USB3.0 Tx/Rx Electrical Compliance Test Procedure

Version 0.98
September 23, 2011

Referencing USB3.0 Electrical Test Specification v0.9
LeCroy MOI for USB3.0 Rx Test v0.98
(Using LeCroy SDA813Zi-A and PeRT³ Eagle)
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MODIFICATION RECORD

Feb 23, 2010 Version 0.7
(Initial Release Draft)
David Li

March 18, 2010 Version 0.8
(Revised based on the latest Electrical spec draft)
David Li

June 9, 2010 Version 0.9
(Revised based on the latest Electrical spec draft)
David Li

June 30, 2010 Version 0.95
(Revised based on the latest updates to the Electrical Spec draft and to include Oscilloscope measurements using SigTest)
David Li

Aug 3, 2010 Version 0.96
(Revised based on the latest updates the USB3.0 Workshop #72 – Eye height measurement method was modified – Host jitter calibration and Host Rx testing setup diagrams are added)
David Li

Feb 22, 2011 Version 0.97
(Revised based on the latest updates the USB3.0 Workshop #76 and using new external 2 tap de-emphasis box)
(Added LFPS Test procedures)
David Li

Sept 12, 2011 Version 0.98
(Revised based on the latest updates the USB3.0 Workshop #78 and adding Tx compliance testing procedure)
David Li
INTRODUCTION
This document provides the method of implementation for testing the receiver of USB3.0 Devices and Host as described in receiver testing portion of the USB3.0 Electrical Test Specification V0.9. A current copy of this specification can be found at www.USB.org
ACKNOWLEDGMENTS

Creation of this document:
   David Li (LeCroy Corp.)

Review and Comments:
USB3.0 Electrical Transmitter Testing:

Detailed Test:

**Purpose:** Verify that the Device Under Test (DUT) meets the jitter tolerance requirements per USB3.0 specification requirements

**References:**
- USB3.0 Base Specifications
- USB3.0 Electrical Test Specifications

**Resource requirements:**
- See appendix A

**DUT requirements:**
- DUT must be able to send LFPS signal after power up
- If DUT does not detect TSEQ after power up, DUT must be able to enter transmit compliance mode and be able to accept LFPS Ping command to transmit CP0 and CP1

**Discussion:**

USB3.0 Transmitter Testing involves the following test items:
- LFPS testing
- SSC* waveform testing using CP1
- Slew Rate testing with CP1
- Random Jitter measurement with CP1 (Sigtest needs clock pattern based RJ to calculate TJ)
- Total Jitter and Deterministic Jitter measurements with CP0
- Eye Margin testing with CP0

All Transmitter Tests are automated through the LeCroy QualiPHY software which includes setup and connections diagrams and wizard guided instructions.

NOTE: SSC is not required to be enabled on a DUT to pass compliance. But if SSC is enabled, it must satisfy the USB3.0 compliance requirements.

The following document describes the test setup, necessary resource requirements, and a step by step test procedure to perform USB3.0 transmitter test.
Test Procedure:
Setup QualiPHY for USB3.0 Transmitter Testing

1. Open QualiPHY software from the Scope GUI

2. Under Standards, select **USB3.0 SS**

3. Under Configuration, select **Device Scope only (Tx Tests)** for device testing and **Host Scope only (Tx Tests)** for host testing

4. Run test
Note: default USB3 test script will ask the user to deskew cables with wizard guided instructions. This can be disabled in QualiPHY under Variable Setup and Deskew Measurement Mode by selecting User Defined.

a. LFSP Testing
1. Configure the setup as shown in Figure XX.
2. Follow the wizard guided instructions and power off the DUT

3. Power on the DUT, now the scope trigger has been setup and will automatically capture the first 6 LFPS burst for measurements

b. SSC Testing (not required if DUT SSC is disabled, but if SSC is enabled, testing is required)
   1. QualiPHY will ask for DUT to send out CP1. This can be done by controlling the PeRT3 Eagle (also used for Rx testing) to send out LFPS Ping signal and command the DUT to switch from CP0 to CP1

2. Configure the setup as shown in Figure 2.

NOTE: On Device Test Fixture 2, only use the upper port, the lower port is not connected!
3. Power on the PeRT3 Eagle and select **USB3.0** under Protocol, then press **Apply**

4. Under Initialize, select **Custom Sequence**

5. Under Sequence, select **USB3.0 Tx Test Init**

6. Go to Channel 1 tab and enable the signal to 1000mV

7. Press **Connect** (this is to initialize the instrument prior to transmitting LFPS Ping)
8. Under Sequence, select **USB3.0 Tx Test Ping**

9. Press **Connect** (minimize the PeRT3 software and the Scope software, you should observe the signal in the scope changing patterns every time you press Connect)

10. After DUT is set to send CP1 (1010 patterns), press OK in QualiPHY to continue the test. SSC will be measured first
c. Slew Rate measurements

1. Since the DUT is already sending CP1 pattern, QualiPHY will automatically make slew rate measurements. The user does not have to do anything.

![Slew Rate measurement graph]


d. RJ measurements with CP1

1. Since the DUT is already sending CP1 pattern, QualiPHY will automatically make RJ measurements. The user does not have to do anything.

e. TJ and DJ measurements with CP0

1. QualiPHY will prompt the user to command the DUT to transmit CP0 (this can be done through sending LFPS Ping 8 times by using the PeRT3 Eagle, or can be done by power cycling the DUT, whichever one is easier)
2. Press OK after verifying DUT is sending CP0 (scrambled PRBS 11 pattern)

3. QualiPHY will automatically make the required TJ and DJ measurement

f. Eye Measurements

1. Since the DUT is already sending CP0 pattern, QualiPHY will automatically make Eye Diagram and measurements. The user does not have to do anything.

At the end of the test, QualiPHY will ask the user to save the test report. The report can be saved in PDF or HTML formats.
USB3.0 Electrical Receiver Testing:

**Detailed Test:**

**Purpose:** Verify that the Device Under Test (DUT) meets the jitter tolerance requirements per USB3.0 specification requirements

**References:**
- USB3.0 Base Specifications
- USB3.0 Electrical Test Specifications

**Resource requirements:**

See appendix A

**Jitter Source Calibration:**

- See appendix D for Oscilloscope setup to measure the following:
  - De-Emphasis
  - Signal Amplitude
  - Random Jitter
  - Sinusoidal Jitter

**Discussion:**

Testing USB3.0 DUT receivers involves 3 main steps:
1) Signal Source Calibration
2) Loopback Initialization
3) Tolerance Testing
   a. LFPS Testing
   b. Jitter Tolerance Sweep

A product must run error free in the specified measurement depth with the required amounts of signal degradation applied.

The following document describes the test setup, necessary resource requirements, and a step by step test procedure to perform USB3.0 receiver test.
Test Procedure:

Step 1: Signal Source Calibration

(The following is a manual procedure for calibration; for the automated calibration procedure, proceed to page xx)

Calibration of Signal Source must meet the parameters described in Table 1:

<table>
<thead>
<tr>
<th>Calibration Parameters</th>
<th>Device Setup</th>
<th>Host Setup</th>
</tr>
</thead>
<tbody>
<tr>
<td>De-emphasis</td>
<td>3.0dB</td>
<td>3.0dB</td>
</tr>
<tr>
<td>Random Jitter (RJ) ± 10% RMS</td>
<td>2.4ps</td>
<td>2.4ps</td>
</tr>
<tr>
<td>Sinusoidal Jitter (SJ) +0/-10%pk-pk</td>
<td>33Mhz – 40ps</td>
<td>33Mhz – 40ps</td>
</tr>
<tr>
<td></td>
<td>20Mhz – 40ps</td>
<td>20Mhz – 40ps</td>
</tr>
<tr>
<td></td>
<td>10Mhz – 40ps</td>
<td>10Mhz – 40ps</td>
</tr>
<tr>
<td></td>
<td>4.9Mhz – 40ps</td>
<td>4.9Mhz – 40ps</td>
</tr>
<tr>
<td></td>
<td>2Mhz – 100ps</td>
<td>2Mhz – 100ps</td>
</tr>
<tr>
<td></td>
<td>1Mhz – 200ps</td>
<td>1Mhz – 200ps</td>
</tr>
<tr>
<td></td>
<td>500khz – 400ps</td>
<td>500khz – 400ps</td>
</tr>
<tr>
<td>Eye Height +10/-0% pk –pk</td>
<td>145mV</td>
<td>180mV</td>
</tr>
<tr>
<td>Total Jitter</td>
<td>85-90ps</td>
<td>85-90ps</td>
</tr>
</tbody>
</table>

Table 1
Test Calibration Setup:
- Setup the test equipment as described in Figure 1a for De-emphasis Calibration:

![De-emphasis Calibration Setup](image)

- Setup the test equipment as described in Figure 1b for Device calibration and Figure 1c for Host calibration:

![De-emphasis Calibration Setup (Device)](image)

NOTE: On Device Test Fixture 2, only use the upper port, the lower port is not connected!
NOTE: On Device Test Fixture 2, only use the upper port, the lower port is not connected!
Signal De-emphasis Calibration:

NOTE: If the LeCroy External De-emphasis box is available, follow the de-emphasis calibration procedure. Otherwise, follow the Pre-emphasis calibration procedure. Both method satisfy compliance test requirements.

De-emphasis calibration procedure:
- Setup the Generator to output proper signal and jitter:
  - Protocol: Generator Only
  - Speed: 5Gb/sec
  - SSC: OFF
  - Press Apply as shown in Figure 2
- PeRT3 Generator Amplitude = 1000mV (used as a starting point for calibration)
- PeRT3 De-emphasis setting: -3.0dB
- Set PeRT3 Pattern to: CP0

- Setup the Oscilloscope for measurements:
  - Connect PeRT3 Tx+ and Tx- to channel 1 and channel 2 of scope at shown in De-emphasis calibration setup (Figure 1a)
  - Adjust channel gain to make sure signal does not clip
  - Setup Math Function 2 to take the difference between Ch1 and Ch2
  - Set signal acquisition to 8MS at 40GS/s
  - Enable measurement VTxD DeRatio
  - Under VTxD DeRatio settings, adjust for 5Gbps
  - Take a single trigger and read the measurement (for example: VTxD DeRatio = 0.723)
  - The value you’re looking for is 3.0 dB + 5/-0% dB or 0.669 to 0.708 on the VTxD DeRatio value

Pre-emphasis setting procedure (only if De-emphasis box is not available):
- Setup the Generator to output proper signal and jitter:
  - Protocol: Generator Only
  - Speed: 5Gb/sec
  - SSC: OFF
  - PeRT3 Generator Amplitude = 1000mV (used as a starting point for calibration)
  - Set PeRT3 Pre-emphasis, Amp=4, Dur=9
  - Set PeRT3 Pattern to: CP0
Random Jitter Calibration:
- Setup the Generator to output proper signal and jitter:
  - PeRT3 Generator Amplitude = 1000mV (used as a starting point for calibration)
  - Use the calibrated De-emphasis setting from De-emphasis calibration (ex: -3.0dB)
  - PeRT3 pattern select CP1 as shown in Figure 3:
  - Start by setting PeRT3 HFRJ = 2.4ps RMS

- Setup the Oscilloscope for measurements:
  - Connect PeRT3 Tx+ and Tx- to channel 1 and channel 2 of scope as shown in Calibration Setup (Figure 1b for Device, and Figure 1c for Host)
  - Adjust channel gain to make sure signal does not clip
  - Setup Math Function 2 to take the difference between Ch1 and Ch2
  - Open Sigtest tab under Analysis in the DSO window tabs
  - Apply the following parameters in the SigTest GUI:
    - SigTest tab - Signal Source: select 1 input and DataSource = F1

  - Settings tab
    - Standard: select USB3.0 Compliance
    - Bitrate: 5Ghz
    - Jitter Filter order: Second Order
    - Corner Freq: 50kHz (in order to measure low frequency Sj)
    - Damping: 707.11e-3
    - CTLE box: check
    - The rest of the selections should be default and shown in Figure 5
**Figure 5**

- Params tab:
  - Enable Jitter Params box: Check
  - Rj(rms) In: 0fs
  - MaxPP Jitter box: Check
  - Rj(rms) box: Check
  - The rest of the selections should be default and shown in Figure 6:

![Image of Figure 5](image1.png)

**Figure 6**

- On Oscilloscope controls, press clear sweeps and single capture (8M Samples at 40GS/s)
- Record the Rj(rms) value measured in SigTest Jitter

![Image of Figure 6](image2.png)

**Figure 7**

- Go back to the PeRT3 GUI
  - Adjust the PeRT3 HFRJ until Rj(rms) measurement in SigTest Jitter reads 2.42ps ±10% RMS
  - The final HFRJ value of PeRT3 will be recorded and fixed for all future tests.

- Back to the Sigtest
  - In Params tab: input the final measured Rj(rms) value in Rj(rms) In box as shown in Figure 9.
  - This Rj value will be used for all future measurements.
Sinusoidal Jitter Calibration:

(Detailed oscilloscope panel setup is described in Appendix C)

- On the PeRT3 GUI:
  - Keep all setting from RJ calibration
  - Change output pattern to CP0

- On the LeCroy Scope SigTest:
  - Maintain all setting from RJ calibration
  - Clear sweeps and take single trigger of 8MS capture
  - Record the Max P-P Jitter value (ex, Max P-P Jitter = 46.017ps)
- Back to the PeRT3
  - Enable HFSJ to 20Mhz, 40ps

Figure 11

- Back to SigTest:
  - Clear sweep and capture single trigger of 8MS capture
  - Record the new Max P-P Jitter value (ex, Max P-P Jitter = 87.761ps)
    
    NOTE: now the difference in Max P-P Jitter before and after adding HFSJ is 41.744ps(=87.761- 46.017), this satisfies the spec requirements. The difference in Max P-P Jitter is beyond the spec requirement, we need to adjust the HFSJ in PeRT3 until Max P-P Jitter difference is within 40ps ± 5%
  - The newly calibrated jitter amplitude value is for SJ=20Mhz
  - Now repeat the Sinusoidal Jitter Calibration procedure for SJ = 50Mhz, 33Mhz, 10Mhz, 4.9Mhz, 2Mhz, 1Mhz, and 0.5Mhz
Eye Height Calibration:

- On the PeRT3:
  - Turn SSC: ON
  - Click on apply settings
- In LeCroy Scope SigTest:
  - Enable JTF by setting Jitter Filter Corner Frequency:
    - Corner Freq = 4.859Mhz

  ![Figure 13](image-url)

  ![Figure 14](image-url)

  - Clear sweeps and take single trigger of 8MS capture
  - Enable **Min Hi Margin** and **Min Lo Margin** measurements as described in Figure 15.
  - Take the different between absolute value of Min Hi Margin and Min Lo Margin

  **Example:**
  - Min Hi Margin = 22.5mV
  - Min Lo Margin = -22.9mV
  - Your eye height = abs(22.5) + abs(22.9) = 45.4mV
  - This means that the eye opening is 45.4mV over the default margin of 100mV which is equivalent to 145.4mV eye opening.
Figure 15

- On the PeRT3:
  o Adjust PeRT3 amplitude until eye height meets the 145mV for Device Channel and 180mV for Host Channel requirements

   **NOTE:** 145mV/180mV eye height requirement which is a recently added modification to the USB electrical spec. This required the presence of the Compliance channel and 3M cable. Otherwise eye will be too open!

**Total Jitter Verification:**

- With the calibrated RJ, SJ, Eye Height, Take the **Max P-P Jitter** measurement on SigTest. (ex, **Max P-P Jitter** = 87.761ps)
- Make sure the **Max P-P Jitter** measured is within 85ps < x < 100ps

**NOTE:**
Table 2 provides a sample calibration result. Please use this calibrated results as a reference for Rx Jitter Source calibration.
The following table can be used for calibration exercise:

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Measured Value</th>
<th>Calibrated Value on PeRT3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RJ - 2.42 (+-10%)</td>
<td>2.452ps</td>
<td>2.2ps</td>
</tr>
</tbody>
</table>

Test Pattern: CP1
Scope Settings (CTLE): Off
Scope Settings (JTF): Off
PeRT3 setting (SSC): Off

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Measured Value</th>
<th>TJ before SJ is on</th>
<th>TJ after SJ is on</th>
<th>Measured TJ difference</th>
<th>Calibrated SJ at Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source: SJ (+5%)</td>
<td>SJ = 50Mhz 40ps</td>
<td>46.017</td>
<td>87.337</td>
<td>41.330</td>
<td>47ps</td>
</tr>
<tr>
<td>Source: SJ (+5%)</td>
<td>SJ = 33Mhz 40ps</td>
<td>46.017</td>
<td>87.125</td>
<td>41.408</td>
<td>47ps</td>
</tr>
<tr>
<td>Test Pattern: CP0</td>
<td>SJ = 20Mhz 40ps</td>
<td>46.017</td>
<td>87.761</td>
<td>41.744</td>
<td>47ps</td>
</tr>
<tr>
<td>Scope Settings (CTLE): On</td>
<td>SJ = 10Mhz 40ps</td>
<td>46.017</td>
<td>87.543</td>
<td>41.562</td>
<td>47ps</td>
</tr>
<tr>
<td>Scope Settings (JTF): Off</td>
<td>SJ = 4.9Mhz 40ps</td>
<td>46.017</td>
<td>86.556</td>
<td>40.539</td>
<td>47ps</td>
</tr>
<tr>
<td>PeRT3 setting (SSC): Off</td>
<td>SJ = 2Mhz 100ps</td>
<td>46.017</td>
<td>146.02</td>
<td>100.003</td>
<td>110ps</td>
</tr>
<tr>
<td></td>
<td>SJ = 1Mhz 200ps</td>
<td>46.017</td>
<td>245.86</td>
<td>199.843</td>
<td>210ps</td>
</tr>
<tr>
<td></td>
<td>SJ = 500khz 400ps</td>
<td>46.017</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Eye Height = 145mV/180mV (+-10%) | 145mV | 640mV |
Test Pattern: CP0
Scope Settings (CTLE): On
Scope Settings (JTF): On
PeRT3 setting (SSC): On

Conditions
Source: TJ (20Mhz SJ) | 87.761ps |
Test Pattern: CP0
Scope Settings (CTLE): On
Scope Settings (JTF): On
PeRT3 setting (SSC): On

Table 2
Automated Signal Source Calibration Software:

NOTE: On Device Test Fixture 2, only use the upper port, the lower port is not connected!

- Configure the setup as shown in Figure XX
- Confirm that the PeRT3 software is closed
- Press on Auto-calibrate
- After the calibration process is complete, press on Create Script and save the script for Compliance testing.
Step 2: DUT loopback Initialization

(Detailed initialization sequence is described in Appendix D)

- Connect the test equipment as illustrated in Figure 16 for Device testing

**Rx Test Setup (Device)**

**Figure 16**

NOTE: On Device Test Fixture 2, only use the upper port, the lower port is not connected!

- Connect the test equipment as illustrated in Figure 17 for Host testing

**Rx Test Setup (Host)**

**Figure 17**

NOTE: On Device Test Fixture 2, only use the upper port, the lower port is not connected!
- Power off the PeRT3 and close the PeRT3 software and power off the DUT
- Power on the PeRT3 hardware and wait for 30secs until the Green/Red LED lights on PeRT3 are off
- Open the PeRT3 software and the software will automatically detect the hardware. Wait until the software completes synchronization (30sec to 1minute)
- In the Main tab, select USB3.0 under protocol, Select SSC to be on
- Press Apply and wait for the logic to be loaded
- Under DUT Initialization, select the proper direction (Device or Host)
- Select Loopback for Initialize, Default for Sequence, Bit Errors for Count

![Figure 18](image)

**If using De-emphasis box:**
- Go into Channel 1 setup and set the following parameters;
  - Enable each field by clicking on the small circle on right bottom side.
  - Signal amplitude = 1000mV
  - De-emphasis = 3.0dB
  - HFRJ (on the right side) = 2.4
  - HFSJ 1: freq = 20Mhz, Amp = 45ps (you can type in the values by clicking on the numbers field)

**If using Pre-emphasis solution:**
- Go into Channel 1 setup and set the following parameters;
  - Enable each field by clicking on the small circle on right bottom side.
  - Signal amplitude = 700mV
  - Pre-emphasis: Amp=4, Dur=9
  - HFRJ (on the right side) = 2.4
  - HFSJ 1: freq = 20Mhz, Amp = 45ps (you can type in the values by clicking on the numbers field)

- Check the DUT and make sure the DUT is in powered off (by confirming the 5V power support to Device Fixture is not connected)
- Go in the Main Tab, then press Connect and observe DUT status (status should show “waiting for DUT”)
- Power up the DUT (by connecting the Device Fixture)
- At this point, if the DUT Status is “signal locked” and the status light of channel 1 is green, then proceed to next step
Otherwise DUT have failed Rx Compliance, refer to appendix D for DUT loopback initialization sequence and troubleshooting
Step 3: Tolerance Testing

LFPS Testing (TBD)

Jitter Tolerance Sweep

If you have performed Rx calibration using USBAutoCal software, then follow the next steps, otherwise proceed to “If you calibrated the Rx jitter sources manually, follow the procedure below”:

- In the PeRT3 GUI, import the calibrated test script
- Right click on the test script and select Run Test
- The compliance test will run automatically and open the test results

If you calibrated the Rx jitter sources manually, follow the procedure below. Otherwise proceed to Observe Results:

- In the PeRT3 GUI, go to test scripts and open “USB Compliance”
- Inside the test script, apply the calibrated Signal Amplitude, Pre-emphasis, Rj and Sj values
- Run the opened test script by right click on the test script and select Run Test

- Test result will load automatically
- In the PeRT3 GUI, go to Analysis Tab and Select Scatter chart view:
**Observe Results:**
- Right click on the test result and select “Spreadsheet View” for Graph Type
- If the column under Errors read all Zeros, this DUT has passed the Electrical Compliance Rx test

**Note:**
Is some cases, the DUT might loss lock when Jitter source change from 1Mhz to 500khz point, and the 500khz point will fail. It is acceptable to restart the test with 500khz enabled prior to loopback initialization and continue the test of 500khz point for compliance testing.
# Index A – Resource Requirements

The resource requirements include two instruments with accessories.

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<th>Units</th>
<th></th>
</tr>
</thead>
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<tr>
<td>LeCroy SDA 813Zi-A (with PeRT3 and QualiPHY Software – QPHY USB3) - Matched SMA-SMA cables (3 pairs)</td>
<td>1</td>
</tr>
<tr>
<td>PeRT3 – 1 Channel</td>
<td>1</td>
</tr>
<tr>
<td>De-emphasis Box</td>
<td>1</td>
</tr>
<tr>
<td>USB3.0 Test fixture set from USB-IF (Sold by USB-IF)</td>
<td>1 set</td>
</tr>
<tr>
<td>a. Host Test Fixture</td>
<td></td>
</tr>
<tr>
<td>b. Device Test Fixture</td>
<td></td>
</tr>
<tr>
<td>c. Host 5inch ref Channel</td>
<td></td>
</tr>
<tr>
<td>d. Device 11inch ref Channel</td>
<td></td>
</tr>
<tr>
<td>e. Device Cal Fixture</td>
<td></td>
</tr>
<tr>
<td>f. 3M USB3.0 cable</td>
<td></td>
</tr>
<tr>
<td>g. 4inch USB3.0 cable</td>
<td></td>
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<tr>
<td>h. 4inch USB3.0 micro-B cable</td>
<td></td>
</tr>
<tr>
<td>i. Vbus Power supply</td>
<td></td>
</tr>
</tbody>
</table>

Table 3

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Appendix B – Test Setups

Pre-emphasis calibration (no channel in between PeRT3 and Scope):

De-emphasis Calibration Setup

Rj/Sj/EyeHeight calibration (reference channel and cable is applied):
Rx test setup:
Rx Test Setup (Host)

To PeRT3 Error Detector

SMA Cables

5° Trace

3M Cable

Host Fixture

Figure 26
Appendix C – Oscilloscope Panel Setup
TBD
Appendix D – DUT Loopback Initialization Sequence/Troubleshooting
TBD
Appendix E – PeRT³ Accuracy
TBD