USB 2.0 Compliance Testing

How to design, test and debug your products for success.

Jim Choate
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Outline

• USB 2.0 Basics
• Agilent’s USB 2.0 Solution
• Design challenges
• Common compliance pitfalls
• What are Waivers?
• Advanced Debug and Testing with the 9000 series Oscilloscope
• Conclusion / Q&A
USB2.0 Basics – General

Universal Serial Bus (USB) 2.0:

- All USB specifications are owned by the USB-IF (Implementers Forum, Inc.)
- USB2.0 is an EXTENSION of USB1.1
- USB-IF states USB2.0 is the CURRENT ver. of the USB. USB1.1 is available for historical reference only.

USB 2.0 Has 3 Transfer Speeds
- Low Speed (LS) = 1.5Mbps
- Full Speed (FS) = 12Mbps
- Hi-Speed (HS) = 480Mbps

USB 3.0 Has 1 Transfer Speed
- Superspeed (SS) = 5Gbps

For more details on the USB 3.0 specification refer to the webinar: USB 3.0 Superspeed PHY Testing Challenges: Verify your 5Gbps design to the specification

http://www.techonline.com/learning/webinar/215400047
USB2.0 Basics - Architecture

- **USB Architecture**
  - Differential Signal
  - Max USB cable length of 5m
  - Up to 5 Hubs
  - Data from PC to the device is called **Downstream**
  - Data from device to PC is called **Upstream**

**Diagram:**
- Host / System
- Hub
- Devices
- USB Cable + Shield
  - \( V_{BUS} \)
  - \( D^+ \)
  - \( D^- \)
  - Ground
USB2.0 Basics - Signal Rates & Levels

<table>
<thead>
<tr>
<th></th>
<th>Low Speed</th>
<th>Full Speed</th>
<th>Hi-Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sig Rate</td>
<td>1.5Mbps</td>
<td>12Mbps</td>
<td>480Mbps</td>
</tr>
<tr>
<td>Sig Level</td>
<td>3.3V</td>
<td>3.3V</td>
<td>400mV</td>
</tr>
<tr>
<td>Rise and Fall Times</td>
<td>75ns &lt; Tr &lt; 300ns</td>
<td>4ns &lt; Tr &lt; 20ns</td>
<td>Tr &gt; 500ps*</td>
</tr>
</tbody>
</table>

*High Speed USB edge rate compliance measurement method and pass/fail criteria have been changed. This will be explained in the compliance requirements section.*
Host test requirements

High-Speed System Test Requirements

The following must be successfully completed for Systems:

- Full-Speed Electrical Tests
- High-Speed Electrical Tests
- Interoperability Tests
- Functional Tests
- Submission of completed System Checklist

http://www.usb.org/developers/docs#comp_test_procedures

USB-IF Compliance Test Procedures

Compliance Test Procedures for High-Speed USB Products

Each set documents the high-speed electrical tests required for the compliance program. Please determine which set of procedures meet your need based on your test equipment choice. NOTE: Some of the following approved test solutions use proprietary software to assess signal quality and inrush current events. The only official analysis tool for certifying signal quality and inrush current is USBET20 published by the USB-IF. Please be sure to run captured signal quality and inrush current test data through USBET for an official assessment of the measurement.
With 480Mbps, higher quality electrical signals are essential. The market requires all USB products meet the specification by passing the tests. 

The **USB 2.0 Compliance Tests** are mandatory. When you pass the tests, you can:

- Use the High Speed USB 2.0 Logo
- Be listed on the Integrator’s List

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**The HS Logo**

**The FS/LS Logo**

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Compliance Workshop Test Suites

- **USB 2.0 Interoperability Gold Suite**
  - Interoperability with “gold tree” components
  - USB Command Verifier

- **USB 2.0 Electrical Test Suite**
  - Signal Quality Testing
  - Receiver Testing
  - Packet parameters
  - EVM Test Suites

- **USB 2.0 debug suite**

- **1:1 Interoperability System Suites**
  - Staffed and equipped by product vendor
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Agilent USB 2.0 Solution

• Test all aspects of your USB product using Agilent USB test solutions

• At its heart: **N5416A USB 2.0 Compliance Test Software**

Additional USB testing products:
• N5417A USB OTG Test Fixture
• N5464A/B USB Protocol Triggering and Decode
• E2649A High speed test fixtures
• E2646A Low/Full speed test fixture
• InfiniiMax probes
• Infiniium 90000 and 9000 series scopes
USB Transmitter testing

The world's most popular USB test solution joins with the Infiniium 9000 series scope
• Same automation and ease of use
• NEW protocol analysis and triggering

NEW: Infiniium 9000 series Oscilloscope
Transmitter electrical test coverage

Application automates all compliance tests and provides summary of all testing performed.
Receiver Testing

SE0_NAK Mode

- Test mode SW places DUT into RX test mode
- Scope application auto adjusts amplitude and packet types to test RX

- N5416A USB test application measures results automatically with histogram

Connection diagrams and integrated test procedures make setup and execution of testing simple

Industries only automated RX test solution

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Receiver Jitter tolerance testing

- Why Test USB 2.0 jitter tolerance?
- The N5990A option 102 provides unprecedented USB 2.0 receiver device test coverage.

![N5990A USB test solution](image1)

![USB 2.0 jitter tolerance test result](image2)
Completing the Solution: Fixtures and probing

- E2649A High speed USB compliance test fixture set

- 9000 Series ships standard with N2873A probes

- E2646A SQiDD fixture
  - FS/LS Signal quality, Inrush

- Automated drop/droop

- InfiniiMax Differential Probes:
  - The world’s best probing system
  - The right BW for the job

- N2774A Current Probe

- N5417A USB OET

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Design Challenges

• HS Signal Integrity
  – Trace and Driver Impedance
  – Proper decoupling

• Current Draw
  – Operating current
  – Unconfigured current
  – Suspend current

• Receiver Testing

• Test Modes
USB Impedance Spec Explained

- What does the spec say?
- High-Speed Zo
  - \( Z_{\text{cable}} = 90 \pm 15 \% \)
  - \( Z_{\text{HSTERM}} = 80 \text{ to } 100 \text{ ohms differential} \)
  - \( Z_{\text{HSTHRU}} = 70 \text{ to } 110 \text{ ohms differential} \)
- FS Driver Impedance
  - Not HS capable: \( Z_{\text{drv}} = 28-44 \text{ ohms} \)
  - HS Capable: \( Z_{\text{drv}} = 40.5-49.5 \text{ ohms} \)
USB Impedance Measurement

- 86100C DCA-J paired with 54754A Differential TDR module

Test Bed PC

TDR Test Fixture

USB Connector reference location

ZHSTHTRU 110
ZHSTERM 100
BGA discontinuity 80

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Proper Decoupling

- Prevent signal integrity problems by understanding how to properly decouple power and grounds on your chip
- Bulk vs filter capacitance
  - Electrolytic Bulk Capacitance
    \[ C = \frac{I}{(dV/dt)}, \text{ size in uF depends on max transients} \]
    For example: \( I_{\text{peak}} = 3\text{A}, V_{\text{nom}} = 3.3\text{V}, 10\% \text{ V tolerance}, 10\text{us} \text{ delta time} \)
    \[ C = 3\text{A} \times \frac{10\text{us}}{3.3\text{V} \times 0.10} = 90.9\text{uF} \Rightarrow \text{use 100uF Bulk cap}^* \]
  - Ceramic High Frequency Capacitance
    Typical values are 0.01uF, 0.1uF to 1uF depending on filtering frequency needed

*note: Devices are required to limit inrush on hot attach by limiting load to 10uF in parallel with 44ohms.
Proper Cap Selection and routing

- Proper route/placement of capacitors
- Choose the right kind of capacitor depending on its purpose
  - NPO (lowest ESR), X7R, X5R, Y5V

**Standard method of Cap routing**

- Vcc
- Gnd

**Lowest pad inductance**

**Much smaller ground loop**

[Diagram showing correct and incorrect capacitor placement]
Measuring Device Inrush Current

- Inrush is a function of device load on hot attach and hub port voltage/ESR

- Spec limit = ~50uC
- Inrush waiver built in to scripts
- Limit inrush events by using sequential power on for controller logic

N2774A Current Probe
Rise and Fall time

- As designs move to smaller process technology the edge rates are increasing
- USB 2.0 specification limits RT/FT to 500ps as measured at 10%-90%
- Errors in consistency of these measurements due to:
  - Shape of signal edge
  - Noise
  - Amplitude variations
  - Probe peaking due to insufficient BW
- Slow corners give 10/90 rise time that is slower than actual edge rate
- RT/FT faster than 400ps have observed
- Oscilloscope AND Probe BW must be at least 2.5Ghz to accurately observe and measure these fast edges
Slew rate RT/FT methodology

10-90% Method
small $\Delta V$ of 10% and 90% = large $\Delta RT/FT$

Refer to http://compliance.usb.org/index.html for the latest compliance test updates
Test Modes

- Test_SEO_NAK
  - Receiver test mode
- Test_J
- Test_K
- Test_Packet
- Other tests driven by HSET using normal USB device requests
  - Example: suspend, resume, reset, etc
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Compliance Pitfalls

- Failure to properly support USB suspend
  - Low power state required of all devices
    - < 2.5mA (spec says 500μA = auto waiver)
- Improperly report bus vs self powered if battery powered
- RX Sensitivity failure vs Squelch
- Backdrive
- SW Driver loading sequence
- Test mode not implemented
Compliance Pitfalls – RX Test

- Misinterpretation of RX sensitivity and Squelch requirements has caused considerable confusion and discrepancy in test results.
- As you can see from the waveform at the right the artifacts on the transition and non-transition bits due to reflections are significant.
Compliance Pitfalls – RX Test

• Agilent uses a histogram function to standardize measurement of sensitivity and squelch thresholds
• Other solutions require manual placement cursors based on “flat spot” on waveform
• This automation greatly improves consistency of test results at workshops and test labs
Receiver Sensitivity (EL_17) and Squelch (EL_16)

Please note that it is the combination of EL_16 and EL_17 that validates the "transmission detection envelope" defined in section 7.1.4.2 of the USB 2.0 Specification.
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Waivers

- Some failures are due to measurement errors or non-critical failures
- It is important to understand how the USBIF handles some types of failures
- Automatic waivers
  - Always granted
  - May be built into test tools
- Conditional waivers
- Permanent waivers

Non-Critical = No End User Impact
Waivers

• The criterion for granting a waiver varies greatly and tends to be specific to the device. Some general factors used to consider granting or denying waiver requests are:
  – Violation's effect on end-user experience
  – Violation's affect on other USB product
  – Market share of affected product
  – Cost of corrective action to the vendor

• Waiver decisions are at the discretion of the USB-IF Compliance Chairman and members of the Certification Review Board.
Waivers

- Products with waivers post to IL and receive logo usage rights
- General USBIF rule is waivers are not published
- Design to specification not to waiver limits
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USB Protocol Triggering and Decode

- Industries first on-scope USB protocol triggering and decode capability
- Debug protocol issues
- Trigger on different packet types
- Test embedded designs
- Isolate logical from electrical issues
Testing a Complex Bus Topology with the Agilent Infiniium 9000 Scope

In today’s world many subsystems are tightly integrated into multi function Embedded products:

- USB 2.0 interface
- IDE parallel interface
- SATA interface

Best 3-in-1 Instrument

Scope:
- Up to: 4 GHz BW, 20 GSa/s, 1 Gpts
- Powerful triggering
- Packed with rich features/analysis.

Logic Analyzer:
- 16 integrated channels
- 128 Mpts std memory, up to 2 GSa/s
- Precise analog + digital triggering

Protocol Analyzer:
- I2C, SPI, CAN, RS-232/UART, USB, PCIe, 8B/10B
- HW trigger and decode
- First scope with multi-tab viewer
- Phy to protocol time correlation

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Debugging multiple bus interfaces

- In the **past** each interface would need to be tested separately often with different types of equipment.
- **Today** you can use the 9000 series oscilloscope to test it all with a single instrument.

To LA

Testing and debugging a USB 2.0 to IDE and SATA adapter

LA on IDE

Diff probe on USB2

E2649A USB test fixture
Data read latency shown by read arrows.
Advanced protocol triggers for debugging

The serial search and real time HW trigger capabilities open a new realm of debug capabilities.
Summary

• USB compliance testing has grown over the years to address real product problems
• Agilent has been a key partner with the USBIF in the growth and phenomenal success of the USB compliance test program
• Agilent offers everything you need to test and certify all of your USB products
• The N5416A USB Test Option offers the most accurate and highest level of USB test automation in the industry today
• Agilent’s N5990A test automation sw takes testing to the next level with full USB 2.0 jitter tolerance characterization
• The Infiniium 9000 Series is the best 3-in-1 instrument with scope, logic analyzer, protocol analyzer test capabilities

Agilent Delivers the Worlds Best USB Test Solutions
Additional Information

- Go to [www.usb.org](http://www.usb.org) to get additional information on certifying your USB products
- For specific updates to compliance requirements go to [http://compliance.usb.org/index.html](http://compliance.usb.org/index.html)
- Agilent Application Note: Debugging USB 2.0: It’s Not Just a Digital World
- Go to [www.agilent.com/find/usb](http://www.agilent.com/find/usb) to find more about Agilent Superior Signal Integrity Solutions and Probing for Your Applications
Miscellaneous topics

- Workshops
  - Very good place for hands on training
  - Talk to experts
- USBET – required for compliance, integrated into Agilent’s sw solutions
- HSET tool issues – supports Win7/8 with by disabling signed driver requirement (F8 on boot)
- Fixture standardization
  - USBIF will soon require probe less test method – using only SMA probing.
  - Agilent fixtures support this now.