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Sampled FBG based all optical wavelet analyzer for high speed optical communication signals

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Abstract

All optical wavelet analysis system for high speed fiber-optic communication signals using sampled FBG based optical wavelets is proposed and investigated numerically. With this analyzer, the root cause of signal degradation is easily identified.

1 Introduction

Wavelet analysis is a popular group of the time-frequency analysis method in signal processing field. They use a finite length or localized function known as 'mother wavelet' as the basis function. Although the effectiveness of the wavelet analysis is widely known, it requires convolution integrals between the analyzed signal and the scaled and time-shifted 'wavelets', therefore it requires a huge amount of computation.

To the knowledge of the author, there is no real time wavelet analyzer for the high speed fiber-optic communication signals due to above huge computation requirements. In addition, the slow operation frequency of the electrical digital signal processors, compared to the speed of the fiber-optic communication signals, is another reason for the non-existence of the real time wavelet analyzer for high speed optical signals.

The authors have studied the sampled FBG based optical transversal filters (SFBG-OTFs) and its applications to high speed fiber-optic communications. A SFBG-OTF consists of serially placed FBGs with partial reflectivity and a certain interval between adjacent FBGs. The output of the SFBG-OTF is considered as a convolution integral between the input signal and the impulse response of the SFBG-OTF. Therefore, by using the SFBG-OTFs, all-optical wavelet analysis can be realized. In this paper, all-optical wavelet analyzer is proposed and investigated numerically.

2 All-optical wavelet analysis based on SFBG-OTF

The wavelet analysis is done by convolution integral between the signal $g(t)$ to be analyzed and a scaled and time-shifted 'wavelet' function $\psi((t-b)/a)$ as shown in Eq.(1).

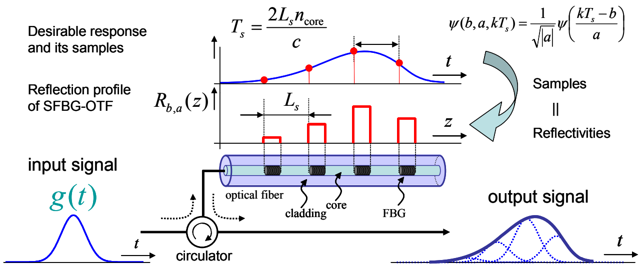

Fig.1 All-optical wavelet analysis using SFBG-OTF.

$$W(b,a) = \frac{1}{\sqrt{|a|}}\int_{-\infty}^{\infty}\psi\left(\frac{t-b}{a}\right)g(t)dt, \quad (1)$$

where a is the frequency scaling factor and b is the time-shifting factor. To implement this operation by all-optical processing, a SFBG-OTF, of which reflection profile is corresponding to the scaled and time-shifted wavelet, is used.

Fig.1 shows the basic concept of the SFBG-OTF based optical wavelet, where the reflection profile of the SFBG is corresponding to the sampled values of the desirable wavelet function. The sampling period T_s of the target wavelet function is determined as $T_s=2L_s n_{core}$, where L_s, n_{core} and c is the FBG interval, the refractive index in the fiber core and the speed of light in vacuum, respectively. For example, if L_s=1mm and n_{core}=1.4491, T_s=9.7ps and more than 100GS/s operation is achieved.

Fig.2 shows how to implement optical wavelets corresponding to the different scaling factor a. The wavelets in Fig.2 are the Gabor wavelet given as follows.

$$\psi(x) = \frac{1}{2\sqrt{\pi\sigma}}e^{-\frac{x^2}{\sigma^2}}e^{-jx}, \quad (2)$$

where $x=2\pi c\, t/\lambda_m$ and λ_m is the Bragg wavelength of the m-th optical wavelet. Namely, changing the Bragg wavelength of the SFBG-OTF also changes the scaling factor a. Though it is drawn in Fig.2 that the FBG interval

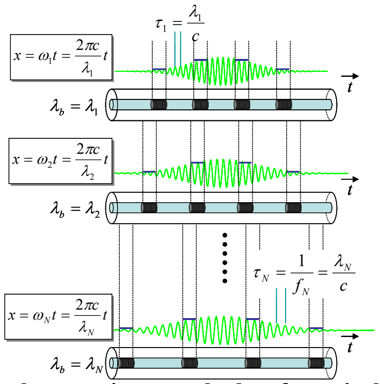

Fig.2. Implementation method of optical wavelets corresponding to the different scaling factor *a*.

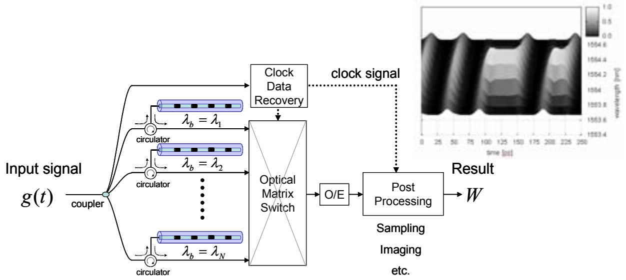

Fig.3. Block diagram of the proposed all-optical wavelet analyzer using SFBG-OTF based optical wavelets.

is also changed in conjunction with the Bragg wavelength of the SFBG-OTF, it is not essential when the bandwidth of the optical wavelet analyzer is narrow.

Fig.3 is the block diagram of the proposed all-optical wavelet analyzer. It consists of a splitter, circulators, SFBG-OTFs as the optical wavelets, an optical matrix switch, a clock data recovery circuit, an O/E converter, and a computer system for data acquisition and image processing. The output of this analyzer is magnitude of the wavelet transformation of the analyzed signal.

3 Computer simulation

In prior to the proof-in-principle experiments, some computer simulations were performed to investigate that how the distorted optical communication signals were observed by the proposed optical wavelet analyzer. Fig. 4 shows the simulation model. For simplicity, the 40Gbit/s NRZ-OOK signal was chosen as the target signal to be analyzed and its transmission through tens kilo-meters of the dispersion shifted fiber was simulated by numerically solving the Schrödinger's equation. The signals, passed through the SFBG-OTFs, were O/E converted and contour plots were composed from them. In the contour plots, the horizontal and vertical axes are time and wavelength (i.e. frequency), respectively.

Fig. 5 shows the simulation results. The left column is for waveforms and the right one is for their wavelet transformations. Through these simulations, the signal power launched into the fiber was 20dBm and a optical fiber without loss was assumed to enhance the SPM effects in the fiber. Although the waveform degrades according to the transmission, the reason why it degrades is not able to be known directly from the waveforms and also from the optical spectra. On the other hand, by observing the wavelet transformations, it is clearly seen that the leading and trailing edges of the signal got blue and red shifts, respectively. Therefore, it is easily known that the main cause of the signal degradation is the SPM effects in this case.

4 Conclusion

A concept for all-optical wavelet analyzer for high speed fiber-optic communication systems was proposed. The computer simulation results indicate its validity for characterization of the high speed fiber-optic communication signals. The implementation of the optical wavelets by the SFBG-OTFs, and the proof-in-principle experiments of the proposed all-optical wavelet analyzer are subjects in future.

Acknowledgement

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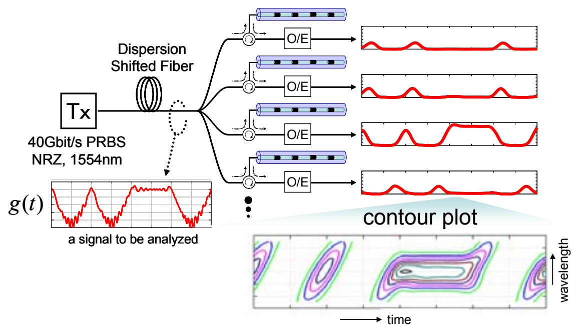

Fig.4. Simulation model.

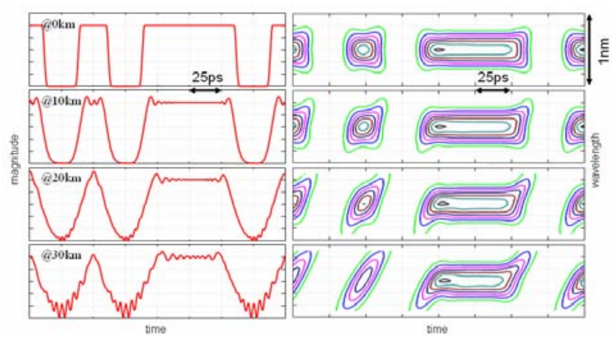

Fig.5. Simulation results for 40Gbit/s NRZ signal. P_{peak}=20dBm, 40km DSF, Gabor wavelet, N_{wl}=10, N_{FBG}=20, L_{FBG}=0.2mm, L_g=0.2mm.