System z

# Fibre Channel Connection (FICON) I/O Interface Physical Layer

SA24-7172-08

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**Note**

Before using this information and the product it supports, read the information in "Safety" on page v, Appendix D, "Notices," on page 29, and *IBM Systems Environmental Notices and User Guide, Z125-5823*.

This edition, SA24-7172-08, applies to fiber optic channel links, which includes both single-mode and multimode fibre channel connection links. This edition replaces SA24-7172-07.

There might be a newer version of this document in a PDF file available on Resource Link. Go to *http://www.ibm.com/servers/resourcelink* and click Library on the navigation bar. A newer version is indicated by a lowercase alphabetic letter following the form number suffix. For example: 00a, 00b, 01a, 01b.

# Contents

# Safety

## Safety notices

Safety notices may be printed throughout this guide. **DANGER** notices warn you of conditions or procedures that can result in death or severe personal injury. **CAUTION** notices warn you of conditions or procedures that can cause personal injury that is neither lethal nor extremely hazardous. **Attention** notices warn you of conditions or procedures that can cause damage to machines, equipment, or programs.

There are no **DANGER** notices in this guide.

## World trade safety information

Several countries require the safety information contained in product publications to be presented in their translation. If this requirement applies to your country, a safety information booklet is included in the publications package shipped with the product. The booklet contains the translated safety information with references to the US English source. Before using a US English publication to install, operate, or service this IBM® product, you must first become familiar with the related safety information in the *Systems Safety Notices*, G229-9054. You should also refer to the booklet any time you do not clearly understand any safety information in the US English publications.

## Laser safety information

All System z® models can use I/O cards such as PCI adapters, ESCON®, FICON®, Open Systems Adapter (OSA), InterSystem Coupling-3 (ISC-3), or other I/O features which are fiber optic based and utilize lasers or LEDs.

## Laser compliance

All lasers are certified in the US to conform to the requirements of DHHS 21 CFR Subchapter J for Class 1 or Class 1M laser products. Outside the US, they are certified to be in compliance with IEC 60825 as a Class 1 or Class 1M laser product. Consult the label on each part for laser certification numbers and approval information.

**CAUTION:**
**Data processing environments can contain equipment transmitting on system links with laser modules that operate at greater than Class 1 power levels. For this reason, never look into the end of an optical fiber cable or open receptacle. (C027)**

**CAUTION:**
**This product contains a Class 1M laser. Do not view directly with optical instruments. (C028)**

# About this publication

This publication provides the I/O interface physical link characteristics for optical signal transmission and reception of fibre channel standard interfaces on IBM servers. This publication refers to both the single-mode and multimode fibre channel links. Although it contains general information relating to fiber optic cables, components, and optical fiber data processing environments, it includes only what is supported for a fibre channel standard link. It should be used as reference information for anyone requiring the physical link characteristics of a fibre channel connection I/O interface.

This document specifies the physical layer for point-to-point connectivity between a FICON adapter card in the server and a FICON device, which may include a storage device, a FICON switch, or a distance extension device, such as a Dense Wavelength Division Multiplexor (DWDM) product. If a switch or distance extension device is in the path, that physical layer is separate and not covered by this document. The specification for that portion of the link is owned by the manufacturer of that product.

This publication contains 3 chapters and 4 appendixes:
- Chapter 1, “Summary”, provides a brief introduction to fiber optic information transfer.
- Chapter 2, “The Multimode Physical Layer” describes the physical and optical requirements in a multimode link.
- Chapter 3, “The Single-Mode Physical Layer” describes the physical and optical requirements in a single-mode link.
- Appendix A, “Test Methods” describes optical measurement procedures.
- Appendix B, “Spectral Width and Center Wavelength Examples” contains graphs referencing the maximum spectral width and center wavelength for 1.0625 Gbps.
- Appendix C, “Normative References” lists supported fiber optic test procedures (FOTPs).
- Appendix D, “Notices” contains legal notices and trademark information for IBM publications.

A **Glossary** is provided at the back of this publication for your convenience.

## Where to find more information

The following publications contain information related to the information in this publication:
- *Introducing Enterprise Systems Connection*, GA23-0383, provides a summary of the products and services that are part of the ESCON environment.
- *Enterprise Systems Architecture/390 ESCON I/O Interface*, SA22-7202, contains information that might be of interest to designers and manufacturers of equipment to be attached to an IBM server.
- *Link Fault Isolation*, G229-9021 contains information used to isolate link faults when the environment does not use the ESCON Analyzer.
- *Planning for Fiber Optic Links (ESCON, FICON, Coupling Links, and Open System Adapters)*, GA23-0367, provides information that can be used when planning for fiber optic links.
- *Maintenance Information for Fiber Optic Links (ESCON, FICON, Coupling Links, and Open System Adapters)*, SY27-2597, provides problem determination, verification, and repair procedures for fibre channel standard links.
- *Maintenance Information for FiberDistributed Data Interface Links*, SY27-0331, provides problem determination, verification, and repair procedures for FDDI links.

Fibre channel links are designed to be optically compatible with the FC-0 or physical layer industry standard*ANSI Fibre Channel Physical Interfaces (FC-PI-2)* , published by the American National Standards

 

Institute, New York, NY. Although this standard uses the term "fiber" in reference to both optical fiber and copper media, only fiber optic attachments are supported on IBM servers.

These links do not require the open fiber control (OFC) interface for laser safety. Although the ANSI standard does not include the use of long wavelength (1300 nm) lasers on multimode fiber, IBM servers will support this combination as specified in Chapter 2, "Multimode physical layer," on page 3. This specification closely follows the corresponding standard for Gigabit Ethernet, ANSI/IEEE 802.3Z.

## Revisions

A technical change to the text is indicated by a vertical line ( | ) to the left of the change.

## Accessibility

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# Chapter 1. Introduction

This publication applies to both single-mode and multimode fibre channel links. There are two distinct physical layers that can be used as part of a fiber optic channel link: multimode and single-mode. The multimode physical layer is intended for use with either 62.5/125-micrometer or 50/125-micrometer multimode fiber optic cable. The single-mode physical layer is intended for use with dispersion-unshifted, single-mode fiber optic cable. Each physical layer provides a common, compatible I/O interface that products can use to communicate with each other through light pulses sent over multimode or single-mode optical transmission fibers.

## Fiber optic information transfer

Generally, an individual link consists of a transmitter and receiver at each device capable of sending and receiving optical data pulses over a duplex fiber transmission cable. A duplex link uses one fiber to transmit data to a device and the other fiber to receive data from a device. Both fibers in the link are simultaneously active.

Typically, a point-to-point link uses a trunk cable, with short sections of duplex jumper cable, either SC duplex or LC duplex, at either end of the trunk for routing within the building or machine room (see Figure 1 on page 2). A point-to-point link is not required to be constructed with this configuration and can have alternate forms. For example, a short link could have only one jumper cable and no trunk cable. Distribution panels provide a central location for attachment of trunk and jumper cables and can be mounted in a rack, wiring closet, or on a wall.

For attachment to a fibre channel link device, the end of the transmission cable is terminated in a duplex connector that mates with a duplex receptacle on the device. When attached, the connector is optically coupled to the transmitter and receiver, and the device can send and receive optical signals over the cable.

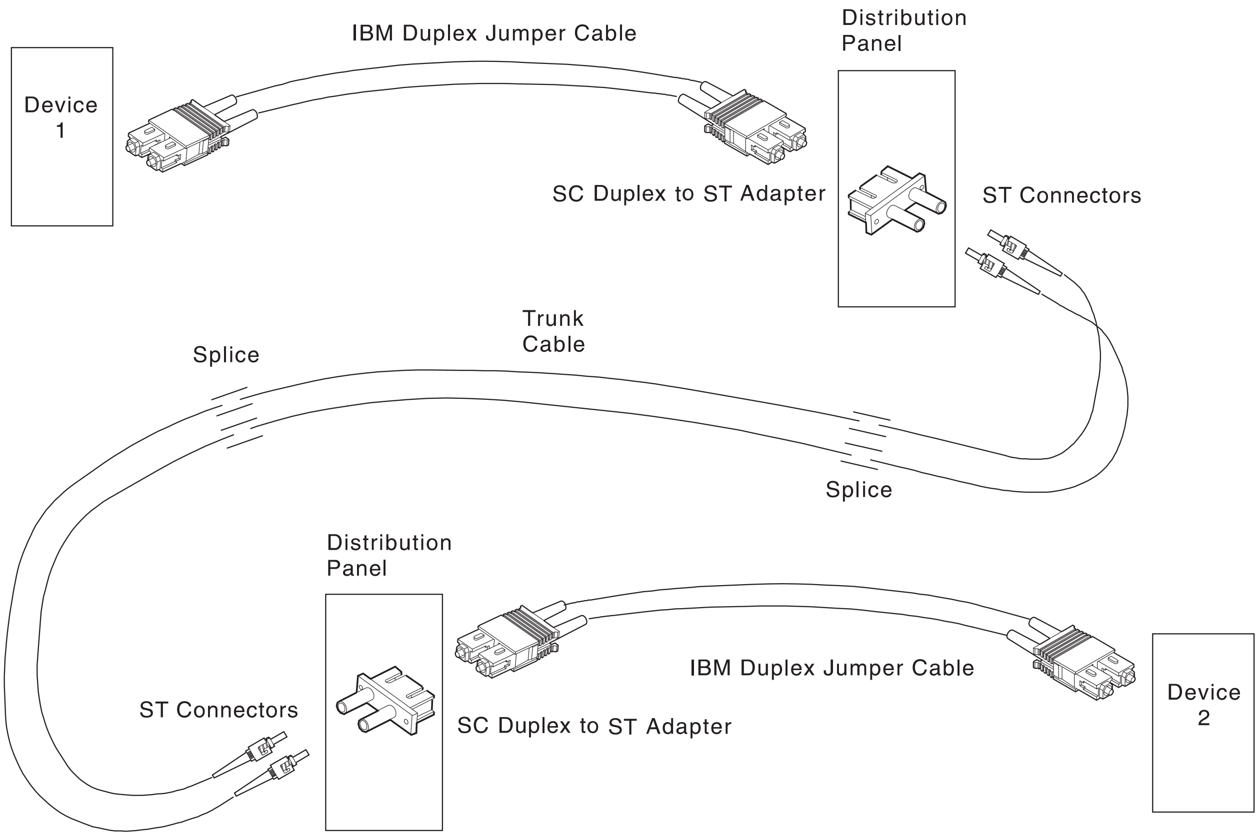



*Figure 1. Example of a fiber optic link*

## Data transmission

The data transmitted over a link is based on an 8-bit/10-bit nonreturn-to-zero code. See*Enterprise Systems Architecture/390 ESCON I/O Interface* or the *ANSI Fibre Channel Physical Interfaces (FC-PI-2)*, published by the American National Standards Institute, New York, NY. In the 8B/10B transmission code, the high optical power level designates a 1-bit, while the low optical power level designates a 0-bit. The idle function or one of the sequence functions is sent repetitively during periods when information is not being sent. The data-transmission rates on both multimode and single-mode channels are:

- 1.0625 Gbps, which is equivalent to 100 MBytes
- 2.1250 Gbps, which is equivalent to 200 MBytes.
- 4.2500 Gbps, which is equivalent to 400 MBytes.

Devices exist that only work at 1.0625 Gbps. Later devices only work at 1.0625 Gbps and 2.125 Gbps. The newest devices that function at 4.25 Gbps also work at the slower data rates. They will autonegotiate with the attached device to choose the fastest common data rate.

# Chapter 2. Multimode physical layer

The multimode physical layer allows the operating distances outlined in Table 1. It is important that a multimode link consist of only one fiber type; for example, all 50/125 micron fiber or all 62.5/125 micron multimode fiber. Mixed fiber types in a multimode link are not supported. The 50/125 micron fiber is now available in both standard (500 MHz•km) and high bandwidth (2000 MHz•km). Mixing the two is not supported.

*Table 1. Operating ranges for multimode links*

| Multimode Core Size | 100-M5-SN-I (1.0625 Gbps) | 200-M5-SN-I (2.125 Gbps) | 400-M5-SN-I (4.250 Gbps) | 800-M5-SN-S (8.500 Gbps) |
|---|---|---|---|---|
| 50/125 µm (500 MHz•km) | 0.5 – 500 m | 0.5 – 300 m | 0.5 – 150 m | 0.5 – 50 m |
| 50/125 µm (2000 MHz•km) | 0.5 – 860 m | 0.5 – 500 m | 0.5 – 270 m | 0.5 – 150 m |
| 62.5/125 µm | 0.5 – 300 m | 0.5 – 150 m | 0.5 – 70 m | 0.5 – 21 m |

*Table 2. Center wavelengths for multimode links*

| Multimode Core Size | 100-M5-SN-I (1.0625 Gbps) | 200-M5-SN-I (2.125 Gbps) | 400-M5-SN-I (4.250 Gbps) | 800-M5-SN-S (8.500 Gbps) |
|---|---|---|---|---|
| 50/125 µm (500 MHz•km) | 770 – 860 nm | 830 – 860 nm | 830 – 860 nm | 840 – 860 nm |
| 50/125 µm (2000 MHz•km) | 840 – 860 nm | 840 – 860 nm | 840 – 860 nm | 840 – 860 nm |
| 62.5/125 µm | 770 – 860 nm | 830 – 860 nm | 830 – 860 nm | 840 – 860 nm |

The use of LX multimode fiber links will require the appropriate mode conditioning patch cable or equivalent installed on both ends of a duplex link (the mode conditioner must be plugged directly into the optical transceiver on the adapter card, it cannot be inserted at a patch panel or elsewhere in the middle of a link). The mode conditioning patch cable is a special fiber optic jumper cable which contains both single-mode (yellow jacket) and multimode (orange jacket) optical fiber. A different mode conditioner is required for operation with 50/125-µm or 62.5/125-µm multimode trunk fiber cable. These cables, along with the appropriate duplex adapters, are available from IBM.

**Note:** In some fiber optic applications, it is possible to use a long wavelength (1300 nm) single-mode laser adapter with multimode fiber by placing a special device known as an optical-mode conditioner at both ends of the link. The optical mode conditioner resembles a standard 2 meter jumper cable, and is sometimes known as a mode conditioning patch (MCP) cable. Note that MCP is only supported at 1.0625 Gbps. As shown in Figure 2 on page 4, the MCP is unique in that it contains both single-mode (yellow) and multimode (orange) fibers in a single jumper cable assembly. Without the MCP, it is not possible to use a single-mode laser transmitter over multimode fiber because the laser source does not launch an equal amount of optical power into all modes of the fiber; this leads to excessive dispersion of the data pulses, and the link will not function. The MCP is designed to “condition” the laser launch so that the optical power fills all modes of the fiber equally.

The MCP is installed on both ends of a link, and occupies the same space as a standard 2 meter jumper cable. Adapter kits containing the MCPs and suitable duplex couplers for attachment to the existing ESCON multimode cable infrastructure are available from IBM. Different MCPs are required for 50.0 micron or 62.5 micron multimode fiber.

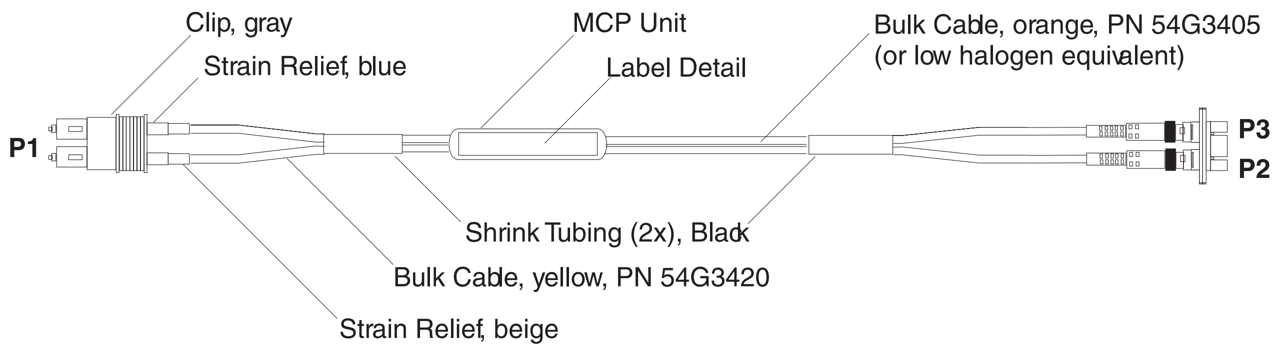



*Figure 2. Mode conditioner patch (MCP) cable*

## SX multimode output interface

Table 3 defines the serial optical signal at the multimode duplex receptacle when coupled into a multimode duplex jumper cable. The parameters specified are based on the requirement that the bit error rate does not exceed $10^{-12}$, including operation at the minimum interface power level. The use of a *coherent* light source, such as a laser diode, is required.

*Table 3. SX 50/125 µm and 62.5/125 µm multimode output interface optical signal*

| Parameter | Unit | 100-M5-SN-I (1.0625 Gbps) | 200-M5-SN-I (2.125 Gbps) | 400-M5-SN-I (4.250 Gbps) | 800-M5-SN-S (8.500 Gbps) |
|---|---|---|---|---|---|
| Average power, maximum[1] | dBm | | | | |
| Average power, minimum [2] | dBm | -10 | -10 | -9 | -8.2 |
| Center wavelength, minimum [3] | nm | 770 | 830 | 830 | 840 |
| Center wavelength, maximum | nm | 860 | 860 | 860 | 860 |
| RMS spectral width, maximum | nm | 1.0 | 0.85 | 0.85 | 0.65 |
| Rise/Fall Time (20-80%), maximum [4] | ps | 300 | 150 | 90 | Note 7 |
| Optical Modulation Amplitude (OMA), maximum [5] | mW | 0.156 | 0.196 | 0.247 | 0.302 |
| Relative intensity noise ($RIN_{12}$) [6] | dB/Hz | -116 | -117 | -118 | -128 |

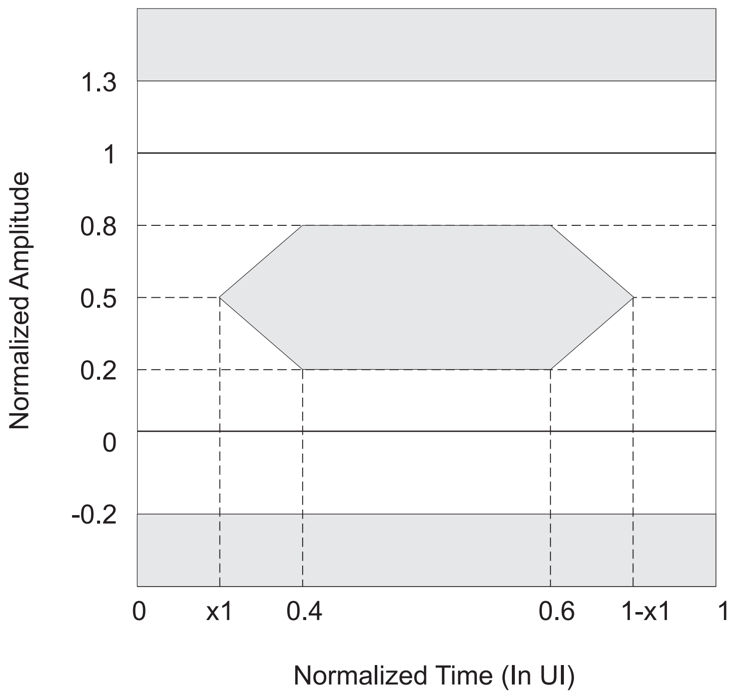
**Notes®:**

1. Lesser of class 1 laser safety limits (CDRH and EN 60825) or receiver power, maximum.
2. Based on any valid 8B/10B code pattern. The length of jumper cable between the output interface and the instrumentation is 4 meters.
3. If using the higher bandwidth cable option of 2000 MHz•km in (see *ANSI FC-PI-2*), the center wavelength minimum is further restricted to 840 nm.
4. Optical rise and fall time specifications are based on the unfiltered waveforms. For the purpose of standardizing the measurement method, measured waveforms shall conform to the Transmitter Eye Diagram Mask as defined in ANSI FC-PI-2. If a filter is needed to conform to the mask, the filter response effect should be removed from the measured rise and fall times using the equation:
   $T_{RISE/FALL} = [(T_{RISE/FALL\_MEASURED})^2 - (T_{RISE/FALL\_FILTER})^2]^{1/2}$
   The optical signal may have different rise and fall times. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson Filter. See the *ANSI FC-PI-2* standard.
5. Optical Modulation Amplitude (OMA) values are peak-to-peak. OMA is defined in terms of Extinction Ratio (ER) and optical average power (Pavg), which can be derived from the equation OMA = 2Pavg ((ER-1)/(ER+1)). The specified OMA at 1.0625 Gbps is equivalent to an average power of -9 dBm at ER = 9.
6. See Appendix A, “Test methods,” on page 21.
7. Transmitter deterministic performance is controlled by TWDP.

## Multimode eyemask diagram, LX and SX

The transmitter and receiver output signals must conform to the eyemask defined in Fibre Channel FC-PI Rev. 12 for 1062.5 Mbps data rates. The fibre channel eyemask follows. A low-pass filter is recommended for the transmitter (between scope and O/E converter), in order to eliminate the relaxation oscillation of the laser during measurement. A fourth-order Bessel Thompson filter is recommended for this measurement with cutoff frequency equal to 0.75 times the bit rate.

The mask of the transmitter eye diagram is shown in Figure 3.




**Note:** x1 shall be half the value given for total jitter at the gamma T point. The test or analysis shall include the effects of a single-pole, high-pass frequency-weighting function that progressively attenuates jitter at 20 dB/decade below a frequency of bit rate/1 667. The value of x1 applies at a total jitter probability of 10-12. At this level of probability, direct visual comparison between the mask and actual signals is not a valid method for determining compliance with the jitter output requirements.

*Figure 3. Eyemask diagram*

## SX multimode input interface

Table 4 specifies the input interface requirements. To assist in fault isolation, the input interface activates a loss-of-signal (LOS) state when the optical data cannot be detected.

*Table 4. SX 50/125 µm and 62.5/125 µm multimode input interface characteristics*

| Parameter | Unit | 100-M5-SN-I (1.0625 Gbps) | 200-M5-SN-I (2.125 Gbps) | 400-M5-SN-I (4.250 Gbps) | 800-M5-SN-S (8.500 Gbps) |
|---|---|---|---|---|---|
| Saturation level (Pavg received), maximum [1] | dBm | 0 | 0 | 0 | 0 |
| Optical Modulation Amplitude (OMA) (sensitivity), minimum [3] | mW | 0.031 | 0.049 | 0.061 | 0.076 |
| Return loss, minimum [2] | dB | 12 | 12 | 12 | 12 |

**Notes:**

1. Based on any valid 8B/10B code pattern measured at, or extrapolated to, $10^{-12}$ BER. Must meet this specification with worst-case conditions as specified in Table 3 on page 5 for the output interface and Table 5 on page 8 for the fiber optic link.
2. This measurement is made using a 4-meter single-mode duplex jumper cable and includes only the power in the fundamental mode of the single-mode fiber.
3. FC-PI specifies receiver Optical Modulation Amplitude (OMA) instead of sensitivity and Extinction Ratio (ER). Receiver sensitivity is the minimum optical average power (Pavg) required, which can be derived from the equation Pavg = OMA ((ER+1)/2 x (ER-1)). The specified OMA at 1.0625 Gbps is equivalent to an average power of -17 dBm at ER=9dB.

## SX multimode link specifications

Table 5 lists the specifications for links using multimode fiber cable. The trunk cable to which the IBM jumper cables are connected must have optical properties that conform to the specifications in the table.

*Table 5. Maximum link loss (at 850 nanometer (nm) wavelength)*

| Data Rate | Maximum Link Length in km (Miles) [1] | Maximum Link Loss (dB) [2] | Trunk Size (µm) | Minimum Trunk Modal Bandwidth (MHz•km) |
|---|---|---|---|---|
| 1.0625 Mbps | 0.50 (0.311) | 3.85 | 50.0 | 500 |
| 1.0625 Mbps | 0.86 (0.534) | 4.62 | 50.0 | 2000 |
| 2.1250 Mbps | 0.30 (0.186) | 2.62 | 50.0 | 500 |
| 2.1250 Mbps | 0.50 (0.311) | 3.31 | 50.0 | 2000 |
| 4.2500 Mbps | 0.15 (0.093) | 2.06 | 50.0 | 500 |
| 4.2500 Mbps | 0.38 (0.23) | 2.88 | 50.0 | 2000 |
| 8.5000 Mbps | 0.050 (0.03) | 1.68 | 50.0 | 500 |
| 8.5000 Mbps | 0.15 (0.09) | 2.04 | 50.0 | 2000 |
| 1.0625 Mbps | 0.30 (0.186) [3] | 3.00 | 62.5 | 200 |
| 2.1250 Mbps | 0.15 (0.093) | 2.10 | 62.5 | 200 |
| 4.2500 Mbps | 0.07 (0.043) | 1.78 | 62.5 | 200 |
| 8.5000 Mbps | 0.021 (0.01) | 1.58 | 62.5 | 200 |

**Notes:**
1. The maximum link length includes both jumper cables and trunk cables.
2. See “Link loss verification” on page 22 for details on link loss verification.
3. The maximum link distance is 0.2 km if modal bandwidth is 160 (MHz•km).

## LX multimode output interface

Table 6 identifies the serial optical signal at the multimode duplex receptacle when coupled into a multimode duplex jumper cable. The parameters specified are based on the requirement that the bit error rate does not exceed $10^{-12}$, including operation at the minimum interface power level. The use of a *coherent* light source, such as a laser diode, is required.

**Note:** MCP is only supported at 1.0625 Gbps data rate.

*Table 6. Multimode output interface optical signal*

| Parameter | Unit | Minimum | Maximum |
|---|---|---|---|
| Average Power to SMF [1] | dBm | -9.5 | -4 |
| Center wavelength [4] | nm | | |
| Spectral width (RMS) [4] | nm | | |
| Rise/Fall time (20-80%) [1,2] | ps | | 320 |
| Optical Modulation Amplitude [5] | mW | | 0.189 |
| Relative intensity noise ($RIN_{12}$) [3] | dB/Hz | | -116 |

**Notes:**

1. Based on any valid 8B/10B code pattern. The length of jumper cable between the output interface and the instrumentation is 4 meters.
2. The minimum frequency response bandwidth range of the optical waveform detector is 800 kHz to 1 GHz.
3. See "Relative Intensity Noise (RIN) measurement" on page 21.
4. Spectral width may be increased based on center wavelength and distance trade-offs. Link budget analysis is required for any such change. Trade-offs are available between spectral width, central wavelength, and minimum Optical Modulation Amplitude (OMA). See Appendix B, "Spectral width and center wavelength examples," on page 23.
5. Optical Modulation Amplitude (OMA) is defined in terms of Extinction Ratio (ER) and optical average power (Pavg), which can be derived from the equation OMA = 2Pavg ((ER-1)/(ER+1)). The specified OMA is equivalent to an average power of -9 dBm at ER = 9dB.

## LX multimode input interface

Table 7 specifies the input interface requirements. To assist in fault isolation, the input interface activates a loss-of-signal (LOS) state when the optical data cannot be detected.

*Table 7. Multimode input interface characteristics*

| Parameter | Unit | Minimum | Maximum |
|---|---|---|---|
| Saturation level [1] | dBm | | -3 |
| Optical Modulation Amplitude (sensitivity) [3] | mW | 0.015 | |
| Return Loss [2] | dB | 12 | |

**Notes:**

1. Based on any valid 8B/10B code pattern measured at, or extrapolated to, $10^{-12}$ BER. Must meet this specification with worst-case conditions as specified in Table 6 on page 9 for the output interface and Table 8 for the fiber optic link.
2. This measurement is made using a 4-meter single-mode duplex jumper cable and includes only the power in the fundamental mode of the single-mode fiber.
3. FC-PI specifies receiver Optical Modulation Amplitude (OMA) instead of sensitivity and Extinction Ratio (ER). Receiver sensitivity is the minimum optical average power (Pavg) required, which can be derived from the equation Pavg = OMA ((ER+1)/2 *(ER-1)). The specified OMA is equivalent to an average power of -20 dBm at ER = 9dB.

## LX multimode link specifications

Table 8 lists the specifications for links using multimode fiber cable. The trunk cable to which the IBM jumper cables are connected must have optical properties that conform to the specifications in the table.

*Table 8. Maximum link loss (at 1300-nanometer wavelength)*

| Maximum Link Length in km (Miles) | Maximum Link Loss (dB) | Trunk Size (µm) | Minimum Trunk Modal Bandwidth (MHz•km) |
|---|---|---|---|
| 0.55 (0.34) | 5.0 | 50.0 | 500 |
| 0.55 (0.34) | 5.0 | 62.5 | 500 |

**Notes:**

1. The maximum link length includes both jumper cables and trunk cables.
2. See “Link loss verification” on page 22 for details.

## Multimode trunk cable optical specifications

These specifications are for multimode trunk cable support attachment of fibre channel devices:

*Table 9. 62.5/125-μm multimode trunk cable*

| | |
|---|---|
| Type of Fiber | Graded index with glass core and cladding |
| Operating wavelength | 1300 nm or 850 nm |
| Core diameter [1] | 62.5 ± 3.0 μm |
| Core noncircularity | 6% maximum |
| Cladding diameter [2] | 125 ± 3.0 μm |
| Cladding noncircularity | 2% maximum |
| Core and cladding offset | 3 μm maximum |
| Numerical aperture [3] | 0.275 ± 0.015 |
| Minimum modal bandwidth [4] | 200 MHz•km |
| Attenuation [5] | 0.5 dB/km at 1300 nm 4.0 dB/km at 850 nm |

**Notes:**

1. Measured in accordance with EIA 455 FOTP 58, 164, 167, or equivalent.
2. Measured in accordance with EIA 455 FOTP 27, 45, 48, or equivalent.
3. Measured in accordance with EIA 455 FOTP 47 or equivalent.
4. Measured in accordance with EIA 455 FOTP 51 or equivalent.
5. This attenuation is a typical value, not a specification. Use the actual dB/km attenuation value when completing a Calculated Link Loss Work Sheet. The total link loss, however, cannot exceed specifications in this manual.

*Table 10. 50/125-μm multimode trunk cable*

| | |
|---|---|
| Type of Fiber | Graded index with glass core and cladding |
| Operating wavelength | 1300 nm or 850 nm |
| Core diameter [1] | 50.0 ± 3.0 μm |
| Core noncircularity | 6% maximum |
| Cladding diameter [2] | 125 ± 3.0 μm |
| Cladding noncircularity | 2% maximum |
| Core and cladding offset | 3 μm maximum |
| Numerical aperture [3] | 0.200 ± 0.015 |
| Minimum modal bandwidth [4] | 500 MHz•km |
| Attenuation [5] | 0.5 dB/km at 1300 nm<br>4.0 dB/km at 850 nm |

**Notes:**

1. Measured in accordance with EIA 455 FOTP 58, 164, 167, or equivalent.
2. Measured in accordance with EIA 455 FOTP 27, 45, 48, or equivalent.
3. Measured in accordance with EIA 455 FOTP 47 or equivalent.
4. Measured in accordance with EIA 455 FOTP 51 or equivalent.
5. This attenuation is a typical value, not a specification. Use the actual dB/km attenuation value when completing a Calculated Link Loss Work Sheet. The total link loss, however, cannot exceed specifications in this manual.

## Multimode duplex jumper cable specifications

These specifications are for multimode duplex jumper cable support attachment to fibre channel devices:

*Table 11. Multimode duplex jumper cable*

| | |
|---|---|
| Type of Fiber | Graded index with glass core and cladding |
| Operating wavelength | 1300 nm or 850 nm |
| Core diameter [1] | 62.5 ± 3.0 µm or 50.0 ± 3.0 µm |
| Cladding diameter [2] | 125 ± 3.0 µm |
| Ferrule outer diameter | 2.4985 ±0.0016 mm |
| Numerical aperture [3] | 0.200 ± 0.015 |
| Minimum modal bandwidth [4] | 500 MHz•km |
| Attenuation | 0.5 dB/km maximum at 1300 nm<br>4.0 dB/km maximum at 1300 nm |
| Connector Color | Beige |
| Jacket color | Orange |

**Notes:**
1. Measured in accordance with EIA 455 FOTP 58, 164, 167, or equivalent.
2. Measured in accordance with EIA 455 FOTP 27, 45, 48, or equivalent.
3. Measured in accordance with EIA 455 FOTP 47 or equivalent.
4. Measured in accordance with EIA 455 FOTP 51 or equivalent.

## Multimode interface connection

Some multimode FICON links use the multimode fibre channel standard SC duplex connector (see Figure 4). This connector is polarized to prevent inverting the fiber connection to the interface. It is mechanically retained in a duplex receptacle by a latch that engages the receptacle when the connector is inserted. The mating, external dimensions, and interface requirements of the multimode duplex receptacle and multimode duplex connector may be found in the industry standard, *ANSI Fibre Channel Physical Interfaces (FC-PI-2)*, published by the American National Standards Institute, New York, N.Y.

Some multimode FICON links use the LC duplex connector (see Table 6 on page 9). This connector is polarized to prevent inverting the fiber connection to the interface. It is mechanically retained in a duplex receptacle by an RJ–45 type latch that engages the receptacle when the connector is inserted. Adapter kits are available from IBM to convert between SC duplex and LC duplex interfaces.

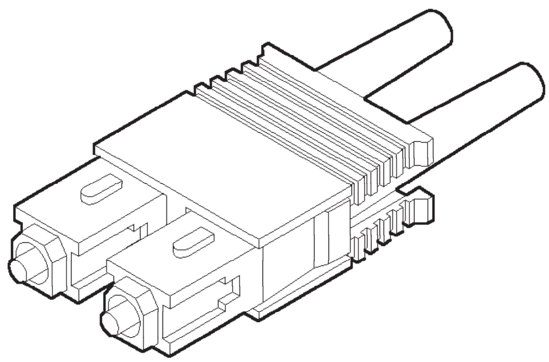


*Figure 4. Multimode fibre channel standard SC duplex connector*

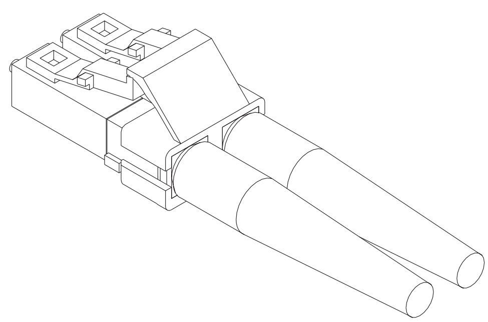


*Figure 5. LC duplex connector*

## Class 1 laser safety

Meeting the requirements for Class 1 certification is very important for an optical interconnect system in a computer environment due to the potential for customer exposure to laser radiation. See “Laser compliance” on page v for details of the compliance certification of the fibre channel standard modules.

# Chapter 3. Single-mode physical layer

The fibre channel single-mode physical layer allows links to extend up to 10 km (6.20 miles), without retransmission, using dispersion-unshifted, single-mode trunk fiber cable.

## Single-mode output interface

Table 12 defines the serial optical signal at the single-mode duplex receptacle when coupled into a single-mode duplex jumper cable. The parameters specified in this section are based on the requirement that the bit-error rate does not exceed $10^{-12}$, including operation at the minimum interface power level.

*Table 12. Single-mode output interface optical signal*

| Parameter | Unit | 100-SM-LC-L (1.0625 Gbps) | 200-SM-LC-L (2.125 Gbps) | 400-SM-LC-L (4.250 Gbps) | 400-SM-LC-M (4.250 Gbps) | 800-SM-LC-L (8.500 Gbps) |
|---|---|---|---|---|---|---|
| Distance, maximum | km | 10 | 10 | 10 | 4 | 10 |
| Average power, maximum [1] | dBm | | | | | |
| Average power, minimum [2] | dBm | -9.5 | -11.7 | -8.4 | -11.2 | -8.4 |
| Center wavelength, minimum [5] | nm | | | | | 1260 |
| Center wavelength, maximum [5] | nm | | | | | 1360 |
| RMS spectral width, maximum [5] | nm | | | | | |
| Rise/Fall Time (20-80%), maximum [3] | ps | 320 | 160 | 90 | 90 | |
| Optical Modulation Amplitude (OMA), maximum [5] | mW | | | | | |
| Relative intensity noise ($RIN_{12}$) [4] | dB/Hz | -116 | -117 | -118 | -120 | -128 |

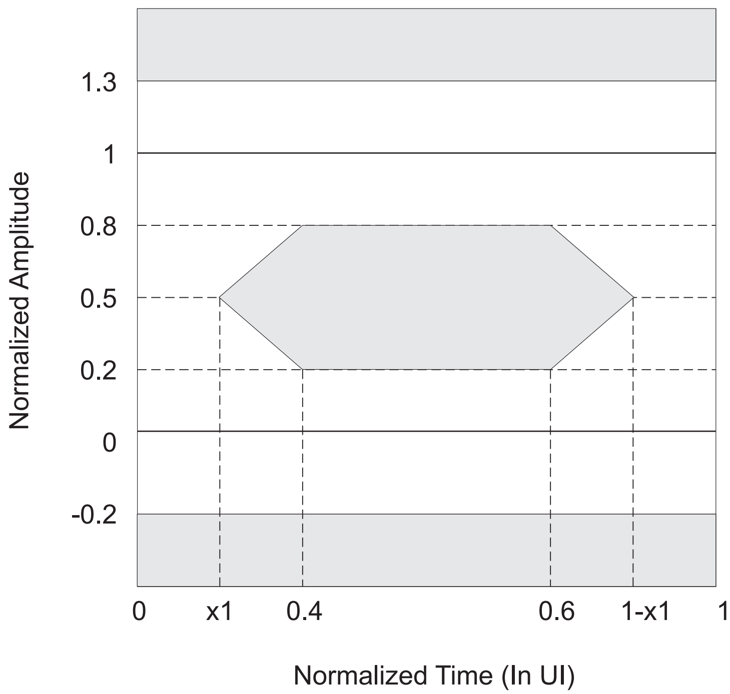
**Notes:**

1. Lesser of class 1 laser safety limits (CDRH and EN 60825) or receiver power, maximum.
2. Based on any valid 8B/10B code pattern. The length of jumper cable between the output interface and the instrumentation is 4 meters.
3. Optical rise and fall time specifications are based on the unfiltered waveforms. For the purpose of standardizing the measurement method, measured waveforms shall conform to the mask as defined in Figure 6 on page 16. If a filter is needed to conform to the mask, the filter response effect should be removed from the measured rise and fall times using the equation:
   $T_{RISE/FALL} = [(T_{RISE/FALL\_MEASURED})^2 - (T_{RISE/FALL\_FILTER})^2]^{1/2}$
   The optical signal may have different rise and fall times. Any filter should have an impulse response equivalent to a fourth order Bessel-Thomson Filter.
4. See Appendix A, “Test methods,” on page 21.
5. Spectral width may be increased based on center wavelength and distance trade-offs. Link budget analysis is required for any such change. Trade-offs are available between spectral width, central wavelength, and minimum Optical Modulation Amplitude (OMA). See Appendix B, “Spectral width and center wavelength examples,” on page 23.

## Eyemask diagram

The transmitter and receiver output signals must conform to the eyemask defined in Fibre Channel FC-PI Rev. 12 for 1062.5 Mbps data rates. The fibre channel eyemask follows. A low-pass filter is recommended for the transmitter (between scope and O/E converter), to eliminate the relaxation oscillation of the laser during measurement. A fourth-order Bessel Thompson filter is recommended for this measurement with cutoff frequency equal to 0.75 times the bit rate.

The mask of the transmitter eye diagram is shown in Figure 6.




**Note:** x1 shall be half the value given for total jitter at the gamma T point. The test or analysis shall include the effects of a single-pole, high-pass frequency-weighting function that progressively attenuates jitter at 20 dB/decade below a frequency of bit rate/1 667. The value of x1 applies at a total jitter probability of 10-12. At this level of probability, direct visual comparison between the mask and actual signals is not a valid method for determining compliance with the jitter output requirements.

*Figure 6. Eyemask diagram*

## Single-mode input interface

Table 13 specifies the input interface requirements.

*Table 13. Single-mode input interface characteristic*

| Parameter | Unit | 100-SM-LC-L (1.0625 Gbps) | 200-SM-LC-L (2.125 Gbps) | 400-SM-LC-L (4.250 Gbps) | 400-SM-LC-M (4.250 Gbps) | 800-SM-LC-L (4.250 Gbps) | 800-SM-LC-L (8.500 Gbps) |
|---|---|---|---|---|---|---|---|
| Saturation level (Pavg received), maximum[1] | dBM | -3 | -3 | -1 | -1 | -0.5 | +0.5 |
| Optical Modulation Amplitude (OMA) (sensitivity), minimum [3] | mW | 0.015 | 0.015 | 0.029 | 0.029 | 0.042 | 0.042 |
| Return loss, minimum [2] | dB | 12 | 12 | 12 | 12 | 12 | 12 |

**Notes:**
1. Based on any valid 8B/10B code pattern measured at, or extrapolated to, $10^{-12}$ BER. Must meet this specification with worst-case conditions as specified in Table 12 for the output interface and Table 14 for the fiber optic link.
2. This measurement is made using a 4-meter single-mode duplex jumper cable and includes only the power in the fundamental mode of the single-mode fiber.
3. FC-PI specifies receiver Optical Modulation Amplitude (OMA) instead of sensitivity and Extinction Ratio (ER). Receiver sensitivity is the minimum optical average power (Pavg) required, which can be derived from the equation Pavg = OMA ((ER+1)/2*(ER-1)). The specified OMA at 1.0625 Gbps is equivalent to an average power of -17 dBm at ER=9dB.

## Single-mode link specifications

Table 14 lists the specifications for links using 9/125-µm fiber cable. The trunk cable to which the IBM jumper cables are connected must have optical properties that conform to the specifications in the table.

*Table 14. Maximum link loss (at 1300-nanometer wavelength)*

| Link Type | Maximum Link Length in km (Miles) | Maximum Link Loss (dB) | Trunk Size (µm) |
|---|---|---|---|
| fibre channel | 10 | 7.8 | 9~10 |

**Notes:**
1. The maximum link length includes both jumper cables and trunk cables.
2. Single-mode connectors and splices must meet a minimum return loss specification of 12 dB.
3. In a single-mode jumper cable, the minimum distance between the connectors or splices is 4 meters (13.1 ft.).
4. In a single-mode trunk cable, the distance between the connectors or splices must be sufficient to ensure that only the lowest-order bound mode propagates.
5. See “Link loss verification” on page 22 for details on link loss verification.

## Single-mode trunk cable specifications

These specifications are for single-mode trunk cable support attachment to fiber optic channel devices:

| | |
|---|---|
| Type of fiber | Dispersion unshifted |
| Operating wavelength | 1270 to 1355 |
| Mode field diameter [1] | 8.7 to 10.0 |
| Core concentricity error [2] | 1.0 µm maximum |
| Cladding diameter [2] | 125 ±2.0 µm |
| Cladding noncircularity [2] | 2% maximum |
| Zero dispersion wavelength [3] | 1300-1322 nm (nominal 1310 nm) |
| Zero dispersion slope [3] | 0.095 ps/(nm2-km) maximum |
| Cutoff wavelength (λc) [4] | 1280 nm maximum |
| Cutoff wavelength (λcc) [5] | 1260 nm maximum |
| Attenuation above nominal [6] | 0.06 dB/km maximum |
| Attenuation [7] | 0.5 dB/km at 1300 nm |

**Notes:**
1. Measured in accordance with EIA 455 FOTP 164, 167, or equivalent.
2. Measured in accordance with EIA 455 FOTP 45, 48, or equivalent.
3. Measured in accordance with EIA 455 FOTP 168 or equivalent.
4. Measured in accordance with EIA 455 FOTP 80 or equivalent.
5. Measured in accordance with EIA 455 FOTP 170 or equivalent.
6. The maximum attenuation for wavelengths from 1270 to 1355 nm must not exceed the attenuation at 1310 nm by more than 0.06 dB/km. (Typically, this specification can be met by fiber with 1383-nm OH absorption peaks below 2 dB/km.)
7. This attenuation is a typical value, not a specification. Use the actual dB/km attenuation value when completing a Calculated Link Loss Work Sheet. The total link loss, however, cannot exceed 7 dB for an fibre channel link.

## Single-mode duplex jumper cable specifications

These specifications for single-mode duplex jumper cable support attachment to fiber optic channel devices:

| | |
|---|---|
| Type of fiber | Dispersion unshifted |
| Operating wavelength | 1270 to 1355 nm |
| Mode field diameter [1] | 8.7 to 10 µm |
| Ferrule outer diameter | 2.499 ±0.0005 mm |
| Zero dispersion wavelength [2] | 1310 to 1322 |
| Dispersion (1285-1300 nm) [2] | 3.5 ps/(nm-km) maximum |
| Cutoff wavelength [3] | 1260 nm maximum |
| Attenuation (1300 nm) [4] | 0.5 dB/km maximum |
| Connector color | Blue |
| Jacket color | Yellow |

**Notes:**

1. Measured in accordance with EIA 455 FOTP 164, 167, or equivalent.
2. Measured in accordance with EIA 455 FOTP 168 or equivalent.
3. Measured in accordance with EIA 455 FOTP 80 or equivalent.
4. Measured in accordance with EIA 455 FOTP 78 or equivalent.

## Single-mode interface connection

Some single-mode FICON links use the single-mode fibre channel standard SC duplex connector (see Figure 7). This connector is polarized to prevent inverting the fiber connection to the interface. It is mechanically retained in a duplex receptacle by a latch that engages the receptacle when the connector is inserted. The mating, external dimensions, and interface requirements of the single-mode duplex receptacle and single-mode duplex connector may be found in the industry standard *ANSI Fibre Channel Physical Interfaces (FC-PI-2)*, published by the American National Standards Institute, N.Y.

Some single-mode FICON links use the LC duplex connector (see Figure 8 on page 20). This connector is polarized to prevent inverting the fiber connection to the interface. It is mechanically retained in a duplex receptacle by an RJ–45 type latch that engages the receptacle when the connector is inserted. Adapter kits are available from IBM to convert between SC duplex and LC duplex interfaces.

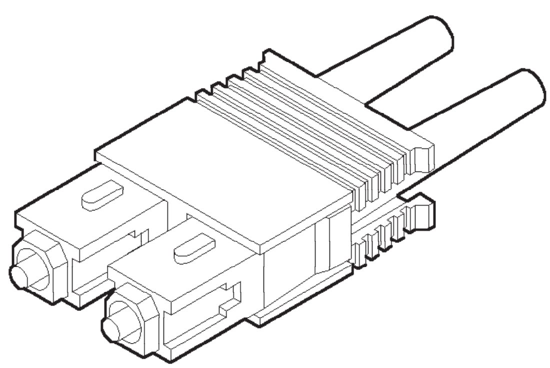


*Figure 7. Fibre channel single-mode duplex connector*

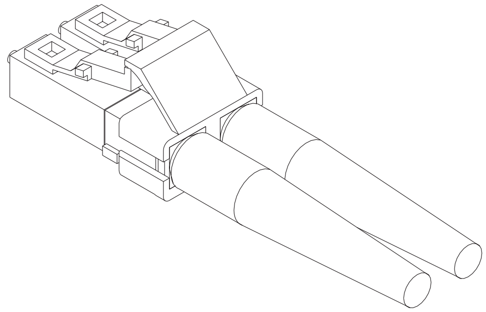


*Figure 8. Fibre channel single-mode duplex connector*

## Class 1 laser safety

Meeting the requirements for Class 1 certification is very important for an optical interconnect system in a computer environment due to the potential for customer exposure to laser radiation. See "Laser compliance" on page v for details of the compliance certification of the fibre channel modules.

# Appendix A. Test methods

## A.1 Eye-window measurement

The output interface optical eye-window (EW) measurement involves measuring the open eye-window on a bit-by-bit basis, using a BERT (bit error rate test) test set. The bit error rate (BER) is measured at various $T$ sub $_d$'s (decision points) within the eye pattern to ensure conformance to the eye-window specification.

The eye-window is given by:

$$EW = | T_d \text{ (max)} - T_o | + | T_o - T_d \text{ (min)} |$$

Where:

- $T_o$ = Center of the baud interval
- $T_d$ = BER decision point as referenced from $T_o$
- $T_d$ (max) = Rightmost decision point
- $T_d$ (min) = Leftmost decision point

For each position of $T_d$ from $T_d$(min) to $T_d$(max), a BER measurement is taken, giving the probability of error at the $T_d$ position. In effect, $T_d$ is swept across the eye pattern, measuring the probability of error at each point in the eye. The range of $T_d$ values that result in a BER $\leq 10^{-12}$ establishes the eye-window, and the smallest range from $T_o$ must be ≥ half the appropriate eye-window specification.

In practice, a BERT test set is used to generate and sweep the decision point (using the BERT clock in conjunction with a precise delay generator), to make the bit-by-bit error count and to calculate the measured BER. The center of the baud interval ($T_o$) pattern is the midpoint between positioning $T_d$ to the left and right edges of the eye to achieve a BER > $10^{-2}$ while transmitting a square wave pattern. Subsequent measurements are made while transmitting allowed 8/10 code patterns. The measured BER at $T_o$, $T_d$ (max), $T_d$ (min) must be $\leq 10^{-12}$ and the values of both ($T_d$ (max) - $T_o$) and ($T_o$ - $T_d$ (min)) must be greater than or equal to half the appropriate eye-window specification. All measurements are made with respect to a linear phase, low-pass filter with a 3 dB cutoff frequency of 800 MHz for single-mode fiber optic channel links and 300 MHz for multimode fiber optic channel links. It is important that the BERT retiming data latch be significantly faster than the timing resolution of interest.

A common practice used to save time is to measure the eye-window at higher probabilities (for example, $10^{-6}$) and then extrapolate to the eye-window at a $10^{-12}$ probability.

## Relative Intensity Noise (RIN) measurement

When lasers subject to reflection-induced noise effects are operated in a cable plant with a low optical return loss, the lasers will produce an amount of noise which is a function of the magnitude and polarization state of the reflected light. For ESCON or fibre channel standards, the magnitude of the reflected light can be 12 dB, resulting in the notation of $RIN_{12}$ for the relative intensity noise.

An example of a RIN test arrangement is shown in Figure 9 on page 22. The test cable between the device under test (DUT) and the detector forms an optical path having a single discrete reflection at the detector with the specified optical return loss. There must be only one reflection in the system because the polarization rotator can only adjust the polarization state of one reflection at a time. The polarization rotator should be adjusted to maximize the noise read by the power meter.

Two measurements are made by the photodetector: average optical power and noise. The average optical power is determined by measuring the average current (Ipd) through the detector. The noise is measured by ac-coupling the detector into the high frequency electrical power meter. A low-pass filter is used between the photodetector and the power meter to limit the noise measured to 800 MHz for single-mode fiber optic channel links and 300 MHz for multimode links.

In order to measure the noise, the modulation to the DUT must be turned off. You can calculate the RIN from the observed detector current and electrical noise using this equation:

$$RIN = 10 \log\left(\frac{P_e}{BW\ 25\ I_{pd}^2}\right) - G \ \ dB/Hz$$

Where:

| | |
|---|---|
| $I_{pd}$ | = Current® through the detector in amps |
| $P_e$ | = Electrical noise power in watts |
| BW | = Bandwidth of the measuring system in hertz |
| | = Low pass bandwidth of filter; high-pass bandwidth of dc blocking capacitor |
| G | = Gain in dB of any amplifier in the noise measurement path |

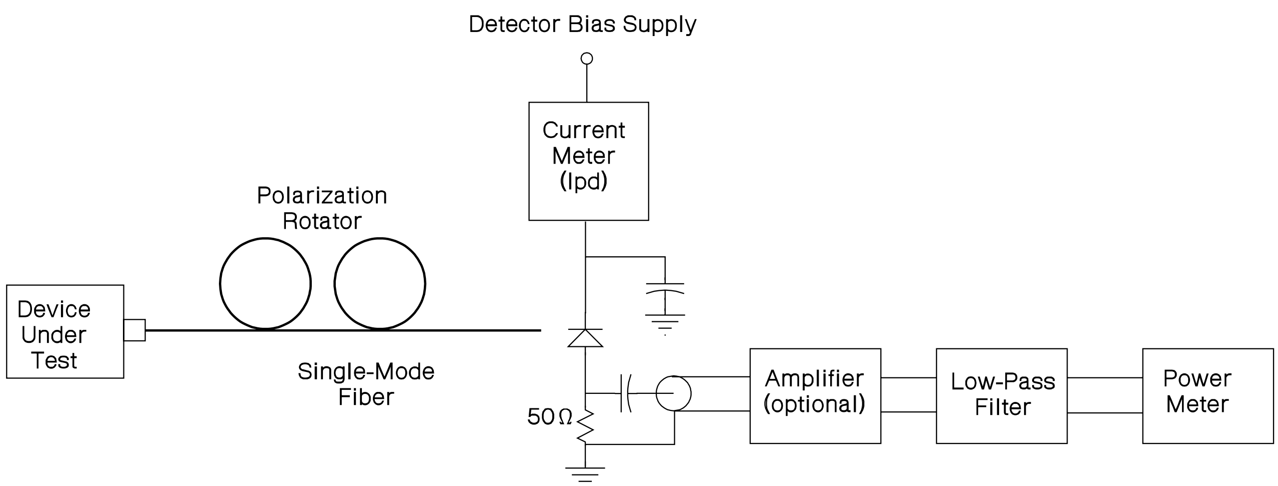



*Figure 9. Example of a RIN test setup*

## Link loss verification

See*Maintenance Information for Fiber Optic Links (ESCON, FICON, Coupling Links, and Open System Adapters)* for details on the link loss verification procedure for multimode and single-mode coupling facility links.

# Appendix B. Spectral width and center wavelength examples

To meet the link power budget, the transmitter can trade-off OMA, spectral width, and center wavelength as show in the following.

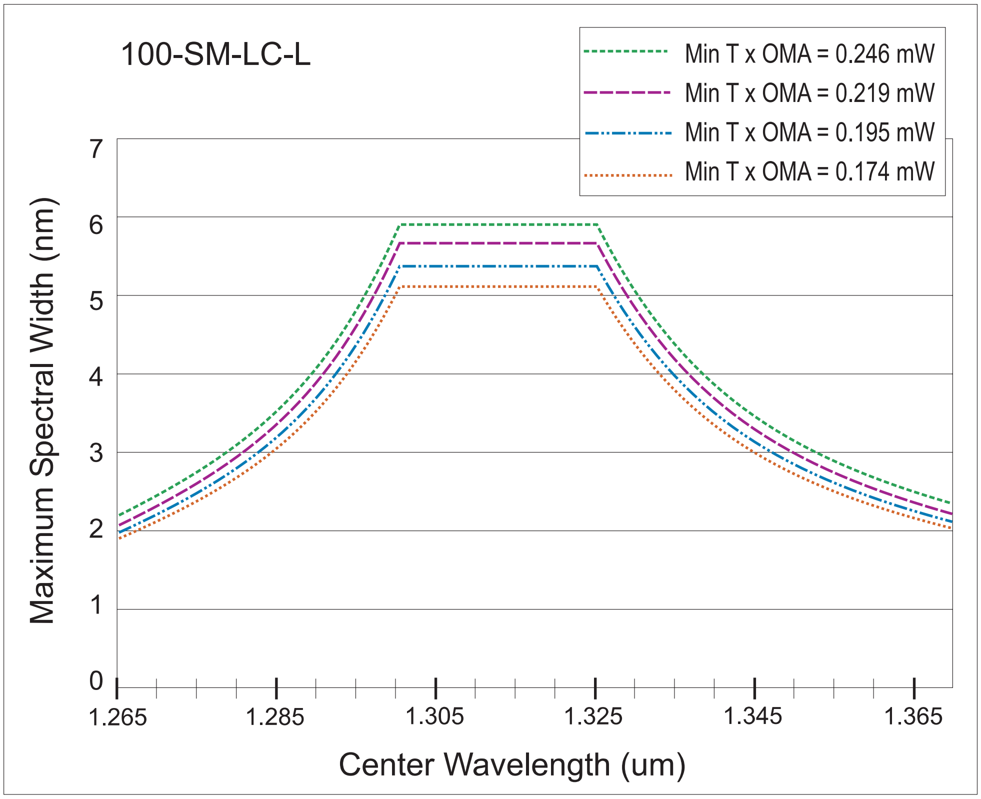



*Figure 10. 1.0625 Gbps single-mode 10 km link*

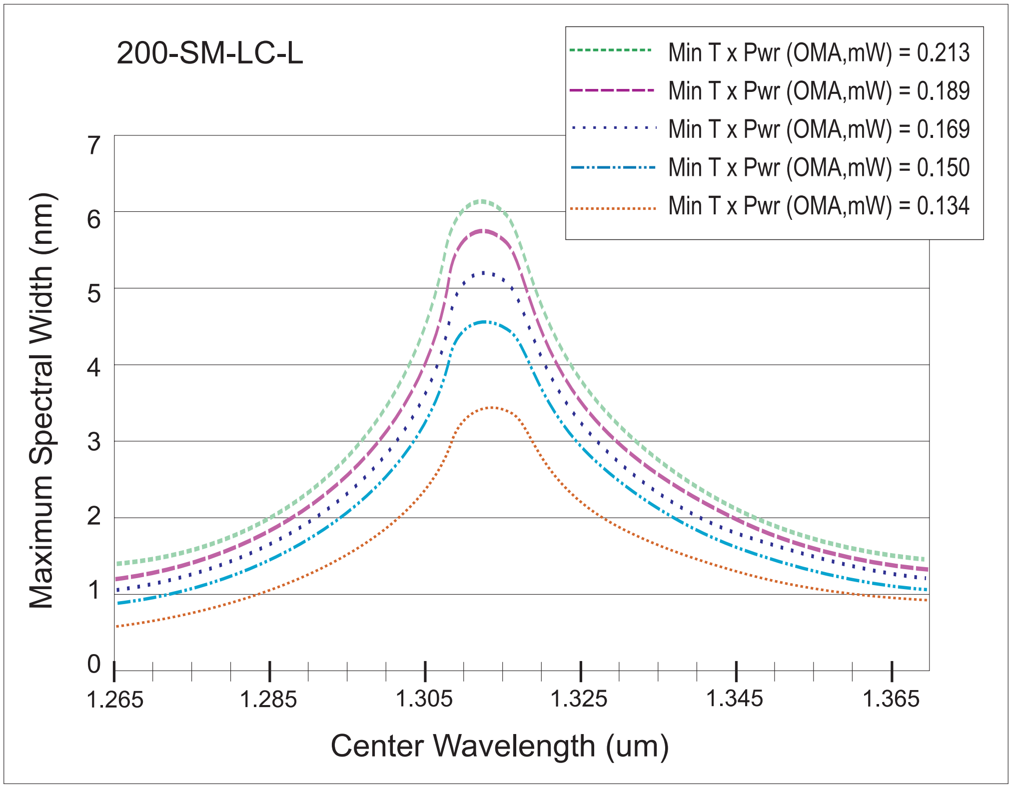



*Figure 11. 2.125 Gbps single-mode 10 km link*

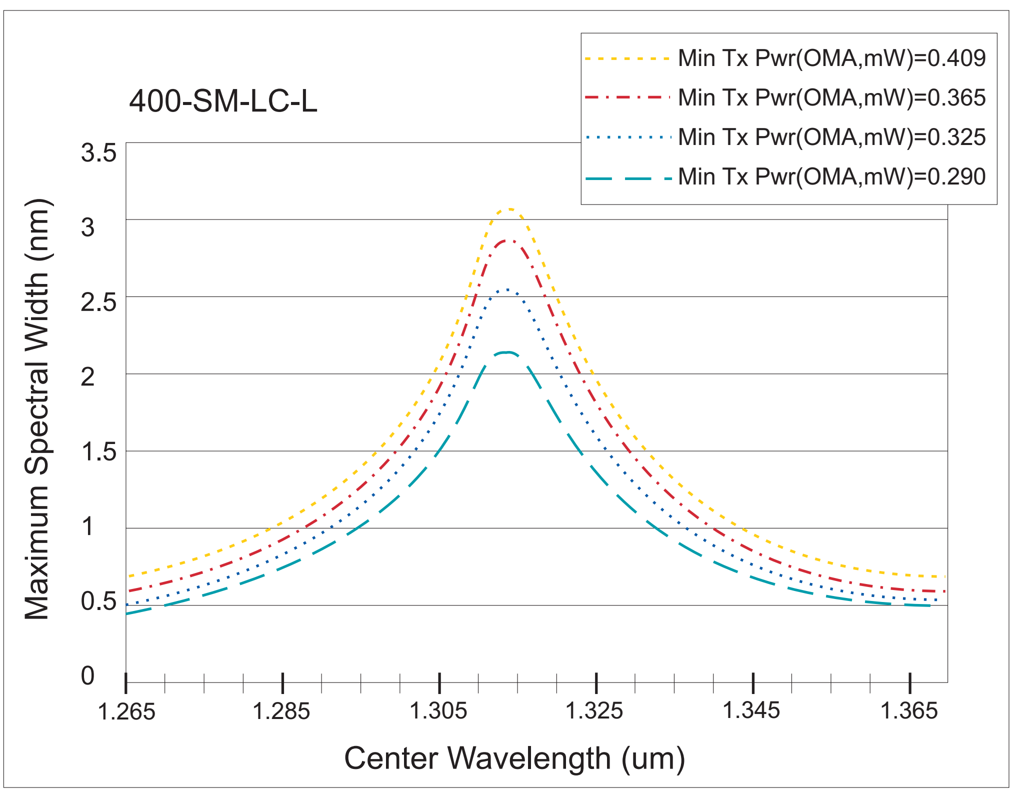



*Figure 12. 4.25 Gbps single-mode 10 km link*

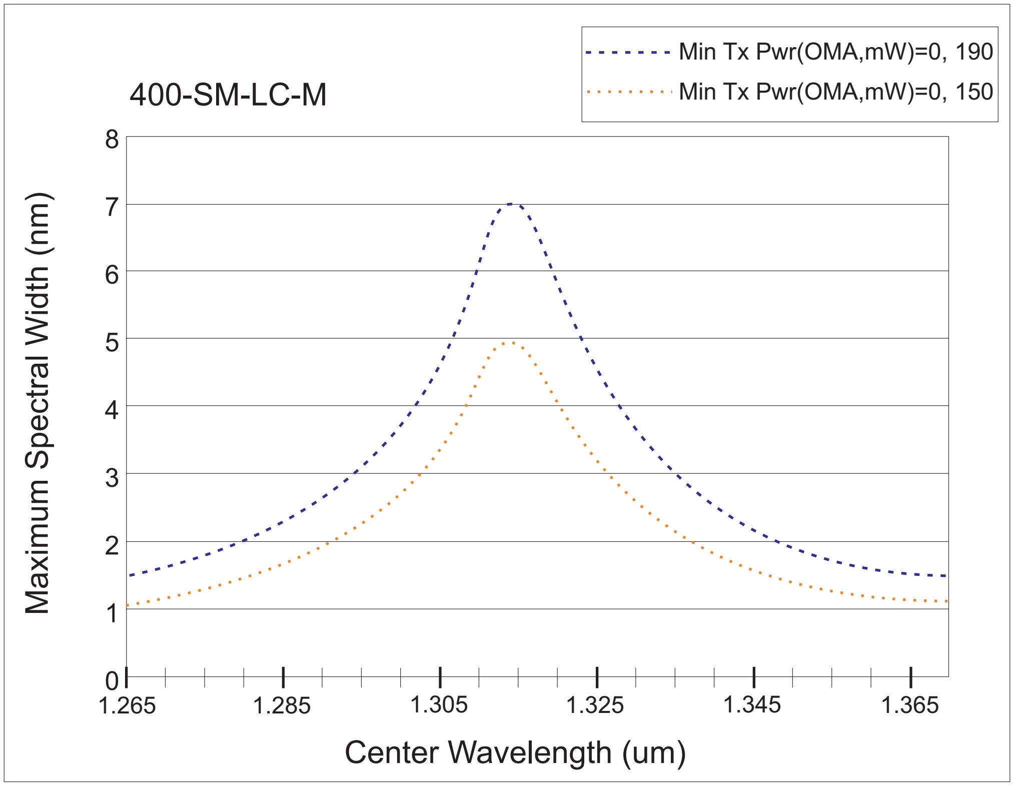



*Figure 13. 4.25 Gbps single-mode 4 km link*

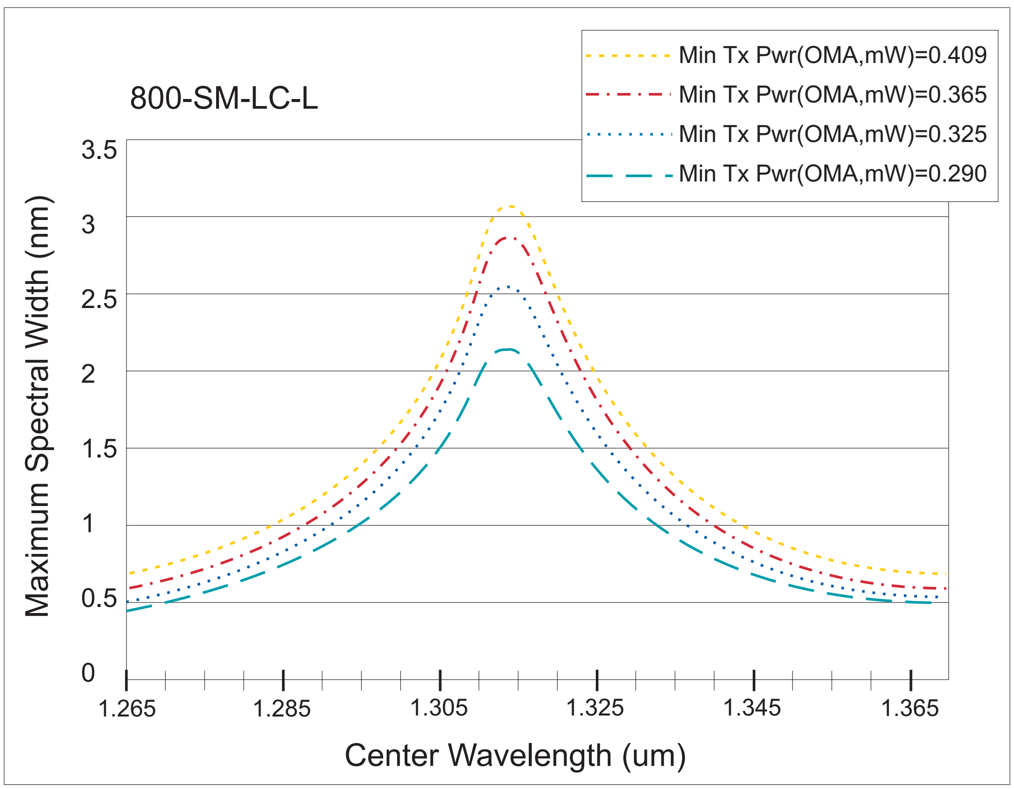



*Figure 14. 8.5 Gbps single-mode 4 km link*

# Appendix C. Normative references

The following standards contain provisions that, through reference in this text, constitute provisions of this publication. These documents are subject to change and may be revised, replaced, or supplemented. Consult the latest available revisions or supplements.

Equivalent EIA test procedures as specified in CCITT G.651 or G.652 can be used.

All FOTPs are EIA/TIA-455-XXX.
- FOTP-27 Methods for Measuring Outside (Uncoated) Diameter of Optical Waveguide Fibers
- FOTP-30 Frequency Domain Measurement of Multimode Optical Fiber Information Transmission Capacity
- FOTP-45 Microscopic Method for Measuring Fiber Geometry of Optical Waveguide Fibers
- FOTP-47 Output Far-Field Radiation Pattern Measurement
- FOTP-48 Measurement of Optical Fiber Cladding Diameter Using Laser-Based Instruments
- FOTP-51 Pulse Distortion Measurement of Multimode Glass Optical Fiber Information Transmission Capacity
- FOTP-54 Mode Scrambler Requirements for Overfilled Launching Conditions to Multimode Fibers
- FOTP-58 Core Diameter Measurement of Graded-Index Optical Fibers
- FOTP-80 Cutoff Wavelength of Uncabled Single-Mode Fiber by Transmitted Power
- FOTP-107 Return Loss for Fiber Optic Components
- FOTP-127 Spectral Characteristics of Multimode Lasers
- FOTP-164 Single-Mode Fiber, Measurement of Mode Field Diameter by Far-Field Scanning
- FOTP-167 Mode Field Diameter Measurement - Variable Aperture Method in the Far-Field
- FOTP-168 Chromatic Dispersion Measurement of Multimode Graded-Index and Single-Mode Optical Fibers by Spectral Group Delay Measurement in the Time Domain
- FOTP-170 Cable Cutoff Wavelength of Single-Mode Fiber by Transmitted Power
- FOTP-171 Attenuation by Substitution Measurement - for Short-Length Multimode Graded-Index and Single-Mode Optical Fiber Cable Assemblies Short-Length Multimode Graded-Index and Single-Mode Optical Fiber Cable Assemblies
- FOTP-176 Measurement Method of Optical Fiber Geometry by Automated Grey-Scale Analysis
- FOTP-177 Numerical Aperture Measurement of Graded-Index Optical Fibers

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**Deutschland: Einhaltung des Gesetzes über die elektromagnetische Verträglichkeit von Geräten**

Dieses Produkt entspricht dem "Gesetz über die elektromagnetische Verträglichkeit von Geräten (EMVG)". Dies ist die Umsetzung der EU-Richtlinie 89/336/EWG in der Bundesrepublik Deutschland.

**Zulassungsbescheinigung laut dem Deutschen Gesetz über die elektromagnetische Verträglichkeit von Geräten (EMVG) vom 18. September 1998 (bzw. der EMC EG Richtlinie 89/336) für Geräte der Klasse A.**

Dieses Gerät ist berechtigt, in Übereinstimmung mit dem Deutschen EMVG das EG-Konformitätszeichen - CE - zu führen.

Verantwortlich für die Konformitätserklärung nach Paragraf 5 des EMVG ist die IBM Deutschland GmbH, 70548 Stuttgart.

Informationen in Hinsicht EMVG Paragraf 4 Abs. (1) 4:

**Das Gerät erfüllt die Schutzanforderungen nach EN 55024 und EN 55022 Klasse A**.

update: 2004/12/07

**People's Republic of China Class A Compliance Statement**

This is a Class A product. In a domestic environment, this product may cause radio interference in which case the user may need to perform practical actions.

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# Glossary

This glossary includes terms and definitions from:

- The *Dictionary of Computing*, SC20-1699.
- The *American National Standard Dictionary for Information Systems*, ANSI X3.172-1990, copyright 1990 by the American National Standards institute (ANSI). Copies can be purchased from the American National Standards Institute, 1430 Broadway, New York, New York 10018. Definitions are identified by the symbol (A) after the definition.
- The *ANSI/EIA Standard - 440A: Fiber Optic Terminology*, copyright 1989 by the Electronic Industries Association (EIA). Copies can be purchased from the Electronic Industries Association, 2001 Pennsylvania Avenue N.W., Washington, D.C. 20006. Definitions are identified by the symbol (E) after the definition.
- The *Information Technology Vocabulary*, developed by Subcommittee 1, Joint Technical Committee 1, of the International Organization for Standardization and the International Electrotechnical Commission (ISO/IEC JTC1/SC1). Definitions of published parts of this vocabulary are identified by the symbol (I) after the definition; definitions taken from draft international standards, committee drafts, and working papers being developed by ISO/IEC JTC1/SC1 are identified by the symbol (T) after the definition, indicating that final agreement has not yet been reached among the participating National Bodies of SC1.

The following cross references are used in this glossary:

**Contrast With.**
This refers to a term that has an opposed or substantively different meaning.

**See.** This refers the reader to multiple-word terms in which this term appears.

**See also.**
This refers the reader to terms that have a related, but not synonymous, meaning.

**Synonym for.**
This indicates that the term has the same meaning as a preferred term, which is defined in the glossary.

## A

**ac.** Alternate current.

**adapter.** (1) Hardware that provides some transitional functions between two or more devices. (2) A mechanism for attaching parts, for example, parts having different diameters. (3) In an ESCON environment, link hardware used to join different optical fiber connector types. Contrast with *coupler*.

**attenuation.** (1) A decrease in magnitude of current, voltage, or power of a signal in transmission between points. (2) In fiber optics, a decrease in magnitude of average optical power.

**Note:** In an optical fiber, attenuation results from absorption, scattering, and other radiation. Attenuation is usually expressed in decibels (dB).

**average power.** In an optical fiber, a value expressed in dBm or milliwatts (mW) that indicates the average signal power.

## B

**bandwidth.** The difference, expressed in hertz, between the highest and the lowest frequencies of a range of frequencies. See *modal bandwidth*.

**BER.** Bit error rate.

**bit .** Either of the digits 0 or 1 when used in the binary numeration system. (T)

**bit error rate (BER).** In fiber optics, a comparison of the number of bits received incorrectly to the total number of bits transmitted. The BER relates directly to receiver sensitivity, transmitter power output, pulse dispersion, and total link attenuation.

## C

**cable.** See *optical cable*.

**calculated link loss.** In an ESCON environment, the total optical attenuation (loss) calculated for a specific link, the value of which should not be more than the maximum loss allowed for that link.

**CCITT.** Comité Consultatif International Télégraphique et Téléphonique. The International Telegraph and Telephone Consultative Committee.

**center wavelength.** In fiber optics the average value of the two wavelengths, expressed in nanometers, at which the magnitude of the optical spectrum drops to half the maximum value.

**central wavelength.** In fiber optics the statistically-weighted average wavelength of the optical spectrum.

**channel.** The system element that controls one channel path, whose mode of operation depends on the type of hardware to which it is attached.

**chromatic dispersion coefficient [D(λ)].** The derivative of the normalized group delay, ι(λ), of a fiber with respect to wavelength (E).

$$D(\lambda) = \frac{d\tau(\lambda)}{d\lambda}$$

**chromatic dispersion slope [S(λ)].** The derivative of the chromatic dispersion coefficient, D(λ), of a fiber with respect to wavelength (E).

$$S(\lambda) = \frac{dD(\lambda)}{d\lambda}$$

**cladding.** In an optical cable, the region of low refractive index surrounding the core. See also *core* and *optical fiber*.

**coherent.** Characterized by a fixed phase relationship between points on an electromagnetic wave. (E)

**concentricity error.** When used in conjunction with a tolerance field to specify the core/cladding geometry, the distance between the center of the two concentric circles specifying the cladding diameter and the center of the two concentric circles specifying the core diameter. Sometimes referred to as the core-to-cladding concentricity or core eccentricity. (E)

**control unit data rate.** The rate at which a control unit can move data between itself and a transmission link during the data transfer portion of an I/O operation.

**core.** (1) In an optical cable, the central region of an optical fiber through which light is transmitted. (E) (2) In an optical cable, the central region of an optical fiber that has an index of refraction greater than the surrounding cladding material. (E) See also *cladding* and *optical fiber*.

**coupler.** In an ESCON environment, link hardware used to join identical optical fiber connector types. Contrast with *adapter*.

**cutoff wavelength.** In fiber optics, the wavelength at which a particular waveguide mode ceases to be a bound mode. (E)

**Note:** In a single-mode fiber, concern is with the cutoff wavelength of the second order mode.

# D

**dBm.** A power level, expressed in decibels, relative to 1 milliwatt of radiant power.

**dc.** Direct current.

**decibel (dB).** (1) One tenth of a bel. (2) A unit that expresses the ratio of two power levels on a logarithmic scale. (3) A unit for measuring relative power. The number of decibels is 10 times the logarithm (base 10) of the ratio of the measured power levels; if the measured levels are voltages (across the same or equal resistances), the number of decibels is 20 times the log of the ratio.

**detector.** In fiber optics, a device that converts optical power to other forms. (E)

**device data rate.** The rate at which data can be moved between a device and a control unit during the data transfer portion of an I/O operation.

**dielectric.** Nonconductor of direct electric current.

**dispersion.** A term used to describe the chromatic or wavelength dependence of a parameter as opposed to the temporal dependence which is referred to as distortion. The term is used, for example, to describe the process by which an electromagnetic signal is distorted because the various wavelength components of that signal have different propagation characteristics. (E) See also *chromatic dispersion coefficient*.

**dispersion-unshifted fiber.** A single-mode fiber that has a nominal zero-dispersion wavelength in the 1300 nm transmission window, and has a dispersion coefficient approximated by a differentiated Sellmeier equation. Also known as dispersion-unmodified, nonshifted, or EIA Class IVa fiber. (E)

**distribution panel.** In an ESCON environment, a panel that provides a central location for the attachment of trunk and jumper cables and can be mounted in a rack or wiring closet, or on a wall.

**duplex.** Pertaining to communication in which data can be sent and received at the same time.

**duplex connector.** In an ESCON environment, an optical fiber component that terminates both jumper cable fibers in one housing and provides physical keying for attachment to a duplex receptacle.

**duplex receptacle.** In an ESCON environment, a fixed or stationary optical fiber component that provides a keyed attachment method for a duplex connector.

## E

**effective data rate.** The rate at which data can be moved over a number of I/O operations. The effective data rate depends on several factors such as the distance between a channel and a control unit, the specific control units and devices attached, the channel programs used, and the amount of data moved.

**element.** A major part of a component (for example, the buffer control element) or a major part of a system (for example, the system control element).

**emitter.** In fiber optics, the source of optical power. (E)

**error.** A discrepancy between a computed, observed, or measured value or condition and the true, specified, or theoretically correct value or condition. (I) (A) Contrast with *failure* and *fault*.

**ESCON.** Enterprise Systems Connection.

**ESCON environment.** The data processing environment having an Enterprise Systems Connection channel-to-control-unit I/O interface that uses optical cables as a transmission medium.

**extinction ratio.** In fiber optics, a measure of the modulation depth of an optical waveform, expressed in dB as 10 log (*Ph/Pl*), where Ph equals high optical power level and Pl equals low optical power level.

## F

**failure.** An uncorrected hardware error. Contrast with *error* and *fault*.

**Note:** Failures are either recoverable or not recoverable by the software or the operator. The operator is always notified when failures occur. Usually, system recovery occurs through a hardware reconfiguration. If this is not possible, recovery requires a repair of the failed hardware.

**fault.** An accidental condition that causes a functional unit to fail to perform its required function. (I) (A) Contrast with *error* and *failure*.

**ferrule.** In fiber optics, a mechanical fixture, generally a rigid tube, used to confine the stripped end of a fiber bundle or a fiber. (E)

**Notes:**

1. Typically, individual fibers of a bundle are cemented together within a ferrule of a diameter designed to yield a maximum packing fraction.
2. Nonrigid materials, such as shrink tubing, can also be used for ferrules for special applications.

**fiber.** See *optical fiber*.

**fiber bundle.** An assembly of unbuffered optical fibers, usually used as a single transmission channel, as opposed to multifiber cables, which contain optically and mechanically isolated fibers, each of which provides a separate channel. (E) See also *ferrule*, *fiber optics*, *multifiber cable*, and *optical fiber*.

**Notes:**

1. Fiber bundles used only to transmit light, as in optical communications, are flexible and are typically unaligned.
2. Fiber bundles used to transmit optical images may be either flexible or rigid, but must contain aligned fibers.

**fiber optic cable.** See *optical cable*.

**fiber optics.** The branch of optical technology concerned with the transmission of radiant power through fibers made of transparent materials such as glass, fused silica, and plastic. (E)

**Note:** Telecommunication applications of fiber optics use optical fibers. Either a single discrete fiber or a nonspatially aligned fiber bundle can be used for each information channel. Such fibers are often called *optical fibers* to differentiate them from fibers used in noncommunication applications.

**Fibre Connection.** See *optical fiber*.

**FICON.** See *optical fiber*.

**filter.** A device or program that separates data, signals, or material in accordance with specified criteria. (A)

**ft.** Foot.

**fusion splice.** In fiber optics, a splice accomplished by the application of localized heat sufficient to fuse or melt the ends of two lengths of optical fiber, forming a continuous, single fiber. (E)

## H

**hertz (Hz).** A unit of frequency equal to one cycle per second.

## I

**infrared.** Invisible radiation having a wavelength longer than 700 nm. (T)

**input interface.** In an ESCON link environment, the interface that receives coded serial optical data and converts it to retimed parallel electrical data.

**input/output (I/O).** (1) Pertaining to a device whose parts can perform an input process and an output process at the same time. (I) (2) Pertaining to a functional unit or channel involved in an input process, output process, or both, concurrently or not, and to the data involved in such a process. (3) Pertaining to input, output, or both.

**input/output subsystem data rate.** The rate at which data can be moved between processor storage and a device during the data transfer portion of an I/O operation. This rate is the lowest of the channel data rate, the control unit data rate, or the device data rate.

**Note:** In cases where the data for an I/O operation comes from or is stored to a control unit and not directly to a device, the I/O subsystem data rate is the lower of the channel data rate or the control unit data rate.

**intensity.** In fiber optics, the square of the electric field amplitude of a light wave. The intensity is proportional to irradiance and can be used in place of the term "irradiance" when only relative values are important. (E).

**interface.** (1) A shared boundary between two functional units, defined by functional characteristics, signal characteristics, or other characteristics as appropriate. The concept includes the specification of the connection of two devices having different functions. (T) (2) Hardware, software, or both, that links systems, programs, or devices.

**I/O.** Input/output.

## J

**jacket.** In an optical cable, the outermost layers of protective covering.

**jumper cable.** In an ESCON environment, an optical cable having two conductors that provides physical attachment between two devices or between a device and a distribution panel. Contrast with *trunk cable*.

## L

**laser.** A device that produces optical radiation using a population inversion to provide light amplification by stimulated emission of radiation and (generally) an optical resonant cavity to provide positive feedback. Laser radiation can be highly coherent temporally, or spatially, or both. (E)

**link.** (1) In an ESCON environment, the physical connection and transmission medium used between an optical transmitter and an optical receiver. A link consists of two conductors, one used for sending and the other for receiving, providing a duplex communication path. (2) In an ESCON I/O interface, the physical connection and transmission medium used between a channel and a control unit, a channel and an ESCD, a control unit and an ESCD, or, at times, between two ESCDs.

**link rate.** The rate at which bits can be placed onto or removed from a transmission link.

**loss of signal (LOS).** In an ESCON link environment, a state that exists when the input interface does not detect optical data.

## M

**mechanical splice.** In fiber optics, a splice accomplished by fixtures or materials rather than thermal fusion. Index matching material can be applied between two fiber ends. (E) Contrast with *fusion splice*.

**megahertz (MHz).** A unit of measure for frequency. One megahertz equals 1 000 000 hertz.

**micrometer.** One millionth part of a meter.

**min.** Minute.

**mm.** Millimeter.

**modal (or mode) dispersion.** Synonym for *multimode distortion*.

**modal bandwidth.** The lowest frequency at which the magnitude of the fiber transfer function decreases to one-half the zero frequency value.

**modulation.** The process by which a characteristic of a carrier is varied in accordance with the characteristic of an information-bearing signal. (T).

**monomode optical fiber.** Synonym for *single-mode optical fiber*.

**ms.** Millisecond.

**multifiber cable.** An optical cable that contains two or more fibers. (E) See also *jumper cable* and *trunk cable*.

**multimode distortion.** In an optical fiber, that distortion resulting from differential mode delay. (E)

**Note:** The term *multimode dispersion* is often used as a synonym; such usage, however, is erroneous because the mechanism is not dispersive in nature.

**multimode laser.** A laser that produces emission in two or more transverse or longitudinal modes. (E).

**multimode optical fiber.** A graded-index or step-index optical fiber that allows more than one bound mode to propagate. (E) Contrast with *single-mode optical fiber*.

## N

**nanosecond (ns).** One thousand millionth of a second.

**nm.** Nanometer.

**numerical aperture.** Colloquially, the sine of the radiation or acceptance angle of an optical fiber, multiplied by the refractive index of the material in contact with the exit or entrance face. This usage is approximate and imprecise, but is often used.

## O

**optical cable.** A fiber, multiple fibers, or a fiber bundle in a structure built to meet optical, mechanical, and environmental specifications. (E) See also *jumper cable* and *trunk cable*.

**optical fiber.** Any filament made of dielectric materials that guides light, regardless of its ability to send signals. (E) See also *fiber optics.*

**optical fiber cable.** Synonym for *optical cable*.

**optical fiber connector.** A hardware component that transfers optical power between two optical fibers or bundles and is designed to be repeatedly connected and disconnected.

**optical power.** Synonym for *radiant power*.

**optical source.** A device that converts other forms of power to optical power. (E)

## R

**radiant power.** In fiber optics, the time rate of flow of radiant energy, expressed in watts. The prefix is often dropped and the term power is used. (E)

**refractive index.** In fiber optics, the ratio of the velocity of light in a vacuum to the phase velocity in the medium, expressed as *n*.

**relative intensity noise (RIN) .** In fiber optics, laser noise expressed in dB/Hz and measured relative to the average optical power.

**return loss.** In fiber optics, the ratio, expressed in dB, of optical power reflected by a component or an assembly to the optical power incident on a component port when that component or assembly is introduced into a link.

## S

**saturation level.** In fiber optics, the maximum input power that can be received without increasing the error rate.

**scattering.** In fiber optics, the change in direction of light rays or photons after striking a small particle or particles. In can also be regarded as the diffusion of a light beam caused by the inhomogeneity of the transmitting medium. (E)

**sensitivity.** In optical system receivers, the minimum power required to achieve a specified quality of performance in terms of output signal-to-noise ratio or other measure. (E) For example, sensitivity could be expressed in decibels with reference to 1 milliwatt (dBm) at a specific bit error rate (BER).

**single-mode optical fiber.** An optical fiber in which only the lowest-order bound mode (which can consist of a pair of orthogonally polarized fields) can propagate at the wavelength of interest. (E) Contrast with *multimode optical fiber*.

## T

**transmission code.** (1) A code for sending information over telecommunication lines. (2) In an I/O interface, a 10-bit code that forms transmission characters. Data is encoded 8 bits at a time into 10-bit transmission characters. Information is received over the link 10 bits at a time, and those transmission characters used for data are decoded into the correct 8-bit codes. Other 10-bit special transmission characters are used for functions that must be distinguishable from the contents of the frame.

**transmission medium.** The physical medium that conveys signals between data stations; for example twisted pair, optical fiber, and coaxial cable. (T)

**Note:** Free space is a transmission medium for electromagnetic waves.

**trunk cable.** In an ESCON environment, a cable consisting of multiple fiber pairs that do not directly attach to an active device. This cable usually exists between distribution panels and can be located within, or external to, a building. Contrast with *jumper cable*.

## W

**waveform.** The mathematical representation of a wave, especially a graph of deviation at a fixed point versus time.

**wavelength.** The distance from one point in a periodic waveform to the same point in the next cycle.

**Note:** ESCON links operate using a wavelength of 1300 nm. However, other typical wavelengths can be 850 or 1550 nm.

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