Vector Indexing Algorithm for Post Processing of OTDR Data

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Vector Indexing Algorithm for Post Processing of OTDR Data

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***Abstract*—The paper details the vector indexing algorithm for post processing of data in optical time domain reflectometer. Post processing is necessary in OTDR for event detection and feature extraction from the acquired traces. The vector indexing algorithm uses the acquired data trace to extract accurate event location and improve upon the spatial resolution of the OTDR. The proposed algorithm has been tested on our self-developed OTDR board and its performance has been benchmarked against the real measured event locations.**

Keywords—; Optical Time Domain reflectometer (OTDR), Fiber Under Test (FUT), Vector Index, Event Detection, Feature Extraction.

I. Introduction

Optical time domain reflectometery or backscattering has been widely used for measuring the distribution of attenuation along an optical fiber since 1976 [1]. OTDR is a valuable technique for characterizing losses and locating faults in fiber communication links [2]. OTDR testing is the most common method available for determining the exact location of break in an installed fiber optic cable when the cable jacket is not visibly damaged [3]. OTDRs are used to measure a fiber's length, end-to-end loss, location of optical loss and reflectivity of components along the fiber [4]. OTDR works on the principle of Rayleigh backscattering. The basic idea lies in transmitting a short pulse of light through a fiber and examining the time dependent response of the resulting backscattered signal.

A small part of injected light is captured by the core of the fiber and propagates backwards. Any change in the backscattered level along the fiber is due to a defect or an alteration in the properties of the fiber often called an 'event'. OTDR measures the backscatter light as a function of time from the initial pulse injection. Performance metrics for comparing and contrasting various approaches in optical time domain reflectometery exists and primarily uses one way fiber attenuation range L(dB) which results in a reflectometer output SNR of unity [1].

As the users of optical fiber have migrated to longer transmission wavelengths because of lower loss and as higher quality fibers have become available, there is literally less backscattered light to be measured [5]. Event detection and classification becomes tough for minute reflections in OTDR signal processing, as the Rayleigh backscatter is about 45dB lower than the launch power. Variety of techniques has been used to detect such weak signals. A composite coding scheme for SNR enhancement has been used for such weak signal detection and tested for our in-house built OTDR. The notion lies in combining complementary correlation codes with the simplex codes to achieve higher gain than conventional coding techniques [6,7].

Research in the post-processing algorithm for OTDR revolves around the ways of improving the method of extracting the event information and features from the OTDR signature. In this paper an algorithm is presented for the detection of the discontinuities in OTDR signature that will describe optical fiber attenuation characteristic buried in high level additive signal. Such algorithms are employed to post process the output of an OTDR that will not only locate the position of the connector, splice, crack, bend and cut along the fiber it will also provide loss characteristic of each individual event.

An OTDR output consists of two parameters the distance in km and attenuation in dB. An OTDR plot its output in a graph format on the OTDR screen with distance on X-axis and attenuation on Y-axis. A conventional OTDR trace is shown in figure 1.

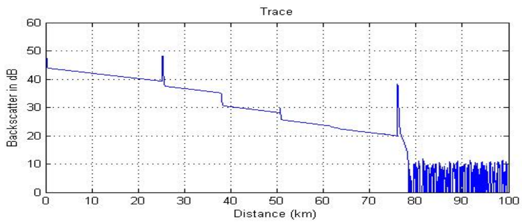

Fig. 1. Examplary OTDR Trace

In upcoming sections: existing techniques for post processing of OTDR data, our proposed methodology and experimental testbed is discussed, followed by a section on main requirements for post processing and finally the achieved results are quantified in the experimental results section.

II. Existing Event Detection Techniques

Three distinct techniques exist which are useful for the post processing of OTDR output data.

A. Least Square Approximation

Least square approximation is the most famous method used in post processing algorithms for

OTDRs. Best line fit is calculated for noisy data which ensures minimum mean square error (MMSE). Then it is subjected to threshold detection, sharp changes in the backscatter data are identified and extracted. A general rule with least square approximation is that an event's magnitude should be at least double the magnitude of noise to be accurately located [8]. If data is very noisy the line fitted to the data may not represent the true slope and would produce inaccurate results. The accuracy of processing is difficult to ensure in acquired low SNR data.

B. Wavelet Analysis

Wavelet analysis method is used for finding discontinuities in the OTDR signature's data. Curve data is subjected to wavelet transform and the coefficients are subjected to a threshold value filter to extract the high frequency information, as sharp changes lies in the high frequency portion. Denoising is performed and finally the positions of the sharp changes are located by using Maximum Mold Algorithm [9]. The whole process is summarized in the figure 2.

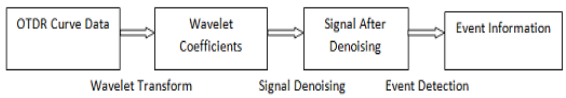

Fig. 2. Event Detection using Wavelet Transform

Another approach using Morlet's complex wavelet transform has also been used which incorporates two important properties

a) The phase of the wavelet transform (WT) of an exponentially decaying function f(t) is independent of time shifting, since f(t) is a homogeneous function.

b) The phase of the WT of a Gaussian white noise has a special distribution in [-π, π].

Property (a) is applied for estimating attenuation parameters and property (b) is used to identify end of fiber. A binary detection criterion is established based on phase of WT of the OTDR data to detect events. Morlet's complex wavelet transform approach faces difficulties in limited operation time and uncertainty in detected events [10].

C. Wave-Shape Analysis

Wave-Shape analysis is the most advanced approach in OTDR event detection algorithms. Wave shape analysis algorithm is the highly sophisticated method of data processing that accurately locates the events in the data based on inflection points in the data. Previously discussed algorithm can give inappropriate events or even miss some events. Wave shape algorithm has the capacity to overcome these shortcomings. Wave shape algorithm can accurately locate and measure events having magnitude one half of the magnitude of the noise in the data [8]. This improvement in performance is achieved by analyzing the curve shape of whole data. This technique produces superior amplitude measurements of the event. Wave shape analysis is the proprietary algorithm of "NetTek OTDR".

III. Vector Indexing Algorithm

The proposed algorithm works on vector index matching. Fiber response consist of two parameters namely Distance and Backscatter power which are plotted on x-axis and y-axis simultaneously. The response out of OTDR board will be discrete in nature and looks like exponentially decaying signal as shown in Fig.1. The events in the signature curve are abrupt changes in the consecutive recorded values. First OTDR curve data is stored in two separate vectors, distance vector and backscatter vector simultaneously. Since the sudden changes in information exist in the backscatter vector the numerical difference operation is applied on it prior to threshold detection. Values crossing the threshold limit are events and cardinality of each event is mapped on the distance vector to find corresponding distance of the event. Meanwhile, the value of sample before the event and the value after the event are gathered and linear interpolation is performed to find the exact sample that crosses the threshold. This helps to improve the efficiency and accuracy in terms of distance measurement. The computational complexity is reduced and the spatial resolution capability of event detection improves. The details of vector indexing algorithm are being provided through the pseudo code.

Vector indexing algorithm

Input: *Backscatter vector*
Distance vector
Threshold
Output: *Distance from source to event location.*
Attenuation of events
Begin
Store the cardinality of backscatter vector in c1
Foreach *counter <= c1*
Apply numerical difference operation on backscatter vector store in 'result' vector.
End foreach
Pad zero to starting index of the result vector
Store the cardinality of result in c2
While *counter <= c2*
Compare the result index values with threshold
If *result value is greater than threshold*
Store the value and its index in output vector
Else *print "No event is detected"*
EndWhile
Foreach counter<=*distance*
Compare the index number of the value stored in output with distance vector
Extract the value of the matched index
Perform interpolation
Store to event array
End foreach
End

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IV. EXPERIMENTAL SETUP

To experimentally verify our post processing algorithm an in-house OTDR board was built. A Pigtailed Pulsed type laser photo diode was used as an optical source and laser power was coupled into the fiber spool by using a fiber directional coupler. An InGaAs PIN Photo diode receiver was used to detect the response from the fiber to the front end. A trans-impedance amplifier is used to convert the receiver's current into voltage. Then a 12-bit two port ADC was used to sample the incoming voltage to 20Mbps with a 12 bit resolution, offering enough dynamic range to detect the events properly. Whole assembly (source, coupler, receiver, TIA and ADC) was built on the daughter board called Analog front end (AFE) showed in figure 3.

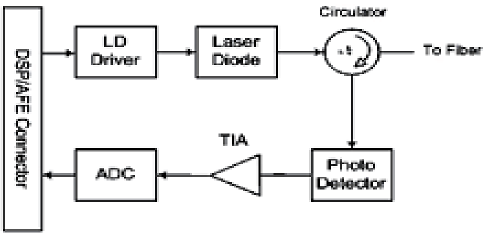

Fig. 3. AFE Daughter Board

For signal processing an on-board signal processor Blackfin BF532 DSP was used which performs control, decoding and post signal processing functions, meanwhile Xilinx Spartan III FPGA was also used to perform down-conversion of 20Mbps for the processor and additionally FPGA control triggering, capturing received optical signals and averaging. FPGA is controlled by ADSP which uses its control signals to initiate the acquisition process. Whole assembly (ADSP, FPGA and memories) was built on a separate board as shown in figure 4.

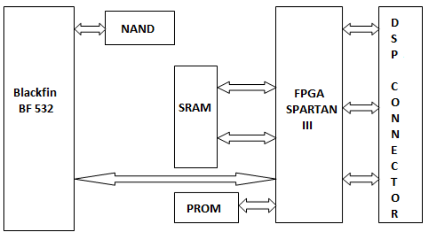

Fig. 4. Signal Processing Board

AFE and signal processing board was connected together via DSP/AFE connector. SRAM and PROM are used for data storage and they are connected and controlled by FPGA. Figure 5 is a picture of the in-house build OTDR including the AFE and signal processing board.

Fig. 5. Self Developed OTDR Board

Trace is captured by shooting controlled coded pulse into the fiber and response is collected for a specified time period and stored in SRAM, after that averaging is performed to get the final trace and then post processing algorithm is employed to extract events.

V. POST PROCESSING OF OTDR DATA

A. *Offset Compensation*

Once the trace is acquired it needs to be converted in final presentable form by performing logarithmic operation on the OTDR signal. The logarithmic operations are sensitive to any fixed/DC offset added to the signal. All ADC's have some inherent fixed/DC offset which is defined as the difference between the ideal least significant bit (LSB) transition to the actual transition point. If the offset is not properly removed the logged trace rolls up when the backscatter reaches the noise floor. It is necessary to remove the ADC offset before post processing. After the offset is removed the final trace needs to be analyzed for events and their parameters. Offset compensation is an important task in post processing of acquired traces as it ensures offset errors removed and a linear trace display.

B. *Trace Analysis*

The purpose of the trace analysis step is to find different reflective and non-reflective events along the fiber and to measure their locations and losses. Non-reflective events are of two types namely loss and gain. For each non-reflective event the insertion loss is measured. The accurate method of determining the non-reflective event is to find four marker locations: two before the event and two after the event.

For each non-reflective event, the insertion loss, (IL) needs to be measured. The accurate method for determining the loss is to find four marker locations, two before the event and two after the event. Least square (LS) fits are found for sections of fiber between each pair of markers as shown in figure 6.

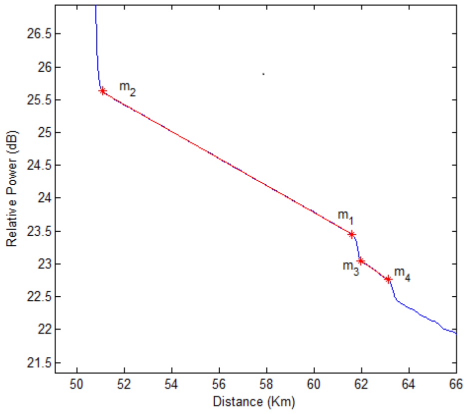

Fig. 6. Use of Markers and LS fitting

The red lines show the fits between markers m2 and m1 and between m3 and m4. The loss is found as the difference between the two fits from which expected fiber loss needs to be subtracted. A user defined input “loss threshold” puts a lower limit for the identification of a non-reflective event. Reflective events begin with a slope rising sharply, hitting the peak and then falling back to the normal value. This identifies reflective event.

VI. EXPERIMENTAL RESULTS

In this section the experimental results are discussed which are gathered by employing proposed post processing algorithm to the OTDR data from live optical fibers of 100km each named as fiber under test FUT-1 and FUT-2. Once the signatures are acquired and converted into the final presentable form by performing filtering, averaging, correlation and logarithmic operations, they need to be analyzed for events. Since the logarithmic operation is sensitive to any fixed/DC offset that may have been added to the OTDR signal. The source of such offset is usually the ADC. All ADC’s have some inherent offset value. If the offset is not removed properly the logged trace rolls up or down when the backscatter reaches the noise floor level. It is very important point in acquiring the final trace that offset must be removed. The signature of FUT-1 is given in figure 7.

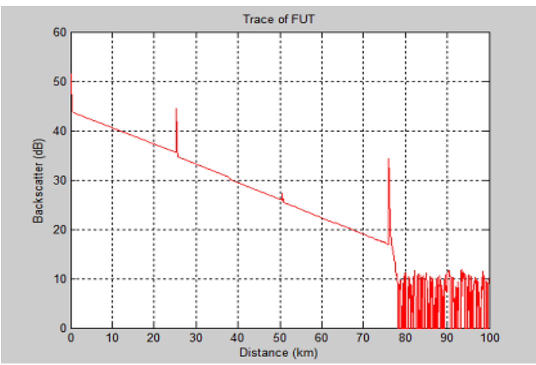

Fig. 7. Signature of Fiber under Test (FUT-1)

After the post processing algorithm the resultant detected events are shown by the normalized bar plot in figure 8.

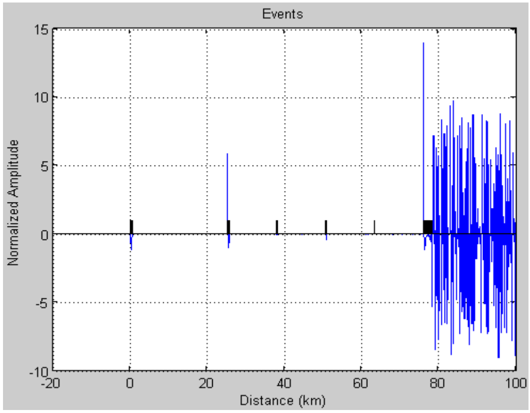

Fig. 8. Bar Plot of Detected Events in FUT-1

Similarly proposed algorithm is applied on FUT-2 and results are gathered. The trace plot and detected events for FUT-2 are shown in figure 9 and 10 respectively.

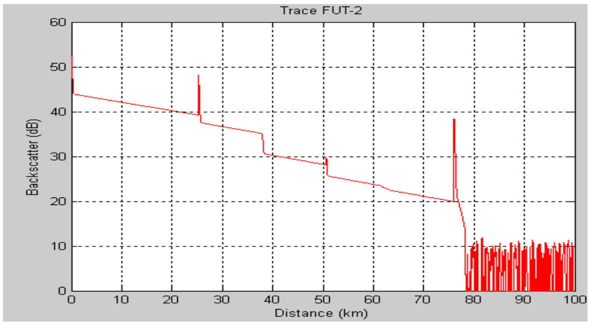

Fig. 9. Signature of FUT-2

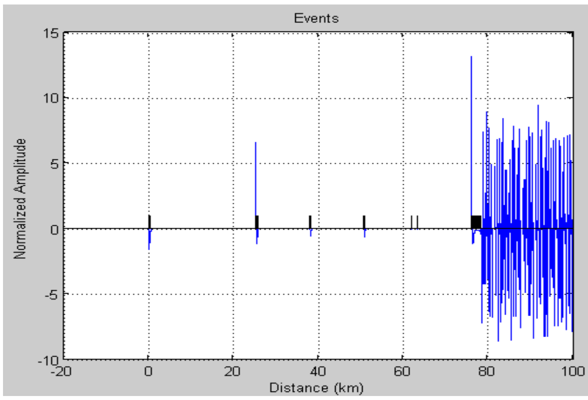

Fig. 10. Bar Plot of Detected Events in FUT-2

Results are compared in terms of distance with the actual values of distance and the values of the events from commercially available OTDR. Specifying the distance from the point of injection is critically important in the post processing of OTDR data. Increasing the spatial resolution of the distance measurement has been achieved through the vector indexing algorithm. Table 1 summarizes the experimental results showing that the vector indexing algorithm on the OTDR curve data is practical, feasible and highly accurate.

TABLE I.

Fiber No.	Actual Event Position /km	Calculated Event Position /km	Event Type
1	---	0.09800km	0
	25.1456km	25.145625km	1
	37.8636km	37.86300km	2
	50.5204km	50.52050km	1
	63.2384km	63.23825km	2
	75.8570km	75.860125km	3
2	---	0.08110km	0
	25.1729km	25.17250km	1
	37.9045km	37.90425km	2
	50.5674km	50.56725km	1
	61.7095km	61.70862km	2
	63.1538km	63.15600km	2
	75.9160km	75.91608km	3

Note:
Event Type: 0: Blind spot 1: Reflective events 2: Non-Reflective Events 3: End of Fiber

Blind spot occurs when the receiver is saturated by a very high reflection and its duration depends upon the pulse width selected and recovery time of OTDR detector. The sudden change due to reflective event is followed by a return of the Rayleigh backscatter to its nominal value. For reflective events the reflectance threshold is set by the OTDR user at the start of testing. Events having threshold less than the specified threshold are not identified. Non-reflective events are identified by subjecting the numerical difference values to the lower loss threshold. End of fiber (EOF) is identified by using EOF threshold depending upon the user defined input parameters at the start of testing. Detection thus remains dependent on the threshold definition for different types of events.

VII. CONCLUSION

In this paper, we have focused our work on the post processing algorithm for event detection and feature extraction from acquired OTDR traces. By using numerical difference operation combined with vector index matching, improvement in event detection, feature extraction and spatial resolution has been achieved. The performance results on experimental setup indicate that the implementation of the vector indexing algorithm shall allow accurate event detection and classification. Hence the proposed vector indexing algorithm provides an effective solution for event detection in optical time domain reflectometers.

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