HDMI Physical Layer Compliance Testing
Accelerate your compliance testing with automated test solutions

Introduction

High Definition Multimedia Interface (HDMI) is the digital video interface for consumer electronics applications. HDMI 2.1, developed by the HDMI Forum’s Technical Working Group, is backwards compatible with earlier versions of the HDMI specification and significantly increases transmission bandwidths up to 48 Gbps.

Since the transmission rate of HDMI 2.1 is double that of HDMI 2.0, interoperability issues due to signal quality distortions introduce new technical requirements for compliance testing of HDMI 2.1 sink and source devices.

Keysight’s certified HDMI 2.1 test solution covers all physical layer compliance tests, including source, cable, and sink.

This application brief provides an overview of HDMI 2.1, highlights the test challenges, and describes Keysight’s HDMI test solution, including the Infinium oscilloscope, the M8195A AXIe arbitrary waveform generator (AWG), N5399E HDMI electrical performance validation and compliance software, N5990A test automation software (“ValiFrame”) for HDMI compliance, and test fixtures.

What’s new in HDMI 2.1:
- 8K60Hz and 4K120Hz support
- 10K resolutions
- Dynamic HDR
- Bandwidth increases to 48 Gbps
- Ultra-high-speed HDMI cable support
- eARC simplifies audio connectivity and improves audio performance
- Enhanced refresh rate ensures smooth and seamless motion and transitions
Application Overview

The data rates needed to serve next-generation displays and video formats exceed the capability of most of today’s HDMI chipsets. The new HDMI 2.1 specification significantly increases bandwidth and adds enhancements to support new and future market needs. New features include:

- Up to 8K @ 60Hz and 4K @ 120Hz video format supported for immersive viewing and smooth fast-action detail
- Resolutions to 10K supported for commercial AV and industrial and specialty usages
- Dynamic HDR (High Dynamic Range) support ensures every moment of a video is displayed at its ideal values for depth, detail, brightness, contrast, and wider color gamuts, on a scene-by-scene, or even a frame-by-frame basis
- Ultra-high-speed HDMI cable supports the 48 Gbps bandwidth for uncompressed HDMI 2.1 feature. Low EMI emission and backward compatible with existing HDMI devices
- Enhanced Audio Return Channel (eARC) simplifies connectivity and supports the most advanced audio formats and highest audio quality
- Enhanced refresh rate features ensure an added level of smooth and seamless motion and transitions for gaming, movies and videos. These features include:
  - Variable Refresh Rate (VRR), which reduces lag, stutter and frame tearing
  - Quick Media Switching (QMS) for movies and videos, to eliminate delay in blank screen before content is displayed
  - Quick Frame Transport (QFT) reduces latency for smoother gaming and interactive virtual reality
- Auto Low Latency Mode (ALLM) enables the ideal latency setting to be set automatically, allowing smooth, lag-free and uninterrupted viewing and interactivity

The HDMI 2.1 specification is backward compatible with earlier versions and is available to all HDMI 2.0 adopters.

HDMI 2.1 Technology

There are two major physical layer changes from HDMI 2.0:

- Fixed rate link (FRL), a new video transport method, is introduced to replace TMDS. FRL can operate with 3 or 4 lanes from 3 Gbps per lane to 12 Gbps per lane for a maximum composite bit rate of 48 Gbps. It is encoded as 16b/18b, which increases video data throughput by 12.5% over the HDMI 2.0 8b/10b method. The HDMI 2.1 specification will continue to support TMDS for backward compatibility purposes.
- Enhanced Audio Return Channel (eARC) is introduced. eARC improves the differential audio information over single ended signaling and uses the IEC 61937 specifications. It covers common mode discovery management for both the TX and RX to simplify audio control. In real world terms, this means the TV can be the hub of a home with other media devices plugged directly to the TV and the audio control can be easily controlled by a single TV remote.

The increase in the maximum bandwidth is achieved by increasing the data rate of the data channel and the number of data channels. Previous HDMI versions used three data channels with an additional TMDS clock signal which runs at one 1/40th of the speed of the data channels (150 MHz in HDMI 2.0 operating at 6 Gbps bit rate). HDMI 2.1 doubles the data rate of each data channel to 12 Gbps. The structure of the
data has also been changed to use a new packet-based format whereby the clock is embedded. This allows the formally TMDS clock channel to be used as the fourth data channel and increase the composite bit rate from 18 Gbps (3 x 6 Gbps in HDM 2.0) to 48 Gbps (4 x 12 Gbps in HDMI 2.1). In addition, the encoded scheme is also changed from 8b/10b to 16b/10b with less signaling overhead, a 12.5% increase in the data rate per channel. This in combination with the doubling of data rate per channel and the additional fourth data lane raises the maximum AV payload data rate from 14.4 Gbps to 42.66 bps, a 2.96x increase.

There are also new Category 3 connector and cable specifications with new test regimen. The cable can only be shipped after complying with the HDMI 2.1 Compliance Test Specification (CTS). This new cable must also support higher resolution modes and higher frame rates as well as new features like eARC and VRR, and will maintain compatibility with older HDMI devices.

As signal frequencies increase, the connectors and cables appear more like complex transmission lines rather than simple devices, and engineers need to apply high speed design principles to ensure correct operation. Today’s real time oscilloscopes have the high bandwidth and picosecond rise-time specifications that make high speed data measurements straightforward, given the correct fixturing. Active effects such as timing jitter, oscilloscope phase noise and amplifier linearity, and passive effects such as reflections and delay variations within the board traces, connectors and cables have greater impact to device performance than for lower rates.

Figure 1: HDMI interface between transmitter and sink device

Whether a product is a Blu-Ray player, computer, graphics card or any of the other many product types that use the successful HDMI interface, it must first be submitted to one of the worldwide HDMI Authorized Test Centers (ATC) for certification. Certification requirements are documented in the HDMI 2.1 Compliance Test Specification, or CTS. Specifications and compliance tests are defined by the HDMI
Forum’s technical workgroup. The CTS defines the tests that must be run on one or more of the four high-speed lanes at each of the various resolution settings for both the HDMI 1.4b and HDMI 2.1 specifications. HDMI 2.0 no longer exists and it is now referred to as HDMI 2.1 TMDS. HDMI 2.1 FRL now operates at 3, 6, 8, 10 Gbps and support three and four lanes operations at 3 and 6 Gbps, while four lanes operations at 8, 10 and 12 Gbps.

To test an HDMI transmitter, the test equipment must be connected to a Test Point Access adapter (TPA) that breaks out the test signals to a standard coaxial connector. An illustration of how HDMI signals are accessed by the measurement system is shown in Figure 2.

![Figure 2: Typical HDMI transmitter test connection showing the test point location, Practical Testpoint 1 (PTP1)](image)

It is not common that all HDMI signals can be connected to the measurement system at the same time, so the test process will likely include the reconnection of signals. In addition, the results must be manipulated to remove the effects of the TPA and cabling used. The required processing functions for HDMI 2.1 are shown in Figure 3. These include fixture de-embedding to remove the effects of the fixture; applying a cable model that is considered a worst-case acceptable cable in an HDMI system (loss vs. frequency); adding worst-case skew to either side of the differential pair (one signal at a time); and modeling the minimum equalization an HDMI receiver will have (the HDMI reference equalizer).
Figure 3: HDMI transmitter measurement with test point adapter, cabling and correction
Keysight Test Solutions

HDMI physical layer compliance tests can be segmented into four areas: source design and test, category 3 cable and connector design and test, sink design and test, and eARC design and test. In each of these areas, the HDMI CTS recommends procedures, methods and equipment to perform these tests. In many cases, there are multiple methods, tools or processes to get the job done. Keysight offers solutions in each area to meet your needs in the electrical physical layer, as shown in Figure 4. Method of implementation (MOI) is available for each of these solutions, and adopters can download them free of charge from the HDMI Forum website.

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Figure 4: Keysight HDMI test solutions

The Keysight HDMI 2.1 TMDS test solutions have been certified by the HDMI Forum as an official compliance test tool. The eARC and Category 3 connectors test solutions have been approved as well. As of August 2018, the Category 3 cable and source test solutions are under review and solutions for FRL testing will be submitted soon. Certification was achieved at test events organized by the HDMI Forum. Keysight solutions are used at several Authorized Test Centers in the USA, China and Korea. The measurement equipment used to address the test standards include the Keysight E5071C ENA Option TDR and M937x PXI multiport vector network analyzer, the Infiniium X-Series, Z-Series or UXR oscilloscope, and the new M8195A Arbitrary Waveform Generator (AWG) with low jitter and high-quality output. The M8195A supports physical-level testing, including 12G physical-level jitter tolerance and eye diagram, which are important in identifying IC level performance.

In addition to complete compliance tests, equipment options are available for specific test requirements.
Source Test

The source test solution is based on Keysight’s industry performance-leading Infiniium oscilloscope families. HDMI 2.1 TMDS or FRL Test IDs do not explicitly specify the analog bandwidth requirements. Keysight suggests the following bandwidths based on HDMI versions to achieve accurate rise time measurements:

- HDMI 1.4b (TMDS clock rates to 340 MHz): 8 GHz (4 GHz useable for clock rates to 148.5 MHz)
- HDMI 2.1 TMDS (HDMI 2.0): 13 GHz [16 GHz recommended]
- HDMI 2.1 FRL: 20 GHz

The available choices are the S series (for HDMI 1.4b only), V, Z and UXR Series Infiniium oscilloscopes. This oscilloscope bandwidth recommendations are based on rise time specifications of 42.5 ps for HDMI 2.1 TMDS and 22.5 ps for HDMI 2.1 FRL.

An issue with source testing is that different tests need to be run at different data rates. That is, some tests require the highest possible data rate while other tests require the lowest possible data rate. Automation software needs to know the supported data rates of your device. Then, based on this information, a test plan is constructed. In addition, for each test ID the source device must be set to a mode that outputs the correct video data rate in order to test at the correct data rate.

Keysight has developed a fully automated test solution that enables the source device to output the required data rate. This is accomplished by using an EDID/SCDC controller as shown in Figure 5. The purpose of the EDID/SCDC controller is twofold: one, to enable the setup of an arbitrary EDID image, thus emulating an arbitrary display device), and two, to write and read the SCDC values to set up test conditions and to message the device-under-test (DUT) as if the DUT has established a real connection. The EDID/SCDC controller is available through Allion as a AJSC-1 product.

Figure 5: Fully automated source test solution

The oscilloscope application controls the contents of the EDID/SCDC so that the source device is forced to operate at the data rate that is required for the currently executed test. This feature allows the compliance test software to run fully automated test cycles with minimal user interference.
HDMI 2.1 source measurement requires the use of a probe amplifier and probe head to terminate tested and untested lanes into 50 ohms pulled up to 3.3 V. The measurement also requires single-ended acquisitions for single-ended and differential parameter measurements.

- The Keysight N7003A 20 GHz probe amplifier and N5444A probe head allow single, differential or any combination of measurements among the four lanes without manually changing the hardware connection. This enables one connection for all FRL testing. HDMI 2.1 TMDS testing will require one reconnection as the configuration requires a clock signal.

- A lower cost and lower noise alternative is to use the Keysight N7010A 30 GHz active termination adapter. It enables direct connection to TPA and one-meter matched cable pairs are typically used. This connection allows single-ended measurements on four high-speed lines at a time so multiple reconnection is required. It requires no power supply and offers the lowest noise possible.

Figure 6a: Source measurement connection setup using N7003A and N5444A for one connection FRL testing

Figure 6b: Source measurement connection setup using N7010A

Switching can be added to both setups to obtain full measurements on the DUT without reconnections. The Optional BitiEye switch bundled solution can be added to achieve this.

The Keysight N5399E HDMI electrical performance validation and compliance software (EPVC) provides a complete test execution environment for validating and troubleshooting the electrical performance of HDMI 1.4b and HDMI 2.1 source devices. The software is one of the measurement tools accepted in the methods of implementation (MOI) of HDMI components already well-established globally through HDMI ATCs, and operates on Keysight’s Infiniium oscilloscope family.

By using the N5399E software for the development and pre-compliance steps, you can be confident in a successful outcome when undergoing the compliance process for certification at HDMI ATCs. Companies who use approved equipment and documented test processes may become an HDMI self-certifier.
The N5399E software also supports offline analysis. You can acquire the waveforms and offload saved waveforms for processing on a PC or laptop when you have Infiniium Offline installed. With this capability, you can easily double the productivity of your oscilloscope.

Figure 7: HDMI 2.1 Transmitter Electrical Performance Validation and Compliance Software (N5399E)
Category 3 Cable and Connector Test

HDMI 2.1 introduced new category 3 cable and connector performance. The new ultra high speed HDMI cable supports the 12 Gbps per lane bandwidth for uncompressed HDMI 2.1 feature support. The cable also features very low EMI emission and is backward compatible with earlier versions of the HDMI specification so it can be used with existing HDMI devices.

Keysight Category 3 connector MOIs have been approved and as of August 3018, the Category 3 cable test MOIs are under review. These cable MOIs are designed to provide measurement procedures for HDMI cable assemblies defined in the HDMI CTS, and uses the Keysight E5071C ENA Option TDR and test fixtures as shown in Figure 8. The Keysight ENA test solution performs all the cable’s S-parameter measurements. From the S-parameters, processing software included inside the instrument calculates a stressed eye diagram as shown in Figure 9. You define your eye parameters at the input of the cable and then let the software calculate the eye opening at the end of the cable. With four-port configurations, the ENA requires 15 reconnections to measure all four differential lanes and completes the test in approximately 90 minutes. The ENA is the industry workhorse solution that is widely used in the industry.

Figure 8: HDMI cable assembly test setup using E5071C
An alternative solution is to use the Keysight M937x PXI multiport vector network analyzer (PXI VNA). The PXI VNA enables full 16-port VNA testing and measures all four differential lanes with just one connection. With just one connection, this solution provides more reliable test results due to fewer operator errors and increases system accessories lifetime. Measurements can be completed in approximately 15 minutes.

One additional measurement for source and sink is the impedance test measurement. Due to higher data rates, the Technical Work Group mandated new impedance tests as part of the CTS. The transition points from the signals out of the source device to the cable and from the cable to the sink device must adhere to the specified impedance matching to guarantee device interoperability. If impedance matching is neglected, signal impairments can occur due to multiple reflections in the link between the source and the sink devices. Therefore, an impedance measurement should be done for source and sink as specified in the CTS. In addition, the impedance measurement is required to be done while the source device is
transmitting a signal. This is because impedance can vary dramatically when the device is turned off and turned on.

Measurements include intra- and inter-pair skew, differential impedance, far end crosstalk and attenuation, and phase.

Sink Test

As of August 2018, the HDMI Forum has not yet completed the definition of HDMI 2.1 sink compliance test. It is anticipated that they will release the definition in November 2018. Keysight presently expects to leverage the approved sink solution for HDMI 2.0 for the HDMI 2.1 version.

Sink testing requires a source capable of generating a wide range of test pattern and the ability to add a precise amount of impairments to the output signal. The major high-speed tests are sensitivity, skew, jitter tolerance and timing. HDMI 2.1 TMDS sink testing uses visual checking of the display while the requirements in HDMI2.1 FRL will require a character error detection from the sink to gain compliance. Measurement accuracy is determined by the source noise floor (intrinsic jitter), and the ability to control the signal attributes such as injected jitter. The core of the Keysight HDMI sink test solution is based on the M8195A AWG and the N5990A option 151 test automation software, which guides you through the test procedure and required system connectivity with detailed instructions. The Keysight HDMI sink test solution supports full HDMI 2.1 TMDS and FRL data rates, character error detection for FRL and video inspection for TMDS. This test solution enables independent clock and data jitter injection for accurate sink characterization.

With the industry's first channel duplication capability, the M8195A-based signal generator allows for the addition of an intra-pair skew within the instrument. This eliminates the need for external delay lines, which in the past, engineers had to adjust manually during a sensitive calibration process. This approach also allows for a very quick check on the design margin of a DUT as engineers can dynamically adjust the intra-pair skew in real time. The M8195A can achieve less than a picosecond of accuracy in intra-pair skew, which is very critical for FRL testing.

Furthermore, the output stage of the M8195A signal generator was designed to natively support the signaling levels required for HDMI compliance testing, which removes the requirement for external bias tee components in the signal path. The signal generator only requires an HDMI 2.1 approved test fixture to connect to an HDMI sink DUT. No reconnection of external accessories is required when the HDMI receiver electrical compliance tests are performed.

Figure 11: Example sink test setup using M8195A AWG (TMDS setup shown)
The M8195A AWG solution allows flexibility in generating adjustable transition times and ISI emulation. All of the jitter addition and ISI signal emulation can be factored into the waveform with no external equipment required. As a result, it is less expensive and easier to set up.

Based on the capabilities of the sink DUT, the N5990A software framework generates a test procedure that includes all required tests in order to meet the requirements set forth in the HDMI 2.1 CTS document. The resulting test protocol may be used to state the compliance with the HDMI 2.1 specification. Furthermore, the sink test solution allows for margin testing to discover the design margin of your DUT.

This sink test compliance solution consists of two M8195A two-channel modules and a M8197A multi-channel synchronization module. The key features of the M8195A AWG include:

- AXIe form factor (one slot module)
- Sample rate up to 65 GSa/s @ 8-bit resolution
- Deep sample memory, 16G samples per channel (required for generating all video signals. This is important because the CTS requires that a valid video signal be generated for each video resolution. Therefore, a large sample memory is required to generate the video frames)
- Supports data rates up to 32 Gb/s
- Flexible generation of distortions without cable emulators and TTCs
- Will be included in the Keysight MOI for future HDMI sink testing

**eARC Test**

eARC is a new feature released in HDMI 2.1 to simplify connectivity and ensure full compatibility between audio devices and upcoming HDMI 2.1 products.

In a conventional setup, the audio and video signals flow through the AV receiver (AVR) to the TV. If the AVR does not support the new format or feature, you won’t be able to use the AVR to play the signals on the TV.

With the eARC feature, the audio signal flows out of the TV to the audio device. This means that the audio device is not in the video path so you can now play the new format or feature without upgrading your AVR. eARC also supports robust discovery mechanism whereby it can discover all the audio formats supported by the connected audio device. eARC enables very high-speed link and supports advanced audio formats such as Dolby TrueHD or DTS-HD Master Audio.

With the eARC feature, you can connect audio devices such as a soundbar or speaker directly to the TV and play full range of audio formats including high-resolution audio signals. You will no longer need to switch the inputs on both the TV and the AVR. Simply use the TV to choose the source to play and the audio device will play it.
Figure 12a: Conventional connection without eARC

Figure 12b: Connection with eARC

Keysight offers eARC TX and RX compliance test solutions based on the S, V, Z and UXR series oscilloscopes, 81160A function generator and BitifEye dynamic sequencing generator and analyzer (BIT-3000 DSGA) as shown in Figure 13. The oscilloscope is used for signal calibration. The 81160A function generator is used to generate differential eARC signals while the DSGA is used to create common mode eARC signals. The eARC discovery mechanism (communication with DUT) is handled by the BIT-3000 DSGA for both TX and RX test setup. Jitter is injected using the 81160A. In total, the solution covers eight audio sampling rates and up to eight-channel format, providing user the full flexibility and every possible functionality required to perform the tests.

Two eARC test solutions are available:

- N5990A-351 HDMI eARC and HEAC receiver and transmitter tests
- N5990A-352 HDMI eARC and HEAC receiver tests

Figure 13: Example of an eARC RX test setup
The measurement automation is accomplished with the N5990A software and uses built-in eARC measurement algorithms in the N5399E/N5399F HDMI electrical performance validation and compliance software. The N5990A test automation software enables the user to select the DUT capability (e.g., data rates, HEC/ARC support), automate the test tree creation, display connection setup diagrams and generate test reports containing all the test data such as equipment setup, parameters and results.

The eARC TX and RX measurements cover both differential and common modes and are shown in Table 1 below.

### eARC RX tests

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<tr>
<th>HFR5-2-1</th>
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<td>HFR5-2-4</td>
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<td>eARC RX Differential Bit Rate Tolerance at TP1 (ReARC_BIT_AUDIO)</td>
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<td>eARC RX Differential Mode Duty Cycle Tolerance at TP1 (DeARC_DM1)</td>
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<td>HFR5-2-7</td>
<td>Source</td>
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<td>eARC TX Differential Mode Eye Diagram at TP1</td>
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**Table 1: Keysight eARC TX and RX test parameters**
Resources

Keysight is an active member of the HDMI Forum, with consistent participation in seminars and specification issues. To understand the latest HDMI measurement techniques and for resources such as an overview of HDMI design and illustrations of design and debug approaches, go to www.keysight.com/find/HDMI.