TEXAS INSTRUMENTS

Application Report

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How to Measure Total Jitter (TJ)

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ABSTRACT

Today, the jitter specification, TJ, is used in more and more systems, at the same time the jitter requirements get lower and lower. Clock generators or jitter cleaners like the CDCM6208 meet those tough jitter specifications for most systems (for example, TMS320TCI66xx DSP-based systems; see *Hardware Design Guide for KeyStone I Devices* (SPRABI2). The other side of the coin is that the measurement equipment has to be feasible to measure the low-noise clock generators. Therefore, the measurement equipment has to have a lower noise floor than the device under test. This can be achieved by minimizing the noise sources within the measurement equipment.

This application report describes the recommended measurement techniques for TJ. It includes the description of the techniques to minimize the noise sources of the measurement equipment. The CDCM6208 characterization setup is used as an example throughout the application report.

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1 Introduction

Jitter is a time variant noise component that impacts the phase of a signal. Total jitter includes two components; bounded (or deterministic) jitter and unbounded (or random) jitter.

Deterministic jitter is a predictable and repeatable behavior which can be expressed as a peak-to-peak value. Random jitter is the unbounded jitter part of T_J. It is mainly thermal noise, flicker noise or shot noise.

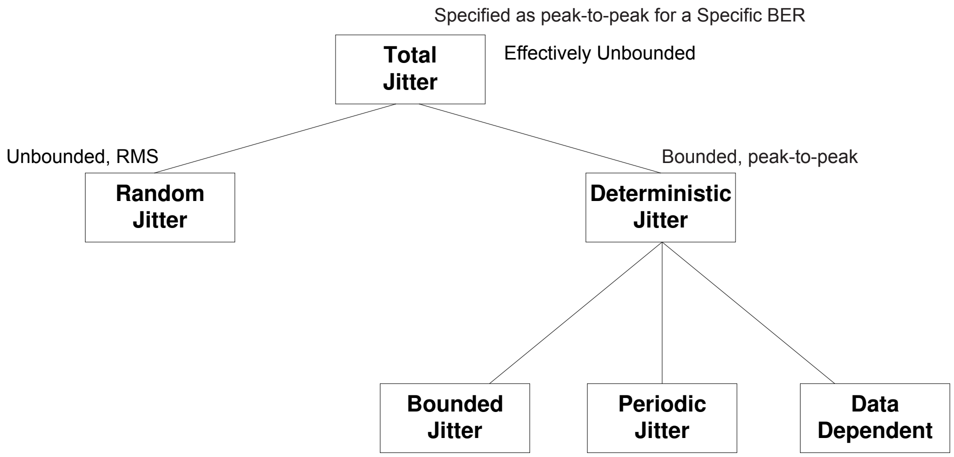

Figure 1. Total Jitter Components

A good technique to measure TJ uses a high-end digital sampling oscilloscope. This oscilloscopes need to have a better noise floor than the device under test, otherwise the performance of the device under test would be degraded and worsen by the noise of the oscilloscope. The noise floor in oscilloscopes is specified as *jitter noise floor* or *jitter measurement floor*.

In most cases, the given jitter measurement floor of an oscilloscope is only valid with a *best case* signal. This means that the input signal has to meet a certain slew rate.

1.1 Noise Sources in an Oscilloscope

In an Agilent application report the jitter noise floor is calculated as:

$$\text{Jitter Measurement Floor} = \sqrt{\left(\frac{\text{Oscilloscope Noise}}{\text{Slew Rate}}\right)^2 + (\text{Sample Clock Jitter})^2} \quad (1)$$

SampleClockJitter is also called intrinsic jitter. It describes the accuracy of the data sampling points and can be seen as horizontal noise impact.

OscilloscopeNoise describes the noise contributed by the oscilloscope itself (mainly voltage noise or vertical noise impact).

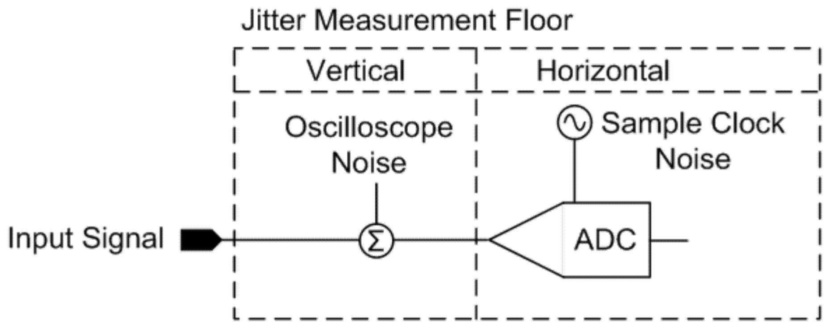

Figure 2. Oscilloscope Noise Sources

The simplified input of an oscilloscope is made of an analog-to-digital converter (ADC) which is clocked by the sampling clock. Additionally, there is the input gain stage which injects the oscilloscope noise.

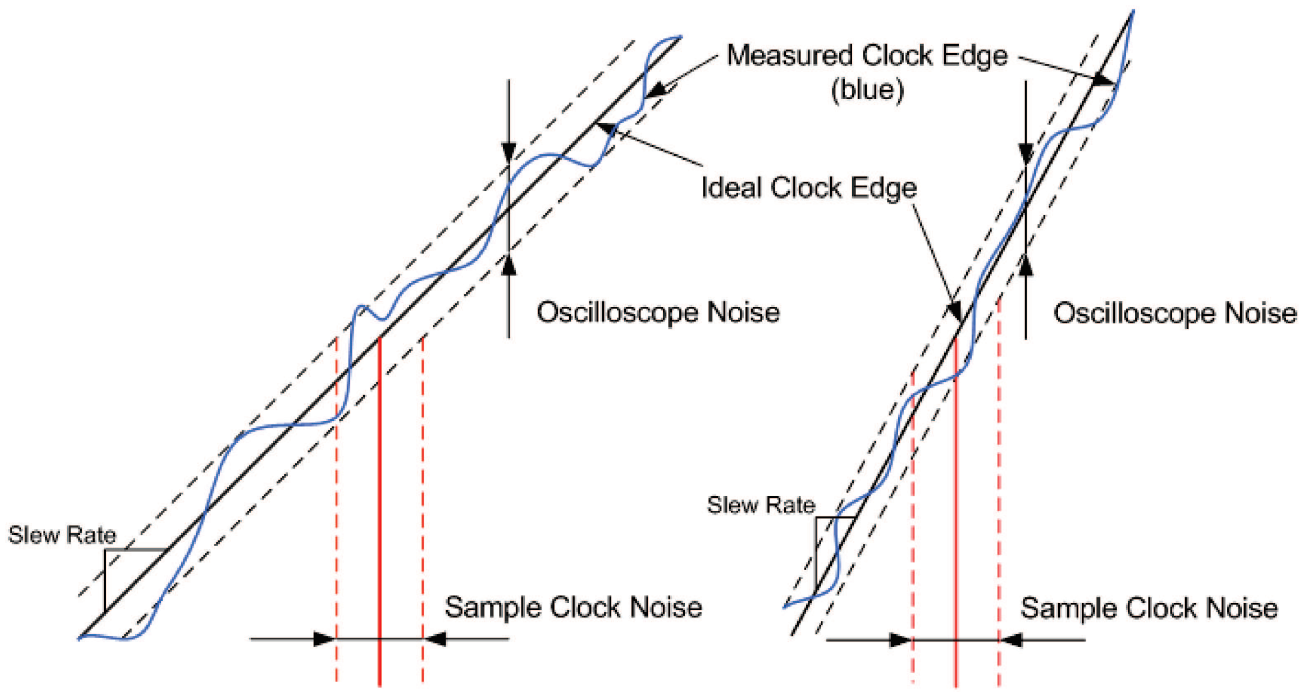

Figure 3. Slew Rate Impact on Measured Clock

In Figure 3 the slew rate of a clock signal was increased whereas the oscilloscope noise is equal. The illustration shows that a signal with a slow slew rate is more susceptible to oscilloscope noise than signals with a high slew rate.

As a consequence, either an oscilloscope which accepts lower slew rate in combination with a very good jitter measurement floor, or a higher signal slew rates has to be used to measure a device with less impact from the oscilloscope. During the device characterization of the CDCM6208 a limiting amplifier (ONET1191P) from TI was used to increase the slew rates of the CDCM6208. The limiting amplifier is called ONET1191P or slew-rate amplifier for the remainder of this document.

2 Comparison: Phase Noise Analyzer Versus Oscilloscope

Table 1 summarizes TJ and random (or RMS) jitter measurement test results with the oscilloscope comparing jitter with and without the ONET1191P. As it can be seen using the ONET1191P, the data measurement on the phase noise analyzer (PNA) and the oscilloscope correlates very well.

RJ or RJ with ONET1191P represents the random jitter component of a TJ measurement. TJ or TJ with the ONET1191P represents the TJ measurements. PNA describes the RMS jitter measurements taken with a PNA with an integration range of 10 kHz to 20 MHz.

Table 1. Jitter Measurement

FREQUENCY (DIVIDER FRACTION)	[ps-rms]	[ps-rms]	[ps-rms]	ps-pp	ps-pp
	PNA (1)	RJ	RJ WITH ONET1191P (1)	TJ	TJ WITH ONET1191P
122.88 MHz (integer)	0.263	1.252	0.507	18.335	7.722
156.25 MHz (6-bit fractional)	0.474	1.715	0.959	49.356	40.84
156.25 MHz (20-bit fractional)	0.635	2.06	0.773	63.69	54.88
312.50 MHz (integer)	0.255	1.212	0.483	17.763	8.205

(1) NOTE: The difference between PNA values and RJ with ONET1191P is because the ONET1191P worsens the signal by its additive jitter

3 T_J Characterization Setup

During TJ characterization of CDCM6208, the setup shown in Figure 6 was used.

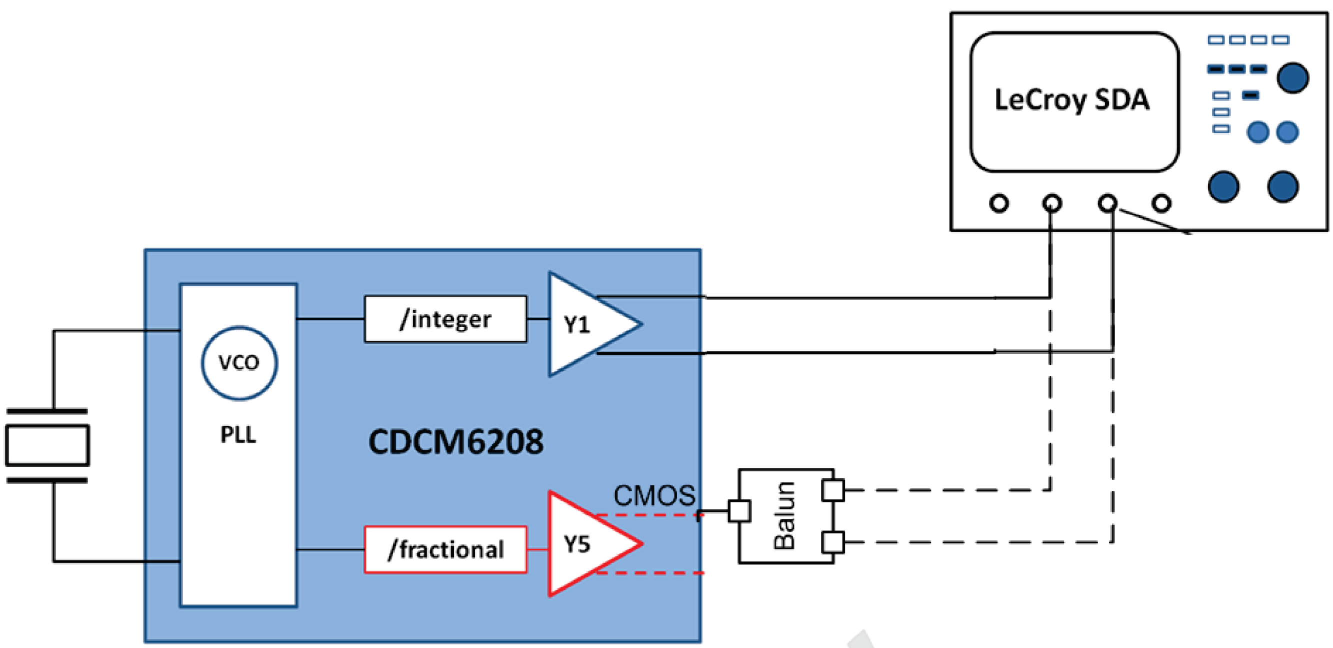

Figure 4. Traditional TJ Measurement Setup

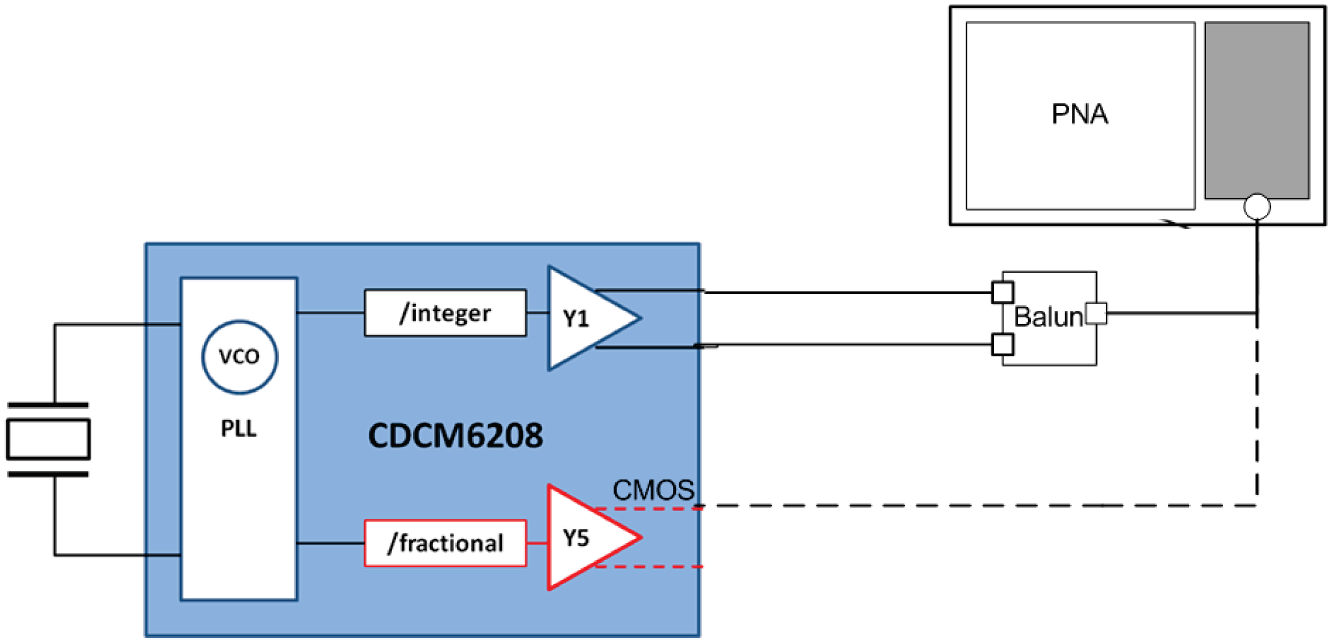

Figure 5. PNA Connection to Measure Random Jitter

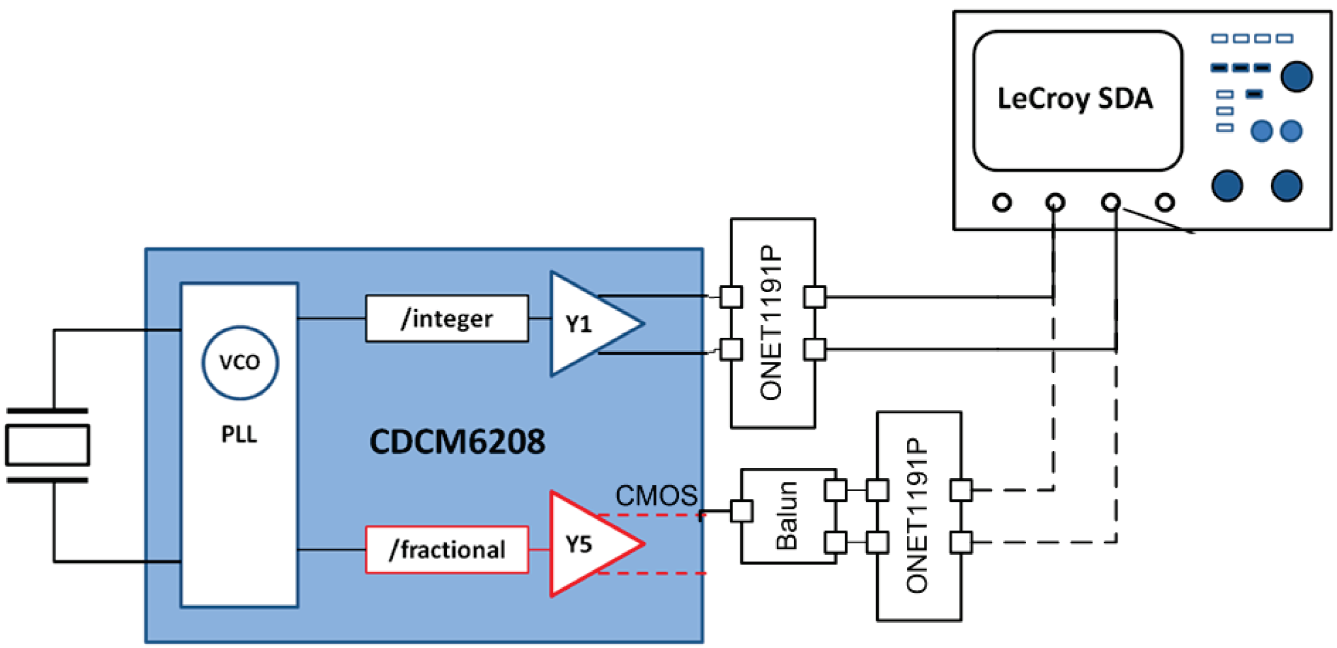

Figure 6. Improved TJ Measurement Setup With ONET1191P

4 Measurement Results

Figure 7 through Figure 14 show the measured results for TJ with and without the ONET1191P with different output frequencies.

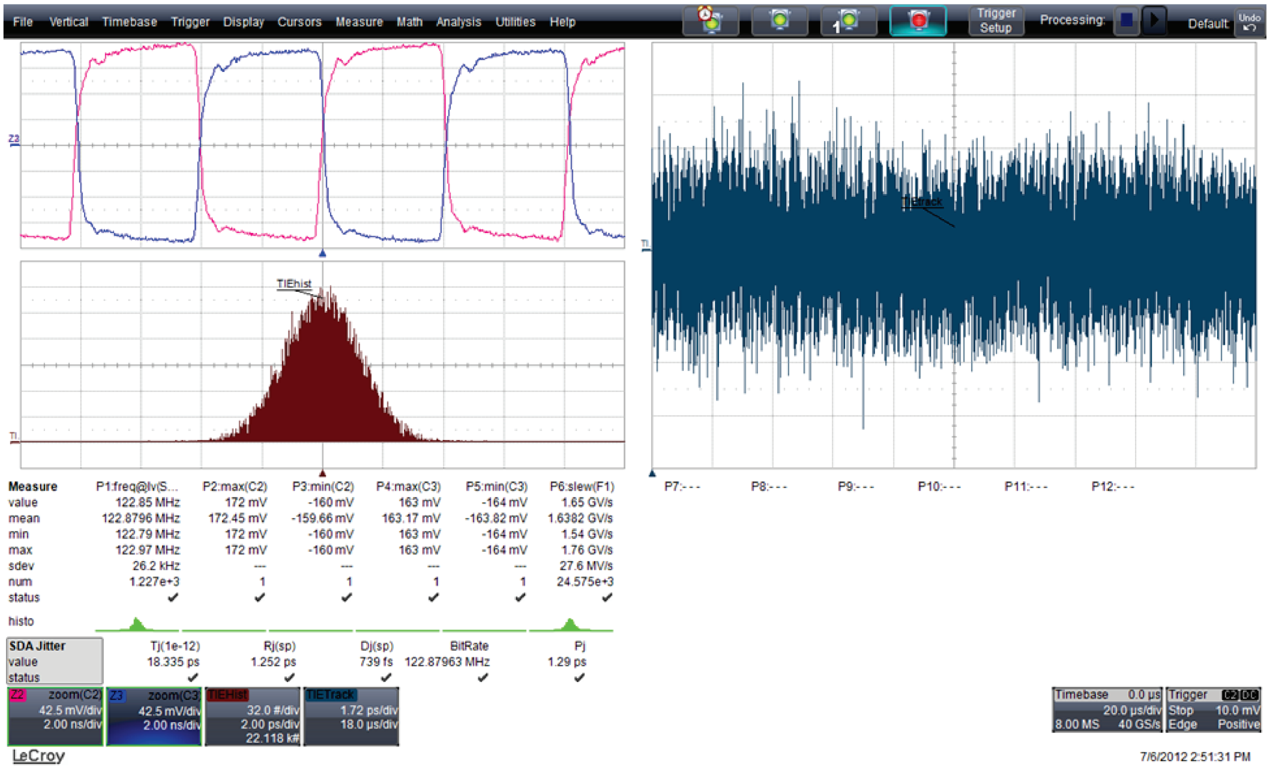

Figure 7. 122.88 MHz (Integer): TJ = 18.335 ps

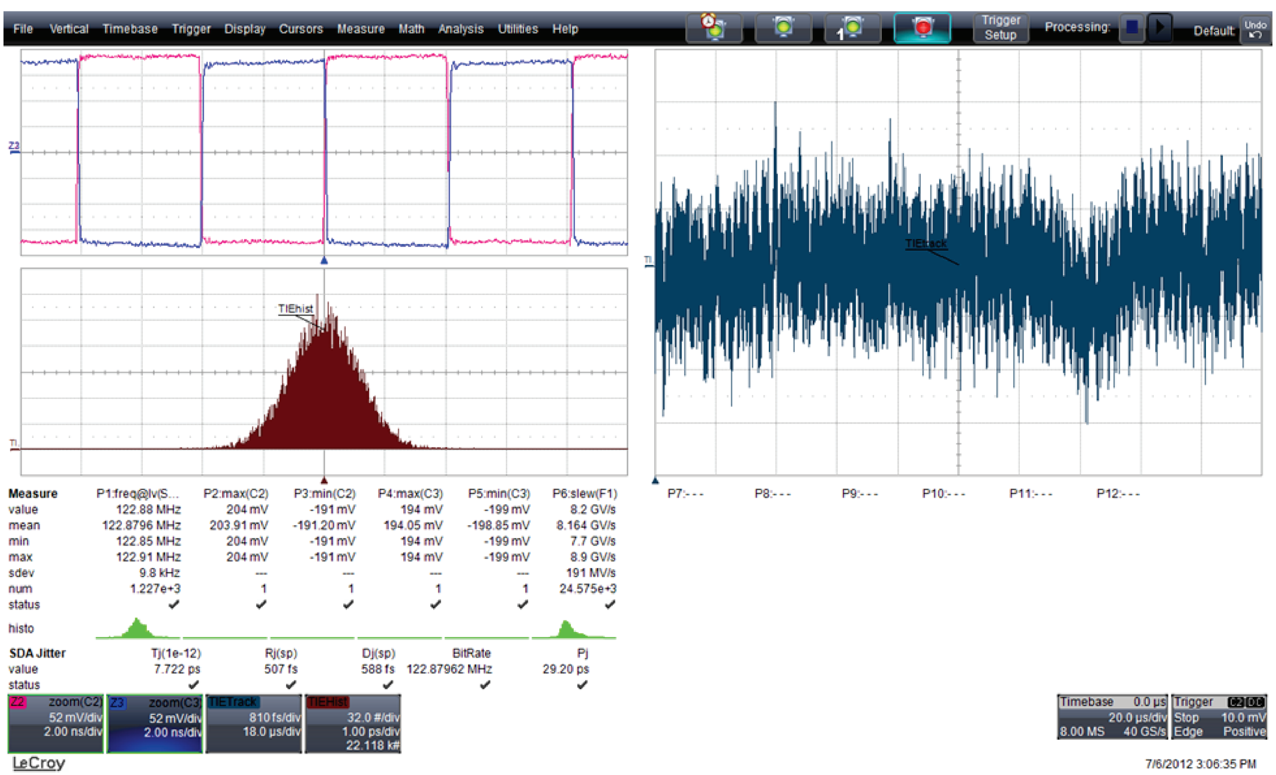

Figure 8. 122.88 MHz (Integer) With ONET1191P: TJ = 7.722 ps

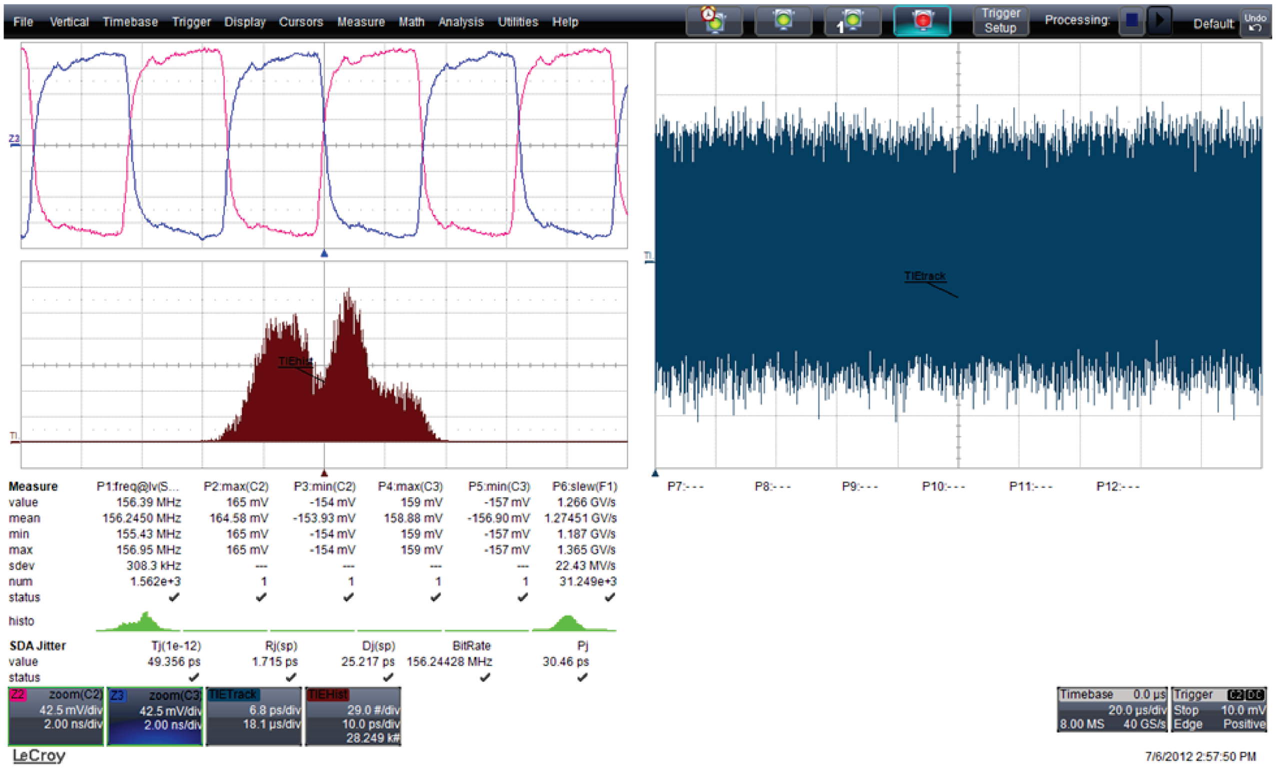

Figure 9. 156.25 MHz (6-Bit Fraction): TJ = 49.356 ps

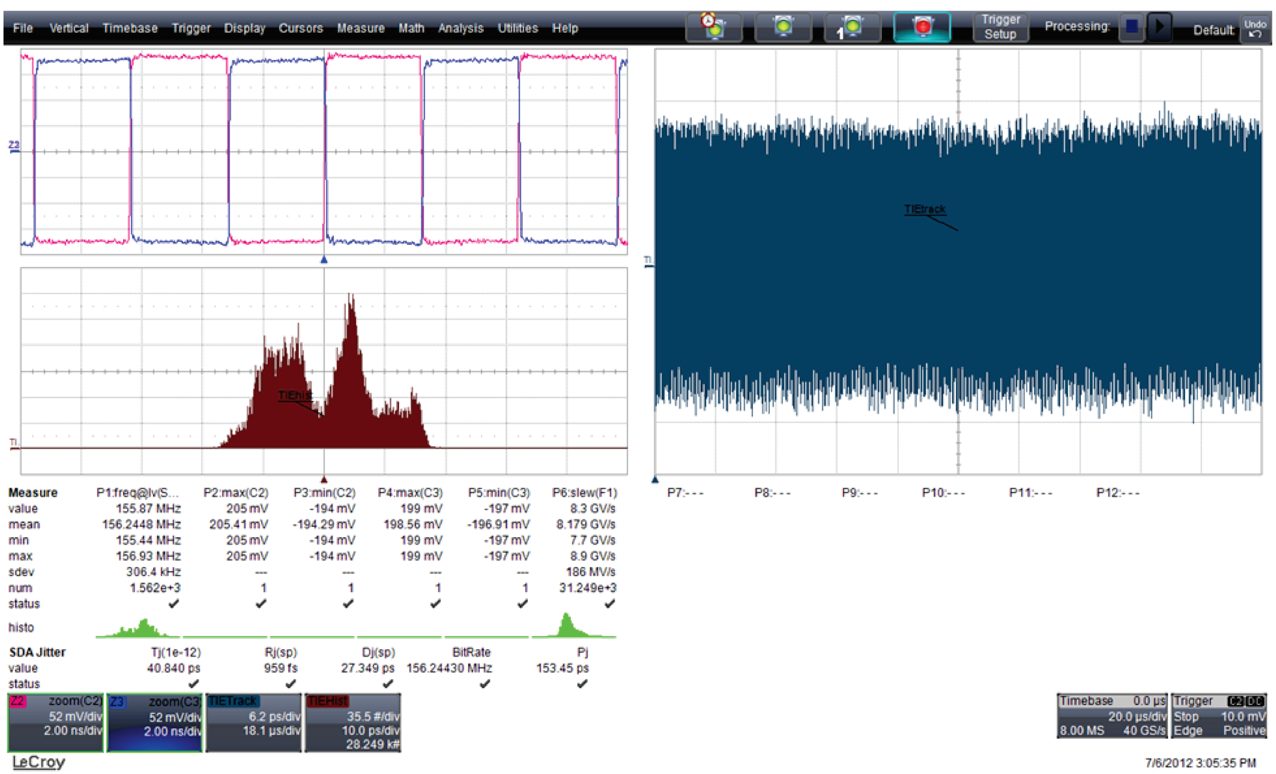

Figure 10. 156.25 MHz (6-Bit Fraction) With ONET1191P: TJ = 40.840 ps

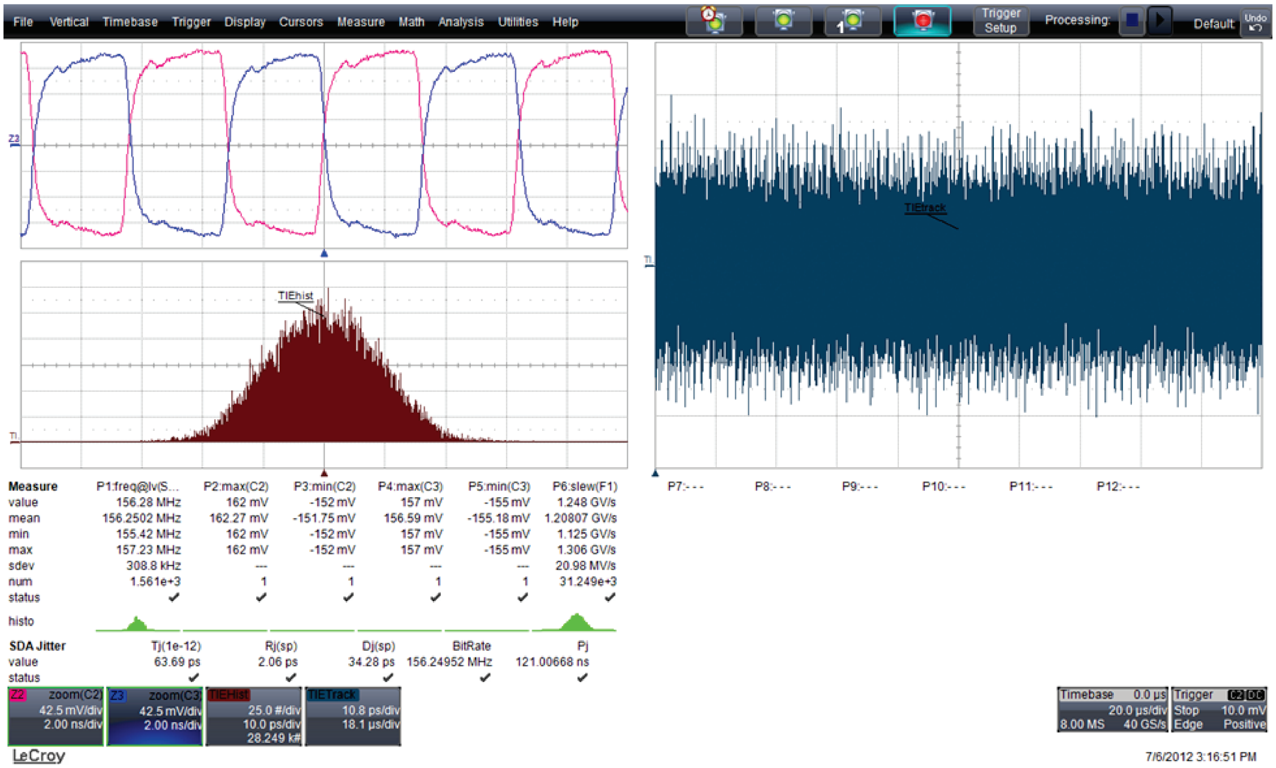

Figure 11. 156.25 MHz (20-Bit Fraction): TJ = 63.69 ps

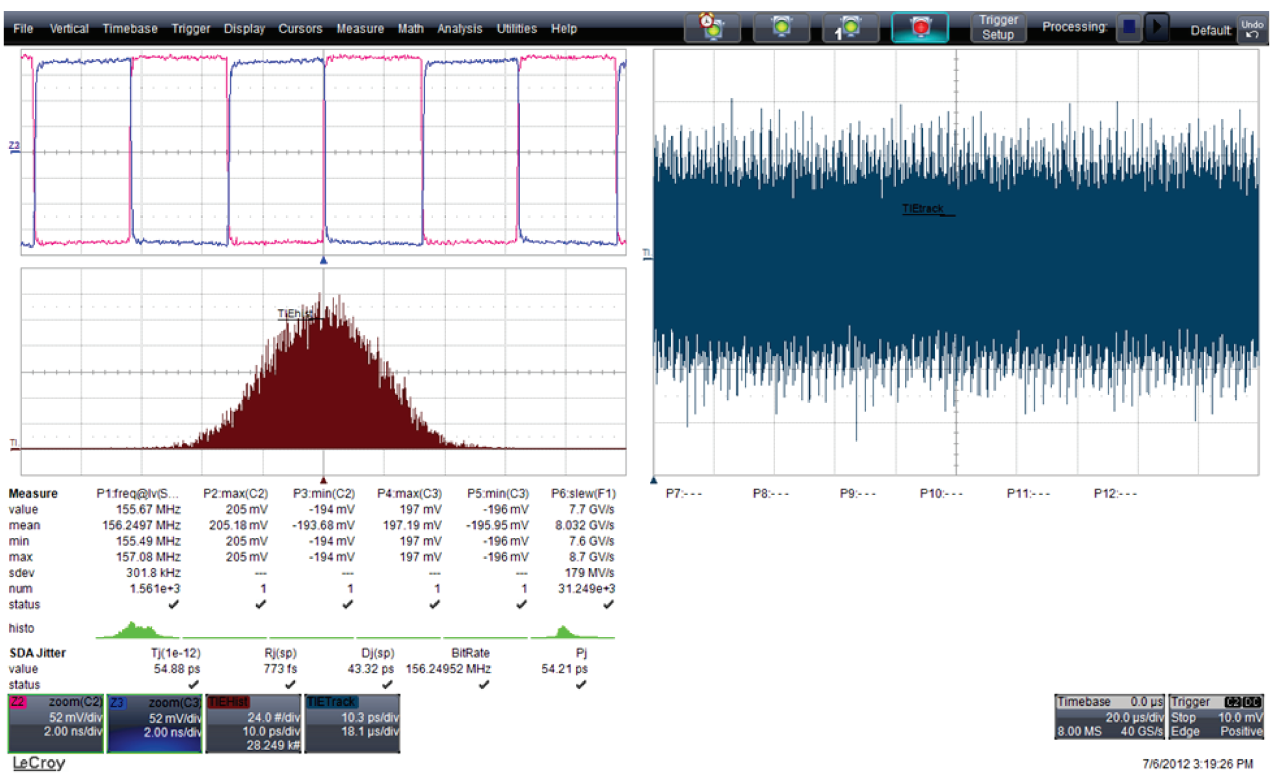

Figure 12. 156.25 MHz (20-Bit Fraction) With ONET1191P: TJ = 54.88 ps

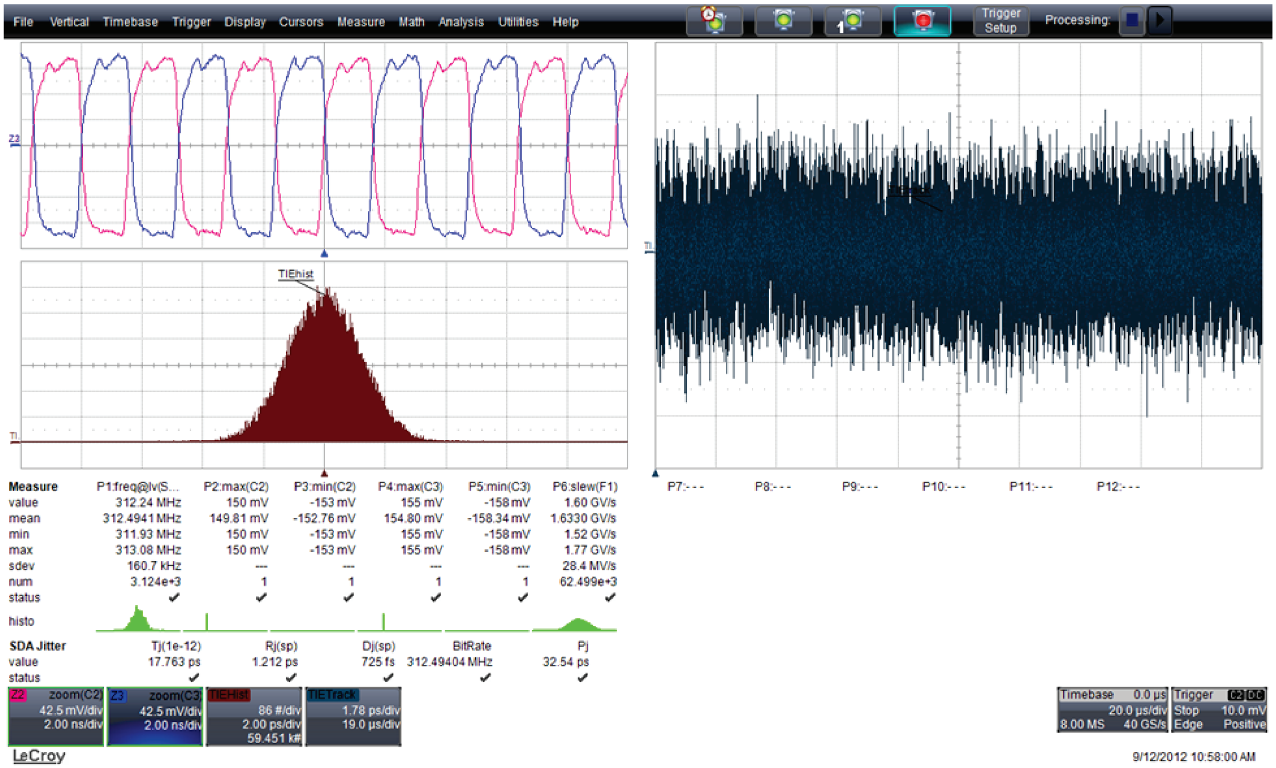

Figure 13. 312.5 MHz (Integer): TJ = 17.763 ps

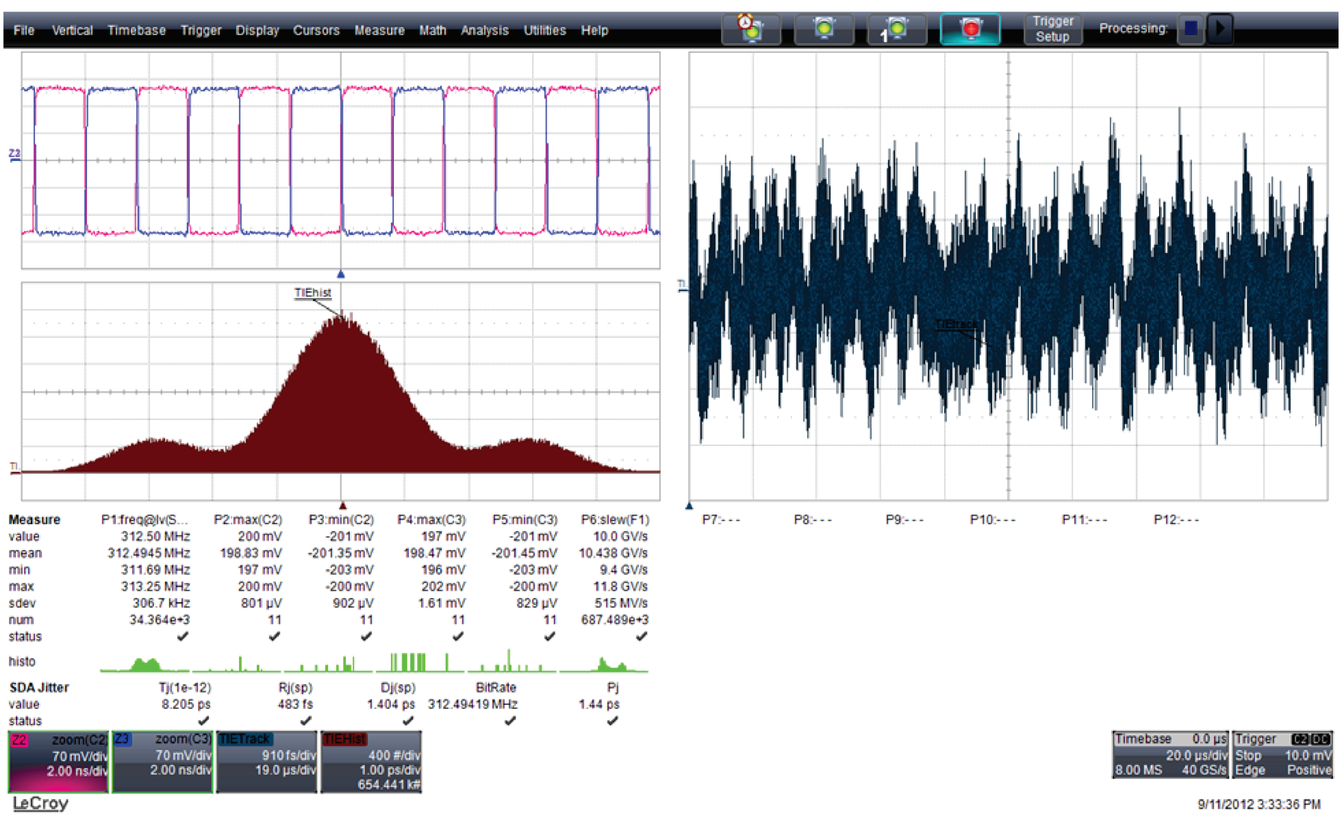

Figure 14. 312.5 MHz (Integer) With ONET1191P: TJ = 8.205 ps

5 Slew Rate Amplifier Alternatives

As an alternative to the ONET1191P, any other differential buffer with a rise and fall time smaller than 100 ps can be used.

CDCLVP12xx or LMK00301 could be used as an alternative, but the rise and fall times are still too slow.

Additionally, oscilloscope manufacturer LeCroy has a proprietary solution called SDA-LNES (Low-noise edge sharper).

6 Tradeoffs

Using a slew-rate amplifier to lower the oscilloscope noise impact, the random jitter component of the device under test is increased. Each component in the measurement chain worsens the random jitter. The impact can be calculated with this formula:

$$\text{Total Jitter} = \sqrt{(\text{Jitter DUT})^2 + (\text{Jitter Slew Rate Amplifier})^2} \quad (2)$$

High slew rates require oscilloscopes with a high sample rate (at least 40 GSPS) and enough memory to capture a signal over a long time. 40 GSPS means that the oscilloscope measurement point resolution is 25 ps. As an example, a 20 GSPS oscilloscope measures every 50 ps. Due to the fact that the ONET1191P has a typical rise time of 45 ps, a 40-GSPS oscilloscope is mandatory to measure the signal edge correctly. Otherwise, the under sampling effect adds additional jitter to the measurement.

7 Digital Serial Analyzer With DPOJET Software

As an example for Jitter measurement, Tektronix 16 GHz 50GS/s Digital Serial Analyzer with DPOJET software can be used for eye width/height and jitter analysis. Common DPOJET measurement parameters configuration used are shown in Table 2. Listed in this instruction set is the recommended process for the eye diagram measurement, using a Tektronix 16-GHz oscilloscope with DPOJET software. This software overlays all the possible unit intervals of data and conducts the horizontal and vertical measurements. The vertical measurement is in terms of voltage and the horizontal is in terms of UI.

Table 2. DPOJET Measurement Parameters Configuration

MEASUREMENT	EDGES	CLOCK RECOVERY	RjDj	FILTERS	GENERAL	GLOBAL	BIT CONFIG.
TJ@BER	Data	Method: PLL-Custom PW PLL Mode: Type I Loop BW: FPCLK/40 Apply to All: Apply	Pattern Detection/Control: Manual Pattern Type: Arbitrary Window Length 5UI Target BER: 1 E-10 Apply to All: Apply	HPF (F1) Filter Spec: 2nd Order Freq (F1): FPCLK/40 LPF (F2) Filter Spec: No Filter Apply to All: Apply	Default	Default	—
Width@BER	Data	Same Above	Same Above	Same Above	Default	Default	—
Height	—	—	—	—	Default	Default	Bit Type: All Bit

8 Conclusion

Total jitter has to be measured with an oscilloscope that has a reasonable jitter measurement floor smaller than 300 fs. In today's oscilloscopes, an external slew rate amplifier must be used to achieve such low jitter measurement floors.

In addition, the oscilloscope must have at least 40 GSPS to ensure a proper amount of sampling points to measure the fast slew rate of the slew rate amplifier and to prevent under sampling. Take the amount of scope memory into account, t as well, because the scopes must have a minimum number of samples to calculate TJ.

9 References

1. *CDCM6208 2:8 Clock Generator, Jitter Cleaner with Fractional Dividers* (SCAS931)
2. *Understanding the Jitter Specification in Oscilloscopes*; EETimes
3. SDA-LNES; LeCroy

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from A Revision (December 2012) to B Revision	Page
• Added the *Digital Serial Analyzer With DPOJET Software* section	10

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