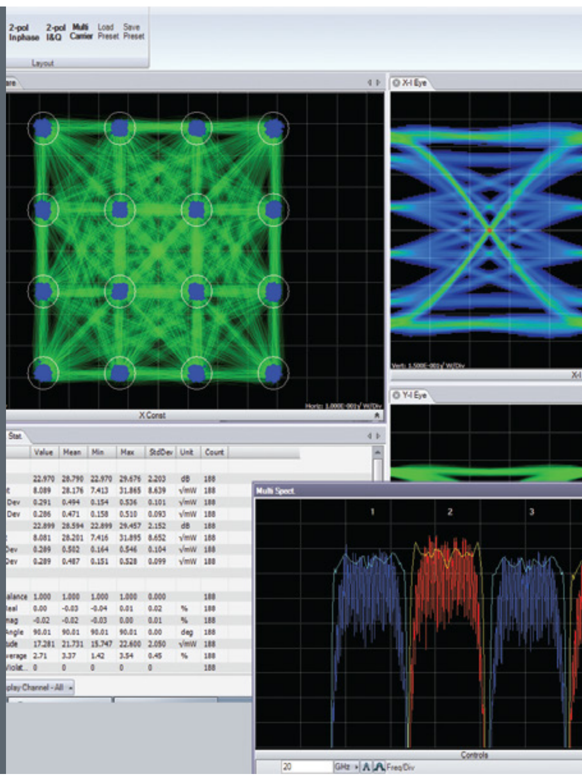
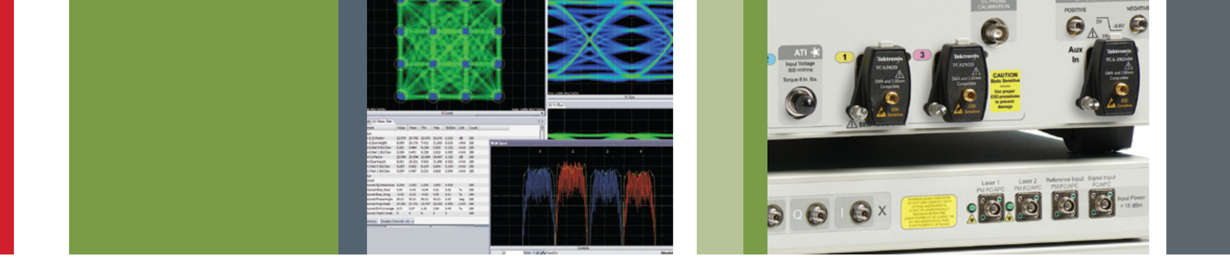
Coherent Optical Measurements

Common Transmitter and Receiver Impairments



Reference Poster

Tektronix®



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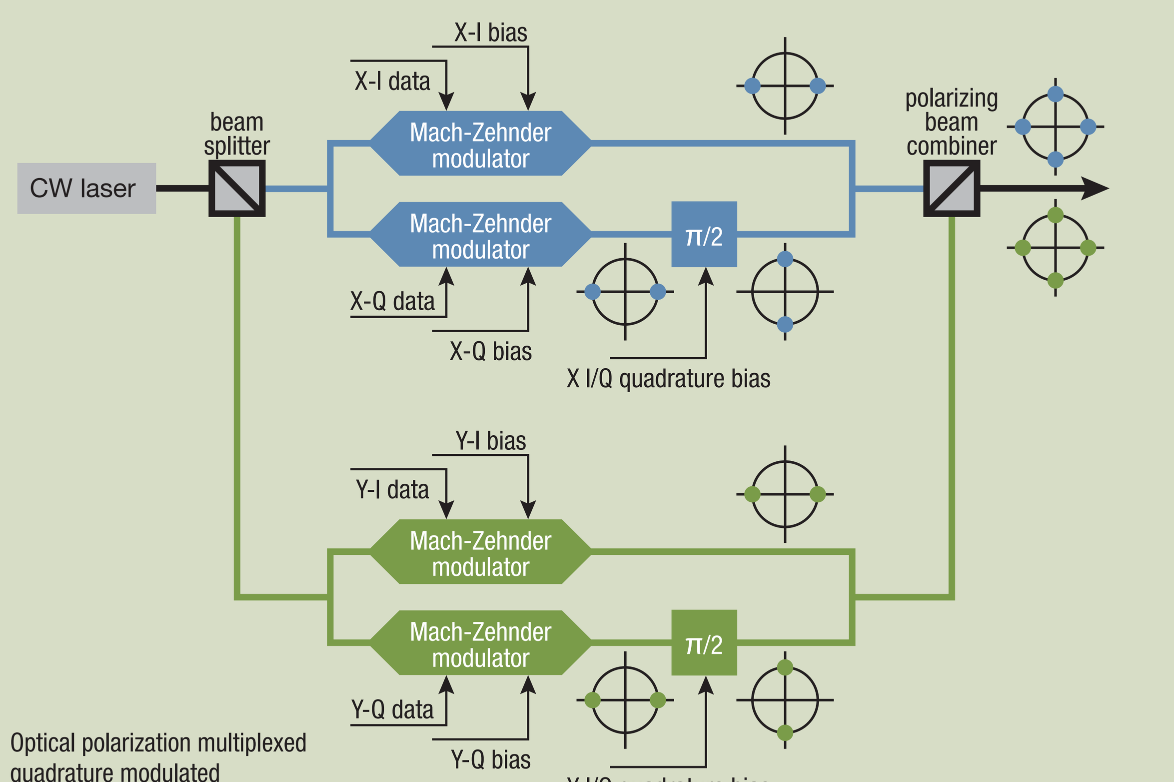
Common Modulation Formats

Format	Polarization	28 GBaud	32 GBaud	40 GBaud	46 GBaud	56 GBaud	64 GBaud
NRZ/PAM2 1 bit per Baud (symbol)	Single Polarization	28 Gb/s	32 Gb/s	40 Gb/s	46 Gb/s	56 Gb/s	64 Gb/s
BPSK 1 bit per Baud (symbol) per polarization	Single Polarization	28 Gb/s	32 Gb/s	40 Gb/s	46 Gb/s	56 Gb/s	64 Gb/s
	Dual Polarization	56 Gb/s	64 Gb/s	80 Gb/s	92 Gb/s	112 Gb/s	128 Gb/s
PAM4 2 bits per Baud (symbol)	Single Polarization	56 Gb/s	64 Gb/s	80 Gb/s	92 Gb/s	112 Gb/s	128 Gb/s
QPSK 2 bits per Baud (symbol) per polarization	Single Polarization	56 Gb/s	64 Gb/s	80 Gb/s	92 Gb/s	112 Gb/s	128 Gb/s
	Dual Polarization	112 Gb/s	128 Gb/s	160 Gb/s	184 Gb/s	224 Gb/s	256 Gb/s
8PSK 3 bits per Baud (symbol) per polarization	Single Polarization	84 Gb/s	96 Gb/s	120 Gb/s	138 Gb/s	168 Gb/s	192 Gb/s
	Dual Polarization	168 Gb/s	192 Gb/s	240 Gb/s	276 Gb/s	336 Gb/s	384 Gb/s
8QAM 3 bits per Baud (symbol) per polarization	Single Polarization	84 Gb/s	96 Gb/s	120 Gb/s	138 Gb/s	168 Gb/s	192 Gb/s
	Dual Polarization	168 Gb/s	192 Gb/s	240 Gb/s	276 Gb/s	336 Gb/s	384 Gb/s
16QAM 4 bits per Baud (symbol) per polarization	Single Polarization	112 Gb/s	128 Gb/s	160 Gb/s	184 Gb/s	224 Gb/s	256 Gb/s
	Dual Polarization	224 Gb/s	256 Gb/s	320 Gb/s	368 Gb/s	448 Gb/s	512 Gb/s
32QAM 5 bits per Baud (symbol) per polarization	Single Polarization	140 Gb/s	160 Gb/s	200 Gb/s	230 Gb/s	280 Gb/s	320 Gb/s
	Dual Polarization	280 Gb/s	320 Gb/s	400 Gb/s	460 Gb/s	560 Gb/s	640 Gb/s
64QAM 6 bits per Baud (symbol) per polarization	Single Polarization	168 Gb/s	192 Gb/s	240 Gb/s	276 Gb/s	336 Gb/s	384 Gb/s
	Dual Polarization	336 Gb/s	384 Gb/s	480 Gb/s	552 Gb/s	672 Gb/s	768 Gb/s

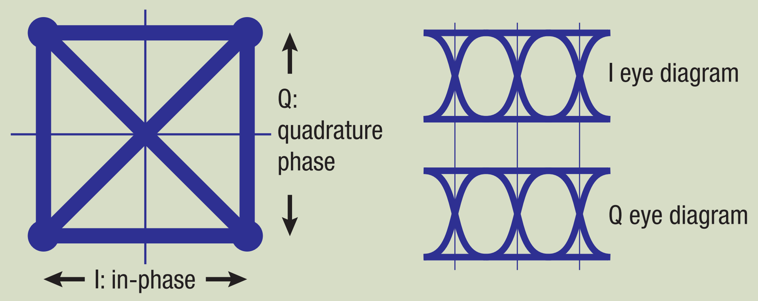
OIF Reference Transmitter



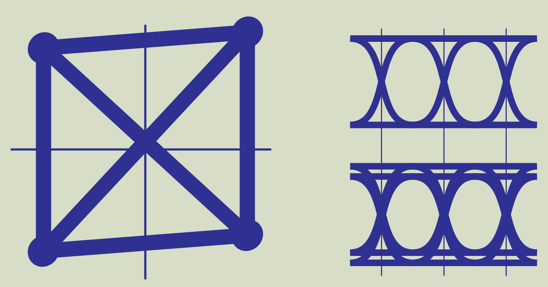
Optical polarization multiplexed quadrature modulated transmitter as outlined by the Optical Internetworking Forum.

Constellation/Eye Measurements and Common Transmitter Impairments

Ideal Constellation



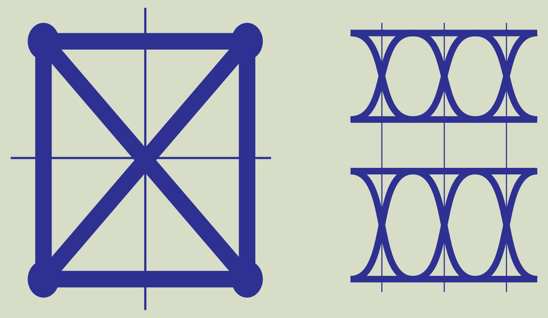
measurement: Phase Angle



Phase Angle: The phase angle between the two tributaries, measured in degrees. 90° is ideal.

possible transmitter impairment:
I/Q Quadrature Error
The modulator I/Q quadrature bias is not optimal.

measurement: Elongation



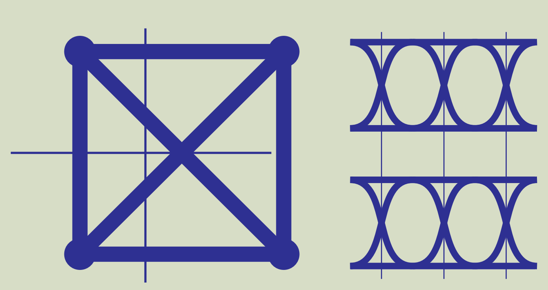
Elongation: The mean inter-symbol spacing of the quadrature (Q) signals divided by the mean inter-symbol spacing of the in-phase (I) signals. "Tall" constellations have Elongation > 1.

possible transmitter impairment:
I/Q Gain Imbalance

"Tall" constellations due to Q gain greater than I gain.

"Wide" constellations due to I gain greater than Q gain.

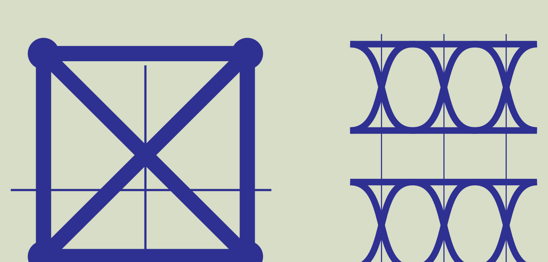
measurement: Real Bias



Real Bias: The real part of the mean value of all symbols divided by the magnitude; expressed as a percent. A positive value means the constellation is shifted right.

possible transmitter impairment:
Real Bias Error
The modulator real, or I, bias point is not optimally set.

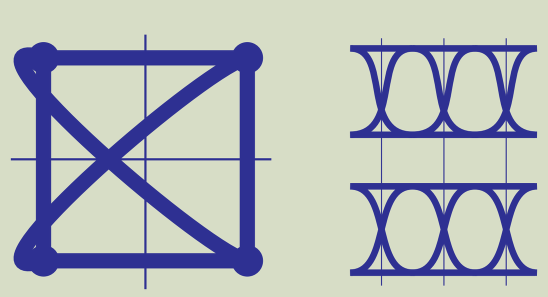
measurement: Imaginary Bias



Imaginary Bias: The imaginary part of the mean value of all symbols divided by the magnitude; expressed as a percent. A positive value means the constellation is shifted up.

possible transmitter impairment:
Imaginary Bias Error
The modulator imaginary, or Q, bias point is not optimally set.

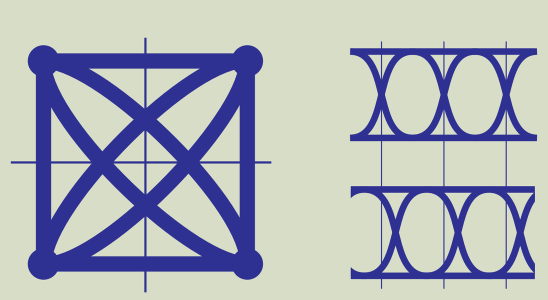
measurement: Crossing Point



Crossing Point: The crossing point of average transitions is not centered vertically within the eye.

possible transmitter impairment:
Duty Cycle Distortion
The driver amplifier may be assymetrically limiting the signal. This could be caused by improper modulator bias of either I or Q, most likely the one showing the distortion, or assymetric modulator driver amplifier limiting due to amplifier bias error.

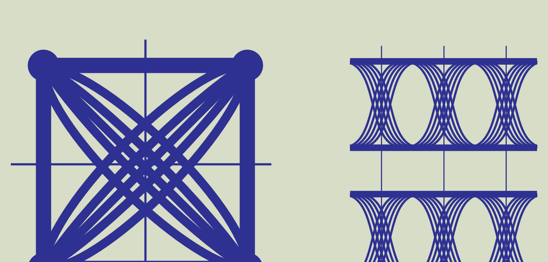
measurement: I/Q Data Skew



I/Q Data Skew: The timing difference between the I or Q data and the power average eye.

possible transmitter impairment:
I or Q Data Delay
I or Q data is being delayed relative to the other. Most often this is due to electrical delays prior to the signal input to the modulator.

measurement: Data Jitter



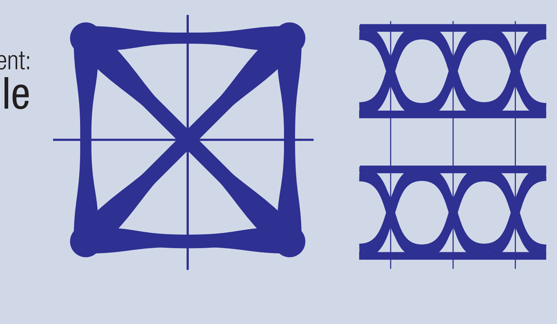
I/Q Data Jitter: The measure of rapid amounts of I/Q data skew.

possible impairment:
Data Jitter
Either I or Q, or both, have noticeable amounts of jitter. (In the eye diagram shown, the jitter is not correlated between I and Q.) Jitter can be decomposed into many different types all of which occur in the electrical domain before the inputs to the modulator.

Constellation/Eye Measurements and Common Receiver Impairments

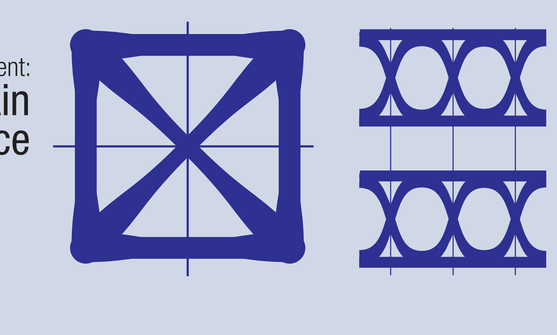
Impairments in transmitters may be simple to diagnose due to the obvious relationships between transmitter gain and bias settings and their result on the constellation and eye diagrams. Impairments in receivers can be more difficult to diagnose in part due to the fact that polarization and phase of the incoming signal is very rarely aligned with the absolute polarization and phase of the receiver hardware. The result of this is that receiver impairments, IQ Phase Angle Error for instance, do not cause the constellation to be tilted as it would for transmitter phase angle error. Rather the affects of the impairments will likely be spread across all polarizations and phases of the recovered signal.

measurement: Phase Angle



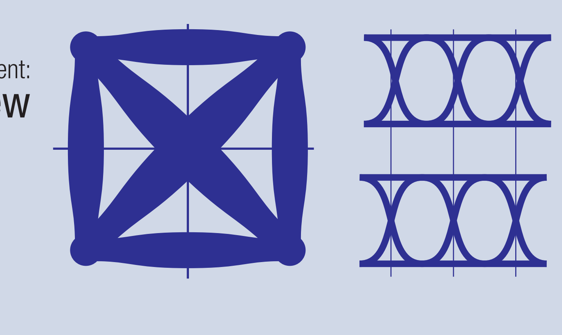
possible receiver impairment:
IQ Phase Angle Error
Optical phase angle error within the receiver does not appear as a tilted constellation as with transmitter phase error. Instead, it appears as a dispersion of transitions as they approach their maximum value.

measurement: IQ Gain Imbalance



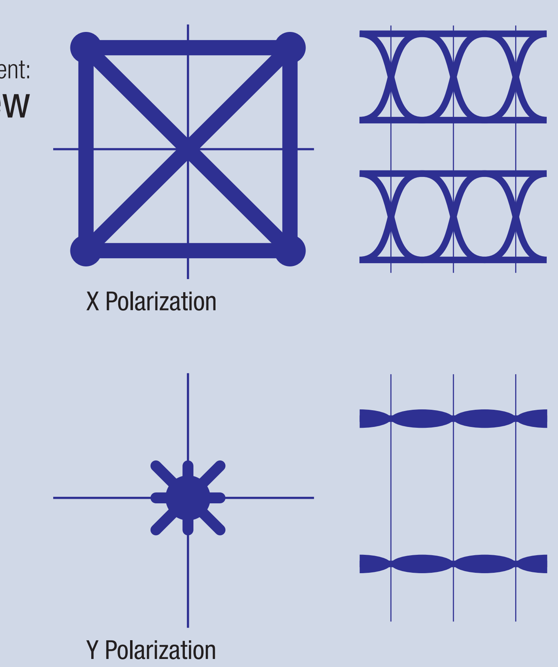
possible receiver impairment:
IQ Gain Error
IQ gain error in the receiver looks very similar to phase angle error. One noticable difference may be that the rails appear thicker than with IQ phase angle errors.

measurement: IQ Skew



possible receiver impairment:
IQ Skew Error
If I and Q are being skewed inside the receiver, one eye diagram may be visibly shifted with respect to the other. The constellation traces will become slightly thinner as they approach the constellation points.

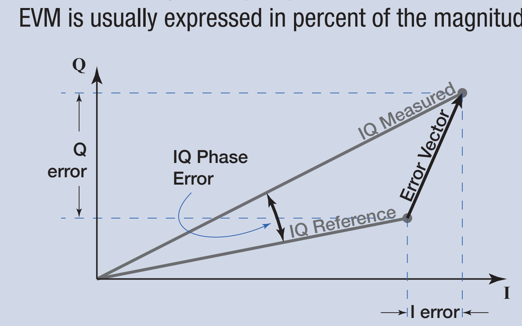
measurement: XY Skew



possible receiver impairment:
XY Skew Error
On a single-polarization signal, the unused polarization should appear with minimal signal. If the receiver is adding skew between the X and Y polarizations, there will be crosstalk appearing from one polarization to the other. Normally the constellation for the unused polarization should be a minimal point and the eye diagram a minimal line. As the skew and resulting crosstalk increases, increasing data structure can be seen on the unused polarization.

EVM Measurement

Error Vector Magnitude (EVM) provides a metric for quantifying the quality of a complex modulated signal. The rms EVM is usually expressed in percent of the magnitude of the longest reference vector.



$$\mathrm{EVM}_{\mathrm{rms}} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} \mathrm{EVM}(n)^2}$$

EVM measurement specification per IEC/TR 61282-10, Version 1.0.

ITU 100GHz Grid

ch*	wavelength nm	frequency THz	ch*	wavelength nm	frequency THz
1	1577.03	190.1	38	1546.92	193.8
2	1576.20	190.2	39	1546.12	193.9
3	1575.37	190.3	40	1545.32	194.0
4	1574.54	190.4	41	1544.53	194.1
5	1573.71	190.5	42	1543.73	194.2
6	1572.89	190.6	43	1542.94	194.3
7	1572.06	190.7	44	1542.14	194.4
8	1571.24	190.8	45	1541.35	194.5
9	1570.42	190.9	46	1540.56	194.6
10	1569.59	191.0	47	1539.77	194.7
11	1568.77	191.1	48	1538.98	194.8
12	1567.95	191.2	49	1538.19	194.9
13	1567.13	191.3	50	1537.40	195.0
14	1566.31	191.4	51	1536.61	195.1
15	1565.50	191.5	52	1535.82	195.2
16	1564.68	191.6	53	1535.04	195.3
17	1563.86	191.7	54	1534.25	195.4
18	1563.05	191.8	55	1533.47	195.5
19	1562.23	191.9	56	1532.68	195.6
20	1561.42	192.0	57	1531.90	195.7
21	1560.61	192.1	58	1531.12	195.8
22	1559.79	192.2	59	1530.33	195.9
23	1558.98	192.3	60	1529.55	196.0
24	1558.17	192.4	61	1528.77	196.1
25	1557.36	192.5	62	1527.99	196.2
26	1556.55	192.6	63	1527.22	196.3
27	1555.75	192.7	64	1526.44	196.4
28	1554.94	192.8	65	1525.66	196.5
29	1554.13	192.9	66	1524.89	196.6
30	1553.33	193.0	67	1524.11	196.7
31	1552.52	193.1	68	1523.34	196.8
32	1551.72	193.2	69	1522.56	196.9
33	1550.92	193.3	70	1521.79	197.0
34	1550.12	193.4	71	1521.02	197.1
35	1549.32	193.5	72	1520.25	197.2
36	1548.51	193.6	73	1519.48	197.3
37	1547.72	193.7			

Frequencies per ITU G.694.1 Feb 2012

*Channel numbers are not defined by ITU G.694.1 and are shown for convenience purposes only.

The wavelengths given in this table are approximations only. ITU G.694.1 defines channels with respect to the nominal central frequencies and not the approximate wavelengths.

Power Conversion

Power dBm	Power mW	Power dBm	Power mW
-40 dBm	0.0001 mW	6 dBm	3.9811 mW
-30 dBm	0.0010 mW	7 dBm	5.0119 mW
-20 dBm	0.0100 mW	8 dBm	6.3096 mW
-10 dBm	0.1000 mW	9 dBm	7.9433 mW
0 dBm	1.0000 mW	10 dBm	10.0000 mW
1 dBm	1.2589 mW	20 dBm	100.0000 mW
2 dBm	1.5849 mW	30 dBm	1000.0000 mW
3 dBm	1.9953 mW	40 dBm	10000.0000 mW
4 dBm	2.5119 mW	50 dBm	100000.0000 mW
5 dBm	3.1628 mW		

PRBS Standards

Sequence	Polynomial	Reference Standard	Number of Bits
PRBS-7	$x^7 + x^6 + 1$	Not standard	127
PRBS-9	$x^9 + x^5 + 1$	ITU-T 0.150	511
PRBS-11	$x^{11} + x^9 + 1$	ITU-T 0.150	2,047
PRBS-15	$x^{15} + x^{14} + 1$	ITU-T 0.150	32,767
PRBS-17	$x^{17} + x^{14} + 1$	OIF-CEI-P-02.0	131,071
PRBS-20	$x^{20} + x^3 + 1$	ITU-T 0.150	1,048,575
PRBS-23	$x^{23} + x^{18} + 1$	ITU-T 0.150	8,388,607
PRBS-29	$x^{29} + x^{27} + 1$	ITU-T 0.150	536,870,911
PRBS-31	$x^{31} + x^{28} + 1$	ITU-T 0.150/ OIF-CEI-02.0	2,147,483,647

As network demands increase, long-haul communications are becoming more complex. Advanced test tools are required to test the latest communication systems for 100G, 400G, 1Tb/s, and beyond. Tektronix is the only test and measurement vendor that can offer a complete coherent optical test system from signal generation, to modulation, acquisition, and analysis.

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