CHAPTER

18

Troubleshooting and Test Equipment

About This Chapter

Fiber-optic troubleshooting usually involves checking for damaged or incorrectly installed equipment, or for components that have failed or malfunctioned in some way. Sometimes the problems are simple, but usually they require specialized test equipment to analyze and identify the problem.

This chapter opens by summarizing common problems likely to be encountered in fiber-optic systems. Then it describes important test equipment and its operation, drawing on measurement concepts you learned in Chapter 17. Finally it reviews some simple procedures to track down problems. The techniques covered are specific to fiber optics, not general to communications. That means you will learn ways to spot a broken cable, but not how to diagnose the hardware or software in an electronic switching system.

This chapter is an introduction to basic concepts and the most important equipment, not a step-by-step description of everything you will need to know on the job. That's a book or a course in itself. Think of it as a quick introduction to fiber-optic first aid. It won't teach you how to perform delicate surgery on the network, but it will help you respond intelligently if the system goes down.

Fiber-Optic Troubleshooting

The goal of troubleshooting is to diagnose and correct problems. This chapter, like the rest of this book, focuses on fiber-optic equipment, but that still leaves a wide range of potential problems. Fiber-optic systems generally are reliable, but they are not perfect. As Murphy said, "If anything can go wrong, it will."

Not all failures have obvious causes like cable breaks.

Our first thought when something fails is usually of a dramatic problem. When your telephone service goes out, you suspect a wire has snapped somewhere. Likewise, it's logical to suspect that a broken cable is behind the sudden failure of a fiber transmission line. Often it is, with culprits ranging from careless backhoe operators to gophers. But cable breaks are not always obvious; construction workers may not notice if their equipment doesn't expose broken cable ends, and gophers don't drag the gnawed cables out to show you. You may need special equipment to spot the damaged cable. In fact, it's much more efficient to use test equipment to spot damaged cable from a convenient point than to drive along a cable route looking for a suspicious construction site.

In practice, many other things can cause complete failures. Fibers may be bent too tightly at junction boxes and snap in response to a small strain. Strain, crushing, or contamination may have damaged the fibers inside a cable without visible impact on the outside of the cable itself. Dirt may have gotten into a connector and blocked light transmission. A laser may have failed in the transmitter, or a component may have failed in the receiver power supply. WDM components may have gradually drifted out of tolerance until signals no longer fall at their assigned wavelengths.

Many failures occur when something changes, so a good starting point is to ask if users changed the system in any way just before it failed.

Some failures are complete; others merely degrade transmission.

All problems are not complete failures. Noise on your phone line can make it impossible to use a dial-up modem, transmit faxes, or carry on a conversation, but you may still get a dial tone. Likewise, a defective connector or an electronic malfunction in the transmitter or receiver might make a fiber line noisy, or attenuate the signal and increase the bit error rate (or, in analog systems, decrease the signal-to-noise ratio).

Fiber-optic troubleshooting also involves installing new services or changing existing ones. Typically new services are added to cables that already carry some traffic, either on other fibers in the same cable sheath, or on other wavelengths in the same fiber. You can't assume the fibers are ready to handle the intended traffic. You may need to measure fiber attenuation, chromatic dispersion, and other properties in order to verify that they can transmit signals at the required data rate over the intended distance. You may need to adjust transmitter power or add (or remove) attenuators to deliver the proper power level to the receiver.

You also may need to verify that the fibers go to the proper destination. One common cause of installation failures is that the fibers don't make the proper connections. Someone may have plugged a connector into the wrong socket, and the fiber may go to a dead line.

In short, troubleshooting is a complex task, and the more complex the system, the more complex it is to troubleshoot. Although manual inspection can spot some problems, test equipment generally can help you diagnose and locate problems faster and more accurately. Thus you will spend most of this chapter learning about test equipment and how it can help you. First, however, you should consider what types of measurements you need for what jobs.

Testing, installation, and troubleshooting are distinct but related tasks.

Testing, Installation, and Troubleshooting

We can divide measurement and troubleshooting tasks into three broad classes, which sometimes overlap.

- *Testing* evaluates equipment in the laboratory, factory, or field. Research engineers test new systems they have assembled on the laboratory bench to see how well they operate. Quality control technicians test new equipment before shipping it to customers. Field engineers test equipment in the field to check that it meets specifications, both after installation and during routine maintenance.
- *Installation* requires testing to verify that equipment works as intended. This may be done both before and after actual installation. If you're installing cable in a difficult site, you spend a few minutes checking that it arrived with all the fibers intact before spending a week laying it. Before adding a transmitter at a new wavelength to a WDM system, you may verify that the system will transmit that wavelength properly. In some cases, you may need to trace the route of a fiber through a system, as you would do in installing an extra home phone line.
- *Troubleshooting* occurs after problems happen with a fiber-optic system, when you try to find the source of the problem and then repair it. Unlike testing and installation, you know there is a problem, but you have to find it. Troubleshooting can require checking many points of possible failure.

The overlaps are many. Installation becomes troubleshooting when you try to turn on the system and it doesn't work. The problem may be a fiber connector plugged into the wrong socket, or it may arise from the interaction of two or more components that are slightly out of specification.

Typically, similar test equipment is used in testing, installation, and troubleshooting. You are likely to use different versions of an instrument on a factory floor and in an all-wheel drive van loaded with troubleshooting equipment for field work, but the measurement principles are the same.

Measurement and Signal Transmission

One important practical consideration in all measurements is whether or not they interrupt communication signals.

Some measurements can be made without interrupting traffic.

Interrupting traffic is not a major concern if the system is not operating because it is being installed or has failed. Interruptions *are* an issue if a system is partly operational, such as when new wavelengths are being added to a WDM system. In that case, you need to be certain that tests on one wavelength channel do not disrupt the operation of others. Avoiding interruption is particularly important for preventative maintenance and testing, when your goal is to verify correct system operation.

One way to avoid interruptions is to make measurements with a wavelength not used in the fiber system. Fiber transmission can be tested with a signal at 1625 nm, which is outside the operating range of normal fiber systems. This is called *out-of-band testing*, and can spot problems such as damaged fibers or bad connectors without disrupting service. However, it obviously can't verify operation of transmitters at other wavelengths. Another approach is to include taps along the system, which divert a small fraction of light to test equipment or an optical performance monitor, as shown in Figure 18.1.

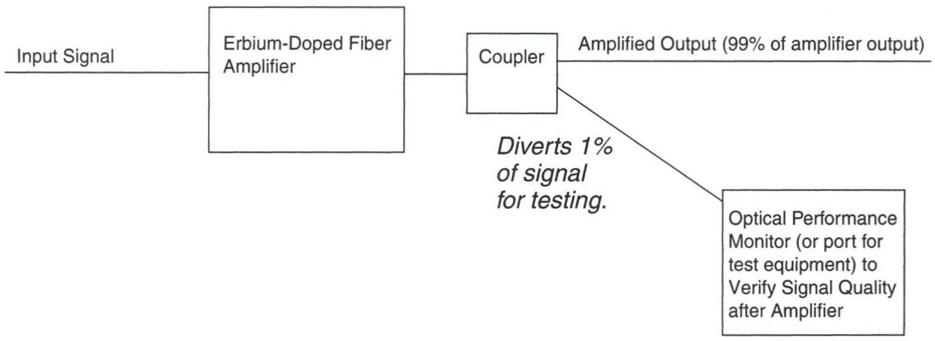


FIGURE 18.1 *Splitting off a small fraction of light for measurement or optical performance monitoring.*

Test and Measurement Instruments

Catalogs from major equipment makers list many types of equipment designed for fiber-optic test and measurement. Trying to cover them all would take a book in itself, so I will focus on the equipment you are most likely to encounter, particularly in general field service, installation and operation. Other equipment is used in manufacturing or in research and development, but much of it is specialized for such tasks as evaluating performance of erbium-doped fiber amplifiers.

Power, attenuation, wavelength, and signal quality are key measurements for troubleshooting.

The basic measurements are those you learned in the last chapter, including power, energy, attenuation, wavelength, and signal quality. We will concentrate on a few major areas (some of which may be measured together, such as optical power and wavelength in an optical spectrum analyzer):

- Fiber continuity and attenuation (usually measured by comparing power levels)
- Optical power
- Wavelength
- Signal quality
- Polarization

Different instruments measure these quantities differently, and may be used for different applications. During an installation, you may need to check continuity between transmitter and receiver; other times you may want to know attenuation of the fiber between them.

Optical Power Meters

Optical power meters are calibrated for specific wavelengths.

Optical power meters are among the simplest optical measurement instruments. Their basic functional elements include a fiber connector, a calibrated detector or detectors, electronics that amplify the signal, controls that set the range and measurement, and a digital display. The display usually is autoranging, and shows measurements on watt or dBm scales selected by the user. The most widely used designs are compact handheld devices like the

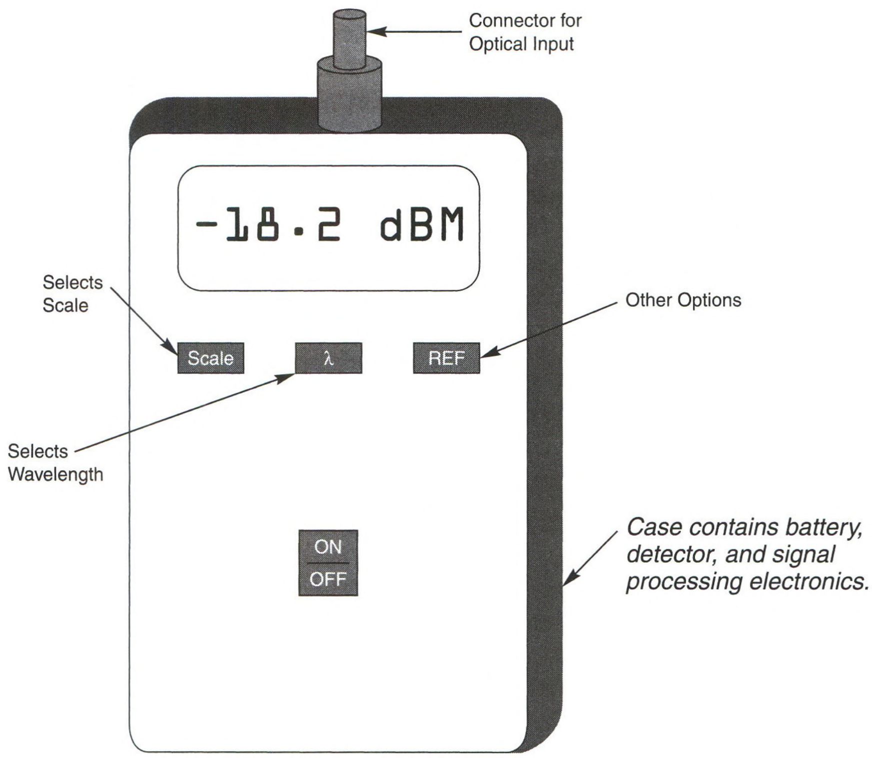


FIGURE 18.2
Handheld optical power meter.

one shown in Figure 18.2, and they are invaluable tools for many measurements. Most instruments can store measurements and have computer interfaces.

Power meters typically use germanium or InGaAs detectors, which are calibrated for selected wavelengths in the standard fiber windows. A bare-bones model may be calibrated for only 850, 1300, and 1550 nm, but more sophisticated models are calibrated at many wavelengths through the range, including 780, 820, 840, 850, 860, 910, 980, 1060, 1200, 1280, 1290, 1300, 1310, 1320, 1330, 1530, 1540, 1550, 1560, and 1600 nm. Special versions are made for high-power measurements of pump laser wavelengths near 980 and 1480 nm. Some switch between long- and short-wavelength detectors, and may be calibrated for the 660-nm plastic fiber window. Because detector response varies with wavelength, care must be taken to match the instrument's range to the wavelength being measured.

Light Sources for Testing

To measure attenuation and other characteristics of fiber systems, you need a light source as well as an optical power meter. A variety of fiber-optic test sources are available, designed for different applications, and you must match the source to the measurement task. In simple light sources the wavelength is fixed, but in more sophisticated (and expensive) instruments the output wavelength is tunable with various degrees of precision.

Test sources supply light at fiber system wavelengths.

Test sources deliver a continuous, calibrated power level for measurements of power and loss. They also may have a separate output mode that modulates signals at an audio frequency to aid in identifying the fiber under test. Some have two outputs. Important types include:

Broadband light sources include tungsten lamps, fiber amplifiers, and edge-emitting LEDs.

- *Broadband sources* normally emit a broad range of near-infrared wavelengths; a familiar example is a tungsten lamp. Typically the entire range of wavelengths is passed through whatever is being measured, with output power measured by a wavelength-selective instrument (an *optical spectrum analyzer*, described later in the chapter). Although the total amount of light is high, the amount of light per unit wavelength is relatively low. Table 18.1 summarizes the key features of the most important types, tungsten lamps, edge-emitting LEDs, and fiber amplifiers operating with no input signal so they generate only amplified spontaneous emission. They generally are not used in the field.
- *Monochromators* are laboratory sources long used in nonfiber measurements. They differ from other types in that their broadband emission is tuned internally by selecting a narrow range of wavelengths with a prism or diffraction grating. Only that narrow range is used for measurements.
- *LED sources* are also used in small portable field instruments. Typically these have center wavelengths of 850, 1300, or 1550 nm and spectral bandwidths of 50 to 100 nm for testing the major glass-fiber windows. They launch microwatts to tens of microwatts into a fiber.
- *Fixed diode laser sources* may emit on one band in a fiber window, or may include many separate lasers to simulate signal transmission in a WDM system. Sources that emit on one wavelength in the 850, 1300, or 1550 nm band typically have linewidth

Table 18.1 Broadband sources and their characteristics

	Tungsten Lamp	**Edge-Emitting LED**	**Amplified Spontaneous Emission from Erbium-Fiber Amplifier**
Wavelength range (nm)	Broadband across infrared	Depends on composition	1500–1600 nm
Spectral width	Whole near-infrared	50–100 nm per LED, multiple LEDs can be used	Peak amplitude 30–40 nm
Total power into single-mode fiber	1 μW	100 μW	1 to 10 mW
Peak power per nm into single-mode fiber	−63 dBm/nm	−25 dBm/nm	−10 dBm/nm

of a few nanometers and deliver more than 100 mW into a fiber. Like LED-based light sources, they normally are used in portable field devices. WDM laser sources include one laser per optical channel, spaced the same as in a transmission system, and are specifically designed for testing WDM system performance.

- *Tunable laser sources* can tune their output wavelength, as described in Chapter 9. Some are erbium-doped fiber lasers, tunable across the entire C- and L-bands. Others are tunable across narrower ranges, but can be combined to give a wider range. They generate very precise wavelengths for tests of DWDM components and systems.

Typically, test sources emit continuous beams for measurements, but their output can be modulated for special purposes and to identify the signal or the transmitting fiber.

Field test sources normally come with a selection of connectors and adapters to allow their use with a variety of equipment.

Optical Loss Test Sets

An *optical loss test set* combines a light source with an optical power meter calibrated to work with it. The amount of power emitted by the light source is known, so the power meter measurement indicates how much the received signal has been attenuated. Optical loss test sets also can measure attenuation by comparing power levels with and without the component being tested, as you saw for a cable in Figure 17.10. Optical loss test sets are offered as distinct instruments, but you can think of them as a light source packaged with a power meter.

An optical loss test set includes a light source and power meter calibrated to work together.

Optical return loss test sets are different in that they measure light reflected back toward the source rather than transmitted through the system. Reflections are very important because they can cause noise in edge-emitting semiconductor lasers, degrading system operation. Reflection measurements, sometimes called *reflectometry*, can check for potential problems.

Fiber-Optic Talk Sets

Many types of measurements require two technicians working at different locations to test a system running between the two points. Fiber-optic talk sets were developed to allow them to communicate with each other and coordinate their tasks. Similar equipment is used on copper telephone wires. Fiber-optic talk sets include a simple transmitter and receiver that can send and receive voice signals through optical fibers. In a sense, they turn any available fiber into a telephone line. They generally have headsets attached.

Typical talk sets also can generate a 2-kHz signal for fiber identification. Multifunction talk sets also can generate a continuous signal to measure fiber attenuation.

Visual Fault Locators

A visual fault locator is a hand-held troubleshooting instrument that sends red light from a semiconductor laser down a fiber to check for faults such as cracked fibers or defective splices. The visible light travels along the core until it reaches a fault, where it leaks out. Light leaking through the fault can be seen through plastic coatings and jackets under suitable illumination. Infrared light in the signal leaks out at the same point, but your eyes can't see it.

A visual fault locator spots faults by sending red light down a fiber.

Attenuation of glass fibers is much higher at the 630 to 670 nm wavelengths of red light than in the 1300 to 1650 nm transmission window, but the red light can still travel up to 5 km through standard fibers. Note that the fibers must be exposed to use visual fault location effectively. If the red light leaks out inside a thick cable wrapped in black plastic, you can't see it. The technique is particularly valuable in equipment bays and other places inside buildings where fibers are exposed.

Shining a flashlight beam down a multimode fiber can serve the same function, and has long been used to trace fiber continuity as well. However, the flashlight couples little light into a single-mode fiber.

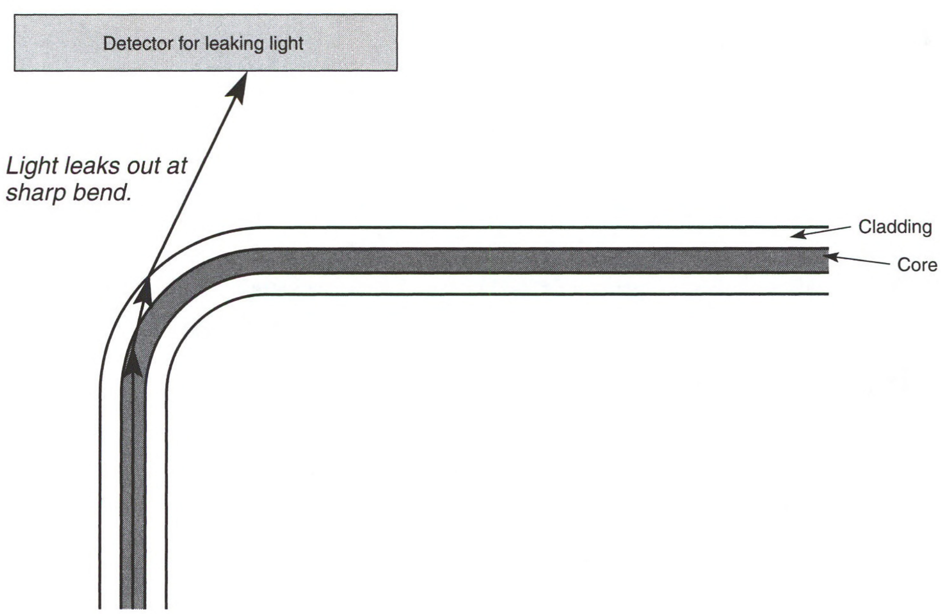
Live Fiber Detectors

A little signal light leaks out when fibers are bent.

The ability to locate fibers carrying live traffic also is important in troubleshooting. This isn't easy because, as you learned earlier, light passing through a fiber does not generate electromagnetic fields or other external signs of its passage. However, traffic can be detected by bending the fiber, as shown in Figure 18.3. The bend causes light in the core to exceed the critical angle for total internal reflection when it hits the core-cladding boundary, so it leaks out.

Detection of live traffic can be invaluable, but the technique requires care. Sensitive detectors are needed because only a small fraction of the signal leaks out. (Recall that you can't see the invisible infrared signal wavelength.) Bending the fiber too tightly can weaken or break it. Thus you use special instruments that can sense the signal wavelengths after they pass through plastic fiber coating and jackets. Sensitivity of the technique depends on the type of fiber.

FIGURE 18.3
Live fiber detector: If light leaks out at a bend, a signal is passing through the fiber.



Optical Time-Domain Reflectometers

The *optical time-domain reflectometer (OTDR)* is a powerful and versatile instrument for fiber-optic measurements. It's essentially an optical radar that shoots a short light pulse down the fiber. Glass atoms scatter a small fraction of the light back toward the instrument because of the Rayleigh scattering that you learned about in Chapter 5. Irregularities such as splices, connectors, and defects in the fiber reflect and scatter additional light.

An OTDR is an optical radar that analyzes fiber properties.

An OTDR plots intensity of the light scattered back to the instrument as a function of time after the pulse is fired down the fiber. This is interpreted as the light intensity along the length of the fiber, as shown in Figure 18.4, with the distance along the fiber calculated from the round-trip time for the light pulse.

To a first approximation, the plot indicates two things: the attenuation of the fiber, and locations of any discontinuities. The attenuation is indicated by the slope of the decline in power along the fiber. The peaks on the plot are reflections from discontinuities, analogous to blips on a radar screen. Sharp drops indicate points where light leaks out of the fiber. Like interpreting radar signals, interpreting OTDR data isn't quite that simple, but let's look at the most important features before we look at the complications.

Figure 18.4 shows a sharp peak at the very left end of the plot, at the start of the fiber. This is a region where an OTDR can't accurately measure the properties of the fiber because the instrument is too close. It's called the *dead zone* and typically is a few meters to 20 meters from the instrument.

OTDRs cannot analyze the near end of the fiber well.

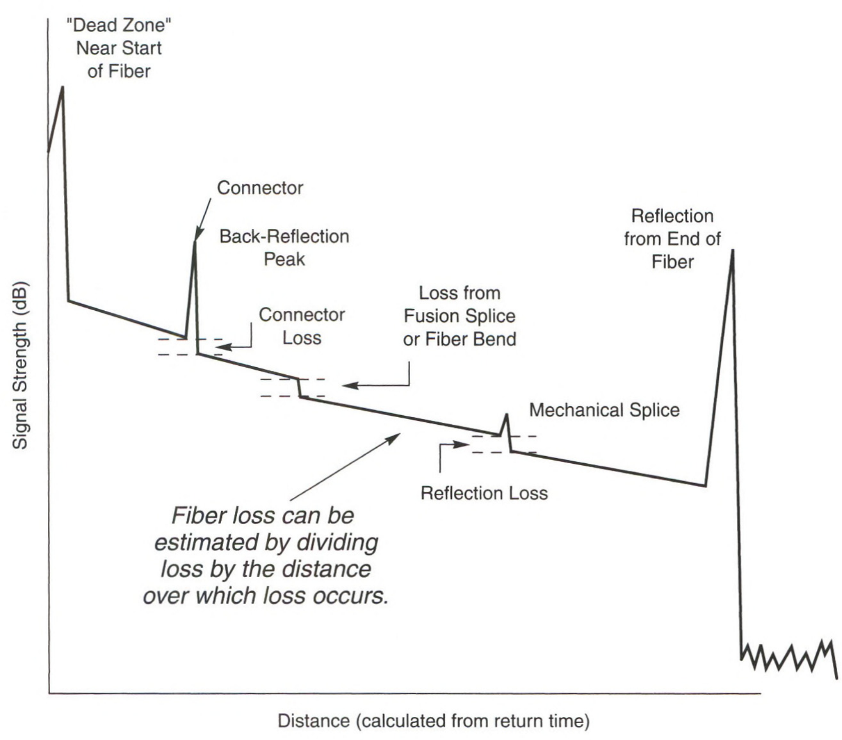


FIGURE 18.4
Features of an OTDR plot.

The largest peak in Figure 18.4 is at the end of the fiber, where light is reflected back toward the instrument. If the fiber is broken, that point is the end of the fiber, with peak reflection. The jagged spikes to the right of the end of the fiber are meaningless noise. The next largest peak is reflection from a connector where the fiber ends are not perfectly butted together. Look carefully and you can see that the light intensity just on the right of the connector is below that just to the left; this drop is the connector loss. A mechanical splice also reflects a little light back to the instrument and has a measurable loss, but in this case both loss and reflection are lower in the mechanical splice. A sudden drop in reflected light, without a reflective peak, may come from the loss within a fusion splice (which should have negligible reflection) or from light leaking from the fiber at a bend.

Early OTDRs simply plotted the returned light for a skilled operator to interpret. Modern instruments analyze the raw data and provide their own interpretation, giving values for quantities such as fiber attenuation, length, and the locations of reflections. They also tabulate points where the plot has peaks or dips as "events," as shown in an actual OTDR display in Figure 18.5. The instruments can expand the scale to study selected parts of the cable in detail, and include options for computer output or printouts.

OTDRs can quickly locate damage to a cabled fiber in the field.

These features make the OTDR a very useful instrument in the field, where it can spot faults up to tens of kilometers away. A single technician can locate the point where a fiber is damaged to within a matter of meters by using an OTDR at one end of the cable. That saves a lot of costly labor searching for damage along the length of a cable, and makes the OTDR a standard tool for repair crews working in the field.

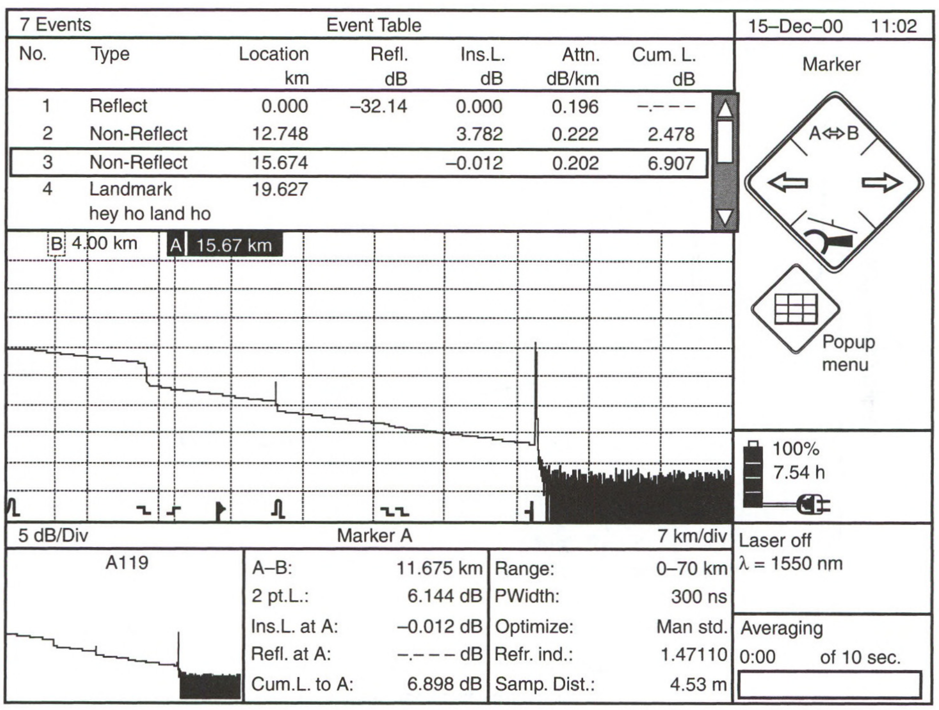


FIGURE 18.5
OTDR display includes log of locations checked, potential anomalies, and loss between points on cable. Spike at right is end of the fiber; reflections beyond that point are noise. (Courtesy of Agilent Technologies)

Yet it's vital to remember that OTDR plots are only approximations. Direct measurements of attenuation are more accurate than calculations from OTDR plots. Accuracy depends on the fraction of light scattered, which differs between types of fiber. Junctions of fibers with different mode-field diameters can cause peculiar effects, such as "gainers," splices where the power appears to be higher on the far side of the fiber than on the near side. This effect occurs when the more distant fiber scatters more light than the near one. Gain is measured in only one direction; the light experiences a loss in the other direction. To get more accurate values, you should take the average of splice loss in both directions. These limitations can be significant in assessing splice quality, but are rarely critical in tasks like locating cable breaks.

Oscilloscopes, Analyzers, and Eye Patterns

Oscilloscopes and analyzers perform eye-pattern analysis.

As you learned in Chapter 17, eye-pattern analysis is based on superimposing a series of received signal pulses on top of each other to show how precisely they replicate each other and verify a clear distinction between on and off states. Originally that was done by aligning pulses on an oscilloscope, and this can still be done where necessary.

Modern oscilloscopes or "communications analyzers" are programmed to perform functions automatically, such as eye-pattern analysis. Optional plug-in modules can provide other functions. Normally oscilloscopes are test instruments used in the laboratory or factory, but they also can be used at terminal points and switching centers to diagnose system performance when needed.

Special Test Sets

Some fiber parameters such as chromatic dispersion and polarization-mode dispersion require complex measurements. They are best performed by test sets designed to measure the raw parameters and process the data internally, yielding the desired measurement results. Typically test sets are used in the lab, factory, or switching center.

Chromatic dispersion testers are large and complex systems that make measurements and calculate results.

Polarization-mode dispersion and *polarization-dependent loss* require measurements with a *polarization analyzer*, that separates light into its two polarized components and measures their transmission through fibers and other components. Polarization characteristics can be important for high-performance fiber systems, so some polarization analysis systems have been developed for field use.

Bit error rate testers transmit a random bit sequence and compare it to the received signal, measuring the number of bits incorrectly received.

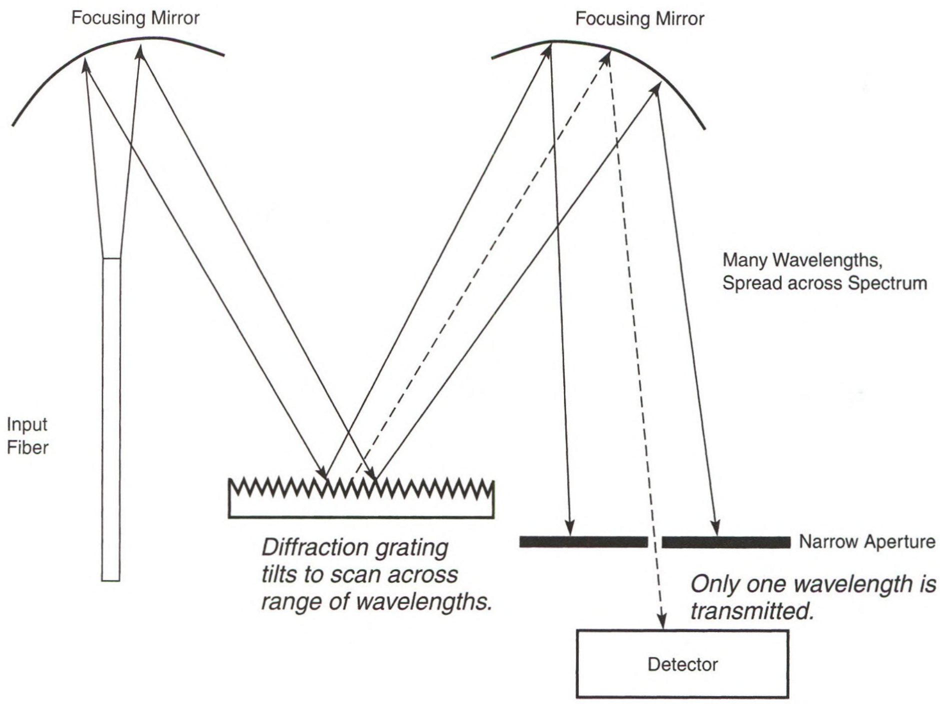
Optical Spectrum Analyzers

Optical spectrum analyzers measure power as a function of wavelength.

An *optical spectrum analyzer* records optical power as a function of wavelength by scanning the spectrum. It can plot power levels on all WDM channels for performance assessments.

Figure 18.6 shows the basic idea of an optical spectrum analyzer. Input optics collect light, generally from an optical fiber, and focus it onto a diffraction grating. As

FIGURE 18.6
Optical spectrum analyzer.



you learned earlier, a diffraction grating spreads out a *spectrum* of wavelengths. This spectrum is then focused onto a flat surface, where a narrow aperture or slit transmits a narrow band of wavelengths to a detector. The detector measures the power at that wavelength.

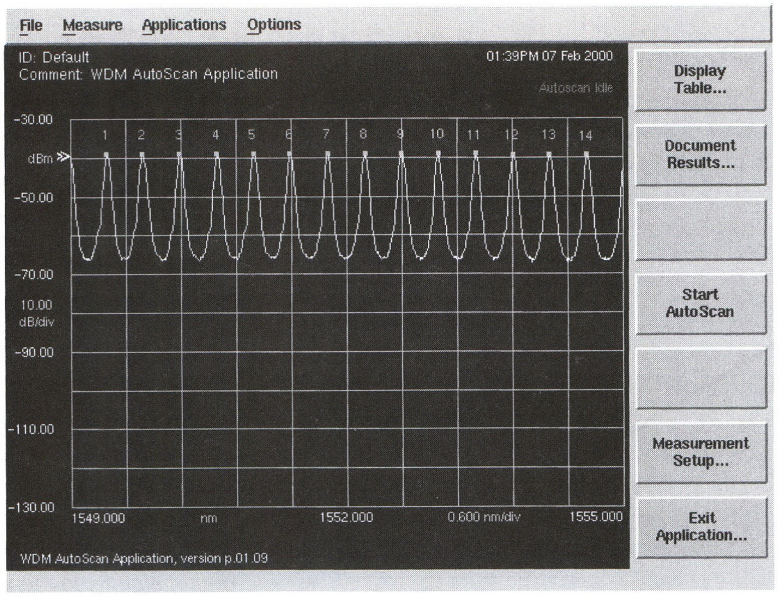
In this design, tilting the diffraction grating moves the spectrum, so a different wavelength passes through the slit. Tilting the grating slowly and continuously scans the entire spectrum across the slit. With proper calibration, the power measured at a certain time is correlated with the wavelength passing through the slit at that instant. This makes it possible to plot power against wavelength, and assess the power levels on different optical channels in a WDM system, as shown in Figure 18.7.

Other designs are possible. The slit and detector can move instead of the grating, scanning across the plane where the spectrum is spread out. Alternatively, the spectrum can be spread across an array of detectors, with each one detecting a separate wavelength, an approach used in optical performance monitors, described below.

Optical spectrum analyzers average power over long intervals.

Note that optical spectrum analyzers measure power over long intervals of time relative to bits, so they show average power on each optical channel.

Optical spectrum analyzers began as high-performance laboratory instruments. As wavelength-division multiplexing spread through the telecommunication network, optical spectrum analyzers were adapted for use in the field and in switching centers. They are important instruments in verifying the proper function of WDM systems and in troubleshooting if problems should arise.



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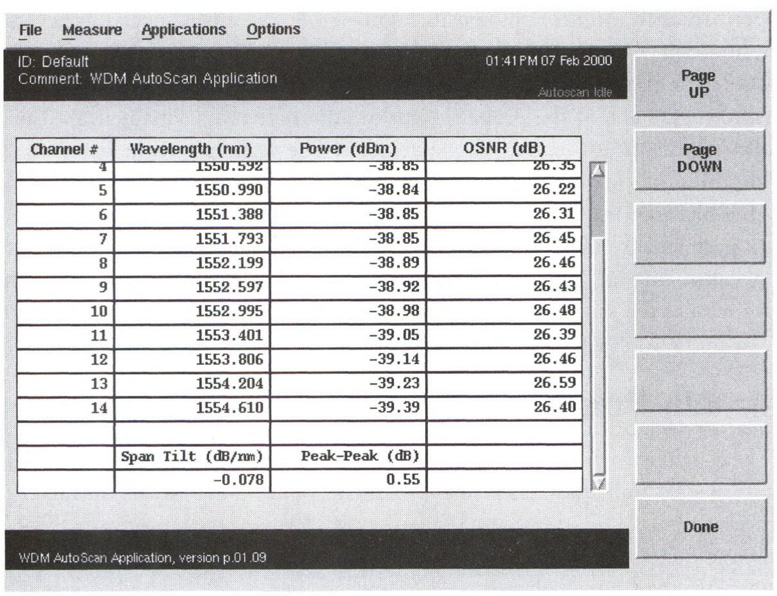

Channel #	Wavelength (nm)	Power (dBm)	OSNR (dB)
4	1550.592	-38.85	26.35
5	1550.990	-38.84	26.22
6	1551.388	-38.85	26.31
7	1551.793	-38.85	26.45
8	1552.199	-38.89	26.46
9	1552.597	-38.92	26.43
10	1552.995	-38.98	26.48
11	1553.401	-39.05	26.39
12	1553.806	-39.14	26.46
13	1554.204	-39.23	26.59
14	1554.610	-39.39	26.40
	Span Tilt (dB/nm)	Peak-Peak (dB)	
	-0.078	0.55	

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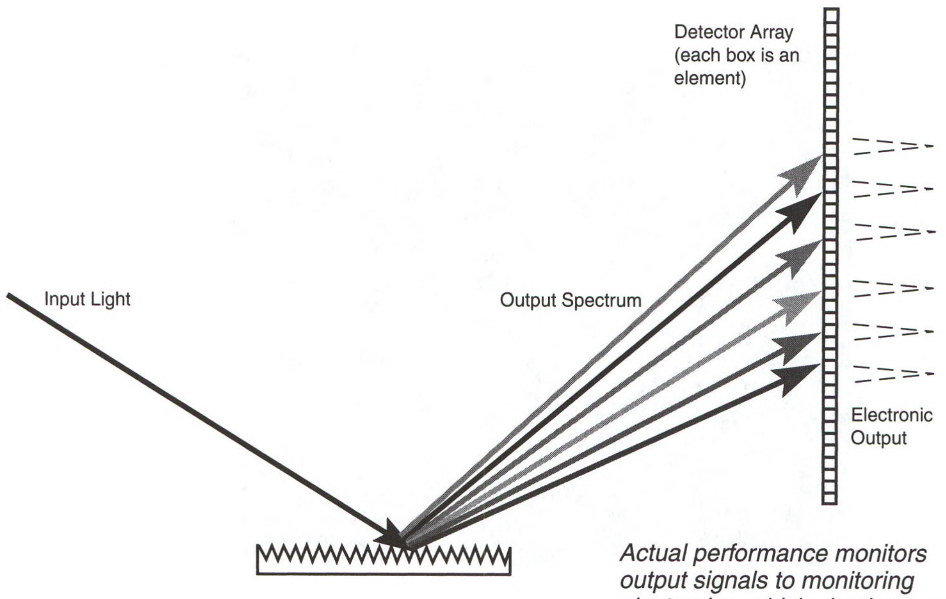
FIGURE 18.7
Optical spectrum analyzer measures wavelength, power, and signal-to-noise ratio of channels in a WDM system. A graphic plot (above) displays the channels; a numerical display (below) gives measurements. (Courtesy of Agilent Technologies)

FIGURE 18.8 *Optical performance monitor.*



Optical Performance Monitors

Optical performance monitors are simple versions of spectrum analyzers.

An *optical performance monitor* is a simple version of an optical spectrum analyzer that can be installed at critical locations in a WDM system. One common version of an optical performance monitor, shown in Figure 18.8, spreads a spectrum across a linear array of photodetectors, so each element measures the power on a particular optical channel. The detector array output goes to monitoring systems that verify the signals are at the proper wavelengths and at the proper intensity. Alternatively, a tunable filter can scan the spectrum, which is measured by a single detector. The variation of the detector array output during the scan measures the power delivered at each wavelength. The detectors don't monitor the bits transmitted, only the signal power and wavelength.

Optical performance monitoring was much discussed during the build-out of long-haul WDM systems, but has not been widely implemented. Although optical performance monitors measure the same quantities as some measurement instruments, they are part of network equipment, not separate instruments.

Wavelength Meters

Accurate wavelength measurements are essential for building and operating WDM systems. Optical spectrum analyzers give approximate values, but wavelength meters can give more precise values.

A wavelength meter is based on the Michelson interferometer.

Wavelength meters are built around a device called the *Michelson interferometer.* It consists of a beamsplitter and a pair of mirrors, as shown in Figure 18.9. The beamsplitter divides input light into equal portions, with one-half transmitted through the beamsplitter and the other half reflected to the other *arm* of the interferometer at the bottom.

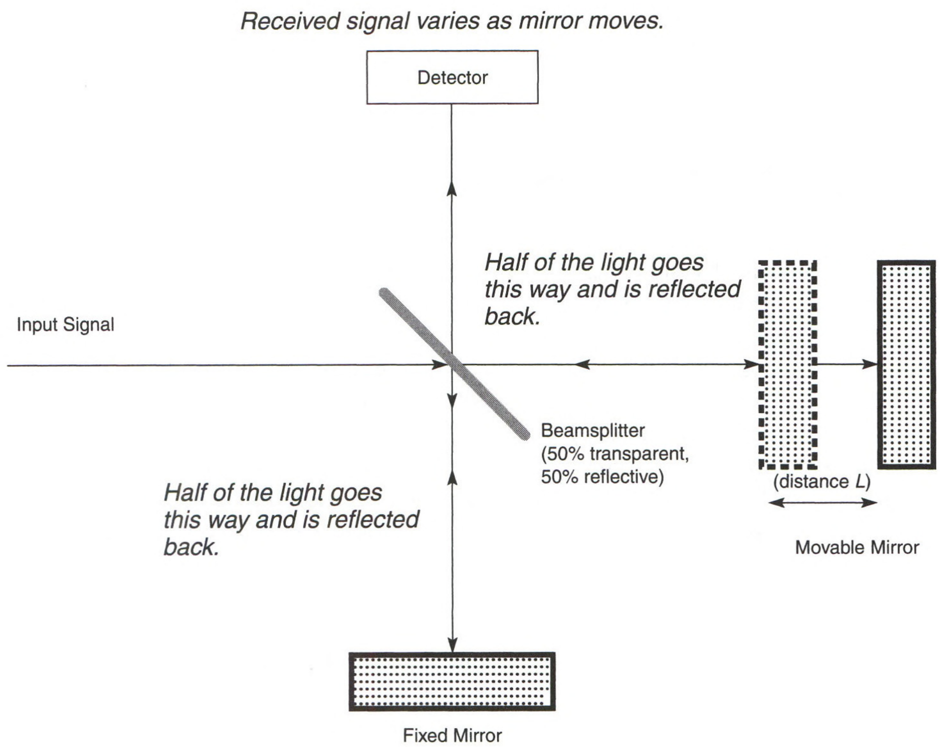


FIGURE 18.9
Wavelength meter counts interference fringes as mirror moves over a known distance.

In Figure 18.9, the bottom arm is a fixed length; a mirror at the end reflects light back toward the beamsplitter. Half the reflected light passes through the beamsplitter to the detector at top; the other half is reflected back toward the light source. The mirror at the end of the horizontal arm is moved back and forth, so its length varies. That mirror also reflects light back toward the beamsplitter, with half the light passing through and the other half reflected toward the detector.

The amplitudes of the beams reaching the detector from each arm are identical. Because the light came from the same source, the waves from the two arms are nominally identical, so they can interfere constructively or destructively. Suppose you initially adjust the moving mirror so the light amplitudes cancel out at the detector. Then you move the mirror a known distance, counting each time the light reaching the detector goes through a light-dark-light cycle. If you know the distance L precisely and find that the light goes through N cycles as the mirror moves that distance, you can calculate wavelength from the equation

$$\lambda = \frac{2L}{N}$$

(The factor of 2 comes from the fact that the light makes a round trip through the arm, so the light travels twice the distance of the arm.)

Precise measurements of wavelength require accounting for the refractive index of dry air, 1.000273 at 1550 nm. Extremely precise measurements require considering air pressure, temperature, and humidity as well, which change the refractive index of air slightly.

Wavelength meters give digital measurements of both wavelength and power at that wavelength for use in the factory or at operating sites. They can be calibrated by measuring known wavelengths.

Troubleshooting Procedures

Fiber-optic systems are far too diverse to give a single, all-purpose guide to troubleshooting. Because this book concentrates on principles of the technology, this section covers basic concepts rather than details. Specific procedures depend on the nature of the system, and often require looking at the electronic parts of the network to isolate the problems.

Troubleshooting systematically analyzes problems.

Troubleshooting is a systematic way of performing tests to isolate problems. You may perform it in different ways depending on the tools you have at hand and your starting location. If you are testing a faulty point-to-point transmission line, your first task is to isolate whether the fault is in the transmitter, the cable, the receiver, or an attached connector. Figure 18.10 gives two alternative approaches for a single technician, starting at either the transmitter or receiver end. The basic idea is to test what you have easy access to first, before traveling to a remote site. A pair of technicians working at each end and able to communicate with each other would follow a different procedure.

The OTDR's ability to spot problems remotely makes it invaluable for troubleshooting point-to-point systems from a single location, although the distance measurements may not be exact. Cables usually include "storage loops"—extra lengths of cable that allow room

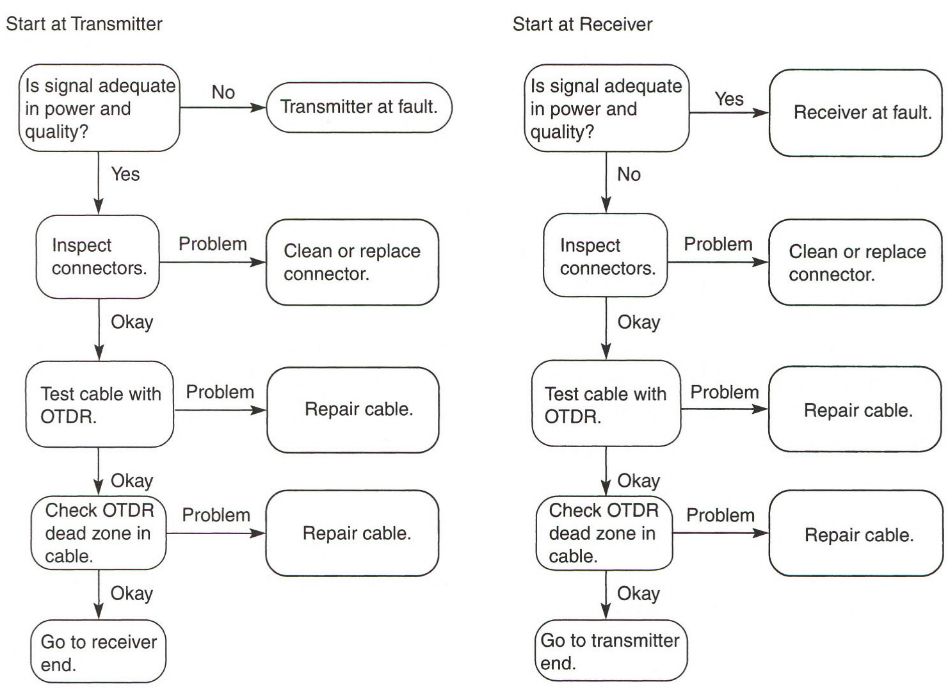


FIGURE 18.10 *Troubleshooting procedures for point-to-point link.*

Table 18.2 Typical problems in point-to-point fiber systems

Problem	Origin	Diagnostic Equipment	Repair
Excess connector loss	Dirt or damage	Inspection microscope	Clean, reinstall, replace
Excess loss localized in fiber or cable	Excess bending	Visual fault locator or OTDR	Straighten fiber or cable
Excess splice loss	Aging, stress, or contamination	OTDR or visual fault locator	Reinstall
Fiber break	Physical damage to cable	OTDR, visual fault locator	Splice or replace cable

to replace damaged cable. Nonetheless, if you can pinpoint a break in a 100-km cable to the nearest 20 m, you have an excellent head start in finding the damage.

Other equipment also assists in diagnosing faults in cable systems. Table 18.2 lists some typical cable problems, their causes, and ways to identify and fix them.

Office local-area networks offer other types of problems in equipment such as patch panels and entry boxes. Cables in office buildings also face different menaces than outdoor cables. People can snap fibers by tripping over loose cables or tugging on equipment attached to the cable. Breaks are most likely near connectors. Cables hidden in walls or suspended ceilings can be cut accidentally. The more equipment connected, the more things can go wrong.

The majority of cable runs in local-area networks generally are too short for OTDRs to be useful, but LANs usually cover small areas, making on-site service easier. Table 18.3 lists a number of steps you can take to check system function. They are divided into tests that don't disrupt system operation and those that interrupt service.

Failure versus System Degradation

One useful way of sorting problems is to determine whether they result in permanent and total system failure or merely degrade system operation. (Degradation includes those maddening intermittent problems that often go away temporarily when you try to diagnose them.) Always check for any changes in system or terminal configuration. If the network worked fine until you moved your workstation to clean the desk, check for damage to the attached cable or dirt in the connector. If a user just installed new communications software, testing the receiver and fiber output may show it's not a hardware problem at all.

Failures may be total or merely degrade system operation.

Typically—but not always—total failures mean some key component has failed or power is down to an essential part of the system. Any obvious changes in the environment are the leading suspects. If a construction crew is digging a hole in the street where your cable runs and that part of the system goes down, they're your number one suspect. Likewise, check for recent changes in junction boxes; somebody may have replaced a cable incorrectly and plugged the connector into the wrong adapter.

Table 18.3 Local-area network troubleshooting

Equipment to Check	Tasks
Does not interrupt network operation	
Patch cords and panels	Trace cabling to verify proper connections are made; correct if needed.
Patch cables and fibers	Check bend radius; correct if too small.
Transmission cables	Inspect for damage or tight bends. Check for signs of recent construction near cable.
Powered equipment	Check power is on and monitors show normal operation. Verify configuration.
Cable connections	Verify connections are secure.
Outdoor plant	Inspect for signs of damage or evidence of recent construction or other disruption.
May interrupt network operation	
Cable connections	Wiggle connectors to hunt for intermittent connections.
Interrupts network operation	
Patch cables and cable connections	Disconnect, test cables, and inspect and clean connectors at all termination points.
Transmission cables	Measure attenuation and compare to specified values.
Long cables	Test with OTDR and compare to records, looking for changes.
All cables with laser transmitters	Check for back reflection toward transmitter, which could disrupt laser operation.
Transmitters	Measure output power level and compare to records and specifications.
Receivers	Measure power arriving through fiber and compare to records. Verify it equals transmitter output minus cable loss.

Intermittent problems suggest loose connectors or partial damage to connectors. A simple check is to wiggle cables and connectors while monitoring for changes in operation.

Degraded operation, such as reduced data transmission speed, may indicate noise in the system. You can rule out a cable break, but not damage to the fiber or bends that cause large light losses. The transmitter or receiver may be generating excess noise, or producing weak signals. Dirt in a connector may be the problem. System degradation also may be a warning of imminent failure of a component or subsystem. Generally such degraded operation is likely to require test equipment to track down the problem.

WDM Troubleshooting

Other challenges arise in systems transmitting multiple wavelengths through the same fiber. So far we've assumed that each fiber carries only one signal. WDM systems carry multiple signals, which means more potential problems to track down.

WDM troubleshooting requires special techniques and instruments.

A total failure of a WDM system—where all channels are out and no light comes through the system—can be treated much like total failure of a single-channel system. No individual laser failure would knock out an entire WDM link, but a power failure could. Cable breaks also could disable an entire WDM system. An obvious first test is to see if power is reaching the receiver end.

Table 18.4 lists some potential failure modes and what parameters to check first as the most likely causes. Optical spectrum analyzers can check the power level on each optical channel. Wavelength meters may be needed for precise measurements of optical wavelengths.

Table 18.4 WDM system failures and likely causes

Type of Failure	Check First
All channels down, no power reaching receiver	Cable break, power failure at transmitter site.
All channels down, power reaching receiver	Optical channels at proper wavelengths using optical spectrum analyzer. Verify power at receiver, performance of demultiplexer. Measure noise levels.
One channel down; all others operating	Failure of transmitter or receiver on that channel. Failure of multiplexer or demultiplexer on that channel. Noise on that channel.
Some channels down, others operating	Drift of some optical channels from assigned wavelengths. Performance of optical amplifiers. Noise on affected channels. Problems in multiplexer or demultiplexer. Look for patterns in failures.
Degradation of one channel only	Degradation of transmitter or receiver on that channel, possibly including wavelength drift. Misalignment of that channel in multiplexer or demultiplexer. Background noise.
Degradation of multiple channels	Problems in multiplexer or demultiplexer. Problems in optical amplifiers. Broad background noise (e.g., amplified spontaneous emission).
Degradation of all channels	Entire multiplexer or demultiplexer. Problems in optical amplifier. Damage to cable or connectors causing noise.

What Have You Learned?

1. The goal of troubleshooting is to diagnose and correct problems.
2. Some failures are complete; others merely degrade transmission. Not all failures have obvious causes.
3. Testing evaluates equipment in the laboratory, field, or factory. Installation requires testing to verify equipment works as intended. Troubleshooting responds to problems.
4. Some instruments directly measure power, attenuation, wavelength, and signal quality; others interpret raw data to analyze system performance.
5. Optical power meters are calibrated for the standard wavelengths used in fiber-optic systems.
6. Test sources include LEDs, fixed diode lasers, broadband sources, and tunable lasers, which operate at fiber system wavelengths.
7. An optical loss test set includes a light source and power meter calibrated to work together to measure attenuation. Optical return loss test sets measure light reflected back to the source.
8. A visual fault locator spots faults by sending red light down a fiber, so you can look for scattered red light.
9. Bending a fiber allows a little signal light to leak out; detecting this light is a simple test for live fibers.
10. An optical time-domain reflectometer (OTDR) analyzes fiber properties by sending a short light pulse down a fiber and measuring light scattered back to the instrument. It allows a technician at one end of a cable to spot distant flaws.
11. Oscilloscopes and communications analyzers perform eye-pattern analysis.
12. Optical spectrum analyzers spread a multiwavelength signal into a spectrum of light and measure the power at each wavelength. They are valuable for testing WDM systems.
13. A wavelength meter uses a Michelson interferometer to measure the wavelength of light.
14. Preferred troubleshooting techniques depend on the tools you have at hand, your starting location, and the type of system you are analyzing.
15. One way to classify problems is to determine whether they cause permanent and total system failures or merely degrade operation.
16. WDM troubleshooting requires special instruments such as optical spectrum analyzers and wavelength meters.
17. Some tests can be performed without disrupting system operation; others interrupt service.

What's Next?

In Chapter 19, we will turn to the basic concepts behind fiber-optic communication systems and optical networking.

Further Reading

Bob Chomycz, *Fiber Optic Installer's Field Manual* (McGraw-Hill, 2000)

Dennis Derickson, ed., *Fiber Optic Test and Measurement* (Prentice Hall, 1998)

Jim Hayes, ed., *Fiber Optics Technician's Manual* (Delmar Publishers, 1996). See Larry Johnson, "Fiber optic restoration" (Chapter 16) and Jim Hayes, "Fiber optic testing," (Chapter 17).

Catalogs:

Agilent Technologies, *Lightwave Test and Measurement Catalog* (*www.agilent.com*)

Exfo Electro-Optical Engineering, *Lightwave Test & Measurement Reference Guide* (*www.exfo.com*)

Questions to Think About

1. Devise a troubleshooting procedure for testing your ability to connect to the Internet using a personal computer, an external modem, and a standard telephone line.
2. Which is more likely to fail: an old fiber-optic cable left undisturbed in an underground duct, or a new office cable that was plugged into a new computer?
3. What is the advantage of measuring fiber attenuation at 1625 nm?
4. You want to test a WDM system by transmitting signals through it one wavelength at a time at the same power generated by the standard transmitters. What sort of light source should you use?
5. You test a 50-km cable with an OTDR and find a sharp peak at 25 km and no signal returning from greater distances. What does this tell you about the cable?
6. When the moving arm in a wavelength meter moves 7 mm, the instrument counts 9,000 fringes. What's the difference between the wavelength in a vacuum and the wavelength in air ($n = 1.000273$)?

Chapter Quiz

1. An optical power meter would be least likely to be calibrated for measurements at
   a. 850 nm.
   b. 1300 nm.
   c. 1400 nm.
   d. 1550 nm.

2. An optical loss test set includes a(n)
    a. wavelength meter and power meter.
    b. optical spectrum analyzer and power meter calibrated across the same range of wavelengths.
    c. power meter and a length of fiber calibrated to work together.
    d. light source and a power meter calibrated to work together.
    e. power meter, light source, wavelength meter, and optical spectrum analyzer.
3. A visual fault indicator does what?
    a. It shines red light down the core of a fiber to make visible any flawed points where light leaks from flaws.
    b. It illuminates the plastic coating of a fiber with red light to spot any uneven spots on the surface.
    c. It shines light through the hollow zone of a loose tube cable to search for any fiber fragments in the cable.
    d. It illuminates the outside of a fiber with ultraviolet light to cause fluorescence where light leaks from the fiber.
    e. None of the above
4. You can test a fiber to see if it's carrying an optical signal by
    a. pointing the end at a white piece of paper and looking for fluorescence.
    b. scraping away the cladding and monitoring for light leaking out.
    c. bending the fiber and monitoring with an infrared sensor for light leaking out.
    d. removing the plastic coating and looking for light in the fiber.
    e. all of the above
5. You use an optical time-domain reflectometer to analyze a fiber with an 10-μm air gap at a connector. What would you expect the OTDR to show at the point where the connector is installed?
    a. nothing
    b. a strong reflection accompanied by a loss
    c. a strong reflection accompanied by a gain
    d. a flat region across the gap
    e. a sharp drop in scattering in the air gap, followed by higher scattering in the glass
6. What type of test equipment can best identify a fiber that has been moved and connected to the wrong point in a patch panel?
    a. an OTDR
    b. an optical loss test set

c. an optical power meter
d. an optical spectrum analyzer
e. manual inspection and comparison with records

7. What type of instrument can display an eye pattern?
a. oscilloscope
b. optical loss test set
c. optical power meter
d. OTDR
e. optical spectrum analyzer

8. An optical spectrum analyzer can record
a. the spectrum of a light source.
b. all the wavelengths transmitted by a WDM system.
c. the optical channels amplified in an erbium-doped fiber amplifier.
d. the wavelengths transmitted by an optical multiplexer.
e. all of the above

9. A wavelength meter is based on what optical system?
a. Mach-Zehnder interferometer
b. optical spectrum analyzer
c. Michelson interferometer
d. Fabry-Perot interferometer
e. Ross-Perot interferometer

10. What is the easiest way to locate a break in an aerial cable?
a. drive along the line and look for fallen cables
b. measure cable loss with an optical return loss meter
c. measure the cable with an OTDR
d. measure power level at the receiver
e. listen to police radio for reports of drunk drivers hitting utility poles

11. The bit error rate of the fiber-optic system connecting your building to the Internet has reached 10^{-3}. What possibility can you rule out when you start troubleshooting?
a. A backhoe broke the cable.
b. The laser transmitter has gotten too warm and drifted off wavelength.
c. dirt in a connector
d. Moisture has contaminated an outdoor splice.
e. a kink in the cable at a junction box

12. An optical spectrum analyzer shows that your WDM system delivers no signal at all at one wavelength but other channels are working fine. Which of the following could have caused the problem?

a. A gopher gnawed one fiber in the cable.

b. The laser for that channel failed.

c. Dirt has gotten into a connector.

d. The cable is kinked at the junction box.

e. failure of an optical amplifier