Self-homodyne Detection in Optical Coherent Transmission Using Extracted Carrier as the Local Oscillator by Saturated SOA

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Abstract— We proposed a self-homodyne coherent detection technique in coherent optical transmission using extracted carrier from the received optical signal by saturated semiconductor optical amplifier (SOA) as LO. Saturated SOA has data erasing characteristic, so LO light can be extracted from the received optical signal by erasing modulated data of the optical signal. In the proposed scheme, there is no CFO because LO light originating from the received signal has a totally same wavelength with the signal. Thus, expensive OFLL or complex CFO compensate algorithm can be avoided; also, colorless operation is possible, and there is no additional requirement of optical fiber for LO light transmission, so it is cost efficient. The test bed has been set up, and the feasibility was experimentally demonstrated.

1. INTRODUCTION

Coherent optical network is one of the possible candidates for next generation optical network because it fits for long-reach transmission in terms of power sensitivity and applicable to single carrier based high order modulation as well as multicarrier modulation: mQAM, OFDM, et cetera. In coherent optical transmission system, the signal is detected by optical mixing it with local oscillator (LO) light; therefore, an unstable relation of these phase and frequency causes phase noise and carrier frequency offset (CFO). In order to realize coherent system, the techniques to mitigate the problems are essential; thus, in coherent communication research area, it is considered for a key technology. Fundamentally, there are two kinds of techniques of solving the problems. It is one of the solution to trace the phase and frequency of the signal, and then match it with that of LO [1, 2]; another solution is using digital signal processing (DSP) which estimates, and compensates phase noise and CFO [3]. However, the first one is inefficient in terms of cost; also, the second one has a disadvantage concerning system latency and complexity.

Self-coherent system, in which LO light is transmitted from the source at transmitter, is a promising alternative in comparison with the aforementioned system [4]. This system is cost efficient because a laser used as LO is not required at the receiver. In addition, CFO compensation algorithm is not needed in the DSP and phase noise occurs less than conventional coherent system because LO light originates from the source; thus, it has an advantage in terms of the system complexity. Especially, self-coherent system is possible to do colorless operation, and the property is a big advantage in case of WDM system expansion. By the way, transmitting LO light at the transmitter through an independent single-mode fiber (SMF) is not efficient; therefore, in self-coherent system, it is one of the main researching issues how transmitting LO light efficiently. There is a scheme using multi-core fiber (MCF) for transmitting LO light through another core with the signal [5]; however, in order to realize the scheme, installation of new MCFs is required. The other technique is using polarization division multiplexing (PDM). In this system, LO light is transmitted through orthogonal polarization with the signal [6]. Using this technique, the transmission capacity increasing by PDM is impossible. Carrier extraction technique, also, can be exploited in self-coherent system. Particularly, in optical OFDM system, dozens of subcarriers around DC is padded with zeros at the transmitter, and then LO light is extracted by Fabry-Perot tunable filter (FP-TF) from the transmitted OFDM signal [7]; also, using injection locked laser, LO light can be enhanced [8]. In case of using FP-TF, its bandwidth should be narrow as laser linewidth ($<$ hundreds of kHz). In addition, the center wavelength of FP-TF should be aligned with that of the carrier; thus, external FP-TF controller is required because of the laser wavelength drift [7].

In this paper, self-homodyne detection scheme using extracted carrier by saturated SOA as LO is proposed. The proposed scheme, in the same manner as the above-mentioned self-coherent system, does not require the laser used as LO and CFO compensation algorithm in the DSP because the LO light is extracted from the transmitted optical signal; therefore, this is comparatively cost efficient and less complex than conventional coherent system. In addition, the high optical power of LO light is gained by SOA. Basically, the receive sensitivity of coherent detection increases in proportion to the optical power of LO light, so typically, about 10 dBm is required as the optical power of LO. In the proposed system, the LO power requirement can sufficiently be satisfied. Meanwhile, there is no additional requirement of SMF or MCF for LO light transmission; thus, it has an advantage in terms of system realization. In the following Section 1, the concept of the proposed scheme which uses extracted carrier by saturated SOA as LO light is discussed. And then, the experimental set-up is explained; also, the demonstration result is discussed in Section 2. Lastly, the conclusion is following.

2. SELF HOMODYNE DETECTION USING SATURATED SOA

When SOA is operated in the deep saturation region, it acts as an optical data eraser because saturated SOA has a property that a low level signal is given more gain than a high level signal [9]. In the deep saturation region, the saturation property much more enhanced. In other words, the high level signal scarcely has gain; whereas, the low level signal has almost whole gain. Consequently, the extinction ratio of the signal extremely decreases, and the optical signal is erased. Meanwhile, according to [10], saturated SOA has high pass filter property caused by carrier-density depletion and fast phenomena such as carrier transport in multiple layers and fast phenomena. Therefore, carrier extraction can be found filtering the baseband signal. The concept is shown in Figure 1. First of all, the modulated optical signal which has frequency f_0 is separated at the ONU input by the optical power splitter; then, a part of signal is entered SOA1 which acts an optical amplifier providing the enough optical input power of SOA2. This is because the input optical power of SOA2 should be big enough so as to operate in the deep saturation region. Subsequently, Saturated SOA erases the modulated optical signal, and extracts the optical carrier using as LO light. The extracted carrier has frequency f_0 which is totally same as the transmitted signal. Lastly, another part of signal separated at the ONU input is entered to coherent receiver, and then the signal is detected by mixing the optical signal with the extracted optical carrier.

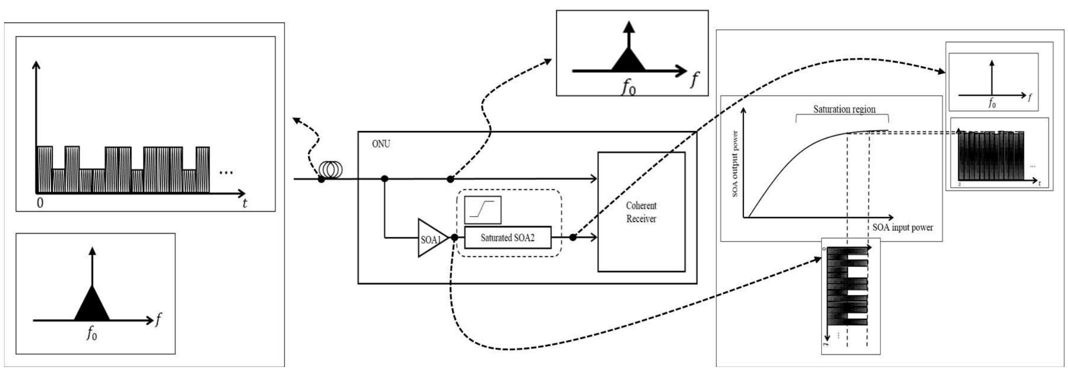

Figure 1: The schematic diagram of self-homodyne detection using extracted optical carrier by saturated SOA as LO light.

3. EXPERIENT AND RESULTS

Figure 2 presents the experimental set-up. An external cavity laser (ECL) which has 50 kHz linewidth and 1550.223 nm center wavelength was used as the optical source. The electrical QPSK signal was generated by arbitrary waveform generator (AWG), and it was modulated to the optical signal using optical IQ modulator which consists of one mother-Mach zehnder modulator (MZM) and two sub-MZMs. The optical IQ modulator was followed by polarization controller (PC) in order to maximize the MZM output power because it is a polarization dependent component. The transmitted optical signal was divided by 3 dB coupler, and one of them was entered to the input port of coherent receiver and another was entered to the LO port after passing through the carrier extraction part which is consisted of two SOAs. The first SOA acted as an optical amplifier to retain the enough input power of SOA2 for the gain saturation and SOA2 functioned as the optical data eraser. The Each SOA was followed by PC for its polarization dependency, and led by optical tunable filter which has 0.25 nm bandwidth in order to cut out amplified spontaneous emission (ASE) noise. As shown in Figure 2, the input power of SOA2, which is amplified by SOA1, was 8.7 dBm and the output was 9.2 dBm; therefore, in accordance with the fact that SOA2 gain decreased to 0.5 dB, SOA2 was in the deep saturation region. This is because, according to the

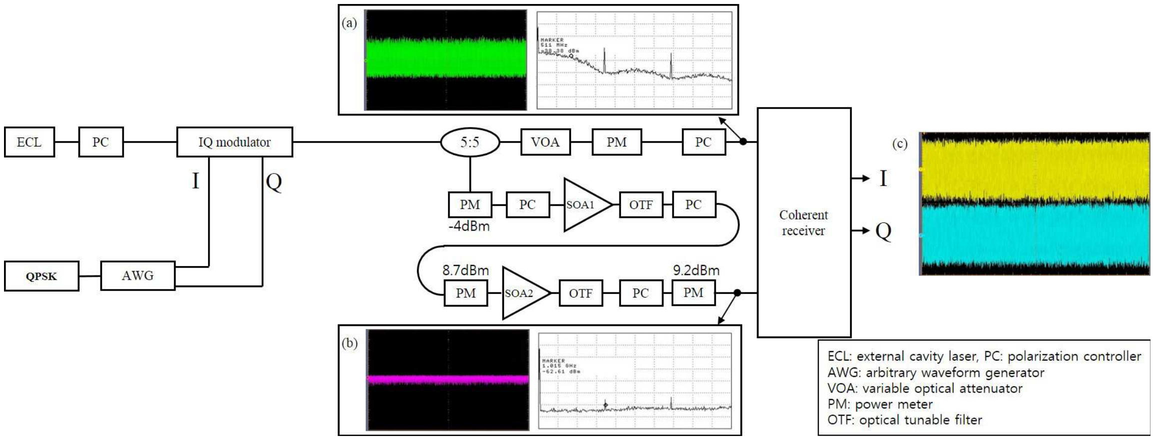

Figure 2: The experimetal setup diagram.

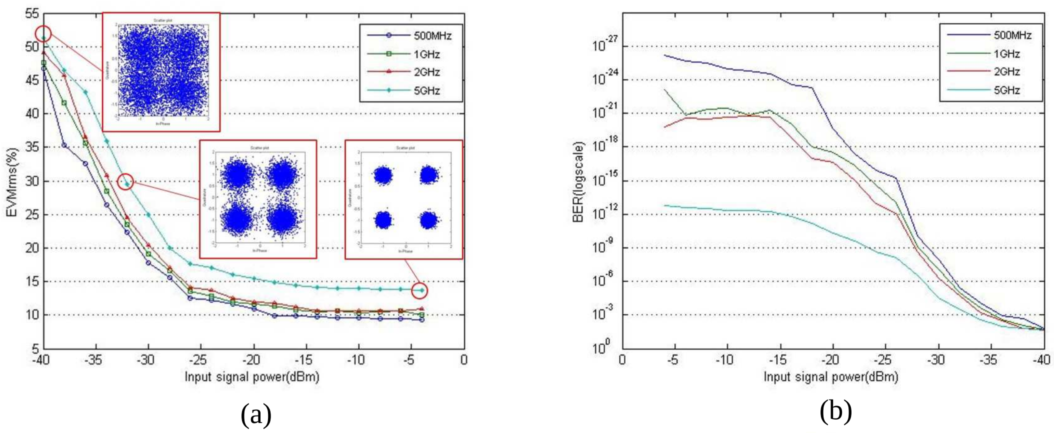

Figure 3: (a) The optical input power vs. EVMrms (%), (b) the optical input power vs. BER.

definition, the output power when SOA gain decreases from typical gain by 3 dB is the saturated output power. The polarization of the optical signal and LO light had to be carefully tuned by PC because the polarization states affects optical mixing process in the coherent receiver.

Figure 2(a) shows the 1 GHz bandwidth QPSK signal which was directly detected in front of the signal input of the coherent receiver in time domain and frequency domain, and erasing the QPSK signal by the saturated SOA is presented in Figure 2(b). After coherent detection using the extracted carrier, each I and Q signal was separately gotten, and each signal in time domain is presented in Figure 2(c).

To evaluate the system performance, EVMrms was measured according to the input signal power in each case of 500 MHz, 1 GHz and 5 GHz. In Figure 3(a), EVMrms of 500 MHz, 1 GHz and 2 GHz was about 10%, and in case of 5 GHz, it was about 14%. EVMrms increased as the input signal power decreased. Also, along with increasing the signal bandwidth, EVMrms increased because of the high pass filter property of the saturated SOA. Figure 3(b) shows the BER performance according to the input signal power, and as the input power decreased, the BER performance got worse. In case of 500 MHz, 1 GHz and 2 GHz, BER of less than 10^{-12} was obtained by -20 dBm and for the 5 GHz case, it was achieved at -15 dBm. Assuming Reed-Solomon Forward error correction (FEC) limit 10^{-3} for error-free operation, the input power margin was achieved at about -33 dBm in case of 5 GHz and is was achieved about -35 dBm in the others.

4. CONCLUSION

Self-homodyne detection using carrier extraction technique by saturated SOA was proposed, and have been discussed in this paper. In brief, the extracted carrier by saturated SOA can be used as LO light of coherent receiver, and this concept was experimentally demonstrated in order to evaluate the system performance. Assuming Reed-Solomon FEC limit 10^{-3}, the power margin of −33 dBm was achieved within 5 GHz QPSK transmission. The proposed technique does not needed an additional laser for LO, and there is no CFO because the LO light originates from the transmitted optical signal. In addition, without additional installation of SMF or MCF, system realization is possible. For the reasons, the proposed system is cost efficient and has low system complexity. Particularly, it is possible to operate colorless system; therefore, in case of expansion to WDM, it would be very useful.

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