TELEDYNE | LECROY



QPHY-HDMI2.1

HDMI 2.1, 2.0 and 1.4b
Serial Data Compliance Software
Instruction Manual

April, 2026

Relating to:

MAUI® v.9.4.x.x and later

QualiPHY™ v.9.4.x.x and later

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About This Manual

This manual assumes that you are familiar with using an oscilloscope–in particular the Teledyne LeCroy oscilloscope that will be used with QualiPHY–and that you have purchased the QPHY-HDMI2.1 software option.

Some of the images in this manual may show QualiPHY products other than QPHY-HDMI2.1, or were captured using different model oscilloscopes, as they are meant to illustrate general concepts only. Rest assured that while the user interface may look different from yours, the functionality is identical.

Introduction

QualiPHY™ is highly automated compliance test software meant to help you develop and validate the PHY (physical-electrical) layer of a device, in accordance with the official documents published by the applicable standards organizations and special interest groups (SIGs). You can additionally set custom variables and limits to test compliance to internal standards.

QualiPHY is composed of a "framework" application that enables the configuration and control of separate tests for each standard through a common user interface. Features include:

- **Multiple Data Source Capability**
- **User-Defined Test Limits** to ensure devices are well within the passing region, even if subsequently measured with different equipment.
- **Flexible Test Results Reporting** that includes XML Test Record generation to help understand device performance distribution or obtain process related information from the devices under test.

QPHY-HDMI2.1 is an automated test package performing all the normative, real-time oscilloscope FRL and TMDS source tests in accordance with version 2.1 of the High Definition Multimedia Interface (HDMI) Compliance Test Specification (CTS) and associated Teledyne LeCroy approved Methods of Implementation (MOIs).

The software can be run on any Teledyne LeCroy oscilloscope with the following minimum bandwidth and sample rate, depending on the tests to be run:

- HDMI 2.1 FRL Tests: at least 20 GHz bandwidth and 80 GS/s sampling rate
- HDMI 2.1 TMDS Tests: at least 13 GHz bandwidth and 40 GS/s sampling rate
- HDMI 1.4 Tests: at least 4 GHz bandwidth and 20 GS/s sampling rate

Required Equipment

Teledyne LeCroy WaveMaster® or LabMaster real-time oscilloscope, ≥ 13 GHz BW, installed with:

- MAUI® v.9.4.x.x minimum with an QPHY-HDMI2.1 option key
- QualiPHY software v.9.4.x.x. minimum with QPHY-HDMI2.1 component selected at installation
- SDAIII-CompleteLinQ software option (includes Eye Doctor II and VirtualProbe)
- 14GBIT-80B-SYMBOL-TD software option (required for Inter-pair skew measurements)

Note: The version of MAUI and QualiPHY software must match, so upgrade QualiIPHY if you have upgraded your oscilloscope firmware. The versions listed above are the minimum versions required for this product. QualiPHY software may be installed on a remote PC, but the MAUI software must be installed on the oscilloscope.

See the Teledyne LeCroy MOI documents published on the HDMI Forum website for a description of the test hardware configuration options and the equipment required for each. HDMI Forum members can download the documents from https://members.hdmiforum.org/.

Test Fixture & EDID Emulator

For HDMI2.1

Teledyne LeCroy recommends using the Wilder Technologies HDMIA2.1-TPA (plug test adapter) or equivalent approved HDMI approved TPA.

QPHY-HDMI2.1 currently supports full automation of the Wilder Technologies HDMI FRL/EDID V2.1 EDID Emulator. Alternative approved EDID emulators may be supported in the future. Testing can also be done manually by choosing “Manual Control” in the Sink Emulation variable.

For HDMI 2.0

Teledyne LeCroy recommends using the Wilder Technologies HDMIA2-TPA-12P (plug test adapter) used in conjunction with GRL-HDMI-CONT (EDID Emulator board from Granite River Labs – if required by customer test configuration).

For HDMI 1.4b

Teledyne LeCroy recommends using the Wilder Technologies HDMI-TPA-P (plug test adapter) used in conjunction with HDMI-TPA-E (EDID board with EEPROM). This equipment is available from Wilder Technologies individually or as part of the HDMI-TPA-PRRCE Test Adapter Kit.

Automation

Optionally, customers can automate their tests using two switch boxes from Mini-Circuits (Model No: RC_8SPDT-A18) and one HDMI Terminator HDMI-TPA-T from Wilder Technologies. See Appendix C: Switch Matrix Configuration.

Required Host Computer System

Usually, the oscilloscope is the host computer for the QualiPHY software, and all models that meet the acquisition requirements will also meet the host system requirements.

However, if you wish to run the QualiPHY software from a remote computer, these minimum host requirements apply:

- Windows 10 or 11 Professional operating system
- 1 GHz or faster processor
- 8 GB of RAM
- Ethernet (LAN) network capability
- Hard Drive:
    - At least 100 MB free to install the wizard.
    - Up to 2 GB per standard installed to store the log database (each database grows from a few MB to a maximum of 2 GB)

See Set Up Remote Control for configuration instructions.

Software Installation and Setup

QualiPHY is a Windows-based application that can be configured with one or more serial data compliance components. Each compliance component is purchased as a separate oscilloscope software option.

Install Base Application

Download the latest version of the QualiPHY software from:

teledynelecroy.com/support/softwaredownload under Oscilloscope Downloads > Software Utilities.

Run **QualiPHYInstaller.exe** and follow the installer prompts. Choose all the components you plan to activate. If you omit any components now, you will need to update the installation to activate them later.

By default, the oscilloscope appears as local host when QualiPHY is executed on the oscilloscope. Follow the steps under Add Connection to QualiPHY to check that the IP address is **127.0.0.1**.

Activate Components

The serial data compliance components are factory installed as part of the main application in your oscilloscope and are individually activated through the use of an alphanumeric code uniquely matched to the oscilloscope's serial number. This option key code is what is delivered when purchasing a software option.

To activate an option on the oscilloscope:

1. From the menu bar, choose **Utilities > Utilities Setup**.
2. On the Options tab, click **Add Key**.
3. Use the Virtual Keyboard to **Enter Option Key**, then click **OK**.

   If activation is successful, the key code now appears in the list of Installed Option Keys.
4. Restart the oscilloscope application by choosing **File > Exit**, then double-clicking the **Start DSO** icon on the desktop.

Set Up Dual Monitor Display

Teledyne LeCroy recommends running QualiPHY on an oscilloscope equipped with Dual Monitor Display capability. This allows the waveform and measurements to be shown on the oscilloscope LCD display, while the QualiPHY application and test results are displayed on a second monitor.

See the oscilloscope Operator's Manual for instructions on setting up dual monitor display.

Set Up Remote Control (optional)

QualiPHY software can be executed from a remote host computer, controlling the oscilloscope through a LAN Connection. To set up remote control:

- The oscilloscope must be connected to a LAN and assigned an IP address (fixed or dynamic).
- The host computer must be on the same LAN as the oscilloscope.

Configure Oscilloscope for Remote Control

1. From the menu bar, choose **Utilities → Utilities Setup...**
2. Open the **Remote** tab and set Remote Control to **TCP/IP**.
3. Verify that the oscilloscope shows an IP address.

Add Connection to QualiPHY

1. On the host PC, download and run **QualiPHYInstaller.exe**.
2. Start QualiPHY and click the **General Setup** button.
3. On the **Connection** tab, click **Scope Selector**.
4. Click **Add** and choose the connection type. Enter the oscilloscope IP address from Step 3 above. Click **OK**.
5. When the oscilloscope is properly detected, it appears on the Scope Selector dialog. Select the connection, and click **OK**.

   QualiPHY is now ready to control the oscilloscope.

Select Connection

Multiple oscilloscopes may be accessible to a single remote host. In that case, go to General Setup and use the Scope Selector at the start of the QPHY session to choose the correct connection.

QualiPHY tests the oscilloscope connection when starting a test. The system warns you if there is a connection problem.

Using QualiPHY

This section provides an overview of the QualiPHY user interface and general procedures. For detailed information about the QPHY-HDMI2.1 software option, see HDMI Testing.

Accessing the Software

Once QualiPHY is installed and activated, it can be accessed from the oscilloscope menu bar by choosing **Analysis > QualiPHY**, or by double-clicking the **QualiPHY desktop icon** on a remote computer.

The QualiPHY wizard illustrates the overall software flow, from general set up through running individual compliance tests. Work from left to right, making all desired settings on each sub-dialog.

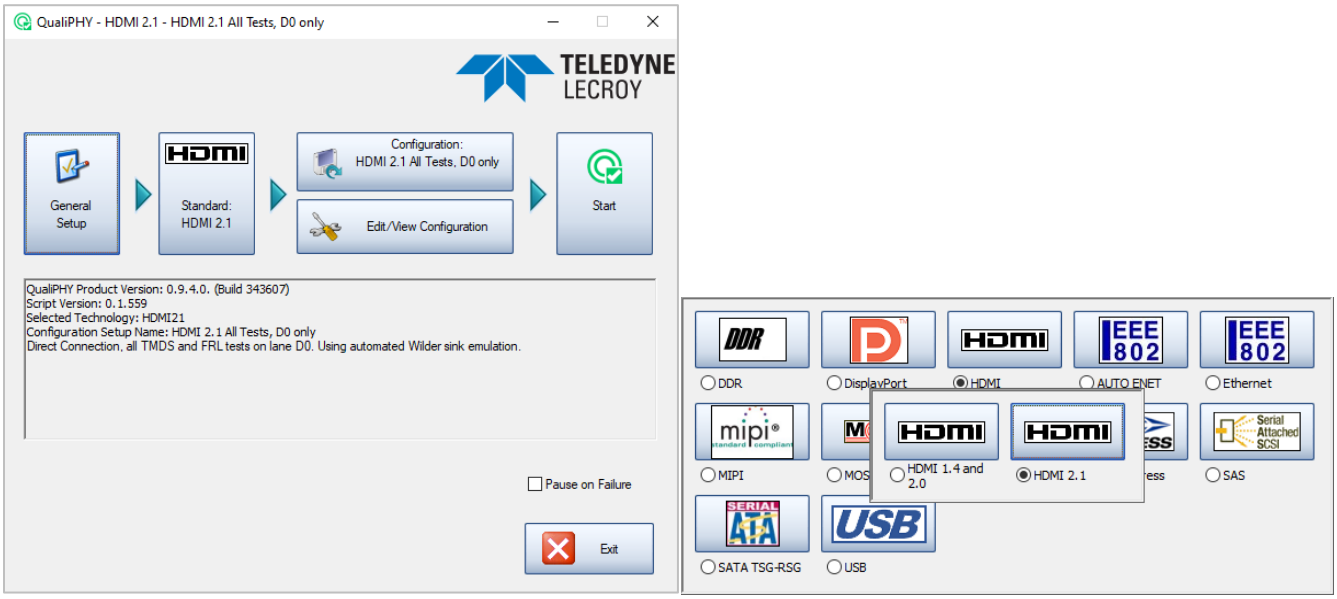


Figure 1: QualiPHY wizard and Standard selection menu.

The **HDMI 2.1** Standard selection supports all HDMI 2.1 FRL and TMDS tests, and HDMI 1.4b TMDS tests. All are covered in this manual.

The **HDMI 1.4 and 2.0** Standard selection supports HDMI 2.0 and HDMI 1.4b TMDS tests **only**. For details on using that script, refer to the *QPHY-HDMI2 Operator's Manual*, available from:

teledynelecroy.com/support/techlib under Manuals > Software Options.

If **Pause on Failure** is checked, QualiPHY prompts you to retry a measurement whenever a test fails.

Report Generator launches the manual report generator dialog.

The **Exit** button at the bottom of the wizard closes the QualiPHY application.

General Setup

The sub-dialogs of the wizard are organized into tabs each containing configuration controls related to that part of the process. These are described in more detail in the following sections.

The first sub-dialog contains general system settings. These remain in effect for each session, regardless of Standard, until changed.

Connection tab

Shows **IP Address** of the test oscilloscope (local host 127.0.0.1 if QualiPHY is run from the oscilloscope). The **Scope Selector** allows you to choose the oscilloscope used for testing when several are connected to the QualiPHY installation. See Set Up Remote Control for details.

Session Info tab

Optional information about the test session that may be added to reports, such as: **Operator Name**, **Device Under Test** (DUT), **Temperature** (in °C) of the test location, and any additional **Comments**. There is also an option to **Append Results** or **Replace Results** when continuing a previous session.

To optimize report generation, enter at least a DUT name at the beginning of each session.

Report tab

Settings related to automatic report generation. Choose:

- **Reporting behavior** of:
    - "Ask to generate a report after tests," where you'll be prompted to create a new file for each set of test results.
    - "Never generate a report after tests," where you'll need to manually execute the Report Generator to create a report.
    - "Always generate a report after tests," to autogenerate a report of the latest test results.
- **Default** report output type of XML, HTML, or PDF.
- A generic **Output file name**, including the full path to the report output folder.

Optionally, check **Allow style sheet selection in Report Generator** to enable the use of a custom .css when generating reports. The path to the .css is entered on the Report Generator dialog.

Report Generator launches the Report Generator dialog, which contains the same settings as the Report tab, only applied to individual reports.

Advanced tab

This tab launches the **X-Replay Mode** dialog. See X-Replay Mode.

About tab

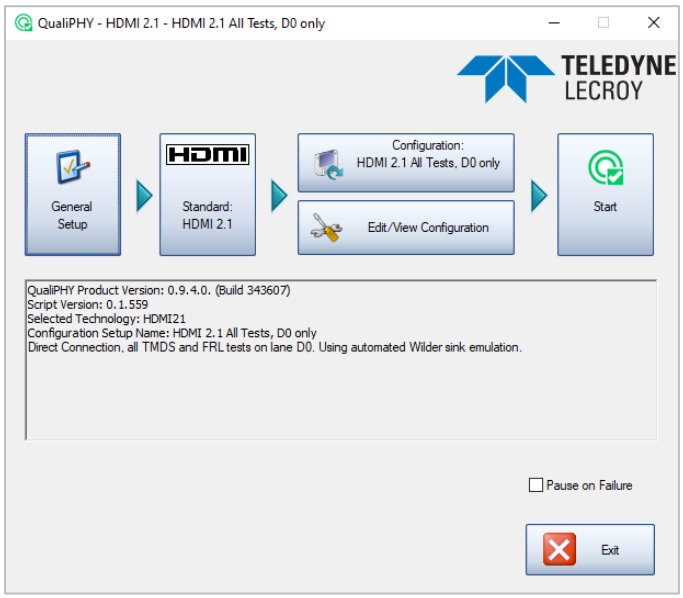
Information about your QualiPHY installation.

QualiPHY Test Process

Once general system settings are in place, these are the steps for running test sessions.

Set Up Test Session

1. Connect the oscilloscope to the DUT.
2. Access the QualiPHY software to display the wizard.



3. If running QualiPHY remotely, click **General Setup** and open the **Scope Selector** to select the correct oscilloscope connection.
4. If you have more than one component activated, click **Standard** and select the desired standard to test against. Otherwise, your one activated component will appear as the default selection.

   The **HDMI 2.1** Standard selection supports all HDMI 2.1 FRL and TMDS tests, and HDMI 1.4b TMDS tests. All are covered in this manual.

   The **HDMI 1.4 and 2.0** Standard selection supports HDMI 2.0 and HDMI 1.4b TMDS tests **only**. For details on using that script, refer to the *QPHY-HDMI2 Operator's Manual*, available from:

   teledynelecroy.com/support/techlib under Manuals > Software Options.

Note: Although all the QualiPHY components appear on this dialog, only those selected when installing QualiPHY are enabled for selection now.

5. Click the **Configuration** button and select the test configuration to run. These pre-loaded configurations are set to run all the required tests and provide a quick, easy way to begin compliance testing. See QPHY-HDMI Test Configurations for a description of configurations.

   You can also create custom configurations for internal compliance tests by copying and modifying the pre-loaded configurations. See Customizing QualiPHY for details.

6. **Close** the Edit/View Configuration dialog to return to the wizard.

Run Tests

1. On the wizard, click **Start** to begin testing.

   When tests are in progress, this button changes to **Stop**. Click it at any time to stop the test in process. You'll be able to resume from the point of termination or from the beginning of the test.

2. Follow the pop-up window prompts. QualiPHY guides you step-by-step through each of the tests described in the standard specification, including diagrams of the connection to the DUT for each required test mode.

3. When all tests are successfully completed, both progress bars on the wizard are completely green and the message "All tests completed successfully" appears. If problems are encountered, you'll be offered options to:

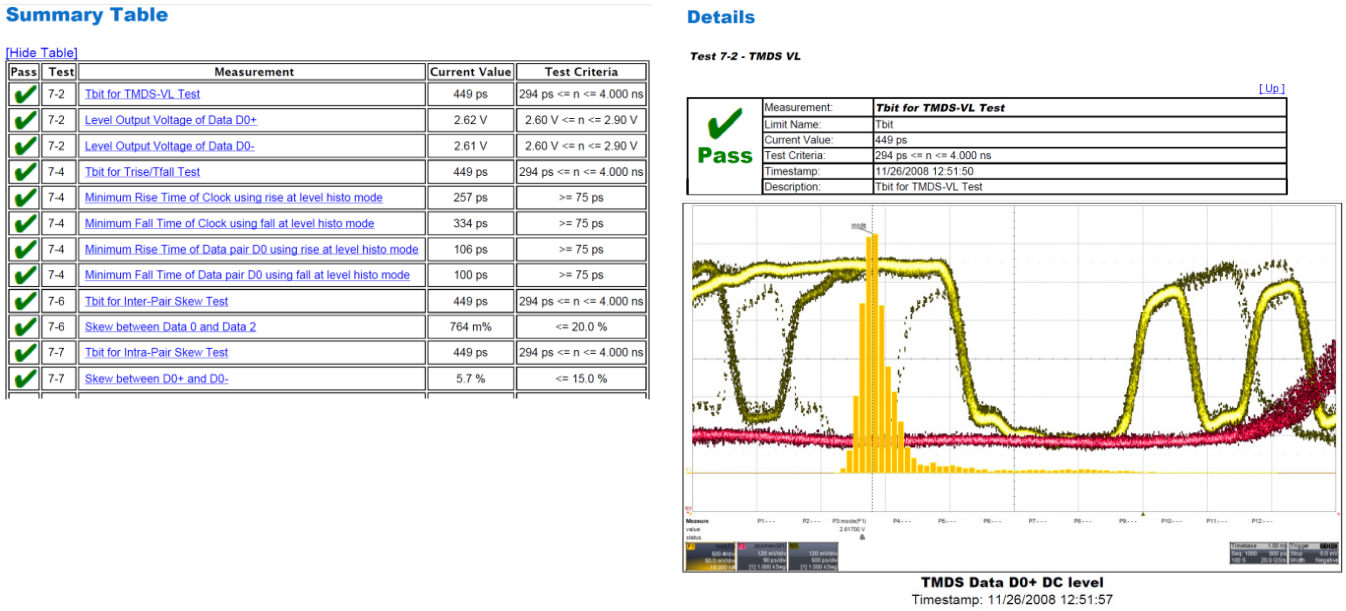
   - **Retry** the test from the latest established point defined in the script
   - **Ignore and Continue** with the next test
   - **Abort Session**

Run Reports

The QualiPHY software automates report generation. On the wizard, go to **General Setup > Report** to pre-configure reporting behavior. You can also manually launch the **Report Generator** from the wizard once a test is run.

The Report Generator offers the same selections as the Report tab, only applied to each report individually, rather than as a system setting. This enables you to save reports for each test session, rather than overwrite the generic report file. There are also options to link a custom style sheet (.xslt) to the report, or to Exclude Informative Results.

The Test Report includes a summary table with links to the detailed test result pages.



Summary Table

[Hide Table]

Pass	Test	Measurement	Current Value	Test Criteria
✔	7-2	Tbit for TMDS-VL Test	449 ps	294 ps <= n <= 4.000 ns
✔	7-2	Level Output Voltage of Data D0+	2.62 V	2.60 V <= n <= 2.90 V
✔	7-2	Level Output Voltage of Data D0-	2.61 V	2.60 V <= n <= 2.90 V
✔	7-4	Tbit for Trise/Tfall Test	449 ps	294 ps <= n <= 4.000 ns
✔	7-4	Minimum Rise Time of Clock using rise at level histo mode	257 ps	>= 75 ps
✔	7-4	Minimum Fall Time of Clock using fall at level histo mode	334 ps	>= 75 ps
✔	7-4	Minimum Rise Time of Data pair D0 using rise at level histo mode	106 ps	>= 75 ps
✔	7-4	Minimum Fall Time of Data pair D0 using fall at level histo mode	100 ps	>= 75 ps
✔	7-6	Tbit for Inter-Pair Skew Test	449 ps	294 ps <= n <= 4.000 ns
✔	7-6	Skew between Data 0 and Data 2	764 m%	<= 20.0 %
✔	7-7	Tbit for Intra-Pair Skew Test	449 ps	294 ps <= n <= 4.000 ns
✔	7-7	Skew between D0+ and D0-	5.7 %	<= 15.0 %

Details

Test 7-2 - TMDS VL

[Up]

Pass

Measurement:	***Tbit for TMDS-VL Test***
Limit Name:	Tbit
Current Value:	449 ps
Test Criteria:	294 ps <= n <= 4.000 ns
Timestamp:	11/26/2008 12:51:50
Description:	Tbit for TMDS-VL Test

TMDS Data D0+ DC level
Timestamp: 11/26/2008 12:51:57

Figure 2 - The Test Report Summary Table and Details pages

Reports are output to the folder D:\QPHY\Reports, or C:\LeCroy\QPHY\Reports if QualiPHY is installed on a remote PC.

You can add your own logo to the report by replacing the file *\QPHY\StyleSheets\CustomerLogo.jpg.

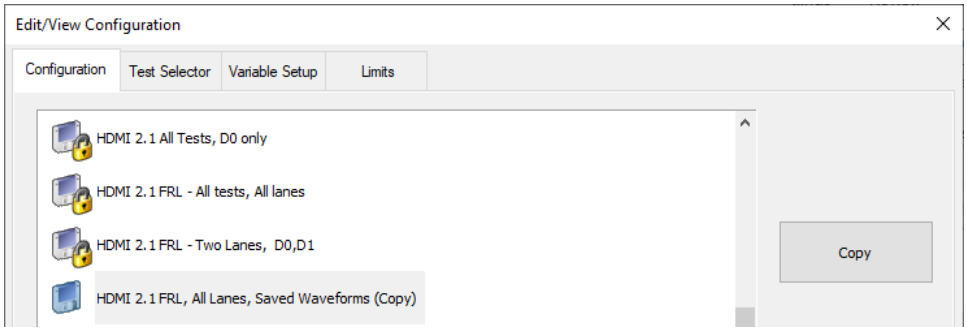
The recommended maximum size is 250x100 pixels at 72 ppi, 16.7 million colors, 24 bits. Use the same file name and format.

Customizing QualiPHY

The pre-loaded configurations cannot be modified. However, you can create your own test configurations by copying one of the standard test configurations and modifying it.

Copy Configuration

1. Access the QualiPHY wizard and select a **Standard**.
2. Click **Edit/View Configuration** and select the configuration upon which to base the new configuration. This can be a pre-loaded configuration or another copy.
3. Click **Copy** and enter a name and description. Once a custom configuration is defined, it appears on the Configuration tab followed by "(Copy)."



4. Select the new, custom configuration and follow the procedures below to continue making changes.

Note: If any part of a configuration is changed, the Save As button on the Configuration tab becomes active. If a custom configuration is changed, the Save button will also become active to apply the changes to the existing configuration, rather than create a new one.

Select Tests

On the **Test Selector** tab, select/deselect the tests that make up the configuration. Each test is defined by the HDMI standard. A description of each test is displayed when it is selected.

To loop any of the tests in this configuration, select the test from the list, then choose to **Loop the highlighted test** until stopped or enter the number of repetitions.

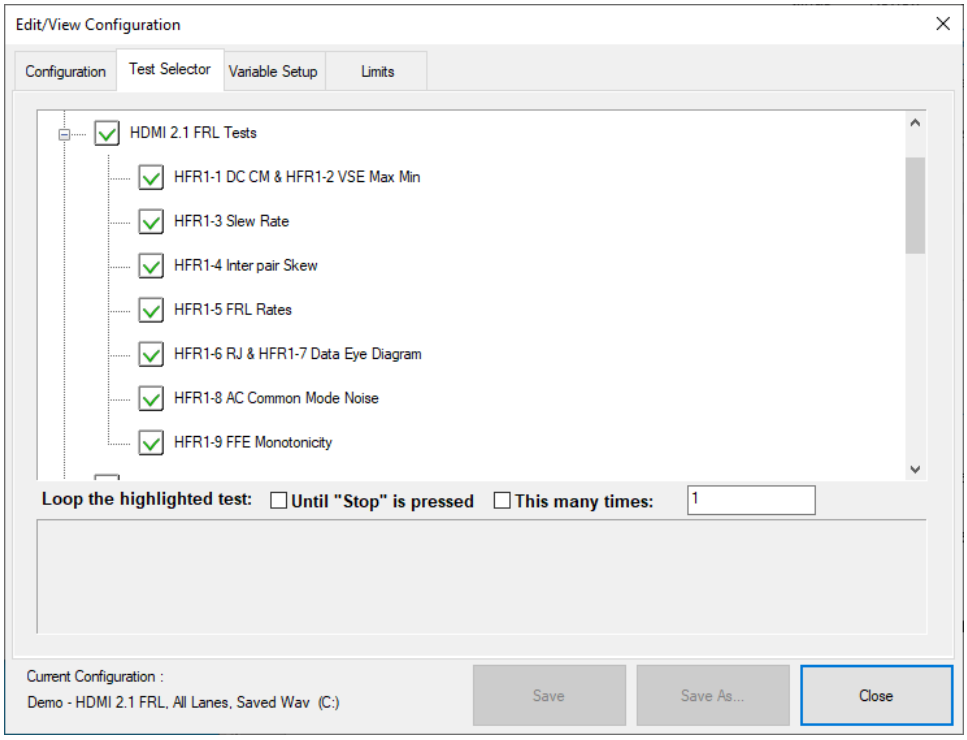


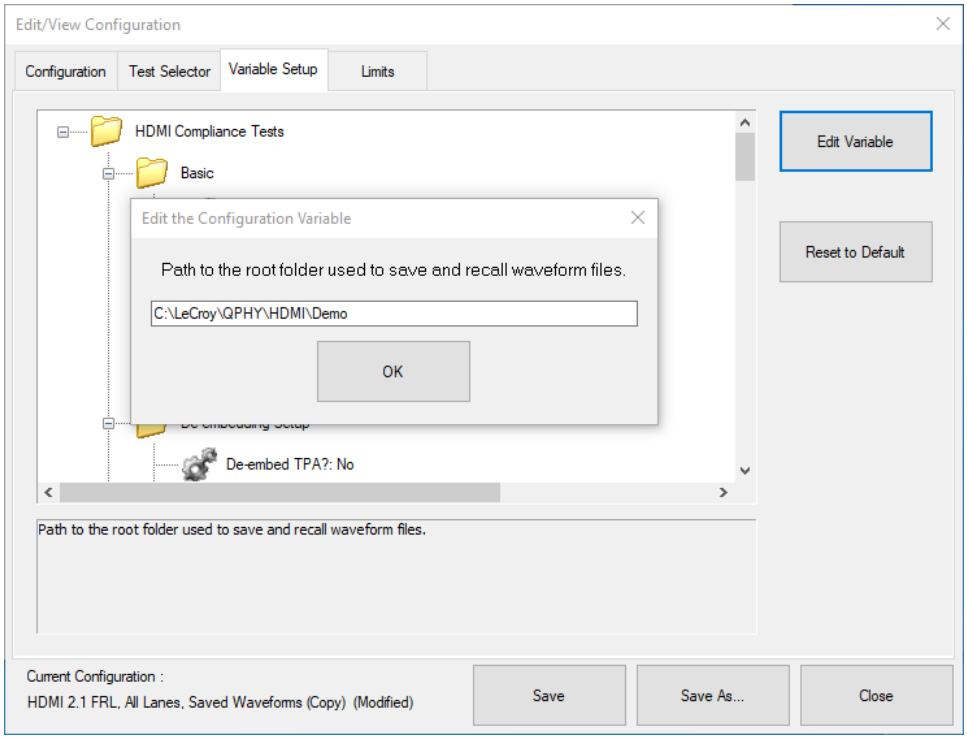
Figure 3 – Configuration Test Selector tab

Edit Variables

The Variable Setup tab contains a list of test variables. See QPHY-HDMI Variables for a description of each.

To modify a variable:

1. Select the variable on the Variable Setup tab, then click **Edit Variable**. (You can also choose to Reset to Default at any time.)
2. The conditions of this variable appear on a pop-up. Choose the new condition to apply.



Edit Test Limits

The Limits tab shows the Limit Set currently associated with the configuration. Any limit set can be associated with a custom configuration by selecting it in this field.

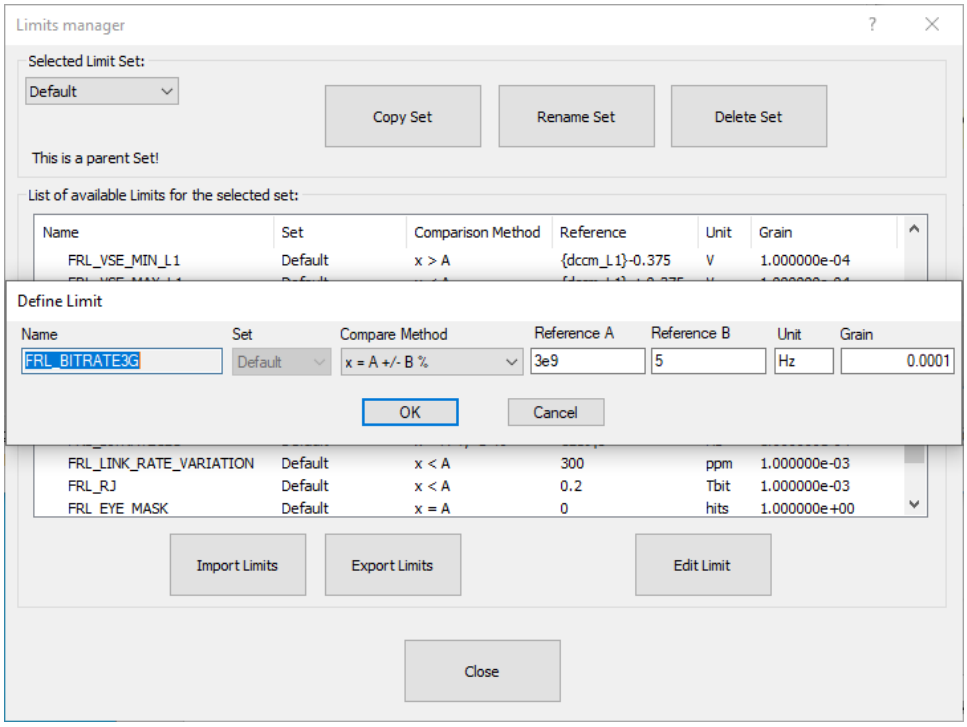
The Limits Manager shows the settings for every test limit in a limit set. Those in the default set are the limits defined by the standard.

To create a custom limit set:

1. On the Limits tab, click **Limits Manager**.
2. With the default set selected, click **Copy Set** and enter a name.

Note: You can also choose to copy and/or modify another custom set that has been associated with this configuration.

3. Double click the limit to be modified, and in the pop-up enter the new values.



You can also **Import Limits** from a .csv file. Navigate to the file location after clicking the button.

Tip: Likewise, Export Limits creates a .csv file from the current limit set. You may wish to do this and copy it to format the input .csv file.

X-Replay Mode

The X-Replay mode window is an advanced (“developer”) view of QualiPHY. The tree in the upper-left frame enables you to navigate to processes in the HDMI test script, in case you need to review the code, which appears in the upper-right frame.

Two other particularly useful features are:

- A **list of recent test sessions** in the lower-left frame. While you can only generate a report of the current test session in the QualiPHY wizard, in X-Replay Mode you can generate a report for any of these recent sessions. Select the session and choose **Report > Create Report** from the menu bar.
- **An event log is shown** the bottom-right frame. The frame can be split by dragging up the lower edge. The bottom half of this frame now shows the **raw Python output**, which can be useful if ever the script needs debugging.

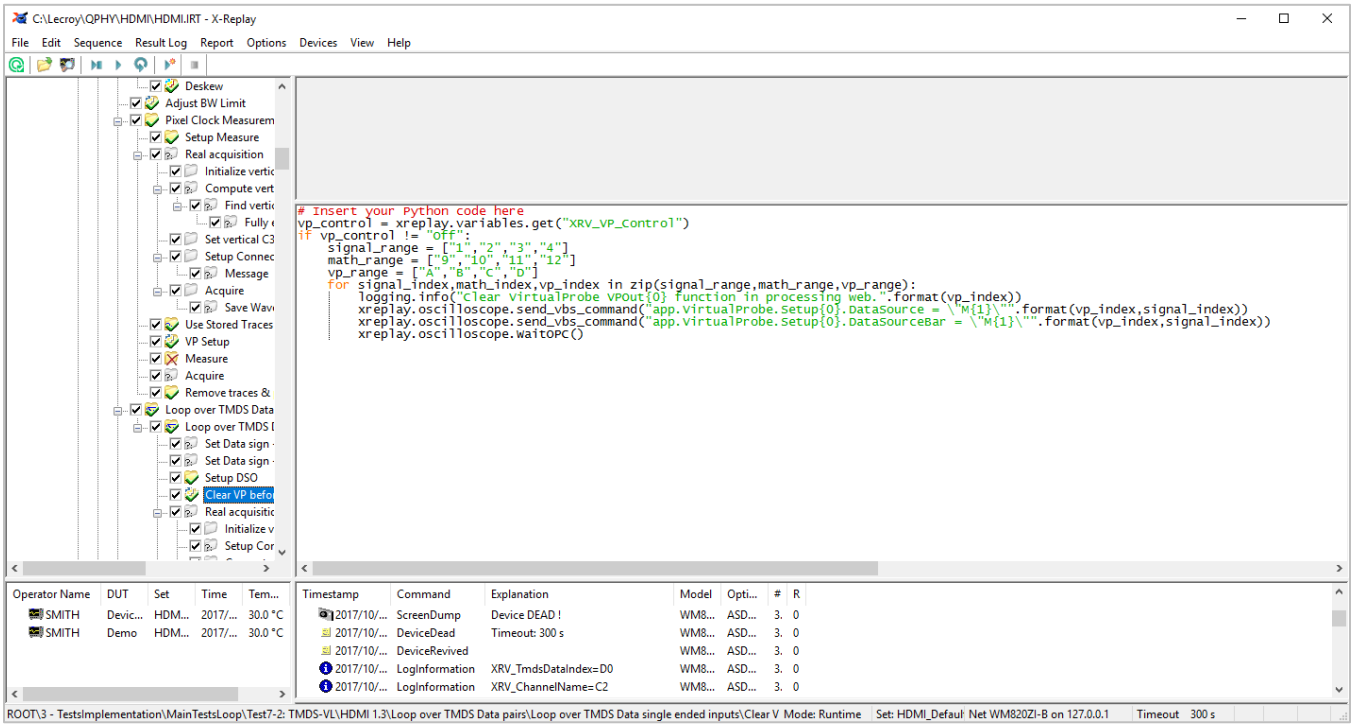


Figure 4 – X-Replay Mode window

HDMI Source Testing

Test Preparation

Before beginning any test or data acquisition, warm the oscilloscope for at least 20 minutes.

Calibration is performed automatically by the oscilloscope software; no manual calibration is required. Calibration is run again if the temperature of the oscilloscope changes by more than a few degrees.

Required Test Modes

The QPHY-HDMI2.1 script requires that you place the DUT (Device Under Test) in the required test modes. The script will prompt you to do so before each specific test, but it is recommended that you ensure the DUT is capable of being placed in the required test modes before beginning testing.

Deskewing Input Channels, Cables and/or Switches

HDMI signals are properly probed using two separate channels on the oscilloscope connected to the appropriate SMA jacks on the test fixture. The highest measurement accuracy is achieved when the timing skew between the two channels is calibrated. The QPHY-HDMI2.1 script includes two deskew “configurations” that will guide you through the steps required to deskew whether using a direct connection or a switch. We highly recommend that you deskew after making your probe connections and before any HDMI tests.

Some higher bandwidth Teledyne LeCroy oscilloscopes (e.g., WaveMaster series) include the unique FastEdge output signal and trigger type to facilitate deskewing. The test script uses this output as a signal source in conjunction with the FastEdge trigger to measure the arrival time of the FastEdge through each channel. Deskew values are stored to file and recalled into each channel’s Deskew setting, which is located in the Pre-processing section of the channel configuration dialog.

There are three basic kinds of deskew that are performed:

1. Deskew only the oscilloscope’s inputs
2. Deskew input cabling + oscilloscope inputs
3. Deskew input switches, cabling and oscilloscope inputs.

In the QPHY-HDMI2.1 script, methods 1 and 2 are handled by the “By Channel” deskew method. Method 3 is handled using “By Lane”.

Deskew Oscilloscope Inputs Only

When wishing only to correct for timing differences between the oscilloscope input connectors and the internal digitizing hardware, the deskew reference plane is the point where the input signal is plugged into the oscilloscope. This type of deskew is used in the case where the test fixture is being connected directly to the oscilloscope inputs.

To do this deskew, disconnect all signals, and use a single cable connected to the FastEdge output. When the software prompts you to plug a cable into an input channel, simply change the connection from one channel to the next **using the same cable.** The result is a deskew of the input path through the TF-HDMI-3.3V adapter and the oscilloscope’s internal circuitry. The script will store to file time offsets between the FastEdge signal and the trigger time. Skew with respect to channel 1 will be used during testing, such that the deskew setting for C1 = 0. The deskew settings for other channels are with respect to the value measured for C1. Deskew values that are small (picoseconds) will result.

Deskew through Input cabling + Oscilloscope inputs

When timing differences between the cables used to connect the DUT to the oscilloscope are not of interest and are to be removed (which is usually the case), then a slightly different deskew procedure is performed. This type of deskew is used in the case where the test fixture is being connected to the oscilloscope via cables.

Leave the cables connected to the oscilloscope, and disconnect them from the DUT. When the software prompts you to plug a cable into an input channel (e.g., C2), leave the cable plugged into C2, and connect the other end of the cable into the FastEdge connect. (Don't forget to torque properly!) The result is a deskew of the input path through the cables specific to each channel, through the TF-HDNI-3.3V adapter, and the oscilloscope's internal circuitry. The script will store to file the time offsets between the FastEdge signal and the trigger. Skew with respect to channel 1 will be used during testing, such that the deskew setting for C1 = 0. The deskew settings for other channels are with respect to the value measured for C1. Deskew values depend on cable lengths used, but if the cables are of the same nominal length (but are not specifically "matched cables"), then channel deskew values can be as high as several tens of picoseconds.

Tip: Label the cables and input adapters with the number of the channel to which they are connected.

Deskew through Input switches, Input cabling + Oscilloscope inputs

When using a switch matrix to route inputs from the test fixture to the oscilloscope, there are two choices. One is to perform a deskew as described below, the other is to **de-embed** the switch matrix and attached cables via S-parameter de-embedding feature of the QualiPHY-HDMI script. **Do not do both**, since this will essentially "Double correct" for any skew.

Note: The S-parameter de-embeding performed by the VirtualProbe feature of the oscilloscope will correct for both loss and skew, since S-parameters include both magnitude and phase information.

If choosing to use de-embedding to perform the "By Channel" method deskew, take care to not have any overlap in the reference planes of the deskew and of the S-parameters. If choosing to only deskew the switches, set the "Deskew Type" variable to "By Lane", and make sure the variable "De-embed switches?" is set to "No".

To perform a deskew through the switches, disconnect the signals from the DUT, but leave all cabling through the switches and into the oscilloscope connected. Connect a cable to the FastEdge output. When prompted, connect the output of this cable to the appropriate switch input. For example, when prompted to connect signal "D2+", connect the FastEdge signal to the D2+ input of the switch matrix (or to the cable connected to this input.) The script will store to file the time offsets between the FastEdge signal and the trigger time. It will also store an appropriate signal path descriptor, such as "D1+C1". During testing, the script will program the oscilloscope with the appropriate skew values for the lane/line under test. Skew with respect to channel 1 will be used during testing, such that the deskew setting for C1 = 0. The deskew settings for other channels are with respect to the value measured for C1. Deskew values will depend on any variations in the cabling to and from the switch matrix and through any interconnecting cables.

Important: Use a torque wrench at each step in the deskew process. If a torque wrench is not used, the accuracy can easily be off by several picoseconds.

De-embedding

QualiPHY-HDMI2 includes the capability to de-embed the test fixure (TPA) as well as any switch matrix and/or cables that sit between the lane under test and the oscilloscope. De-embedding is accomplished by using the VirtualProbe software capability to emulate the effects of the TPA/switches S-parameters. To de-embed, you must provide the Touchstone files containing the complete S-parameters.

Note: De-embedding the TPA or the switch is not a requirement of the HDMI 2.0 Generic CTS, nor is it explicitly recommended. However, you may wish to de-embed if the DUT's performance is on the pass/fail boundary.

TPA

For the TPA (test fixture), this is a 4-port S-parameter file (.s4p), which would be s-parameters that represent any of the main link differential pairs. This file is specific to the TPA in use and should be requested from your TPA vendor if required.

Switch/Cable

For switches/cables, one two-port file (.s2p) is needed for each signal path that connects a single TPA output (such as Lane0) to an oscilloscope channel. The S2P file can be of any part of the path between the TPA output and the oscilloscope channel that you wish to de-embed. For a compete de-embedding, make your S-parameter measurements are from the cable connecting to the TPA outputs (if used) to the end of the cable that is attached to the oscilloscope channel.

The S2P file connecting Lane "N" of polarity "M" to oscilloscope channel "X" must be named using the following syntax:

```
switchD{N}{M}-C{X}
```

Example filenames are shown in the table. (Note that S2P files are needed to route lane D0 to both C1/C2 and to C3/C4. The routing to C3/C4 is needed for the inter-pair skew testing.)

S-parameter filename	Corresponding signal path
switchD0+C1.s2p	D0 (+) to oscilloscope channel C1
switchD0-C2.s2p	D0 (-) to oscilloscope channel C2
switchD1+C3.s2p	D1 (+) to oscilloscope channel C3
switchD1-C4.s2p	D1 (-) to oscilloscope channel C4
switchD2+C1.s2p	D2 (+) to oscilloscope channel C1
switchD2-C2.s2p	D2 (-) to oscilloscope channel C2
switchCLK+C3.s2p	CLK (+) to oscilloscope channel C3
switchCLK-C4.s2p	CLK (-) to oscilloscope channel C4
switchD0+C3.s2p	D0 (+) to oscilloscope channel C1
switchD0-C4.s2p	D0 (-) to oscilloscope channel C2

Preparing to De-embed

Prior to performing de-embedding within QualiPHY, it is good practice to examine the touchstone files with an S-parameter viewer in order to confirm that the S-parameters are "healthy".

Set up the de-embedding in VirtualProbe and examine the de-embedding manually. This separate step will allow you to confirm that S-parameters for the TPA or switch are being properly read-in and yield reasonable results.

After confirming the de-embedding in VirtualProbe, configure QualiPHY to perform the de-embedding.

HDMI Method of Implementation (MOI)

Teledyne LeCroy supplies nine Method of Implementation documents, HFR1-1 through HFR1-9, to satisfy the requirements of the HDMI Generic Compliance Test Specification Version 2.1 (HDMI GCTS 2.1). These MOI define the set of tests performed to verify features described in the HDMI Specification Version 2.1, and the required equipment. The files are:

HFR1-<#>_TeledyneLeCroy_MOI_V1a for HDMI 2.1.pdf

HDMI Forum members can download the documents from https://members.hdmiforum.org/.

Calibrating the TF-HDMI-3.3V

For all channels using the TF-HDMI-3.3V termination adapter, calibrate out the TF-HDMI-3.3V offset on each lane to be tested prior to running the QualiPHY tests. As long as the test setup remains the same, this calibration should be good for all acquisitions made within the same software session.

1. With the signal attached, turn on the input channel to display a DC baseline trace.
2. Set the oscilloscope's MEAN voltage measurement on the input channel.
3. Insert the supplied adjustment tool into the Terminator Adjust port on the TF-HDMI-3.3V adapter and turn it until the measured MEAN is 3.3 V ±10 mV.

Recommended HDMI Hardware Configurations

Below are the recommended HDMI Source Test hardware configurations for Teledyne LeCroy oscilloscopes.

The Teledyne LeCroy solution uses SMA cables to connect two differential signals at one time to the oscilloscope channels through the TF-HDMI-3.3V pull-up termination adapter. SMA cables are also used to terminate the unused signal onto specific TERM inputs. See the description of each test configuration in the MOI for specific set up information.

Option 1: LabMaster MCM/SDA 10 Zi-A plus two LM 10-xxZi-A Acquisition Modules (80 GS/s on 8 channels)

This configuration requires only **one setup** to perform all FRL and TMDS tests on a 4-Lane DUT without any user intervention.

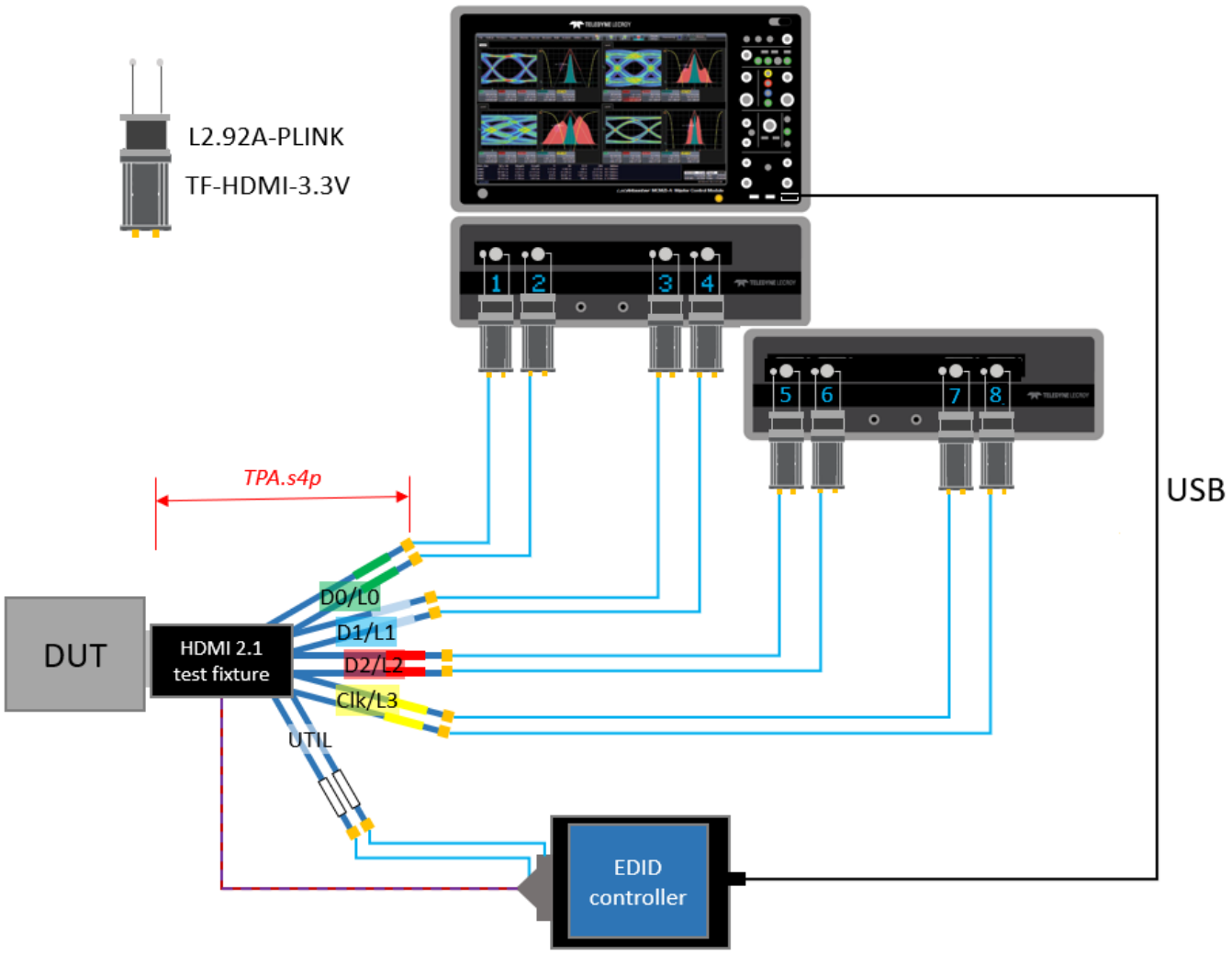


Figure 5: 8-channel LabMaster test configuration.

Option 2: WaveMaster 8000HD or LabMaster MCM/SDA 10-Zi-A

(80 GS/s on 4 channels)

This configuration requires **13 different setups** to perform all FRL and TMDS tests on a 4-Lane DUT. QualiPHY prompts the user with a pop-up dialog box between each setup.

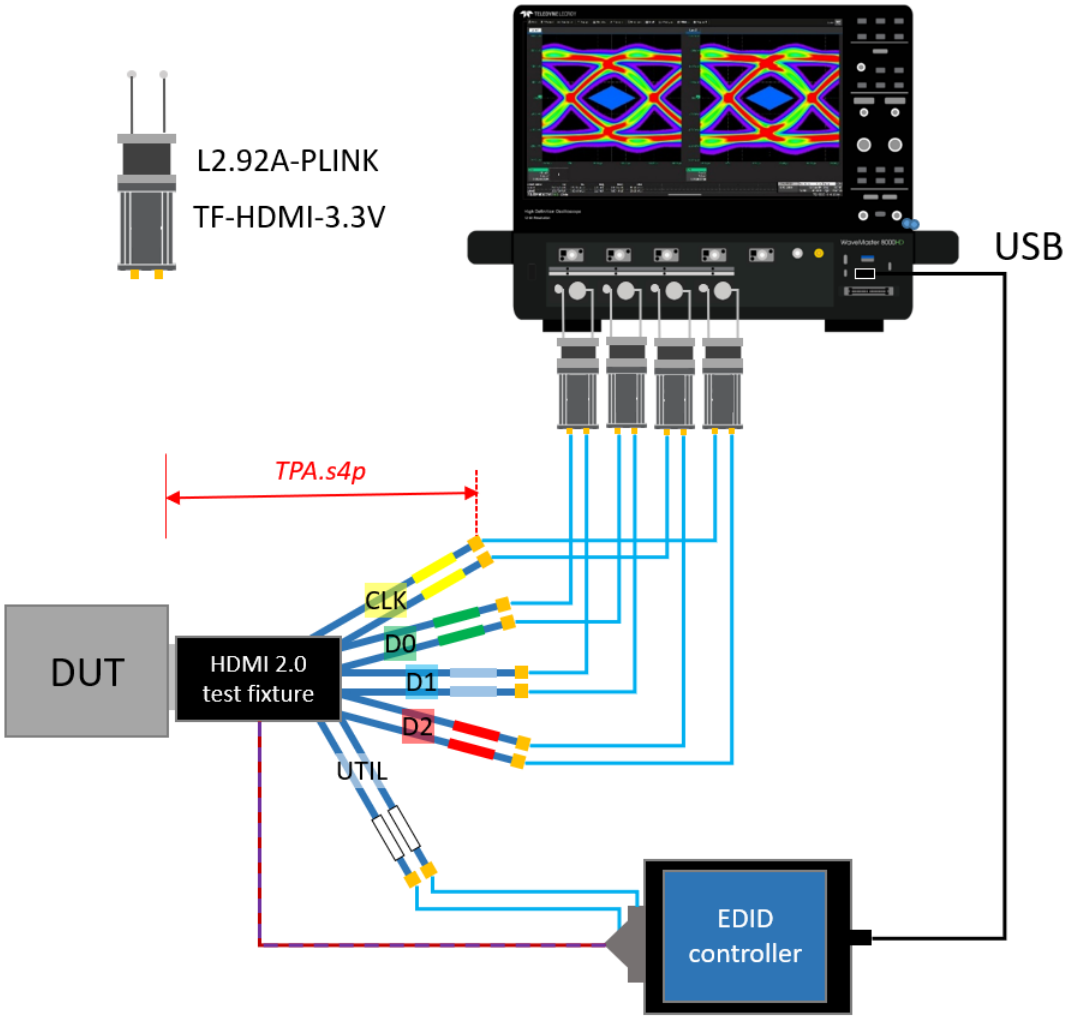


Figure 6: 4-channel LabMaster test configuration.

Option 3: WaveMaster/SDA 8xx Zi-B

(80 GS/s on 2 channels)

This configuration requires **17 different setups** to perform all FRL and TMDS tests on a 4-Lane DUT. QualiPHY prompts the user with a pop-up dialog box between each setup.

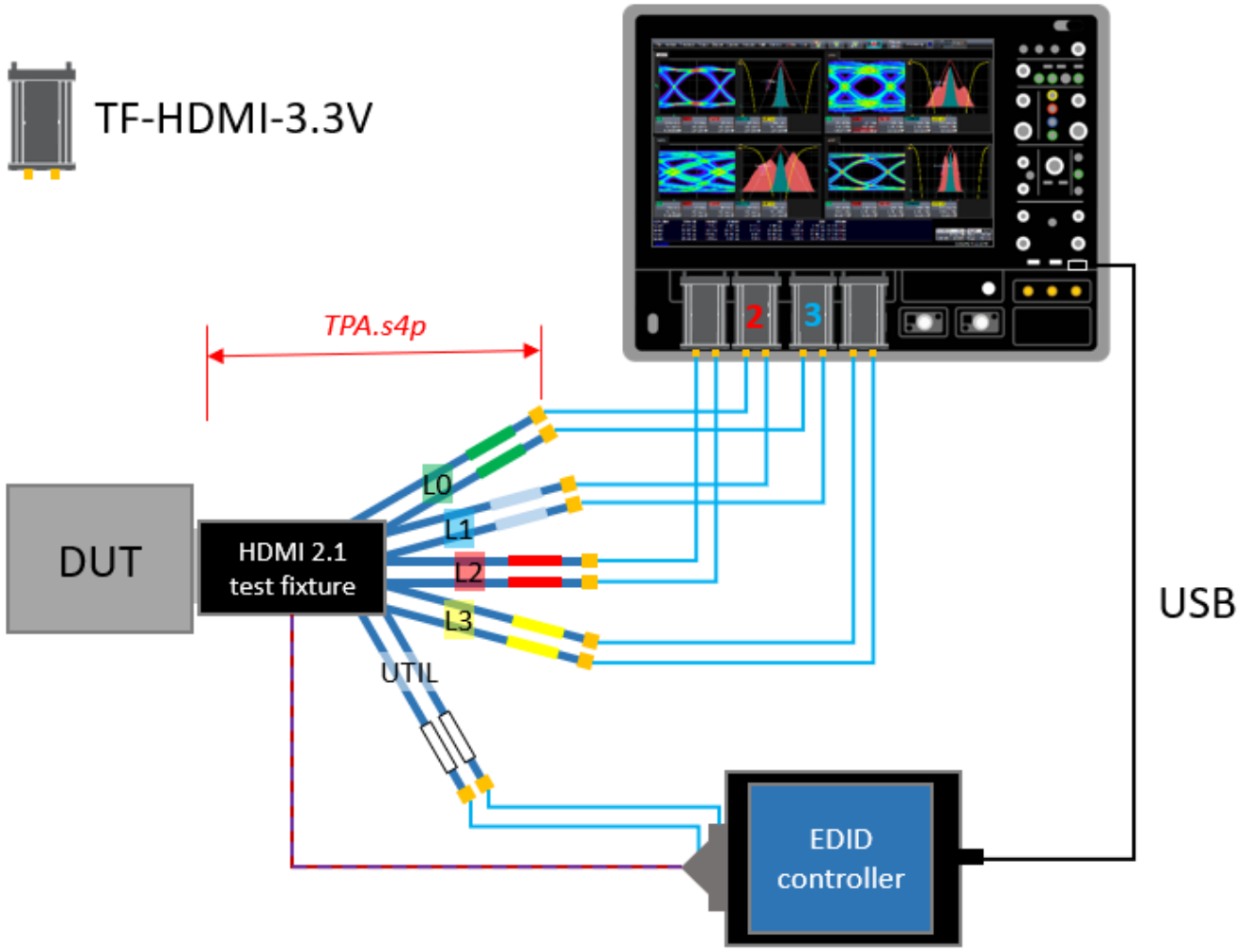


Figure 7: SDA/WaveMaster 8 Zi-B test configuration.

QPHY-HDMI2.1 Test Configurations

QualiPHY test configurations are predefined selections of tests and variable settings. All utilize the Default limit set. See QPHY-HDMI2.1 Test Variables for a description of each variable. See the QPHY-HDMI2.1 Limit Sets for more information about the default test limits.

Demo HDMI 2.1 FRL, All Lanes, Saved Waveforms

This configuration runs all the HDMI 2.1 FRL tests on all lanes using waveform files placed in the Saved Waveform Path folder, by default D:\Waveforms\HDMI21. You will see dialogs and connection diagrams similar to what you would see with a live acquisition.

Demo HDMI 2.1 TMDS, D0, Saved Waveforms

This configuration runs all the HDMI 2.1 TDMS tests on lane D0 using waveform files placed in the Saved Waveform Path folder, by default D:\Waveforms\HDMI21. You will see dialogs and connection diagrams similar to what you would see with a live acquisition.

Deskew Direct Connection

This configuration performs the deskew step only, using the "By Channel" deskew type. Use this either when deskewing only the oscilloscope inputs, or when the input cables are not "matched cables". Results are stored to file for later use.

Deskew Through Switch (TDMS Only)

This configuration performs the deskew step only, using the "By Lane" deskew type. Use this either when deskewing through a switch matrix, or when choosing not to de-embed the switch. Results are stored to file for later use.

HDMI 1.4, All Tests, Mini-Circuits Switch

This configuration runs all the HDMI 1.4 (TMDS) tests for a mini-circuits switch.

HDMI 1.4, D0 only

This configuration runs all the HDMI 1.4 (TMDS) single-lane tests on lane D0.

HDMI 2.1, All Tests, D0 Only

This configuration runs all TMDS and FRL tests on lane D0 using a direct connection to the TF-HDMI-3.3V termination adapter and automated Wilder sink emulation.

HDMI 2.1, FRL Tests, All Lanes

This configuration runs the FRL tests (only) on all lanes using a direct connection to the TF-HDMI-3.3V termination adapter and automated Wilder sink emulation.

HDMI 2.1, FRL Tests, Lanes D0 and D1

This configuration runs the FRL tests (only) on lanes D0 and D1 using a direct connection to the TF-HDMI-3.3V termination adapter and automated Wilder sink emulation.

HDMI 2.1, TMDS Tests, All Lanes

This configuration runs the TMDS tests (only) on all lanes using a direct connection to the TF-HDMI-3.3V termination adapter and automated Wilder sink emulation.

HDMI 2.1, TMDS Tests, Mini-Circuits Switch

This configuration runs all the HDMI 2.1 TMDS tests for a mini-circuits switch on all lanes.

HDMI 2.1, FRL Acquire Signal Library

This configuration runs all the HDMI 2.1 FRL tests except Inter-pair Skew on all lanes, first saving all waveforms, then making measurements on the saved waveforms. This allows you to disconnect the DUT after saving waveforms while the oscilloscope processes measurements.

QPHY-HDMI2.1 Tests

Deskew

This selection performs channel-channel deskew prior to testing. Deskew is performed "By Channel" if deskewing direct inputs to the oscilloscope (via the TF-HDMI-3.3V Termination Adaptor), or “By Lane” if using an RF Switch. Results are stored to file for later use.

Acquire Signal Library

If Acquire Signal Library is selected, all waveforms for all the selected tests are captured prior to making measurements on the waveforms. Otherwise, acquisitions are taken as each selected test is run. This selection allows you to disconnect the DUT and run other tests while the oscilloscope processes and reports measurements on the acquired signals.

HDMI 2.1 FRL Tests

These HDMI 2.1 tests are performed on FRL signals. All tests were introduced in the HDMI 2.1 GCTS.

HFR1-1 DC CM

HFR1-1 verifies the DC bias of each side of each Data Lane, measured at TP1 at 3 Gbps, 6 Gbps, 8 Gbps, 10 Gbps, and 12 Gbps.

Per [HDMI 2.1: Section 6.4.1.3] Table 6-20: DC Common Mode Voltage: FRL Lane 0, 1, 2, 3 must be between AVcc -800 mV to AVcc +30 mV.

HFR1-2 VSE Max Min

HFR1-2 verifies the single-ended max and min voltages, measured at TP1 on each active Data Lane at 3 Gbps, 6 Gbps, 8 Gbps, 10 Gbps, and 12 Gbps.

Per [HDMI 2.1: Section 6.4.1.3] Table 6-21: Single-Ended Voltage, FRL Lane 0, 1, 2, 3 must be between -375 mV and 375 mV from the DC Common Mode Voltage.

HFR1-3 Slew Rate

HFR1-3 evaluates the transition time for an FRL Transmitter for rising and falling edges. The transition time must be more than the specified minimum because of potential for radiated emissions from transmitters with fast edges and skew.

Per [HDMI 2.1: Section 6.4.1.3] Table 6-21: Rise/Fall Time, minimum (20% to 80%) rise/fall time must be > 22.5ps.

HFR1-4 Inter-pair Skew

HFR1-4 measures the difference in time between any two FRL Data lanes when measured at TP1 at 3 Gbps, 6 Gbps, 8 Gbps, 10 Gbps, and 12 Gbps.

Per [HDMI 2.1: Section 6.4.1.3] Table 6-21: Inter-Pair Skew Max, Data Lane 0, 1, 2, 3 skew must be < 4 T_{Bit}.

HFR1-5 FRL Rates

HFR1-5 measures the frequency or data rate accuracy to the nominal FRL data rates when measured at TP1 at 3 Gbps, 6 Gbps, 8 Gbps, 10 Gbps, and 12 Gbps.

Per [HDMI 2.1: Section 6.4.1.3] Table 6-21: Maximum Link Rate, variation must equal ±300 ppm.

HFR1-6 Random Jitter

HFR1-6 evaluates Random Jitter (RJ peak-to-peak and RJ RMS) of the FRL link with a clock pattern transmitted on the target channel. Random Jitter can be used in the Data eye diagram to compensate a 1E-10 BER mask to a 1E-6 BER mask. Measured at the highest and lowest data rates supported at TP2_EQ.

Per [HDMI 2.1: Section 6.4.1.3] Table 6-23: Peak to Peak Random Jitter, RJ for BER 1E-10 must be ≤ 0.2 T_{Bit}.

HFR1-7 Data Lane Eye Diagram

HFR1-7 evaluates the waveform parameters over a significant interval of time to verify that, with proper clock recovery, there is no signal incursion into regions defined by a mask to result in correct demodulation of data.

Per [HDMI 2.1: Section 6.4.1.1] Jitter and Eye Diagram Measurements; [HDMI 2.1: Section 6.4.1.2] Category 3 Reference Cable Equalizer, Figure 6-9 Reference CTLE Reference DFE for 12 Gbps compliance testing; and [HDMI 2.1: Section 6.4.1.3] FRL Mode Source characteristics; Sources shall meet the eye diagram requirements defined by Figure 6-11 and Table 6-24 across all operating conditions specified in H14b Table 4-22 when driving FRL data signals. The TP2_EQ eye diagram shall be measured as described in Sections 6.4.1.1 and 6.4.1.2.

HFR1-8 AC Common Mode Noise

HFR1-8 verifies that the AC common mode noise of a transmitter is limited to a percentage of the nominal DC differential swing to ensure that radiated emissions due to the common mode noise are limited. Measured at TP1 at 3 Gbps, 6 Gbps, 8 Gbps, 10 Gbps, and 12 Gbps.

Per [HDMI 2.1: Section 6.4.1.3] Table 6-21: AC Common Mode Noise, peak-to-peak noise must be < 150 mv.

HFR1-9 FFE Monotonicity

HFR1-9 verifies that HDMI2.1 sources that can link train to different FFE states, and that the parameters of FFE, pre-shoot amplitude and de-emphasis are monotonic from one FFE state to the next FFE state, which guarantees that if during link training more edge management is requested, more of the same will be given.

Per [HDMI 2.1: Section 6.4.1.5] Table 6-30, Sources that implement this feature shall implement an FFE with up to four settings. As TXFFE is increased from TXFFE0 to TXFFE3, Sources shall monotonically increase the pre-shoot amplitude and monotonically decrease the de-emphasis, as shown in Table 6-30.

HDMI 2.1 TMDS Tests

These HDMI 2.1 tests are performed on TMDS signals.

HF1-1 VL and Vswing

HF1-1 performs the VL and VSwing tests introduced in the section 7.1.1 of the HDMI 2.0b Generic CTS (v8) and carried over to the HDMI 2.1 GCTS. The tests are performed on the TMDS Data lanes selected by the user, as well as the Clock lane. After confirming that the bitrate is between 340 and 600 Mcpc, VL and VSwing are measured and compared to the limits defined in the Generic CTS.

VL is the mode of the voltage distribution observed during the last 2 bits of ‘HLLL’ sequences. Similarly, VH is the mode for ‘LHHH’ sequences. VSwing = VH-VL.

HF1-5 Differential Voltage

HF1-5 performs the Differential Voltage tests introduced in section 7.1.1 of the HDMI 2.0b Generic CTS (v8) and carried over to the HDMI 2.1 GCTS. The test is performed on the TMDS Data lanes selected by the user. After confirming that the bitrate is between 340 and 600 Mcpc, the minimum and maximum differential voltage is measured, and compared to the limits defined in the Generic CTS.

The minimum and maximum voltage of the waveform is measured using the Max and Min parameters. An eye diagram is also rendered.

HF1-2 Trise and Tfall

HF1-2 performs the Trise and Tfall tests introduced in section 7.1.1 of the HDMI 2.0b Generic CTS (v8) and carried over to the HDMI 2.1 GCTS. The tests are performed on the selected TMDS data and Clock lanes. After confirming that the bitrate is between 340 and 600 Mcpc, Trise and Tfall are measured and compared to the limits defined in the Generic CTS.

Rise and fall times are measured using the Rise@level and Fall@level parameters, between 20% and 80% of the VL and VH levels (see info for test HF1-1). The values used for Trise and Tfall are the modes of the distributions of Rise@level and Fall@level measurements, respectively.

HF1-4 Intra-pair Skew

HF1-4 performs the Intra-Pair skew tests introduced in section 7.1.1 of the HDMI 2.0b Generic CTS (v8) and carried over to the HDMI 2.1 GCTS. The test is performed on the TMDS Data lanes selected by the user, as well as the Clock lane. After confirming that the bitrate is between 340 and 600 Mcpc, the skew between the (+) and (-) lines of a TMDS signal is measured and compared to the limits defined in the Generic CTS.

Tskew is the mode of the distribution of at least 10,000 skew measurements between the rising edge of the (+) line and the corresponding falling edge on the (-) line of the differential pair under test, using 50% crossing levels.

HF1-8 Data Eye Diagram

HF1-8 performs the Data Eye Diagram Mask test introduced in section 7.1.1 of the HDMI 2.0b Generic CTS (v8) and carried over to the HDMI 2.1 GCTS. This test is performed only on the TMDS Data lanes. After confirming that the bitrate is between 340 and 600 Mcpc, an eye diagram is rendered, and compared to a mask. The eye diagram is shifted horizontally to find a position where there are no mask hits.

This test is performed after applying the 4-port Worst Cable Emulator and Reference Cable Equalizer using the VirtualProbe feature, with ports 1 & 3 of the Worst Cable Emulator first attached to the (+) line and 2 & 4 attached to the (-) line, and then with ports 1 & 3 of the Worst Cable Emulator first attached to the (-) line and 2&4 attached to the (+) line.

HF1-7 Clock Jitter

HF1-7 performs the Clock Jitter tests introduced in section 7.1.1 of the HDMI 2.0b Generic CTS (v8) and carried over to the HDMI 2.1 GCTS. This test is performed only on the TMDS Clock lane. After confirming that the bitrate is between 340 and 600 Mcpc, a persistence map showing the jitter on rising edges is formed, and a pk-pk jitter value is determined by finding the maximum extent of a 1mV horizontal slice centered at 0V. The value is compared to the limit of defined in the Generic CTS.

This test is performed after applying the 4-port Worst Cable Emulator and Reference Cable Equalizer using the VirtualProbe feature.

HF1-6 Clock Duty Cycle

HF1-6 performs the Clock Duty Cycle and Frequency tests introduced in section 7.1.1 of the HDMI 2.0b Generic CTS (v8) and carried over to the HDMI 2.1 GCTS. This test is performed only on the TMDS Clock lane. After confirming that the bitrate is between 340 and 600 Mcpc, the minimum and maximum duty cycle are measured for at least 1000 cycles, along with the clock frequency, and compared to the limits defined in the Generic CTS. The Duty@level parameter is used with the levels at 50%.

HF1-3 Inter-pair Skew

HF1-3 performs the Inter-Pair skew test introduced in section 7.1.1 of the HDMI 2.0b Generic CTS (v8) and carried over to the HDMI 2.1 GCTS. After confirming that the bitrate is between 340 and 600 Mcpc, the skew between selected pairs of Data lanes is measured during a sequence of unscrambled Control Period encoded characters, and compared to the limits defined in the Generic CTS.

Tskew is the mean of the skew measurements taken for a set of ‘1010’ sequences found in the control period.

HDMI 1.4 Tests

These HDMI 1.4 tests are performed on TMDS signals. They may be selected for testing backward compatibility to the HDMI 1.4 standard.

Test 7-2: VL

This test confirms that DC voltage levels on the HDMI link are within specified limits for each TMDS signal.

Requirement

For single-ended, low level output voltage, VL:

- If attached Sink supports only ≤ 165 MHz: (AVcc – 600 mV) ≤ VL ≤ (AVcc – 400 mV)
- If attached Sink supports > 165 MHz: (AVcc – 700 mV) ≤ VL ≤ (AVcc – 400 mV)

Reference: [HDMI: Table 4-15] Source DC Characteristics at TP1

Methodology

1. Connect TPA-P adapter to Source DUT HDMI output connector.
2. Connect TF-HDMI-3.3V to TMDS_DATA0+.
3. Configure the EDID to indicate only 27 MHz formats (480 p and 576 p, no Deep Color support) with the 640 x 480 p Established Timings bit set.
4. Control the Source DUT to output a video format with lowest supported TMDS clock frequency (typically 27 MHz).
5. Capture 1000 or more repetitions, triggered at the vertical mid-point of the High-to-Low transition of an H-L-L-L bit sequence. Each capture must be of duration 3*TBIT.
6. Display the voltage (vertical) histogram on the scope, with the histogram data accumulated only from the last 2-bits of the H-L-L-L sequence.
7. Read the VL value as the most common low-level voltage shown on the histogram.
8. If (VL > 2.90 V) OR (VL < 2.70 V), then capture 10,000 repetitions, triggered at mid-point of waveform, of duration ≥ 2*TBIT to get proper histograms.
9. Display the voltage (vertical) histogram on the scope. If (VL > 2.90 V) OR (VL < 2.70 V), then FAIL
10. Repeat the test for all eight TMDS signals.
11. If CDF field Source_Above_165 , then switch to an EDID that additionally indicates:
    a. Support for 1080 p 50 Hz and 60 Hz
    b. Deep Color 36-bits/pixel
    c. Max_TMDS_Clock of 225 MHz (value = 225/5 = 45)
12. Repeat test sequence above still using lowest clock rate format. If (VL > 2.90 V) OR (VL < 2.60 V), then FAIL.
13. Repeat the test for all eight TMDS signals.

Test 7-4: TRise, TFall

This test confirms that the rise times and fall times on the TMDS differential signals fall within the limits of the specification.

Requirement

75 ps ≤ Rise Time or Fall Time

Reference: [HDMI: Table 4-16] Source AC Characteristics at TP1

Methodology

1. Connect TPA-P adapter to Source DUT HDMI output connector.
2. Configure Source DUT to output a video format and pixel size with highest supported TMDS clock frequency.
3. Accumulate at least 10,000 triggered waveforms.
4. Measure TRISE as the mode of the sampled edge times from 20% to 80% of the differential swing voltage rising edge. If (TRISE < 75 ps) then FAIL.
5. Measure TFALL as the mode of the sampled edge times from 80% to 20% of the differential swing voltage on the falling edge.

   If (TFALL < 75 ps) then FAIL.
6. Repeat the test for all remaining TMDS clock and data pairs.

Test 7-7: Intra-Pair Skew

This test confirms that any skew within any one differential pair in the TMDS portion of the HDMI link does not exceed the limits in the specification.

Requirement

Intra-pair skew between TMDS DATA pairs must not exceed 0.15*TBIT.

Reference: [HDMI: Table 4-16] Source AC Characteristics at TP1

Methodology

1. Connect TPA-P adapter to the Source DUT HDMI output connector.
2. Connect the first TF-HDMI-3.3V to TMDS_DATA0+.
3. Connect the second TF-HDMI-3.3V to TMDS_DATA0-.
4. Configure Source DUT to output a video format and pixel size with highest supported TMDS clock frequency.
5. Set the trigger on TMDS_DATA0+ rising edge.
6. Display the waveform of TMDS_DATA0+ and DATA0-. Accumulate 10,000 or more triggers.
7. Find the closest falling edge of DATA0- (either preceding or following DATA0+ rising edge) and determine the most common 50% crossing point of that TMDS_DATA0- falling edge using a horizontal (time) Histogram method.
8. Measure skew from trigger point to most common 50% crossing point of TMDS_DATA0-. If (skew > 0.15*TBIT) then FAIL.
9. Repeat the test for all remaining TMDS differential pairs.

Test 7-10: Data Eye Diagram

This test confirms that the differential signal on each TMDS differential data pair has an “eye opening” (region of valid data) that meets or exceeds the limits on eye opening in the specification.

Requirement

Refer to the “Eye Diagram Mask at TP1 for Source Requirements.

Reference: [HDMI: Figure 4-18] Eye Diagram Mask at TP1

Methodology

1. Connect TPA-P-TDR to Source DUT HDMI output connector.
2. Connect the first TF-HDMI-3.3V to TMDS Clock and configure as trigger.
3. Connect the second TF-HDMI-3.3V to TMDS_DATA0.
4. Connect 50 Ohm pull-ups to each of the non-probed TMDS lines to 3.3 V.
5. Configure Source DUT to output one video format for the first of the following TMDS clock frequencies supported: 27 MHz (or 25 MHz), 74.25 MHz, 148.5 MHz, or 222.75 MHz.
6. Capture the waveforms on the oscilloscope. Process with the CRU to display the data eye diagram.
7. Set memory length to 16 M samples per-channel.
    a. If test frequency is ≤165 MHz then set Sampling Rate ≥10 GS/s.
    b. If test frequency is > 165 MHz then set Sampling Rate ≥ 20 GS/s.
8. Compare the data eye to the TP1 Eye Diagram Mask. If any part of the waveform exceeds either the high or low maximum voltage (± 780 mV), then FAIL.
9. Shift the mask left or right through one entire TBIT to determine if any horizontal position has no capture points within eye mask. No vertical shifting is allowed. If no shifted position exists where no part of the waveform touches or crosses into the data eye, then FAIL.
10. Measure the data jitter at the zero crossing point. Measurement box vertical setting: 0 V ± 5 mV. If data jitter > 0.3*TBIT, then FAIL.
11. Repeat Steps 5 through 9 for the remaining supported TMDS clock frequencies, plus the highest DUT-supported frequency (if not already covered). Only one video format/pixel-size combination is required per TMDS clock rate.
12. Repeat the test for remaining TMDS_DATA pairs.

Test 7-9: Clock Jitter

This test confirms that the TMDS Clock does not carry excessive jitter.

Requirement

TMDS differential clock jitter must not exceed 0.25*TBIT, relative to the ideal Recovery Clock.

Reference: [HDMI: Table 4-16] Source AC Characteristics at TP1

Test Methodology

1. Connect TPA-P adapter to the Source DUT HDMI output connector.
2. Connect two TF-HDMI-3.3V test fixtures to each line of the TMDS Clock pair.
3. Configure oscilloscope and CRU: evaluate 16 M samples per channel (can be acquired with a single or with multiple smaller captures).
4. Configure Source DUT to output one video format for the first of the following TMDS Clock frequencies supported: 27 MHz (or 25 MHz), 74.25 MHz, 148.5 MHz, or 222.75 MHz..
5. Perform the following:
    a. Capture the waveform and process it with the oscilloscope.
    b. If test frequency is ≤ 165 MHz, then set Sampling Rate ≥ 10 GS/s.

       If test frequency is >165 MHz, then set Sampling Rate ≥ 20 GS/s.
    c. Measure Clock jitter as difference between farthest left sampling point and farthest right sampling point, at Vertical setting = VC = 0 V ± 20 mV. If Clock jitter exceeds 0.25*TBIT then FAIL.
6. Repeat Steps 4 and 5 for remaining supported test frequencies. Only one video format/pixel-size combination is required per TMDS clock rate.

Test 7-8: Clock Duty Cycle

This test confirms that the duty cycle of the differential TMDS clock does not exceed the limits allowed by the specification.

Requirement

Clock duty cycle must be at least 40% and not more than 60%.

Reference: [HDMI: Table 4-16] Source AC Characteristics at TP1

Methodology

1. Connect TPA-P adapter to Source DUT HDMI output connector.
2. Configure Source DUT to output a video format and pixel size with highest supported TMDS clock frequency.
3. Connect TF-HDMI-3.3V to TMDS Clock.
4. Display the waveform of 1 clock period.
5. Configure the oscilloscope as follows: trigger source is the TMDS Clock rising edge, turn on infinite persistence, measurement is duty cycle, capture at least 10,000 or more triggers.
6. Measure minimum duty cycle as earliest crossing of TMDS_CLOCK falling edge.
   If (TDUTY(MIN) < 40%, then FAIL.
7. Measure maximum duty cycle as latest crossing of TMDS_CLOCK falling edge.)
   If (TDUTY(MAX) > 60%, then FAIL.

Test 7-6: Inter-Pair Skew

This test confirms that that any skew between the differential pairs in the TMDS portion of the HDMI link does not exceed the limits in the specification.

Requirement

Inter-pair skew must not exceed 0.20*TPIXEL.

Reference: [HDMI: Table 4-16] Source AC Characteristics at TP1

Methodology

1. Connect TPA-P adapter to Source DUT HDMI output connector.
2. Connect the first TF-HDMI-3.3V to TMDS_DATA0.
3. Connect the second TF-HDMI-3.3V to TMDS_DATA1.
4. Configure Source DUT to output an HDMI signal with a video format and pixel size with highest supported TMDS clock frequency.
5. Capture (trigger) or find a sequence of Control Period encoded characters. Either 10-bit or 20-bit trigger may be used.
6. Measure TIPSKEW:

For 10-bit Trigger	For 20-bit Trigger
Find the first bit of the TMDS character on the two TMDS channels. The CTL encoding pattern 1101010100 corresponds to: TMDS_DATA0: HSYNC=1, VSYNC=0 TMDS_DATA1: CTL0=1, CTL1=0 (any Preamble) TMDS_DATA2: CTL2=1, CTL3=0 (Data Island Preamble) If it is difficult to capture using the above patterns, then any of the following (Control Period) patterns may be used: 0010101011 1101010100 0010101010 1101010101 Examine second channel for any valid CTL code and measure TIPSKEW between channels.	Find the first bit of the following 20-bit sequence on the TMDS channels. For Channel 0: 0010101011 0011001101 For Channel 0: 0010101010 0011001101 For Channel 0: 1101010101 0011001101 For Channel 1: 0010101010 1100110010 For Channel 2: 0010101011 0011001101 Examine second channel for the appropriate sequence and measure TIPSKEW between channels.

   If TSKEW > 0.2*TCHARACTER then FAIL.

7. Repeat the test for remaining combinations of TMDS_DATAx pairs.

QPHY-HDMI2.1 Test Variables

Basic Variables

Channel Bandwidth
Channel Bandwidth limit to be used while performing the tests.

Typically set to 13 GHz fpr HDMI 2.1 TDMS testing. See the channel dialog's Bandwidth selector for allowed values (including 'Full').

Save individual runs?
When Yes, a new subfolder containing waveform files will be created in the Saved Waveform Path after each new acquisition.

Saved Waveform Path
Path to root folder used to save and recall waveforms. Default is D:\Waveforms\HDMI.

Pause after tests to review results?
Enables/disables a pause after each test to allow you to review results on the oscilloscope display. You will be prompted to continue when ready.

Run using saved waveforms?
When Yes, tests are run using previously saved waveform files stored in the Saved Waveform Path. Browse to and select the subfolder containing the files you wish to test.

De-embedding Setup Variables

De-embed TPA?
Select whether or not to de-embed the TPA-P using a 4-port S-parameter Touchstone file. De-embedding the TPA-P is not required by the HDMI compliance test specification.

Note: Prior to running the test, contact the manufacturer of your TPA-P to get the correct file and determine how the ports in the file map to the physical ports of the TPA-P.

Path to TPA-P Touchstone File
Enter the complete filepath and name of the touchstone file for the TPA-P if you are choosing to have it de-embedded.

Note: de-embedding is optional, and not specified by the HDMI compliance test specification.

De-embed switches?
Select “Yes” to de-embed any relays or switches that are in the signal path.

Note: The use of switches, or the de-embedding of switches if used, is not required by the HDMI compliance test specification.

TPA-P Touchstone File Port Mapping
Enter the order in which the port numbers in the touchstone file map to the TPA-P topology ABCD, where:

a. A goes through to B, and C goes through to D
b. A is the (+) line and B is the (-) line in to the TPA-P's HDMI connector
c. C is the (+) line and D is the (-) line out from the TPA-P's SMA cables

For example, the selection '1234' would indicate:

--- A=1, B=2, C=3, D=4
--- Port 1 goes through to Port 2, and Port 3 goes through to Port 4
--- Ports 1 and 3 are the (+) and (-) lines into the HDMI connector
--- Ports 2 and 4 are the corresponding outputs for one differential pair, such as D0

Path to Switch De-embedding S2P Files
Enter the path to the .S2P files to be used when de-embedding a switch matrix.

Delay Through Switch (ns)
If de-embedding a switch, enter the nominal delay in ns. This value is used by the HF1-3 Inter-pair Skew test to optimize the alignment.

Delay Through TPA (ns)
If de-embedding a TPA, enter the delay though the TPA in ns. This value is used by the HF1-3 Inter-pair Skew test to optimize the alignment.

Host Program Control Variables

Host Program Control Sync File
Enter the full path to the Sync file that will be used for HPC when "Use Host Program Control?" is “Yes”.

See Appendix B: Host Program Control Mode in the *QPHY-HDMI2.1 Instruction Manual* for more information.

Use Host Program Control?
Choose “Yes” to enable Host Program Control using Sync file.

See Appendix B: Host Program Control Mode in the *QPHY-HDMI2.1 Instruction Manual* for more information.

Vertical Settings Variables

Use Autoscale?
Select "No" to override the default automatic vertical scaling. If you choose to override, enter the “Fixed Vertical Scale” and “Fixed Offset” values.

Fixed Vertical Scale
Enter a fixed vertical scale (in volts per division) to use when "Use Autoscale?" is set to "No".

Fixed Offset
Enter a fixed offset (in volts) to use when "Use Autoscale?" is set to "No".

Deskew Variables

Deskew Type
Select a deskew type.

By Lane: choose this when using a switch matrix that you do not wish to de-embed using S-parameters, but instead wish to set the deskew reference plane at the inputs to the switch matrix or the output of the TPA-P.

By Channel: choose this when not using a switch matrix, when not wanting to deskew the switch delay, or when using S-parameters to de-embed the switch matrix.

Use saved deskew values?
Select “Yes” to re-use deskew values saved in the file D:\HDMI\SkewCal\SkewCal.cal. This is recommended when you are not performing the manual Deskew test step.

Automated Sink Emulation

FRL Sink Emulation
Choose to automate EDID emulator to be used, or to be prompted to manually control settings. Currently the Wilder EDID emulator is the only one supported.

TMDS Sink Emulation
Choose to automate the EDID emulator settings, or to be prompted to manually control settings.

EDID File for Highest Character Rate
Enter the path to the EDID file for highest character rate when using theEDID Emulator for Sink emulation for HDMI 2.1 TMDS data rates.

EDID File for 594 Mcps
Enter the path to the EDID file for 594 Mcps or the highest supported character rate when using the EDID Emulator for Sink emulation for HDMI 2.1 TMDS data rates.

EDID File for Lowest Character Rate
Enter the path to the EDID file for lowest character rate when using Wilder EDID Emulator for Sink emulation for HDMI 2.1 TMDS data rates.

Pause after signal update?
Choose “Yes” to pause tests after EDID Sink emulator commands are sent to check that the compliance pattern is configured appropriately.

HPD Voltage Level
Select the HPD voltage level to be used by the EDID emulator for setting test patterns.

Source FRL Electrical Tests

(+) Signal Channel
Enter the oscilloscope channel used to input the positive side of the differential pair when performing tests on a single lane.

(-) Signal Channel
Enter the oscilloscope channel used to input the negative side of the differential pair when performing tests on a single lane.

FRL Data Lanes for Inter-pair Skew Test
Select the pair of Data lanes used for the HFR1-4 Inter-pair Skew test.

FRL Data Lanes to Test
Select the lanes under test for FRL data rates.

If test data rate is 3G and four lanes are selected, only D0, D1 and D2 are tested.

If test data rate is 6G, all four lanes are tested unless you make a 3-lane selection.

Note: This variable is not used by HFR1-4 Inter-pair Skew test.

FRL Maximum Supported FFE Setting
Enter the maximum FFE setting supported by the Source under test.

Maximum Supported FRL Rate
Select the maximum supported FRL data rate for the Source under test.

Minimum Supported FRL Rate
Select the minimum supported FRL data rate of the Source under test.

Run on two lanes simultaneously?
Select to enable simultaneous acquisition on two lanes for FRL Data Rate tests.

Data Termination Voltage
Enter the Termination Voltage (AVcc) of the device in volts.

Note: This value is used for calculating test result for FRL DC common mode noise measurement.

Use one channel pair?

Select to use one channel pair for all lanes when using a LabMaster oscilloscope.

Note: Channel pair in use is specified with the “(+) Signal Channel” and “(-) Signal Channel” variables.

HFR1-6 & HFR1-7 Data Eye Diagram Variables

FRL Cable Model
Select the cable model to use for the TP2EQ measurement. WCM3 is worst-case cable model. SCM3 is short cable model.

Source TMDS Electrical 6G Test Variables

Connection Control
Choose the method for connecting signals to the oscilloscope:

Manual: User will be prompted to connect signals to the oscilloscope as necessary.

Mini-Circuits Switches: QualiPHY will control two Mini-Circuits RF switch boxes to route the appropriate signals from the TPA-P to the oscilloscope.

Note: The switch boxes should be connected via USB to the computer running QualiPHY, typically the oscilloscope.

Host Program Control: QualiPHY will use the HPC Sync file to control when input connections are changed. If you select this, be sure to enter the Host Program Control variables.

Data Lanes for Inter-pair Skew Test
Select the pair of Data lanes to test for the Inter-pair Skew test (HF1-3 and 7-6).

Note: When using a switch, D2-D1 is calculated from D2-D0 and D1-D0.

Data Lanes for TMDS Tests
Select the TMDS Data lanes to test.

Note: The CLK lane is always tested along with the selected Data lanes, as required.

HDMI 1.4 Test Variables

DUT TMDS Clock Standard Frequencies
Enter the DUT TMDS Clock standard frequencies to use: 27 MHz (or 25 MHz), 74.25 MHz, 148.5 MHz or 222.75 MHz.

If the highest DUT-supported frequency is not listed, choose “alternate frequency” and define a custom list of frequencies using the "Custom Frequency List" variable.

Custom Frequency List
Enter the list of clock frequencies to use for tests 7-9 and 7-10. Only include frequencies in the following list: 25, 27, 74.25, 148.5 and 222.75.

Test 7-2: VL Variables

Is Source above 165 MHz?
Select “Yes” if the CDF field for the Source is above 165 MHz; else “No”.

QPHY-HDMI2.1 Limit Sets

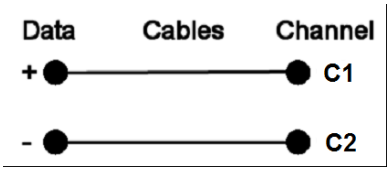
The default installation of QPHY-HDMI2.1 contains only one limit set, called “Default.” In this script, limits are only used to convey Unit labels. The actual limits for each value tested are encoded in or computed by the script and cannot be changed. The default limits used by QPHY-HDMI2.1 are specified in version 2.1 of the High Definition Multimedia Interface Compliance Test Specification (HDMI).

Appendix A: Manual Deskewing Procedure

The following procedure demonstrates how to manually deskew two oscilloscope channels and cables using the differential data signal, without the need for any additional T-connector or adapters.

This can be done once the temperature of the oscilloscope is stable. The oscilloscope must be warmed up for at least a half-hour before proceeding. This procedure should be run again if the temperature of the oscilloscope changes by more than a few degrees.

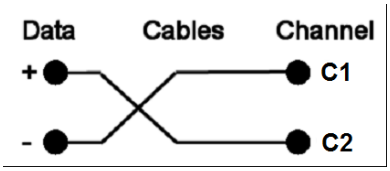
1. Connect a differential data signal to C1 and C2 using two approximately matching cables. Set up the oscilloscope to use the maximum sample rate. Set the timebase for a few repetitions of the pattern (at least a few dozen edges).



2. On the C2 menu, check **Invert**. Now C1 and C2 should look the same.

3. Using the **Measure Setup**, set P1 to measure the Skew of C1, C2. Turn on **Statistics** (**Measure** menu). Write down the mean skew value after it stabilizes. This mean skew value is the addition of Data skew + cable skew + channel skew.

4. Swap the cable connections on the Data source side (on the test fixture), and then press the **Clear Sweeps** button on the oscilloscope (to clear the accumulated statistics; since we changed the input).



5. Write down the mean skew value after it stabilizes. This mean skew value is the addition of (-Data skew) + cable skew + channel skew.

6. Add the two mean skew values and divide the sum in half:

$$\frac{[\text{cable skew} + \text{channel skew}]}{2}$$

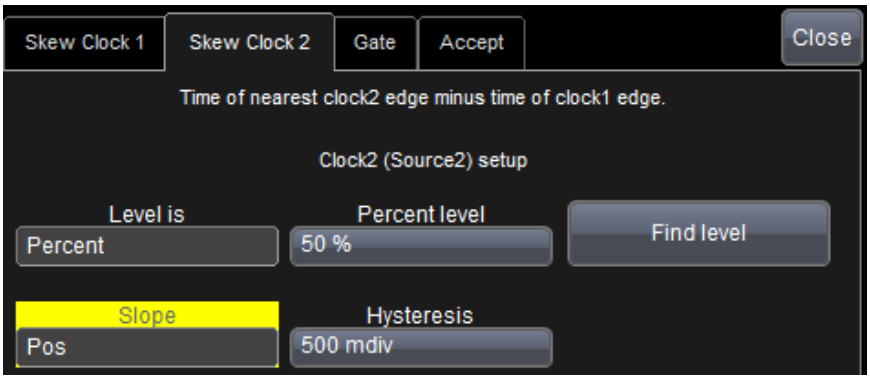
7. Set the resulting value as the Deskew value in C1 menu.

8. Restore the cable connections to their Step 1 settings (previous). Press the **Clear Sweeps** button on the oscilloscope. The mean skew value should be approximately zero - that is the data skew. Typically, results are <1 ps given a test fixture meant to minimize skew on the differential pair.

9. On the C2 menu, clear the **Invert** checkbox and turn off the parameters.

In the previous procedure, we used the default setup of the Skew parameter (which is detecting positive edges on both signals at 50%). We also inverted C2 in order to make C1 and C2 both have positive edges at the same time.

Alternately, we clearly could have not inverted C2 and instead selected the Skew Clock 2 tab in the P1 parameter menu and set the oscilloscope to look for negative edges on the second input (C2). However, we believe that the previous approach is more aesthetically pleasing on the display, as it shows C1 and C2 with the same polarity.



Appendix B: Using Host Program Control Mode

Host Program Control (HPC) mode is a new feature that allows QualiPHY to be started by a user's host program with a number of arguments. Once running, a simple "Sync File" protocol is used by QualiPHY to signal the host program.

When the QualiPHY script requires action from the host program, it writes a User Sync File to the disk in .xml format containing several tags. QualiPHY then pauses execution and waits. The host program should set the requested DUT parameters or test system configuration, respond as necessary, then delete the User Sync File. When QualiPHY sees that the User Sync File is deleted, it continues execution.

In a QPHY-HDMI2.1 script, there are three situations when a Sync File is written out:

1. When the user host program needs to change which signals are connected to the oscilloscope (typically utilized in systems involving an RF switch)
2. When the user host program needs to change the signal type output from the DUT (e.g., the signal's character rate)
3. When an error condition has occurred

In order to use Host Program Control Mode, the following considerations should be taken into account.

Preparing Special Configuration for Host Program Control Mode

In QualiPHY, create a custom Configuration that has the variables configured in the way you will need them when you run in Host Program Control Mode. Make sure you save the configuration after editing the variables so that it will be available to refer to when you startup QualiPHY via command line.

Variables that need to be considered to run in HPC are:

- Host Program Control Sync File
  - Definition: Use to specify sync file path.
  - Default: C:\HDMI*nn*_sync_file.xml
  - Comments: Just use default unless conflict.
- Use Host Program Control?
  - Definition: Set to "Yes" to use the Host Program Control feature, "No" otherwise.
  - Default: No
  - Comment: When set to "Yes", QualiPHY will pause execution after it creates a sync file and while it is waiting for the sync file to be deleted.

Host Program Elements Needed to Control the QualiPHY Script

Launching QualiPHY (XReplay.exe)

The Host program needs to launch the QualiPHY application (the actual program is named XReplay.exe) with the following command, including arguments for HDMI21:

```
def main():
    SyncFilePath = r'D:\QPHY\HDMI21_sync_file.xml'
    args_list = [r'C:\Program Files (x86)\LeCroy\XReplay\XReplay.exe', r'-A', r'-R', r'-E', r'-WIZARD', r'-TECH:tecHDMI\HDMI21', r'-CONFIG:HostProgramControlTests', r'-N:IP address']
```

The path shown above is where the XReplay.exe program (QualiPHY) is placed by the installer.

Arguments are:

`-A`	Stops all manual user interaction. (Always use)
`-R`	Causes the test script (HDMI*nn* in this case) to be run automatically. (Always use)
`-E`	Automatically exit when test script is done executing. (Always use)
`-WIZARD`	Required.
`-TECH:tecHDMI\HDMI21`	Sets the technology to test, HDMI21
`-CONFIG:HostProgramControlTests`	Sets the name of the configuration that will be used; HostProgramControlTests.
`-N:`*`IP Address`*	IP address of the oscilloscope: If QualiPHY is running on the oscilloscope, set to localhost *127.0.0.1*. If QualiPHY is not running on the oscilloscope, set to *Host ID* or *IP Address* of the oscilloscope.

Monitoring for QualiPHY Termination

The host program needs to continuously test to see if the QualiPHY process still exists, to be able to know when the QualiPHY test script has completed and take appropriate action.

File Transfer Synchronization

The host synchronization consists of three parts:

1. Waiting for C:\HDMI21_sync_file.xml (or other name specified in configuration) to be written by QualiPHY.
2. Reading the file and performing the required actions.
3. Deleting C:\ HDMI21_sync_file.xml in order to signal QualiPHY that the operation is complete.

Renaming the Test Report

The test report that is created by the QualiPHY test script is always created with the same name (for example, D:\QPHY\Reports\LeCroyReport.pdf). For this reason, it needs to be renamed after QualiPHY (XReplay.exe) terminates in order to avoid overwriting it the next time QualiPHY is run.

Note: The report path is C:\LeCroy\QPHY\Reports if QualiPHY is installed on a remote PC instead of the oscilloscope.

Sample Host Program

This sample Python host program performs all the essential tasks involved in launching and synchronizing with the QPHY-HDMI21 test script. It is shown below and referred to in the text following it.

```
import time
import os
import shutil
import subprocess
import xml.etree.ElementTree as ET
import ctypes

def mbox(title, text, style = 0):
    '''
    message box with ok
    '''
    return ctypes.windll.user32.MessageBoxA(0, text, title, style)

def main():
    SyncFilePath = r'D:\QPHY\HDMI21_sync_file.xml'
    args_list = [r'C:\Program Files (x86)\LeCroy\XReplay\XReplay.exe', r'-A',
r'-R', r'-E', r'-WIZARD', r'-TECH:tecHDMI\HDMI21', r'-
CONFIG:HostProgramControlTests', r'-N:127.0.0.1']
    process =
subprocess.Popen(args_list,stdout=subprocess.PIPE,stderr=subprocess.PIPE,
shell=True)
    time.sleep(1)
    while process.poll() is None:
        time.sleep(1)
        if os.path.isfile(SyncFilePath) == True:
            file = open(SyncFilePath, 'r')
            xmlstring = file.read()
            file.close()
            root = ET.fromstring(xmlstring)
            #print XML tags
            print('Check XML tags')
            for child in root:
                print((child.tag))
            #print tag if text exists
            print('Check XML text')
            for child in root:
                if child.text != None:
                    print((child.text))
            #send prompt if connectionsReq has text
            print('Pause if connection change required')
```

```
            for child in root:
                if child.tag == 'connectionsReq':
                    if child.text != None:
                        mbox('Pause for Connections', child.text)
                    else:
                        print('No Connections required')
            #send prompt if error detected
            print('Pause if error detected')
            for child in root:
                if child.tag == 'error':
                    if child.text != None and child.text!= '0':
                        mbox('Error!!', child.text)
            ###other actions based on XML may be performed here###
            try:
                os.remove(SyncFilePath)
            except:
                pass
    args_list_report = [r'C:\Program Files
(x86)\LeCroy\XReplay\XReplay.exe',r'-D',r'-WIZARD']
    process =
subprocess.Popen(args_list_report,stdout=subprocess.PIPE,stderr=subprocess.PIP
E, shell=True)
    time.sleep(1)
    print('Generating Report...')
    while process.poll() is None:
        time.sleep(3)
    # Check for report and rename if present
    ReportPathSource = r'D:\Qphy\Reports\LeCroyReport_Auto.pdf'
    ReportPathDest = r'D:\Qphy\Reports\HDMI21_Test_Results.pdf'
    if os.path.isfile(ReportPathSource) == True:
        try:
            shutil.move(ReportPathSource, ReportPathDest)
        except:
            print('Error renaming report')
    else:
        print('File not found')
    done = "Host Program Control python example script complete"
    return done
end = main()
print(end)
```

HPC Sync File

Sync File Tags

The Host Program Control synchronization file includes the following tags:

- **connectionsReq**: describes the connections that should be made.
  - When instructed to, connect bert output channels to the oscilloscope input channels.
  - Example: **"C1, C2, Data_Out1, Data_Out1-bar"**
- **error**: includes an error code. Refer to the "detail" field for information about the error.
- **detail**: gives additional information, especially in situations where the error code is 0, which would indicate an issue. Example: "No trigger: Trigger timed out. Is signal present and trigger set correctly?"

Sample XML Sync Files

Request to change the connections

```
<TestConfig>
<connectionsReq>D0,CLK</connectionsReq>
<detail>New connections:</detail>
<error>0</error>
</TestConfig>
```

Request to check error condition

```
<TestConfig>
<connectionsReq/>
<detail>No trigger: Trigger timed out. Is signal present and trigger set
correctly?</detail>
<error>3</error>
</TestConfig>
```

Appendix C: Switch Matrix Configuration

Follow this diagram when using Mini-Circuits Model RC-8SPDT-A18 switches to automatically connect TPA outputs to oscilloscope inputs. Note that this connection scheme allows lane D0 to be routed to C3/C4 for inter-pair skew tests or to C1/C2 for all other tests. Lanes D1 and D2 always are routed to C1/C2 and CLK to C3/C4:

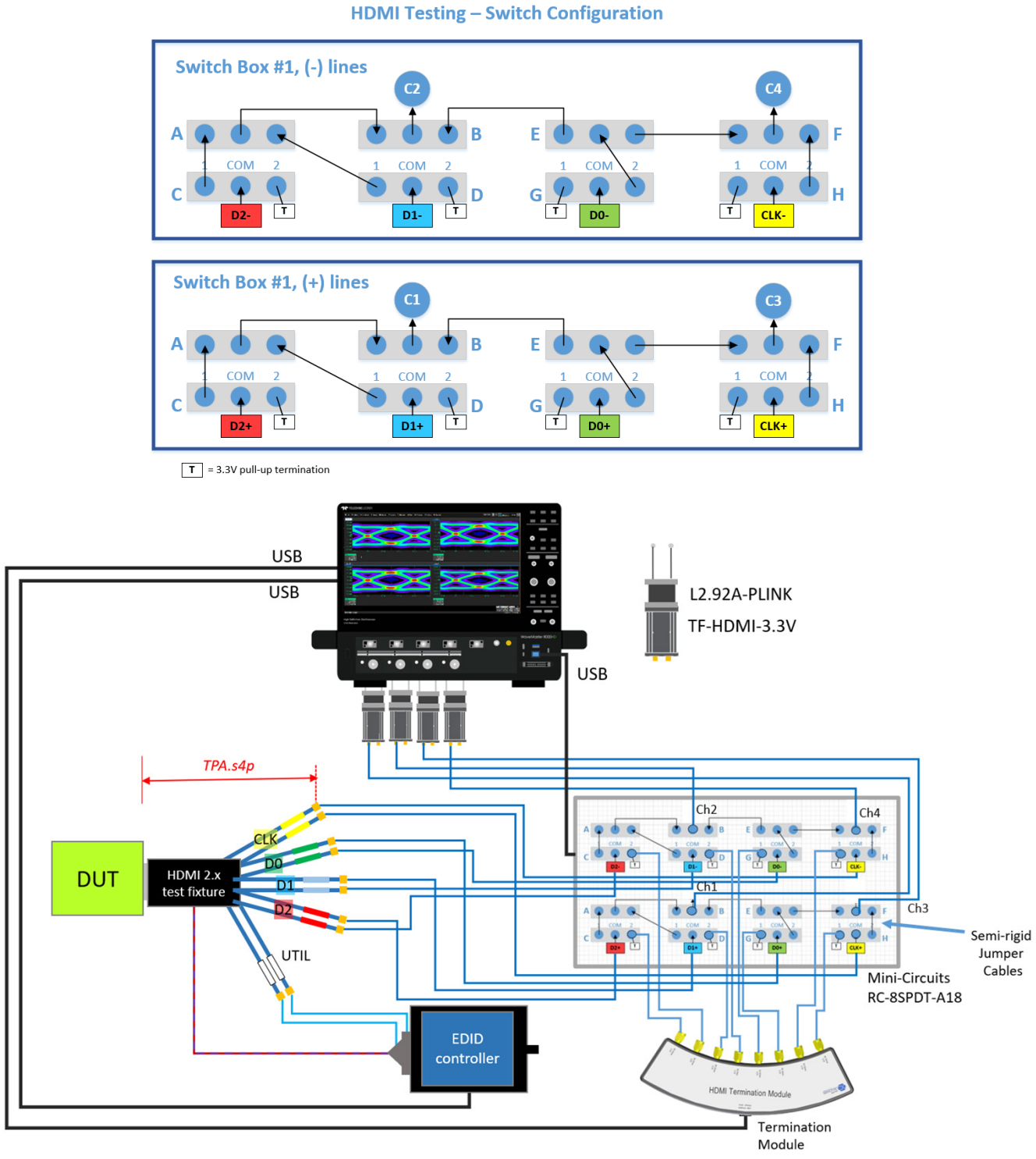


Figure 8: Mini-Circuits Switch Matrix Connections

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