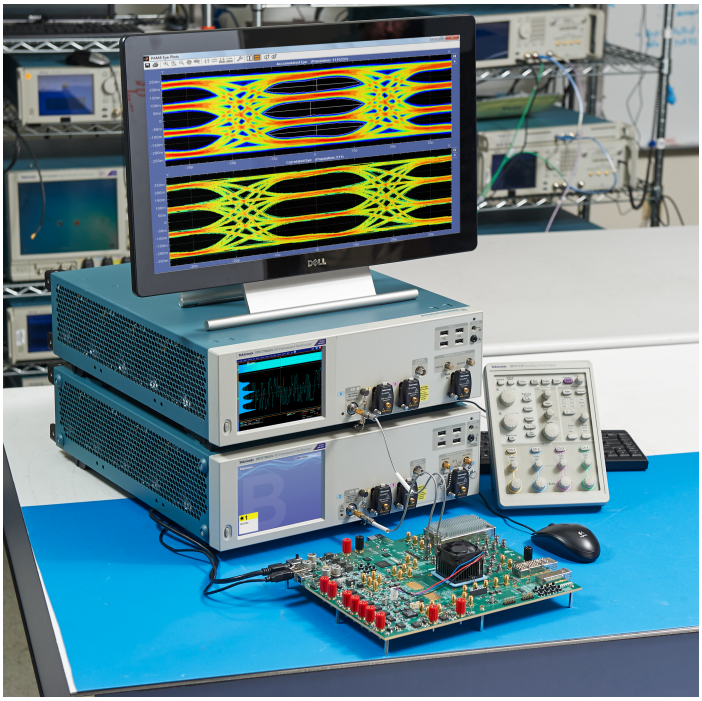
Tektronix

# PAM4 Transmitter Analysis



The PAM4 Transmitter Analysis software application enhances the capabilities of the DPO/MSO70000DX/SX and DPO/DSA/MSO70000 series oscilloscopes (33 GHz or greater bandwidth), adding transmitter and channel testing for four-level Pulse Amplitude Modulation (PAM4) devices and interfaces for both electrical and optical physical domains.

## Key features

- 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.

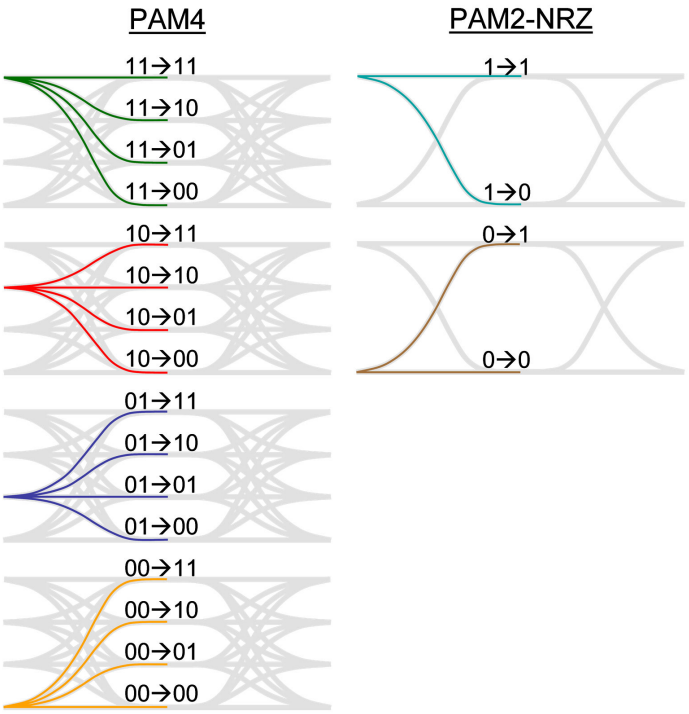
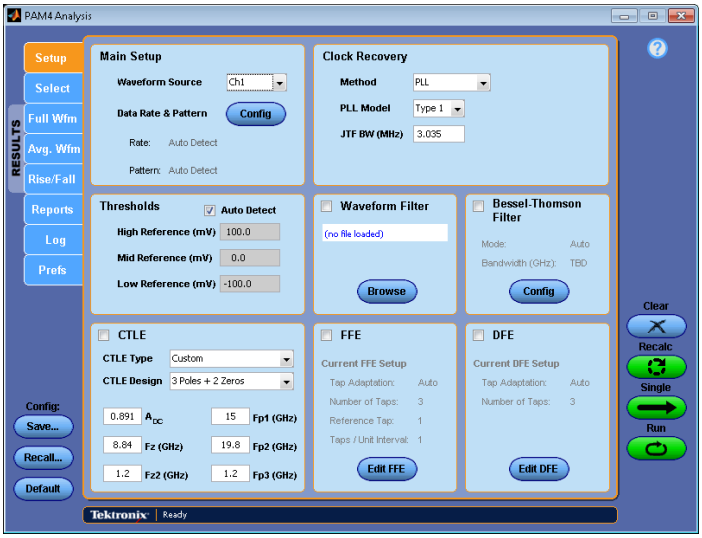



*Figure 1: Assumes linear coding for illustration. In practice, gray coding is frequently used.*

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:

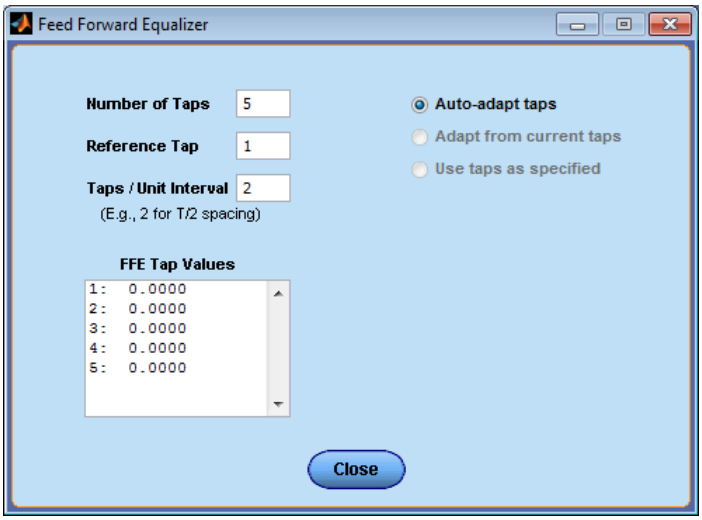
- The effects of a test fixture can be de-embedded to gain visibility of the signal at the transmitter output.
- A channel can be embedded to gain visibility of the signal at the receiver input.

## 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.



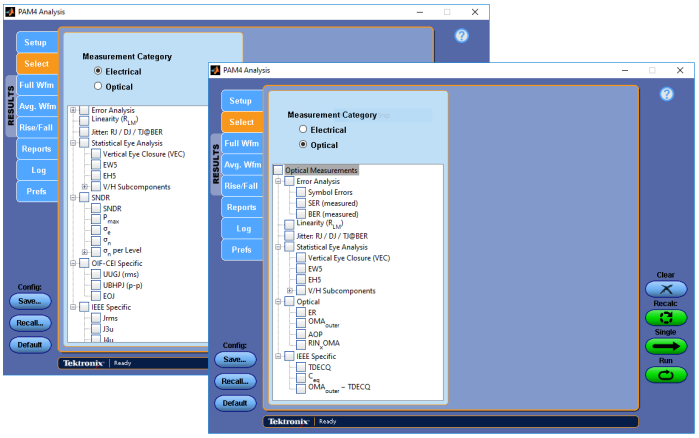

## Auto configure capability

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.

## 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

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** | $R_{LM}$ |
| **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 |
| | $P_{max}$ |
| | $\sigma_e$ |
| | $\sigma_n$ |
| | $\sigma_n$ per Level |
| **OIF-CEI** | UUGJ (rms) |
| | UBHPJ (p-p) |
| | EOJ |
| **IEEE Specific** | Jrms |
| | J3u |
| | J4u |

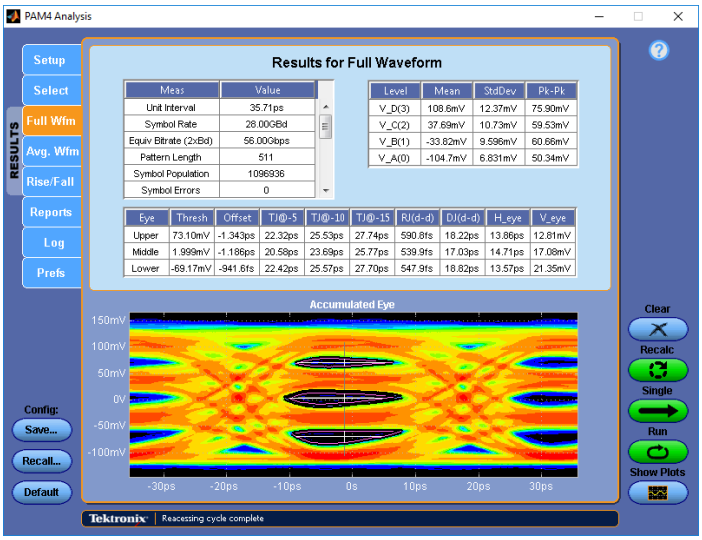
Table continued…

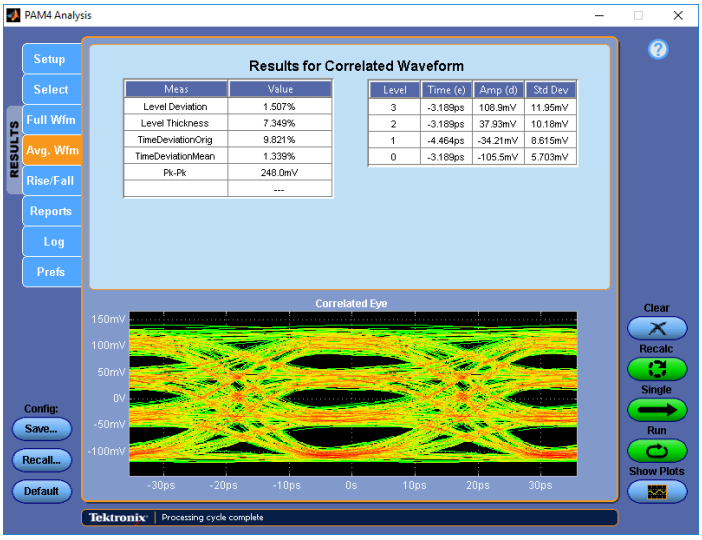
| PAM4 Electrical Measurements | |
|---|---|
| | EOJ |
| | EOJ per Edge |
| | Rise Time |
| | Fall Time |
| | $SNR_{ISI}$ |
| **Correlated Waveform** | Level Deviation |
| | Level Thickness |
| | Time Deviation |
| | Rise and Fall |

## 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.

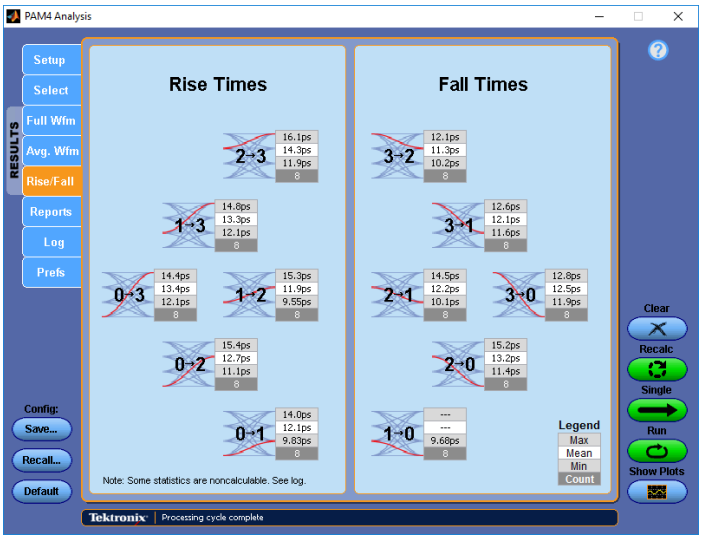
The correlated waveform and eye show how much additional eye opening is theoretically obtainable through equalization. The correlated waveform can be analyzed by tools and techniques similar to those found on Equivalent Time Oscilloscopes. Many performance communications standards assume access to correlated data. The PAM4 Analysis application can effectively model correlated and composite eye diagrams.




## Rise and fall time analysis

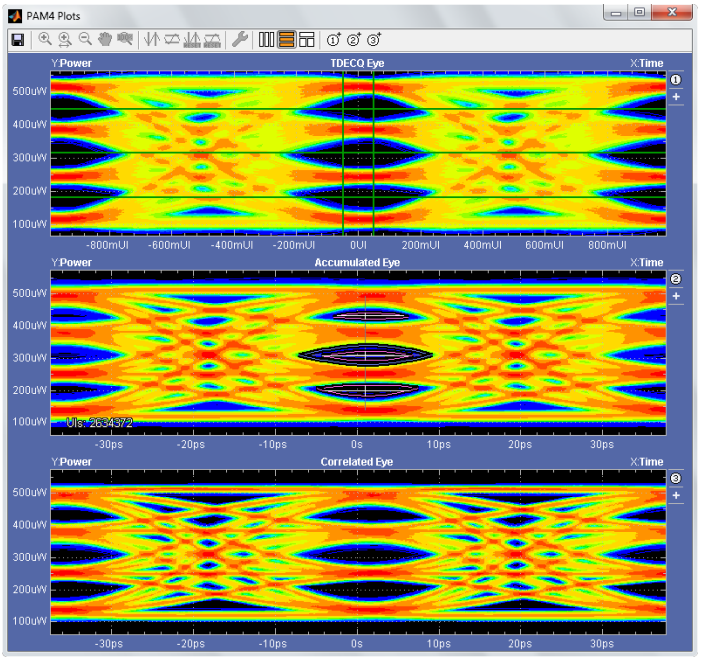
Analysis of the individual transitions rise and fall times helps separate linear impairments (bandwidth, ISI) from nonlinear (slew-rate limiting, clipping). The rise and fall times also support advanced tuning of equalization algorithms. The PAM4 analysis software provides the max, min, and mean rise 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.

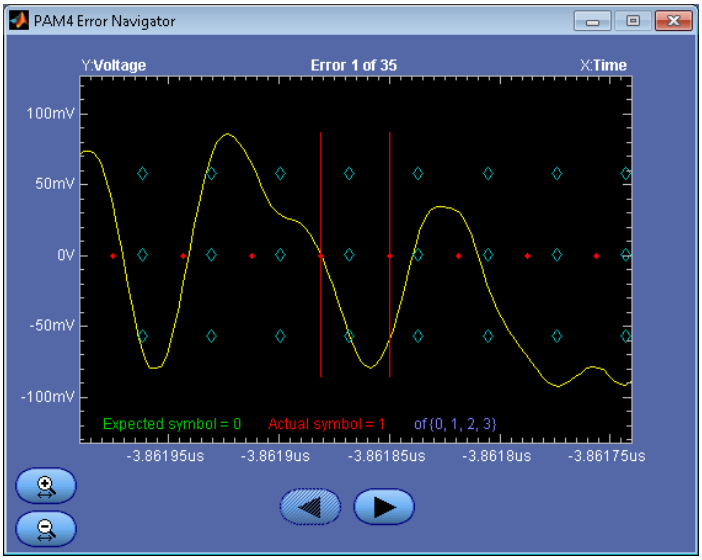
**Results for Full Waveform**

| 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 |
| $\sigma_e$ | 3.474mV |
| $\sigma_n$ | 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 |

*Figure 2: Full waveform results*

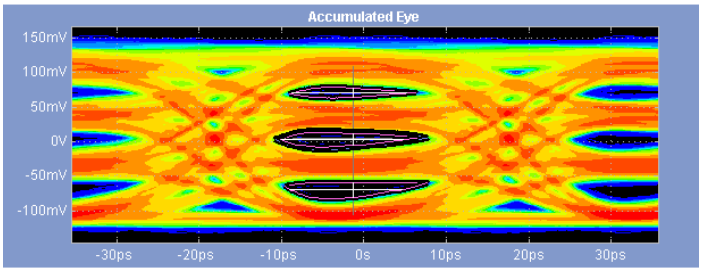



*Figure 3: Full waveform eye diagram*

## 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.


*Figure 4: DPO7OE1 33 GHz optical probe*

## Ordering information

The PAM4 Transmitter Analysis software for Tektronix DPO/MSO70000 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 |

## 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.

**ASEAN / Australasia** (65) 6356 3900
**Belgium** 00800 2255 4835*
**Central East Europe and the Baltics** +41 52 675 3777
**Finland** +41 52 675 3777
**Hong Kong** 400 820 5835
**Japan** 81 (3) 6714 3086
**Middle East, Asia, and North Africa** +41 52 675 3777
**People's Republic of China** 400 820 5835
**Republic of Korea** +822 6917 5084, 822 6917 5080
**Spain** 00800 2255 4835*
**Taiwan** 886 (2) 2656 6688

**Austria** 00800 2255 4835*
**Brazil** +55 (11) 3759 7627
**Central Europe & Greece** +41 52 675 3777
**France** 00800 2255 4835*
**India** 000 800 650 1835
**Luxembourg** +41 52 675 3777
**The Netherlands** 00800 2255 4835*
**Poland** +41 52 675 3777
**Russia & CIS** +7 (495) 6647564
**Sweden** 00800 2255 4835*
**United Kingdom & Ireland** 00800 2255 4835*

**Balkans, Israel, South Africa and other ISE Countries** +41 52 675 3777
**Canada** 1 800 833 9200
**Denmark** +45 80 88 1401
**Germany** 00800 2255 4835*
**Italy** 00800 2255 4835*
**Mexico, Central/South America & Caribbean** 52 (55) 56 04 50 90
**Norway** 800 16098
**Portugal** 80 08 12370
**South Africa** +41 52 675 3777
**Switzerland** 00800 2255 4835*
**USA** 1 800 833 9200

* European toll-free number. If not accessible, call: +41 52 675 3777

**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*.



21 Dec 2020 55W-60239-10
www.tek.com