Monitoring of Drop Optical Fibers in 32-Branched PON using 1.65 µm Pulse-OCDR

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We newly propose 1.65 µm pulse-OCDR with 2.6 cm high spatial resolution, which can monitor reflections from FBGs in a drop section of 15 km-feeder 32-branch PON without the overlaps of peaks.

Keywords: Fiber-to-the-Home (FTTH), passive optical network (PON), remote fiber test system (RFTS)

1. Introduction

Passive optical network (PON) systems based on optical splitters provide low-cost optical access by sharing equipment cost between subscribers. However, it was difficult to monitor a drop fiber section from the central office using reflectometry because of the overlap of reflectometry results derived from multiple drop fiber branches. This difficulty in monitoring has added maintenance costs because in the event of communication faults it is necessary to dispatch service persons for troubleshooting. While it is proposed to integrate the monitoring function in optical network units (ONUs) [(1), (2)], it is simple and would be cost effective to monitor from the central office using reflectometry.

There have been several works on reflectometry for the monitoring drop section. The high-resolution 1.65 µm optical time domain reflectometry (OTDR) [(3)] can detect reflection from fiber Bragg grating (FBG) filters which are installed at the end of drop fibers, where transmission loss from the OTDR is 31.5 dB. However, since the spatial resolution is as large as 2 m, great care will be required to arrange drop fiber lengths to differ from one another by more than 2 m. Therefore, improvement in spatial resolution has been desired to ease the deployment of drop fibers. With optical frequency domain reflectometry (OFDR), a resolution as high as 0.8 mm is realized [(4)]. However, the spatial range is limited to 2 km by laser linewidth. Although the spatial range of OFDR can be extended to 40 km by using phase noise compensation [(5)], the spatial resolution degrades to as large as 1 m. Moreover, since those reported OFDR systems use 1.55 µm wavelength band, and further works will be necessary to avoid conflicts with communication channels.

We propose pulse-OCDR (Optical Coherence Domain Reflectometry) as a new monitoring method for PON, and present the results of laboratory demonstration, where reflections from the FBG filters installed at the end of drop fibers in a 32-branch PON with a 15 km feeder line are detected with 2.6 cm spatial resolution, and fault in drop fibers is detected as the absence of one FBG reflection. Although the location of a fault is not implemented because the current OCDR does not detect Rayleigh scattering from the drop fibers, fault detection alone is still valuable because it can tell whether the fault is in fiber or in ONU and reduce the dispatches of service persons for troubleshooting.

2. Pulse-OCDR Scheme

OCDR is a method that probes the fiber under test (FUT) with periodically frequency modulated light and extracts reflection from a specific distance using correlation between reflected light and reference light [(6)]. It is also known that the spatial range of OCDR is not limited by the coherence length of an optical source, and a spatial resolution of 19 cm is realized at a distance of 5 km [(6)]. However, the conventional OCDR would suffer crosstalk between reflected lights from multiple points because there are several locations where reflected probe light and reference light are correlated.

To solve the problem of crosstalk, we propose the pulse-OCDR. The schematic diagram is shown in **Fig. 1**. The light from the periodically frequency modulated source is divided into probe and reference lights. The probe light is gated by the source gating signal into pulse whose width matches the period of frequency modulation. The probe pulse is launched into the FUT and the reflected pulse light is mixed with the reference light and detected. The photocurrent is gated by the detector gating signal having a delay relative to the source gating signal. After gating, the photocurrent is filtered and detected. While there are multiple locations along the FUT where the reflected probe light and reference light are correlated, only one of those locations comes within the window defined by the overlap between the source and detector gating signals.

The filter after the electric gate is necessary to suppress the noise caused by intensity modulations at the frequency-modulated optical source and the electric gate as described below. The gated photocurrent i is given by:

$$i=g(t)(I_p+I_r)+2g(t)\sqrt{I_pI_r}\times\cos[\{\theta_m(t)-\theta_m(t-\tau)\}+\{\theta_n(t)-\theta_n(t-\tau)\}] \quad \cdots\cdots (1)$$

where g is the detector gating signal, I_p and I_r are respectively photocurrents due to the optical powers of the probe and reference lights, θ_m and θ_n are respectively phase terms caused by source frequency modulation and source phase noise, and τ is the delay between the reflected probe and reference lights. When delay τ is not an integer multiple of modulation period p, the first bracket in the cosine function oscillates widely and the cosine term is diffused becoming negligible. On the other hand,

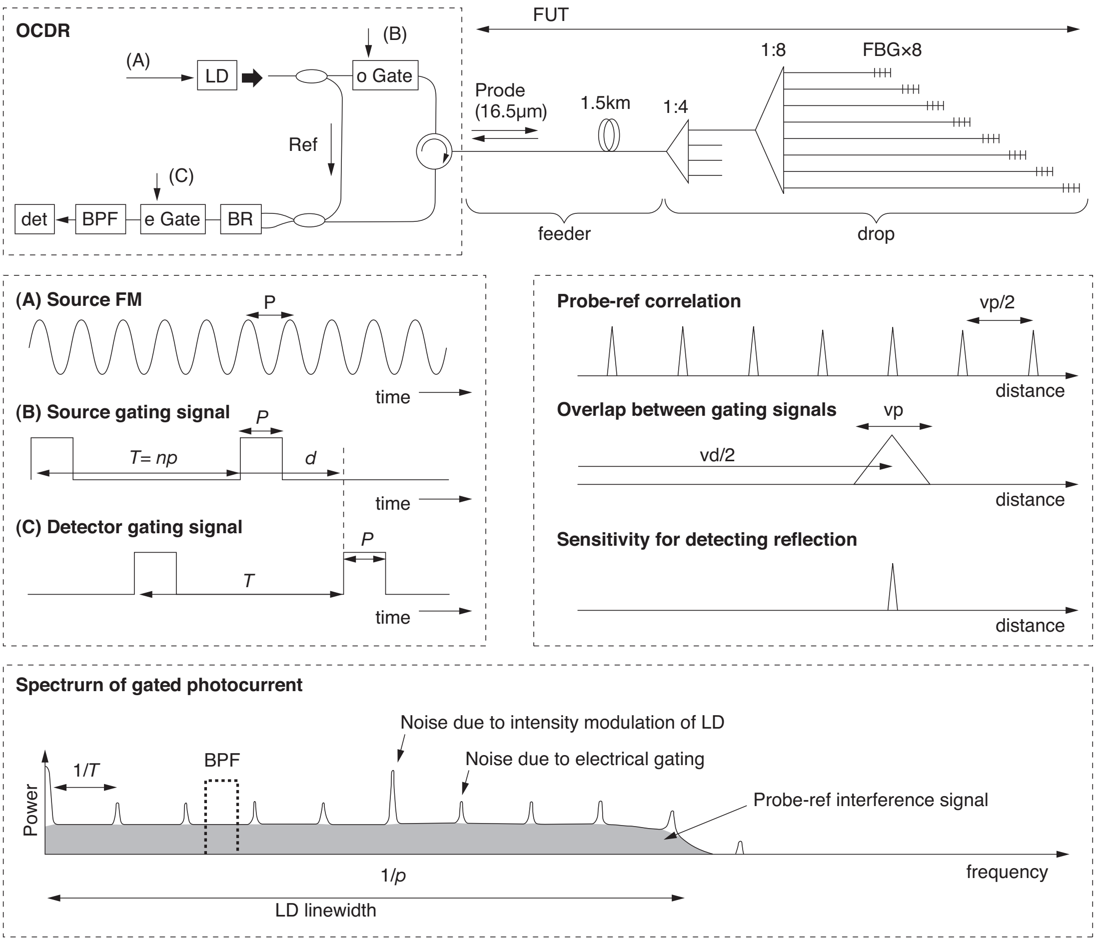

Fig. 1. Schematic diagram of pulse-OCDR.LD: laser diode, oGate: optical gate, FUT: fiber under test, BR: balanced receiver, eGate: electrical gate,BPF: band-pass filter, det: RF detector., FBG: fiber Bragg grating reflecting 1.65μm, *p*: period of frequency modulation, *T*: period of gating signals, *n*: an integer, *d*: delay between the source and detector gating signals, *v*: group velocity of light in the fiber

when delay τ is an integer multiple of modulation period p, the second bracket in the cosine function dominates and the cosine term is localized in the spectral range determined by the source linewidth, which corresponds to the interference signal having information on reflectivity at the measured location. The first term of eq. (1) is noise unrelated to probe-reference interference and can arise in actual systems where frequency modulation of optical source accompanies parasitic intensity modulation, and common-mode rejection of balanced receiver is not ideal. Since the source intensity is modulated at frequency $1/p$ and the detector gating signal has repetition frequency $1/T$, the noise would have frequency components at $i/p + j/T$ with i and j being integers. However, it is possible to localize the noise to frequency j/T by choosing the pulse period T equal to an integer multiple of modulation period p ($T = np$).

3. Experiments

The pulse-OCDR is demonstrated in a setup according to the diagram shown in **Fig. 1**. The source is a 1.65 μm DFB laser having a linewidth of 3 MHz, whose frequency is modulated sinusoidally at amplitude up to 8 GHz and period of typically 0.5 μs, which is varied according to the measured location along the FUT. After dividing probe and reference lights, the probe is gated by an acousto-optic modulator without a frequency shift, and launched to the FUT. The peak power of the launched probe pulse is -3.7 dBm. After combining the reflected probe and reference lights, they are detected by a balanced receiver and the photocurrent is gated electrically. The gated photocurrent is filtered and detected using a spectrum analyzer. The filter has a pass band with a width of 3 kHz at a frequency of typically 100 kHz. The repetition period of gating signal is 50 times per the modulation period, which is typically 25 μs. From the pulse repetition period and the 204 m/μs group velocity of light in the fiber, the crosstalk-free measurement range is 2.6 km. The FUT is composed of a 15 km fiber spool, a 1:4 splitter, and a 1:8 splitter, below which 8 drop fibers and terminating FBG filters reflecting 1.65 μm are connected. The one-way transmission loss from OCDR to the FBGs is 23 dB. During the measurement, the spatial resolution is made smaller step by step, by changing the laser modulation

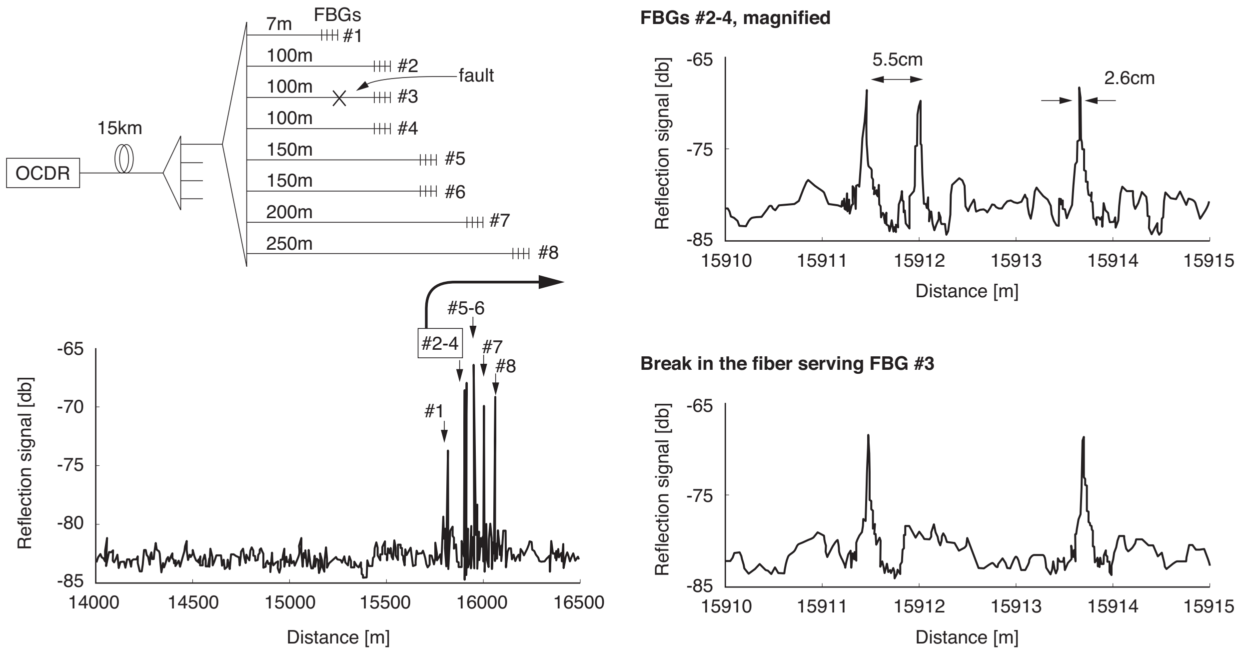

Fig. 2. Experimental results. Reflections from FBGs below 32 branch at 15km distance are detected. Spatial range is 2.6km and spatial resolution is 2.6cm. When a fiber-breaking fault is simulated by disconnecting FBG #3, the fault is detected as an absence of reflection peak

amplitude and frequency, and the regions near reflection peaks are measured with the finest resolution, resulting in a total measurement time less than 5 minutes.

Figure 2 shows the experimental results. The reflection peaks from 8 FBGs below 32-branch at a distance of over 15 km are detected. The full width at half maximum (FWHM) spatial resolution is 2.6 cm, the measurement range is 2.6 km, and the signal-noise ratio (SNR) is 10 dB. When a fiber-breaking fault is simulated by the disconnection of one of the FBGs, the fault is successfully detected as an absence of the corresponding reflection peak.

4. Conclusions

We have proposed the pulse OCDR method and the demonstrated measurement of FBG reflections below 32-branch at 15 km distance. The spatial resolution is 2.6 cm and spatial range is 2.6 km. The pulse-OCDR will be valuable for fault detection in drop fibers of PON systems.

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