# A Practical In-Service Supervisory Technique Using Reflected-Pulse Detection Based on OTDR for Optically Amplified Passive Branched CATV Networks

C. C. Lee and S. Chi

*Abstract*—**We propose and experimentally demonstrate an in-service supervisory tecchnique based on reflected-pulse detection, which can simultaneously monitor the performance of all active network devices (such as optical transmitter, optical amplifiers, and optical receivers) and locate the fiber fault in optically amplified passive branched cable TV networks by using a conventional optical time-domain reflectometer (OTDR) combined with 1 × 2 optical switches. The monitoring parameters such as required dynamic range of OTDR, response time, and the maximum number of element monitoring transponder are discussed.**

*Index Terms*—**Cable TV, fault diagnosis, OTDR.**

## I. Introduction

Passive branched optical networks (PBON's) are very promising and cost-effective for cable TV (CATV) networks. To ensure a reliable video and data transmission, PBON requires a practical supervisory method to offer in-service monitoring and fault-locating capability. Three types of supervisory techniques for PBON had been reported to date by using optical time-domain reflectometer (OTDR) combining with: 1) different time-delay reflected-pulse identification for fiber branches with different lengths [1], [2]; 2) actively optical switch controlled interstaged branched nodes [3]; and 3) by using different wavelength identification for fiber branches with different fiber Bragg gratings (FBG's) [4]. However, the wavelength-identified method can not identify the fiber fault location. Furthermore, all reported methods are not practical for optically amplified CATV PBON since the status of TX, erbium-doped fiber amplifiers (EDFA's), and RX's, and the fiber faults can not be monitored and identified simultaneously.

In this letter, we propose and experimentally demonstrate a practical supervisory method based on reflected-pulse detection, which can simultaneously monitor the performance of all devices (such as TX, EDFA, and RX) and locate a fiber fault in optically amplified passive branched CATV networks by using a conventional OTDR combined with 1 × 2 optical switches (OSW's).

Manuscript received October 26, 1998; revised December 30, 1998.

C. C. Lee is with Chunghwa Telecom Laboratories, Yang-Mei 326, Taiwan, R.O.C. He is also with the Institute of Electro-Optical Engineering, National Chiao-Tung University, Hsinchu, Taiwan, R.O.C.

S. Chi is with the Institute of Electro-Optical Engineering, National Chiao-Tung University, Hsinchu, Taiwan, R.O.C.

Publisher Item Identifier S 1041-1135(99)03621-6.

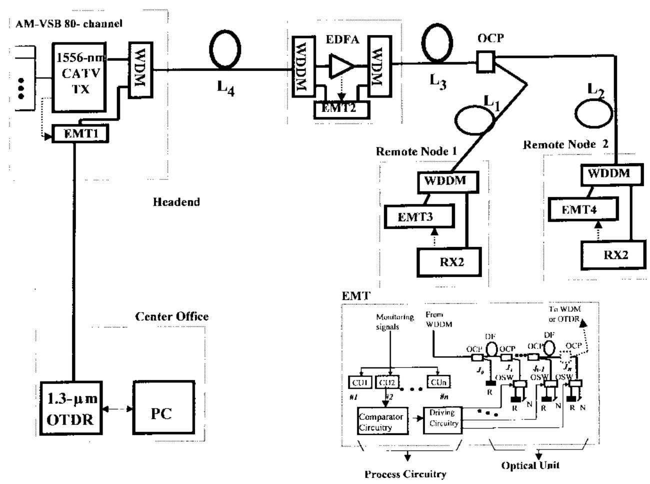


Fig. 1. The proposed surveillance scheme and experimental setup. Inset: the detailed structure of the element monitoring transponder.

## II. Surveillance Scheme and Analysis

### A. Element Monitoring Transponder (EMT) and Surveillance Scheme

EMT's are the key devices to monitor the status of TX, EDFA, RX, and the fiber link, and convert these electrical monitoring messages to the optical domain for OTDR detection. The bottom inset in Fig. 1 shows the schematic diagram of the EMT. Each EMT is composed of a process circuitry and an optical unit. The conversion units (CU's) in the process circuitry receive the monitoring signals, and transfer these signals into related voltage levels. Fault indications are judged by the voltage levels depending whether they are above or below a certain threshold level, which is set by the comparator circuitry following CU's. According to the fault indication, OSW driving signals are generated by the driving circuitry after the comparator circuitry. An optical unit is composed of a cascaded chain of 1 × 2 optical couplers (OCP's) with a dummy fiber (DF) spacing. OSW's are connected to the branches $J_1$ to $J_n$ of OCP's ($n$ is the number of the monitoring signals). For TX or EDFA monitoring, $(n+1)$ OCP's, $n$ OSW's and $n$ DF's are required in an optical unit, but for RX monitoring, only $n$ OCP's, $n$ OSW's and $(n-1)$ DF's are required. The reflected terminal of $J_0$ is used to monitor

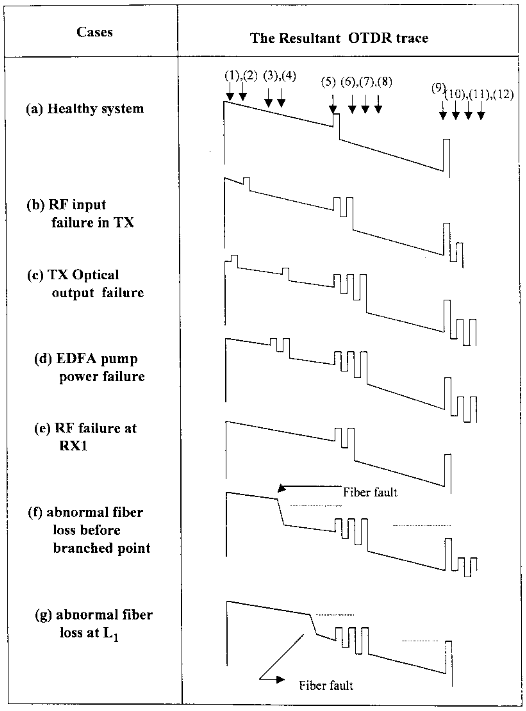


Fig. 2. The fault identification of OTDR traces for the case of (a) a healthy system, (b) an RF input failure in TX, (c) a failure of TX optical output, (d) an EDFA pump power failure, (e) an RF failure of RX1, (f) an abnormal fiber loss before branched point, and (g) an abnormal fiber loss at $L1$.

the fiber-link loss by the reflected-pulse method. Each OSW, connected to the branches $J_1$ to $J_n$, is switched to nonreflected $(N)$ channel by the OSW driving signals from the process circuitry when the corresponding monitoring signal is healthy. On the contrary, each OSW is switched to reflected $(R)$ channel when the corresponding monitoring signal is at fault.

Fig. 1 shows a two-branch PBON with an inline EDFA. Four active network devices (TX, EDFA, RX1, and RX2) of this PBON are supervised by four respective EMT's. EMT3 and EMT4 can also provide the loss monitoring of branched fiber-link $L1$ and $L2$. An OTDR is used to detect the discrete reflected-pulses ,which are generated by EMT's in this PBON. The monitoring items of EMT's include the status of: 1) the optical output power of TX in EMT1; 2) the RF input power of TX in EMT1; 3) the pump power of EDFA in EMT2; 4) the optical output power of EDFA in EMT2; 5) the fiber-link loss of $L1$ in EMT3; 6) the RF output power of RX1 in EMT3; 7) the optical receiving power of RX1 in EMT3; 8) the power-supply voltage of RX1 in EMT3; 9) the fiber-link loss of $L2$ in EMT4; 10) the RF output power of RX2 in EMT4; 11) the received power of RX2 in EMT4; and 12) the power-supply voltage of RX2 in EMT4. As decribed in A, each monitoring signal, except for (5) and (9), will generate a reflected-pulse in the OTDR trace when it is judged as a fault. The fault identifications for $L1$ and $L2$ are judged by the power-levels of the reflected-pulses in $J_0$'s of EMT3 and EMT4.

The fault identifications of OTDR trace for different faults are illustrated in Fig. 2. Considering an RF signal failure in TX, the reflected pulses of (2), (6), and (10) will appear in the OTDR trace since no RF signals are transmitted into TX or out from RX's [see Fig. 2, case (b)]. For the case of TX optical output failure, the reflected pulses of (1), (4), (6), (7), (10), and (11) will be added in the OTDR trace, because the optical output power of EDFA, the received powers at RX's, and the RF output powers of RX's are at fault at the same time [see Fig. 2, case (c)]. When there is a failure of pump laser in the EDFA, the reflected pulses of (3), (4), (6), (7), (10), and (11) will be generated in the OTDR trace [see Fig. 2, case (d)]. If there is an RF failure in RX1, only the reflected-pulse of (6) is added [see Fig. 2, case (e)]. When an abnormal fiber loss occurs before a branched point (that is at $L3$ or $L4$), the power levels of reflected pulses (5) and (9) are decreased. If the received optical powers at RX's are below the decision thresholds, the reflected-pulses of (6), (7), (10), and (11) will be generated in the OTDR trace [see Fig. 2, case (f)]. After compared with the original OTDR trace, the fault location and the variation of the link loss can be indentified. If an abnormal fiber loss happens at $L1$ and causes the received optical power fail, the power levels of reflected pulses (5) is decreased and the reflected-pulses of (6) and (7) are produced [see Fig. 2, case (g)]. Similarly, the fault location and the variation of the link loss can be obtained by comparison of the OTDR traces. Therefore, the active network devices and fiber links in the optically amplified branched CATV network can be monitored simultaneously by conventional OTDR using this reflected-pulse detection method.

### *B. System Analysis*

Each branched fiber-link loss can be monitored by supervising the power level of the corresponding reflected-pulse. The required dynamic range $DR$ (dB) of an OTDR for required measurement accuracy $\varepsilon$ (dB) is given by [1]

$$DR \geq LS_i - H - 5 \cdot \log(1 - 10^{-\varepsilon/10}) \qquad (1)$$

where $LS_i$ (dB) is the fiber loss of the $i$th branch link $H$ (dB) is the height of the end-reflected peak above the backscatter level measured. If a pulse height $H$ exceeding about 8 dB, it can be described approximately as $H = 0.5 \cdot r\ (\mathrm{dB}) - 5 \cdot \log(\eta) - 5 \cdot \log(D)$ [5]. Here $\boldsymbol{r}$ is the power reflectance of the reflector used, $\eta$ is the backscatter parameter, and $D$ is the pulse duration.

The required dynamic range (DR) for providing $m$ EMT's and $k$ monitoring-status for each EMT is affected by the reflectance $\boldsymbol{r}$ of reflector. By neglecting the fiber loss, the required DR for an OTDR can be expressed as

$$DR = 0.5 \cdot \{10 \log(m \cdot k) + \mathrm{SNR} - r + k \cdot (x_1 + x_2) + (m-1) \cdot x_1 + m \cdot x_3\} \qquad (2)$$

where SNR is the required optical SNR, $x_1$ is the excess loss of OCP, $x_2$ is the loss of OSW, and $x_3$ is the loss of WDDM. The empirical value of SNR is at least 10 dB for the monitoring system operated correctly. For SNR $= 10$ dB, $k = 3$, $x_1 = 0.3$ dB, $x_2 = 0.5$ dB, and $x_3 = 1$ dB, the required DR as a function of $m$ and $\boldsymbol{r}$ is shown in Fig. 3. The required DR increases as $m$ increases, but decreases as $\boldsymbol{r}$ increases. For example, an OTDR having a DR of 30 dB, it can provide about only four EMT's for $\boldsymbol{r} = -30$ dB, but it can support up to fourteen EMT's for $\boldsymbol{r} = -10$ dB.

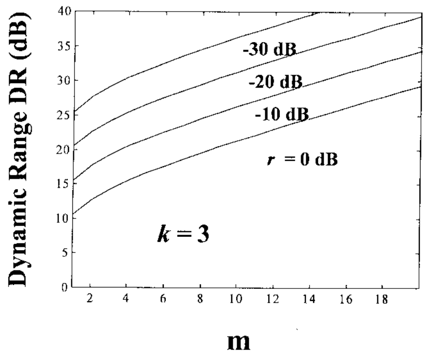


Fig. 3. Required DR of OTDR versus the EMT number $m$ with several values of end reflectance $\boldsymbol{r}$ for the system with parameters of SNR $= 10$ dB, $k = 3, x_1 = 0.3$ dB, $x_2 = 0.5$ dB, and $x_3 = 1$ dB.

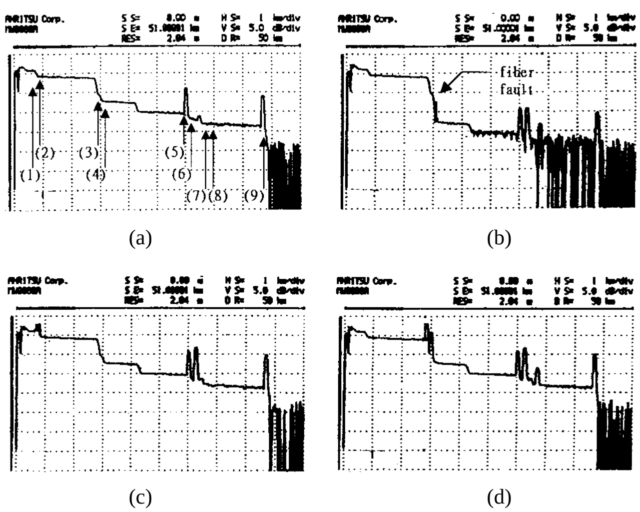


Fig. 4. The monitoring OTDR traces of the system under (a) normal condition, and three abnormal conditions of (b) a fiber bending right after EDFA, (c) an RF input power failure in TX, and (d) a pump power failure in EDFA.

## III. Experiments and Results

The experimental setup is shown in Fig. 1. The optically amplified PBON is composed of a 1556-nm TX, conventional SMF links, a 50 : 50 OCP, an EDFA with 16-dBm saturated output power, and two RX's. These SMF links have different link lengths of $L1 = 1.8$ km, $L2 = 4.4$ km, $L3 = 2.4$ km, and $L4 = 2.8$ km. The used WDM and WDDM have an insertion loss of 1 dB with optical isolation of 40 dB. Simulated AM-VSB 80-channel signals, from 55.25–547.25 MHz, are generated from a Matrix carrier generator and a VCD player, and fed into the TX. The HP 8591C RF spectrum analyzer (SA) and a TV set at RX1 are used to verify the system performance. EMT1 to EMT4 are used to monitor TX, EDFA, RX1 and RX2, respectively, but there is only $J_0$ in the optical unit and no process circuitry in EMT4. The monitoring includes items of (1)–(9) as described in Section II.

Fig. 4(a) shows the 1.3-$\mu$m OTDR trace for the optical CATV network under normal condition. There are only two reflected pulses (5) and (9) in the trace, both reflected-pulses have a normal power level. When a 5-dB fiber bending fault occurs right after EDFA, the reflected-pulse (6) and (7) are generated in the OTDR trace and the (5) and (9) reflected-pulses, representing the fiber loss of $L1$ and $L2$, decrease their power levels about 5 dB as shown in Fig. 4(b). When a failure of RF input power in TX, the (2) and (6) reflected-pulses appear in the OTDR trace as shown in Fig. 4(c). When a failure of pump power in the EDFA occurs, there are four reflected-pulses of 3, 4, 6, and 7 in the OTDR trace as shown in Fig. 4(d), representing the abnormal pump power of EDFA, optical output power of EDFA, optical input power of RX1, and RF output power of RX1, respectively. From the SA measurement and TV observation of the system with or without the OTDR monitoring signal, we verify that there is no degradation induced by this surveillance technique. The response time is determined by the processing time of the personal computer (PC), switching time of OSW, and the travelling time of light pulse. The response time is dominated by the processing time of PC of about 0.1–0.5 s in our experiment.

## IV. Conclusion

We have proposed and experimentally demonstrated a practical in-service supervisory method based on reflected-pulse detection, which can simultaneously monitor the performance of all active network devices (such as TX, EDFA and RX) and locate a fiber fault in optically amplified passive branched CATV networks by using a conventional OTDR combined with $1 \times 2$ optical switches. This technique can be easily developed to an automated in-service surveillance system to provide real-time monitoring to enhance optical CATV network reliability.

## Acknowledgment

The authors would like to thank Dr. Y. K. Tu, Y. K. Chen, and C. H. Chang for their helpful discussions.

## References

[1] I. Sankawa, S. I. Furukawa, Y. Koyamada, and H. Izumita, "Fault location technique for in-service branched optical fiber networks," *IEEE Photon. Technol. Lett.*, vol. 2, pp. 766–768, 1990.
[2] C. C. Lee, T. J. Liaw, F. Y. Tsai, and K. Y. Chen, "Optical fiber monitoring systems for passive optical networks," in *Proc. 1994 Int. Wire and Cable Symp. (IWCS'94)*, Atlanta, GA, Nov. 1994, pp. 494–498.
[3] Y. K. Chen and S. Chi, "Fault-locating and supervisory technique for multistaged branched optical networks," *IEEE Photon. Technol. Lett.*, vol. 6, pp. 876–879, 1994.
[4] C. K. Chan, F. Tong, L. K. Chen, J. Song, and D. Lam, "A practical passive surveillance scheme for optically amplified passive branched optical networks," *IEEE Photon. Technol. Lett.*, vol. 9, pp. 526–528, 1997.
[5] F. P. Kapron, B. P. Adams, E. A. Thomas, and J. W. Peters, "Fiber-optical reflection measurements using OCWR and OTDR techniques," *IEEE Photon. Technol. Lett.*, vol. 7, pp. 1234–1241, 1989.