A Practical Passive Surveillance Scheme for Optically Amplified Passive Branched Optical Networks

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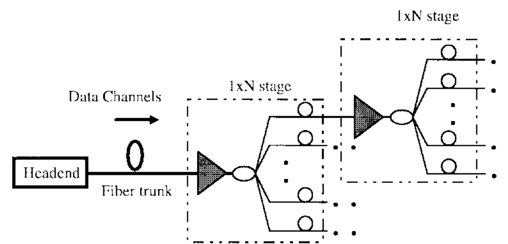
***Abstract*—We propose and experimentally demonstrate a novel and practical surveillance scheme for in-service fault identification in passive optically amplified branched networks. This scheme does not require any wavelength-tunable light source as used in multiwavelength optical time-domain reflectometer (OTDR). Fiber-Bragg gratings are placed at some strategic positions on different fiber branches to slice and reflect the optical amplifier's residual amplified spontaneous emission (ASE) power at some wavelengths other than the signal wavelengths. The conditions of the fiber link and optical amplifier at each branch can be monitored by constantly checking the reflected power level of the corresponding wavelength without suspending the in-service channels.**

***Index Terms*— Fault diagnosis, optical fiber communication, optical fiber testing.**

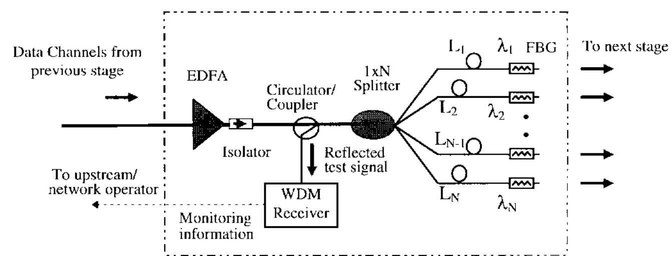
I. INTRODUCTION

PASSIVE branched optical networks (PBON) are very promising and cost-effective for future subscriber and broadband networks such as CATV and fiber-to-the-home systems. In order to improve the transmission span and support more fiber branches in the transmission window at 1.55 μm, Erbium-doped fiber amplifiers (EDFA) are used to compensate the transmission and splitting losses. With the enormous communication capacity that can be carried on optical fiber, any service outage due to fiber cut translates into tremendous loss in business. It is, therefore, essential for network operators to have a good surveillance system to identify the faults along the fiber link timely. Moreover, the monitoring should be performed constantly while other channels are still in service to maximize the link utilization.

In PBON, fault location using conventional optical time-domain reflectometer (OTDR) is not suitable since the Rayleigh back-scattered light from different branches cannot be differentiated at the OTDR. Recently, several methods [1], [2], based on multiwavelength OTDR, have been proposed. All these, however, require a wavelength-tunable pulse light source that imposes high-maintenance cost. For the schemes that allow in-service monitoring [1], [2], the strong monitoring signals from the wavelength-tunable light source may deplete the gain of the in-line optical amplifiers and result in system penalty. In this letter, we propose a novel and practical passive surveillance scheme for in-service fault identification of links and optical amplifiers on PBON's without using any extra light source.



(a)



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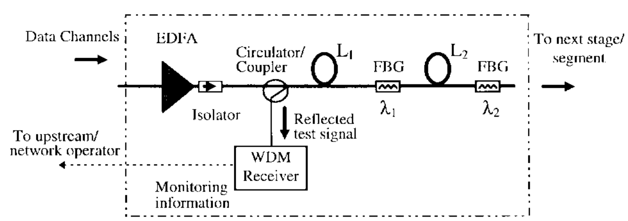

(c)

Fig. 1. (a) An M-ary tree-branched PBON. Our proposed surveillance scheme for (b) a 1 $\times N$ stage, and (c) a single feeder. Note that the optical isolator can be removed when the optical circulator is used instead of the coupler.

II. PASSIVE SURVEILLANCE SCHEME

Fig. 1(a) shows an M-ary PBON which consists of multiple

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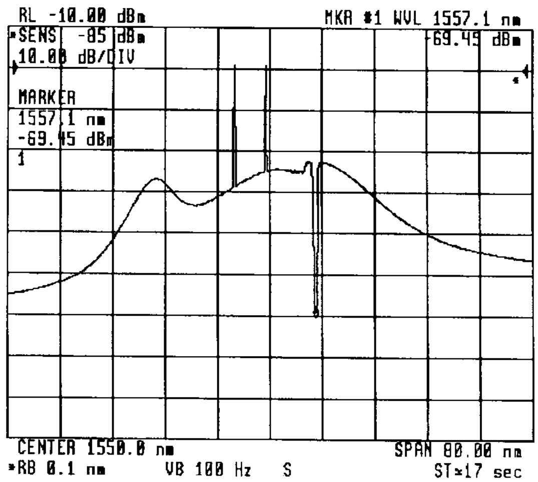
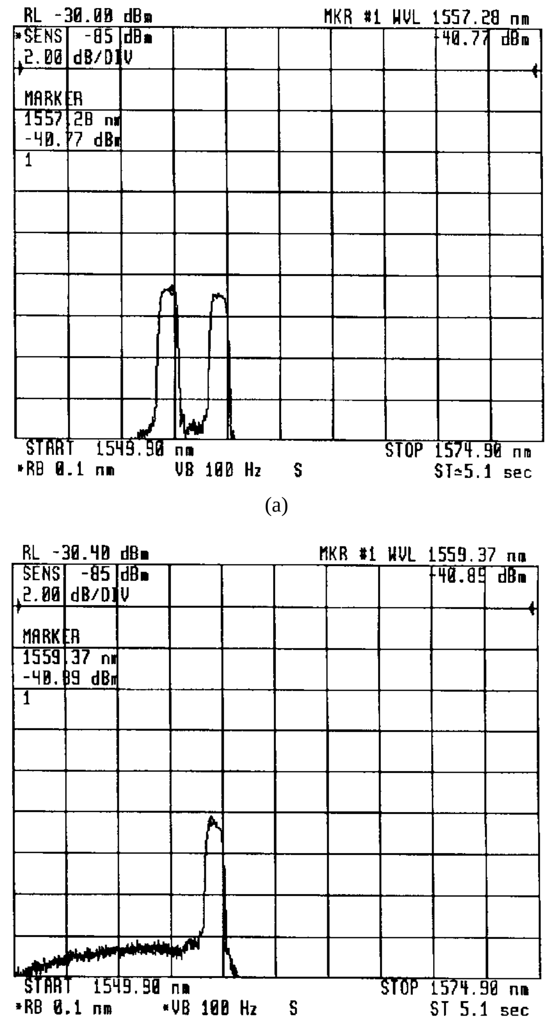


Fig. 2. Experimental results: Transmitted spectrum of branch 1 in a 1 × 4 stage.

$1 \times N$ stages. The monitoring wavelength assignment in each stage can be duplicated. Fig. 1(b) and (c) shows the proposed surveillance schemes for two types of network configuration, 1) a $1 \times N$ stage, and 2) a single feeder (a special case of $1 \times N$ stage). In our scheme, instead of using an extra light source for monitoring, we utilize the EDFA's residual amplified spontaneous emission (ASE) power as a broad-band light source. Fiber Bragg gratings (FBG) placed at some strategic positions on different branches of each stage are used to slice and reflect the ASE power at wavelengths (1525–1540 nm and 1556–1566 nm), which are outside the EDFA's flat gain region reserved for carrying data signal wavelengths. Since individual FBG has different center wavelength, the link quality of each individual fiber branch (tree-branched configuration) or fiber segment (feeder configuration) can be monitored constantly and simultaneously by checking the reflected power level of the corresponding wavelength without suspending the in-service data channels. For a single fiber feeder, several FBG's of different center wavelengths are used to locate the fault along the feeder. In both cases, all reflected ASE signals are extracted using an optical circulator or a fiber coupler and detected by a WDM receiver [3]. If the received ASE power at any designated monitoring wavelength deteriorates after certain time or is below the detection limit, this indicates that there might be a fault or a progressive degradation at the corresponding fiber branch. The monitoring information at each $1 \times N$ stage can then be transmitted back to the network operators via either telephone lines or on a specific subcarrier (SCM) in the upstream channel. Since the positioning of the particular stage can be identified by the WDM receiver, the wavelength assignments for each stage can be duplicated for all stages. Moreover, the condition of the optical amplifier at each stage can be monitored. Failure of signal transmission of all branches in one stage but no link fault at the preceding link implies a failure of optical amplifier at the downstream stage. Therefore, the network operators can take appropriate actions after gathering all monitoring information from each stage of the M-ary PBON.



(b)

Fig. 3. Experimental results: reflected spectra in a 1 × 4 stage when (a) no fault in both branches 1 and 2, (b) branch 1 is broken and no fault in branch 2 (no reflected signal at λ_1).

III. EXPERIMENTS

The experimental setup for the $1 \times N$ stage configuration and the single-feeder configuration are shown in Fig. 1(b) and (c), respectively. First, the $1 \times N$ stage has four branches (via a 1 × 4 coupler) with fiber lengths $L_1 = 4.4$ km, $L_2 = 8.8$ km, and FBG center wavelengths at $\lambda_1 = 1557.5$ nm, $\lambda_2 = 1559.9$ nm. Branch 3 and 4 are left unmonitored. The 3-dB bandwidth and the reflectivity of each FBG are 0.9 nm and 90%, respectively. The insertion loss and the directivity (from amplifier output to the monitoring WDM receiver) of the circulator are 1 and 60 dB, respectively. Two data channels at 1550 and 1545 nm with transmitted power 4 dBm each are inputted to the fiber trunk before splitting. The output ASE power is about -20 dBm at λ_1 and λ_2. Fig. 2 shows the transmitted spectrum at branch 1. The notch at 1557.5 nm indicates that the ASE power at λ_1 is reflected back to the circulator. Fig. 3(a) shows the reflected spectrum when there is no fault in both branch 1 and branch 2. ASE power at both λ_1 and λ_2 are received at the circulator. To simulate the fault identification process, the fiber of branch 1 is intentionally disconnected, and the reflected spectrum is shown in Fig. 3(b).

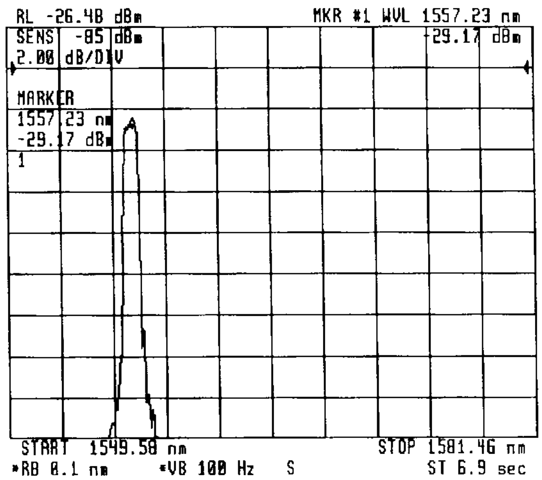


Fig. 4. Experimental results: Reflected spectrum of the single feeder when branch 2 is broken (no reflected signal at λ_2).

There is about 6-dB drop in the reflected power at λ_1 received at the circulator, indicating a fault in branch 1. The residual ASE spectrum shown in Fig. 3(b) is due to the broad-band back-scattered light from the fault. For the single-feeder case, two FBG's are placed on the feeder such that $L_1 = 6.6$ km and $L_2 = 8.8$ km, with FBG center wavelengths at $\lambda_1 = 1557.5$ nm and $\lambda_2 = 1559.9$ nm [see Fig. 1(c)]. Fig. 4 shows the reflected spectrum when the fiber segment 2 is broken. In this case, only the ASE power at λ_1 is reflected. When the fiber segment 1 is broken, no ASE power will be reflected back since the ASE cannot reach all FBG's along the feeder.

IV. Design Considerations

The unused portion of the ASE spectrum of the EDFA is about 25 nm, which can accommodate about 10 monitoring wavelengths using FBG's with central wavelength separation of 0.8 nm and an individual passband of 0.5 nm. These values coincide with those of the commercially available array waveguide demultiplexer which can potentially be used in the WDM receiver. For a practical PBON, it is very desirable to maximize the number of branches and the fiber span of each branch so as to support more users and have a wider geographical coverage. Considering a $1 \times N$ stage, the fiber span L (km) of each branch can be expressed as

$$L \leq \{P - 2C - 20\log_{10} N + 10\log_{10} R - D\}/2\alpha \quad (1)$$

where P is the ASE power in dBm at the specific monitoring wavelength, N is the number of branches, C is the insertion loss of the circulator or the splitting loss of the coupler in decibels, α is the fiber attenuation in dB/km, R is the reflectivity of the FBG and D is the detection threshold of the monitoring receiver in dBm. Fig. 5 shows the plot L versus N for $C = 1$ dB (for circulator), $R = 95\%$, $D = -50$ dBm, $\alpha = 0.2$ dB/km and $P = -20$, -24, -28 dBm. For example, if $L = 20$ km, the maximum N allowed is about 10 for a single stage. More branches result in shorter fiber span because of the larger splitting loss. For the single-feeder case, the maximum L (km) is mainly limited by the fiber loss and the FBG insertion loss I and is given by

$$L \leq \{P - 2C - 2(K-1)I + 10\log_{10} R - D\}/2\alpha \quad (2)$$

where K is the number of FBG placed on the feeder.

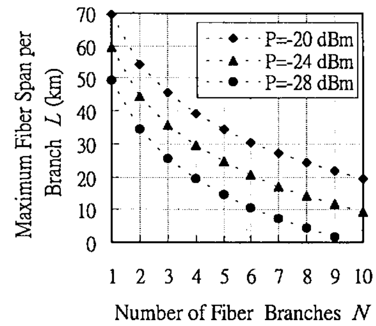


Fig. 5. Maximum fiber span per branch, L, versus number of fiber branches, N, for $P = -20$, -24 and -28 dBm, $C = 1$ dB (for circulator), $R = 95\%$, $D = -50$ dBm, and $\alpha = 0.2$ dB/km.

V. Conclusion

We have proposed and experimentally demonstrated a practical passive surveillance scheme for in-service fault identification in optically amplified PBON's using FBG's to slice and reflected the ASE spectrum as the monitoring wavelengths. No extra light source as used in wavelength-tunable OTDR is needed and the link quality of all fiber branches can be monitored constantly and simultaneously without suspending the data channels.

Acknowledgment

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