The Wavelength Division Multiplexing Passive Optical Network Breakpoint Precision Detection System Based Broadband Chaos Light

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ABSTRACT: *Chaos, a kind of noise like signals, generated by deterministic nonlinear Dynamical system, has good autocorrelation performance. Previous researches indicate that broad bandwidth chaos can be easily obtained by semiconductor laser subjecting optical feedback, optoelectronic feedback, or external optical injection under an appropriate conditions. Break detection for WDM-PON needed to solve the multi-branch; node density problem for the realization of high-precision positioning of each branch proposed a breakpoint detection method based broadband chaotic light lasers, with the help of powerful and elastic computation ability and storage capacity, put proposes a framework of service platform with a collaborative service model of hybrid cloud in the cloud computing environment. On the basis of analysing the characteristics of broadband chaotic sources on a preliminary simulation results show that this method can be highly accurate positioning WDM-PON branch breakpoint location, spatial resolution of 7cm and independent of the detection distance.*

Subject Categories and Descriptors:
C.2.5 [Local and Wide-Area Networks]: High-speed; **C.3 [Special-purpose and application-based systems]:** Signal processing systems; **G.1.2 [Approximation]** Nonlinear approximation

General Terms:
Bandwidth, Non-linear dynamic system

Keywords: Double Optical,Feedback, High Precision Detection, Chaos, WDM-PON

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1. Introduction

Wavelength division multiplexing passive optical network WDM-PON [8] is considered as one of the potential solutions for next generation access network. In order to realize the WDM-PON in access networks, cost-effective optical components and managing techniques are vitally required. Fault detection [32] in local transmission line is of high concern to guarantee reliable operation of the WDM-PON. Fiber faults have been detected by using an OTDR[31,43] in conventional communication systems. With the rapid development of the wavelength division multiplexing passive optical network (WDM-PON) communication, the access network of high density, high frequency events distribution needs high-precision detection. There is the principle of contradiction of measurement accuracy and measurement range by using pulse optical time domain reflection meter on the breakpoint detection [11,33].Because the pulse width is proportional to the measure distance and it is inversely with the resolution. In order to improve the measuring distance, the resolution must be reduced [1]. The correlational method of pulse optical time domain reflect meter using pseudo random pulse sequence instead of a single pulse, measured by cross-correlation operation of the reference signal and the detection signal. But the precision is limited by the electronic bandwidth bottleneck of the pseudorandom modulation, unable to obtain bigger breakthrough in the precision.

In addition, because each branch of the WDM-PON can be discriminated by wavelength difference, there are big difficulties in the WDM-PON fault detection by using a conventional optical time domain reflect meter.

Based on optical time domain reflect meter chaotic[34] cross-correlation method as the optical fiber fault location[38]technology of new generation, using double optical feedback[40]. Semiconductor laser as chaotic source, changing the feedback light mode conditions, the output is broadband chaotic laser[2]. As the detection light to realize the multi-channel detection and locate the fault point by using wideband chaotic signal instead of the traditional pulse signal [36]. The fault distance is measured, the defects of the optical time domain reflection technology is overcome and fault detection in high spatial resolution achieved that is independent of distance measurement can be achieved by the cross-correlation operation of the reference signal and probe light echo signal [3].

2. Double Optical Feedback Broadband Chaotic Mechanism

Chaos[42] is generated by a deterministic nonlinear system[39], with good correlation properties of the noise signal. Research shows that semiconductor lasers in the appropriate external perturbations, such as the existence of optoelectronic feedback, external optical injection or optical feedback, it can easily generate broadband chaotic laser[4].Auto-correlation characteristics of broadband based on chaos laser, optical time domain measurement techniques of chaotic laser correlation method using broadband chaotic laser as probe signal [35], combined with the relevant signal processing technology, can achieve high-precision detection of optical fiber network fault point. [12]. However, the peak side lobe of wideband chaotic signal auto-correlation curve limits signal-to-noise ratio of correlation optical time domain measurement system based on chaotic laser[10].

When the feedback strength is small, influence of laser external disturbance can be basically negligible [37]. So the output after a brief relaxation oscillation achieves stability; enhanced strength, increased significantly influence on laser external disturbance, the disturbance cannot be ignored, the dynamic behaviour of the system becomes increasingly complex, the feedback strength continues to strengthen, the laser output is chaos state [5].Compared with optical injection, optoelectronic feedback semiconductor laser[25], optical feedback semiconductor laser[41] is relatively easy to produce chaotic output of the high complexity. Double optical feedback is more a feedback cavity than the single optical feedback, namely one more degree of freedom, the output of double optical feedback semiconductor laser will be richer and varied[6].Double optical feedback semiconductor laser that introduces a new external cavity, is compared with the single optical feedback, adds a degree of freedom, so the output of the system is more complex and changeable, double optical feedback semiconductor laser chaotic system model is shown in Figure 1.

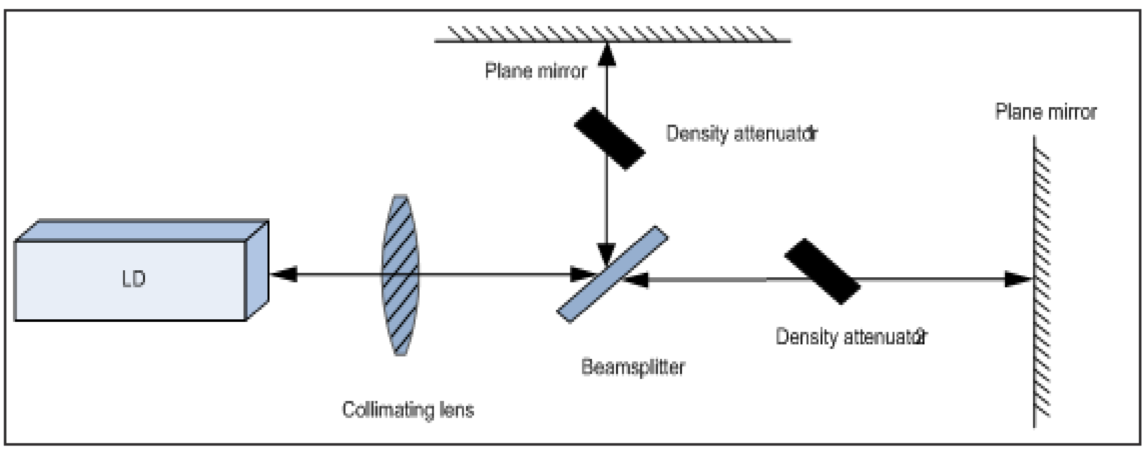

Figure 1. Double optical feedback semiconductor laser chaotic system model

After the light of laser diode through the collimating lens, it is divided into two beams by the beam splitter. A beam of light through the neutral density attenuation plate 1 and the plane mirror 1 feeds semiconductor lasers; the other beam through the neutral density attenuation piece 2 and the plane Mirror 2 feeds semiconductor lasers. By adjusting the neutral density attenuation piece can control the feedback strength, adjusting the mirror plane mirror 1 or 2 position can change two feedback optical delay time.

Lang-Kobayashi rate equation can be used to characterize the nonlinear dynamic behaviour of double optical feedback semiconductor laser [7]:

$$\frac{dE(t)}{dt} = \frac{1}{2}(1+i\beta)[G(t)-\frac{1}{\tau_P}]E(t)+k_1E(t-\tau_1)\exp(-i\omega\tau_1)+k_2E(t-\tau_2)\exp(-i\omega\tau_2)+F(t) \quad (1)$$

$$\frac{dN(t)}{dt} = \frac{I}{e}-\frac{N(t)}{\tau_n}-G(t)\left|E(t)\right|^2 \quad (2)$$

Type (1) (2), subscript 1 and 2 represent the double optical feedback semiconductor laser feedback cavity 1 and a feedback cavity 2. E is a slowly varying amplitude chaotic semiconductor laser output, e is elementary charge, N is carrier number of laser intracavity, τ_p, τ_n is photons life and carrier lifetime of the semiconductor laser intracavity, respectively. K is the feedback strength coefficient, I is the injection current, ω is the angular frequency of free oscillation laser, $F(t) = \sqrt{2a\zeta\alpha}$ Where ζ is white Gaussian noise [26], α is spontaneous radiation intensity. P is coefficient of saturation gain, β is line width enhancement factor, τ is feedback time, then:

$$G(t) = g[N(t) - N_0]/[1 + \rho|E(t)|^2] \quad (3)$$

Where g is the differential gain coefficient, N_0 is laser cavity transparent carrier number.

The feedback strength is in the range of $3ns^{-1}$-$13ns^{-1}$, semiconductor laser output is chaotic. With the increase of feedback strength, complexity of chaotic output is first increased and then decreased[27]. Double optical feedback semiconductor laser has more complex dynamic behaviors. Compared to the single optical feedback system, output chaotic signal of double optical feedback system has the time characteristics of hiding delay feedback and also has higher complexity [13]. Studies show that, the wider chaotic signal bandwidth is, the sharper autocorrelation function is. Using chaotic wideband optical time domain reflect meter can obtain higher resolution[16].That is to say, in the condition of the same spatial resolution, the double feedback system that generated broadband chaotic laser for ranging can obtain greater dynamic range[15] .

3. Experiments and Analysis

The actual design of the system, the probe is no longer pulse light, that is continuous wideband optical signal of a noise generated by double optical feedback, namely the wideband chaotic light[14].The probe cover C band, can also enter the WDM network all branch, combined with the cross-correlation operation, can realize high precision positioning of WDM optical fiber network breakpoint, extremely high spatial resolution measurements, and the resolution independent of detection distance, in the detection terminal through methods of filtering wave can identify the branch[30].The core of design is wideband chaotic light and related operations, in WDM optical fiber network breakpoint high precision positioning, at the same time, also can distinguish between each branch. The measurement system is shown in Figure 2:

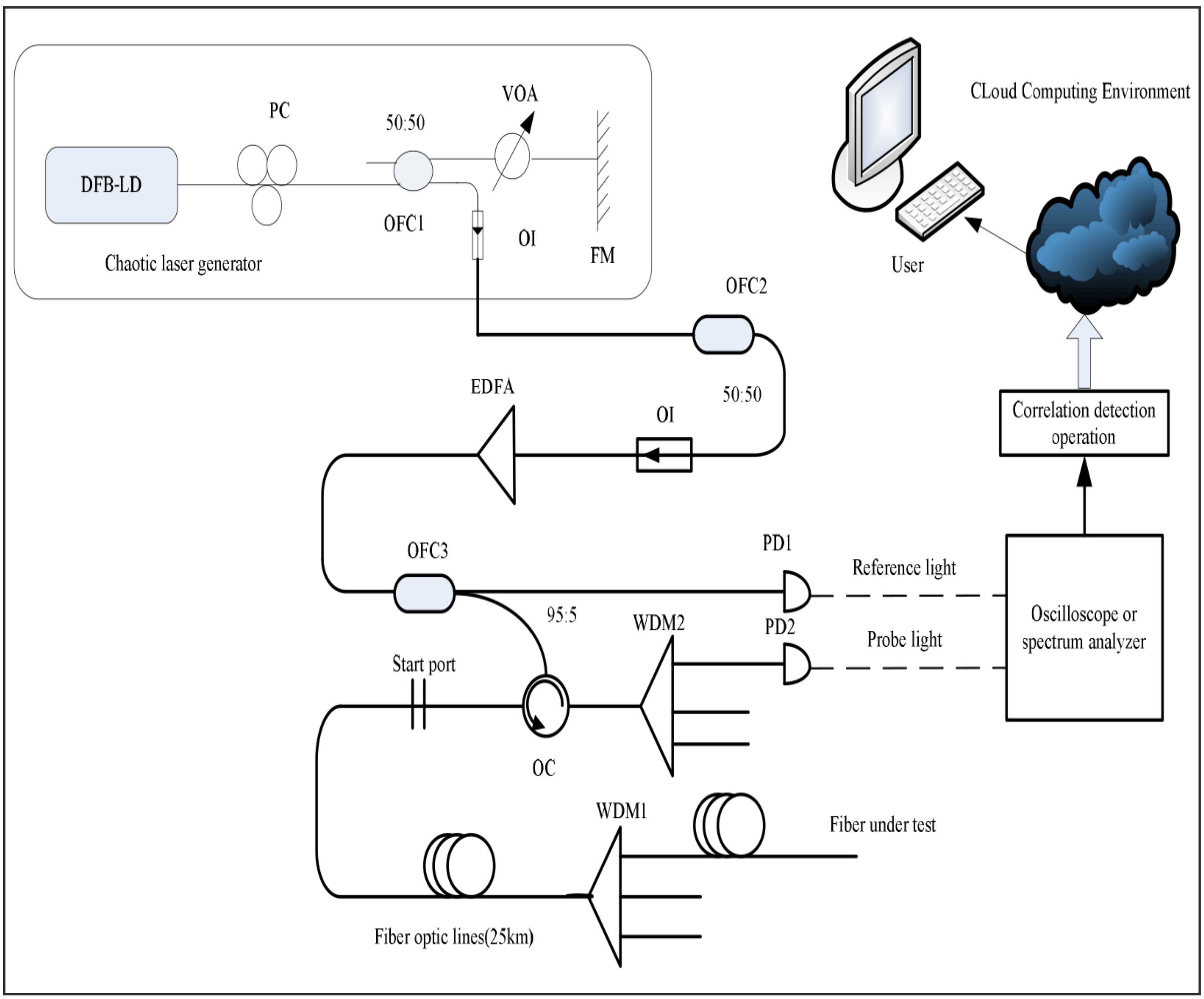

Figure 2. The experimental device of high precision optical fiber break detection

With semiconductor lasers of double optical feedback system generate wideband chaotic laser as light source of chaos, chaotic laser output wavelength changes by the laser feedback strength, feedback delay time, operation current etc., dynamic behavior of laser output will be extremely complex[9]. The cloud computing brought a new service model for information technology, with the help of powerful and elastic computation ability and storage capacity, the service scheduling and resource allocation in cloud environment have a major impact on the whole performance of computing, then turn the resources to interfaces and services, finally put proposes a framework of service platform with a collaborative service model of hybrid cloud in the cloud computing environment. In order to increase the power of the probe, wideband chaotic laser output of chaotic source amplification by erbium doped fiber amplifier to 12.7dBm ,spectra based on oscilloscope or spectrum analyzer display, target center wavelength, optical fiber coupler 95:5 chaotic laser as a reference and probe light, a road 5% as reference light and by the photoelectric detector 1 is converted into electric signal; a road 95% is used as the probe light from the optical circulator input to the optical network, optical signal to be reflected echo damage spot in the network by the photoelectric detector 2. Detection of light through the circulator output to the wavelength division multiplexer, detection light and reference light returning respectively by the photoelectric detector two same parameters (1,2) received by the 500MHz bandwidth, sampling rate of 8 GS/s oscilloscope and spectrum analyzer acquisition, and a computer on the two signal correlation processing, the amplitude and position analysis of correlation peak, can be measured along a location breakpoint in fiber optical fiber distribution determine the fault location, and then the control center wavelength multiplexer channel, can determine the detection circuit, then the WDM-PON system fault point accurately positioning[17] .

In the experiments FP laser bias current is set in 24.6mA, is about twice of the current threshold value, the output power of the laser light is 3dBm, operating wavelength range is 1 530 ~ 1 570nm, TFBG wavelength tuning range is 1 530 ~ 1 570nm, -3dB Line width is 0.5nm what is less than the AWG line width of 0.7nm. Scanning wavelength range of the OSA is 600 ~ 1 700nm, the minimum resolution is 0.06nm, bandwidth of PD1, PD2 are 1GHz, bandwidth of OSC is 6GHz, maximum real-time sampling rate is 40GSampl /s.

From the chaotic signal 30 wavelengths, for example, wavelength of chaotic laser is selected by 1548.51nm, 1549.72nm, 1550.92nm, and 1552.12nm to characterize, where in the mode selection before the spectrum shown in Figure 3, each spectrum SMSR (Side Mode Suppression Ratio, SMSR) are around 24dB.

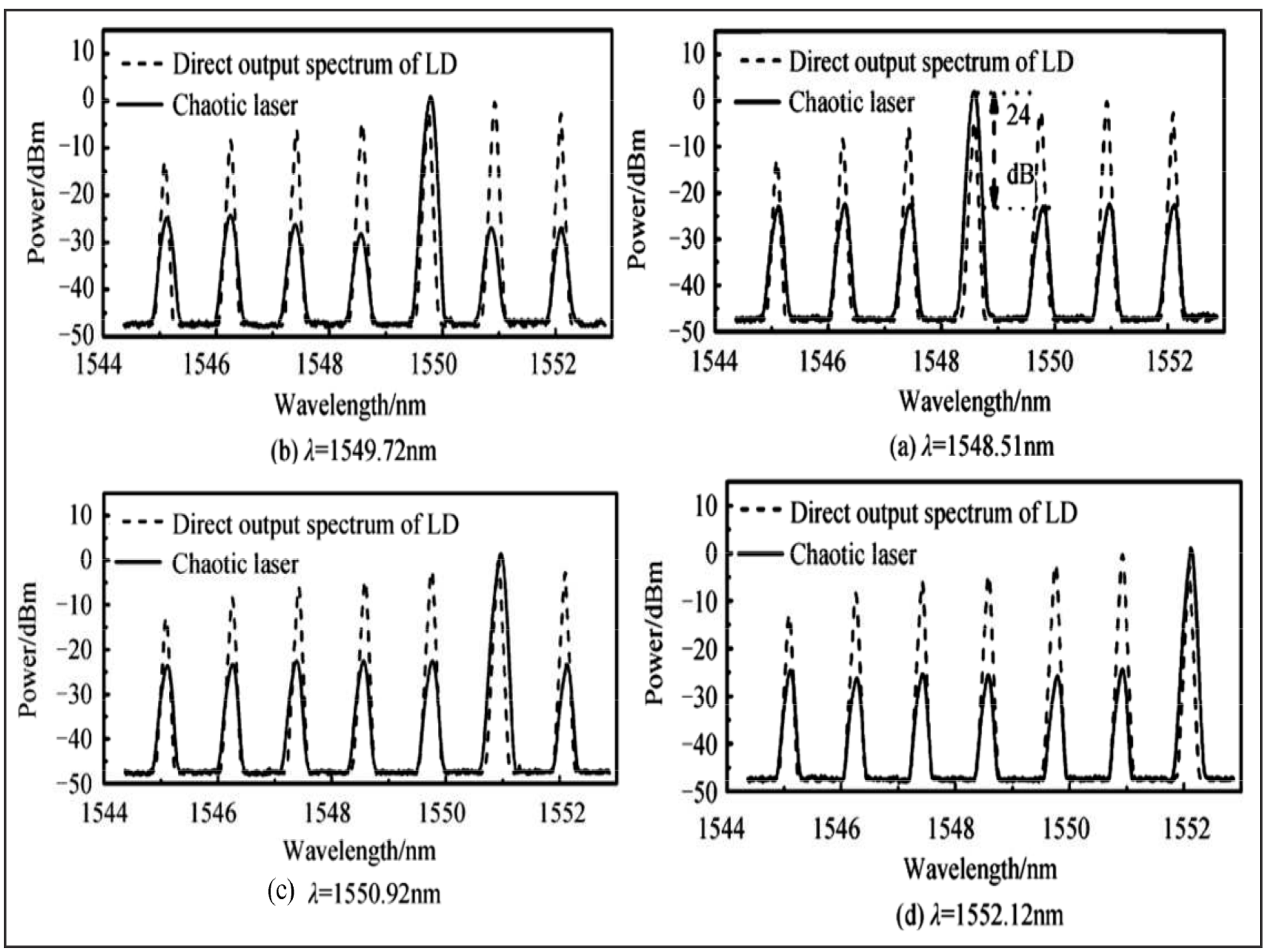

Figure 3. Optical spectrum of the chaotic laser

Since the correlation curve of wideband chaotic signals generated by the double optical feedback is similar to the linear function, cross-correlation function of time series and broadband chaotic laser output optical power and delay sequence also has such properties[16]. It can be the reference signal and the detection signal correlation operation positioning reflection event location[18]. A function relationship between the reference signal to meet the $X(t)$, Echo signal delay:

$$X(t) \otimes \cdot k \cdot X(t-\tau) \approx k \cdot \delta(\tau) \qquad (4)$$

During the experiment, the measurement of optical fiber in a 150m long with broadband chaotic laser correlation method, the curve peak position can determine the fiber length is 148.47m, the peak noise level at 137.63m for -12.9dB, the peak noise away from the location of the fiber end reflection peaks for the 12.37m, which is equivalent to the length of the feedback cavity semiconductor lasers [29]with optical feedback. Thus, the feedback generated chaotic laser cavity length characteristics of semiconductor lasers with optical feedback are also reflected in the correlation curve. The experimental findings, using fiber ring oscillator, the peak side lobe level can reduce the auto-correlation curve generated chaotic signal semiconductor lasers with optical feedback, the signal-to-noise ratio so as to improve the optical time domain measurement system with chaotic laser correlation method[19].Based on the chaotic laser source auto correlation and low frequency power improvement, and improve the signal-to-noise ratio of data by using the processing algorithm, the signal to noise is obtained to improve the level of test results, high accuracy detection of the faults locator can realize 0.8m and independent of the distance.

Data acquisition and recording of correlation optical fiber fault location systems based on chaotic laser are performed by acquisition card[20]. The algorithm is implemented by data acquisition card that connected to personal computer using the Visual Basic language programming[22]. Finally realized that the relation between the acquisition card and computer is controlled by second-developed program[23] of acquisition card, the final results are displayed on computer screen.

Elements	***Parameters***				
DFB-LaserDiode	Threshold Current	Typical Bias Current	Typical Emitting Power	Central Wave length	Spectrum Width
	22 mA	40 mA	2 mW	1553 nm	0.3 nm
Fiber Mirror	Working Wavelength	Working Bandwidth	Reflectivity		
	1550 nm	±40 nm	95%		
Photo-detector	Operating Voltage	Bandwidth	Conversion Gain		
	5 V	125 MHz	1.5 V/mW		
Data Capture Card	Bandwidth	Sampling Ratio	Memory Capacity		
	125 MHz	500 MS/s	2 M bytes		

Table 1. The Sub Part Parameters of Correlation Optical Fiber Fault Location System Based on Chaotic Laser

After chaotic laser with better auto correlation characteristic and higher power at low frequency is employed as probing light, which can help to improve the signal-to-noise ratio level of correlation optical fiber fault location system based on chaotic laser. At the same time, because of the use of data acquisition card and second-developed program of acquisition card, the average processing times and other optimization algorithms become possible. Then based on this kind of structure, this paper explores the data processing algorithm to improve the signal-to-noise ratio level of correlation optical fiber fault location system based on chaotic laser.

The correlation optical fiber fault location system based on chaotic laser is shown in Figure 2. Using this system, the three-section fiber that is connected with length of about 50m, 100m and 65m is measured. The measurement results of different data processing algorithms are shown in Figure 3.

In Figure 4 a) , The correlation operation results of the reference signal and the echo signal are shown which are obtained by means of averaged processing. The peak noise is at 167.8m. The reflected signals of the fiber and connector are submerged in noise. It was found that the signal-to-noise ratio of the system level is negative, when the results are obtained by means of averaged processing. That is to say , there is no signal is detected. The results of the correlation curve that are averaged 50 times are shown in Figure 4 b).The reflected signals of two connector and the fiber end which are located at 48.8m , 146.6m and 210.4m are detected. At this time, the peak noise is at 12.0m and the peak noise level is 15.8dB.However, the connector reflected signals of the measured fiber initial end are still submerged in noise.

These two chaotic signals under the condition of the same length and state is subtracted, then they carry on the auto-correlation operation[21].The results of numerical simulation show that the auto-correlation curve has the same full width at half maximum (FWHM)[24] and lower peak-side lobe[28], compared to the auto-correlation curve of one chaotic signal. Therefore, a novel algorithm is proposed for correlation optical fiber fault location system based on chaotic laser.

This algorithm obtains a new reference signal c=c1-c2 by means of subtract operation of two separate reference signals c1 and c2. The echo signals are e1 and e2 respectively, corresponding to the reference signals c1 and c2. A new echo signal e=e1-e2 is obtained by the same way. The correlation curve is obtained by using correlation operation of the modification reference signal and the echo signal. The results of the cross-correlation curve that are averaged 50 times are shown in Figure 4 c). As can be seen from the figure, the reflected signals of the fiber end and three connectors are both detected. At this time, the maximum noise is at 175.6m and the noise level is 18.8dB. Compared to the only average algorithm, the peak noise level is 15.8dB. This algorithm improves the signal-to-noise ratio level of correlation optical fiber fault location system based on chaotic laser. The chaotic signal under 3G, 1G, 500M acquisition bandwidth (FWHM) from the correlation shown in Figure 5.

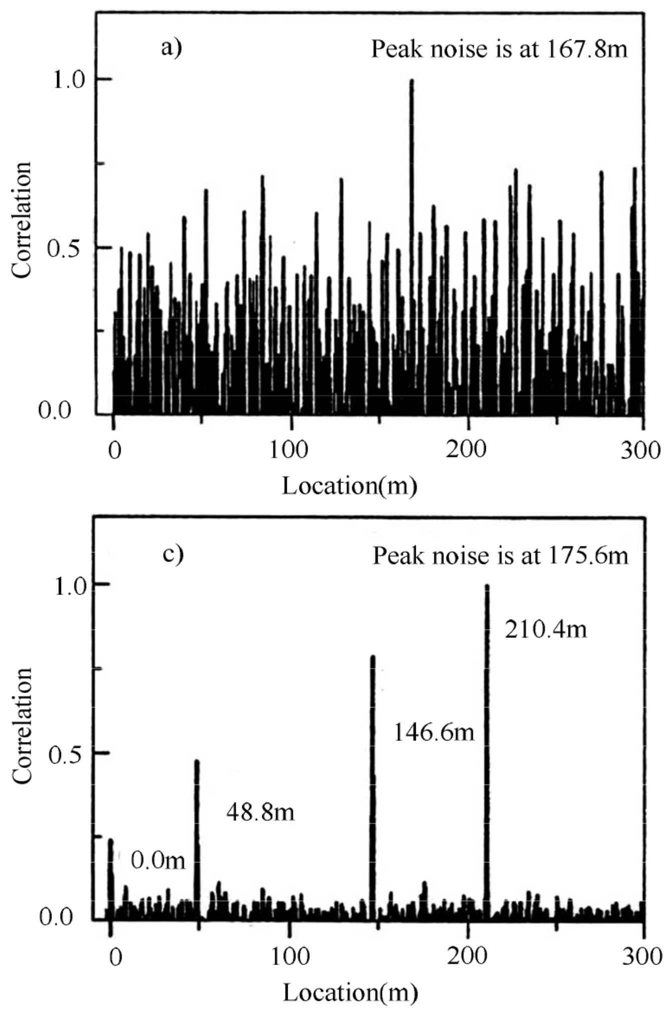

Figure 4. Correlation traces with averaging of 50 times when 48.8m,97.8m,63.8m fibers connected together with open snip end are measured

After the cross-correlation curve and the auto-correlation curve align with their main peaks, subtract the background noise of the auto-correlation curve from the cross-correlation .The results show that when the back scattering signal is strong, the back ground noise suppression ratio can be increased 5dB. According to this method, the auto-correlation curve and the cross-correlation curves of the modification reference signal and the echo signal are averaged 50 times, then carry on discrete elimination operation. The results are shown in Figure 4 d). Where the peak noise is at 28.4m and the peak noise level is 21.6dB. It is clear that this algorithm further improves the signal-to- noise ratio level of correlation optical fiber fault location system based on chaotic laser.

The test results shown in Figure 6, in Figure 6(a), the branch optical fiber end reflection peak and thereafter at a few hundred meters of the AWG are clearly visible; AWG reflection peak of the corresponding amplification, i.e., Figure 6 (b), LC/PC and FC/PC AWG around the connector, which is still close to the fault point can be accurately distinguished. Change detection wavelength, as shown in Fig. 6(c), after AWG to 23 664.26m measured at FC / PC connector at the 33 091.71m in PC end. If the breakpoint occurs at a certain location feeders, because the probe light cannot reach network branch after feeder no longer has a correlation peak, as shown in Figure 6 (d).

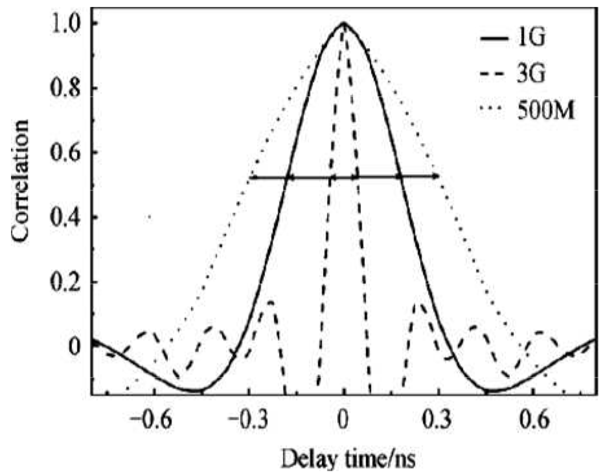

Figure 5. Relationship between FWHM and bandwidth

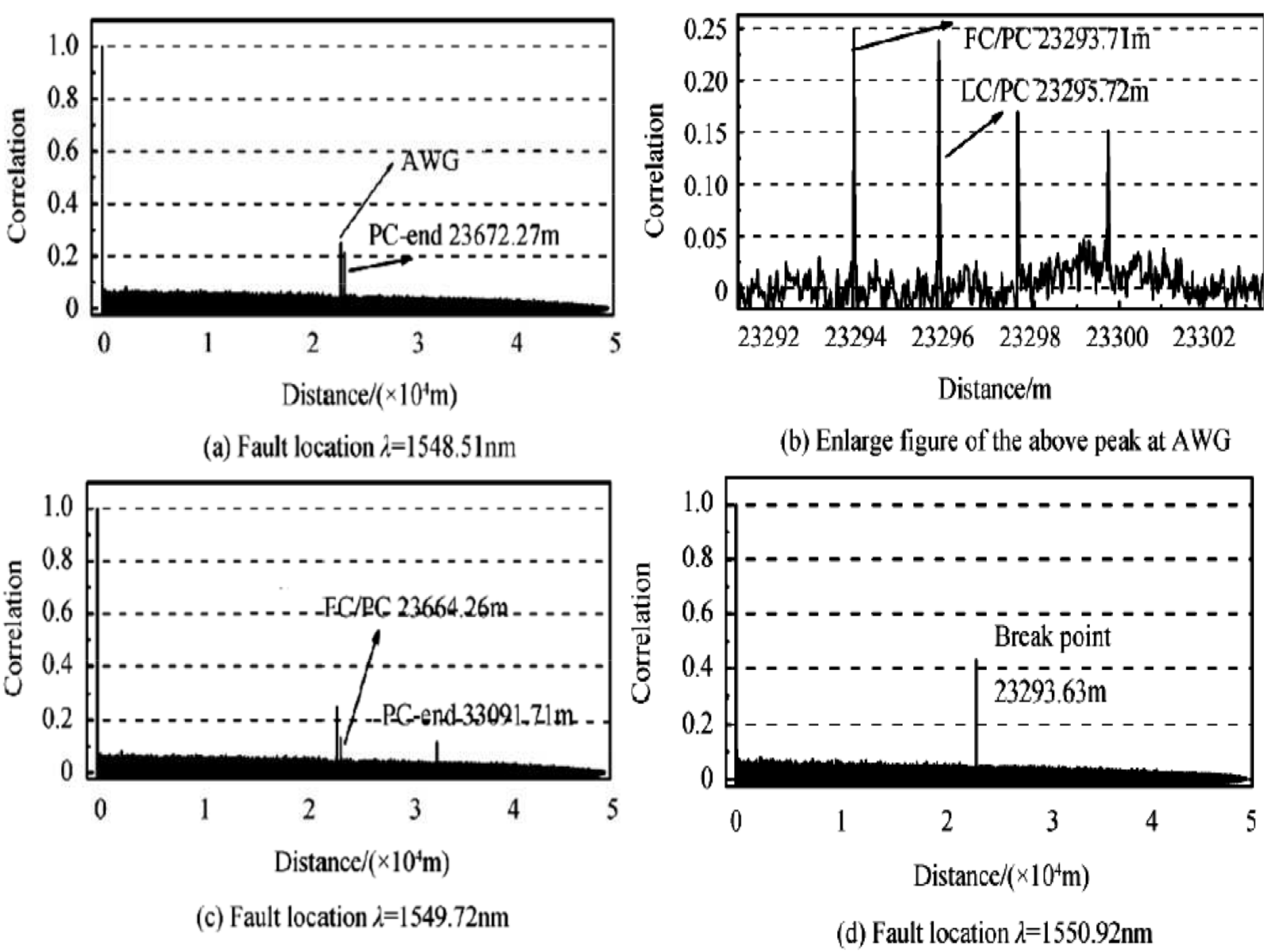

Figure 6. Experimental results of the fault location for WDM-PON utilizing the tunable chaos correlation OTDR

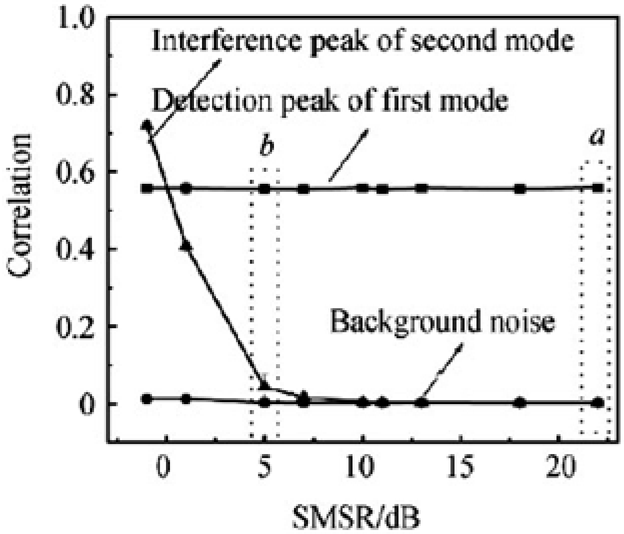

Figure 7. The curve of SMSR impact on the fault detection

Currently, the correlation curve in Figure 5 can pinpoint the location of the connection point and the breakpoint, it is still unable to characterize the Rayleigh scattering trends, and this work is still in progress currently.

With reference to the curve in Figure 7 (c), is the curve of SMSR impact on the fault detection.

4. Conclusion

The main characteristic of WDM-PON is the node-tree structure. In order to preciously locate faults in each branch, a method based on tunable chaotic laser is proposed. Chaotic light emitted from an optical feedback multiple-longitudinal mode semiconductor laser diode is utilized as the probe beam. By selecting the feedback mode, a tunable chaotic laser is obtained. The branches of the optical networks are distinguished by the laser's wavelength, and fault location is realized by calculating the cross-correlation of transmitted and back-reflected signals. In the experiment, we analyses the chaotic property and take a WDM-PON to be detected, the measurement results show that the breakpoints and connectors could be preciously located with this method.

The system adopts broadband chaotic laser produced by double optical feedback semiconductor laser as the light source, using the correlation method can realize the positioning of the WDM-PON reflection events. Wideband chaotic signal to auto correlation characteristics of its broadband characteristics and narrow peak, preliminary achievements have been made in the high precision optical fiber break detection, has wide application prospect. However, research on optical fiber attenuation measurement of wideband chaotic laser has not started, and optical time domain measurement system of broadband chaotic laser correlation method with low level SNR, follow-up can improve SNR to further study.

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References

[1] Wang, A. B., Wang, Y. C. (2010). Chaos correlation optical time domain reflectometry, Science China Information Science, 53, 398-404.

[2] Kanter, I., Aviad, Y., Reidle, I. (2010). An optical ultrafast random bit generator, *Nature Photon,* 2, 8-61.

[3] Lang, R., Kobayashi, K. (1980). External optical feedback effects on semiconductor injection laser properties, IEEE *J. Quantum Electron,* 16, 347-355.

[4] Park, S. - J., Lee, C. -H., Jeong, K. -T., Park, H. -J., Ahn, J. -G., Song, K.-H. (2004). Fiber-to-the-home services based on wavelength-division-multiplexing passive optical network, *J. Lightw. Technol*. 22, 2582-2591.

[5] Banerjee, A., Park, Y., Clarke, F., Song, H., Yang, S., Kramer, G., Mukherjee, B. (2005). Wavelength division multiplexed passive optical network (WDM-PON) technologies for broadband access: A review, *J. Opt. Netw*. 4,737-758.

[6] Lee, C.-H., Sorin, W. V., Kim, B. Y. (2006). Fiber to the home using a PON infrastructure,"J. Lightw. Technol., 24, 4568-4583.

[7] Tanaka, K., Tateda, M., Inoue , Y. (1996). Measuring the individual attenuation distribution of passive branched optical Networks, IEEE Photon. *Technol. Lett*. 8, 915 - 917.

[8] Thollabandi, M., Kim, T. Y., Park, C. S. (2008). Tunable OTDR based on direct modulation of self-injection-locked RSOA for in-service monitoring of WDM-PON, IEEE Photon. *Technol. Lett.*, 20, 1323 -1325,2008

[9] Uchida, A., Amano, K., Inoue, M., Hirano, K., Naito, S., Someya, H., Oowada, I., Kurashige, T., Shiki, M.,

Yoshimori, S., Yoshimura, K., Davis, P., (2008). Fast physical random bit generation with chaotic semiconductor lasers, *Nat. Photon*, 2, 728-732,2008

[10] Hong, Y. H., Lee, M. W., Paul, J., Spencer, P. S., Shore, K. A. (2009). GHz bandwidth message transmission using chaotic vertical-cavity surface-emitting lasers, *J.Lightw. Technol*., 27, 5099 -5105.

[11] Shih, F. Y., Yeh, C. H., Chow, C. W., Wang, C. H., Chi, S. (2010). Utilization of self-injection Fabry-Perot laser diode for long-reach WDM-PON, *Opt. FiberTechnol*.,16, 46-49.

[12] Wang, A. B., Zhang, M. J., Xu, H., Wang, Y. C., Location of wire faults using chaotic signal, *IEEE Electron Device Lett*., 32, 372 -374.

[13] Wang, A. B., Wang, Y. C., He, H. C. (2008). Enhancing the bandwidth of the optical chaoticsignal generated by a semiconductor laser with optical feedback, IEEE Photon. *Technol. Lett*., 20, 1633-1635,2008

[14] Uchida, A., Heil,T., Liu, Y., Davis, P., Aida, T. (2003). High-frequency broad-band signal generation using a semiconductor laser with a chaotic optical injection, IEEE *J. Quantum Electron*., 39, 1462-1467.

[15] Fischer, A. P. A., Yousefi, M., Lenstra, D., Carter, M. W., Vemuri, G. (2004). Experimental and theoretical study of semiconductor laser dynamics due to filtered optical feedback, IEEE *J. Sel. Topics Quantum Electron*., 10, 944 -954.

[16] Maurizio, Z., Paolo, B. (1983). High spatial resolution OTDR attenuation measurements by a correlation technique, *Appl. Opt*, 22, 3680-3681.

[17] Noguchi, K. A. (1984). 100-km-long single-mode optical- fiber fault location, *Lightwave Technol*, 2, 1-6.

[18] Mendietal, F. J., Trevino, A. Martinez, C.A. (1996). Complementary sequence correlations with applications to reflectometry studies, *Journal of the Mexican Society of Instrumentation*, 3, 37-46.

[19] Takushima, Y., Chung, Y. C. (2007). Optical reflectometry based on correlation detection and its application to the in -service monitoring of WDM passive optical network, *OPt.Express*, 15, 5318-5326.

[20] Healey, P. (1981). Optical orthogonal pulse compression codes by hopping, *Electron.Lett*., 17, 970-971.

[21] Healey, P., Hensel, P. (1980). Optical time-domain reflectometry by Photon counting, *Electron.Lett*., 16, 631-633.

[22] Healy, P. (1981). Multichannel Photon-counting backscatter measurement on monomode fiber, *Electron.Lett*., 17, 751-752.

[23] Bernard, J. J., Depresles, E. (1988). Submeter resolution OTDR for single-mode fiber LAN cabling tests, In Proceedings EFOC/LAN-88(Amsterdam, Holland),127-130.

[24] Danielson, B. L., Whittenberg, C. D. (1987). Guided-wave reflectometry with micrometer resolution, *Appl.Opt*., 26, 2836-2842.

[25] Lin, F. Y., Liu, J. M. (2004). Chaotic Lidar, IEEE J. Sel. Top. *Quantum Electron*, 10, 991-997.

[26] Lin, F. Y., Liu, J. M. (2004). Chaotic Radar Using Nonlinear Laser Dynamics, *IEEE J. Quantum Electron*., 40, 815-520.

[27] Wang, Y. C., Wang, B. J., Wang, A. B. (2008). Chaotic correlation optical time domain reflectometer utilizing laser diode, IEEE Photo. *Tech.Lett*., 20, 1636-1638.

[28] Lin, F. Y., Liu, J. M. (2004). Diverse Waveform Generation Using Semiconductor Lasers for Radar and Microwave Applications, *Quantum Electron*., 40, 682-689.

[29] Tkach, R. W., Chraplyvy, A. R. (1986). Regimes of feedback effects in 1.5-um distributed feedback lasers, *Lightwave Technol*.,1986, 4, 1655-1661.

[30] Tholbandi, M., Kim, T. Y., Hann, S. (2008). Tunable OTDR based on direct modulation of self-injection-locked RSOA for in-service monitoring of WDM-PON, *Photonics Technology Letters*, 20, 1323-1325.

[31] Wang An-bang., Wang Yun-cai. (2010). Chaos correlation optical time domain reflectometry," Science China *Information Sciences*, 40, 512-518.

[32] Bao, X., Chen, L. (2011). Recent progress in Brillouin scattering based fiber sensors, *Sensors,* 11, 4152-418.

[33] Shin, W., Yu, B. A., Lee, Y. L., et al. (2009). Wavelength tunable optical timedomain refletometry based on wave length swept fiber laser employing two dimensionaldigital micromirro array,*Optics Communication*, 282,pp.1191-1195.

[34] Yang Cong-yuan., Wang An-bang., Zhang Zhao-xia., et al. (2011). Correlation optical fiber fault locator based on chaotic laser and its experimental application research, *Chinese Journal Lasers*,38, 0208002-1-0208002-5.

[35] Bao, X., Li, W., Li, Y., et al. (2009). Distributed fiber sensors based on stimulated Brillouin scattering with centimeter spatial resolution, SPIE, 7158: 715802-12

[36] Xu Hang., Wang An-bang., Han Xiao-hong., et al. (2011). Measuring breakpoints and impedance mismatch for dielectric transmission lines by using correlation method of chaotic signals, *Acta Physica Sinica*, 60, 090503-1-090503-6.

[37] Jamioy, G., Jose, M. (2011). Decimeter spatial resolution by using differential preexcitation BOTDA pulse technique, *IEEE Sensors Journal*, 11, 2344-2348.

[38] Han Guo-hua., Wang Yun-cai. (2011). Faults location for transmission lines by using chaotic laser signal, *Chinese Journal of Lasers*, 2011, 38, 0208002-1- 0208002-5.

[39] Horiguchi, T., Tateda, M. (1989). BOTDA-nondestructive measurement of single-mode optical fiber attenuation characteristics using Brillouin interaction:

theory, *Journal of Lightwave Technology*, 7, 1170-1176.

[40] Ding Ling., Wu Jia-gui., Xia Guang-qiong., et al, (2011). Effect of external optical feedback strength on time delay signatures in semiconductor laser with double optical feedback, *Acta Photonica Sinica*, 4, 740-745.

[41] Behnia, S., Mabhouti, K., Jafari, A., et al,. (2012). Observations on the dynamics of external cavity semiconductor Lasers, *Optik*, 123, 1555-1561.

[42] Wang Yan-bin., Zhang Sheng-hai., Shao Ming., et al. (2008). Chaos and chaotic synchronization in current-modulated semiconductor lasers, *Acta Photonica Sinica*, 37, 2167-2171.

[43] Suzuki, K., Noguchi, K., Uesugi, N. (1986). Long-range OTDR for single-mode optical fiber using a P20s highly doped fiber Raman laser, *Electron. Lett*., 22, 1273-1274.

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