Troubleshooting USB 2.0 Signal Quality

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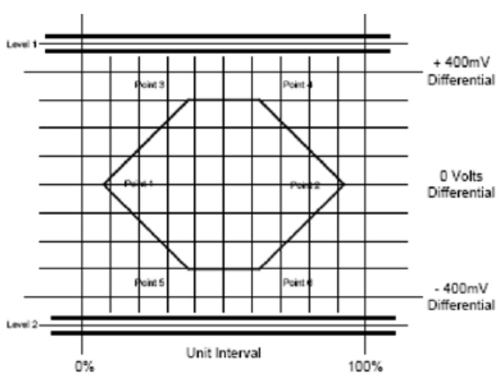
AN13632 describes problems that can occur when measuring the signal quality of the universal serial bus (USB) 2.0. Its purpose is to help the designer isolate setup issues from design issues.

Introduction

This application note helps the designer recognize setup problems and ensure proper measurement of the signal quality of USB data lines.

The measurement starts with a plot of a single bit width of the data. When a violation area is added to it, the violation plot shown in Figure 1 is created. The violation area has three boundaries: an upper limit, a lower limit, and a center eye.

Figure 1. Violation Plot



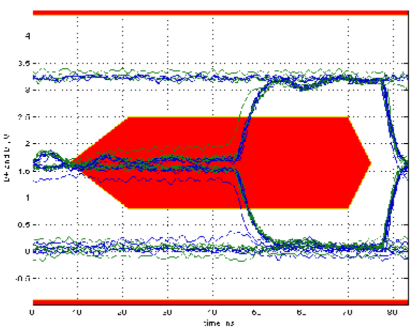
The signal must not pass through the violation area. If it does, at least one of the USB specification requirements has been violated. The limits of the violation area depend on the configuration of the device being tested. If the device has a "captive" cable, it has a different set of limits than a device that has a standard B connector. The USB-IF specification contains the plots for each of these tests. After the proper test limits have been selected for the configuration, a test packet is used to generate each bit over this template. If the signal is monotonic and does not pass through the violation areas, the signal passes the signal quality measurement. One exception to this is the edge rate of the signal. The signal must not have too sharp a rise or fall.

Device Setup

The first step when you set up a device for measurement is to select the proper location for measuring the signal quality. If the device has a "captive" cable, the signal must be measured at the far end of the cable (the end of the cable that is five meters away from the device emitting the signal). If the device has a standard USB connector, it should measure the full-speed signals at the far end of a five-meter cable and the high-speed signals at the near end of the cable (the connector of the device that is emitting the signal).

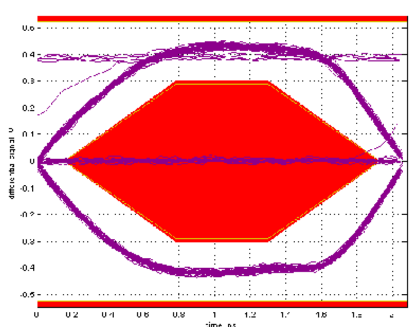
Make sure the data is being measured in the proper direction. (The data being measured is from the test device and not from the host.) When you work with high-speed signals, check the test switch on the test fixture. If it is in test mode (test LEDs are lit), you can measure only the signals from the unit under test. If the signals being measured are full speed, the signals are in both directions and the data must be checked to make sure that it is being measured in the proper direction. That is, check to see whether the signal is sent down the length of a cable to the measurement point (this is a far end measurement). The best way to do this is to look at the crossover points. If the signal comes from the near end of the cable, the signal travels past the measurement point down the cable and then back. This creates two images, and one has a phase shift in the signal. The result of combining these two images is a null point at the crossover. This null point has a width directly related to the length of cable that the signal is traveling down (see Figure 2).

Figure 2. Measurement at Wrong End of Cable



Another typical mistake when working with high-speed signals is connecting the differential probe backward. This causes the image that appears in Figure 3.

Figure 3. Measurement with Reverse Polarity

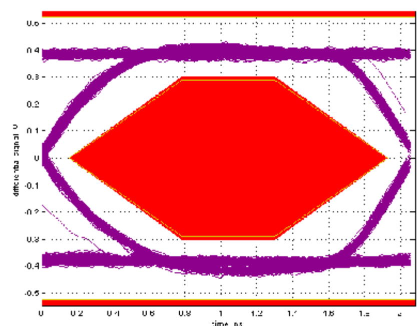


This happens because the scripts that synchronize to the data patterns make an assumption about the probe's polarity. They expect the signals in a specific sequence. When the signals are reversed by connecting the probe 180 degrees out, they measure the D+/D– differential pair as a D–/D+ differential pair. This causes the algorithm to plot the leading edge of the signal, which creates the lines through the center. Reversing the probe connection removes this problem.

Signal Quality Issues

When test setups are properly connected, the resulting eye diagram should appear as in Figure 4. Impedance, cabling, and calibration issues can affect signal quality.

Figure 4. Proper Eye Measurement



Impedance Issues

Added impedance, can decrease amplitude, change the edge rates, and introduce overshoot. By adding capacitance to the traces, to the cabling, or to the test fixture, the rise time of the leading edge decreases. As little as 2 pF causes the leading section to rise slower and round off the edge of the signal, as shown in Figure 5.

Figure 5. 2 pF Capacitance Added to Test Fixture

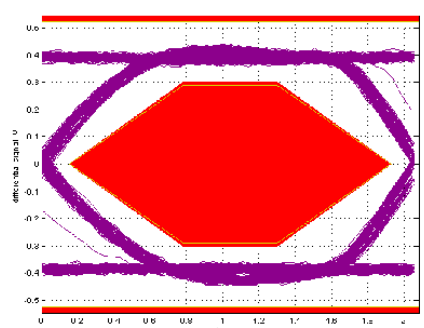
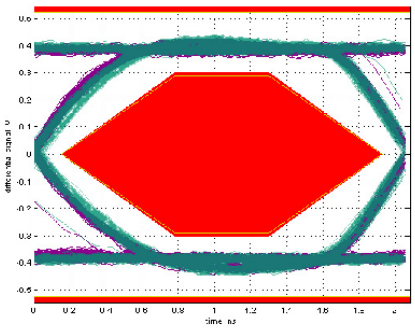


Figure 6 shows both images overlaid with the majority of the differences in the leading edge of the image. This is where the rising and falling edges show a lowering of the signal edge rate by approximately half the width of the jitter. The purple trace is the true measurement, and the green overlaid trace is the same device with 2 pF of capacitance added to the test fixture.

Figure 6. Edge Rate Change Due to 2 pF Capacitance



The signal is not only affected in the rise time but also with a slight increase in jitter. If the design were to add up to 8 pF, it would start to show signs of eye violations. When inductance is added to the traces, the signal has an overshoot and may round off both the top and bottom of the eye.

Items that affect this measurement can range from trace impedance to the connector that is used on the device. When you use connectors that are not certified USB connectors, verify that the impedance effects of these connectors meet the USB specification.

Cabling Issues

When measuring the signal quality, another area of concern is in the connections that are made. If you use a test fixture with an A receptacle and a device with a mini B connector, the standard four-inch cable requires an adapter to connect the devices. This adapter introduces extra connectors in the signal path.

This type of measurement is more critical when the series impedance is near the limits of the USB specification. Figure 7 shows such a device measured with an adaptor that has a mini B connector on one end and an A connector on the other. When a standard four-inch cable is used (B connector to an A connector) along with an adaptor to convert the mini B receptacle to the B connector, the image shown in Figure 8 is produced.

Figure 7. Signal near the USB Limits for Series Impedance

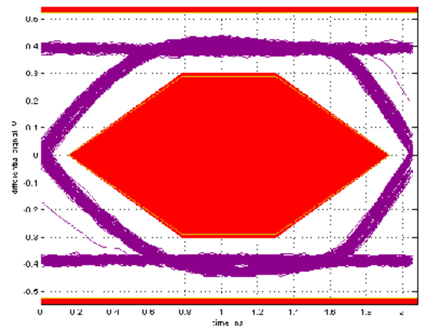
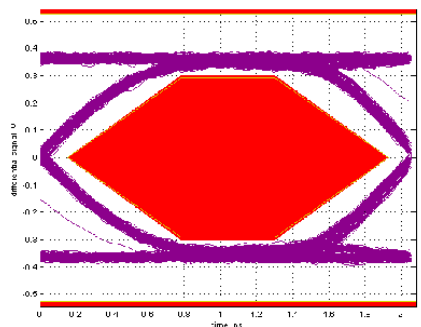
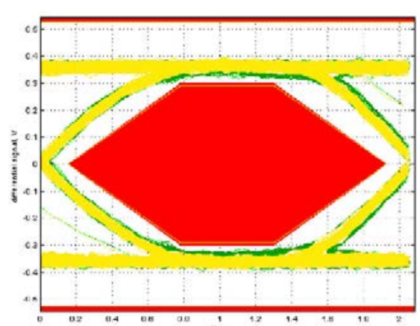


Figure 8. Standard 4-Inch Cable with Adaptor



Because of the converters, these extra connectors lower the margin around the violation area. Minimizing the connections in the setup helps acquire a true signal quality measurement. Figure 9 shows the two images overlaid. In this figure, the yellow trace is the true reading, and the green trace is the result of multiple connections through the use of adaptors. These adaptors cause a decrease in the amplitude and lower the margin around the violation area.

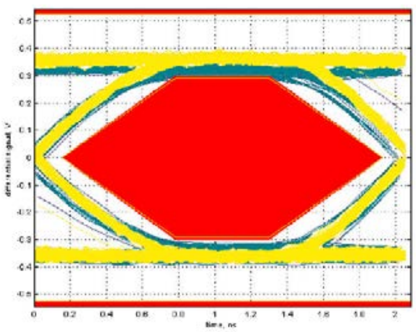
Figure 9. Extra Connector in the Test Path



Calibration Issues

Another potential problem is failure to calibrate the scope probes. When using lab equipment, people often forget very basic things such as the calibration of probes. If the probes are outside the calibration temperature range or just have not been calibrated for a long period of time, you should calibrate them. Figure 10 shows a case in which the probes are not properly calibrated. The blue-green traces are the uncalibrated traces, and the yellow traces are taken after the probes were calibrated. This figure also shows that both the jitter and the amplitude are affected by the calibration of the probes.

Figure 10. Differences from Probe Calibration



Summary

When measuring signal quality, follow the procedures on the USB-IF web site. Then, if problems occur, check items such as adapters that have been placed into the signal path. Make sure the proper measurement point is used, along with the proper cable length. Each of these can induce issues that can cause the signal quality to appear to be in violation of the USB specification.

Also, look for multiple problems. Some issues induce only a small error, but can add up and cause failures.

About the Author

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**	841540	YIS	03/16/2007	New application note.
*A	3169691	LRDK	02/10/2011	Changed name of document. Performed copyedit. Applied new template.
*B	3198792	AASI	03/17/2011	Changed the title.
*C	4337818	PRJI	04/09/2014	Updated in new template. Completing Sunset Review.

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