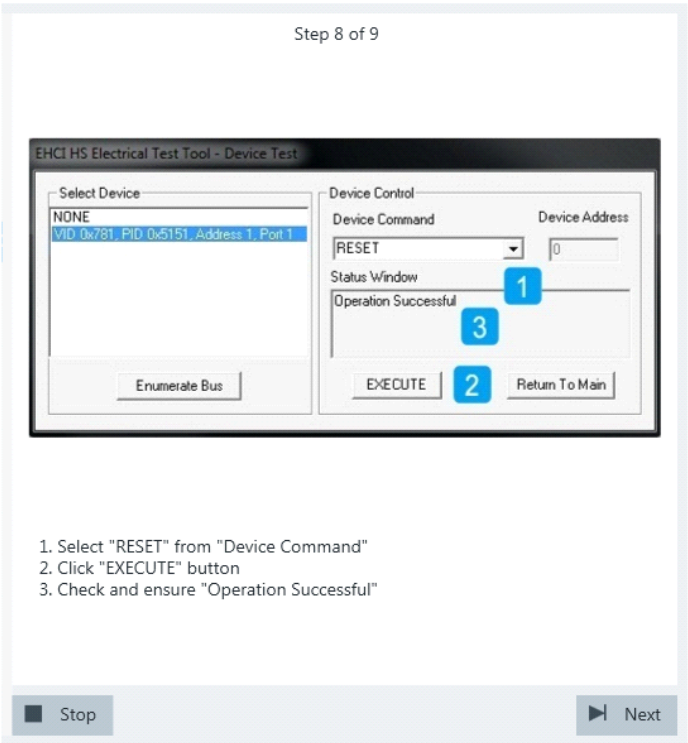
A waveform is captured as pictured below.



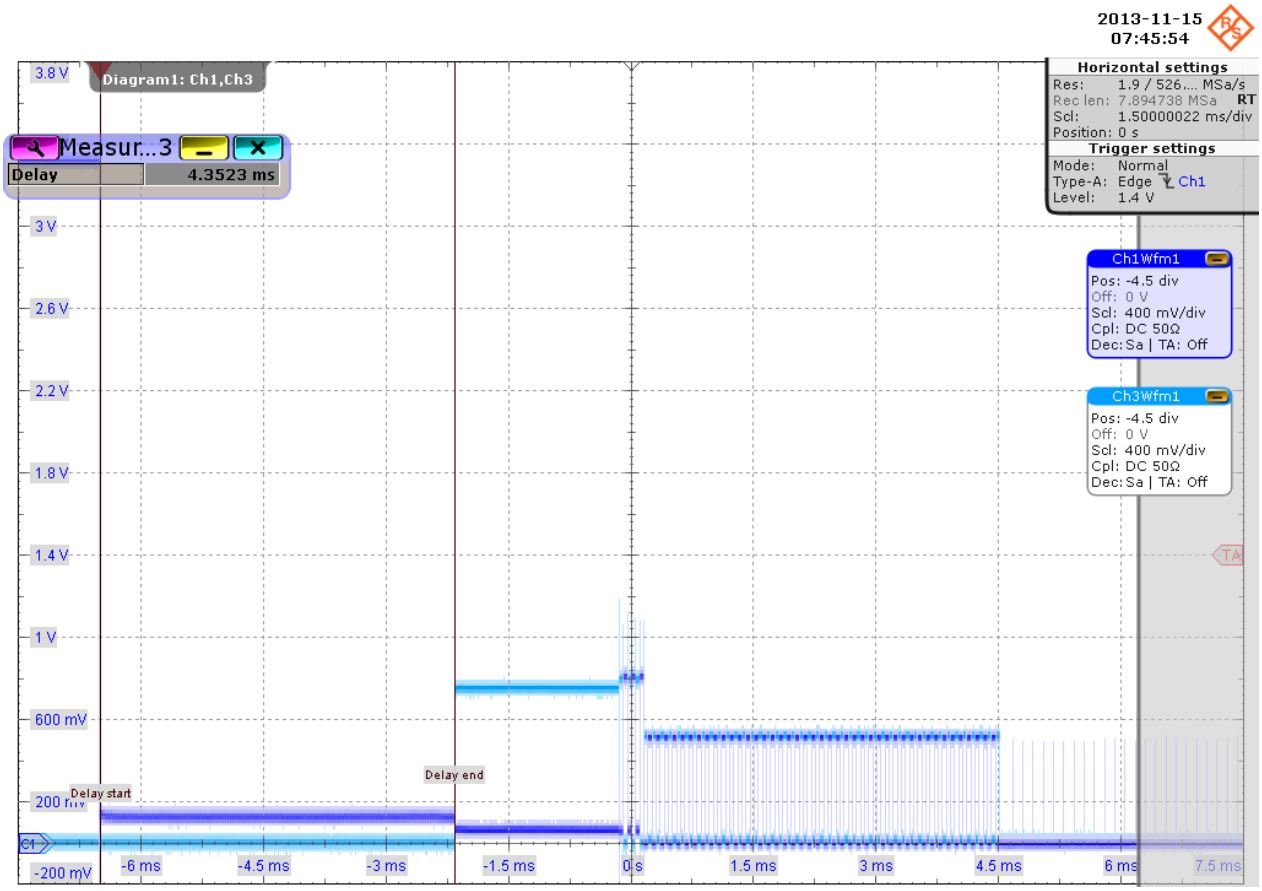
The application measures the time between the DUT reset from the non-suspended state (i.e., the last falling edge of the last “Start of Frame” packet) and the start of the chirp handshake (i.e., the assertion of Chirp K). This is EL_27.

10. Proceed in the HS Electrical Test Tool as shown in the picture.

11. Proceed in the HS Electrical Test Tool as shown in the picture.

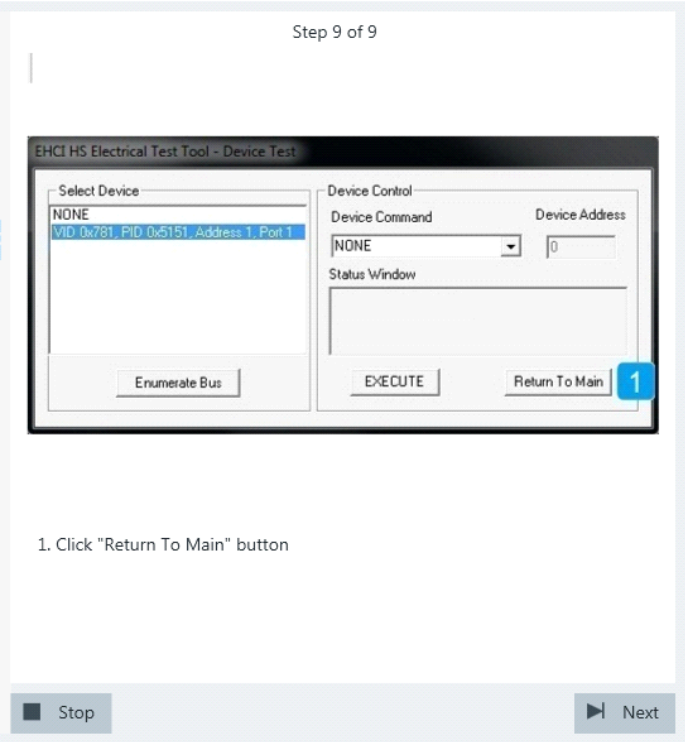


Waveforms are captured as pictured below.



The application measures the time between the DUT reset from the suspended state (i.e., D+ pulls from ~+3 V to ~0 V) and the start of the chirp handshake (i.e, the assertion of Chirp K). This is EL_28.

12. Finish the test as shown in the picture.



The results are saved and can be viewed in the report.

4.1.5 Test J/K, SE0_NAK

Table 4-5: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Single-ended probe	at least 2 GHz bandwidth	2
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable 1.3 m	to connect computer and test fixture	1

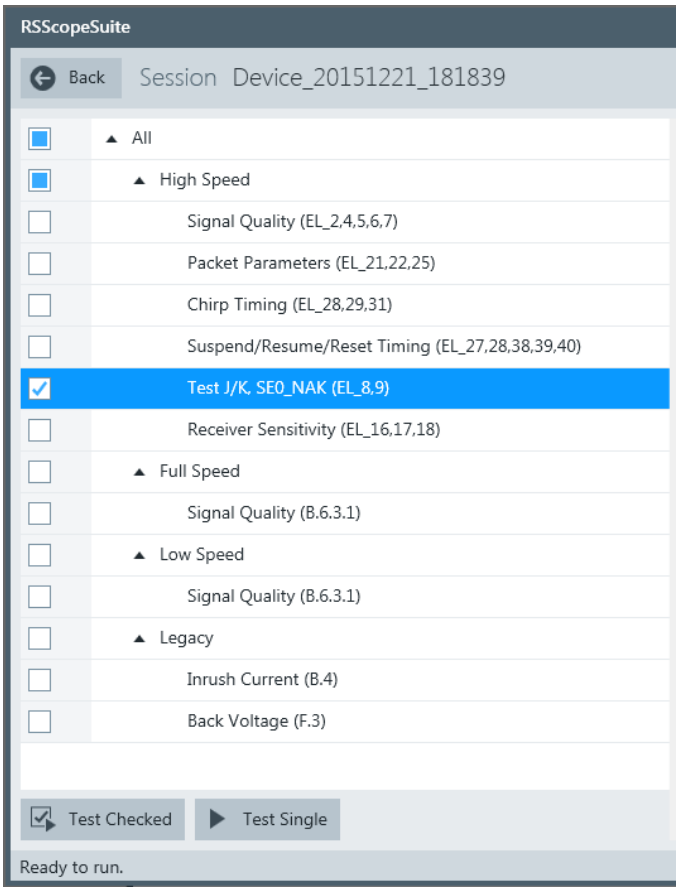
Test preparation

Before you run the test, complete the following actions:

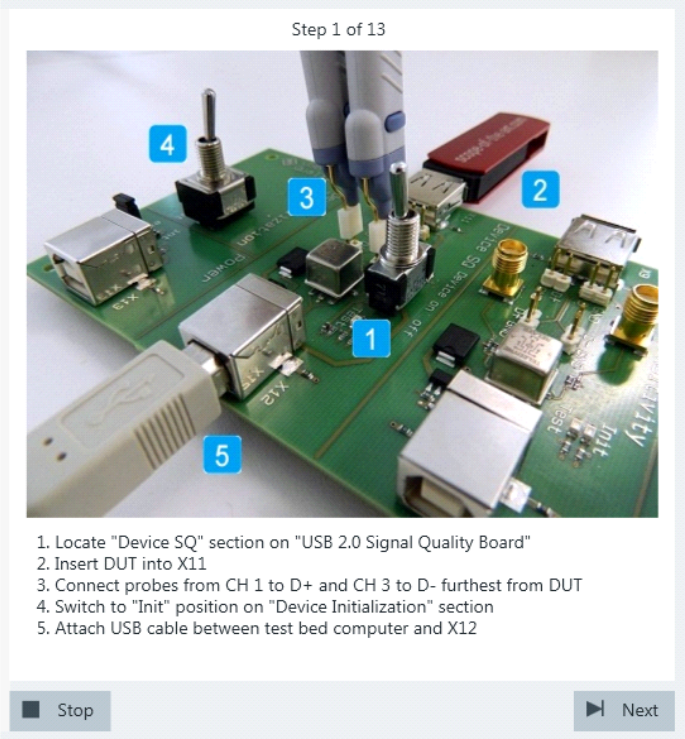
- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Device"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

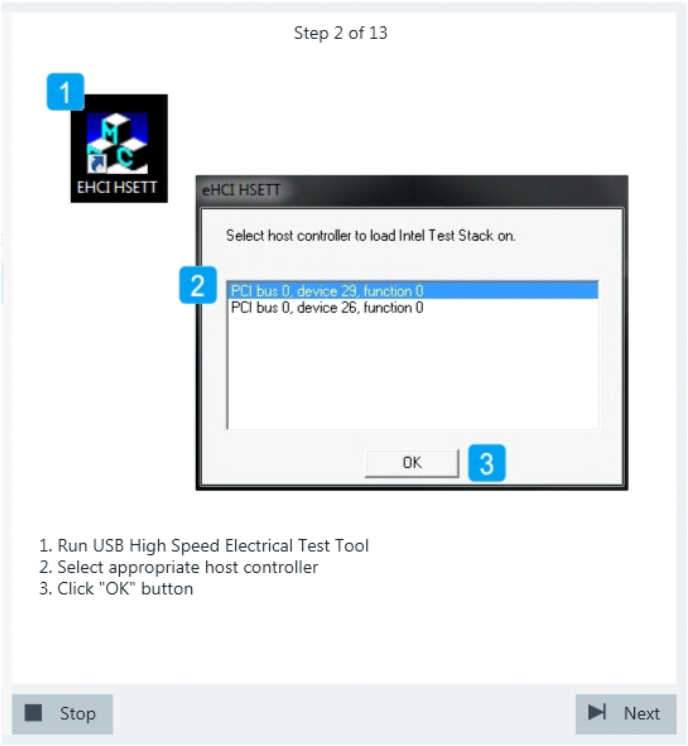
1. Select the "Test J/K, SE0_NAK" test case and click "Test Single".



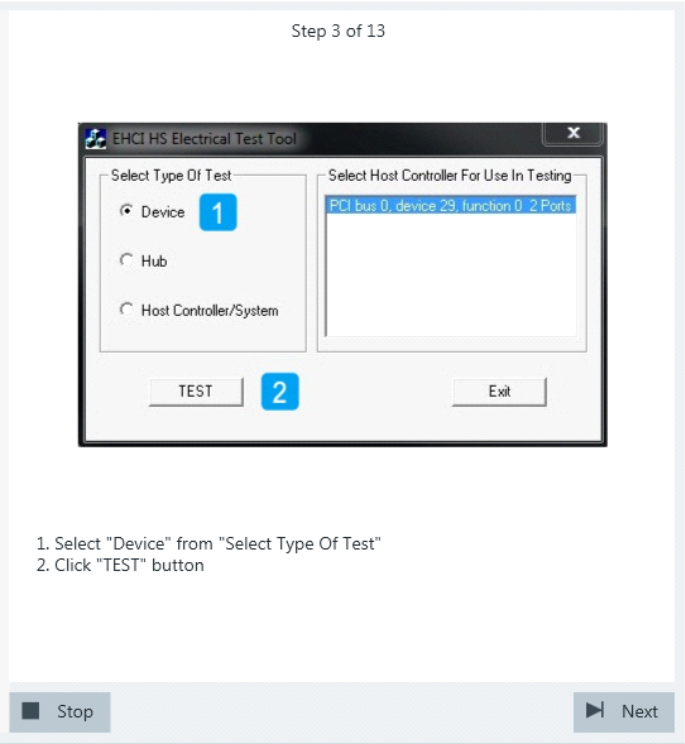
2. Connect the DUT to the test fixture as shown in the picture and click "Next".



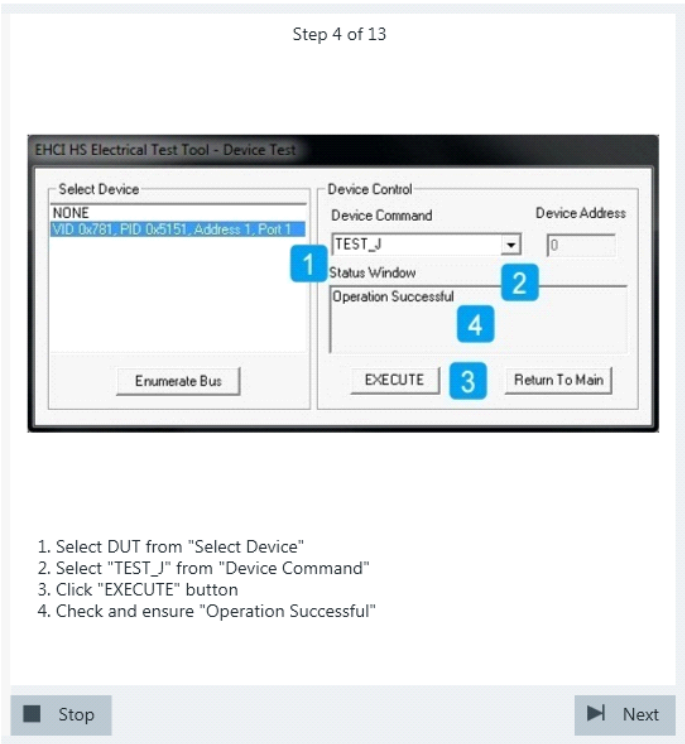
3. Start the HS Electrical Test Tool on the test bed computer.
4. Select the host controller to which the DUT is connected and click OK.
   Note: the values in the list may vary.
   Click "Next" in the R&S ScopeSuite.



5. Select "Device" on the left side, and click "TEST"

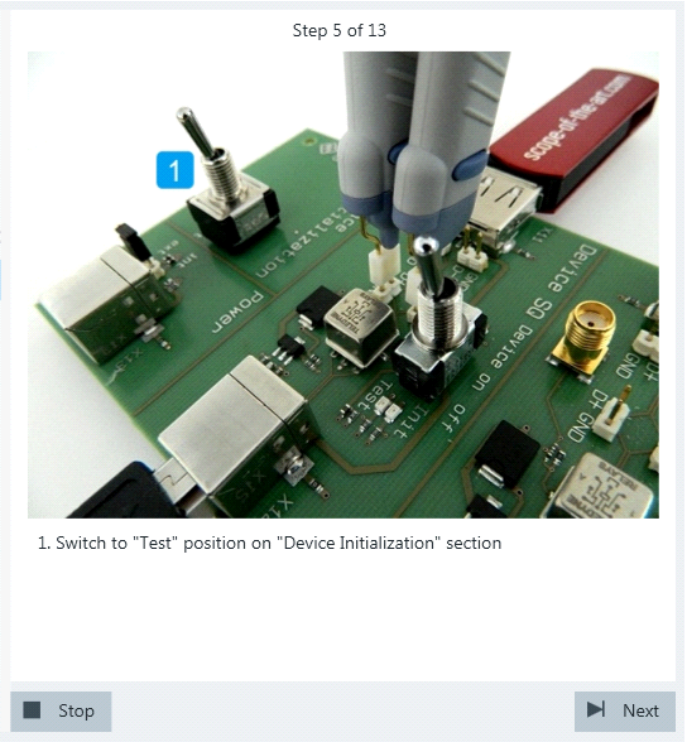


6. Configure the HS Electrical Test Tool as shown in the picture.



If the DUT has a type A connector attached, plug it into the test fixture directly. Otherwise, connect the DUT to the test fixture using a 4-inch cable.
Use a 1-meter non-captive cable to connect the test bed computer to the test fixture.

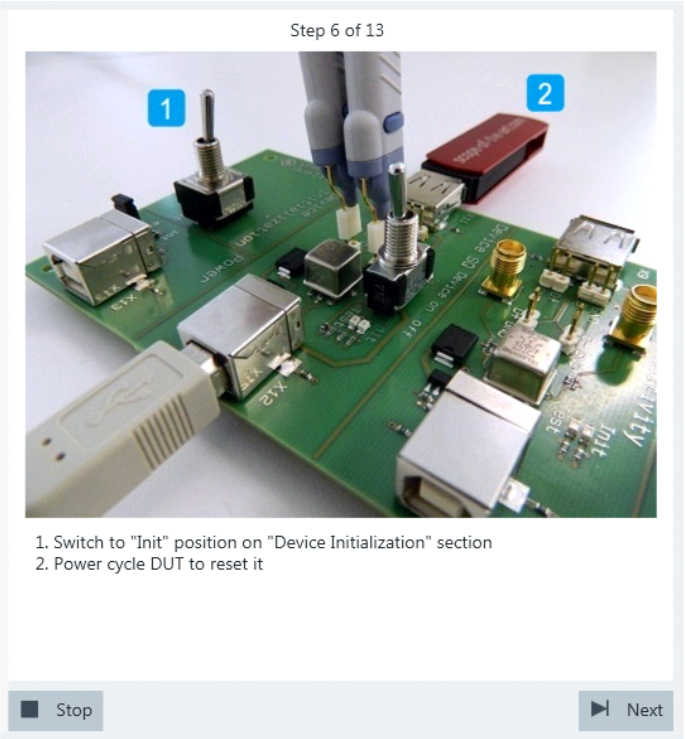
7. Switch the "Device Initialization" switch to "Test" position.



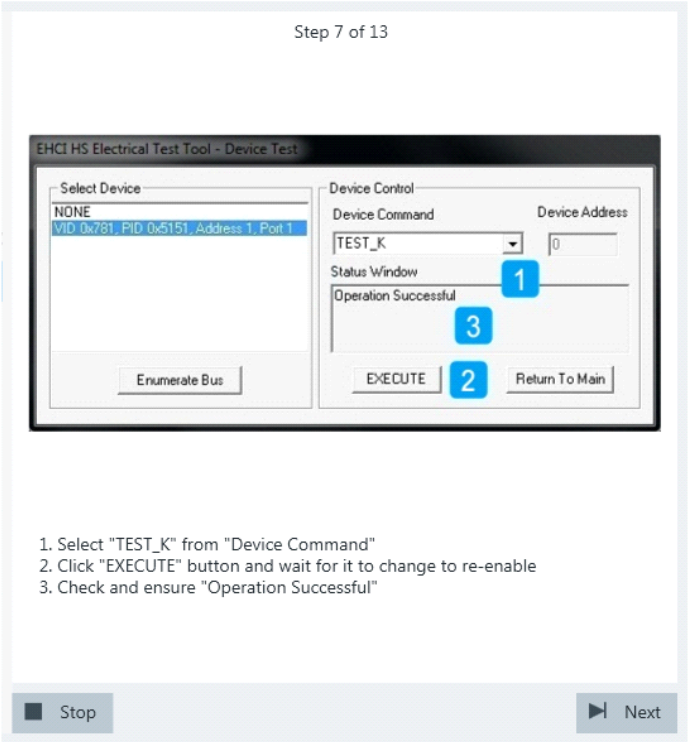
The probe at least 2 GHz bandwidth contains a built-in digital voltmeter known as ProbeMeter. The application automatically reads the voltages of D+ and D- from the ProbeMeter. However, if the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user to enter the voltages of D+ and D-.

8. Switch the "Device Initialization" switch to "Init" position, and reset the DUT. If the DUT is bus-powered, simply toggle the "Device on off" switch.

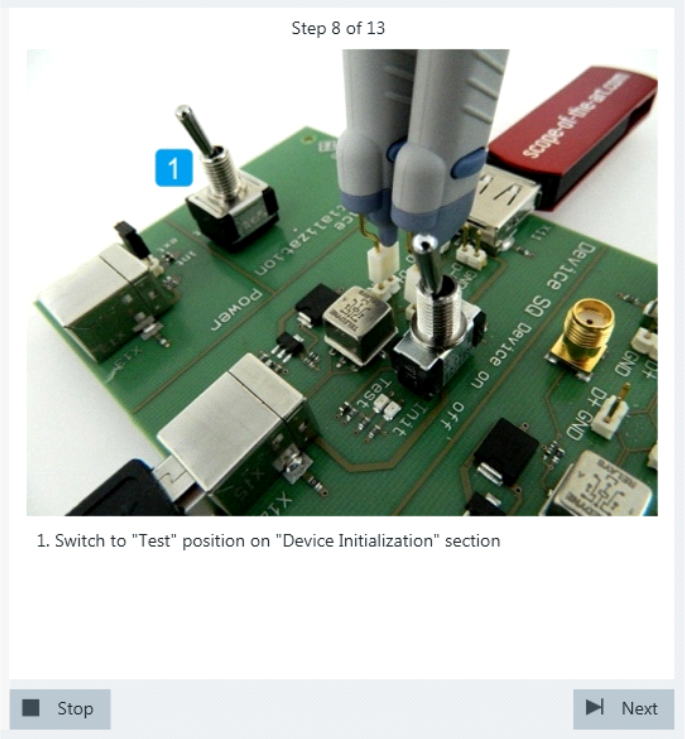
If the DUT is self-powered, switch it off and switch it back on.



9. Configure the HS Electrical Test Tool as shown in the picture and execute the test.



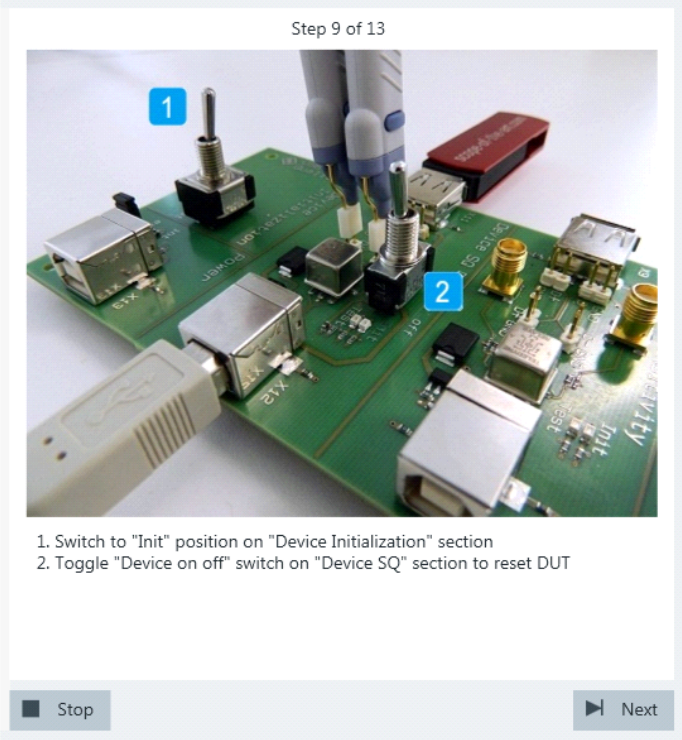
10. Switch the "Device Initialization" switch to "Test" position.



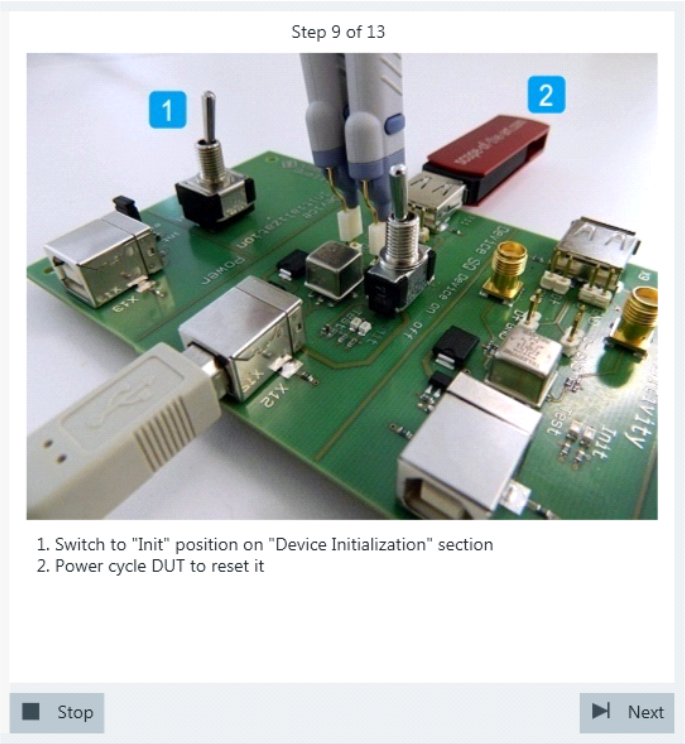
If the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user

to enter the voltages of D+ and D-. Otherwise it automatically reads them from the ProbeMeter.

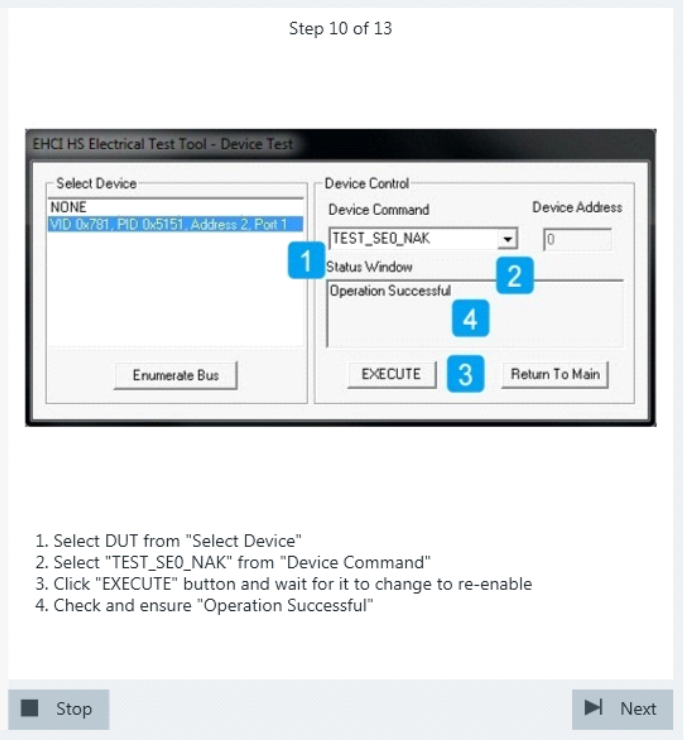
11. Switch the "Device Initialization" switch to the "Init" position and reset the DUT.
If the DUT is bus-powered, simply toggle the "Device on off" switch.



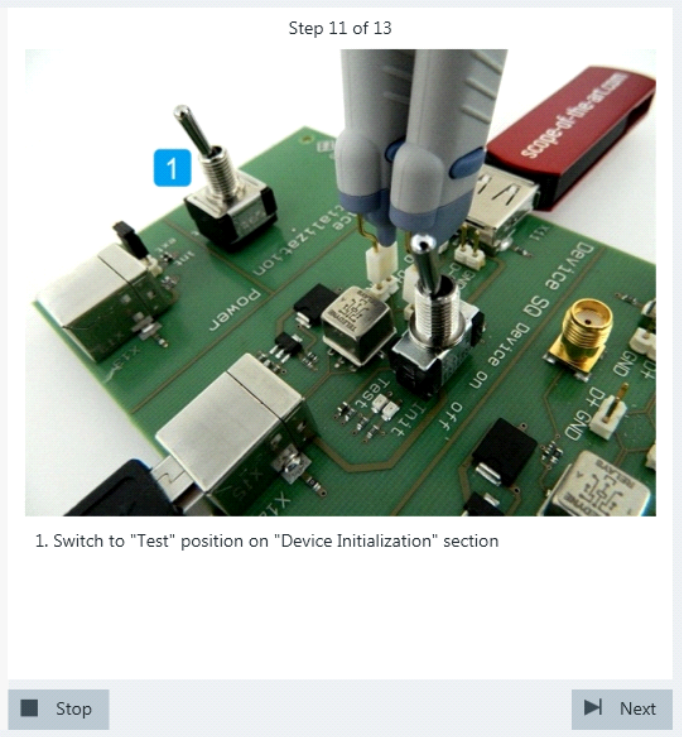
If the DUT is self-powered, switch it off and switch it back on.



12. Configure the HS Electrical Test Tool as shown in the picture, and execute the test.

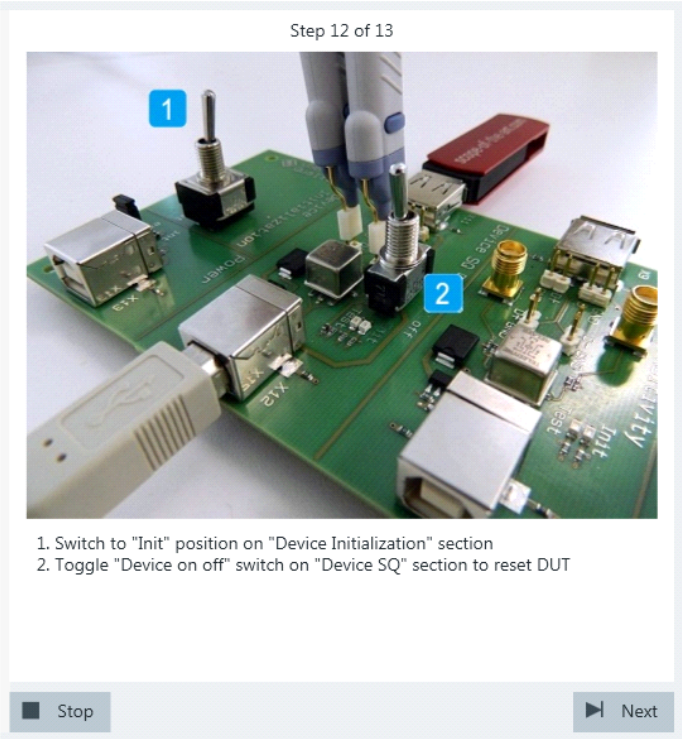


13. Switch the "Device Initialization" switch to "Test" position.

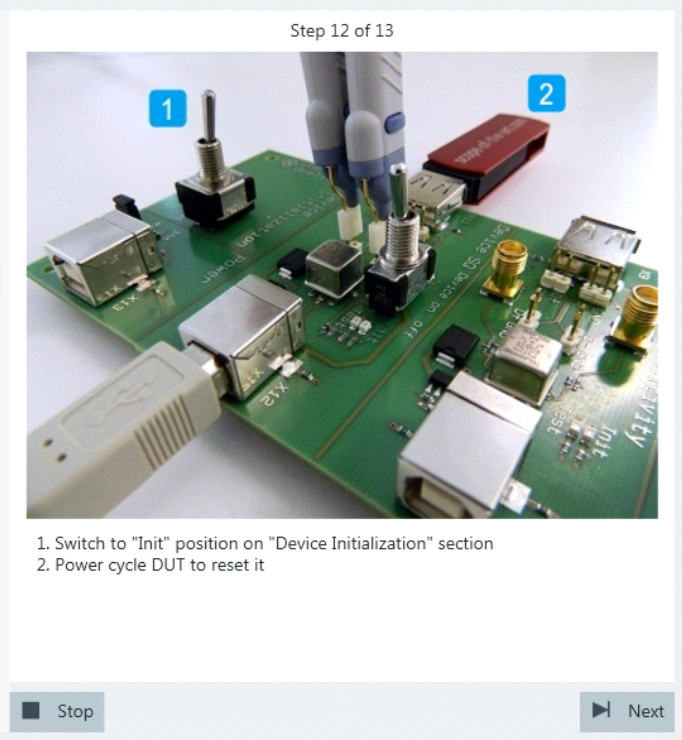


If the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user to enter the voltages of D+ and D-. Otherwise it automatically reads them from the ProbeMeter.

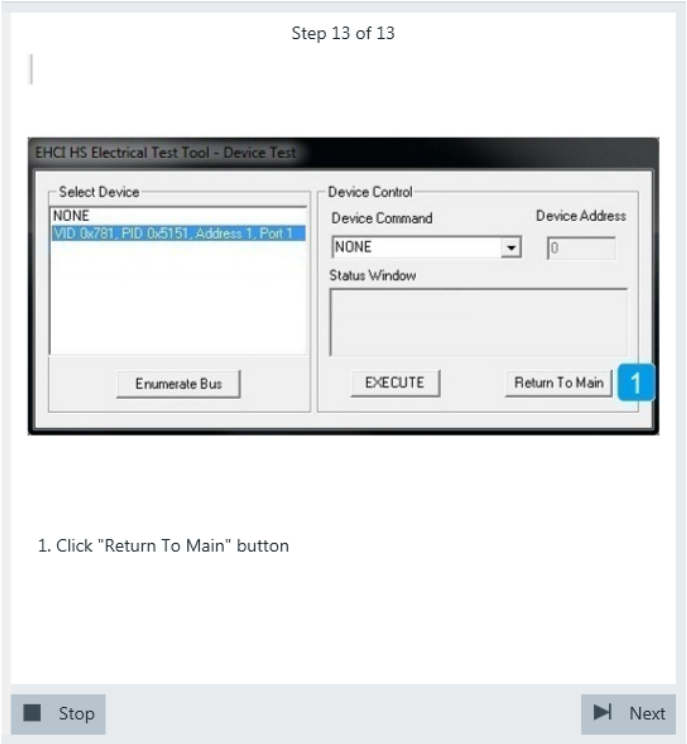
14. Switch the "Device Initialization" switch to the "Init" position and reset the DUT.
If the DUT is bus-powered, simply toggle the "Device on off" switch.



If the DUT is self-powered, switch it off and switch it back on.



15. Proceed in the HS Electrical Test Tool as shown in the picture.



The results are saved and can be viewed in the report.

4.1.6 Receiver Sensitivity

Table 4-6: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
Signal quality board, "Reveiver Sensitivity" section	R&S RT-ZF1	1
Dual channel arbitrary waveform generator (AWG)	e.g. Tabor WX2182B/WX2182C	1
SMA cable	to connect the signal generator to the test fixture	2
50 Ω SMA terminators	to terminate unused outputs of the AWG	2
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

Test preparation comprises common preparation steps and the connection of the AWG.

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S ScopeSuite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Device"**, see Chapter 3.3, "Initiating the Test", on page 19

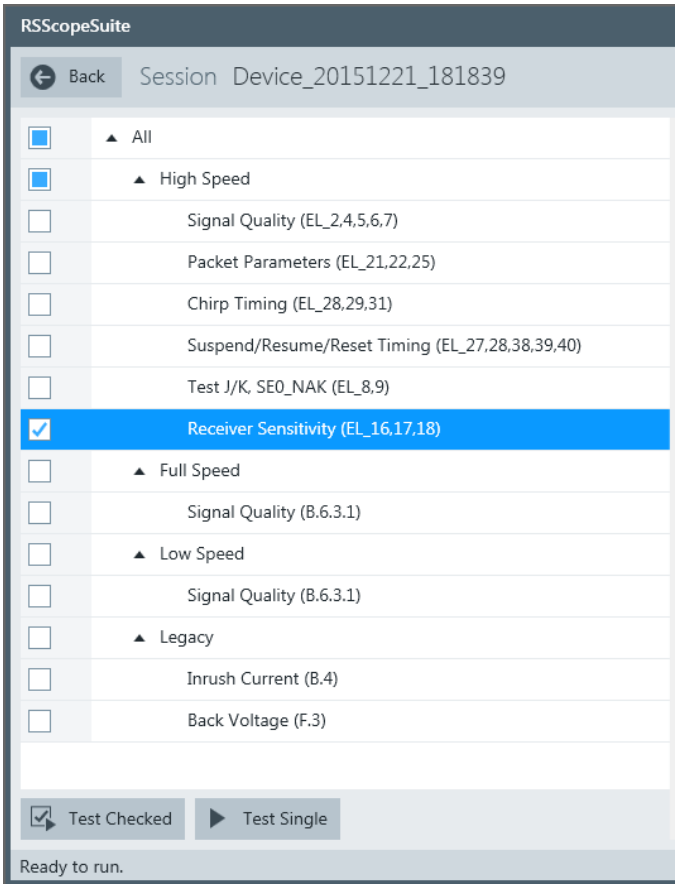
Additional preparation step:

- LAN connection of the AWG and the computer running the R&S ScopeSuite, see Chapter 2.6, "Connecting the Arbitrary Waveform Generator", on page 11.
- Make sure that all unsued outputs of the AWG waveform generator are terminated with a 50 Ω SMA terminators.

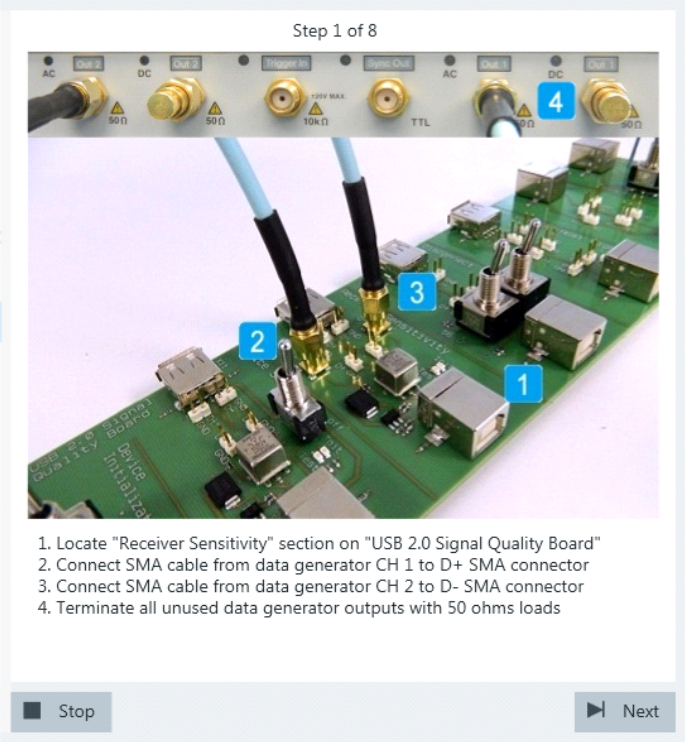
To execute the the receiver sensitivity test in manual mode, the AWG has to output waveforms that simulate the IN token. These waveforms are described in Chapter 4.1.7, "Setup of Test Waveforms ", on page 76.

Running the test

1. Select the "Receiver Sensitivity (EL_16,17,18)" test case and click "Test Single".

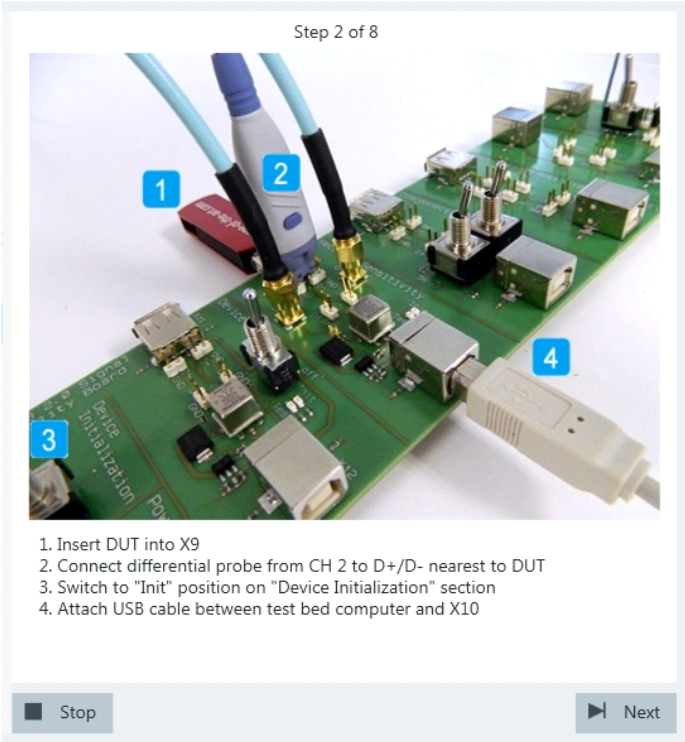


2. Connect the Tabor generator to the test fixture as shown in the picture.



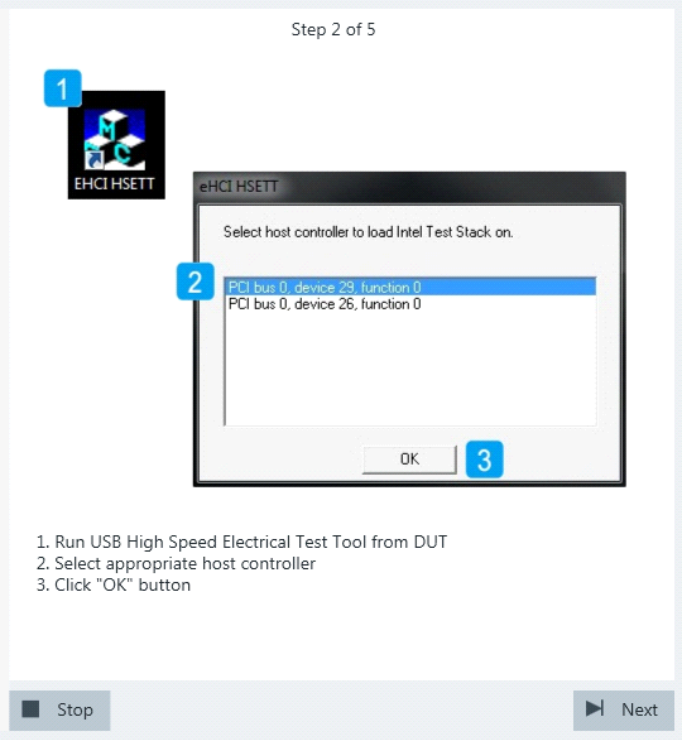
Click "Next".

3. Connect the DUT to the test fixture as shown in the picture, and click "Next".

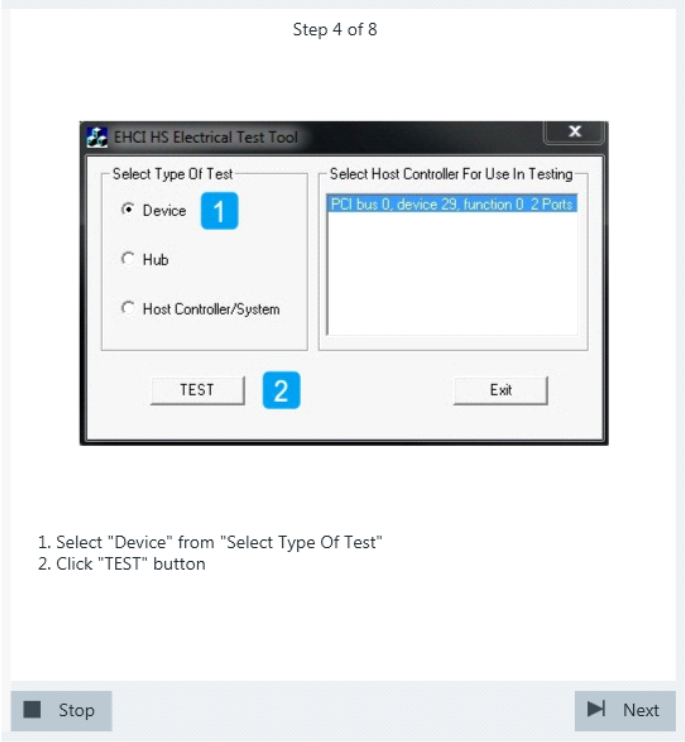


If the DUT has a type A connector attached, plug it into the test fixture directly. Otherwise, connect the DUT to the test fixture using a 4-inch cable.
Use a 1-meter non-captive cable to connect the test bed computer to the test fixture.

4. Start the HS Electrical Test Tool on the test bed computer.
5. Select the host controller to which the DUT is connected and click OK.
Note: the values in the list may vary.

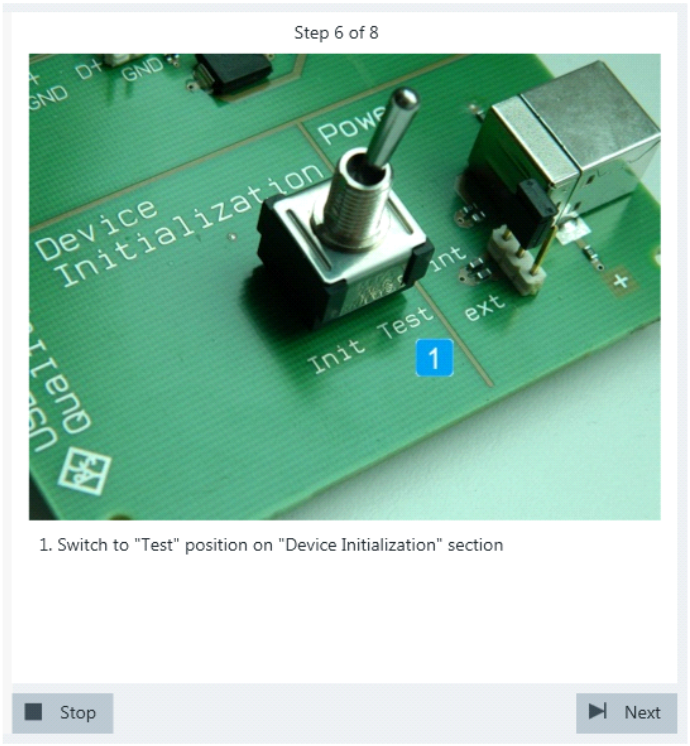


6. Select "Device" on the left side.
Note: the values in the list may vary.
Click "TEST".

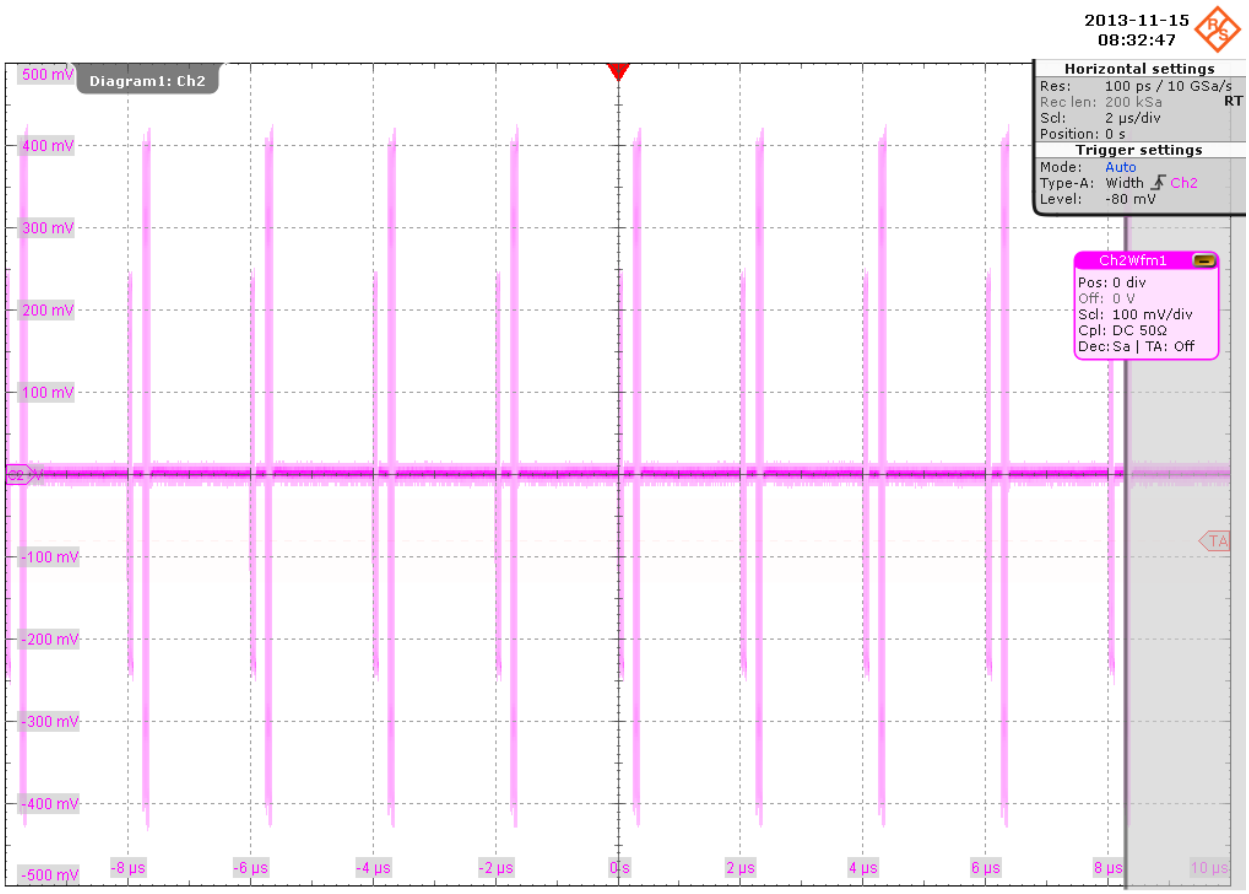


7. Select DUT from "Select Device"
   Select "Test_SE0_NAK" from "Device Command".
   Click "EXECUTE" and wait until "Operation Successful" is shown in "Status Window".

8. Switch to "Test" position on "Device Initalization" section. Now the device (negative) acknowledges all signals send by the Tabor generator.

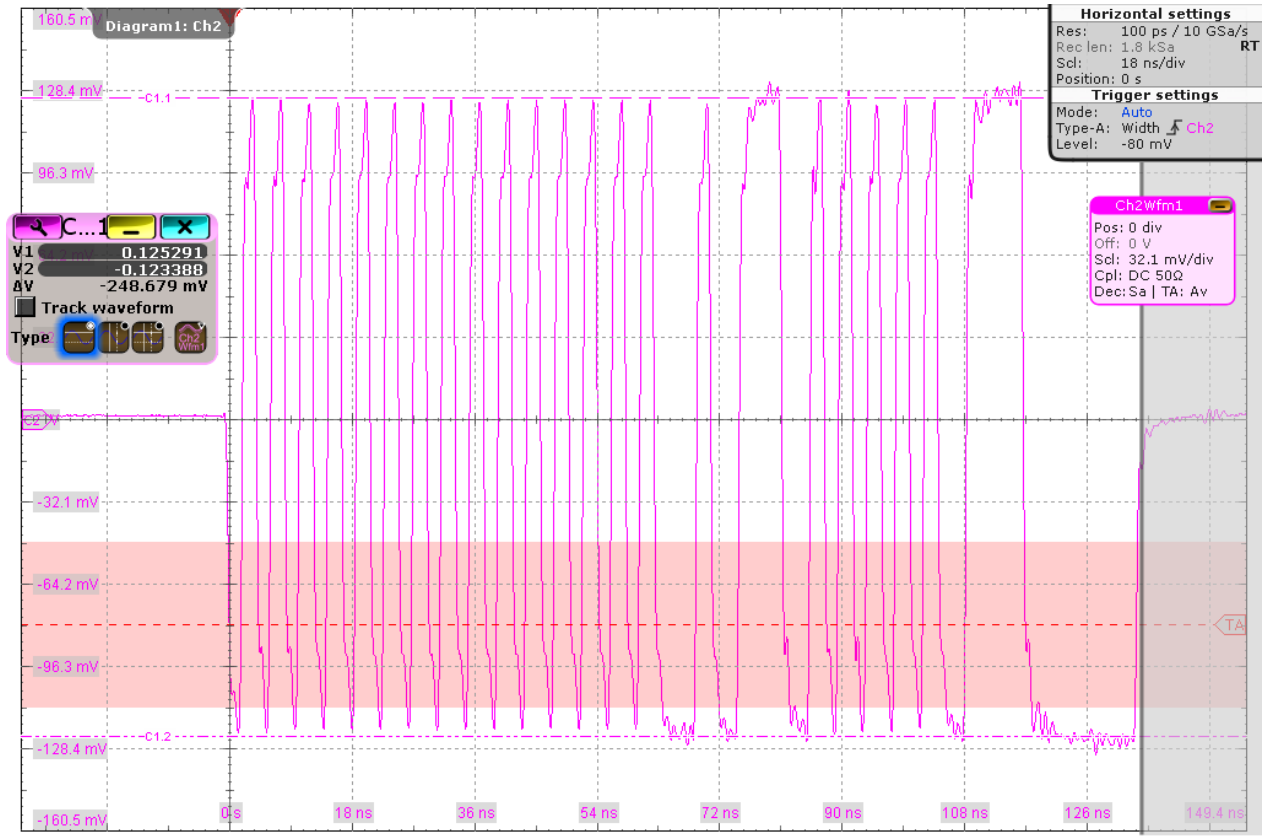


9. The application loads the “MIN_ADD1” waveform onto the Tabor generator. A waveform like this is captured.



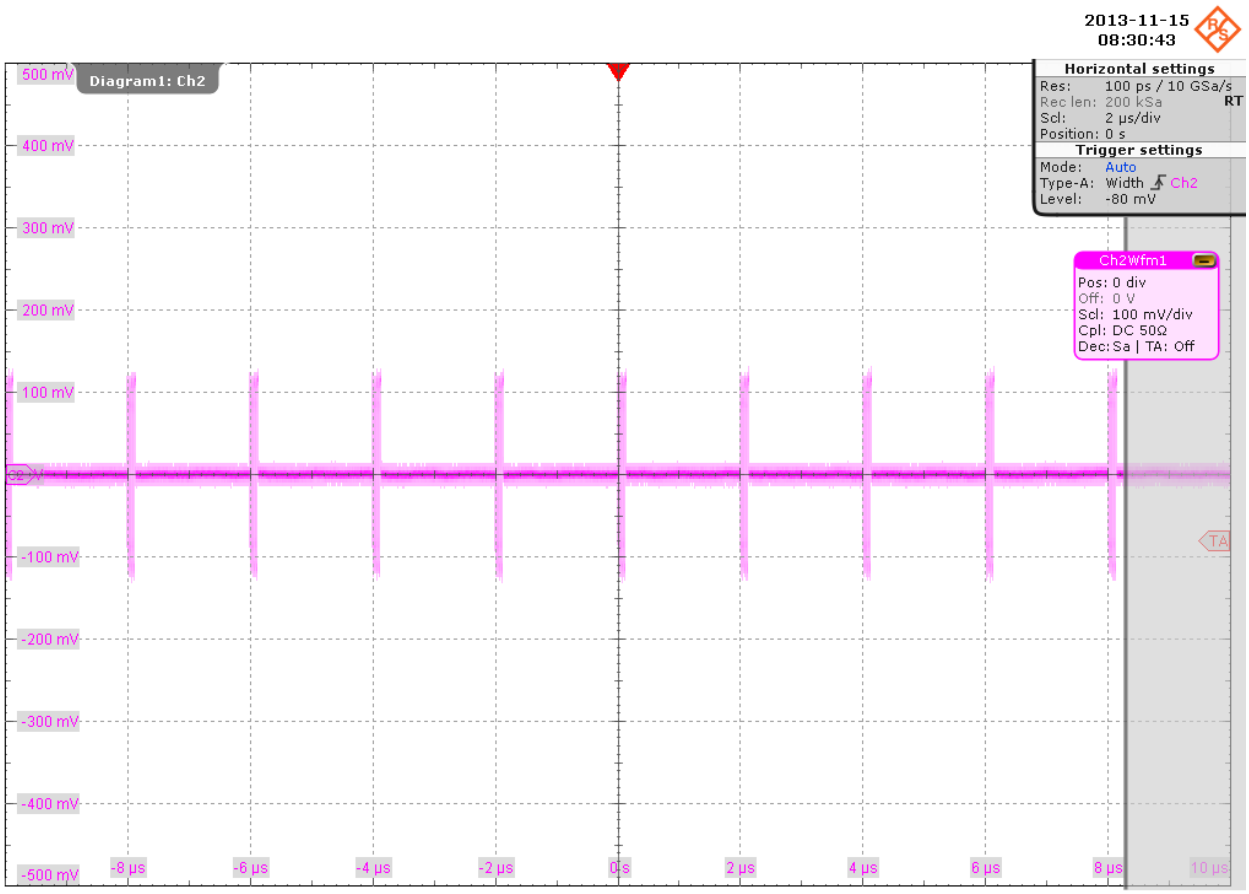
The bigger peak is the (negative) acknowledgement of the device and the smaller peak is the packet sent by the Tabor generator.
The application verifies that all packets from the Tabor generator are (negative) acknowledged. This is EL_18.

10. The application loads the “IN_ADD1” waveform onto the Tabor generator.
    The waveform looks like this:

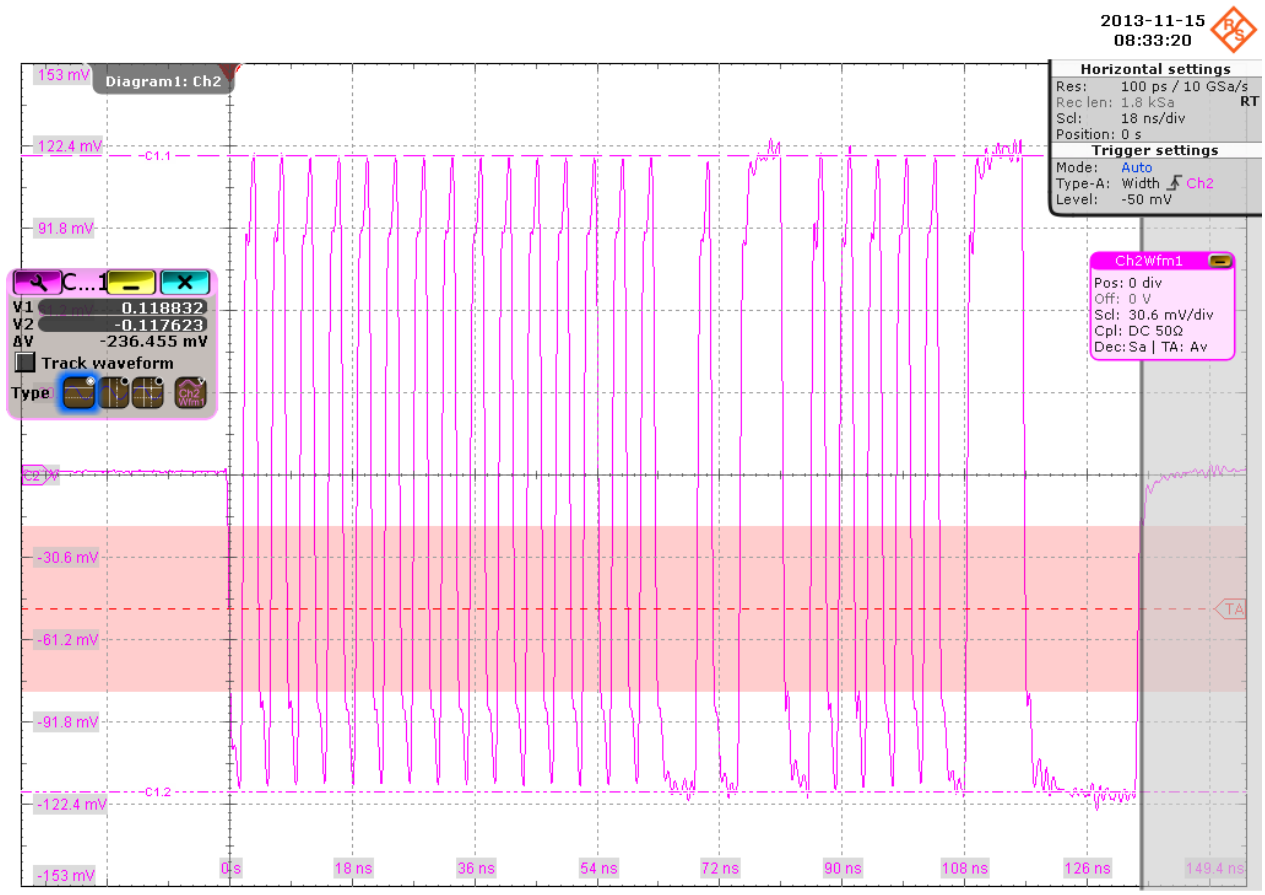


The application decreases the output voltages of the Tabor generator in a step size of 50 mV until the (negative) acknowledgement packets begin to become intermittent.
The application then increases the output voltages of the Tabor generator in a step size of 5 mV until all packets from the Tabor generator are (negative) acknowledged again. The application measures the D+ and D- voltages of the packet from the Tabor generator. The reading is taken at the plateaus of the wider pulses to avoid inflated reading due to overshoots. This is EL_17.

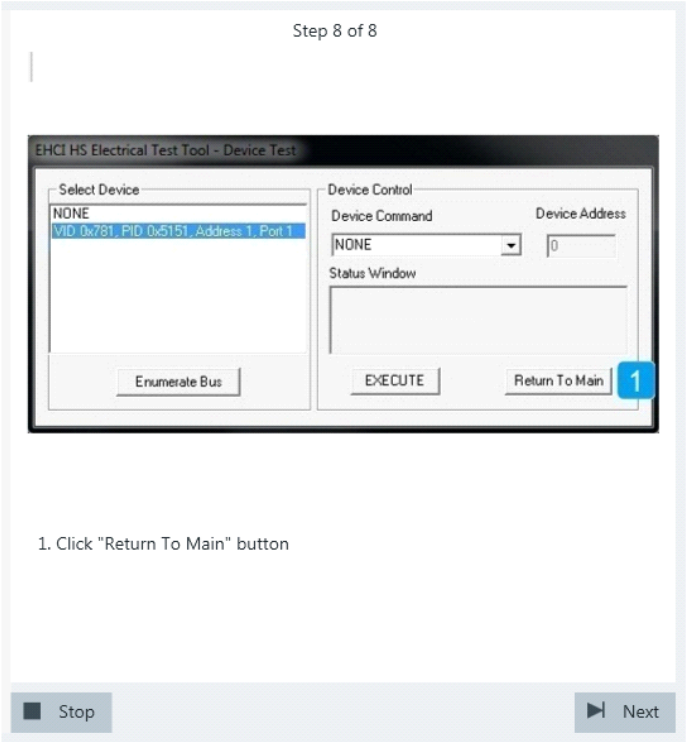
11. The application decreases the output voltages of the Tabor generator in a step size of 5 mV until there is no more (negative) acknowledgement packet like this:



The application measures the D+ and D- voltages of the packet from the Tabor generator. The reading is taken at the plateaus of the wider pulses to avoid inflated reading due to overshoots. This is EL_16.



12. In the HS Electrical Test Tool, click “Return to Main”.



The results are saved and can be viewed in the report.

4.1.7 Setup of Test Waveforms

This section describes the characteristics of the required waveforms used for device or hub receiver sensitivity testing. For these tests, a Tabor WX2182B/WX2182C 2.3 GS/s dual channel arbitrary waveform generator or similar can be used. If you use the Tabor generator, you can create the waveforms using the Waveform Composer with the files `MIN_ADD1.txt` and `IN_ADD1.txt`. The files are provided in the installation directory of the R&S ScopeSuite.

`MIN_ADD1`

- IN token of nominal bit rate and amplitude with shortest allowable sync field (12 bits)
- Bit rate: 480 Mb/s
- High level (both channels): 350 mV
- Low level (both channels): 0 mV
- Pattern length: 44 bits
- Repetition rate: 2 µs (both channels should be at 0 mV for 916 bits following the pattern)

Table 4-7: Pattern bits of MIN_ADD1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CH1 (D+)	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0
CH2 (D-)	1	0	1	0	1	0	1	0	1	0	1	1	1	0	1

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
CH1 (D+)	0	1	1	1	0	0	1	0	1	0	1	0	1	0	1
CH2 (D-)	1	0	0	0	1	1	0	1	0	1	0	1	0	1	0

	31	32	33	34	35	36	37	38	39	40	41	42	43	44
CH1 (D+)	0	0	1	1	1	1	0	0	0	0	0	0	0	0
CH2 (D-)	1	1	0	0	0	0	1	1	1	1	1	1	1	1

IN_ADD1

- IN token of nominal bit rate, amplitude and sync field (32 bits)
- Bit rate: 480 Mb/s
- High level (both channels): 350 mV
- Low level (both channels): 0 mV
- Pattern length: 64 bits
- Repetition rate: 2 µs (both channels should be at 0 mV for 896 bits following the pattern)

Table 4-8: Pattern bits of IN_ADD1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CH1 (D+)	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
CH2 (D-)	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
CH1 (D+)	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
CH2 (D-)	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	1

	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
CH1 (D+)	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
CH2 (D-)	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
CH1 (D+)	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
CH2 (D-)	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	1

4.2 Legacy Device Tests

In addition to the high-speed tests described in the preceeding chapter, the device under test must also pass a set of full speed and low speed compliance tests applicable to high-speed devices. The documentation of these legacy tests can be found in the "USB-IF Full and Low Speed Compliance Test Procedure" manual issued by the USB-IF. The manual is available at http://www.usb.org/developers.

To perform full speed and low speed compliance tests, you can use also a 4-channel R&S RTO with less than 2 GHz bandwidth.

5 Hub Tests

5.1 High-Speed Hub Tests

- Upstream Signal Quality 79
- Downstream Signal Quality 80
- Downstream Jitter 86
- Upstream Packet Parameters 92
- Upstream Receiver Sensitivity 93
- Upstream Repeater 94
- Downstream Repeater 101
- Upstream Chirp Timing 105
- Upstream Suspend/Resume/Reset Timing 106
- Upstream Test J/K, SE0_NAK 107
- Downstream Test J/K, SE0_NAK 108

5.1.1 Upstream Signal Quality

Table 5-1: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Device SQ" section or USB-IF USB2.0 hi-speed signal quality device test fixture	R&S RT-ZF1	1
Differential probe or a pair of SMA cables if USB-IF device test fixture is used	differential probe with at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S ScopeSuite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

The upstream signal quality test for hubs is mainly the same as the signal quality test for devices. Follow the instructions in the R&S ScopeSuite, and refer to the test description in Chapter 4.1.1, "Signal Quality", on page 21 Make sure to select "Hub" in the "HS Electrical Test Tool" (step 5).

5.1.2 Downstream Signal Quality

Table 5-2: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Host Signal Quality" section, or USB-IF USB2.0 hi-speed signal quality host test fixture	R&S RT-ZF1	1
Differential probe or a pair of SMA cables if USB-IF host test fixture is used	differenttial probe with at least at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

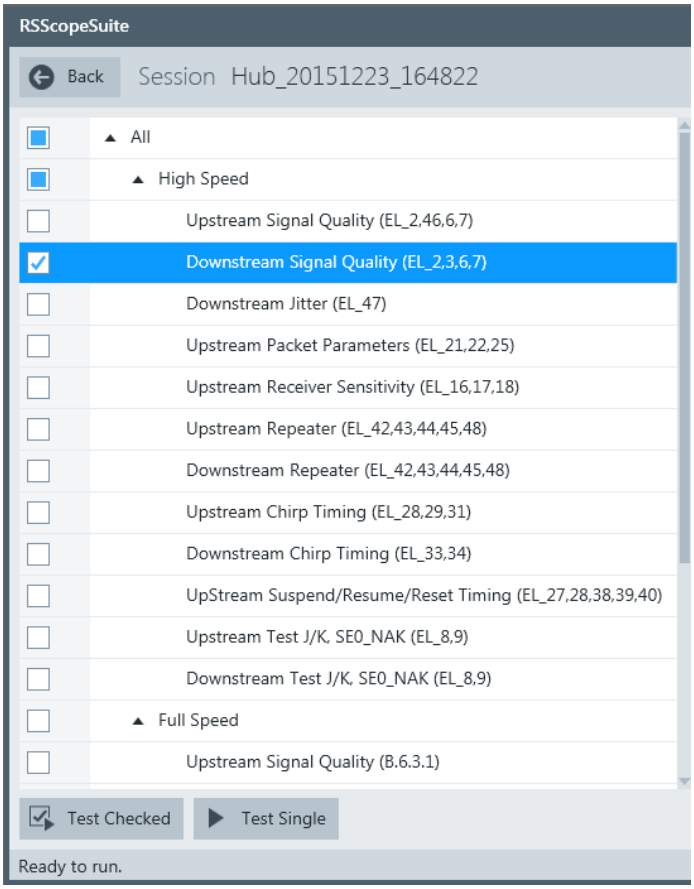
Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S ScopeSuite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Downstream Signal Quality (EL_2,3,6,7)" test case and click "Test Single".



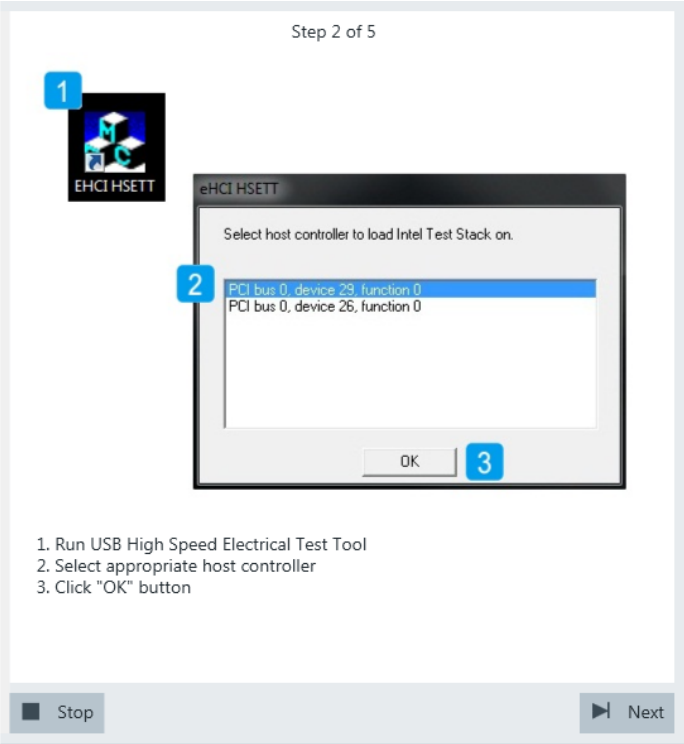
2. Connect the DUT to the test fixture as shown in the picture.

Figure 5-1: R&S RT-ZF1: connection to DUT

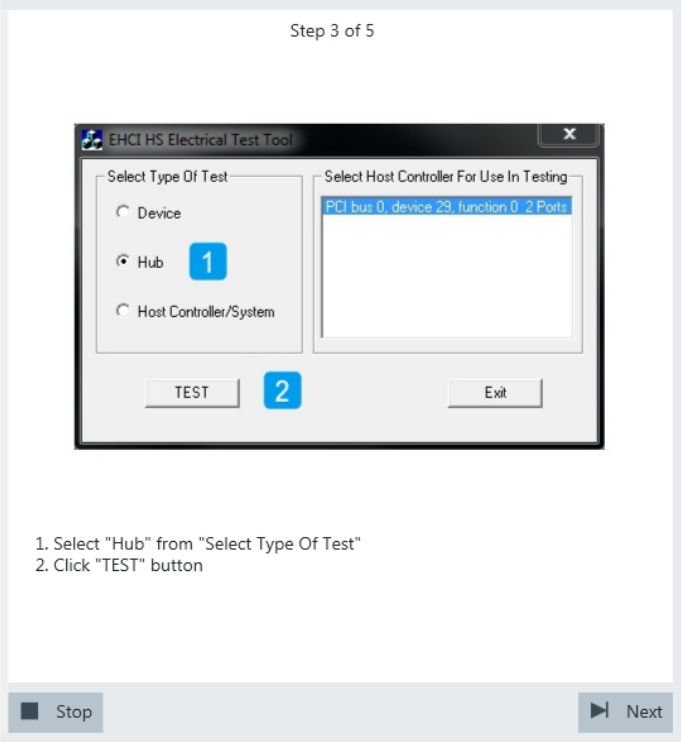
Figure 5-2: USB-IF USB2.0 Hi-Speed Signal Quality host test fixture: connection to DUT

If R&S test fixture is used, connect the test fixture to the downstream port under test with a 4-inch non-captive cable. If USB-IF test fixture is used, connect the test fixture directly to the downstream port under test.
If the DUT has a cable attached, plug it into the test bed computer directly. Otherwise, use a 1-meter cable to connect the test bed computer to the upstream port.
Click "Next".

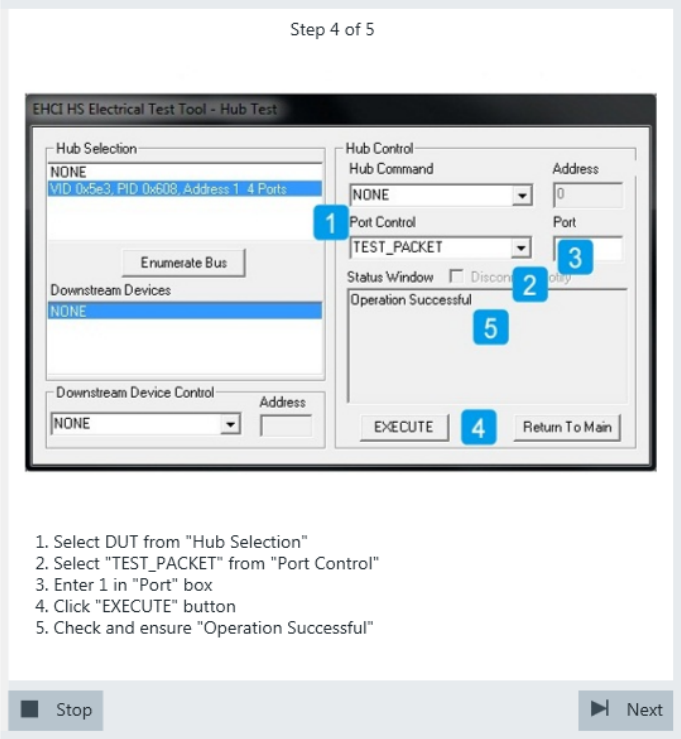
3. Start the HS Electrical Test Tool on the test bed computer.
4. Select the host controller to which the DUT is connected and click OK.
   Note: the values in the list may vary.
   Click "Next" in the R&S ScopeSuite.



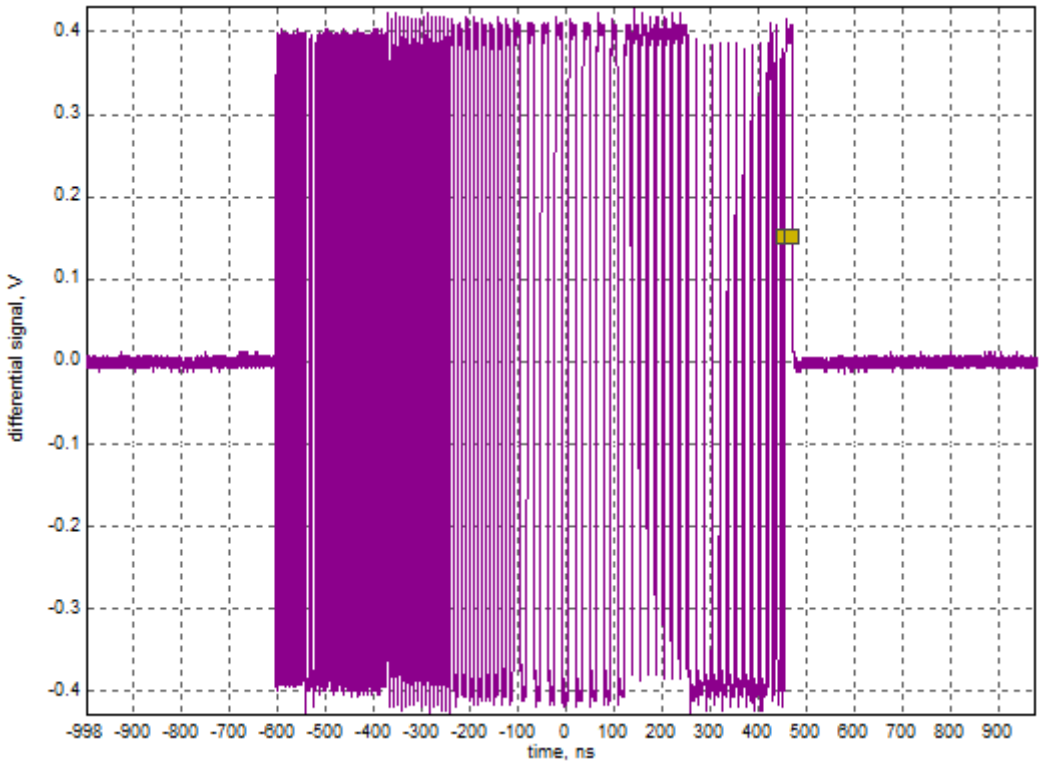
5. Select "Hub" on the left side, and click "TEST"

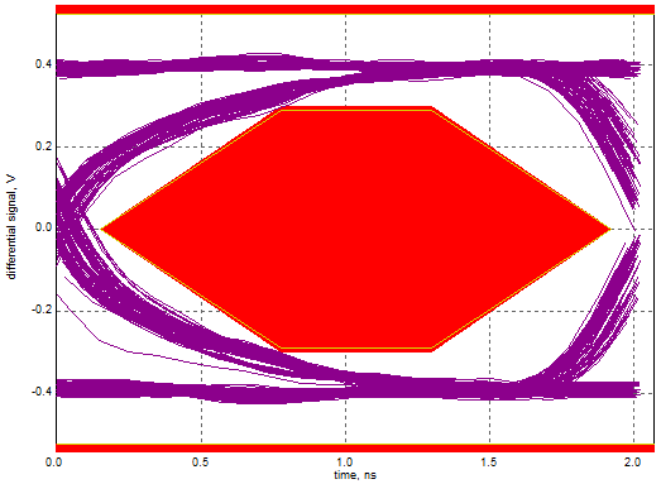


6. Configure the HS Electrical Test Tool as shown in the picture.

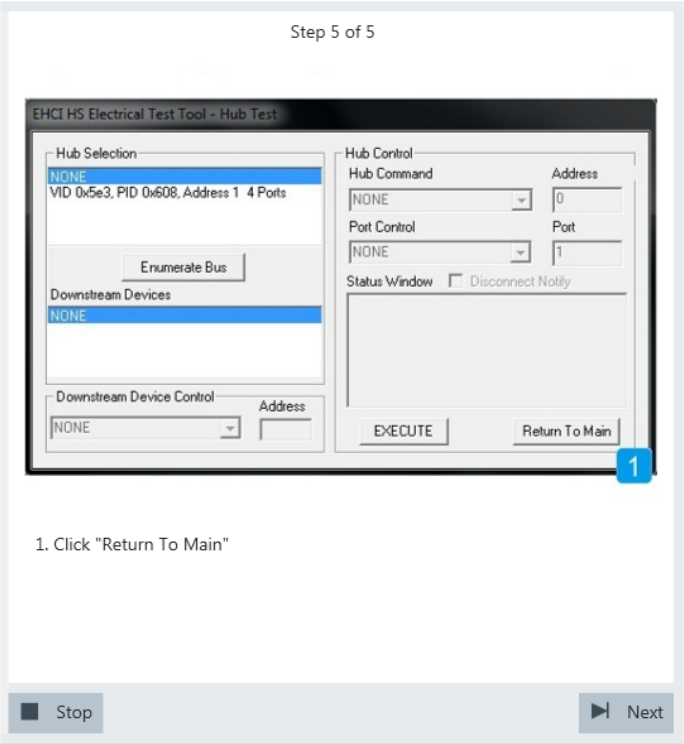


The test packets are sent to the oscilloscope. They are analyzed in an eye diagram.





7. Proceed in the HS Electrical Test Tool as shown in the picture.



The results are saved and can be viewed in the report.

5.1.3 Downstream Jitter

Table 5-3: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Host Signal Quality" section, or USB-IF USB2.0 hi-speed signal quality host test fixture	R&S RT-ZF1	1
Differential probe, or a pair of SMA cables if USB-IF host test fixture is used	Differential probe with at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

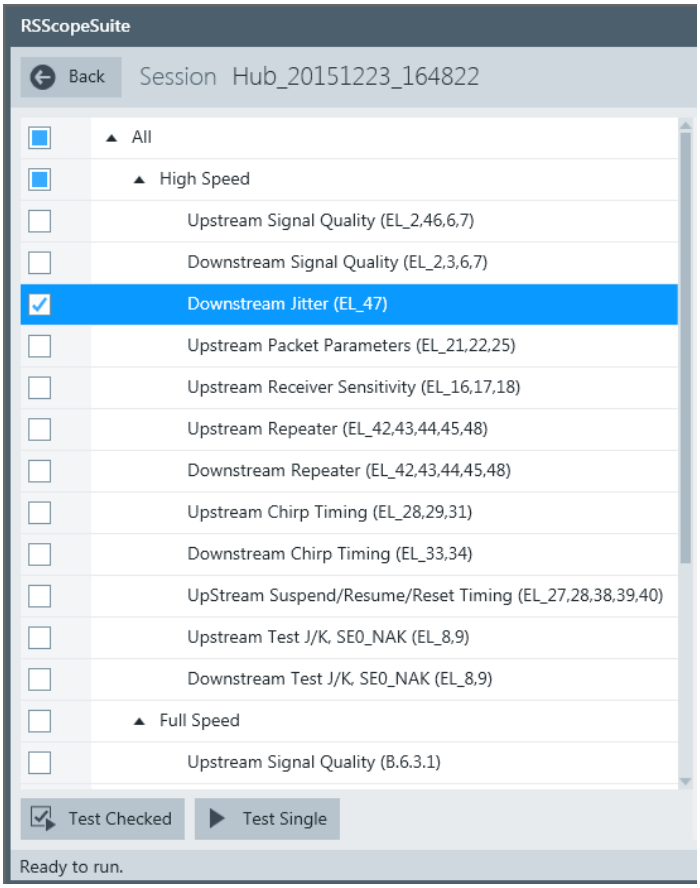
Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Downstream Jitter (EL_47)" test case and click "Test Single".



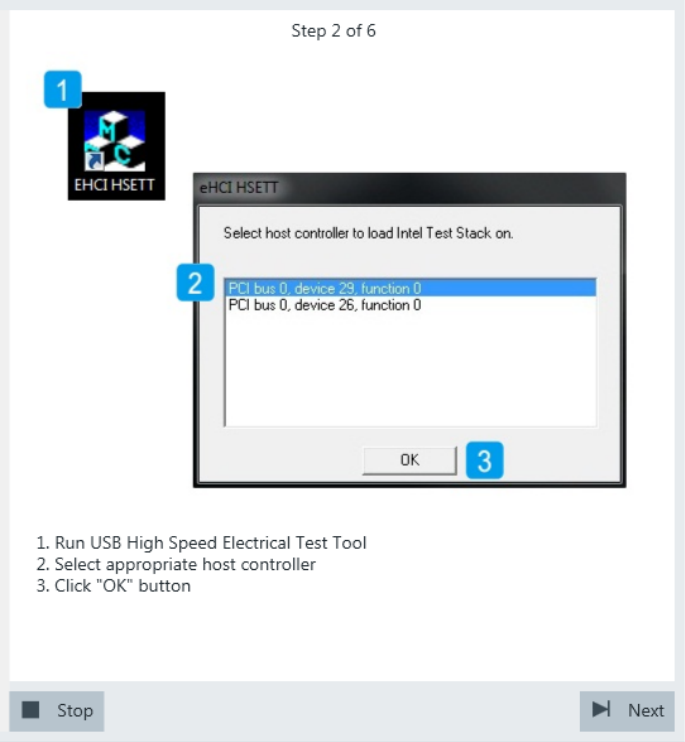
2. Connect the DUT to the test fixture as shown in the picture.

Figure 5-3: R&S RT-ZF1: connection to DUT

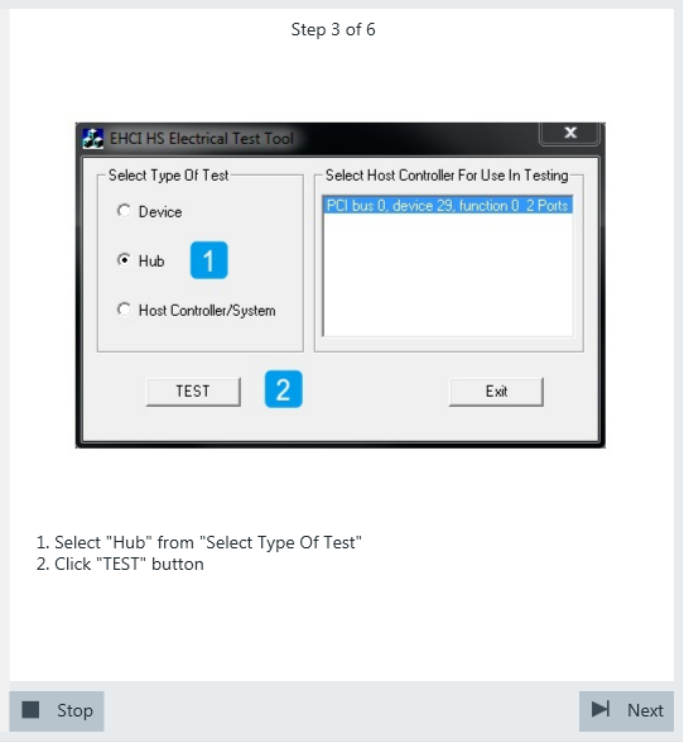
Figure 5-4: USB-IF USB2.0 hi-speed signal quality host test fixture: connection to DUT

If the DUT has an attached cable, connect it directly to the test bed computer. Otherwise, use a 1-meter cable to connect the upstream port and the test bed computer.
Click Next.

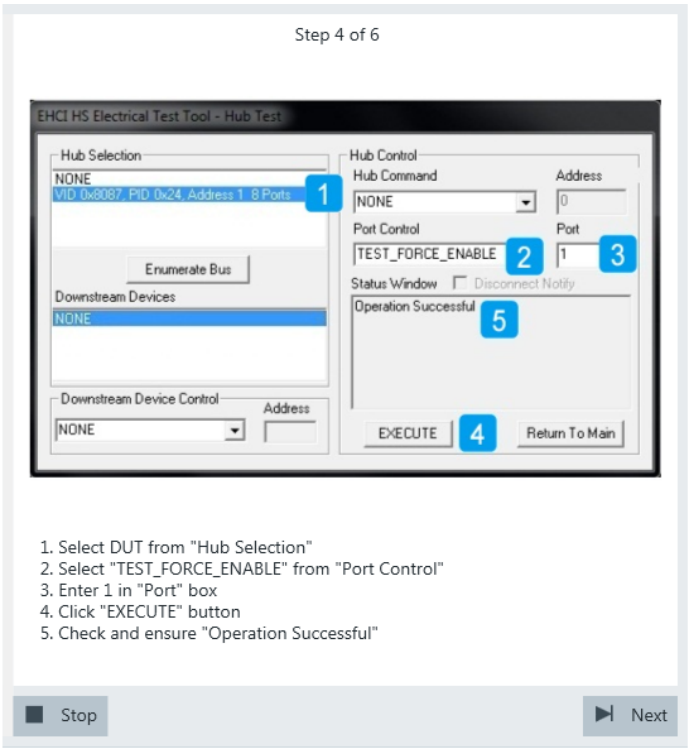
3. Start the HS Electrical Test Tool on the test bed computer.
4. Select the host controller to which the DUT is connected and click OK.
Note: the values in the list may vary.



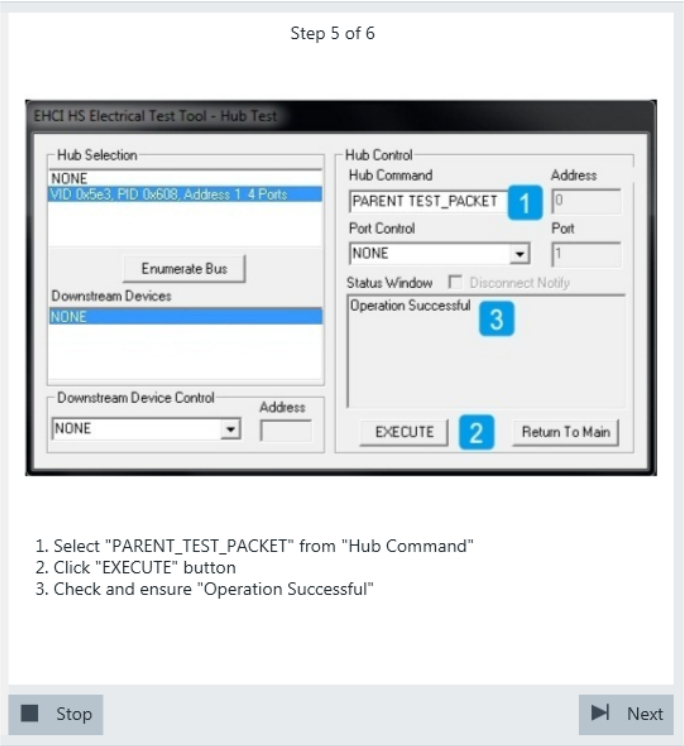
5. Select "Hub" on the left side, and click "TEST"



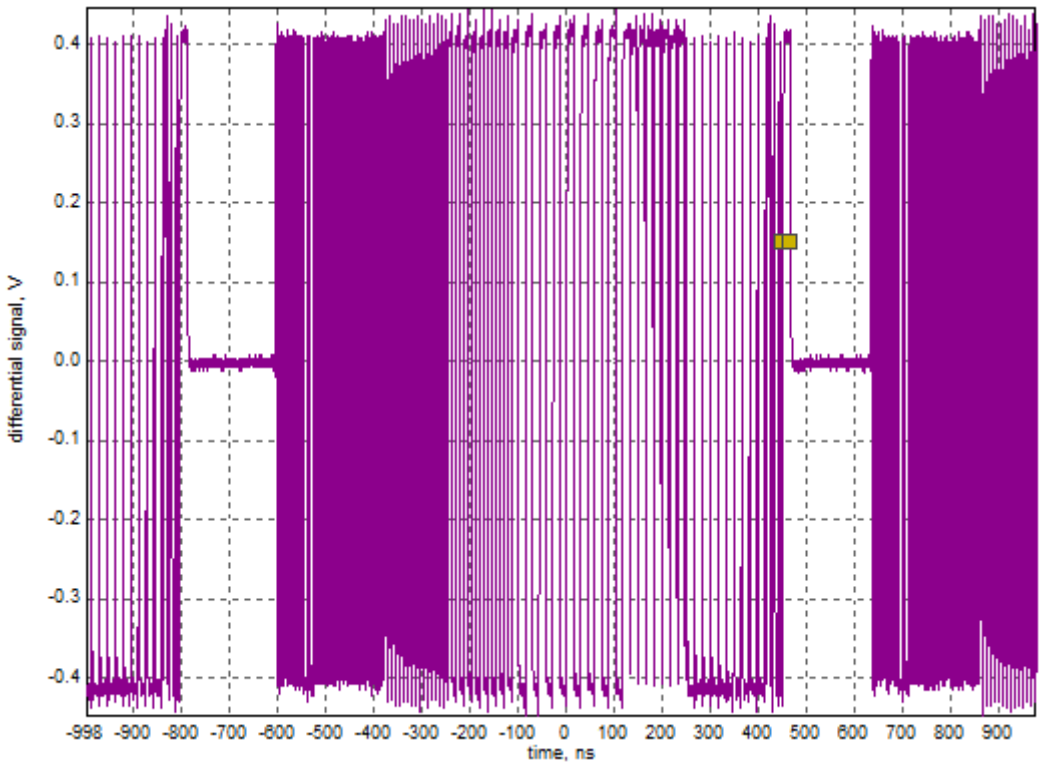
6. Configure the HS Electrical Test Tool as shown in the picture.

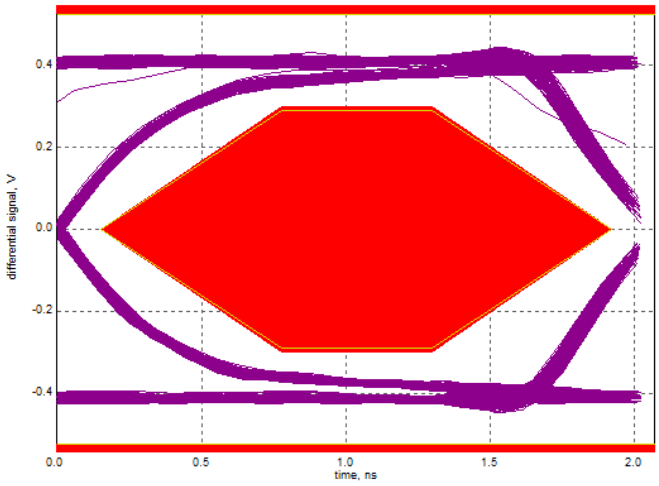


7. Configure the HS Electrical Test Tool as shown in the picture.



The test packets are sent to the oscilloscope. They are analyzed in an eye diagram.





The results are saved and can be viewed in the report.

5.1.4 Upstream Packet Parameters

Table 5-4: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S ScopeSuite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

The upstream packet parameter test for hubs is mainly the same as the packet parameter test for devices. Follow the instructions in the R&S ScopeSuite, and refer to the test description in Chapter 4.1.2, "Packet Parameters", on page 29. Make sure to select "Hub" in the "HS Electrical Test Tool" (step 5).

5.1.5 Upstream Receiver Sensitivity

Table 5-5: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Receiver Sensitivity" section	R&S RT-ZF1	1
Dual channel arbitrary waveform generator (AWG)	Tabor WX2182B/WX2182C 2.3 GS/s	1
SMA cable	to connect the signal generator to the test fixture	2
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

Test preparation comprises common preparation steps and the connection of the AWG.

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S ScopeSuite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Additional preparation step:

- LAN connection of the AWG and the computer running the R&S ScopeSuite, see Chapter 2.6, "Connecting the Arbitrary Waveform Generator", on page 11.

Running the test

The upstream receiver sensitivity test for hubs is mainly the same as the receiver sensitivity test for devices. Follow the instructions in the R&S ScopeSuite, and refer to the test description in Chapter 4.1.6, "Receiver Sensitivity", on page 65. Make sure to select "Hub" in the "HS Electrical Test Tool" (step 6).

5.1.6 Upstream Repeater

Table 5-6: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Receiver Sensitivity" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

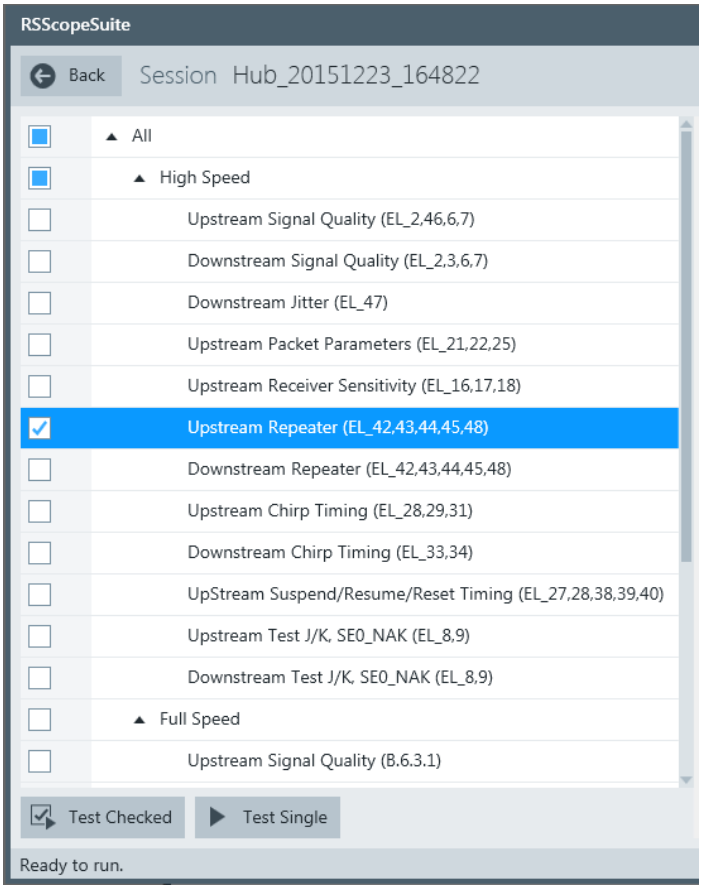
Test preparation

Before you run the test, complete the following actions:

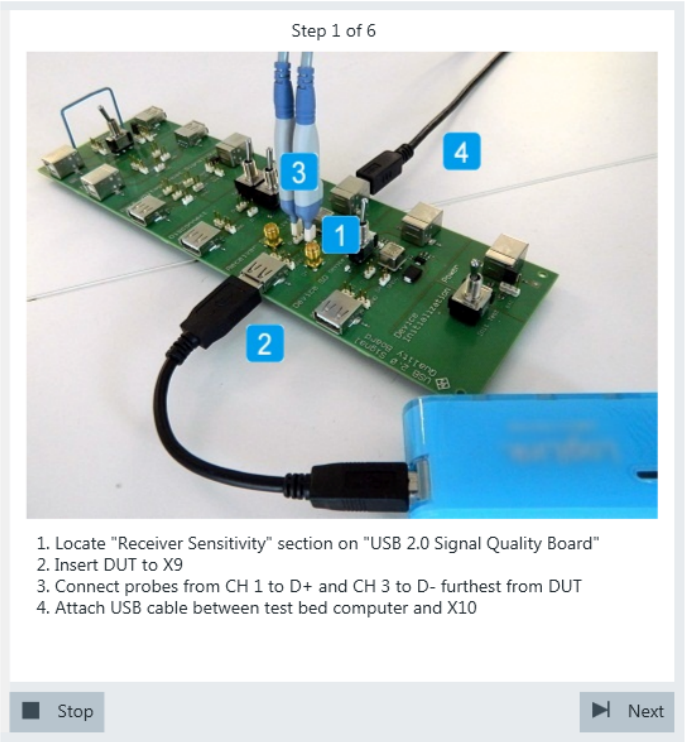
- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the “Upstream Repeater (EL_42,43,44,45,48)” test case and click "Test Single".

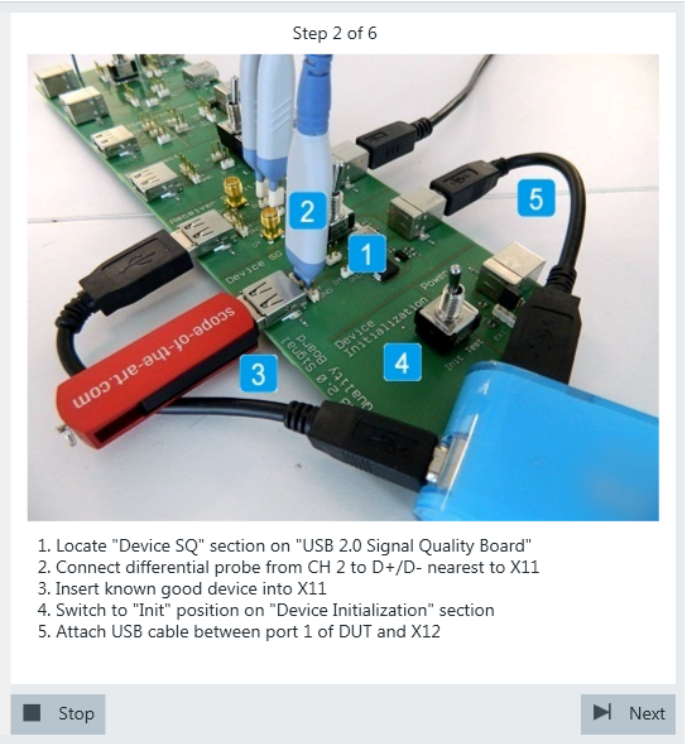


2. Connect the DUT to the “Receiver Sensitivity” section of the test fixture as shown in the picture, and click "Next".



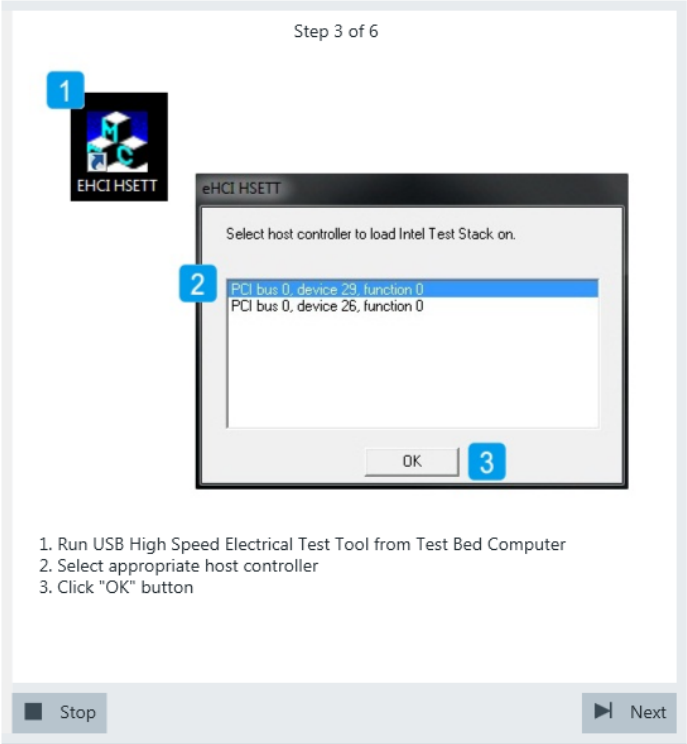
If the DUT has a cable attached, plug it into the test fixture directly. Otherwise, use a 4-inch non-captive cable to connect the test fixture to the upstream port.
Use a 1-meter cable to connect the test fixture to the test bed computer.

3. Connect the DUT to the “Device SQ” section of the test fixture as shown in the picture and click "Next".

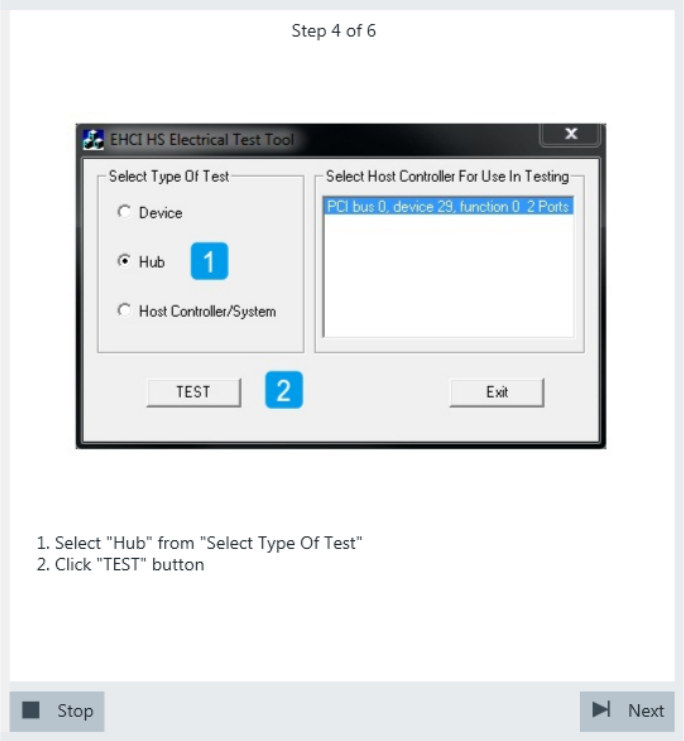


Use a 4-inch non-captive cable to connect the downstream port to the test fixture.

4. Start the HS Electrical Test Tool on the test bed computer.
5. Select the host controller to which the DUT is connected and click OK.
   Note: the values in the list may vary.

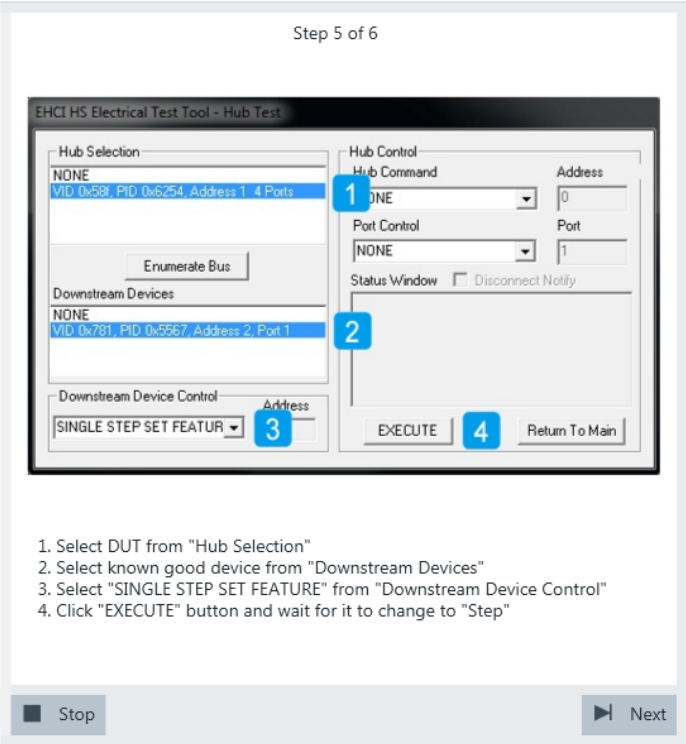


6. Select “Hub” on the left side, and click “TEST”.

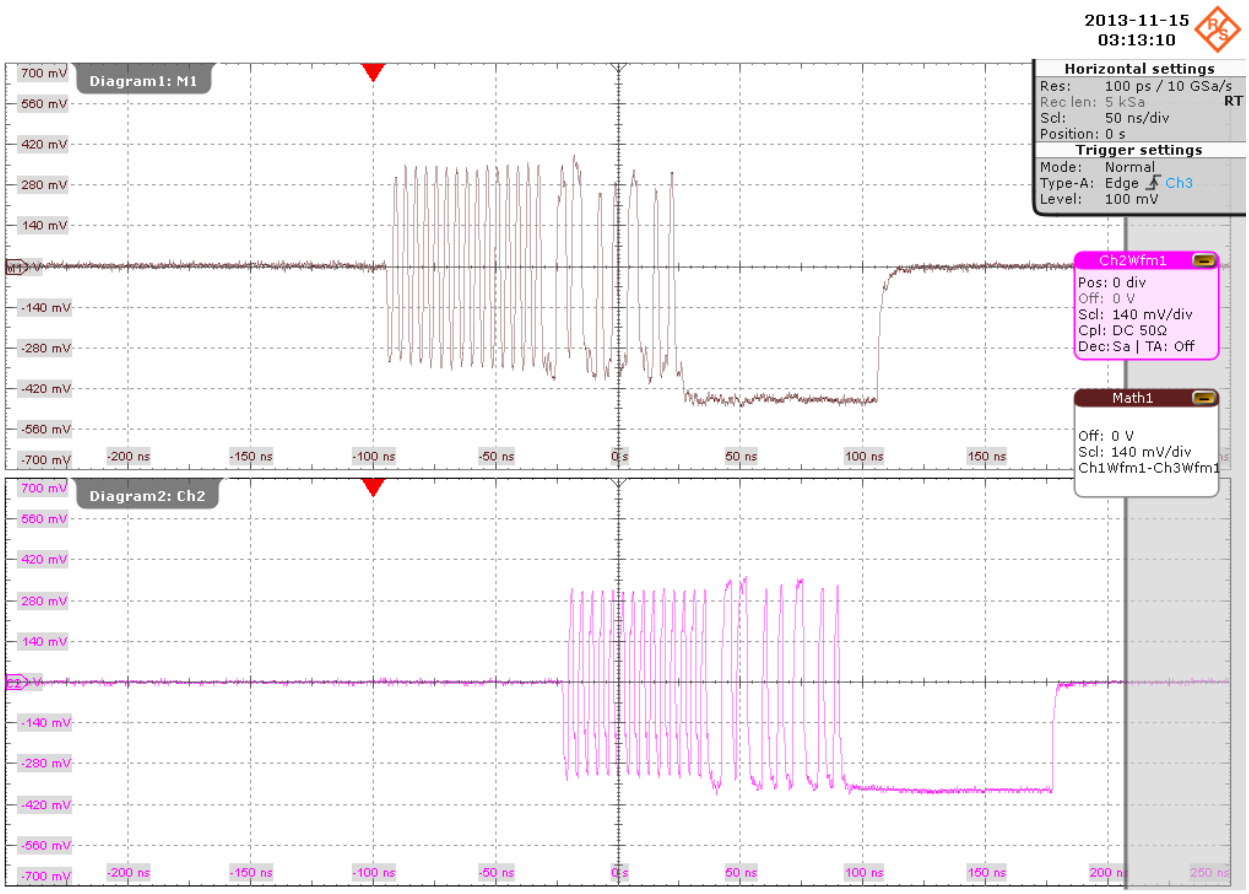


7. Configure the HS Electrical Test Tool:
   a) Under “Hub Selection”, click “DUT”.

b) Under “Downstream Devices”, select a known good device.
c) Under “Downstream Device Control”, click “Single Step Set Feature”.
d) Click “EXECUTE” and wait until the button changes to “Step”.

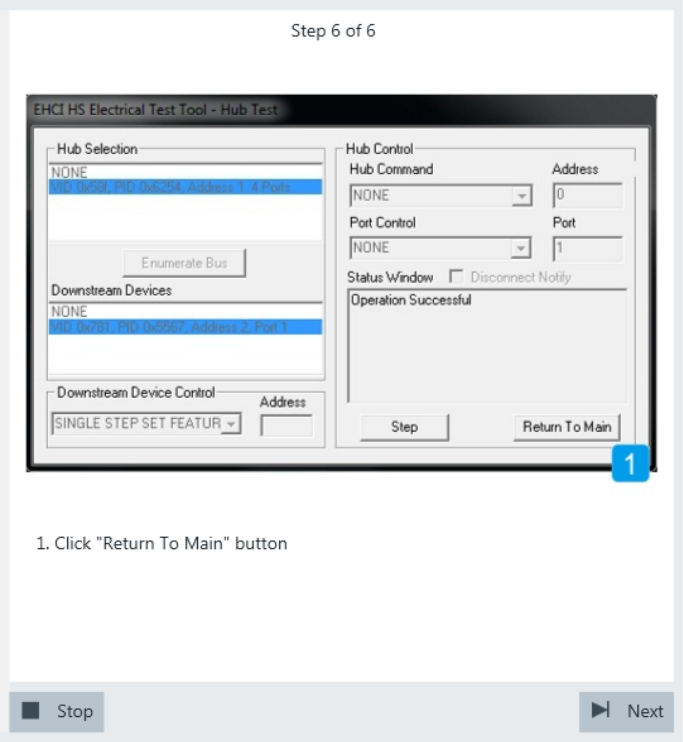


Waveforms like this are captured.



The packets at the top are captured from the upstream port of the DUT.
The packets at the bottom are captured from the downstream port of the DUT.
The two packets with lower amplitude at the top left are sent by the test bed computer. They are repeated downstream by the DUT to the known good device (bottom left).
The packet with higher amplitude at the bottom right is response from the known good device. It is repeated upstream by the DUT to the test bed computer (top right).
The application downloads the waveforms and compares the differences between the two response packets in term of the number of truncated bits in the SYNC field, the number of added bits in the EOP field and the time taken for the response packet to move upstream.

8. In the HS Electrical Test, click “Return to Main”.



The results are saved and can be viewed in the report.

5.1.7 Downstream Repeater

Table 5-7: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Receiver Sensitivity" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

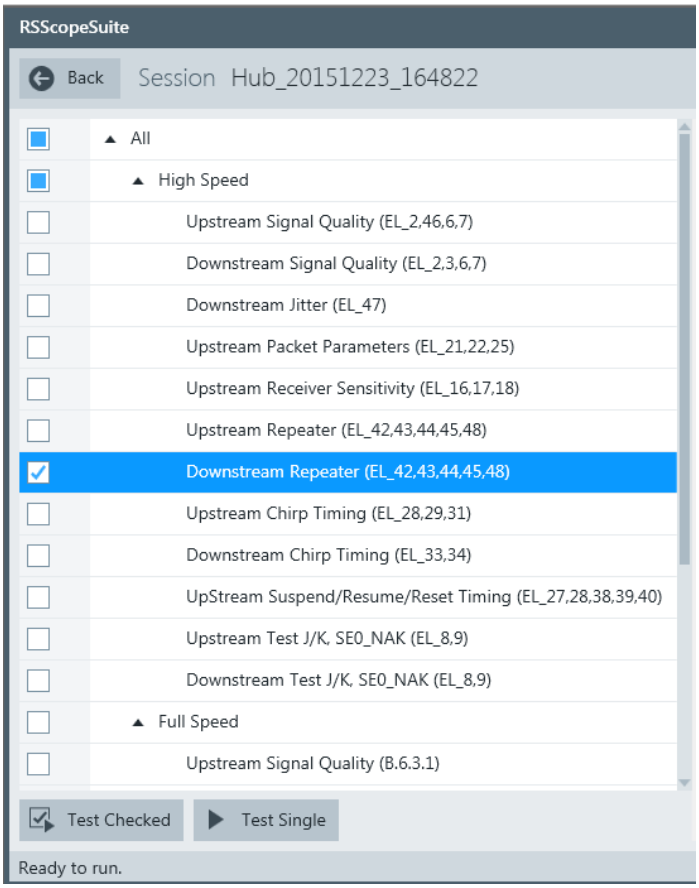
Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9

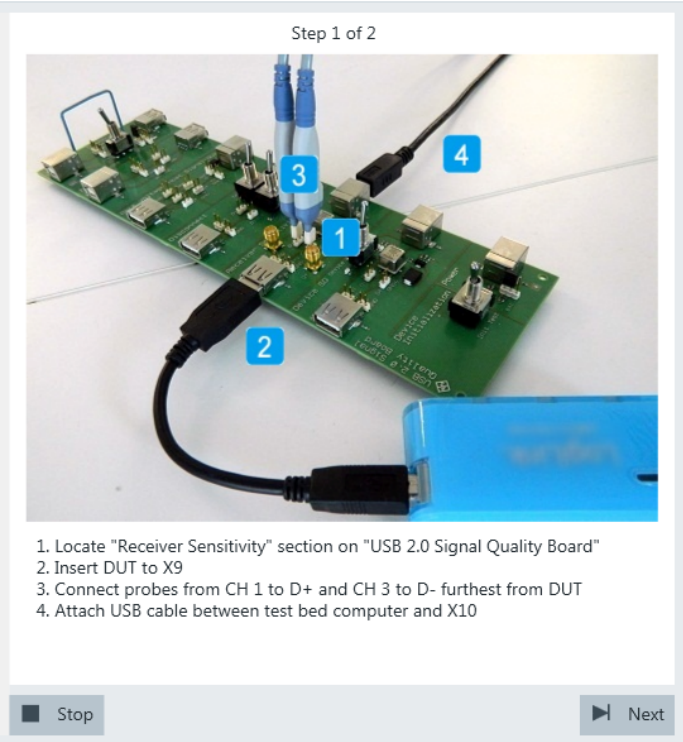
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Downstream Repeater Test (EL_42,43,44,45,48)" test case and click "Test Single".

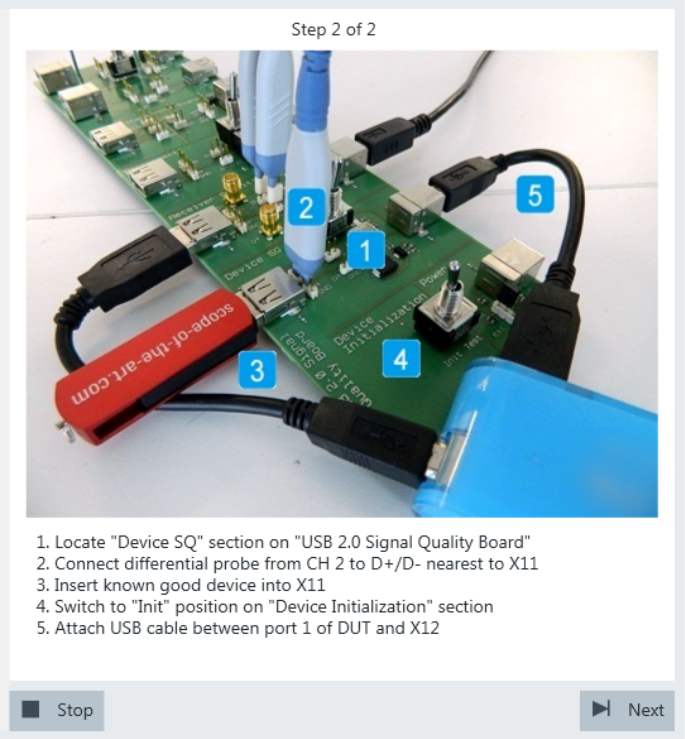


2. Connect the DUT to the "Receiver Sensitivity" section of the test fixture as shown in the picture, and click "Next".



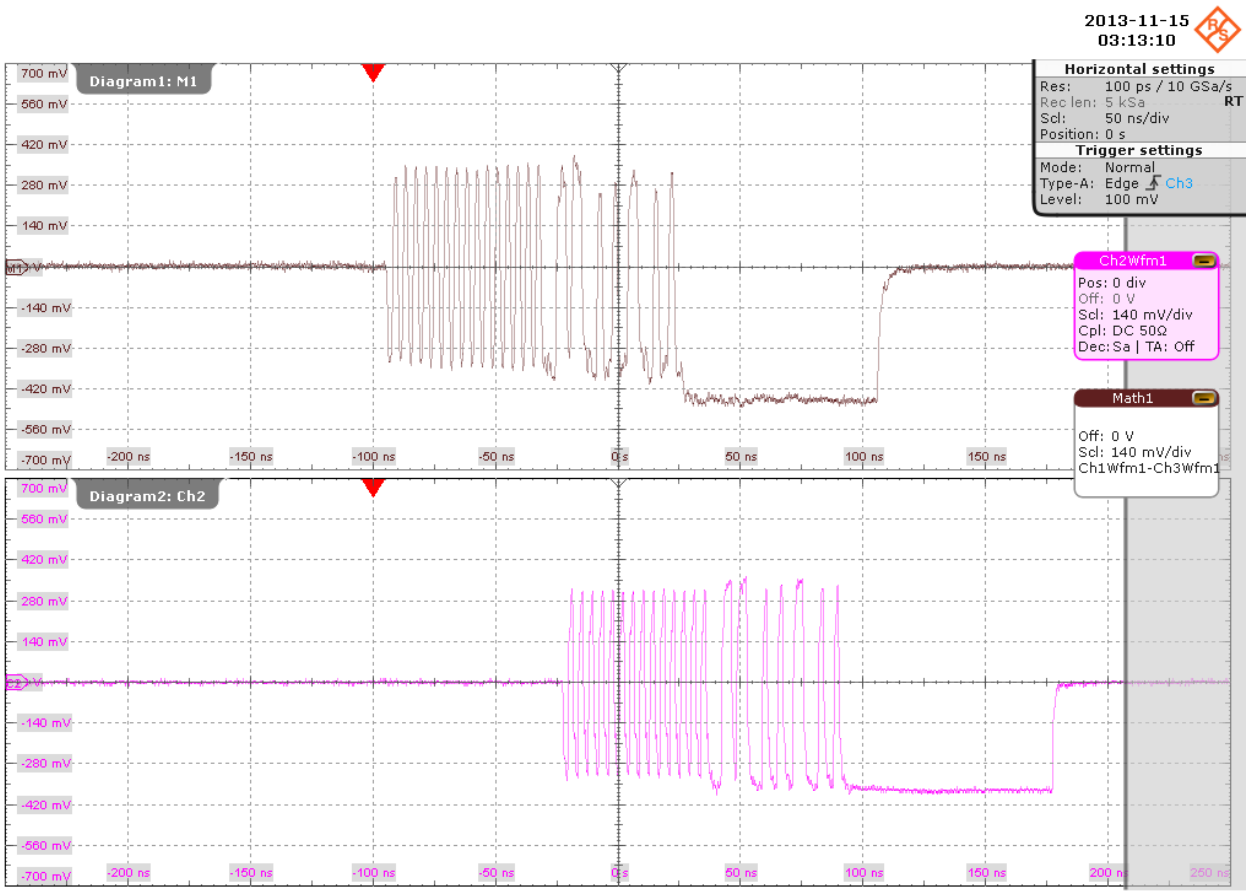
If the DUT has a cable attached, plug it into the test fixture directly. Otherwise, use a 4-inch non-captive cable to connect the test fixture to the upstream port.
Use a 1-meter cable to connect the test fixture to the test bed computer.

3. Connect the DUT to the "Device SQ" section of the test fixture as shown in the picture, and click "Next".



Use a 4-inch non-captive cable to connect the downstream port to the test fixture.

Waveforms like this are captured.



The packet at the top is the “Start of Frame” packet from the test bed computer. The packet at the bottom is the repeated “Start of Frame” packet from the DUT. The application downloads the waveforms and compares the differences between the two packets in term of the number of truncated bits in the SYNC field, the number of added bits in the EOP field and the time taken for the “Start of Frame” packet to move downstream.

The results are saved and can be viewed in the report.

5.1.8 Upstream Chirp Timing

Table 5-8: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1

Item	Description, model	Quantity
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S ScopeSuite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

The upstream chirp timing test for hubs is mainly the same as the chirp timing test for devices. Follow the instructions in the R&S ScopeSuite, and refer to the test description in Chapter 4.1.3, "Chirp Timing", on page 36. Make sure to select "Hub" in the "HS Electrical Test Tool" (step 5).

5.1.9 Upstream Suspend/Resume/Reset Timing

Table 5-9: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S ScopeSuite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

The upstream suspend/resume/reset timing test for hubs is mainly the same as the suspend/resume/reset timing test for devices. Follow the instructions in the R&S ScopeSuite, and refer to the test description in Chapter 4.1.4, "Suspend/Resume/Reset Timing", on page 41. Make sure to select "Hub" in the "HS Electrical Test Tool" (step 7).

5.1.10 Upstream Test J/K, SE0_NAK

Table 5-10: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S ScopeSuite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

The upstream test J/K, SE0_NAK for hubs is mainly the same as the test J/K, SE0_NAK for devices. Follow the instructions in the R&S ScopeSuite, and refer to the test description in Chapter 4.1.5, "Test J/K, SE0_NAK", on page 54. Make sure to select "Hub" in the "HS Electrical Test Tool" (step 6).

5.1.11 Downstream Test J/K, SE0_NAK

Table 5-11: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the hub you want to test	1
Signal quality board, "Host Signal Quality" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

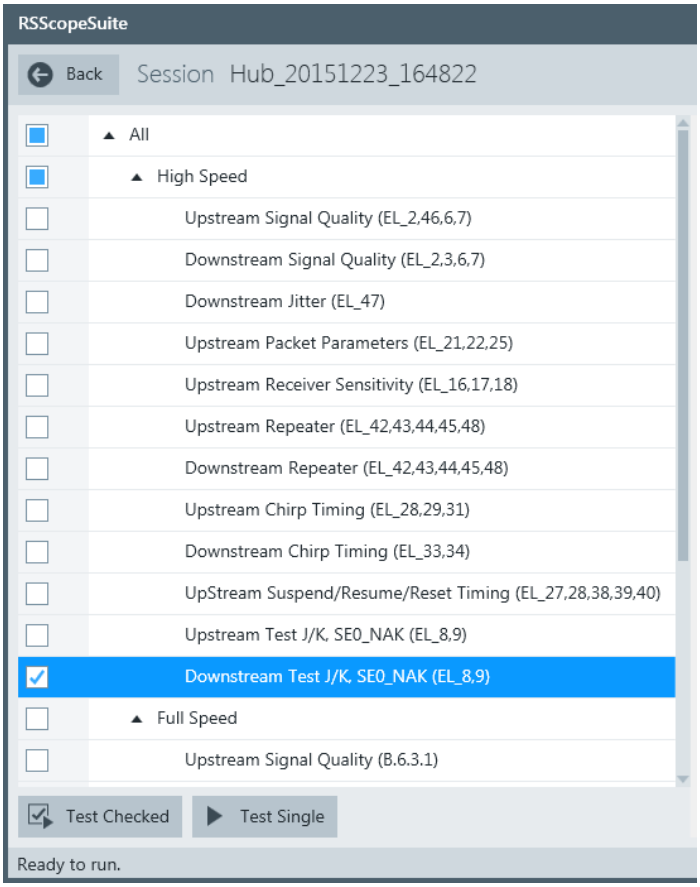
Test preparation

Before you run the test, complete the following actions:

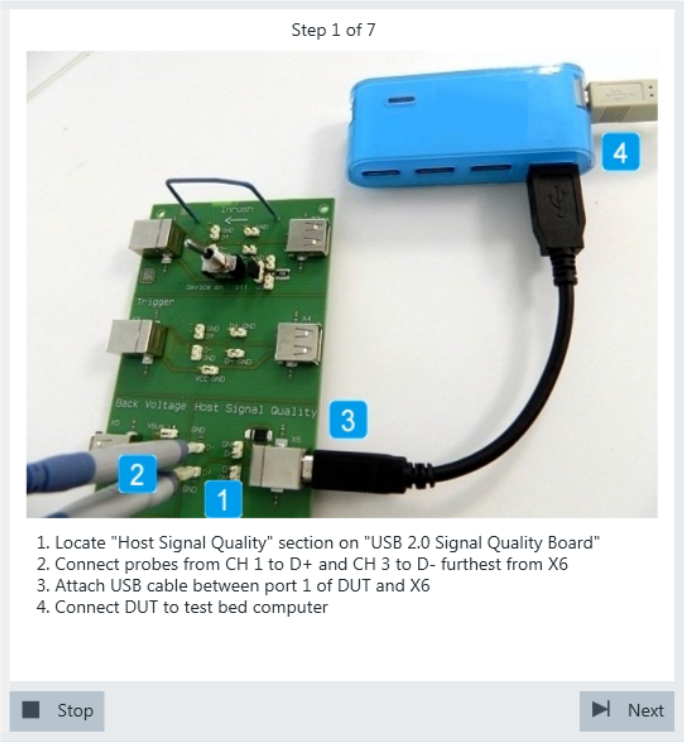
- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Hub"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Downstream Test J/K, SE0_NAK (EL_8,9)" test case and click "Test Single".

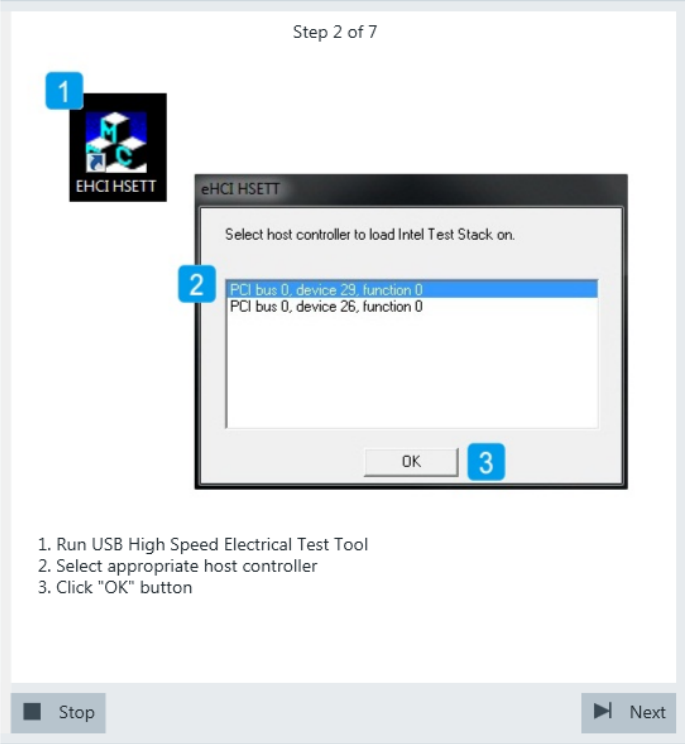


2. Connect the DUT to the test fixture as shown in the picture, and click "Next".

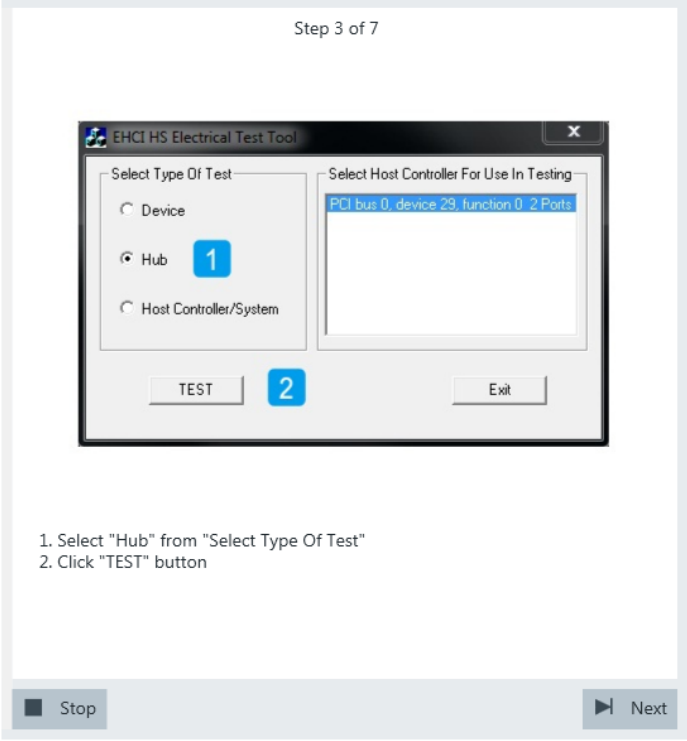


Use a 4-inch non-captive cable to connect the downstream port to test fixture. If the DUT has a cable attached, plug it into the test bed computer directly. Otherwise, use a 1-meter cable to connect the upstream port to the test bed computer.

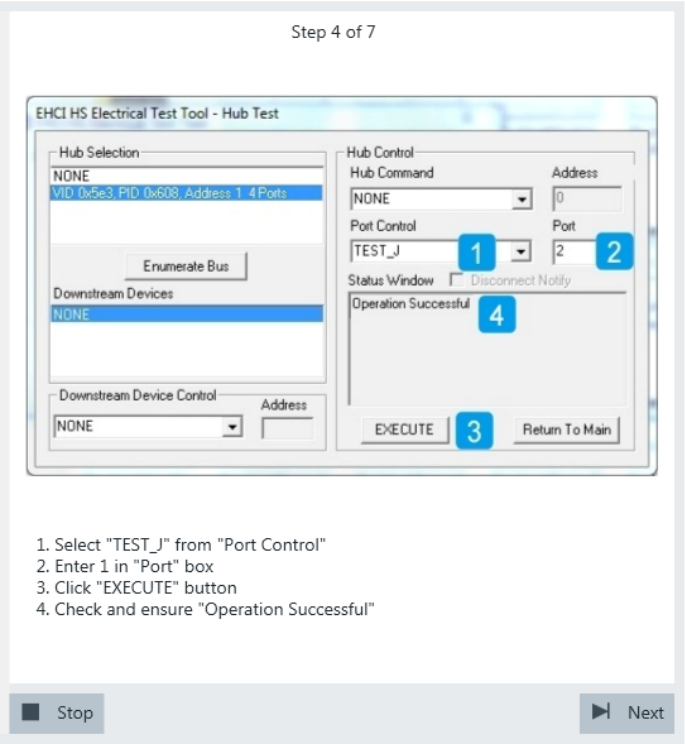
3. Start the HS Electrical Test Tool on the test bed computer.
4. Select the host controller to which the DUT is connected and click OK.
   Note: the values in the list may vary.



5. Select "Hub" on the left side, and click "TEST"

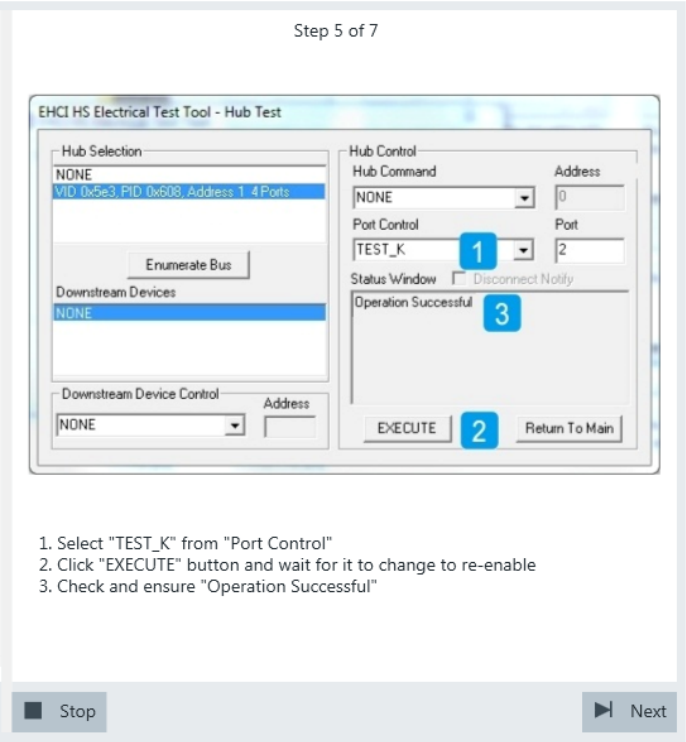


6. Configure the HS Electrical Test Tool as shown in the picture.



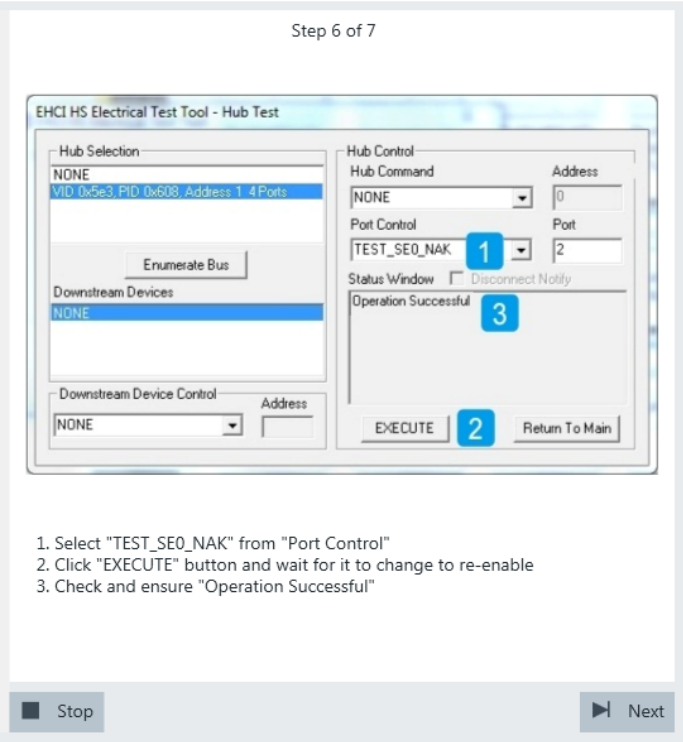
The probe at least 2 GHz bandwidth contains a built-in digital voltmeter known as ProbeMeter. The application automatically reads the voltages of D+ and D- from the ProbeMeter. However, if the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user to enter the voltages of D+ and D-.

7. Configure the HS Electrical Test Tool as shown in the picture.



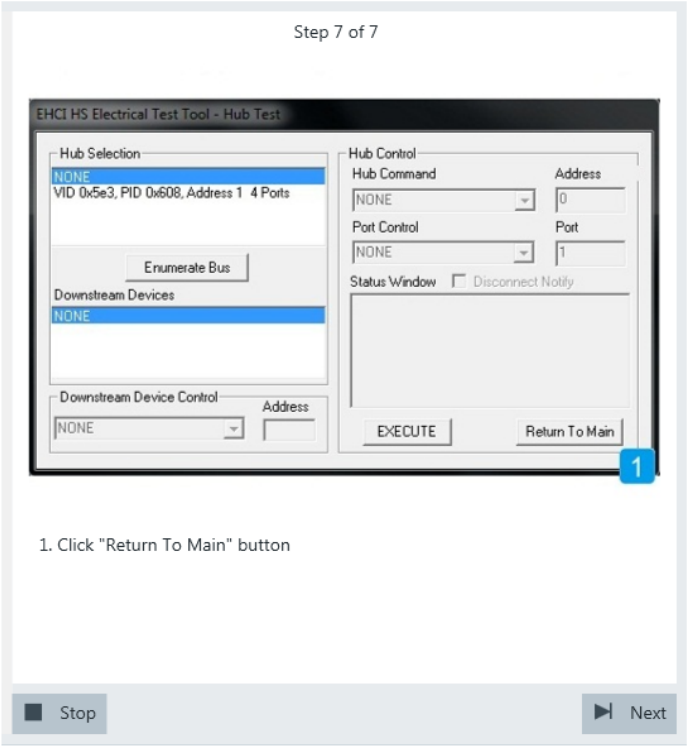
If the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user to enter the voltages of D+ and D-. Otherwise it automatically reads them from the ProbeMeter.

8. Configure the HS Electrical Test Tool as shown in the picture.



If the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user to enter the voltages of D+ and D-. Otherwise it automatically reads them from the ProbeMeter.

9. Proceed in the HS Electrical Test Tool as shown in the picture.



The results are saved and can be viewed in the report.

5.2 Legacy Hub Tests

In addition to the high-speed tests described in the preceeding chapter, the device under test must also pass a set of full speed and low speed compliance tests applicable to high-speed devices. The documentation of these legacy tests can be found in the "USB-IF Full and Low Speed Compliance Test Procedure" manual issued by the USB-IF. The manual is available at http://www.usb.org/developers.

To perform full speed and low speed compliance tests, you can use also a 4-channel R&S RTO with less than 2 GHz bandwidth.

6 Host Tests

6.1 High-Speed Host Tests

- Signal Quality....116
- Packet Parameters....122
- Chirp Timing....134
- Suspend/Resume Timing....144
- Test J/K, SE0_NAK....151

6.1.1 Signal Quality

Table 6-1: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the host you want to test	1
Signal quality board, "Host Signal Quality" section or USB-IF USB2.0 hi-speed signal quality host test fixture	R&S RT-ZF1	1
Differential probe or a pair of SMA cables if USB-IF host test fixture is used	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

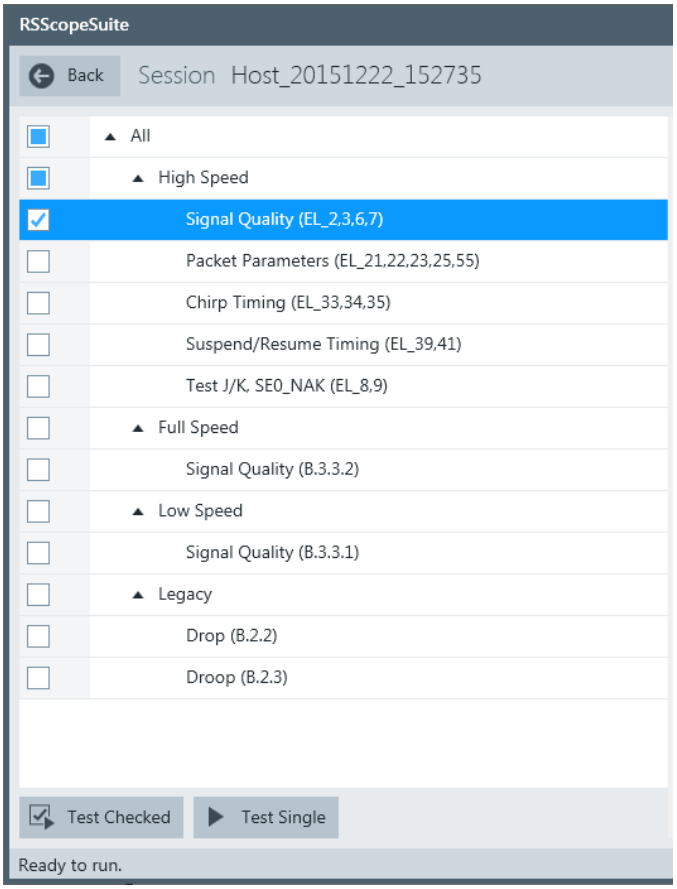
Test preparation

Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Host"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Signal Quality (EL_2,3,6,7)" test case and click "Test Single".



2. Connect the DUT to the test fixture as shown in the picture.

Figure 6-1: R&S RT-ZF1: connection to DUT

Use a 4-inch non-captive cable to connect the DUT to the test fixture.

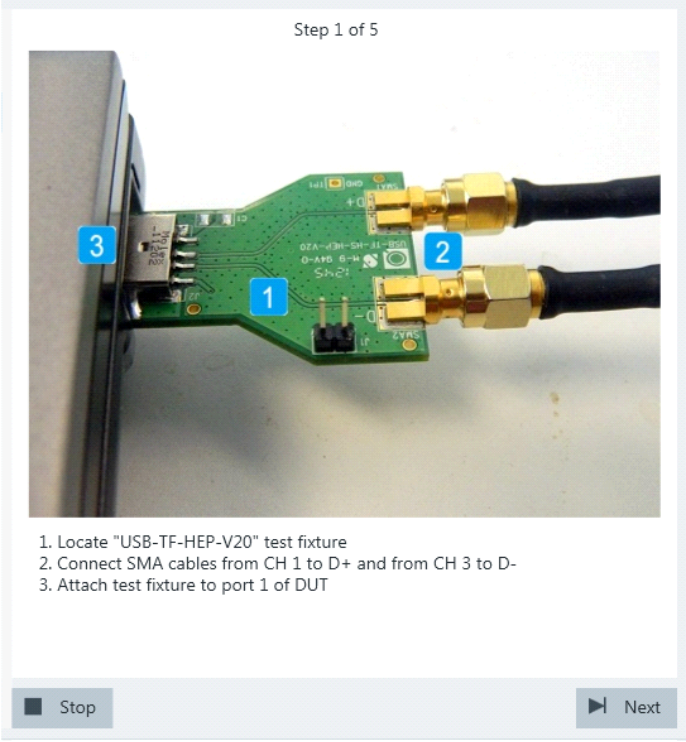
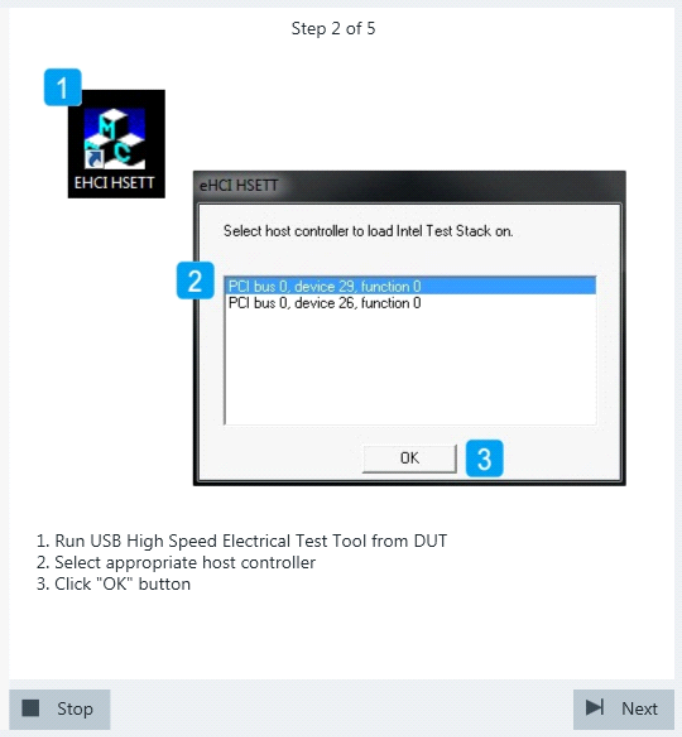
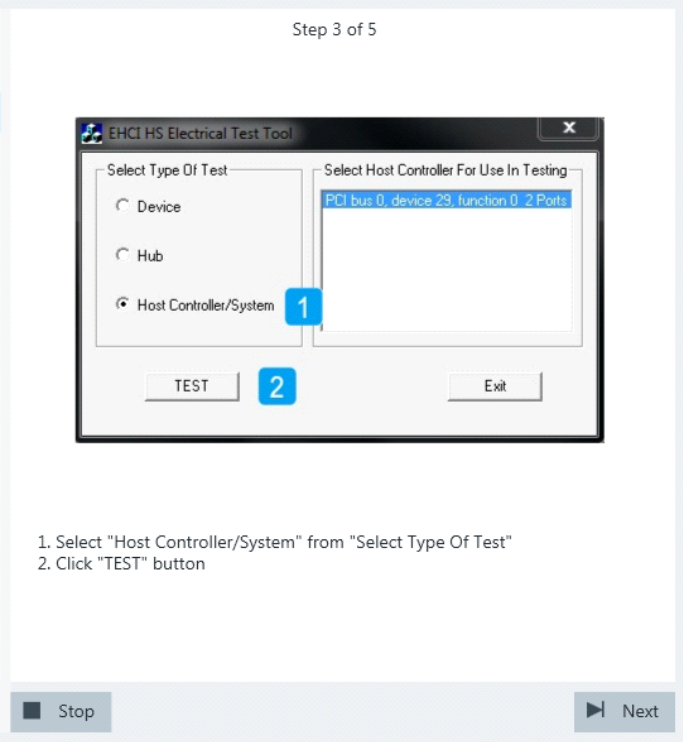


Figure 6-2: USB-IF USB2.0 Hi-Speed Signal Quality host test fixture: connection to DUT

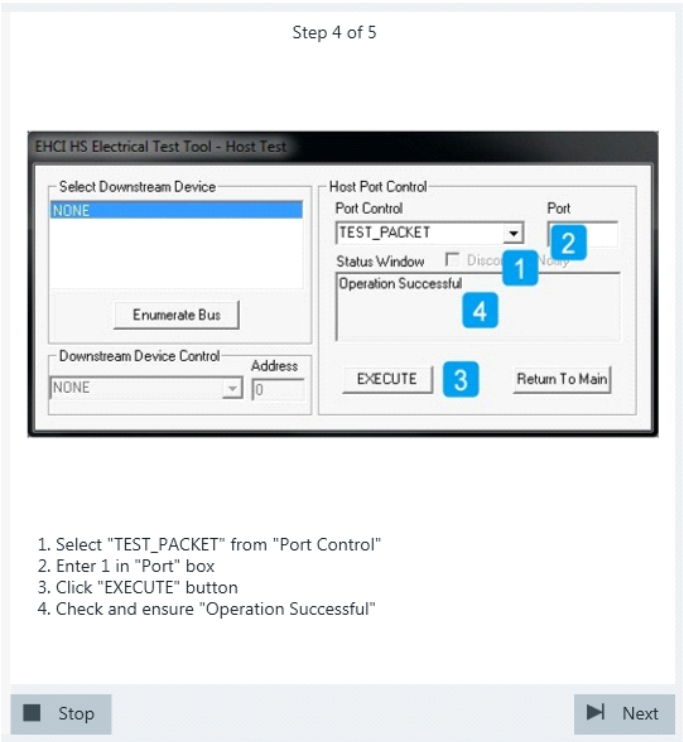
3. Click "Next".
4. Start the HS Electrical Test Tool on the DUT.
5. Select the DUT from the list of host controllers and click OK.
   Note: the values in the list may vary.



6. Select "Host Controller/System" on the left side.
   Click "TEST".

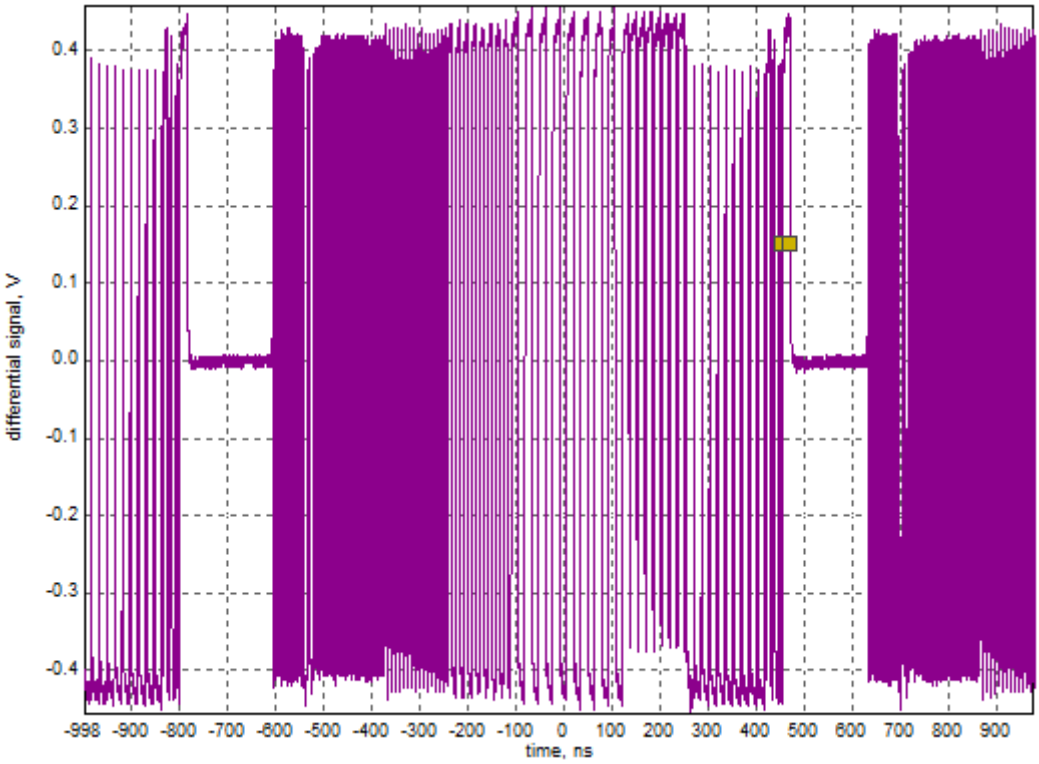


7. Select "Test_Packet" from "Port Control".
   Enter the "Port" of the host you are testing.
   Click "EXECUTE" and wait until "Operation Successful" is shown under "Status Window".

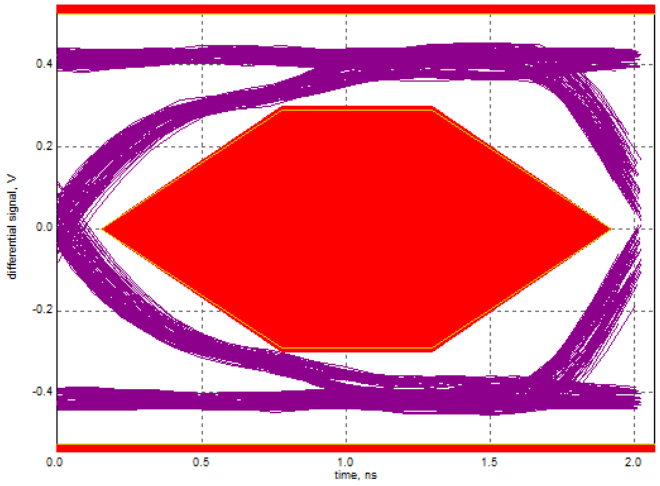


8. Click Next.

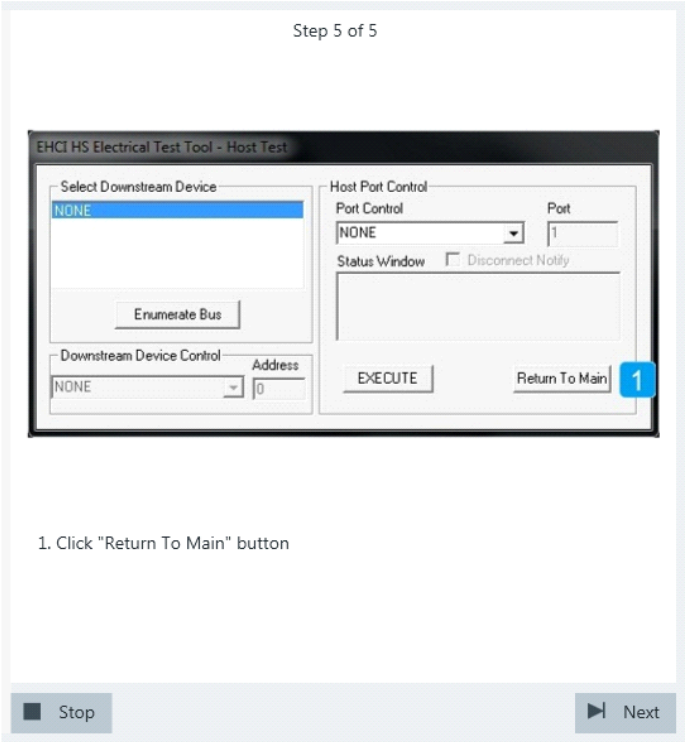
   The DUT sends TestPackets that look like this:



9. These packages are analyzed in an eye diagram.



10. In the Electrical Test Tool, return to the "Main" menu.



The results are saved and can be viewed in the report.

6.1.2 Packet Parameters

Table 6-2: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the host you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Differential probe	at least 2 GHz bandwidth	1
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1
USB Device	known good device	1

Test preparation

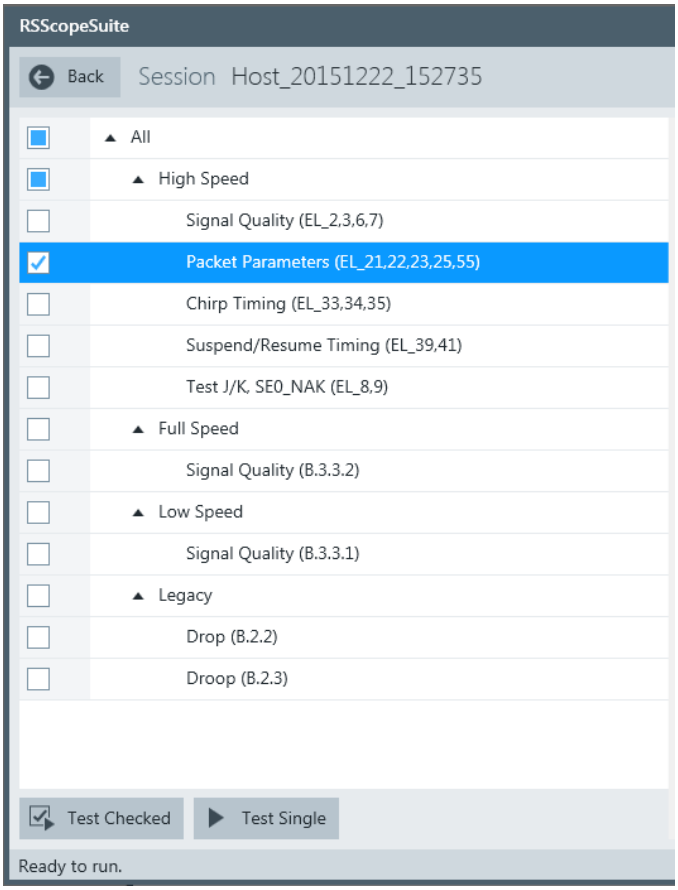
Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9

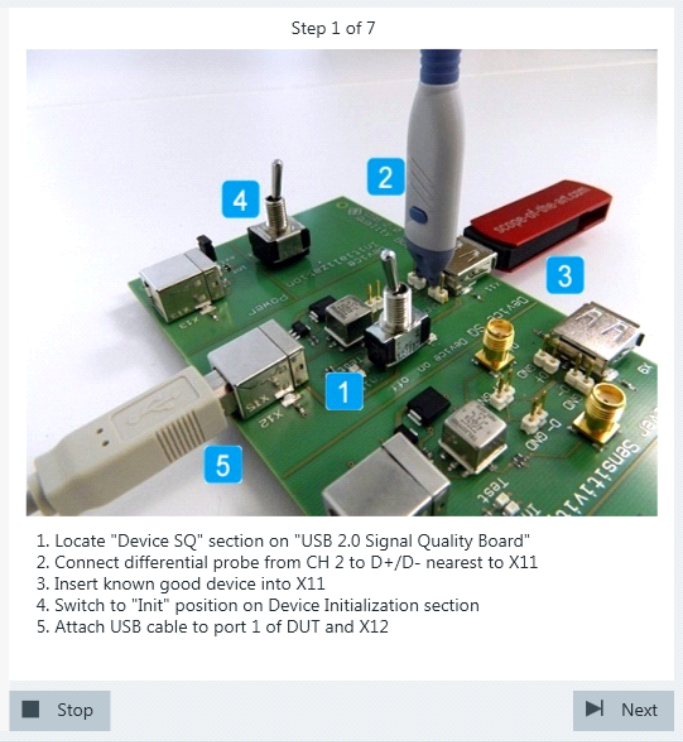
- Configure and initiate the test with DUT type = **"Host"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Packet Parameters (EL_21,22,23,25,55)" test case and click "Test Single".

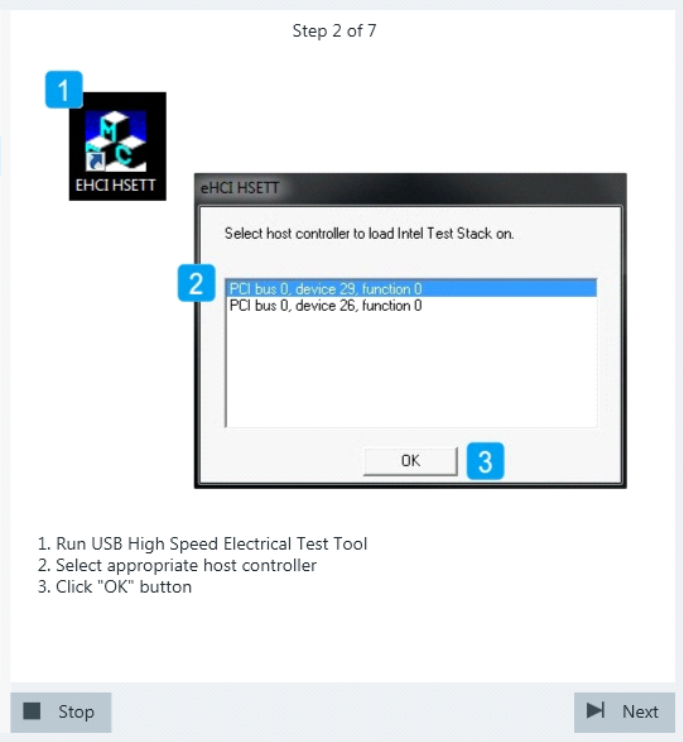


2. Connect the DUT to the test fixture as shown in the picture.

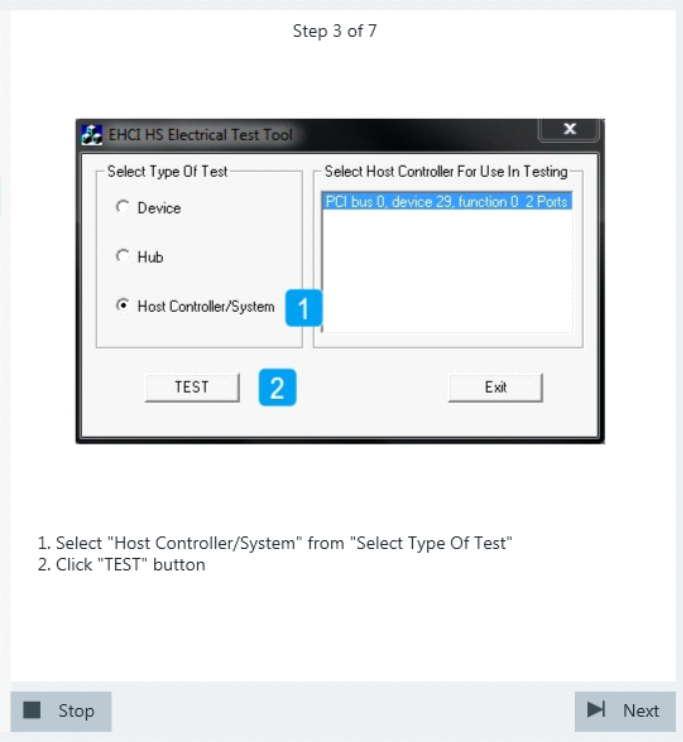


Use a 4-inch non-captive cable to connect the DUT to the test fixture.

3. Click "Next".
4. Start the HS Electrical Test Tool on the DUT.
5. Select the DUT from the list of host controllers and click OK.
   Note: the values in the list may vary.

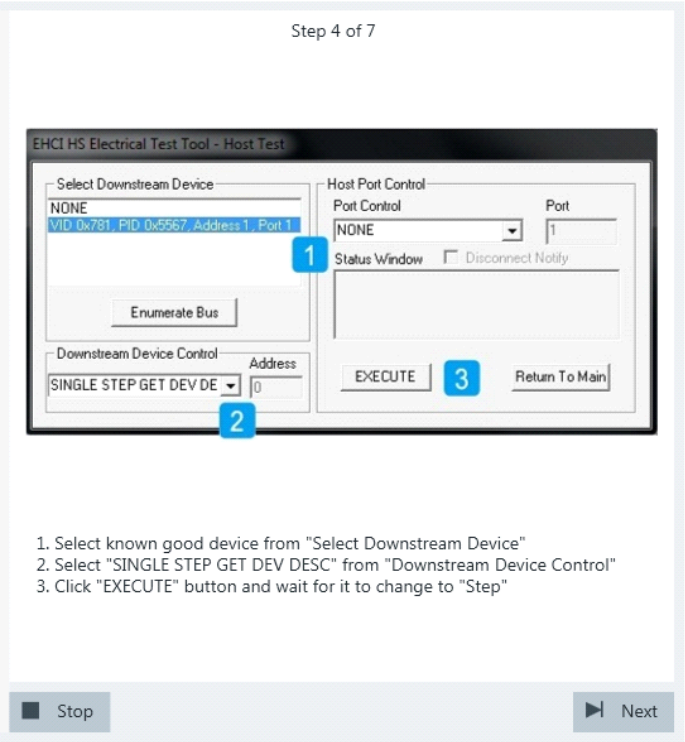


6. Select "Host Controller/System" on the left side.
   Click "TEST".

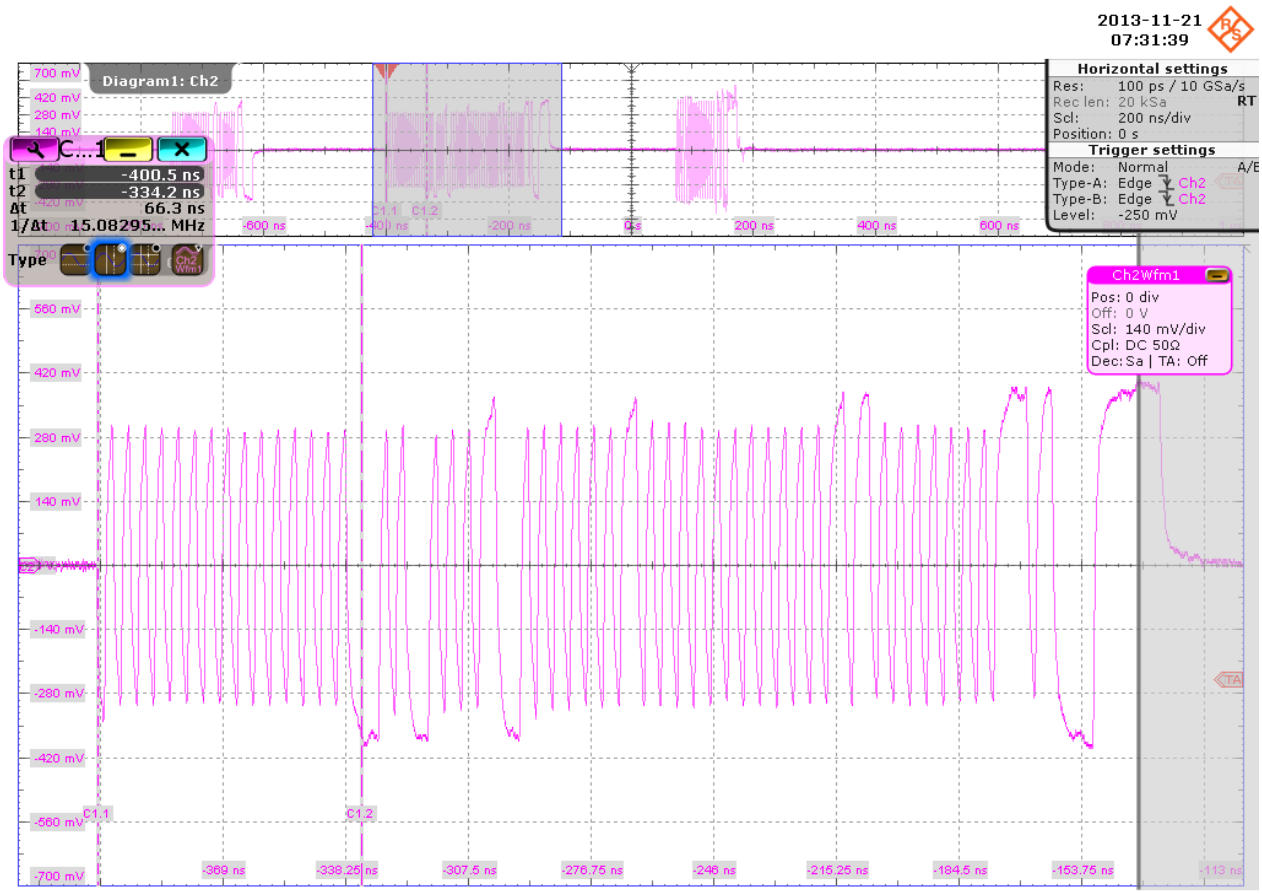


7. Select known good device from"Select Downstream Device".
   Select"SINGLE STEP GET DEV DESC" from "Downstream Device Control".

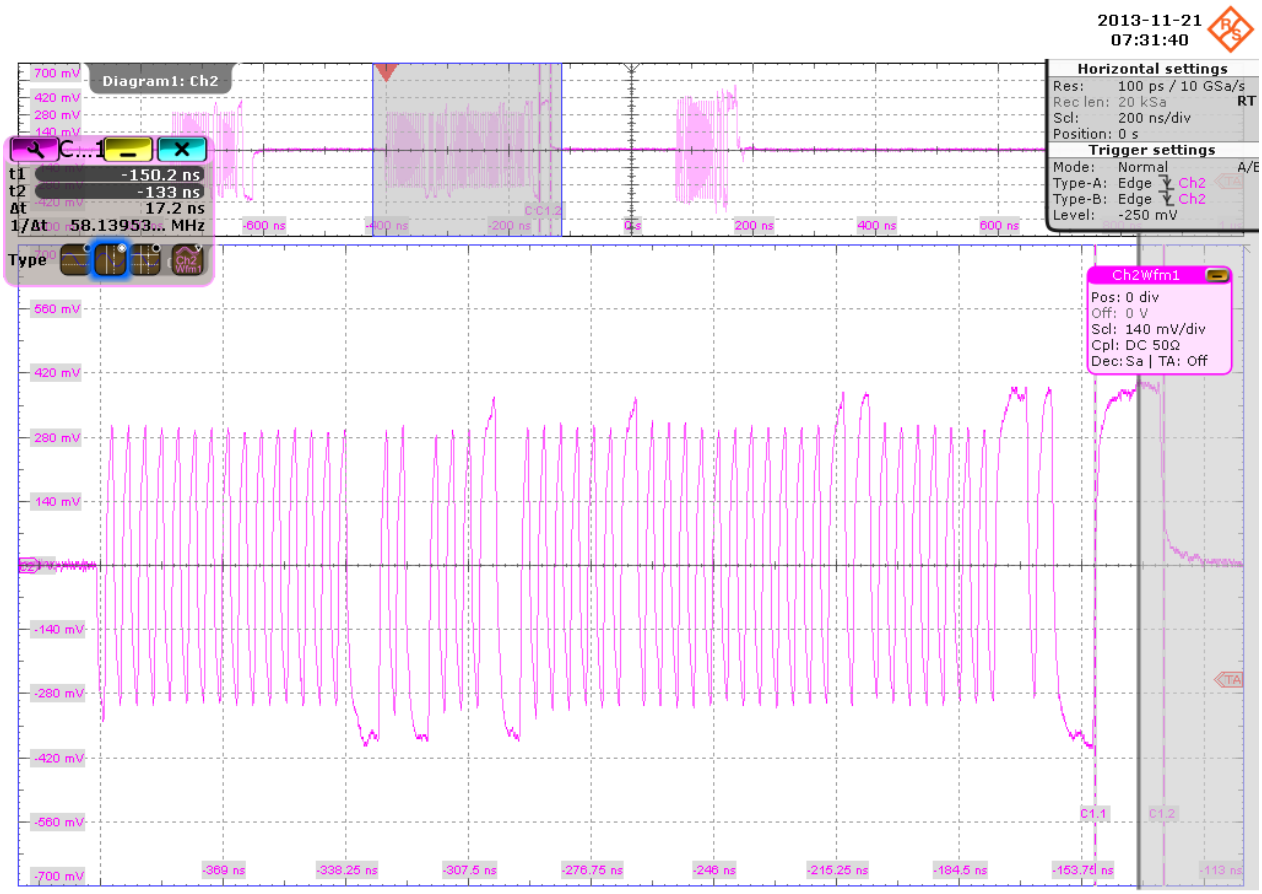
Click "EXECUTE" and wait until "Step" is shown on the button.



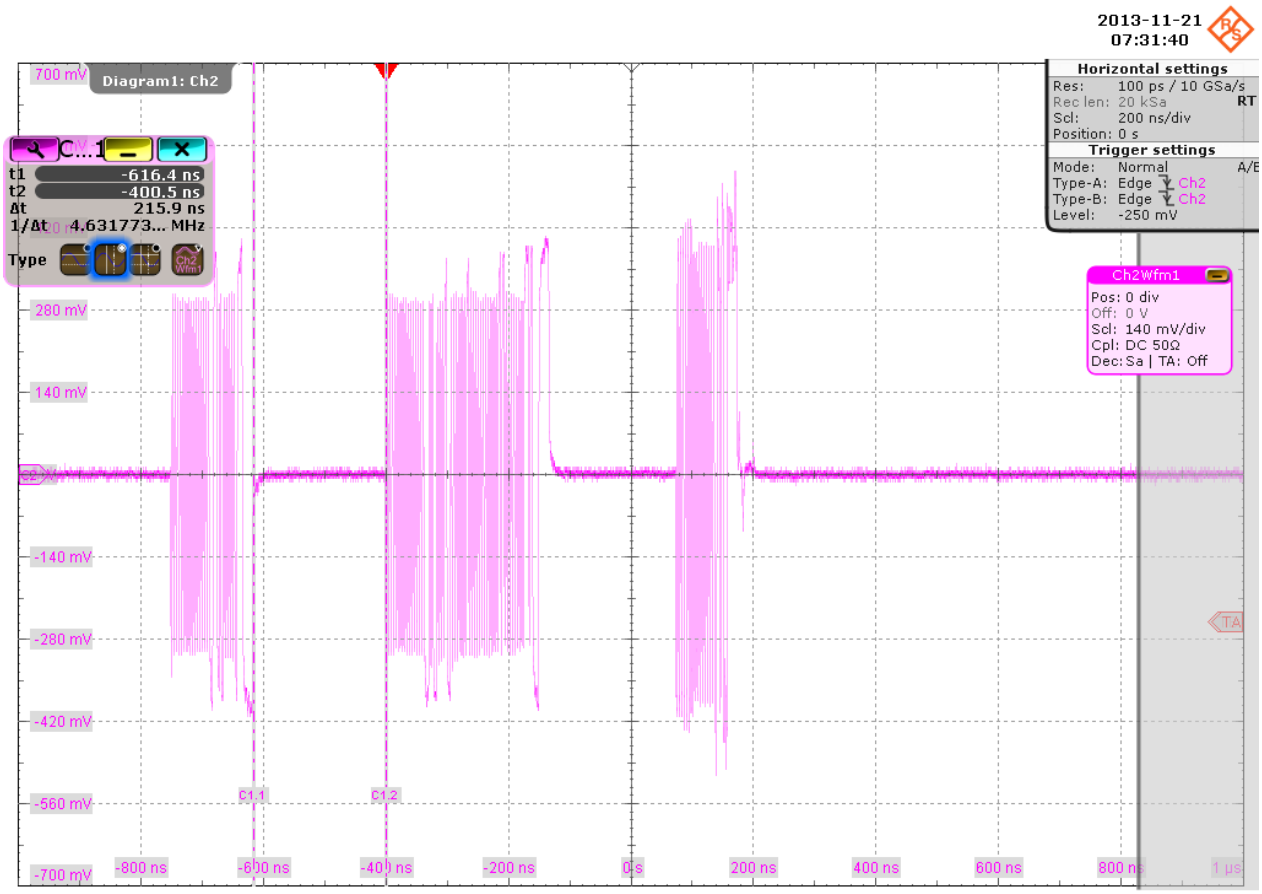
A waveform is captured as pictured below.



The first packet on the left is an "IN" packet sent by the DUT. It is followed by a "Get Device Descriptor" packet (middle) also sent from the DUT. On the right you can see the answer from the known good device with higher amplitude than the packets from the DUT.
The application counts the number of bits in the "Get Device Descriptor" packet SYNC field by measuring the duration of the first 30.5 pulses (the 31st pulse contains 4 'K's). This is EL_21.

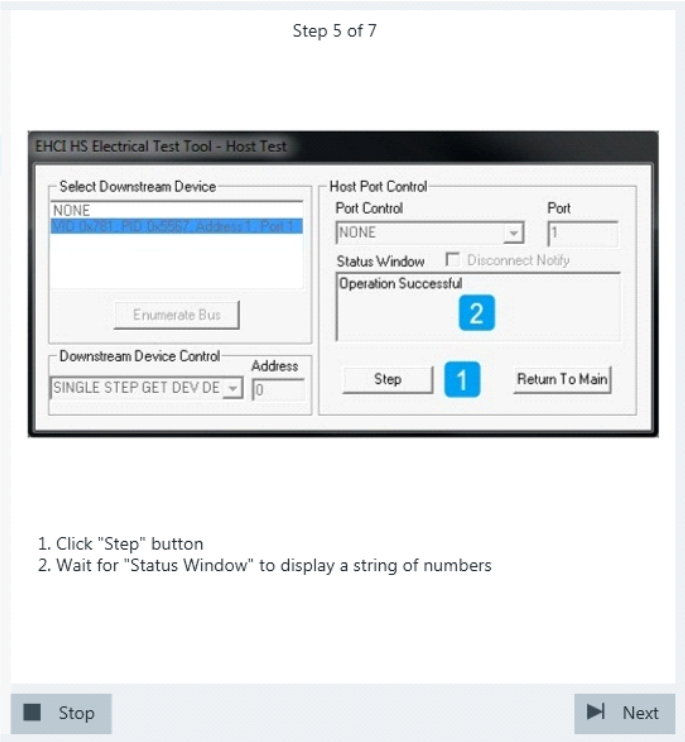


The application counts the number of bits in the "Get Device Descriptor" packet EOP field by measuring the duration of the widest pulse. This is EL_25.

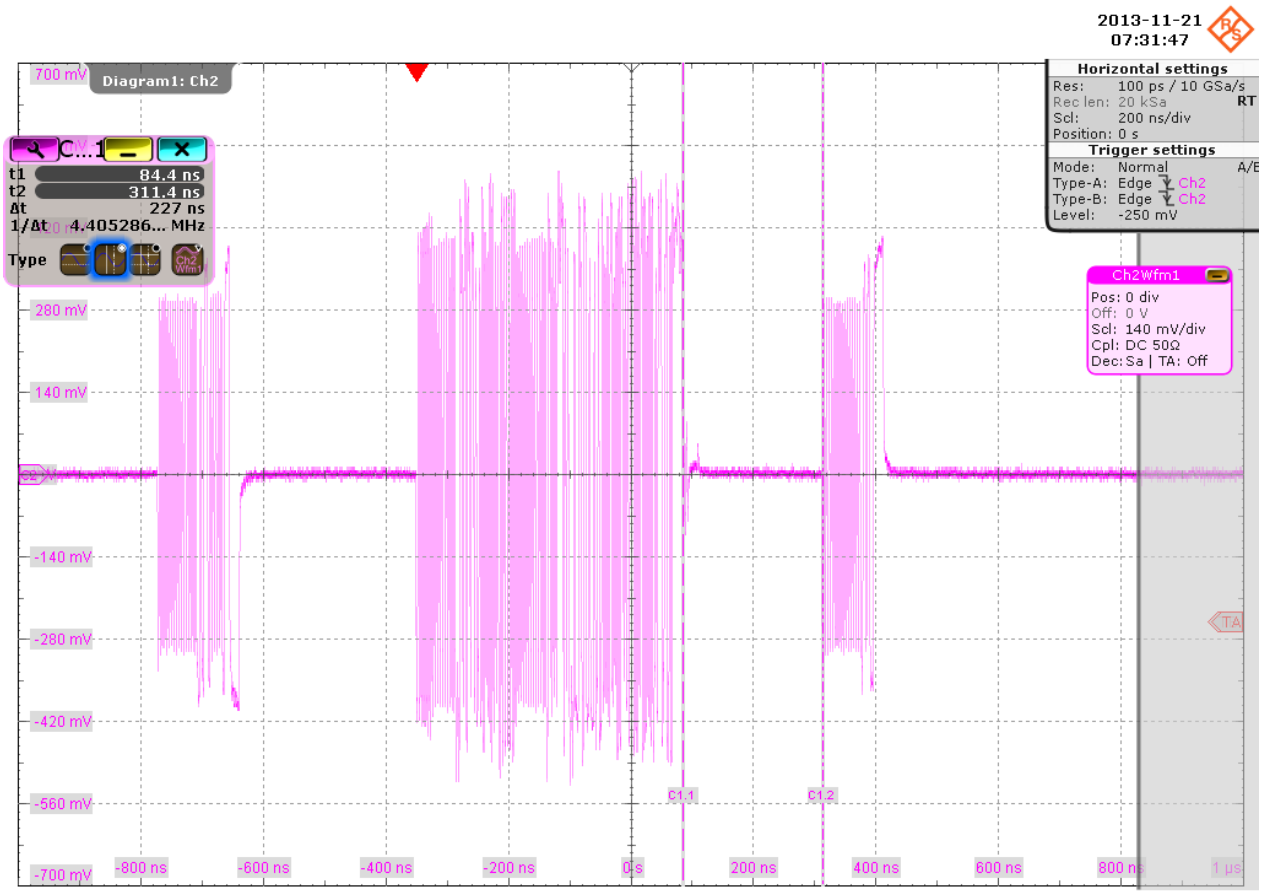


The application measures the time between the “IN” packet and the "Get Device Descriptor” packet. This is EL_23.

8. Click "Next".
9. Click "Step" and wait until a string of numbers is shown under "Status Window".

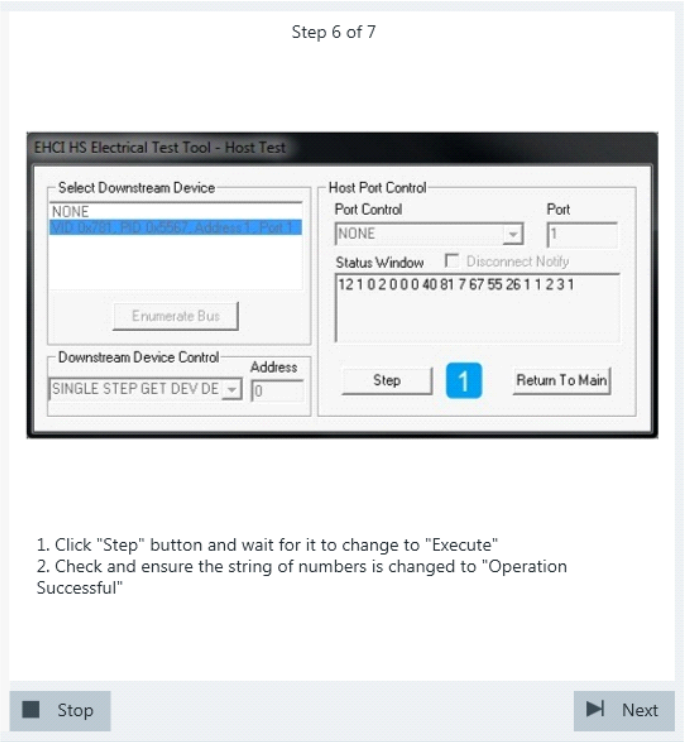


A waveform is captured as pictured below.

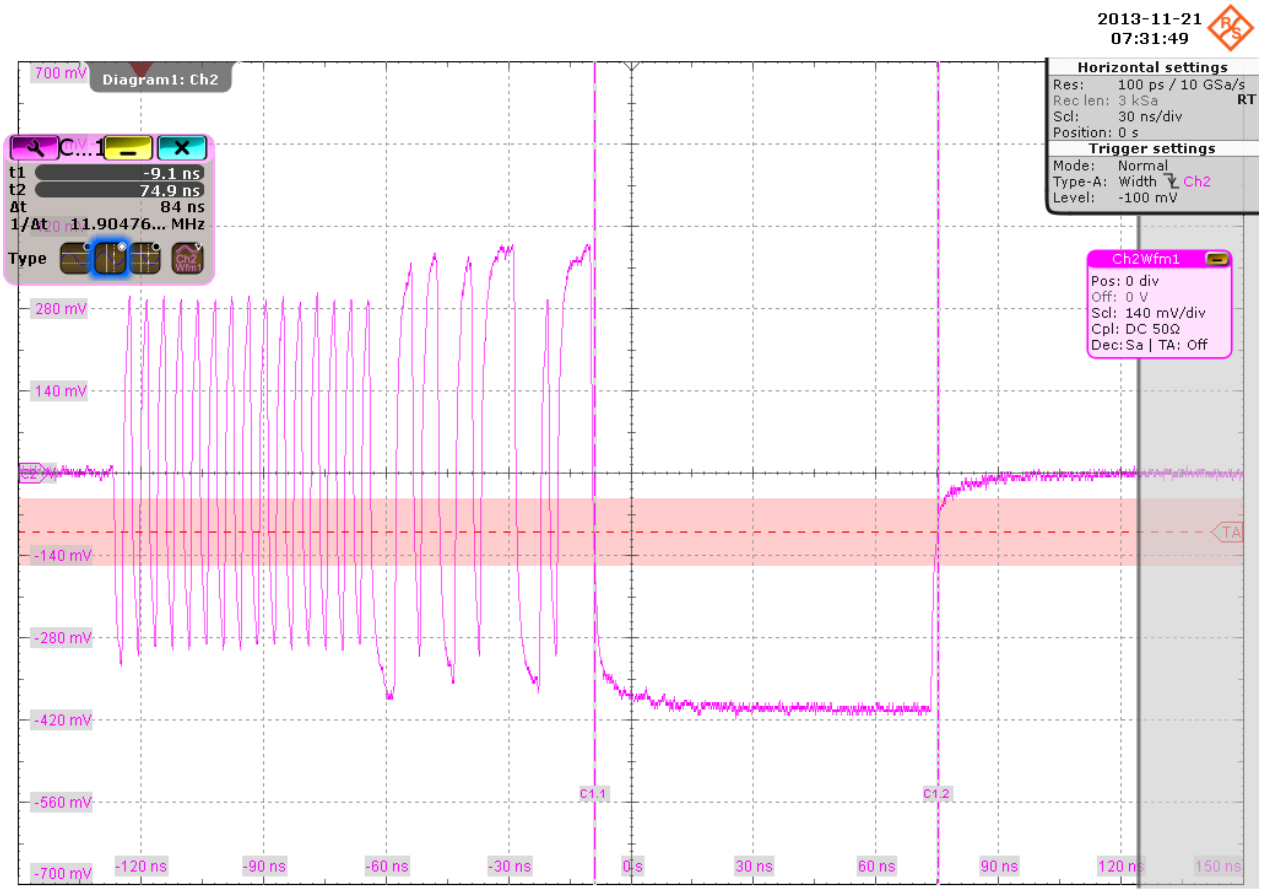


The second packet in the middle is sent by the known good device. The last packet on the right is the acknowledgement packet from the DUT.
The application measures the time between these two packets. This is EL_22.

10. Click "Step" and wait until "Execute" is shown on the button.
    Ensure that the string of numbers is replaced by "Operation Successful" in the "Status Window".

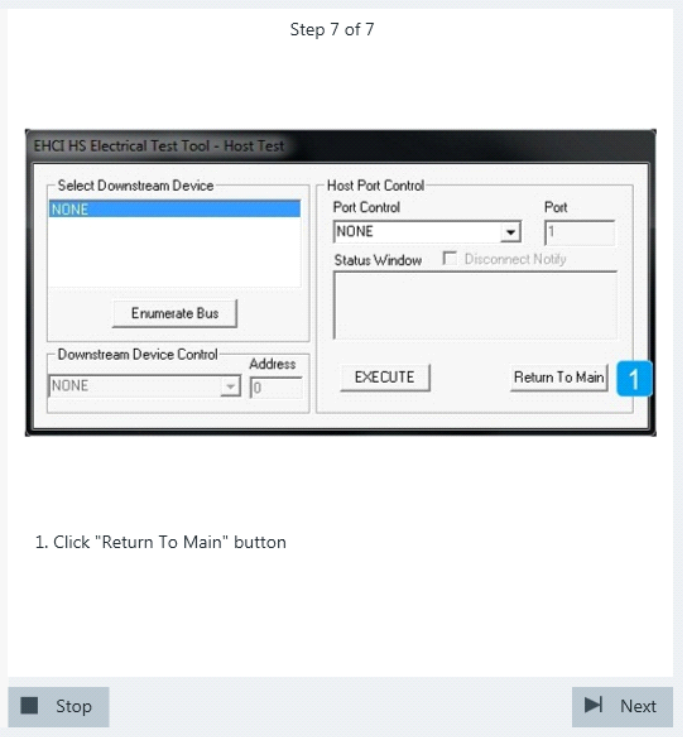


A waveform is captured as pictured below.



This is a “Start of Frame” packet sent by the DUT. The application counts the number of bits in the EOP field by measuring the duration of the widest pulse. This is EL_55.

11. Return in the HS Electrical Test Tool to the Main menu.



The results are saved and can be viewed in the report.

6.1.3 Chirp Timing

Table 6-3: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the host you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Single-ended probe	at least 2 GHz bandwidth	2
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1
USB Device	known good device	1

Test preparation

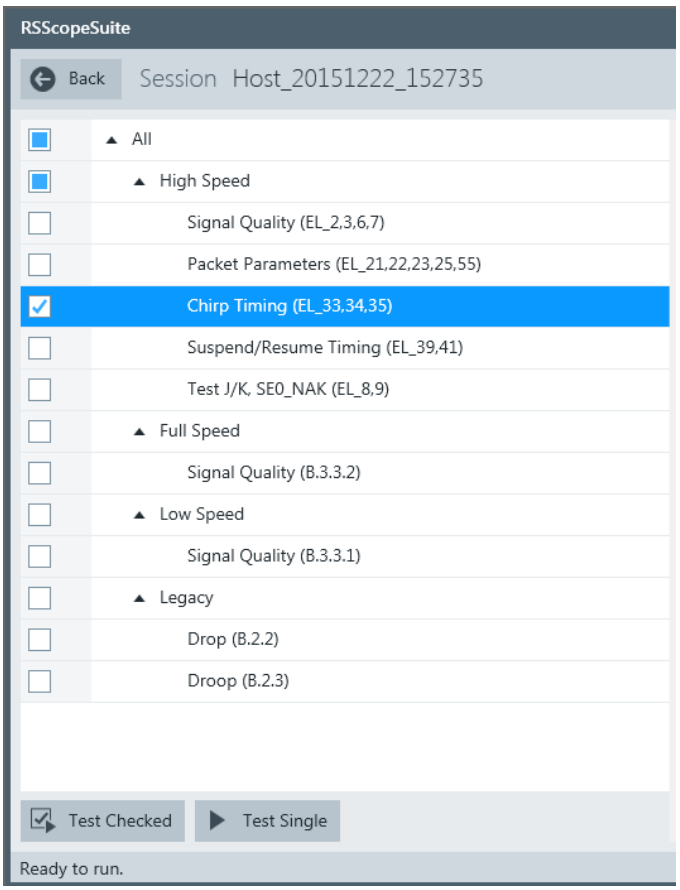
Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9

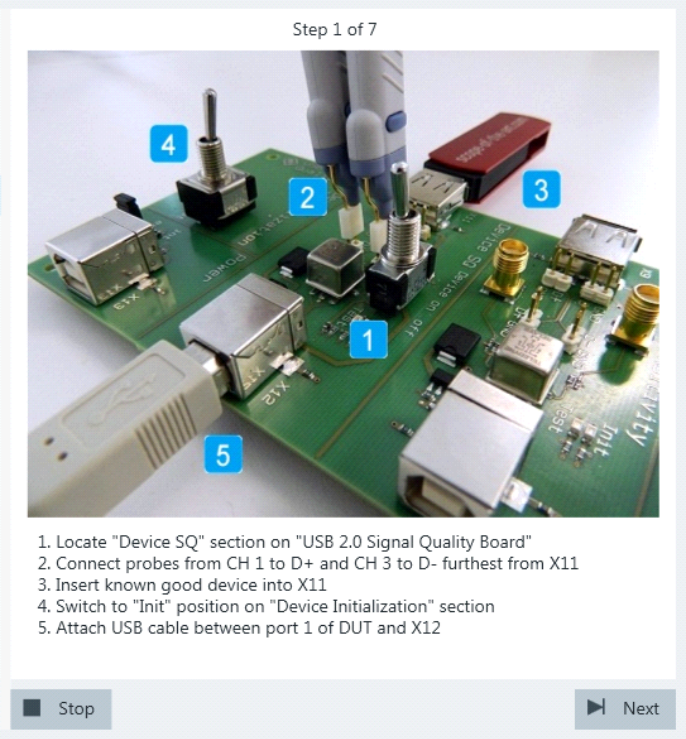
- Configure and initiate the test with DUT type = **"Host"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Chirp Timing (EL_33,34,35)" test case and click "Test Single".

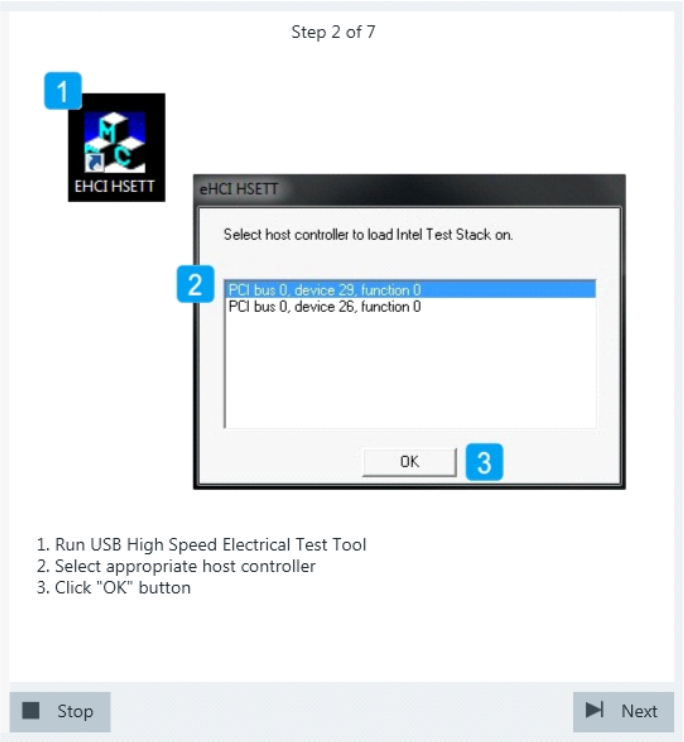


2. Connect the DUT to the test fixture as shown in the picture.

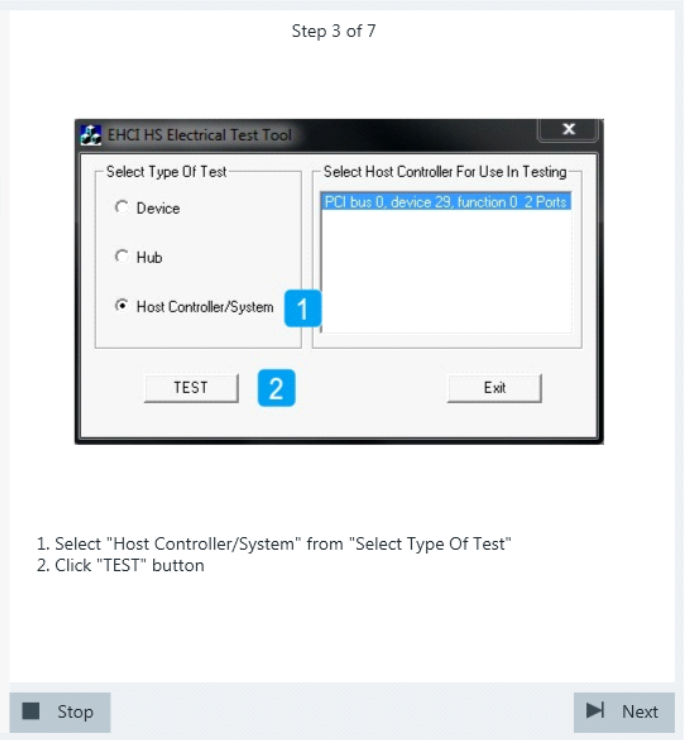


Use a 4-inch non-captive cable to connect the DUT to the test fixture.

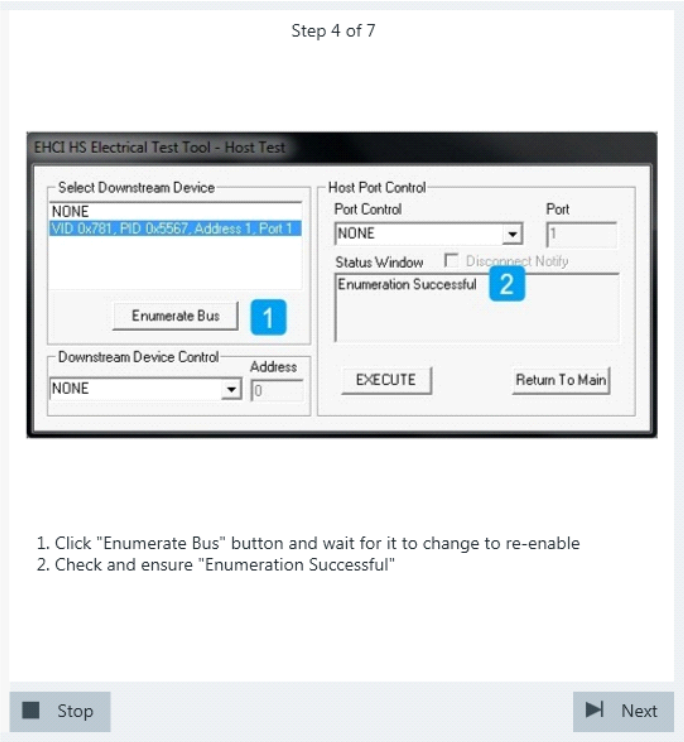
3. Click "Next".
4. Start the HS Electrical Test Tool on the DUT.
5. Select the DUT from the list of host controllers and click OK.
   Note: the values in the list may vary.



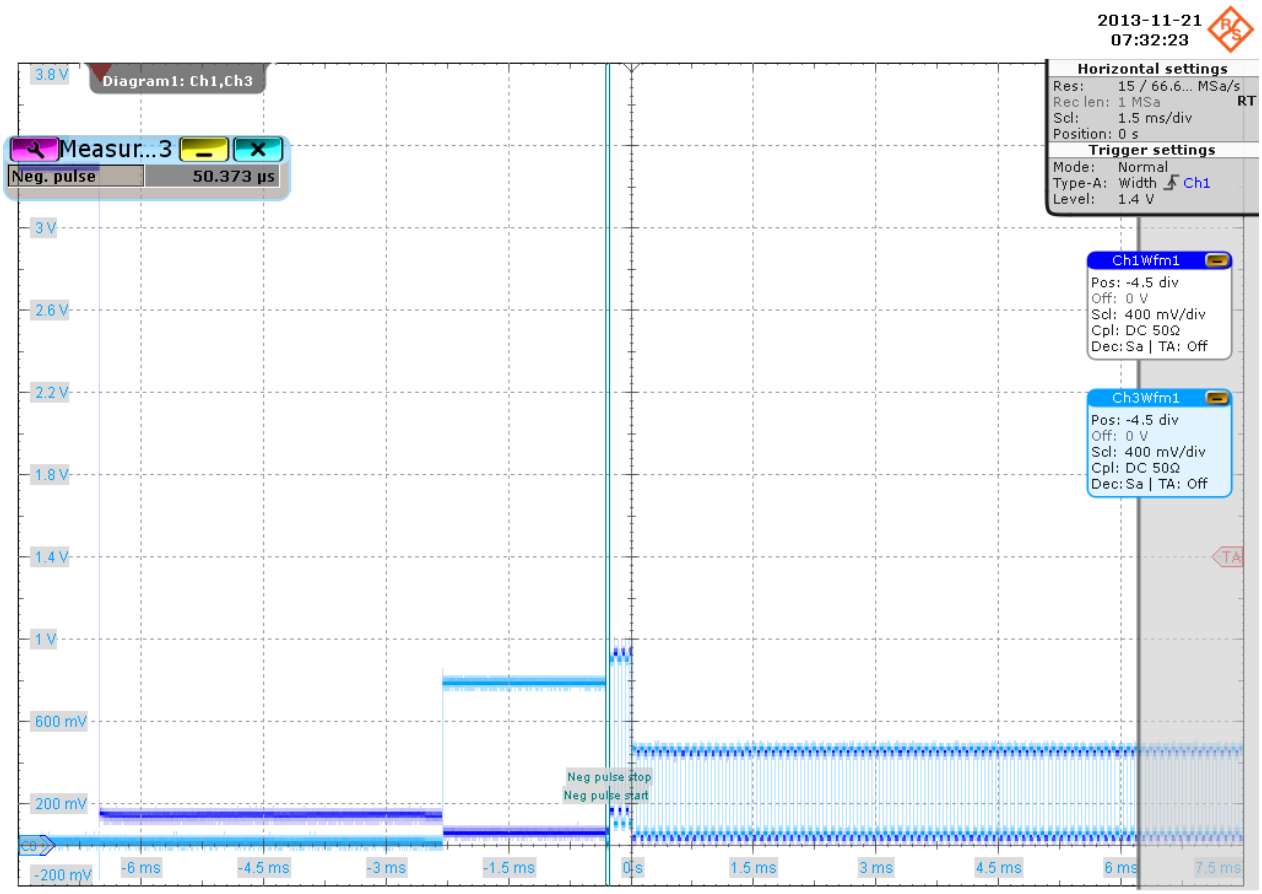
6. Select "Host Controller/System" on the left side.
   Click "TEST".



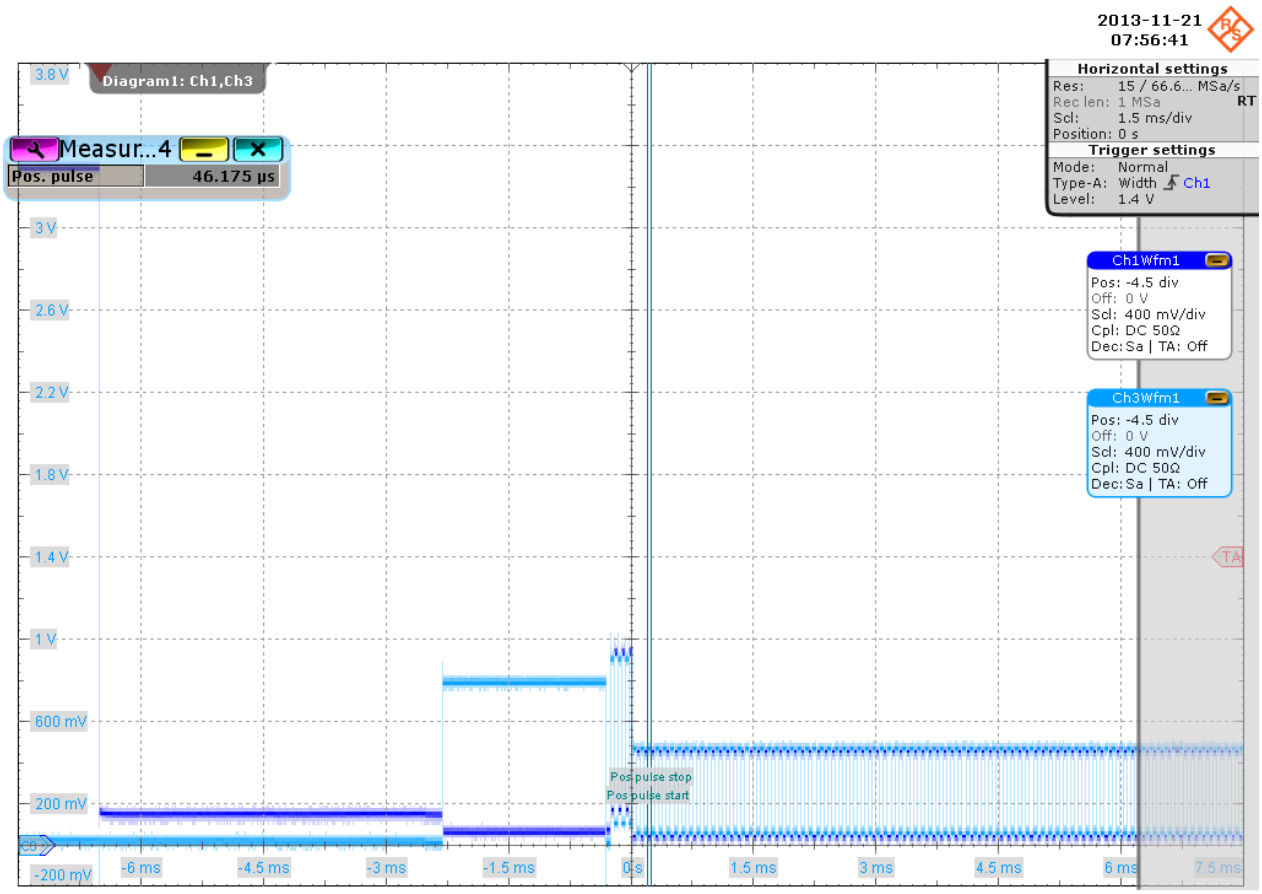
7. Click "Enumerate Bus" and wait until it re-enables.
   Make sure that "Operation Successful" is shown under "Status Window".



Waveforms are captured as pictured below.

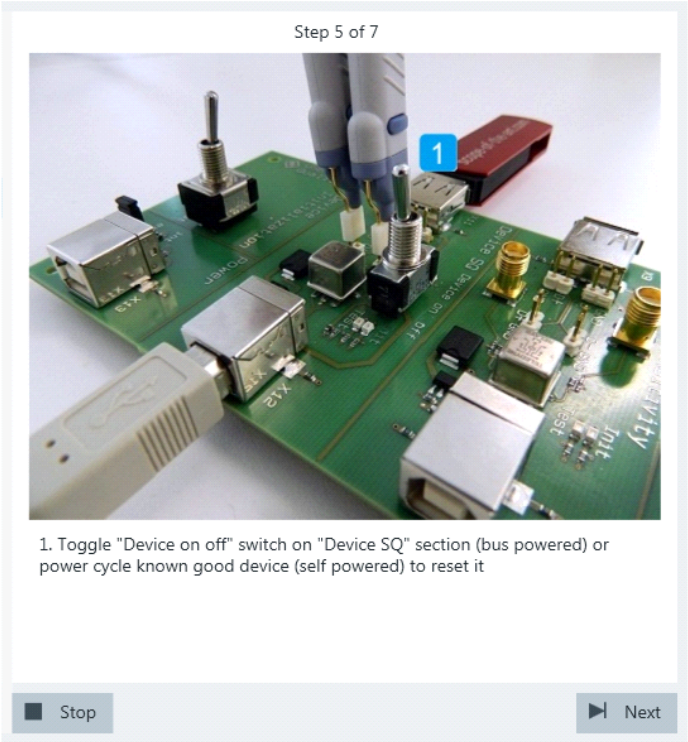


The pulse in the middle is the Chirp K from the known good device. The alternating sequence of Chirp K's and J's are sent by the DUT.
The application measures the time between the known good device Chirp K and the start of the alternating sequence of Chirp K's and J's. This is EL_33.

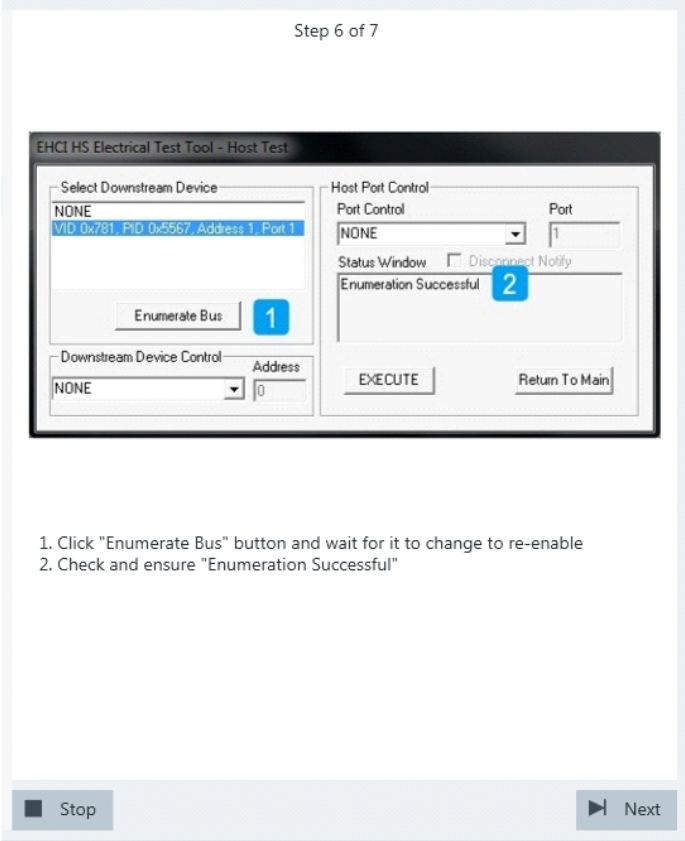


The application measures the durations of the alternating sequence of Chirp K's and J's captured in the waveforms. This is EL_34.

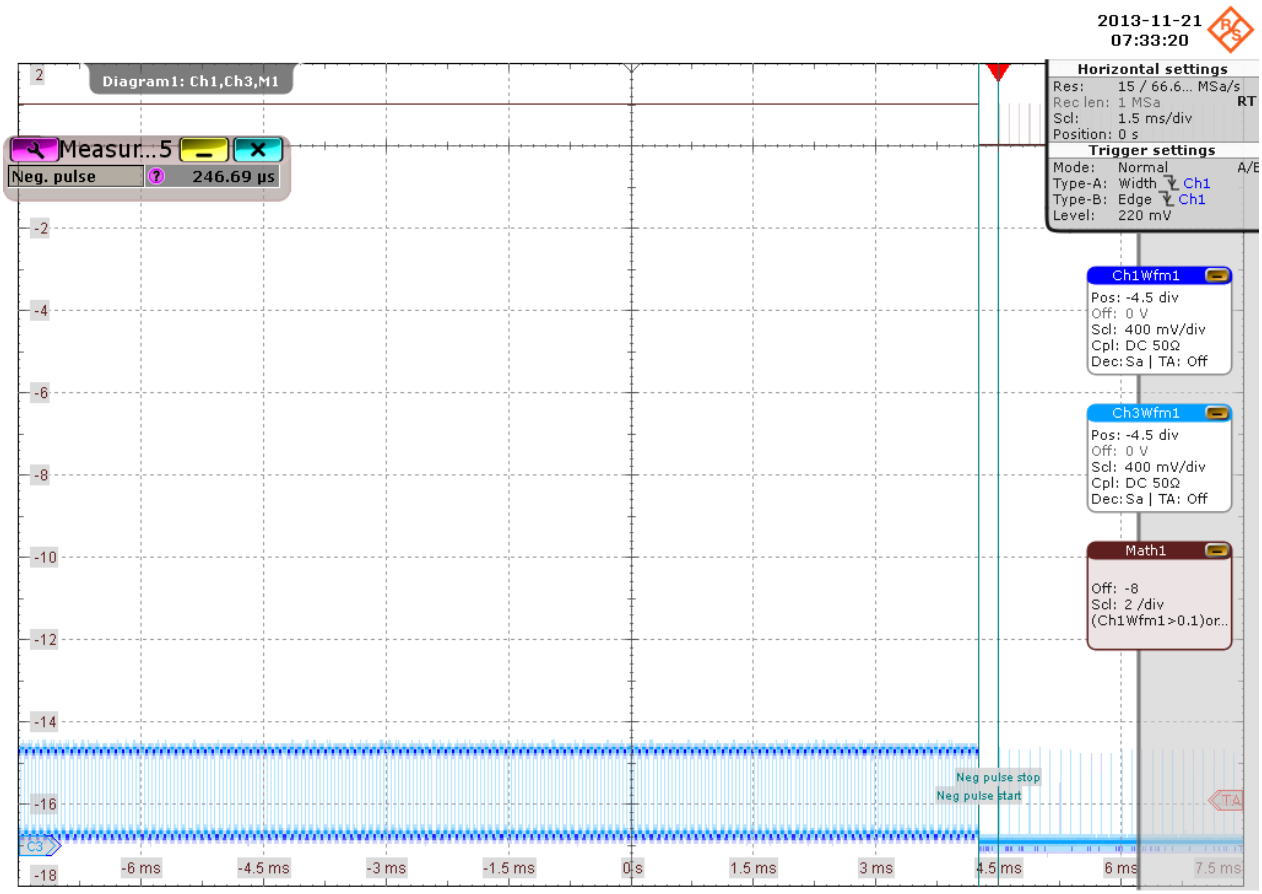
8. Click "Next".
9. Reset the known good device.
   If it is bus-powered, simply toggle the "Device SQ" section's "Device on off" switch.
   If it is self-powered, switch it off and switch it back on.



10. Click "Enumerate Bus" and wait until it re-enables.
    Make sure that "Operation Successful" is shown under "Status Window".

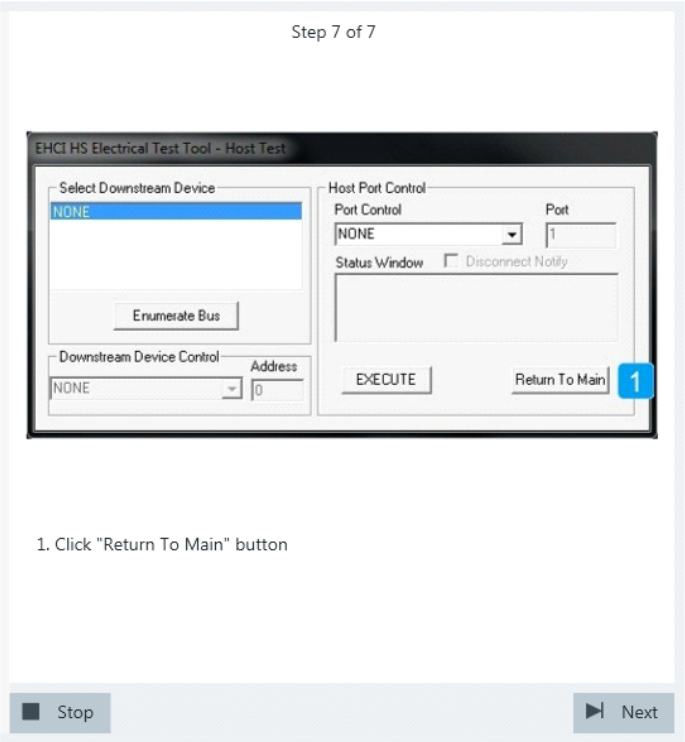


Waveforms are captured as pictured below.



Shortly after the last chirp, the DUT starts sending “Start of Frame” packets. The application measures the time between the last chirp and the first “Start of Frame” packet. This is EL_35.

11. Return in the HS Electrical Test Tool to the Main menu.



The results are saved and can be viewed in the report.

6.1.4 Suspend/Resume Timing

Table 6-4: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the host you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Single-ended probe	at least 2 GHz bandwidth	2
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1
USB Device	known good device	1

Test preparation

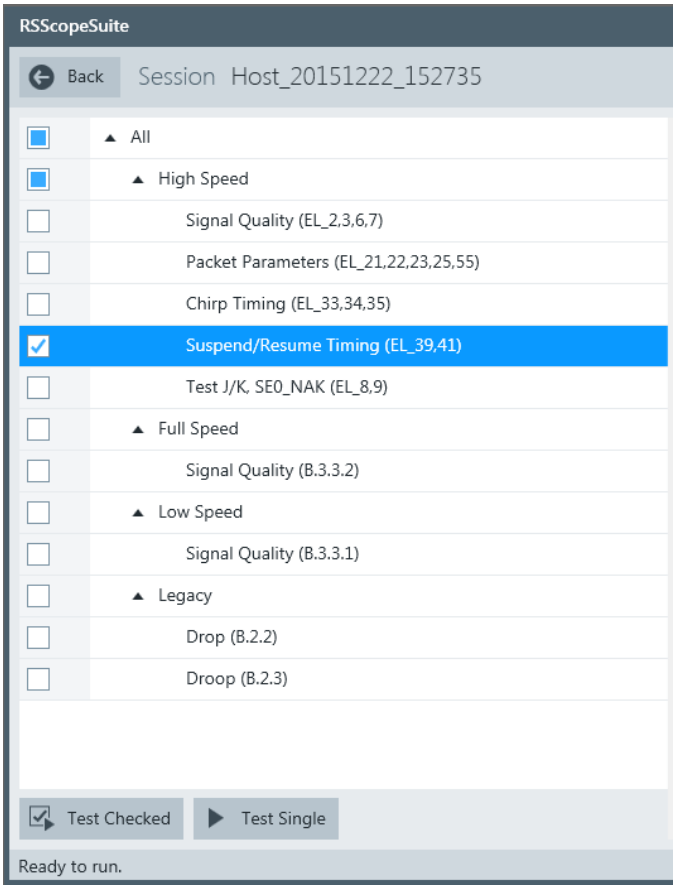
Before you run the test, complete the following actions:

- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9

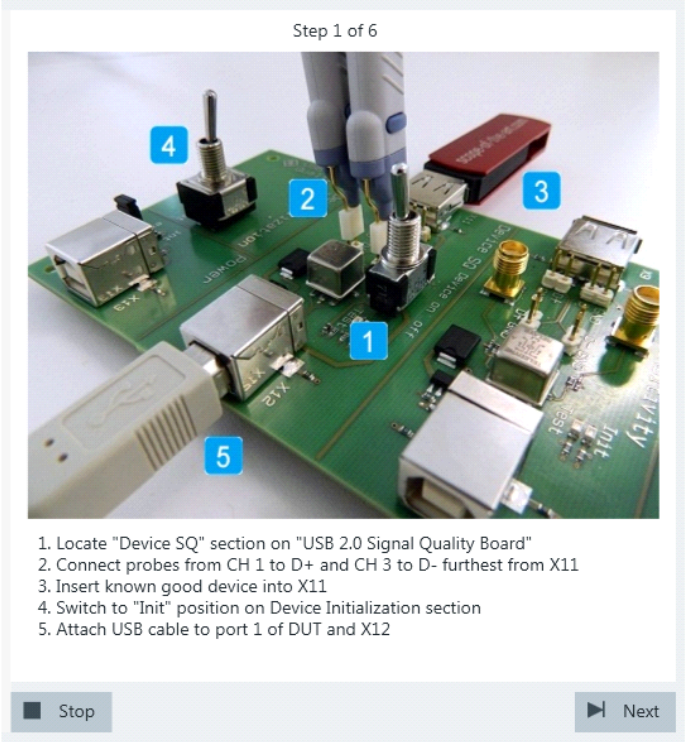
- Configure and initiate the test with DUT type = **"Host"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Suspend/Resume Timing (EL_33,34,35)" test case and click "Test Single".

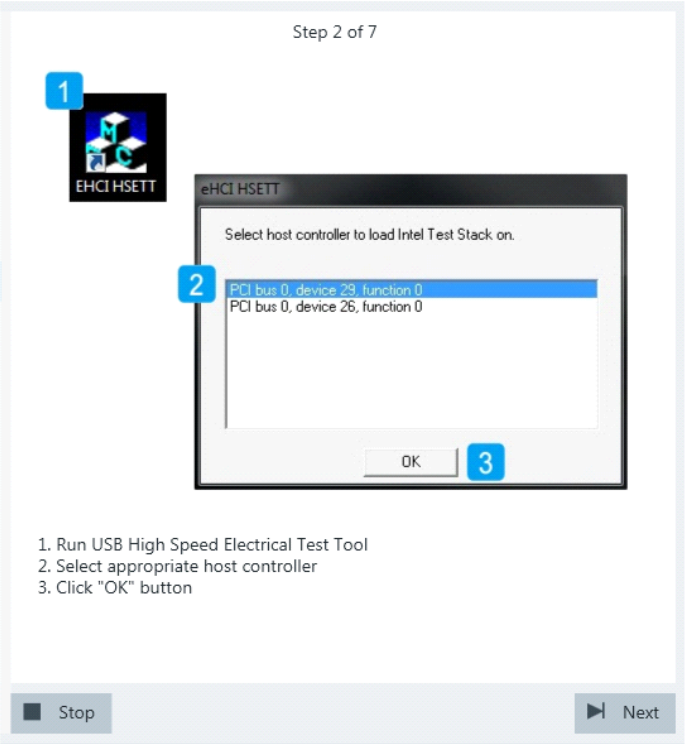


2. Connect the DUT to the test fixture as shown in the picture.

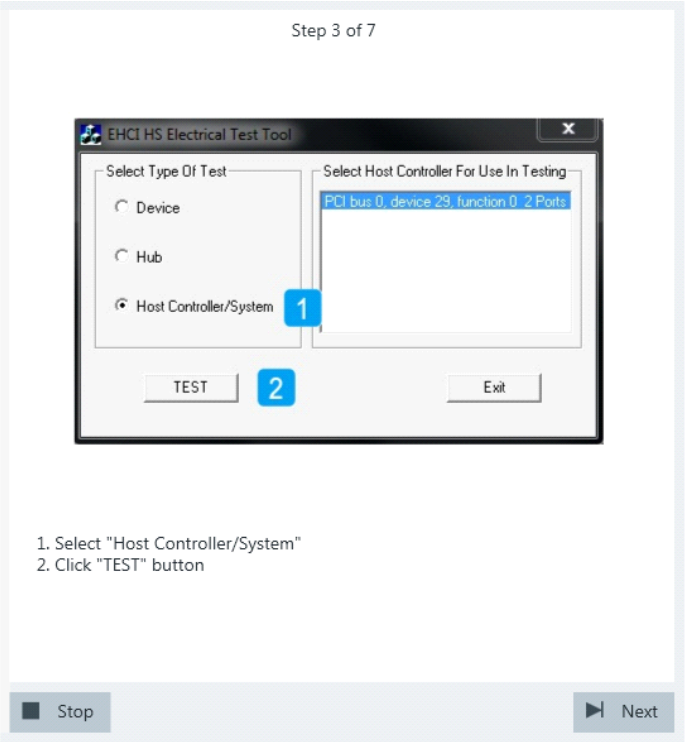


Use a 4-inch non-captive cable to connect the DUT to the test fixture.

3. Click "Next".
4. Start the HS Electrical Test Tool on the DUT.
5. Select the DUT from the list of host controllers and click OK.
   Note: the values in the list may vary.

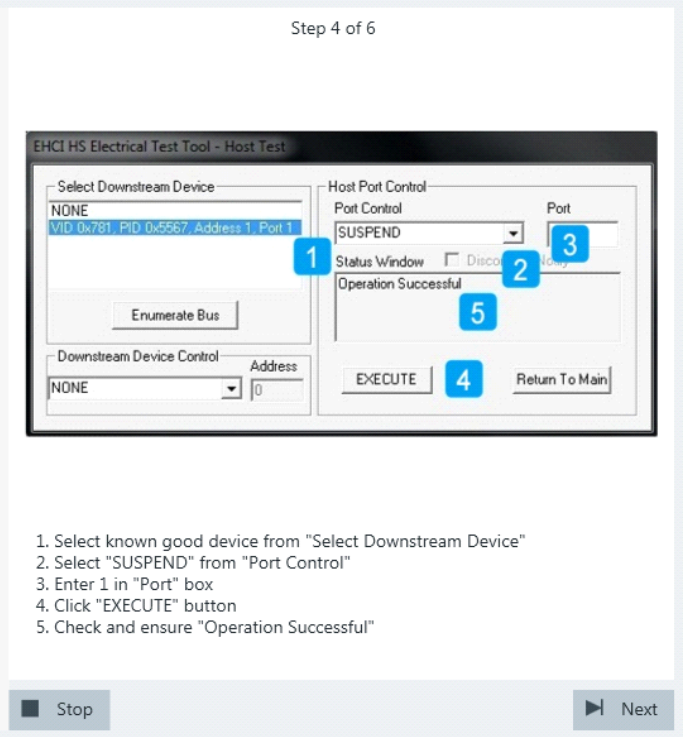


6. Select "Host Controller/System" on the left side.
   Click "TEST".

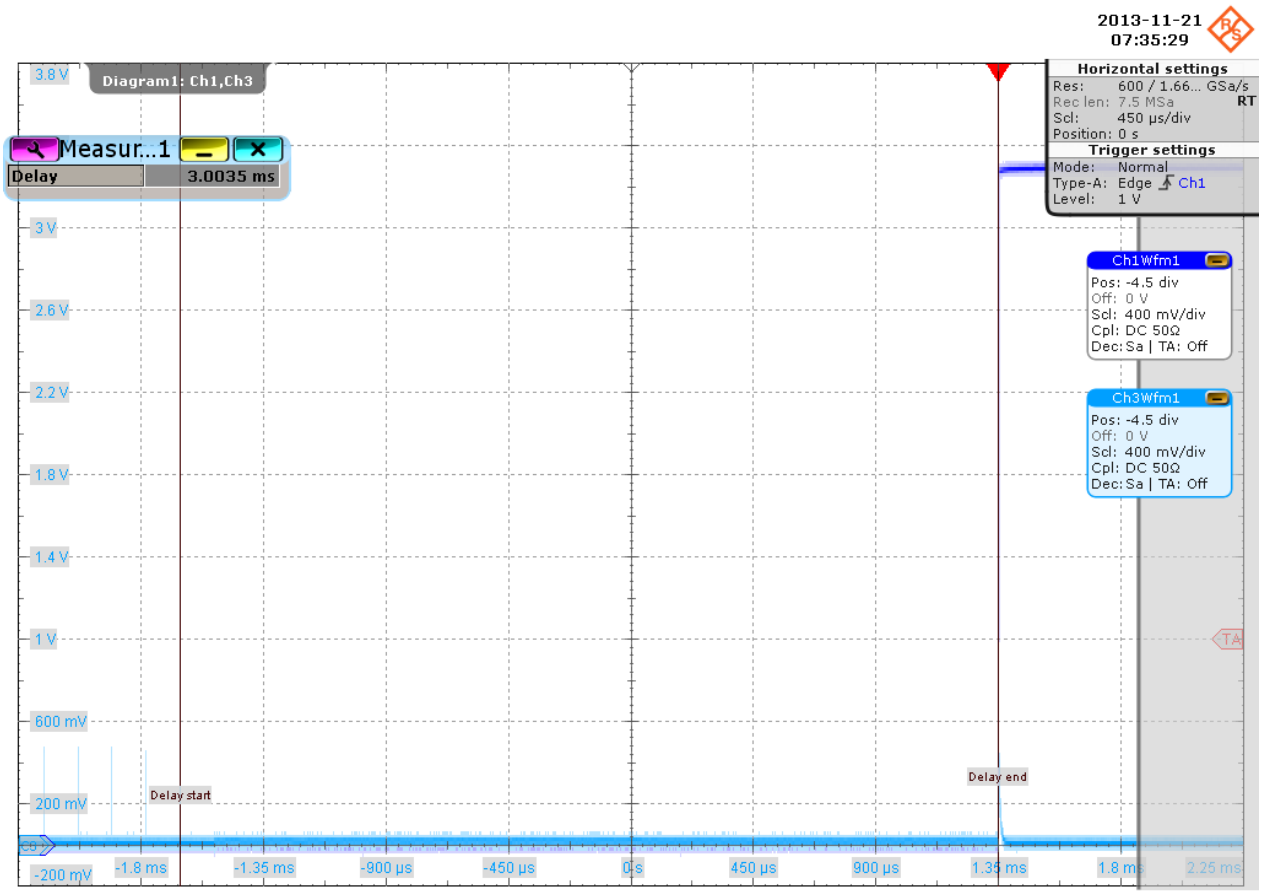


7. Select known good device from "Select Downstream Device".
   Select "SUSPEND" from "Port Control".

Enter the “Port” number of the DUT you are testing.
Click "EXECUTE" and wait until "Operation Successful" in the "Status Window" is shown.

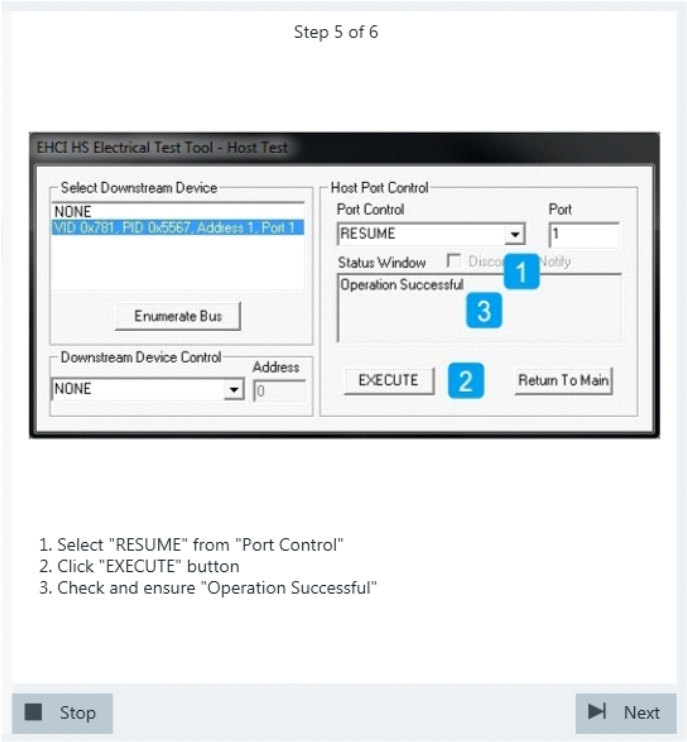


Waveforms are captured as pictured below.

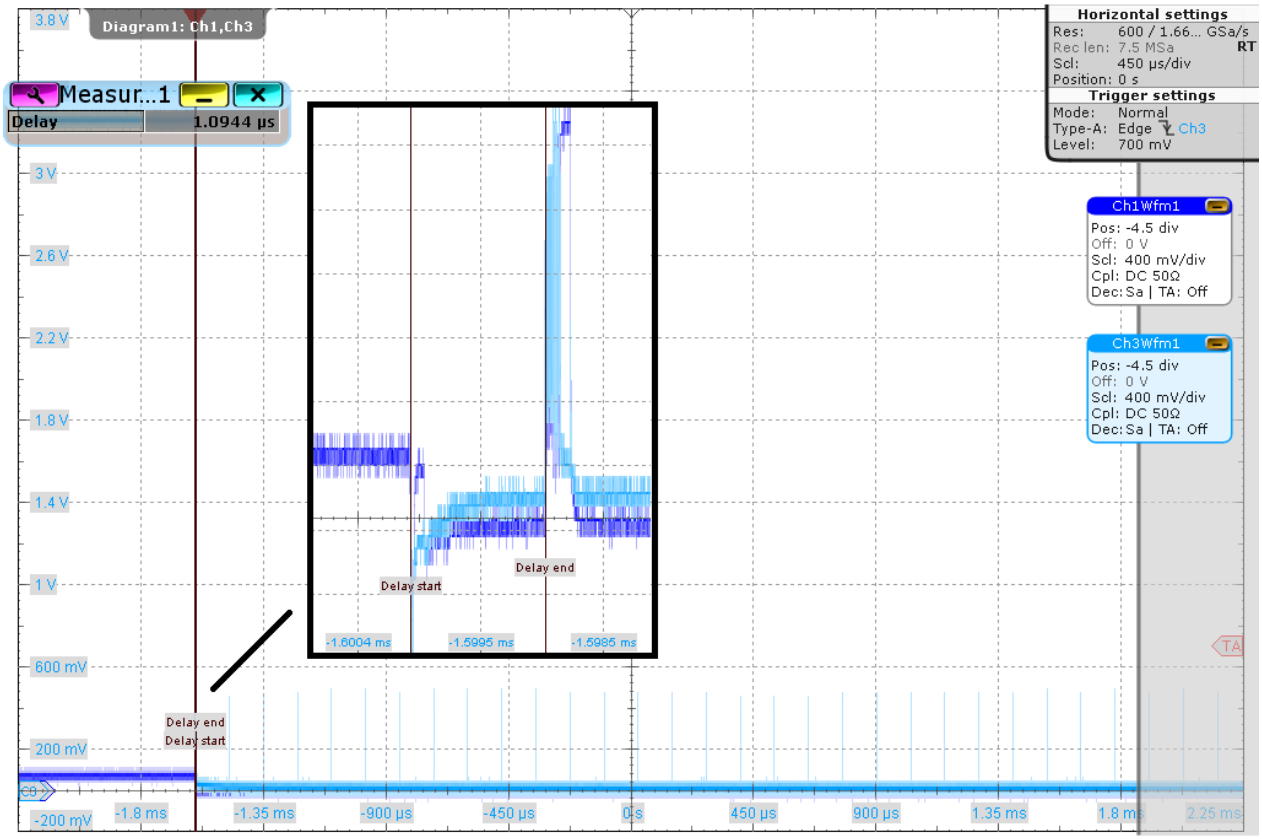


The application measures the time between the last falling edge of the last “Start of Frame” packet and the start of the suspended state. This is EL_38.

8. Click "Next".
9. Select"RESUME" from "Port Control".
   Click "EXECUTE" and wait until "Operation Successful" in the "Status Window" is shown.

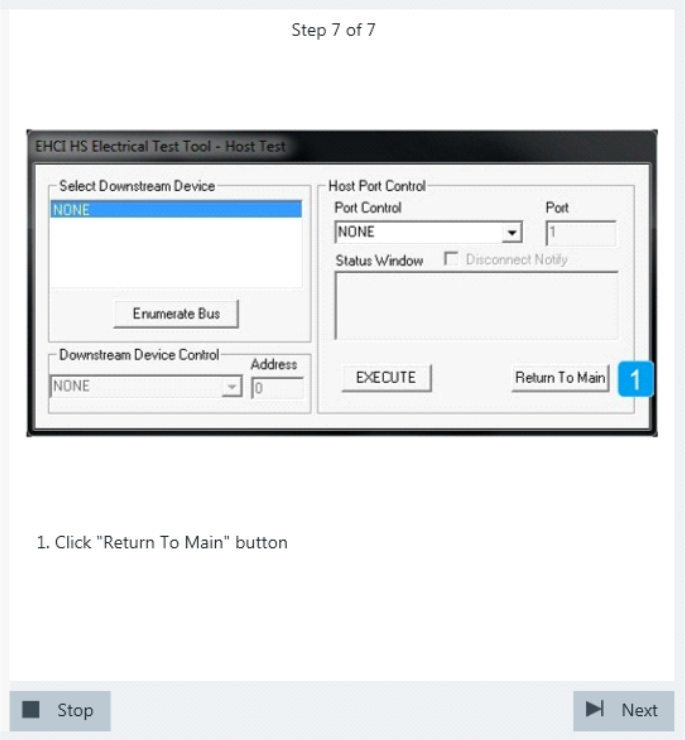


Waveforms are captured as pictured below.



The application measures the time between the end of the suspended state (i.e., D + pulls from ~+3 V to ~0 V) and the first “Start of Frame” packet (i.e., high speed operation resumes). This is EL_41.

10. Return in the HS Electrical Test Tool to the Main menu.



The results are saved and can be viewed in the report.

6.1.5 Test J/K, SE0_NAK

Table 6-5: Equipment

Item	Description, model	Quantity
Rohde & Schwarz oscilloscope	R&S RTO with 4 channels and at least 2 GHz bandwidth	1
DUT	the host you want to test	1
Signal quality board, "Device SQ" section	R&S RT-ZF1	1
Single-ended probe	at least 2 GHz bandwidth	2
Host test bed computer	any computer with high-speed USB ports and HS Electrical Test Tool	1
USB cable	to connect computer and test fixture	1

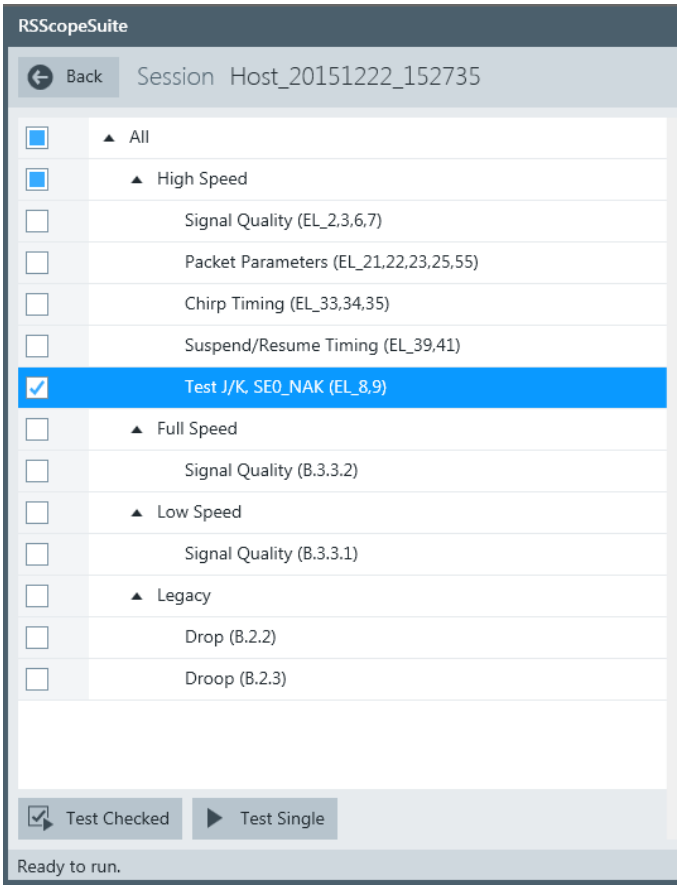
Test preparation

Before you run the test, complete the following actions:

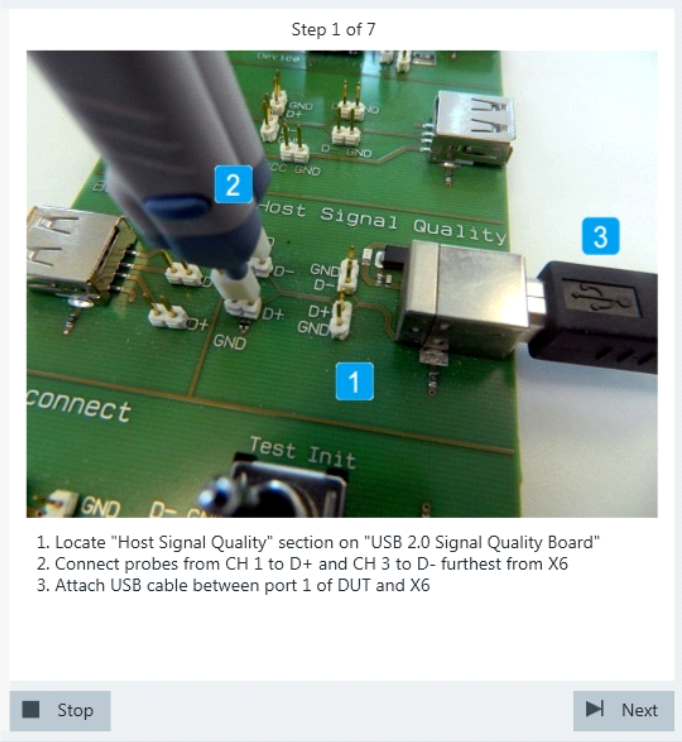
- Initial setup of the equipment, see Chapter 2.2, "Installing Software and License", on page 7
- LAN connection of the oscilloscope and the computer running the R&S Scope-Suite, see Chapter 2.5, "Connecting the R&S RTO", on page 9
- Configure and initiate the test with DUT type = **"Host"**, see Chapter 3.3, "Initiating the Test", on page 19

Running the test

1. Select the "Test J/K, SE0_NAK (EL_8,9)" test case and click "Test Single".

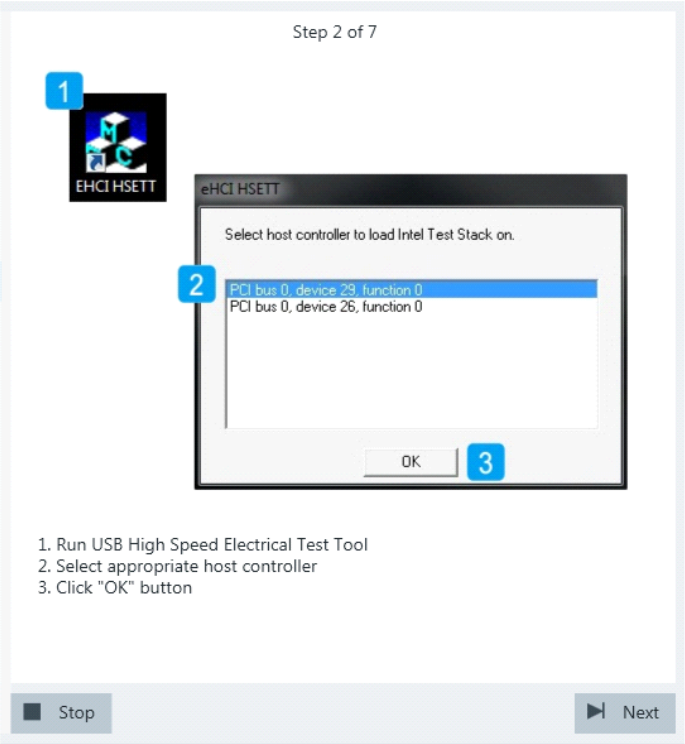


2. Connect the DUT to the test fixture as shown in the picture.

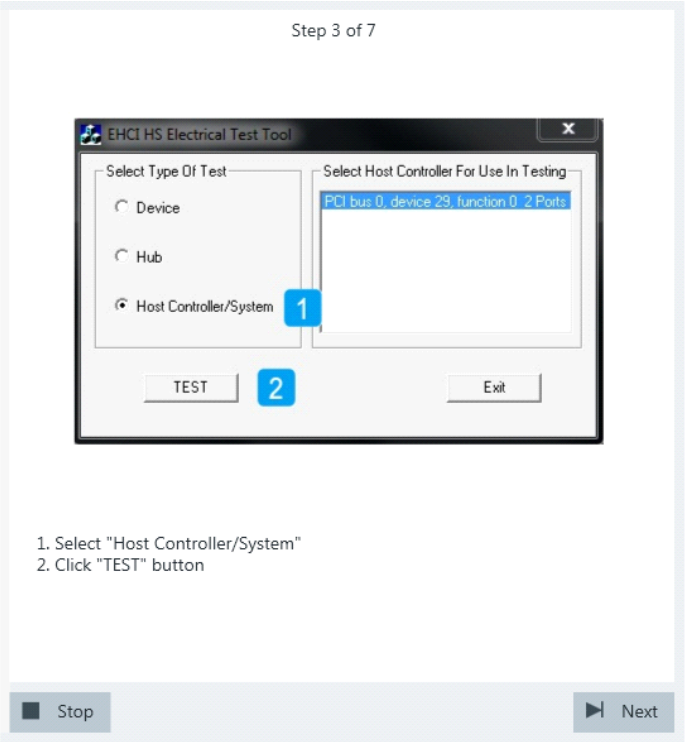


Use a 4-inch non-captive cable to connect the DUT to the test fixture.

3. Click "Next".
4. Start the HS Electrical Test Tool on the DUT.
5. Select the DUT from the list of host controllers and click OK.
   Note: the values in the list may vary.

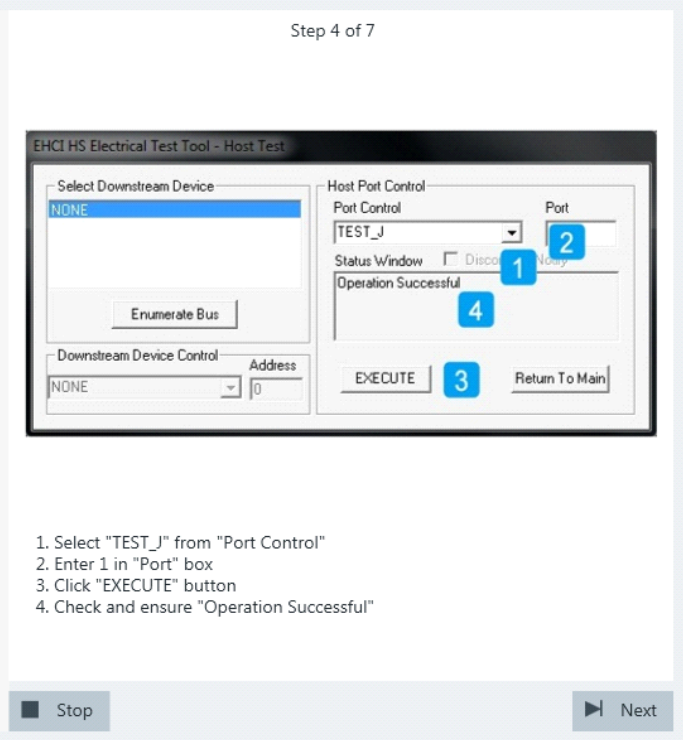


6. Select "Host Controller/System" on the left side.
   Click "TEST".



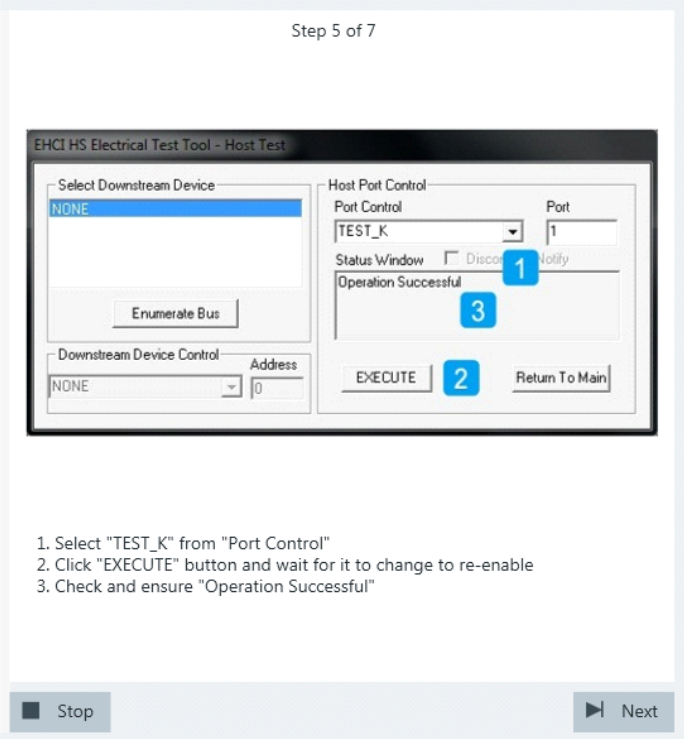
7. Select"TEST_J" from "Port Control".
   Enter the “Port” number of the DUT you are testing.

Click "EXECUTE" and wait until "Operation Successful" in the "Status Window" is shown.



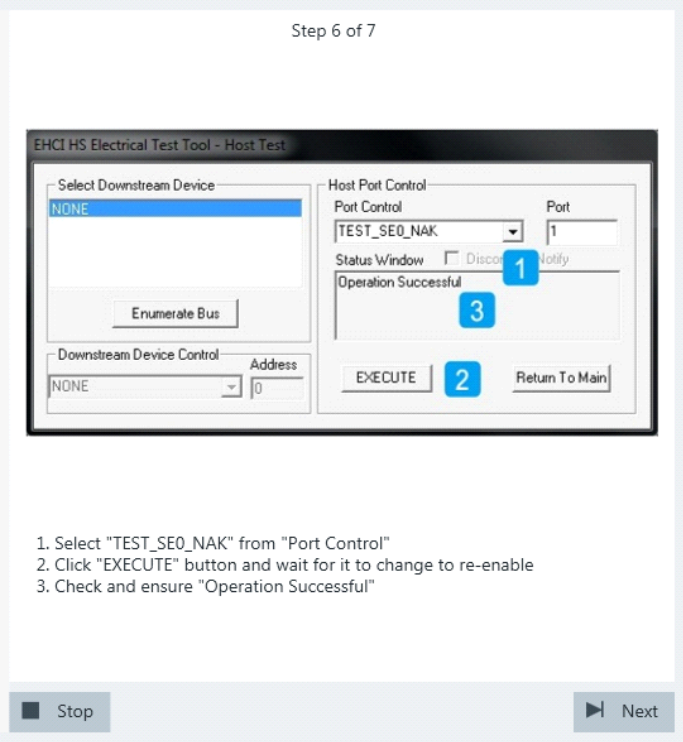
The probe at least 2 GHz bandwidth contains a built-in digital voltmeter known as ProbeMeter. The application automatically reads the voltages of D+ and D- from the ProbeMeter. However, if the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user to enter the voltages of D+ and D-.
Click "Next".

8. Select"TEST_K" from"Port Control".
   Click "EXECUTE" and wait until "Operation Successful" in the "Status Window" is shown.



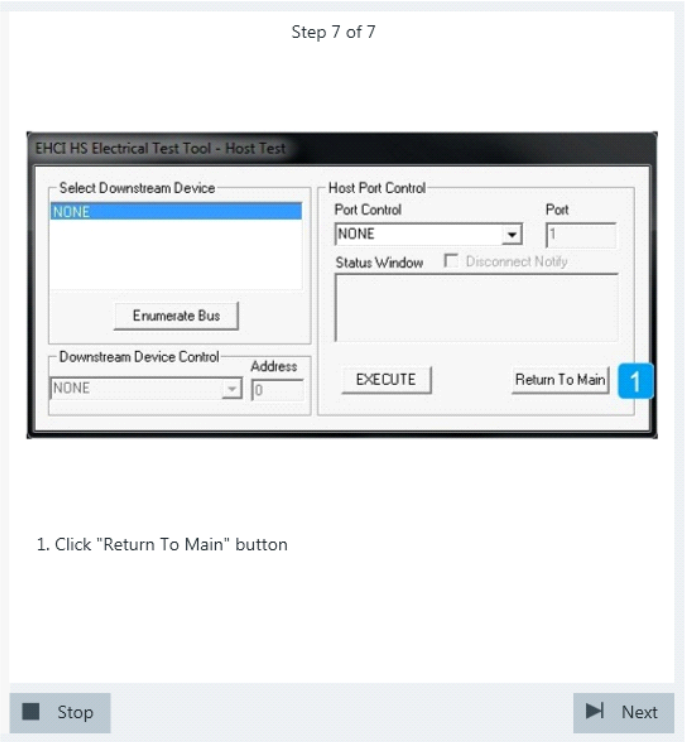
If the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user to enter the voltages of D+ and D-. Otherwise it automatically reads them from the ProbeMeter.

9. Select"TEST_SE0_NAK" from"Port Control".
   Click "EXECUTE" and wait until "Operation Successful" in the "Status Window" is shown.



If the user has selected "Digital Multimeter (Manual)" in the test configuration (see Chapter 3.2, "Configuring the Test", on page 15), the application prompts the user to enter the voltages of D+ and D-. Otherwise it automatically reads them from the ProbeMeter.

10. Return in the HS Electrical Test Tool to the Main menu.



The results are saved and can be viewed in the report.

6.2 Legacy Host Tests

In addition to the high-speed tests described in the preceeding chapter, the device under test must also pass a set of full speed and low speed compliance tests applicable to high-speed devices. The documentation of these legacy tests can be found in the "USB-IF Full and Low Speed Compliance Test Procedure" manual issued by the USB-IF. The manual is available at http://www.usb.org/developers.

To perform full speed and low speed compliance tests, you can use also a 4-channel R&S RTO with less than 2 GHz bandwidth.

Annex

A Ordering Information

Designation	Type	Order No.
USB 2.0 Compliance Test - Software	R&S®RTO-K21	1317.4103.02
The R&S®RTO-K21 option requires that the host PC be connected to an R&S®RTO digital oscilloscope via LAN.		
System requirements		
Windows 7 with .NET Framework 4 Redistributable Package, LAN with installed VISA driver for remote device control.		
Test Fixture		
USB 2.0 Test Fixture Set	R&S®RT-ZF1	1317.3420.02
Supported oscilloscopes		
Digital Oscilloscope, four channels	R&S®RTO	1316.1000.xx
Supported probes		
Single-ended probes		
1.0 GHz, active, 1 MΩ ||0.8 pF, R&S®ProbeMeter, micro button	R&S®RT-ZS10	1410.4080.02
1.5 GHz, active, 1 MΩ ||0.8 pF, R&S®ProbeMeter, micro button	R&S®RT-ZS20	1410.3502.02
3.0 GHz, active, 1 MΩ ||0.8 pF, R&S®ProbeMeter, micro button	R&S®RT-ZS30	1410.4309.02
6.0 GHz, active, 1 MΩ ||0.3 pF, R&S®ProbeMeter, micro button	R&S®RT-ZS60	1418.7307.02
Differential probes		
1.0 GHz, active, differential, 1 MΩ ||0.6 pF, R&S®ProbeMeter, micro button, including 10:1 external attenuator, 1.3 pF, 70 V DC, 46 V AC (peak)	R&S®RTO RT-ZD10	1410.4715.02
1.5 GHz, active, differential, 1 MΩ ||0.6 pF, R&S®ProbeMeter, micro button	R&S®RTO RT-ZD20	1410.4409.02
3.0 GHz, active, differential, 1 MΩ ||0.6 pF, R&S®ProbeMeter, micro button	R&S®RTO RT-ZD30	1410.4609.02
4.5 GHz, active, differential, 1 MΩ ||0.4 pF, R&S®ProbeMeter, micro button	R&S®RTO RT-ZD40	1417.0867.02
Current probes		
100 MHz, current probe, AC/DC, 0.1 V/A, 30 A (RMS)	R&S®RT-ZC20	1409.7766.02
Probe Power Supply	R&S®RT-ZA13	1409.7789.02
Automated arbitrary waveform generator		
2.3 Gsample/s Dual-Channel Arbitrary Waveform Generator	WX2182B WX2182C	available from Tabor

Check the brochure at www.scope-of-the-art.com/en/oscilloscopes/RTOK21-|-Brochures_and_Data_Sheets-|-19-|-111.html for updates, if available.