# Fault Surveillance of Branched Optical Networks using an Amplifier-Generated Wavelength-Sweeping Monitoring Source

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Passive optically-amplified branched networks are very promising and cost effective architecture for future access networks such as fiber-to-the-curb (FTTC) and fiber-to-the-home (FTTH) systems. With the presence of an Erbium-doped fiber amplifier (EDFA) placed before the optical tree-coupler, more fiber branches can be supported while the transmitted signal quality can also be improved. Since the network accommodates a large number of subscribers, any service outage due to fiber cut translates into tremendous loss in business for the service providers. Therefore, a good fault surveillance system is essential to identify the fiber faults in real time without interrupting the data services.

Conventionally, single-wavelength optical time-domain reflectometer (OTDR) is used for fault detection in branched networks but it suffers from the problem that the Rayleigh back-scattered light from different branches cannot be differentiated at the OTDR [1]. Multi-wavelength OTDR was also proposed to solve this problem but the cost of the wavelength tunable monitoring source is quite expensive. Recently we have proposed a passive surveillance scheme [2] which used fiber Bragg gratings to reflect the unused EDFA's amplified spontaneous emission (ASE) power to detect the exact faulty fiber branch. However, a wavelength-division multiplexing (WDM) receiver with high sensitivity was needed. In this paper, we propose and demonstrate a simple yet effective fault surveillance scheme is based on a new monitoring source that utilizes the unused EDFA's ASE to generate a strong wavelength-sweeping monitoring. All fiber branches can be monitored continuously in the form of periodic reflected optical pulses in time-domain. Thus high sensitivity WDM receiver can be replaced with a low cost regular photodiode.

Fig. 1 shows the proposed fault surveillance scheme for an 1×N optically-amplified branched network. The data channels are transmitted in the EDFA's flat-gain region of 1540-1555 nm. The ASE power outside this region is used as the light source in our surveillance scheme. At the EDFA, a feedback loop with a tunable Fabry-Perot etalon filter (FPF) is built to generate a saturated laser emission, as in the case of gain-clamped EDFA [3]. By apply a periodic sawtoothed voltage to the FPF at a frequency of a few kHz, which is limited by the frequency response of the FPF, the gain-clamping or amplifier-generated signal is made to sweep through the unused EDFA gain spectrum periodically and thus serves as a wavelength-sweeping monitoring source. A fiber Bragg grating (FBG) of distinct reflection wavelength is placed at the end of each fiber branch as branch identifier. Ideally, the FBGs should have similar 3-dB bandwidth and their center reflection wavelengths are chosen to be equally-spaced within the unused EDFA gain spectrum. In each sweeping cycle, the amplifier-generated monitoring signal is swept through that unused EDFA gain spectrum and as illustrated in Fig. 2, an optical pulse is formed and reflected from the FBG on every fiber branch when that FBG's center reflection wavelength matches the monitoring signal instantaneously. In this way, the reflected optical pulses from all fiber branches form an optical pulse train that can be detected by a photodiode at the monitoring module via an optical circulator. Thus the 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. Such simple detection process facilitates the implementation.

We have experimentally demonstrated the proposed fault surveillance scheme in a 1×4 branch 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 PRBS NRZ data, are amplified by the EDFA and transmitted to the fiber branches. The length of fiber branch #1 is 8.8 km and that of both fiber branches #2, #3 are 6.6 km while fiber branch #4 is left unmonitored. 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 of 70 nm and a passband of 0.7 nm, are used to form the feedback loop at the EDFA to generate the wavelength-sweeping monitoring signal. A periodic sawtoothed signal at a frequency of 2 kHz is applied to the FPF such that the monitoring signal sweeps through 1555 nm to 1561 nm periodically. Three FBGs with center reflection wavelengths of 1556.4 nm, 1558 nm, 1559.7 nm and with 3-dB passband of 0.4 nm, 0.8 nm and 0.9 nm are placed on fiber branches #1, #2 and #3 respectively. Their power reflectivities are about 99%. Fig. 3 shows the transmitted optical spectrum at the end of fiber branch #3 in the absence of the feedback loop at the EDFA. The deep notch indicates the presence of the FBG(#3). Fig. 4(a) shows that detected optical pulse train at the photodiode in the case that no fiber branch is broken. Three optical pulses, each signifies one fiber branch, are present. Due to the shape of the sawtoothed signal applied to the FPF, weak residual pulses are also detected in the flyback period. Figs. 4(b), (c) and (d) show the detected optical pulse train in the cases that only fiber branches #3, #2 and #1 are broken, respectively. Note the absence of the optical pulse that corresponds to the broken fiber branch in each sweeping period. From these results, we can monitor the status of the individual fiber branch by demultiplexing the detected optical pulses in each sweeping time period. We have also measured the bit-error-rate performance of the data wavelength at 1551 nm which carries 1-Gb/s $2^{10}$-1 PRBS NRZ data and the results are shown in Fig. 5. It is shown that there is about 1-dB power penalty when the amplifier-generated monitoring signal is 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. A sweeping region with a flatter EDFA gain can alleviate such penalty.

In summary, we have proposed and experimentally demonstrated a simple yet effective fault surveillance scheme for optically-amplified branched networks. The monitoring signal is generated by the EDFA itself by an all-optical feedback loop, thus no extra dedicated monitoring source is required. The monitoring process is in time-domain and thus facilitates simple implementation. Higher monitoring power also allows the surveillance of a larger network.

**References**


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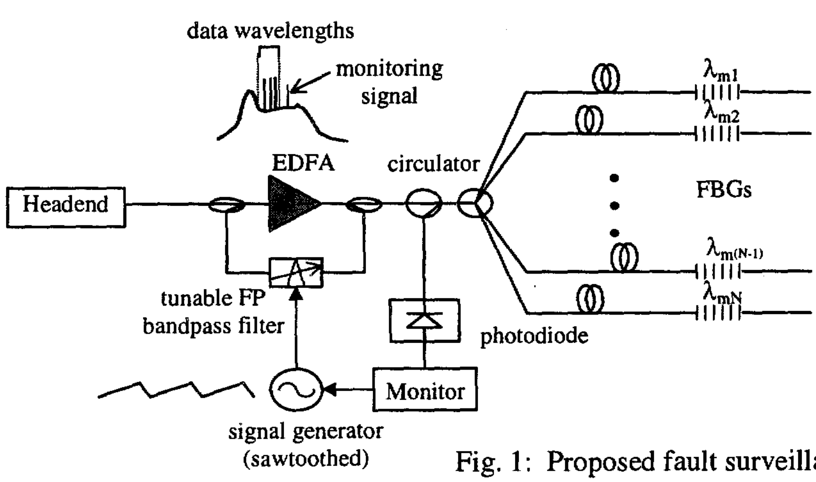


Fig. 1: Proposed fault surveillance scheme in an optically amplified branched network

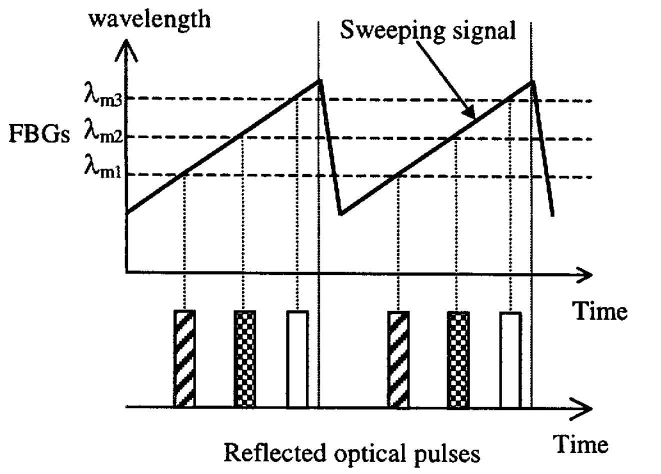


Fig. 2: Operation principle of the surveillance scheme

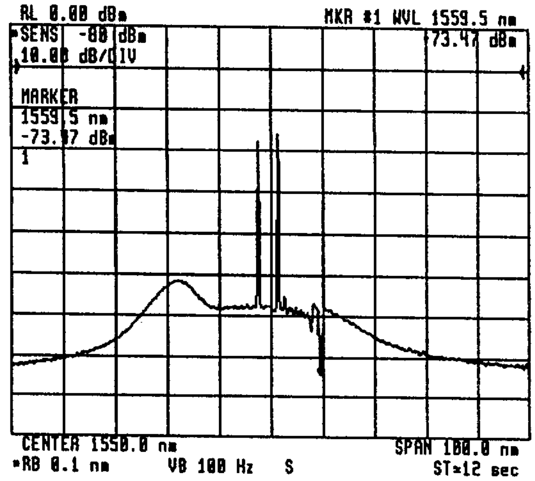


Fig. 3: Transmitted spectrum at branch #3

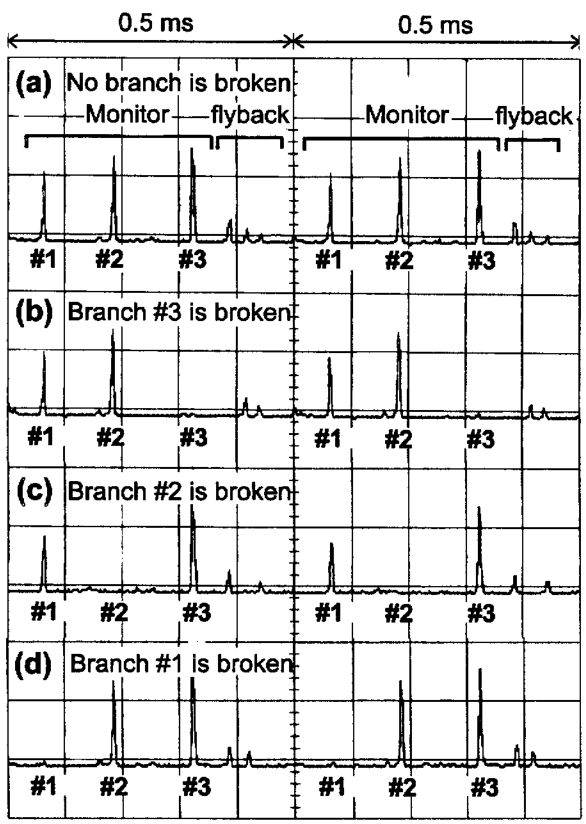


Fig. 4: Reflected optical pulse train at the monitoring module for different scenarios

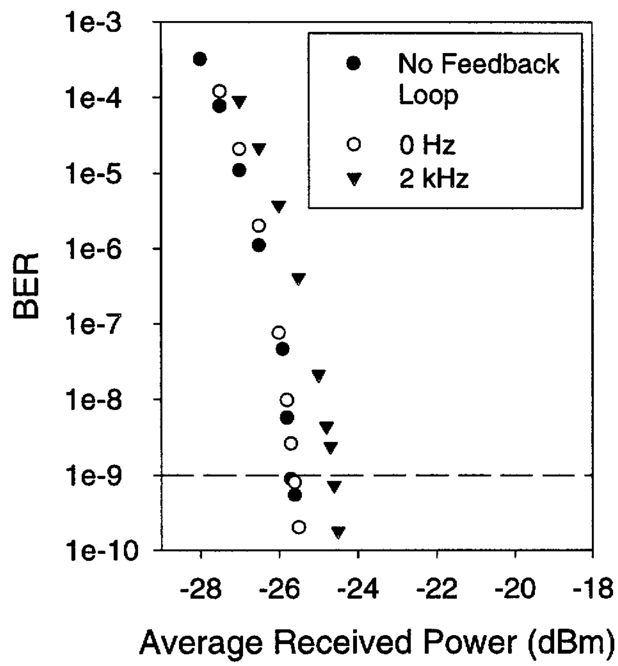


Fig. 5: BER performance of a 1-Gb/s $2^{10}$-1 PRBS NRZ data on data wavelength at 1551 nm when the monitoring signal is sweeping at 2 kHz