November 6, 2020

Please be advised that BICSI has recently published technical changes to the Telecommunications Distribution Methods Manual, 14th edition.

While none of these changes are classified as "life safety" issues, there were many other changes to some text, table numbers, figures, etc. The changes to each item on a page are clearly marked with a revision bar to the immediate right or left of the change, and the date of the change in the footer at the bottom of the page. The RCDD 14th edition curriculum has also been updated to reflect these changes, as well as the exam database. Please print the pages and insert them into your existing manual. Because our manuals' pages are double-sided, please print these as such. This will allow you to do a page-for-page changeout in your manual.

You will notice that many of the pages you have printed do not have these revision bars and changed footers. The reason for this is the page-for-page change outs (meaning only one side of the double-sided page received a change). We want you to be able to pull out your old double-sided page and replace it with the new double-sided page.

If you have any questions, please e-mail me at chammersley@bicsi.org.

Thank you:

Clarke W. Hammersley
BICSI Director of Publications

advancing the information and communications technology profession

Tables

Chapter 1: Principles of Transmission

Chapter 2: Electromagnetic Compatibility

Chapter 3: Telecommunications Spaces

Chapter 4: Backbone Distribution Systems

Chapter 5: Horizontal Distribution Systems

Figures

Tables

Description of Conductors

Table 1.1 gives a brief description of the most common conductors.

Table 1.1
Conductor descriptions

Conductor	Description
Copper	Sets the standard for comparing the conductivity of other metals. Annealed copper is used as the reference value (e.g., 100% conductivity). Other common conductors have less than 100% of annealed copper's electrical conductivity.
Copper-covered	Also known as copper-clad steel, it combines the conductivity of copper with the strength of steel. It is typically used as a conductor for aerial, self-supporting drop wire. In the production of this type of conductor, a copper layer is bonded to a steel core.
High-strength copper alloy	A mixture of copper and other metals to improve certain properties and characteristics of copper. Alloys such as cadmium–chromium copper and zirconium copper offer important weight reductions or greater strength. These factors are especially important in aerospace and computer applications. However, the alloying of pure copper always has an adverse effect on its conductivity. The alloys mentioned above have 85% conductivity ratings.
Aluminum	A bluish silver-white malleable ductile light trivalent metallic element that has good electrical and thermal conductivity, high reflectivity, and resistance to oxidation. It has about 60% conductivity compared with copper and is lighter in weight than copper. Aluminum is most commonly used in electrical utility distribution lines.

Comparison of Solid Conductors

The properties of solid conductors made of different metals or alloys are shown in Table 1.2.

Table 1.2
Solid conductor properties

Property	Copper	Copper-covered	High-Strength Alloys	Aluminum
Electrical conductivity	Sets the standard	Less than copper	85% typical	60% typical
Ductility	Good	Good	Best	Good
Solderability	Good	Good	Good	Special techniques
Corrosion resistance	Good	Good	Poor	Good
Oxidation resistance	Good	Good	Good	Poor
Weight	≈14.25 kg (31.4 lb)	≈13.06 kg (28.8 lb)	—	≈4.32 kg (9.5 lb)
Tensile strength	250,000 kPa (36,259 psi)	380,000 kPa (55,114 psi)	To 550,000 kPa (79,771 psi)	69,000 kPa (10,008 psi)

NOTE: Weight and strength are approximate and based upon ≈305 m (1001 ft) of 10 AWG solid conductor at 20 °C (68 °F).

Solid Conductors versus Stranded Conductors

Solid conductors consist of a single piece of metal wire. Stranded conductors bundle together a number of small-gauge solid conductors to create a single, larger conductor.

Advantages of solid conductors include the following:

- Less costly
- Less complex termination systems
- Better transmission performance at high frequencies
- Less resistance

Advantages of stranded conductors include the following:

- More flexible
- Longer flex life
- Less susceptible to damage during crimp termination processes

Light-Source Characteristics that Influence Optical Fiber Selection, continued

Modulation Frequency

The modulation frequency of a transmitter is the rate at which the transmission changes in intensity. Typically, the transmitter is modulated by a string of bits that turn the transmitter's light source on and off. LEDs have a relatively low modulation frequency and are limited to data rates of 622 Mb/s and below. Lasers have a higher modulation frequency and can support data rates in excess of 50 Gb/s.

Transmitter Light Sources

The three major types of transmitter light sources are:

- LEDs.
- Short-wavelength lasers.
- VCSELs.
- LDs.

Light-Emitting Diode (LED)

The LED is a common and relatively inexpensive transmitter light source. Table 1.20 describes the characteristics of typical LED sources.

Table 1.20
Characteristics of typical LED sources

Item	Characteristics
Cost	Relatively inexpensive
Use	Primarily used with multimode optical fiber telecommunications systems
Center wavelength	• 800 to 900 nm • 1250 to 1350 nm
Spectral width	Usually: • 30 to 60 nm FWHM in the lower region (near 850 nm) • Up to 150 nm FWHM in the higher region (near 1300 nm) because lower material dispersion LED sources operating near 850 nm are typically more economical. Data rates up to 100 Mb/s typically use short wavelength LEDs; long wave length LEDs are for data rates of 100 to 622 Mb/s.
Modulation frequency	• Most are under 200 MHz • Can be as high as 600 MHz
Average launched optical power level	–10 to –30 dBm into multimode fiber

FWHM = Full width half maximum
LED = Light-emitting diode

Transmitter Light Sources, continued

Short Wavelength Lasers

Table 1.21 describes the characteristics of typical short wavelength laser.

Table 1.21
Characteristics of typical short wavelength laser

Item	Characteristic
Cost	Relatively inexpensive
Use	Primarily used with multimode optical fiber information technology systems at the higher data rates from 200 Mb/s to 1 Gb/s. Principal application is Fibre Channel
Center wavelength	780 nm
Spectral width	Narrow compared with LEDs (4 nm)
Modulation frequency	Higher than LEDs (can exceed 1 Ghz), allowing them to operate at higher data rates
Average launched optical power level	+1 to –8 decibels per mW (dBm)

LED = Light-emitting diode

Vertical Cavity Surface Emitting Laser (VCSEL)

VCSELs were introduced as a cost-effective multimode transmitter for Gigabit Ethernet and Fibre Channel. They are also used for 10 Gigabit Ethernet and 8 Gb Fibre Channel and data rates such as 40 Gb and more.

Comparison of transmitters

Table 1.24 provides a summarized comparison of LED, short-wavelength laser, VCSEL, and LD.

Table 1.24
Comparison of transmitters

	LED	Short-wavelength laser	VCSEL	Laser (LD)
Cost	Less expensive	Less expensive	Less expensive	More expensive
Primary optical fiber type	Multimode	Multimode	Multimode	Singlemode
Center wavelength	850 nm and 1300 nm	780 nm	850 nm	1310 nm and 1550 nm
Spectral width	For 850, 30 to 60 nm FWHM For 1300, up to 150 nm FWHM	4 nm FWHM	1 to 6 nm FWHM	1 to 6 nm FWHM
Modulation frequency	Usually under 200 MHz	Can exceed 1 GHz	Up to 10 GHz	Can exceed 10 GHz
Average launched optical power level	–10 to –30 dBm	+1 to -8 dBm	–1 to –8 dBm	+4 to –9 dBm

FWHM = Full width half maximum
LED = Light-emitting diode
VCSEL = Vertical cavity surface emitting laser

Optical Fiber Receivers

Overview

Almost all types of optical fiber receivers incorporate a photodetector to convert the incoming optical signal to an electrical signal.

The receiver is selected to match the transmitter and the optical fiber.

Characteristic Parameters

The characteristic parameters of optical fiber receivers are the:

- Sensitivity.
- BER.
- Dynamic range.

Sensitivity and Bit Error Rate (BER)

Receiver sensitivity and BER are related:

- The sensitivity of a receiver specifies the minimum power level an incoming signal must have to achieve an acceptable level of performance, which is usually specified as a BER.
- BER is the fractional number of errors allowed to occur between the transmitter and receiver. For example, a BER of 10^{-9} means one bit error for each one billion bits sent. (This error rate is readily available in current systems.)

If the power of the incoming signal falls below the receiver sensitivity, the number of bit errors increases beyond the maximum BER specified for that receiver.

If too little power is received at the detector, the results can be:

- A detected signal with high bit errors.
- No signal detection.

Dynamic Range

Too much received signal power can also compromise the receiver's operation.

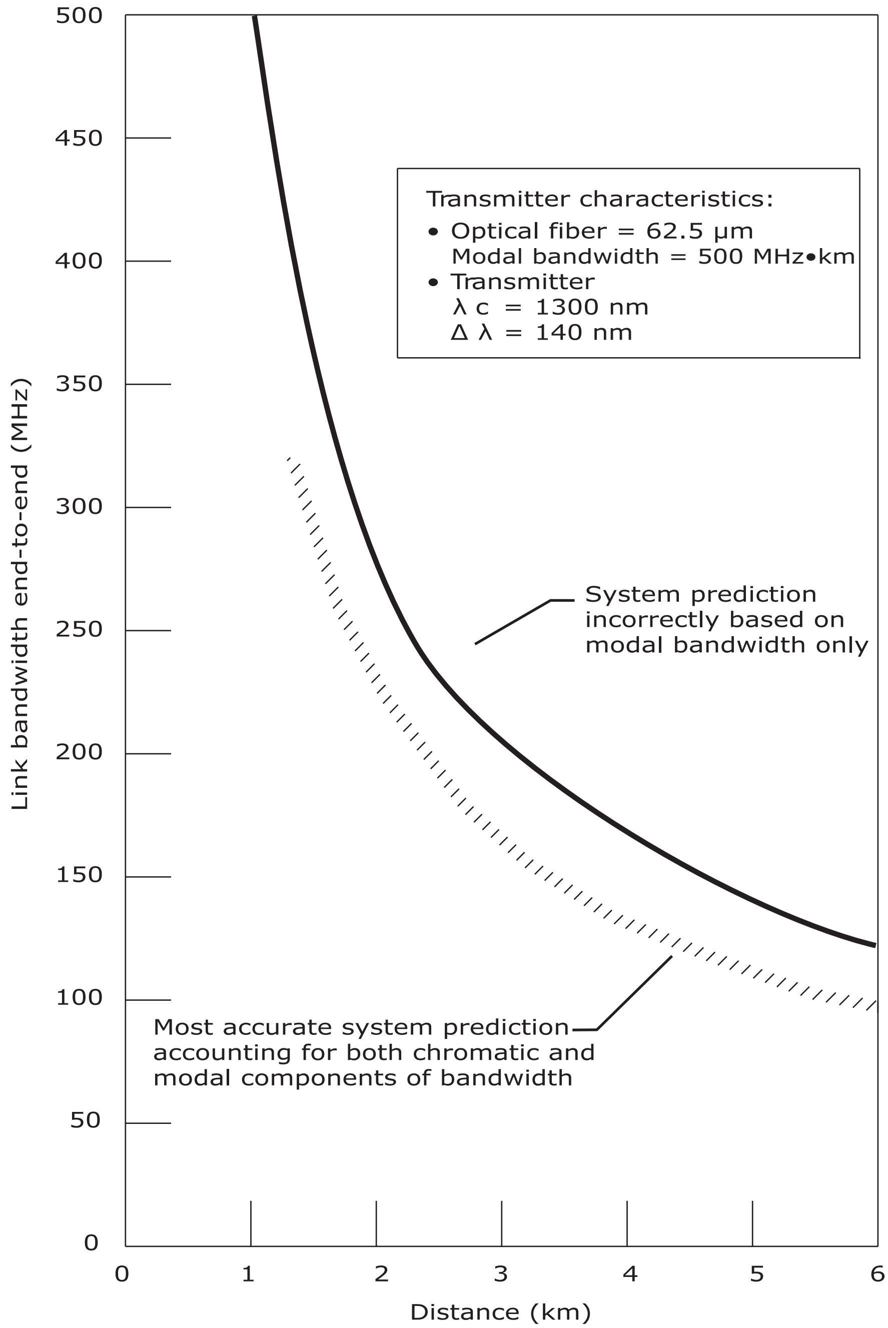
If too much power is received at the detector, the results can be:

- Higher than acceptable BER.
- Possible physical damage to the receiver.

The dynamic range is the range of power that a receiver can process at a specified BER. This is determined by the difference between the maximum power and the minimum power that the receiver can process at a specified BER.

Measurement and Specification of Multimode Systems, continued

Figure 1.29
Link bandwidth at 1300 nm using 62.5/125 micrometer multimode optical fiber



Determining the required optical fiber bandwidth is best left to the electronics, cable, or optical fiber manufacturer.

Classification of Optical Fiber

The two major classifications of optical fiber are multimode and singlemode.

Multimode optical fiber is best suited for premises applications where links are less than:

- ≈2000 m (6562 ft) for data rates of 155 Mb/s or less.
- ≈550 m (1804 ft) for data rates of 1 Gb/s or less.
- ≈300 m (984 ft) for data rates of 10 Gb/s or less.
- ≈100 m (328 ft) for data rates of 100 Gb/s or 40 Gb/s or less.

Multimode optical fiber's higher numerical aperature allows the use of relatively inexpensive LED and VCSEL transmitters. These are more than adequate for short-distance applications.

NOTE: See Multimode Optical Fiber in this chapter for typical characteristics of multimode optical fiber.

Singlemode optical fiber is best suited for:

- Bandwidth requirements exceeding multimode's capability.
- Distances exceeding multimode's capability.
- When the application requires singlemode.

NOTE: See Singlemode Optical Fiber in this chapter for typical characteristics of singlemode optical fiber.

Multimode Optical Fiber

The typical characteristics of multimode optical fiber are shown in Table 1.26.

Table 1.26
Typical characteristics of multimode optical fiber

Item	Characteristic
Optical fiber size	The two popular sizes of multimode optical fibers were: • 62.5/125 µm. • 50/125 µm. But now only OM3/4/5 can be chosen in greenfield. See Tables 1.27 and 1.28 for more information. NOTE: Multimode optical fibers are frequently referred to by the core and cladding diameter in micrometers (see Figure 1.30). For example, a multimode optical fiber with a core diameter of 62.5 µm and a cladding diameter of 125 µm is typically designated as a 62.5/125 µm optical fiber.
Cost	While the multimode optical fiber cable is more expensive than singlemode, the installed system is less expensive than singlemode systems because of the more cost-effective electronics and connectors.
Distance	Used mostly for information technology systems links less than ≈2 km (1.2 mi) long.
Capacity	• Data rates of 155 Mb/s are common for campus links of less than ≈2 km (1.2 mi). • Data rates of 1 Gb/s are common for building or campus backbones of less than ≈550 m (1804 ft). • Data rates of 10 Gb/s are for building backbones less than ≈300 m (984 ft).
Operating wavelength	Operates at: • 850 nm (first window—LED or VCSEL). • 1300 nm (second window—LED or laser diode).
System type	Used for voice, data, security, and closed-circuit video systems.

LED = Light-emitting diode
VCSEL = Vertical cavity surface emitting laser

Multimode Optical Fiber, continued

Figure 1.30
Core and coating

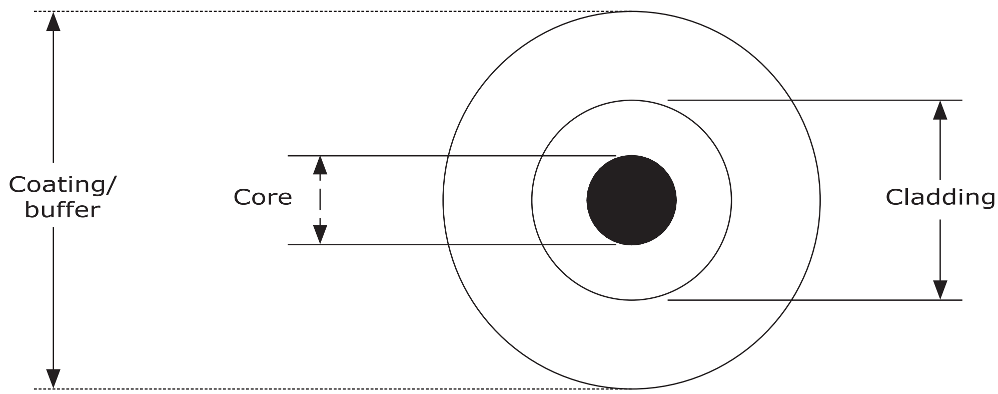


Table 1.27 shows the characteristics of 50/125 µm multimode optical fiber.

Table 1.27
Characteristics of 50/125 µm multimode optical fiber

Item	Characteristic
Attenuation	Low attenuation at 850 nm and 1300 nm wavelength regions.
Bandwidth	Higher than that of 62.5/125 µm multimode fiber.
Numerical	Lower NA and smaller core size results in less coupling power compared with that of 62.5/125 fiber for LED systems aperture (NA). Laser systems (VCSELs) are not affected.
Mechanical	Compatible with all 62.5/125 µm multimode and singlemode optical fiber connector parts because of the common cladding diameter.

LED = Light-emitting diode
NA = Numerical aperture
VCSEL = Vertical cavity surface emitting laser

As more strict tolerance is required for ferrules used with SM fiber, termination of multimode connector onto singlemode fiber is not recommended. The opposite combination does not adversely affect the performance.

Multimode Optical Fiber, continued

Table 1.28 shows the characteristics of 62.5/125 µm multimode optical fiber.

Table 1.28
Characteristics of 62.5/125 µm multimode optical fiber

Item	Characteristic
Attenuation	Slightly higher attenuation than 50/125 µm optical fiber.
Bandwidth	Moderate bandwidth that accommodates most data applications
Numerical aperture (NA)	Higher NA than 50/125 µm optical fiber, allowing more power coupled from an LED into the optical fiber.
Compatibility	Compatible with all 50/125 µm multimode and singlemode optical fiber connector parts because of the common cladding diameter.

LED = Light-emitting diode
NA = Numerical aperture

As more strict tolerance is required for ferrules used with SM fiber, termination of multimode connector onto singlemode fiber is not recommended. The opposite combination does not adversely affect the performance.

Wavelength Windows

Optical fibers do not transmit all wavelengths of light with the same efficiency. The attenuation of light signals is higher for visible light (wavelengths of 400 nm to 700 nm) than for light in the near infrared region (wavelengths of 700 nm to 1600 nm).

Within this near infrared region, there are wavelength bands of decreased transmission efficiency. This leaves only several wavelengths that optical fibers can operate with low loss. These wavelength areas that are most suitable for optical communications are called windows. The most commonly used windows are found near 850 nm, 1300 nm, and 1550 nm.

Singlemode Optical Fiber

Singlemode optical fiber is similar to multimode optical fiber in physical appearance and composition, but it has performance characteristics that differ by orders of magnitude from those of multimode optical fibers (see Table 1.29).

Table 1.29
Typical characteristics of singlemode optical fiber

Item	Characteristic
Distance	Used by service providers (e.g., telephone, CATV). Unrepeated spans in excess of ≈80 km (50 mi) are achievable with state-of-the-art equipment.
Capacity	Data rate transmission in excess of 40 Gb/s range is common.
System performance	• Very high bandwidth • Very low attenuation • Good for telephony and CATV applications • Ideal for local applications having links over ≈2 km (1.2 mi) long • Satisfies high bandwidth needs in backbone applications up to ≈80 km (50 mi)
Optical fiber	• Core diameter: between 8 and 9 µm characteristic • Cladding diameter: 125 µm • Attenuation: 0.3 to 1.0 dB/km at 1310 nm, 1383 nm, and 1550 nm • Bandwidth: greater than 20 GHz • Numerical aperture: Because the NA is very small, the optical fibers are used almost exclusively with laser sources that can concentrate more power into a smaller launch area.
Cost	Less expensive than multimode optical fiber, but the higher cost of singlemode transmission equipment usually means a higher system cost in short length (premises) systems.
Operating wavelength	1310 nm to 1550 nm

CATV = Community antenna television
NA = Numerical aperture

NOTE: For singlemode optical fiber cable, the following maximum attenuation values are generally specified:

- Outside cable—0.4 dB/km at 1310 nm, 1383 nm, and 1550 nm
- Inside cable—1 dB/km at 1310 nm, 1383 nm, and 1550 nm

Optical Fiber Applications Support Information

Overview

This section provides an overview regarding applications support for many of the available optical fiber LAN applications across the optical fiber media types. This information allows the user to easily access enough basic information to make informed decisions about optical media choices and system design.

With a predetermined knowledge of the required distances, an idea of the applications support required and the cabling system design, the ICT distribution designer can determine the media most appropriate for the situation.

Three primary factors must be considered in optical fiber selection and system design:

- Maximum supportable distance
- Maximum channel attenuation
- Application requirements

The first factor is maximum supportable distance based on bandwidth, transmitter and receiver specifications, propagation delay, jitter, and numerous other factors. Maximum supportable distance is established by the application standards.

The second factor is maximum channel attenuation, which is established by the difference between the minimum transmitter output power coupled into the optical fiber and the receiver sensitivity, less any power penalties established. The channel attenuation can be affected by the system design (e.g., number of connections and/or splices, length, wavelength of operation, loss values of components).

The third factor is application requirements, which is that end devices may require a specific type of interface (e.g., singlemode).

Supportable Distances and Channel Attenuation

For existing systems, measure the channel attenuation. For new installations, use the equations below, which are based on the minimum component specifications, to verify the system design:

- Channel attenuation < Maximum channel attenuation
- Channel attenuation = Cable attenuation + connector attenuation + splice attenuation
- Channel attenuation = [Cable attenuation coefficient (dB/km) x length (km)] + [# connector pairs x 0.75 dB] + [# of splices x 0.3 dB]

Supportable Distances and Channel Attenuation, continued

Therefore, to determine maximum length for a particular system design, the resulting equation is:

$$\text{Maximum length} = \frac{(\text{Maximum channel attenuation} - [\#\text{ connector pairs x } 0.75\text{ dB}] - [\#\text{ splices x } 0.3\text{ dB}])}{\text{Cable attenuation coefficient}}$$

The maximum cable attenuation coefficients are listed in Table 1.30.

NOTE: The maximum supportable distances and maximum channel attenuation listed apply to the specific assumptions and constraints provided in the notes. Different assumptions or constraints may change the maximum supportable distance and maximum channel attenuation.

Table 1.30
Maximum cable attenuation coefficient

Optical Fiber Cable Type	Wavelength (nm)	Maximum Attenuation
62.5/125 µm multimode grandfathered	850 1300	3.5 dB/km 1.5 dB/km
50/125 µm multimode grandfathered	850 1300	3.5 dB/km 1.5 dB/km
OM3/4	850	3.0 dB/km
OM5	850	3.0 dB/km
Singlemode inside plant cable	1310 1383 1550	1.0 dB/km 1.0 dB/km 1.0 dB/km
Singlemode outside plant cable	1310 1383 1550	0.4 dB/km 0.4 dB/km 0.4 dB/km

Verifying Optical Fiber Performance and Electronics Compatibility

Overview

This section is designed to provide an understanding of the relationship of the link to the requirements of the electronics (transmitter and receiver). However, it is more critical to ensure that the installed link meets the requirements of a generic cabling system, independent of a specific application or electronic product.

Standards have been developed for generic cabling systems, both for multimode and single mode systems, and for horizontal and backbone cabling. These requirements are based on long-standing and field-proven test procedures, allowing both the end user and contractor to certify the installation.

It is necessary to verify that the overall system will work properly whenever new components are installed to reconfigure an existing system.

This is true whether the changes involve a new:

- Optical fiber cabling system for active components that have already been chosen.
- Active component system retrofitted to previously installed optical fiber cabling.

This verification is a repetitious process. Decisions regarding route, electronics, wavelength, and system configuration are all interrelated. Often a trade-off analysis—varying one or more of these parameters—is necessary.

Industry standardization is making verification easier. More manufacturers have developed multimode LAN systems, which operate over multimode optical fiber. However, it is still important that the ICT distribution designer or end user understand some of the fundamental concepts and calculations necessary to verify that a system will work properly.

For short or basic systems, performance requirements have often already been considered by the manufacturer and translated into system specifications for the:

- Optical cable lengths.
- Number of splices and connectors.
- Optical cable performance.

For longer or complex applications, it is generally recommended that the ICT distribution designer analyze the proposed system.

Key Parameters

The two key parameters in optical fiber cabling performance that must be verified for compatibility with the proposed electronics are:

- Bandwidth.
- Attenuation.

It is important to consider how specific grades of optical fiber affect system performance.

Verification Theory and Methodology

The theory and methodology used to verify appropriate optical fiber performance are the same for both singlemode and multimode optical fibers at any wavelength.

IMPORTANT: The specifications used for each of the components (e.g., transmitter, receiver, optical fiber, connectors) must correspond to the optical fiber type and wavelength.

For example, if designing a singlemode system to operate at 1310 nm, the attenuation specified for a 50/125 µm multimode connector cannot be used, nor can the transmitter average power from an 850 nm LED source specified for 50/125 µm optical fiber. Only the singlemode optical fiber specifications for 1310 nm and connector loss specification for singlemode optical fiber can be used.

Additionally, any transition from 50/125 µm optical fiber (or a transmitter source specified for 50/125 µm optical fiber) into 62.5 µm fiber for LED systems will have to take into account the attenuation at that junction (see Table 1.31).

To increase testing accuracy for optical fiber link and channel loss measurements, it is recommended to use an LED light source with an EF mode conditioner to control the near field at the output of the launching test cord. The EF test method is specified in ANSI/TIA-526-14-C and IEC 61280-4-1.

Table 1.31
Mismatch of core size and power loss

Receiving Fiber \ Transmitting Fiber	50 µm (NA = 0.20)	62.5 µm (NA = 0.275)
50 µm (NA = 0.20)	0.00	-5.7 dB
62.5 µm (NA = 0.275)	0.00	0.00

NA = Numerical aperture

Verification Theory and Methodology, continued

NOTE: Total loss = Total loss using OFL launch = Loss (numerical aperature) + Loss (dia)

Loss (numerical aperature) = $10\log_{10} (0.20/0.275)^2$ = -2.8 dB

Loss (dia) = $10\log_{10} (50/62.5)^2$ = -2.9 dB

For telecommunications networks that have more than one optical fiber link, the ICT distribution designer may:

- Choose the longest, most complex link to verify system performance and select that optical fiber grade for the entire network.
- Select a specific optical fiber grade for each individual link. This is generally unnecessary and is not recommended.

Bandwidth

The bandwidth for an optical fiber cannot be tested or validated in the field. Validation of the bandwidth can only be through manufacturer's specification and quality checking of the product specification sheets with the installed components. Specifically, for laser-optimized 50/125 µm, OM3, OM4, and OM5 optical fiber, the bandwidth performance for each glass element of the end-to-end optical fiber channel, cable, cords, and pigtails should always be of the same specification and preferably from the same manufacturing source and type.

When choosing the fiber type, it is important to know the applications that are to be supported by the optical fiber channels and the applications bandwidth requirements for each of the optical fiber types being considered. High-speed LAN applications (e.g., 10 Gigabit Ethernet, 40 Gigabit Ethernet) require the use of a VCSEL to deliver the light source. Because a VCSEL illuminates a smaller number of modes in the optical fiber than an LED, the bandwidth statement for these laser-optimized optical fiber are higher than for the LED.

Most optical fibers that are suitable for medium distance delivery of high-speed applications have two bandwidth statements in the 850 nm window—one for an LED source OFL and one for the VCSEL EMB.

Attenuation

The maximum permissible end-to-end system attenuation in a given link is determined by the average transmitter power and the receiver sensitivity. To analyze a system's attenuation and determine whether the proposed electronics will operate over the cable plant, follow the nine steps shown in Table 1.32 and then check the minimum system loss (see Checking Minimum System Loss in this chapter). The nine steps are explained in detail on the pages following Table 1.32.

NOTE: Be sure the test setup simulates the actual system. (Select the required minimum transmission-rate-capable transmitter and receiver and use the jumpers or at least include their losses in final calculations.)

Attenuation, continued

Table 1.32
Calculating optical fiber performance

Objective	Step	Calculation
A. Calculate the link loss budget	1	Calculate the system gain.
	2	Determine the power penalties.
	3	Calculate the link loss budget by subtracting the power penalties from the system gain.
B. Calculate the passive cable system attenuation loss	4	Calculate the optical fiber loss.
	5	Calculate the connector loss.
	6	Calculate the splice loss.
	7	Calculate other component losses (e.g., bypass-switches, couplers, splitters).
	8	Calculate the total passive cable system attenuation by adding the results of Steps 4-7.
C. Verify performance	9	Subtract the passive cable system attenuation (result of Step 8) from the link loss budget (result of Step 3). The result is the system performance margin. If this result is a negative number, the system will not operate.

Attenuation, continued

Example 1.1 illustrates how to calculate the system performance margin to verify adequate power. Detailed information is provided on the following pages.

Example 1.1
Optical fiber performance calculations example

A. Calculating the Link Loss Budget

Example manufacturer's electronic specifications	System Wavelength	1310 nm
	Optical fiber type	Singlemode
	Average transmitter output	-3.0 dBm
	Receiver sensitivity (10^{-12} BER)	-19.0 dBm
	Receiver dynamic range	16.0 dB

1. Calculate system gain		Average transmitter power	−	0.5 dB
	−	Receiver sensitivity	−	(−19.0 dBm)
	=	System gain		19.5 dB
2. Determine power penalties		Operating margin (none stated)		3.0 dB
	+	Receiver power penalties (none stated)	+	0.0 dB
	+	Repair margin (2 fusion splices) at 0.3 dB each)	+	0.6 dB
	=	Total power penalties		3.6 dB
3. Calculate link loss budget		System gain		19.5 dB
	−	Power penalties	−	3.6 dB
	=	Total link loss budget		15.9 dB

B. Calculating the Passive Cable System Attenuation

4. Calculate optical fiber loss at operating wavelength		Cable distance		1.5 km
	x	Individual optical fiber loss	x	0.4 dB/km
	=	Total optical fiber loss		0.6 dB
5. Calculate connector loss (exclude transmitter and receiver connectors)		Connector pair loss		0.75 dB
	x	Number of connector pairs	x	4
	=	Total connector loss		3.0 dB
6. Calculate optical splice loss		Individual splice loss		0.3 dB
	x	Number of splices	x	3
	=	Total splice loss		0.9 dB
7. Calculate other component losses		Total components (none)		0.0 dB
8. Calculate total passive cable system attenuation		Total optical fiber loss		0.6 dB
	+	Total connector loss	+	3.0 dB
	+	Total splice loss	+	0.9 dB
	+	Total components	+	0.0 dB
	=	Total system attenuation		4.5 dB

C. Verifying Performance

9. Calculate system performance margin to verify adequate power		Link loss budget		15.9 dB
	−	Passive cable system attenuation	−	4.5 dB
	=	System performance margin		11.4 dB

Attenuation, continued

A. Calculating the Link Loss Budget

The link loss budget is the maximum allowable loss for the end-to-end cable system. To calculate the link loss budget, calculate the system gain and power penalties:

- System gain is the difference between the transmitter average power and the receiver sensitivity.
- Power penalties are factors that adjust the system gain, including the operating margin, receiver power penalty, and repair margin.

Attenuation, continued

Table 1.33 explains how to calculate the system gain, power penalties, and link loss budget.

NOTE: For information on link loss budget calculations by the manufacturer, see the footnote at the end of Table 1.33.

Table 1.33
System gain, power penalties, and link loss budget calculations

To Calculate the…	You Must…
System gain	Subtract the receiver sensitivity (in dBm) from the transmitter average power (in dBm). This gives the maximum allowable loss (in dB) between the transmitter and receiver for the BER specified for the receiver. NOTE: If the transmitter power is not based on the optical fiber type of the system, it can be adjusted using the information in Table 1.30.
Power penalties	Add the loss values for the: • Operating margin*—This loss accounts for: – Variations in the transmitter center wavelength. – Changes in the transmitter average power and receiver sensitivity that result from age. – Variations in the component temperature within the operating range of the system. If the system manufacturer does not specify the operating margin, use value of: • 2 dB for LEDs. • 3 dB for lasers. • Receiver power penalty*—Some manufacturers may specify other power penalties (dispersion, jitter, bandwidth, or clock recovery) that must be subtracted from the system gain. If these are provided, they must be subtracted from the available system gain. • Repair margin*—If the cable is located where it could be cut or damaged by accident, allow sufficient loss margin in the design to accommodate at least two repair splices. If the cable is in a high-risk area or reroutings are anticipated, the ICT distribution designer may decide to allow for more than two splices.
Link loss budget*	Subtract the total value (in dB) for all of the power penalties from the system gain. The result is the link loss budget.

* In some cases, the electronics manufacturer will have already calculated the link loss budget. In these cases, it is usually safe to assume the operating margin (e.g., transmitter aging) and receiver power penalties have been included in the manufacturer's calculations. However, the repair margin is usually not included in a manufacturer's link loss budget calculations, unless the product documentation specifically states a repair margin. When a repair margin is not stated by the manufacturer, the ICT distribution designer must subtract it from the system gain to determine the link loss budget.

BER = Bit error rate
ICT = Information and communications technology
LED = Light-emitting diode

Attenuation, continued

B. Calculating the Passive Cable System Attenuation

To calculate the passive cable system attenuation, total the values for the:

- Optical fiber loss.
- Connector loss.
- Splice loss.
- Other component losses.

NOTE: When working with existing cable plant, passive cable system attenuation can be measured directly. Table 1.34 explains how to calculate each of these losses.

Table 1.34
Calculating losses

To Calculate the…	You Must…
Optical fiber loss	Multiply the length of the proposed link by the normalized cable attenuation (dB/km) for the optical fiber at the operating system wavelength. NOTE: Temperature may affect the loss of the optical fiber cable. See Effects of Temperature on Optical Fiber Loss.
Connector loss	Add the individual attenuation values (in dB) for every connector pair along the optical fiber route, from transmitter to receiver, excluding the transmitter and receiver connectors (see Connector Loss Values). NOTE: A connector as described here refers to a mated connector pair in a channel where all the connectors are the same type. The channel may have two, three, or four connectors. For channels with more than two connectors, a lower loss connector is required to meet the loss budget.
Splice loss	Add the individual local attenuation values (in dB) for every splice along the optical fiber route, from transmitter to receiver (see Splice Loss Values).
Other component	Add the attenuation values of any other components that contribute to losses in the optical fiber route, from transmitter to receiver.
Total loss	Add the values for each of these losses to get the total passive cable system attenuation.

NOTE: Example calculations for the passive cable system attenuation and its four components are shown in Example 1.1.

Attenuation, continued

Effects of Temperature on Optical Fiber Loss

Temperature changes may affect the loss of optical fiber cable. Loss variations because of temperature changes can sometimes be as high as 0.2 dB/km. Some manufacturers' specifications indicate the cable's loss only at room temperature rather than throughout the operating temperature range.

Add an additional margin (in dB/km) to the normalized optical fiber attenuation value when calculating the optical fiber link loss, as explained earlier in this section, if the cable's specifications are:

- For room temperature only.
- Based on an average of several optical fibers.

Connector Loss Values

When designing links with:

- Zero to four connector pairs, use the maximum value.
- Five or more connector pairs, use the typical value.

NOTE: The maximum connection loss of 0.75 dB is recommended. SFF connectors should meet or exceed these attenuation requirements. Consult the connector manufacturer to provide the average and maximum loss values for the connector type selected.

Splice Loss Values

General splice loss values for system planning and link loss analysis are given in Table 1.35. Specific suppliers or contractors may use other values.

NOTE: A maximum splice loss of 0.3 dB is recommended.

Table 1.35
Splice loss values in decibels

	Multimode		Singlemode	
Splice Type	**Average**	**Maximum**	**Average**	**Maximum**
Fusion	0.05	0.3	0.05	0.3
Mechanical	0.10	0.3	0.10	0.3

C. Verifying Performance

To verify performance, subtract the passive cable system attenuation from the link loss budget. If the result is:

- Above zero (i.e., the passive cable system attenuation is less than the link loss budget), the system has enough power to operate over the passive portion of the link.
- Below zero (i.e., the passive cable system attenuation is more than the link loss budget), the system does not have enough power to operate.

NOTE: For this purpose, maximum transmitting average power should be considered.

Attenuation, continued

If the result is below zero and the system has not been installed, make design changes (e.g., use lower loss connectors, splices, or optical fibers; reroute the design) to reduce passive system losses. In rare cases, it may be necessary to add active components with greater system gains.

When working with an existing cable plant, passive cable system attenuation can be measured directly. Remember that the test setup should simulate the actual system (e.g., use the jumpers or at least include their losses in the final calculations).

Example link loss calculations are shown in Example 1.1.

Checking Minimum System Loss

After verifying that the electronics have enough power to operate, one more attenuation check of the system design remains. Compare the link attenuation with the receiver's dynamic range to ensure there is not too little loss in the link (see Table 1.36).

Insufficient minimum system loss (e.g., too little loss in the link) is sometimes a problem when a laser source is used in premises environments (where lengths are short).

To calculate the minimum required system loss, subtract the receiver's dynamic range from the system gain (both in dB, see Example 1.1):

	System gain		19.5 dB
–	Receiver's dynamic range	–	16 dB
=	Minimum required system loss	=	3.5 dB

Table 1.36
Minimum system loss

If the Result Is…	Then…
Less than zero	No further checking is necessary as it is impossible to overdrive that transmitter/receiver combination.
Greater than zero	The resulting number represents the minimum loss that must be introduced into the link between the transmitter and receiver to maintain the specified BER. The total optical fiber, connector, and splice loss must exceed this value. Using Example 1.1: Optical fiber loss 0.6 dB Connector loss + 3.00 dB Splice loss + 0.90 dB Total = 4.5 dB Because 4.5 > 3.5, the system will operate as installed.

BER = Bit error rate

Attenuation, continued

If additional loss is required in a given link, it is easy to add an appropriate link attenuator to the system. Attenuators are devices that can be inserted into optical fiber transmission systems, usually at a point where there is a connector, to introduce additional loss. There are two types of attenuators:

- Fixed attenuators cause a specific level of additional loss.
- Variable attenuators can be tuned to a given link.

Determine if the minimum loss criteria are met by measuring the attenuation of each link after it is installed.

Selecting an Optical Fiber Core Size to Application or Original Equipment Manufacturer (OEM) Specifications

Applications standards (e.g., IEEE) specify the maximum supportable distance of each optical fiber type for specific applications.

OEMs of optical transmission equipment also determine the maximum distance over which their systems can operate. They recommend a specific core size and optical fiber performance for given lengths and data rates.

Deviations from the OEM recommendations may be justified in the following circumstances:

- Optical fiber selection is made during the cabling design process and before the selection of active components.
- Cabling systems are designed for potential upgrades for which the active elements are not yet available.
- Existing installed optical fibers are used whether or not they are the type recommended for the particular end equipment.

Therefore, it is important for the ICT distribution designer to understand:

- The characteristics of the application and the active equipment.
- How the characteristics of the application and the active equipment affect optical fiber selection.

Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) Concepts

Similar in nature to digital hierarchy for balanced twisted-pair transmissions, standards have been established for optical fiber carrier transmissions.

SONET is the standard for North America, and SDH is the international standard. These two standards are basically identical. These standards organize transmission into 810-byte frames that include bits related to signal routing and destination as well as the data being transported.

The term synchronous means that all network nodes ideally derive their timing signals from a single primary clock; however, because this is not always practical, SONET and SDH can accommodate nodes with different primary clocks.

Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) Concepts, continued

Table 1.37 shows the common SONET and SDH transmission rates.

Table 1.37
Common SONET and SDH transmission rates

Rate Name	Data Rate (Mb/s)	Voice Channels
STS-1/OC-1	51.84	672
STS-3/OC-3	155.52	2016
STS-12/OC-12	622.08	8064
STS-48/OC-48	2488.32	32,256
STS-96/OC-96	4976.64	64,512
STS-192/OC-192	9953.28	129,024
OC-768	39,813.12	516,096
OC-1536	79,626.12	1,032,192
OC-3072	159,252.24	2,064,384

OC = Optical carrier
STS = Synchronous transport signal

Unlike the T and E multiplex formats covered previously, SDH allows single channels to be extracted from the signal at any of the data rates. This makes it far more flexible and cost effective.

Other key advantages of SDH are that the line-side transmission format and alarm format are identical between all vendors, which allows for greater equipment choice. Previously, the transmit and receive terminals had to be from the same vendor to ensure compatibility.

The SDH concept is based around the ability that any signal from a lower order multiplex stage can be inserted directly into a higher order signal.

System Example

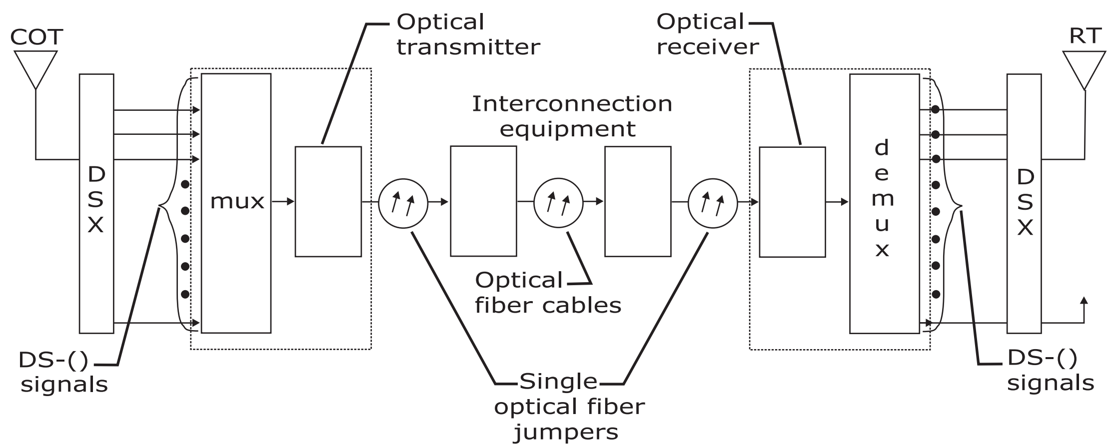
Prior to the optical transmitter receiving the electrical signal, there may be some conditioning or multiplexing of the electrical signal for use on the optical network. For typical LAN applications, either no changes are made to the electrical signal, or the signal is slightly modified to be placed in the proper optical format.

NOTE: See Chapter 15: Data Networks for more information.

For channel transmissions, specifically synchronous transmissions such as DSX and SONET, often the individual channels are multiplexed prior to being sent to an optical receiver.

Figure 1.31 illustrates a configuration that multiplexes like-DSX signals onto one or more optical fibers.

Figure 1.31
DSX optical multiplexing design

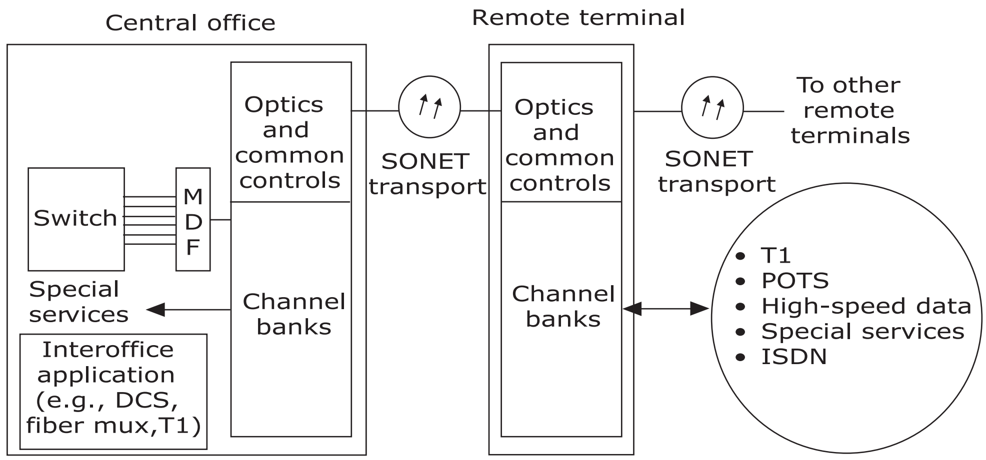


COT = Central office terminal
demux = Demultiplexer
DS = Digital signal
DSX = Digital signal cross-connect
mux = Multiplexer
RT = Remote terminal

System Example, continued

Figure 1.32 illustrates a configuration that multiplexes different types of signals onto SONET.

Figure 1.32
SONET multiplexing design



DCS = Digital cellular system
ISDN = Integrated services digital network
MDF = Main distribution frame
mux = Multiplexer
POTS = Plain old telephone service
SONET = Synchronous optical network

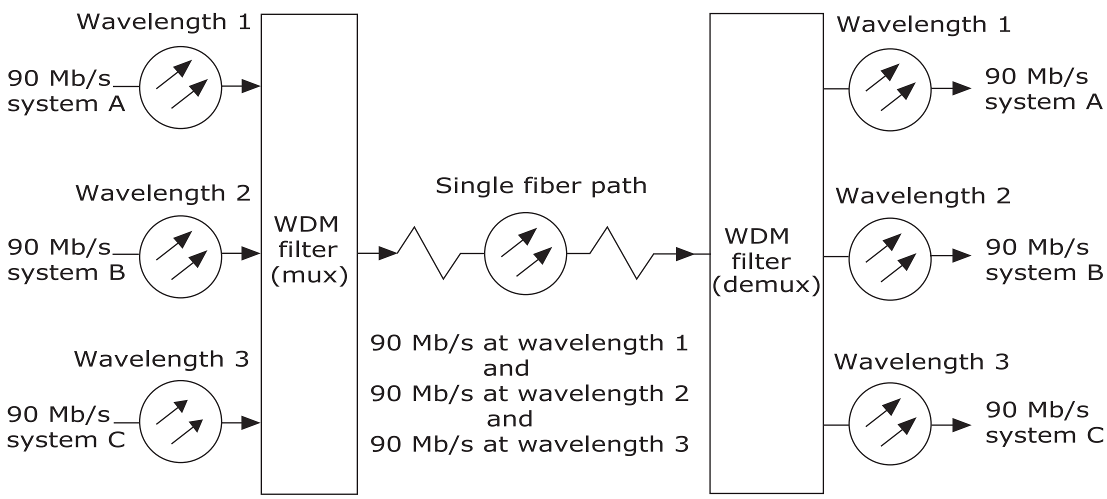
WDM is an alternative means of multiplexing signals onto an optical fiber system. WDM multiplexes multiple electrical signals to separate optical wavelengths at the source that are sent along one optical fiber to its receiver at the opposite end. To accomplish this, WDM uses a series of lenses to refract and direct light pulses into a single optical fiber that carries the combined wavelengths.

At the other end of the optical fiber cable, a WDM receiver separates the wavelengths and converts them to separate electrical signals. WDM may also be used to enable a single optical fiber to both transmit and receive. WDM is most commonly used in long-haul, high-bandwidth data transmissions.

System Example, continued

Figure 1.33 illustrates WDM being used to transmit three separate 90 Mb/s signals over a single optical fiber.

Figure 1.33
WDM



demux = Demultiplexer
mux = Multiplexer
WDM = Wavelength division multiplexer

Appendix

North American Digital Signal (DS)

The levels of multiplexing used in North America are DS0, DS1, DS1C, DS2, and DS3.

Digital Signal Level Zero (DS0)

The lowest level of digital carrier is known as DS0. In PCM systems, a DS0 channel contains 64 kb/s of information.

Digital Signal Level One (DS1)

The first level of TDM is DS1, which:

- Uses a transmission rate of 1.544 Mb/s.
- Can transmit up to 64 kb/s data over any one of 24 channels if the transmission system has clear channel capability.

NOTE: Many systems can transmit only up to 56 kb/s per channel because of pulse density requirements of clock recovery.

- Is capable of handling 24 standard (3100 Hz bandwidth) analog voice channels when standard 64,000 b/s PCM is used. Forty-eight voice channels are available if 32,000 b/s ADPCM encoding is used.
- Can operate over standard balanced twisted-pair cables within specific distance limits and design conditions.

NOTE: The transmit and receive pairs are normally separated in non-adjacent binder groups or screened compartments.

- Is widely used for short-haul carrier transmission (up to ≈322 km [200 mi]).

A DS1 rate system without clear channel capability is capable of handling approximately 1344 kb/s of data (24 x 56 kb/s); 1536 kb/s of data (24 x 64 kb/s) can be handled if clear channel capability is available. Therefore, these systems can be used with wideband data terminals.

Repeater T1 carrier operated at the DS1 rate is coded bipolar AMI with a 50 percent duty cycle.

North American Digital Signal (DS), continued

Digital Signal Level One C (DS1C)

The special requirements for T2 carrier led to the development of an intermediate level, known as DS1C (T1C), which:

- Uses a process called pulse stuffing to synchronize the two DS1 signals.
- Makes more use of existing cable plant for short and medium distances.
- Has not been designated for use with higher level multiplexing.
- Can transmit two DS1 signals (48 voice channels total) at a 3.152 Mb/s transmission rate (DS1C rate).

NOTE: This system is no longer being deployed.

Digital Signal Level Two (DS2)

The second full level of multiplexing is DS2, which:

- Typically handles four DS1 channels, for a total of 96 voice channels.
- Employs a 6.312 Mb/s pulse stream.

NOTE: This is slightly more than four times the DS1 rate because of bit stuffing.

For distances beyond ≈300 m (984 ft), T2 carrier requires special balanced twisted-pair cable (e.g., low-capacitance [locap cable]) that has special crosstalk and attenuation characteristics. Balanced twisted-pair systems using T2 carrier are obsolete; however, low-speed optical fiber systems carry DS2 signals.

Digital Signal Level Three (DS3)

The DS3 level is seeing increased use between customer locations and between customer and main entrance facility locations.

The DS3 level:

- Is used to multiplex 28 DS1 or 7 DS2 signals at 44.736 Mb/s.
- Is a common speed for optical fiber and digital radio systems.
- Uses bit stuffing to synchronize the incoming DS1 or DS2 streams to the multiplex terminal.

North American Digital Signal (DS), continued

Higher Levels

Higher levels of multiplexing and carrier transmission are summarized in Table 1.38.

Table 1.38
Levels of multiplexing and carrier transmission in North America

Digital Signal	Rate (Mb/s)	Channels	Facility	Notes
DS1	1.544	24	Paired cable	Basic North American system
DS1C	3.152	48	Paired cable	Expansion system for existing DS-1
DS2	6.312	96	Special locap paired cable or optical fiber	
DS3	44.736	672	Optical fiber, digital radio, or coaxial cable	
DS4	274.176	4032	Optical fiber, microwave radio, or coaxial cable	High-density long-haul system

DS1 = Digital signal level 1
DS1C = Digital signal level 1C
DS2 = Digital signal level 2
DS3 = Digital signal level 3
DS4 = Digital signal level 4

European E

The levels of multiplexing used in Europe are E1, E2, E3, and E4.

B Channel

A single 64 kb/s channel is sometimes referred to as a B channel.

E1 Level

The first level of TDM is E1, which:

- Uses a transmission rate of 2.048 Mb/s.
- Can transmit up to 64 kb/s data over any one of 30 channels if the transmission system has clear channel capability.

  NOTE: Two additional 64 kb/s channels perform alignment and carry signaling.

- Is capable of handling 30 standard (3100 Hz bandwidth) analog voice channels when standard 64 kb/s PCM is used. 60 voice channels are available if 32 kb/s ADPCM encoding is used.
- Can operate over standard balanced twisted-pair cables within specific distance limits and design conditions.

  NOTE: The transmit and receive pairs are normally separated in non-adjacent binder groups or screened compartments.

- Is widely used for short-haul carrier transmission (up to ≈322 km [200 mi]). A repeated carrier operated at the E1 rate is coded bipolar HDB3.

E2 Level

The second full level of multiplexing is E2, which:

- Typically handles four E1 channels for a total of 120 voice channels.
- Employs an 8.192 Mb/s pulse stream.

For distances beyond ≈300 m (984 ft), E2 carrier requires special balanced twisted-pair cable (e.g., locap cable) that has special crosstalk and attenuation characteristics. Balanced twisted-pair systems using E2 carrier are obsolete; however, low-speed optical fiber systems carry E2 signals.

E3 Level

The E3 level is seeing increased use between customer locations and between customer and main entrance facility locations. The E3 level:

- Is used to multiplex four E2 signals at 34.816 Mb/s.
- Is a common speed for optical fiber and digital radio systems.
- Uses bit stuffing to synchronize the incoming E2 streams to the multiplex terminal.

European E, continued

Higher Levels

Higher levels of multiplexing and carrier transmission are summarized in Table 1.39.

Table 1.39
Levels of multiplexing and carrier transmission in Europe

Digital Signal	Rate (Mb/s)	Channels	Facility	Notes
E1	2.048	30	Paired cable	Basic system
E2	8.192	120	Special locap paired or coaxial cable or optical fiber	
E3	34.816	480	Optical fiber, digital radio, or coaxial cable	
E4	139.264	1920	Optical fiber, microwave radio, or coaxial cable	High-density long-haul system

E1 = European 1
E2 = European 2
E3 = European 3
E4 = European 4

Electromagnetic Compatibility (EMC)

Introduction

EMC is the ability of a device, equipment, or system to operate properly in its intended electromagnetic environment without introducing significant EMI into the environment.

EMI is the transfer of electromagnetic energy from one device or system to another device or system operating in the same environment that causes interference with the normal operation of devices or systems.

The potential for EMI increases when devices or systems share a common electromagnetic environment and their operation’s frequencies overlap. If they operate over a different range of the electromagnetic spectrum, lower levels of EMI between them are expected.

The coupling between two circuits or systems can occur because of one or more of the following mechanisms:

- Conductive coupling (when a common branch circuit is shared between two devices)
- Inductive coupling (by magnetic fields)
- Capacitive coupling (by electric fields)
- Electromagnetic coupling (by electromagnetic fields and waves)

Three essential elements to any EMC problem are:

- The source of an EMI or electromagnetic energy transfer between an interfering source and a susceptible device or system.
- The susceptible device or system that cannot perform as designed, configured, or programmed because of the EMI event.
- A coupling path that promotes the disturbance between the interfering source and the susceptible device or system.

Mitigate EMC problems by identifying at least two of these elements and eliminating, or reducing the influence of, the third one.

Electromagnetic Spectrum

Overview

EMR is radiation composed of oscillating electrical and magnetic fields and propagated through a medium. EMR includes gamma, X-ray, UV, visible (i.e., light), and IR radiation as well as radar, microwaves and radio waves. All of these are fundamentally similar in that they propagate at the speed of light (≈300,000 km/s [186,300 mi/s] in a vacuum).

Electromagnetic waves are distinguished by their wavelength, which is expressed in meters, or their frequency, which is expressed in hertz:

$\lambda = c/f$

Where:

f = frequency in hertz

λ = wavelength in meters

c = velocity of light in meters per second in a vacuum

The entire spectrum is the range of frequencies of EMR from zero to infinity.

Radio Spectrum Groups

The electromagnetic spectrum was formerly divided into 26 alphabetically designated bands. This usage still prevails to some degree. However, the ITU recognizes 12 bands from 3 Hz to 3 THz:

- ELF, ITU Band 1 = 3 Hz to 30 Hz
- SLF, ITU Band 2 = 30 Hz to 300 Hz
- VF, ITU Band 3 (ULF) = 300 Hz to 3000 Hz
- VLF, ITU Band 4 = 3 kHz to 30 kHz
- LF, ITU Band 5 = 30 kHz to 300 kHz
- MF, ITU Band 6 = 300 kHz to 3 MHz
- HF, ITU Band 7—e.g., aviation communications and RFID = 3 MHz to 30 MHz
- VHF, ITU Band 8—e.g., FM radio = 30 MHz to 300 MHz
- UHF, ITU Band 9—e.g., mobile phones and wireless LAN = 300 MHz to 3000 MHz (3 GHz)
- SHF, ITU Band 10—e.g., radar and microwave radio = 3 GHz to 30 GHz
- EHF, ITU Band 11—e.g., radio astronomy and millimeter wave scanner = 30 GHz to 300 GHz
- THZ, ITU Band 12—e.g., medical imaging = 300 GHz to 3000 GHz (3 THz)

NOTE: See Figure 2.1 for a representation of the electromagnetic spectrum.

Ceilings

The general requirements for ceilings in telecommunications spaces include the following:

- The minimum ceiling height should be ≈2.4 m (8 ft) AFF. Consideration should be given to having a ≈3 m (10 ft) height.
- When a ceiling distribution system is used, telecommunications spaces should be designed with adequate pathways or openings through walls and other obstructions into the accessible ceiling space.
- Alterations of structural steel or structural concrete require the approval of a structural engineer.
- To permit maximum flexibility and accessibility of cabling pathways, a suspended ceiling is not recommended in telecommunications spaces unless it is part of the air cooling strategy. If a suspended ceiling is specified it should be a grid system with removable metal or other non-fibrous tiles no larger than ≈0.6 m x 0.6 m (2 ft x 2 ft).
- Equipment may require additional ceiling clearance, depending upon the manufacturer's specifications. Excessive equipment and rack, cabinet, or enclosure height should be avoided because it may require special lighting and wider working clearances (e.g., taller than ≈2.4 m [8 ft] AFF).
- The ceiling finish should minimize dust and be light colored to enhance the room lighting.

Clearances

The following clearances should be provided for equipment and cross-connect fields in telecommunications spaces:

- Provide ≈1 m (3.28 ft) of clear, unobstructed space for the installation and maintenance of all cabling and equipment mounted on walls, racks, cabinets, or enclosure.
- It may not be possible to achieve ≈1 m (3.28 ft) of clear, unobstructed space when cabling is mounted below access floors or above ceilings. In such cases, provide as much clear, unobstructed space as possible.
- Provide at least ≈150 mm (6 in) depth off the wall for wall-mounted equipment.
- For racks and cabinets, the working clearance shall take into account the depth of rack-mounted equipment as well as wall-mounted equipment and hardware.
- Provide minimum working clearance (front and rear) of ≈1 m (3.23 ft) from installed equipment.
- In corners, a minimum side clearance of ≈300 mm (12 in) is recommended.
- Consult the manufacturer's documentation and local codes for specific requirements.
- The ICT distribution designer should always consider adequate clear space in the area of cabling terminations and equipment connections for safety considerations.

NOTE: In many cases, equipment and connecting hardware may extend beyond racks, cabinets, enclosures, and backboards. It is important to note that the clearance is measured from the outermost surface of these devices rather than from the mounting surface of the rack, cabinet, enclosure, or backboard.

Codes, Standards, and Regulations

All applicable codes, standards, and regulations during the design, construction, and use of telecommunications spaces should be observed. See Appendix A: Codes, Standards, Regulations, and Organizations for additional details.

Conduits, Trays, Slots, Sleeves, and Ducts

If possible, sleeves, slots, or conduits should be located such that cable terminations on the wall can be performed from left to right. Trays and conduits located within the ceiling should protrude into the room a distance of ≈25.4 mm (1 in) to ≈51 mm (2 in) without a bend and above ≈2.4 m (8 ft) high. The type and location of the cross-connect fields may influence the optimal placement of pathways.

IMPORTANT: The location of structural and facility systems elements shall be identified prior to locating penetrations.

Slot/sleeve systems should be located in places where pulling and termination will be easy to achieve.

Where vertical and horizontal offsets are required, bend radius requirements and service loop guidelines should be considered.

Sleeves and slots shall not be left open after cable installation. All sleeves and slots shall be firestopped in accordance with the AHJ and project requirements. See Chapter 7: Firestop Systems for detailed information on firestopping of cabling pathways.

The size and number of conduits or sleeves used for backbone pathways depend on the usable floor space served by the backbone distribution system. However, at least four ≈103 mm (4 trade size) sleeves are recommended to serve a TR, ER, or EF. See Chapter 4: Backbone Distribution Systems to determine the exact size and number of conduits or sleeves required for backbone pathways.

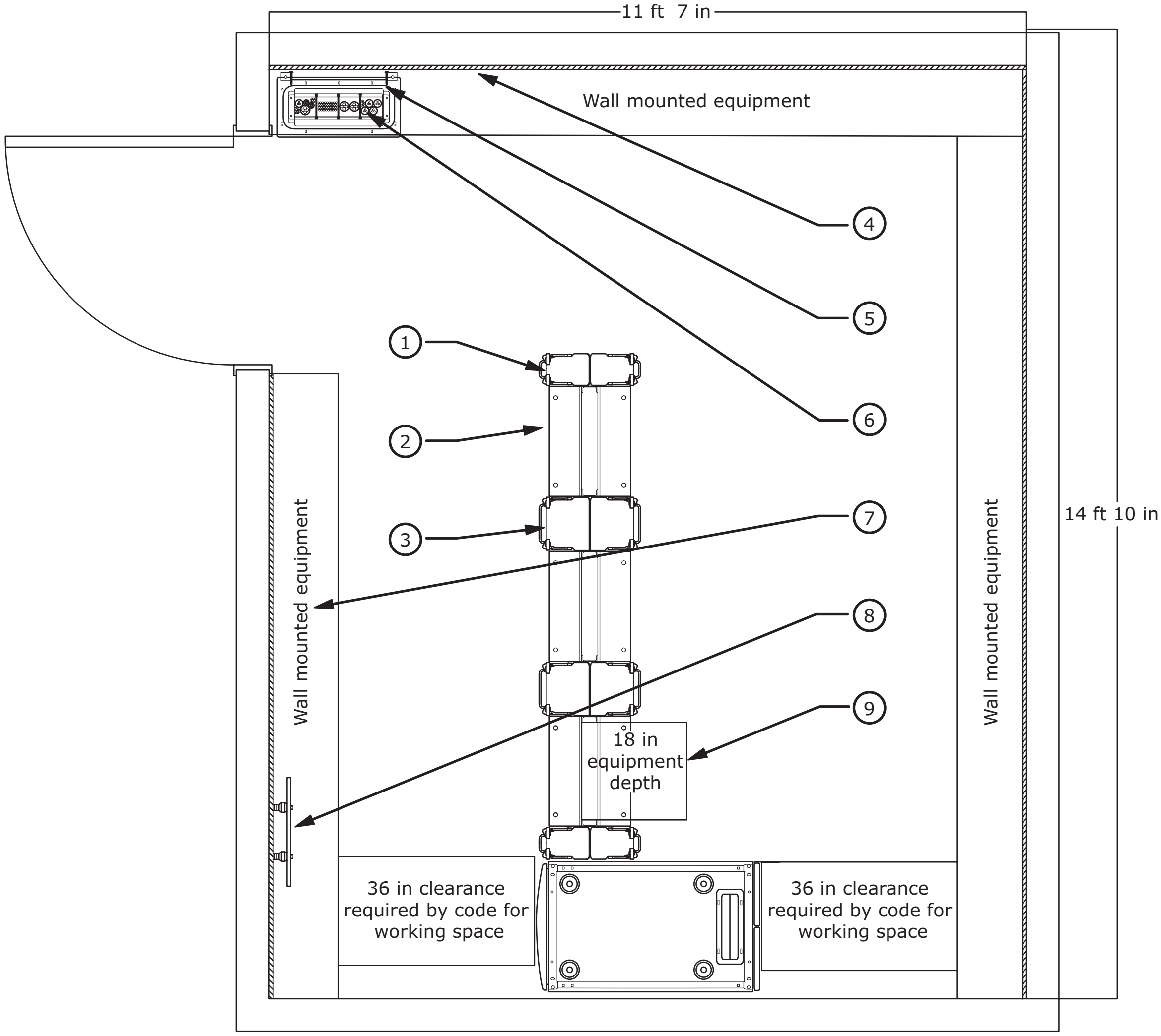
Multiple telecommunications spaces on the same floor shall be interconnected with a minimum of two ≈103 mm (4 trade size) conduits or a pathway that provides equivalent capacity. For horizontal pathways, use the requirements for conduits, trays, and ducts provided in Chapter 5: Horizontal Distribution Systems.

IMPORTANT: The ICT designer shall coordinate all of the above requirements concerning backbone pathways with the applicable stakeholders (e.g., client, other trades and disciplines, AHJs).

Walls and Wall Linings, continued

NOTE: Plywood should be painted on all sides and within cutout areas with two coats of fire-retardant light-colored paint. Fire-rated plywood may be required in some facilities. Alternately, the plywood may be covered with drywall to satisfy building code requirements in some areas; however, this should be avoided if possible and verified with the AHJ prior to installation.

Figure 3.3
Space considerations when sizing a telecommunications space



1. 6 in wide double sided vertical cable manager
2. 45 RU 2 post rack
3. 10 in wide double sided vertical cable manager
4. 3/4 in 4 ft x 8 ft fire rated plywood - grade AC
5. Cable runway to secure riser cables
6. EZ-path riser location
7. 12 in clearance for wall space mounted equipment
8. Telecommunications grounding busbar
9. Space allocated for rack mounted equipment

Telecommunications Rooms (TRs) and Telecommunications Enclosures (TEs)

Overview

TRs and TEs differ from ERs and EFs in that they are generally considered to be floor-serving or tenant-serving (e.g., as opposed to building- or campus-serving) spaces that provide a connection point between backbone and horizontal infrastructures.

TR and TE design should consider incorporation of other building information systems in addition to traditional voice and data needs (e.g., CATV, wireless networks, alarms, security, audio, other building signaling systems).

TRs and TEs provide an environmentally suitable and secure area for installing:

- Cables.
- Cross-connects.
- Connecting hardware.
- Telecommunications equipment.

The design of TRs and TEs depends on the:

- Size of the building.
- Floor space served.
- Occupant needs.
- Telecommunications service used.
- Future requirements.
- Number and type of cables being served from the space.

BICSI specifies a telecommunications infrastructure that distributes telecommunications services to each individual work area.

Central to this function are the TR and TE that allow, in a structured way, the interconnection of work areas on the same floor or to other floors via the backbone cabling.

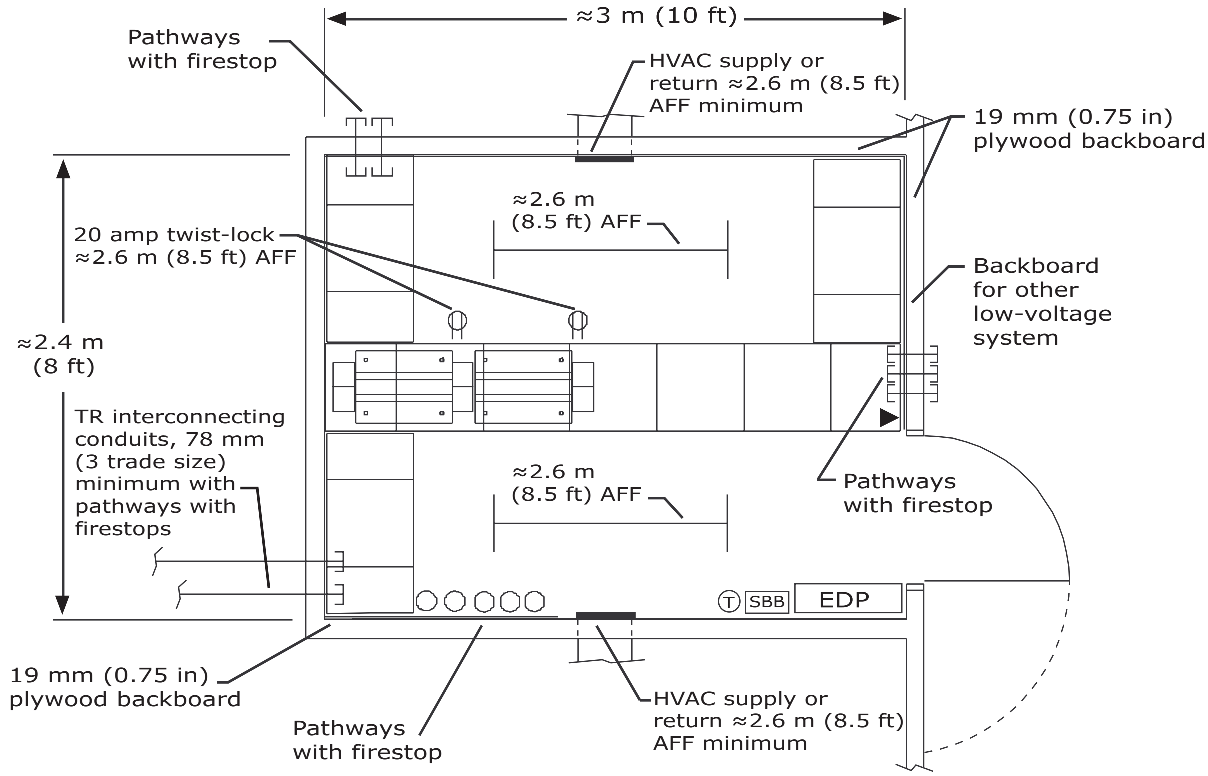
Responsibility of the Information and Communications Technology (ICT) Designer

The ICT designer must understand the design and customer requirements of the building. This is accomplished by meeting with building stakeholders. ICT designers should optimize the ability of the telecommunications spaces to accommodate change and avoid limitations by vendor requirements.

The designer should review all documentation including manufacturer's specifications and operating manuals to determine all applicable system requirements.

Telecommunications Room (TR) Diagram, continued

Figure 3.4
Typical TR layout

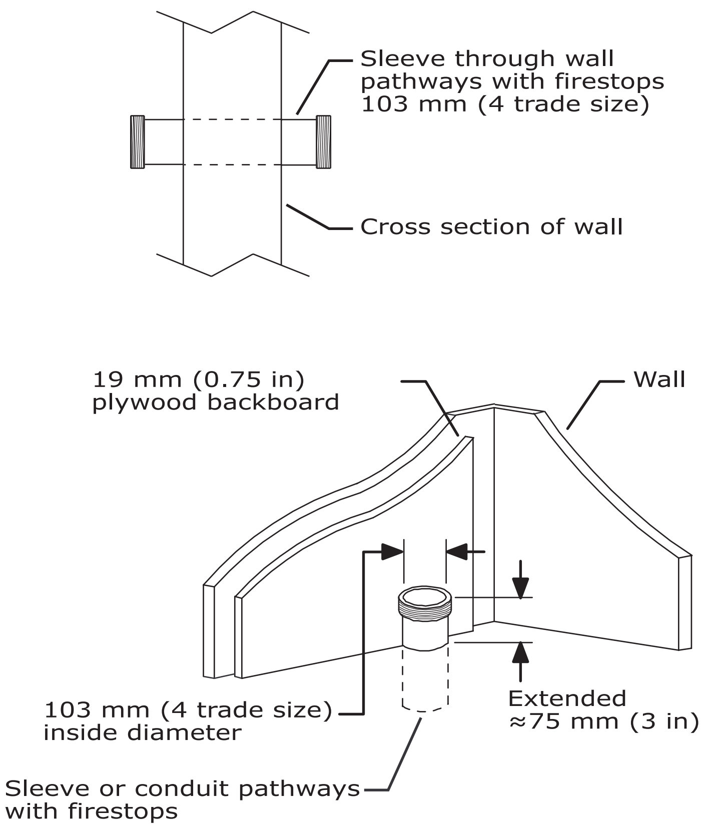


▶ = Telecommunications outlet/connector
Ⓣ = Thermostat
AFF = Above finished floor
EDP = Electrical distribution panel
HVAC = Heating, ventilation, and air-conditioning
SBB = Secondary bonding busbar
TR = Telecommunications room

Telecommunications Room (TR) Diagram, continued

Figure 3.5 shows a typical sleeve/conduit through a TR floor.

Figure 3.5
Typical sleeve/conduit



Determining Size Based on Area Served

When the ICT distribution designer does not know what specific equipment will be used in an ER, the designer can use the amount of floor space that the room will serve to determine the minimum size of the ER.

The following steps can be used to determine the minimum size of an ER.

Step	Task
1	Divide the amount of usable floor space by ≈9.3 m^2 (100 ft^2) to determine the number of individual work areas that the ER will serve through both backbone and horizontal cabling. NOTES: Usable floor space includes the building area used by occupants in their normal daily work functions. For planning purposes, this should include hallways but not other common areas of the building. If the usable floor space is unknown, deduct 20 percent of the total floor area to estimate the usable floor space. An area of ≈9.3 m^2 (100 ft^2) is an industry average used to calculate work areas. If work areas are smaller, the size of the ER shall be increased accordingly.
2	Divide the amount of total floor space by ≈23.2 m^2 (250 ft^2) to determine the number of BAS devices that the ER will serve through both backbone and horizontal cabling.
3	Multiply the number of work areas to be served by ≈0.07 m^2 (0.75 ft^2) and the number of BAS devices to be served by ≈0.023 m^2 (0.25 ft^2) to determine the ER size.

If there are fewer than 200 work areas, the ER shall be no less than ≈14 m^2 (150 ft^2). For special-use buildings (e.g., hospitals, hotels), ER size requirements may vary.

Arranging Equipment

An ER shall have a layout that is easy to use and maintain. All aspects of the layout should be flexible enough for equipment to be changed without structural renovation. Planned growth in the areas served by the ER shall be considered in the initial design.

The ease with which equipment can be serviced, upgraded, or replaced should also be considered when planning the layout of equipment and cross-connects. The layout of the ER should be designed to allow future system changes with a minimum of labor and service disruption. Under optimum conditions, a system cutover should be invisible to the users and other systems supported by the ER.

Arranging Equipment, continued

When designing equipment layouts, the ICT distribution designer should review all manufacturer's documentation for all specifications, including the:

- Weight of equipment.
- Physical dimensions.
- Number of RUs.
- Clearances.
- Distance limitations between cabinets.
- Power requirements (e.g., ac, dc).
- Cable management (e.g., vertical, horizontal).
- Installation requirements.

Client equipment space requirements should also be obtained.

NOTE: Chapter 18: Data Centers may also be useful in the design of large ERs.

Working Clearances

Applicable codes generally require a minimum working clearance around equipment. This minimum is determined by a number of factors, including the:

- Voltage.
- Exposure of live parts.
- Equipment orientation.
- AHJ.
- Location of grounded parts.

Typical equipment cabinets require ≈0.9 m^2 (10 ft^2) of floor area and an additional ≈0.9 m^2 (10 ft^2) of area for working clearance. The ICT distribution designer should check the manufacturer's working clearance requirements when planning installations.

Access Provider (AP) Space Requirements

If equipment or cable terminations that are owned or maintained by an AP shall be located in the ER, determine the location and amount of space that is required. Include this AP space in the ER design.

Work Area Space

Most ERs include work areas (e.g., desk space) for system administrators. Some ERs include workstation, display, and printout areas. Also, customers may need to integrate business functions related to information management (e.g., report collation, forms processing) within or adjacent to the ER. The space and layout of the ER shall accommodate such functions.

Passive Optical Networks (PONs), continued

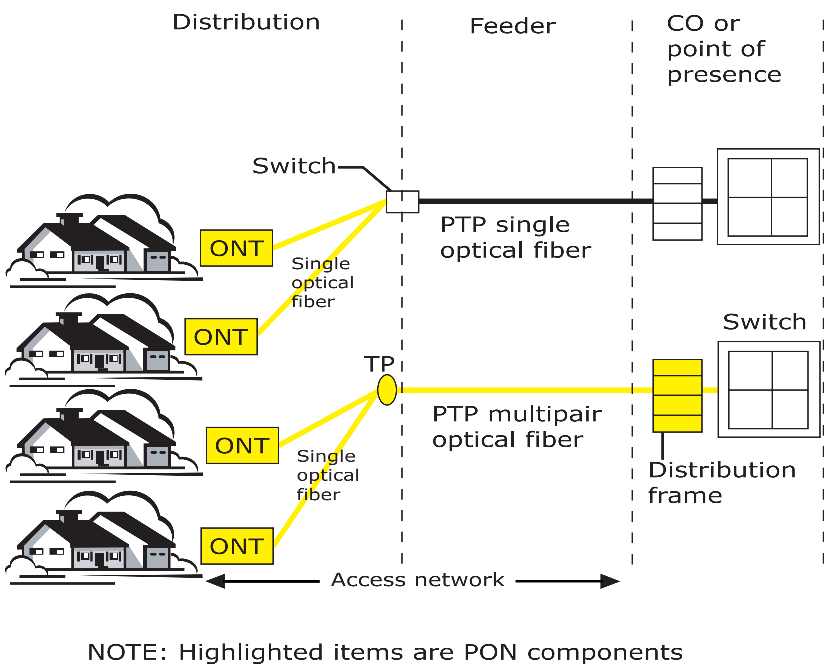
Point-to-Point (PTP) Topology

The 1000BASE-X deployment on a single strand of singlemode optical fiber reduces the cost of optical fiber deployment in the link between the business or house and the distribution or access switch. The 1000BASE-X extended temperature range optical fiber enables SPs to locate the ONT outside the residence at the demarcation point between the optical fiber network and the business or home network (i.e., operational temperature ranges from – 4.4 °C [– 40 °F] to 85 °C [185 °F]).

Gigabit Ethernet over PTP optical fiber provides enough bandwidth to ensure a very long lifespan for the network infrastructure; namely, the optical fiber infrastructure may be amortized over periods of time ranging from 20 or more years.

Figure 4.13 shows the topology of a PTP network over optical fiber. Multiple devices in the home can be connected to a single Ethernet port from the home to the carrier. The ONT is responsible for media conversion from the optical fiber to the balanced twisted-pair network or other media in the home.

Figure 4.13
PTP optical fiber



CO = Central office
ONT = Optical network terminal
PTP = Point-to-point
TP = Transition point

Passive Optical Networks (PONs), continued

Optical Fiber Specifications

Table 4.2 provides a reference to the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) Series G recommendations that collectively represent 99 percent of the installed base of singlemode optical fibers for PON networks. The ITU-T recommendations have been used extensively in subscriber access networks primarily in support of the SDH and SONET digital transmission hierarchies. ITU-T G series specifications may also be found in IEC 60793-2-50.

Table 4.2
EFM installed singlemode optical fiber

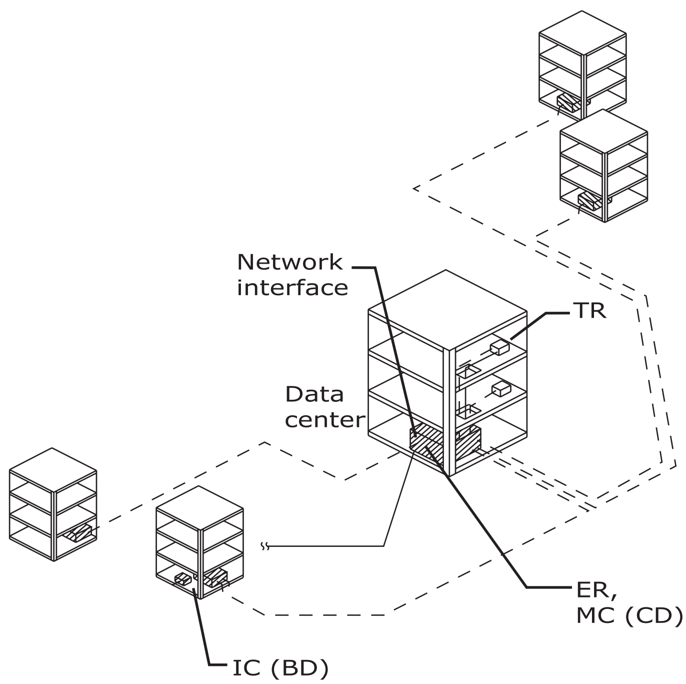
ITU-T Recommendation	Zero-Dispersion Wavelength Range	Notes
G.652		Dispersion unshifted fiber
G.652.B	1300 to 1324 nm	Supports 1 Gigabit Ethernet, 10 Gigabit Ethernet and SONET. Supports some higher bit rate applications, (e.g., STM-64, STM-256) depending on the system architecture.
G.652.D	1300 to 1324 nm	Supports G.652.B and allows transmissions in portions of the 1260 nm to 1625 nm wavelength range.
G.653		Dispersion shifted fiber
G.653.A	1525 to 1575 nm	Supports STM-64 and SDH systems with an unequal channel spacing in the 1550 nm wavelength region.
G.653.B	1460 nm to 1625 nm and within a pair of bounding curves defined by wavelength	Supports G.653.A applications, some STM-256 applications, and allows STM-64 systems to lengths longer than 400 km.
G.655		Non-zero dispersion shifted fiber. Primarily utilized in submarine and long-haul terrestrial applications.
G.655.C	1530 to 1565 nm	C and L-band compatible
G.655.D	1460 nm to 1625 nm and within a pair of bounding curves defined by wavelength	Supports G.655.C applications at wavelengths greater than 1530 nm. Can support CWDM at channels greater than 1471 nm.
G.655.E	1460 nm to 1625 nm and within a pair of bounding curves defined by wavelength	Supports small channel spacings and G.655.C applications.

Equipment Rooms (ERs) and Access Provider (AP) Cabling System Interface Cabling

Ideally, the MC (CD) would be co-located in the ER with a PBX, security monitoring equipment, and other active equipment being served. However, this is not required and physical constraints sometimes make co-location impossible (e.g., when the MC [CD] serves multiple ERs that are not centralized). The location of the MC (CD) may be based entirely on geographic and physical constraints (e.g., duct space, termination space).

A building cabling system shall have only one MC (CD). Connection to the ER can then be provided by balanced twisted-pair or optical fiber, which is either in separate sheaths or combined under a single sheath (see Figure 4.25).

Figure 4.25
ERs and AP cabling system interface cabling



——— = Access providers trunk cables
— — — = Backbone cables
ER = Equipment room
IC (BD) = Intermediate cross-connect (building distributor)
MC (CD) = Main cross-connect (campus distributor)
TR = Telecommunications room

For ultimate flexibility, manageability, and versatility of the cabling system, all backbone cables and links to ERs should be terminated at the MC (CD). Each link can then be cross-connected to its ER on an as-needed basis by installing a patch cord, whether optical fiber or balanced twisted-pair.

Choosing Media

Overview

The choice of transmission media may depend upon the application. The factors to be considered include the:

- Flexibility of the medium with respect to supported services.
- Required useful life of backbone cabling.
- Site size and user population.
- User needs analysis and forecast.

The telecommunications service needs of a commercial building's occupants will vary as time passes and occupants change. Future uses of the backbone cabling may range from highly predictable to unpredictable.

Whenever possible, determine the different service requirements first. It is often convenient to group similar services together in categories (e.g., voice systems, LAN, and other digital connections). Then, identify the individual media types and projected quantities required within each group.

When requirements are uncertain, use worst-case estimates to evaluate backbone cabling alternatives. The more uncertain the requirements, the more flexible the backbone cabling system must be.

Each cable has individual characteristics that make it useful in a variety of situations. In some situations, a single cable type may not satisfy all the user requirements. In these cases, use more than one medium in the backbone cabling.

The different media should use the same physical topology within the same telecommunications spaces for cross-connects, splices, and terminations.

Multimode Optical Fiber Cable

OM4 or higher is recommended.

Singlemode Optical Fiber Cable

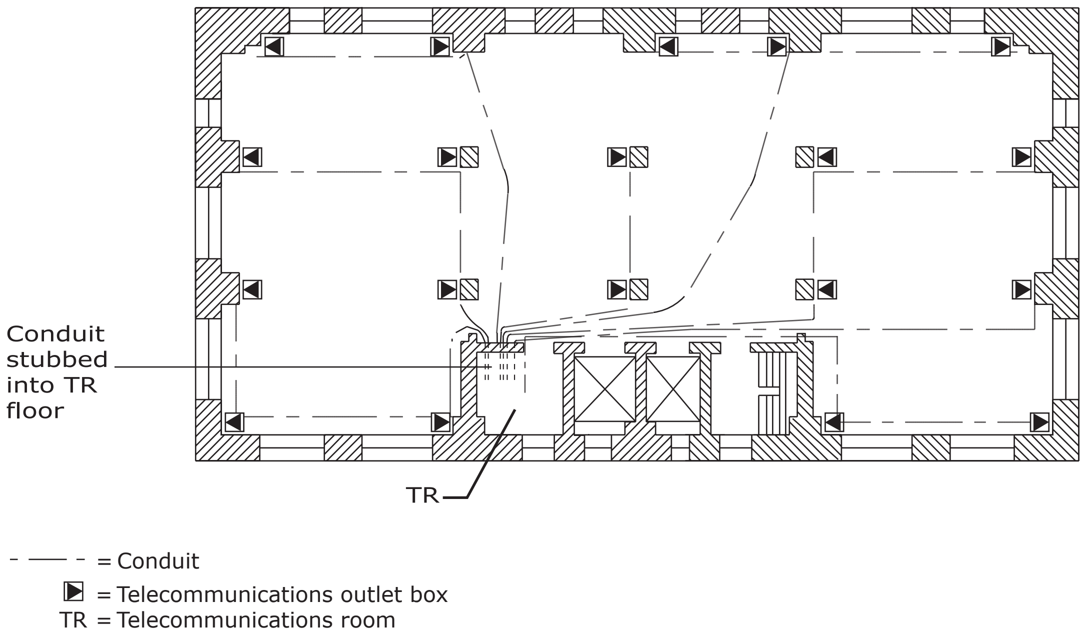
Although the vast majority of deployed optical fiber transmission systems are digital in nature, they can also be used for AM and FM analog signal transmission. Variations in the optical fiber signal source intensity or the frequency can be used to create analog optical signals. One example of this application is the use of singlemode optical fiber to transmit optical analog RF signals within DAS deployments.

100-Ohm Balanced Twisted-Pair Copper Cable

The recommended balanced twisted-pair cable for building backbone consists of 24 AWG or up to 22 AWG round, solid copper conductors with a nominal characteristic impedance of 100 ohm.

Conduit Distribution Systems, continued

Figure 5.25
Typical underfloor conduit system



Suitability and Acceptability of Conduits

The ICT distribution designer should design and install conduit runs:

- To achieve the best direct route (e.g., usually parallel to building lines) with no single bend greater than 90 degrees or an aggregate of bends in excess of 180 degrees between pull points or pull boxes.
- That do not contain continuous sections longer than ≈30.5 m (100 ft). For runs that total more than ≈30.5 m (100 ft) in length, pull points or pull boxes should be inserted so that no segment between points or boxes exceeds the ≈30.5 m (100 ft) limitation.
- Bonded to ground on one or both ends in accordance with national or local code requirements.
- That can withstand the environment to which they will be exposed.
- To avoid areas over or adjacent to heat sources such as:
  - Boilers.
  - Incinerators.
  - Hot water lines.
  - Steam lines.

NOTE: Refer to Chapter 4: Backbone Distribution Systems for information on types of conduit.

Conduit Distribution Systems, continued

Conduit Body

A conduit body is a conduit coupling that has a removable cover to allow access to the cable for placing purposes (see Figure 5.26). It is primarily used to give access to or to change the direction of the conduit system. It is important to meet the minimum bend radius requirements when cables are installed into a conduit system and conduit bodies are used to change direction.

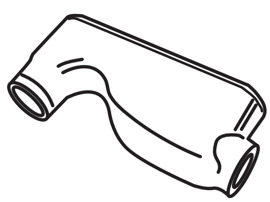
IMPORTANT: Standard conduit bodies do not meet the recommended bend radius and shall not be specified for ICT cable installation.

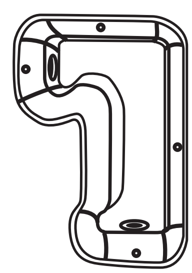
A conduit body features an internal radius that accommodates a standards-based cable bend radius once cable is installed in the lay position of the conduit body device. Only the telecommunications cabling style conduit bodies should be used in a telecommunications cabling installation.

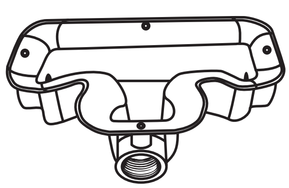
The most common styles are the:

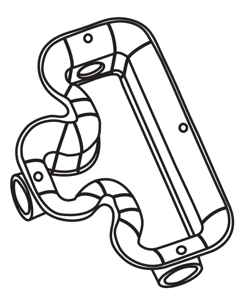
- 90-degree bend left, right, or back.
- T configuration.
- C or straight inline fitting.

Figure 5.26
Conduit bodies recommended for telecommunications cables


Elbow back (LB)


Elbow right (LR)


T Conduit Body – side view


T Conduit Body – top view

Conduit Distribution Systems, continued

In some buildings, a conduit system can furnish cable support and concealment. In such installations, conduit bodies manufactured to provide ample room for telecommunications cables may be used to enable access to the cabling (e.g., C conduit bodies) or to enable access to the cabling with a 90 degree corner (e.g., elbow left, elbow right, elbow back conduit bodies).

Conduit bodies designed for use with electrical wiring systems are not recommended for use with telecommunications cabling. Conduit bodies designed for use with telecommunications cabling systems that provide standards-based internal bend radii may be used where applicable.

ICT distribution designers shall consider codes, standards, regulations, and AHJ rulings, as well as aesthetics and other customer needs, when designing any conduit system.

Capacity

To ensure proper capacity for cabling, a conduit from the TR should not extend to more than two and shall not extend to more than three telecommunications outlet boxes.

Conduit size is generally designed so its diameter increases incrementally as the run approaches the ER or TR from the farthest telecommunications outlet box.

The conduit size for horizontal cabling shall accommodate cables placed at different times.

To determine the cross-sectional area of a cable or conduit from its nominal diameter, use the following formula (where d = diameter):

$$\text{Cross-sectional area} = 0.785 \times d^2$$

For conduit terminated at smoke- or fire-rated partitions, design to meet the firestop listed assembly. If fill percentage is too high, then there may not be enough space to install the correct amount of firestop material to perform its intended duty.

NOTE: For cables with an elliptical cross section, use the larger diameter of the ellipse as the diameter in the equation above.

Tables 5.6 and 5.7 provide guidelines and recommendations on conduit fill for horizontal cabling, assuming that a straight run of conduit is used and no conduit bends are applied.

The tables offer conduit sizes ranging from ≈16 mm (1/2 trade size) to ≈103 mm (4 trade size).

Conduit Distribution Systems, continued

Table 5.6
EMT 30 percent conduit fill rate

Trade Size	metric designator	Conduit ID mm (in)		4.6 mm (0.18 in)	5.0 mm (0.20 in)	6.0 mm (0.24 in)	7.0 mm (0.28 in)	8.0 mm (0.31 in)	9.0 mm (0.35 in)
1/2	16	15.8	(0.622)	3	2	2	1	1	0
3/4	21	20.93	(0.824)	6	5	3	2	2	2
1	27	26.65	(1.049)	10	8	5	4	3	3
1 1/4	35	35.05	(1.380)	17	14	9	7	5	5
1 1/2	41	40.89	(1.610)	24	19	13	9	8	8
2	53	52.5	(2.067)	39	32	22	16	13	13
2 1/2	63	62.71	(2.469)	56	45	31	23	19	19
3	78	77.93	(3.068)	87	70	49	36	29	29
3 1/2	91	90.12	(3.548)	116	94	65	48	39	39
4	103	102.3	(4.026)	150	121	84	62	50	50

NOTE: The calculations used in Table 5.6 to determine cable fill are based on a 30 percent initial fill factor assuming a straight run of conduit is used and no conduit bends are applied. These conduit sizes are typical in the United States and Canada and may vary in other countries. The metric trade designators and imperial trade sizes are not literal conversions of metric to imperial sizes. This table shall not be used when penetrating a smoke or fire barrier; the appropriate Listed Assembly instruction sheet shall be used to determine fill ratio.

Conduit Distribution Systems, continued

Table 5.7
Typical EMT 40 perent conduit fill rate diameters

Trade Size	metric designator	Conduit ID mm (in)		4.6 mm (0.18 in)	5.0 mm (0.20 in)	6.0 mm (0.24 in)	7.0 mm (0.28 in)	8.0 mm (0.31 in)	9.0 mm (0.35 in)
1/2	16	15.8	(0.622)	4	3	2	1	1	1
3/4	21	20.93	(0.824)	8	6	4	3	2	2
1	27	26.65	(1.049)	13	11	7	5	4	4
1 1/4	35	35.05	(1.380)	23	19	13	9	7	7
1 1/2	41	40.89	(1.610)	32	25	18	13	10	10
2	53	52.5	(2.067)	52	42	29	21	17	17
2 1/2	63	62.71	(2.469)	75	60	42	31	25	25
3	78	77.93	(3.068)	116	94	65	48	39	39
3 1/2	91	90.12	(3.548)	155	125	87	64	52	52
4	103	102.3	(4.026)	200	162	112	82	67	67

NOTE: The calculations used in Table 5.7 to determine cable fill are based on a 40 percent initial fill factor assuming a straight run of conduit is used and no conduit bends are applied. These conduit sizes are typical in the United States and Canada and may vary in other countries. The metric trade designators and imperial trade sizes are not literal conversions of metric to imperial sizes. This table shall not be used when penetrating a smoke or fire barrier; the appropriate Listed Assembly instruction sheet shall be used to determine fill ratio.

The higher the conduit's percentage fill, the more friction, resulting in stress that is applied to the cables in the conduit. This cable friction and resulting stress may be amplified when conduit bends occur throughout a section of conduit without a pull point.

See Tables 5.8 and 5.9 for conduit with one and two bends, respectively.

Conduit Distribution Systems, continued

Table 5.8
Conduit fill with 1 bend

Trade Size	metric designator	Conduit ID mm (in)		4.6 mm (0.18 in)	5.0 mm (0.20 in)	6.0 mm (0.24 in)	7.0 mm (0.28 in)	8.0 mm (0.31 in)	9.0 mm (0.35 in)
1/2	16	15.8	(0.622)	4	3	2	1	1	1
3/4	21	20.93	(0.824)	7	5	4	2	2	1
1	27	26.65	(1.049)	11	9	6	4	3	3
1 1/4	35	35.05	(1.380)	19	16	11	8	6	5
1 1/2	41	40.89	(1.610)	27	22	15	11	9	7
2	53	52.5	(2.067)	44	36	25	18	15	11
2 1/2	63	62.71	(2.469)	63	51	35	26	21	16
3	78	77.93	(3.068)	98	80	55	40	33	26
3 1/2	91	90.12	(3.548)	132	106	74	54	44	34
4	103	102.3	(4.026)	170	137	95	70	57	44

NOTE: The calculations used in Table 5.8 to determine cable fill are based on a 40 percent initial fill factor assuming straight runs with one 90 degree bend. These conduit sizes are typical in the United States and Canada and may vary in other countries. The metric trade designators and imperial trade sizes are not literal conversions of metric to imperial sizes. This table shall not be used when penetrating a smoke or fire barrier, the appropriate Listed Assembly instruction sheet shall be used to determine fill ratio.

Building Automation Systems (BAS) Software, continued

Other standard programs are often embedded in BAS software. A spreadsheet may be an integral part of the trend report utility. This allows the operator to view the output of the requested report and review and edit the report in the spreadsheet format. The spreadsheet also can be called up as a stand-alone utility.

The trend for software at the field- and system-level controllers is to communicate using a peer-to-peer configuration, but these levels may communicate using primary/secondary token passing. Software at the management level communicates with all system- and field-level processors in a peer-to-peer fashion.

When using multiple management-level processors, one is defined as the database server where all current databases reside. Databases also may reside in each system-level controller to provide a more robust system (e.g., one that keeps working if a single system-level controller fails).

Any management-level processor may initiate a system change (e.g., graphic or text modification, operator assignment, schedule), but all changes are made to the server database and are downloaded to field- or system-level controllers. The server is a software function that may be a dedicated computer or any other LAN processor.

NOTE: All LAN processors operate from the server that periodically updates the databases of the other LAN processors. When the server (LAN) is down, the processors operate from their own database. This same method of operation also applies to the system- or field-level controllers that can operate independently in the event of a management-level processor failure.

Communications Protocols

Communications protocols are an essential element of the BAS configuration because of the amount of data transferred from one point to another and because distributed processors may be dependent on each other for data pertinent to resident programs. Communications links, or buses, generally use either a poll-response or a peer protocol.

Early BAS used poll response protocols where most system intelligence and data processing was at the central processor. Today, most BAS use peer protocols at the management level and share the communications bus equally among all bus devices with no primary device.

Peer-communications protocol has the following advantages over poll-response communications protocol:

- Communications is not dependent on a single primary device.
- Direct communications between bus-connected devices occurs without going through the BAS central processor.
- Global messages can be transmitted to all bus-connected devices.

Communications Protocols, continued

In peer communications, a time slot is automatically passed from one bus-connected device to another as a means of designating when a device has access to the bus. Since the time slot passes in an orderly sequence from one device to the next, the communications network is sometimes termed a ring. However, the bus is not necessarily physically looped nor the devices physically connected to form a ring. Any device on the bus can be designated as the first to receive the time slot and any other device the next to receive it, and so on.

Some of the commonly used BAS protocols include:

- Building automation and control network (BACnet®, Modicon®, MODBUS®).
- European installation bus.
- LonTalk®.
- BAS Internet protocol (TCP/IP, HTTP, XML).

While the BAS industry and interested users have tried to establish a common communications protocol that would encourage open networking and development of interoperable products, most BAS protocols are proprietary. Each protocol is different, and not all permit sharing of data and communications between different BAS vendors or may require the use of additional or proprietary converters, bridges, routers, or gateways.

This has increased the difficulty to:

- Standardize on a common BAS protocol.
- Incorporate design flexibility into BAS networks (e.g., process interaction and media sharing).
- Mix and match systems from different BAS vendors.
- Expand or upgrade without going back to the original BAS vendor.
- Establish a competitive bidding process.

The ICT distribution designer needs to verify the interoperability and specific functionality of the products and protocols intended to be used.

Active Distribution Equipment, continued

Backend Equipment/Secondary Elements

DAS backend equipment typically consists of active components that transmit and receive signals from the headend equipment or other backend elements and radiate RF signals into antennas. Backend equipment can include signal repeaters, expansion modules, and remote units. Backend equipment is usually the same make, model, and manufacturer as the headend equipment. Open standards currently do not exist that will support integration of multiple manufacturers.

Backend equipment operates as a secondary to the headend and, therefore, cannot operate independently of the headend. The backend equipment typically is located in TRs or where coverage is needed and is deployed to support antennas that serve the intended coverage area.

Typical backend equipment consists of the following components:

- Secondary processors—Signal processing for headend synchronization
- Power supplies—Voltage supply and conditioning
- Host ports—Communications interface between backend and host unit equipment:
  - Backend equipment ports—Communications interface between backend unit and other backend units farther down the system
  - Power ports—Connectors for cables feeding power from backend unit to other backend units farther down the system
  - Signal converters and combiners—Frequency conversion and consolidation
- Amplifiers and transceivers—Signal regeneration and transmission
- Antenna ports—Connector for coaxial cable to antennas
- Antennas (discrete and radiating cable)

Backend equipment is interconnected to headend equipment via a backbone consisting of coaxial, balanced twisted-pair, or optical fiber cabling. Cabling types will be determined for each manufacturer of DAS equipment. Backend equipment with antenna ports is usually connected to the antennas via coaxial cabling, but may have an optical fiber connection instead.

Backend equipment typically has a set number of devices or antennas it will serve. Sizing requirements vary per manufacturer and are unique to each system. The backend equipment is commonly located in a TR. This is best determined during the site survey phase of a DAS implementation. The ICT distribution designer should consult the manufacturer's installation guide to determine the required space for installation. Installation spaces may include wall- or rack-mounted configurations (see Figure 16.17).

Communications between Headend and Backend Equipment

Most active DAS process radio signals into another format for transport over an alternate medium besides coaxial cable. This allows RF signals to be sent over long distances without incurring cable losses associated with coaxial. Standard media used include multimode or singlemode optical fiber cabling, and balanced twisted-pair cabling. The type of cabling used depends on the method of communications between the MCU and backend equipment.

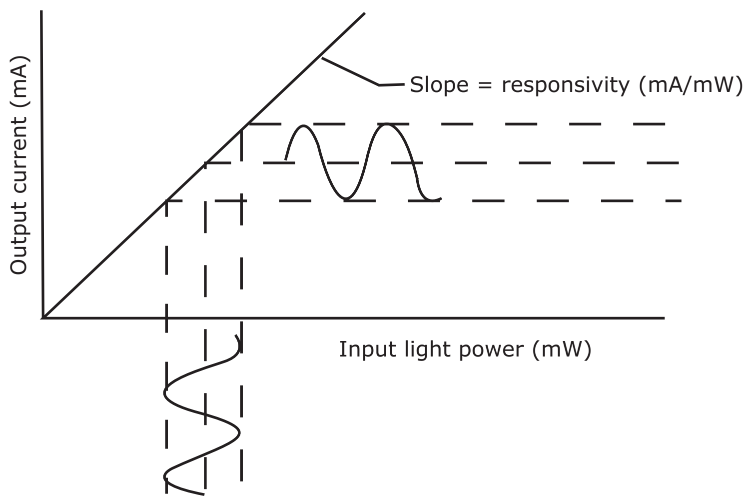
Active Distribution Equipment, continued

Active DAS use three primary means to transport radio signals:

- Analog modulation of RF signals onto an optical carrier
- Down conversion of RF signals to IF
- Digital sampling of RF signals

Analog modulation varies the optical power in accordance with the characteristic of the input RF signal (see Figure 16.18). The envelope of the modulated optical signal is an analog representation of the instantaneous power envelope of the RF signal. Analog systems typically use distributed feedback lasers with recovery of the signal using direct detection by a photodiode.

Figure 16.18
Optical to RF coupling power relationship



An advantage of analog modulation of RF signals is the ability to modulate a large portion of radio spectrum over one optical path. These systems often are referred to as wideband. A single system can support the transport of cellular, PCS, LMR, trunked radio, ESMR, paging, and ISM frequencies.

One of the major problems of analog systems is a direct dependency of the modulation and recovery of the RF signal to the optical transport. The dependency to the optical media limits these systems to using singlemode optical fiber almost exclusively.

Most analog systems compensate for the dependency on optical losses by using AGC as a feedback loop to maintain constant optical signal strength over the optical fiber plant. Typical optical budgets with an AGC mechanism range from 2 to 3 dB with optical losses outside of the AGC window subject to reduction of the RF gain. Some systems will use multimode optical fiber over short distances with some level of intermodulation of the RF signals or can support long-range transport of signals with optical budgets of 10 to 13 dB.

System Inputs and Outputs

When the FA system is required to provide control functions, system modules with the appropriate outputs are provided. FA control modules usually do not supply (e.g., source) the control voltage; therefore, equipment being controlled shall provide a control circuit voltage.

Control modules typically provide dry contact outputs that can be interconnected with equipment control circuits to provide start/stop, open/close, and similar control functions. Outputs (e.g., pager notification) also can be initiated to alert maintenance personnel to an alarm or trouble condition.

When monitoring functions are required, modules with terminals to receive the appropriate normally open or normally closed dry contact inputs are provided. FA monitoring modules usually source the control voltage, and the devices being monitored shall provide dry contacts.

FA monitoring and control modules are permitted or required to interface with other building systems to provide auxiliary functions. The non-FA equipment or devices should not interfere with the operation of the FA system.

Some examples of the FA system interfaces are:

- Security systems and door EAC.
- Fire-sprinkling system.
- Building automation systems.
- Heating and ventilation systems.
- Elevator systems.
- Smoke zone fire-rated door releases.

Remote Monitoring and Control Units

A building's FA system is required to interface with many systems and devices external to the FA system. This is necessary to provide a unified life safety system. Monitoring and control modules provide this interface.

FA system control modules are used to interface with fire suppression systems, elevators, heating, ventilation, and air-conditioning systems, and security systems. When modules are required to provide a monitoring function, it is achieved through monitoring a digital (on/off) output from the building system device. This output is often a dry contact that opens or closes as an indication of some abnormal event.

Control modules can control other building components. An example of a common control function is the closing of doors in fire-rated walls and the recalling of elevators to a designated level of the building upon the initiation of a fire event.

Smoke detectors in specific locations initiate a signal to the central control panel. The central control panel then signals the control modules that interface with the components' control circuit (e.g., door closers' control unit, elevator control panel). These control units are external to the FA system and actuate to close doors and return elevators to a designated floor.

Remote Monitoring and Control Units, continued

Remote Control Panels

When large FA control systems are installed, it often becomes necessary to install remote control panels. These panels are connected to the central control panel and can include some or all of the features contained in the central control panel.

Remote control panels are often installed when the single power supply within the central control panel is not sufficient to service all of the FA devices in the system. This is often the case for systems that contain a large number of visual alarm-indicating devices. When used solely as power supplies for alarm-indicating devices, remote panels are referred to as NAC panels. Remote control panels can include functional logic as does the central control panel, or they can simply be secondary units to the central panel.

Remote panels also can be installed to provide alarm, supervisory, and trouble indications at locations within the facility to alert personnel responsible for the system operation and maintenance (e.g., facility personnel). Remote panels containing only these features are often referred to as remote annunciators.

Fire department personnel responding to alarm conditions can use remote annunciators to quickly identify the alarm location within the facility. Remote annunciators are usually required to be installed at locations where emergency personnel enter when responding to an FA if the central control panel is not installed at this location.

pair scanner	*See* wire map.
pair twist	The uniform twist of an insulated copper pair that helps to reduce the negative effects of capacitance imbalance and electromagnetic induction.
pairing	A connection between two devices using Bluetooth®.
panel antenna	A style of radio frequency (RF) antenna constructed in a flat panel shape. A flat panel antenna is highly directional and usually a phased array antenna.
panelboard (electrical)	A single panel or groups of panel units designed for assembly in the form of a single panel, including buses and automatic over-current devices such as fuses or molded-case circuit breakers, accessible only from the front. *See also* switchboard and switchgear.
panic bar	A push bar and latch mechanism that is installed on the secure side of an opening. When the push pad is pressed, the latch will be released and the opening will be unsecured.
parabolic antenna	A directional antenna often shaped like a dish (concave reflector) used to produce a parallel beam when the source is placed at its focus (transmission) or to focus an incoming parallel beam (reception).
parallel telephone system	A telephone system in which an individually wired circuit is used for each fire alarm box.
parity	The information needed to recover the data stored on a failed disk drive in a redundant array of independent disks (RAID) configuration.
parked state	Refers to a secondary device in Bluetooth®. A parked secondary is not active on the channel but will remain synchronized to the clock of the master.
partitioned LAN	*See* virtual LAN (VLAN).
passive card	A type of access card that is dependent on a battery to provide the power necessary to allow the card to transmit its data.
passive equipment	Equipment that does not require electric power. *See also* active equipment.
passive hub	A hub that does not require electrical power to operate. Such devices function as simple signal distribution units, where an incoming signal on one port is directed to another port with no amplification, retiming, or regeneration. *See also* hub.
patch antenna	Comprises a patch of conductive material fixed above a conductive plane and separated from the plane by a thin dielectric substrate.

patch cord — A length of cable with a plug on one or both ends. (TIA) Patch cords are used for connections between two passive cross-connect terminations or direct connection from one active equipment to another active equipment. *See also* equipment cord and line cord.

patch cord adjuster — A mechanical device to which a patch cord is mated that enables the cord to be managed within the patch cord field. It permits the bend radius of the cable to be controlled and allows for periodic readjustment of the length of the patch cord.

patch panel — A connecting hardware system that facilitates cable termination and cabling administration using patch cords or equipment cords. (TIA)

patching — The means of connecting circuits via cords and connectors that can be easily disconnected and reconnected at another point.

path loss — In a communications system, the attenuation undergone by an electromagnetic wave in transit between a transmitter and a receiver. It may be caused by many effects such as free-space loss, refraction, reflection, aperture-medium coupling loss, and absorption.

pathway — **1.** Physical infrastructure (e.g., conduit, cable tray, raceway) used to facilitate the placement of information and communications technology (ICT) or electronic safety and security (ESS) cabling media. **2.** A term used within the United States to denote any method of connecting elements of the fire alarm system (e.g., electrical, optical, radio frequency [RF]).

pathway barrier penetration plates (PBPP) — A firestopping solution designed to centralize the installation and administration of multiple firewall penetrations.

payout box — A cardboard container with a hole for cable distribution directly from the box.

peak envelope power (of a radio transmitter) — The average power supplied to the antenna transmission line by a transmitter during one radio frequency (RF) cycle at the crest of the modulation envelope taken under normal operating conditions. (ITU)

peak output power — Maximum allowable output power of a transmission source.

peak power (PP) — Maximum electrical energy available in an alternating current (ac). It is a factor of voltage multiplied by the current (amperage). *See also* average power and power.

pedestal — **1.** In outside plant (OSP) systems, a protective aboveground enclosure used most commonly to house a splice point or administrative terminal location. **2.** In access floor systems, a fixed height or adjustable height structural element that supports the access floor panel and raises it off the slab to create an interstitial space for service distribution. *See also* access floor and stringer.

phase modulation (PM) An angle modulation in which the phase angle of a carrier is caused to depart from its reference value by an amount proportional to the instantaneous value of the modulating signal.

phase velocity *See* nominal velocity of propagation (NVP).

phased array antenna An antenna that can transmit and receive electromagnetic fields at and from any direction without any mechanical movement. Such antennas usually support broad bandwidth and carry more information. They have low visibility and are difficult to detect due to the absence of moving parts.

phased cutover A progression of transferring an old system to a new system. *See also* cutover.

phase-shift keying (PSK) In digital transmission, angle modulation in which the phase of the carrier is discretely varied in relation either to a reference phase or to the phase of the immediately preceding signal element, in accordance with data being transmitted.

photoelectric (photoelectric effect) The property of a material to conduct electricity when light is applied to it where the amount of current can be varied depending on the frequency or intensity of the applied light.

photoelectric light-obscuration smoke detection The principle of using a light source and a photosensitive sensor onto which the principal portion of the source emissions is focused. When smoke particles enter the light path, some of the light is scattered and some is absorbed, thereby reducing the light reaching the receiving sensor. The light reduction signal is processed and used to convey an alarm condition when it meets preset criteria.

photoelectric light-scattering smoke The principle of using a light source and a photosensitive sensor arranged so that the rays from the light source do not normally fall onto the detection photosensitive sensor. When smoke particles enter the light path, some of the light is scattered by reflection and refraction onto the sensor. The light signal is processed and used to convey an alarm condition when it meets preset criteria.

photon A fundamental element of light.

photosensitive epilepsy A medical condition presented by seizures due to a reaction from rapidly flickering light impulses. As a preventive measure, strobe-type notification appliances can be synchronized so that multiple appliances do not cause overly rapid and disorienting light pulses.

physical address *See* media access control (MAC) address.

physical design process A network design process where the network designer begins by assessing the site where the proposed network is to be implemented. Also called bottom-up design.

physical layer	The Open Systems Interconnection (OSI) Reference Model layer responsible for the transfer of bit streams over a specific medium. Also called Layer 1.
physical layer interface (PHY)	Typically, the circuit in a network interface card (NIC) or similar device that inserts the signal onto the transmission medium (e.g., cabling system). It includes the connector configuration, or medium dependent interface (MDI).
physical medium attachment (PMA)	In Ethernet, the part of the physical layer that controls transmission, reception, collision detection, clock detection, and skew alignment.
physical security	Measures that deter, detect, delay, mitigate, or notify any attempt to injure, damage, modify, or remove an asset or person. This includes damage by accident, fire, environmental elements, crime, vandalism, and industrial espionage. It can be a simple device or multiple layers of electronic measures.
physical topology	The physical layout of a network as defined by its cabling architecture.
picocell	A small cellular base station typically covering a small area, such as in-building (e.g., offices, shopping malls, train stations, stock exchanges), and more recently in aircraft. The range of a picocell is typically ≈200 meters (m [656 feet (ft)]) or less. Most picocells are connected to headend equipment on the premises using in-building cabling. The headend processes the signals and sends them on into the cellular network. Some picocells have increased intelligence, giving them the capability required to connect directly to the internet, without the need for the headend infrastructure. This form of picocell is sometimes called an access point base station or enterprise femtocell. One type of small cell.
picofarad	One-trillionth of a farad.
piconet	A single Bluetooth® wireless personal area network (WPAN) that can contain a maximum of eight active devices. Each primary device and the secondary device, or devices associated with it, form a piconet. It provides a base level of connectivity to even the simplest of sensing and computing objects. *See also* scatternet.
picowatt of noise power (pWp)	Psophometrically weighted, 1.0 pWp is equivalent to an 800 hertz (Hz) test tone at –90 decibels per meter (dBm).
piggybacking	*See* tailgating.
pigtail	One or more conductors or fibers with only one end terminated. (TIA) *See also* cable assembly and jumper.

surface transfer impedance — The ratio of the conductor-to-shield voltage per unit length to the shield current. Surface transfer impedance is usually measured in milliohm/meter or ohm/foot.

surge arrestor — A protective device for limiting surge voltages by discharging or bypassing surge current. It also prevents the continued flow of follow current while remaining capable of repeating these functions. (*NEC*®)

surge protection device (SPD) — A protective device for limiting transient voltages by diverting or limiting surge current. It has a nonlinear voltage-current characteristic that reduces voltages exceeding the normal safe system levels by a rapid increase in conducted current. Also called a voltage limiter, overvoltage protector, (surge) arrestor, or transient voltage surge suppressor (TVSS).

survivability — The ability of the network to function after a disruption.

susceptibility (electromagnetic) — *See* electromagnetic susceptibility.

suspended ceiling — A ceiling that creates an area or space between the ceiling material and the structure above. (TIA) Also called a false ceiling or a drop ceiling.

sweep — A bend that has a gentle arc rather than a sharp bend.

swell — An increase in the nominal root mean square (rms) voltage or current lasting from 0.5 cycles to one minute.

swing-floor phasing — The act of moving personnel and property from one location to another in order to facilitate renovation of the space vacated.

switch — **1.** A network access device that provides a centralized point for LAN communications, media connections, and management activities where each switch port represents a separate communications channel. A network switch operates at Layer 2 or Layer 3 of the Open Systems Interconnection (OSI) model. Sometimes referred to as a multiport bridge. **2.** A voice communications device that uses switching technology to establish and terminate calls. **3.** A device designed to close or open, or both, one or more electrical circuits. (IEEE).

switchboard — A single-panel frame or assembly of panels, typically front access, containing electrical disconnects, fuses, and circuit breakers used to isolate electrical equipment. Switchboards are typically rated 400 amperes (A) to 5000 A, and are characterized by fixed, group-mounted, molded case, or insulated case circuit breakers, but may include draw-out circuit breakers, and usually require work on de-energized equipment only. *See also* panelboard (electrical) and switchgear.

switched telephone network	An assembly of telecommunications facilities and central office (CO) equipment operated jointly by authorized service providers that provides the general public with the ability to establish transmission channels via discrete dialing.
switched virtual circuit (SVC)	A virtual circuit created on an as-needed basis. It is a temporary connection lasting only as long as the connected devices are communicating.
switch fabric	A network topology where network nodes connect with each other via one or more network switches, particularly via crossbar switches.
switchgear	An electrical enclosure, typically both front and rear access, containing over-current protective devices such as fuses and circuit breakers used to isolate electrical equipment. Switchgear is typically rated 800 A to 5000 A and is characterized by segregated, insulated-case or low-voltage power circuit breakers, usually draw-out, and frequently containing monitoring and controls as well as features to permit addition or removal of switching devices on an energized bus. *See also* panelboard (electrical) and switchboard.
switching	**1.** A networking protocol in which a station sends a message to a switch, which then routes the message to the specified destination station. **2.** The action of opening or closing one or more electrical circuits by establishing a direct signal path from one device to another.
switch latency	The amount of time it takes for an incoming message to be inspected, processed, and forwarded through a switch.
switch matrix	The connections that link each port to every other port in a switch. Also called a backplane.
symmetric key cryptography	*See* private key encryption.
synchronization profile	A set of data commonly used in a personal area network (PAN) to update calendar and scheduling information between devices. Once the devices come within range, the synchronization can automatically occur.
synchronous communication	*See* synchronous signaling.
synchronous connection-oriented (SCO) link	A point-to-point (PTP) link between the primary device and one secondary device, used primarily for synchronous voice traffic.
synchronous optical network (SONET)	A scalable transport technology designed to provide a uniform, consistent method of transferring data over extended geographic distances, by using an optical fiber transmission infrastructure. SONET provides the Open System Interconnection (OSI) Reference Layer 1 details of how to pass high-speed data over optical links.

