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Guidelines for Testing and Troubleshooting Fiber Optic Cable Systems

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1. Introduction

This document discusses two common measurement techniques that are used to test and measure optical fiber cable systems – Optical Time Domain Reflectometer (OTDR) and insertion loss measurements (power measurements). OTDR measurements are used to evaluate the performance of system components, e.g., fiber, splices, and connectors, as well as the overall system performance. Insertion loss measurements are used to provide a more accurate measurement of the end-to-end system attenuation.

OTDR measurements require access to only one end of the fiber optic system. The OTDR operates by launching a pulse of light into the fiber and measuring the backscattered and reflected light that returns to the internal detector of the OTDR. OTDR measurements can be used to evaluate the performance of discrete cables and splices and are often performed during pre-installation and construction as well as during final acceptance testing. Insertion loss measurements are performed using an optical source and power meter and require access to both ends of the optical system. In general, insertion loss measurements are used to measure the end-to-end system attenuation and are only performed during final acceptance testing. Both types of tests are required in order to completely and accurately characterize the performance of the optical fiber cable system. The tests are usually conducted at both 1310 nm and 1550 nm wavelengths; however, DWDM and CWDM systems may require measurements at additional wavelengths.

2. Test Methods

2.1 OTDR Measurements

The OTDR (Figure 1) operates by launching a pulse of light into the fiber and measuring the time it takes for backscattered and reflected light to return to the internal receiver. As the light pulse travels along the fiber, some of the light will strike molecular defects in the fiber and scatter in a spherical pattern (Rayleigh scattering). The part of the scattered light which travels back to the OTDR is called "backscatter" and is the basis for the OTDR fiber attenuation measurements.

In contrast, light is ***reflected*** back to the OTDR when the light pulse reaches a discontinuity in the refractive index, e.g., at a glass/air interface at the end of the fiber or at an air gap in a fiber splice or connector. Reflected energy is much higher in magnitude compared to backscattered light and therefore connectors, fiber ends, fiber breaks, etc. are easily identified by the OTDR.

The OTDR uses an internal timing circuit to convert the “time of flight” of the returned signal into fiber length. The OTDR graphically displays the returned power as a function of distance. Fiber attenuation is determined from the slope of the graph. Note that the slope is always negative because the magnitude of the return signal decreases with fiber length (the signal is attenuated). When the optical fiber is in good condition, the attenuation slope is uniform. However, a sudden change or discontinuity in the slope may indicate fiber degradation at that point, e.g., a fiber break or micro-bend. At a reflective feature, e.g., the end of the fiber, a connector, or a mechanical splice, the OTDR displays a reflective pulse that corresponds to the location of the event. The ability of the OTDR to identify and locate fiber discontinuities, splices, and connectors makes OTDR testing invaluable for system verification and maintenance activities.

OTDR testing has several advantages over the insertion loss method. One significant advantage is that the OTDR measurement is conducted from one end of the fiber and requires only one operator. Another advantage is that the OTDR can be used to evaluate individual splices, connectors, and fiber sections. By comparing periodic measurements to the "as-built" traces, the periodic measurements can be used to detect splice or cable degradation. However, in spite of these advantages, OTDR measurements do have limitations. One limitation arises from the fact that reflected light is several orders of magnitude higher than the backscattered light. When the OTDR receives reflected light, the internal circuitry of the OTDR becomes saturated and it takes a finite period of time for the OTDR to recover. During this time, backscattered light is masked by the reflected signal and the fiber attenuation cannot be measured. Likewise, a second closely spaced connector may not be seen if it falls within the reflection of the first connector.

OTDR "dead zones" refer to the length of fiber immediately adjacent to the OTDR that cannot be seen because of the large reflection that occurs at the bulkhead connector. Dead zones may also occur at mechanical splices and connectors. Among other things, the length of the dead zone is dependent on the pulse width. A long pulse width results in a long dead zone; consequently, spatial resolution can be improved by using a short pulse rate. The better the spatial resolution, the more effective the OTDR is in measuring closely spaced connectors and splices. For a given dynamic range setting, it is usually best to select the longest pulse width that will provide the required spatial resolution. In some cases, multiple measurements are required to get both the spatial resolution and dynamic range that are required to analyze the optical fiber system.

Figure 1 – Optical Time Domain Reflectometer

Another disadvantage of the OTDR is a measurement error known as "splice gain". Splice gain arises when two adjacent fibers have different backscatter coefficients. When the two fibers are spliced together, the magnitude of the backscattered light will differ in the two fibers. If the amount of backscattered light in the first fiber is less than the backscattered light in the second fiber, the OTDR displays the difference as an apparent increase in power. If the apparent increase in power is greater than the attenuation of the splice, the splice loss appears to be negative (the power increases) and the OTDR displays an apparent splice gain. If this same splice is measured in the opposite direction, the OTDR displays an exaggerated splice loss.

The amount of splice gain measured in one direction is equal and opposite to the exaggerated splice loss measured in the other direction. The actual splice loss is determined from the average of two OTDR measurements taken in opposite directions (bi-directional measurements). Further information regarding bi-directional splice loss measurements is available in EIA/TIA FOTP-61, "Measurement of Fiber or Cable Attenuation Using an OTDR".

2.2 Insertion Loss Measurement

The insertion loss measurement is also called "Attenuation by Substitution Method" and is described in EIA/TIA 455-171, "Attenuation by Substitution Measurement for Short Length Multimode Graded Index and Singlemode Optical Fiber Cable Assemblies". The equipment required to perform this test includes a stabilized light source (typically a laser), an optical power meter or receiver, and various jumpers used to emulate and access the fiber cable system (Figure 2). Unlike OTDR measurements, insertion loss measurements include the attenuation of the end connectors and therefore provide a more accurate measurement of the end-to-end system attenuation.

Figure 2 - Optical Power Meter & Light Source

Insertion loss measurements are performed by first measuring the output power of the light source. This measurement includes two or three jumpers and is used as a reference value of the optical power. Next, one of the jumpers is removed from the test set and replaced by the fiber system under test. Optical power is transmitted through the system and measured at the receiver end. The received power is compared to the reference power to determine the attenuation of the optical system.

3. Field Tests

3.1 Pre-Installation Tests

OTDR measurements are often performed on fiber optic cables prior to network deployment. Typically, these “acceptance tests” are performed by the cable operator to assure that no cable damage has occurred during transit and that the cable is performing as specified. During the acceptance tests, the OTDR technician should verify fiber continuity, length, attenuation, and review the traces for fiber anomalies. The test data should be recorded electronically for future reference. Since the cables are not spliced, bi-directional testing is not required.

Most fiber optic cable systems are intended for dual (or multiple) wavelength operation. If required, the cables should be tested at all wavelengths that will be used in the optical system. However, optical fibers are more sensitive to micro-bending induced attenuation at long wavelengths. If the fibers will only be tested at one wavelength, it is recommended that they be tested at 1550 nm.

It is the operator's choice to perform pre-installation testing and will depend on their level of confidence with the cable manufacture, shipper, and installation contractor. Sometimes the acceptance tests are conducted jointly by the cable operator and the installation contractor. This cooperation may preclude later difficulties in the event a cable is damaged during installation. In lieu of 100% testing, random fiber testing is sometimes performed to reduce the time and expense of the acceptance tests. However, random fiber testing does not guarantee 100% compliance. If no fiber testing is performed, at a minimum, the reels should be thoroughly inspected for shipping damage.

3.2 Installation/Splicing

OTDR measurements are sometimes performed during the construction phase to verify fiber and splice attenuation. The choice of conducting measurements during construction may depend on the complexity of the network, availability of technicians, and contractual requirements.

Most fusion splice machines provide an estimated splice loss based on the geometric alignment of the two fibers. In general, the estimated splice loss is fairly accurate and sufficient for use during the construction phase. However, it is important to note that the actual splice loss must be measured using bi-directional OTDR measurements. Both estimated and measured splice loss values should be recorded for comparison to final end-to-end measurements.

3.3 Post-Installation/Final Acceptance

Final end-to-end measurements should be made after all splicing is complete and all connectors have been installed. Final acceptance testing should consist of OTDR measurements on all fibers at all required wavelengths. The OTDR traces are invaluable for future maintenance, trouble shooting, and fault locating activities in the outside plant cable. If feasible, fibers should be tested before optical splitters have been spliced into the system. Additionally, an insertion loss test should be performed to ensure that the actual end-to-end attenuation is within spec. By performing both the OTDR and insertion loss tests, the operator is assured of having all the necessary data required to characterize the optical fiber system.

Measured results should be compared to design values to assure that the system is operating within specifications. The end-to-end design attenuation is obtained by summing the specified cable loss, splice loss, connector loss, jumper loss, and splitter loss (if applicable). It is not unusual to see variation between the measured and design attenuation values. These variations may be due to differences between actual and specified cable loss, and variability in splice and connector loss. Large or unusual variations between the actual and specified attenuation should be investigated to ensure there are no potential problems with the cable plant.

In general, it is more time efficient to measure all fibers in the span before troubleshooting any abnormal results. Typically, all fibers in a given span should have similar attenuation results. If a particular fiber differs significantly from the average span attenuation, this may be an indication of a potential problem which should be identified and corrected. All component losses (splices, connectors, and fiber) should be verified to be within specifications before the "abnormal" span attenuation is accepted.

3.4 Periodic System Testing

Periodic attenuation measurements of the cable system may provide early warning of system degradation and indicate a need for cable repair and/or maintenance activities. The objective of the periodic measurements is to locate and repair potential problems before they cause system failure. Typically one or more fibers in the cable system are dedicated to the periodic measurements. The measurements can be taken using either an OTDR or optical attenuation test set.

4. Documentation

The minimum documentation required for a fiber optic cable system should include the following.

1. As-built drawings showing cable and splice locations, cable lengths, fiber counts, sheath markings, etc.
2. Fiber attenuation
3. Splice loss
4. Connector loss
5. End-to-end OTDR traces
6. End-to-end insertion loss measurements
7. Equipment power levels (transmit and receive)

This documentation is required for cable maintenance, troubleshooting, and emergency restoration procedures. The documentation should be readily available to maintenance technicians so that they can quickly identify, locate, and repair any problems that may occur in the cable plant.

5. Troubleshooting Guide for Fiber Optic Cable Systems

The intent of this guide is to locate faults in a fiber optic cable system and provide a systematic approach to the resolution of the trouble. In general, cable system faults can be grouped in the following categories.

- Bad fiber splice
- Fiber macro-bend
- Bad connector or sleeve

- Loosely coupled or dirty connector
- Defective fiber jumper
- Small-radius cable bend
- Cable damage
- Extreme environment conditions
- Cable defect

The most effective troubleshooting tool is a high resolution OTDR. Unfortunately, many of the potential faults can cause similar indications on an OTDR trace. Therefore, a systemic technique must be used to identify the fault from the many possibilities listed above. Understanding the proper use of an OTDR is assumed in this guide. In cases where the system is too short to test with an OTDR, optical power meters and visible light sources, e.g., HeNe lasers, can be used to help isolate the fault.

5.1 General Guidelines and Precautions

1. The wavelength of light used in optical cable systems is outside the visible spectrum and cannot be detected by the human eye. Use caution when examining optical connectors by eye or with magnifying scopes. Always confirm that optical power is not being transmitted on the fiber. Serious eye damage can result from exposure to optical laser sources.

2. Fiber optic connectors and interconnect sleeves are sensitive. Never force connectors into position. Threaded connectors should be tightened until they are just snug or finger tight. Do not over tighten. Connectors should be cleaned thoroughly with alcohol prior to insertion into equipment or interconnect sleeves.

3. Be familiar with the various types of optical connectors and their general performance characteristics. Specifically, SMA and Biconic connectors may have to be un-mated and re-mated several times before satisfactory attenuation results are obtained. In general, the attenuation of these connectors is significantly higher than most modern connector types.

4. Ensure that keyed connectors (SC, FC, D4, ST) are properly aligned in the key slots of the interconnect sleeve prior to insertion.

5. When using SMA 906 connectors, ensure that one red alignment sleeve is installed on one SMA 906 prior to mating two SMA 906 connectors together in the interconnect sleeves. Ensure that threaded SMA 905 sleeves are used in SMA 905 applications, and that SMA 906 interconnect sleeves are used in SMA 906 applications.

6. Be sure to set the correct index of refraction on the OTDR.

7. Use an appropriate pulse width and range scale on the OTDR. In general, choose the longest pulse width that still allows spatial resolution of known system features e.g., splice and/or connector locations. As a starting point, set the range scale to about twice the distance to the point of interest. Longer or shorter pulse widths may have to be used depending on the system features.

8. Use a launch fiber that is longer than the OTDR dead zone so that nearby features are not obscured by the bulkhead reflection. If feasible, e.g., for non-connectorized systems, temporarily fusion splice the launch fiber to the fiber under test.

9. When using an OTDR to determine the distance to a fault, expand the horizontal and vertical scales to improve the accuracy of distance measurements. Normally a vertical scale of 1.0 dB/div and horizontal scale of 10 m/div is sufficient for accurate distance measurements.

10. Be sure to account for excess fiber length in the cable when determining the location of an optical fault. The excess fiber length is also known as the helix factor and is expressed as the ratio of measured fiber length divided by the physical sheath length. Depending on the cable design, the helix factor may vary from 1.00 to about 1.05. In other words, the excess fiber length may exceed the sheath length by about 5%. Failure to consider the helix factor when determining the location of fiber damage may lead to large errors in the physical location of the optical fault.

11. To accurately determine the location of an optical fault, perform the following steps using an OTDR.

    a) Ensure the correct index of refraction is set on the OTDR.

b) Accurately measure the length of the launch fiber.

c) Accurately measure the distance to the fault (including the launch fiber).

d) Subtract b from c above.

e) Carefully estimate the length of fiber enclosed in fiber optic hardware (if present) and contained in the cable sheath until the first legible sheath mark is found. Subtract this length from d above.

f) Divide the length obtained in e by the helix factor of the cable. The result is the sheath distance from the nearest legible sheath marking to the optical fault.

12. Fiber attenuation can be caused by small-radius bends in the fiber, buffer tubes, and cable. Some of the common minimum bend-radius requirements are summarized below.

a) The minimum bend-radius for single-mode and multi-mode fiber is 25 mm.

c) The minimum bend-radius for 3.0 mm or smaller buffer tubes or transport tubes is 30 mm.

d) In general, the minimum bend-radius for loose tube cables is 10 × OD for no-load conditions and 15 × OD during installation. For ribbon-in-loose-tube cables, the minimum bend radius is 15 × OD for both no-load and installation conditions. For central tube cables containing up to 216 fibers, the minimum bend radius is 10 × OD for no-load conditions and 20 × OD during installation. For central tube cables containing more than 216 fibers, the minimum bend radius is 15 × OD for no-load conditions and 20 × OD during installation. Larger bend radius requirements may apply for cable storage-coil applications. Please contact OFS Customer Support at 888-FIBER-HELP (888-342-3743) for further information regarding you specific cable design.

5.2 TROUBLESHOOTING CHECKLIST

Begin the trouble shooting checklist at one end of the optical cable system. If no problems are apparent, go to the other end and repeat the checklist. If active system traffic was lost, check the alarms on the electronic equipment. Troubleshoot the electronic equipment as required.

STEP 1: Set up an OTDR and appropriate launch fiber at one end of the system. Select a short or medium pulse width and examine the connectors, jumpers, vault splice, etc. at the near end of the system. If high attenuation is present at the near end of the system, perform the following until the problem is corrected.

a) Remove and clean both connectors mated in the patch panel interconnect sleeve. Ensure connectors are properly inserted and/or tightened in the interconnect sleeves.

b) Examine the connector end faces using a magnifying scope. Cracks, pits, fissures, or chips may cause high loss. Replace the connector or the connector assembly as required.

c) Test the connector pairs using a separate interconnect sleeve that is known to be good. Clean and/or replace bad sleeves.

d) Check the pigtail and vault splices (if applicable). Re-splice if necessary.

e) Check the splice trays and hardware for small-radius bends or pinch points in the fiber. Light will escape the fiber at pinch points, partial breaks, and small radius bends; therefore, use a visible light source, e.g., a HeNe laser, during this step to help locate fiber faults.

f) Check the fiber shelves and apparatus for small-radius bends in cable sub-units (e.g., buffer tubes, core tubes, or fiber ribbons). When in doubt, straighten them out.

g) In applications where tight-buffered products are used, examine the cables for excessively tight cable ties. When in doubt, remove all cable ties and re-check the attenuation.

h) Inspect the building cables for damage. Inspect floor and wall penetrations for possible crushing forces on cables.

i) Remove all near-end connectors from the measurement by measuring the fiber from a pigtail or vault splice. This step will require cutting the fiber at the existing splice and connecting the launch fiber at that point to re-measure the fiber. If the outside plant fiber is confirmed to be OK, replace the connector or connectorized assembly. Re-splice the cut fiber and re-test from the end of the system.

STEP 2: Perform the following steps if the source of high attenuation is located in the outside plant cable.

a) Determine the sheath sequential where the attenuation is located. Go to that sheath sequential location and carefully examine the cable for sheath damage and/or small-radius bends. Common locations and causes of cable damage include road bores, directional drilling activities, setting poles and anchors, adjacent road or utility construction, gunshot damage, and rodent damage.

NOTE: High attenuation dispersed along the length of the cable can be an indication of installation damage, extreme environmental conditions, or cable defects. Please contact OFS Customer Support at 888-FIBER-HELP (888-342-3743) for assistance in these cases.

b) If the cable damage cannot be found, go to the splice point nearest the fault and re-test the fiber. Locating the damage from the nearest splice point will minimize measurement errors and provide a more accurate location of the fault. Calculate the exact sheath sequential of the fault location. Go to this sheath mark and carefully examine the cable for sheath damage or small radius bends.

c) If the high attenuation is at a splice point, perform the following steps.

1. Check the slack storage near the splice point for small-radius cable bends. When in doubt, straighten the cable bends and re-measure the fiber. If small-radius bends are the cause of attenuation, reconfigure the cable slack taking care to prevent bends smaller than the minimum recommended bend-radius.

2. Open the splice closure and examine the internal assembly for small-radius bends in buffer tubes and/or transport tubes.

3. Open the splice trays and examine the fiber for small-radius bends, pinch points, and fiber breaks.

4. Re-splice the fiber(s) exhibiting high loss.

5. If a high loss still exists, measure the fiber in both directions to determine which cable contains the fault. Fiber breaks sometimes occur when tubes are momentarily kinked and then straightened during closure preparation. If the broken fiber cannot be salvaged, then rebuild the entire splice closure.

d) If no sheath damage can be found, contact OFS Customer Support at 888-FIBER-HELP (888-342-3743) for assistance.

STEP 3: If no problems can be found from patch panel to patch panel, use power meters and HeNe lasers to check the performance of fiber jumpers used between the electronic equipment and patch panels.

a) Make sure all connectors and interconnect sleeves are clean prior to testing. Discard jumpers with high attenuation or replace bad connectors.

b) HeNe lasers can be used to help locate bad connectors. Light will usually escape from damaged connectors causing the connector to glow bright red.

c) Note that different colors of fiber coatings and buffer materials can greatly affect the ability of the HeNe laser light to escape through the coating. For example, orange and white coatings may allow some leakage even though little or no attenuation is present. Green and blue coatings may totally block the light in the presence of high attenuation. If unsure, an optical power meter should be used to determine the condition of the fiber jumpers.

If you have any questions or require additional information, please contact OFS Customer Support at 888-FIBER-

HELP (888-342-3743) for assistance.