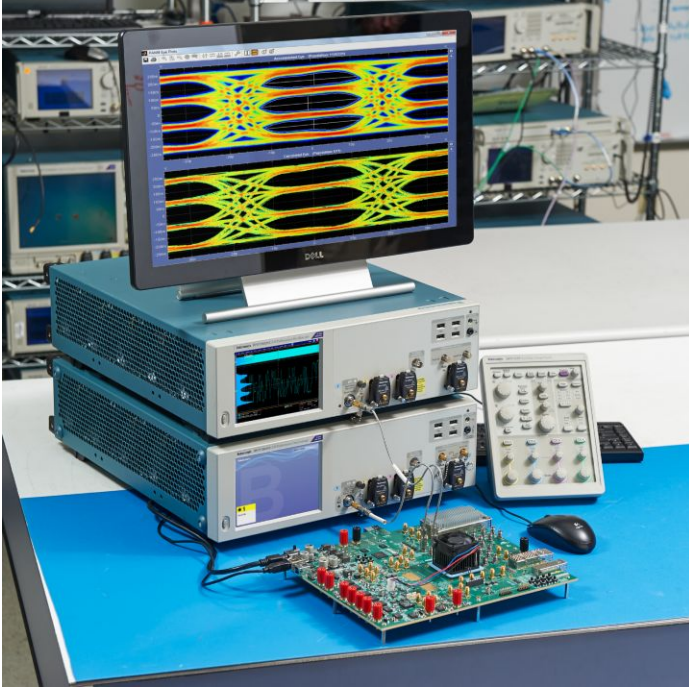# Tektronix®

PAM4 Transmitter Analysis

Comprehensive PAM4 Analysis, showing detailed jitter analysis for each eye and global link measurements

Features and benefits

The PAM4 Transmitter Analysis software application enhances the capabilities of the DPO/MSO70000DX/SX and DPO/DSA/MSO70000 series oscilloscopes, adding transmitter and channel testing for four-level Pulse Amplitude Modulation (PAM4) devices and interfaces for both electrical and optical physical domains.

- Single Integrated Application for PAM4 Electrical and Optical Signal Debug and Validation
  - This application brings together all the capabilities needed for comprehensive PAM4 analysis and debug
  - Dashboard style configuration panel enables quick and easy configuration of all the necessary parameters for PAM4 analysis
- Enhanced Clock Recovery
  - Software clock recovery offers the industry's most robust clock recovery capability even from heavily impaired signals
- Configurable Bessel-Thomson Filter
  - Offers the flexibility to tune bandwidth of the measurement receiver, either manually or automatically, based on detected data rate

- Waveform Filter enables embed or de-embed test fixtures 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
  - Apply CTLE, FFE and DFE equalization to the acquired waveform to open a closed eye.
  - Model different types of receiver settings to perform what-if analysis
  - Support for standard based equalization presets
- Jitter Measurement and Eye Analysis
  - Full Characterization of the PAM4 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 providing greater insight
  - Flexible controls to automatically acquire a desired symbol population across multiple acquisitions
- Noise Analysis and BER Contours
  - Eye width and height analysis per OIF-CEI 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 and IEEE based PAM4 standards; such as OIFCEI-VSR-56G-PAM4, 802.3bs, and CDAUI-8.

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.
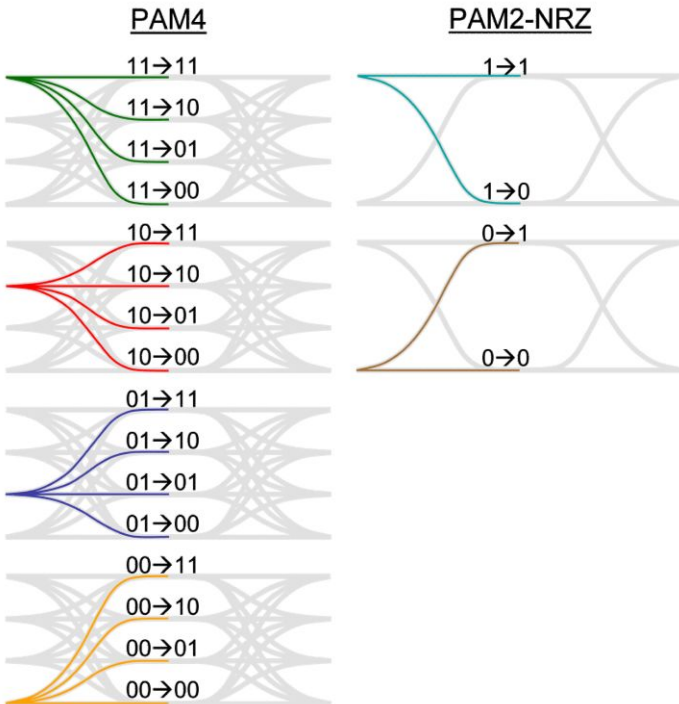

Assumes linear coding for illustration. In practice, gray coding is frequently used.

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

PAM4 Measurement configuration

The configuration panel is a dashboard within the PAM4 analysis tool that enables you to configure most elements for a PAM4 analysis run. The panel includes; measurement source selection, Clock recovery, Threshold, and Bessel-Thomson filter and Equalization configuration. It also has the ability to embed or de-embed a channel using a waveform filter.
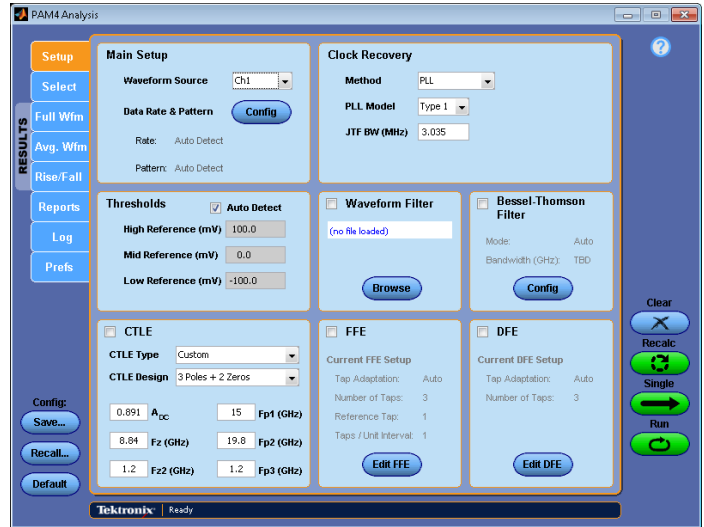
Clock recovery

Configurable PLL (phase-locked loop) clock recovery reliably extracts the symbol clock, even with highly impaired signals, 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.

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 PAM4 analysis 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.

- Observe the tap values that have been chosen.
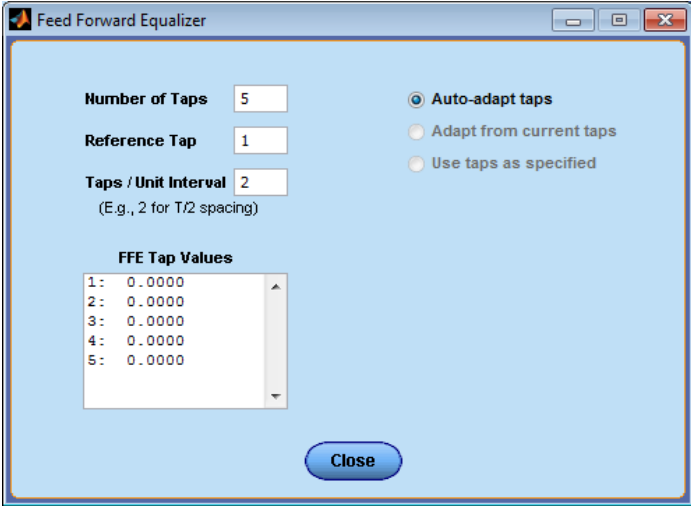
Measurement Selection

The new Select panel enables you to select between 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.
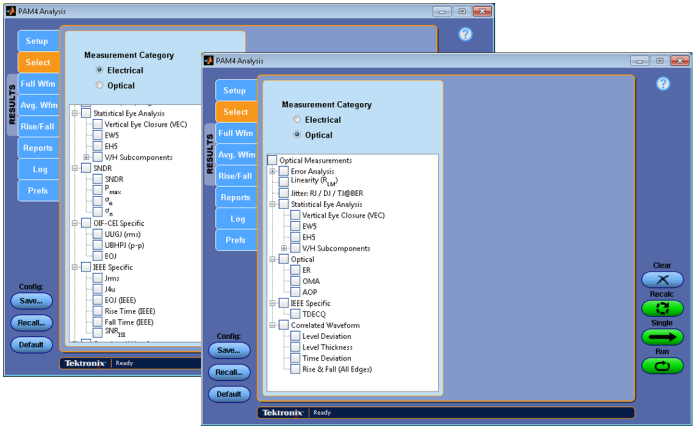
Auto Configure Capability

The PAM4 analysis 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.

PAM4 Measurements

PAM4 analysis 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/cd) and OIF-CEI Standards based measurements or SNDR and TDECQ when enable characterized of electrical and optical PAM4 Transmitter.

PAM4 Optical Measurements	
Error Analysis	Symbol Errors
	SER
	BER
Linearity	
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}

PAM4 Optical Measurements		
Optical	ER	
	OMA_{OUTER}	
	AOP [1]	
	RIN x OMA [2]	
IEEE Specific	TDECQ	
	Launch Power in OMA_{OUTER} minus TDECQ [2]	
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		
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	
OIF-CEI	UUGJ	
	UBHPJ	
	EOJ	
IEEE Specific	Jrms	
	J4	
	EOJ	
	Rise Time	
	Fall Time	
	SNR_ISI	

PAM4 Electrical Measurements		
Correlated Waveform	Level Deviation	
	Level Thickness	
	Time Deviation	
	Rise and Fall	

## Full Waveform and Correlated Waveform analysis

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

The correlated waveform and eye show how much additional eye opening is theoretically obtainable through equalization. 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 PAM4 Analysis application can effectively model correlated and composite eye diagrams.


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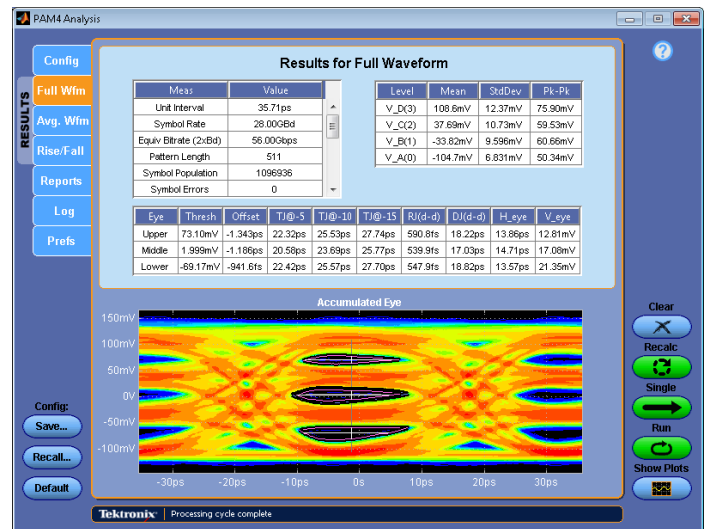
[1] Supports Average Launch Power of Off Transmitter as per IEEE 802.3bs/cd specifications.

[2] This measurement not available until December 2018.
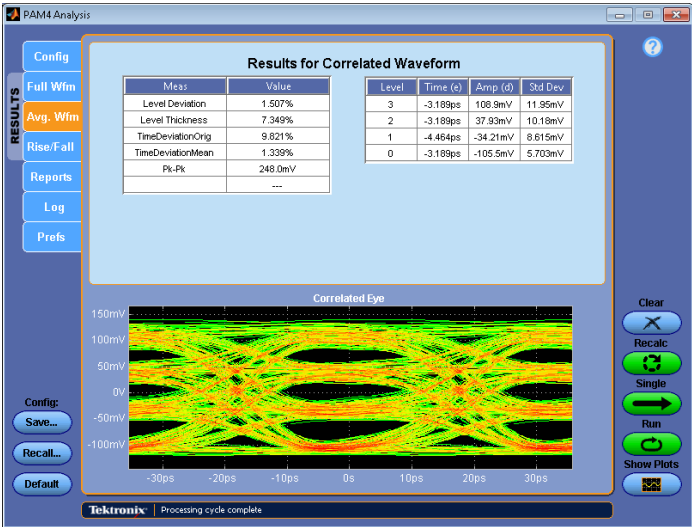
Rise and Fall Time analysis

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 PAM-4 analysis software provides the max, min, and mean rise and fall time for each of the six transition types within the PAM4 eye.
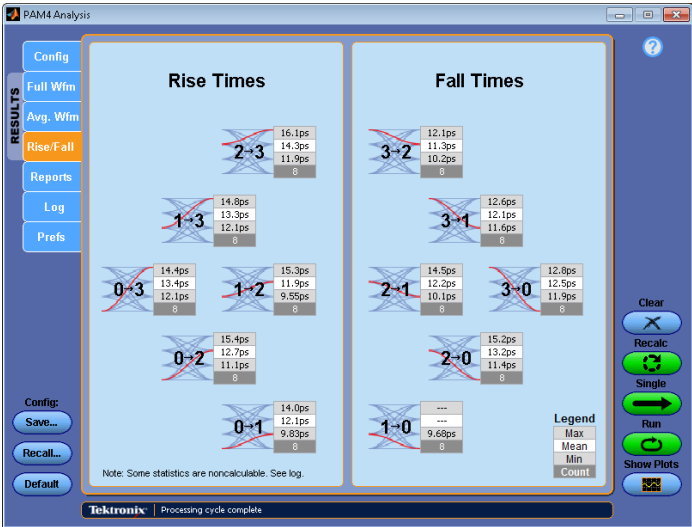

Visualization

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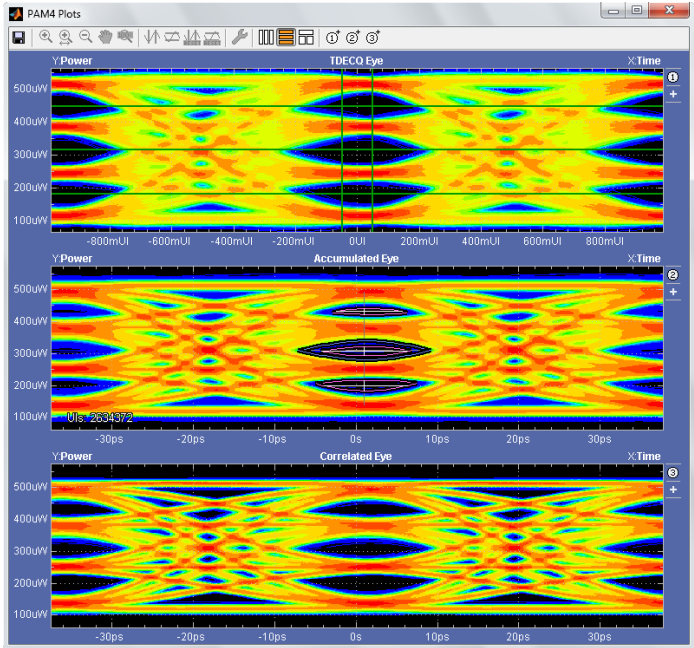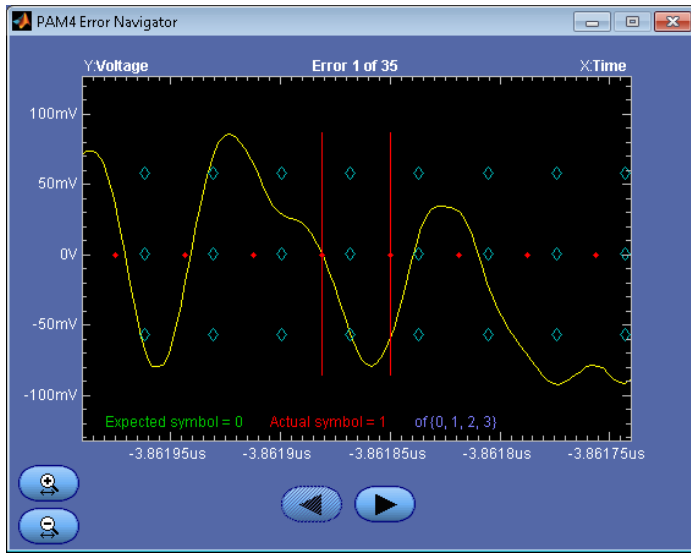

Error Detector

The PAM4 analysis 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.
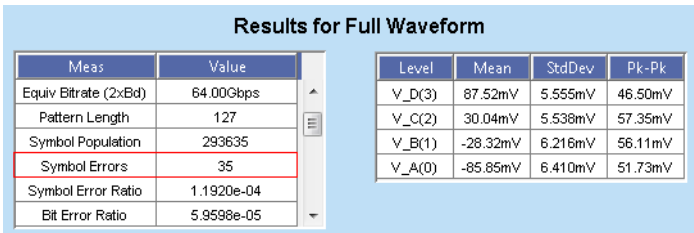
The error navigator has several capabilities that makes it easy to quickly navigate and zoom into the error location. The additional information for the following detected errors offer help debugging symbol errors on the link:

- Location of recovered clock

- Location of symbol error reference thresholds

- Expected symbol displayed

- Actual symbol displayed

Full waveform eye diagram

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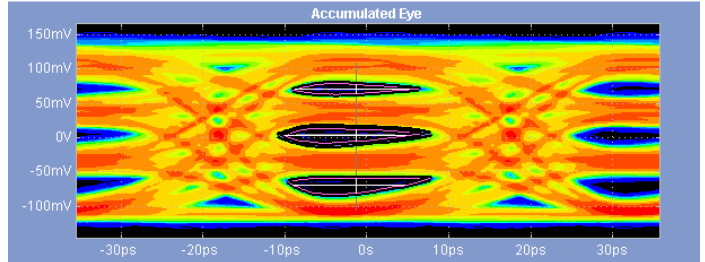
The measurement results across multiple acquisitions can also be exported to a single CSV file for further analysis.

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

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 for 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 PAM4 Transmitter analysis software for Tektronix DPO/MSO70000 Win7 Series oscilloscopes

For new DPO/MSO70000 Series oscilloscopes

Product	Option	Description
DPO/MSO70000DX/SX	PAM4	PAM4 Analysis software for electrical signals
DPO/MSO70000DX/SX	PAM4-O	PAM4 Analysis Software for optical signals

For users with existing DPO/DSA/MSO70000 Series oscilloscopes

Product	Option	Description
DPO-UP	PAM4	PAM4 Analysis Software Upgrade for electrical signals
DPOFL PAM4	-	PAM4 Analysis software floating license for electrical signals
DPOFT PAM4	-	PAM4 Analysis software trial license for electrical signals
DPO-UP	PAM4-O	PAM4 Analysis Software Upgrade for optical signals
DPOFL PAM4-O	-	PAM4 Analysis software floating license for optical signals
DPOFT PAM4-O	-	PAM4 Analysis software trial license for optical signals

Required options

DJA	DPOJET Eye and Jitter Analysis
DJAN	DPOJET Noise Analysis
SDLA64	SDLA Visualizer channel de-embedding, embedding, and equalization

Recommended Probes

DPO7OE1	33 GHz optical probe
DPO7OE2	59 GHz optical probe

Tektronix is registered to ISO 9001 and ISO 14001 by SRI Quality System Registrar.

Product(s) complies with IEEE Standard 488.1-1987, RS-232-C, and with Tektronix Standard Codes and Formats.

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For Further Information. Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit www.tek.com.

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