Development of High-resolution Card OTDR for monitoring of PON system

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[Summary] Deployment of FTTH (Fiber To The Home) services using PON (Passive Optical Network) systems is expanding worldwide to meet the demand for broadband communications. We have developed the MW9087B Card OTDR optimized for monitoring PON systems with a 50-cm event dead zone and 41-dB dynamic range, supporting high-resolution measurement of ONU Fresnel reflection, which is essential for PON monitoring, as well as for measuring splitter loss and backscatter beyond the splitter.

1 Introduction

Recently, the Internet is being used not just for data services and there has been explosive growth in video and audio streaming as well as in backhaul services to smartphones, access networks, etc. To meet these needs economically and efficiently, Fiber To The Home (FTTH) services are being deployed increasingly in countries worldwide. A key part of FTTH technology is the Passive Optical Network (PON) system featuring an Optical Line Terminal (OLT) at the central office side and Optical Network Units (ONUs) at the subscriber side with optical splitters connecting the multiple ONUs to the OLT, resulting in a low-cost, high-speed, and effective optical FTTH distribution network.

However, in the management of PON system service, maintenance of the optical fiber is extremely important. Therefore, for quick detection of faults in optical fibers, installation of fiber monitoring systems including an Optical Time Domain Reflectometer (OTDR) at the office side has been investigated.

This article describes our development of the MW9087B Card OTDR with a very short event dead zone and wide dynamic range for increasing demand of monitoring optical fibers in PON systems using high-resolution measurements of Fresnel reflections, splitter loss, and backscattered light beyond the splitter.

2 PON Monitoring using OTDR

2.1 Monitoring Method

Monitoring of optical fibers in PON systems basically uses OTDR measurements from the central office (CO). However, a PON system may be configured with up to 128 optical splitters between the CO and subscribers and the backscattered lights coming from each branch fiber can be overlapped in this case. Consequently, it can be difficult to evaluate exactly which branch has a fault(1). This is an important problem in monitoring PON systems. To solve this problem, the ITU-T L.53 standard suggests inserting an optical filter in the ONUs and measuring reflections from the optical filters(2). As shown in Figure 1, in this method, the level of Fresnel reflections from the ONU connected to each branch fiber is compared with previously saved normal data and when a value below the normal level is detected, the faulty splitter fiber can located. However, even using this method, when the distance from the splitter to each ONU is about the same, the Fresnel reflection from each ONU can be contiguously superimposed, making it difficult to specify the faulty splitter fiber. Consequently, the OTDR used for monitoring must be able to measure the contiguous Fresnel reflection distances with high resolution, meaning it requires high event dead zone performance.

Furthermore, specifying the location of the fault in the branch fiber requires wide dynamic-range performance because the backscatter after the splitter must be measured despite the high loss due to the splitter.

Clearly, monitoring PON systems in this way requires an OTDR with high event dead zone performance and wide dynamic range.

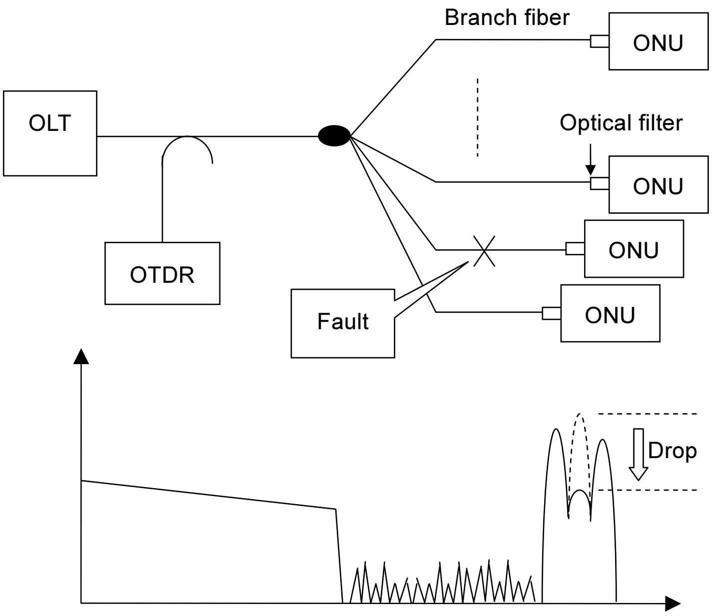

Figure 1 Example of PON monitoring using OTDR

2.2 In-service Monitoring

Monitoring of PON system optical fibers using an OTDR is performed while the optical fiber is in-service, which means carrying communication signals. To suppress the effect of the probe light from the OTDR on the communication and the effect of the communication light on the OTDR measurement, the OTDR must support appropriate wavelengths for monitoring. The wavelength band used for monitoring has been standardized previously[(3)] and ITU-T L.41 recommends the U-band (1625 to 1675 nm)[(4)]. On the other hand, since some PON systems are using the 1600-nm band for communications, the new ITU-T L.66 standard recommended wavelength for PON in-service system monitoring is 1650 nm[(5)].

In addition to the center wavelength, it is necessary to consider the spectrum bandwidth of the light source used in the OTDR. Since the OTDR probe light is reflected by the optical filter in the ONU, the OTDR spectrum bandwidth must be sufficiently narrower than the filter reflection wavelength band; the previously described ITU-T L.66 recommendation requires a range of 1650 ±5 nm.

3 Development Concept

We established the following development concepts for the MW9087B Card OTDR to meet the PON system monitoring requirements.

(1) Short Event Dead Zone

As described previously, in most cases in the PON system, there are adjacent Fresnel reflections from different ONUs close to about 1m; these reflections must be measured separately. However, even the current high-performance OTDRs on the market have a limited event dead zone of about 80 cm[(6)], which is inadequate for separating reflections from ONUs. Consequently, our development aim for the MW9087B was to improve the event dead zone performance to better than 50 cm.

(2) High-Density Sampling

The sampling resolution of conventional OTDRs depends on the distance range and the sampling resolution degrades at longer distances. When measuring a PON system with a distance range such as 20 km, it is impossible to measure with a sampling resolution of less than 1 m. Consequently, when the distance of the Fresnel reflections from the ONUs is about 1 m, it is impossible to identify separate reflection points. To solve this problem, we developed a high-density sampling function within a specified section, achieving a sampling resolution of 5 cm whatever the distance range. Used in combination with the short event dead zone performance, it is possible to perform high-resolution measurements of Fresnel reflections from ONUs and separate out adjacent Fresnel reflections for measurement.

(3) Wide Dynamic Range

Since there is large loss from splitters in PON systems, OTDRs must have sufficient dynamic range to measure branch fibers after the splitter. For example, using a 64 splitter, the loss is about 20 dB and measurement of backscattered light from branch fibers is impossible if the dynamic range is not better than this. To measure the backscattered light beyond the splitter in a PON system with this amount of loss, we aimed to develop an OTDR with a dynamic range of better than 20 dB at a pulse width of 500 ns.

(4) In-service Measurement

To support in-service measurements, we developed a narrow-spectrum-width LD with a center wavelength of 1650 nm meeting the ITU-T L.66 recommendations as a light source for the OTDR. In addition, a bandpass filter is inserted at the OTDR I/O to prevent leakage of the LD ASE and side modes into the connected optical fiber and insertion of the optical signal used for communication into the OTDR, stopping any impacts on the PON system communications and OTDR performance.

4 Key Development Points

4.1 Basic Structure

The basic structure of the MW9087B is shown in Figure 2. An optical pulse from the narrow spectral-width LD in the transmitter section is inserted into the fiber under test, and the optical signal returning from the fiber is O/E converted by the APD in the receiver, amplified by the AMP, and then A/D converted by the ADC. The Gate Array controls the measurement and LD emission timing as well as the AD-converted data acquisition. 10/100Base-T and USB interfaces are provided for external control using common RJ45 and USB-B connectors, respectively. Remote control supports ASCII commands that are backwards compatible with commands used by the earlier MW9077A. The cabinet dimensions are 165 × 50 × 270 mm and the OTDR fits easily in a 19-inch rack. The power supply voltage is 12 Vdc.

Figure 3 shows an external view of the MW9087B.

Figure 3 External view of MW9087B

4.2 50-cm Event Dead Zone

The OTDR event dead zone is caused by the spatial distance of the optical pulse width in the optical fiber as well as by receiver pulse response characteristics. Consequently, shortening the event dead zone requires narrowing the optical pulse width, widening the optical receiver bandwidth, and speeding-up the waveform response.

To achieve an event dead zone of 50 cm for the MW9087B, we optimized the circuits of both the transmitter and receiver sections.

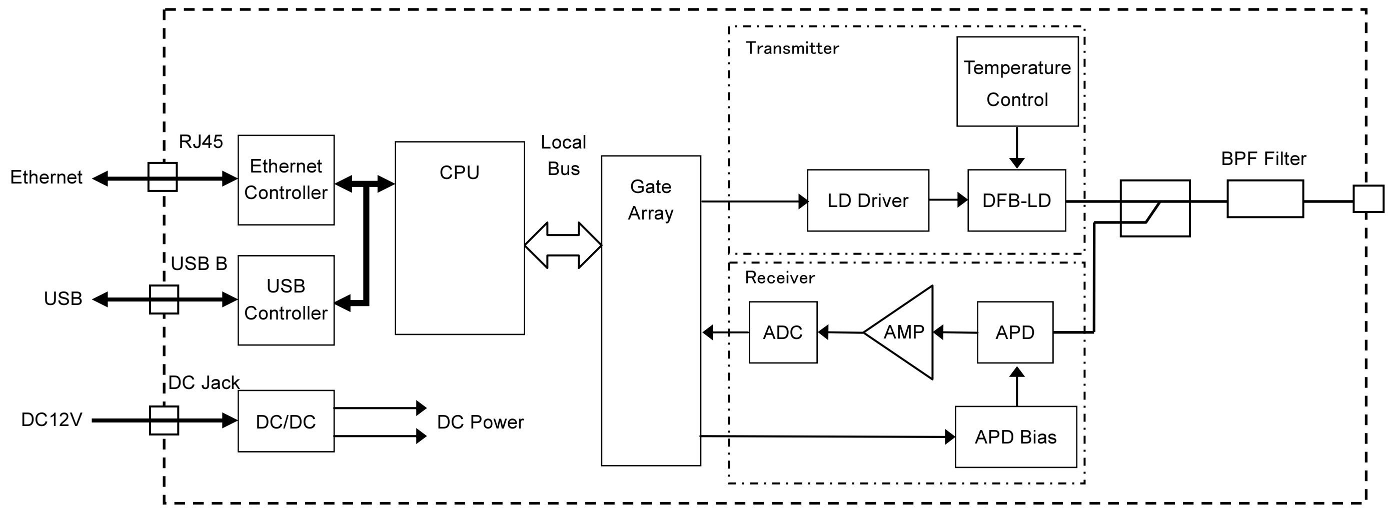

Figure 2 MW9087B Block diagram

By speeding up the transmitter pulse signal generator logic circuit and the driver circuit outputting a narrow optical pulse from the LD, we achieved an optical pulse width of less than 3 ns without reducing the peak power of the injected optical pulse. Simulation of the receiver waveform response and performing basic design to obtain the required results increased the frequency bandwidth by about threefold compared to previously. General wideband amplifiers can easily generate undershoot, ringing, etc., in the pulse response but we suppressed waveform distortion by optimizing the circuit patterns and impedance. In addition, the previous amplifier gain performance was maintained to prevent a degraded SNR.

Figure 4 shows the system for evaluating the event dead zone performance and the test results. In the test system, the optical pulse output from the OTDR is attenuated by the variable optical attenuator and split at the optical coupler before passing into optical fibers with a length difference of 50 cm before reflection by a 1650-nm high optical reflectivity filter to return to the OTDR.

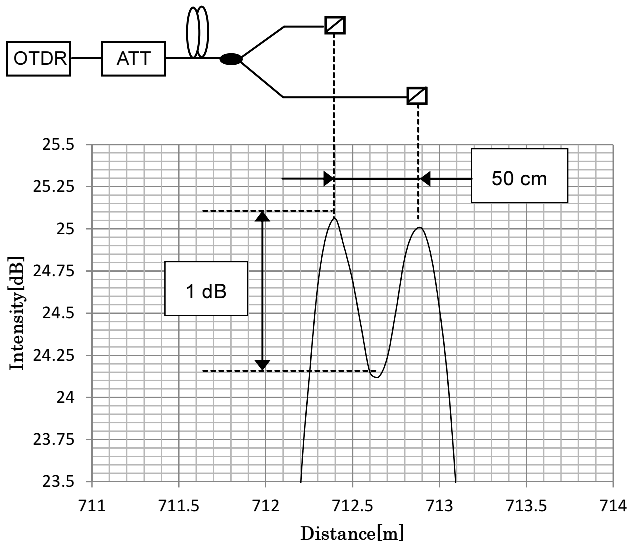

Figure 4 Event dead zone evaluation result

The measurement results are shown for a path loss of 25 dB from the OTDR to the optical filter with a measurement sampling resolution of 5 cm. From the results, we can clearly see the level difference between the peak level of the highest Fresnel reflection to the "trough" level between the two Fresnel reflections is about 1 dB. and this shows we can measure adjacent Fresnel reflection points of 50 cm separately.

4.3 Development of Partial Sampling Function

To measure with fine resolution over long distance ranges, it is necessary to increase the number of sampling points. However, increasing the number of sampling points requires a larger built-in memory, in turn increasing the cost. In addition, since the waveform data from the OTDR is also large, using an OTDR for monitoring optical fiber causes problems with lower measurement speeds and with needing a large hard drive for saving data.

To solve these problems, we developed a partial sampling function for measuring a specific section at high density. Previously, OTDRs sampled the entire trace for a specified distance range from the near end of the fiber to be measured (optical connector at OTDR) as the sampling start position (zero position) to the far end. However, with partial sampling, the zero position is shifted by controlling the LD emitted light and sampling start timing using the Gate Array, changing the sampling range to sample only the specified section at high resolution.

Figures 5 (a) and (b) show measurement examples using partial sampling. The examples are for a 20-km fiber with 4 and 16 splitters. Figure 5 (a) shows the entire waveform measured by normal sampling while Figure 5 (b) shows the section enclosed by the rectangle in 5 (a) comparing the normal sampling waveform and the partial sampling waveform with the same number of measurement points.

From Figure 5 (b), it is clear that with normal sampling it is impossible to separate the contiguous Fresnel reflections because the resolution is too coarse, but using partial sampling makes it possible to separate and measure the Fresnel reflection points in the monitored section with high resolution even with few measurement points.

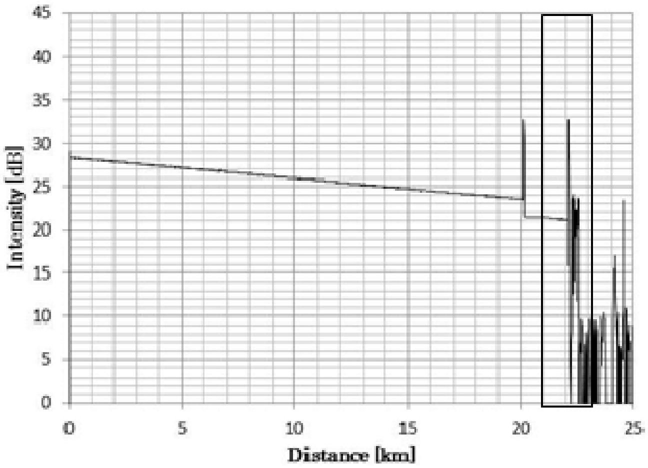

Figure 5 (a) Entire trace at normal sampling

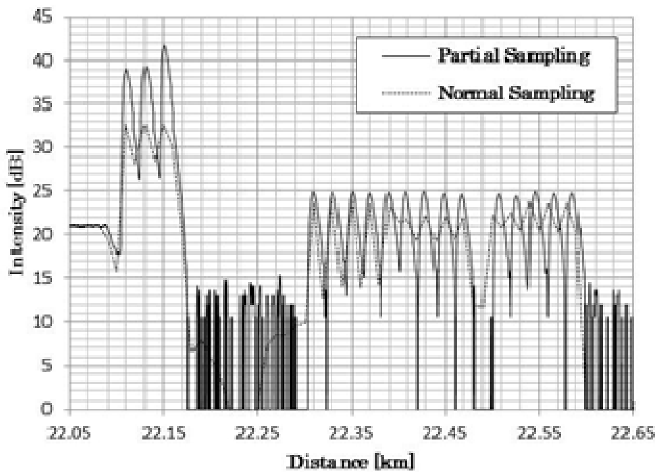

Figure 5 (b) Comparison of normal and partial sampling

4.4 Widening Dynamic Range and Improving Waveform Response

With previous OTDRs, at backscatter measurement beyond the splitter, the receiver waveform response characteristics could cause undershoot and waveform tailing at the point where the waveform changes suddenly due to the splitter loss, resulting in problems measuring backscatter accurately immediately after a splitter.

With the MW9087B, the backscatter signal and noise level diagram is simulated at each pulse width and the receiver amplifier gain and frequency bandwidth optimization values are calculated. Additionally, using low-noise and low-distortion devices in the amplifier both helped improve the waveform response characteristics and the dynamic range. As a result, dynamic ranges of 20 dB and 41 dB were achieved, respectively, for an optimum pulse width of 500 ns and for the maximum pulse width at backscatter measurement of branch fibers after the splitter.

Furthermore, since amplifier gain and frequency bandwidth are correlated in an inverse proportion, there is a tradeoff between dynamic range and the previously described event dead zone performance. Consequently, in the MW9087B, the optical receiver circuit is divided for each pulse width and a short dead event zone and wide dynamic range are achieved by using the optimum circuit for each.

4.5 Optical System

The newly designed LD light source has a wavelength of 1650 nm with a narrow spectral bandwidth and high wavelength accuracy. Additionally, wavelength stability is maintained using temperature control to counter environmental changes, such as external temperature. At –20 dB from the spectrum peak, the MW9087B LD maintains a spectrum bandwidth accuracy of 1645 to 1655 nm. Figure 6 shows an example of the spectrum waveform at a pulse width of 1 μs.

In addition, the bandpass filter has an isolation value for wavelengths used for communications of better than 50 dB in the 1645 to 1655 nm filter band. Consequently, measurement without degraded dynamic range is supported even when optical communication wavelengths of –20 dBm are injected into the OTDR.

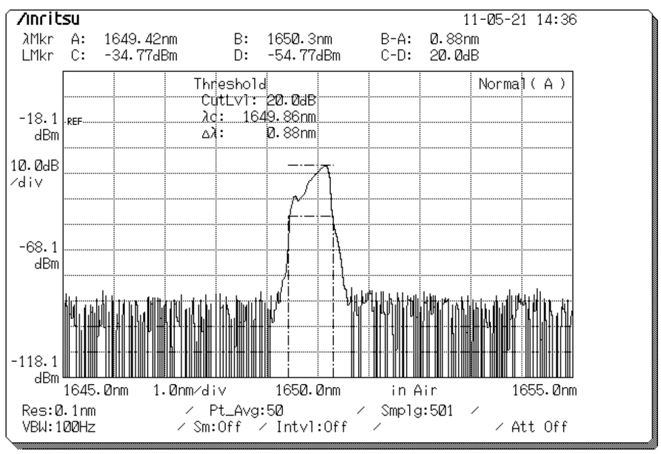

Figure 6 OTDR Spectrum with 1 s pulse width

5 MW9087 Series

There are two models in the MW9087 series: the MW9087B for monitoring PON systems described so far and the MW9087D for monitoring core and metro networks. The MW9087D features a high-power, 1550-nm wavelength LD with an ultra-wide dynamic range of 50 dB. It supports monitoring of long-distance networks exceeding 200 km with an event dead zone of better than 1.0 m.

Figure 7 shows an example of the waveform for a 220-km optical fiber measured using the MW9087D, and Table 1 lists the specifications of the MW9087 series.

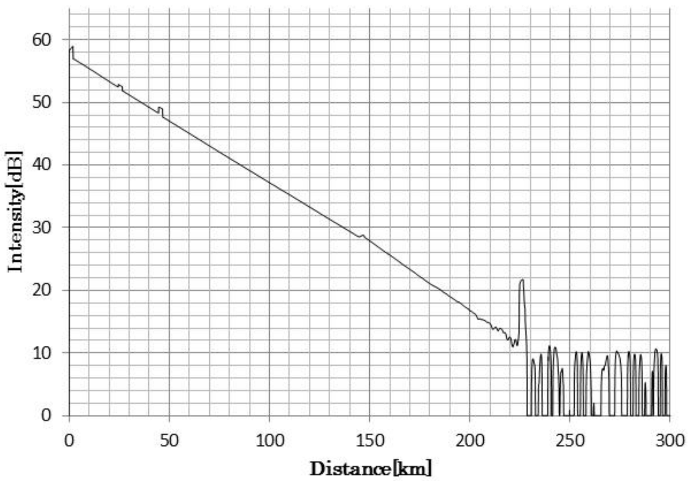

Figure 7 Example of 220-km fiber measured using MW9087D

6 Summary

The spread of FTTH networks worldwide is increasing demand for PON system monitoring. We developed the optimized MW9087B Card OTDR as a PON system optical fiber monitoring device. It has a short dead zone of 50 cm and a partial sampling function, making it possible to measure contiguous Fresnel reflection points from ONUs with high accuracy as required for monitoring a PON system. In addition, the high dynamic range of 41 dB supports splitter loss measurements as well as backscatter measurements beyond the splitter, offering high-accuracy detection of faults in PON systems.

The MW9087 series assures high-reliability PON system monitoring and maintenance to help further deployment of optical networks.

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Table 1 MW9087 Series Specifications

Model	MW9087B	MW9087D
Wavelength	1645 to 1655 nm	1550 ±25 nm
Pulse peak power	≤+15 dBm	–
Measured fiber	10/125-μm SM fiber (ITU-T G.652)	
Dynamic range (typical)	41 dB	50 dB
Dead zone (Fresnel)	≤0.5 m	≤1.0 m
Dead zone (Backscatter)	≤6.5 m	≤4.3 m
LD Type	DFB-LD	FP-LD
In-service cut filter	Mounted	Unmounted
Pulse width	3, 10, 20, 50, 100, 200, 500 ns, 1, 2, 4, 10, 20 μs	
Distance range	1, 2.5, 5, 10, 25, 50, 100, 200, 300 km (IOR = 1.500000)	
Sampling resolution	0.05 to 60 m (IOR = 1.500000)	
Distance measurement accuracy	±1 m ±3 x measurement distance x 10^{-5} ± sampling resolution (excluding uncertainty due to fiber IOR)	
Loss minimum unit	0.001 dB	
Linearity (loss measurement accuracy)	±0.05 dB/dB or ±0.1dB (whichever greater)	
Sampling points	Coarse: 5001 Medium: 20,001 or 25,001 Fine: 100,001, 125,001 or 150,001	
IOR Setting	1.000000 to 1.999999 (0.000001 steps)	
Averaging time (Averaging count)	1 to 9999 times or 1 to 9999 s (settable range)	
Auto-measurement	**Measurements:** Total Loss, Distance of Each Event, Splice Loss, Return Loss, or Reflectance **Threshold:** Splice Loss 0.01 to 9.99 dB (0.01-dB steps) Reflectance –60 to −20 dB (0.1-dB steps) Far End 1 to 99 dB (1-dB steps) **Number of Detected Events:** ≤99 **Automatic Setting:** Distance Range, Pulse Width, and Averaging Count (period)	
Manual measurement	**Measurements:** 2-point Loss, 2-point LSA, dB/km Loss, Splice Loss, Return Loss or Level Difference	
Other functions	Partial sampling Remote control High dynamic range mode (50-ns to 2-μs pulse width)	
Interface	**Ethernet:** RJ45 Ethernet 10Base-T/100Base-Tx Auto-negotiation Full Duplex/Half Duplex **USB 1.1:** Type Bx1	
Power	12 Vdc ±10%	
Power consumption	≤20 W	
Dimensions	165(H) x 50(W) x 270(D) mm (excluding projections)	
Weight	≤1.5 kg	
Temperature/Humidity	**Operating:** 0° to 50℃, ≤95% (no dewing) **Storage:** −20° to 60℃, ≤95%	
Laser safety	IEC 60825-1: 2007 Class 1 (MW9087B) IEC 60825-1: 2007 Class 1M (MW9087D)	