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Overcoming USB measurement-test-setup issues

DESIGNERS MUST MEET STRINGENT CONSTRAINTS TO COMPLY WITH THE USB-IF SPEC. CLEVER TECHNIQUES CAN HELP YOU DESIGN YOUR SYSTEM TO MEET THESE SPECS.

Measuring the signal quality of USB (Universal Serial Bus) interfaces requires that designers meet the stringent constraints of the USB-IF (USB Implementers Forum, www.usb.org) specification. Nothing is more frustrating, however, than attempting to hunt down signal-quality issues in your design when your test setup has introduced curve errors. By isolating setup-testing issues from design-testing issues, designers can ensure that they are making proper measurements of the signal quality of USB-data lines. This accomplishment will lead to uncovering rather than masking design problems.

The foundation of measuring USB-signal quality is a violation plot (**Figure 1**). This plot is the width of a single bit; three boundaries—upper limit, lower limit, and center eye—outline this plot of data, and these boundaries create the violation area and define the area that the signal must not pass through. If the signal enters the violation area, then the design has violated at least one of the USB-specification requirements. The violation area depends on the configuration of the DUT (device under test). For example, a "captive" cable has a different set of limits from a device using a standard B connector. The USB-IF specification contains the plots for each of these tests. Once you have selected the proper test limits for the configuration, you use a test packet to generate each bit over this template. If the signal is monotonic and does not pass through the violation areas, then the signal passes the signal-quality measurement. You must also consider the edge rate of the signal and ensure that the signal does not have too sharp a rise or fall.

DEVICE SETUP

The first step is to configure the limits of the test. You accomplish this task by selecting the proper location for measuring the signal, and this location depends on the DUT. If the device has a captive cable, you must measure the signal at the far end of the cable. If the device has a standard USB connector, then you measure full-speed signals at the far end of a 5m cable and high-speed signals at the near end of the cable. The far end is 5m from the device emitting the signal, and the near end is the connector of the device emitting the signal. Be sure to measure in the proper direction; that is, the data should be originating from the DUT rather than the host.

When working with high-speed signals, check the test switch on the test fixture. If the switch is in test mode—that is, the test LEDs are lit—then you can measure signals only from the DUT. If you are measuring full-speed signals, then signals are coming from both directions, and you must check the data to ensure that you are measuring it in the proper di-

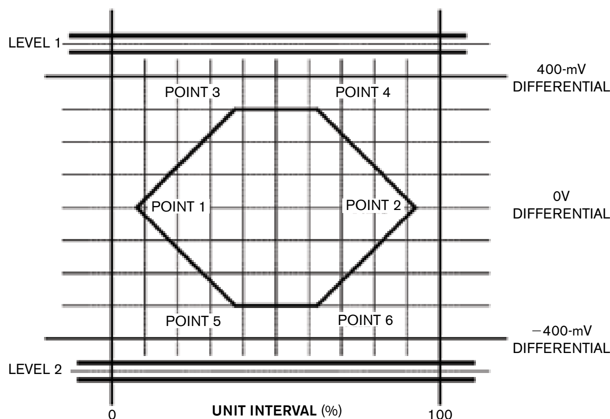

Figure 1 The foundation of measuring USB-signal quality is a violation plot that is the width of a single bit; three boundaries–upper limit, lower limit, and center eye–outline this plot of data.

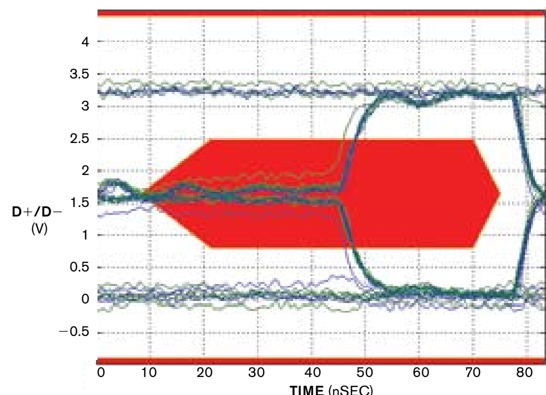

Figure 2 The null point has a width that directly relates to the length of cable over which you are making the measurement.

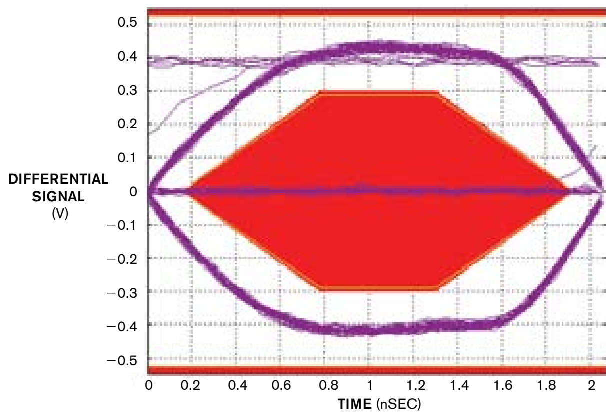

Figure 3 A typical setup problem you encounter when dealing with high-speed signals is accidentally connecting the differential probe backward.

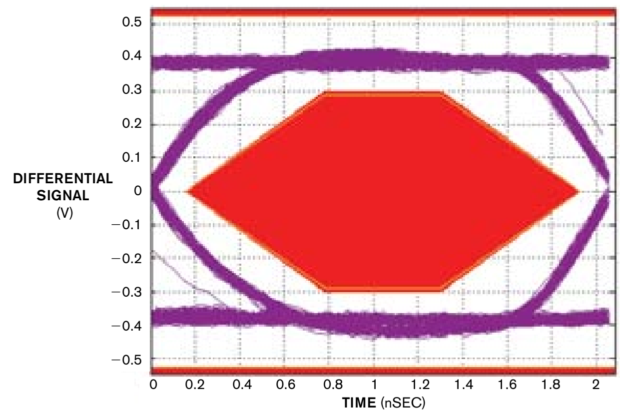

Figure 4 When you properly configure and connect the test setup, you should get a clean eye diagram.

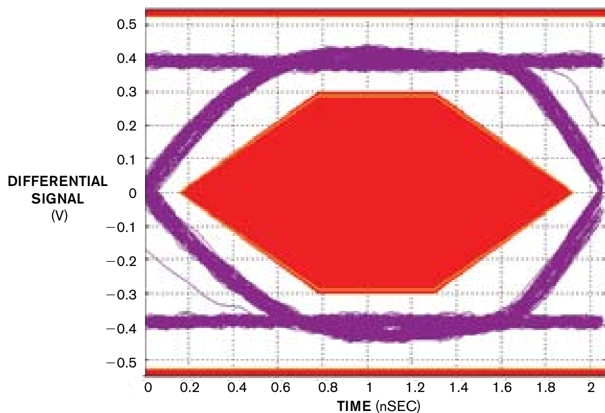

Figure 5 As little as 2-pF capacitance can cause the leading section to rise slower and round off the edge of the signal.

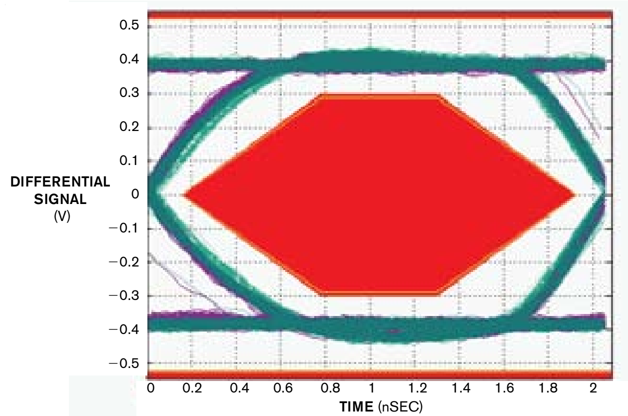

Figure 6 The effect of added capacitance on measurements shows both the desired eye diagram of Figure 4 (purple trace) and the eye diagram of Figure 5 when you add 2-pF capacitance to the test fixture (green-overlaid trace).

rection. To confirm the measurements, check to see whether the signal is traveling the length of the cable to the measurement point—that is, a far-end measurement.

The best method for accomplishing this goal is to look at the crossover points. If the signal is coming from the near end of the cable, it will travel past the measurement point, down the cable, and then back again, creating two images, with the second exhibiting a phase shift compared with the first. The results of summing these two images is a null point at the crossover. This null point has a width that directly relates to the length of cable over which you are making the measurement (**Figure 2**).

Another typical setup problem you encounter when dealing with high-speed signals is accidentally connecting the differential probe backward (**Figure 3**). The root cause of this error is that scripts that synchronize with data patterns make an assumption about the probe's polarity and expect signals to arrive in a given sequence. When you reverse the signal by connecting the probe 180° out of phase, you measure the D+/D− differential pair as a D−/D+ differential pair. This approach causes the algorithm to plot the leading edge of the signal, which creates lines through the center. Reversing the probe connection resolves this problem. When you properly configure and connect the test setup, you should get a clean eye diagram (**Figure 4**).

Unintended impedance adversely affects measurements. If you inadvertently add impedance, signal amplitude can decrease, edge rates can change, and overshoot can appear. Adding capacitance to traces, cabling, or the test fixture decreases the rise time of the leading edge. As little as 2-pF capacitance can cause the leading section to rise slower and round off the edge of the signal (**Figure 5**). **Figure 6** shows the effect of added capacitance on measurements; the **figure** shows both the desired eye diagram of **Figure 4** (purple trace) and the eye diagram of **Figure 5** when you add 2-pF capacitance to the test fixture (green overlaid trace). Most of the difference appears in the leading edge of the image; the rising and falling edges show a lowering of the signal edge rate by approximately half the width of the jitter. Rise time affects this signal, which also experiences a slight increase in jitter. Increasing added capacitance to 8 pF, for example, would begin to result in eye violations. Similarly, when you add inductance to the traces, the signal experiences overshoot and may round both the top and bottom of the eye.

Factors that can affect measurement range from trace impedance to the connector that the device uses. When using

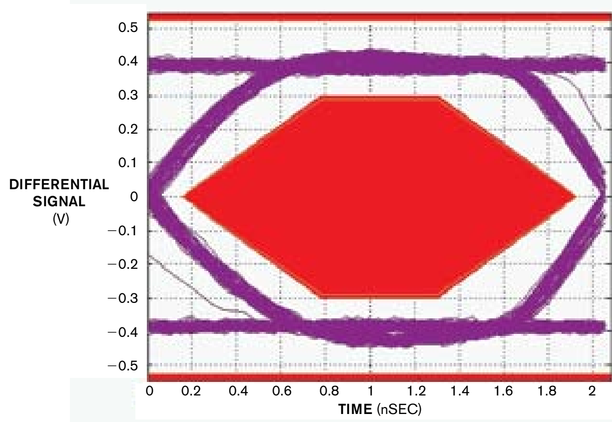

Figure 7 This adapter has a mini-B connector on one end and an A connector on the other.

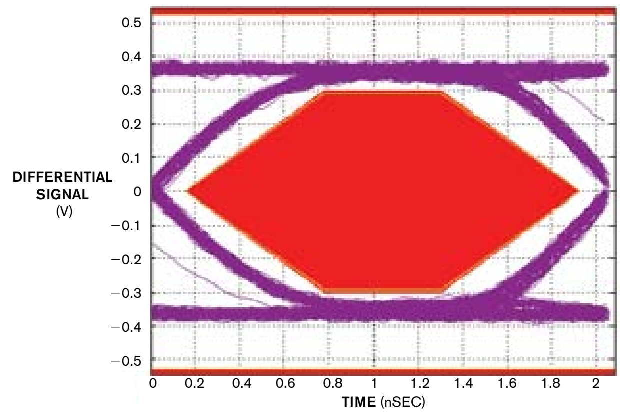

Figure 8 This measurement occurs when you use a standard 4-in. cable, which connects the B connector to an A connector along with an adapter to convert the mini-B receptacle to the B connector.

connectors other than certified USB connectors, you should verify that the impedance effects of these connectors meet the USB specification before testing the system.

CABLING ISSUES

When measuring USB-signal quality, another area of concern is in the connections that the device is making. For example, to connect a device with an A receptacle to a device with a mini-B connector requires an adapter and introduces extra connectors into the signal path. **Figure 7** shows the measurement across an adapter with a mini-B connector on one end and an A connector on the other. **Figure 8** shows the measurement when you use a standard 4-in. cable to connect a B connector to an A connector along with an adapter to convert the mini-B receptacle to the B connector.

These extra connectors decrease amplitude and lower the margin around the violation area. Minimizing the number of connections in the test setup helps you acquire a truer signal-

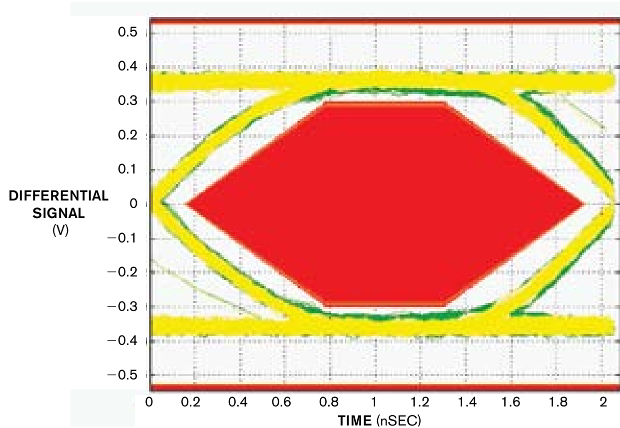

Figure 9 The impact of extra connectors is even more critical when the series impedance is already near the limits of the USB specification.

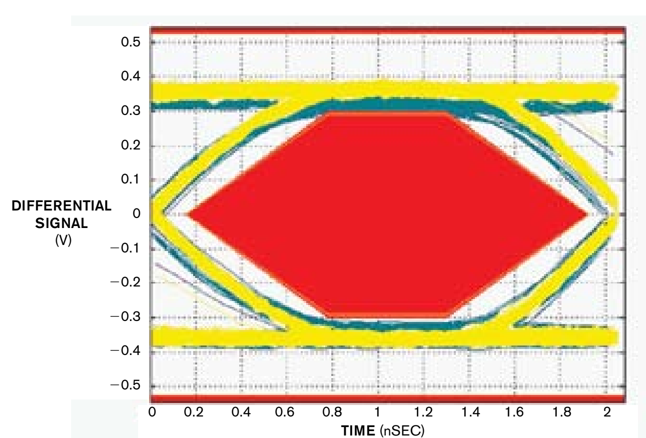

Figure 10 The bluish-green traces are uncalibrated traces, and the yellow traces show the effect of calibrating the probes. Failing to calibrate the probes affects both jitter and amplitude.

quality measurement. **Figure 9** shows the impact of an extra connector. (The yellow trace in **Figure 7** is the true reading, and the green trace in **Figure 8** shows multiple connections through the use of adapters). The impact of extra connectors is even more critical when the series impedance is already near the limits of the USB specification.

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CALIBRATION ISSUES

Another common setup problem is the failure to calibrate the scope probes. You should calibrate the probes if they are outside the calibration-temperature range or you have not calibrated them for months. **Figure 10** shows the impact of calibration on measurements: The bluish-green traces are uncalibrated traces, and the yellow traces show the effect of calibrating the probes. Failing to calibrate the probes affects both jitter and amplitude.

In summary, when measuring USB-signal quality, begin by following the procedures that the USB-IF Web site outlines. If problems appear, first confirm that your test setup and configuration are correct by ensuring that the intended measurement point is what you are measuring, that you are using the proper-length cable, that you have accounted for items such as adapters that you have placed in the signal path, and that you have recently calibrated your test tools. Each of these factors can induce errors that can cause compliant signals to appear to be in violation of the USB specification. Finally, consider that multiple issues may be in effect. Even though the impact of each factor may induce only a small error, several errors at the same time can cause failures. EDN

AUTHOR'S BIOGRAPHY

Keith Klepin is a senior staff application engineer at Cypress Semiconductor, where he has worked for seven years. Klepin is responsible for application development and USB-compliance testing. He received a master's degree in electrical engineering from San Diego State University. His leisure-time interests include photography, digitizing photos, and gardening.