ZANCO Journal of Pure and Applied Sciences
The official scientific journal of Salahaddin University-Erbil
https://zancojournals.su.edu.krd/index.php/JPAS

ISSN (print):2218-0230, **ISSN (online):** 2412-3986, **DOI: http://dx.doi.org/10.21271/zjpas**

RESEARCH PAPER

Study of Fault Detection Techniques for Optical Fibers

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A B S T R A C T:

This paper represents a review of several published papers, white papers and posted articles with a view to explain background of fault detection techniques for optical fibers. Optical fibers usually carry enormous data capacity. Therefore, fault detection and localizing it plays a major role in providing a stable and reliable network. So, it is very important to identify faults at first, the most fault that face optical fibers is fiber cut, which is phenomenon of interrupting active fiber optic that carry traffic due to working on the path that optical fiber cable implemented. There is another fault that fiber optic may experience as a result of high attenuation. Low attenuation is a major feature of fiber optics that encourages their use instead of metal cables. For this reason, any increase in their value causes a significant disruption of fiber optics and leads to interruption of services. Dispersion also leads to distortion of the information signal when fiber optic transmission is carried out. After passing through the fiber, the light impulses spread, and this phenomenon is called "pulse dispersion". The dispersion level determines the system's capacity because the largest number of pulses that can be received and resolved at the receiver are sent. The OTDR (Optical Time Domain Reflectometer) is the most common technique used to detect faults in fiber optics, but it is not the only one. In this paper, several techniques for detecting faults of optical fibers were studied.

KEY WORDS: Optical Fiber; Fiber cable cut; Optical Fiber Faults; Optical Fiber Fault Detection.
DOI: http://dx.doi.org/10.21271/ZJPAS.31.s3.20
ZJPAS (2019) , 31(s3);143-149 .

INTRODUCTION :

Nowadays, the communication systems rapidly develop in compare with traditional systems. Optical fibers which is a thin ultra-pure glass or plastic become the main building block of it due to its low attenuation or loss power and very large bandwidth capabilities. The new technologies need to transfer data from one point to another with high speed, reliable and secure system over thousands of kilometers, these properties made develop of Optical fibers in the early of the 1970s mandatory. Therefore, optical fiber systems are more suitable for gigabit transmission and beyond.

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Article History:
Received: 29/01/2019
Accepted: 05/04/2019
Published: 09/08 /2019

The most important challenge facing fiber optics is to localize faults and identify them immediately because their corruption leads to interruption of service and a significant loss of data and may cause a significant social impact. Connection loss due to improper installation of cables and non-low cables and signal latency can also be recorded as a fault (Ilouno, Awoji, Kwaha, & Chagok, 2018). Therefore, an effective oversight mechanism is needed to detect and identify the error and Shorten service interruption. However, for compatibility with the highest reliability standards, most optical networks have been designed with a protection mechanism that can interact with the fiber separator by redirecting data to a backup fiber path in less than 50ms (Boitier et al., 2017). Optical fibers can sometimes be damaged by the presence of causes in the ocean. For example, *ships can break up optical* fibers, and even sharks and other marine animals can chew on the protective layer of fibers. On the ground, optical fibers are used in the wake of physical infrastructure such as highways, railways, power transmission lines and can be broken due to work, storms or accidents. One method of detecting the failure of optical fiber communications systems is to use a Rayleigh-based scatter control system. There are some types of techniques that take advantage of this phenomenon, but what certainly stands out is the OTDR. Fiber integration information can be derived by accessing one end of the fiber through the use of OTDR, which means that all associated fiber can be monitored without the need to install a controller in each of the optical network nodes. High quality OTDR provides good spatial accuracy (less than 20 meters) and a long range (greater than 200 kilometers). (Calliari, Herrera, von der Weid, & Amaral, 2018). OTDR involves measuring part of a scattered probe pulse (by Rayleigh scattering) of silica fibers. Due to very small levels of backscatter in optical fibers with long wavelengths, sensitive optical detection is necessary to perform proper range performance(Kumar, Rajouria, & ISSN).

In this paper we studied fault detection techniques for optical fibers. In section two the fault types are discussed via analyzing of last year local company data regarding their trouble ticket number and classifying it according of type, root cause and impacting on services. In section three several kinds of fault detection techniques for optical fibers are discussed and presented their advantages and disadvantages. In the last section comparison result of two different techniques are clarified.

1. FAULTS IN OPTICAL FIBERS

To detect faults in optical fiber systems, we must first identify faults that may occur in the system. There are two main faults that may take place in optical fibers when operated within any communication systems which are fiber cable attribute faults and fiber cuts.CAL FIBERS

1.1 Fiber cable attribute faults

Fiber cable attribute faults are of paramount importance when fiber optic suitability is investigated for communication systems. The most important transmission characteristics are bandwidth characteristics determined by the level of dispersion and attenuation which is the loss of signal capacity and controlled by different mechanisms, including radiation, absorption, and, scattering.

1.1.1 Attenuation

It has been shown that attenuation or loss of fiber optic transmission is one of the most important factors in achieving its broad acceptance in communications. Since the attenuation of the channel has largely determined the maximum transmission distance before the signal is restored, optical fiber connections have become particularly charming when fiber transmission losses have been decreased to less than those for competing metal connectors (< 5 dB/km). Significant progress occurred in 1970 when the first fibers with attenuation less than 20 dB/km were reported. This level of attenuation was considered the absolute minimum to be achieved before the fiber-optic system competed in any way with the existing communications systems. when we come to fault detection level of attenuation, there is different techniques which is use for fault detection or pre fault detection for example the mechanism that is use for link attenuation monitoring is variant totally from the mechanism that use for testing optical fiber cable attenuation after installation and before launching it to carry traffic(Kumar et al.).

for cable attribute usually OTDR will use to determine the end to end cable attenuation amount as shown in Figure 1. The attenuation A(λ) at wavelength (λ) of a fiber between two different cross-sections, distance between them are L defined, as:

$$A(\lambda) = 10\log\frac{P1\ (\lambda)}{P2(\lambda)}\ (\mathrm{dB}) \qquad (1)$$

where:

P1(λ) : optical power traversing the first cross-section, and

P2(λ): optical power traversing the second cross-section at the wavelength (λ).

For a uniform fiber, it is possible to define attenuation per unit length, or an attenuation coefficient which is independent of the length of the fiber:

$$a(\lambda) = \frac{A(\lambda)}{L} \text{ (dB per length unit)} \qquad (2)$$

(Agrawal, 2012)

1.1.2 Dispersion

In digital communication systems, information is encoded in the form of pulses and then these light pulses are transmitted from the transmitter to the receiver. The larger the number of pulses that can be sent per unit time and still be resolvable at the receiver end, the larger is the capacity of the system. However, when the light pulses travel down the fiber, the pulses spread out, and this phenomenon is called Pulse Dispersion. The general impact of dispersion on the performance of a fiber optic framework is known as Inter symbol Interference. Inter symbol interference happens when the pulse spreading caused by scattering causes the output pulse of a framework to overlap, rendering them undetectable. Dispersion in optical fibers can be divided into two types, Intermodal (multipath) and Intramodal (chromatic). Intermodal dispersion is caused by different distance lengths of the modes in the fiber and different effective velocities which results in flattening of the transmitted pulses through the fiber. This type of dispersion occurs in multi-mode fibers and is known as modal dispersion. Intramodal dispersion is a term used to describe the spreading of a light pulse as it travels down a fiber when light pulses launch close together (high data rates). In this way, they spread too much and result in errors and loss of information. Intramodal dispersion occurs in single-mode fibers and causes the pulse broadening in these fibers(Hatamian, Barati, Berenjian, Naghizadeh, & Razeghi, 2015).

1.2 Fiber cable cut

An active fiber-optic cable interrupt incident that carries traffic because of any work at the location where the fiber-optic cable is located is called fiber cut phenomenon. The number of services affected depends on the location and the number of active fiber optic cable cut. In addition, the impact of these risks in the telecommunications industry has a significant impact on the quality of network connectivity in addition to the operation, maintenance and revenue margin.

due to its superior and attractive features on the traditional transmission medium. it has become clear that fiber optics consistently replace the traditional microwave transmission system in the communication field. And because usually optical fiber carries huge data traffic, the reliability and continuous service without outage are large challenges that face optical fiber system. Continuous fiber cutting has been the most difficult issue to deal with today's telecom operators as shown in the Tab.1. The following statistics belong to the local optical fiber company for 2018 in relation to all trouble tickets that have been opened for all types of failures encountered by the entire main system parts. Faults are classified according to the influenced system partition, impaction on the service and root cause of failure.

There are some points that need to be clarified with respect to the ratios in Tab.2. In the backbone network, the length of the fiber cable is much longer than the metro network where node numbers are larger than the backbone network. This means that the fiber length parameter should be more interested to be protected because of the high failure rate in comparison with equipment node numbers. In the Table 3. The root causes of fiber cuts are presented.

Optical fiber systems usually include complex parts that make deployment of communication system just for experiments and simulation uneconomic and nonrealistic specially for fiber cable cut when we talk about 100km cable distance. Opti system is simulator program that is use for testing, design and simulating optical links of broad-spectrum physical layer of optical systems. The model release determines the system simulation level. the ability to interference with the other tools expands its capacity of simulation. The other interested properties of Opti system is may include several blocks in the way that each block simulate its inputs independently. For the above reasons we suggested the diagram in the Fig.2. to simulate the fiber cuts in the optical fiber systems (Zhao et al., 2013).

2. FAULTS DETECTION TECHNIQUES

The most famous techniques that use for fiber cut fault detection is OTDR. The OTDR provides some properties that is very important to check optical fiber performances. Using OTDR will provide fiber technicians the ability of measurement of the following optical fiber characteristics: loss/length, insertion of connector, total loss of fiber, connector reflections, inter-splice loss, length of fiber, micro/macro loss and finally the most important properties of it which is detection of position of cable breaks. However, the technique faces the challenges including precision and accuracy because of increased variation in measured distance that cause more mistakes in fault locating. OTDR working principle is depend on Rayleigh scattering and Fresnel reflection theories to calculate the properties of optical fiber. Rayleigh scattering take place when the small changes like change in the refractive index because of changes in the material or when pulse moves down the fibers. Both make lights send out to all directions. The phenomenon of reflection of a small amount of light directly towards the transmitter which is the principle of Rayleigh scattering. Sudden changes in the density of materials when lights traveling the fiber cable is called Fresnel reflection and these happen because of an air gap in the cable breaks or connectors (Ilouno et al., 2018).

(Duncan et al., 2007) used Optical Frequency Field Reflection (OFDR) technique and its applications in single and multimode avionics fiber optics. In many respects, traditional OTDR is not well suited for aeronautical applications, which are usually dominated by short optical fiber (less than 100 meters) marches. This is due to the technological limitations of launch and the dead zone of the event inherent in the OTDR. Therefore, the OFDR measurement technique will be used. It provides the possibility of detecting high resolution faults and distributed sensor along standard non-modified fiber optic communications with spatial accuracy of millimeters.

(Brendel, 2008) used a hybrid structure consisting of two types of Photon Counting Optical Time Domain Reflectometers (ν-OTDR). While one ν-OTDR presents a 32dB dynamic range (which is expressed in dB, and refers to the maximum length of an optical link that can be measured; it can also be understood as the maximum attenuation that can be measured in an optical fiber link.) with spatial resolution (which reflects the sensitivity to resolve two adjacent events) of 6 m and minute-range measurements, the other has a 14dB dynamic range and a resolution of 3 cm with hour-range measurements. (ν-OTDR) advantages with compare to OTDR are higher spatial resolution, better dynamic range, better 2-point resolution, lower timing jitter and superior behavior concerning after pulsing. And disadvantages are dead zones after large loss events (charge persistence effect); and trace speed, depending on the application. Their experimental results performed with multiple optical fiber links attest the structure's capability of automatically detecting faults in an optical fiber link with ultra-high-resolution and minute-range measurements.

While (Herrera, Calliari, Garcia, do Amaral, & von der Weid, 2016) used Photon Counting OTDR setups and presented (3.5 cm, 12 dB and 2.25 m, 29 dB) allied to a signal processing technique for automatic results.

The (Cen, Chen, Moeyaert, Mégret, & Wuilpart, 2016) use TRA technique for single mode optical fiber. The principle of TRA is depend on transmitted power (PT) and backscattered power (PB) for a known fiber length. When the light with power (P0) injected to the near end of the Optical fiber, the (PT) can be measured at the far end of the Optical fiber while the backscattered power (PB) due to Rayleigh backscattering theory can be measured at the near end. Therefore, if there is only one even and it is not reflection type, the location of the event (fault) can be easily determine by relation between (PT) and (PB). This technique is very simple and can't be used for all fault types therefore when apply TRA technique to PON monitoring, a novel two-wavelength TRA (2λ-TRA) technique are proposed.

(Zhao et al., 2013) used traffic signal transmitted at the network as a probe signal and then locate the fault by correlation technique. In compare with the conventional technique which use by OTDR, several advantages can count. A simple structure and low operation expenditure because no need for extra equipment such as signal generator and light source. Also, this technique method overcomes the tradeoff between spatial resolution and measurement range in pulse ranging technique. And the last important point is property of ability using it for multimode optical fiber while OTDR have ability for single mode.

(Swain, Sahoo, Prasad, & Palai, 2015) proposed smart fault detection for optical fiber by using Arduino in the communication systems. The principle of the work depends on monitoring the received power in the optical fiber. To simulate this, the Arduino UNO, which consists of the Atmega 328 controller, is used together with the sensor module. After any received power change on the output sensor, the fault message will appear at the LCD screen and the date and time of fault occurrence will sent by Arduino to the web server.

(Vamsi, Rao, & Technology, 2016) proposed to measure the single photon count using the coherent anti-stokes Raman scattering and to measure the position of the fault in fiber optical cable the counts are correlated with the time. by selecting high range pump lasers and advanced filters, it can be used for longer fiber length. It is very accurate in compare with other techniques.

In Tab.4, the features, applications and advantages of the main techniques are clarified:

3.RESULT COMPARISON FOR TWO DIFFERENT TECHNIQUES

When come to the field and discuss results you should be careful with outputs even very small amount of it. In the below, we discuss results of two fiber cut on 7.12.2019 and 11/12/2019 on the same cable. The OTDR result shown below, first fiber cut test result in Fig.3, second fiber cut test result in figure 4 and finally Fig. 5 include all event detail of the fiber cable such as splice and connector (location, loss and attenuation). The fiber cuts occurred according to OTDR test results at 21.470 Km and 23.454 Km. Herein, we focus on the attenuation that caused by splicing the fiber cable to resolve the first fiber cable which is appeared at the second fiber cut test result at the marker 12.the detail of all events of second fiber cut cable include first fiber cut splice attenuation (marker 12) are clarified at Fig.5. At the marker 12 we found that the attenuation is 0.198 (dB) and this in compare with the traditional technique is laser source and power meter is too much different. In the DWDMs which connected by these cables the Tx and Rx at the first node and second recorded before and after the first fiber cut. The results were like below: before fiber cut (Tx 1.6 (dB) Rx -12.14 (dB) attenuation13.74 (dB), after fiber cut (Tx 1.6 (dB) Rx -12.19 (dB) attenuation13.79 (dB). That’s mean only (0.05 (dB). As shown in the below Tab.5.

4.CONCLUSIONS

Optical fiber is an important block of modern communication systems. fiber optic has been used extensively in new communication systems compared to traditional communication systems. Fiber optic broadband with a high data rate is the most needed for new systems. In addition, the transmission of long-distance signals (low attenuation), signal security and non-conductivity (installation capability near RFI, EMI and power lines) encourages the use of optical fibers rather than metal cables. Therefore, during operation and maintenance using appropriate fault detection technique and efficiency, it is extremely important to manage all these optical fibers that are used everywhere.

There are different techniques used to detect faults for fiber optics. The most famous technique is OTDR because of its ability to detect faults from 200 km of fiber cable and other properties. However, for short distances, for example in aeronautical electronics when the distance is short all the time, another technique is used to detect optical fiber faults which is OFDR, it has characteristics, including detection of high-resolution faults and millimeter spatial resolution. ν-OTDR technique used to detect faults with ultra-high-resolution and minute-range measurements. As a result, we can say that due to widely using Optical fibers, it is very important to select suitable technique to detect faults for it, to minimize the cost and time of each fault that face optical fiber.

Table (1) System Failure Part Name.

2018 System Failure Part Name				
system failure part name	Number	%	Impacted	Not Impacted
Fiber cut	81	59.5 %	83%	17%
Equipment (active part)	30	22%	26%	74%
Power System and Cooling System	24	17.5 %	8%	82%
Total	136	100%		

Table (2) Network type

2018 Network type		
Network type	Number	%
Backbone	87	64%
Metro	49	36%
Total	136	100%

Table (3) Network type

2018 Root cause		
Root Cause	Number	%
Fiber company	9	11.11%
Private company	27	33.33%
Government project	34	41.9%
Natural accident	5	6%
Others	6	7.4%
total	81	100%

Table (4) Features, applications and advantages of the main techniques

No	Fault Detection Techniques	Main Features, Applications and advantages
1	OTDR	Fault location detection, splice, bending and connector attenuation
2	OFDR	Singlemode and multimode avionics, short distance (less than 100 m), detecting high resolution faults with spatial accuracy of millimeters.
3	v-OTDR	higher spatial resolution, better dynamic range, better 2-point resolution, lower timing jitter and superior behavior concerning after pulsing
4	TRA	for single mode optical fiber, known length, is very simple and can't be used for all fault types
5	Traffic signal as a probe signal	correlation technique, A simple structure and low operation expenditure, ability of using it for multimode optical fiber
6	Using Arduino	the fault message will appear at the LCD screen and the date and time of fault occurrence will sent by Arduino to the web server.
7	Using the coherent anti-stokes Raman scattering	it can be used for longer fiber length, it is very accurate in compare with other techniques.

Table (5) Network type

Physical	Ports	6/12/2018 before fiber cut	8/12/2018 after fiber cut

connection Name		TX dB	RX dB	Attenuation	TX dB	RX dB	Attenuation
NODE 1-NODE2	NODE-1/AHP LG-1-2-LINE	1.6		13.74	1.6		13.79
	NODE-2/AHP LG-2-2-LINE		-12.74			-12.19	

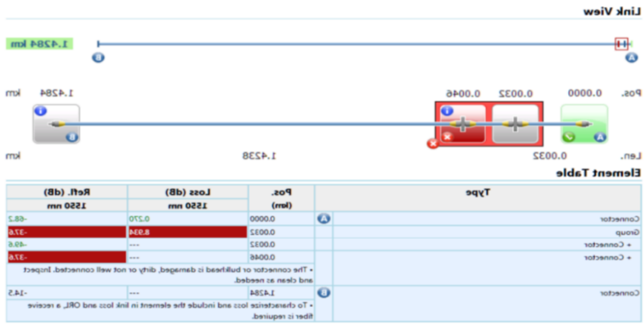

Figure 1. OTDR test result

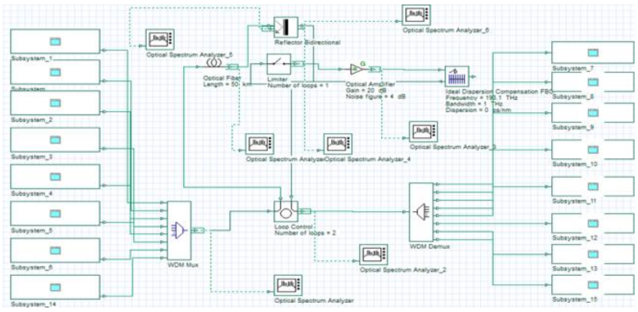

Figure 2. Opti system diagram (fiber cut)

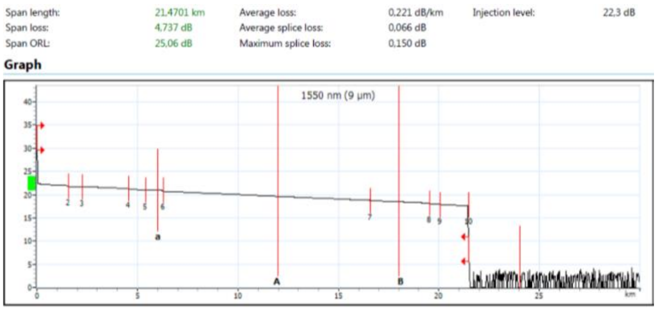

Figure 3. First fiber cut

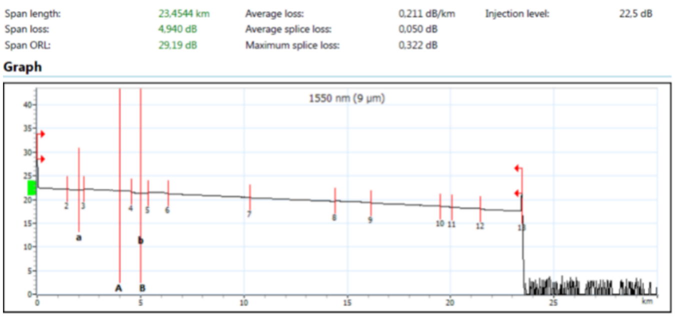

Figure 4. Second fiber cut

Event Table

Type	No.	Pos./Length (km)	Loss (dB)	Reflectance (dB)	Attenuation (dB/km)	Cumulative (dB)
First Connector	1	0,0000	---	-31,5		0,000
Section		1,4586	0,328		0,225	0,328
Non-Reflective	2	1,4586	0,021			0,349
Section		0,7899	0,125		0,158	0,474
Positive	3	2,2485	-0,198			0,275
Section		2,3123	0,447		0,193	0,723
Non-Reflective	4	4,5607	0,322			1,045
Section		0,8256	0,127		0,154	1,172
Positive	5	5,3863	-0,258			0,914
Section		0,9373	0,184		0,197	1,099
Non-Reflective	6	6,3236	0,200			1,299
Section		3,9897	0,730		0,183	2,029
Non-Reflective	7	10,3133	0,086			2,115
Section		4,1052	0,756		0,184	2,872
Positive	8	14,4184	-0,088			2,784
Section		1,7291	0,321		0,185	3,104
Non-Reflective	9	16,1475	0,149			3,253
Section		3,3555	0,616		0,184	3,869
Non-Reflective	10	19,5030	0,114			3,983
Section		0,5717	0,104		0,182	4,087
Non-Reflective	11	20,0747	0,074			4,161
Section		1,3699	0,272		0,198	4,433
Non-Reflective	12	21,4446	0,123			4,556

Figure 5. Event detail

REFERENCE

Agrawal, G. P. (2012). Fiber-optic communication systems (Vol. 222): John Wiley & Sons.

Boitier, F., Lemaire, V., Pesic, J., Chavarría, L., Layec, P., Bigo, S., & Dutisseuil, E. (2017). Proactive fiber damage detection in real-time coherent receiver. Paper presented at the Proc. ECOC.

Brendel, J. (2008). High-resolution photon-counting OTDR for PON testing and monitoring. Paper presented at the Optical Fiber communication/National Fiber Optic Engineers Conference, 2008. OFC/NFOEC 2008. Conference on.

Calliari, F., Herrera, L. E., von der Weid, J. P., & Amaral, G. C. (2018). High-dynamic and highresolution automatic photon counting OTDR for optical fiber network monitoring. Paper presented at the Proceedings of the 6th International Conference on Photonics, Optics and Laser Technology.

Cen, M., Chen, J., Moeyaert, V., Mégret, P., & Wuilpart, M. J. O. e. (2016). Full monitoring for long-reach TWDM passive optical networks. 24(14), 15782-15797.

Duncan, R. G., Soller, B. J., Gifford, D. K., Kreger, S. T., Seeley, R. J., Sang, A. K., . . . Froggatt, M. E. (2007). OFDR-based distributed sensing and fault detection for single-and multi-mode avionics fiber-optics. Paper presented at the Joint Conference on Aging Aircraft.

Hatamian, M., Barati, H., Berenjian, S., Naghizadeh, A., & Razeghi, B. J. A. i. C. S. A. I. J. (2015). Error control coding in optical fiber communication systems: an overview. 4(2), 70-80.

Herrera, L. E., Calliari, F., Garcia, J. D., do Amaral, G. C., & von der Weid, J. P. (2016). High resolution automatic fault detection in a fiber optic link via photon counting otdr. Paper presented at the Optical Fiber Communication Conference.

Ilouno, J., Awoji, M., Kwaha, B., & Chagok, N. (2018). Comparative Analysis on Fault Detection Techniques in Fiber Optics Communication Links.

Kumar, V., Rajouria, D. J. I. J. o. E. T., & ISSN, A. E. Fault Detection Technique by using OTDR: Limitations and drawbacks on practical approach of measurement. 2250-2459.

Swain, K., Sahoo, J., Prasad, M., & Palai, G. J. I. J. o. A. E. R. (2015). Fault Detection System in an Optical Fiber Using Arduino. 10(44), 2015.

Vamsi, A. V. N., Rao, A. B. J. I. J. o. S., & Technology. (2016). Fault Detection in Fiber Optic Communication Cable by Coherent Anti-Stokes Raman Scattering using Superconducting Nanowire Single-Photon Detectork. 9(S1).

Zhao, T., Wang, A., Wang, Y., Zhang, M., Chang, X., Xiong, L., & Hao, Y. J. O. E. (2013). Fiber fault location utilizing traffic signal in optical network. 21(20), 23978-23984.