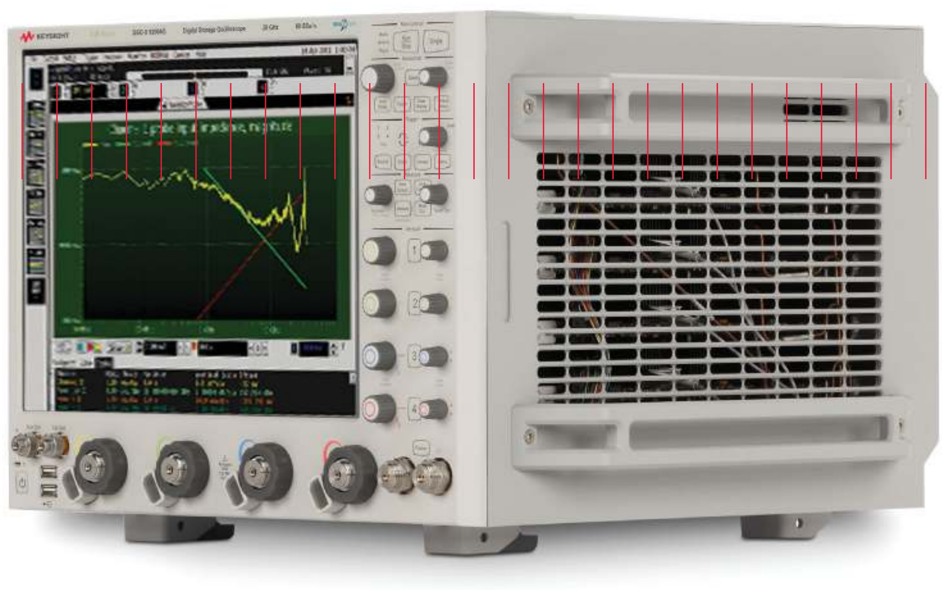
# Keysight Technologies

## Oscilloscope Considerations for Multilane MIPI M-PHY Transmitter Validation

Application Note



KEYSIGHT TECHNOLOGIES

# Introduction

The Mobile Industry Processor Interface (MIPI) Alliance is a standard body that promotes hardware and software standardization in mobile designs. The specifications are developed not only with performance in mind but methods to lower power consumption, making these standards ideal for mobile applications. One of the high-speed, low-power physical layer specifications is the M-PHY specification, which can be flexibly adapted for different protocol applications. In addition, the M-PHY physical layer is scalable where the number of upstream and downstream lane implementation are not restricted. Applications can take advantage of this scalability to specify and design multilane signals to take advantage of the data rate performance without sacrificing on the energy consumption. Protocols such as DigRF v4, low latency interface (LLI), universal flash storage (UFS), camera serial interface (CSI), display serial interface (DSI) and SuperSpeed USB inter-chip (SSIC) have already adopted the M-PHY physical layer.

The M-PHY supports two different speed modes, namely the high-speed (HS) and low-speed (LS). Obviously, the HS mode is used when large set of data has to be transmitted, where LS mode is used mostly for device control and configuration. In each of these modes, there are also different data rates, also known as gears. In HS mode, the official M-PHY specification is released for Gear 1 with the maximum data rate of around 1.5 Gbps. The current roadmap includes plan to increase the speed to Gear 2 and 3, with a maximum speed of approximately 3 Gbps and 6 Gbps respectively. Although not official, there are already plan in place to further push the data rate to Gear 4 at 12 Gbps. With this increasing trend, the validation tasks of the M-PHY design will only get more challenging.

In today's mobile design, a lot of components have to be squeezed into a small, tight space. Design considerations such as power supply delivery, heat dissipation, signal crosstalk and coupling become more prominent. In addition, the digital and RF circuits that are fitted together in this confined space will promote electromagnetic interference (EMI). MIPI Alliance promotes the designs to be tested against the conformance test suites (CTS), which is the test requirement for the transmitter and receiver circuits. The intention is to increase the chance of system interoperability, or the guarantee that the designs from different vendors will work well when they are used together. The challenges to accurately validate the designs become increasing more difficulty with these high-speed, multilane M-PHY designs. To help improve your electrical validation, there are a few considerations in choosing the oscilloscope to validate your multilane M-PHY designs.

## Bandwidth Requirements

Oscilloscope bandwidth requirement is correlated with the minimum rise or fall time of the signal that you want to measure. The faster the edge, the more energy it contains and therefore, the more bandwidth you will need to accurately measure that edge. The current M-PHY specification specifies the minimum rise and fall time to be 0.1 factor of a signal unit interval (UI).

For instance, if you want to determine the bandwidth you will need for Gear 3 at data rate of 6 Gbps, you first need to know the fastest rise time of the signal. Then, using the oscilloscope bandwidth equation, the required bandwidth can be calculated.

Fastest rise or fall time
(20-80%)=0.1×UI=0.1×171.5ps=17.15ps

Bandwidth requirement = 0.4÷Fastest rise or fall time
= 0.4÷17.15ps=23.3GHz

| High-speed gears | Data rate (Gbps) | Approximate UI (ps) | Fastest rise or fall time (ps) | Bandwidth required (GHz) |
|---|---|---|---|---|
| HS-G1 (A/B) | 1.248 or 1.4576 | 686 | 68.6 | 5.82 |
| HS-G2 (A/B) | 2.496 or 2.9152 | 343 | 34.3 | 11.6 |
| HS-G3 (A/B) | 4.992 or 5.8304 | 171.5 | 17.15 | 23.3 |

Although it is common to estimate the bandwidth based on the fifth harmonic of the data rate, it may not always be accurate. In the case of Gear 3 signal with a fundamental frequency at 3 GHz, the fifth harmonic where the fundamental frequency is multiplied by a factor of 5 tells you that 15 GHz of bandwidth is sufficient to validate this signal. Although it sounds reasonable, this oscilloscope bandwidth may not be sufficient to measure the fastest rise and fall time as required in the specification. This rule of thumb provides a good estimate, but not necessarily the accuracy you need.

Measurement system bandwidth= $\sqrt{(\sum(\text{Component bandwidth})^2}$

Another common mistake is thinking that the bandwidth consideration is only for the oscilloscope, but in fact the whole measurement system has to be considered as well. The bandwidth should include the probing system which should meet the required bandwidth. If the probing bandwidth is not sufficient, the whole bandwidth is only as good as the lowest bandwidth in the measurement chain.

Lastly, you will need to consider whether you need to measure the skew between the high-speed lanes in your multilane system. As long as 2 lanes can be measured at the same time, you can fully characterize the skew of all your lanes since one lane can always be used as the reference. If you are probing each lane single-ended, you will need 2 scope channels to measure one lane. For this skew measurement, you will need 4 scope channels with the full bandwidth to make this measurement.  The risk of insufficient scope bandwidth is the signal edge may be slowed down, hence producing a larger skew than what the design can really achieve.

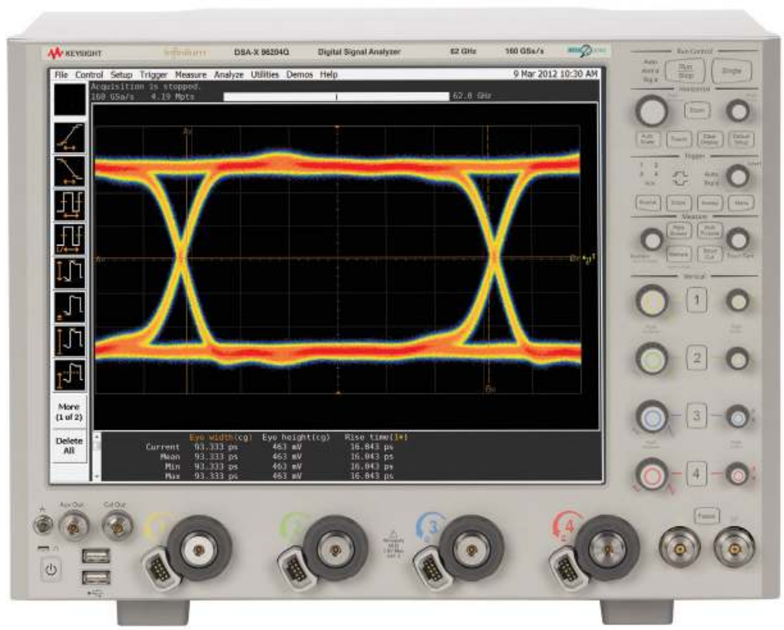



*Figure 1. Infiniium 90000 Q-Series 4-channel high-bandwidth oscilloscope with a bandwidth of up to 33 GHz, ideal for multilane M-PHY electrical validation*

## Noise Floor Performance

Engineers have a tendency to first look for more bandwidth when accuracy is at stake, but bandwidth is only part of the story. Oscilloscope and probing noise floor performance are also critical. Without sufficiently low noise floor performance, you cannot reap the benefit of additional bandwidth. Having more bandwidth with poor noise floor performance will just increase your uncertainty and decrease your measurement accuracy, which could lead to reduced design margins. In this case, you may have enough bandwidth to make the rise and fall time measurement but may not have the accuracy to measure other parameters such as amplitude and jitter in your design.

Noise floor performance of the measurement tools is critical for M-PHY electrical characterization because of the tight amplitude parameters defined in the spec. For instance, the AC voltage parameters defined for "small amplitude with termination" specifies the minimum and maximum voltages to be 80mV to 140mV. The range in this case is really tight at 60mV so noise contributed by the measurement system can really impact the measurement and could potentially marginally failing your design. Thus, it is an important consideration to not only look at the datasheet but also verify the performance of the oscilloscope and probing systems to determine the noise is acceptable.

Beware of oscilloscope that apply digital signal processing (DSP) boosting to achieve higher bandwidth. What this means is the actual oscilloscope bandwidth is lower than what it can achieve. In order to reach the higher bandwidth, DSP is applied to increase the bandwidth at the higher region. The tradeoff is higher noise because when the DSP is applied to boost higher frequency, it also boosts the noise floor.

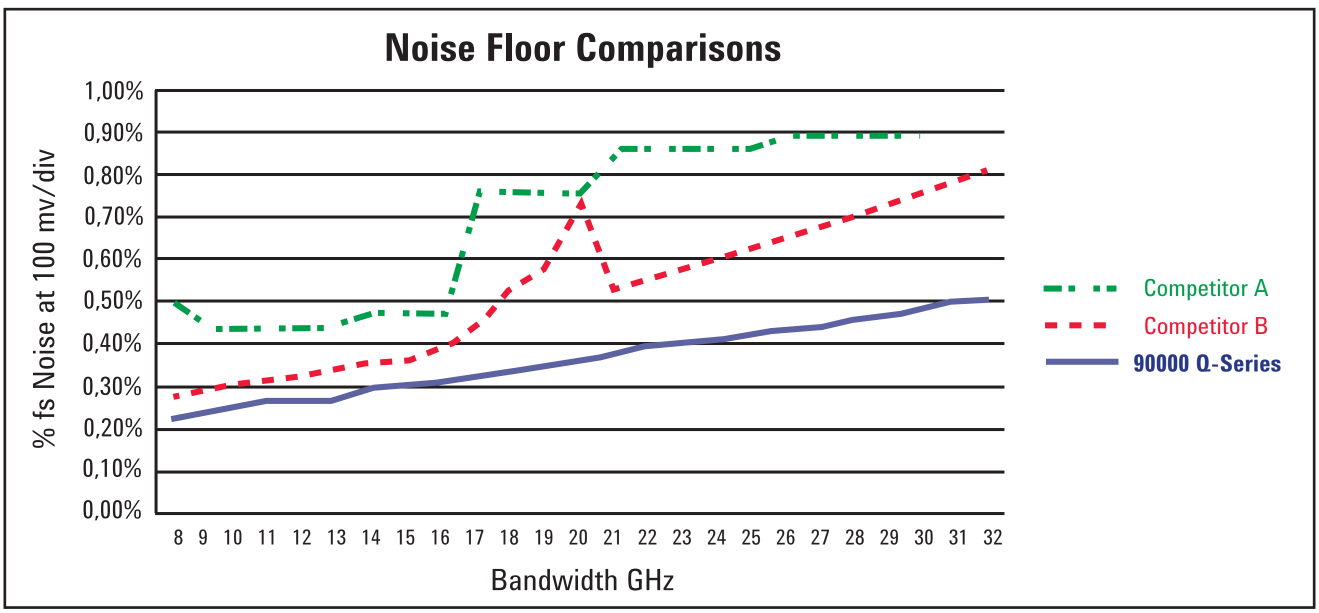



*Figure 2. Graph showing the oscilloscope noise floor using different techniques to boost bandwidth. Choose the scope that provides the true bandwidth performance, not only with lowest but also linear noise floor to reduce the impact of noise to your measurement.*

# Probe Capacitive Loading

Slew rate control is an effective means of limiting electromagnetic interference (EMI). The faster the slew rate, the more emission there will be. Therefore, the M-PHY specification requires the control of the slew value for different slew rate states. In the spec, the minimum and maximum slew rates that can be applied are 0.35 V/ns and 0.9 V/ns. In addition, the slew rate have to be monotonically decreasing when stepping from faster to slower slew rate states within a 30 percent resolution. For instance, the next step in the slew rate after 0.8 V/ns can be 0.7 V/ns since it falls within the 30 percent resolution, but not 0.4 V/ns because it is outside of that resolution.

When you are verifying the slew rate, it is important to know that your measurement system has very low capacitive loading so it does not artificially slow down or misrepresent the slew rate that you are trying to measure. Especially when you are making measurement for high speed signals, probe loading that seems insignificant can cause a huge drop in the slew rate. There are probes that can provide the full bandwidth requirement without compromising the slew rate. When you are choosing probes, make sure they have very low capacitive loading at the range of tens of femto-Farad (fF). There are probes available today that can provide capacitive loading to as low as 50 fF, which would be able to guarantee high quality slew rate measurement. Moreover, choose the probes with the right form factor that allows you to reach the tight places that you need to make your measurements.

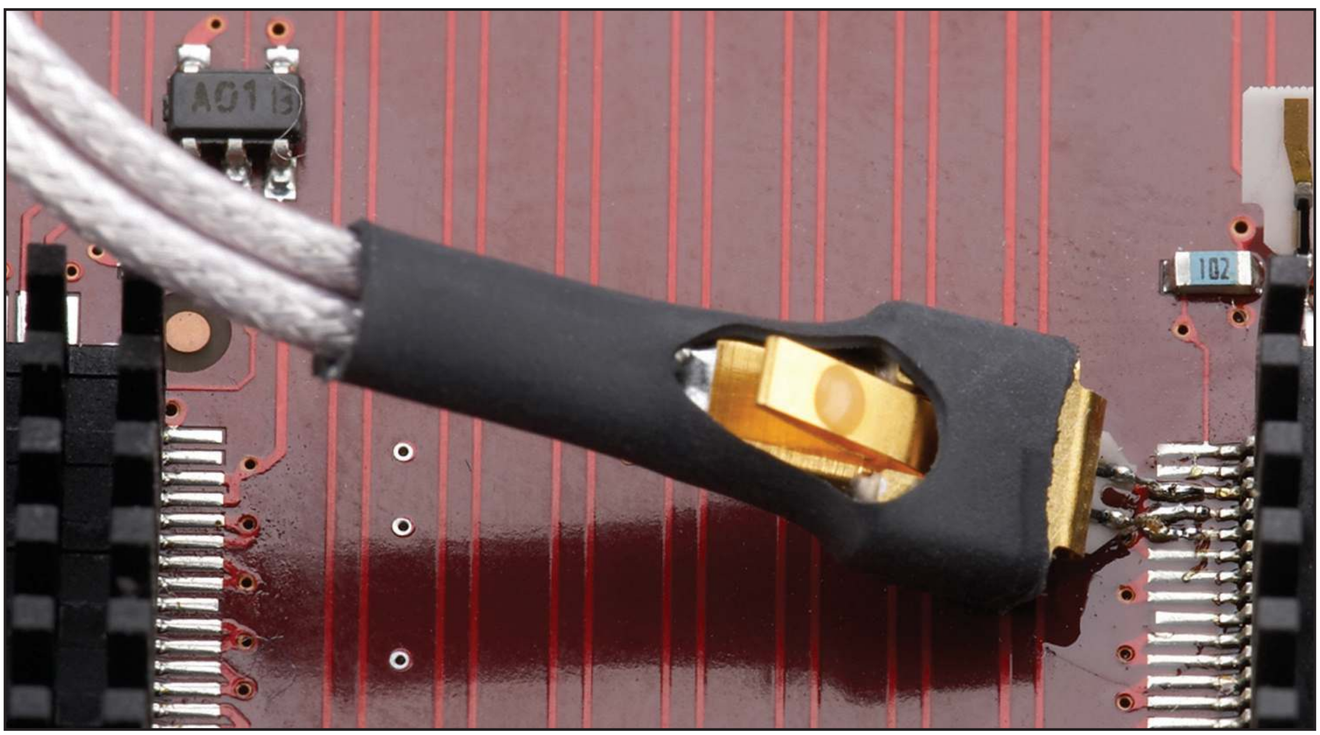



*Figure 3. Choose the probe that has sufficient bandwidth, low loading and a small form-factor to reach the probe points or pins on your designs.*

# Probe Correction Method

Probes and cables have inherent loss and variation. The loss at times can be substantial, or merely different enough from the nominal to cause variation in measurements. For M-PHY transmitter electrical validation, common probing methods include active differential probes that are soldered down directly at the signal path of the product and SubMiniature version A (SMA) coaxial cables to probe the signals on the test vehicle board where the chip is mounted on. It is important that the probes that you use are properly matched and have the same loss performance profile so the signals that you measure represent the true performance of your design.

On the left side screenshot in Figure 4, a pair of improperly matched probes with slightly different frequency response profiles is used to make the common-mode voltage measurement by probing at the differential signals. You can observe that the waveform profiles of both signals are slightly different and when the signals are summed together, you can see the bumps caused by the probe difference. The bumps that are caused by the difference in frequency response of the cables contribute to about 75 mV of common mode error which would fail the test. As compared to the right side measurement, made with a highly matched probes pair, the common-mode voltage only measures about 6 mV, which shows the true performance of the design and passes the test. Thus, the effect of skew and frequency response have great impact to measurement accuracy.


*Figure 4. The left side screenshot shows probes with slightly different frequency responses when making common-mode voltage measurement. The result shows 75 mV, which is mainly caused by probes frequency response that are not exactly matched. On the right side, well-matched probes are used for the same measurement and the results show only 7 mV of common-mode voltage, which is the true performance of your design*

There is an emerging innovate solution to easily characterize and corrects for insertion loss caused by cables and probes. They can be corrected using just the oscilloscope, using a built-in fast calibrated edge step response from the oscilloscope, which is launched into the probe. The impact to the step response with and without the probe is analyzed and a mathematical S-parameter model can be computed to account for the loss introduced by the probe. This capability provides full AC calibration for probes, not just DC calibration and skew correction. Issues such as phase non-linearity, magnitude non-flatness and effect of probe loading can be corrected quickly.

The added margins are especially valuable in situations where the probe setups consume measurement margins without it being apparent to the user. By computing the changes in the baseline response, a correction filter can be applied to the lossy cables in order to obtain the corrected cable response. This capability will correct for the probe frequency response so they are perfectly matched when you are using them. Such capability is useful when using a probe switch matrix to validate the M-PHY multilane signals. When you are validating a protocol such as the LLI design which can support up to eleven lanes, it can be challenging to switch the probe connection each time a new lane is characterized. By hooking up the lanes into a switch matrix that has been fully corrected using the scope, you not only improve measurement margins but also save you valuable time.

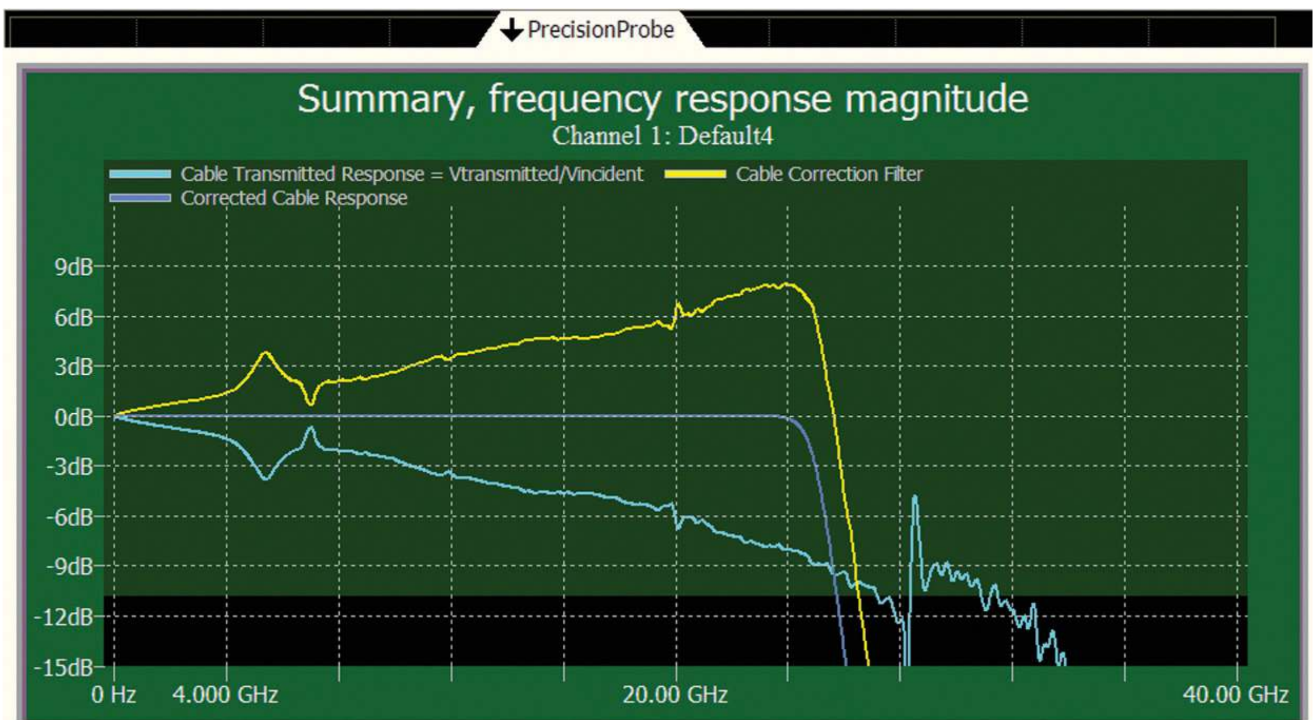



*Figure 5. The poor response of cable pair is properly corrected by applying a correction filter using the built-in source from the oscilloscope. This capability corrects and matches the probe response of any probes used with the measurement. The correction used in the measurement will guarantee high quality and repeatable measurements.*

# Conformance Test Automation

Once you have all the physical measurement systems setup, it is still necessary to spend time to manually validate the long list of transmitter test parameters defined in the MIPI CTS. Often, it can be challenging not only to exhaustively characterize every test parameter but also to run them through different process, voltage and temperature cycles over your multilane design. Worse still, the results are difficult to track since they have to be manually recorded and formatted in test reports.

To save time and effort, many of the required steps can be automated with dedicated "applications" built into an oscilloscope. Using these automated routines, measurements of every test parameter can be repeated multiple times to thoroughly analyze a signal with complete statistical results along with screen captures of worst-case results. Many applications also automatically generate comprehensive test reports for archiving or sharing.

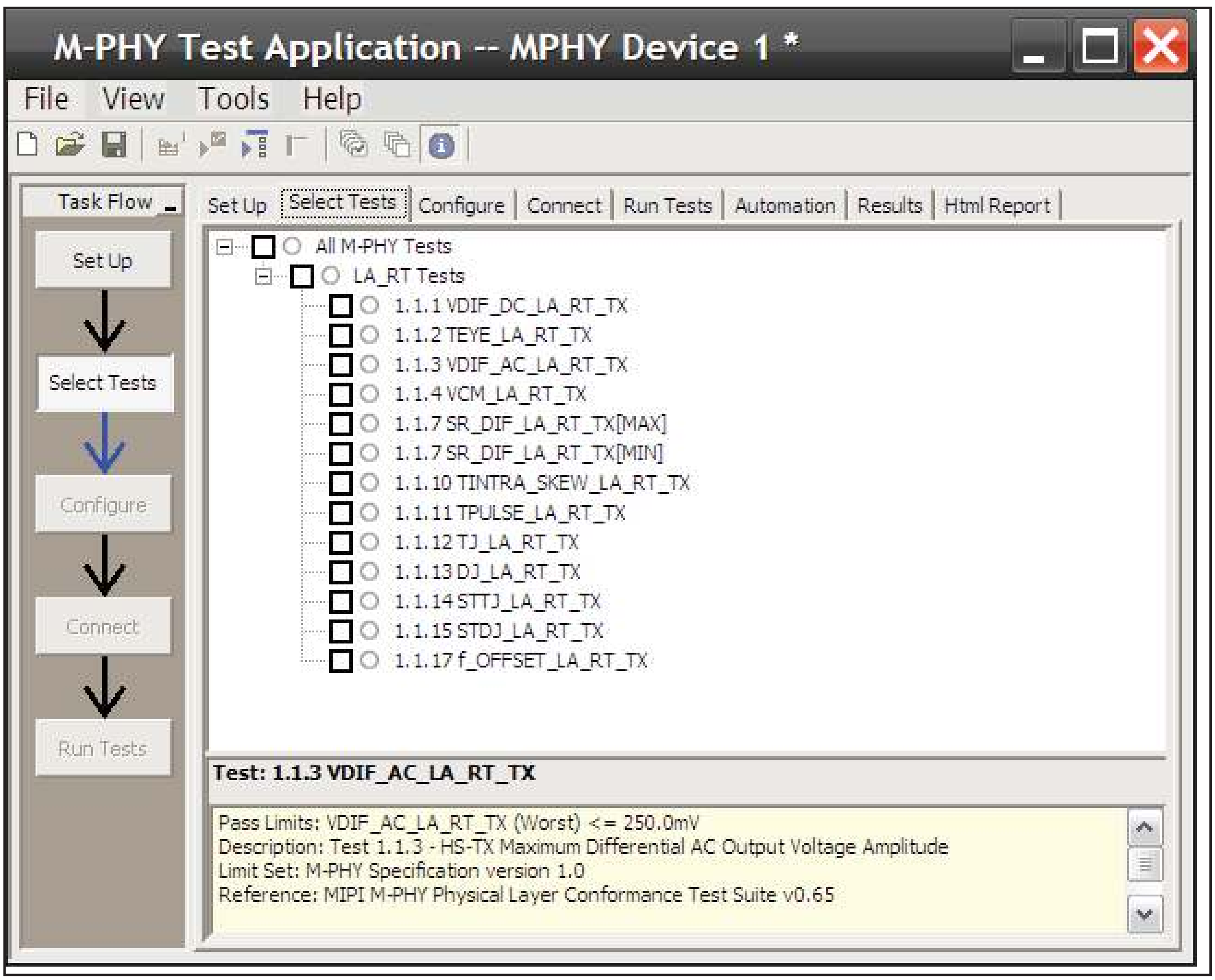



*Figure 6. A compliance application is available to save you time and effort to validate your multilane M-PHY design across multiple process, voltage and temperature settings*

# Protocol Debug

If you are debugging protocol issues that could be related to the electrical performance, the oscilloscope has the capability to decode the M-PHY protocols into frames and packets. This way, you do not have to manually convert the captured ones and zeros to protocol because it could take significant time and effort. Especially with a multilane M-PHY interface, the payload can span across multiple lanes so trying to stitch the information back together can be painful.

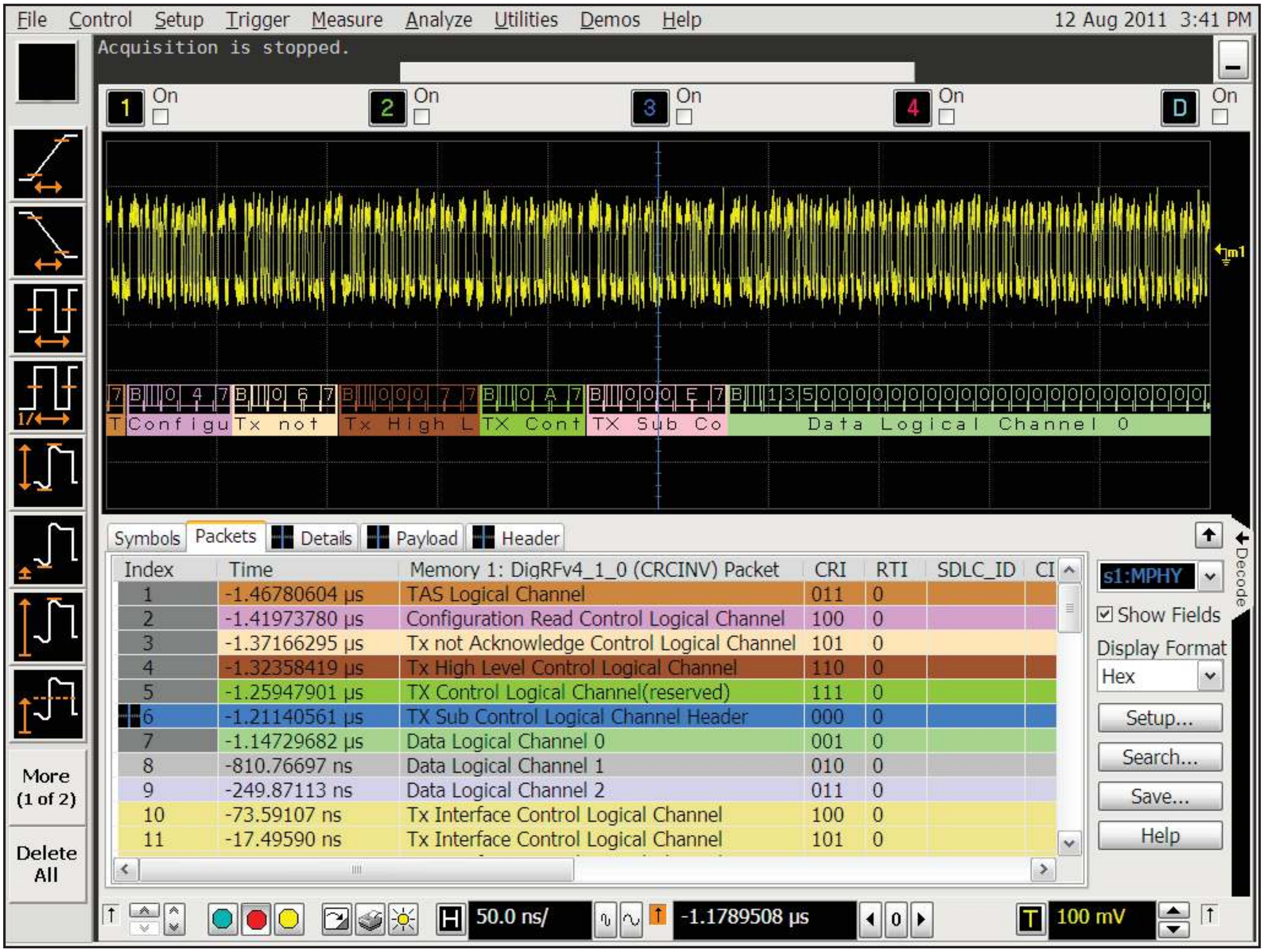



*Figure 7. Oscilloscope M-PHY multilane protocol decode translates and displays the protocol level symbols, packets and frames so you can quickly debug and correlate protocol errors related to signal integrity issues.*

# Summary

The multilane M-PHY designs operating at higher data rates or gears can post significant challenges to electrical validation. The bandwidth, noise performance and loading effect of your oscilloscope and probing system play a huge role in the accuracy of the measurements. Choosing the right configuration is the first step in achieve better design margins and shorter design cycles. There is innovative way to correct for imperfect scope, probe and switch matrix responses so take advantage of the capability as well. Making all the required measurements can take a lot of effort and time but an automated application built into the scope can help you achieve your validation test plan faster. Lastly, M-PHY protocol decode feature can translate the electrical waveforms into protocol level symbols, packets or frames that allow you to quickly debug signal integrity issues. Applying these considerations, they will pay off by generating better quality products and getting them to market faster

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