Fiber-Fault Identification for Branched Access Networks Using a Wavelength-Sweeping Monitoring Source

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***Abstract*—We propose and experimentally demonstrate a new fiber-fault identification scheme for optically amplified branched networks. The scheme makes use of fiber Bragg gratings and an internally generated light source from an erbium-doped fiber amplifiers through an optical feedback loop, and no additional dedicated monitoring source is required. The monitoring technique invokes both frequency and time domain by sweeping the wavelength of the monitoring source. By combining with a conventional optical time-domain reflectometer technique, exact location in fiber cut in branched network can be identified readily.**

***Index Terms*—Fault detection, optical networks.**

I. Introduction

PASSIVE optically amplified branched networks are very promising and cost effective architecture for future access networks. For these networks, erbium-doped fiber amplifiers (EDFA's) are often placed before the optical tree-coupler to support more fiber branches and to improve the transmitted signal quality. Since such network can accommodate a large number of subscribers, any service outage due to a fiber cut can be translated into tremendous financial loss for the service providers. A real-time, nonintrusive fault surveillance system for fiber-fault identification is therefore essential.

Conventionally, optical time-domain reflectometer (OTDR) based on a single-wavelength source was used for fault detection in branched networks, but such scheme suffers from Rayleigh back-scattered light from different branches which could not be differentiated at the OTDR [1]. OTDR based on a multiwavelength source [2] was also proposed but the high cost of the wavelength tunable monitoring source prohibited it as a practical solution. Recently we proposed a passive surveillance scheme [3] which used fiber Bragg gratings (FBG's) to slice and reflect the unused portion of the amplified spontaneous emission (ASE) of EDFA as a means for faulty fiber branch detection. However, the relative weak ASE power limits the length of the fiber segment in the branches. In this letter, we propose and demonstrate a new fiber-fault identification scheme that is simple to implement. It makes use of an FBG with a wavelength-sweeping monitoring laser source formed by feeding the ASE back into the EDFA through a wavelength tunable filter. The fiber branches can continuously be supervised by monitoring the periodic reflected optical pulses in time-domain.

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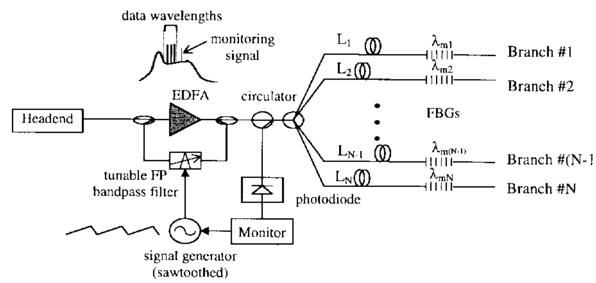

Fig. 1. Our proposed fiber-fault identification scheme for an optical amplified branched network.

II. Fiber Identification Scheme

Fig. 1 shows the proposed fiber-fault identification scheme for a $1 \times N$ optically amplified branched network. The data channels are transmitted in the EDFA's flat-gain region of 1540–1555 nm while the ASE power in the unused gain spectrum (1556–1562 nm) is used as the monitoring light source. The light source is constructed by looping back some of the EDFA emission to its input through a tunable Fabry–Perot etalon filter (FPF), thus generating a gain-clamped saturated laser emission [4] with wavelength-tuning capability. By applying a periodic saw-toothed voltage at a few kilohertz to the FPF, in which the sweeping speed is only limited by the frequency response of the FPF, the gain-clamped signal is made to sweep through the unused EDFA gain spectrum periodically and thus serves as a wavelength-sweeping monitoring light source. An FBG of distinct center reflection wavelength is placed at the end of each fiber branch as the branch identifier. Ideally, the FBG's should have similar 3-dB bandwidths and their center reflection wavelengths are spaced equally within the unused EDFA gain spectrum. For surveillance application, the FBG's must have stable thermal response, and can be achieved by means of temperature-compensated package [5].

In each sweeping cycle, the emission wavelength of the monitoring signal is swept continuously through the unused

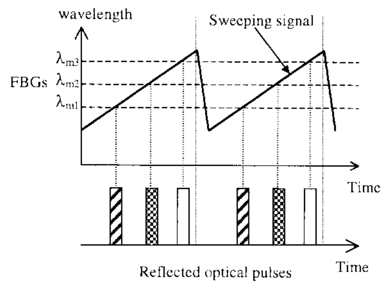

Fig. 2. Operation principle of the fiber-fault identification scheme.

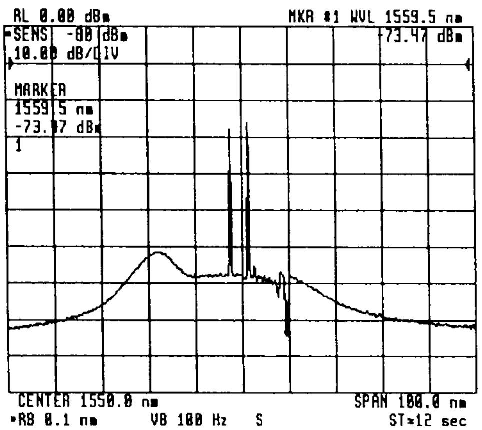

Fig. 3. Tansmitted spectrum at branch #3.

EDFA gain spectrum. As illustrated in Fig. 2, when the FBG center wavelength matches with that of the wavelength sweeping monitoring source, an optical pulse will be generated and reflected upstream to a monitoring photodiode via a circulator (see Fig. 1). Thus the health status of a certain fiber branch is signified by the presence of the respective optical pulse in each sweeping period. By demultiplexing the detected optical pulses in each sweeping time period, the status of all fiber branches can be monitored continuously.

Comparing to the ASE as a monitoring source in [3], the light source is a ring laser and thus provides a better power budget. Unlike the application in conventional fiber ring laser [6], our scheme is insensitive to possible polarization-induced power fluctuations, as the health status of all fiber branches is signified by either the presence or the absence of the reflected optical pulse in each sweeping period. Major constraint of this scheme will be the collision of reflected optical pulses. To avoid pulse collision requires $(2nL/c) < 1/(Nf)$, where n is the refractive index of fiber core, c is the speed of light in vacuum, N is the number of fiber branches, L is the length of a fiber branch or segment and f is the sweeping frequency of the monitoring source. For example, for $N = 8$, $f = 1$ kHz, $n = 1.5$, the maximum length of each fiber branch L is 12.5 km.

III. Experiments

We have experimentally demonstrated the proposed fault surveillance scheme in a 1×4 branched optical network. The experimental setup is similar to Fig. 1. Two data channels at 1548 nm and 1551 nm, carrying 1-Gb/s $2^{10}-1$ pseudorandom bit sequence (PRBS) nonreturn-to-zero (NRZ) data, are amplified by an EDFA and distributed over all the fiber branches with $L_1 = 8.8$ km, $L_2 = L_3 = 6.6$ km while fiber branch #4 is left unmonitored. Three FBG's (power reflectivities ∼99%) with center reflection wavelengths of 1556.4, 1558, and 1559.7 nm, and with 3-dB passband of 0.4, 0.8, and 0.9 nm are placed on fiber branches #1, #2, and #3, respectively. At the EDFA, the wavelength tunable feedback loop is constructed by two 1×2 optical couplers with splitting ratios of 50/50 and 95/5, and a tunable FPF (JDS TB2500M) with a free-spectral range (FSR) of 70 nm and a passband of 0.7 nm. A periodic sawtoothed signal at a frequency of 2 kHz is applied to the FPF. Together with the correct bias dc voltage, the monitoring signal sweeps through 1555–1561 nm periodically.

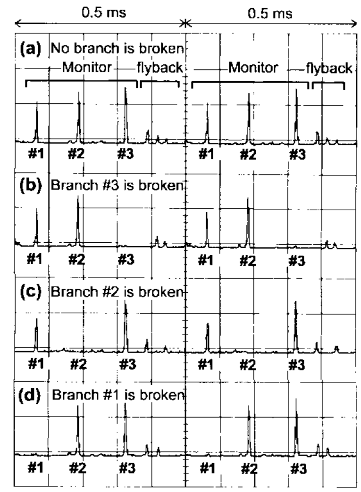

Fig. 4. Reflected optical pulse train measured at the monitoring module for four different scenarios.

Fig. 3 shows the optical spectrum measured at the terminating end of fiber branch #3 without connecting the feedback loop. The presence of the deep notch indicates the reflection at FBG #3. With the feedback loop closed, the detected optical pulse trains measured at the photodiode are shown in Fig. 4 for different scenarios. As shown in the figure, the sawtoothed period is about 0.5 ms consisting of 0.35 ms of scanning period and 0.15 ms of flyback period. For healthy state as shown in Fig. 4(a), all three optical pulses, each signifying one fiber branch, are present. Weak residual pulses are also detected in the flyback period. Fig. 4(b)–(d) shows the detected optical pulse train for fiber cut in fiber branches #3, #2, and #1, respectively. Any fiber cut is indicated by the absence of the corresponding optical pulse in each sweeping period. Bit-error-rate (BER) performances of the data wavelength operating at 1-Gb/s $2^{10}-1$ PRBS NRZ data at 1551 nm were also measured and are shown in Fig. 5. A 1-dB power penalty is found with the monitoring source sweeping at 2 kHz. This is due to the difference in EDFA gain in the sweeping region, causing slight power fluctuation at the data channel. Sweeping in a region with a flatter EDFA gain can alleviate such penalty.

IV. Summary

We have proposed and experimentally demonstrated a simple and practical fiber-fault identification scheme for optically

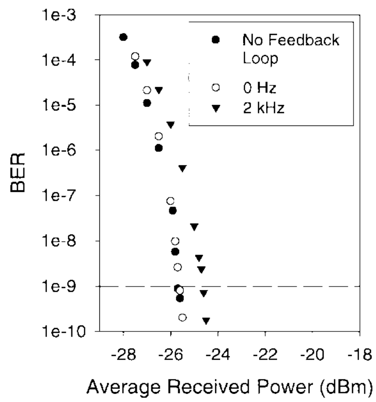

Fig. 5. BER performance measurements for a 1-Gbs/s $2^{10}-1$ PRBS NRZ data at data wavelength of 1551 nm. The monitoring signal is sweeping at 2 kHz.

amplified branched networks. The scheme makes use of FBG's and internally generated light source from an EDFA through an optical feedback loop, and no additional dedicated monitoring source is required. The monitoring technique invokes both time and frequency domain and can be implemented easily. By combining with conventional OTDR techniques, exact location in fiber cut in a branched network can be identified readily.

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