Available Online at www.ijcsmc.com

International Journal of Computer Science and Mobile Computing

A Monthly Journal of Computer Science and Information Technology

ISSN 2320–088X
IMPACT FACTOR: 6.017

IJCSMC, Vol. 7, Issue. 5, May 2018, pg.61 – 69

INVESTIGATION OF OPTICAL RETURN LOSS (BACK-REFLECTION) IN OPTICAL FIBER TRANSMISSION LINKS

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Abstract: *Optical Return Loss (ORL) is the total amount of light returned from an optical fiber relative to the injected light. ORL can adversely affect fiber optics systems which indirectly affects the quality of the fiber network. One of the effects of this loss (multiple reflections) contributes greatly to the noise levels at the optical detector. Optical Return Loss could be caused by intrinsic material scattering (Rayleigh scattering) and Fresnel reflection. This paper however, focuses on the investigation of ORL using an Optical Time Domain Reflectometer (OTDR) amongst Optical Continuous Wave Reflectometer (OCWR), Optical Low Coherence Reflectometer (OLCR), and Optical Frequency Domain Reflectometer (OFDR). The OTDR was able to establish the ORL in every portion of the fiber under test. An ORL average level of 72.54 dB was obtained over span length of 2.86709 – 2.868.11 km. This is beyond the acceptable tolerance level (32 dB) of both the transmission and receiving equipment suggesting serious problem with the links. By implication, ORL can be used to determine the overall efficiency or performance of a fiber plant.*

Keywords: *Optical Return Loss, Rayleigh scattering, Fresnel reflection, OTDR*

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Introduction

ORL is the total amount of light coming back towards the transmitter from the entire fiber. This includes all backscatter and all reflections [1]. It describes how much light comes back to the transmitter (light source). Too much optical return can cause problems in Television and high-speed digital systems (like SONET). Fusion splicing tends to produce negligible reflection but mechanical splices can result in high reflection levels. There are two primary factors that cause ORL: Fresnel back-reflection and Rayleigh backscattering [2].

Fresnel back-reflection occurs in different network elements where there are transitions through different media. Optical connectors are especially prone to reflections because of air gaps, impurities, geometry misalignments, and manufacturing imperfections. Other sources of Fresnel back-reflection are open fiber ends, mechanical splices, and cracks in the optical fiber. Significant light is back-reflected to the source when light travels from the fiber core to air. Fresnel reflection is related to Optical Return Loss as [3]:

$$\text{ORL} = -10 \log_{10} r$$

where

r is the Fresnel reflection, $r = \left(\frac{n-1}{n+1}\right)^2$, and n is the effective Index of Refraction.

Rayleigh backscattering is an intrinsic property of optical fiber that causes light pulse to scatter. This is usually caused by defects and impurities introduced into the fiber core during the manufacturing processes or by regions under mechanical stress, such as microbending. A fraction of the scattered light pulse directed back to the source is detected as ORL, while majority of the scattered light is lost. Rayleigh scattering occurs along the total length of fiber. The magnitude of backscatter depends on the transmitted optical power level, optical

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wavelength, and fiber type. The approximate intrinsic ORL levels due to Rayleigh scattering are shown in Table 1 [4].

Table 1: Return loss levels due Rayleigh scattering

Link length	**Return loss due to Rayleigh Backscatter**
1 meter	70 dB
10 meters	60 dB
100 meters	50 dB
1 km	40 dB
Infinite	32 dB

The transmission distance will also affect the backscatter level: the longer the fiber network, the greater the backscattering [5]. This property can be calculated and is an important parameter to consider when setting up test equipment, such as an Optical Time Domain Reflectometer.

When light travels in a material (such as an optical fiber) it encounters different density material (such as air). Some of the light up to 4% is reflected back towards the light source while the rest move down the material to the end [6]. These sudden changes in density occur at fiber breaks, ends of fibers, and sometimes at splice points. The amount of the reflection depends on the magnitude of change in material density described by the Index of Refraction (IoR). ORL can be measured using Optical Time Reflectometer amongst Optical Continuous Wave Reflectometer (OCWR), Optical Low Coherence Reflectometer (OLCR), and Optical Frequency Domain Reflectometer,OFDR [7].

Optical Time Domain Reflectometor (OTDR) consists of a laser light source (laser diode), LCD display, a controller, and optical detector as shown in Figure 1 [8].

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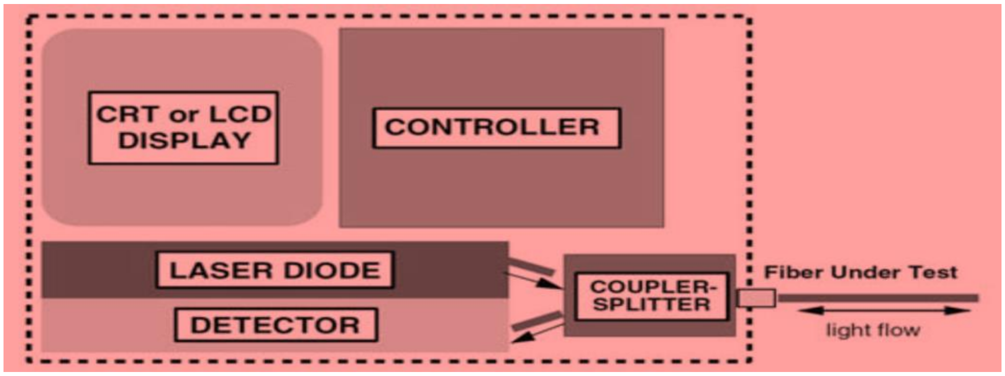

Figure 1: OTDR block diagram

The laser diode sends out pulses of light on command from the controller. The duration of the pulse (the Pulse Width) can be selected for different measuring conditions. The light pulse goes through the coupler-splitter and into the fiber under test. The coupler comprises of ports: one each for the source, the fiber under test, and the sensor. The coupler permits light to travel only in specific directions: From the laser source to the fiber under test, and from the fiber under test to the sensor. The light pulse is not allowed to go directly from the source to the sensor. Thus, pulses from the source go out into the fiber under test, and the returning backscatter and Fresnel reflections are routed to the sensor. The sensor measures the power level of the light coming in from the fiber under test. It converts the optical power in the light into corresponding electrical level. The higher the optical power, the higher the electrical level at the receiving end [9]. The sensors are specially designed to measure the extremely low levels of backscattered light.

The controller acts as the brain of the OTDR. It tells the laser when to pulse; it gets the powerlevels from the sensor; it calculates the distance to scattering and reflecting points in the fiber; it stores the individual data points; and sends the information to the display section. The main component of the controller section is a very accurate clock circuit used to precisely measure the time difference between when the laser pulses and when the sensor detects returning light. By multiplying this round-trip pulse travel time by the speed of light in fiber (which is the

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speed of light in free space corrected by the Index of Refraction), the round-trip distance can be calculated. Backscattering occurrence along fiber causes continuous flow of light back into the OTDR. The controller samples the measured level by the sensor at regular time intervals to obtain its data points.

Each data point is described by its sequence time (which relates to distance from the OTDR) and power level. Because the original pulse gets weaker as it travels down the fiber (due to Rayleigh scattering induced loss), the corresponding returned backscatter level gets weaker further down the fiber. After the controller has gathered all its data points, it plots the information on the display screen. The first data point is displayed at the left edge of the graph as the starting point of the fiber. Its vertical position is based on its returned signal power level: a higher power is plotted higher up on the graph. Subsequent data points are placed to the right, one data point every resolution setting. The resultant trace is a sloping line that runs from the upper left towards the lower right. The slope of the line indicates its loss per-unit-distance (dB/km) value a seen in Figure 2. Steep slopes mean larger dB/km values [10]. Data points corresponding to backscatter level make up the line. Fresnel reflections look like spikes emanating from the backscatter.

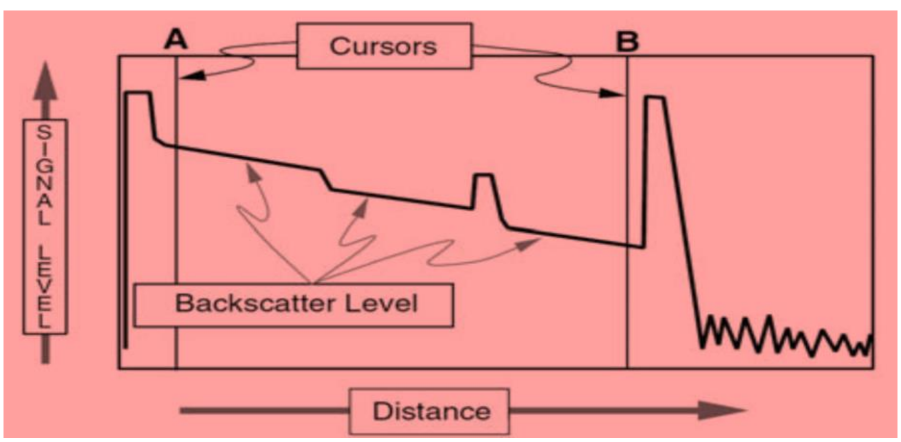

Figure 2: Components of OTDR Trace Display

2.0 Materials & Methods

Materials:

1. Single-Mode Patch cords
2. Power meter
3. Optical Time Domain Reflectometer (OTDR)
4. Media Converter/Transmission Equipment
5. Flash drive

OTDR test procedures

Fiber Type: SM 36 CORE FIBER

Device: M210

Module: M210 Num. 2

The OTDR parameters were set as:

Wavelength: 1550 nm

Range (Km): 4.084

Pulse: 100

Resolution: --

Index: 1.468200

A power meter was used in testing for continuity along the cable before the measurements were taken. A single-mode patch cord was attached to the OTDR and to cable plant (Core 010) under test via the patch panel at point A as shown in Figure 3. The OTDR was preset manually as stated above and it emitted light power pulses along the cable in a forward direction by the injection laser. The light pulses then bounced back and were measured by the factoring out of time and distances. The backscattered light was detected by the Avalanche photodiode receiver. The output of the photodiode receiver was driven by an integrator which improved the Signal to Noise Ratio (SNR) by giving an arithmetic average over a number of measurements at one point. This signal was fed into a logarithmic amplifier and the average measurements for successive points within the fiber were plotted and recorded with the chart recorder. The media converter was then used in converting the trace to readable format and retrieved with an external drive. The same procedure was repeated for cores 011 to 24 and results tabulated as seen in Table 2.

Figure 3: OTDR connected to fiber under test

3.0 Results

Table 1: Optical Return Loss (ORL) Values

Fiber Number	Total Loss OTDR (dB)	Link ORL (dB)	Total Length (m)	Number of Event
010	1.045	72.42	2867.34	3
011	0.862	72.95	2868.37	3
012	0.864	72.94	2868.37	3

013	0.781	72.51	2868.62	3
014	0.551	72.81	2868.62	2
015	0.556	72.80	2868.62	2
016	1.320	72.83	2867.86	3
017	1.320	72.83	2867.86	3
018	1.321	72.84	2867.86	3
019	1.303	72.84	2868.11	3
020	0.822	70.84	2867.09	3
021	0.820	70.84	2867.09	3
022	1.107	72.90	2868.62	3
023	1.086	72.88	2868.62	3
024	1.065	72.87	2868.63	3

4.0 Discussion

The average ORL level of 32.54 dB obtained from this research shown in Table 2 when compared with standard tolerance level given in Table 1 depicts poor performances in the fiber links. This is a threat to quality and uninterrupted fiber network. The possible faults within these links can be attributed to dirty connectors, broken optical fibers, poorly mated connectors or multiple interference from multiple high reflection points. Minimizing this loss is critical to getting maximum performance out of high bit rate laser systems. The back reflection could be reduced by removing the source and using low reflection connectors and low reflection (fusion) splices or using a low reflection detector arrangement or installing isolators or using transmitters

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with in-built isolators. The loss could also be reduced by minimizing tight bend and the number of splices or connectors in the links.

5.0 Conclusion

OTDR was used to investigate Optical Return Loss in optical fiber links. The results demonstrated that an OTDR is capable of producing repeatable ORL measurements even for wildly different values of the insertion loss in close proximity to the reflection event. This capability greatly adds to the utility of the measurement, as the uncertainty due to the insertion loss at the connection to the instrument is eliminated. For example, high transmission network bandwidth will require higher ORL performance.

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