FIELD TESTING OF FIBER OPTIC CABLE SYSTEMS

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Abstract

Cable operators need to perform certain field tests on their passive fiber optic cable systems in order to provide for the long term operation and maintenance of those cable systems. This paper will discuss the field testing required to properly characterize the optical condition of that plant so as to ensure the reliability of day to day operations. This paper discusses the relevancy and interrelationship of the data obtained from each of these different field tests normally conducted before, during, and after the installation of the passive fiber optic cable system.

INTRODUCTION

The process used to manufacture optical waveguides and subsequently to cable those fibers into a robust product suitable for installation in some of the harshest environments, is incredibly complex, technically sophisticated, and necessarily requires the strictest quality controls for both manufacturing and testing. The fiber optic cable that arrives at your warehouse door has been thoroughly tested and re-tested both as individual material components and as an assembled product. These rigorous testing procedures, now becoming standard for all fiber cable, ensure that the cable you are receiving meets the very highest standards established by regulatory bodies.

Nevertheless, the day that the finished cable product arrives on the operator's loading dock is the time to begin field testing in order to continue maintaining these high standards of quality and to ensure the technical excellence of the finished product -- the passive fiber optic cable system. See Figures 1 and 2. The largest investment of most operators is in their passive fiber transmission system. The amount of technical, logistical, and financial resources required to build the passive cable plant, mandate that extraordinary care be taken to verify the quality of the finished transmission system. Field testing by the operator or his contractor will provide verification of compliance with certain specifications required contractually of the manufacturer and contractor.

Fiber Optic Transmission System

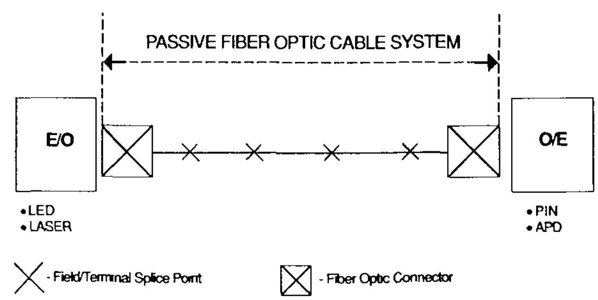


Figure 1

Typical End Termination Detail
Not To Scale

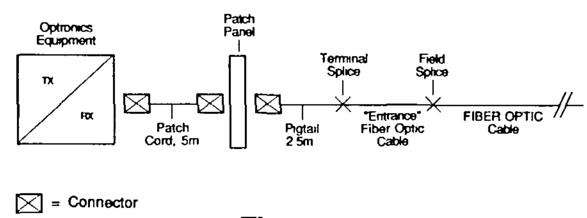


Figure 2

Reels should be unloaded in accordance with the manufacturer's recommendation. Normally, this means keeping the reel upright. Any lifting or movement of the reel should be done using appropriate materials handling equipment designed to handle the large reels typical of fiber cable. Any rotation of the reel should be done as recommended by the manufacturer. Most manufacturers place an arrow on the reel showing direction of rotation. The first field test to be done by the operator is simply a visual inspection of the reel to ensure that no obvious physical damage has occurred during shipment.

GENERAL

The operator is now ready to begin optical field testing of the fiber cable. Testing can be divided into three phases. They are as follows:

1. Pre-Installation
2. Installation/Splicing
3. Post-Installation/Final Acceptance

Optical characteristics that can be measured in the field include attenuation and dispersion. Dispersion characteristics are very closely controlled during the manufacturing of the optical waveguide and the test equipment is extremely expensive; therefore, dispersion tests are rarely performed and generally not required in the field.

Two methods of measuring attenuation employed in the field are the back scattering and two-point methods. More common terms sometimes used to describe these methods are an Optical Time Domain Reflectometer (OTDR) test and the Insertion/Cutback Loss test, respectively. Additionally, the two-point method is often referred to as an Optical Power Test. Both types of tests are required in order to completely and accurately characterize the overall optical condition of a fiber cable system.

Depending on cable and system specifications these tests may be done at both the 1300 and 1550 nanometer wavelengths as well as from both directions. Normally, the Optical Power Test is only performed as part of the Final Acceptance Testing. These test methods provide data which is complementary but may vary slightly as a result of equipment, technique, and skill of the technician performing the test. The key to successful characterization of the fiber cable plant is following correct procedures consistently. This will improve the correlation between measured and calculated optical losses.

TEST METHODS

Backscattering Method

The first and most common method used is the backscattering method. This test is performed using an Optical Time Domain Reflectometer (OTDR). The OTDR is primarily used for locating faults, discontinuities, and anomalies, and general attenuation checks. The OTDR measures distance and loss in an optical fiber by transmitting an optical pulse through the fiber and measuring the optical power reflected back to a sensor in the OTDR instrument. A block diagram of an OTDR is shown in Figure 3.

The OTDR calculates distance along a fiber by measuring the interval between the pulse's launch and the time the reflected energy is detected at the sensor. Loss is calculated by comparing the received power to the transmitted power. As the pulse moves along the fiber, thousands of data points corresponding to distance and relative power are gathered and displayed on the CRT. The result is a linear trace of the fiber displayed as distance from the source (horizontal axis) versus relative power (vertical axis).

The power reflected back from the fiber is caused mainly by Rayleigh scattering. This occurs when light traveling in a fiber strikes a non-uniform part of the core's molecular structure, or a non-silicon dioxide particle and is scattered in a spherical pattern. The part of the scattered energy which travels back towards the optical source is called the "backscatter" and is the basis for the OTDR measurements. Every fiber has a unique "backscatter coefficient." This is a measure of how well optical energy is reflected back to the source. The backscatter coefficient depends on the fiber's relative refractive index difference (the difference between the indices in core and cladding), the core refractive index, and the core diameter.

General attenuation checks include cable reel acceptance, splice loss verification, and final end-to-end measurements. Signature traces should be made of all fibers after connectors are installed, depicting the entire cable route. See Figure 4. These traces will be invaluable should trouble develop on the passive cable plant. Most important, the OTDR is essential for fault locating in the outside plant cable.

OTDR PRINCIPLES & TERMINOLOGY

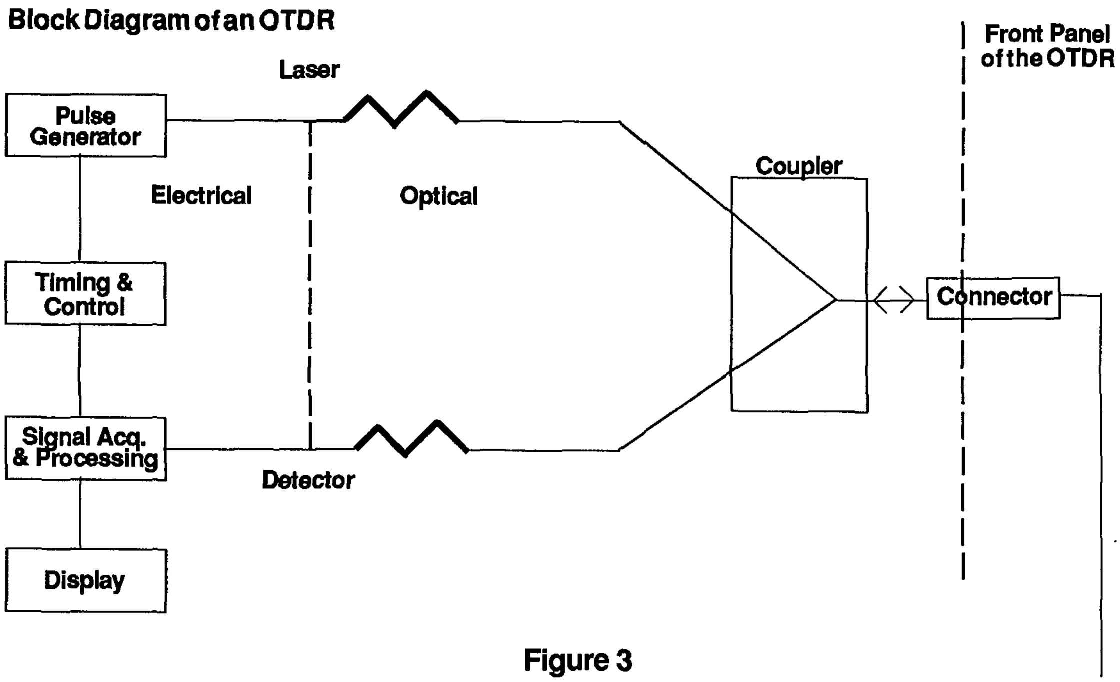


Figure 3

The OTDR has several significant advantages over other test methods. It is an extremely versatile instrument that can be operated by the technician with a minimal amount of training. It is the optical device normally used to locate fiber discontinuities in the cable plant. Through periodic comparison with the initial signature traces, the OTDR may provide early warning of a potential catastrophic failure by indicating points of stress in the cable. When the end configuration depicted in Figure 2 is used, the OTDR can be readily used to access the fiber system through the connnectors.

Although the OTDR is a very accurate and important test instrument, several inherent factors make the OTDR the least accurate of the attenuation methods that may be employed in the field. For very precise attenuation measurements, the cut-back or insertion loss method should be used.

Typical OTDR End-To-End Trace (Courtesy of ANRITSU)

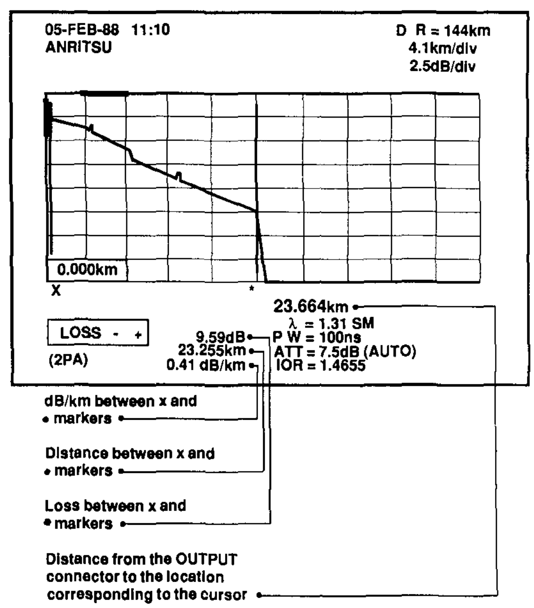


Figure 4

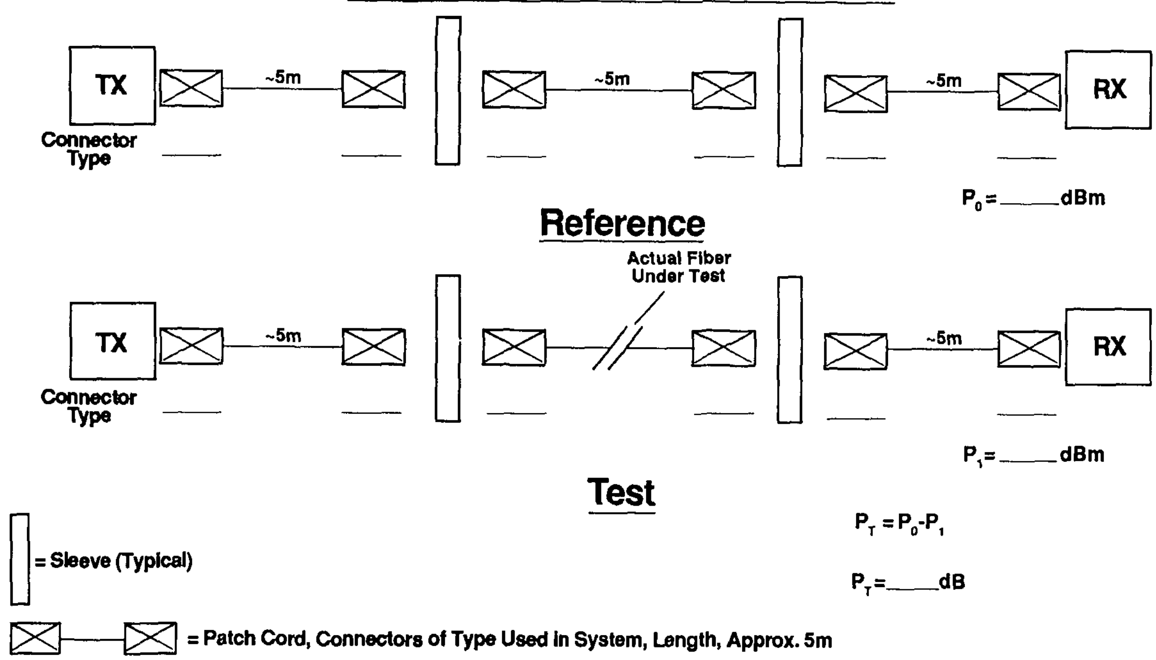
Cut-Back or Insertion Loss Method

By definition, the cut-back method is a destructive test and is not normally used for a fully concatenated fiber optic cable syste. It is not commonly seen in the field, but because of its accuracy and precision, it is often specified and used in cable manufacturing for acceptance test. Since this test is seldom used in the field, it will not be discussed in this paper. For additional information the reader is invited to see EIA Standard, EIA-455-78, Spectral Attenuation Cutback Measurement for Single Mode Optical Fibers.

The insertion loss test method is very similar to the cut-back method. It is also called the Attenuation by Substitution Method. This test method is defined in EIA Standard, EIA-455-171, Attenuation by Substitution Measurement -- for Short-Length Multimode Graded-Index and Single-Mode Optical Fiber Cable Assemblies. The equipment required to perform this test will include a stabilized light source, normally a laser, an optical power meter or receiver, and various patchcords or jumpers used to emulate and to access the fiber cable system.

With this method the first step is to establish a "reference"value to characterize the transmitter, receiver, and connector assemblies. This consists of inserting a short reference cable between the transmitter and receiver of the attenuation measuring (optical power meter test) set and in measuring the transmitter output power P_0 coupled into the fiber/jumper assembly. In the second step the reference cable is replaced by the cable link to be measured and (inserted) attenuation is obtained by comparing the level available at the output side of the cable link P_1 with the reference level P_0. Figure 5 is a depiction of an Insertion Loss Test.

Typical Insertion Loss Test - Field



EQUIPMENT DATA	TRANSMITTER (TX)	RECEIVER (RX)
Manufacturer		
Serial Number		
Type		
Wavelength		N/A
Output Power		N/A

Figure 5

This method has the advantage in that it is simple to perform and it can be used for fully connectorized/concatenated cables. This method has one disadvantage advantage in that the varying coupling conditions on the transmitter or receiver side may cause the reference level to deviate from the level coupled into the cable link resulting in minor measuring errors.

FIELD TESTING

Pre-Installation Field Testing

Pre-installation field testing consists of cable acceptance from the manufacturer by the operator. The operator conducts this test with an OTDR. The objective of pre-installation is to assure the operator that no damage has occurred during the transit from the manufacturer to the end-user's dock. The technician should be verifying optical length, attenuation, anomalies, and continuity. This data should be recorded either electronically or with a chart recorder. The majority of cables now being specified are for dual wavelength operation. Because of the sensitivity of fiber to attenuation related difficulties at the 1550 nm wavelength, it is recommended that this pre-installation test be conducted at that wavelength assuming an OTDR with that wavelength is available.

All fibers must be checked in order for this test to be effective! Random testing can result in less than desirable assurances of delivered product. This is a result of one of the innovative and very positive features of most fiber cable designs. These designs will allow damage to occur to fibers within the cable in a random and unpredictable manner. This means that it is possible to have an incident such as an air driven nail inadvertently driven into a cable during the lagging process that may damage only a few fibers in a multiple count fiber cable. At this point, our good friend Murphy steps in and the technician is guaranteed not to select the damaged fiber in his random checks. It is only after that particular 30,000 foot reel is installed in a very troublesome area that the broken fiber is discovered and at the very least a splice is added or worse, a reel of cable is replaced. Therefore, if pre-installation tests are conducted, then it is recommended that *all* fibers be tested.

This pre-installation check can provide assurances to the operator and to his construction group as to the quality of the fiber cable prior to installation. Many times these checks are conducted jointly by the contractor and the owner. This cooperation may preclude difficulties later should a cable be damaged during the construction operation.

Installation/Splicing

Installation or splicing field tests can be categorized into five main categories. They are as follows:

1. Optical Time Domain Reflectometer (OTDR)
2. Optical Power Monitoring
3. Local Injection Detection (LID)
4. Profile Alignment Systems (PAS)
5. Some Combination of the Above

There are several advantages and disadvantages to each of the five approaches. Detailed papers are available for each of the techniques that the operator may use. The major points to consider are availability of skilled technicians, equipment, and the logistics of communications during the splicing operation. In all cases the resulting splice loss should be recorded so that this value can be used when calculating the expected system loss. See Figure 6.

Typical OTDR Splice Loss Measurement (Courtesy of ANRITSU)

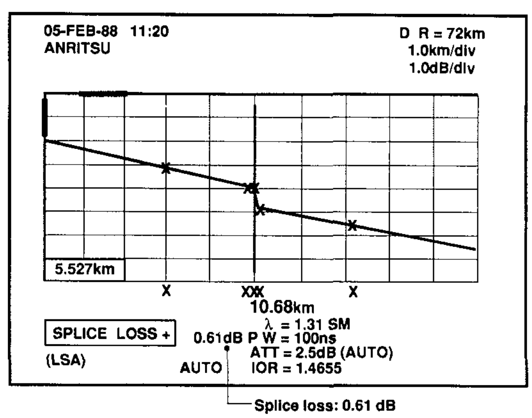


Figure 6

Post-Installation/Final Acceptance

Post Installation and Final Acceptance testing should consist of end-to-end OTDR test made from both directions at both 1300 and 1550 nm wavelengths. Additionally, an Optical Power Test using the Insertion Loss Method should be done at both wavelengths from both directions, if connectors are used. By performing these tests, the operator is assured of having all the necessary data required to characterize the passive optical system.

DOCUMENTATION

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

1. As Built Drawings
2. Splice Loss
3. End-to-End Optical Loss Measurements
4. End-to-End OTDR Signature Traces

The purpose of this data is to provide historical references for maintenance and emergency restoration. By maintaining this data, the operator is assured that he will be able to quickly respond, identify, locate, and repair, any problem that may occur within his passive cable plant. Examples of a Splice Log, End-to-End Loss Measurement, and Summary of Field Data-Attenuation Loss, are included as Examples 1, 2, and 3.

RESULTS

Analysis and Correlation of Test Results

The data that has been acquired during the field testing of the fiber cable is then analyzed. This measured field data is compared to that data that was obtained by summing cable loss, splice loss, and pigtail splice loss. See Figure 7 and Sample 3. It is not unusual to see variations on the order of ±5% between the results calculated or measured

Calculated Cable Loss

PROJECT:	ANYTOWN, USA							DATE.	2-Oct-89	
SPAN:	SOUTHPORT HEADEND TO NODE AT ELM STREET							TECHNICIANS:		
OPTICAL LENGTH	18,579									
SHEATH LENGTH:	18,616									
WAVELENGTH:	1300 NM									
FIBER NUMBER LOCATION LENGTH (KM)	END SPLICE HEADEND SOUTHPORT	CABLE LOSS #890108 3.295	SPLICE LOSS MAIN STREET SP #1	CABLE LOSS #890206 5.569	SPLICE LOSS OAK STREET SP#2	CABLE LOSS #890207 4.351	SPLICE LOSS HWY 428 SP#3	CABLE LOSS #890308 5.364	END SPLICE NODE AT ELM STREET	CONCATENATED SUMMARY LOSS (dB)
1	0.08	1.02	0.05	1.73	0.14	1.48	0.03	1.88	0.08	6.48
2	0.08	1.25	0.04	1.95	0.12	1.57	0.02	1.72	0.08	6.82
3	0.08	1.12	0.07	1.89	0.05	1.52	0.11	1.66	0.08	6.59
4	0.08	1.29	0.11	2.17	0.06	1.74	0.12	1.88	0.08	7.52
5	0.08	1.05	0.14	1.73	0.03	1.35	0.11	2.09	0.08	6.66
6	0.08	1.32	0.06	1.89	0.09	1.48	0.05	2.04	0.08	7.08
7	0.08	1.19	0.00	2.12	0.08	1.61	0.04	1.82	0.08	7.01
8	0.08	1.22	0.12	2.00	0.14	1.57	0.09	1.88	0.08	7.17
AVERAGE SPLICE LOSS (dB):		0.08								
AVERAGE TOTAL LOSS (dB):		6.92								
CABLE #890108		CABLE #890206		CABLE #890207		CABLE #890308				
FIBER NUMBER	LOSS db/km	FIBER NUMBER	LOSS db/km	FIBER NUMBER	LOSS db/km	FIBER NUMBER	LOSS db/km			
1	0.31	1	0.31	1	0.34	1	0.35			
2	0.38	2	0.35	2	0.36	2	0.32			
3	0.34	3	0.34	3	0.35	3	0.31			
4	0.39	4	0.39	4	0.40	4	0.35			
5	0.32	5	0.31	5	0.31	5	0.39			
6	0.40	6	0.34	6	0.34	6	0.38			
7	0.36	7	0.38	7	0.37	7	0.34			
8	0.37	8	0.36	8	0.36	8	0.35			

Figure 7

from these multiple tests. Values outside of these ranges should be investigated. These differences can be caused by any or all of the following:

1. Optical Loss Calculation Methods
2. Physical Layout of Pigtails in Fiber Distribution Panels
3. Testing Procedures
4. Cleaning Procedures
5. Condition of Optical Connectors
6. Differences in Test Equipment

The values derived from the OTDR test and the Insertion Loss test are complementary. The OTDR provides an overall "picture" of the condition of the installed fiber optic cable system. The Insertion Loss test provides an absolute value of optical power through all connectors, sleeves, splices, and fiber.

SUMMARY

Three (3) sets of field data need to be collected during the installation process in order to maintain complete records about the optical properties of the passive cable system. This data is as follows:

1. Calculated Data-Obtained from Cable Reel Data Sheets and Splicing Logs
2. OTDR Data-Obtained from end-to-end cable test
3. Insertion Loss Data-Obtained from end-to-end cable test

This data then becomes part of the permanent record for both the customer and the cable manufacturer's files.

It is essential that any operator of a fiber transmission system maintain adequate information about that system for maintenance, trouble-shooting, and emergency restoration procedures. Information required to maintain that system include results from Optical Time Domain Reflectometer (OTDR) and Optical Power tests. The two measured and one calculated tests provide complementary information that accurately and completely characterize the optical condition of the passive fiber cable plant.

By periodically verifying the attenuation loss of the cable system with either an OTDR or Optical Attenuation Test Set, the cable operator may be able to preclude difficulties with the transmission medium at some future date. The objective is to ensure by field testing that the installation of the pasive cable plant was completed at the same high levels of quality as both the manufacturing and cabling operations.

REFERENCES

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Wilson, Paul; Bonnyman, Al; "Practical Considerations in the Testing of Fiber Optic Cables at the System Level, *"SCTE Fiber Optics Papers 1990,* pg. 33-37.

Matthews, James, "Q & A," *Guidelines,* Volume 5, Number 2, pg. 13.

Matthews, James, "Measuring Fiber Transmission Systems," *CED,* April 1990, pg. 52-61.

ADDITIONAL SOURCES OF INFORMATION

EIA Standard, EIA-455-57, FOTP-57, Optical Fiber End Preparation and Examination.

EIA/TIA Standard, EIA/TIA-455-60, FOTP-60, Measurement of Fiber or Cable Length Using an OTDR.

EIA/TIA Standard, EIA/TIA-455-61, FOTP-61, Measurement of Fiber or Attenuation Using an OTDR.

EIA Standard, EIA-455-78, FOTP-78, Spectral-Attenuation Cutback Measurement for Single-Mode Optical Fibers.

EIA Standard, EIA-455-95, FOTP-95, Absolute Optical Power Test for Optical Fibers and Cables.

EIA Standard, EIA-455-171, FOTP-171, Attenuation by Substitution Measurement -- For Short-Length Multimode Graded-Index and Single-Mode Optical Fiber Cable Assemblies.

Splice Log

PROJECT:				DATE:		
SPAN:				TECHNICIANS:		
OPTICAL LENGTH:				WEATHER CONDITIONS:		
SHEATH LENGTH:						
SPLICE POINT LOCATION:						
OTDR LOCATION:						
	FIBER	SPLICE ATTEMPT (LOSS IN dB)				
IDENTIFIER	NUMBER	1	2	3	4	COMMENTS

Example 1

Comm/Scope, Inc.

End To End Loss Measurement

PROJECT:				DATE:	
SPAN:				TECHNICIANS:	
OPTICAL LENGTH:					
SHEATH LENGTH:					
TRANSMITTER LOCATION:					
RECEIVER LOCATION:					
WAVELENGTH:					
TRANSMITTER SN:					
RECEIVER SN:					

IDENTIFIER	FIBER NUMBER	MEASURED POWER (dBm)	REFERENCE (dBm)	ACTUAL POWER (dB)	COMMENTS

Example 2

Comm/Scope, Inc.

Summary Of Field Data, Attenuation Loss

PROJECT:				DATE:	
SPAN:				TECHNICIANS:	
OPTICAL LENGTH:					
SHEATH LENGTH:					
WAVELENGTH:					

	FIBER	CALCULATED	OTDR	INSERTION	
IDENTIFIER	NUMBER	LOSS (dB)	LOSS (dB)	LOSS (dB)	COMMENTS

Example 3

Comm/Scope, Inc.