



PAM4 Signal Generation and BER Measurement Solution

Signal Quality Analyzer
MP1800A Series

Introduction

The recent spread of smartphones and cloud computing applications is driving exponential growth in traffic at data centers. To transfer these large data volumes at high speed, Ethernet communications standards are progressing with deployment of 100GbE equipment, and 400GbE is already being targeted for next-generation standards.

Transmission technologies for implementing high-speed, large-volume transfers are centered on PAM (Pulse Amplitude Modulation) methods offering both faster symbol rates than earlier NRZ signal methods as well as increased transmission capacity without increased symbol rates.

This presentation introduces the MP1800A Signal Quality Analyzer as a measurement solution supporting next-generation transmission standards, such as 200GbE and 400GbE.

Standards for High-Speed Interconnects using PAM4

Optical Interface

Standard		Distance	Format	Baud Rate
400G	400G BASE-SR16	100 m	NRZ	26.6G
	400G BASE-DR4	500 m	PAM4	53.1G
	400G BASE-FR8	2 km	PAM4	26.6G
	400G BASE-LR8	10 km	PAM4	26.6G
200G	200G BASE-SR4*	100 m*	PAM4	26.6G
	200G BASE-DR4*	500 m*	PAM4	26.6G
	200G BASE-FR4*	2 km*	PAM4	26.6G
	200G BASE-LR4*	10 km*	PAM4	26.6G
100G	100G BASE-SR10	100/150 m	NRZ	10.3G
	100G BASE-SR2*	100 m*	PAM4	26.6G
	100G BASE-DR*	500m*	PAM4	53.1G
	100G BASE-SR4	70/100 m	NRZ	25.8G
	100G SWDM	400 m	NRZ	25.8G
	100G PSM4	500 m	NRZ	25.8G
	CWDM4/CLR4	2 km	NRZ	25.8G
	100G BASE-LR4	10 km	NRZ	25.8G
	100G BASE-ER4	40 km	NRZ	25.8G
	100G BASE-CR4		NRZ	25.8G
	100G BASE-KR4		NRZ	25.8G
100G BASE-KP4		PAM4	13.6G	
50G	50G BASE-SR*	100 m	PAM4	26.6G
	50G BASE-FR*	2 km	PAM4	26.6G
	50G BASE-LR	10 km	PAM4	26.6G
25G	25G BASE-SR	100 m	NRZ	25.8G
	25G BASE-FR	2 km	NRZ	25.8G
	25G BASE-LR	10 km	NRZ	25.8G

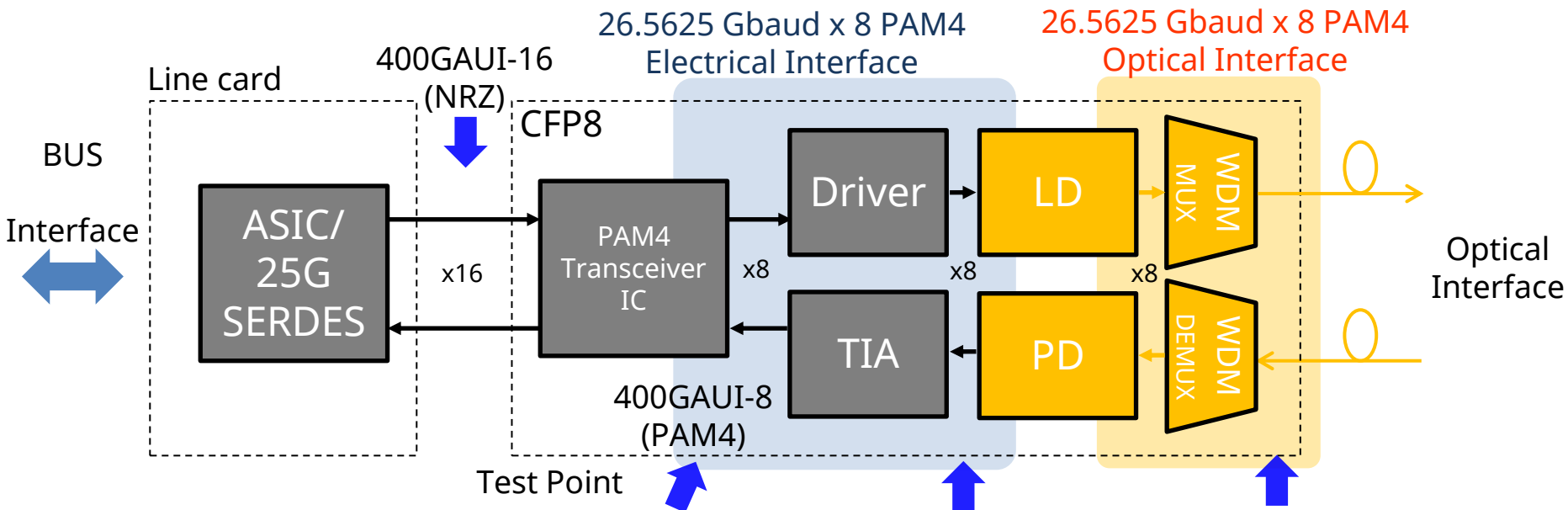
*Standard now under review

Electrical Interface

Electrical Interface (OIF-CEI)		Format	Baud Rate
400G	400GAUI-16	NRZ	25.8G
	400GAUI-8	PAM4	26.6G
200G	200GAUI-8	NRZ	25.8G
	200GAUI-4	PAM4	26.6G
100G	CAUI-10	NRZ	10.3G
	CAUI-4	NRZ	25.8G
50G	50GAUI	PAM4	26.6G
25G	25GAUI	NRZ	25.8G

Example of PAM4 Signal Applications (1)

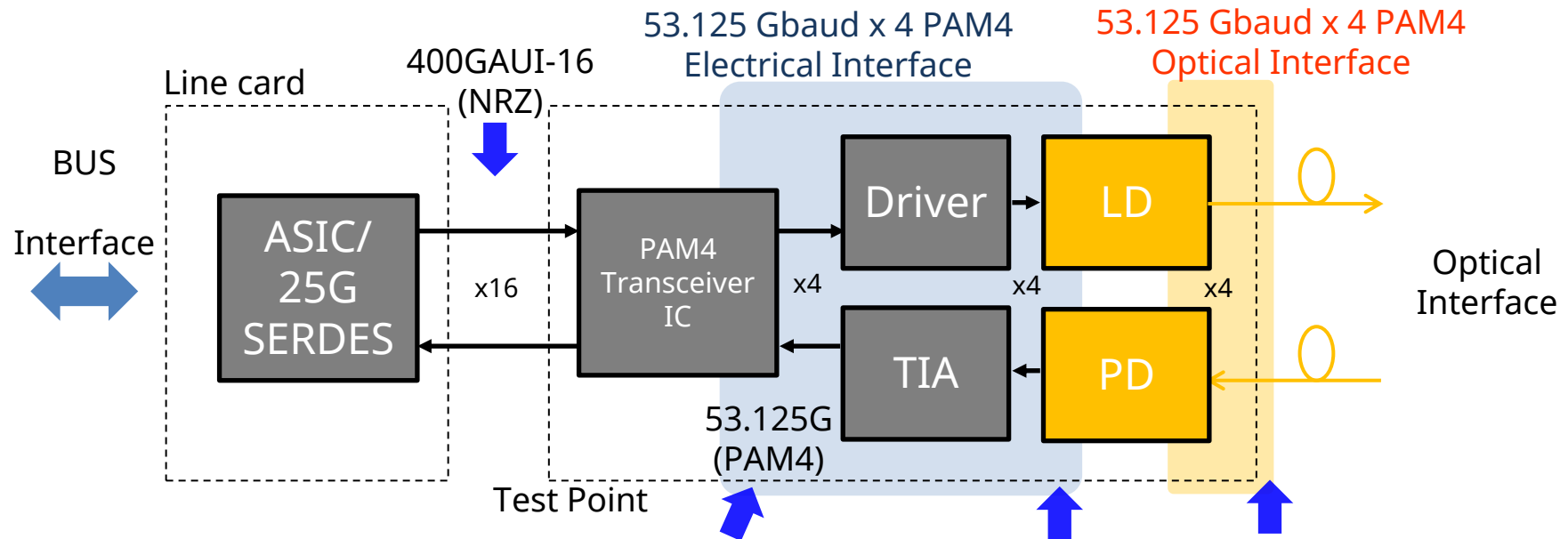
- 26.5625 Gbaud 400GAUI-8 Electrical and 400GBASE-FR8, LR8 Optical Interfaces



	400GAUI-8 Electrical Interface	Driver Output, LD Input Electrical Interface	400GBASE-FR8,LR8 Optical Interface
Baud Rate	26.5625 Gbaud (53.125 Gbit/s)/Lane		
Lane Number	8		1 Single-mode Fiber (1310-nm Wavelength)
Main Measurement Items	<ul style="list-style-type: none"> • BER Test • Eye Mask (EH, EW, Linearity) • Tx/Rx Equalizer Function • Jitter Addition Test (RJ/SJ/DCD) • Crosstalk Test 	<ul style="list-style-type: none"> • Eye Mask (EH, EW, Linearity) • I/O Power Characteristics 	<ul style="list-style-type: none"> • Average Optical Power • OMA (Optical Modulation Amplitude) • Extinction Ratio • Optical Stress Test

Example of PAM4 Signal Applications (2)

- 53.125 Gbaud 4-lane Electrical and 400GBASE-DR4 Optical Interfaces



	53 Gbaud 4-lane Electrical Interface	Driver Output, LD Input Electrical Interface	400GBASE-FR8,LR8 Optical Interface
Baud Rate	53.125 Gbaud (106.25 Gbit/s)/Lane		
Lane Number	4		4-lane Single-mode Fiber (1310-nm Wavelength Band)
Main Measurement Items	<ul style="list-style-type: none"> • BER Test • Eye Mask (EH, EW, Linearity) • Tx/Rx Equalizer Function • Jitter Addition Test (RJ/SJ/DCD) • Crosstalk Test 	<ul style="list-style-type: none"> • Eye Mask (EH, EW, Linearity) • I/O Power Characteristics 	<ul style="list-style-type: none"> • Average Optical Power • OMA (Optical Modulation Amplitude) • Extinction Ratio • Optical Stress Test

Features of MP1800A Series PAM4 Measurement Solution

- Supports high 64 Gbaud rate both PAM4 and NRZ
- 32 Gbaud 4ch PAM4 transmissions (256 Gbit/s/one MP1800A)
- Excellent expandability
 - 32 Gbaud 4ch multi-channel
 - Expandable from 32 Gbaud to 64 Gbaud
- Low Intrinsic Jitter and high-quality waveform output
- High-input sensitivity BER detection
- Supports receiver jitter tolerance tests

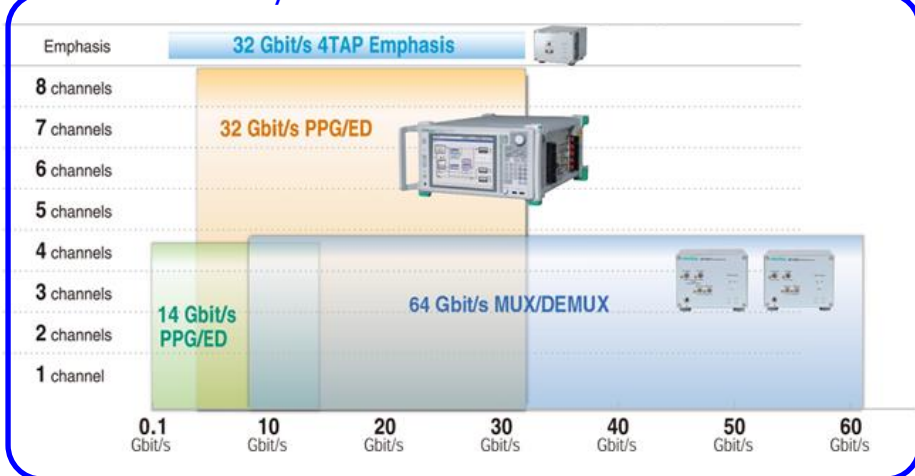
**Future-proof
instrument
configuration**

**Efficient inspection
supported by functions
and performance**

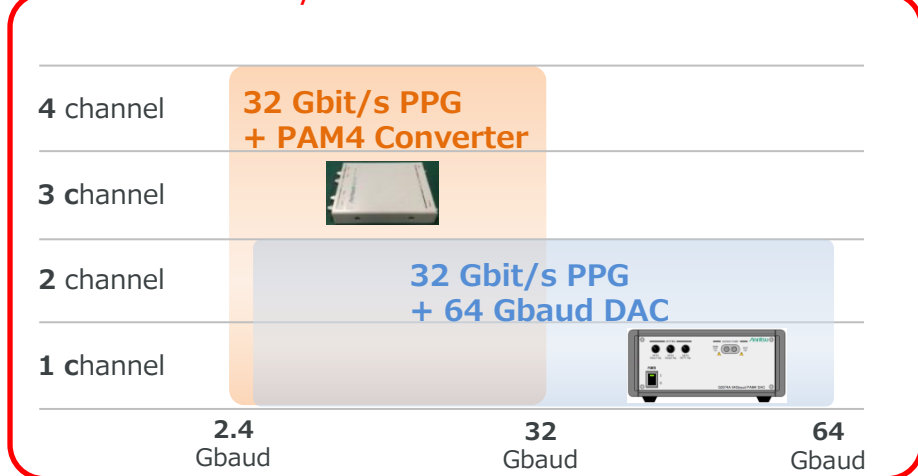
[PAM4 Applications]

- 28 Gbaud PAM4 ICs, backplanes, active optical cables, CEI-56G-PAM4
- 53 Gbaud/26 Gbaud 200 GbE/400 GbE optical modules, optical devices, ICs

NRZ/Multichannel Solution



PAM4/Multichannel Solution



Recommended PAM4 BER Measuring Instruments

32 Gbaud Standard Configuration

Model	Name	Option	Qty	Remark
MP1800A	Signal Quality Analyzer	001, 002, 007, 015, 032	1	
MU181000B	12.5 GHz 4 port Synthesizer	-	1	
MU181500B	Jitter Generation Source	-	1	For Jitter Tolerance Test
MU183020A	28G/32Gbit/s 2ch PPG	023, 031	1	Two units for 3Eye level independent control
MU183040B	28G/32Gbit/s High Sensitivity ED	010	1	1ch sequential BER measurement
MZ1834A/B	4PAM Converter	-	1	
MZ1838A	8PAM Converter	-	1	For 3Eye level independent control

64 Gbaud Standard Configuration

Model	Name	Option	Qty	Remark
MP1800A	Signal Quality Analyzer	001, 002, 007, 015, 032	1	
MU181000B	12.5 GHz 4 port Synthesizer	-	1	
MU181500B	Jitter Generation Source	-	1	For Jitter Tolerance Test
MU183020A	28G/32Gbit/s PPG	022, 031	2	Also possible with Option 023
MU183040B	28G/32Gbit/s High Sensitivity ED	020	1	
G0374A	64Gbaud PAM4 DAC	-	1	
MP1862A	56G/64Gbit/s DEMUX	-	1	

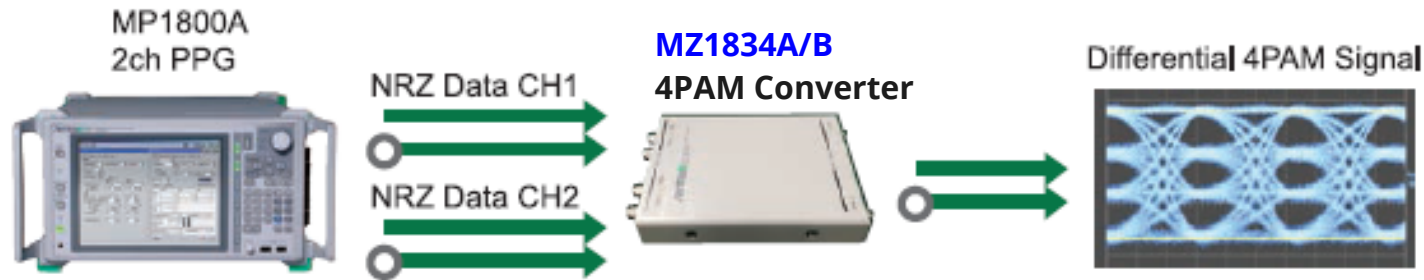
PAM4 Signal Generation (1)

- Low Intrinsic Jitter and high-quality waveform output support efficient verifications
- Expandability for measurement application and baud rate

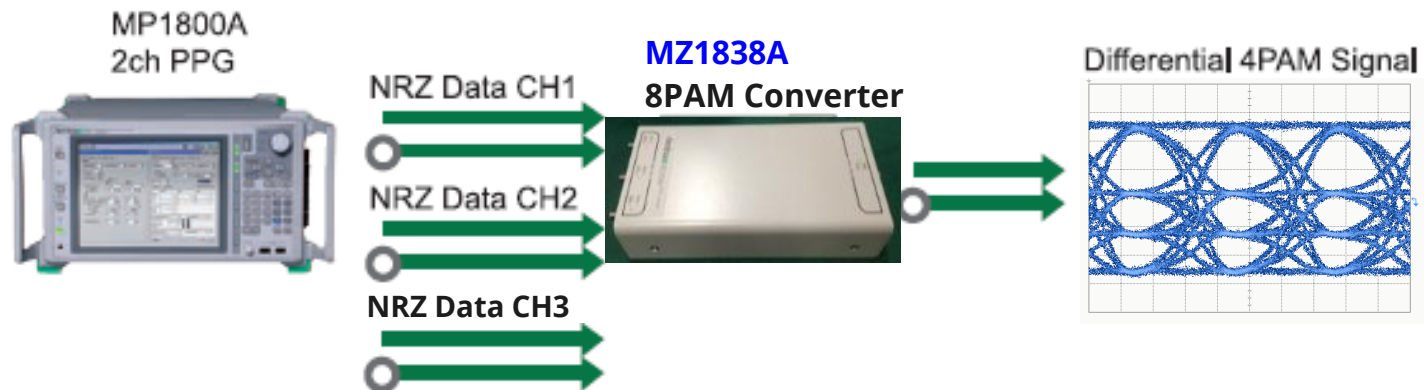
	32 Gbaud Signal Generation PAM4 Converter + MU18302xA PPG	64 Gbaud Signal Generation G0374A/G0361A + MU18302xA PPG (4ch)
Baud Rate	2.4 to 32.1 Gbaud (4.8 to 64.2 Gbit/s)	4.8 to 64 Gbaud (9.6 to 128 Gbit/s)
Amplitude (Single-End)	<ul style="list-style-type: none"> • MZ1834A + 2 ch PPG 0.238 to 0.475 V (w/ 2V option PPG) 0.238 to 0.832 V (w/ 3.5V option PPG) • MZ1834B + 2 ch PPG 0.376 to 0.753 V (w/ 2V option PPG) 0.376 to 1.318 V (w/ 3.5V option PPG) • MZ1838A + 3 ch PPG (3Eye independently variable level) 0.119 to 0.378 V (w/ 2V option PPG) 0.119 to 0.662 V (w/ 3.5V option PPG) 	0.7 V (typ.) >6 dB controllable
Tr/Tf (20% to 80%)	12 ps (typ.)	8 ps (typical)

PAM4 Signal Generation (2)

- 32 Gbaud PAM4 Signal Generation 1
(3 Eye equivalent or symmetrical variable level)



- 32 Gbaud PAM4 Signal Generation 2
(Supports evaluations of LDs and optical devices using 3Eye independently variable level)



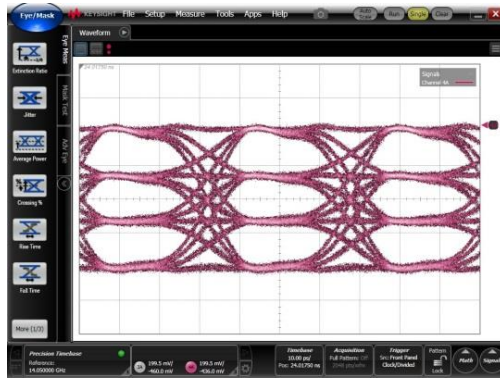
PAM4 Signal Generation (3)

➤ Typical MZ1834A/B Waveforms

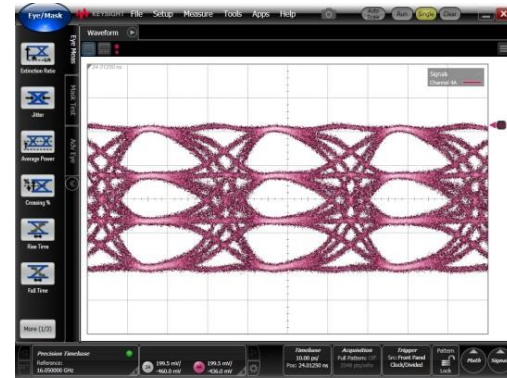
Supports accurate Eye Margin and high-reproducibility measurements using high-quality output waveforms with low Intrinsic Jitter

- **MZ1834A**

28 Gbaud, 0.832 V

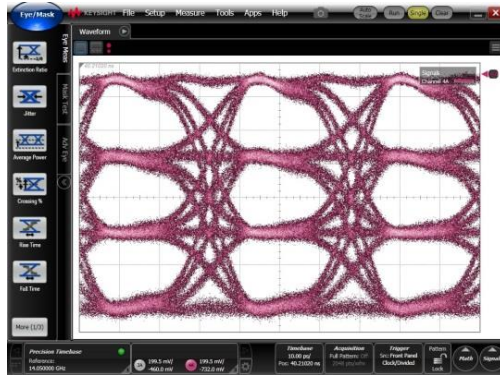


32.1 Gbaud, 0.832 V

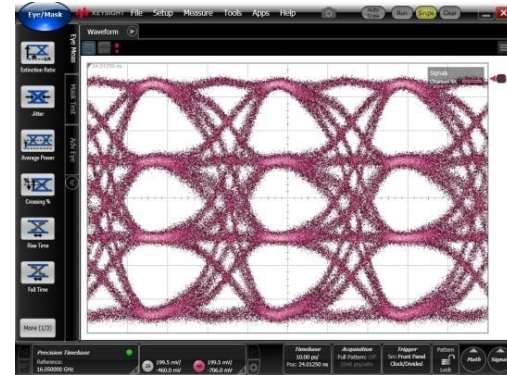


- **MZ1834B**

28 Gbaud, 1.318 V



32.1 Gbaud, 1.318 V



Measured with J1439A 80 cm cable +41V-6 Attenuator+ 70-GHz Band Oscilloscope.

PAM4 Signal Generation (4)

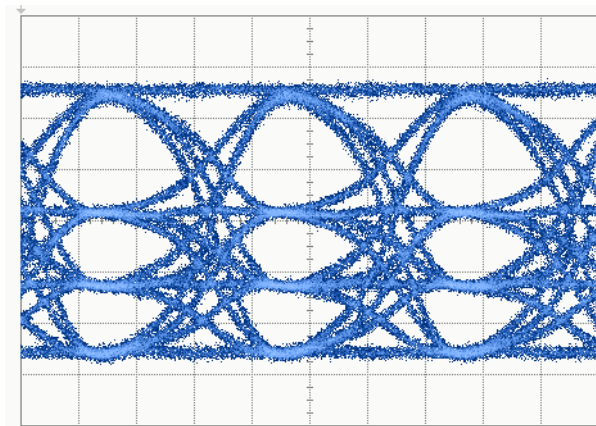
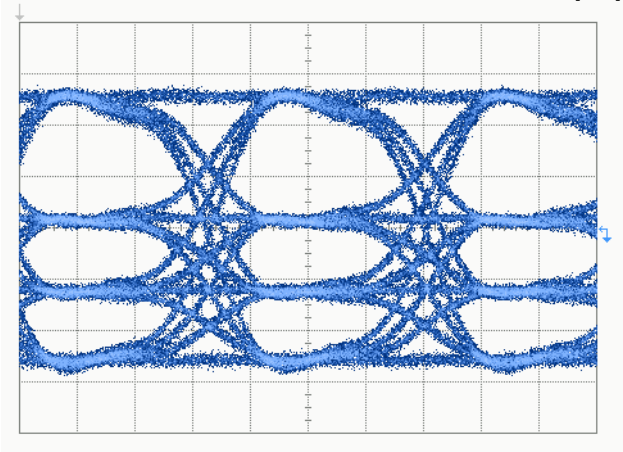
➤ Typical MZ1838A PAM4 waveforms

3Eye Independent Level Control support transmitter linearity test and stressed receiver test.

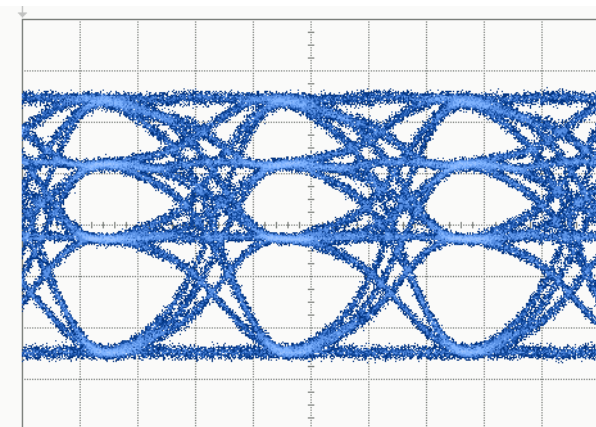
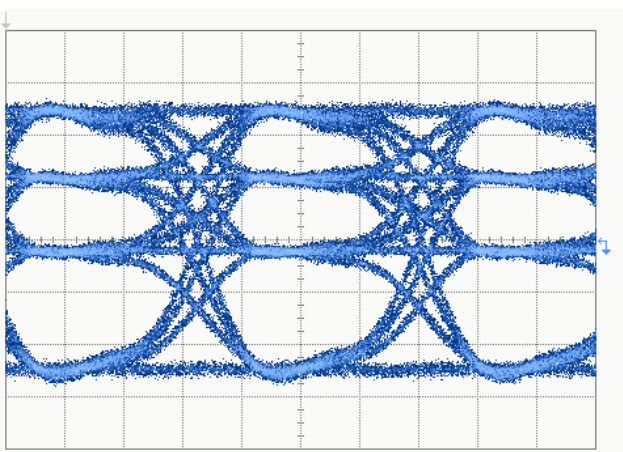
26.5625 Gbaud QPRBS13, 0.5 Vp-p

32.1 Gbaud QPRBS13, 0.5 Vp-p

Example of
Wide Upper
Eye Opening

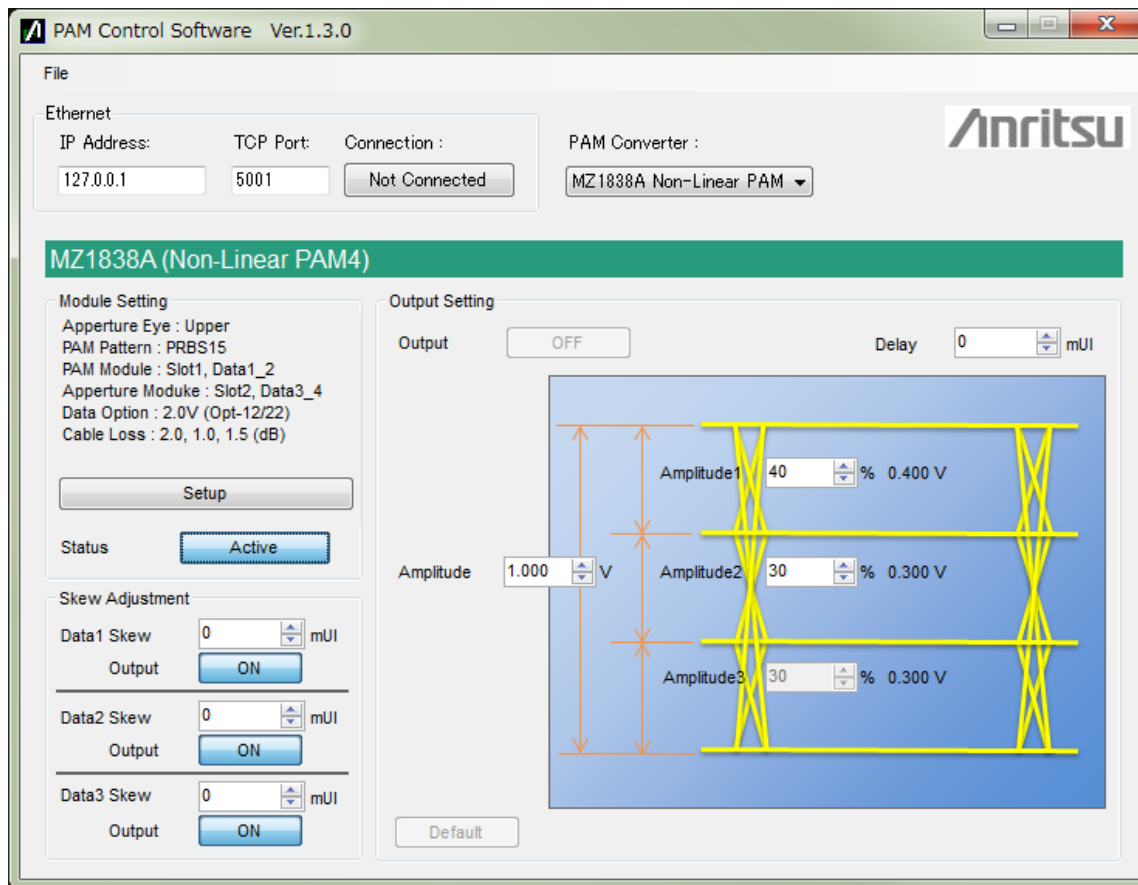


Example of
Wide Lower
Eye Opening



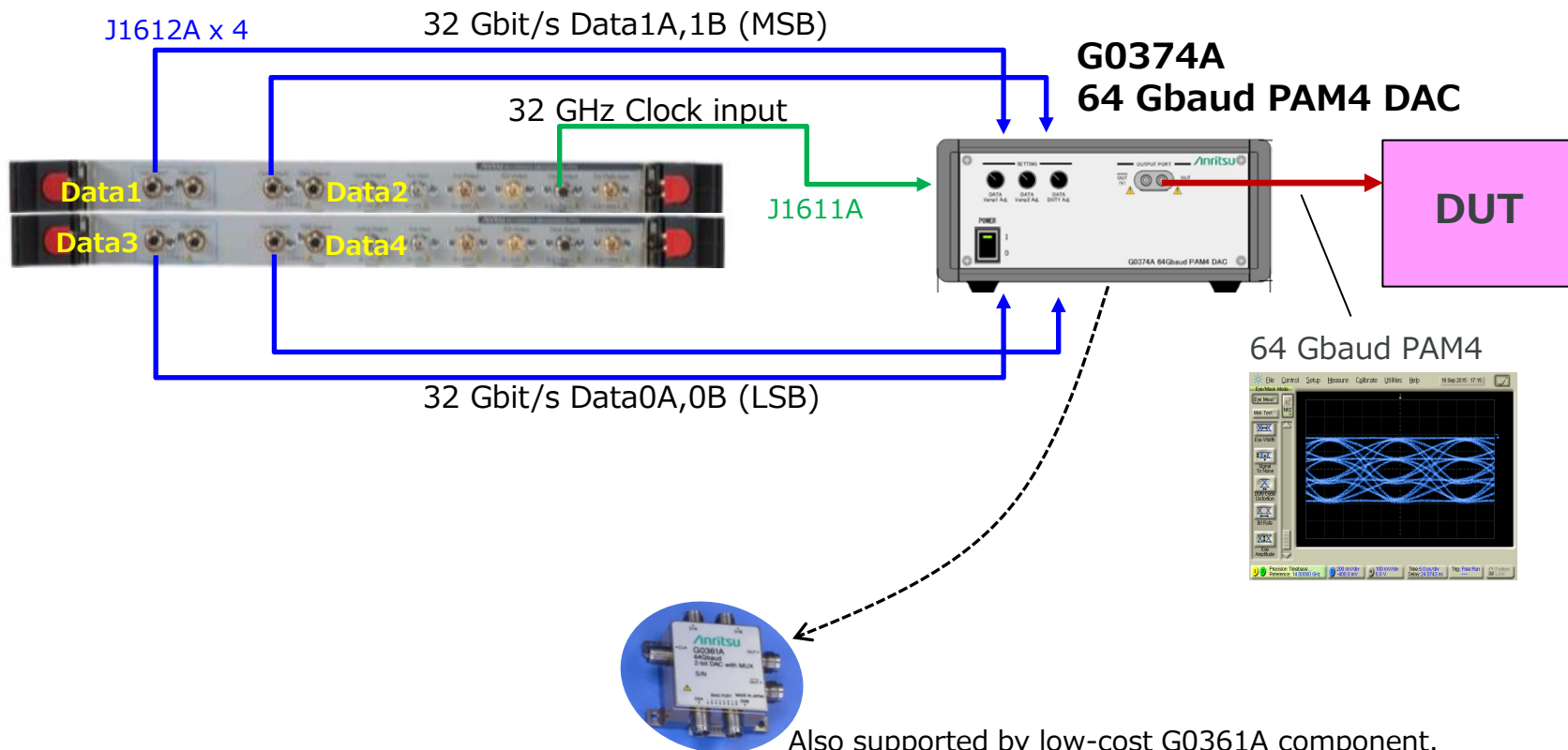
PAM4 Signal Generation (5)

- PAM4 Signal level and pattern control using PAM control software
 - Independent control of Upper, Middle, Lower Eye amplitude (using MZ1838A)
 - Pattern settings using PAM control software



PAM4 Signal Generation (6)

- 64 Gbaud PAM4 Signal Generation (G0374A + MU18302xA PPG (4 ch))
Supports 64 Gbaud rates with minimum additional investment costs in instruments



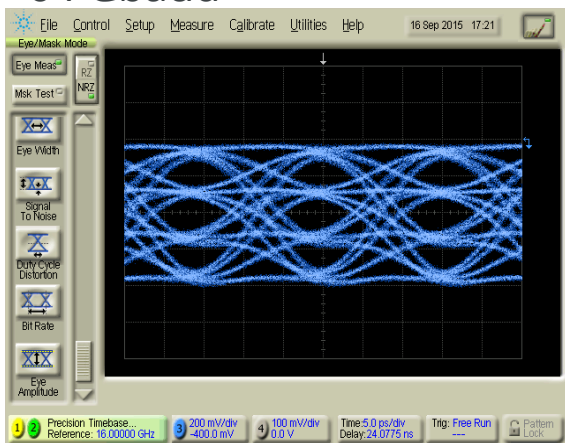
Also supported by low-cost G0361A component.
In this case, requires adjustment using separate external power source as well as coaxial cables.

PAM4 Signal Generation (7)

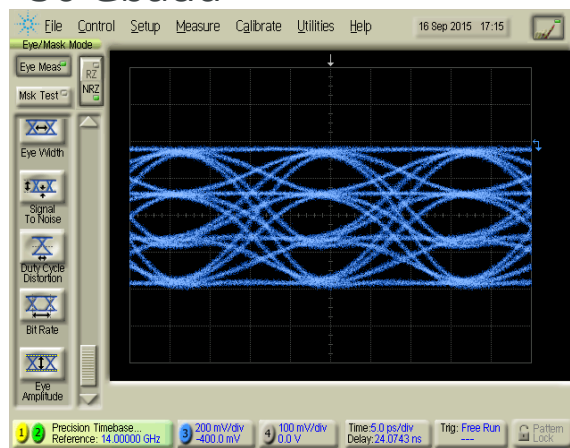
➤ G0374A/G0361A Typical Waveforms (Measured with 41V-6 Attenuator + 34V50 Adapter + 70-GHz band oscilloscope)
 Implements high-accuracy and high-reproducibility measurements using fast Tr/Tf waveforms with low Intrinsic Jitter

- **PAM4**

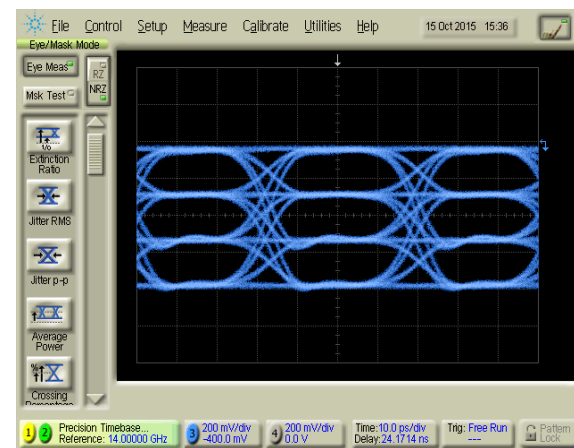
64 Gbaud



56 Gbaud

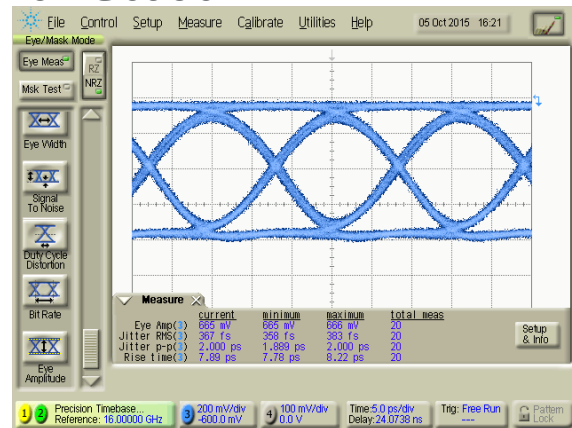


28 Gbaud

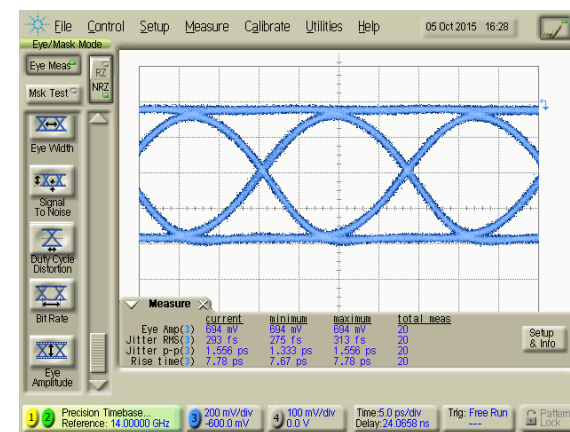


- **NRZ**

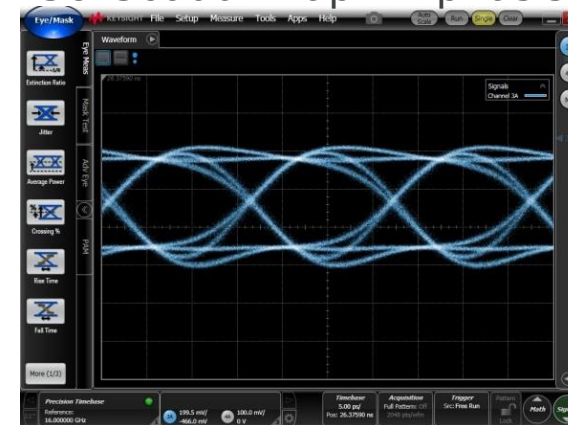
64 Gbaud



56 Gbaud



56 Gbaud 2Tap Emphasis



PAM4 BER Measurements using MP1800 Series (1)

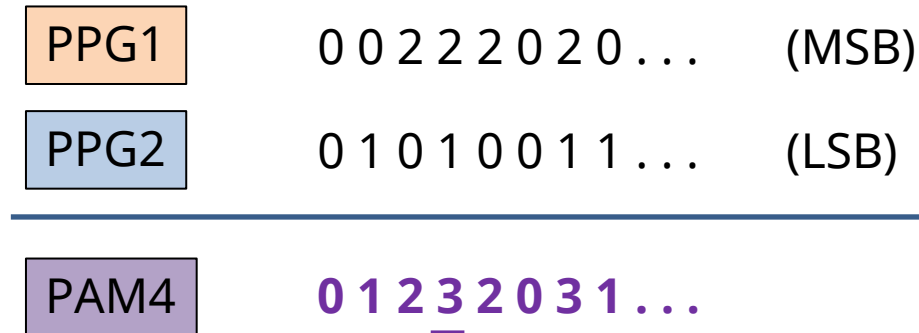
- High-input sensitivity BER detection (Eye Height 10 mV @ 28.1 Gbaud, 25 mV @ 56.2 Gbaud) support efficient verifications
- Supports 56 Gbaud BER measurements*

	32 Gbaud BER Measurements MU183040B or MU183041B 28 G/32 Gbit/s High Sensitivity ED	64 Gbaud BER Measurements MP1862A 56 G/64 Gbit/s DEMUX + MU183040B 28 G/32 Gbit/s High Sensitivity ED
Baud Rate	2.4 to 32.1 Gbaud (4.8 to 64.2 Gbit/s)	4.8 to 56* Gbaud (9.6 to 112 Gbit/s)
Data Input	Differential Input Input Amplitude 1.0 Vp-p maximum	
Input Sensitivity	MU18304xB Data Input 10 mV (typ.) Eye Height @ 28.1 Gbaud	MP1862A Data Input 25 mV (typ.) Eye Height @ 56.2 Gbaud
Measurement Method	3Eye sequential measurement using 1ch ED, or simultaneous measurement using 3ch ED	3Eye manual measurement using 1ch ED

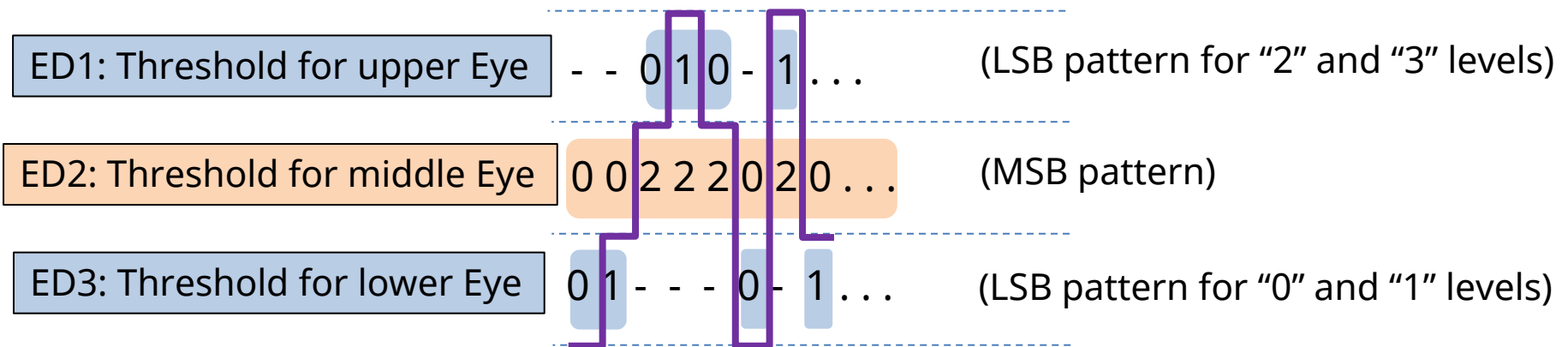
*PRBS15 patterns to 56 Gbaud (typ.) and error free with G0374A/G0361A-MP1862A

PAM4 BER Measurements using MP1800 Series (2)

- BER measurement setup using MP1800A series
 - PAM4 signal generation by combining 2ch NRZ signals



- PAM4 BER Measurement
 - Each of Upper, Middle, Lower Eye openings recognized as H or L by observing two NRZ signal levels

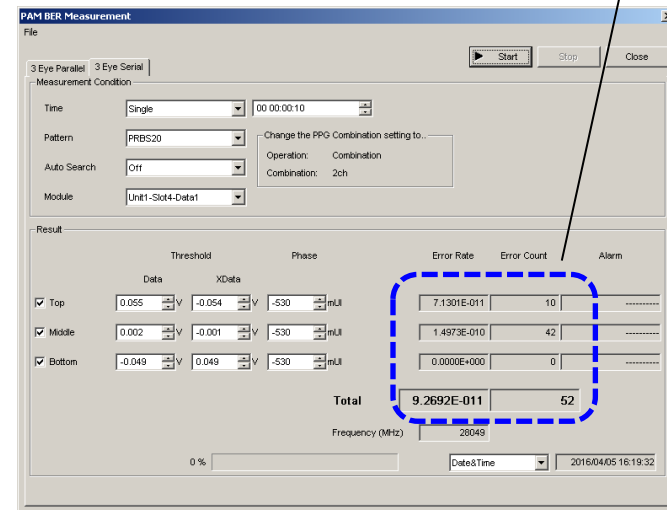
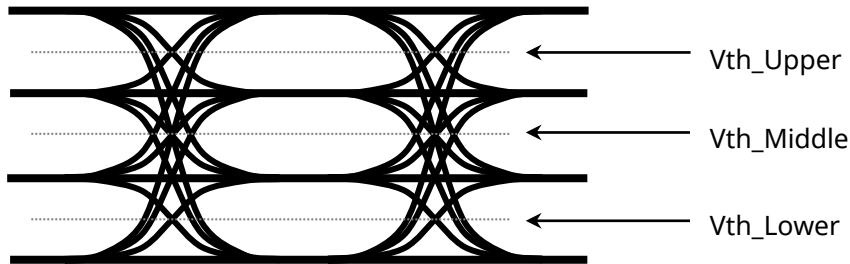
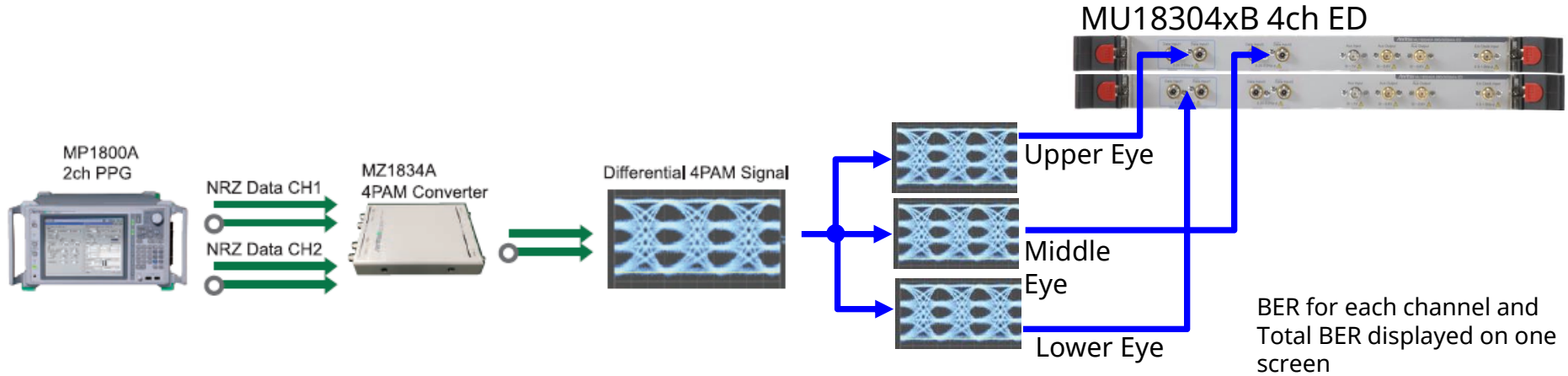


↑ED1, 2, 3 measure simultaneously using 3ch ED or sequentially using 1ch ED

The 3Eye Rx pattern is set based on the PPG1 (MSB), and PPG2 (LSB) patterns. LSB "2" and "3" levels measured by ED1 and "0", and "1" levels measured by ED3.

PAM4 BER Measurements using MP1800 Series (3)

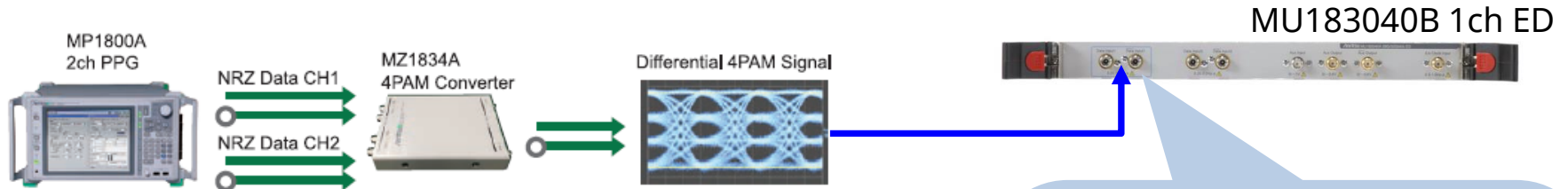
- PAM4 BER Measurement using 32 Gbaud 3ch ED:
 - The BER of the PAM4 3Eye (Upper/Middle/Lower) pattern is measured accurately in real-time using the 3ch ED and redundant bit Mask function, and the total BER result is calculated.



PAM4 BER Measurements using MP1800 Series (4)

➤ BER Measurement using 32 Gbaud 1ch ED:

- BER measurement is performed continuously by auto-searching using a 1ch ED and the PAM4 3Eye (Upper/Middle/Lower) sampling method. **This is a low-cost PAM BER measurement method for calculating the total BER.**
- Measurement leverages **32G ED high-input sensitivity performance (10 mV typ. Eye Height).**
- **PAM4 BER is measured using the Clock Recovery function.**



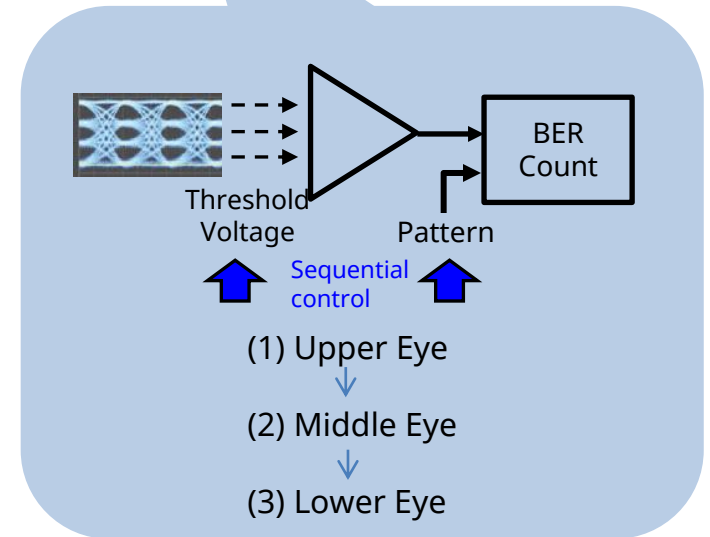
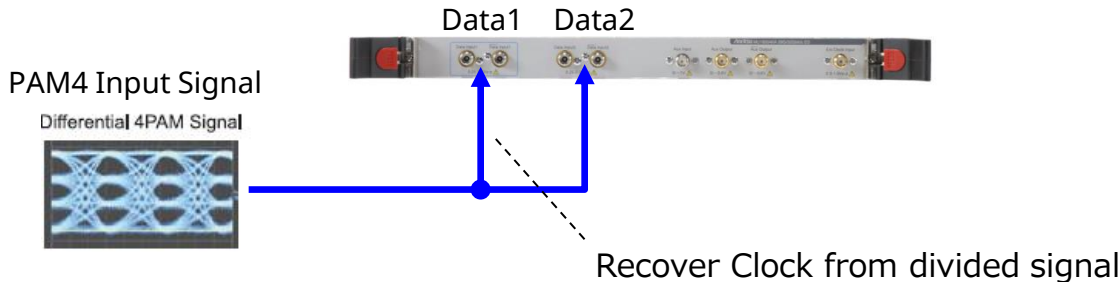
Example of Measurement using Clock Recovery Function

Recover Clock from Data1 Input signal Middle Eye pattern.

Measure BER of Data2 Input signal sequentially at three Eyes.

MU183040B 1ch ED

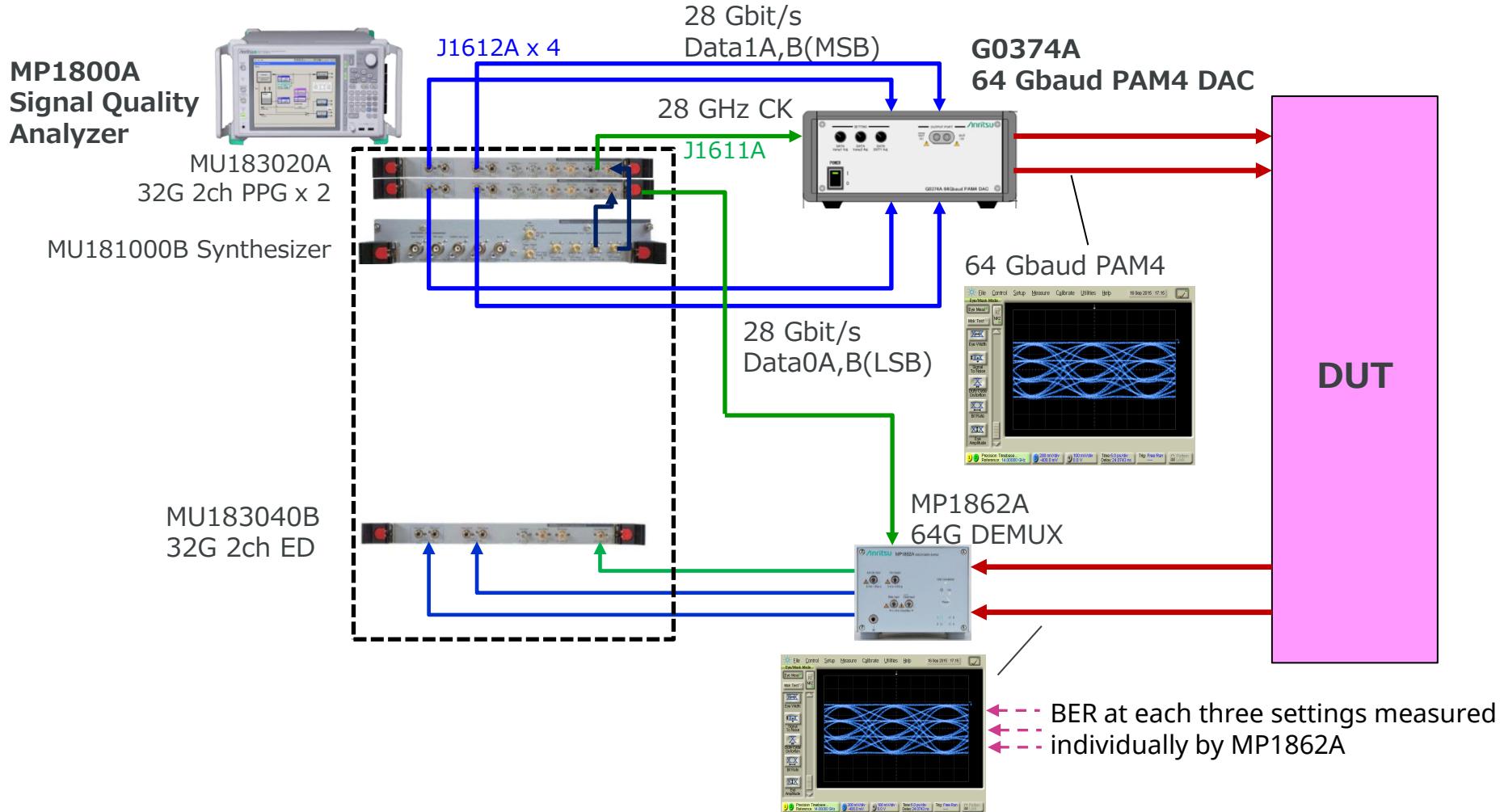
Opt-022 (2.4 to 28.1 Gbit/s Clock Recovery)



PAM4 BER Measurements using MP1800 Series (5)

➤ 56 Gbaud PAM4 BER Measurement:

- Supports high-baud-rate BER measurement
- Supports accurate and high-reproducibility measurement using 56 G/64 Gbit/s DEMUX MP1862A with high input-sensitivity performance (25 mV typ. Eye Height)



PAM4 BER Measurements using MP1800 Series (6)

➤ Supported Test Patterns

Supported Test Patterns
PRBS
PRBS13Q, PRQS10
Gray PRBS13Q
SSPR
JP03A, JP03B
Square
Transmitter Linearity Test Pattern

➤ Details

PRBS 7, 9, 10, 11, 15, 20, 23*,31* (*Only PPG support)

PRBS13Q, PRQS10: Quaternary Sequence Patterns

These patterns are defined as PAM4 test patterns because they are easily generated from PRBS generation circuits and PAM4 has about the same randomness as PRBS

Gray PRBS13Q:

This pattern is for evaluating the Transmitter Output and Receiver Input amplitude, Eye Height, Eye Width, VEC (Vertical Eye Closure) defined by CEI-56G-VSR-PAM4 using an oscilloscope. The pattern length (8191 bits) can be captured by an oscilloscope and high-order randomness can be selected.

Although PAM4 signals have four levels implemented as 2-bit pairs, sometimes a 2-bit change such as 01 to 10 is wrongly detected for a 1 level change. To prevent this, the Tx side uses a Gray code (00→00, 01→01, 10→11, 11→10) and the Rx side uses the opposite Gray decode.

PAM4 BER Measurements using MP1800 Series (7)

SSPR (Short Stress Pattern Random) :

This 32,762-bit pattern is defined by CEI 3.1. The pattern length is equivalent to PRBS15 and it is used as a PAM4 evaluation pattern due to its features as a high-stress test signal.

JP03A:

This “0303...” pattern string is used for evaluating Transmitter RJ.

JP03B:

This 62-symbol pattern has 15 repetitions of “03” followed by 16 repetitions “30”.

030

It is used for evaluating Transmitter Even-Odd Jitter.

Square:

This “3333333300000000” pattern string is for Optical Modulation Amplitude (OMA) evaluation of optical interfaces.

Transmitter Linearity Test Pattern:

This 160-symbol pattern is for evaluating transmitter linearity. It has 10 continuously repeated sequence levels of “0, 1, 2, 3, 0, 3, 0, 3, 2, 1”. Each level moves to the next level after an interval of 16UI.

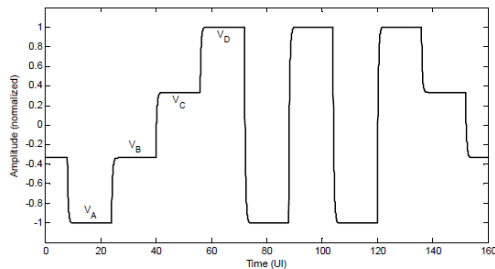
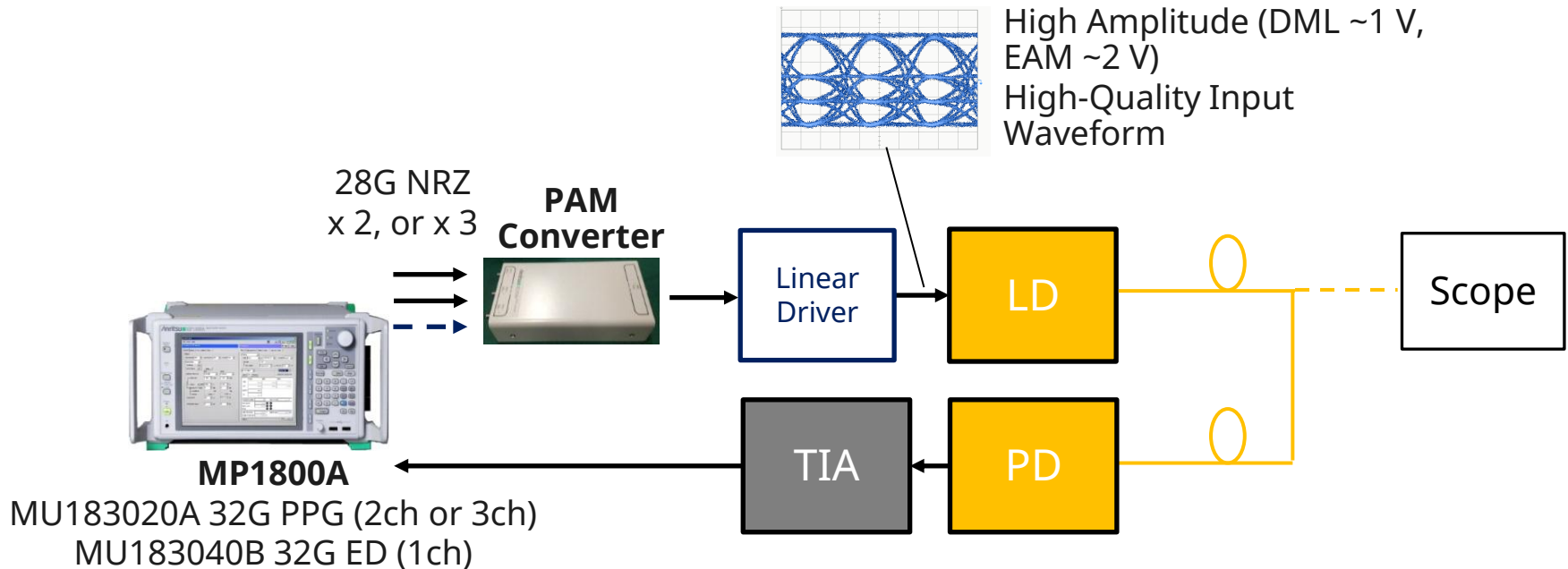


Figure 94-18—Transmitter linearity test pattern

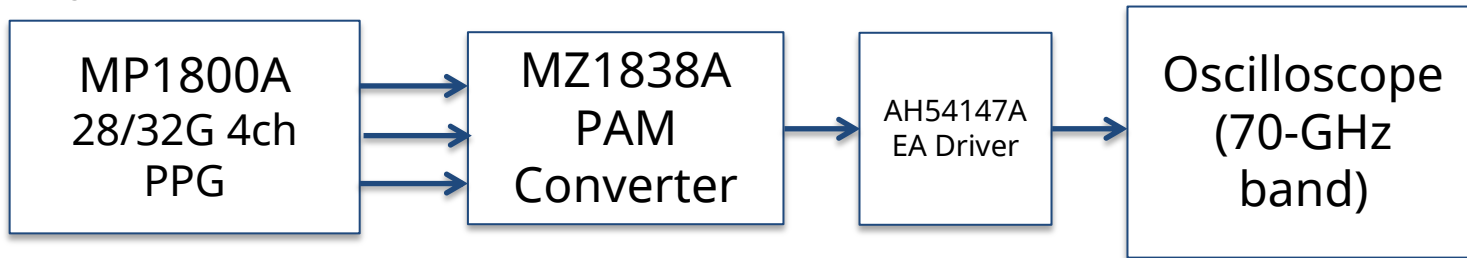
Main Applications (1)

- Evaluation of 28 Gbaud TOSA/ROSA in 400GbE Transceiver
 - MU183020A 32G PPG High-quality waveforms
 - Any PAM4 waveform level using multichannel 3Eye independent level control
 - PAM4 BER margin measurement using high-input sensitivity 32G ED



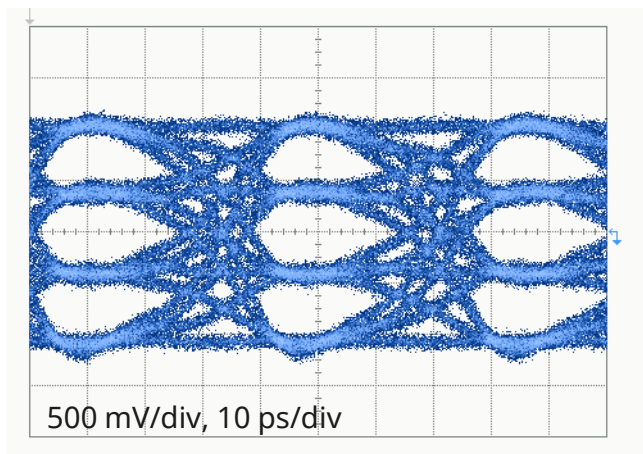
Typical LD Evaluation Waveforms

Output >2 Vp-p amplitude PAM4 signal by adding driver amplifier to drive LD directly

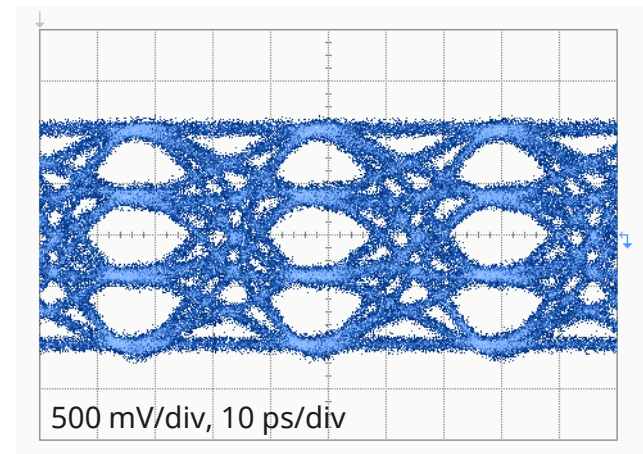


2 V Output Amplitude, QPRBS13 Pattern

26.5625 Gbaud

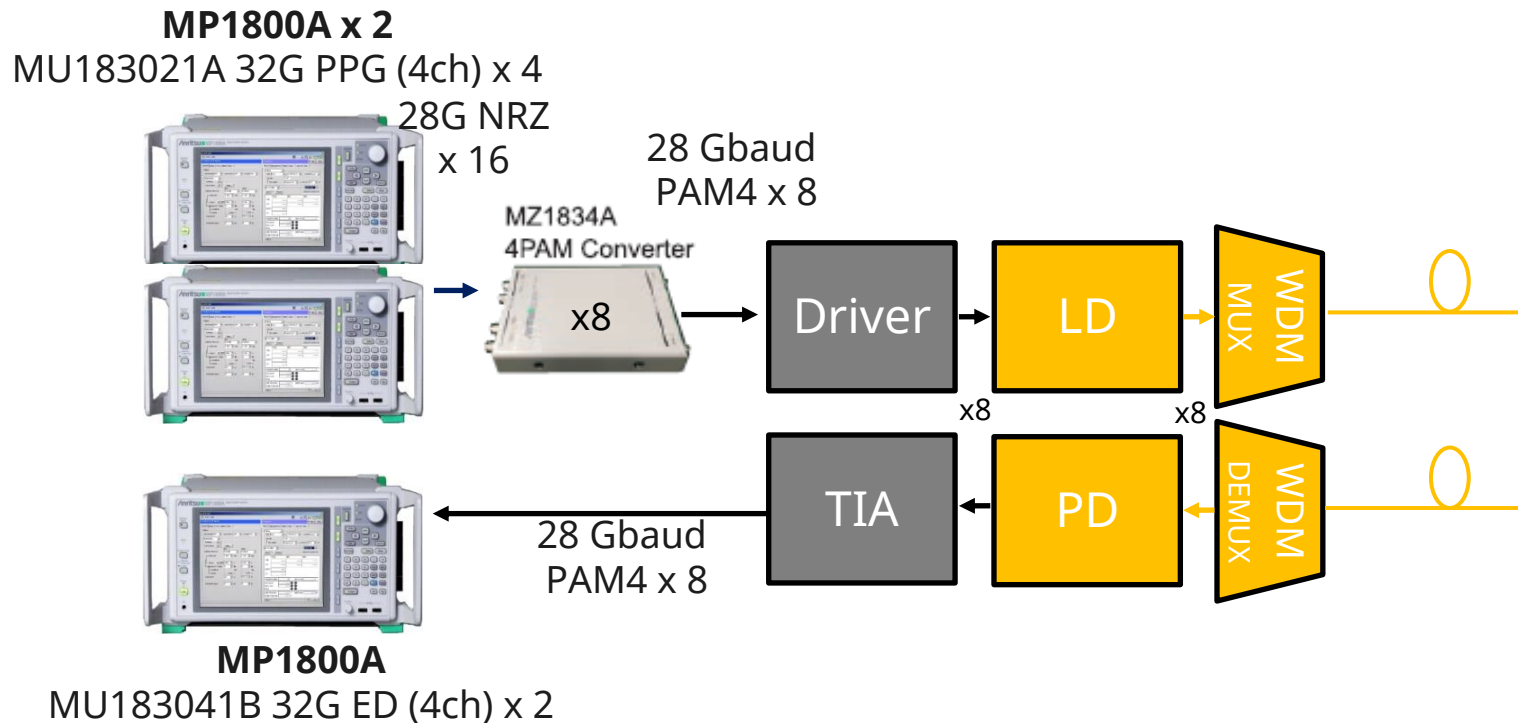


32.1 Gbaud



Main Applications (2)

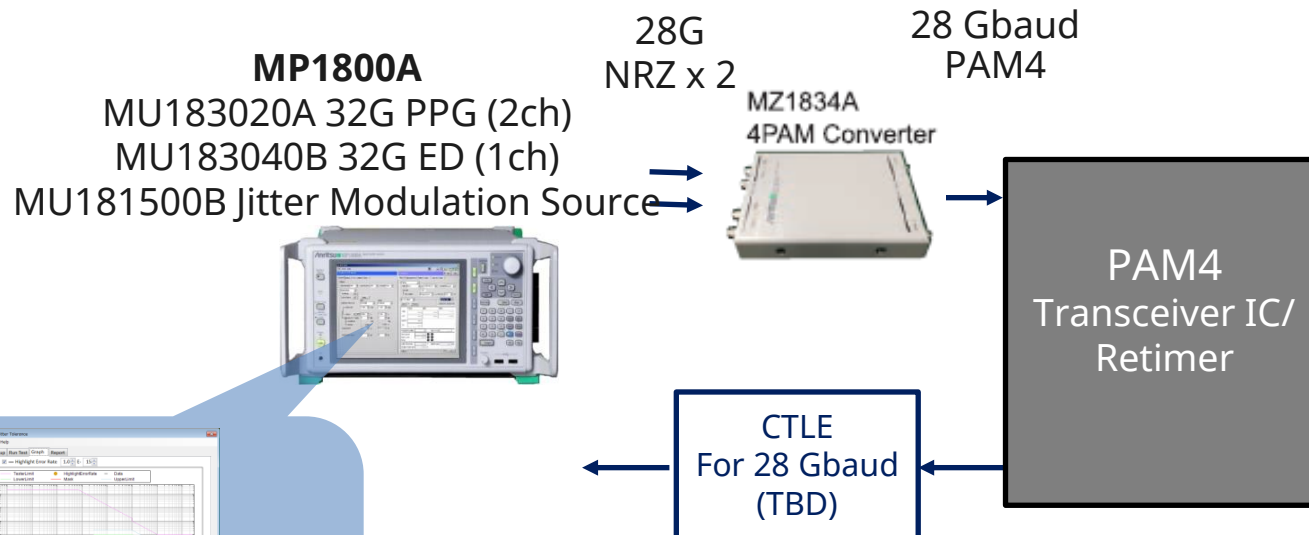
- Evaluation of 400 GAUI-8 in 400GbE Transceiver
 - 8ch PAM4 multichannel and expansion
 - Support crosstalk validation



Main Applications (3)

- Measurement of 400GbE PAM4 Transceiver IC, Retimer, 400GAUI-8 Interface
 - 32G PPG High-quality waveforms
 - Jitter Addition RJ/BUJ/SJ
 - PAM4 Jitter Tolerance measurement

Automated Jitter Tolerance measurement using MX183000A High-Speed Serial Receiver Test software



Automated Jitter tolerance measurement using MX183000A-PL001 Jitter Tolerance Test

