Photonic Validation Methods Handbook

D-18230

by

George Lutes

with assistance from

Meirong Tu

1999
NASA Electronics Packaging Program (NEPP)

September 27, 1999

Contents

1. Introduction to Photonic Tests and Measurements

This manual is meant to be a starting place for those who are not well versed in photonics but have a need for basic knowledge about how to test photonic devices and systems. More detailed information about how to make a particular measurement are available from the manufacturers of the test equipment and various testing standards.

Unless otherwise stated the information in this manual is limited to either free space systems using TEM-00 modes or closed systems using single-mode optical fibers. Although much of the information also relates to multimode systems there are some special problems that are unique to multimode systems. This manual does not discuss these problems. However, the literature published by the manufactures of the test equipment and the various standards cover this subject in depth.

2 Optical Measurements

2.1 Optical Power Measurements

Optical power is the most fundamental parameter to be measured in a photonic system. It is usually measured with an optical power meter or an optical multi-meter. The measurement accuracy for these meters is typically ±2.0 % to ±2.5% (0.09dB to 0.11dB).

Most optical power meters use a semiconductor photodetector as the sensing element. The sensitivity of these devices varies with wavelength. Therefore, they must be calibrated for the wavelength to be used. Fortunately, there are only three wavelengths in common use in photonic system. They are 850 nm, 1310 nm, and 1550 nm. Most optical power meters are calibrated at all three wavelengths. Many of them come with tables of correction factors for other wavelengths between 850 nm and 1550 nm.

The wavelength of the test source must match the wavelength that the device under test is designed to operate at. For instance, if the device under test is designed to operate at 1550 nm wavelength and the test equipment is designed or calibrated for 850 nm wavelength a large measurement error is likely to result.

When making optical power measurements care must be taken that all of the optical power to be measured is incident on the photodetector. This is achieved by using either a photodetector which is large enough to intercept all of the optical power or by precisely controlling the shape and size of the optical source so all of the optical power is incident on the photodetector.

The photodetector must be shielded from all external light sources which are not to be included in the optical power measurement. Some materials appear to the eye to be effective optical shields when in reality some wavelengths of light will penetrate them to some degree. This will result in erroneous measurements.

Many photodetectors are polarization sensitive so the power reading is slightly higher for one polarization than for others. For precise measurements the polarization should be scrambled or the polarization should be rotated and the average reading measured. Error due to polarization sensitivity of the detector is small and is most often neglected.

2.2 Optical Loss Measurements

Optical loss measurements consist of multiple optical power measurements to determine the optical loss in a device. In this section we will talk about special considerations and techniques for measuring the loss in a number of devices including optical fiber.

2.2.1 Optical Fiber Loss (cutback method)

Optical loss in optical fiber is usually measured using a unique method called the cutback method. In this method light of the desired wavelength is launched into a long piece of optical fiber and the optical output power at the far end of the fiber is measured with an optical power meter. Then a precisely known length of optical fiber is cut off the far end of the fiber and the optical power is measured at the end of the remaining length. The difference between the two measurements is the loss in the fiber for the length that was cut off. This loss is nearly always normalized to a 1 km length of fiber and is stated in dB/km.

The equation for determining the average attenuation per km of an optical fiber using the cutback method is,

$$A_{\ell} = \frac{10^4}{\ell_c} \cdot \log\left(\frac{P_1}{P_2}\right), \qquad (1)$$

where,

$\ell_c =$ the length of fiber cutback,

P_1 = the power measured at the output of the long fiber, and

P_2 = the power measured at the output of the remaining fiber after it is cut back.

The cutback method for measuring optical fiber loss eliminates the errors associated with connector losses (see below) and losses due coupling mismatches between the optical fiber and the test source. However, this method requires that sufficient fiber be cut off to obtain an accurate measurement. When the fiber is cutback the change in optical power must be much larger than the useable resolution of the power meter to get an accurate measurement.

2.2.2 General Considerations for Measuring the Loss in Devices

You measure the optical loss through a device by measuring the optical power launched into it and then measuring the optical power emitted from the output of the device. This sounds simple but there are a number of pitfalls that can result in inaccurate measurements.

These pitfalls have to do with mode mismatches at the interfaces, cladding modes, reflections, misalignment of interfaces, obstructed optical paths, optical wavelength, and stray light. It will be pointed out in the text where these pitfalls are likely to occur and what can be done about them.

Before making any measurement you must make sure that the wavelength being used is correct for the device being measured, that there is no significant stray light incident on the photodetector, and that polarization errors are considered.

2.2.3 Fiber Optic Connector Losses

In systems that use fiber optic interfaces the most likely source of error is the fiber optic connector that interfaces with the optical power source. There is no reasonable way to precisely determine the loss in this connector. All you can do is to make sure the connector is installed correctly, is clean, and is properly mated. You can gain some confidence in the integrity of the connector if you connect about 30 meters of fiber optic cable from the source connector to the input to the optical power meter. The loss should be no more than the maximum specified loss for a mated pair of the type of connector being used. The optical fiber loss should be negligible for this length of cable.

The 30 meters of fiber optic cable should be left on the optical source. It will assure a good launch condition and it will save the connector on the optical source since it will only be de-mated when the connector on the far end of the cable is worn out.

2.2.4 Cladding Modes

When two fiber optic connectors are mated some of the light will leak into the cladding of the fiber and if it is sufficiently large could result in measurement error. The light in the cladding is referred to as cladding modes. This light will leak out of the cladding in a few tens of meters. This is the reason in the previous paragraph I suggest using a thirty meter length of fiber optic cable. Nearly all of the optical

power that leaked into the cladding at the connector will be lost before it gets to the end of the 30 meter cable. If the cable is too short the power meter will measure the light in the cladding as well as the desired light in the core of the fiber. This will result in an error when a device is measured.
The 30 meter length of optical cable should always be left on the optical source to save the connector and to reduce cladding modes at the input to the device being measured. A 30 meter length of fiber optic cable should also be connected to the optical power meter. This cable will assure that cladding modes generated in the device being measured will be lost before they reach the power meter.

The specified mean loss of the best fiber optic connectors is about 0.2 dB for a clean connector which has been properly installed. A nine micron spec of dust on the end of the fiber can completely block the optical signal. It is essential to keep the connector clean.

Fiber optic connectors should always be protected with a cover when not connected. Virtually every fiber optic connector comes with a cover designed to keep it clean. A cover should be attached to the cable at each connector and it should be used if the connector is de-mated.

2.2.5 Cleaning Fiber Optic Connectors

Installation personnel should clean every connector every time prior to mating. The following cleaning procedure should be used. If the connector adapter is not fresh out of the package, it should be cleaned also.

1. Soak a clean cotton swab or special cleaning pad designed for this purpose in pure isopropyl alcohol.

2. Gently wipe the end of the connector to rinse away any grit which could scratch the connector end.

3. Soak a fresh cotton swab or pad and rub the end of the connector firmly. Use a fresh dry cotton swab to dry the connector end. Do not let it air dry as it may leave a film.

4. Examine the end of the connector with a microscope designed for this purpose to assure that it is clean.

5. If it is not clean, go back to step 3.

6. When the connector is clean insert it into the connector adapter carefully without touching the end of the connector on anything particularly the adapter. If the end of the connector comes in contact with the adapter it may be damaged and become unusable. Insert the connector as straight into the adapter as possible so as not to scrape any material from the adapter which could contaminate the connector end.

2.2.6 Optical Losses in Two Terminal Devices

To measure the optical attenuation of a two terminal device first connect the two 30 meter test cables together and measure the power with the optical power meter. This reading serves as a reference. Next connect the device under test as shown in Fig. 1 and measure the optical power. These measurements should be made as close together in time as possible so any drifts will be minimized. The attenuation of the device under test is the power difference in dB between these two measurements. The equation is,

$$A_s = A_2 - A_1 \qquad (2)$$

where,

A_1 = the power in dB measured with the two 30 meter lengths of cable connected, and

A_2 = the power in dB measured with the device under test inserted.

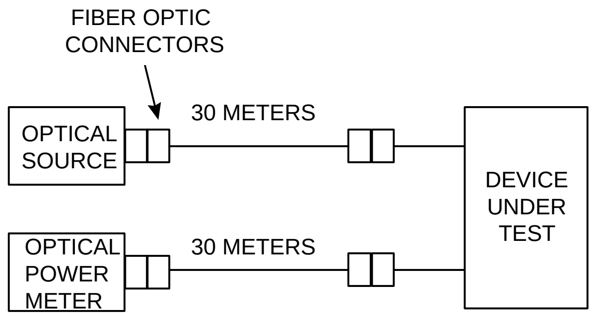


Fig. 1 - Setup for two port device loss measurement.

2.2.7 Optical Losses in Multi-port Devices

In many multi-terminal devices such as optical couplers there is an additional loss term called excess loss. It is the loss over and above the loss in an ideal device. For instance if the device is a 4 port coupler (4 way power splitter) the power at each output port should be one-fourth (-6 dB) of the input power. The equation for ideal loss to each port in such a device is,

$$A_i = 10 \cdot \log\left(\frac{1}{n}\right), \tag{3}$$

where,

n = the number of equal outputs.

Any loss greater than this is called excess loss.

A block diagram of the measurement setup for multi-port devices is shown in Fig. 2.

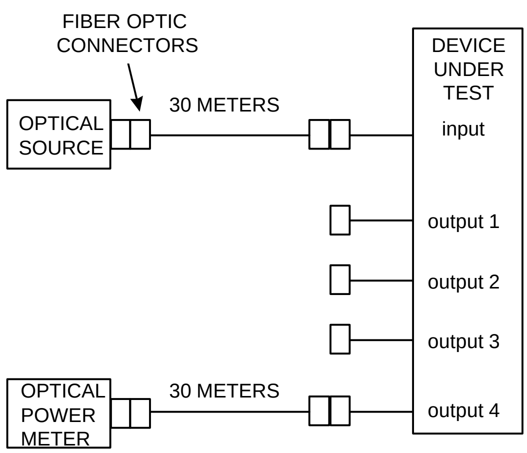


Fig. 2- Setup for multi-terminal device loss measurement.

The loss to each port is measured separately as follows. First measure the optical power with the two 30 meter long test cables connected together. This is the reference. Then with the 30 meter cable from the source connected to the input of the device under test measure the optical power at each output port. Use equation 2 to calculate the loss in dB for each output port. The equation for excess loss from (2) and (3) is,

$$A_e = (A_2 - A_1) - 10 \cdot \log\left(\frac{1}{n}\right) \qquad (4)$$

Another measurement of multi-terminal devices is port-to-port isolation. This is a loss measurement between output ports. The port-to-port loss of an optical coupler should be very high, on the order of 50 to 60 dB. Port-to-port isolation will degraded if there is a reflection at the input port of the coupler. A reflection can be the result of a scratched or dirty input connector.

A block diagram of the setup for measuring port-to-port isolation is shown in Fig. 3.

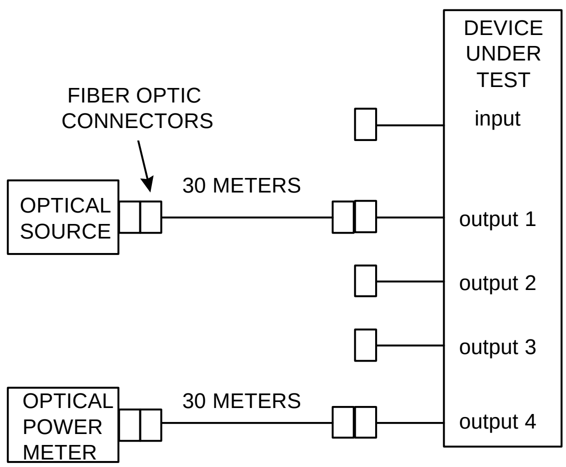


Fig. 3 - Setup for multi-terminal device port-to-port isolation.

In this test first measure the optical power with the two 30 meter long test cables connected together. This is the reference. Then with the 30 meter cable from the source connected to one of the output ports measure the optical power at the other output ports. Every combination of output ports should be measured. Use equation (2) to determine the isolation between each port.

2.2.8 Optical Return Loss Measurements

Reflections cause interferometric noise and laser instability in photonic systems. The performance of analog fiber optic systems, such as CATV transmission links, can be seriously degraded by the noise resulting from reflections. In order to control reflections it is necessary to measure them. This is done with an optical reflection meter or optical multi-meter with a return loss function.

A block diagram of a reflection meter is shown in Fig. 4. It consists of an optical source, a two way fifty-fifty coupler (an optical coupler that splits the input signal into two equal output signals), and an optical power meter.

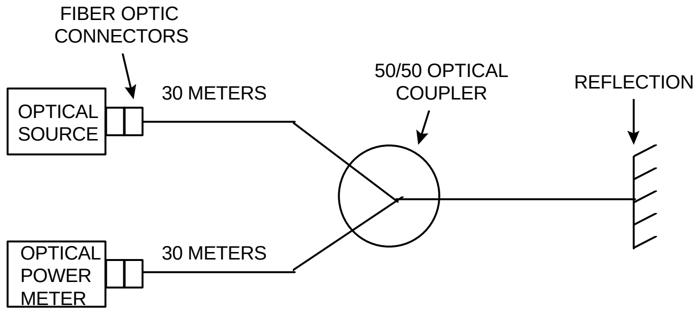


Fig. 4. - Reflection meter block diagram.

Referring to Fig. 3, an optical signal is applied to one port of the optical coupler. The port-to-port isolation is on the order of 70 dB so very little of the signal from the optical source leaks into the optical power meter port directly. The coupler has very little loss from the optical source port to the reflection port so the signal from the optical source readily passes through the coupler and is reflected by the reflection. The reflected signal is split evenly by the coupler into the optical source port and the power meter port. The half that goes to the optical source port is lost and the other half is measured by the optical power meter.

The sensitivity of a reflection meter is about -65 dB.

2.3 Optical Time Domain Reflectometry (OTDR)

When light from an optical source is launched into an optical fiber some of it is reflected back toward the source. This reflected light is due to imperfections in the optical fiber such as variations in the index of refraction. This reflection is called Raleigh-scattering.

The optical time domain reflectometer (OTDR) uses this effect to measure losses and reflections in a long optical fiber. Fiber optic cable installers used OTDRs extensively because they measure the fiber loss, connector losses, microbend losses, splice losses, reflections, and the distance to each imperfection that creates a loss or reflection.

A simple block diagram of an OTDR is shown in Fig. 1. An optical pulse generator sends out a string of optical pulses. As each pulse travels down the optical fiber some of its light is reflected back to the optical directional coupler where it is split evenly between the optical pulse source and the optical receiver. The light that goes to the optical pulse generator is lost. The light that goes to the optical receiver is converted to an electrical current. The magnitude of the current is linear with the amount of light being received. The magnitude of the electric current, which is a measure of the reflected optical power, is displayed on a screen as a function of distance. The X axis shown on the screen is actually time measured with the clock that has been converted to distance. This is only a matter of putting the correct scale on the screen since there is a linear relationship between time and distance along the fiber.

Keep in mind that the pulse is attenuated as it travels down the fiber and the reflected light is also attenuated by the same amount. So the signal you see is actually the two way loss. This is invisible to the operator because the OTDR processes the information in the reflected signal and provides the one way loss to him.

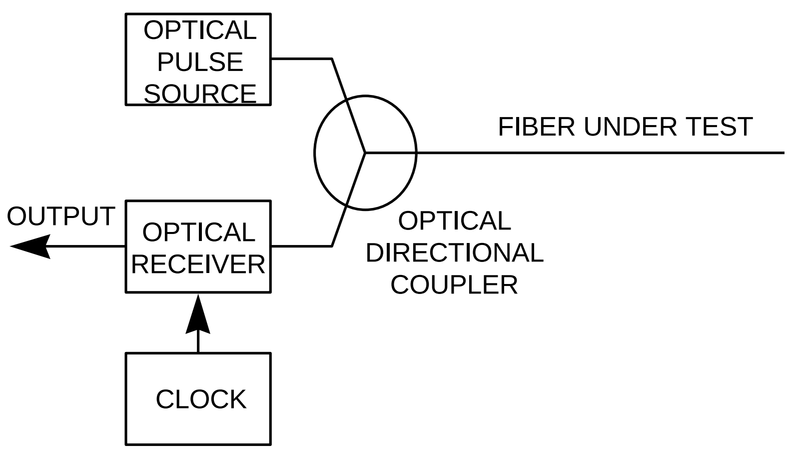


Fig. 1 - A block diagram of an optical time domain reflectormeter.

Figure two illustrates the relationship between the OTDR display and the cable parameters it is measuring. The optical fiber has loss along its entire length so the farther from the source the optical pulse is in the fiber the less reflected light is received by the photodetector. This reduction of received reflected light is a measure of the loss in the optical fiber per unit length. The optical loss in the fiber is logarithmic as a function of distance this makes it linear in dB.

You can see in Fig. 2 that when the optical pulse is launched it is so strong that some of the light leaks over into the receiver and masks any reflected signal. This is called a dead zone because no reading can be made on the first few meters of the fiber corresponding to the length of the pulse. After this initial dead zone is Raleigh-scattering from the fiber.

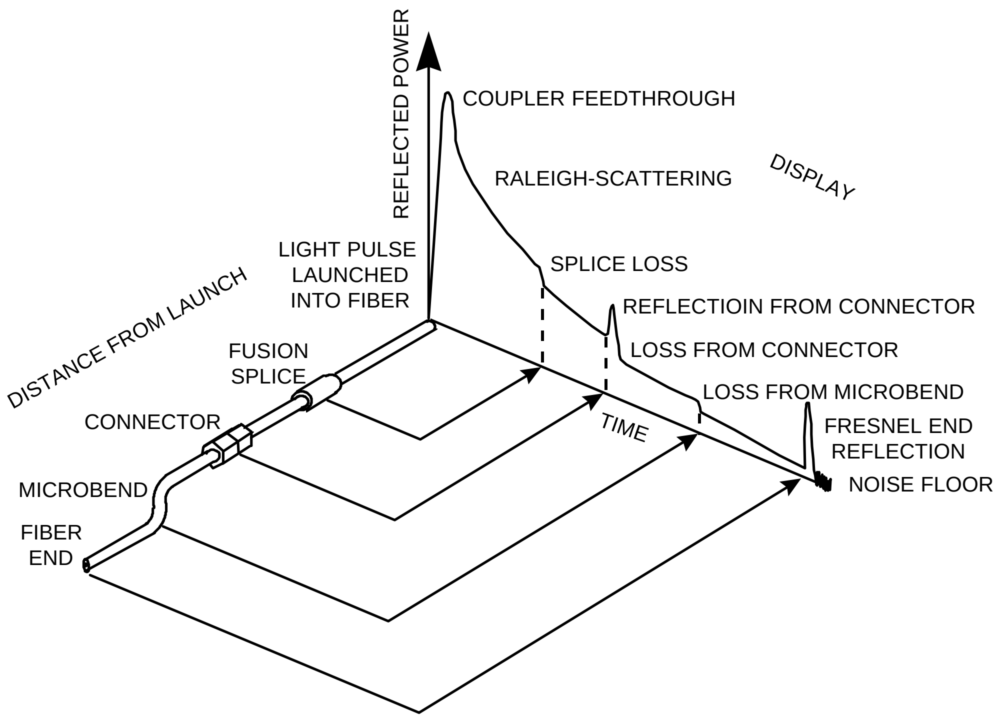


Fig. 2 - Illustration of the relationship between the OTDR display and cable irregularities.

The loss in an optical fiber is determined from the slope of the Raleigh-scattering curve. In single-mode fiber at 1300 nm the loss is about 0.4 dB/km. The attenuation and Raleigh-scattering in different optical fibers is not the same. This leads to what appears to be a gain in some connectors or splices. This happens when two different fibers are spliced or connected together and the second fiber has more reflection than the first. Since more light is being reflected in the second fiber the measured reflected light is greater and the displayed curve is higher and gives the appearance of gain.

The third feature shown is the loss in a splice. Fusion splicers are so good today that often you cannot measure the splice loss. Fusion splices virtually never reflect light. Mechanical splices virtually always reflect light.

The fourth feature is the reflection and loss of a fiber optic connector. With the exception of angle-polished connectors most connectors will reflect measurable light. Dirt on the end of a connector will reflect light even if the connector is angle polished.

The fifth feature is the loss due to a microbend. When an optical fiber is bent too sharply light is lost out through its side at the bend. If the bend is sharp enough virtually all of the light will be lost. This does not cause a measurable reflection.

Finally if the fiber end is flat and at right angles to the fiber there will be a large (14%) reflection. This is called a Fresnel reflection and is caused by the abrupt change in index of refraction at the glass to air interface. If the fiber end is not perpendicular to the fiber there may not be a reflection and the signal will just fall off into the noise.

There is no more reflection after the end of the fiber so the system noise is displayed.

However, if there are multiple reflections in the fiber under test the light from a pulse will be reflected back and forth in the fiber and displayed more than once. The OTDR will display these multiple reflections after the end of the fiber and give the appearance that there is a reflection after the end of the fiber.

2.3.1 Precision Optical Time Domain Reflectometer

Hewlett-Packard manufactures a precision OTDR that has high precision and gets rid of the dead zone. It is designed to be used over short spans from 1 mm to 270 mm. The span can be offset in distance as long as the attenuation in the offset fibers does not exceed the dynamic range of the instrument. Its purpose is to measure reflections internal to optical devices.

This device uses a different technique from the normal OTDR. A block diagram of it is shown in Fig. 3.

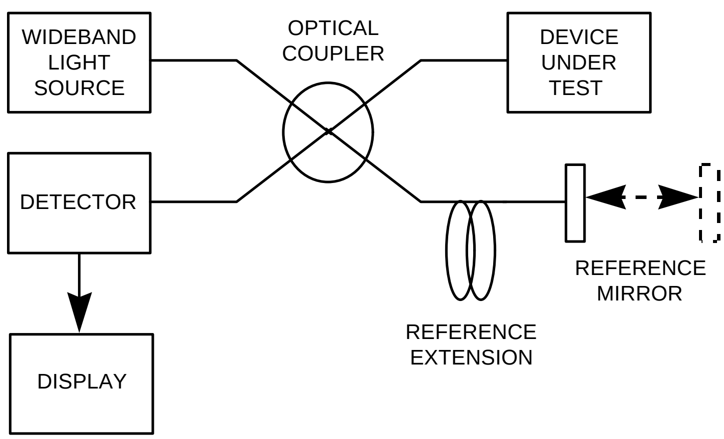


Fig. 3 - Block diagram of the precision OTDR.

This OTDR uses a Michelson interferometer. Light from the wideband light source goes to the optical coupler where it is split evenly between two outputs. One output goes to the device under test and the other output goes to a reference mirror. Light from both the device under test and the reference mirror are reflected back toward the wideband light source and the detector. The reflected light is evenly split by the coupler and half of it goes to the wideband light source where it is lost. The other half of the reflected light goes to the detector where it generates a current that is proportional to the amount of reflected light.

The reflected light from the device under test and the reference mirror are combined at the output of the coupler and interfere if they are coherent. When the interference is constructive the reflected light from the two paths adds and when it is destructive they subtract. When they add the photodetector output is large and when they subtract the photodetector output is small.

However, since the light from the wideband light source has a very short coherence length the light from the two reflections is only coherent over a very short difference in distance, less than 25 microns. In other words, the distance from the output of the coupler to each of the reflections must be exactly the same within a few microns to get coherent interference and a response from the detector.

In operation the reference mirror is slowly moved. When the distance from the coupler to a reflection in the device under test is exactly the same as the distance from the coupler to the reference mirror the two reflections will constructively interfere and a response will show up on the display.

This instrument will distinguish between two reflections as close as 25 microns apart and display them. It will only display discrete reflections so it will not see the Raleigh-scattering in a fiber because it is a distributed reflection.

2.4 Polarization

Polarization is explained in the Photonics Handbook which is a part of this series so this discussion will be limited to some thoughts about the effects of polarization and how it is measured.

Most light signals are only partially polarized. The part of the light that is not polarized is referred to as randomly polarized or unpolarized. The degree of polarization (DOP) is,

$$DOP = \frac{polarized\ \ power}{total\ \ power} \cdot 100 \tag{1}$$

2.4.1 Polarization Dependent Loss

Some optical components have polarization dependent loss (PDL). The loss in these components depends on the polarization state to some degree. The range of PDL is from 0.5 dB for connectors and standard optical fibers to greater than 30 dB for optical polarizers.

Optical power meters, lightwave polarization analyzers, and optical spectrum analyzers can all be used to measure PDL. All that is required is a means to rotate the polarization of the light signal over the entire range of possible polarization states, a polarization analyzer, and a piece of test equipment that can measure optical power.

One way to alleviate problems with PDL is to scramble the polarization of the optical signal. Another way is to transmit the signal using polarization preserving optical fiber or polarizing optical fiber which keep the polarization state from changing.

2.4.2 Polarization Mode Dispersion

As stated before, all light signals consist of two orthogonally polarized modes. Each of these modes travel at a different speed through an optical fiber. When the information in one of them gets out of phase with the information in the other one the information being transmitted gets distorted. This is called polarization mode dispersion (PMD). If the information gets near or at 180 degrees the signal fades. This can be a problem with high speed fiber optic communications systems.

PMD is specified at one wavelength in picoseconds or as the average PMD over a range of wavelengths.

2.4.3 Polarization Test Instruments

Test instruments are available that fully characterize the polarization state of an optical signal. These instruments will measure the state of polarization, PMD, PDL, and polarization maintaining fiber launch conditions. Most of them operate over a wavelength range of 1200 to 1600 nm. The accuracy ranges around 2% to 5%.

2.5 Photonic Network Analysis

Photonic network analyzers measure the “S” parameters of photonic systems that utilize photonic components such as fiber optic transmitters and receivers, fiber optic amplifiers, fiber optic modulators, fiber optic attenuators, and fiber switches. Another name for this instrument is “lightwave component analyzer”.

Much like the electrical equivalent, photonic network analyzers measure the forward gain, reverse isolation, and input and output reflections. These instruments are standard radio frequency (RF) network analyzers with optical to electrical and electrical to optical converters so any combination of electrical and optical inputs and outputs can be measured..

Photonic network analyzers are very handy for measuring the gain and phase characteristics of analog RF fiber optic links.

2.6 Optical Spectrum Analysis

Optical spectrum analyzers are used to measure the spectrum of optical signals. They can be used to measure the spectrums of LEDs, lasers and other light sources and the response of couplers, fibers, filters, isolators, and wavelength division multiplexing components.

A block diagram of an optical spectrum analyzer is shown in Fig. 1. It consists of 4 basic parts, a monochromator, an optical receiver, a control function, and a display.

In operation an optical signal is injected into the monochromator which is a very narrow band tunable optical filter. The control circuit tunes the monochromator across the band of interest and scans the "X" axis of the display which is calibrated in wavelength. The optical receiver converts the output of the monochromator to a current that is proportional to the optical power out of the monochromator. This current drives the "Y" axis of the display which is calibrated in optical power. The result of this is a display of optical power as a function of wavelength.

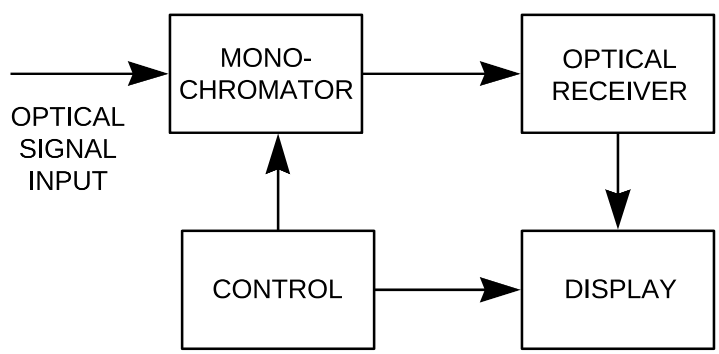


Fig. 1 - A block diagram of an optical spectrum analyzer.

2.6.1 LED Spectrum Measurements

If the output of an LED is injected into an optical spectrum analyzer it will measure and display the LED's spectral full-width half maximum value, mean wavelength position, and peak power density.

Fabry-Perot Laser Spectrum Measurements

If the output of a Fabry-Perot Laser is injected into an optical spectrum analyzer it will measure and display the laser's spectral full-width half maximum or envelope bandwidth, center wavelength, mode spacing, and total power. Some of these instruments will provide a Gaussian or Lorentzian curve fit to the laser.

2.6.2 DFB Laser Spectrum Measurements

If the output of a distributed feedback laser (DFB) is injected into an optical spectrum analyzer it will measure the laser's center wavelength and side-mode suppression. DFB lasers have an internal grating that filters the output spectrum and greatly reduces all but the desired mode. The power ratio between the desired mode and the largest of the other modes is called side-mode suppression.

2.6.3 Spectral Response Measurements

By adding a wideband light source an optical spectrum analyzer will measure the spectral response of couplers, fibers, filters, isolators, photodetectors, receivers, and other photonic devices over the 1200 nm to 1600 nm wavelength range. A block diagram of the monochromator setup for these kinds of measurements is shown in Fig. 2.

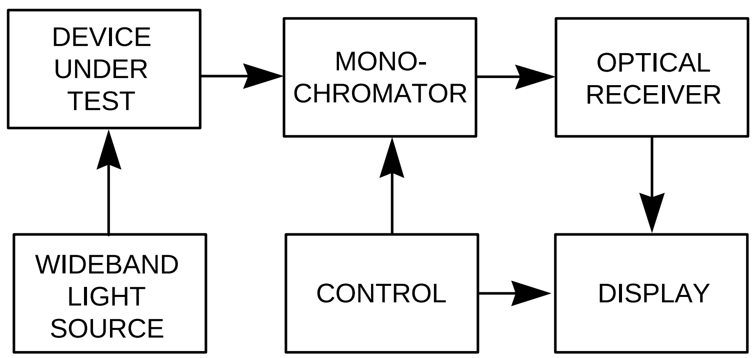


Fig. 2 - block diagram of the monochromator setup for response measurements.

The instrument is calibrated so that when only the wideband light source is injected into the monochromator the displayed output is flat with wavelength. To measure the response of a device the wideband light source is transmitted through the device into the monochromator. If the device attenuates the light from the wideband light source anywhere in the range of the instrument the attenuation as a function of wavelength will be measured and displayed.

2.7 Thermal Coefficient of Delay (TCD) of optical fibers and fiber optic cables and how to measure it

In this section we discuss thermal coefficient of delay (TCD) of cables, why it is important in some applications, and how to measure it. The discussion is focused on the TCD of single-mode optical fiber and fiber optic cable.

2.7.1 Introduction

Fiber optic cables with high delay stability are used for a growing number of applications, such as optical and radio wave interferometers, synthetic aperture radar, radio science, and precision navigation of spacecraft. In general the delay in fiber optic cables is much more stable with changing temperature than coaxial cables are. Fiber optic cables can also carry high frequency signals over much greater distances than coaxial cables.

The NASA/JPL Deep Space Network uses stable fiber optic cables to connect widely separated antennas for long baseline interferometery measurements. This technique was used to measure the bending of a radio wave by the gravitational field of Jupiter. The results agreed with the predictions of Einstein's theory of general relativity.

The Shuttle Radar Topography Mission (SRTM), a spaceborne imaging radar system, which will map the entire earth's surface in 10 days uses a stable fiber optic cable. It is part of a fiber optic system that provides an extremely stable reference signal to a receiver at the end of a 60 meter mast.

The Keck Observatory on Mauna Kea volcano in Hawaii uses stable fiber optic cables to connect multiple antennas together to form an interferometer which is used to detect planets around other stars.

It is important for system designers of these highly stable electronic/photonic systems to know the stability of various cables they can select from. However, this information is usually not provided by the manufacturer and must be measured by the user. This section explains how to make these measurements.

2.7.2 Fundamentals

A cable's thermal coefficient of delay (TCD) is the slope of its change of group delay versus temperature. The TCDs of cables vary depending on their construction and the materials used. The TCD is also a good indication of the stresses on an optical fiber enclosed in a cable when the cable is stressed by a large change in temperature. Differences in thermal coefficients of expansion of the various materials in a cable cause these stresses.

Although this discussion is limited to measuring the TCD of an optical fiber or fiber optic cable the general procedure can be used to measure the TCD of any type of transmission line.

In optical fiber or fiber optic cable the change of group delay resulting from a temperature change is generally a smooth function. Abrupt changes in group delay sometimes occur in coaxial cables. It is caused by sudden slippage between the center conductor and the surrounding dielectric material brought on by differences in thermal coefficient of expansion of the materials.

For the rest of this discussion the cable under test will be referred to as optical fiber or merely as fiber. In this section group delay will be denoted by t, and refers to the end to end delay in an optical fiber.

Thermal coefficient of delay (TCD) is the normalized derivative of the delay with respect to temperature. For convenience a symbol b has been introduced to denote TCD, which can be expressed as,

$$b = \frac{(10^6)}{t}\frac{dt}{dT} \qquad (1)$$

where, t is the delay through the signal path. The factor of 10^6 is introduced for the conventional expression of b in units of parts-per-million per degree Celsius (ppm/^{o}C). Since the change of delay is small compared to the total delay in the optical fiber path, and for testing purposes the temperature is changed in steps, b can also be written as,

$$b = \frac{(10^6)}{t_o}\frac{\Delta t}{\Delta T} \qquad (2)$$

where, t_o is the nominal group delay through the optical fiber, commonly measured at room temperature, 25 ^{o}C.

The TCD of a cable is determined in a three step process.

1. The system is calibrated.
2. The nominal delay is measured.
3. The TCD is measured.

In an ideal measurement system the phase measurement device (vector voltmeter or phase detector) would be connected directly to each end of the cable to be measured with no additional delays. However, in practice there are always extraneous delays such as, test cables and fiber optic receivers, in both signal paths. Calibrating the measurement system minimizes the affect of these delays.

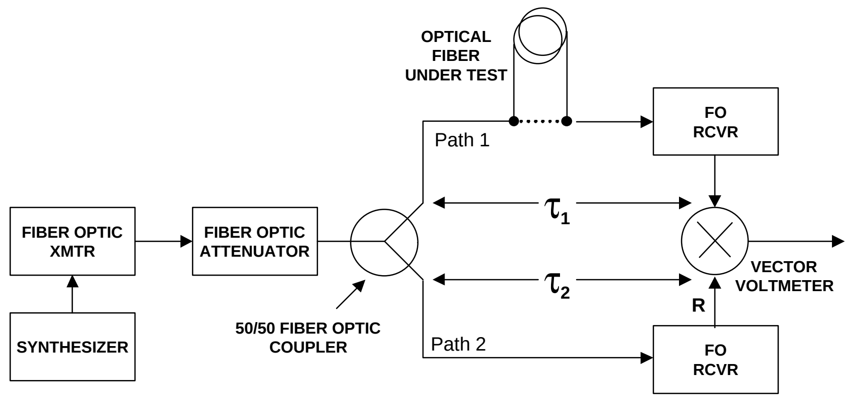


Figure 1 – Block diagram of the measurement system.

2.7.3 Test System Description

Referring to Fig. 1, a synthesizer generates an RF signal which is used to modulate an optical carrier emitted by the fiber optic transmitter. This optical signal passes through a fiber optic attenuator that limits the optical power to a level that is safe for the fiber optic receivers.

A fiber optic coupler splits the signal from the fiber optic attenuator into two equal signals. One signal follows Path 1 and the other signal follows Path 2 as shown in Fig. 1. Path 1 consists of a test system cable, the optical fiber under test, and another test system cable that goes to a fiber optic receiver. Path 2 is a test system cable connected directly to a fiber optic receiver. During system calibration the two test system cables in Path 1 are connected together bypassing the optical fiber under test as shown with a dotted line in Fig. 1. Path 1 and Path 2 should have equal lengths when the cable under test is not connected.

The fiber optic receivers convert the modulated optical signals back into electrical signals that are applied to the two probes of a vector voltmeter. In Fig. 1, “R” designates the vector voltmeter’s reference probe. It is important that the reference probe is always connected as shown. The vector voltmeter measures the phase difference between the two signal paths at the output of the receivers. This phase difference information is used to, calibrate the measurement system, and determine the nominal delay and TCD of the fiber under test.

This test configuration minimizes the effect of delay variations in the synthesizer, fiber optic transmitter, fiber optic attenuator, fiber optic receivers, and connecting cables.

The optical fiber or cable under test is enclosed in a test chamber whose temperature must be controllable to cover the desired range. The test fiber or cable must be enclosed in a paper box or other container within the test chamber to keep air from the circulating fans from blowing directly on it. The reason for this is that the temperature of the air in the chamber is not homogeneous so the fiber would be subjected to rapid variations of temperature if not covered. Because of the small mass of the optical fiber or cable its temperature will follow these rapid variations in air temperature and the delay in the fiber will vary accordingly. This generates noise in the measurement.

A test chamber's temperature controller is usually not accurate enough for good measurements. It is prudent to suspend a thermocouple in the chamber to measure the air temperature and place another thermocouple on the optical fiber to monitor its temperature.

If test temperatures will be below the dew point the oven should be purged with dry nitrogen to keep the cable dry. Alternatively you could use a vacuum chamber.

2.7.4 Analysis

The phase of each of the two signals at the output of the coupler is,

$$q_i = 360 \cdot f \cdot t \qquad (3)$$

The phase at the output of signal path 1 is,

$$q_1 = 360 \cdot f \cdot (t - t_1) \qquad (4)$$

The phase at the output of signal path 2 is,

$$q_2 = 360 \cdot f \cdot (t - t_2) \qquad (5)$$

(5)

The difference in phase between the outputs of the two signal paths is,

$$q_d = -360 \cdot f \cdot (t_1 - t_2) \qquad (6)$$

(6)

If (τ_1-τ_2) is not zero, θ_d will change with frequency (f).
The derivative of (6) with respect to (f) is,

$$\frac{dq_d}{df} = -360(t_1 - t_2) \qquad (7)$$

Solving (7) for the difference in time delay as a function of frequency,

(8)

$$(t_1 - t_2) = -\frac{1}{360} \cdot \frac{dq_d}{df} \qquad (8)$$

The first step in the three step process is to find a calibration factor by measuring the difference in delay between Path 1 and Path 2 without the fiber under test as follows.

2.7.5 System Calibration

1. Connect the test system as shown in Fig. 1 without the fiber under test.
2. Set the synthesizer to the low end of the frequency range to be used.
3. Increase the frequency of the synthesizer in smaller steps than calculated from (9).
4. Record the total phase change that occurs over the frequency range.
5. Calculate the difference in delay from (8) and record it as (τ'_1-τ_2) where τ'_1 is the delay in Path 1 without the fiber under test.

To insure that no full cycles of phase are missed, each frequency step should be small enough to not result in a change in phase difference, $\Delta\theta$, exceeding 360 degrees as calculated from,

$$\Delta q_d = 360 \cdot t_{ne} \cdot (f_1 - f_2) \qquad (9)$$

(9)

where, τ_{ne} is the estimated nominal delay of the fiber under test,

f_1 is the low frequency end of the frequency step, and

f_2 is the high frequency end of the frequency step.

A good estimate of the delay, τ_{ne}, for an optical fiber is 5 ns per meter.

It is important to know the sign of the slope of the phase change versus frequency because it is subtracted from the results of the nominal delay measurement. To assure that the sign is correct use the following convention.

The reference probe "R" of the vector voltmeter must be connected as shown in Fig. 1. Also, the synthesizer frequency must start at the low end of the frequency range and be increased. Under these conditions if τ_1 is greater than τ_2 the slope will be negative. If τ_2 is greater than τ_1 the slope will be positive. If the reference probes on the vector voltmeter are reversed or the synthesizer frequency is changed from high to low the slope of (6) will be reversed.

Without the fiber under test, delays τ_1 and τ_2 should be as nearly identical as practical. With the fiber under test, τ_1 should always be longer than τ_2 and the slope of (4) should be negative.

The second step in the three step process is to determine the nominal delay of the fiber.

2.7.6 Preliminary Fiber Delay Measurement

1. Insert the fiber under test into the test system as shown in Fig. 1.
2. Set the synthesizer to the low end of the frequency range to be used.
3. Increase the frequency of the synthesizer in smaller steps than calculated from (9).
4. Record the total phase change that occurs over the frequency range.
5. Calculate the difference in delay (τ_1-τ_2) from (8).

2.7.7 Calculating the Nominal Delay of the Fiber Under Test

The nominal delay of the fiber under test is calculated from the delay measured in the system calibration measurement and the delay measured in the preliminary fiber delay measurement, and is,

$$t_n = (t_1 - t_2) - (t'_1 - t_2) \quad (10)$$

Now that we have calibrated the system and determined the nominal delay in the fiber under test we are ready to measure its TCD.

2.7.8 Measuring TCD

1. Leave the test setup as it was for the preliminary fiber delay measurement with the fiber under test installed.
2. Set the synthesizer to a frequency in the test range that results in a vector voltmeter reading of zero degrees.
3. Change the temperature of the test chamber in steps and record the difference phase for each temperature step.
4. Calculate the TCD for each temperature step using (2).

Although the size of the temperature steps are arbitrary, the authors usually change the temperature in steps of 5^{o}C. Each temperature step should be held until the phase, as read on the vector voltmeter, is stable. This may take more than 30 minutes.

2.7.9 Test Results

Figs. 2-4 show the TCD of several optical fibers as measured using this technique.

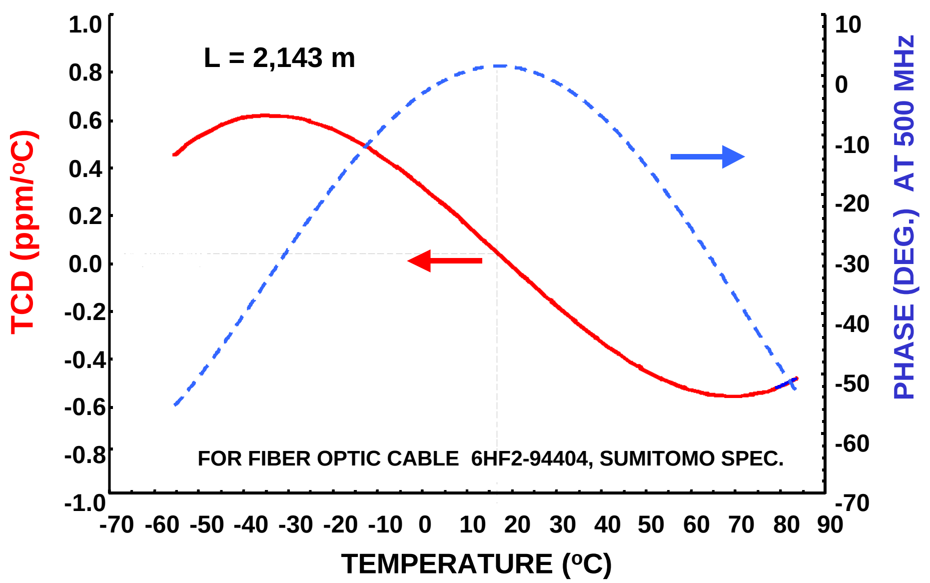
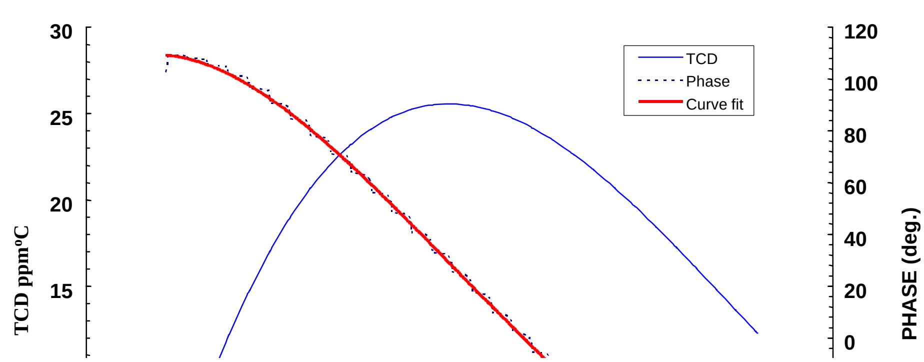


Fig. 2. The TCD and phase change of Sumitomo low thermal coefficient of delay optical fiber.



2.7.10 Conclusion

We have discussed why the TCD of cables is important in some applications.

We described in detail how to accurately measure the TCD of cables that have a very low TCD. Although the description of this measurement technique is focused on single-mode optical fiber and fiber optic cable, the technique is applicable to any transmission medium.

Measurement results are given for some cables designed for use in spacecraft applications. The TCD of one of these cables is < 1ppm/^{o}C over the temperature range of –60^{o}C to +80^{o}C.

3.0 Standards Related to Photonic Measurements

• EIA TIA-455-113	TP-113	larization-Mode Dispersion Measurement for Single-Mode Optical Fibers by the Fixed Analyzer Method
• EIA TIA-455-122	TP-122	larization-Mode Dispersion Measurement for Single-Mode Optical Fibers by Jones Matrix Eigenanalysis
• EIA TIA-455-127	TP-127	ectral characterization of multi-mode laser diode
• EIA TIA-455-170	TP-170	ble Cutoff Wavelength of Single-Mode Fiber by Transmitted Power
• EIA -455-171	TP-171	enuation by substitution measurement –for short –length multi-mode optical fiber cable assemblies
• EIA TIA-455-175A	TP-175	romatic Dispersion Measurement of Single-Mode Optical Fibers by the Differential Phase Shift Method
• EIA TIA-455-180	TP-180	easurement of the optical transfer coefficients of a passive branching device (coupler)
• EIA TIA-526		ndard test procedures for fiber optic systems
• EIA TIA-455-46A	TP-46	ectral attenuation measurement for long-length, graded-index optical fibers
• EIA TIA-455-50A	TP-50	ght launch conditions for long-length graded-index optical fiber spectral attenuation measurements
EIA TIA-455-53A	TP-53	enuation by Substitution Measurement for Multimode Graded-Index Optical Fibers or Fiber Assemblies Used in Long Length Communications Systems
• EIA TIA-455-54A	FOTP-54	Mode scrambler requirements for overfilled launching conditions to multi-mode fiber
• EIA TIA-455-57B	FOTP-57	Preparation and examination of optical fiber for testing purposes
• EIA TIA-455-59	FOTP-59	Measurement of fiber point defects using an OTDR
EIA TIA-455-60	FOTP-60	Measurement of Fiber or Cable Length Using an OTDR
• EIA TIA-455-61	FOTP-61	Measurement of fiber or cable attenuation using an OTDR
• EIA TIA-455-62A	FOTP-62	Measurement of optical fiber macrobend attenuation
• EIA TIA-455-77	FOTP-77	Procedures to qualify a higher-order mode filter for measurements on single-mode fiber
• EIA TIA-455-78A	FOTP-78	Spectral-Attenuation cutback measurement for single-mode optical fibers
• EIA TIA-455-80	FOTP-80	Measuring Cutoff Wavelength of Uncabled Single-Mode Fiber by Transmitted Power

• EIA TIA-455-107	FOTP-107	Return loss for fiber optic components
• EIA TIA-455-113	FOTP-113	Polarization-Mode Dispersion Measurement for Single-Mode Optical Fibers by the Fixed Analyzer Method
• EIA TIA-455-122	FOTP-122	Polarization-Mode Dispersion Measurement for Single-Mode Optical Fibers by Jones Matrix Eigenanalysis
• EIA TIA-455-127	FOTP-127	Spectral characterization of multi-mode laser diode
• EIA TIA-455-170	FOTP-170	Cable Cutoff Wavelength of Single-Mode Fiber by Transmitted Power
• EIA -455-171	FOTP-171	Attenuation by substitution measurement –for short –length multi-mode optical fiber cable assemblies
• EIA TIA-455-175A	FOTP-175	Chromatic Dispersion Measurement of Single-Mode Optical Fibers by the Differential Phase Shift Method
• EIA TIA-455-177A	FOTP-177	Numerical Aperture Measurement of Graded-Index Optical Fibers
• EIA TIA-455-180	FOTP-180	Measurement of the optical transfer coefficients of a passive branching device (coupler)
• EIA TIA-455-188	FOTP-188	Low temperature testing of fiber optic components
• EIA TIA-526		Standard test procedures for fiber optic systems

4.0 References

BS EN 167 Personal Eye Protection- Optical Test Methods

EIA 455-162 Fiber Optic Cable Temperature - Humidity Cycling

EIA 455-33A Fiber Optic cable Tensile Loading and Bending Test

EIA SP2824 Procedure for Measuring Tadiation Induced Attenuation in Optical Fibers and Optical Cables

EIA SP3401 Optical Fiber Cable Temperature-Humidity Cycling

EIA SP3455A Measurement of Optical Fiber Ribbon Dimensions

EIA/TIA 455-107 Return Loss for fiber Optic Components

EIA/TIA 455-3A Procedure to Measure Temperature Cycling Effects on Optical Fiber , Optical Cable, and Other Passive fiber Optic Components

EIA/TIA 455-42A Optical Crosstalk in Fiber Optic Components

EIA/TIA 455-62A Measurement of Optical Fiber Macrobend Attenuation

EIA/TIA 544-4B Fiber Optics Component Temperature Life Test

IEC 61315 Calibration of Fiber Optic Power Meters

ISO 10109-6 Optics and Optical Instruments - Environmental Requirements - Part 6 Test Requirements

ISO 10109-8 Optics and Optical Instruments - Environmental Requirements - Part 8 Test Requirements

ISO 11421 Optics and Optical Instruments- Accuracy of Optical Transfer Function (OTF) Measurement

ISO 12857-1 Optics and Optical Instruments - Geodetic Instruments - Field Procedures for Determining Accurately - Part 1: levels

ISO 12857-2 Optics and Optical Instruments - Geodetic Instruments - - Field Procedures for Determining Accurately - Part 2: Theodolites

ISO 7944 Optics and Optical Instruments - Reference Wavelengths

ISO 8721 Measurement Techniques in Impact Tests-Optical Instrumentation

ISO 9022-1 Optics and Optical Instruments - Environmental Test Methods - Part 1: Definitions, Extent of Testing

ISO 9022-11 Optics and Optical Instruments - Environmental Test Methods - Part 11: Mold growth

ISO 9022-12 Optics and Optical Instruments - Environmental Test Methods - Part 12: Contamination

ISO 922-14 Optics and Optical Instruments - Environmental Test Methods - Part14: Dew, Hoarfrost, Ice

ISO 9022-17 Optics and Optical Instruments - Environmental Test Methods - Part17: Combined Contamination, Solar Radiation

ISO 9022-2 Optics and Optical Instruments - Environmental Test Methods - Part 2: Cold, Heat, Humidity

ISO 9022-3 Optics and Optical Instruments - Environmental Test Methods - Part 3: Mechanical Stress

ISO 9022-4 Optics and Optical Instruments - Environmental Test Methods - Part 4: Salt Mist

ISO 9022-5 Optics and Optical Instruments - Environmental Test Methods - Part 5: Combined Cold, Low Air Pressure

ISO 9022-6 Optics and Optical Instruments - Environmental Test Methods - Part 6: Dust

ISO 9022-7 Optics and Optical Instruments - Environmental Test Methods - Part 7: Drip, Rain

ISO 9022-8 Optics and Optical Instruments - Environmental Test Methods - Part 8: High Pressure, Low Pressure, Immersion

ISO 9022-9 Optics and Optical Instruments - Environmental Test Methods - Part 9: Soar Radiation

ISO 9039 Optics and Optical Instruments - Quality Evaluation of Optical Systems - Determination of Distortion

ISO 9335 Optics and Optical Instruments - Optical Transfer Function - Principles and Procedures of Measurement

ISO/DIS 9022-20 Optics and Optical Instruments - Environmental Test Methods - Part 20: Humid Atmosphere Containing Sulfur Dioxide or Hydrogen Sulfide

ISO/DIS 9211-4 Optics and Optical Instruments - Optical Coatings - Part 4: Specific Test Methods

JIS K7105 Testing Methods for Optical Properties of Plastics

JIS Z8714 Retroreflectors - Optical Properties - Measuring Method

MIL DOD -STD-1678 Fiber Optics Test Methods and Instrumentation

TIA/EIA 455-11B Vibration test Procedure for Fiber Optic Components and Cables

TIA/EIA 455-2C Impact Test Measurements for Fiber Optic Devices

TIA/EIA 455-35A Fiber Optic Component Dust (Fine Sand) Test

TIA/EIA 455-4B Fiber Optics - Component Temperature Life Test

TIA/EIA 455-5B Humidity Test Procedure for Fiber Optic Components

TIA/EIA 455-64 Procedure for Measuring Radiation Induced Attenuation in Optical Fibers and Optical Cables

ASTM D5424-98 Standard test Method for Smoke Obscuration of Insulating Materials Contained in Electrical or Optical Fiber Cables when Burning in a Vertical Cable Tray Configuration

ASTM D5537-97 Standard Test Method for Heat Release, Flame Spread and Mass Loss Testing of Insulating Materials Contained in Electrical of Optical Fiber Cables when Burning in a Vertical Cable Tray Configuration

ASTM D6113-97 Standard test Method for Using a Calorimeter to Determine Fire-Test-Response Characteristics of Insulating Materials Contained in electrical or Optical Fiber Cables

ASTM E1614-94 Standard Guide for Procedure for Measuring Ionizing Radiation-Induced Attenuation in Silica-Based Optical Fibers and Cables for Use in Remote Fiber-Optic Spectroscopy and Broadband Systems

ASTM E1654-94 Standard guide of Measuring Ionizing Radiation -Induced Spectral Changes in Optical Fibers and Cables for Use in Remote Raman Fiber-Optics Spectroscopy

ASTM D5424-98 Standard Test Method for Smoke Obscuration of Insulating Materials Contained in electrical or Optical Fiber cables when Burning in a Vertical Cable Tray Configuration

ASTM D5537-97 Standard test Method for Heat Release, Flame Spread and Mass Loss testing of Insulating Materials Contained in Electrical or Optical Fiber Cables When Burning in a Vertical Cable Tray Configuration

EIA SP3538 Polarization Mode Dispersion Measurement for Single-Mode Optical Fibers by Interferometric Method

EIA/TIA 455-100A Gas Leakage Test for Gas-Blocked fiber Optic Cables

EIA/TIA 455-187 Engagement and Separation Force Measurement of Fiber Optic Connector Sets

EIA/TIA 455-190 Low Pressure (High Altitude) testing of Fiber Optic Components

EIA/TIA 455-30 Frequency Domain Measurement of Multimode Optical Fiber Information Transmission Capacity

EIA/TIA 455-51A Pulse Distortion Measurement of Multimode Glass Optical Fiber Information Transmission Capacity

EIA/TIA 455-55C End-View Methods for Measuring Coating and Buffer Geometry of Optical Fibers

EIA/TIA455-69A Test Procedure for Evaluating the Effect of Minimum and Maximum Exposure Temperatures on the Optical Performance of Optical Fibers

EIA/TIA 455-71 Procedure to Measure Temperature - Shock Effects on Fiber Optic Components

EIA/TIA 526-11 Measurement of Single-Reflection Power for Fiber Optic Terminal Equipment

TIA/EIA 455-132   FOTP-132 Measurement of the Effective Area of Single-Mode Optical Fiber

TIA/EIA 455-50B Light Launch Conditions for Long-Length Graded Index Optical Spectral Attenuation Measurements - FOTP 50

TIA/EIA 455-7 Numerical Aperture of Step-Index Multimode Optical Fibers by output Far-Field Radiation Pattern Measurement

TIA/EIA 455B Standard test Procedure for Fiber Optic Fibers, Cables, Transducers, Sensors, Terminating Devices, and Other Fiber Optic Components

UL 1666 Test for Flame Propagation Height of Electrical and Optical fiber Cables Installed Vertically in Shafts

UL 1685 Vertical-Tray Fire Propagation and Smoke-Release Test for Electrical and Optical Fiber Cables

UL 910 Test for Cable Flame-Propagation and Smoke-Density Values for Electrical and Optical Fiber Cables Used in Spaces Transporting Environmental Air

ASTM F524-77 (R1992) Tentative test Methods for Measurng Beam Divergence of Pulsed Lasers by the Apertured-Detector Technique

EIA/TIA 455A Standard Test Procedure for Fiber Optic Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and other Fiber Optic Components

EIA/TIA 455-6B FOTP -6 Cable Retention Test Procedure for Fiber Optic Cable Interconnecting Devices

EIA/TIA 455-20A FOTP-20 Measurement of Change in Optical Transmittance

EIA/TIA 455-25B FOTP-25 Repeated Impact testing of Fiber Optic Cables and Cable Assemblies

EIA/TIA 455-28B   FOTP-28 Method for Measuring Dynamic Tensile Strength of Optical Fiber

EIA/TIA 455-29A   FOTP-29 Refractive Index Profile, Transverse Interference Method

EIA/TIA 455-30B   FOTP-30 Frequency domain Measurement of Multimode Optical Fiber Information Transmission Capacity

EIA/TIA 455-31   FOTP-31 Proof Testing Optical Fibers by Tension

EIA/TIA 455-32A FOTP-32 Fiber Optic Circuit Discontinuities

EIA/TIA 455-34 FOTP-34 Interconnection Device Insertion Loss Test

EIA/TIA 455-37A FOTP-37 Low or High Temperature Bend Test for Fiber Optic Cable

EIA/TIA 455-41   FOTP-41   Compressive Loading resistance of Fiber Optic Cables

EIA/TIA 455-43   FOTP-43 Output Near-Field Radiation Pattern Measurement of Optical Waveguide Fibers

EIA/TIA 455-44B   FOTP-44   Refractive Index Profile, Refracted Ray Method

EIA/TIA 455-45B   FOTP-45 Method for Measuring Optical Fiber Geometry Using a Laboratory Microscope

EIA/TIA 455-46A   FTOp-46 Spectral Attenuation Measurement for Long-Length, Graded Index Optical Fiber

EIA/TIA 455-47B   FOTP-47 Output Far Field Radiation Pattern Measurement

EIA/TIA 455-53A FOTP-53 Attenuation by Substitution Measurement for Multimode Graded-Index Optical Fibers or Fiber Assemblies Used in Long Length Communication Systems

EIA/TIA 455-56B FOTP-56 Test Method for Evaluating Fungus Resistance of Optical Fiber and Cable

EIA/TIA 455-58A FOTP-58 Core Diameter Measurement of Graded-Index Optical Fibers

EIA/TIA 455-67 FOTP-67 Procedure for Assessing High Temperature Exposure of Optical Fibers

EIA/TIA 455-76 FOTP-76 Method for Measuring Dynamic Fatigue of Optical Fibers by Tension

EIA/TIA 455-81A FOTP-81 Compound Flow (Drip) Test for Filled Fiber Optic Cable

EIA/TIA 455-82B FOTP-82 Fluid Penetration Test for Fluid-Blocked Fiber Optic Cable

EIA/TIA 455-84B FOTP-84 Jacket Self-Adhesion (Blocking) Test for Fiber Optic Cable

EIA/TIA 455-93 FotP-93 Test Method for Optical Fiber Cladding Diameter and Noncircularity by Noncontacting Michelson Interferometry

EIA/TIA 455-106 FOTP-106 Procedure for Measuring the Near-Infrared Absorbance of Fiber Optic Coating Materials

EIA/TIA 455-119 FOTP-119 Coating Geometry Measurement for Optical Fiber by Grayscale Analysis

EIA/TIA 455-165A FOTP-165 Mode-Field Diameter Measurement by Near-Field Scanning Technique

EIA/TIA 455-176 FOTP-176 Method for Measuring Optical Fiber Cross-Sectional Geometry by Automated Grey-Scale Analysis

EIA/TIA 455-178A FOTP-178 Measurements of Strip Force for Mechanically Removing Coatings From Optical Fibers

ANSI/EIA 455-95-1986 Absolute Optical Power Test for Optical Fibers and Cables

ISO 9342:1996 Optics and Optical Instruments - Test Lenses for Calibration of Focimeters

ISO 13653:1996 Optics and Optical Instruments - General Optical Test Methods - Measurement of Relative Irradiance in the Image Field

ISO 10345-1:1992 Glass- Determination of Stress-Optical Coefficient - Part 1: Tensile Strength

ISO 10345-2:1992 Glass- Determination of Stress-Optical Coefficient Part 2: Bending Test

IEC 61290-2-3 Ed. 1.0 b:1998 Optical Fiber Amplifiers - Basic Specification - Part 2-3: Test Methods for Optical Power Parameters - Optical Power Meter

ISO 11551:1997 Optics and Optical Instruments - Laser and Laser-Related Equipment - Test Method for Absorptance of Optical Laser components

IEC 61290-2-1 Ed. .0 b:1998 Optical Fiber amplifiers - Basic Specification - Part 2-1: Test Methods for Optical Power Parameters - Optical spectrum Analyzer

ANSI/TIA/EIA 455-75A-1996 Fluid Immersion Test for Optical Waveguide Fiber

IEC 61290-1-1 Ed. 1.0 b:1998 Optical Fiber Amplifiers - Basic specification - Part 1-1: Test Methods for Gain Parameters - Optical Spectrum Analyzer
IEC 61290-6-1 Ed. 1.0 b:1998 Optical Fiber Amplifiers - Basic Specification - Part 6-1: Test Methods for Pump Leakage Parameters - Optical Demultiplexer

IEC 61290-2-2 Ed. 1.0 b:1998 Optical Fiber Amplifiers - Basic Specification - Part 2-2: Test Methods for Optical Power Parameters - Electrical Spectrum Analyzer

IEC 61290-7-1 Ed. 1.0 b:1998 Optical Fiber Amplifiers - Basic Specification - Part 7-1: Test Methods for Out-Of-Band Insertion Losses - Filtered Optical Power Meter

IEC 61280-1-1 Ed. 1.0 b:1998 Fiber Optic communication Subsystem Basic Test Procedures - Part 1-1:Test Procedures for General communication Subsystems - Transmitter Output Optical Power Measurement for Single-Mode Optical Fiber Cable

ANSI/EIA 455-36A-1987 Twist Test for Fiber Optic Connecting Devices

ANSI/EIA/TIA 455-87B-1993 Knot Test for Fiber Optic Cable

ANSI/EIA/TIA 455-85A-1992 Fiber Optic Cable Twist Test

ANSI/EIA 455-98-1983 External Fiber Optic Cable External Freezing Test

ANSI/TIA/EIA 455-2C-1998 Impact Test Measurements for Fiber Optic Devices

ANSI/TIA/EIA 455-39A-1989 Fiber Optic Cable Water Wicking Test

ANSI/TIA/EIA 455-14A-1992 Fiber Optic Shock Test (Specified Pulse)

ANSI/TIA/EIA 455-104A-1993 Fiber Optic Cable Cyclic Flexing Test

ANSI/TIA/EIA 455-91-1985 (R1996) Fiber Optic Cable Twist-Bend Test

ANSI/TIA/EIA 455-16A-1991 Salt Spray (Corrosion) Test for Fiber Optic Components

ANSI/TIA/EIA 455-A-1991 standard test Procedure for Fiber Optic Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and Other Fiber Optic Components

ANSI/TIA/EIA 455-184-1991 (R1995) Coupling Proof Overload Test, Fiber Optic Interconnecting Devices

ANSI/TIA/EIA 455-99-1983 (R1993) Gas Flame Test for Special Purpose Fiber Optic Cable

ANSI/TIA/EIA 455-21A-1988 Fibre Optics - Mating Durability for fiber Optic Interconnecting Devices

ANSI/TIA/EIA 455-1A-1988 Cable Flexing for Fiber Optic Interconnecting Devices