Technical Reference

Tektronix

DPOJET Opt. USB3
SuperSpeed (USB 3.0) Measurements and Setup Library
Methods of Implementation (MOI) for Verification, Debug and Characterization

Version 3.0

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Revision History			
Version	**Issue Date**	**Pages**	**Nature of Change**
1.0	21-March-2009	All	First released MOI for USB3.0
2.0	Aug-2009	4-5, 29-33,	Updated Algorithms for new measurements.
2.1	March 5, 2010		Updated Clock Recovery BW from 10MHz to 4.9MHz.
3.0	April 21, 2010	3,5, 34-38	Updated Algorithms for SSC & LFPS measurements

Table of Contents

1 Introduction to the DPOJET USB 3.0 Setup Library

This document provides the Methods of Implementation (MOI) for making USB 3.0 measurements with Tektronix DPO/DSA70000 Series real time oscilloscopes (8 GHz models and above) and probing solutions.

DPOJET (Jitter and Eye Analysis Tools) is available on DPO/DSA70000 Series instruments. Instrument Setup files using DPOJET measurements are used to perform USB 3.0 specific measurements. DPOJET along with its associated setup files, provides transmitter path measurements (amplitude, timing, and jitter), waveform mask testing and limit testing described in the USB 3.0 specification at respective test points.

Table 1 – Supported Specifications

Spec Revision	USB 3.0 Specification Title	MOI Test Points Defined
Rev1.0	Universal Serial Bus 3.0 Specification	Informative Transmitter and Normative Transmitter

Refer to http://www.usb.org/developers/docs/usb_30_spec.zip for the latest specifications.

In the subsequent sections, step-by-step procedures are described to help you perform USB 3.0 measurements. Each measurement is described as a Method of Implementation (MOI).

For the latest version of this document and the latest USB 3.0 DPOJET Setup Library refer to www.tek.com/software, (keyword ‘DPOJET USB 3.0’).

For further reference on USB test specifications and compliance testing, consult documents offered to USB-IF members at www.usb.org.

2 USB3.0 Physical Layer - Transmitter Specifications

2.1 Differential Transmitter (TX) Eye Diagrams

Fixture-1 shows the eye mask definitions for the USB 3.0. The eye diagrams are a graphical representation of the voltage and time limits of the signal. This eye mask applies to jitter after the application of the appropriate jitter transfer function and reference receiver equalization. In all cases, the eye is to be measured for 10^6 consecutive UI. The budget for the link is derived assuming a total 10^{-12} bit error rate and is extrapolated from a measurement of 10^6 UI assuming the random jitter is Gaussian.

Referring to the figure, the time is measured from the crossing points of Txp/Txn. The time is called the eye width, and the voltage is the eye height. The eye height is to be measured at the maximum opening (at the center of the eye width ± 0.05 UI).

The eye diagrams are to be centered using the jitter transfer function (JTF). The recovered clock is obtained from the data and processed by the JTF. The center of the recovered clock is used to position the center of the data in the eye diagram.

The eye diagrams are to be measured into 50-Ω single-ended loads.

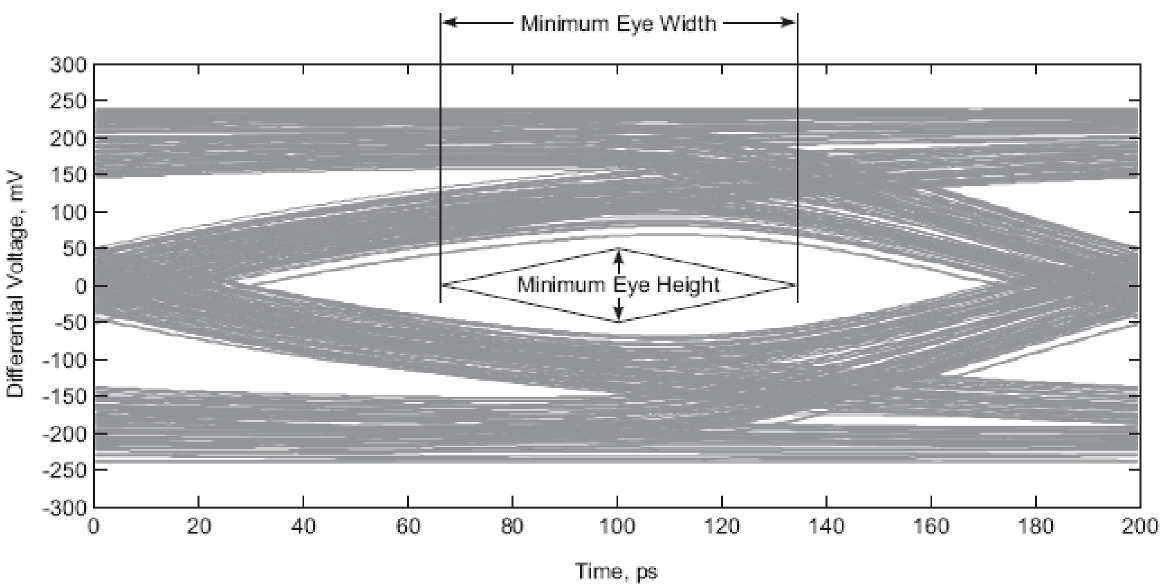


Figure 1: Generic Eye Mask

This section provides a summary of the test parameters measured in DPOJET and how they are related to the symbol and test limits in the specification.

2.2 SuperSpeed USB Setup Library

The SuperSpeed USB Setup Library consists of the following software file types.

USB 3.0 Setup Files for the DPO/DSA70000

System Location: C:\TekApplications\DPOJET\Setups\USB

Description: The USB folder contains two sub folders, Host and Device. Under these two folders, according to the test points(Normative and Informative) and DUT signals (CP0, CP1 and LFPS) setup files are created. Refer to Section 3.5 of this document for further description.

Saved Setups have been created by using the Save > Setup function of the DPO/DSA70000 Series oscilloscope. If any changes are made to the Setup file it is recommended you re-save the file as a different name so not to change the parameters in the distribution files.

USB 3.0 Channel Model Filters

Filter Library File Path: C:\TekApplications\DPOJET\Filters\USB

Description: The USB 3.0 Math Arbitrary Filters library allows you to perform SW Channel Emulation of the reference channels defined in the specification. Refer to Section 3.5 for details and a full listing of the available filters in the distribution.

USB 3.0 Waveform Masks

Mask Library File Path: C:\TekApplications\DPOJET\Masks\USB

Description: The USB 3.0 Mask library contains the waveform mask files used by the various setup files. Waveform masks are used to perform Pass/Fail template testing on the waveform eye diagram. Refer to Section 3.5 for a full listing and description of the masks available in the distribution.

USB 3.0 Limits Files

Limit Library File Path: C:\TekApplications\DPOJET\Limits\USB

Description: The USB 3.0 Limits library contains the measurement limit files used by the various setup files. Measurement limits are used to provide Pass/Fail indication for each measurement. Refer to Section 3.5 for a full listing and description of the masks available in the distribution.

Important: The Setup file defines the system location of the Channel Model Filter, Mask, and Limits files used for the test. Thus, all files must be in the proper location for correct operation.

2.3 Differential Transmitter Specifications (Informative & Normative)

The following table shows the available measurements in DPOJET and their test limits defined at each test point in the Specification. The Informative Tx test point is defined at the pins of the transmitter device in a USB 3.0 link. The Normative Rx test point is defined at the end of a reference channel.

Table 2- Supported MOIs - USB 3.0 specification transmitter measurements

Spec Reference	Symbol(s)	Parameter	DPOJET Measurement Method	Measurements Supported in Setup Files		
				Informative Tx (ie, Near-end)	Informative Tx Low Power (ie, Near-end)	Normative Rx (ie, far-end)
Figure 6-9	Clock Recovery			2nd Order PLL Fc = 4.9MHz 0.707 Damping	2nd Order PLL Fc = 4.9MHz 0.707 Damping	2nd Order PLL Fc = 4.9MHz 0.707 Damping
Table 6-12	Eye Height	Transmitter Eye Mask	Eye Height1 (Tbit or Both) Eye Height2 (nTbit with De-Emphasis)	Height1: 0.8 V (min) Height2: 0.505 V (min)	Height 1: 0.4 V (min)	Height1: 100mV (min)
Table 6-11	TTX-EYE	Transmitter Eye - Dual Dirac at 10^{-12} BER	Width@BER (min)	0.625 UI (min) *125 ps (min)*	0.625 UI (min) *125 ps (min)*	0. 34 UI (min) *68 ps (min)*
Table 6-8 Table 6-12	Dj, TTX-DJ-DD	Tx deterministic Jitter – Dual Dirac	DJ–δδ (max)	*0.205 UI (max)* 41 ps (max)	*0.205 UI (max)* 41 ps (max)	0.43 UI (max) *86ps (max)*
Table 6-8 Table 6-12	Rj	Tx random jitter - Dual Dirac	RJ–δδ (max)	*0.0121 UI (max)* 2.42 ps (max) RMS	*0.0121 UI (max)* 2.42 ps (max) RMS	0.23 UI (max) *46 ps (max)* Pk-Pk *3.29 ps (max)* RMS
Table 6-8 Table 6-12	Tj	Tx total jitter - Dual Dirac at 10^{-12} BER	TJ@BER (max)	0.*375 UI (max)* 75 ps (max)	0.*375 UI (max)* 75 ps (max)	0.66 UI (max) *132 ps (max)*
Table 6-10	UI	Unit Interval (no SSC)	USB UI	199.94 (min) 200.06 (max)	199.94 (min) 200.06 (max)	199.94 (min) 200.06 (max)
Table 6-10	VTX-DIFF-PP VTX-DIFF-PP-LOW	Differential p-p Tx voltage swing	USB VTx-Diff-PP (max/min)	0.8 V (min) 1.2 V (max)	0.4 V (min) 1.2 V (max)	100mV (min) 1.2 V (max)

Spec Reference	Symbol(s)	Parameter	DPOJET Measurement Method	Measurements Supported in Setup Files		
				Informative Tx (ie, Near-end)	Informative Tx Low Power (ie, Near-end)	Normative Rx (ie, far-end)
Table 6-10	VTX-DE-RATIO	De-emphasized output voltage ratio	T/nT Ratio (max/min)	-3.0 dB (min) -4.0 dB (max)		
Table 6-10	Tcdr_SLEW_MAX	Maximum Slew Rate (df/dt)	USB TCdr-Slew-Max	10ms/s (max)	10ms/s (max)	10ms/s (max)
Table 6-11	$t_{MIN-PULSE-Tj}$	Tx min pulse	USB Tmin-Pulse-Tj	*0.90 UI (max)* 180 ps (max)	*0.90 UI (max)* 180 ps (max)	
Table 6-11	$t_{MIN-PULSE-Dj}$	Deterministic min pulse	USB Tmin-Pulse-Dj	*0.96 UI (max)* 192 ps (max)	*0.96 UI (max)* 192 ps (max)	
Table 6-11	VTX-DC-CM	Txr DC Common mode voltage	Common Mode Mean (min/max)	0 (min) 2.2 (max)	0 (min) 2.2 (max)	
Table 6-11	VTX-CM-AC-PP-ACTIVE	Tx AC Common mode voltage active	Common Mode Pk-Pk (max)	2.2 V (max)	100 mV (max)	
Table 6-9	tSSC-MOD-RATE	SSC Modulation Rate	USB-SSC-MOD-RATE	30 KHz (min) 33 kHz (max)	30 KHz (min) 33 kHz (max)	30 KHz (min) 33 kHz (max)
Table 6-9	tSSC-FREQ-DEVIATION-MAX	SSC Deviation Max	SSC-FREQ-DEV-MAX	+300 to -300 ppm (min) +300 to -300 ppm (max)	+300 to -300 ppm (min) +300 to -300 ppm (max)	+300 to -300 ppm (min) +300 to -300 ppm (max)
Table 6-9	tSSC-FREQ-DEVIATION-MIN	SSC Deviation Min	SSC-FREQ-DEV-MIN	-3700 to -5300 ppm (min) -3700 to -5300 ppm (max)	-3700 to -5300 ppm (min) -3700 to -5300 ppm (max)	-3700 to -5300 ppm (min) -3700 to -5300 ppm (max)
Table 6-10	tPeriod	LFPS Period	Period			20 ns(min) 100 ns(max)
Table 6-10	Vcm-AC-LFPS	LFPS Common mode voltage	Common Mode			100mV(max)
Table 6-10	tRiseFall2080	LFPS Rise Time	Rise Time			4 ns(max)
Table 6-10	tRiseFall2080	LFPS Fall Time	Fall TIme			4 ns(max)
Table 6-10	Duty Cycle	LFPS Duty Cycle	+Duty Cycle			40%(min) 60%(max)
Table 6-10	Vtx-DIFF-PP-LFPS	Differential p-p LFPS voltage swing	USB VTx-Diff-PP			0.8 V (min) 1.2 V (max)

3 Preparing to Take Measurements

3.1 Required Equipment

The following equipment is required to take the measurements:

- Oscilloscope:

It is recommended that ≥12.5 GHz system BW is used for USB 3.0 Informative measurements or normative measurements when channel emulation is being used. This ensures that any 5th harmonic frequency content is considered in the analysis. Tektronix models that meet this recommendation are DPO/DSA71254 and above. The DPO70804 (8 GHz) model is also suitable for Normative measurements if the waveform is being acquired at the receiver (TP1 defined in Figure 6-14 of the specification).

- DPOJET Jitter and Eye Analysis Tool application (v1.2.0 build2 or later) installed.
- SDLA software for Channel De-Embed and custom filter development (optional)
- Probes – Two TCA-SMA or one P7300SMA/P7500 differential probe.
- SMA Breakout Fixture - 'Early' breakout fixture are orderable directly from Ellisys Corp. www.ellisys.com (It's Japan distributor: www.gailogic.co.jp)
- AWG7122B Arbitrary Waveform Generator (v3.0.136.602 or later) (optional) for initiating electrical loopback and receiver testing(optional).

3.2 Probing Options for Transmitter Testing

Two TCA-SMA Connectors (Ch1-Ch2 Pseudo-Differential)

The differential signal is created by the DPOJET from the math waveform Ch1-Ch2. This probing technique requires breaking the link and terminating into a 50 Ω/side termination of the oscilloscope. Ch-Ch deskew is required using this technique because two channels are used. This configuration does not compensate for cable loss in the SMA cables. The measurement reference plane is at the input of the TCA-SMA connectors on the oscilloscope. Any cable loss should be measured and entered into the vertical attenuation menu for accurate measurements at the SMA cable attachment point.

One P7300SMA Differential SMA Probe (Ch1 True Differential)

The differential signal is measured across the termination resistors inside the P7300SMA series probe. This probing technique requires breaking the link. Matched cables are provided with the probe to avoid introducing deskew into the system. Only one channel of the oscilloscope is used. The P7300SMA provides a calibrated system at the Test Fixture attachment point, eliminating the need to compensate for cable loss associated with the probe configuration. The P7300SMA series is best suited for Compliance applications where the link is broken.

One P7500 Tri-Mode Differential Probe (Ch1 True Differential)

The differential signal is measured across the termination resistors inside the DUT. Probing must be performed at TP1 in the system (at the receiver pins) to be considered valid per the specification. This probing technique can be used in an active system and the exact compliance test pattern may not be available. Only one channel of the oscilloscope is used. The P7500 Tri-Mode probe provides the added ability to view and make measurements on D+, D-, Ddiff, and Dcm with a single probing connection. The P7500 Tri-Mode probe is better suited for Design Validation and Debug applications where the DUT is in an active system.

3.3 Initial Oscilloscope Setup

After connecting the DUT by the proper probing configuration for the test, click **DEFAULT SETUP** and turn on **Ch2 t**o view the signal.

3.4 Accessing the DPOJET USB 3.0 Measurement Menu

1. On DPO70000 series, go to **Analyze> USB 3.0 Essentials**

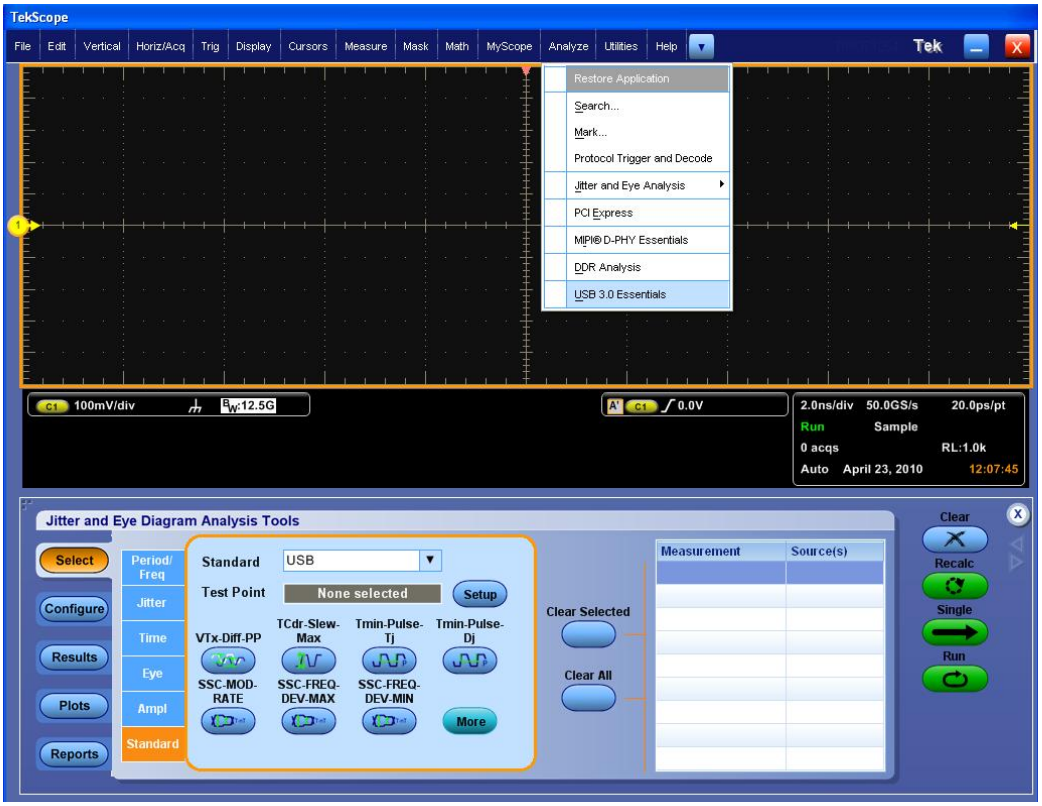


Figure 2: **Default menu of the DPOJET software**

Figure shows the oscilloscope display. The default mode of the software is the Serial Analysis module.

3.5 Configuring the Software to take various measurements

Selecting Measurements

In the DPOJET USB 3.0 menu, select the desired measurements. One can select either a single measurement or recalling a setup file he/she can run multiple measurements at a time. Recalling the setup files will give all the required setup for those measurements by default.

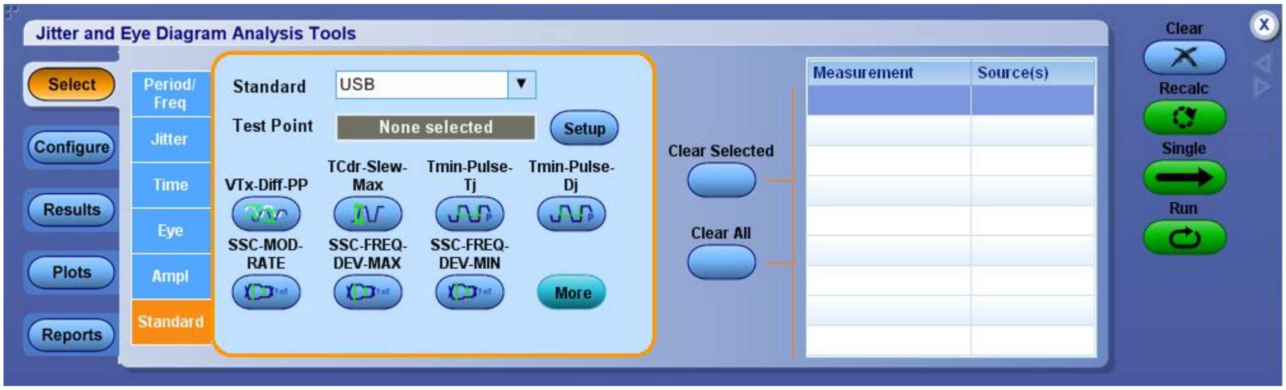


Figure 3: Jitter and Eye Analysis window for single measurement selection

Selecting Limit Files

If a measurement has a pass/fail limit associated with it in the test point file, go to Analyze>Jitter and Eye Analysis>Limits to select the limit file from the folder where the limit files are saved. Measurements with pass/fail limits will show up in the Results Summary panel when the compliance test is run.

Configure Mask file:

i. In the DPOJET application go to ‘Plots’ if you want to enable the Mask file.

ii. Select measurement from the measurement column.

iii. Click ‘Configure’ to change the default setup for that measurement. The mask selection window opens as shown:

iv. In the Mask file selection window, press the ‘Off’ button first and then click ‘Browse’ to select the Mask file.

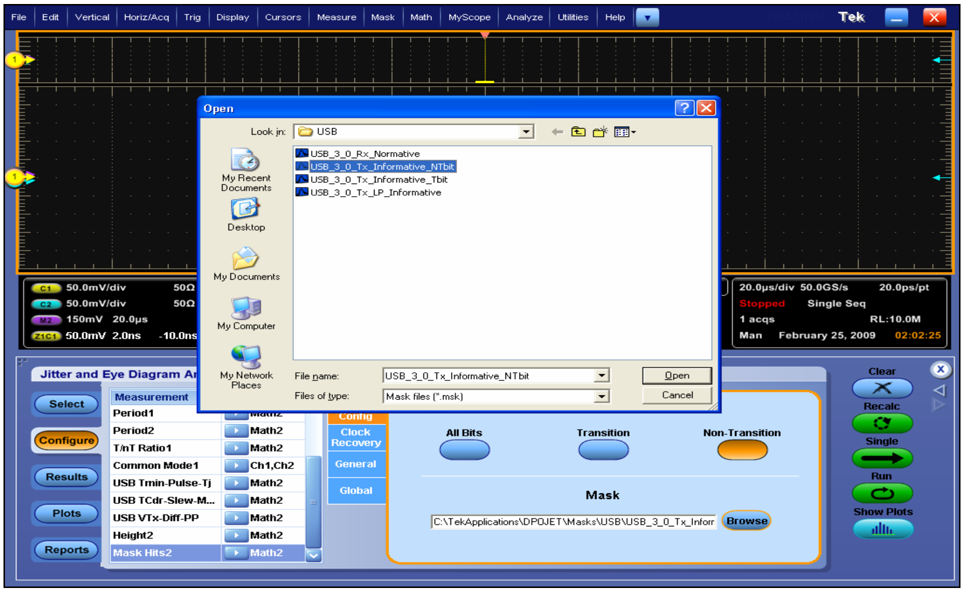


Figure 4: Mask File Selection

v. Select the relevant mask file (For example, USB_3_0_NORMATIVE.msk) file and click 'Open'.

vi. Enable the file by selecting the 'On' button, and click OK.

Configuring Source of Waveforms

Source selections are dependent on which probe type is selected. The selections are as follows:

If Differential is selected as Probe Type:

- **Live/Ref/Math** source selection (uses single differential signal as data source)

Live channel selections–Ch1, Ch2, Ch3, Ch4

Reference waveform selections–Ref1, Ref2, Ref3, Ref4

- **File** source selection <TBD>

If Single-Ended is selected as Probe Type:

- **Live/Ref/Math1** source selection (uses two single-ended signals as data source)

Live source selections–Select Math1 and then put (Ch1-Ch2), (Ch1-Ch4), (Ch2-Ch3), (Ch2-Ch4) which one is required in Math1. Select Math1 to perform selected measurement.

- **Reference waveform selections** – Select Math1 and then put (Ref1-Ref2), (Ref1-Ref4), (Ref2-Ref3), (Ref2-Ref4) which one is required in Math1. Select Math1 to perform selected measurement.

Configure Clock Recovery

In the Configure menu, select Clock Recovery and select the type of clock recovery to be used.

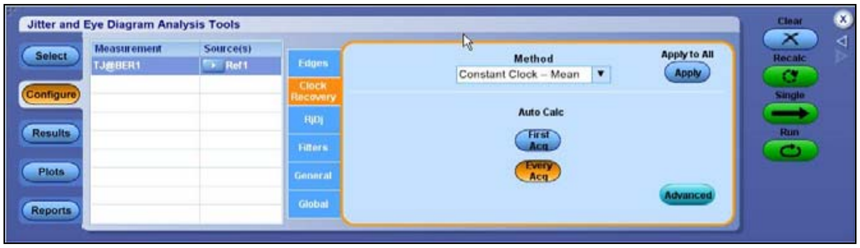


Figure 5. Clock recovery

From the Figure. 6.9 in base specification, Clock recovery configuration is given below.

Select **Method >PLL-Custom Bandwidth**.

Select PLL **Model > Type II**

Select **Damping > 0.707**

Select **Bandwidth 4.9MHz**. select Advanced button and configure **Bit Rate to 5Gb/s.**

If more than one measurement is selected at a time, then click Apply to All buttons.

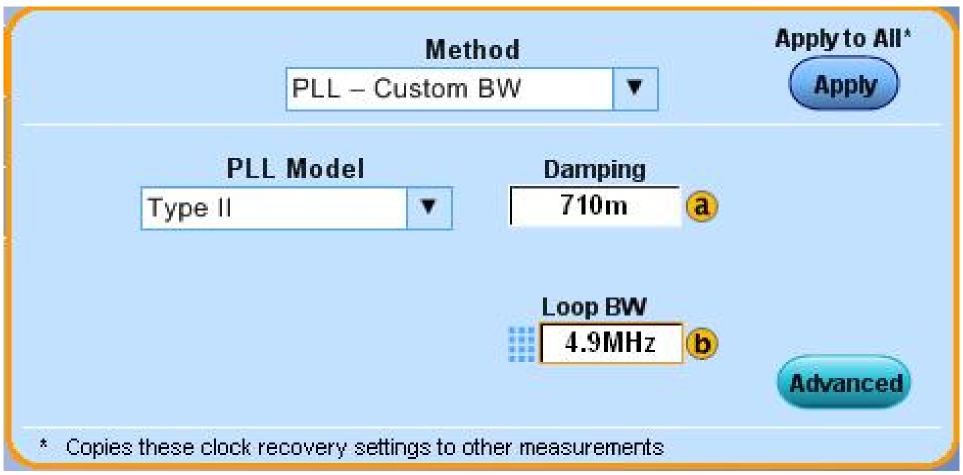


Figure 6: Clock Recovery selection window

Source and Reference Level Autoset

Below steps are recommended before taking any measurement. However, these steps are not required if you are using the setup files.

Select the **'Source Configuration'** window (Figure 1)

Press **'Vert & Horiz'** under **'Source Autoset'**

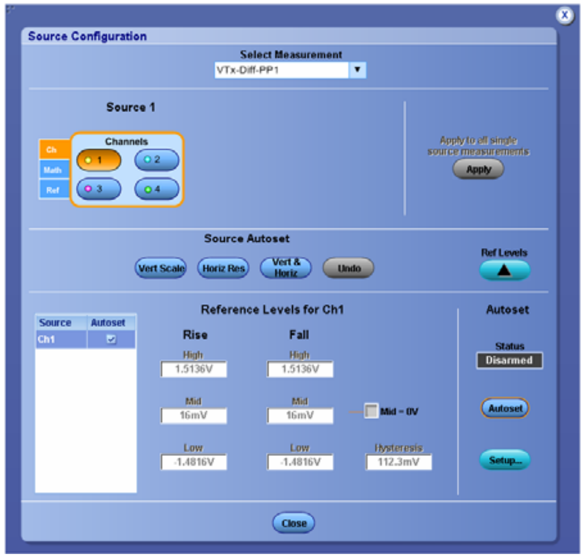


Figure 7: Source Configuration window

Press '***Autoset***' under **'Reverence Levels Source Configuration'**

Horizontal Setup

Now go to the 'Horiz/Acq'→ 'Horizontal /Acquisition Setup'

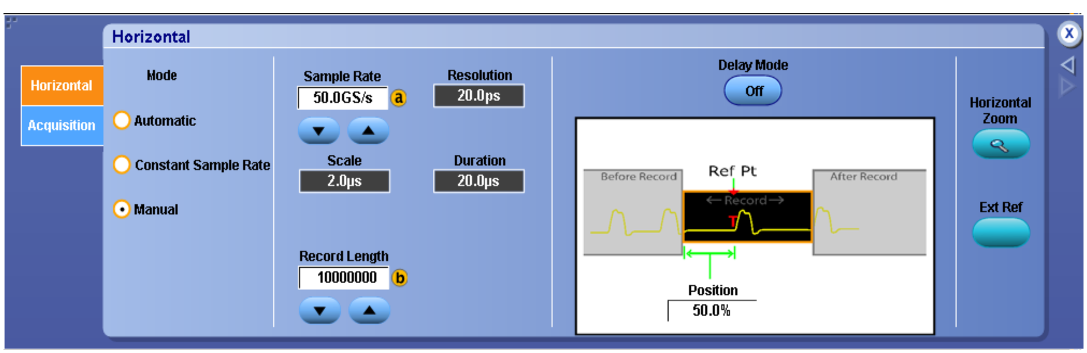


Figure 8: Horizontal/Acquisition setup

Change the 'Record Length' to the required value.

For all the measurements 10M record length (at 50GS/s sample rate) is required to meet the specification.

Selecting a Test Point and Channel Model

Two compliance points are defined in the specification - Normative Transmitter Test Point (TP1) and Informative Transmitter Test Point.

Normative Transmitter Test Point (TP1)

Table 6-12 of USB 3.0 specification represents the *Normative Test Point*, defined as TP1 in Figure 6-14 in the specification. Compliance measurements in Table 6-12 are made after acquiring the waveform at **‘TP1’** for the device under test as shown in the following diagram.

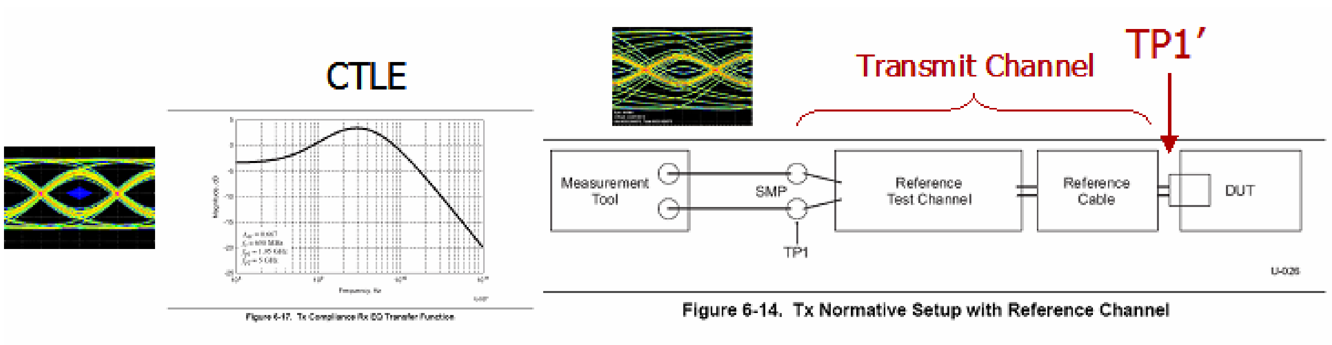


Figure 9: Test points

The compliance channel model is combined with the CTLE (Continuous Time Linear Equalization) function into a single filter. (FIR filter). It is then applied to the acquired waveform and analyzed for compliance using DPOJET. The result gives the measurement values along with the Pass/Fail report.

Informative Transmitter Test Point

Tables 6-10 and 6-11 of the specification define parameters to be taken at the pins of the transmitter device and represent the Informative Transmitter Test Point. This test point requires the measurement channel be De-Embedded from the measurement. The waveform is acquired at ‘TP1’ as with the Normative test.

Channel Models:

The Channel Models are available in the “DSA/Channel Filters” folder in the distribution, with the functions described as below:

Table 4 – Supported Channel Models and Corresponding Pre-defined Filter Files

Channel Model for Silicon Testing	
Filter-File Name	**Description of Filter Function**
USB3_Front_Cable_Device_CTLE.flt	Combines Host Front Panel, Cable, Device Reference Channel and CTLE

USB3_Back_Cable_Device_CTLE.flt	Combines Host Back Panel, Cable, Device Reference Channel and CTLE

Channel Model for Host or Device Testing	
Filter-File Name	**Description of Filter Function**
USB3_Cable_Back_CTLE.flt	Combines Cable, Host Back Panel Reference Channel, and CTLE for Device Testing.
USB3_Cable_Front_CTLE.flt	Combines Cable, Host Front Panel Reference Channel, and CTLE for Device Testing.
USB3_Cable_Device_CTLE.flt	Combines Cable and Device Reference Channel for Host Testing.

Individual Channel Filters	
Filter-File Name	**Description of Filter Function**
USB3_BackPanel.flt	Host Back Panel Reference Channel.
USB3_FrontPanel.flt	Host Front Panel Reference Channel.
USB3_Cable.flt	3 Meter USB 3.0 Cable
USB3_Device.flt	Device Reference Channel
USB3_CTLE.flt	USB 3.0 CTLE Filter

4 USB3.0 Transmitter Test Procedure

This section provides the Methods of Implementation (MOIs) for Transmitter tests using a Tektronix real-time oscilloscope, probes, and the DPOJET software.

4.1 Step-by-Step Normative Testing

The following procedure discusses how to use DPOJET to test the Normative test point in the USB 3.0 Specification. Differences in the procedure for testing the Informative test point are discussed but not detailed.

Initial Scope Setup

i. Configure the DUT to transmit the compliance pattern (CP0 – Scrambled D0.0)

ii. Connect to the Transmitter port of the DUT using one of the probing configurations described in Section 3.2 of this document. If using pseudo-differential input (Ch1-Ch2), perform channel-channel deskew procedure and record the deskew value for Ch2. If using a differential probe de-skew is not necessary.

iii. Press the **DEFAULT SETUP** button.

iv. Turn on **Ch2** (if using pseudo-differential input) to view the signal under test.

v. Confirm that the D0.0 pattern is being transmitted from the DUT.

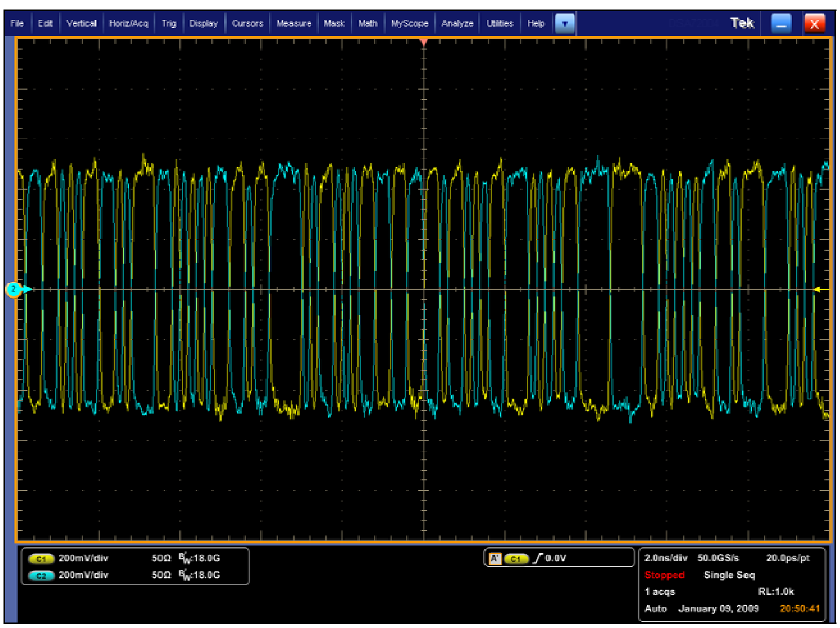


Figure 10: Scrambled D0.0 (CP0) Pattern

Recalling the Setup file

vi. Start DPOJET Application. go to Analyze> USB3.0 Essentials.

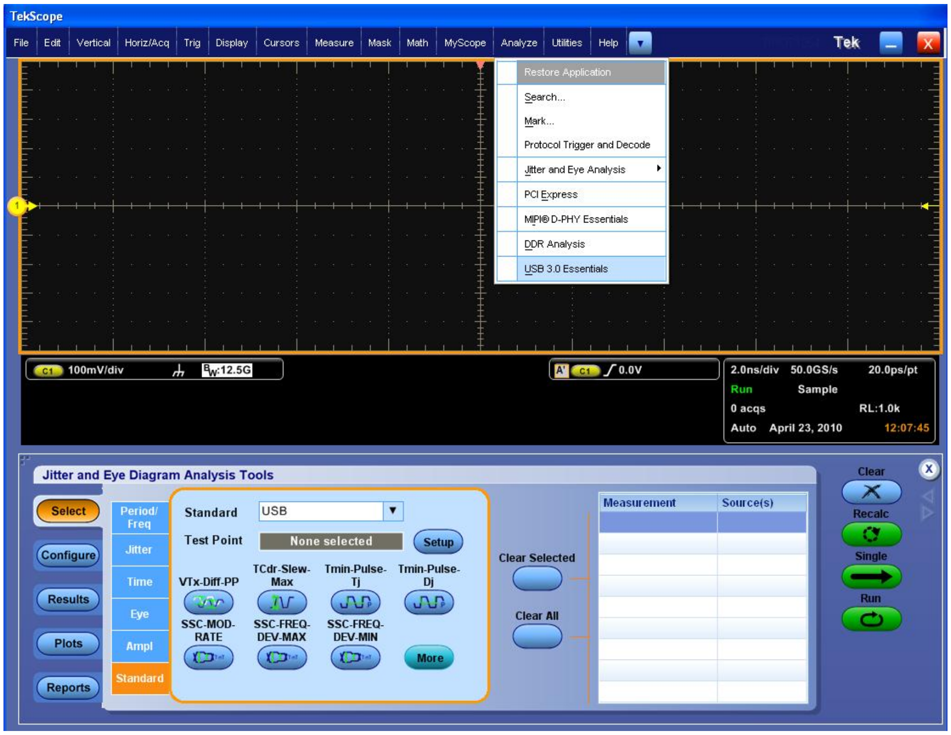


Figure 11: Selecting DPOJET

vii. From the test point, click setup and recall the setup form USB3.0 setup library.

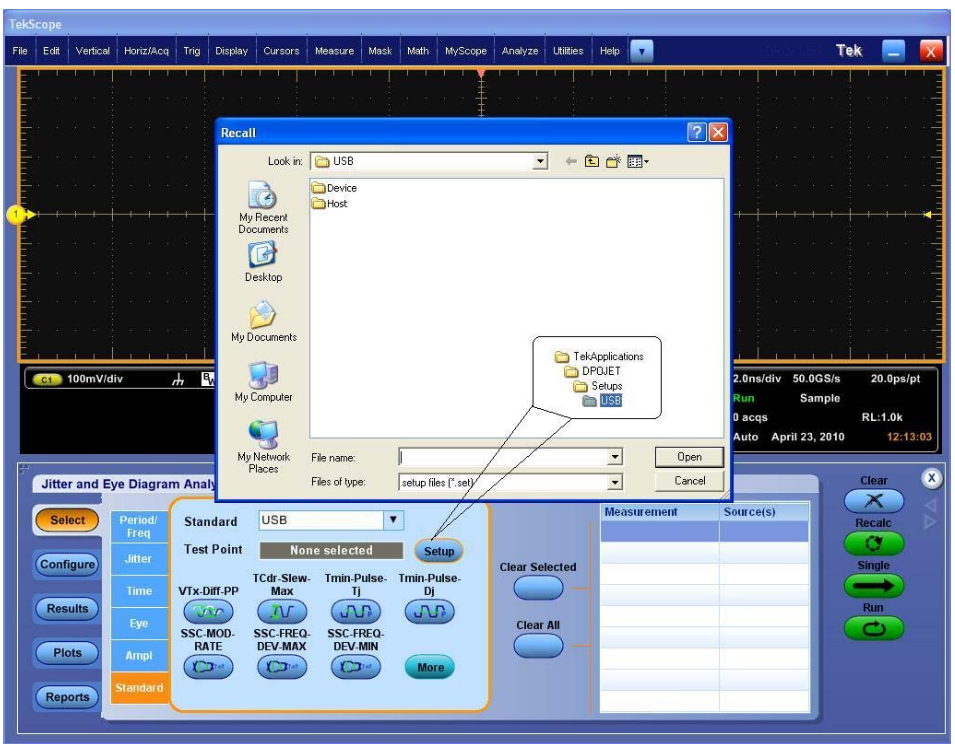


Figure 12: Recalling Setup File

viii. Select the appropriate setup file from the USB setups folder. Example: Select USB_3_0_Normative.set to test for Compliance at TP1 of the specification.

ix. Select ‘Recall’ to open the setup file.

Adjust the Vertical Amp and ensure proper De-skew calibration

This part of the procedure should be carried out the first time the Setup file is recalled on the oscilloscope to get accurate measurements.

x. Press the Zoom button to turn off zoom.

xi. Turn off Math2 in the Math Menu.

xii. Adjust Horizontal Scale to 2 nsec/div.

xiii. Press the Run/Stop button so that the acquisition is running.

xiv. Adjust the vertical amplitude of the active channels to be 9-10 divisions on the screen. This takes full advantage of the oscilloscopes A/D range without clipping the waveform. In this below example, Ch1 and Ch2 is set to 120 mV/div.

xv. Go to the Deskew menu and enter the proper value for Ch2.

xvi. Adjust Horizontal Scale back to 20 usec/div.

xvii. Turn on the Zoom and return the Zoom factor to 20000. The display should look similar to the following:

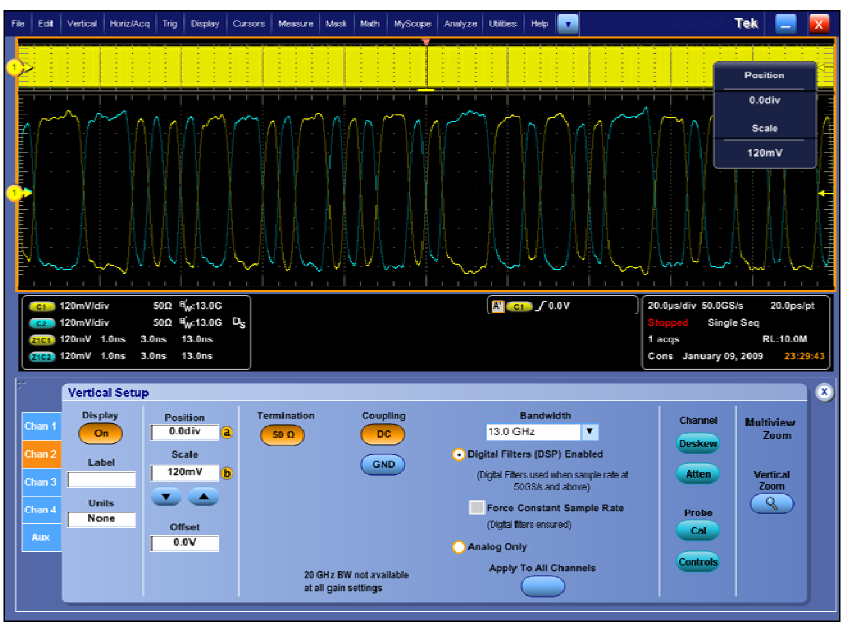


Figure 13: Optimized Vertical Settings with 1Million UI Capture

Configuring the desired Test Point as Math2:

xviii. In the 'Math' window, Select 'Math2' and then go to Math editor using 'Editor' button.

xix. Clear the default values from the 'math2' using 'Clear' button in the Math editor.

xx. Go to 'Filter' menu in the 'Math' window. Select 'Load' button.

xxi. From the Channel Filter File, select 'USB3_Front_Cable_Device_CTLE' file and click 'Open'.

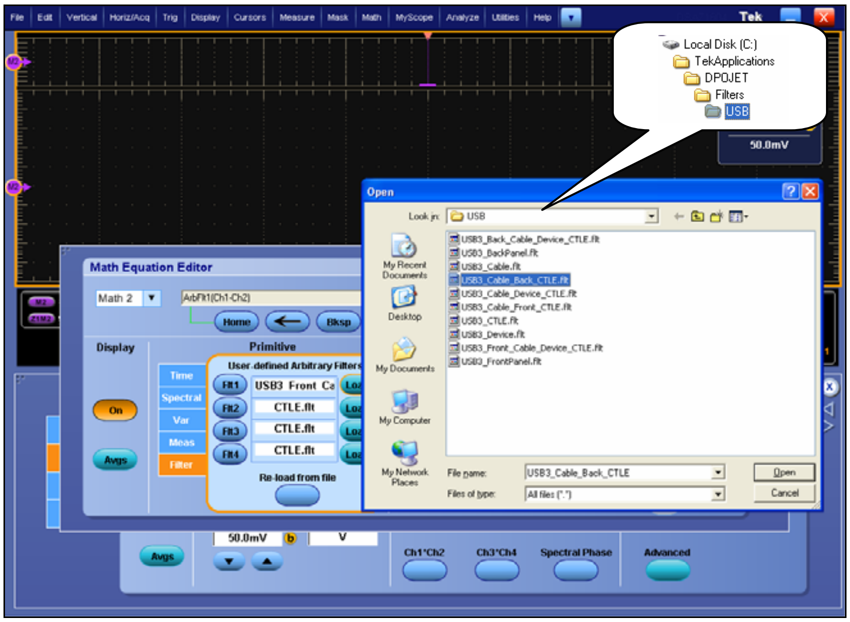


Figure 14: Math2 Selection

xxii. Click the button 'Flt1' from the Math Editor. Enter Ch1-Ch2 as the argument of the ArbFlt1 function.

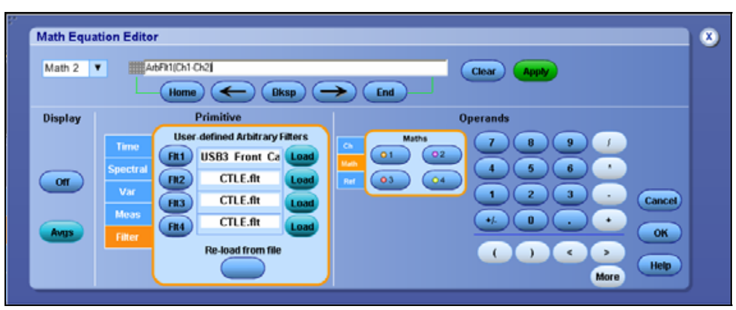


Figure 15: Filtering differential data signal

xxiii. Click 'Apply'. And then click 'OK' button in the Math Editor.

xxiv. Apply 'Ch1-Ch2' in 'Math1' clicking 'Apply' button

Figure 16: Math2 Waveform Appears

Run the Normative Setup file

xxv. After configuring the Acquisition Channel and the desired Reference Channel, return to Analyze > Jitter and Eye Analysis > Select.

xxvi. Select 'Single' to run the setup.

xxvii. After running the application, the results are as shown:

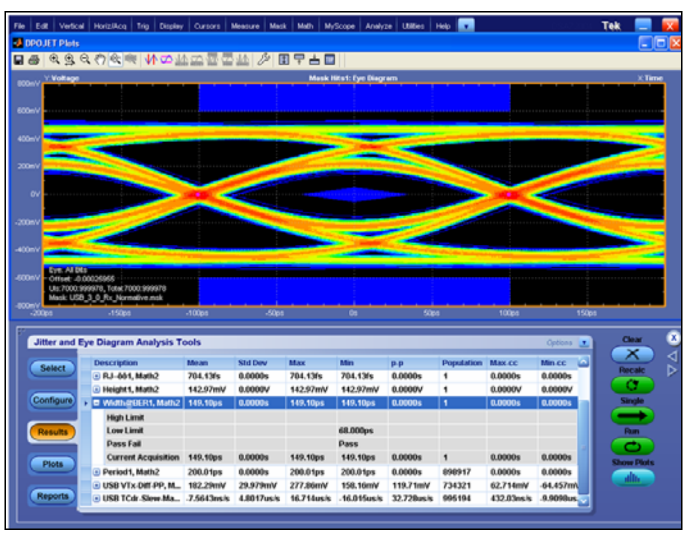


Figure 17: Normative Results

Run and Save Test Report:

xxviii. Select the Reports button in the DPOJET menu.

xxix. Press the 'Save As' button and enter the report name.

xxx. The Report is as shown:

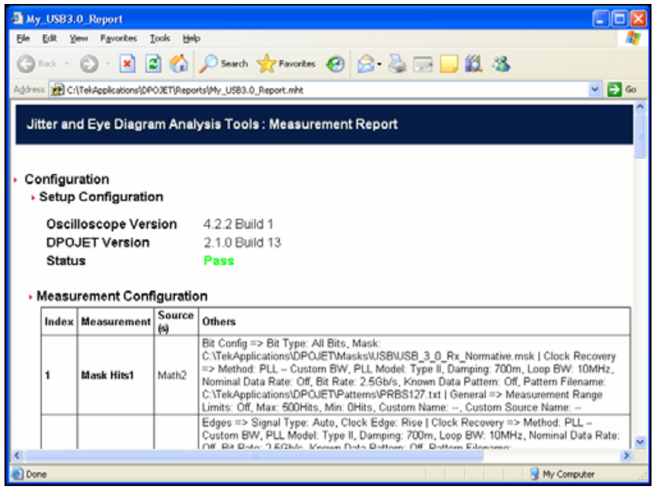


Figure 18: Test Report Giving Pass/Fail Status

4.2 Informative Test Point Example

The following procedure discusses how to use DPOJET to test the Normative test point in the USB 3.0 Specification. Differences in the procedure for testing the Informative test point are discussed but not in detail.

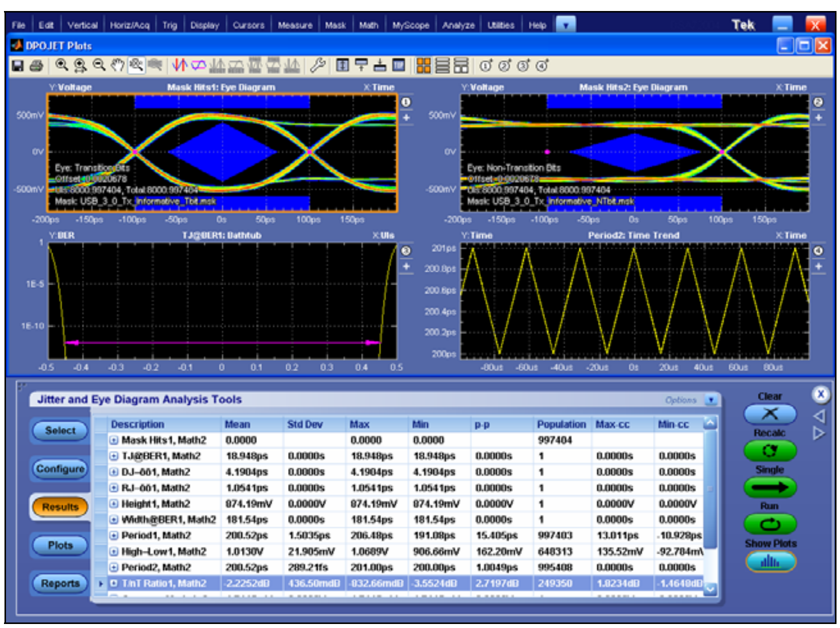


Figure 19: Transmitter Test Point Example

4.3 Informative Low Power Test Point Example

The following procedure discusses how to use DPOJET to test the Normative test point in the USB 3.0 Specification. Differences in the procedure for testing the Informative test point are discussed but not detailed.

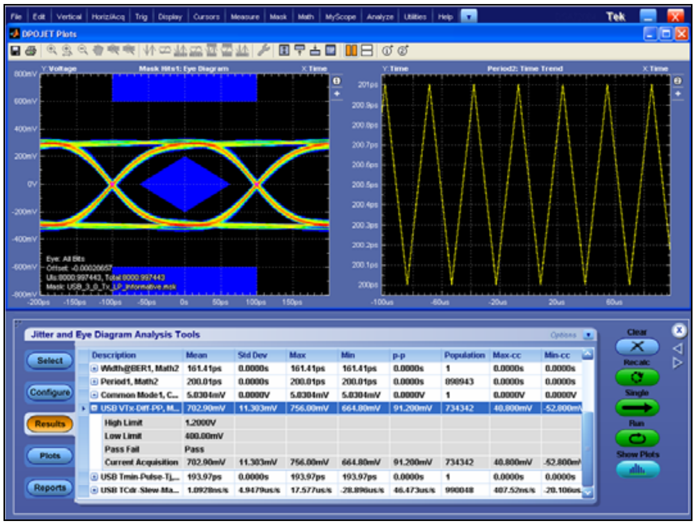


Figure 20: Low Power Transmitter Test Point Example

4.4 Tx Eye Height MOI

Definition:

Eye Height measurement is defined as the clear vertical eye opening at the center of the unit interval. Height = High(min) – Low(max)

Limits:

Refer to Table 1 for the specified limits on the T_{TX-EYE} measurement.

Test Procedure:

Ensure that **Eye Height** is selected in the **Select** menu.

Measurement Algorithm:

The Eye Height measurement is the measured minimum vertical eye opening at the zero reference level.

The application calculates this measurement using the following equation:

There are three types of eye height values:

Eye Height:

$$V_{EYE-HEIGHT} = V_{EYE-HI-MIN} - V_{EYE-LO-MAX}$$

Where:

$V_{EYE-HI-MIN}$ is the minimum of the high voltage at mid UI

$V_{EYE-LO-MAX}$ is the maximum of the low voltage at mid UI

Eye Height – Transition

$$V_{EYE-HEIGHT-TRAN} = V_{EYE-HI-TRAN-MIN} - V_{EYE-LO-TRAN-MAX}$$

Where:

$V_{EYE-HI-TRAN-MIN}$ is the minimum of the high transition bit eye voltage at mid UI

$V_{EYE-LO-TRAN-MAX}$ is the maximum of the low transition bit eye voltage at mid UI

Eye Height – Non-Transition

$$V_{EYE-HEIGHT-NTRAN} = V_{EYE-HI-NTRAN-MIN} - V_{EYE-LO-NTRAN-MAX}$$

Where:

$V_{EYE-HI-NTRAN-MIN}$ is the minimum of the high non-transition bit eye voltage at mid UI

$V_{EYE-LO-NTRAN-MAX}$ is the maximum of the low non-transition bit eye voltage at mid UI

4.5 TX Deterministic and Random Jitter (Dual Dirac) MOI

Definition:

DJ–δδ (Deterministic jitter only assuming the Dual Dirac Distribution) Deterministic Jitter is the statistics for all timing errors that follow deterministic behavior. Deterministic Jitter is typically characterized by its peak-to-peak value. Deterministic Jitter as defined above, but calculated based on a simplified assumption that the histogram of all deterministic jitter can modeled as a pair of equal-magnitude Dirac functions (impulses known as delta-functions).

Limits:

Refer to Table 2 for specified limits on the **DJ–δδ** and **RJ–δδ** measurements.

Test Procedure:

Ensure that **Jitter DJ–δδ** is selected in the **Select > Jitter** menu.

Measurement Algorithm:

Dual Dirac Deterministic Jitter (DJ–δδ) is the peak-to-peak magnitude for all timing errors exhibiting deterministic behavior, calculated based on a simplifying assumption that the histogram of all deterministic jitter can modeled as a pair of equal magnitude Dirac functions (impulses). A single DJ–δδ value is determined for each acquisition, by means of RJ/DJ separation analysis.

Rj/Dj Separation Based on Dual Dirac Model:

Dual Dirac model based Rj/Dj separation method fits the Bathtub curve to a theoretical model of Rj and Dj where Rj is assumed to have a Gaussian distribution, Dj is assumed to have a distribution of two Dirac impulses with the same height. Curve fitting at different BER levels in Bathtub curve yields the standard deviation value of Rj and peak-to-peak value of Dj. The Bathtub curve is obtained from the spectrum analysis based or the arbitrary pattern analysis based Rj/Dj separation methods. Rj and Dj based on the Dual-Dirac model can be denoted as RJ_g and DJ_{dd}.

After RJ_g and DJ_{dd} are obtained, Tj can be calculated using

$$TJ(BER) = 2Q(BER) \times RJ_g + DJ_{dd}$$

where Q is the function of BER that has a value of about 7 when $BER = 10^{-12}$. Eye opening is computed in the same way as it is computed in the spectrum analysis based Rj/Dj separation.

Dual Dirac model based Rj/Dj separation method is used. Usually, actual Dj does not have a pure Dual-Dirac distribution. So the value of RJ_g is often greater than the value of Rj obtained from the spectrum analysis based or the arbitrary pattern analysis based Rj/Dj separation. The value of DJ_{dd} is often less than that of its corresponding one.

4.6 TX Total Jitter MOI

Definition:

TJ@BER (Total Jitter at a specified Bit Error Rate (BER)). This combines the Random and Deterministic effects, and predicts a peak-to-peak jitter that will only be exceeded with a probability equal to the BER.

Limits:

Refer to Table 1 for specified limits on the T_{TX-EYE} measurement.

Test Procedure:

Ensure that **Jitter TJ@BER** is selected in the **Select > Jitter** menu.

Measurement Algorithm:

Total Jitter at a specified Bit Error Rate (BER). This extrapolated value predicts a peak-to-peak jitter that will only be exceeded with a probability equal to the BER. It is generally not equal to the total jitter actually observed in any given acquisition. A single TJ@BER value is determined for each acquisition, by means of RJ/DJ separation analysis.

4.7 TX Unit Interval Measurement MOI

Test Definition Notes from the Specification:

- UI (Unit Interval) is specified to be +/- 300 ppm

- UI does not account for SSC dictated variations

Definition:

UI is defined in the base specification.

Limits:

Refer to Table 2 for specified limits on UI measurement.

Test Procedure:

Ensure that the Unit Interval is selected in the **Measurements > Standard > USB > Select > USB UI** menu.

Measurement Algorithm:

This measurement is made over the analysis window of 250 consecutive bits (or over the entire record if the sw PLL is used) as defined in the base specification.

The Unit Interval measurement calculates the cycle duration of the recovered clock.

$$UI(n) = t_{R-CLK}(n+1) - t_{R-CLK}(n)$$

$$UI_{AVG} = Mean(UI(n))$$

Where:

t_{R-CLK} is the recovered clock edge

n is the index to UI in the waveform

4.8 TX De-Emphasized Differential Output Voltage (Ratio) MOI

Definition:

$V_{TX-DE-RATIO}$ (De-Emphasized Differential Output Voltage (Ratio)) is defined in the base specification.

Test Definition Notes from the Specification:

- This is the ratio of the $V_{TX-DIFFp-p}$ of the second bit and following bits after a transition divided by the $V_{TX-DIFFp-p}$ of the first bit after a transition.

- Specified at the measurement point into a timing and voltage compliance test load as shown in the base specification over the specified number of UIs. Also refer to the transmitter compliance eye diagram shown in the base specification.

Limits:

Refer to Table 2 for specified limits on the $V_{TX-DE-RATIO}$ measurement.

Test Procedure:

Ensure that De-Emphasis is selected in the Analyze > Jitter and Eye Analysis > Select > Ampl > T/nT Ratio menu.

Measurement Algorithm:

The de-emphasis measurement calculates the ratio of any non-transition eye voltage (2nd, 3rd, etc. eye voltage succeeding an edge) to its nearest preceding transition eye voltage (1st eye voltage succeeding an edge), it is the ratio of the black voltages over the blue voltages. The results are given in dB.

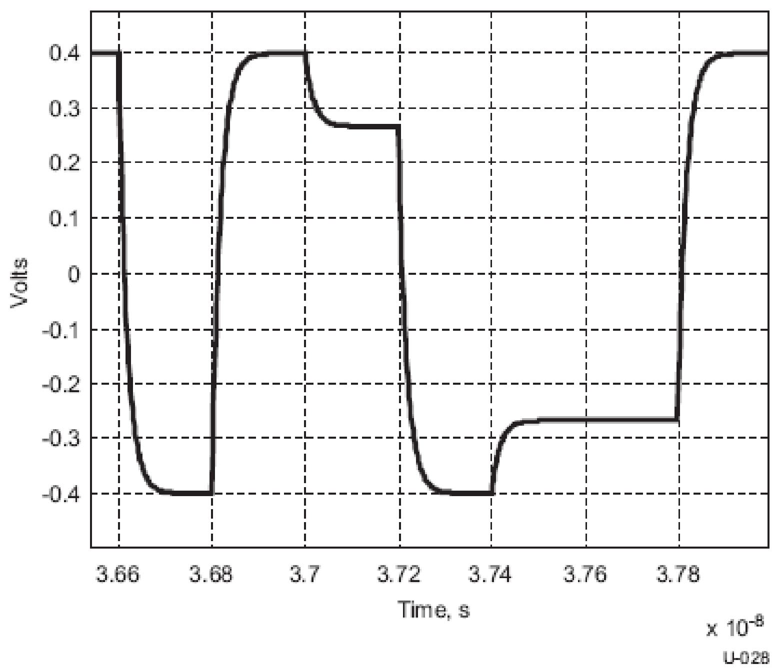


Figure 21: De-emphasis measurement

$$DEEM(m) = dB\left(\frac{v_{EYE-HI-NTRAN}(m)}{v_{EYE-HI-TRAN}(n)}\right)$$

or

$$DEEM(m) = dB\left(\frac{v_{EYE-LO-NTRAN}(m)}{v_{EYE-LO-TRAN}(n)}\right)$$

Where:

$v_{EYE-HI-TRAN}$ is the high voltage at mid UI following a positive transition

$v_{EYE-LO-TRAN}$ is the low voltage at mid UI following a negative transition

$v_{EYE-HI-NTRAN}$ is the high voltage at mid UI following a positive transition bit

$v_{EYE-LO-NTRAN}$ is the low voltage at mid UI following a negative transition bit

m is the index for all non-transition UIs

n is the index for the nearest transition UI preceding the UI specified by *m*

4.9 Minimum TX Eye Width MOI

Definition:

T_{TX-EYE} (Minimum TX Eye Width) is defined in the base specification. It is defined as, clear horizontal eye opening at the middle reference level.

Width = UI(mean) – TIE(max) – TIE(min)

Limits:

Refer to Table 2 for specified limits on the T_{TX-EYE} measurement.

Test Procedure:

Ensure that **Eye Width** is selected in the **Select** menu.

Measurement Algorithm:

The Eye Width measurement is the measured minimum horizontal eye opening at the zero reference level.

The application calculates this measurement using the following equation:

$T_{EYE\text{-}WIDTH} = UI_{AVG} - TIE_{pk\text{-}pk}$

Where:

UI_{AVG} is the average UI.

$TIE_{pk\text{-}pk}$ is the Peak-Peak TIE.

4.10 TX DC Common Mode Voltage MOI

Definition:

$V_{TX\text{-}DC\text{-}CM}$ (DC Common Mode Voltage between D+ and D-) is defined in the base specification.

Test Definition Notes from the Specification:

$$|V_{TX-CM-DC-D+} - V_{TX-CM-DC-D-}| \leq 25mV$$
$$V_{TXCM-DC-D+} = DC_{(avg)} of\ |V_{TX-D+}|$$
$$V_{TX-CM-DC-D-} = DC_{(avg)} of\ |V_{TX-D-}|$$

- Specified at the measurement point into a timing and voltage compliance test load as shown in the base specification and measured over the specified number of UIs.

Limits:

Refer to Table 2 for specified limits on $V_{TX\text{-}DC\text{-}CM}$ measurement.

Test Procedure:

Ensure that Differential Average is selected in the **Measurements > Select> Ampl > Common Mode** menu.

Measurement Algorithm:

The **Differential Average** measurement returns the mean of the differential voltage waveform.

$$V_{DIFF-AVG} = Mean(v_{DIFF}(i))$$

Where:

i is the index of all waveform values

v_{DIFF} is the differential voltage signal

4.11 TX AC Common Mode Output Voltage MOI

Definition:

$V_{TX-CM-ACp}$ (RMS AC Pk Common Mode Output Voltage) is defined in Rev1.0 Base Specification. The nomenclature ACp-p is retained to be consistent with the specification. However, the measurement is defined and reported as an RMS value, not a Pk value.

Test Definition Notes from the Specification:

$$V_{TX-CM-ACp} = RMS(|\frac{V_{TX-D+} + V_{TX-D-}}{2}| - V_{TX-CM-DC}) V_{TX-CM-DC} = DC_{(avg)} of \, |\frac{V_{TX-D+} + V_{TX-D-}}{2}|$$

- Specified at the measurement point into a timing and voltage compliance test load as shown in the base specification and measured over the specified number of TX UIs.

Limits:

Refer to Table 2 for specified limits on $V_{TX-CM-ACp}$ measurement.

Test Procedure:

Ensure that 'Comm Mode Voltage' is selected in the Measurements> Select menu.

Select **Math=** (Ch1 + Ch2)/ 2 and then perform the measurement.

Note: This measurement is available only when the probe type is single-ended.

Measurement Algorithm:

AC CM RMS Voltage: The AC Common Mode RMS Voltage measurement calculates the RMS statistic of the common mode voltage waveform with the DC value removed.

$$v_{AC-RMS-CM}(i) = RMS(v_{AC-M}(i))$$

Where:

i is the index of all waveform values

$v_{AC-RMS-CM}$ is the RMS of the AC common mode voltage signal

v_{AC-M} is the AC common mode voltage signal

4.12 TX Differential Pk-Pk Output Voltage MOI

Definition:

$V_{TX-DIFF--pp}$(Differential Output Pk-Pk Voltage) is defined in the base specification Rev 1.0. This measurement is done using T-Tx-Diff-PP measurement available under **Standards >> USB 3.0** tab. The Result panel would display the Mean , Maximum and Minimum differential output pk-pk voltage.

Test Definition Notes from the Specification:

$V_{TX-DIFFp-p} = 2*|V_{TX-D+} - V_{TX-D-}|$ - Specified at the measurement point into a timing and voltage compliance test load as shown in the base specification and measured over specified number of UIs. Also refer to the transmitter compliance eye diagram shown in the base specification.

Limits:

Refer to Table 2 for specified limits on the $V_{TX-DIFFp-p}$ measurement.

Test Procedure:

Ensure that ***V*** is selected in the **Jitter and Eye diagram Analysis Tools > USB 3.0 > Select** menu. This measurement is available under **Standards >** USB 3.0 tab.

Select the **Jitter and Eye diagram Analysis Tools > Configure** from the panel and set the **Configure** > **Clock Recovery** >PLL – Custom BW > PLL model – Type II > Damping –0.707 > Loop BW – 4.9MHz **(Which is selected by default)** as shown in figure below.

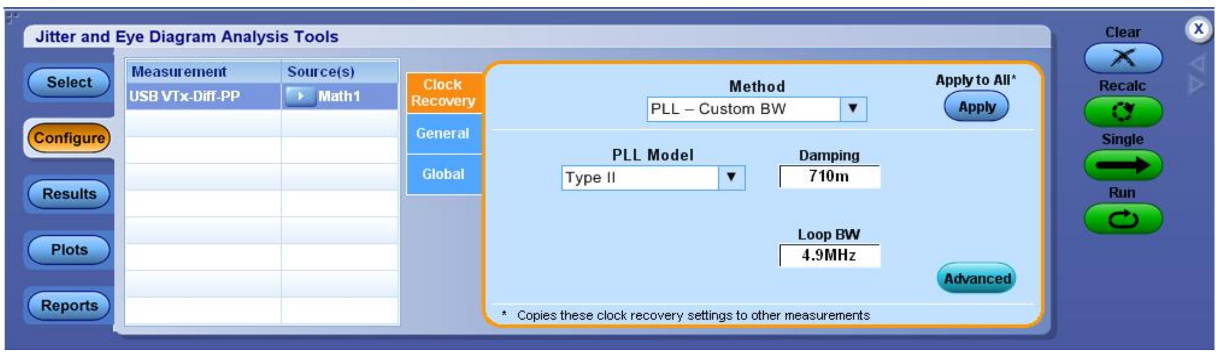


Figure 22: USB 3.0 Clock Recovery

Configure > General >Off

Configure > Global > Off

Measurement Algorithm:

Differential Peak Voltage Measurement: The Differential Peak Voltage measurement returns two times the larger of the Min or Max statistic of the differential voltage waveform.

$$V_{DIFF-PK} = 2 * Max(Max(v_{DIFF}(i)); Min(v_{DIFF}(i)))$$

Where:

i is the index of all waveform values

v_{DIFF} is the differential voltage signal

4.13 TX Minimum Pulse Width MOI

Definition:

$T_{MIN\text{-}PULSE\text{-}TJ}$ (Instantaneous lone pulse width including all Jitter source measurement) is defined in the base specification Rev1.0.

This measurement is done using the USB3.0 Tmin-Pulse-Tj measurement available under **Standards** > USB 3.0 tab. The Result panel would display the minimum pulse width results.

Test Definition Notes from the Specification:

$T_{MIN\text{-}PULSE\text{-}TJ}$ (Instantaneous lone pulse width including all Jitter source) is measured from transition center to the next transition center, and that the transition centers will not always occur at the differential zero crossing point. In particular, transitions from a de-emphasized level to a full level will have a center point offset from the differential zero crossing.

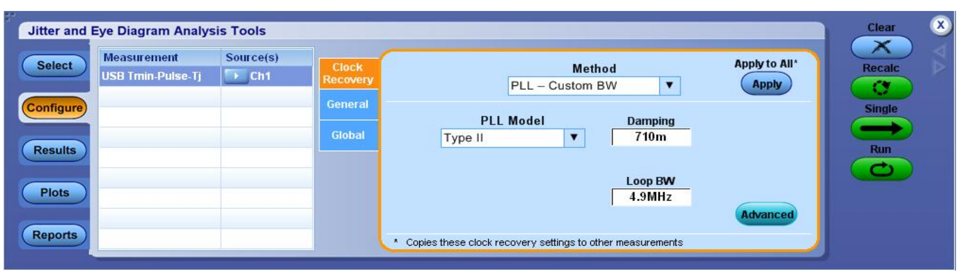
Limits:

Refer to Table 2 for specified limits on the $T_{MIN\text{-}PULSE\text{-}TJ}$ measurement.

Test Procedure:

Ensure that $T_{min\text{-}Pulse\text{-}Tj}$ is selected in the **Jitter and Eye diagram Analysis Tools** > **USB 3.0**> **Select**menu. This measurement is available under **Standards >** USB 3.0 tab.

Select the **Jitter and Eye diagram Analysis Tools >** **Configure** from the panel and set the **Configure** > **Clock Recovery** > PLL – Custom BW > PLL model – Type II > Damping –0.707 > Loop BW – 4.9MHz (**which is selected by default**) as shown in figure below.



Configure > General >Off

Configure > Global > Off

Measurement Algorithm:

Tmin-Pulse-Tj (minimum single pulse width TMin-Pulse including all Jitter source) is measured from one transition center to the next.

The application calculates TMin-Pulse-Tj using the following equation:

$T_{min\text{-}Pulse\text{-}Tj} = (T_{n+1} - T_n)$

Where:

Tmin-Pulse-Tj is the minimum pulse width

T is the transition center

4.14 TX Minimum Pulse Width (Deterministic Jitter source) MOI

Definition:

$T_{MIN\text{-}PULSE\text{-}DJ}$ (Instantaneous lone pulse width including only deterministic jitter source measurement) is defined in the base specification Rev1.0.

This measurement is done using the USB3.0 Tmin-Pulse-Dj measurement available under **Standards** >> USB 3.0 tab. The Result panel would display the minimum pulse width results.

Test Definition Notes from the Specification:

$T_{MIN\text{-}PULSE\text{-}DJ}$ (Instantaneous lone pulse width including only deterministic jitter source) is measured from transition center to the next transition center, and removing all random jitter source from the total jitter.

Limits:

Refer to Table 2 for specified limits on the $T_{MIN\text{-}PULSE\text{-}DJ}$ measurement.

Test Procedure:

Ensure that $T_{min\text{-}Pulse\text{-}Dj}$ is selected in the **Jitter and Eye diagram Analysis Tools** >>**USB 3.0**>> **Select** menu. This measurement is available under **Standards >>** USB 3.0 tab.

Select the **Jitter and Eye diagram Analysis Tools >> Configure** from the panel and set the **Configure** >> **Clock Recovery** >>Constant Clock mean (Which is selected by default) as shown in figure below.

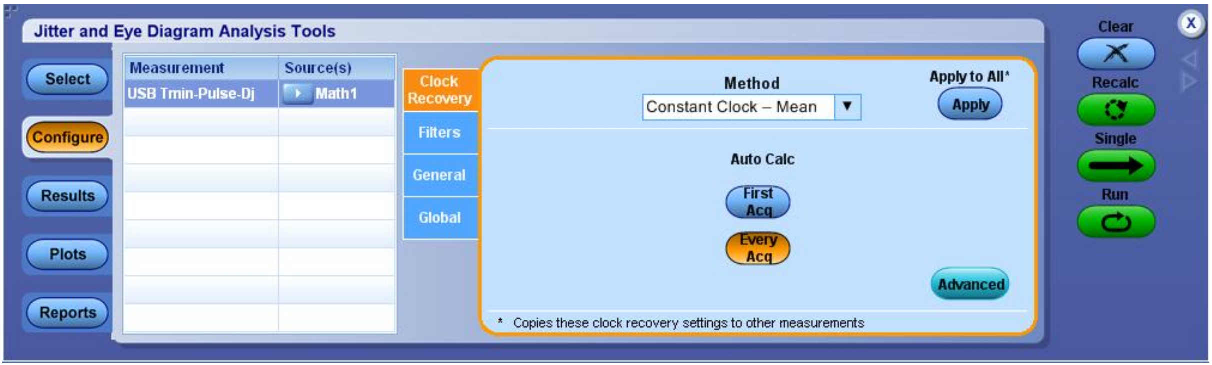


Figure 23: Clock Recovery for T-min-Pulse

Configure > Filters >Off

Configure > General >Off

Configure > Global > Off

Measurement Algorithm:

Tmin-Pulse-Dj (minimum single pulse width TMin-Pulse including only deterministic jitter) is measured from one transition center to the next.

The application calculates Tmin-Pulse-Dj using the following steps:

- Find the TIE trend for the given waveform
- Take the FFT of the TIE trend.
- Separate the Rj and Dj values from the TIE spectrum
- Remove the Rj components from the TIE spectrum (Find the noise floor and replace the Rj values with the noise values)
- Take IFFT of the TIE spectrum without Rj component and reconstruct the clock based on the TIE trend without Rj components.
- Find the minimum pulse width in this reconstructed clock.

4.15 TX Maximum Slew Rate MOI

Definition:

$T_{Cdr\text{-}Slew\text{-}Max}$(minimum single pulse width TMin-Pulse including all Jitter source) is defined in the base specification Rev1.0.

This measurement is done using the USB3.0 T-Cdr-Slew-Max. The Result panel would display the maximum results.

Test Definition Notes from the Specification:

The CDR is a slew rate limited phase tracking function. The combination of SSC and all other jitter sources within the bandwidth of the CDR must not exceed the maximum allowed slew rate. The measurement is performed by filtering the phase jitter with the CDR function and taking the first difference of the phase jitter to obtain the filtered period jitter. The peak of the peak jitter must not exceed $T_{Cdr\text{-}Slew\text{-}Max}$ given in the base specification.

Limits:

Refer to Table 2 for specified limits on the $T_{Cdr\text{-}Slew\text{-}Max}$ measurement.

Test Procedure:

Ensure that $T_{Cdr\text{-}Slew\text{-}Max}$ is selected in the **Jitter and Eye diagram Analysis Tools** >>**USB 3.0**>> **Select** menu.

Select the Jitter and Eye diagram Analysis Tools > Configure from the panel and set the Configure > Constant Clock-Mean and,

Configure > Filter > Low pass > 2^{nd} Order > Frequency > 1.98 MHz (Which is selected by default) as shown in figure below.

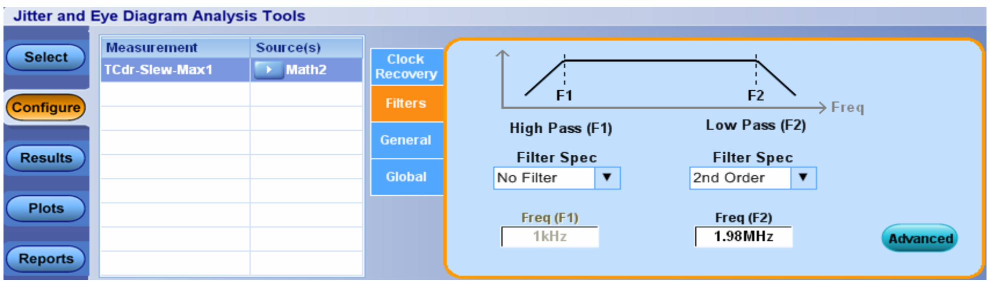


Figure 24: Filter for Slew measurement

Configure > General >Off

Configure > Global > Off

Measurement Algorithm:

- Find the period jitter. DPOJET period measurement with a LPF of 1.98MHz is used to find the period jitter.
- Get the phase jitter (taking the cumulative sum of the period jitter gives the phase jitter)
- Filter the phase jitter with the CDR transfer function.

$$H_{CDR}(s) = \frac{2s\zeta\omega_n + \omega_n^2}{s^2 + 2s\zeta\,\omega_n + \omega_n^2}$$

- Get the filtered period jitter from the phase jitter.
- Find out the peak-to-peak period jitter.
- Compare the peak to peak slew rate with the below specification limit.

4.16 TX SSC Modulation Rate MOI

Definition:

Spread spectrum modulation, which can be defined as any modulation technique that requires a transmission bandwidth much greater than the modulating signal bandwidth, independently of the bandwidth of the modulating signal.

Test Definition Notes from the Specification:

-- All ports are required to have Spread Spectrum Clocking(SSC) modulation.

-- The SSC Modulation may not violate phase slew rate specification.

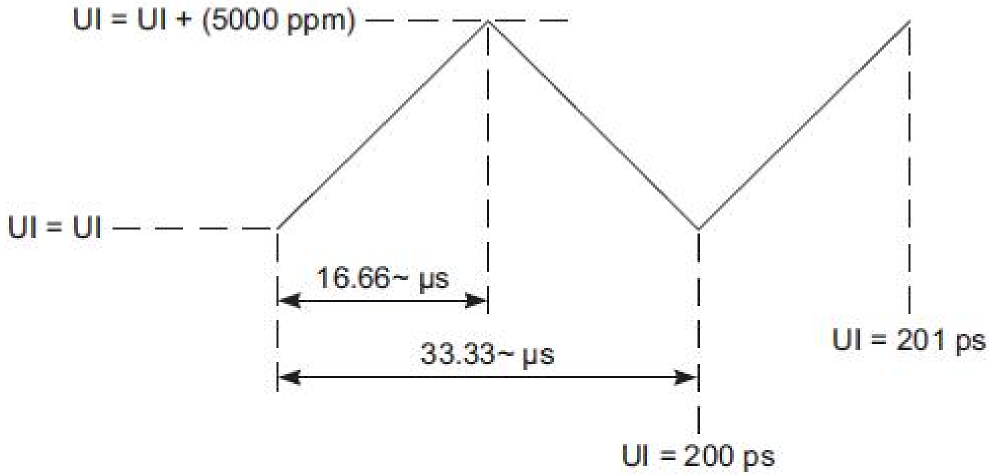


Figure 25: Period Modulation from triangular SSC

Limits:

Refer to Table 2 for specified limits on $t_{SSC\text{-}MOD\text{-}RATE}$ measurement.

Test Procedure:

Ensure that $T_{SSC\text{-}MOD\text{-}RATE}$ is selected in the **Jitter and Eye diagram Analysis Tools** >**USB 3.0 Essentials** > **Select** menu.

Select the **Jitter and Eye diagram Analysis Tools > Configure** from the panel and set the **Configure** > **Constant Clock > Mean** and,

Configure > Filter > Low pass > 2nd Order > Frequency > 1.98 MHz (Which is elected by default) as shown in figure below.

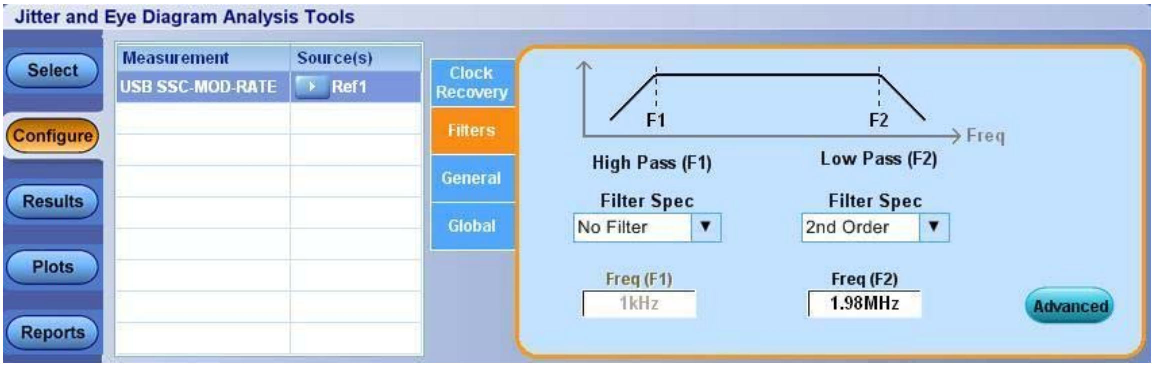


Figure 26: Filter for SSC Mod Rate measurement

Configure > General >Off

Configure > Global > Off

Measurement Algorithm:

- Run the measurement and get the SSC profile
- Find the 50% edges on the SSC profile.
- Find time difference between the consecutive crossings of the mid reference voltage level ($\Delta t = T_{n+1} - T_n$; where T_n - is the VRefMid crossing time, T_{n+1} – is next VRefMid crossing time)
- Calculate the Modulation Rate as $1/\Delta t$ (Modulation Rate = $1/\Delta t$)

4.17 TX SSC Frequency Deviation Max MOI

Definition:

SSC Frequency Deviation Max, can be defined as the maximum frequency shift as a function of time.

Test Definition Notes from the Specification:

-- The data rate is modulated from 0 to -5000 ppm for nominal data rate frequency and scales with data rate.

-- This is measured below 2MHz only.

Limits:

Refer to Table 2 for specified limits on $t_{SSC\text{-}FREQ\text{-}DEV\text{-}MAX}$ measurement.

Test Procedure:

Ensure that SSC-FREQ-DEV-MAX is selected in the **Jitter and Eye diagram Analysis Tools** >>**USB 3.0 Essentials** >> **Select** menu.

Select the **Jitter and Eye diagram Analysis Tools >> Configure** from the panel and set the **Configure** >> **Constant Clock-Mean** and,

Configure >> Filter >> Low pass >> 2nd Order >> Frequency >> 1.98 MHz (Which is selected by default) as shown in figure below.

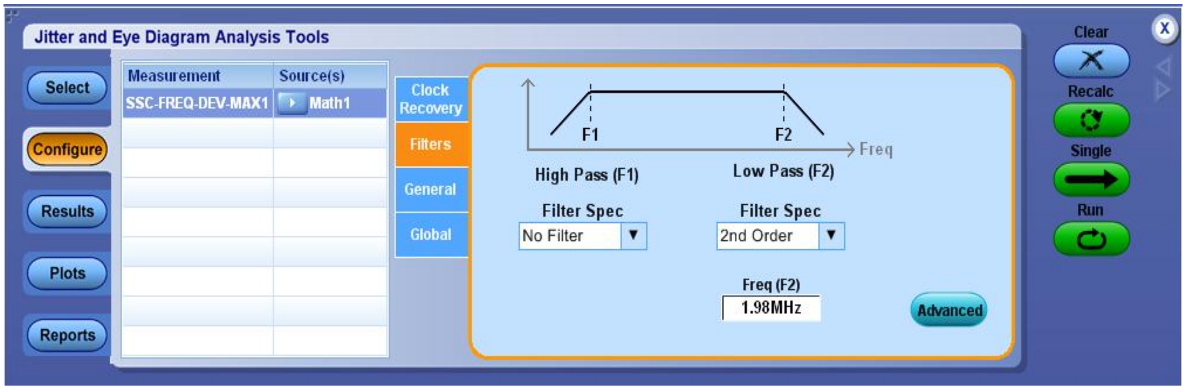


Figure 27: Filter for SSC Frequency Deviation Max measurement

Configure >> General >>Off

Configure >> Global >> Off

Measurement Algorithm:

- Find the 50% edges on the SSC profile
- Between the 'n' and 'n+1' th edge find the High value.
- Find the Maximum Frequency deviation as High.
- Freq Dev Max (ppm) = {(Maximum Frequency - nominal Data rate)/ nominal Data rate} * 1e6. Represent the FreqDev in terms of ppm (parts per million)

4.18 TX SSC Frequency Deviation Min MOI

Definition:

SSC Frequency Deviation Min, can be defined as the minimum frequency shift as a function of time.

Test Definition Notes from the Specification:

-- The data rate is modulated from 0 to -5000 ppm for nominal data rate frequency and scales with data rate.

-- This is measured below 2MHz only.

Limits:

Refer to Table 2 for specified limits on $t_{SSC\text{-}FREQ\text{-}DEV\text{-}MIN}$ measurement.

Test Procedure:

Ensure that SSC-FREQ-DEV-MIN is selected in the **Jitter and Eye diagram Analysis Tools** >>**USB 3.0 Essentials** >> **Select** menu.

Select the **Jitter and Eye diagram Analysis Tools >> Configure** from the panel and set the **Configure** >> **Constant Clock-Mean** and,

Configure >> Filter >> Low pass >> 2nd Order >> Frequency >> 1.98 MHz (Which is selected by default) as shown in figure below.

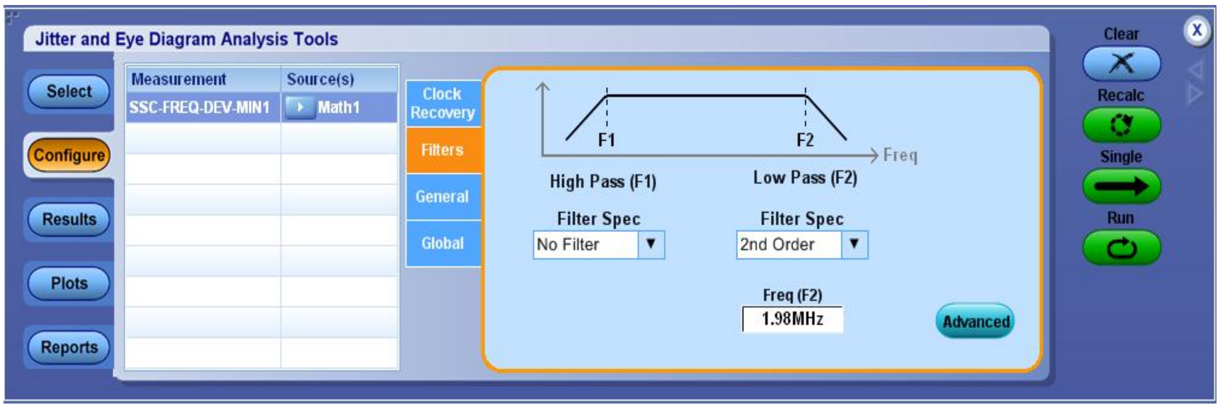


Figure 28: Filter for SSC Frequency Deviation Min measurement

Configure >> General >>Off

Configure >> Global >> Off

Measurement Algorithm:

- Find the 50% edges on the SSC profile
- Between the 'n' and 'n+1' th edge find the Low value.
- Find the Minimum Frequency deviation as Low.
- Freq Dev Min (ppm) = {(Minimum Frequency - nominal Data rate)/ nominal Data rate} * 1e6. Represent the FreqDev in terms of ppm (parts per million)

4.19 LFPS Measurements MOI

Definition:

Low Frequency Periodic Signaling (LFPS) is used for side band communication between two ports across a link that is in a low power link state. There are few parameters which have to measure to perform complete LFPS measurements. Those parameters are: tperiod, tRiseFall2080, Duty cycle, VCM-AC-LFPS, and VTX-DIFF-PP-LFPS.

Limits:

Refer to Table 2 for specified limits on LFPS measurements.

Test Procedure:

Scope Settings:

- Enable Ch1 and Ch 2 and set the vertical scale to 100mV/Div.
- Set the Record Length to 5M and Sample rate to 50GS/s.
- Trigger on Ch1 and set the Trigger level to 50 mV. Put the acquisition mode into 'Single'.

Math Settings:

- Go to Math Setup and set Math1-Math4 with the following:
- Math1=CH1-CH2.
- Math2=Arbfilt(Math1). Use usb3_Cable_Device_CTLE.flt filter for Host and USB3_Cable_Back_CTLE.flt filter for Device.
- Math3=Arbfilt(CH3). Arbfilt equals a 30 KHz High Pass filter.
- Math4=Arbfilt(CH4). Arbfilt equals a 30 KHz High Pass filter

To measure all LFPS parameters, select the following measurements from **Jitter and Eye Analysis** >> **Select** menu.

LFPS Parameter	**DPOJET measurement**	**Source**
tPeriod	Period	Math1
Duty Cycle	+ Duty Cycle	Math2
tRiseFall2080	Rise Time	Math2
tRiseFall2080	Fall Time	Math2
$V_{CM-AC-LFPS}$	Common Mode	Math3,Math4
$V_{TX-DIFF-PP-LFPS}$	USB VTx-Diff-PP	Math1

Select the measurements listed above and from **Jitter and Eye diagram Analysis Tools >> Configure** tab, set **Configure** >>**Global >> Gating >> Cursors.** All other configurations are by default.

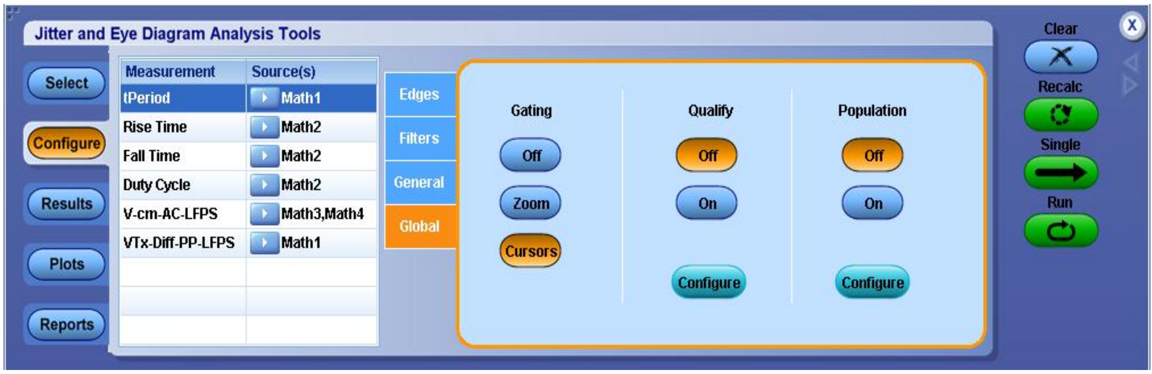


Figure 29: Gating for LFPS measurements

Measurement Algorithm:

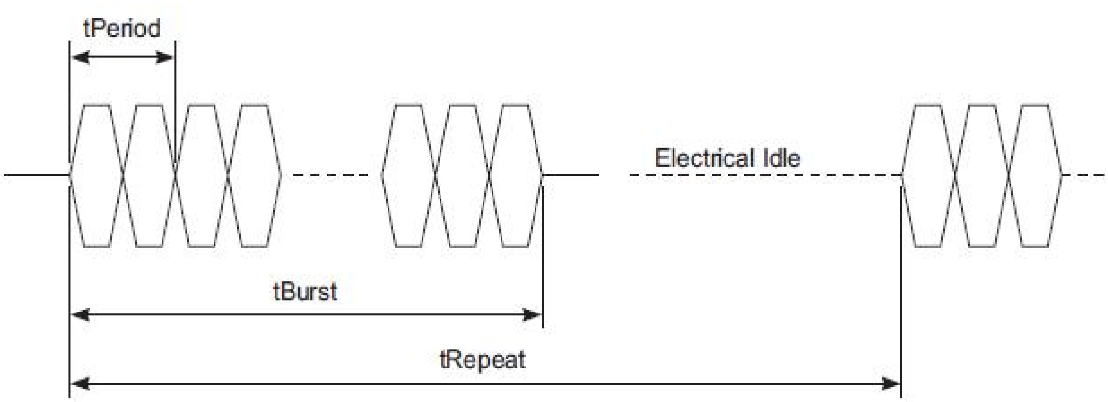


Figure 30: LFPS signaling

- For tperiod, tRiseFall2080, Duty cycle, VCM-AC-LFPS, and VTX-DIFF-PP-LFPS measurements the start of an LFPS burst is defined as starting when the absolute value of the differential voltage has exceeded 100 mV and the end of an LFPS burst is defined as when the absolute value of the differential voltage has been below 100 mV for 50 ns.
- LFPS parameters are only measured during the period from 100 nanoseconds after the burst start to 100 nanoseconds before the burst stop.