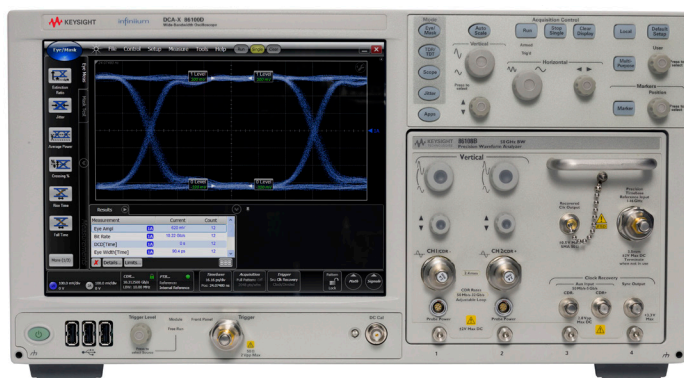


# Tips and Techniques for Accurate Characterization of 28 Gb/s Designs

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# Introduction

The worldwide demand for data capacity in networks greatly increases every year, driven by services like cloud computing and Video on Demand. As installed networks approach their capacity, operators need to either add physical capacity, which is very expensive, or transfer more data through the existing networks. These factors drive the need for much higher data rates, and the medium and long haul transmission is handled by fiber optic networks. Data is initially and finally handled within electrical circuits, and is limited to relatively short distances primarily because of the loss in electrical channels. Within a few short years, the challenges of developing solutions that handle 10 Gb/s have faded and have been replaced with new challenges at rates of 14 Gb/s to 120 Gb/s, resulting in a proliferation of multi-channel standards and applications.

Keysight Technologies, Inc. continues to anticipate and provide innovative test solutions as designers move through early development and validation cycles. This application note focuses on test solutions for electrical transmitters operating from 10 Gb/s to 28 Gb/s and beyond, and covers the commonly required test parameters and techniques.

## Measurement Challenges

### Lower jitter budgets

As rates increase, the bit periods become shorter. With shorter bit periods, the jitter must be lower than ever before, even to the sub-picosecond range. To ensure accurate transmitter characterization, the intrinsic jitter of test equipment must be significantly less than the specified transmitter jitter.

### Clock recovery required

While sampling oscilloscopes are known for their high measurement accuracy, they require a synchronous clock as a trigger. Often there is no access to a suitable clock, or clock recovery must be utilized for compliance reasons, and hardware clock recovery must be employed.

### High measurement fidelity required

To ensure the signal is accurately represented by the oscilloscope, high data rate applications require more measurement bandwidth, lower noise and minimization of delays between trigger and data stream.

### Analyzing closed eyes

After high speed signals have passed through a backplane or similar lossy channel, the inter-symbol interference (ISI) that is introduced may close the eye entirely. Innovative measurement techniques allow the user to re-open the eye and characterize the parameters.

## Applicable Standards and Measurements

Earlier standards such as SONET and SDH have been replaced by standards such as IEEE's 802.3 and the Optical Internetworking Forum Common Electrical I/O (OIF CEI). Some standards focus on the optical interfaces, some on electrical interfaces, and some on both. This application note focuses on the electrical portions of key standards that govern the much higher data rates. Please refer to other Keysight application notes that provide extensive coverage of optical measurements and standards at lower rates. Devices within the overall system include chips, modules, backplanes and cables. Table 1 summarizes the applicable standards, corresponding data rates, common devices and typical transmission distances.

Each standard uses a different set of parameters to characterize the transmitters, driven by differences in network requirements and data rates. Parameters like output voltage and rise/fall times are common to nearly all standards and are mandatory to verify that a transmitter complies with a given standard. Other parameters are found only in a few standards, and may be mandatory or optional (informative). This application note provides deeper insights into the parameters and how to effectively and quickly measure each of the common parameters, by both manual control and automatic control.

Standard	Data Rates	Link Type	Distance
IEEE 802.3ap, 10 G	10.3125 Gb/s	Backplane	<1m
IEEE 802.3ba, 40 G	4 x 10.3125 Gb/s	Chip-to-chip Backplane Copper cable	<1m <7m
IEEE 802.3ba, 100 G	10 x 10.3125 Gb/s	Chip-to-module	
IEEE 802.3ba, 100 G	4 x 25.78 Gb/s	Chip-to-chip Chip-to-module Copper cable	<7m
OIF CEI 25G-LR	N x 19.6-28.05 Gb/s	Chip-to-chip Chip-to-module	<650 mm
OIF CEI 28G-SR	N x 19.6-28.05 Gb/s	Chip-to-chip	<300 mm
OIF CEI 28G-VSR	N x 19.6-28.05 Gb/s	Module PCB trace Host PCB trace	>50 mm >100 mm
Fibre Channel 16X	14.025 Gb/s	Cable Module PCB trace Host PCB trace	<5 m
32X	28.05 Gb/s		
InfiniBand	10 x 10.3125 Gb/s 12 x 10.5 Gb/s 4 x 25 Gb/s	Cable Host PCB trace	<20 m
SFF-8431	1 x 10 Gb/s	Host board trace	<300 mm

Table 1. High speed standards operating at data rates from 10 Gb/s to 28 Gb/s

## Typical Devices and Topologies

Several new semiconductor integrated circuits on the market today include input-output (I/O) ports that operate at rates from a few to 28 Gb/s, with emerging standards pushing data rates even higher. The IC's occupy less board space and often use lower power for new designs. Other designs utilize lower cost components and generate high bit rate signals through the use of discrete circuits such as multiplexers. System block diagrams then depend on having full rate data streams only over very short distances, or just prior to entering the optical portion of the network such as through modulators.

Many developers use application specific integrated circuits (ASIC's) within their designs, which provide greater flexibility when considering design topologies and troubleshooting. A common use of ASIC's is for multiplexers, which combine multiple data streams into fewer data streams, or fewer into multiple data streams; these topologies are often called "gearboxes". One example is to design the source data streams at 10 Gb/s, then multiplex ten data streams to four 25 Gb/s streams as shown in Figure 1. These four streams can be used to directly modulate four wavelengths on the fiber or be further multiplexed into one stream at 100 Gb/s as conceived in emerging architectures.

With increasingly more complex systems being developed, designers need to characterize sub-assemblies to verify proper operation before use in the full system. In order to validate a reference design, and to facilitate accurate waveform performance, designers make use of test fixtures such as shown in Figure 2 to connect to the device under test (DUT) through coaxial connectors.

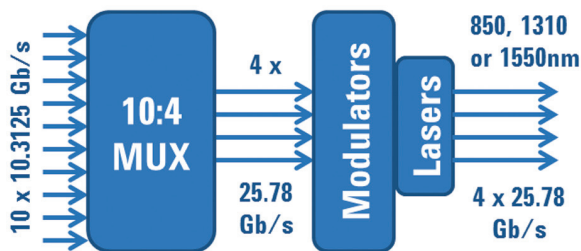


Figure 1a. Example block diagram of high data rate transmitters for 4 x 25 Gb/s



Figure 1b. Example block diagram of high data rate transmitters for 100 Gb/s



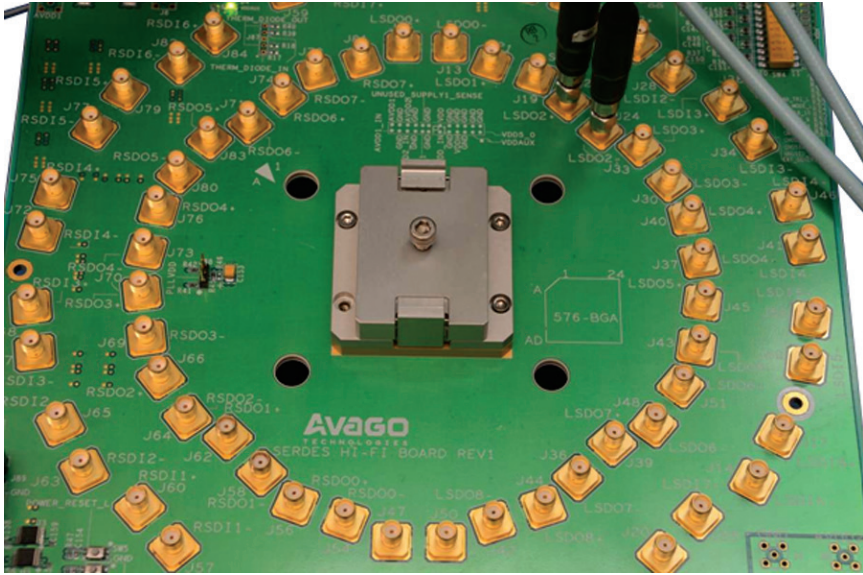


Figure 2. Typical test fixtures used to characterize performance of integrated circuit I/O

## Choosing the Optimal Test Solution

Designers are faced with several key requirements when making measurements on high data rate devices:

- Measurement receiver with sufficient bandwidth and fidelity to capture edge speeds and accurately show eye shape
- Clock recovery to obtain the clock from data is required for compliance and to track low frequency jitter
- Very low intrinsic timebase jitter, typically provided by a precision timebase to maximize jitter margins and to minimize the impact of test equipment

Previously, measurement equipment could only accommodate two of these three requirements in a single instrument when operating at higher rates. Keysight has a rich legacy of providing innovative solutions in time for early development and subsequent validation, and honed for fast and efficient characterization during manufacturing. Regular introductions of new hardware and software solutions add to the range of high data rate test solutions already available.

For example, the 86100D Digital Communications Analyzer (DCA-X) improves measurement speed and enhances the already industry-leading user interface. For native 40 Gb/s measurements, the 86118A 70 GHz Dual Remote Sampling Head is an ideal choice. The 86108A precision waveform analyzer introduced all of this functionality and these benefits into one convenient plug-in measurement module.

Accelerated development of rates to 28 Gb/s requires even more discerning measurement solutions. The 86108B precision waveform analyzer is the all-in-one solution for design verification and validation of high-speed electrical communication systems and components to 32 Gb/s. The 86108B covers all standards listed in Table 1, providing clock recovery and data coverage to 32 Gb/s, and adding additional sub-rate clock capabilities. Figure 3a demonstrates the very simple configuration to make complex measurements. Please refer to Appendix A for the block diagram and description of the 86108B. An alternative solution would be to use a dual channel measurement module and precision timebase in the mainframe and use an external clock recovery module as shown in Figure 3b. However, this setup adds measurement complexity and trigger-to-sample delay.

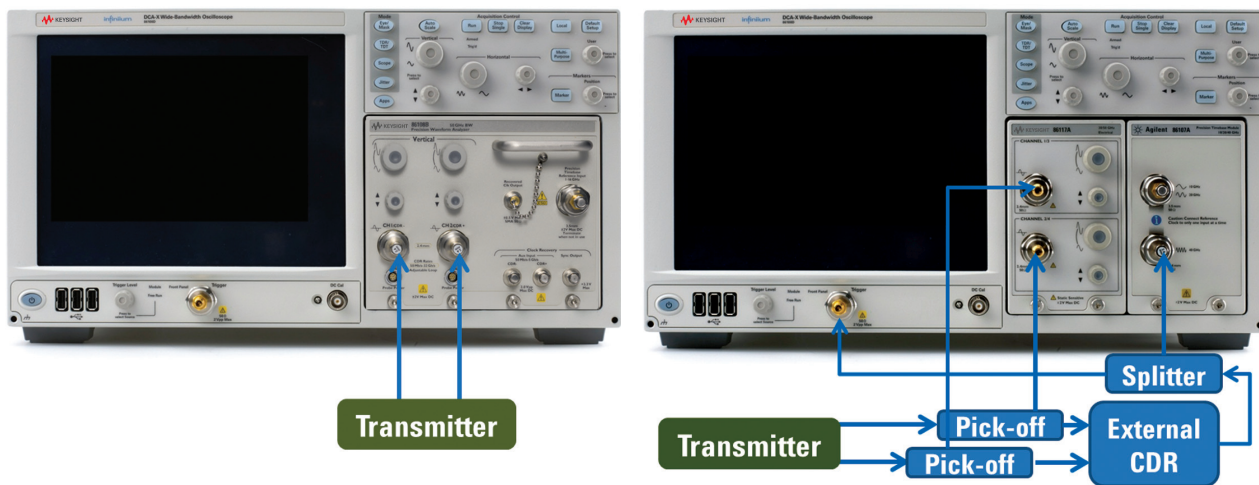


Figure 3a and b. Two typical test equipment set-ups for high data rate, low jitter measurements

# Choosing the Optimal Test Solution

## Trigger delay

When a trigger event occurs in a standard sampling oscilloscope configuration, at least 20 ns elapse before a waveform sample is acquired. This trigger-to-sample delay can lead to measurement inaccuracies. An important benefit provided by the precision time base (PTB), beyond the reduction of residual oscilloscope jitter, is mitigation of the delay between the trigger event and when a waveform sample is taken. Because of the tight timing alignment required for accurate measurements, the integrated PTB of the 86108 receiver addresses the cable matching typically necessary when separate external units are used.

There are no 25 Gb/s standards that currently use spread spectrum clocks (SSC), but SSC illustrates the effect of trigger delay. As the amount of trigger delay is increased, the edge transitions are further distributed as shown in Figure 4a. Note the very broad transitions and very large jitter, particularly the periodic jitter (PJ). The precision timebase (PTB) within the 86108 reference receiver reduces the trigger delay to near 0 ns, and greatly improves the eye and jitter results as shown in Figure 4b. Total jitter (TJ) improves from 30 ps to 14 ps, periodic jitter (PJ) from 8 ps to 2 ps and random jitter (RJ) from 1.3 ps to about 450 fs.

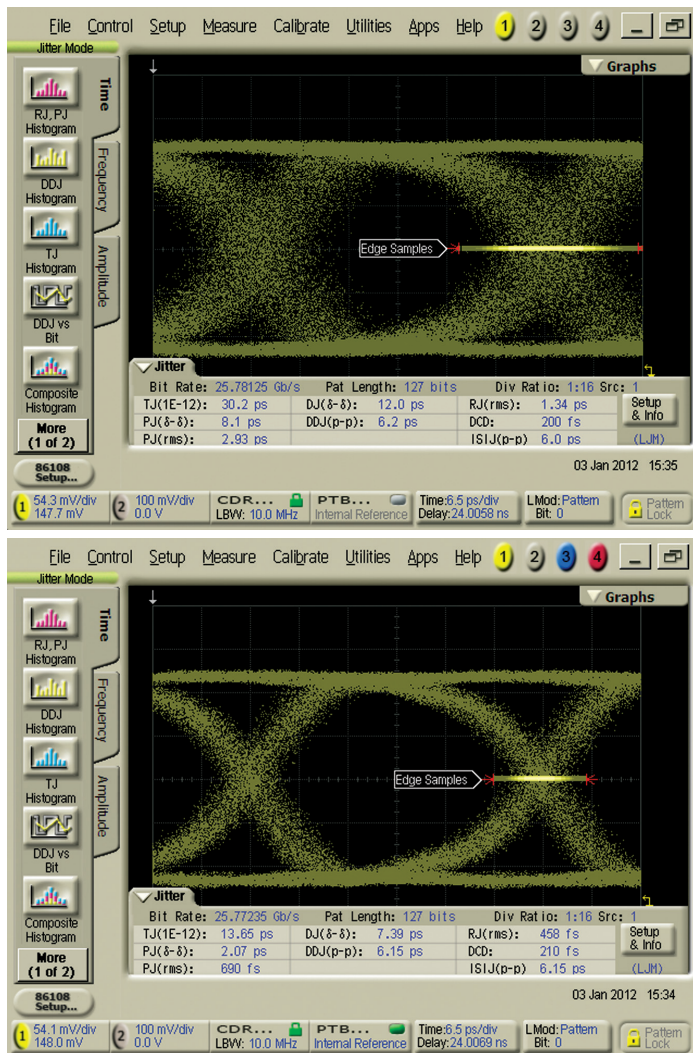


Figure 4a and b. Data stream at 25.78 Gb/s with SSC. Top response is without the PTB; bottom response shows the benefit of the PTB as it reduces random jitter and mitigates the effect of data to clock trigger delay.

## Choosing the Optimal Test Solution

Keysight offers a range of test solutions to cover different data rates and device parameters. To characterize low jitter transmitters using clock recovery (for compliance reasons or because there is no direct clock available), the 86108B plug-in modules provide the most accurate solution in one convenient package. To assure the best characterization of the transmitters, users need to choose sufficient measurement bandwidth, which may be the 3rd or 5th harmonic of the fundamental of the signal. For example, to measure the 3rd harmonic of a 32 Gb/s signal, the measurement receiver needs 48 GHz of bandwidth. Please refer to the table to the right for recommended solutions based on level of jitter, type of clock and data rates. Appendix C provides additional detail on the relationship between equipment, device and total measurement jitter.

Data Rate >>	Clock Recovery Required		Explicit Clock Available		
	To 14.2 Gb/s	To 32 Gb/s	To 14.2 Gb/s	To 32 Gb/s	To 43 Gb/s
Lowest jitter (RJ < 2 ps)	86108A/B	86108B	86108A/B Or 86112A 86107A-020	86108B Or 6117A 86107A-040	86118A-H01 86107A-040
Moderate jitter (RJ > 2 ps)	86108A/B Or 86112A 83496B	86108B Or 86117A External CDR	86108A/B Or 86112A	86108B Or 86117A	86118A-H01

## Probing

When coaxial connections are not available, the user may need to probe the design. Additionally, a pair of differential probes converts a dual channel DCA module, such as the 86108B which can normally measure one differential pair at a time, into a measurement solution capable of measuring two differential pairs at a time. Keysight offers a wide variety of probe amplifiers and tips that allow user to analyze in-circuit signals. The InfiniiMax series of probes provide probe bandwidth to 30 GHz, and may be adapted to 86100C/D DCA electrical receiver modules using:

- N1022B – Adapts to InfiniiMax I/II system probes
- N5477A - Adapts to InfiniiMax III system probes



Figure 5. The InfiniiMax series of probes provide probe bandwidth to 30 GHz

# Effectively Using Clocks and Triggering

## Case A:

### Lowest device jitter and embedded clock

Most signals may be characterized using the setup shown in Case A, a very simple configuration that also provides optimal measurement fidelity. Data is provided directly to the data channel inputs on the 86108 precision waveform analyzer, while a custom pick-off routes some of the signal to an instrument-grade clock recovery circuit. The internal precision timebase (PTB) further reduces the intrinsic jitter. Standards for the rate of 25.78 Gb/s (UI is 38.8 ps) typically requires that transmitters have a random jitter of less than 416 fs. This is well-characterized by the 86108, has ultra-low intrinsic jitter of less than 50 fs. (For a bit error rate of  $10E-12$ , the Q factor is 7. The standards specification for RJ is to be less than 0.15 UI, which is 5.8 ps. The desired transmitter RJ for this BER is obtained by dividing the 5.8 ps by 2 times the Q factor, resulting in 416 fs.)

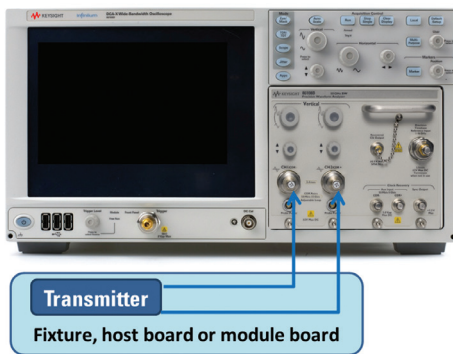


Figure 6a. Very simple set-up to measure high data rate transmitter

## Case B:

### Lowest device jitter, small signal or closed eye, and clock available

Sometimes the user needs to analyze signals after they have passed through a channel or the signal may be very small. In those cases, the eye diagram continues to close which makes recovery of the clock very challenging. An auxiliary clock input, which provides about 12 dB more dynamic range for clock recovery is used to trigger the sampling scope while the user observes the degraded signal on CH1/CH2. This auxiliary CR input can also accommodate very low frequency reference clocks (low MHz range) since it includes a limit amp that minimizes AM to PM conversion.

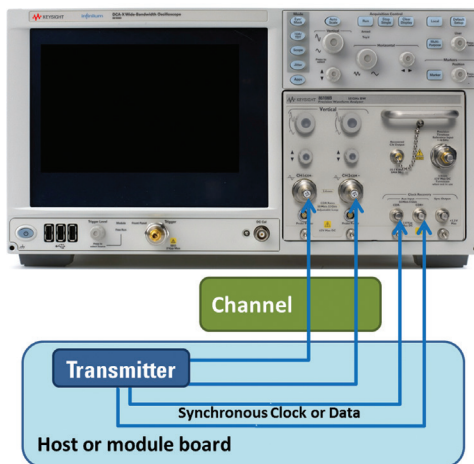


Figure 6b. Modified set-up for use with a synchronous clock or data signal



## Selected Measurements – How to Set Up, Optimize and Obtain Results

Each standard specifies a number of parameters for transmitters. Some parameters are required for compliance, and some are optional. Many of these parameters are commonly shared with requirements from earlier or other standards. This section summarizes the most frequently referenced parameters, and organizes the parameters by type.

Table 2 includes common measurements by section number that are performed on transmitters in the range of 10 Gb/s to 28 Gb/s per these standards:

- Optical Internetworking Forum (OIF): Maintains standards for Common Electrical I/O (CEI)
- Institute of Electrical and Electronics Engineers (IEEE): Maintains 802.3 family of standards
- SFF Committee: SFF-8431 Specifications for Enhanced Small Form Factor Pluggable Module SFP+

	Parameter	CEI-11G-SR	CEI-11G-LR/MR	CEI-28G-SR	CEI-25G-LR	CEI-28G-VSR	802.3ba-2007	802.3ba-2010	SFF-8431
Waveform Parameters	Differential Output Voltage	8.3.1	9.3.1	10.3.1	11.3.1	1.3.3	72.7.1	84.8.1	Single 3.5.1
	Differential Output Voltage, TX Disabled						72.7.1	84.8.1	
	Transmitter Output Waveform						72.7.1.11	84.8.1	
	Rise and Fall Times	8.3.1	9.3.1	10.3.1	11.3.1	1.3.3 & 1.3.8	72.7.1	84.8.1	
	Transmitter Common Mode Noise	8.3.1	9.3.1	10.3.1	11.3.1	1.3.2			
	Eye Mask	8.3.1	9.3.1	10.3.1	11.3.1	1.3.3			3.5.1
Jitter Parameters	Random Jitter (Uncorrelated Unbounded Gaussian Jitter)	8.3.1	9.3.1	10.3.1	11.3.1	13.B.1.1	72.7.1	84.8.1	
	Deterministic Jitter						72.7.1	84.8.1	
	Uncorrelated Jitter					1.3.3			3.5.1
	Uncorrelated Bounded High Probability Jitter	8.3.1	9.3.1	10.3.1	11.3.1	13.B.1.1			
	Duty Cycle Distortion		9.3.1	10.3.1	11.3.1	13.B.1.1	72.7.1	84.8.1	
	Data Dependent Jitter								3.5.1
	Data Dependent Pulse Width Shrinkage								3.5.1
Total Jitter	8.3.1	9.3.1	10.3.1	11.3.1		72.7.1	84.8.1	3.5.1	
Channel Parameters	Output Return Loss	8.3.1	9.3.1	10.3.1	11.3.1	1.3.3	72.7.1	84.8.1	3.5.1
	Common Mode Output Return Loss	8.3.1	9.3.1	10.3.1	11.3.1		72.7.1 69B.4.5	84.8/1 69B.4.5	3.5.1
	Common Mode to Differential Conversion Loss					1/3/3			
	Insertion Loss						69B.4.1	69B.4.1	
	Insertion Loss Deviation						69B.4.1	69B.4.4	
	Insertion Loss to Crosstalk Ratio						69B.4.6.4	69B.4.6.4	

Table 2. Common parameters required by high data rate standards

# Selected Measurements

## – How to Set Up, Optimize and Obtain Results

### Waveform Parameters

Every standard prescribes the range of values for the bits or sequence of bits in terms of time and amplitude. The table below summarizes the most common parameters and typical values, and shows an image from the DCA-X sampling oscilloscope. Transmitter output waveform is covered in a later section of this application note.

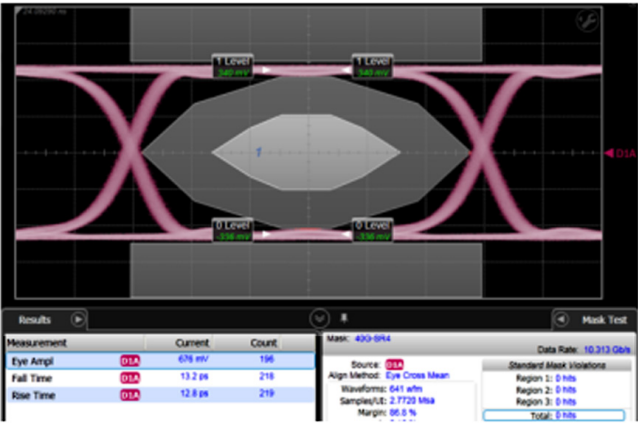
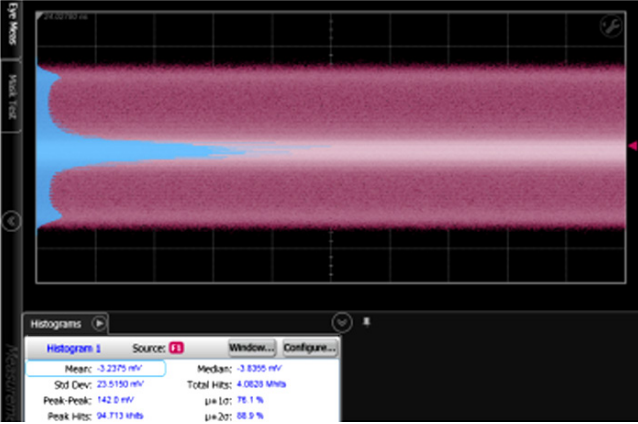
Waveform Parameters	Typical Values	Results View
Differential Output Voltage	600 to 1200mV	 <p>The screenshot shows an eye diagram with a pink signal trace and a grey mask. Below the plot is a 'Results' table with columns for Measurement, Current, and Count. The table lists Eye Amplitude (678 mV), Fall Time (13.2 ps), and Rise Time (12.8 ps). To the right, there are settings for Mask (400-804), Source (D1A), and Data Rate (10.313 Gbit/s). A 'Standard Mask Violations' section shows zero violations for three regions.</p>
Rise and Fall Times	10 to 50 ps (20% to 80%)	
Eye Mask	Specified as X and Y coordinates as fraction of UI and eye height	
Transmit Common Mode Noise	10-20 mV	 <p>The screenshot shows a histogram of signal levels. Below the plot is a 'Histograms' table with columns for Mean, Std Dev, Peak-Peak, Peak Hits, Median, Total Hits, <math>\mu+1\sigma</math>, and <math>\mu+2\sigma</math>. The table lists Mean: -3.2375 mV, Std Dev: 23.5150 mV, Peak-Peak: 142.0 mV, Peak Hits: 94.713 mbit/s, Median: -3.8305 mV, Total Hits: 4.0820 Mbits, <math>\mu+1\sigma</math>: 75.1 %, and <math>\mu+2\sigma</math>: 58.9 %.</p>
Transmitter Output Waveform	See next section	

Table 3. Waveform Parameters

# Selected Measurements – How to Set Up, Optimize and Obtain Results

## Transmitter Output Waveform

Standards such as IEEE 802.3ap-2007 require very specific measurements of the waveform for a run of at least 8 consecutive ones and zeros as shown to the right. Note the measurement of six specific voltages at six different times in the waveform. These can be measured manually using markers and cursors, but this approach may be time consuming and is only recommended if performing this measurement a few times. For the developer that is enhancing or tuning the design, or for the user that is measuring multiple devices, Keysight has developed an Excel utility that quickly makes these measurements then reports the desired values in a table and graphically as shown in Figure 7.

Many standards also specify that transition times be measured on the waveform at the edges adjacent to a run of at least 8 consecutive ones and zeros. The Keysight Excel utility also provides those times as shown in Figure 7. Please refer to Appendix D for instructions on how to set up and use this Excel utility.

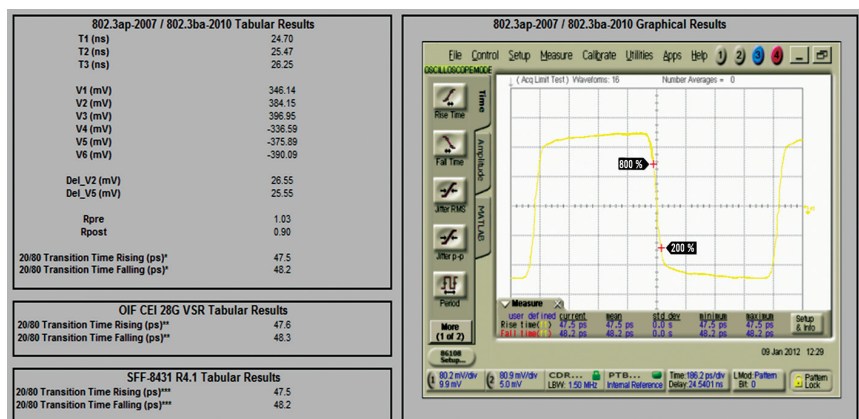
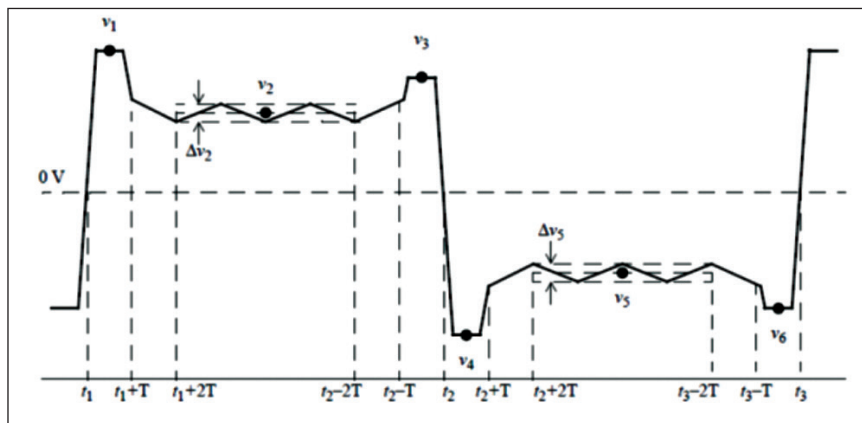


Figure 7. Results for transmitter output waveform for 25.78 Gb/s data stream



# Selected Measurements

## – How to Set Up, Optimize and Obtain Results

### Jitter parameters

Accurate crossings for each bit are even more important at higher data rates to ensure very low bit error rates and open eyes. Common parameters for jitter in time are listed below. Standards committees are also considering addition of amplitude interference parameters, which are quickly measured by the 86100C/D DCA using Option 300.

Jitter Parameters	Typical Values
Random Jitter (Uncorrelated Unbounded Gaussian Jitter)	250 fs to 1 ps
Deterministic Jitter	5 to 15 ps
Duty Cycle Distortion	1 to 4 ps
Uncorrelated Jitter	< 2 ps
Total Jitter	10 to 30 ps



# Selected Measurements

## – How to Set Up, Optimize and Obtain Results

### Channel parameters

To ensure the data stream is accurately delivered from point to point, the characteristics of the channel must be understood and optimized. These channel parameters are the most helpful to assure DUT and network performance:

- Output Return Loss
- Common Mode Output Return Loss
- Insertion Loss
- Insertion Loss Deviation
- Insertion Loss to Crosstalk Ratio

Typical devices only have coaxial connectors in a few locations so devices are often characterized when connected via test fixtures, controller boards or interface cables, which have their own unique loss performance. Techniques such as de-embedding are used to remove the effects of the fixtures or interface cables from the measurement of waveform, jitter and path parameters, therefore providing the most accurate view of the DUT performance.

For characterization to 20 GHz, the 54754A TDR Module with Option 202 on the DCA-X provides quick and intuitive measurement of the above path parameters. Option SIM on the DCA-X enables de-embedding of the interface cables or fixtures. See Figure 8a parameters typically obtained to accomplish de-embedding.

For characterization above 20 GHz or at higher dynamic Keysight Vector Network Analyzers (VNA) with multi-port test sets are an ideal choice to capture the S-parameters. The N1930B Physical Layer Test System software quickly transforms the captured network analyzer measurements into .s4p files for use in de-embedding as shown in Figure 8b.

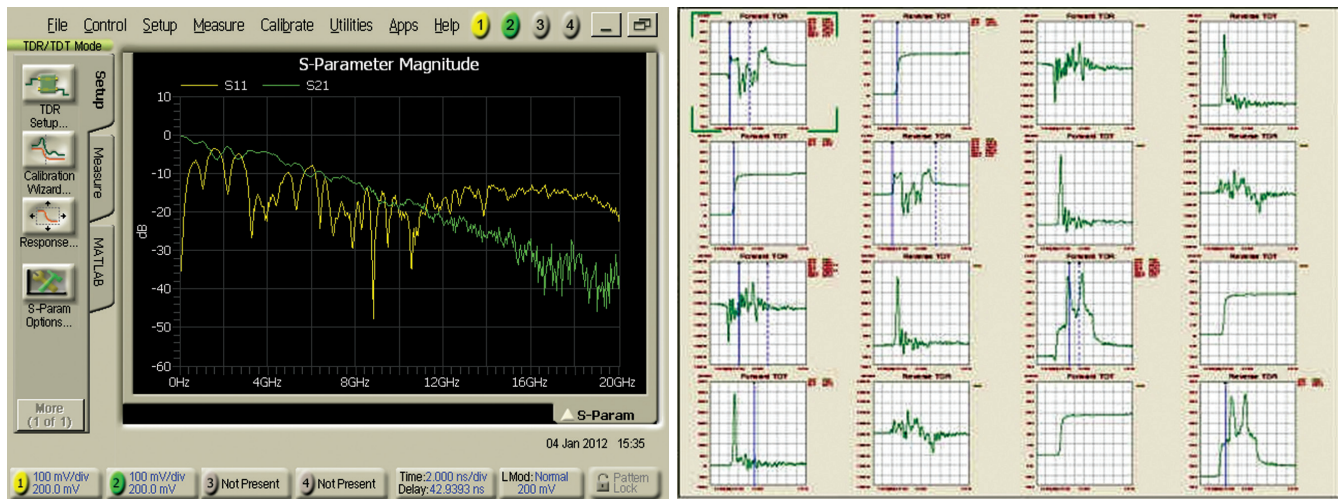


Figure 8a and b. Typical measurements using DCA-X with TDR and VNA with PLTS

## Other DCA Capabilities

Keysight test equipment has other powerful capabilities to make these challenging measurements

### Advanced eye application

Higher data rates have necessitated the use of additional measurement parameters to characterize the subtleties of waveforms. These parameters include: additional jitter measurements, jitter measurements using much longer patterns, and eye/mask tests using an extrapolated eye contour. The 86100C/D DCA mainframes work seamlessly with the 86100-401 Advanced Eye Analysis application, which enables the user to obtain jitter and amplitude results for long patterns such as PRBS23 and PRBS31 along with extrapolated contour mask testing. Advanced Eye Analysis works with Microsoft Excel, which can be running on a remote computer or on the DCA mainframe.

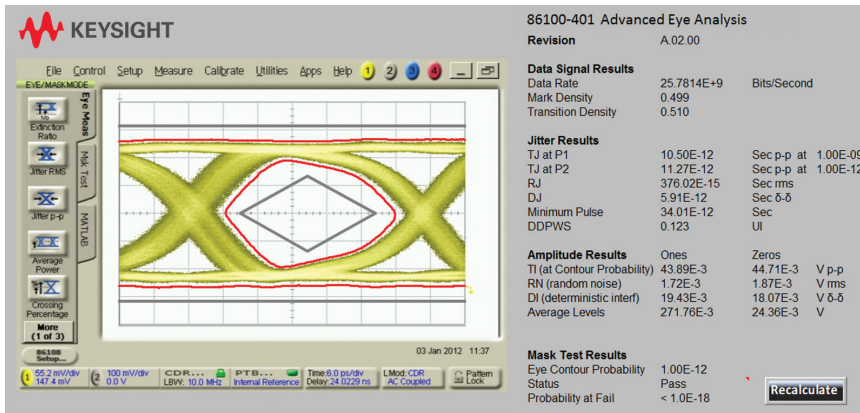


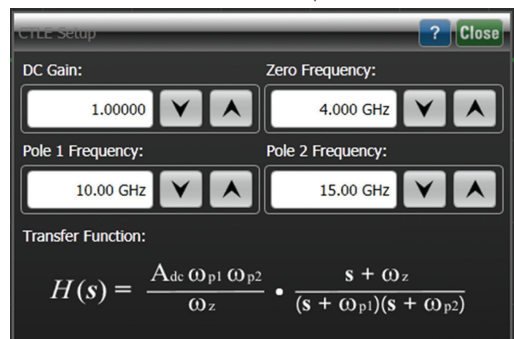
Figure 9. Advanced Eye Analysis works with Microsoft Excel, which can be running on a remote computer or on the DCA mainframe.

## Equalizers

Standards such as OIF CEI 28G VSR require that the reference receiver contain a Continuous Time Linear Equalizer (CTLE), which allows the receiver to apply a specified amount of gain and peaking in an effort to open the eye and optimize bit error ratio (BER) performance. The dialog box here is from the FlexDCA Interface and shows the transfer function and the adjustable parameters to emulate specific CTLE settings as specified by standards.

Another commonly used equalizer in today's high-speed designs is the linear feed forward equalizer. The 86100D Option 201 provides an LFE up to 64 taps. Clicking on the icon allows the user to adjust the tap parameters.

– Continuous Time Linear Equalizer



– Linear Feed Forward Equalizer (LFE)



Figure 10. Continuous Time Linear and feed forward equalizer

## Other DCA Capabilities

Keysight test equipment has other powerful capabilities to make these challenging measurements

### Embedding/de-embedding

Access to the differential ports on high speed devices is very challenging, particularly for devices operating above 10 Gb/s that utilize ball-grid arrays to connect directly to the FPGA's. The FPGA's are normally mounted on a module, which has transmission lines out to coaxial connectors. The additional insertion loss of the transmission lines veils the performance of a 32 Gb/s device as shown by the blue trace as shown in Figure 11. The brown trace shows the performance of the device with the effects of the module removed. 86100D-SIM InfiniiSim-DCA provides a very fast and easy means to de-embed the effects of the module transmission lines, which have been characterized within .s4p files. The de-embed features are enabled by clicking on the Math icon, selecting Simulation tools, and clicking on the de-embed icon as shown in Figure 12.

InfiniiSim-DCA also makes it easy to embed a channel and simulate what a signal would look like at the end of backplane, for example.

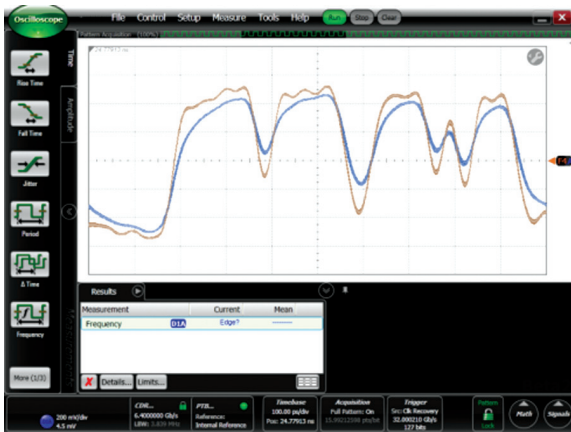


Figure 11. 86100D-SIM InfiniiSim-DCA provides a very fast and easy means to de-embed the effects of the module transmission lines



Figure 12. Math icon, selecting Simulation tools

### 86108 PTB input

The 86108 also allows the user to directly input to the precision timebase using the Reference Input, bypassing the internal clock recovery circuitry. This explicit clock input is often used to see "all" the jitter on an incoming signal connected to CH1/CH2. Please refer to Appendix A which shows the block diagram of the 86108B precision waveform analyzer and describes functionality.



Figure 13. The 86108 Precision timebase reference input

# Effective Use of Remote Control

Automating measurements saves time and ensures measurement consistency. However, the upfront effort to design and troubleshoot test software for an automated test system is often time-consuming and expensive. A strategic approach to control of the test instruments and their remote commands minimizes the upfront investment. Appendix E includes a typical test script with SCPI commands to test a differential transmitter using the 86108A/B; the script includes the techniques described in the previous sections.

The graphical user interface of the DCA-X is intuitive and very fast, enabling the user to capture many parameters in the order they desire, or perhaps focusing on the few parameters that are the most difficult. When many devices and measurements need to be completed, the DCA-X provides powerful remote programming features, some of which are detailed in this section.

## Typical test scenario

Let's consider the following test scenario:

- DUT: Differential transmitter operating at 25.78 Gb/s
- Oscilloscope
  - Clock recovery – required for compliance
  - Mainframe: 86100D DCA-X
  - Measurement module: 86108B Wide Bandwidth Receiver
- Task: Measure output voltage, jitter, amplitude interference and rise/fall times

## Remote programming

Development and manufacturing engineers would like to focus their time on improving the performance of their devices and meeting desired yields. Effective use of remote commands makes this task much faster and easier, and the DCA-X mainframe has a rich set of commands to set up, capture and display results. Please refer to Appendix E which provides examples of measuring a 25.78 Gb/s differential data stream for common waveform and jitter parameters; note that examples for Classic DCA interface and FlexDCA interface are included. Figure 14 shows typical eye diagram based measurements and jitter parameters after executing the script in the FlexDCA interface.

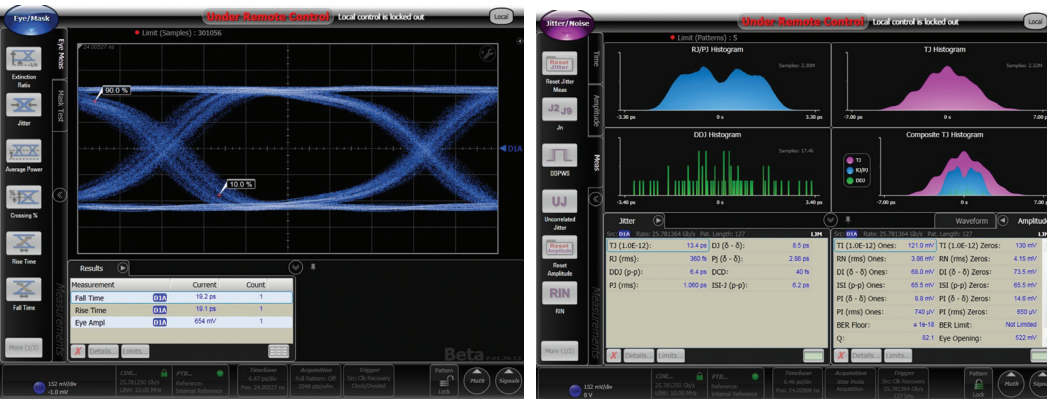


Figure 14. Typical measurement results from use of remote script on data stream at 25.78 Gb/s

# Effective Use of Remote Control

## SCPI recorder

To facilitate much faster test software development, the FlexDCA interface includes the SCPI Recorder feature. The SCPI Recorder captures manual interactions with the oscilloscope (mouse, touch screen and front panel). To launch this feature, click on Tools > SCPI Programming Tools > SCPI Recorder. Click on START REC to enable recording of the commands. Use the mouse, touch screen and front panel buttons to select the desired controls in order of execution; you will see the appropriate commands listed in the dialog box. Once done, click STOP REC. You may save the sequence as a SCPI file, and later execute the same or other files by choosing the Load command.

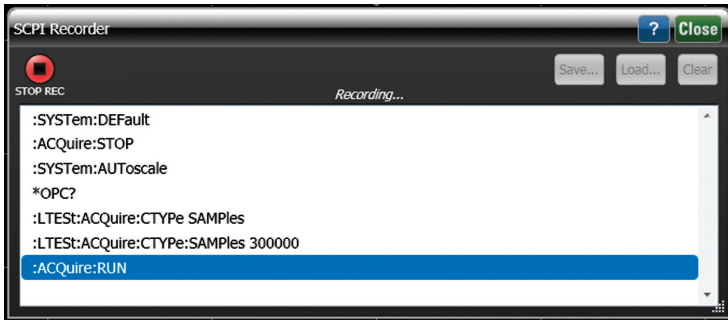


Figure 15. SCPI Recorder to facilitate much faster test software development

## Interactive SCPI command tree

In addition to the SCPI Recorder, the FlexDCA Interface provides an intuitive, hierarchical view of the available remote commands. The tree is organized by major remote command categories, and can be expanded and collapsed to see the desired commands. Once a command is clicked, the syntax appears in lower box of the dialogue; the user can execute that command and see results.

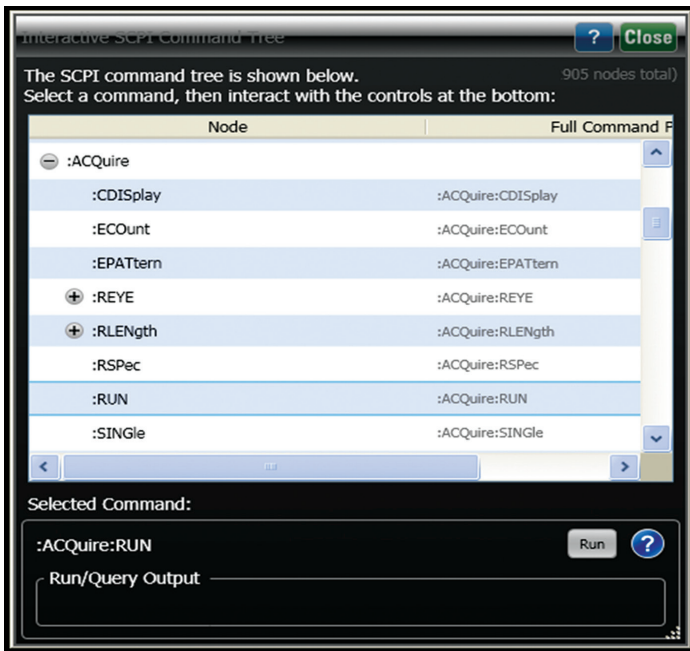


Figure 16. Interactive SCPI Command Tree



# Key Considerations When Measuring High Performance Electrical Transmitters

As data rates increase to 28 Gb/s and beyond, accurate system component characterization becomes more difficult. Optical Internetworking Forum (OIF) CEI 3.0, IEEE 802.3ba (40 GbE/100GbE), INCITS T-11 32G Fibre Channel, and high-speed proprietary systems require high performance test equipment to accurately capture and report specified waveform and jitter parameters.

The Keysight 86100D DCA-X wide bandwidth oscilloscope, in combination with the Keysight 86108B precision waveform analyzer, is designed to accurately characterize these high-speed electrical designs. The 86108B, with industry-best intrinsic jitter below 50 femtoseconds, channel bandwidths to 50 GHz, and clock recovery to 32 Gb/s, allows designers to be confident that they are seeing the true performance of their designs.

## **Use appropriate host or module board for transmitter.**

A well-designed and characterized board that connects to the transmitter is very important to obtain the most accurate measurements. Use of de-embedding to remove the effects of the board improves accuracy further.

## **Choose test equipment consistent with measurement challenges.**

Measurement bandwidth, intrinsic jitter, trigger delay, and availability of clock recovery are oscilloscope parameters that will determine which equipment is best suited for the range of transmitters being designed and tested.

## **Carefully set up clock recovery and triggering.**

When using clock recovery to derive a compliant clock to trigger the oscilloscope it is best to avoid use of external splitters and extra cables. These complicate measurement setup and degrade signal integrity due to additional loss and clock to data delay. Also pay careful attention to loop bandwidth and peaking settings to optimize the accuracy of measurement results.

## **Take advantage of latest measurement advances.**

Keysight has introduced several new tools to provide additional insights, more accuracy and enhanced functionality. Advanced Eye Software provides additional jitter analysis capabilities such as making jitter measurements when using long patterns (PRBS31). Integrating a high bandwidth receiver, precision timebase, and clock recovery into one module simplifies measurement setup and provides greater measurement accuracy. Features such as CTLE and de-embedding make compliance measurements much more convenient and accurate.

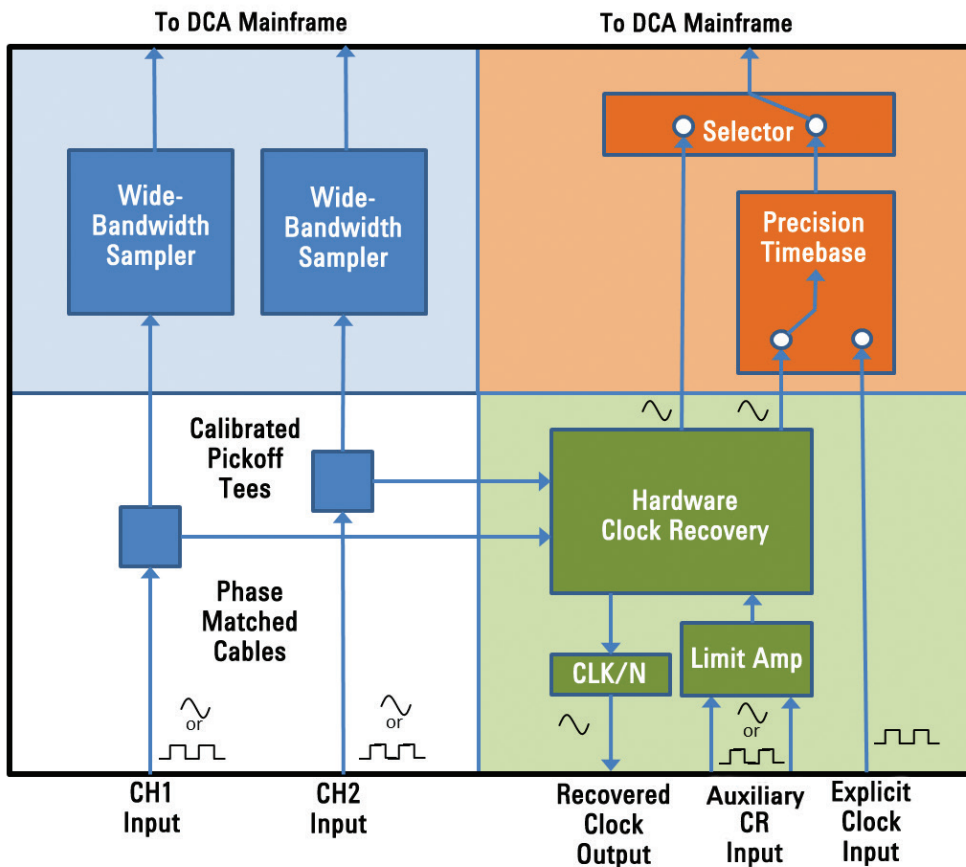
## **Become more effective using remote programming tools.**

More effective use of remote commands and enabling the SCPI Recorder provide a quick path to the most complete and accurate measurement results.

## Appendix A: Description of 86108B Precision Waveform Analyzer

The 86108B precision waveform analyzer builds on the legacy of the 86108A which set new thresholds for convenience, bandwidth and intrinsic jitter. Key attributes in the block diagram contribute to these key benefits:

- Wide bandwidth samplers to 50 GHz provide the most accurate representation of eye diagrams and waveforms
- New proprietary pick-off tees minimize the impact on the signal and transfer a portion of the signal to clock recovery
- Matched cables reduce the need for path matching, reducing the total path loss
- Hardware clock recovery to 32 Gb/s extracts a compliant clock from the incoming data
- Precision timebase greatly improves intrinsic jitter and removes the effects of clock to trigger delay
- Limit amplifier on auxiliary clock recovery input that minimizes the AM/PM conversion
- Explicit clock input allows user to see all of the jitter on the incoming signal





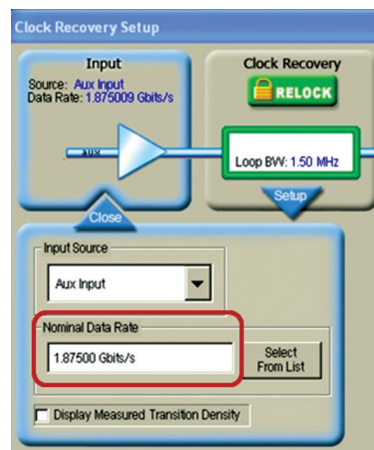
## Appendix B: Use of Sub-Rate Clocks and Data

The key goal is to choose equipment that will minimize loss of jitter budget due to the test equipment. This section provides additional set-up instructions for the auxiliary differential input when using sub-rate clocks or data through two examples. (Please refer to the Application Note entitled Precision Waveform Analysis for High-Speed Digital Communications for detailed information on the 86108 modules and how to choose most settings.) Choose the Source as Aux Input to select the auxiliary input connectors. Determine the data rate for clock recovery using the examples in the table below, and enter that value into Data Rate.

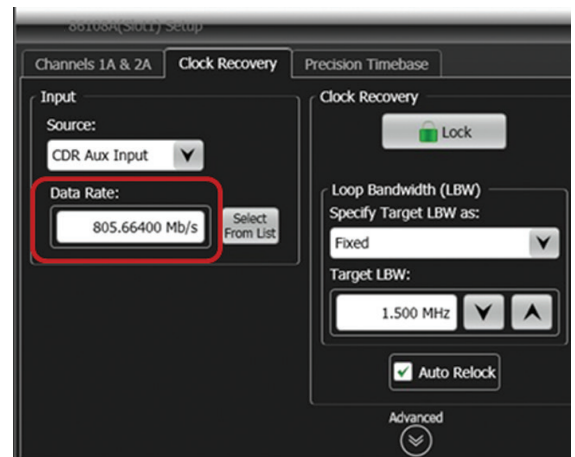
	Example A	Example B
Data Rate	15 Gb/s	25.78 Gb/s
Clock Divide Ratio	48	64
Reference Clock Rate (sub-rate)	312.5 MHz	402.832 MHz
Convert Reference Clock frequency to data rate (X2)	625 Mb/s	805.664 Mb/s
Multiplier (see next paragraph)	3 or 6	1, 2 or 4
Product of data rate and Multiplier	312.5 X 3 = 1.875 Gb/s or 312.5 X 6 = 3.75 Gb/s	402.832 X 1 = 805.664 Mb/s or 402.832 X 2 = 1.611 Gb/s or 402.832 X 4 = 3.223 Gb/s

Enter value into Data Rate in the Clock Recovery Setup dialog

Classic DCA Interface



FlexDCA Interface



The measured waveforms and reported data are best with higher transition densities; the 86108 receivers are specified for transition densities between 0.25 and 1.0, and often work well below transition densities of 0.2. The clock recovery circuitry depends upon the sub rate clock being the data rate divided by a power of 2, therefore the entered value for the clock recovery data rate can be data rate divided by 2, 4, 8, 16, 32, or 64. If the clock divide ratio is not a common multiple of 2, then a lower divide ratio in conjunction with a multiplier is used to determine the clock recovery data rate value. After applying these constraints, we obtain these multipliers for each clock divide ratio.

- For divide ratio of 2, use multiplier of 1 (sub-rate clock)
- For divide ratio of 4, use multiplier of 1 or 2
- For divide ratio of 8, 16, 32, 64 or 128, use multiplier of 1, 2 or 4
- For divide ratios of 10, 20, 40 and 80, use multiplier of 5
- For divide ratios of 24, 48 and 96, use multiplier of 3 or 6
- To maintain the highest transition density, use the largest available multiplier

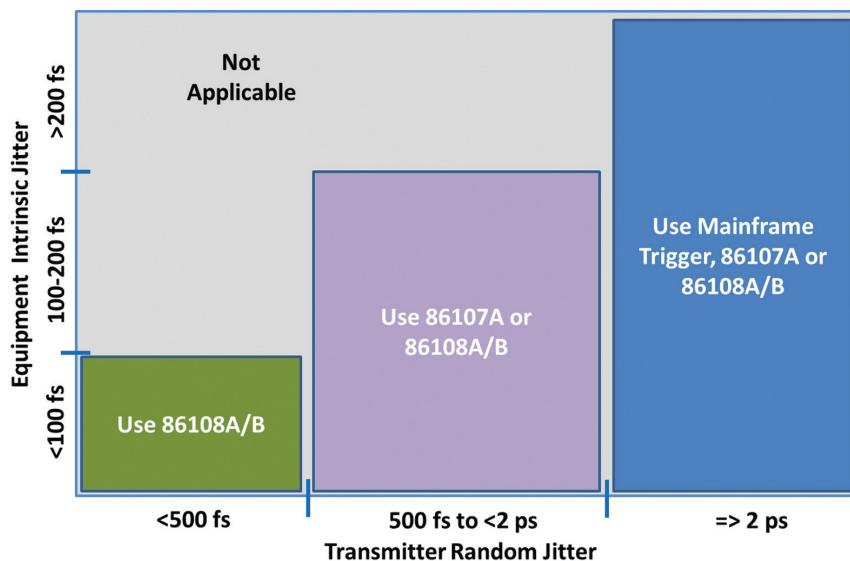
## Appendix C: Estimating the Influence of Test Equipment on Jitter Measurements

Demanding jitter specifications for high data rate transmitters require that users understand the jitter contributions from both the transmitter and equipment used to characterize the transmitter. The measured jitter displayed on the equipment is the combination of both contributions, and the uncorrelated portion of jitter is given by this equation:

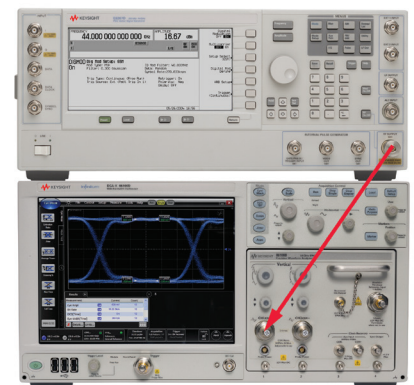
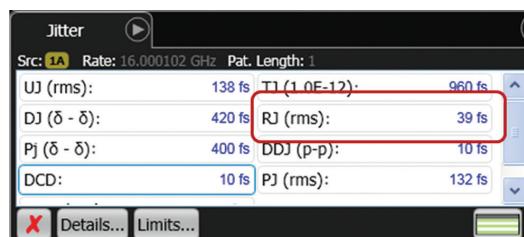
$$\text{Measured Jitter} = \sqrt{(\text{Equipment Intrinsic Jitter}^2 + \text{Transmitter Random Jitter}^2)}$$

For example, if the equipment intrinsic jitter is 1 ps and the transmitter random jitter is 1 ps, the equipment will display the measured jitter of 1.41 ps. Often users would like the test equipment to not affect the measurement by more than 10% which means the equipment intrinsic jitter will need to be much smaller than that of the device under test.

This calculation is more critical when the desired transmitter random jitter is below 1 ps, such as 350–400 fs for 25G data rates. Typical intrinsic jitter (consisting mainly of random jitter) of the standard 86100D is <800 fs, of the 86107A is < 200 fs and of the 86108 is typically < 50 fs. If we assume the measurement equipment can contribute only 10% of the measured jitter, then we obtain the recommended usages shown in this table.



To best understand the contribution to total jitter by the transmitter and the measurement equipment, the user can easily verify the intrinsic jitter of the measurement receiver. Set up a microwave source with very low phase noise, such as the E8267D, to generate a sine wave at one-half of the data rate. Route the sine wave into one channel of the measurement receiver, lock the clock recovery and turn on the precision timebase. Enable Jitter Mode on the 86100C/D DCA and observe the random jitter. For the 86108A/B, this is typically less than 50 fs as shown below.



# Appendix D: User Guide for Excel Transmitter Waveform Utility

Keysight has developed a utility in Excel for analyzing the transmitter output waveform. Detailed instructions are provided in one of the Excel worksheets. The overall steps are:

1. Connect remote computer to 86100C/D DCA via LAN or GPIB
2. Configure the transmitter to provide a 16 bit pattern which contain 8 consecutive ones followed by 8 consecutive ones
3. In the Instrument Address box, enter the GPIB or IP address
4. In Data Rate, enter the rate in Gb/s
5. Click on Start Measurement.
6. Activity will be seen on the DCA display, and the Tabular Results table will be updated as results are collected. When all measurements are done, the screen shot is updated in Graphical Results.
7. Click on Copy Image to Clipboard for using the screen shot in another document.
8. If viewing the individual voltage measurements is desired, click on the 86100 Images tab at the bottom of the Excel window. Scroll down in Excel to find the desired measurement and waveform. The waveform screen shot can also be copied to the Clipboard for use in another document.

**KEYSIGHT**

**Transmitter Output Waveform Utility**

Instrument GPIB/TCPIP Address: **TCPIP0::156.140.158.223::inst0::INSTR**

Instrument ID: Agilent Technologies,86100D,MY50260104,A.10.60

Start Measurement      Copy Image to Clipboard

Data Rate (Gb/sec): **10.3125**

Period - T (sec): 9.69697E-11

**Operating Notes**

- \*Requires Matlab and Opt. 201 installed on 86100C/D
- \*Display 8x 1 and 8x 0 pattern as a single valued waveform (i.e. pattern lock ON)
- \*Make sure ONLY 1x Channel or Math function is active
- \*User needs to provide GPIB/LAN Address and Data Rate in **light blue cells**
- \*Period T is calculated from user defined Data Rate
- \*Need a signal with 50% point at 0 V (i.e. differential signal)

**802.3ap-2007 / 802.3ba-2010 Tabular Results**

T1 (ns)	24.70
T2 (ns)	25.47
T3 (ns)	26.25
V1 (mV)	346.14
V2 (mV)	384.15
V3 (mV)	396.95
V4 (mV)	-336.59
V5 (mV)	-375.89
V6 (mV)	-390.09
DeL_V2 (mV)	26.55
DeL_V5 (mV)	25.55
Rpre	1.03
Rpost	0.90
20/80 Transition Time Rising (ps)*	47.5
20/80 Transition Time Falling (ps)*	48.2

**OIF CEI 28G VSR Tabular Results**

20/80 Transition Time Rising (ps)**	47.6
20/80 Transition Time Falling (ps)**	48.3

**SFF-8431 R4.1 Tabular Results**

20/80 Transition Time Rising (ps)***	47.5
20/80 Transition Time Falling (ps)***	48.2

**802.3ap-2007 / 802.3ba-2010 Graphical Results**

File Control Setup Measure Calibrate Utilities Apps Help 1 2 3 4

OSCILOGCOPEMODE (Acq Limit Test) Waveforms: 16 Number Averages = 0

Time Amplitude Filter RMS Filter p-p Period

80.0% 20.0%

Measure

user defined current	mean	std. dev	minimum	maximum	Setup & Info
Rise time	47.5 ps	0.0 s	47.5 ps	47.5 ps	
Fall time	48.2 ps	0.0 s	48.2 ps	48.2 ps	

86100 Setup... 09 Jan 2012 12:29

1 80.2 mV/div 9.9 mV 2 80.9 mV/div 5.0 mV CDR... PTB... Time 106.2 ps/div Delay: 24.5401 ns LMod: Pattern Bit: 0 Pattern Lock

## Appendix E: Typical Test Scripts

The 86100D DCA-X includes two user interfaces : Classic DCA and FlexDCA. The “Classic DCA” user interface provides 100% code compatibility with the 86100A/B/C mainframes whereas FlexDCA provides new measurement features such as embedding and de-embedding. Shown below are scripts for both interfaces.

### Test script outline, classic DCA interface

Efficiently using remote commands is an effective means to improve your design and validation time. The table below summarizes the overall test flow for measuring a differential high data rate transmitter using an 86108B with the Classic DCA interface. The test script listed below the table measures common parameters, including some that are required in the standards documents. The succeeding table and script listing are for the FlexDCA interface.

Lines	Description
1-6	Set up the instrument for mode, bandwidth and data rate
7-16	Set up and turn on clock recovery and precision timebase
17-20	Autoscale and obtain the samples
21-27	Measure eye for amplitude, rise time and fall time, and save screen shot
28-35	Set up jitter mode, enable amplitude measurements and measure common parameters, and save screen shot

### Test script listing, classic DCA interface

1	*RST	20	OPC?
2	STOP	21	MEASure:CGRade:AMPLitude FUNCTioN4
3	SYSTem:MODE EYE	22	MEASure:CGRade:AMPLitude? FUNCTioN4
4	TIMEbase:BRATe 25.78E9	23	MEASure:RISetime FUNCTioN4
5	CHANnel1:BANDwidth LOW	24	MEASure:RISetime? FUNCTioN4
6	CHANnel2:BANDwidth LOW	25	MEASure:FALLtime FUNCTioN4
7	CRECOvery1:INPut DIFFerential	26	MEASure:FALLtime? FUNCTioN4
8	CRECOvery1:CRATE 25.78E9	27	DISK:SIM "Amplitude & Transitions", SCReen, NORMAl, FUNCTioN4
9	CRECOvery1:LBWMode RDEPendent	28)	SYSTem:MODE JITTer
10	CRECOvery1:RDIVider 2578	29)	MEASure:AMPLitude:ANALySis ON
11	CRECOvery1:LSElect:AUTomatic OFF	30)	*OPC?
12	CRECOvery1:LSElect LOOP1	31)	MEASure:JITTer:RJ?
13	CRECOvery1:RELock	32)	MEASure:JITTer:DJ?
14	TIMEbase:PRECision ON	33)	MEASure:JITTer:DCD?
15	FUNCTioN4:SUBTract CHAN1,CHAN2	34)	MEASure:AMPLitude:RN? ONE
16	FUNCTioN4:DISPlay ON	35)	DISK:SIM "Jitter & Interference", SCReen, NORMAl, FUNCTioN4
17	AUToscale		
18	ACQuire:RUNTil SAMPlEs, 3e5		
19	RUN		

## Appendix E: Typical Test Scripts

### Test script outline, FlexDCA interface

Lines	Description
1-9	Set up the instrument for mode, bandwidth and data rate
10-19	Set up and turn on clock recovery and precision timebase
20-26	Autoscale and obtain the samples
27-28	Measure eye for amplitude, rise time and fall time, and save screen shot
39-54	Set up jitter mode, enable amplitude measurements and measure common parameters, and save screen shot

### Test script listing, FlexDCA interface

1	*RST;	29	MEASure:EYE:AMPLitude?
2	SYSTem:DEfault	30	MEASure:EYE:RISetime:SOURce DIFF1
3	ACQuire:STOP	31	MEASure:EYE:RISetime
4	SYSTem:MODE EYE	32	MEASure:EYE:RISetime?
5	TIMEbase:BRATe 25.78E9	33	MEASure:EYE:FALLtime:SOURce DIFF1
6	CHAN1A:BANDwidth BANDwidth1	34	MEASure:EYE:FALLtime
7	CHAN2A:BANDwidth BANDwidth1	35	MEASure:EYE:FALLtime?
8	:DIFF1A:DMODE ON	36	DISK:SIMage:FNAME "D:\User Files\Screen Images\Waveform parameters.jpg"
9	*OPC?	37	DISK:SIMage:SAVE
10	CRECovery1:CRATe 2.5781250E+10	38	*OPC?
11	CRECovery1:SOURce DIFFerential	39	MEASure:AMPLitude:DEFine:ANALysis ON
12	CRECovery1:LBWMode RDEPendent	40	SYSTem:MODE JITTer
13	CRECovery1:RDIVider 2578	41	LTEST:ACQuire:CTYPe:PATterns 5
14	CRECovery1:LSElect:AUTomatic OFF	42	LTEST:ACQuire:STATe ON
15	CRECovery1:LSElect LOOP1	43	ACQuire:RUN
16	CRECovery1:RELock	44	*OPC?
17	*OPC?	45	MEASure:JITTer:RJ?
18	PTIMEbase1:STATe ON	46	MEASure:JITTer:DJ?
19	*OPC?	47	MEASure:JITTer:DCD?
20	SYSTem:AUToscale	48	MEASure:AMPLitude:RNONes:SOURce DIFF1
21	*OPC?	49	MEASure:AMPLitude:RNONes?
22)	LTEST:ACQuire:CTYPe SAMPLes	50	MEASure:AMPLitude:RNZeros:SOURce DIFF1
23	LTEST:ACQuire:CTYPe:SAMPLes 300000	51	MEASure:AMPLitude:RNZeros?
24	LTEST:ACQuire:STATe ON	52	DISK:SIMage:FNAME "D:\User Files\Screen Images\Jitter & Interference.jpg"
25	ACQuire:RUN	53	DISK:SIMage:SAVE
26	*OPC?	54	*OPC?
27	MEASure:EYE:AMPLitude:SOURce DIFF1		
28	MEASure:EYE:AMPLitude		

## Literature

<b>Publication</b>	<b>Publication Type</b>	<b>Publication Number</b>
<i>Keysight data sheet for 86108B Precision Wave Analyzer</i>	Data Sheet	5990-9754EN
<i>Infiniium DCA-X Keysight 86100D Wide-Bandwidth Oscilloscope Mainframe and Modules</i>	Technical Specification	5990-5824EN
<i>Infiniium DCA-J Keysight 86100C Wide-Bandwidth Oscilloscope Mainframe and Modules</i>	Technical Specification	5989-0278EN
<i>Infiniium DCA and DCA-J and DCA-X Keysight 86100A/B/C/D Wide-Bandwidth Oscilloscope</i>	Programmers Guide	86100-90131
<i>Keysight data sheet for Advanced Eye Analysis Software</i>	Data Sheet	5990-3818EN
<i>Triggering Wide-Bandwidth Sampling Oscilloscopes</i>	Product Note	5989-2603EN
<i>Precision Waveform Analysis for High-Speed Digital Communications Using the 86100C and 86108A</i>	Application Note	5989-8362EN

## References

1. IEEE Standard 802.3ap-2007 Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications; Amendment and 4: Ethernet Operation over Electrical Backplanes
2. IEEE Standard 802.3ba-2010 Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications; Amendment and 4: Media Access Control Parameters, Physical Layers, and Management Parameters for 40 Gb/s and 100 Gb/s Operation
3. Optical Internetworking Forum, Common Electrical I/O – Electrical and Jitter Interoperability agreements for 6G+ bps, 11G+ bps and 25G+ bps I/O, Implementation Agreement # OIF-CEI-03.0
4. Optical Internetworking Forum, Common Electrical I/O, CEI-28G-VSR Working Clause Proposal, Implementation Agreement Draft 1.4
5. SFF Committee, SFF-8431 Specifications for Enhanced Small Form Factor Pluggable Module SFP+, Rev 4.1





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