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Coherent WDM-PON using heterodyne detection with transmitter-side polarization diversity

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Abstract: Coherent detection can improve the receiver sensitivity and spectral density, so it has become a key technology in realizing the advanced access network. Adding optical heterodyne detection to the wavelength division multiplexing passive optical network (WDM-PON) makes it possible to increase the number of accommodated optical network units (ONUs) and the transmission distance.

In this letter, we propose and demonstrate a heterodyne detection scheme that realizes polarization diversity with one photo detector and one receiving circuit by centralizing diversity devices at the transmitter. We experimentally achieved the cost-effective polarization diversity technique which receiver sensitivity fluctuation was 1.2 dB, and the power penalty was less than 0.8 dB after transmission through 10 km single-mode fiber.

Keywords: wavelength division multiplexing, passive optical network, optical heterodyne detection, polarization diversity

Classification: Fiber-optic communication

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1 Introduction

A lot of recent research has tackled the wavelength division multiplexing passive optical network (WDM-PON) [1, 2] to realize a high-capacity and transparent access network. PON makes it possible to achieve a low-cost access network because one fiber is shared by multiple users. Moreover, by assigning one wavelength to each accommodated PON user, it provides each optical network unit (ONU) with a transmission speed equaling that of a point-to-point network. In addition, even though different services have different modulation formats, the WDM-PON system can transmit multiple services simultaneously because wavelength channels are independent of the optical modulation formats.

Optical heterodyne detection is also highly attractive for the future access network, because it has high receiver sensitivity and high wavelength resolution [3]. Therefore, we are researching the addition of optical heterodyne detection to a coherent WDM-PON system [4, 5]. Coherent WDM-PON makes it possible to increase WDM channel number, total capacity, transmission distance, and PON branch number compared to the conventional WDM-PON system.

Fig. 1(i) shows our proposal, the coherent WDM-PON system. As can be seen, because it uses optical heterodyne detection in the ONUs and optical line terminal (OLT), this system supports super high-density WDM. Furthermore, the high sensitivity receiver enables PON branch number, transmission distance and WDM channel number to be increased. Optical heterodyne detection can select and receive an arbitrary wavelength channel as determined by the wavelength of the local laser diode (local LD), so wavelength channel selectivity can be realized by locating the local LD, which can slightly tune its wavelength, at the ONU. In addition, this system uses a power splitter instead of a WDM splitter. This makes the system suitable for not only point to point communication but also broadcasting because the same signal can be delivered to multiple ONUs. Moreover, the large wavelength channel numbers offered by the proposed system can be utilized for both communication and broadcasting services, and thus heralds the creation of the hybrid network.

In this letter, we propose and investigate polarization independent het-

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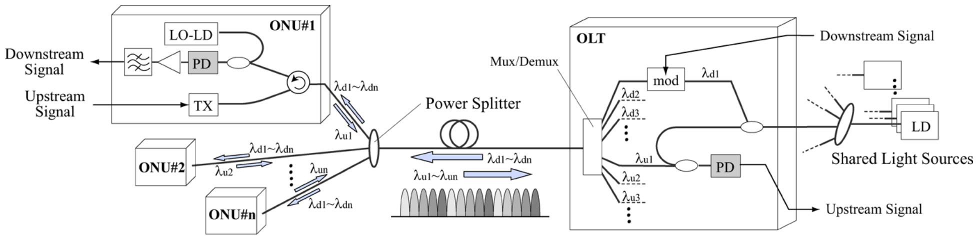
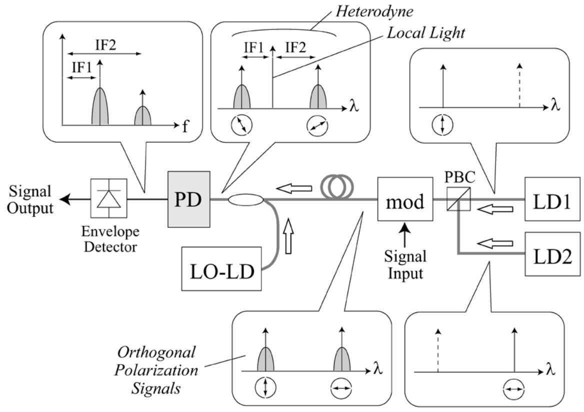


(i) Schematics of coherent WDM-PON access system



(ii) Basic structure of transmitter-side polarization diversity

Fig. 1. Coherent WDM-PON access system

erodyne detection for the future high-capacity WDM-PON system; factors considered include component sharing and the integration of the functional components into the transmitter-side.

2 Transmitter-side polarization diversity

Optical heterodyne detection has several problems, and one of its most serious problems is polarization dependence. Optical heterodyne detection needs a local light to receive the optical signal, but this technique fails when the local light and optical signal have orthogonal polarization. To overcome this problem, several solutions have been proposed; one example being the polarization diversity receiver [6]. This technique is the most popular method; however, it complicates the receiver, because extra optical and electric devices are required in the receiver. In a PON system, especially at the ONU side, the receivers must be simple. This is because the sheer number of polarization diversity devices required because the device is implemented in every ONU.

Our approach is to use polarization diversity at the transmitter side which simplifies the optical receiver. This technique requires one photo detector (PD) and no extra devices, unlike the conventional heterodyne receiver. Our method, by contrast, places the device at the OLT side. Thus, only one diversity device at the OLT is needed since the device can be shared by all PON users. This drastically reduces the system cost.

Fig. 1(ii) shows our proposed transmitter-side polarization diversity system. In the transmitter, the state of polarization of two light sources with slightly different wavelengths is set to be orthogonal. The two beams are

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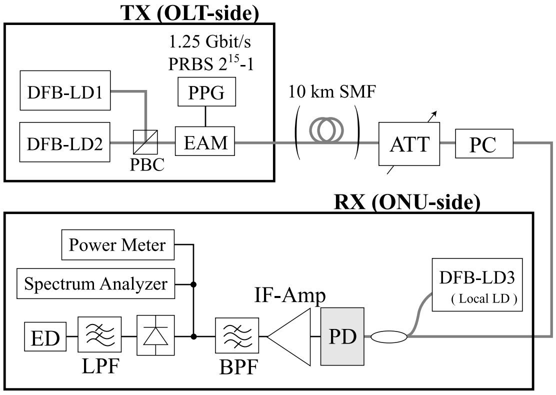

Fig. 2. Experimental set-up

coupled by a polarization beam coupler (PBC), modulated by one modulator simultaneously, and transmitted. At the receiver side, two heterodyned IF signals are observed due to the different wavelengths. These two IF signals are detected simultaneously by one square-law detector. In this case, either one or both of the two IF signals are detected because their polarization states are orthogonal even after transmission. As a result, the total IF output power after the square-law detector is constant regardless of the polarization changes that occurred in the transmission fiber.

3 Experimental result and discussion

We experimentally confirmed the principle of the proposed method. Our experimental set-up is shown in Fig. 2. The orthogonally polarized beams from two 1552 nm band and low linewidth distributed feed-back laser diodes (DFB-LDs) were coupled by a PBC and modulated by a polarization independent electro-absorption modulator (EAM), simultaneously, using a 1.25 Gbit/s NRZ signal [pseudo random binary sequence (PRBS) $2^{15} - 1$]. We set the optical frequency difference between the two LDs to 10.5 GHz by adjusting LD temperature. These two orthogonally optical signals were transmitted to the receiver through the optical attenuator (ATT) and polarization controller (PC). In the receiver, a temperature controlled DFB-LD was used as the local oscillator LD, as in the transmitter; its optical frequency was set to lie between the two wavelengths of the transmitted signals whose the IF frequencies were 4 GHz and 6.5 GHz, respectively. These IF frequencies were set not to overlap the spectrum of two IF signals. After PD detection, we measured the IF signal power and IF spectrum by using an electrical power meter and spectrum analyzer. We also measured the bit-error rate (BER) performance in the case of back-to-back and 10 km SMF transmission after IF signal demodulation by IF amplifier, IF band-pass filter, square-law detector, and base-band filter.

Output spectra before the square-law detector for three combinations of the relative polarization states are shown in Fig. 3(i). In (a): the polarization states of LD1 and the local LD were identical, (b): the polarization states of LD1 and LD2 were 45 degrees to that of the local LD, (c): the states of LD2

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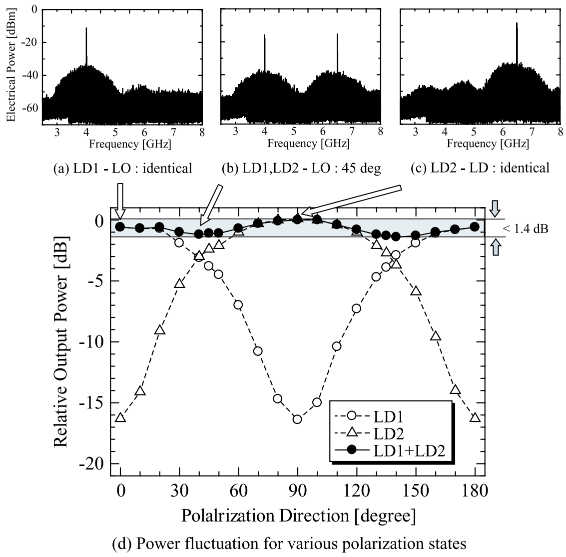
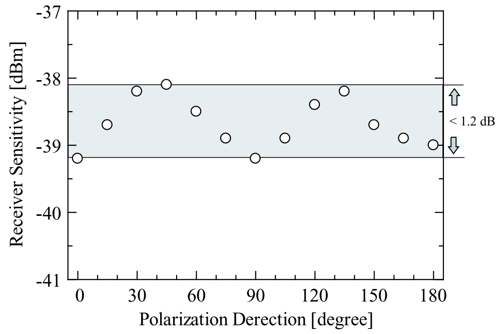
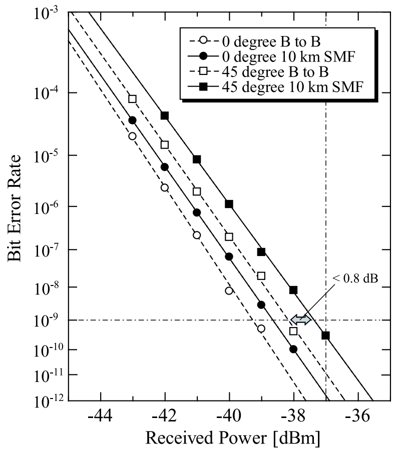


(i) IF Spectrum and relative output signal power after PD



(ii) Receiver sensitivity @ BER 10^{-9}



(iii) Bit error rates before and after 10 km transmission

Fig. 3. Experimental Result

and the local LD were identical. Fig. 3(i) (d) also shows the power fluctuation of the IF signal for the various polarization states, which were generated by rotating a wave plate. The open circles show the output of the case of using LD1 only, the open triangles are for LD2 only, and the closed circles are for both LD1 and LD2, that is, polarization diversity. As can be seen, no

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output was obtained in the case of LD1 or LD2 only which polarization state was orthogonal to the local LD. In contrast, almost constant output was obtained by using our proposed polarization diversity technique. The power fluctuation was less than 1.4 dB.

Next, the receiver sensitivity as a function of polarization state is shown in Fig. 3(ii). Here, the receiver sensitivity was defined at the BER of 10^{-9} with no transmission fiber (= back-to-back). From this figure, the sensitivity deviation was less than 1.2 dB and we achieved the sensitivity of better than −38 dBm for all polarization states.

These power and sensitivity fluctuations were mainly caused by the characteristics and nonlinearity of electrical components; band-pass characteristics of IF-amp and BPF, frequency response and saturation characteristics of the envelope detector. However, these fluctuations are quite small, and the results show the effectiveness of transmitter-side polarization diversity.

Finally, the transmission performance was measured and the results are shown in Fig. 3(iii). The circles show the result for the case when the polarization states of LD1 and the local LD were identical; the squares show the case when the states of LD1 and LD2 were 45 degrees to that of the local LD. The open marks show the case of back-to-back transmission and the closed marks are after transmission through 10 km of SMF. As shown in Fig. 3(iii), the power penalty between back-to-back and 10 km fiber transmission was less than 0.8 dB at BER of 10^{-9} in both polarization states, and the receiver sensitivity of better than −37 dBm was achieved in the worst case. Thus, our proposed method realized a significantly low transmission penalty in the face of wavelength dispersion, frequency chirp and fiber nonlinearity, so our method has sufficient performance to be used in access systems.

4 Conclusion

We have proposed a novel method for polarization independent heterodyne detection for realizing high-capacity and high-density WDM-PON access. One key feature is that the polarization control components are centralized at the transmitter side. This structure does not increase the number of the components in the receiver, and can share the components for the polarization diversity at the transmitter in the PON system. This realizes a very cost-effective polarization insensitive system. In experiments, the polarization dependence of the receiver sensitivity was better than 1.2 dB. Furthermore, the 10 km SMF transmission penalty was less than 0.8 dB and the receiver sensitivity was better than −37 dBm in the worst case. These results show the effectiveness of transmitter-side polarization diversity.

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