Interoperability for Long Reach and Extended Reach 10 Gb/s Transponders and Transceivers

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Working Group: **Physical Link Layer**

TITLE: **Interoperability for Long Reach and Extended Reach 10 Gb/s Transponders and Transceivers**

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ABSTRACT: This document provides the methodology and process for testing transponders and transceivers for long reach and very long reach applications at 10 Gb/s data rates.

The OIF is an international non profit organization with over 130 member companies, including the world's leading carriers and vendors. Being an industry group uniting representatives of the data and optical worlds, OIF's purpose is to accelerate the deployment of interoperable, cost-effective and robust optical internetworks and their associated technologies. Optical internetworks are data networks composed of routers and data switches interconnected by optical networking elements.

With the goal of promoting worldwide compatibility of optical internetworking products, the OIF actively supports and extends the work of national and international standards bodies. Formal liaisons have been established with The ATM Forum, IEEE 802.3, IETF, ITU-T Study Group 13, ITU-T Study Group 15, MEF, NPF, T1M1, T1X1, TMF, UXPi and the XFP MSA Group.

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Working Group: Physical Link Layer

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VERSION	DATE	DESCRIPTION
OIF-LRI-01.0 OIF-LRI-02.0	2/28/2005	• Initial Release • Minor text modifications to add VR application code • Added Golden Tx for reduce bandwidth signaling format • Added Golden Rx with integrated preamp • Added Golden Path for 2400 ps/nm residual dispersion • Minor text corrects from previous release

2 Introduction

The long reach (LR) and very long reach (VR) interoperability document provides a manufacturing setup and testing methodology for the suppliers of transponders and transceivers. This document will help to ensure multivendor compatibility of modules installed into network equipment that is compliant to a particular application code. This is achieved by defining a golden transmitter, a golden receiver and an optical path that is developed from the various application codes referenced in approved ITU-T recommendations and using them for module setup and testing. Vendors would then use a golden transmitter to test their receiver and use a golden receiver to test their transmitter. The tests are done for both back-to-back and over-fiber configurations. A module that meets the performance requirements against the golden transmitter and the golden receiver is then presumed to be interoperable with modules from other vendors. The golden transmitter and golden receiver defined in this document are not meant to define a vendor's module implementation.

Long reach and very long reach applications at 10 Gb/s can be implemented in several ways: modifying the characteristics of the transmitter and/or receiver, optical accommodation, electronic dispersion compensation, etc. How well modules from multiple vendors interoperate depends on the approach(es) used by a manufacturer. This document uses ITU application codes to define families of modules that will interoperate when compliant with this document.

The approach used to develop this document is incremental. The first family of modules included in the document was for long reach (80 km) TDM applications. The current version of this Implementation Agreement is adding a 120 km application realized by using transmitters that transmit NRZ data at a reduced optical bandwidth (for example, duobinary and chirp managed lasers). Additional forward looking applications are planned that include technologies that will allow 2.5 Gb/s upgrades to 10 Gb/s and next generation optical networks. In addition, future document versions will consider the standardization of long haul (LH) and ultra long haul (ULH) transmitters and receivers. Figure 2-1 summarizes some module configurations being considered for inclusion into this Implementation Agreement. Early revisions are planned to include applications that address reaches of 120 km (2400 ps/nm) and 160 km (3200 ps/nm). Later revisions are planned to address the LH and ULH applications where OSNR and FEC are primary design considerations.

- NRZ Tx, Chirped, 1600 ps/nm, High OSNR, NRZ Rx
- NRZ Tx, 0 Chirp, 1200 ps/nm, High OSNR, NRZ RX
  - Supports interoperability of the optically compensated links
- NRZ Tx, 0 Chirp, 1200 ps/nm, Low OSNR, NRZ RX
  - Supports multi-span link
- NRZ Tx, 0 Chirp, 2400 ps/nm, High OSNR, EDC Rx
  - Metro applications
  - Direct OC-48 to OC-192 upgrades
- NRZ Tx, 0 Chirp, 2400 ps/nm, Low OSNR, EDC Rx
  - Multi-span applications
  - Direct OC-48 to OC-192 upgrades
- Duobinary Tx, 0 Chirp, 3200 ps/nm, High OSNR, NRZ Rx
  - Metro application with +/- dispersion and in line amps

Figure 2-1 Interoperability Configurations Under Considered for the Implementation Agreement and Planned Revisions

The reference to 0-Chirp in the figure is nominal and does not exclude modules that utilize transmitters that have residual chirp as long as they support the positive and negative values of residual dispersion present in the fiber optic links. Advanced technologies being considered (but are not limited to) for longer reach (higher levels of residual dispersion) fiber optic links are; electronic dispersion compensation (EDC), multi-level modulation (MLM) (duobinary, duobinary “like”, DPSK, QPSK), and chirp managed lasers.

The body of the document is partitioned as follows:

A summary of the module configurations in the current Implementation Agreement is presented followed by the definition of the Golden units. The document concludes with the tests to be performed accompanied with a high level procedure.

3 Reference Documents

- ITU-T G.691 Optical interfaces for single channel STM-64 systems and other SDH systems with optical amplifiers
- ITU-T G.957 Optical interfaces for equipments and systems relating to the synchronous digital hierarchy
- ITU-T G.959.1 Optical transport network physical layer interfaces
- GR-253 Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria
- IEC 61280-x-x – family of documents describing optical test procedures
- IEC 61281-1 Fibre optic communication subsystems – Part 1: Generic specification
- IEC 62007-2 Semiconductor optoelectronic devices for fibre optic system applications – Part 2: Measuring methods
- Fiber Optic Test and Measurement, Editor Dennis Derickson, Published by Prentice Hall, Inc.

4 List of Abbreviations

% full scale	Rx decision threshold; 100% = 1 level, 0%= 0 level
BER	Bit Error Ratio
COTS	Commercial-Off-The-Shelf
DPSK	Differential Phase Shift Key
DUT	Device Under Test
EDC	Electronic Dispersion Compensation
FEC	Forward Error Correction
GRx-N-A	Golden Receiver with APD photodetector for NRZ signal format
GRx-N-P	Golden Receiver with PIN photodetector for NRZ signal format
GRx-N-Pre	Golden Receiver with optical preamp and PIN for NRZ signal format
GTx-N-H	Golden Transmitter, NRZ Modulation, High OSNR - Extinction Ratio (8.2, 9, 10 dB) and Chirp (0, -0.7) are User Defined
GTx-RB-H	Golden Transmitter, NRZ-RB Modulation, High OSNR
ITU	International Telecommunications Union
LH	Long Haul
LR	Long Reach
LR1200	Optical Path Characteristics with 1200 ps/nm residual dispersion
LR1600	Optical Path Characteristics with 1600 ps/nm residual dispersion
MLM	Multi-Level Modulation
MPI-R	Main Path Interface, Receiver Reference Point for ITU Document
MPI-S	Main Path Interface, Transmitter Reference Point for ITU Document
MZM	Mach-Zehnder Modulator
NRZ	Non Return to Zero
NRZ-RB	Reduced BW NRZ modulation; for example duobinary modulation
OSNR	Optical Signal to Noise Ratio
QPSK	Quadrature Phase Shift Key
R	Receiver Reference Point for OIF Document
Rx	Receiver
S	Transmitter Reference Point for OIF Document
SBS	Stimulated Brillouin Scattering
SSMF	Standard Single Mode Fiber
SMSR	Side Mode Suppression Ratio

SPM	Self Phase Modulation
TDM	Time Division Multiplexed
Tx	Transmitter
ULH	Ultra Long Haul
VR	Very Long Reach
VR2400	Optical Path Characteristics with 2400 ps/nm residual dispersion

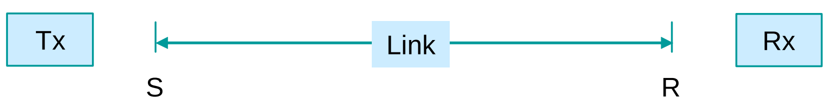
5 LR and VR Module Configurations

This document addresses modules for use in network equipment that is compliant to application codes with 10 Gb/s data rates that must support residual dispersions of 1200 ps/nm, 1600 ps/nm (long reach (LR) applications) and 2400 ps/nm (very long reach (VR) applications). The reference application codes are contained in ITU-T G.691 (also listed in GR-253) and ITU-T G.959.1.

For the purposes of this document, the reference points in an optical link have been modified as compared to ITU document G.691. Figure 5-1 presents the ITU definition of a fiber optic link and the reference points (Main Path Interface – Source (MPI-S) and Main Path Interface – Receiver (MPI-R)) in the link for the application codes. Figure 5-2 illustrates the fiber optic link with the identified reference points for the transmitter (S) and the receiver (R) used in this document. The reference points have been modified from those in the ITU document to place the emphasis on the interoperability of the transmitter and receiver when presented with a fixed amount of loss and distortion due to the optical path. All optical amplification (booster or preamp), signal loss due to fiber, passive components and interfaces, and dispersion due to fiber or in line components are treated as an effective cumulative total effect in the optical path. If the application codes explicitly calls out a preamplified receiver, this document makes the optical preamplifier part of the receiver to accurately reflect the performance impact from the noise figure of the preamplifier (i.e. the OSNR into the PIN receiver).

- ITU defines a fiber optic link between the transmit and receive points MPI-S and MPI-R
- Link definitions do not take into account any items in the black box on the transmit or receive side of the link

Figure 5-1 ITU G.691 Fiber Optic Link Reference Points



- Interoperability looks at the Tx and Rx and ignores optics in the link
  - Amplifiers and DCM modules affect the effective dispersion and the loss values
  - In multi-span links, amplifiers will affect OSNR into the receiver

Figure 5-2 OIF Fiber Optic Link Reference Points

6 Definition of Golden Units

The approach taken by the OIF for interoperability testing is to utilize golden (reference) modules for each of the key interface points in the physical layer; transmitter, receiver and optical path. The utilization of these golden modules in the defined tests provides a means of evaluating interoperability without defining a particular technology or implementation to a manufacturer of compliant modules. It also allows for compliance testing of modules based on new technologies (not specifically identified in this document) without need for modification/revision to this Implementation Agreement. All of the test parameters are defined for a PRBS 2^31 test pattern. Other patterns may be used when directed by specific customer requirements.

The nomenclature for each of the golden units is defined in the following paragraphs. Table 6-1 presents the cross reference golden Tx, golden Rx, and golden optical path for compliance to an ITU application code. The high level test procedure is present in Paragraph 7.

Table 6-1 Cross Reference of Golden Units to 10 Gb/s Application Codes

Link Configuration	L-64.2a	L-64.2b[3]	L-64.2c	P1L1-2D2	P1V1-2C2
GTx	GTx-N-H	GTx-N-H	GTx-N-H	GTx-N-H	GTx-RB-H
GRx[1]	GRx-N-*	GRx-N-P	GRx-N-P	GRx-N-A	GRx-N-Pre
Reference Path[2]	LR1200	LR1200	LR1600	LR1600	VR2400

Notes:

1 - In links that could have amplification the photodetector could either be an APD or PIN; where a preamp is defined, a PIN is assumed

2 - Links defined to have passive dispersion accommodation or utilizing SPM are assumed to interoperate if a Tx/Rx pair can work properly at 1200 ps/nm as defined in interoperability testing

3 - SPM compensated links will depend on the specific fiber characteristics in the link, the launch power and the SBS tone and therefore may require additional customer specific tests to guarantee interoperability

L-64.2b applications rely on SPM to provide some compensation for the dispersion of the link (which may be up to 1600 ps/nm). In this document it is assumed that a transmitter able to operate through 1200 ps/nm of dispersion at low power will also be able to operate through 1600 ps/nm with SPM. The correlation between dispersion penalty under these two conditions (through 1200 ps/nm at low power and 1600 ps/nm with SPM) will, however, depend on the specific characteristics of the transmitter and the fiber in the link so customer specific tests at high power may be required to ensure interoperability for this application.

6.1 Transmitter

The golden transmitter must provide a standard interface that is "easily" set-up in a laboratory environment and/or lends itself to being implemented in test equipment. Currently there are two types of Golden transmitters defined; NRZ transmitters for LR applications and reduced bandwidth NRZ (NRZ-RB) transmitters for VR applications. The following subparagraphs will provide the requirements for each.

The transmitter requirements do not specify optical gain management, therefore manufacturers must ensure the links operate in the proper regime of the fiber for the application code being verified to avoid unwanted nonlinear penalties.

Verification of the configuration of the golden transmitters must be done through the optical path and into the golden receiver. The optimal sensitivity through fiber should be at the threshold level as specified for the receiver to ensure the critical characteristics of the transmitter are correct.

6.1.1 NRZ LR Transmitter

Table 6.1.1-1 presents the parameters for the LR golden units. The golden units are based on MZM technology that is readily available. Alternate modulators could be used, however, they should be verified against the MZM modulators to provide equivalent performance in both back-to-back and through optical path.

Table 6.1.1-1 Golden Transmitter Parameter Specifications

Parameter	GTx-N-H		GTx-RB-H
Output Optical Power (dBm)	-2 ±0.2		0 ±0.2
Wavelength (nm)	1530-1565		1560.61
Maximum Central Frequency Deviation (GHz)	N/A		40
Linewidth (MHz)	<10		<10
SMSR (dBc)	>35		>35
Output OSNR (dB) (RBW 0.1 nm)	>40		>40
Chirp (effective alpha)[1]	0, -0.7 ±0.1		0
RIN (dB/Hz)	<-130		<-130
Extinction Ratio (dB)[2,3]	Min	Max	
8.2 dB Nominal	7.74	8.70	
9.0 dB Nominal	8.48	9.58	>9
10.0 dB Nominal	9.38	10.70	
Eye Crossing (%)[4]	50 ±5		72.5 ±5
Eye Mask	See Paragraph 6.1.1.1		6.1.2.1
Tx Upper BW (Hz) (FactorxDataRate)[5]	0.8 ±0.05		0.25 ±0.05
Tx Lower BW (kHz)[5]	<50		<50
Group Delay Variation (ps) (100k-50% DataRate)[5]	<35		<35
Jitter Generation (UI) (50k-80M)[6]	<0.09		ffs
Sensitivity dBm (Back-to-Back)[7,10]	<-16		<-31
Sensitivity dBm (At Reach)[8,10]	<PRxb+1.8		<PRxb+0.8
Decision Threshold (% Full Scale)[11]	Variable		Variable
Sensitivity dBm (minimum OSNR)[9,12]	<-14		N/A

Notes

1 - NRZ Transmitter needs to support both 0 chirp and -0.7 effective chirp (relative to LiNBO3, other technologies may have different measured values when meeting performance MZM would at -0.7)

2 - NRZ Transmitter must support 8.2, 9 and 10 dB ER for high OSNR applications

3 - ER measured in center 20% of eye into 0.75x bit rate BW Bessel filter for NRZ and NRZ-RB

4 - Eye crossing for NRZ-RB is based on a duobinary implementation with low pass filter

5 - The BW for the NRZ-RB is based on a duobinary implementation with a low pass filter

6 - Jitter Generation measured against NRZ receiver and per GR-253; response of test equipment is still under study for NRZ-RB

7 - Measured against golden Rx

8 - Measured against golden Rx though fiber; 1200 ps/nm for 0 chirp NRZ, 1600 ps/nm for -0.7 chirp, 2400 ps/nm for NRZ-RB: high OSNR measurement (>30 dB measured in 0.1 nm RBW)

9 - Measured against golden Rx back-to-back at OSNR of 23±.5 dB (1e-12 BER) for NRZ transmitters; all referenced to 0.1 nm RBW

10 - Golden Rx to verify Golden Tx performance is PIN for NRZ and preamp for NRZ-RB - unless noted, sensitivity is at a BER of 1e-12

11- Golden Tx Effective Chirp must have optimal threshold through optical path as defined in Golden Rx to verify modulator characteristics; values listed in Golden Rx are based on 0 chirp and Z-cut MZM with -0.7 chirp

12 - NRZ-RB OSNR into the PIN is set by the signal level into the preamp

6.1.1.1 Eye Mask for the LR Golden Transmitter

An eye mask for the golden transmitter is used to help ensure the golden transmitter and golden receiver perform properly by allowing for the inclusion of receiver margin that provides for a 1 dB margin at beginning of life and a 1 dB margin that compensates for the test being performed with a transmitter having a better eye opening than one having a worst case eye mask.

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Figure 6.1.1.1-1 illustrates the mask for the Golden transmitter with the associated test points. The mask follows the mask definition listed in ITU-T G.691 with the provision for an increase eye opening.

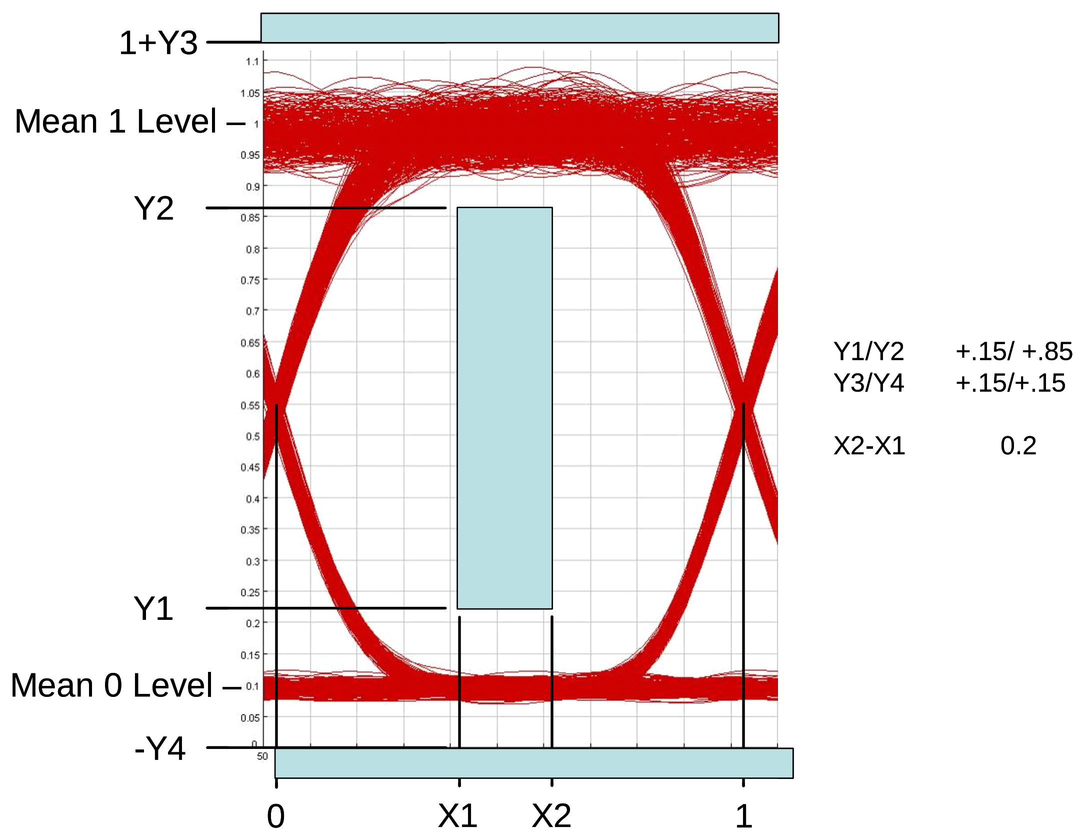

Figure 6.1.1.1-1 Golden Transmitter Eye Mask

6.1.2 NRZ-RB VR Transmitter

Table 6.1.1-1 presents the parameters for the VR golden unit. The golden unit is based on MZM technology with a duobinary signaling format that can readily be implemented from commercially available components. It is recommended that alternate modulators and signaling schemes not be used for the Golden transmitter due to the asymmetric characteristics of the optical eye and the characteristics of the eye in the presence of dispersion. Other technologies that are suitable for the VR application code would not provide the same types of stresses to the receive chain which could lead to interoperability issues.

6.1.2.1 Eye Mask for the VR Golden Transmitter

The eye mask for the VR golden transmitter serves a different purpose than the eye mask for the LR golden transmitter. The LR golden transmitter eye mask ensures that there is enough margin in the quality of the transmitted signal to add beginning of life margin to the receiver performance measurements. The VR golden transmitter eye mask combined with extinction ratio measurements ensures that the duobinary transmitter has a properly balanced modulator, approximately the correct bandwidth, and good VSWR. Figure 6.1.2.1-1 shows a transmit eye with an amplified NRZ eye mask when the modulator is perfectly balanced, the RF transmit signal bandwidth is 25% of the bit rate and perfect matching when received with a receiver that has a Bessel response and a bandwidth equal to 75% of the bit rate. The extinction ratio of the signal in this case is set by the band limiting of the receiver which induces intersymbol interference. Figure 6.1.2.1-2 shows a transmit eye with an amplified NRZ eye mask when the modulator drive is ~0.5 dB unbalanced and the low pass filter BW is 5% below the design BW (in this example, from 2.8 GHz to 2.66 GHz which reduces the BW from 25% of the bit rate to 24% of the bit rate). The eye also has 0.090 UI of jitter added to it which is realistic for a duobinary transmitter. The figure shows the extinction ratio is slightly degraded, the edges of the pulse show a pattern dependent jitter, and the 1 level is split. The last figure presents a “perfect eye” with a receiver chain that has an effective bandwidth of 60% of the bit rate; Figure 6.1.2.1-3. The figure demonstrates the intersymbol interference increases reducing the available back-to-back sensitivity (assuming stable phase on the sample point) while enhancing the sensitivity through fiber (more closely approaches a matched filter for a symmetric NRZ waveform).

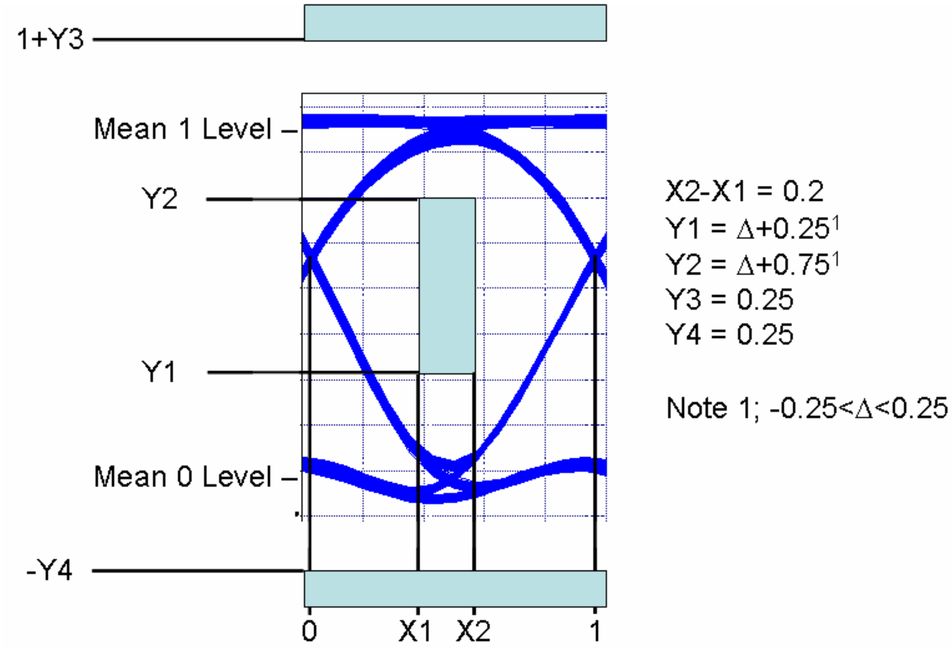

Figure 6.1.2.1-1 NRZ Amplified Eye Mask with Ideal NRZ-RB Transmitter

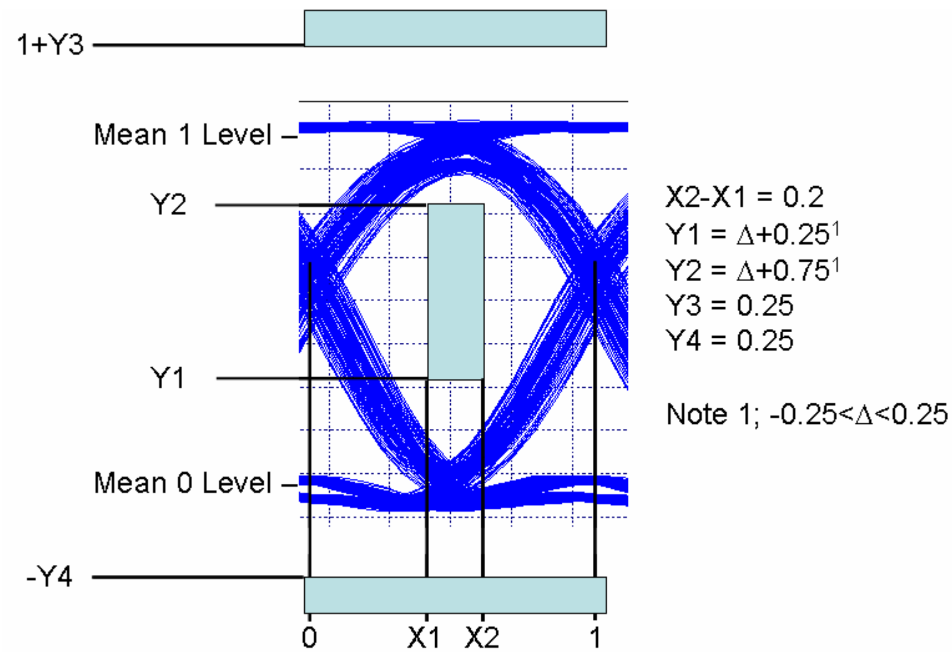

Figure 6.1.2.1-2 NRZ Amplified Eye mask with Realistic NRZ-RB Transmitter

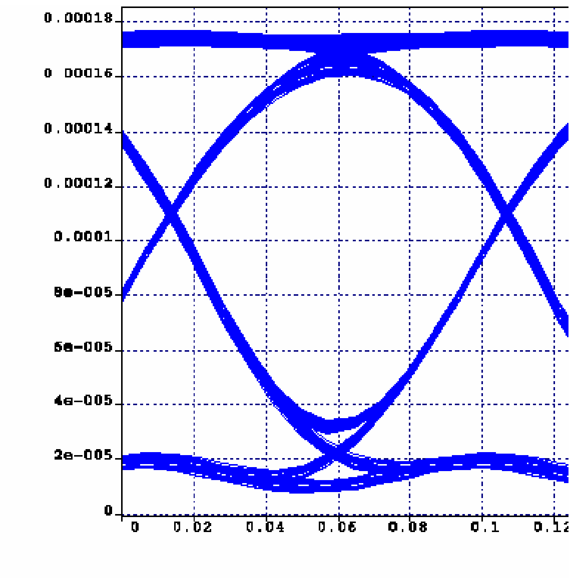

Figure 6.1.2.1-3 NRZ-RB Transmitter Detected with a Rx with a BW at 60% the Bit Rate

6.2 Receiver

The golden receiver must provide a standard interface that is "easily" set-up in a laboratory environment and/or lends itself to being implemented in test equipment. Table 6.2-1 presents the parameters for the "standard" NRZ golden units used for both LR and VR applications. The golden units are based on PIN, APD, and optically preamplified receiver technology that is readily available as commercial-off-the-shelf products. This Implementation Agreement is for modules used with variable receiver decision thresholds to optimize performance. Modules using fixed thresholds must modify the test conditions appropriately to account for path effects.

Table 6.2-1 Golden Receiver Parameter Specifications

Parameter	GRx-N-P	GRx-N-A	GRx-N-Pre
Overload Input Optical Power (dBm)	-2	-6	-13
Wavelength (nm)	1528-1565	1528-1565	1560.61
Optical Filter BW (GHz)	N/A	N/A	50 ±15
Rx Upper BW (FactorxDataRate)[6]	0.6 ±0.05	0.6 ±0.05	0.6 ±0.05
Rx Lower BW (kHz)	<50	<50	<50
Group Delay Variation (ps) (100k-50% Data Rate)	<40	<40	<40
Decision Threshold (% Full Scale)[1]	Variable +/-5%	Variable +/-5%	Variable +/-5%
Jitter Tolerance (UI) (50k-80M)[2]	above mask	above mask	above mask
Sensitivity dBm (Back-to-Back)[3]	<-16	<-26	<-31
Sensitivity dBm (At Reach)[4]	<PRxb+1.8	<PRxb+1.8	<PRxb+0.8
Sensitivity dBm (minimum OSNR)[5]	<-14	<-24	N/A

Notes

1- NRZ: High OSNR, 0 chirp/-0.7 chirp no dispersion - 50%; High OSNR, 0 chirp/-0.7 chirp, through fiber - 42.5%/37.5% respectively; NRZ-RB no dispersion 60% ±10% (range due to implementation variation), High OSNR through fiber 42.5%.

2 - Jitter tolerance is measured per GR-253 and must include the effects of the CDR used after the Rx for data and clock recovery

3 - Measured against a standard NRZ golden Tx with ER of 8.2 dB; Preamplified version measured against GTx-RB-H

4 - Measured against a golden NRZ Tx designed for the reach; 1200 ps/nm, 0 chirp, 1600 ps/nm, -0.7 chirp, 2400 ps/nm, NRZ-RB transmitter

5 - Measured against golden Tx back-to-back at OSNR of 23±.5 dB (1e-12 BER); all referenced to 0.1 nm RBW

6- Rx Upper BW is the total effective BW of the Receiver, includes spectral shape, TIA and any filtering prior to the decision circuit

6.3 Path

The optical path is based on characteristics of standard single mode fiber (SSMF) as defined in ITU-T G.652. The dispersion is the primary factor for specifying optical path versus reach (Reach is often the reference parameter for an application assuming 20 ps/nm-km.). The amount of residual dispersion defined for a path depends on the transmitter type and the receiver type. Table 6.3-1 presents the parameters for the optical path for LR and VR applications.

Table 6.3-1 Reference Optical Path Parameter Specifications

Parameter	LR1200	LR1600	VR2400
Minimum Attenuation (dB)[1]	0	0	13
Maximum Attenuation (dB)[1]	14.2	14.2	30.2
Minimum Dispersion (ps/nm)[2]	0	0	0
Maximum Dispersion (ps/nm)[2]	1200 +/- 2.5%	1600 +/- 2.5%	2400 +/- 2.5%
Group Delay Variation (ps) (100k-50% DataRate)[3]	ffs	ffs	ffs
Differential Group Delay[3]	ffs	ffs	ffs
Polarization Mode Dispersion[3]	ffs	ffs	ffs
Single Reflection[3]	ffs	ffs	ffs
Total Reflected Power[3]	ffs	ffs	ffs

Notes

1 - Attenuation value can be met by combination of fiber, attenuators, and amplifiers as long as dispersion and OSNR parameters are met, value specified for LR paths is with a PIN, APD value for min/max attenuation is 4/24.2 dB respectively

2 - Dispersion value can be met by combination of fiber, DCM, and active techniques as long as attenuation and OSNR parameters are met

3 - ffs - for future study, need controlled, easy to implement method to set parameters if determined to be critical to system interoperability

7 Test Configurations

Testing for interoperability utilizes the golden transmitter and receiver modules to verify the performance of the device under test (DUT) against a standard reference point. The golden transmitter is routed to the DUT's receiver either back-to-back or through the optical path. The DUT's transmitter is verified by being routed to the golden receiver either back-to-back or through the optical path. Table 7-1 presents a matrix that cross references the golden transmitters, golden receivers, and reference optical paths to the application codes defined in ITU-T G-691 and ITU-T G-959.1 for 10 Gb/s links.

Table 7-1 Cross Reference of Golden Units to 10 Gb/s Application Codes

Link Configuration	L-64.2a	L-64.2b[3]	L-64.2c	P1L1-2D2	P1V1-2C2
GTx	GTx-N-H	GTx-N-H	GTx-N-H	GTx-N-H	GTx-RB-H
GRx[1]	GRx-N-*	GRx-N-P	GRx-N-P	GRx-N-A	GRx-N-Pre
Reference Path[2]	LR1200	LR1200	LR1600	LR1600	VR2400

Notes:

1 - In links that could have amplification the photodetector could either be an APD or PIN; where a preamp is defined, a PIN is assumed

2 - Links defined to have passive dispersion accommodation or utilizing SPM are assumed to interoperate if a Tx/Rx pair can work properly at 1200 ps/nm as defined in interoperability testing

3 - SPM compensated links will depend on the specific fiber characteristics in the link, the launch power and the SBS tone and therefore may require additional customer specific tests to guarantee interoperability

7.1 Transmitter Tests

Transmitter tests are those tests that can be accomplished on the DUT with standard laboratory test equipment independent of the golden receiver and reference optical path. Any or all of these tests could be specified by a customer. High level explanation of the procedure for the tests is given. For a more detailed explanation of any of these tests, the reader is referred to either the family of test procedures published by IEC (IEC 61280) or to Fiber Optic Test and Measurement published by Hewlett Packard Professional Books. These tests are included in this document to help clarify how to measure the parameters specified for the Golden Transmitter and Golden Receiver.

7.1.1 Output Optical Power

Output optical power is measured by placing a jumper on the transmitter output connector and routing it into an optical power meter that is calibrated for the wavelength being measured. The jumper should be long enough to ensure the cladding modes are not coupled in the power meter. IEC recommends a 10 m cable with an 80 mm loop for the jumper.

7.1.2 Wavelength

Output optical wavelength is measured by placing a jumper on the transmitter output connector and routing it into either an optical spectrum analyzer or wavelength meter. The optical wavelength measurement equipment should be set to vacuum for the measurement.

7.1.3 Laser Linewidth

Laser linewidth is a parameter provided by the laser manufacturer. Should independent verification be desired, refer to Fiber Optic Test and Measurement. Test equipment is available or an interferometer can be set up in the lab for this measurement. Laser linewidth should be measured without any modulation on the laser.

7.1.4 SMSR

Output SMSR is a parameter guaranteed by the laser manufacture. This parameter can be independently verified using the wavelength test set-up. Measure the average optical power at the peak output wavelength and the average optical power on the next highest mode in the laser optical output power spectrum. SMSR is the difference in dB between the two power levels.

7.1.5 Output OSNR

Output OSNR can be measured with the wavelength test set-up. The OSNR is referenced to 0.1 nm resolution measurement bandwidth. The 10 Gb/s modulation rate can spread the signal energy beyond the 0.1 nm measurement bandwidth. To compensate for this signal spreading, measure the peak average optical power out of the optical power spectrum with a 0.2 nm filter bandwidth and the average optical power due to noise offset 0.5 nm from the signal peak output. The OSNR is the difference between the signal power and the noise power in dB plus 3 dB due to integration of additional noise in the 0.2 nm measurement filter bandwidth.

7.1.6 Chirp Parameter

There are several techniques as well as test equipment to measure the chirp parameter. Fiber Optic Test and Measurement describes 2 methods for making the measurement. Manufacturers of the modulators have data on their device that can be provided. If independent verification is required, correlation with the modulator manufacturer may be required especially if they are meeting path penalty specifications with a device other than a LiNbO3 MZM.

7.1.7 Relative Intensity Noise

Relative intensity noise is guaranteed by the laser manufacturer. To accurately measure RIN, careful calibration is required. RIN is one of 3 noise terms in a receiver output. Fiber Optic Test and Measurement and IEC 62007-2 provide techniques for measuring RIN. Small errors in measurement and calibration can result in large errors in RIN measurements.

7.1.8 Extinction Ratio

Most of the modern digitizing oscilloscopes have the ability to measure extinction ratio. Extinction ratio is measured with a 4^{th} order Bessel filter at 0.75 the bit rate as defined in ITU-T G.957 with the provisions listed in ITU-T G.691. Extinction ratio is expressed in dB and is calculated by multiplying 10 times the log of the ratio of mean optical power level at the center of a 1 to the mean optical power level of the center of a 0 after subtracting off the bias term (level of the 0 on the oscilloscope when the optical transmitter output is turned off). The mean value of the 1 and 0 level is calculated in the region that is 40% to 60% between the eye crossings.

7.1.9 Eye Crossing

Most of the modern digitizing oscilloscopes have the ability to measure eye crossing. Eye crossing is measured without an electrical Bessel filter (The filter in a reference receiver can cause the eye to shift closer to the 50% point and therefore should not be used.). Eye crossing is the point in an optical eye that the 0 to 1 transition and the

1 to 0 transition intersect. The measured eye crossing is calculated by dividing the optical power level corresponding to the crossing point by the difference between the 1 and the 0 level and multiplying the result by 100 to express it as a percentage. The crossing value, 1 level, and 0 level are the mean values for each.

7.1.10 Eye Mask

Most of the modern digitizing oscilloscopes have the ability to measure eye mask. The mask used depends on the signal type and data rate. For standard NRZ transmission, the mask used should be called from the digitizing scopes menu and the measurement should be made with a 4^{th} order Bessel filter at 0.75 the bit rate as defined in ITU-T G.957 with the provisions listed in ITU-T G.691. The oscilloscope will properly scale the transmitted optical signal to fit the mask and detect and count violations of the mask. For the amplified NRZ mask, the offset of the mask region in the inner portion of the eye can be done manually by keeping the same voltage difference and shifting the mask area up or down as required by the received signal. Eye mask measurements could be done manually (but not recommended due to measurement accuracy and measurement correlation) by using the mask definition in the document defining the application code and drawing it on transparent material that can be overlaid on a variable persistence oscilloscope. The signal would then have the gain adjusted to place the mean 1 and 0 levels at the 1 and 0 points on the mask template. With persistence set to a long value (seconds) any traces that violate the mask would be noted.

7.1.11 Jitter Generation

Jitter generation is a challenging measurement at 10 Gb/s. Several vendors have test equipment that can measure the jitter generated by the transmitter per GR-253. Each has limitations and some remove intrinsic jitter by mathematical subtraction. No method is recommended for this test other than commercial test equipment due to correlation issues between test sets.

Duobinary transmitters have inherent pattern dependence and, as shown in paragraph 6.1.2.1, small imperfections exacerbate the problem. Additionally, testing of receivers in commercially available jitter test sets has shown difficulty in properly receiving the back-to-back duobinary eye. The current release of this Implementation Agreement shows this parameter as ffs for the golden transmitter due to this problem. Additional work is required to ascertain a method of reliably measuring jitter with a duobinary transmitter and the affect the apparent measured jitter has on the network performance.

7.1.12 Jitter Transfer

Jitter transfer can be measured using COTS test equipment based on the limits set by GR-253. It can also be measured by precisely measuring the jitter transfer of a test set-up and then measuring the jitter transfer of the DUT and subtracting the two measurements with the difference being the contribution of the DUT. IEC 61280-2-5 presents a procedure for measuring jitter transfer if COTS equipment is not available.

7.2 Receiver Tests

Receiver tests are those tests that can be accomplished on the DUT with standard laboratory test equipment independent of the golden transmitter and reference optical path. Any or all of these tests could be specified by a customer. High level explanation of the procedure for the tests is given. For a more detailed explanation of any of these tests, the reader is referred to either the family of test procedures published by IEC (IEC 61280) or to Fiber Optic Test and Measurement published by Hewlett Packard Professional Books. These tests are included in this document to help clarify how to measure the parameters specified for the Golden Transmitter and Golden Receiver.

7.2.1 Jitter Tolerance

Jitter tolerance can be measured using COTS test equipment based on the limits set by GR-253. It can also be measured manually by precisely imposing a jitter on the optical signal into the receiver and seeing the optical penalty that results. The jitter tolerance mask is presented in Telcordia GR-253. Determine the sensitivity (10-12 BER) of the receiver with no impairments due to path or the transmitter (high OSNR and no jitter). For each jitter frequency, apply the proper UI of jitter to the data and measure the optical power penalty to reach the 10-12 BER. If the penalty is less than 1 dB, the unit passes for that jitter frequency. Repeat the process until all jitter frequencies are tested. (Jitter tolerance may be tested at a higher BER due to test equipment limitations.)

7.3 Link Tests

Link tests are the tests that utilize the golden transmitters and golden receivers. Each link test is made with a golden transmitter connected to the DUT receiver and with a DUT transmitter connected to a golden receiver. The characteristics of the golden transmitter and golden receiver are determined by the application code the module is being built to support. Figure 7.3-1 illustrates a functional block diagram of a test set-up that could be utilized to implement the interoperability testing.

Table 7.3-1 summarizes the standard test limits, eye crossing, chirp, extinction ratio and receiver threshold conditions for the various application codes for 10 Gb/s LR and VR modules.

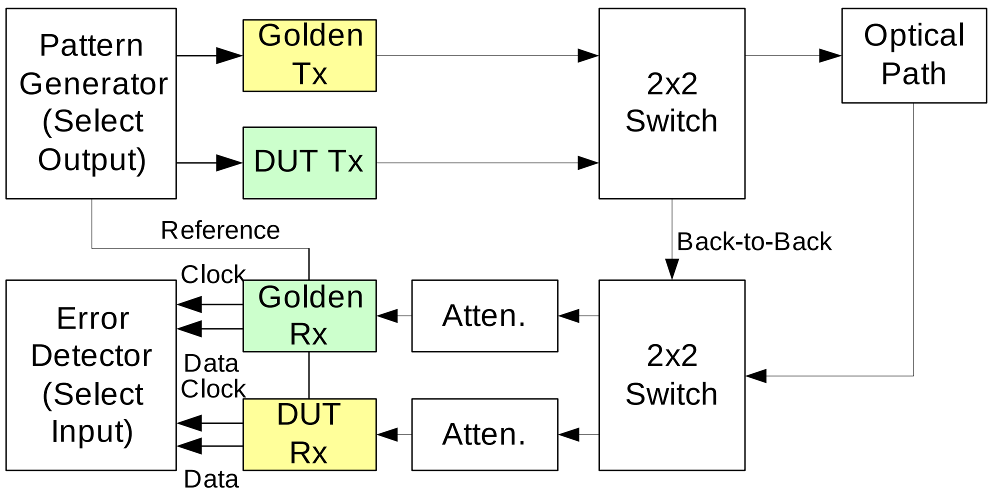

Figure 7.3-1 Functional Block Diagram of a Notional Interoperability Test Set-Up Showing the DUT and the Golden Transmitter and Receiver

(Signal path for a compliance test is shown by going from a box to a box of the same color)

Table 7.3-1 Test Conditions for Link Testing 10 Gb/s Application Codes

Link Testing[1]	L-64.2a	L-64.2b[7]	L-64.2c	P1L1-2D2	P1V1-2C2
Golden Tx Sensitivity dBm (Back-to-Back)[2,6] PRxb	<-16/-26	<-16	<-16	<-26	<-31
Golden Rx Sensitivity dBm (Back-to-Back)[2,6] PRxb	<-15/-25	<-15	<-15	<-25	<-31
Sensitivity dBm (At Reach)	<PRxb+1.8	<PRxb+1.8	<PRxb+1.8	<PRxb+1.8	<PRxb+0.8
Sensitivity dBm (minimum OSNR)[3]	N/A	N/A	N/A	N/A	N/A
Chirp Parameter	0 +/-0.1	0 +/-0.1	-0.7 +/-0.1	-0.7 +/-0.1	0
Extinction Ratio[8]	>10 dB	>8.2 dB	>10 dB	>9 dB	>9 dB
Eye Crossing[5]	50 +/- 5%	50 +/- 5%	50 +/- 5%	50 +/- 5%	
Decision Threshold (% Full Scale)[4]	42.5 +/- 5%	42.5 +/- 5%	37.5 +/- 5%	37.5 +/- 5%	42.5 +/-5%
Overload Input Optical Power (dBm)[2,6]	-3/-9	-3	-3	-7	-14

Notes:

1 - Test is performed by testing Tx side of DUT with golden Rx and Rx side of DUT with golden Tx for each parameter; both the golden modules and the DUT must be in the range specified for a test

2 - 1st number is for PIN, 2nd number is for APD

3- Measured at OSNR of 23±.5 dB (1*10e-12 BER) and 15±.5 dB (1*10e-5 BER) OSNR for low OSNR applications; referenced to 0.1 nm RBW

4- High OSNR no dispersion - 50% for NRZ, 60% +/-10% for NRZ-RB; High OSNR, through fiber - as listed when tested against golden Tx

5 - Eye crossing for the DUT for P1V1-2C2 is implementation dependent

6 - if the loss is 10 dB lower than for L-64.2a, then a PIN may be specified (amplification is in the link)

7- Systems using SPM may require additional customer specific testing since the fiber, launch power, and SBS suppression tone all affect path penalty at 1600 ps/nm residual dispersion

8 - The value specified is for the device under test transmitter, the value for the golden Tx to test the Rx with tolerance is as specified in golden Tx.

7.3.1 Sensitivity

IEC 61280-2-1 presents a procedure for measuring sensitivity. To measure the sensitivity at a BER of $1x10^{-12}$, measure the average optical power for a minimum of 3 points with BER in the range of $1x10^{-8}$ to $1x10^{-11}$. Extrapolate the data points forward until the curve crosses the $1x10^{-12}$ BER. The average optical power at the point the BER curve intersects the $1x10^{-12}$ BER line is the receiver sensitivity.

Verification of the optical power level measured for sensitivity (calculated as defined above for $1x10^{-12}$ error ratio) requires a long term measurement. This should be done to qualify an optical module design to verify that there is not a noise floor in the receiver. To perform this test, set the optical power into the receiver to the optical power calculated by the sensitivity test. Monitor the BER for a time that can be calculated as follows assuming a 90% confidence is required for the measurement:

Dwell (100 errors) = (1/BER)·(1/Bit Rate)·(# errors) seconds

For a BER of $1x10^{-12}$ and a Bit Rate of 10 Gb/s, the dwell time is 10,000 seconds (2.8 hours). (Verification of a noise floor below $1x10^{-15}$ at 10 Gb/s would require a dwell time of 10,000,000 seconds (116 days).)

Error free seconds can be used as an alternate measurement technique due to the steepness of the error curves. (When the DUT is slightly better than the spec, there will not be any errors. See G.sup39 section 9.4.) For a confidence level of 90% of a BER less than 10^{-12}, $2.3x10^{12}$ error free bits are needed (4 minutes at STM-64 rate).

7.3.1.1 Back-to-Back

To perform a back-to-back measurement, connect the golden transmitter to the DUT receiver for a sensitivity measurement as described above. Optimize the decision threshold to achieve the best sensitivity (this allows for compensation of a DC offset that may exist at the input of the decision circuit; the value for the decision threshold should be close to 50% for NRZ transmitters and may shift up for the golden NRZ-RB transmitter depending on the “splitting” of the one level as shown in paragraph 6.1.2.1). Record the value. Connect the DUT transmitter to the golden receiver for a sensitivity measurement as described above. Record the value. Both transmitter and receiver of the DUT must pass to pass this test.

7.3.1.2 Dispersion

To perform a dispersion measurement, connect the golden transmitter to the DUT receiver through the reference optical path for a sensitivity measurement as described above. Optimize the decision threshold to achieve the best sensitivity (this allows for compensation of a DC offset that may exist at the input of the decision circuit; the value for the decision threshold should be close to that listed in the table for the optical path used in the test). Record the value. Connect the DUT transmitter to the golden receiver through the reference optical path for a sensitivity measurement as described above. Record the value. Dispersion sensitivity is typically specified as a path penalty at the sensitivity BER ($1x10^{-12}$). To compute path penalty, subtract the DUT transmitter sensitivity from the DUT transmitter sensitivity through the reference optical path. If the value is less than 1.8 dB for LR 10 Gb/s and less than 0.8 dB for VR 10 Gb/s application codes the module transmitter passed. Repeat for the DUT receiver measurements. Both transmitter and receiver DUT must pass for the units to pass this test.

Note that this test has specific limits on the transmitter eye crossing points and the receiver decision threshold points. Sensitivity measurement through fiber must be made with the specified values for the DUT and the golden transmitters and receivers. For example, the L-64.2c application code has the eye crossing at 50% +/- 5% and the decision threshold at 37.5% +/-5%.

7.3.1.3 Noise Loaded

For future study.

7.3.2 Overload

IEC 61280-2-1 presents a procedure for measuring overload. To measure the overload at a BER of $1x10^{-12}$, measure the average optical power for the maximum input optical power and verify the BER is below $1x10^{-12}$. Verification of the optical power level measured for overload requires a long term measurement. This should be done to qualify an optical module design to verify that there is not a performance issue in the receiver. To perform this test, set the optical power into the receiver to the maximum optical power and monitor the BER for a time that can be calculated as follows assuming a 90% confidence is required for the measurement:

Dwell (100 errors) = (1/BER)·(1/Bit Rate)·100 (seconds) = 10,000 (s)

After qualification of the design is complete, reducing the dwell to 1 error period is acceptable (~2 minutes).

Error free seconds can be used as an alternate measurement technique due to the steepness of the error curves. (When the DUT is slightly better than the spec, there will not be any errors. See G.sup39 section 9.4.) For a confidence level of 90% of a BER less than 10^{-12}, $2.3x10^{12}$ error free bits are needed (4 minutes at STM-64 rate)

8 APPENDIX A (Definition of Parameters)

Most of the definitions of the parameters in this document are from IEC 61281-1.

8.1 Transmitter

8.1.1 Optical Power

Average optical power expressed in dBm measured at the output connector of the transmitter

8.1.2 Wavelength

Peak wavelength out of the transmitter expressed in nm.

8.1.3 Laser Linewidth

The spectral width in Hz corresponding to the full width half maximum point of the transmitter in the optical power spectrum.

8.1.4 SMSR

Side mode suppression ratio expressed in dB below the power of the peak output wavelength of the transmitter. Side modes are modes other than the peak mode that are lasing at a lower gain value.

8.1.5 Output OSNR

Optical signal to noise ratio expressed in dB reference to a 0.1 nm measurement bandwidth in the optical power spectrum. Difference in dB between the mean signal power to mean noise power in the reference measurement bandwidth.

8.1.6 Chirp Parameter

Chirp parameter as it relates to the transmitter is the dynamic change in frequency on the leading edge and falling edge of a data transition. The conventional definition of chirp for a MZM is the change of phase with time divided by 2 times the change of intensity with time and is valid at the 50% intensity point of a pulse for high modulation levels.

Chirp Parameter $(\alpha(t)) = (d\varphi/dt)/[(1/2I)\cdot(dI/dt)]$

Other technologies which have multiple sources of dynamic chirp may have a value of chirp different than a MZM that provides optimal compensation for a given amount of residual dispersion. As a result, the chirp parameter defined for the transmitter is referenced to a MZM for optimal transmission at 1600 ps/nm residual dispersion with a “standard” NRZ receiver.

8.1.7 Relative Intensity Noise

RIN is the difference between the average fluctuations in light power (expressed per unit Hz) to the average desired light power measured in dBm. RIN values for transmitters are expressed as dB/Hz.

8.1.8 Extinction Ratio

In a digital system, extinction ratio is ten times the log of the ratio of the mean value of optical power at the center of the ones minus the average value of optical power at the center of the zeros accounting for any offset that is present on the zero level when the transmitter is off.

8.1.9 Eye Crossing

Is the point in time that a zero to one transition and one to zero transition intersect. Eye crossing is expressed as a percentage of the height where the crossing occurs between the 0 and 1 levels.

8.1.10 Transmitter Bandwidth

Is the difference in the highest and lowest modulation frequencies (expressed in Hz) which the complex transfer function is one-half the peak value in the electrical power spectrum.

8.1.11 Group Delay Variation

Is the deviation from the mean time delay any frequency in the transmitter bandwidth experiences between the input of the transmitter to the output of the transmitter.

8.1.12 Jitter Generation

Is random or data pattern dependent variations in the transmitted phase of the optical waveform when compared to the waveform input to the transmitter.

8.1.13 Sensitivity

Is the minimum receiver average optical power level that required BER can be maintained. For this document, the required BER is defined to match ITU documents; 1x10-12.

8.1.13.1 Back-to-Back

Back-to-back sensitivity has minimal residual dispersion in the optical path (<30 ps/nm) and operates with a high OSNR (>30 dB)

8.1.13.2 Dispersion

Dispersion sensitivity is measured with the specified residual dispersion for the application. For 10 Gb/s LR applications, the values are either 1200 ps/nm or 1600 ps/nm. For the 10 Gb/s VR application, the value is 2400 ps/nm.

8.1.13.3 Optical Noise

Optical Noise sensitivity is measured with a degraded OSNR with a given amount of residual dispersion. This is for future study.

8.2 Receiver

8.2.1 Overload

Is the maximum receiver average optical power level that required BER can be maintained. For this document, the required BER is defined to match ITU documents; 1x10-12.

8.2.2 Wavelength

Range of optical wavelengths into the optical receiver that the receiver meets a minimum set of performance requirements.

8.2.3 Bandwidth

Is the difference in the highest and lowest modulation frequencies (expressed in Hz) which the complex transfer function is one-half the peak value in the electrical power spectrum.

8.2.4 Group Delay Variation

Is the deviation from the mean time delay any frequency in the receiver bandwidth experiences between the input of the receiver to the output of the receiver.

8.2.5 Decision Threshold

Is the voltage point at which the clock and data recovery circuit makes a decision of being either a one or zero. Decision threshold is expressed as a percentage of the height of the electrical signal into the CDR (or equivalent point in the receiver path were the decision is made; i.e. limiting amplifier) between the 0 and 1 level.

8.2.6 Jitter Tolerance

Is the amount of jitter expressed in data rate unit intervals that a receiver and CDR can tolerate before seeing a 1 dB degradation in sensitivity. Jitter tolerance is defined by a maximum jitter deviation in UI and a sinusoidal jitter rate in Hz.

8.2.7 Sensitivity

Is the minimum receiver average optical power level that required BER can be maintained. For this document, the required BER is defined to match ITU documents; 1x10-12.

8.2.7.1 Back-to-Back

Back-to-back sensitivity has minimal residual dispersion in the optical path (<30 ps/nm) and operates with a high OSNR (>30 dB)

8.2.7.2 Dispersion

Dispersion sensitivity is measured with the specified residual dispersion for the application. For 10 Gb/s LR applications, the values are either 1200 ps/nm or 1600 ps/nm. For the 10 Gb/s VR application, the value is 2400 ps/nm.

8.2.7.3 Optical Noise

Optical Noise sensitivity is measured with a degraded OSNR with a given amount of residual dispersion. This is for future study.

8.2.8 Path

8.2.8.1 Attenuation

Is the loss in average optical power between the transmitter and the receiver expressed in dB.

8.2.8.2 Dispersion

Is the residual dispersion due to chromatic effects in the fiber expressed in ps/nm. Polarization mode dispersion is not part of this defined parameter. The characteristics of the chromatic dispersion are consistent with SSMF as defined in ITU-T G.652.

8.2.8.3 Differential Group Delay

Is the time difference an optical pulse arrives at the receiver due to polarization mode dispersion. A transmitted optical pulse sees a different velocity for each polarization state resulting in a pulse arriving at the receiver at two different times. Differential group delay is for future study and does not appear to be a key parameter for interoperability between manufactures modules.

8.2.8.4 Reflected Power

Is the power reflected by discrete and distributed scatterers along the length of the optical path to the transmitter. Reflected power is for future study and does not appear to be a key parameter for interoperability between manufactures modules.

9 Appendix B Histogram statistics method for finding optimum threshold for a given input waveform

9.1 Theory

Using statistical data obtained from an ideal optical receiver with a 4-pole Bessel filter, it is possible to calculate an optimal decision threshold for any TX waveform including the effects of fiber dispersion. The closest approximation to an ideal optical receiver that is generally available is a Digital Communications Analyzer (DCA) with a reference Bessel filter for the particular data rate, since its frequency response is calibrated to the G.691 filter shape specifications. The one level and zero level statistics from the center 20% of the bit time of the eye can be used to model an ideal receiver with an optimal clock sampling phase. The statistics of the entire bit time are used to calculate the effects of the AC coupling present in most receivers. The setup in Figure 1 was used to capture the waveforms in Figures 2, 3 and 4 to illustrate a dispersed Mach-Zehnder transmitter optical waveform. This method is applicable to non-dispersed waveforms as well.

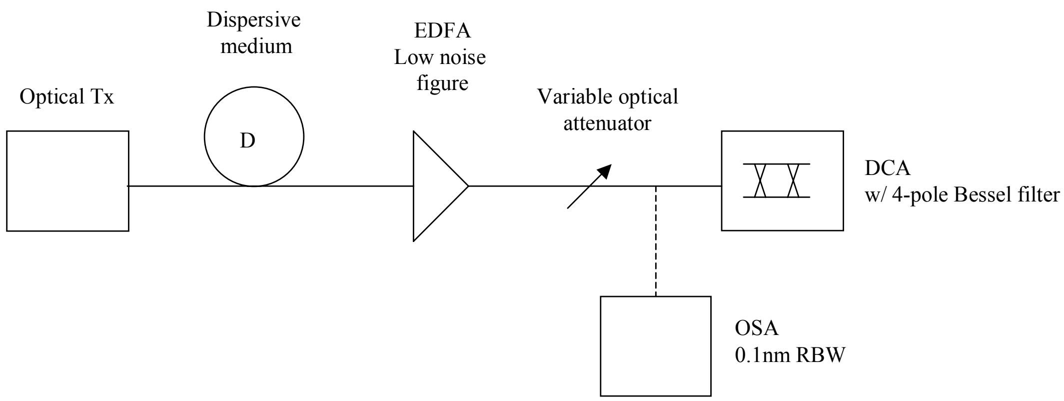

Figure 9.1-1 Test Setup To Capture Eye Statistics

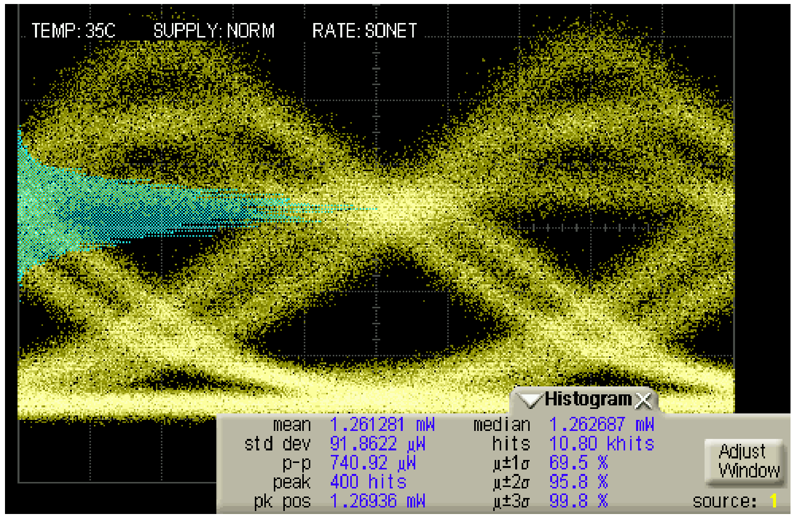

Figure 9.1-2 One Level Statistics

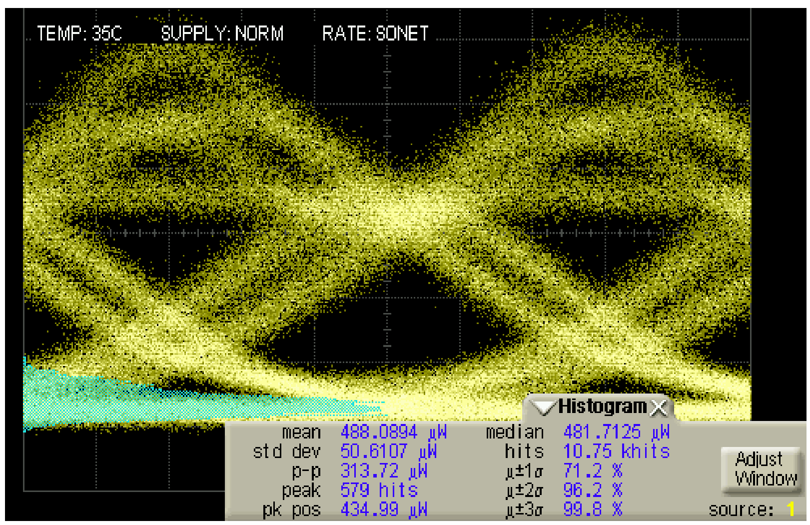

Figure 9.1-3 Zero Level Statistics

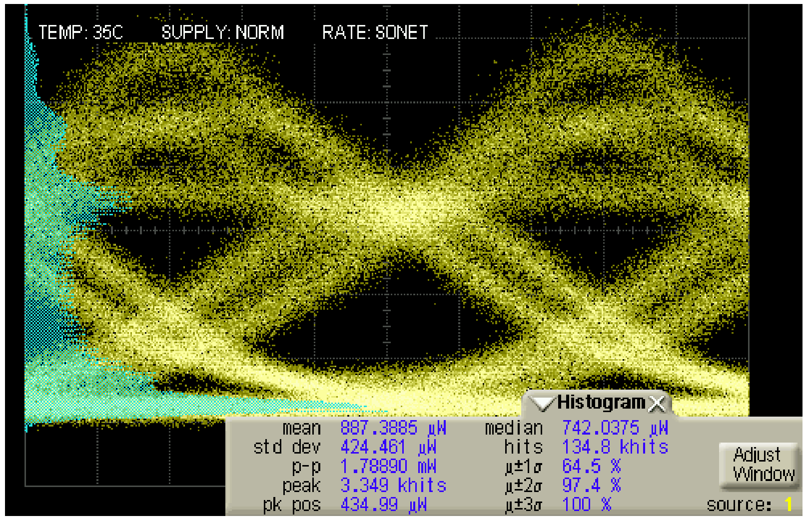

Figure 9.1-4 Dispersed Eye Average Power

9.2 Procedure

Using the setup in Figure 1, the TX is subjected to the rated dispersion for the TX wavelength using a span of fiber. The output of the fiber span is amplified by an EDFA with a composite output OSNR >30dB at 0.1nm resolution bandwidth. The EDFA output is attenuated to a suitable level at least 10 dB above the noise floor of the DCA input. The DCA histogram window is set to capture statistics of the center 20% of the bit time for the one and zero level and then set to measure the average power of the entire bit time. Statistics must be captured using a minimum of 500 waveforms.

9.3 Calculations

Using the following equations, the theoretical optimum decision threshold can be calculated:

$\sigma 0$ - is the one standard deviation of the optical power of the zero level

$\sigma 1$ - is the one standard deviation of the optical power of the one level

Level_0 - is the statistical mean optical power of the zero level

Level_1 - is the statistical mean optical power of the one level

Pavg - is the average optical power for a bit time measured by an AC coupled receiver.

Avg % = (Pavg- Level_0)/(Level_1- Level_0)*100

This is the effective threshold of an AC coupled receiver with zero DC offset.

Optimum Threshold % = 100 / (1+ $\sigma 1/\sigma 0$)

This is the decision threshold % for lowest error rate.

Effective Threshold % = Optimum % + 50% - Avg %

This is the optimum % threshold setting for an AC coupled receiver with compensation for offset between average power of the entire waveform and the 50% point of the center 20% of the bit time.

9.4 Example

Calculations for the eye illustrated in figures 2, 3, and 4:

Level_1	1261.3
$\sigma 1$	91.9
Level_0	488.1
$\sigma 0$	50.6
Pavg	887.4

Avg % = (887.4-488.1)/(1261.3-488.1)*100 = 51.6%

Optimum Threshold % = 100 / (1+ 91.9/50.6) = 35.5%

Effective Threshold % = 35.5% + 50% - 51.6% = 33.9%

An AC coupled receiver must be tuned to an effective threshold of 33.9% as measured with a perfect source waveform (Avg% = 50%) to actually achieve the optimum threshold of 35.5% for this waveform (Avg% = 51.6%).

10 Appendix C Bathtub curve method for setting receiver threshold percentage and finding optimum threshold for a given input waveform

10.1 Theory

Measurement of BER with different values of RX threshold offset allows the determination of the location of the optimum RX threshold value for any given test condition. If the threshold adjustment mechanism is linear and the gain of the receiver prior to the threshold point is constant and linear, the slopes of the BER curves vs. threshold offset can also be used to determine the location of the average one and zero levels and to calibrate the RX threshold location as a percentage of the zero to one range. This can be done without any independent measurement of the transmitter parameters, but is only valid for the particular test condition. This is useful to evaluate a transmitter that is specified to have a particular optimum crossing point after dispersion.

For most receivers, the linearity conditions apply for a range of input power near sensitivity. If the RX input power, Extinction Ratio and the Average power % level are known for the calibration case, it is possible to make a valid prediction of RX threshold % value vs. threshold control input value for a range of transmitter parameter values and RX input power levels. This is useful to set a golden receiver to a desired % crossing for testing DUT transmitters.

Average power % is defined as follows:

Average power % =100*(2*average power/(average one level + average zero level))

Note: Average power is measured for the entire waveform, and the one and zero levels are determined using only the center 20% of the bit time. Average power % will be near 50% for back-to-back measurements on well tuned transmitters. However, dispersion effects and offsets in transmitter eye crossing can cause significant offsets.

This parameter is important because most receivers are AC coupled prior to the threshold adjustment point. This causes any applied threshold offset to be referenced to average power, not the 50% point. For example, consider a signal with an average power equal to 52% of the zero to one range. After AC coupling, the average voltage of the signal must be zero, with the one level at +48% and the zero level at –52% of the zero to one range. If a fixed threshold offset voltage equal to -2% of the zero to one range is applied, the effective threshold can be set to 50%. Unfortunately, this is only valid for a fixed set of input conditions. If the zero to one range (affected by RX power and ER) or the Average power % levels are changed, the fixed offset voltage is no longer the correct value to achieve 50% effective threshold. However, if the signal parameters are known for the calibration case, a corrected threshold offset value can be determined for any other set of parameter values within the linear range of the receiver. A reference procedure to measure Average power % using a sampling scope is provided in Appendix B.

Because the primary measurement device used is a BER tester, the actual value of the average zero and one levels can not be directly measured. Most BERT's will not maintain sync for BER levels much above 1E-3, and the error rate for thresholds equal to the zero or one level is 25% or 250E-3. However, this method provides much better accuracy for low BER levels than a sampling scope, since a scope would require very large waveform counts for good measurement of low BER levels. In order to resolve this problem, the statistics of the one level and zero level noise are assumed to be Gaussian, thus allowing prediction of the location of the one and zero levels from measurements of the BER slopes. A wide range of BER values is used to minimize errors in the extrapolation of both high error (one and zero level) and low error (optimum threshold) regions of the BER curves. As above, 1E-3 is near the maximum level that can be measured, and 1E-10 is a compromise between the 1E-12 spec level and reasonable gate time limits. A third point at about 1E-7 is used with the 1E-3 point to predict the one and zero levels or with the 1E-10 point to predict the optimum threshold level. This allows the high BER and low BER portions of the curve to have different slopes (slightly non-Gaussian statistics) and still get reasonably accurate predictions.

10.2 Assumptions

1. Receiver threshold adjustment is linear over the range used.
2. Receiver is AC coupled and linear (not in limiting) over the range of threshold adjustment at the power levels used.
3. Receiver threshold % is insensitive to input power when set equal to input average power. (This is characteristic of an AC coupled receiver with threshold offset applied after the AC coupling.)
4. Transmitter 1 level and 0 level noise (including ISI) is approximately Gaussian.

10.3 Procedure:

Attenuate the RX input signal to produce approximately 1E-12 BER in the receiver with nominal threshold (about 2.5dB above the power for 1E-7 BER) and measure the resulting RX input power. Measure BER and threshold control input level for approximately 1E-3, 1E-7, and 1E-10 BER for both positive and negative threshold offset. Use the 1E-3 and 1E-7 BER data to compute the value of the 1 and 0 levels in terms of the threshold control input. Use the 1E-7 and 1E-10 data to compute the optimum RX threshold setting for this test condition.

Use the procedure in Appendix B or equivalent to measure ER and Average power % of the RX input signal. Use this data with the RX input power and one and zero level data from above to calculate the threshold setting required for any desired % threshold at any other set of Average power % offset, ER, and RX input level conditions within the linear range of the receiver.

10.3.1 Inverse Error Function Calculations:

These calculations require an inverse cumulative error function accurate to below 1E-12 BER. Common spreadsheet programs (Excel) provide an inverse error function that is useful only above about 1E-7 BER. A useful function for this purpose can be constructed by performing a curve fit to the normal error function, since this function is accurate to below 1e-12. Since the function is strongly nonlinear, it helps to map the function into a more linear space before curve fitting. In the low BER region (the tails of the curve) the function is approximately equal to k*e^(-x^2/2), so a useful mapping space is log (BER) vs. x^2. In this space, the low BER region is very nearly a straight line. The result of this mapping is x=SQRT (polynomial (log (BER)). After curve fitting, the equations are as follows:

BER (total) = (BER (ones) + BER (zeros))/2 - for equal numbers of ones and zeros
for offset threshold conditions, the vast majority of errors are of one type, so:
BER (worst: ones or zeros) = 2*BER (total: offset threshold)
for x = |Threshold – Mean (one or zero)|/Sigma (of one or zero)
BER (ones or zeros) = NORMSDIST (-x) - this is the cumulative normal distribution
and for the inverse:
x = -NORMSINV(BER) - using the Excel function (good from BER = 1E-3 and up)

or

x = SQRT(polynomial (log (BER))) - good from BER =1E-3 to 1E-13

polynomial (log(BER)) =

+31.5002

-4.47223*(log (BER)+8)

+8.44E-03*(log (BER)+8)^2

+6.30E-04*(log (BER)+8)^3

+1.14E-04*(log (BER)+8)^4

+1.55E-05*(log (BER)+8)^5

(note: (log (BER)+8) is used to center the curve in the region of interest before fitting)

The error of this model for the value of x^2 is less than +/- .002 from 1E-3 to 1E-13. This is better than 0.1% BER accuracy – much better than can be achieved with reasonable gate times in low BER measurements.

Calculation of % threshold and optimum threshold for the test condition:

BER3P = Measured BER at approximately 1E-3 for positive threshold offset

THR3P = Threshold control value for BER3P measurement

BER7P = Measured BER at approximately 1E-7 for positive threshold offset

THR7P = Threshold control value for BER7P measurement

BER10P = Measured BER at approximately 1E-10 for positive threshold offset

THR10P = Threshold control value for BER10P measurement

BER3N = Measured BER at approximately 1E-3 for negative threshold offset

THR3N = Threshold control value for BER3P measurement

BER7N = Measured BER at approximately 1E-7 for negative threshold offset

THR7N = Threshold control value for BER7P measurement

BER10N = Measured BER at approximately 1E-10 for negative threshold offset

INV(BERxx) = SQRT(polynomial (log (2*BERxx)))

this is the inverse error function defined above corrected for offset threshold

(all errors are of one type)

One_Level = THR3P*(1-(THR7P/THR3P-1)/(INV(BER7P)/INV(BER3P)-1))

Zero_Level = THR3N*(1-(THR7N/THR3N-1)/(INV(BER7N)/INV(BER3N)-1))

One_Slope = (INV(BER10P)-INV(BER7P))/(THR10P-THR7P)

Zero_Slope = (INV(BER10N)-INV(BER7N))/(THR10N-THR7N)

Optimum_Threshold =

(-INV(BER10N)+INV(BER10P)+ Zero_Slope*THR10N- One_Slope*THR10P)

(Zero_Slope- One_Slope)

Optimum_% = 100*(Optimum_Threshold- Zero_Level)/(One_Level-Zero_Level)

Calculation of the threshold value for a desired % threshold:

Reference conditions:

PRXREF = Measured power of the reference RX input signal

ERDBREF = ER (in dB) of the reference RX input signal

AVG%REF = Average Power % of the reference RX input signal (per Appendix B.)

Threshold_Center=Zero_Level + (One_Level-Zero_Level)*AVG%REF/100

- this is the threshold control input value for threshold=average power (zero DC offset)

New conditions:

PRX = New RX input power

ERDB = ER (in dB) of the new RX input signal

AVG% = Average Power % of the new RX input signal (per Appendix B.)

ER_correction = (10^(ERDB/10)-1)*(10^(ERDBREF/10)+1)

(10^(ERDB/10)+1)*(10^(ERDBREF/10)-1)

OneZero_New = (One_Level-Zero_Level)*10^((PRX-PRXREF)/10)*ER_correction

K%_Threshold_Value = OneZero_New *(K-AVG%)/100 + Threshold_Center

- this is the threshold control input value for K% threshold under the new conditions

11 Appendix D: List of companies belonging to OIF when document was approved

ADVA Optical Networking
Aevix Systems
Agere Systems
Agilent Technologies
Alcatel
Altera
AMCC
Analog Devices
Anritsu
Apogee Photonics, Inc.
AT&T
Avici Systems
Azna
Bookham
Booz-Allen & Hamilton
Broadcom
China Telecom
Ciena Corporation
Cisco Systems
CoreOptics
Cortina Systems
Cypress Semiconductor
Data Connection
Department of Defense
Deutsche Telekom
Elisa Communications
Ericsson
Essex Corporation
Finisar Corporation
Flextronics
Force 10 Networks
Foxconn
France Telecom
Freescale Semiconductor
Fujitsu
Furukawa America
Hi/fn
Huawei Technologies
IBM Corporation
IDT
Infinera
Intel
IP Infusion
JDSU
KDDI R&D Laboratories
Kodeos Communications
KT Corporation
Lambda Optical Systems
LSI Logic
Lucent
MergeOptics GmbH
Mindspeed
MITRE Corporation
Mitsubishi Electric Corporation
Molex
Motorola
NEC
Nortel Networks
NTT Corporation
Opnext
Optovia
OpVista Inc
PMC Sierra
Radisys Corp
Redfern Integrated Optics, Inc.
Sandia National Laboratories
Santur
Scintera Networks
Siemens
Silicon Laboratories
Silicon Logic Engineering
StrataLight Communications
Sun Microsystems, Inc.
Sycamore Networks
Syntune
Tektronix
Telcordia Technologies
Telecom Italia Lab
Tellabs
TeraSea
Texas Instruments
Time Warner Cable
Toshiba Corporation
Transwitch Corporation
Tyco Electronics
Verizon
Vitesse Semiconductor
Xelerated
Xilinx