

Go to Market with 400G

Intra Data Center | Metro | Long Haul



Electrical & Direct Detection Optical Standards

Standard / Implementation Agreement (IA)	Multiple-Source Agreements (MSA)			IEEE (Institute of Electrical and Electronics Engineers) 802.3								OIF-CEI 4.0 (Optical Internetworking Forum - Common Electrical I/O)						Fiber Channel (FC) PI-7, PI-7P		InfiniBand		
	400G-BD4.2	100G-FR100G-LR	400G-FR4	50GBASE-SR/100GBASE-SR2/200GBASE-SR4	200GBASE-DR4	100GBASE-DR/400GBASE-DR4	50GBASE-FR1/LR/200GBASE-FR4/LR4/400GBASE-FR8/LR8	50GAUI-1 C2M / 100GAUI-2 C2C / 200GAUI-4 C2M / 400GAUI-8 C2C	50GAUI-1 C2C / 100GAUI-2 C2C / 200GAUI-4 C2C / 400GAUI-8 C2C	50G-KR / 100G-KR2 / 200G-KR4	50G-CR / 100G-CR2 / 200G-CR4	CEI-56G-XSR-NRZ	CEI-56G-XSR-PAM4	CEI-56G-VSR-NRZ	CEI-56G-VSR-PAM4	CEI-56G-MR-PAM4	CEI-56G-LR-PAM4	CEI-56G-LR-eNRZ	64GFC / 256GFC	600G HDR		
Clause / Section				138	121	140 / 124	139 / 122	Annex 135G / Annex 132E	Annex 135F / Annex 132D	137	136	19	20	15	16	17	21	22	5	6		
Application	Fiber optic data link	Fiber optic data link	Fiber optic data link	Fiber optic data link	Fiber optic data link	Fiber optic data link	Fiber optic data link	Chip to pluggable optical module	Chip to chip on same circuit board	Backplanes with daughter cards	Passive copper cable	Chip to adjacent chip	Chip to adjacent chip	Chip to pluggable optical module	Chip to pluggable optical module	Chip to chip on large circuit board	Backplanes / passive copper cable	Backplanes / passive copper cable	Fiber optic data link	Chip to pluggable optical module	Top-of-rack (TOR) switch to blade server	
Link media	Multimode fiber	Single-mode fiber	Single-mode fiber	Multimode fiber	Single-mode fiber	Single-mode fiber	Single-mode fiber	Circuit board trace + 1 connector	Circuit board trace	Circuit board trace + 3 connectors	Twisted copper cable + 2 connectors	Circuit board	Circuit board	Circuit board + 1 connector	Circuit board + 1 connector	Circuit board trace	Circuit board + 2 connectors	Circuit board + 2 connectors	Multimode fiber & single-mode fiber	Circuit board trace + 1 connector	Electrical	
Modulation format	PAM4	PAM4	PAM4	PAM4	PAM4	PAM4	PAM4	PAM4	PAM4	PAM4	PAM4	NRZ	PAM4	NRZ	PAM4	PAM4	eNRZ	PAM4	PAM4	PAM4	PAM4	
Symbol rate, per lane/wire	26.5625 Gbd	53.125 Gbd	53.125 Gbd	26.5625 Gbd	26.5625 Gbd	53.125 Gbd	26.5625 Gbd	26.5625 Gbd	26.5625 Gbd	26.5625 Gbd	26.5625 Gbd	39.8 - 58.0 Gbd	18.0 - 29.0 Gbd	39.0 - 56.0 Gbd	18.0 - 29.0 Gbd	18.0 - 29.0 Gbd	18.0 - 29.0 Gbd	33.16 - 37.5 Gbd	28.9 Gbd	28.9 Gbd	26 - 56.25 Gbd	
Maximum reach (channel loss at Nyquist frequency)	150 m	2 km / 10 km	2 km	100 m	500 m	500 m	2 km / 10 km	10.2 dB (= 100 mm)	20 dB (= 25 cm)	30 dB (= 1 m)	16.06 dB (= 3 m) (cable assembly only)	8 dB @ 29 GHz (= 50 mm)	4.2 dB @ 14.5 GHz (= 50 mm)	13 dB @ 29 GHz (Type A) 20 dB @ 29 GHz (Type B) (= 150 mm)	10.0 dB @ 14.5 GHz (= 500 mm)	20 dB @ 14.5 GHz (= 500 mm)	30 dB @ 14.5 GHz (= 1000 mm)	33.6 dB @ 18.75 GHz	100 m (MMF) 10 km (SMF)	~ 150 mm	2 m	
Number of parallel lanes	8 bi-directional	1	1	1/2/4	4	1/4	1	1/2/4/8	1/2/4/8	1/2/4	1/2/4	1 - n	1 - n	1 - n	1 - n	1 - n	1 - n	1 - n (each lane has 4 wires)	1/4	1/4	8	
Number of wavelengths	2	1	4	1	1	1	1/4/8												1	1		
Forward error correction (FEC) overhead	RS(544,514)	RS(544,514)	RS(544,514)	RS(544,514)	RS(544,514)	RS(544,514)	RS(544,514)	RS(544,514)	RS(544,514)	RS(544,514)	RS(544,514)	Not used	Not used	Not used	Assumed	Assumed	Assumed	Not used	Required	Required	Required	
Pre-FEC bit error ratio (BER)	2.4 E-4	2.4 E-4	2.4 E-4	2.4 E-4	2.4 E-4	2.4 E-4	2.4 E-4	1 E-5	1 E-4	2.4 E-6	2.4 E-4	1 E-15	1 E-15	1 E-15	1 E-6	1 E-6	1 E-6	1 E-15	1.09 E-4	1.09 E-5	1 E-4	
Frame loss ratio (FLR) for 64 octet frames	1.7 E-12 (link only) 6.2 E-11 (with AUJ)	9.2 E-13 (link only) 6.2 E-11 (with AUJ)	1.7 E-12 (link only) 6.2 E-11 (with AUJ)	50GBASE-SR/100GBASE-SR2: 9.2 E-13 (link only) 6.2 E-10 (with AUJ) 200GBASE-SR4: 1.7 E-12 (link only) 6.2 E-11 (with AUJ)	1.7 E-12 (link only) 6.2 E-11 (with AUJ)	100GBASE-DR: 9.2 E-13 (link only) 6.2 E-10 (with AUJ) 400GBASE-DR4: 1.7 E-12 (link only) 6.2 E-11 (with AUJ)	50GBASE-FR1-LR: 9.2 E-13 (link only) 6.2 E-10 (with AUJ) 200GBASE-FR4-LR4/400GBASE-FR8-LR8: 1.7 E-12 (link only) 6.2 E-11 (with AUJ)			50G-KR/100G-KR2: 1 E-10 (link only) 6.2 E-10 (with AUJ) 200G-KR4: 2.000 E-10 50G-CR/100G-CR2: 1 E-10 (link only) 6.2 E-10 (with AUJ) 200G-CR4: 2.000 E-10												
Novel test requirements	<ul style="list-style-type: none"> Transmitter and dispersion eye closure for PAM4 (TDECQ) Outer modulation amplitude Outer extinction ratio Relative intensity noise (RIN/OMA) TDECQ equalizer noise enhancement factor (Ceq) 					<ul style="list-style-type: none"> Eye width (EW) Eye height (EH) Eye symmetry mask width (ESMW) Transition time (specific edge) 	<ul style="list-style-type: none"> Signal-to-noise-and-distortion ratio (SNDR) Output waveform measurements (e.g., RLM, linear fit pulse peak) Output jitter (JMS, JA, even-odd jitter) Separate jitter tolerance and interference tolerance tests for Rx input testing Interference test requires broadband random noise source with high Q factor 	<ul style="list-style-type: none"> Clock jitter (JUGJ-h) Clock phase noise 	<ul style="list-style-type: none"> Eye width (EW) Eye height (EH) Eye linearity Transition time 	<ul style="list-style-type: none"> Signal-to-noise-and-distortion ratio (SNDR) Eye width (EW) Eye height (EH) Eye linearity Transition time (specific edge) 	<ul style="list-style-type: none"> Signal-to-noise-and-distortion ratio (SNDR) Output waveform measurements (e.g., RLM, linear fit pulse peak) Output jitter (JBPJ, UUGJ, even-odd jitter) 	<ul style="list-style-type: none"> Reference receiver based on 802.3 Clause 138, but not returned to higher FC data rates (uses Ethernet frequencies) 										
Challenges	Achieving the pre-FEC BER condition is not sufficient to ensure a target frame loss ratio (FLR). FLR must be measured under stress test conditions defined by the standard.					Channel operating margin (COM) is a new figure of merit defined as follows: COM represents the signal-to-noise amplitude at the receiver pins of a channel after integrating the effects of loss, near-end crosstalk, far-end crosstalk, and statistical noise. A typical COM number is 8.5 dB. It is the result of inputting multiple variables, including S-parameter measurements, into a large MATLAB program specifically written per the standard COM definition. Some test and measurement tools have integrated COM calculations to help automate this normally complex characterization technique.																

Coherent Optical Standards

Standard / IA	OIF 400ZR 0x01	OIF 400ZR 0x02	CableLabs	ITU*	Open ROADM
Net data rate	400G	400G	100G / 200G	100G	100G / 200G / 300G / 400G
Application	DCI	DCI	Cable Network	Metro	Metro
Network type	DWDM	Single-channel unamplified point-to-point	DWDM	DWDM	DWDM
Channel spacing	75 / 100 GHz	NA	100 GHz / 100 GHz or 50 GHz	50 / 100 GHz	Flexgrid
Channel frequency	193.7 - 196.1 THz	193.7 THz	191.3 - 196.2 THz	186.0 - 196.2 THz	191.35 - 196.1 THz
Modulation format	DP-16QAM	DP-16QAM	DP-DQPSK / DP-QPSK or DP-16QAM	DP-DQPSK	DP-DQPSK / DP-QPSK / DP-8QAM / DP-16QAM
Symbol rate	59.84375 Gbd	59.84375 Gbd	27.95 Gbd / 63.14 Gbd or 31.57 Gbd	25.775 Gbd - 28.185 Gbd	27.9524934 Gbd / 63.1 Gbd / 63.1 Gbd
Maximum reach	80 km	40 km	80 km	Not explicitly defined	Not explicitly defined
FEC	C-FEC	C-FEC	Staircase FEC / dFEC	Staircase FEC	Staircase FEC / dFEC
Pre-FEC BER	1.25 E-2	1.25 E-2	4.5 E-3 / 2 E-2	4.5 E-3	4.5 E-3 / 2 E-2

Some standards are still under development and subject to change.
*G.698.2

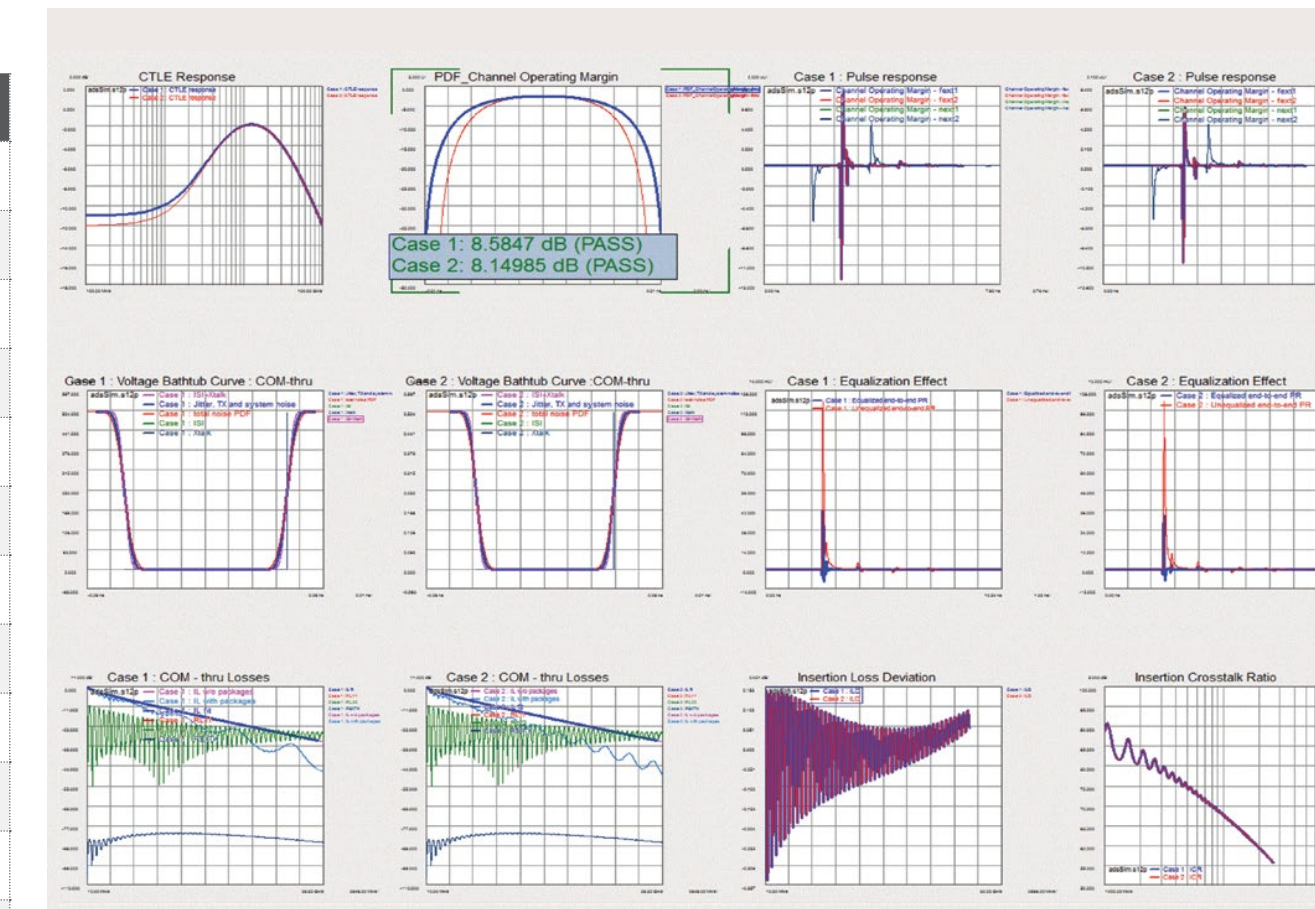
Keysight Solutions

- Infinium LXR-Series Oscilloscopes
- N1930B Physical Layer Test System (PLTS)
- D9010PAMA Pulse Amplitude Modulation PAM-N Analysis Software
- N1930B Physical Layer Test System (PLTS) 2019 Software
- N1000A DCA-X Wide Bandwidth Mainframe and Modules
- M8040A 64 Gbaud High-Performance BERT
- N1010100A R&D Software Package for the DCA-X Oscilloscopes
- N1091BSCB Electrical TX Test Software for IEEE 802.3bs/cd
- M8194A 120 Gsa/s Arbitrary Waveform Generator
- N4373E Lightwave Component Analyzer
- 81195A Optical Modulation Generator Software
- M8290440A Test Solution for Coherent Optical Transmit and Receive Devices
- N776C Tunable Laser-Based Swept-IL/PDL Test Solution
- N4391B Optical Modulation Analyzer
- 817700A Photonic Application Suite Software
- M8290A Optical Modulation Analyzer and High-speed Digitizer Test Solution
- N4391B Optical Modulation Analyzer
- M8290400A Optical Modulation Analyzer Software Package

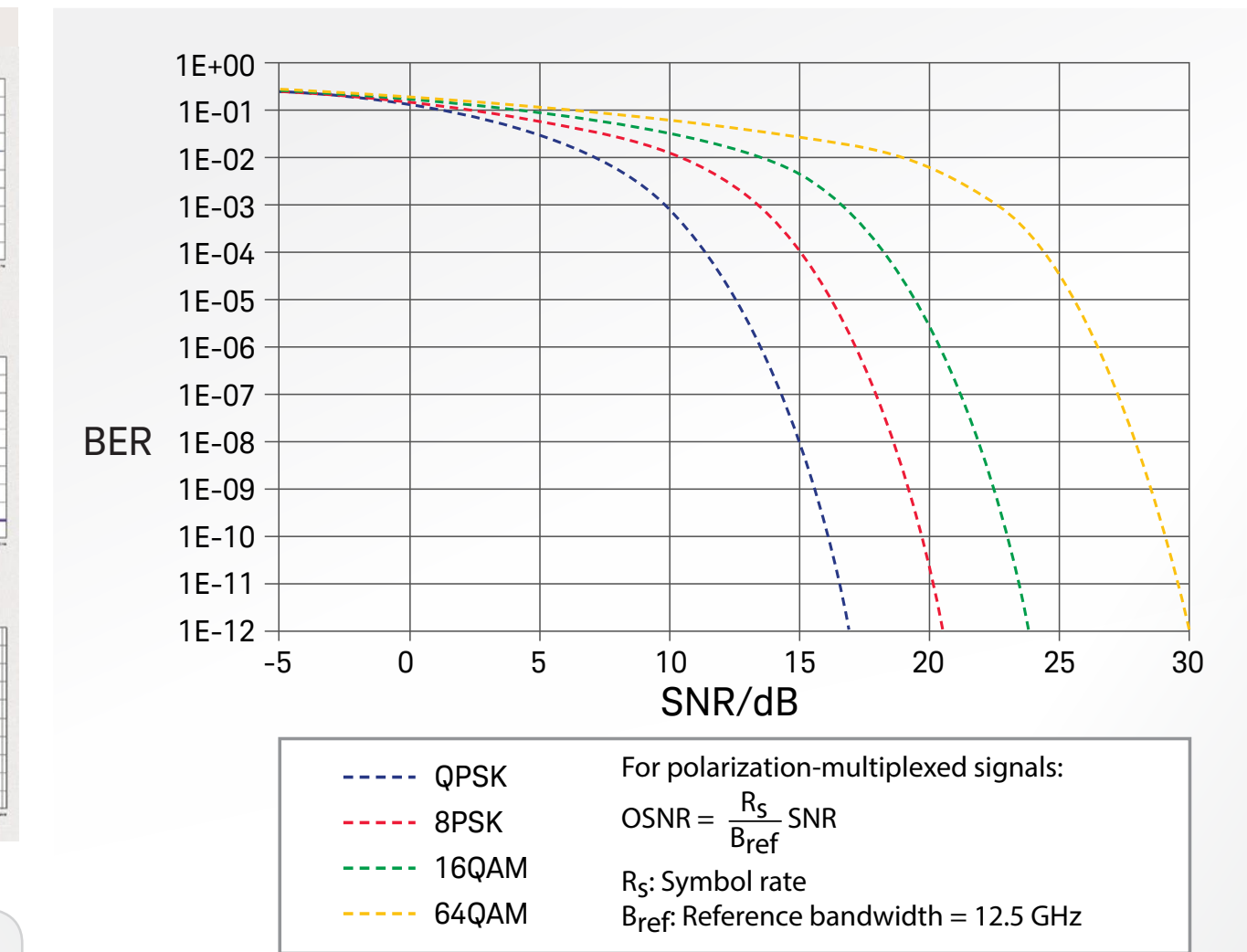
COM Parameter Definitions

Code/parameter ref	Example setting
Coding/port type	NRZ clause 93 D1.1
Unit interval (UI)	Unit interval in seconds
tx_tfe	[1,4] Transmitter equalizer max. pre and post cursor coefficient
ndfe	12 Victim single bit response exception window (in UI)
max_cde	12 Continuous time filter, max. DC gain
a_thru	0.4 Transmitter differential peak output voltage for victim
a_fext	0.4 Transmitter differential peak output voltage for far-end aggressor
a_next	0.6 Transmitter differential peak output voltage for near-end aggressor
AG	1/(L-1) 1 Related to number of levels, L (symbol gain)
specBER	SER_D 1.00E-12 Target uncorrected symbol error ratio
Allowance	COM_0 0 Minimum channel operation margin
G_s_noise	sigma_G 0.01 Normalized RMS Gaussian noise
g_dd_noise	A_DD 0.1 Normalized peak dual-Dirac noise
Na_rms	0 Voltage sensitivity RMS Gaussian noise
Samples per UI	M 32
Port order	Port order [1 3 2 4] For the 4 ports the first two listed are inputs and respective last two are outputs (RX)
G01	Gamma_01 0.01 Transmitter reflection coefficient DC value. Value < 0.01 disables
G02	Gamma_02 0.01 Receiver reflection coefficient DC value. Value < 0.01 disables
Fscale1	Fscale1 2 Transmitter reflection coefficient reference frequency scale. Value > 2 disables
Fscale2	Fscale2 2 Receiver reflection coefficient reference frequency scale. Value > 2 disables
cte_step	1 Continuous time filter step size dB
tx_tfe_step	0.02 Transmitter equalizer, pre/post cursor coefficient step size
maxc1	1 Max. value for DFE1
maxcx	1 Max. in W region
L_v	L_v 0.55 Transmitter 3 dB bandwidth for victim. Set to > 2 to deactivate
L_f	L_f 0.55 Transmitter 3 dB bandwidth for far-end aggressor. Set to > 2 to deactivate
L_n	L_n 1 Transmitter 3 dB bandwidth for near-end aggressor. Set to > 2 to deactivate
L_r	L_r 0.75 Receiver 3 dB bandwidth

Channel Operating Margin (COM)



BER from SNR



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