# Jitter Analysis:

- DJ Analysis
- DJ and ISI Measurement Floor


## DJ Analysis

Deterministic Jitter (Dj) is jitter caused by non-random events. Dj is caused by several major sources: Periodic jitter (Pj) is due to repetitive noise sources like power supplies, adjacent oscillators, and in some cases crosstalk of adjacent buses; Duty Cycle Distortion (DCD) is caused by an imbalance in the drive circuit bias levels or thermal effects within the transmitting device; Inter Symbol Interference (ISI), also called Data Dependent jitter (DDj), is caused by frequency related losses in the signal path, and most commonly due to interconnect and cabling losses.

### DJ Jitter and ISI Measurement Floor

The ability to resolve ISI is important. It is a good measure of the quality of the transmission path, and is an important factor in a total jitter budget. Budget used to allow for ISI can often be better used to allow for less controllable sources of jitter.

This paper will show how a TDS6604 using TDSJIT3 Jitter and Timing Analysis software measures various levels of ISI and what a typical minimum value is for high-speed serial signals.

The test setup is an HP BERT sourcing a 3.25Gb/s PRBS $2^7$-1 pattern at –0.250v to 0.250v, with a 10% to 90% risetime of about 24 ps. This source is driving a 20 inch length of SMA terminated RG142, an ISI load board with various lengths of 50 Ω trace terminated with SMA connectors, a male to male adapter, and an 8 inch length of RG142 that terminates at the instrument. See Figure 1 for the basic test configuration. The 20 inch cable was required to allow adequate room between instruments and load board – a shorter cable would have been better to minimize the true test system ISI floor.

The instruments used were:

HP70004A Display with HP70843A Pattern Generator / Pattern Detector
- together form a 12Gb/s bit error-ratio test system (BERT)

TDS8000B with 80E03
- together form a 20GHz equivalent-time oscilloscope system

TDS6604 with TDSJIT3 Jitter and Timing Analysis Software
- together form a 6GHz real-time jitter and timing analysis system

Custom ISI Load Board
- 12”, 24” and 36” 50 Ω traces on FR-4 laminate ECB

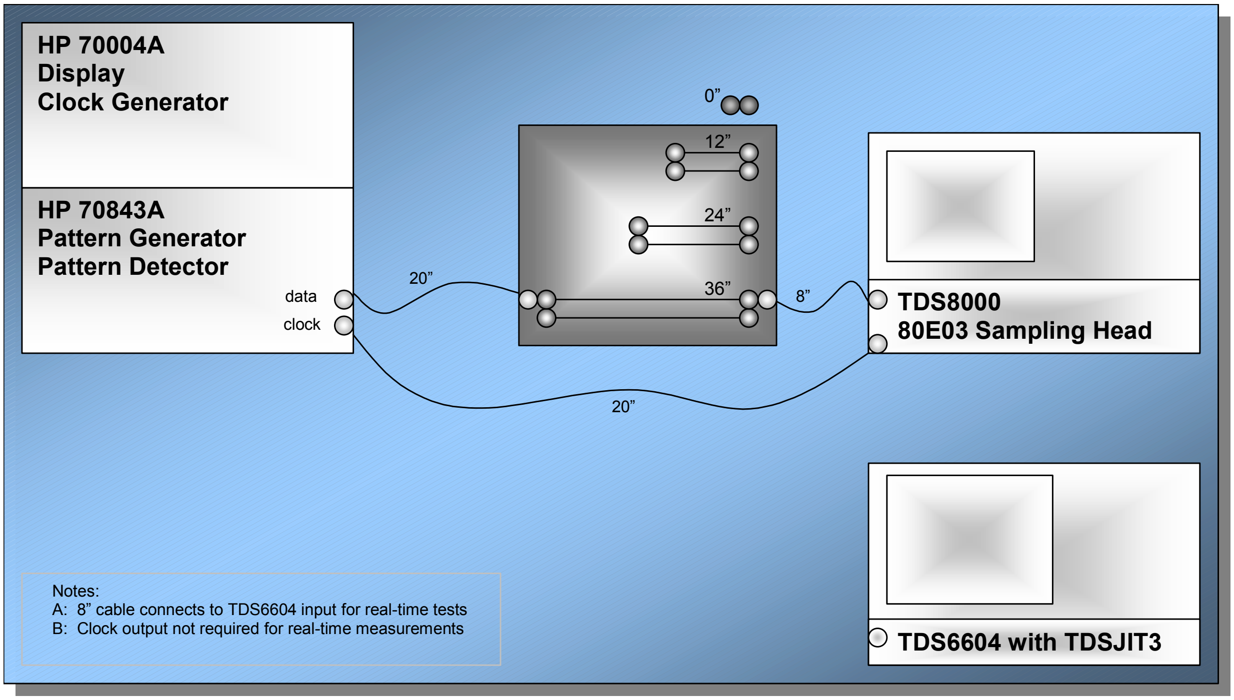


**Figure 1 – Basic Test Setup**

## Direct Connection Results

The unfiltered signal risetime displayed on the TDS8000 was about 30ps between the 10% and 90% points as shown in Figure 2. The nearly Gaussian shape of the histogram included in Figure 2 also shows that there is little or no ISI in the signal. Clearly, the ISI is less than the peak-to-peak composite jitter shown: 12.0 ps peak-to-peak, 1.5 ps RMS.

This signal was then connected to the TDS6604 and a 10us, 200k record acquired at 20GS/s. TDSJIT3 was then used to measure the deterministic jitter components. The results are shown in Figure 3. The measured ISI is 3.2 ps peak-to-peak. Total jitter (Tj) estimated for $10^{12}$ bits is 21.6 ps peak-to-peak.

These results are representative of the typical TDS6604 total jitter noise floor for data signals.

Figure 4 shows the measured rise time at the TDS6604. To make the rise-time measurement easier to view, the BERT was set to output a 1010 clock-like pattern at 3.25Gb/s.

Using SinX/X interpolation resolving 16 ps per sample point, the TDS6604 with TDSJIT3 reports the 10% to 90% risetime as 51 ps. Remembering that the TDS8000, itself with a 17.5 ps risetime, measured the signal risetime at 30 ps. This infers the BERT output signal has a true risetime in the range of 24 ps[1]. The 20GHz oscilloscope exceeds the risetime of the source instrument, therefore should show little ISI due to bandwidth limitations. It should also be clear some ISI must be incurred due to the TDS6604 bandwidth limitation of 6Ghz; the cabling required to make the measurements is inducing some amount of ISI; and that a minimal amount of ISI is present in the source signal:  a non-zero ISI value is always expected for any data signal.

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[1] $t_{rt} = \sqrt{t_{r1}^{\,2} + t_{r2}^{\,2}}$



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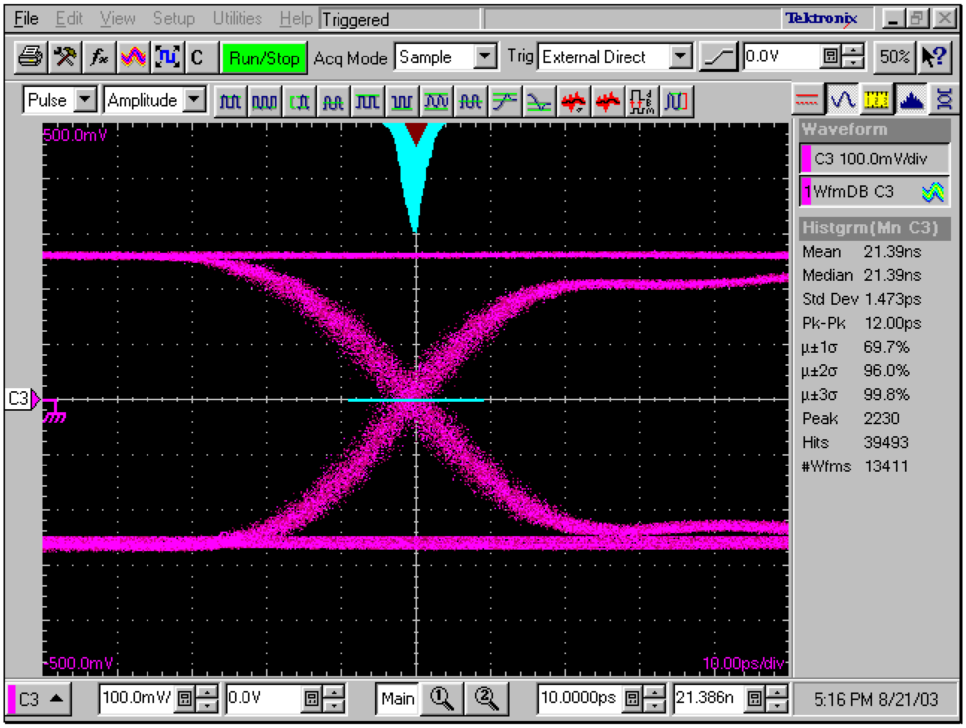


**Figure 2 – TDS8000 Direct Connection (28" RG142)**


**Figure 3 – TDS6604 Direct Connection (28" RG142)**



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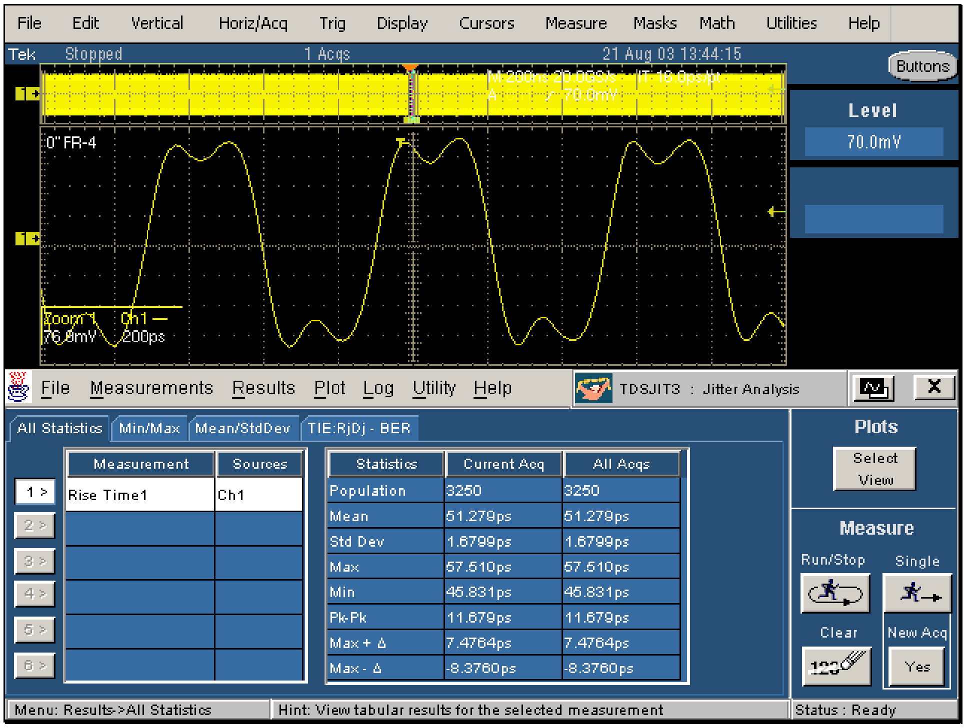


**Figure 4 - TDS6604 Direct Connection Risetime 10%-90%**

In the following TDS8000 plots, cursors were placed to approximate where a casual observer might determine where the ISI boundaries are. This is a mechanical and very subjective placement and as shown: quite inaccurate. Please note that while not used for this paper the TDS8000 offers Frame-Scan, an acquisition mode that provides a more accurate measurement of DDj.



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## Low ISI Results

In Figure 5, the TDS8000 is measuring the BERT signal after it has propagated through 12 inches of 50 Ω transmission line in a typical FR-4 (fiberglass) etched circuit board. The risetime is degraded and there is now a perceptible amount of visible ISI in the histogram as a subtle spreading, though since the ISI is over several bit periods it is not clearly viewable as peaks in the histogram.

Figure 6 shows the same test using the TDS6604. TDSJIT3 easily discerns the added ISI and provides a direct readout of the new value. ISI has risen to 12.9 ps peak-to-peak. Tj at $10^{12}$ bits is now 34.8 ps. The equivalent eye opening for $10^{12}$ bits is 0.886 UI or 272 ps.

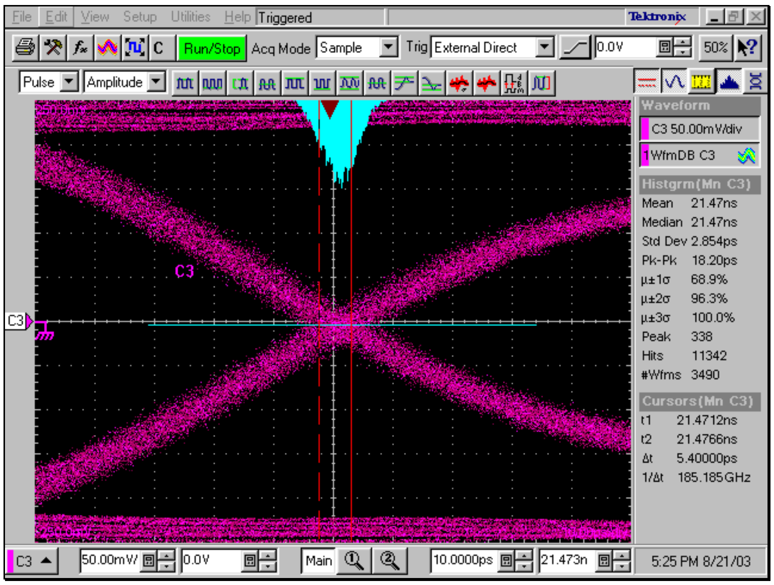


Figure 5 - TDS8000 Low ISI (28" RG142 plus 12" FR-4)

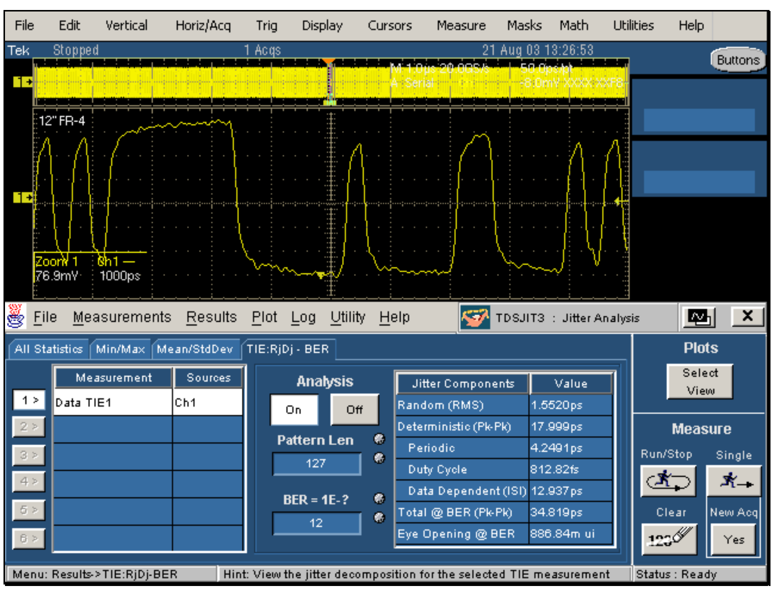


Figure 6 - TDS6604 Low ISI (28" RG142 plus 12" FR-4)

In this test, the BERT reported 278 ps eye opening for a population of $10^7$ bits, or 30 ps peak-to-peak jitter over a 3-millisecond measurement period.

## Moderate ISI Results

In Figure 7, the TDS8000 is measuring the BERT signal after it has propagated through 24 inches of 50 Ω transmission line in FR-4. The risetime is further degraded and there is now a clearly visible amount of ISI in the histogram. Cursors are placed at a visual guess of where the ISI ends: about 25 ps peak-to-peak.

Figure 8 shows the test using the TDS6604. Again TDSJIT3 easily discerns the ISI and provides a direct readout of the value. ISI has risen to 32.4 ps peak-to-peak. Tj at $10^{12}$ bits is now 61.8 ps. Note that the Tj does not correlate to 14Rj+Dj. This is due to the fact the Dj encountered does not match the dual-Dirac requirement that deterministic sources be bi-modal for the equation to properly model long term performance. TDSJIT3 takes the true PDF of the Dj and calculates the Tj correctly, and accurately.

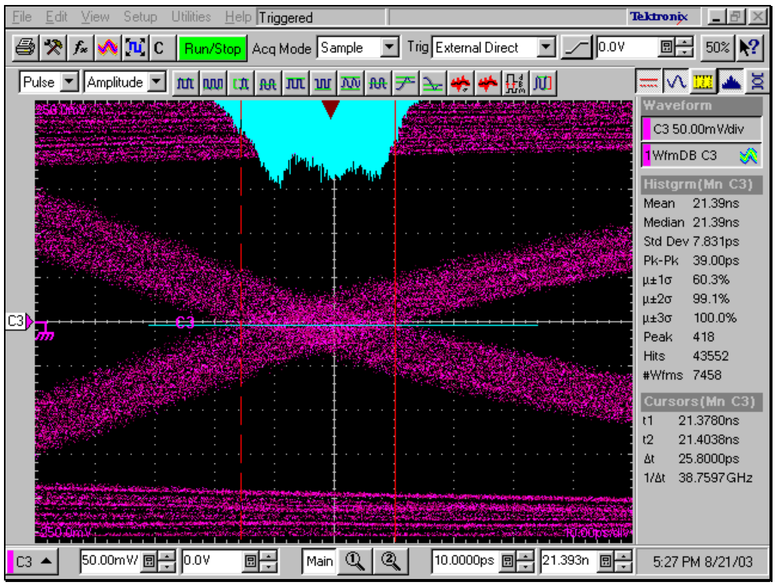


**Figure 7 - TDS8000 Moderate ISI (28" RG-142 plus 24" FR-4)**

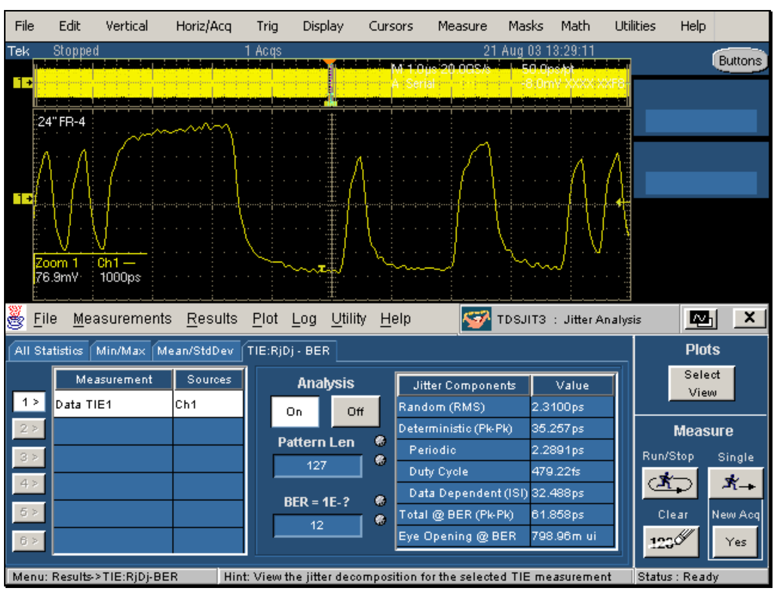


**Figure 8 - TDS6604 Moderate ISI (28" RG142 plus 24" FR-4)**



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## High ISI Results

In Figure 9, the TDS8000 is measuring the BERT signal after it has propagated through 36 inches of 50 Ω transmission line in FR-4. The risetime is now significantly degraded and the ISI shows up as very distinct peaks in the histogram.

Figure 10 shows the test using the TDS6604. Once again TDSJIT3 easily discerns the ISI and provides a direct readout of the value. ISI has risen to 65.8 ps peak-to-peak. Tj at $10^{12}$ bits is now 108.9 ps. Once again note that the Tj does not correlate to 14Rj+Dj. TDSJIT3 takes the true PDF of the Dj and accurately calculates the Tj.

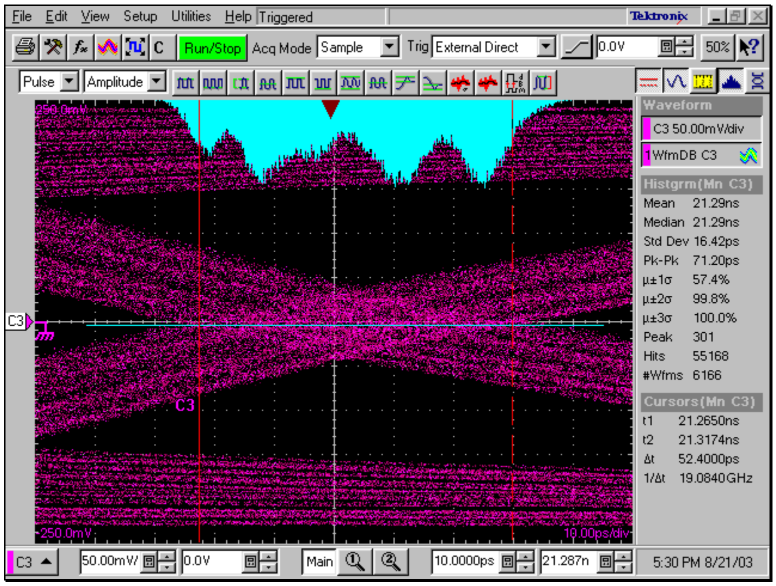


**Figure 9 - TDS8000 High ISI (28" RG-142 plus 36" FR-4)**

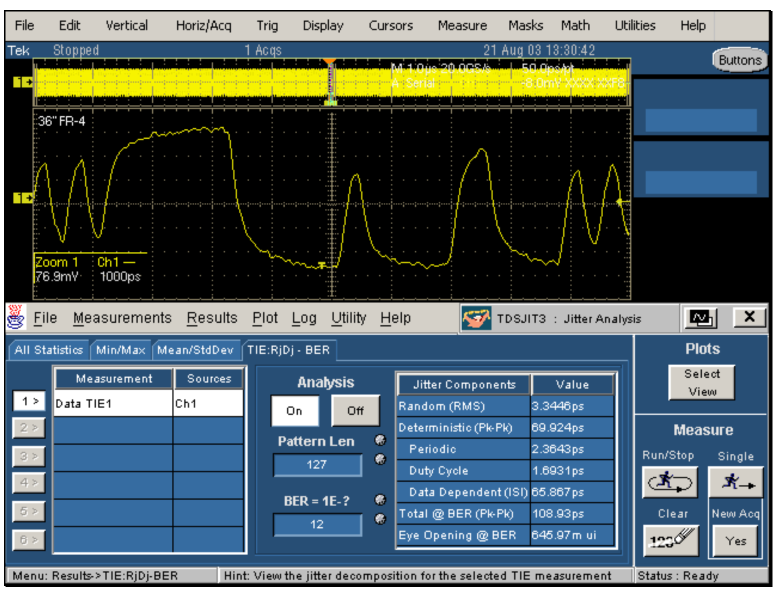


**Figure 10 - TDS6604 High ISI (28" RG-142 plus 36" FR-4)**

In all cases, adding ISI also adds some Rj component due to the added dv/dt related noise associated with the acquisition system.



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## In Summary

ISI, or DDj, is an especially important component of jitter because it is one of the more controllable sources that reduce jitter margins. Being able to accurately identify and measure DDj gives designers the ability to more carefully characterize their designs. In some cases providing valuable insight to allow tradeoffs between manufacturing costs and system performance, or in some cases insight into the causes of marginally meeting a system design specification.

With a typical composite jitter noise floor of 0.7ps RMS, the TDS6604 is the best performing oscilloscope based measurement instrument available today.

Running on a Tektronix real-time oscilloscope like the TDS6604, TDSJIT3 provides the ability to decompose jitter into random and deterministic components; and further will decompose Dj into the three major forms DCD, Pj, and ISI or DDj. Making this ability available in a convenient and general purpose tool like the oscilloscope, allows smaller engineering capital budgets to be used much more effectively than was previously possible.

For more information, please contact your local Tektronix sales representative.

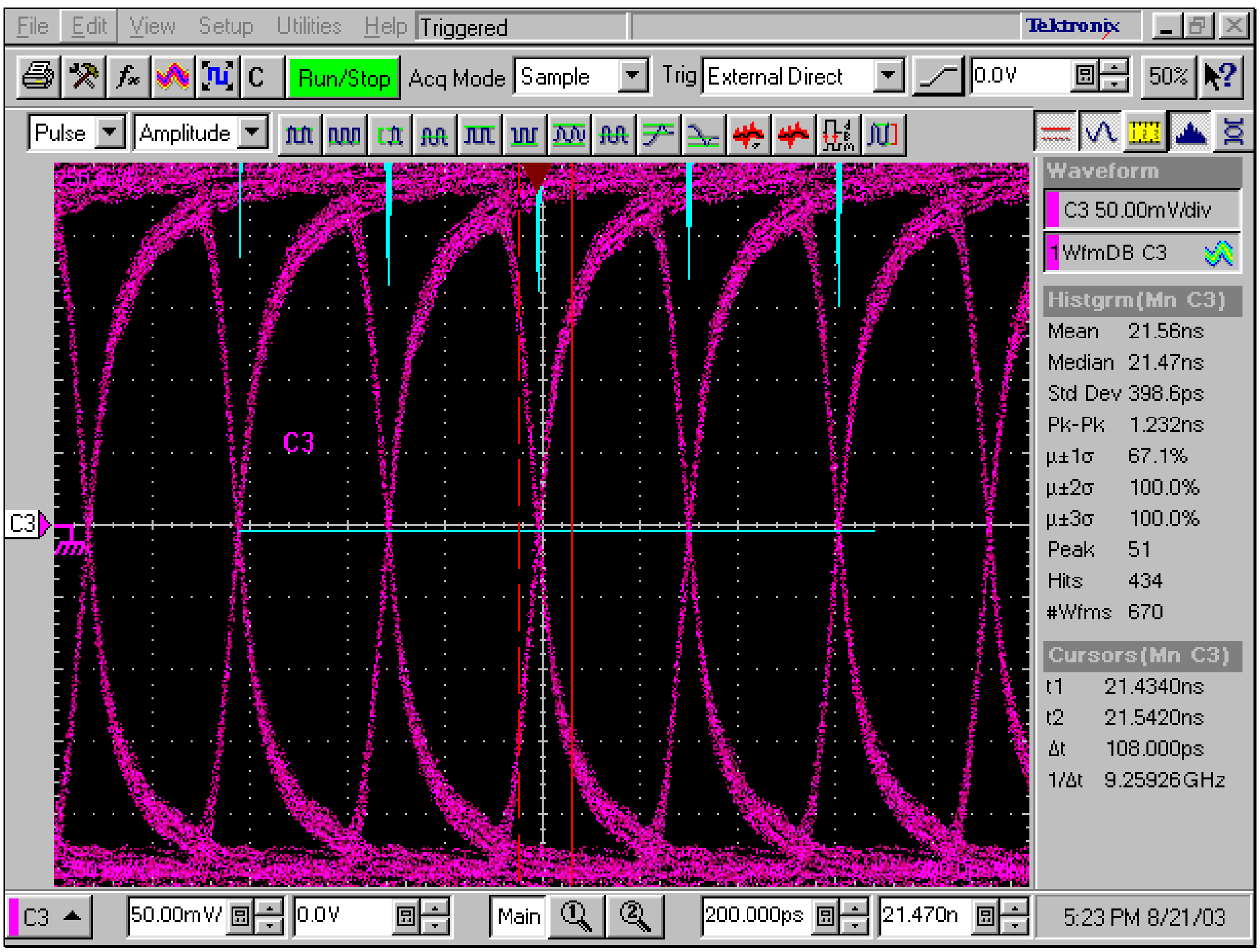


**Figure 11 - PRBS $2^7$-1 Data with Various Run Lengths**



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