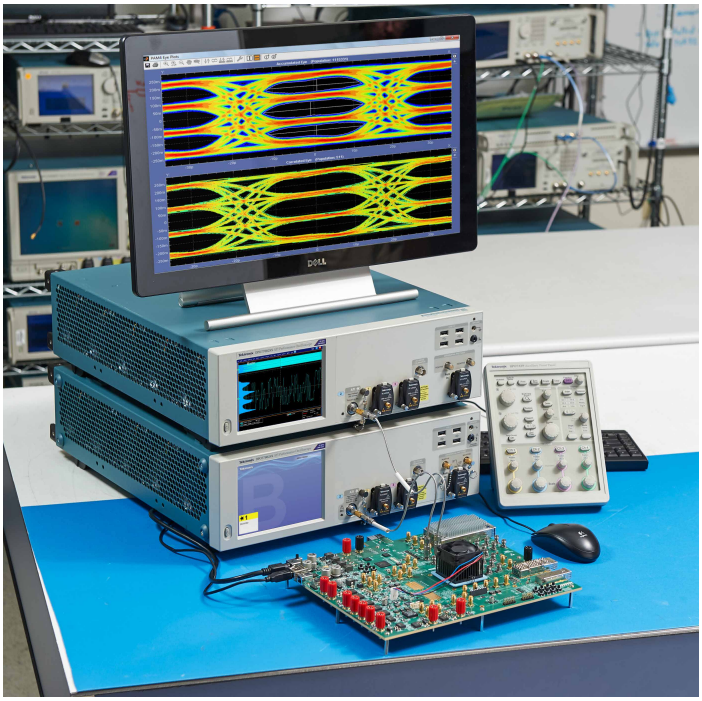
PAMJET Signal Analysis of PAM4 Signal

Datasheet



The PAMJET Signal Analysis software application enhances the capabilities of the DPO/MSO70000DX/SX and DPO/DSA/MSO70000 series oscilloscopes (13 GHz or greater bandwidth), adding signal analysis, characterization, and compliance test for four-level Pulse Amplitude Modulation (PAMJET) devices and interfaces for both electrical and optical physical domains.

Key features

- Single Integrated Application for PAMJET Electrical and Optical Signal Debug and Validation
  - PAMJET brings together all the capabilities needed for comprehensive PAM analysis and debug
  - Dashboard style configuration panel enables quick and easy configuration of all the necessary parameters for PAM analysis
- Enhanced Clock Recovery
  - PAMJET's build-in clock recovery offers the industry's most robust clock recovery capability; clean, low-jitter clock is recovered immediately even from heavily impaired signals, even when SSC is present.
- Configurable Bessel-Thomson and other Reference Receiver Filters
  - Offers the flexibility to tune bandwidth of the measurement receiver, either manually or automatically, based on detected data rate
- Integrated embedding or de-embedding of test fixtures, cables, or channel models
- Auto Configuration
  - Auto detect thresholds, symbol rate, pattern type and length, enabling ease of configuration
- Symbol and Bit Error Detector
  - Detect and navigate to individual errors with annotations of clock recovery, eye centers, and expected symbols
  - Accumulate SER and BER over multiple acquisition cycles
- Integrated Receiver Equalization
  - Scan CTLEs through given settings and calculate taps for, and apply FFE, and DFE equalization to the acquired waveform to open a closed eye. Find and apply approximate settings quickly with the Rapid CTLE algorithm.
  - Model different types of receiver equalizer settings to perform what-if analysis
  - Support for standard based equalization presets
- Jitter Measurement and Eye Analysis
  - Full Characterization of the PAM eyes to support standard-based and debug analysis
  - Isolate the effects of ISI and show the potential for receiver equalization using correlated eye
  - Rise and Fall times for all 12 PAM4 transitions offers the capability to analyze each transition type in PAM4 signal.
  - Flexible controls to automatically acquire a desired symbol population across multiple acquisitions
- Noise Analysis and BER Contours
  - Eye width and eye height analysis per standards or to custom BER targets
  - Eye diagram annotated to show BER contours and width/height measurement locations
- SNDR Analysis
  - Automates a complex Electrical PAM4 transmitter measurement useful for characterization
- TDECQ Analysis
  - Automates a complex Optical PAM4 measurement that is used to characterize the optical transmitter vertical eye closure
- Plots and reports
  - Comprehensively interact with plots for measurement visualization and deep analysis

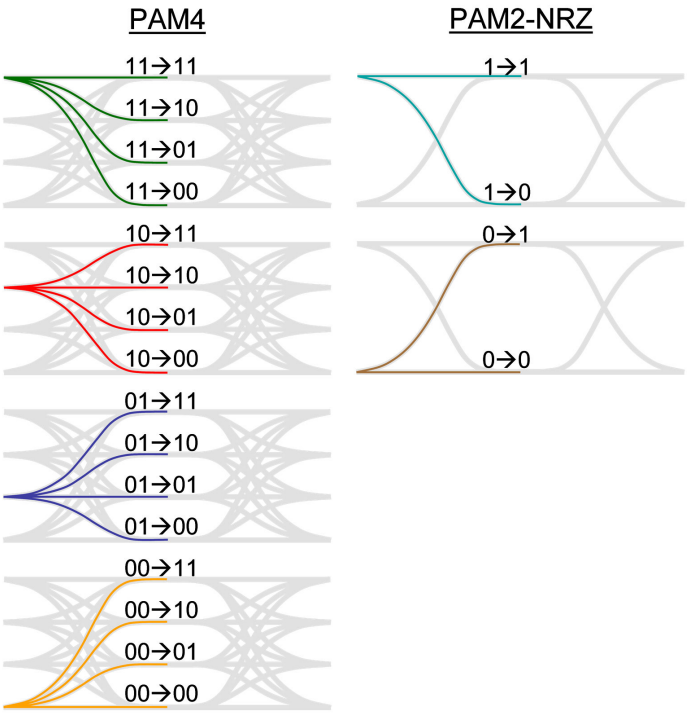
- HTML report captures all the relevant setup configuration, measurement test results, and plot in single file that is easy to read and share
- Measurement results across multiple acquisitions can be exported to a consolidated CSV file useful for additional analysis

Applications

- Debug, Analysis, and Characterization of Electrical and Optical PAM4 signals
- Characterization of OIF-CEI, PCIe and IEEE based PAM4 standards; such as OIFCEI-VSR-56G-PAM4, 802.3bs, 802.3ck and higher - with 25GBASE, 50GBASE and 100GBASE KR, CR, DR, FR and AUI/GUAI/CAUI/CDAUI, PCIe Gen6 64G 1.0.

PAM4 overview

The frequency content of the NRZ signal increases linearly with bit-rate. PAM4 signaling needs half the bandwidth as NRZ for the same data rate. 400G Ethernet standards, both electrical and optical interfaces, adopted PAM4 signaling to support the forecasted growth in the datacenter and network traffic. PCI Express standards introduced PAM4 signaling in the 6.0 Base specification adding a 64GT/s line speed.



Assumes linear coding for illustration. In practice, gray coding is frequently used.

The 4 levels of PAM4 introduce additional complexity in signaling and place new demands on the test methodology. The PAM analysis PAMJET tool offers several measurement and visualization capabilities aimed at making the task of validating PAM4 designs more efficient.

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PAM4 measurement configuration

The configuration panel is a dashboard within the PAM analysis (PAMJET) tool that enables you to configure most elements for a PAM analysis (PAMJET) run. The panel includes: measurement source selection, Clock recovery, Threshold, and Bessel-Thomson filter Equalization configuration. It also has the ability to embed or de-embed a channel using a waveform filter.

Clock recovery

Configurable PLL (phase-locked loop) clock recovery reliably extracts the symbol clock, even with highly impaired signals, uses it internally and exports the reconstructed clock waveform to a reference channel where it may be viewed.

Channel embedding / de-embedding

The waveform filter option offers the ability to embed or de-embed different channel elements. For example:

- The effects of a test fixture can be de-embedded to gain visibility of the signal at the transmitter output.
- A channel can be embedded to gain visibility of the signal at the receiver input.

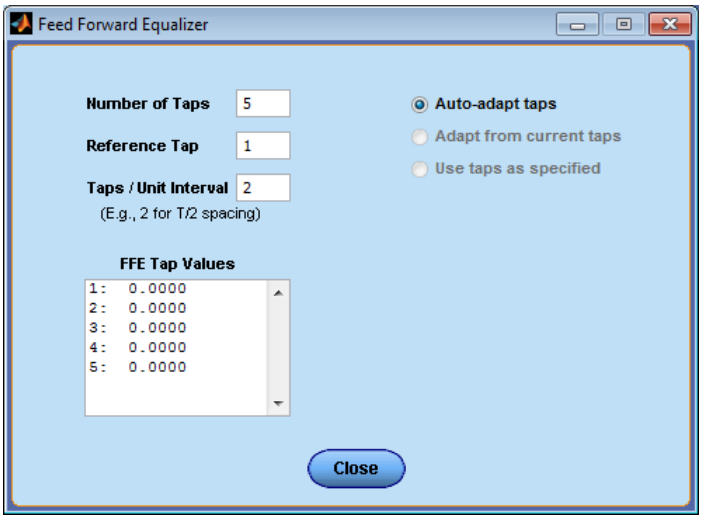
You can use the Tektronix SDLA software application to further analyze and process S-parameters and create signal filters as needed, for emulation, de-embedding etc.

Equalization

It is often necessary to apply receiver equalization to open the eyes before measurements can be performed. In most cases the lack of physical access makes it impossible to verify the receiver circuit behavior and monitor the effects of clock recovery and equalization.

A comprehensive equalizer in the PAM analysis PAMJET tool offers the ability to do the following:

- Apply CTLE either using custom poles and zeros or standards based presets.
- Apply configurable length FFE and / or DFE with auto-adapted tap values.
- Calculate the tap values, and observe the tap values that have been calculated.



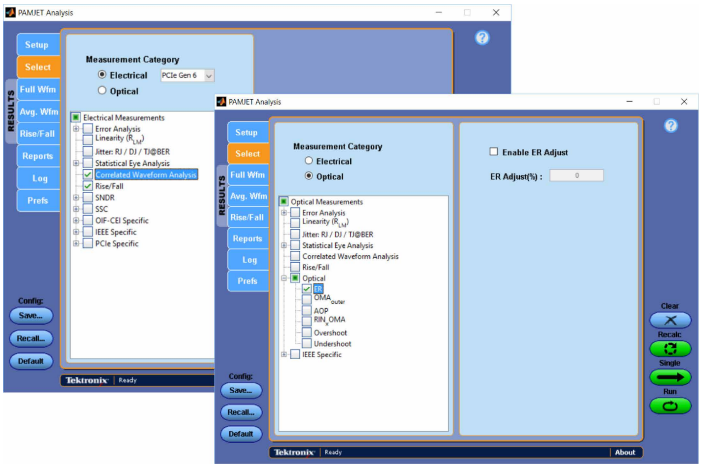
Auto configure capability

The PAM analysis PAMJET application can automatically detect the signal's symbol rate and pattern, and choose the appropriate decision thresholds based on analysis of the eye diagram. This allows quick and error-free set-up, as well as, verifying your signal's key characteristics.

Measurement selection

The Select panel enables you to select either electrical and optical PAM4 measurements.

The selection list allows you to choose window measurements and configure the display for ease of use and execution speed.



PAM4 measurements

The PAM analysis (PAMJET) package provides a comprehensive set of measurements that offer greater insight into signal characteristics, speeding up validation or characterization of PAM4 designs.

The supported list includes IEEE (802.3bs/802.3cd/802.3ck) and OIF-CEI Standards based measurements, SNDR and TDECQ of electrical and optical PAM4 Transmitter.

PAM4 Optical Measurements	
Error Analysis	Symbol Errors
	SER
	BER
Linearity	R_{LM}
Jitter	Rj
	Dj
	Tj@BER
Statistical Eye Analysis	Vertical Eye Closure
	EW6 / EW5
	EH6 / EH5
	V_{upp} / V_{mid} / V_{low}
	H_{upp} / H_{mid} / H_{low}
Optical	ER
	OMA_{OUTER}
	AOP [1]
	RIN x OMA

Table continued…

[1] Supports Average Launch Power of Off Transmitter as per IEEE 802.3bs/cd specifications.

PAM4 Optical Measurements	
IEEE Specific	TDECQ
	C_{eq}
	Launch Power in OMA_{OUTER} minus TDECQ
Correlated Waveform	Level Deviation
	Level Thickness
	Time Deviation
	Rise and Fall
Data Rate	Signaling rate

PAM4 Electrical Measurements	
Error Analysis	Symbol Errors
	SER
	BER
Linearity	R_{LM}
Jitter	Rj
	Dj
	Tj@BER
Statistical Eye Analysis	Vertical Eye Closure
	EW6 / EW5
	EH6 / EH5
	V_{upp} / V_{mid} / V_{low}
	H_{upp} / H_{mid} / H_{low}
SNDR	SNDR
	P_{max}
	σ_e
	σ_n
	σ_n per Level
OIF-CEI	UUGJ (rms)
	UBHPJ (p-p)
	EOJ
IEEE Specific	Jrms
	J3u
	J4u
	EOJ
	EOJ per Edge
	Rise Time

Table continued…

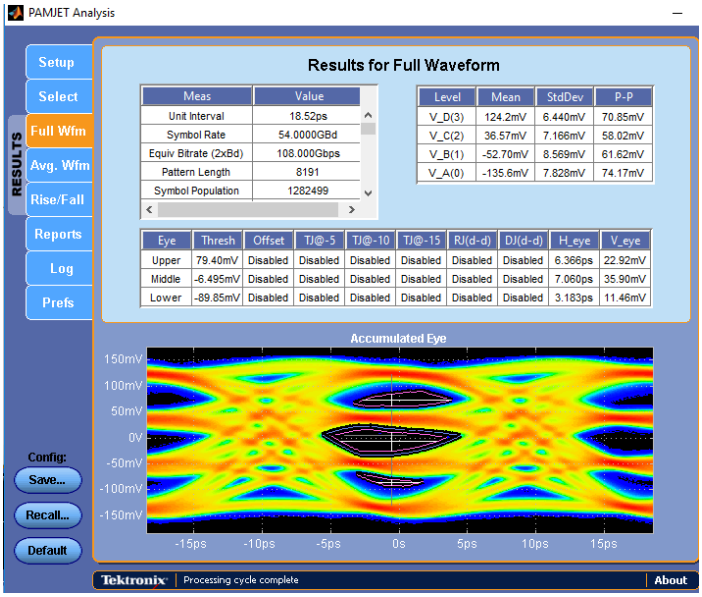
PAM4 Electrical Measurements	
	Fall Time
	SNR_{ISI}
Correlated Waveform	Level Deviation
	Level Thickness
	Time Deviation
	Rise and Fall
PCIe 6.0 Specific	$T_{TX\text{-}uTJ}$
	$T_{TX\text{-}uDJDD}$
	$T_{TX\text{-}RJ}$
	$T_{TX\text{-}UPW\text{-}TJ}$
	$T_{TX\text{-}UPW\text{-}DJDD}$
802.3ck Specific	VMA
	V_{dl}(pk-pk)
	ISI_{res}
	dv_f
	dR_{peak}

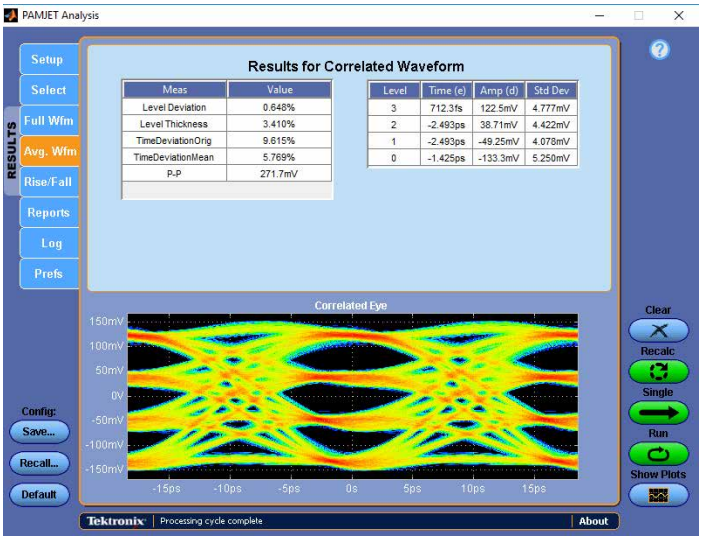
Full waveform and correlated waveform analysis

A full eye analysis can also be performed by overlaying all the unit intervals on the acquired PAM4 signal. A jitter analysis is done on the individual eyes and on the BER eye contours. Both tests can give insight into eye closure at all timing phases and reference levels simultaneously.

The correlated waveform and the correlated eye shows the signal without the random noise and jitter (and other uncorrelated components) for greater clarity of insight. The correlated waveform can be analyzed by tools and techniques similar to those found on Equivalent Time Oscilloscopes. Many performance communications standards assume access to correlated data. The PAMJET application

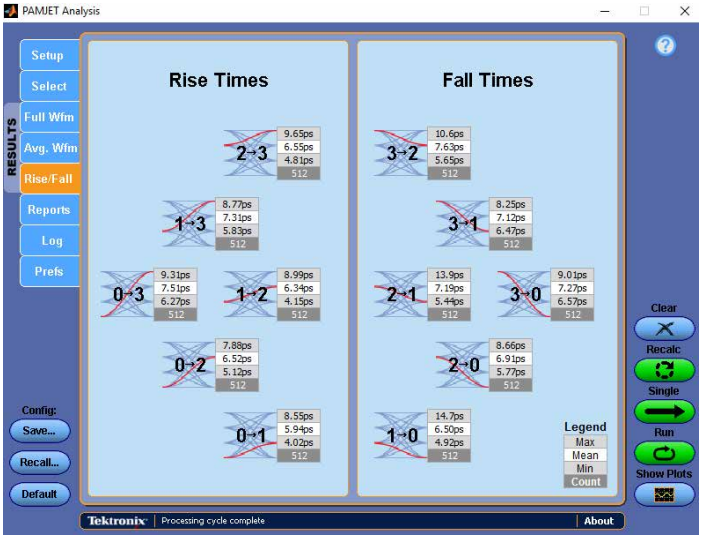
can effectively model correlated and composite eye diagrams.





Rise and fall time analysis

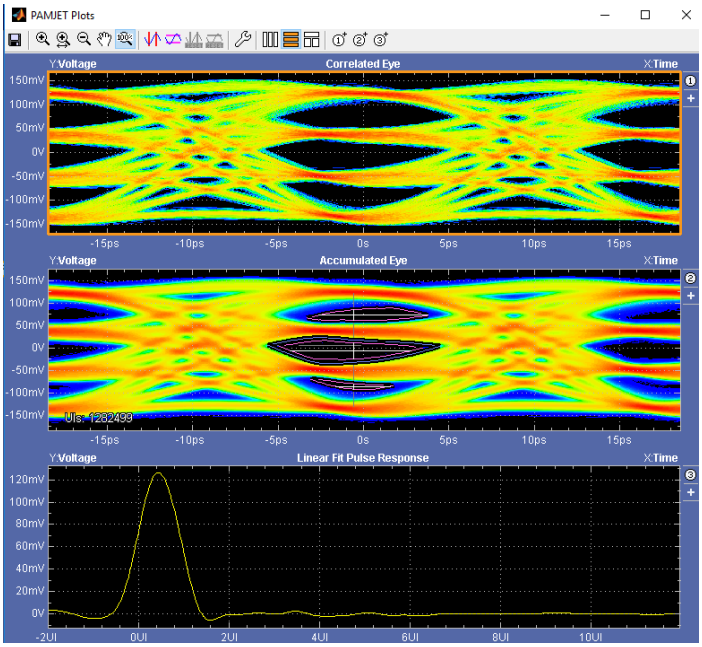
Analysis of the individual transitions, rise and fall times helps separate linear impairments (bandwidth, ISI) from nonlinear (slew-rate limiting, clipping). The rise and fall times also support advanced tuning of equalization algorithms. The PAMJET software provides the max, min, and mean rise and fall time for each of the six transition types within the PAM4 eye.



Visualization

A comprehensive set of plots can be used to visualize measurement data. The plots provide additional insight into the signal characteristics and are useful for debugging.

The PAMJET toolset enables interaction with the plots and can focus in on an area of interest for closer examination and further analysis.



Error detector

The PAMJET tool comes with a built in error detector that can identify individual symbol errors in the current source waveform. The identified error can be viewed in a dedicated error navigator window.

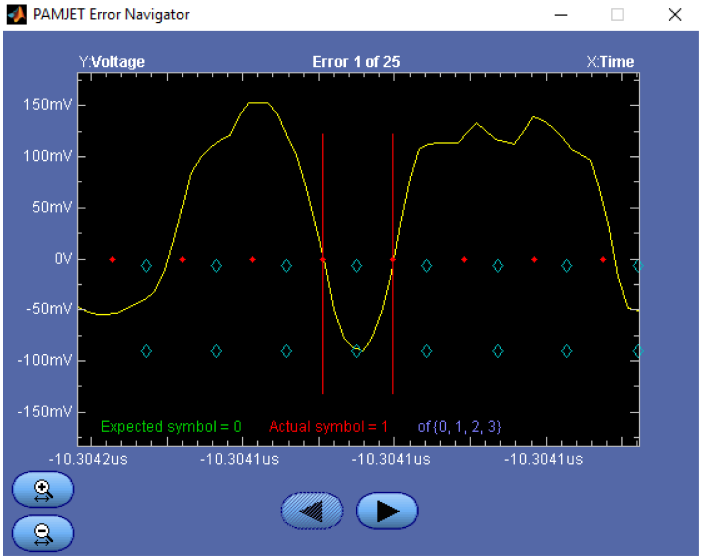
Results for Full Waveform

Meas	Value
Equiv Bitrate (2xBd)	64.00Gbps
Pattern Length	127
Symbol Population	293635
Symbol Errors	35
Symbol Error Ratio	1.1920e-04
Bit Error Ratio	5.9598e-05

Level	Mean	StdDev	Pk-Pk
V_D(3)	87.52mV	5.555mV	46.50mV
V_C(2)	30.04mV	5.538mV	57.35mV
V_B(1)	-28.32mV	6.216mV	56.11mV
V_A(0)	-85.85mV	6.410mV	51.73mV

The error navigator has several capabilities that makes it easy to quickly navigate and zoom into the error location. The additional information for the following detected errors offer help debugging symbol errors on the link:

- Location of recovered clock
- Location of symbol error reference thresholds
- Expected symbol displayed
- Actual symbol displayed



Comprehensive test report and data export

The measurement results can be saved in the form of a test report. The report includes; the configuration of the oscilloscope, application configuration, measurement results, and plots all available in an easy to read or share format.

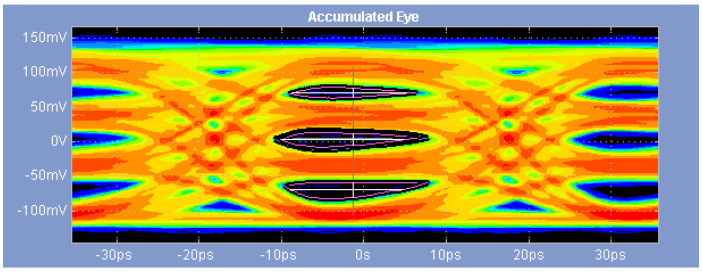
The measurement results across multiple acquisitions can also be exported to a single CSV file for further analysis.

Measurement	Value
Unit Interval	35.71ps
Symbol Rate	28.00GBd
Equiv Bitrate (2xBd)	56.00Gbps
Pattern Length	511
Symbol Population	1096936
Symbol Errors	0
Symbol Error Ratio	0
Bit Error Ratio	0
Linearity (R_{LM})	99.70%
EW4	13.57ps
EH4	12.81mV
VEC	14.88dB
SNDR	28.64dB
P_{max}	101.1mV
σ_e	3.474mV
σ_n	1.389mV

Level	Mean	StdDev	Pk-Pk
V_D(3)	108.6mV	12.37mV	75.90mV
V_C(2)	37.69mV	10.73mV	59.53mV
V_B(1)	-33.82mV	9.596mV	60.66mV
V_A(0)	-104.7mV	6.831mV	50.34mV

Eye	Thresh	Offset	TJ@.5	TJ@.10	TJ@.15	RJ(d-d)	DJ(d-d)	H_eye	V_eye
Upper	73.10mV	-1.343ps	22.32ps	25.53ps	27.74ps	590.8fs	18.22ps	13.86ps	12.81mV
Middle	1.999mV	-1.186ps	20.58ps	23.69ps	25.77ps	539.9fs	17.03ps	14.71ps	17.08mV
Lower	-69.17mV	-941.6fs	22.42ps	25.57ps	27.70ps	547.9fs	18.82ps	13.57ps	21.35mV

Full waveform results



Full waveform eye diagram

DPO7OE series optical probes

The DPO7OE series optical probes can be used as an optical reference receiver for high speed serial data signals (using selectable Bessel-Thomson ORR filters), or can be used as a conventional O/E converter for general wide-bandwidth optical signal acquisition. The DPO7OE series is compatible with DPO/MSO70000 C/DX/SX models. Connected to TekConnect channels provides up to 33 GHz bandwidth. Connected to ATI channels, the DPO7OE1 provides up to 42 GHz electrical response; the DPO7OE2 provides up to 59 GHz electrical bandwidth response.

DPO7OE1 33 GHz optical probe

Ordering information

The PAMJET Transmitter Analysis software for Tektronix DPO/MSO70000 Series oscilloscopes.

For new DPO/MSO70000 Series oscilloscopes

Product	Option	Description
DPO/MSO70000DX/SX	PAMJET-E [2]	PAM Analysis (PAMJET) software for electrical signals
DPO/MSO70000DX/SX	PAMJET-O	PAM Analysis (PAMJET) software for optical signals
DPO70000SX	PAMPCIE6 [3]	PAM Analysis (PAMJET) software for PCIe Gen6
DPO70000SX	PAM400GCK [3]	PAM Analysis (PAMJET) software for 802.3ck

For users with existing DPO/DSA/MSO70000 Series oscilloscopes

Product	Option	Description
DPO-UP	PAMJET-E [2]	PAM Analysis (PAMJET) Software Upgrade for electrical signals
DPOFL PAMJET-E	-	PAM Analysis (PAMJET) software floating license for electrical signals
DPOFT PAMJET-E	-	PAM Analysis (PAMJET) software trial license for electrical signals
DPO-UP	PAMJET-O [2]	PAM Analysis (PAMJET) Software Upgrade for optical signals
DPOFL PAMJET-O	-	PAM Analysis (PAMJET) software floating license for optical signals
DPOFT PAMJET-O	-	PAM Analysis (PAMJET) software trial license for optical signals
DPO-UP	PAMPCIE6 [3]	PAM Analysis (PAMJET) software for PCIe Gen6
DPOFL-PAMPCIE6 [3]	-	PAM Analysis (PAMJET) software floating license for PCIe Gen6
DPOFT-PAMPCIE6 [3]	-	PAM Analysis (PAMJET) software trial license for PCIe Gen6
DPO-UP	PAM400GCK [3]	PAM Analysis (PAMJET) software for 802.3ck
DPOFL-PAM400GCK [3]	-	PAM Analysis (PAMJET) software floating license for 802.3ck
DPOFT-PAM400GCK [3]	-	PAM Analysis (PAMJET) software trial license for 802.3ck

Required options

DJA	DPOJET Jitter and Eye Analysis Tools - Advanced

Recommended probes

DPO7OE1	33 GHz optical probe
DPO7OE2	59 GHz optical probe

[2] PAM4 and PAMJET-E are equivalent options. PAM4 is the older option name that has been superseded by PAMJET-E. If the PAM4 is already owned, it will still be compatible with the solution. PAMJET-E has superseded the PAM4 option for new orders. Similarly, PAM4-O has been superseded by PAMJET-O.

[3] PAMPCIE6 and PAM400GCK require PAMJET-E. Please refer the PCI Express® and Ethernet 400G test solution datasheets for more details and supported scope models.

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