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A new technique of real-time monitoring of fiber optic cable networks transmission

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Abstract

A new technique of fiber-break detecting and monitoring in optical communication network systems is proposed and experimentally demonstrated. The subsystem, namely fiber-break monitoring system is designed to be simpler, significantly less expensive and yet gives an appropriate measurement to the distance break in place of the optical time domain reflectometer. This new approach has a bright prospect to be utilized in existing optical communication network systems. The proposed technique gives a minimal insertion loss of 1.7 dB and measurement accuracy of 0.285 km.

Keywords: Fiber monitoring; Fresnel reflection; OTDR; Fault locator

1. Introduction

A network failure due to fiber break in current optical communication systems network could make the telecommunication operators very difficult to restore their system back to normal. They would face major problems locating the faulty cable and the break point along the optical cable.

According to the cases reported to the Federal Communication Commission (FCC), more than one-third of service disruptions are due to fiber-cable problems [1]. This kind of problem usually take longer time to resolve compared to the transmission equipment failure. Several developed test gears are invented to locate a fiber-break such as optical time domain reflectometer (OTDR) and fault locator [2]. Whenever a fault occurs, test gears are plugged manually to the faulty cable by the operators to detect where the failure is located. This conventional technique delays the restoration time of the network system. To reduce the time delay, one of the solutions is to install an OTDR or a fault locator to the system permanently. However, it is not cost effective since an OTDR is very expensive. Adding them to the system will increase the cost of the system extremely [5]. On top of that, adding these test gears into the system is impractical, especially when considering that the event of fiber-break does not occur frequently. Therefore, the requirement for a low-cost fiber-break monitoring system must be emphasized. The faster the fault is detected, the faster the restoration/protection can be done, thus reducing the probability of service disruption. This solution is certainly attractive to service providers.

In this paper, a new technique for real-time monitoring of fiber break is introduced. The device, named as fiber-break monitoring system (FBMS) is designed to detect a break of a fiber optic cable with significantly low cost but yet, giving an acceptably accurate result as to the position of the fault location. This new application is suggested for the optical network communication system, complementing the existing equipment.

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2. Experimental setup

The proposed FBMS is separated into seven modules. Each of them is designed and tested separately to optimize the performance and to reduce the troubleshooting time. Fig. 1 shows the block diagram of the FBMS.

The microcontroller, which acts as the heart of the device, controls the optical switch, laser-pulse module, detector module, display module and processing distance algorithm. The signal loss detection module is designed to monitor the live signals in the transmission line. It acts as an alarm indicator to the microcontroller which will activate the microcontroller when the signal loss occurs. Any loss of signals in the line will trigger the signal loss detection module to send an alarm to the microcontroller. Signal power is assumed lost when the module detects optical power less than −45 dBm. Hence, the microcontroller is activated and immediately switched from the main path to the modules by changing the switching path of the optical switch module.

The microcontroller activates laser-pulse module which sends a sequence of pulses to the main fiber. The wavelength used in laser-pulse module is similar to the transmission signal, which is 1550 nm.Concurrently, sampling is done by detecting the reflected pulses from detector module. The sampling event is important since the reflected signals obtained by the detector must be analyzed carefully in order to retrieve the accurate position of the fiber-break. Reflected signals are sampled by using the time-sampling method. The time taken by the propagating signal will be used to measure the distance of the fiber break.

The distance measured by FBMS is based on the theory of light propagation [6]. From this theory, time taken for the light to propagate in a medium depends on the distance it travels [7,8]. Refering to Eq. (1), the distance measured can be written as

$$D = \frac{ct}{2n_{\mathrm{IOR}}}, \tag{1}$$

where D is the distance, c is the speed of light in a vacuum, t is the time taken for the light to travel, and n_{IOR} is the index of refraction of the fiber under test. By measuring t, the distance of the fiber under test can be calculated.

3. Results and analysis

To analyze the distance measurement of FBMS, fiber under test with length of 4.498 km is used. A calibrated OTDR is used as a reference measurement to get the exact length. The fiber is then connected to FBMS and analyzed by the oscilloscope probe, tapped at the output of the detector module. Fig. 2 shows the example of the measurement where the propagation time is taken starting from the transmitted pulse by the laser-pulse module until the detector module detects the high signal, which is due to Fresnel reflection.

There are two wave signals probed from Channel 1 and Channel 2 of the oscilloscope that represent the laser-pulse and detector modules, respectively. The sampling resolution used for the oscilloscope is 5 Mega Sample per second (MSps). The propagation time is measured by taking the duration time, starts from sending the pulse until the detector module detects high signal from the reflected signal. The high signal indicates as Fresnel reflection effect due to the break at the end of the fiber [9]. In the experiment, the pulse signals are assigned to send continuous pulses so that the reflected signal can be monitored in the oscilloscope. Two signal peaks show that the continuous reflected signals occur in the fiber caused by the repetition of the transmitted laser pulses. Knowing the

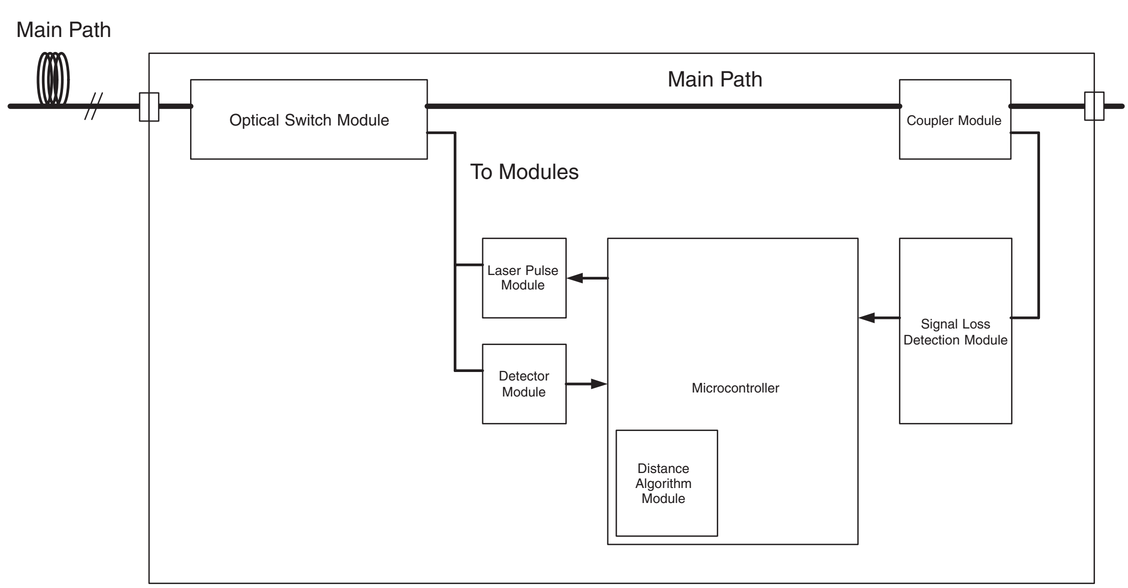

Fig. 1. FBMS block diagram consists of detector module, coupler module, signal loss detection module, laser-pulse module, distance algorithm module, display module and optical-switch module.

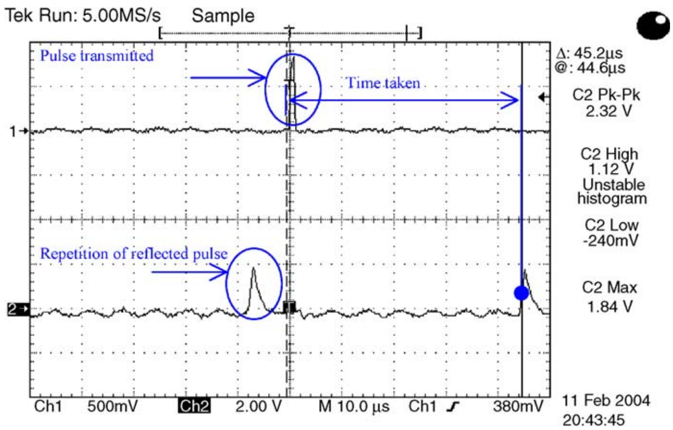

Fig. 2. Sample of reflected signals in detector module probed by oscilloscope.

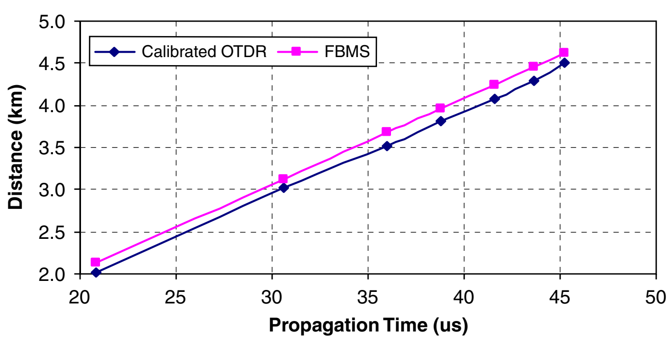

Fig. 3. Distance measured from fiber under test versus propagation time.

propagation time t, distance of the fiber break can be calculated.

Fig. 3 depicts the distance measured by the FBMS and OTDR for different lengths of fiber. The distance measured increases linearly as the propagation time is increased. The reflected signals took 20.8 µs to propagate inside the 2.020 km fiber. The maximum fiber length tested is 4.498 km where the propagation time taken is 45.2 µs. OTDR gives almost similar trend with FBMS in terms of its pattern and gradient. By comparing both results, it is proven that the distance measurement algorithm is valid. However, there are still differences in the results between them. The differences determine the performance of the developed FBMS in terms of the accuracy. Accuracy is one of the main issues, where it benchmarks the performance of FBMS against commercial test gears [10]. To test the accuracy, the distance measurement obtained from the FBMS is compared to the result measured by the OTDR.

Fig. 4 depicts the measurement differences between a calibrated OTDR and the detector module inside FBMS with respect to distance. From the graph, the trend of the discrepancy is analyzed. The difference is less than 0.11 km as it is measured from 2.0 km up to 3.0 km. The slope rate of the difference with respect to the distance increases as it goes further than 3 km. The difference is maintained above 0.15 km between 3.5 km up to 4.298 km. After that, the slope decreases as it reaches 4.498 km. The maximum difference occurred at 4.085 km fiber length, where FBMS measured it as 4.249 km thus, the difference is 0.164 km. The minimum difference occurs at 2.020 km where FBMS measures it as 2.124 km.

The tolerance of the measured distance by detector module can be set at 0.164 km. The value of 0.164 km is taken since it is the biggest difference achieved by the detector module, thus representing the worst case. However, the results are measured by the oscilloscope with sampling resolution of 5 MSps or 0.2 µs per sample. When, the FBMS is operated using a microcontroller, its sampling resolution is 1.6 µs per sample. Therefore, the accuracy of

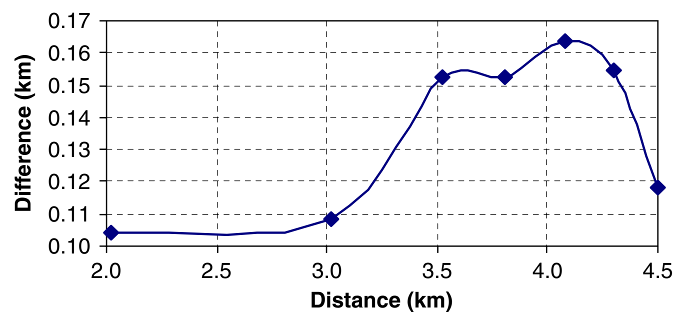

Fig. 4. Difference measurement between OTDR and FBMS.

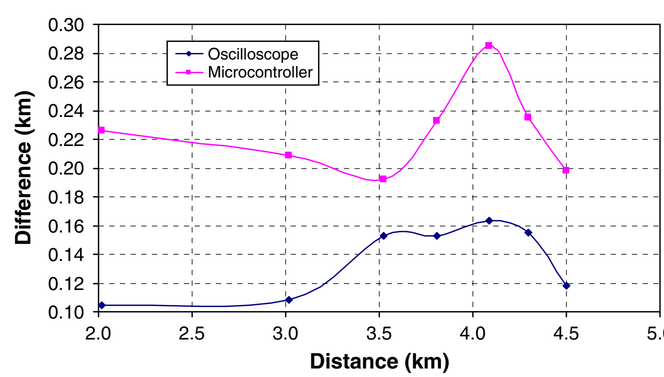

Fig. 5. Difference measurement inside FBMS.

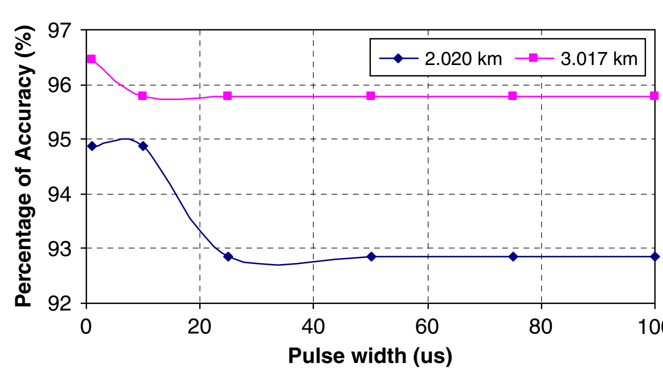

Fig. 6. Accuracy measured with variation of pulsewidth.

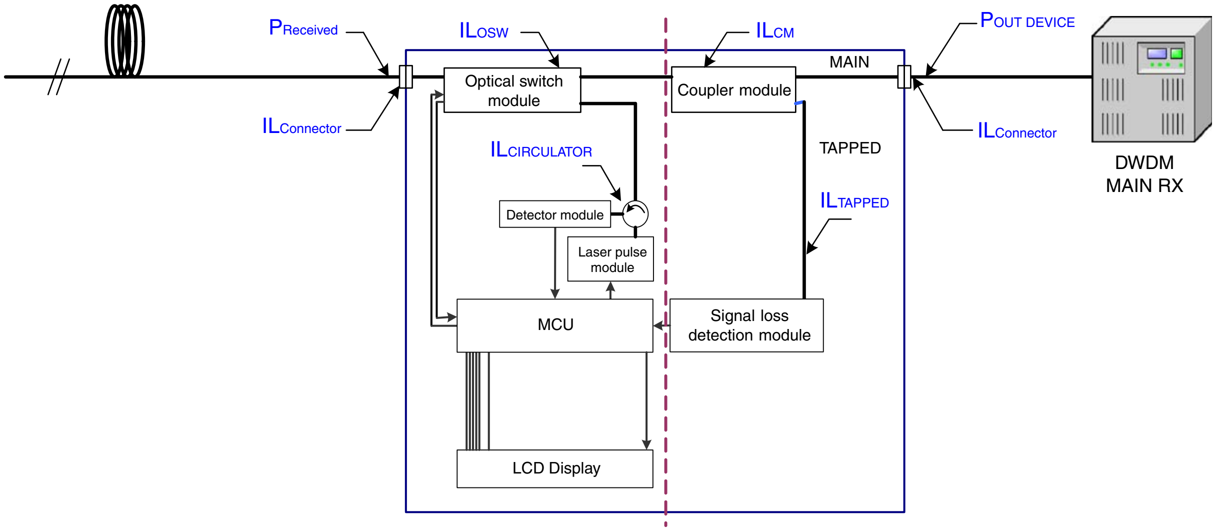

Fig. 7. Parameters involved in measuring the dynamic range of FBMS.

the measurement deteriorates since its sampling resolution is higher than the one used for the oscilloscope. This low resolution is caused by the limitation of the microcontroller's command execution speed.

Fig. 5 shows the difference between the sampling resolution results done with the oscilloscope and microcontroller compared to the OTDR. From the graph, the difference obtained in the microcontroller measurement is higher than the oscilloscope sampling. The highest difference for both oscilloscope and microcontroller is at 4.085 km, which is 0.285 and 0.164 km, respectively. The lowest difference for the microcontroller is at 3.524 km, which is 0.192 km. As discussed earlier, the tolerance for the sampling resolution with oscilloscope is 0.164 km. For the microcontroller, the tolerance is bigger since the limitation of the microcontroller's speed as expected. Thus, the measurement tolerance for the microcontroller is around 0.285 km.

The accuracy is measured based on the pulsewidth of 1 μs. In order to check whether the pulsewidth can affect the accuracy of FBMS, several pulsewidths are then analyzed. The performance is tested by using two fiber lengths, 2.020 km and 3.017 km. The result is shown in Fig. 6.

The accuracy is high at the pulsewidth less than 5 μs and becomes lower when the pulsewidth increases. For the distance of 2.020 km and 3.017 km, the smallest difference achieved at the pulsewidth is 1 μs. The difference is 94.87% and 96.85%, respectively. The accuracy value decreases as the pulsewidth used is bigger than 1 μs. The values become constant at 92.85% and 95.77% for both distances when 50 μs and more pulsewidth are used. Hence, the pulsewidths are verified in affecting the accuracy to the measurement. The best accuracy can be achieved when the pulsewidth is small. Hence, to get the best performance of the accuracy, the pulsewidth below 1 μs is suggested.

All the components' insertion losses, IL inside the device must be taken into account, namely, circulator, optical switch, and connector. The amount of power transmitted by the laser-pulse module and the minimum power detected by detector module must be considered. The other important parameter is the value of Fresnel reflection. Fig. 7 below illustrates the parameters discussed earlier. Eq. (2) shows the relationship of all IL.

$$\begin{aligned} IL_{FBMS} &= IL_{Connector} + IL_{CIRCULATOR} + IL_{OSW} \\ &= 1.7\ \text{dB}. \end{aligned} \tag{2}$$

4. Conclusion

The accuracy of the fiber-break monitoring system (FBMS) is compared to the existing test gear, OTDR. From the experimental results, the tolerance obtained is around 0.285 km.The tolerance can be improved if a higher-speed microcontroller is used in the architecture of FBMS. Even though its measurement tolerance cannot match with the OTDR, it can monitor a fiber break in real time. Thus, remote monitoring can be deployed and the fault can be restored as quickly as possible. Referring to its cost and acceptable tolerance, the proposed FBMS is one of the candidates to fulfill requirement of a remote monitoring system in telecommunication networks.

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Further reading

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