A Novel Synchronous Coherent Optical Receiving Technique without Active Phase Tracking

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Abstract: A novel synchronous coherent optical receiving technique is proposed. With this technique, active phase tracking with an optical phase locked loop is eliminated by canceling out the phase and frequency fluctuations of the signal light.

OCIS codes: (060.4510) Optical communications; (060.1660) Coherent communications ;(060.4370) Nonlinear optics

1. Introduction

With the development of optical access systems such as passive optical networks (PON), the demand for higher speed data communication has been increasing. As a way of satisfying this demand, the application of coherent detection techniques [1, 2] to access networks has been studied such as an orthogonal frequency division multiple access PON system [2]. Coherent detection, in which the received signal light is mixed with the local light from a high-power local oscillator laser, provides high sensitivity and out-of-band noise suppression [3]. Synchronous coherent detection is one such coherent detection technique. It requires high-speed active phase tracking using high-speed optical phase-locked loops (OPLL). An OPLL is a negative feedback control system that forces the local light to track the frequency and phase of the signal light. Without high-speed active phase tracking to synchronize the signal and local lights, the phase of the intermediate frequency signal fluctuates and the signal cannot be recovered accurately [4]. The phase tracking time is limited by the linewidth of the local light and the loop length of the OPLL. Thus the application of a narrow linewidth local oscillator laser [4] and an OPLL with a short loop length [5] has been proposed to achieve a short phase tracking time.

In this paper, we propose a novel synchronous coherent receiver without active phase tracking. It realized constant phase synchronization between mixed two light where active phase tracking by optical phase locked loop is eliminated by cancelling out the fluctuation in the phase and frequency of signal light. To cancel out the fluctuation, we demodulate beat between multiple replications of the received signal light. When the signal light is replicated in four wave mixing (FWM) by using phase locked pump lights, the phases and frequencies of the replications, or idlers are the same. Thus, the fluctuations are canceled out. This canceling out allows a constant and robust synchronous coherent detection without active phase tracking. By eliminating the need of the active phase tracking, the limitation of phase tracking time can be eliminated. The proposed technique is described in section 2 and a proof-of-concept of synchronous coherent receiver demonstration is described in section 3.

2. Proposed technique

The proposed technique is based on dual-pump FWM in a nonlinear medium where the phases of two pump lights are locked together. The conceptual scheme of this technique is shown in Fig. 1. The synchronous coherent optical receiver includes a nonlinear medium, a light source to generate phase locked dual pump lights, a photodiode (PD), a frequency doubler and a mixer. An amplitude-phase hybrid modulated light source [6, 7] is a candidate light source for the phase locked lights. It generated phase locked lights by modulation using a signal from an electrical oscillator. This is desirable because it provides lights with a stable frequency difference. The stability depends on an electrical oscillator incorporated in the light source and such an oscillator has an accuracy of 10^{-6}. The received signal light is coupled with the phase locked dual pump lights and inputted into the nonlinear medium. In the medium, the signal and pump lights generate multiple idlers by FWM. The idlers outputted from the medium are inputted into the PD. Here, two idlers act as a signal and local light set for the proposed synchronous coherent receiver. The beat signals between the idlers generated at the PD are mixed with an electrical sinusoidal wave from the oscillator in the pump light source where the frequency of the sinusoidal wave is doubled. When a set of two outer idlers, or idlers that are generated in degenerate FWM by different pump lights, are used for the detection, the frequency of the sinusoidal wave is quadrupled. For synchronous detection, the path length from the oscillator to the mixer is adjusted so that the initial phases of the selected beat signal and the electrical sinusoidal wave coincide.

Here we describe the canceling out of the fluctuations in the phase and frequency of the signal light in the proposed technique. The beat between the two outer idlers is used as an example. The frequency and initial phase of the beat can be shown as follows.

$$f_{IF} = \{2 f_p 2 - f_a\} - \{2 f_p 1 - f_a\} = \{2 (f_p 1 + f_D) - f_a\} - \{2 f_p 1 - f_a\} = 2 f_D \quad (1)$$

$$O_{IF} = \{2\, O_p 2 - O_a\} - \{2\, O_p 1 - O_a\} = 2\, \{O_p 2 - O_p 1\} \quad (2)$$

Here f_{IF} and O_{IF} are the intermediate frequency and initial phase of the beat signal, respectively. f_a and f_p1 and f_p2 are the frequencies of the signal and pump lights, respectively. f_D is the frequency difference between two pump lights. O_a and O_pj (j = 1 to 2) are the initial phases of the signal and pump lights, respectively. As shown in the above equations, the effects of the fluctuations in the frequency and the initial phase of the signal light are canceled out in the beat signal. Thus, the initial phase of the beat signal is always fixed regardless of the fluctuations in the frequency and initial phase of the signal light. The stability of the beat signal depends on the frequency stability of the electrical oscillator in the pump light source.

3. Proof-of-Concept Demonstration

A simplified schematic of the proof-of-concept arrangement is shown in Fig. 2. As a nonlinear medium for a synchronous coherent receiver, we used a highly nonlinear optical fiber (HNLF), because it does not distort the idlers with a femtosecond order response, and it has a low connection loss with single-mode fiber. Its quick response actually eliminates the phase tracking time. The light source for dual phase locked pump lights consisted of a distributed feedback laser diode (LD), intensity modulators (IM) to yield a double sideband and suppress the carrier, and a 625 MHz oscillator to drive the modulator, which generated two lights with a 1.25-GHz separation. The signal light was modulated by an IM driven at a bit rate of 100 Mbit/s with a fixed pattern of 10 from a pulse pattern generator (PPG). The phase of the signal light was shifted with a phase modulator (PM) to confirm that the phase fluctuation of the signal light has no effect on detection. The signal light was coupled with the local light and inputted into the HNLF via an optical amplifier. The output of the HNLF was passed through an optical filter (pass band = 1 nm), and the idlers generated by the FWM between signal and dual pump lights were inputted into a PD. The optical and electrical spectra of the signal and pump lights and idlers after the optical filter are shown in Fig. 3. As seen in Fig. 3A, the wavelength difference between signal and pump lights are nearly 1.2 nm. As seen in Fig. 3B, the frequency differences of adjacent idlers were 1.25 GHz. The output of the PD was filtered with a BPF (pass band = 1.5 to 3.5 GHz). The BPF extracted the beat signal between the two outer idlers. The extracted beat signal or the IF signal was demodulated by mixing it with a 2.5-GHz electrical sinusoidal wave at a mixer. Here the sinusoidal wave for this demodulation was generated by an oscillator that differed from the oscillator for the pump light source. The two oscillators were synchronized with a 10 MHz external clock. The waveform of the demodulated signal, which was observed on an oscilloscope, did not change when the phase of signal light was shifted. The phase was shifted by changing the bias to the PM. Figure 4 shows the signal amplitude of the observed waveform with the phase shift. The lines show the calculation result without phase synchronization and the solid circles show the results of this experiment. As shown in Fig. 4, the phase change hardly affects the demodulated signal. This indicated that synchronous coherent detection was achieved with the proposed technique without active phase tracking. In this experiment, we demonstrated the applicability of the proposed technique.

4. Conclusion

We proposed a novel synchronous coherent optical receiving technique. A simple proof-of-concept demonstration confirmed the feasibility of the proposed technique. The experimental results indicate the good potential of the approach.

5. References

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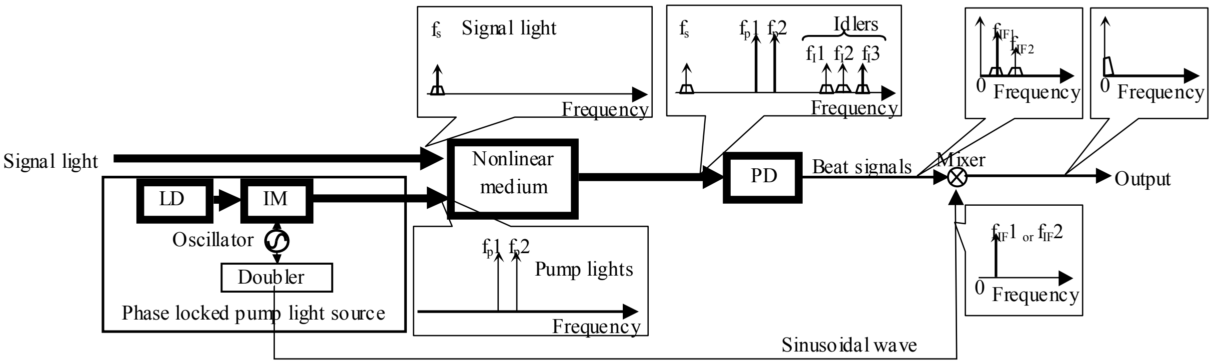
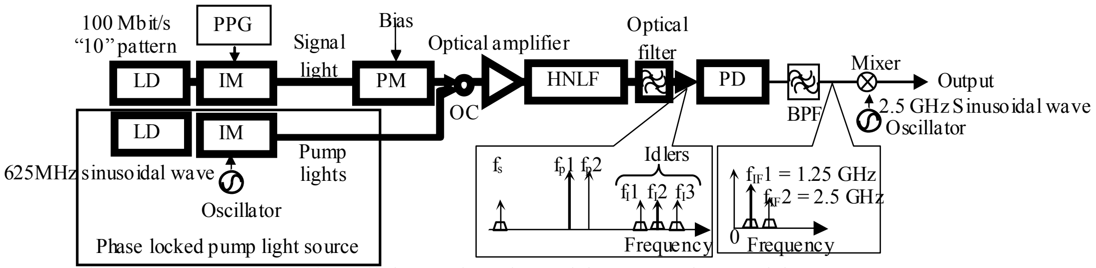


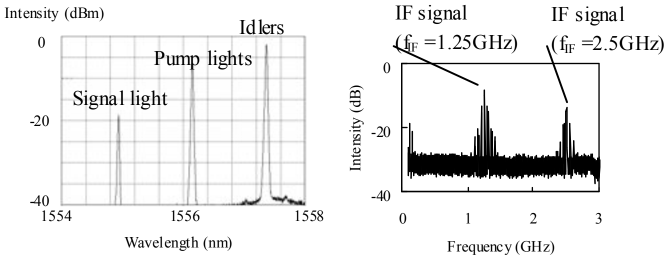
f_s: signal light frequency, f_p1-2: pump light frequencies, f_i1-3; idler frequencies, $f_{IF}1$-2: intermediate frequencies, PD: photo detector

Fig. 1: Configuration



PPG: pulse pattern generator, LD: laser diode, IM: intensity modulator, PM: phase modulator,
HNLF: highly nonlinear optical fiber, BPF; band-pass filter, OC; optical coupler

Fig. 2: Experimental setup



A) Optical spectra B) Electrical spectra

Fig. 3: spectra after optical filter

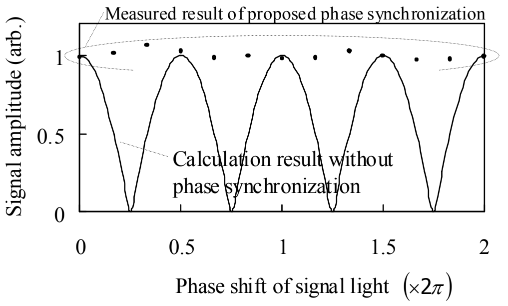


Fig. 4: Signal amplitude versus phase shift