Testing USB 3.0 on the Physical & Protocol Layers

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Summary
The Universal Serial Bus (USB) was initiated in 1996. Since then it has undergone major revisions to levels 1.1, 2.0 and now 3.0. Each revision substantially increased the rate of data transfer.

USB 2.0 had data rates of 1.5 Mbit/s (Low Speed mode), 12 Mbit/s (Full Speed) and 480 Mbit/s (High Speed). In USB 3.0, known as Super Speed (or SS) USB, the four previous transfer types (bulk, control, isochronous, and interrupt) remain, as does the concept of an endpoint. However, the physical electrical hardware for the interface and the data handling of the USB 3.0 protocol are completely different from that of the USB 2.0 standard. USB 3.0 is actually closer to PCI Express Gen 2 in its implementation than to USB 2.0. Because USB 3.0 and PCIe Gen 2 are both 5-Gbit/s standards and share some similarities in electrical hardware, it is not surprising to find that the testing problems in both are similar. One of the biggest changes compared to testing USB 2.0 is that the USB 3.0 standard requires receiver testing in addition to transmitter testing.

The Evolution of Test Equipment
In physical-layer testing of USB 1.0, 1.1 and 2.0, an oscilloscope such as a LeCroy WaveSurfer is an excellent tool. It can even decode USB HSIC (High-Speed Inter-Chip) data. But the faster data rates of the USB 3.0 standard call for a scope with higher sampling rate and bandwidth, such as a WavePro or WaveMaster. Of course a WavePro or WaveMaster also is able to test the slower versions of USB. If needed, they can even capture and decode USB 2.0 and 3.0 simultaneously. On the protocol layer, LeCroy’s Voyager M3i is its sixth generation of USB protocol test equipment. It has native USB 3.0 connectors that bifurcate USB 3.0 and 2.0 signals and allows concurrent recording of the two protocols. It is also available in a USB 2.0-only configuration that is upgradable to USB 3.0.

Testing USB 3.0 Receiver Signals
Receiver testing (as mentioned above) is especially challenging for USB 3.0 because the Host (for example a computer) and Device (for example a memory stick or camera) operate with two different clocks running independently of each other. The Host and Device transmit data with embedded SKP symbols and by injecting and removing additional SKP symbols, each side can control and match the other side’s clock speed.
This challenges receiver testing because the addition and removal of SKP symbols in the data stream means that data sent out of a BER tester is always different from data received for BER comparison. Thus the requirement for protocol awareness to filter the SKP symbols prior to BER comparison for receiver testing is critical. The LeCroy PeRT3 (Protocol Enabled Receiver Tester) is designed specifically to handle this requirement. This process is illustrated in Figure 1. The PeRT3 is also capable of operating as a jitter generation enabled Bit Error Rate Tester.

Figure 1: This block diagram illustrates the process of USB 3.0 communication. Both the computer and device can insert or remove SKP commands. The LeCroy PeRT3 error detector has protocol awareness which allows it to perform receiver testing under these conditions.

Examples of Testing USB 3.0 Transmitter Signals

When testing the first iteration of any device that incorporates communication busses it is a good idea to use an oscilloscope to look at the physical-layer signals. An oscilloscope will show signal features such as overshoot, reflections, crosstalk, glitches and other physical-layer problems that may only show up as occasional error messages of unknown origin on the protocol layer. An example of the capture and decode of a USB 3.0 physical-layer signal is shown in Figure 2.
Figure 2: A USB 3.0 data stream is captured at 20 GS/s and shown in the upper trace. The lower trace is a zoomed portion. The user can see the waveshape of the raw data samples as well as the decoded data. The table at the bottom allows the user to find interesting parts of the waveform.

The upper trace has too much information to reasonably interpret except to see that the link is active and sending data. The table at the bottom of the display gives a short-hand description of the captured transmission. Note there is a scroll bar on the right-hand side of the table. Each piece of the transmission is characterized in the table by its time of arrival, type (such as Idle, Skip, DPH, and DPP) and details (such as address, endpoint, sequence number and data values). The user can find interesting portions of the signal and click on the corresponding line of the table. The scope will display the physical shape of that portion of the signal, along with its decoding, in the center of the screen. In Figure 2 this zoomed detail shows the data packet header including address, sequence number and endpoint number. Another way to find portions of the signal which are interesting is to use the 14.1 Gbit serial data trigger which is available in the LeCroy WaveMaster and LabMaster oscilloscopes. This is a true hardware NRZ serial data pattern, symbol, and primitive trigger. A specially-programmed hardware FPGA constantly monitors for specified events in real time and triggers the oscilloscope on every occurrence found.

Typically, a serial-data standard has a list of physical-layer specifications such as voltage level, rise time and signal shape stability (such as jitter and eye pattern) which the signal must meet. This list can be fairly long and complicated to test. A program such as QualiPHY for physical-layer “qualifying” of a USB 3.0 device is a very useful compliance test suite that will verify the device’s conformance to applicable electrical standards. An engineer can perform these tests in the lab and then bring a product to a USB 3.0 workshop or certified testing where the same type of LeCroy equipment can be used to perform the final certification. Tests include eye diagrams, characterization of the SSC (spread-spectrum clock), jitter (total, random and deterministic) and a wide range of other physical-layer tests. These tests were originally written by Intel and are called “sigtest”.
To generate the type of eye patterns shown in Figure 3, an oscilloscope can acquire a long, continuous waveform, recover the embedded clock, slice the data at the end of each bit and display all the bits on the screen. Often protocols differentiate between signal performance in the case of a “transition bits” (the ones on the right-hand side of Figure 3) and non-transition bits (those on the left in Figure 3).

![Figure 3: Bits which are not preceded by transitions appear on the left side of the display while transition bits appear on the right side. Note also that many parameter values have been computed concerning the physical shape of the signal](image)

Many measurements can be made using both the eye diagrams and the long stream of data which is retained in the memory of the scope. The lower portion of Figure 3 lists measurements which have been made on the captured signal. The measurements to confirm a device meets USB 3.0 physical layer requirements are computed by the Intel sigtest algorithms. The sigtest dll is uniquely incorporated in LeCroy’s USB 3.0 tests such that the user can see sigtest results “live” on the scope screen in real time.

Once everything looks good on the physical level, it is time to check the proper transmission of data on the protocol layer. In addition to building six generations of USB protocol testers, LeCroy is also a leader in physical and protocol-layer testing of PCIe Gen 2 signals. This technology enables industry-leading testing of USB 3.0 signals on both the physical and protocol layers.

**Summary**

There are a variety of oscilloscopes which can capture the physical layer USB 3.0 signal. LeCroy offers a uniquely powerful solution for transmitter testing which verifies performance on the physical and protocol layers. An even more important consideration is the new requirement for receiver testing. LeCroy has the sole test solution which can test receivers with USB 3.0 protocol awareness and receiver asynchronous testing. For further information, consult [www.lecroy.com](http://www.lecroy.com).