Bidirectional Radio-on-Fiber Transport Systems Using Fiber Nonlinearity and Injection Locked Technique

W. S. Tsai and G. C. Lin
Department of Electrical Engineering, Ming Chi University of Technology, Taiwan

Abstract— We propose a novel bidirectional transmission system based on stimulated Brillouin scattering (SBS) effect and injection locked distributed-feedback (DFB) laser to achieve optical single sideband (OSSB) modulation for downlink transmission. For uplink transmission, we reuse transmitting light by phase modulation (PM) to avoid signal interference each other in bidirectional transport After 25 km single mode fiber (SMF) transmission, we can observe the sideband power ratio (SBPR) $>$ 15 dB for downlink transmission and system's power penalty is $<$ 2.8 dB. Good performances for bit error rate (BER) analysis are observed in our proposed bidirectional transmission system.

1. INTRODUCTION

Optical carrier reuse conception is widely employed in bidirectional light transmission systems due to its economic and colorless characteristic. By replacing a light source in each subscriber premise, the optical network installation process will become easier, and the service providers can flexibly manage the network resources. Radio-onfiber (ROF) can apply to transmit microwave signal by optical fiber. The communication system with ROF technology transmits microwave signal for a long distance with high performances which makes the broad bandwidth and low transmission loss of the fiber, and solves the last mile problem to the user. In traditional intensity modulation, the optical carrier is modulated to generate an optical double sideband (DSB) format. Over a long haul fiber transmission, RF signal will cause severe power degradation due to chromatic dispersion [1]. In order to overcome RF power degradation, optical single sideband (OSSB) modulation technique must be implemented. OSSB modulation can remove a half of the optical spectrum is expected to attain a dispersion benefit [2–4]. By eliminating one of the sidebands, OSSB modulation not only immunizes to fiber dispersion but it also increases the spectral efficiency twice.

Bidirectional light wave transmission systems transmit downlink and uplink signals simultaneously which produce large crosstalk because transmit signals are disturbed each other. Phase modulation (PM) systems utilize optical phase shifting to record signal state, which provides high robustness to against crosstalk and fiber nonlinearities with high gain and low noise figure Nonlinear effects are interactions between light waves, which can cause noise and crosstalk. The nonlinear effect for Stimulated Brillouin scattering (SBS) occurs when signal power reaches a level sufficient to generate tiny acoustic vibrations in the glass. Acoustic waves change the density of a material, and thus alter its refractive index. Since the light wave being scattered itself generates the acoustic waves, it can cause input light degradation. The Brillouin frequency is about 10.8 GHz in 1550-nm region in single mode fiber.

In this letter, we propose a bidirectional transmission system with OSSB modulation scheme using stimulated Brillouin scattering (SBS) effect in fiber and injection locked distributed-feedback (DFB) laser for downlink transmission For uplink transmission, we reuse the transmission light to carry uplink data with its phase by PM to avoid transmission signals interference. The results show that good performance is achieved in this bidirectional ROF transport system.

2. EXPERIMENTAL SETUP

The bidirectional ROF transport system based on SBS effect and DFB laser injection is shown in Fig. 1. The tunable laser is used for master laser and the DFB laser is as slave laser. The wavelength of DFB laser is 1546.58 nm. The main parts of transmitter consists of a tunable laser source (TL), a microwave signal generator, a RF power amplifier, a RF power splitter, a mixer, a semiconductor optical amplifier (SOA), and a Mach-Zehnder modulator (MZM). The microwave signal is generated at 10.8 GHz by a microwave signal generator then fed into a RF power splitter to split two copies. One copy of RF signal passes through a RF power amplifier to increase signal power then couples into a mixer. The other copy supplies to another RF power amplifier to increase signal power as local oscillation (LO) signal of receiver. The 622 Mb/s non return-to-zero (NRZ) pseudorandom bit sequence (PRBS) length of $2^{31}-1$ is mixed with a 10.8 GHz microwave carrier to generate the

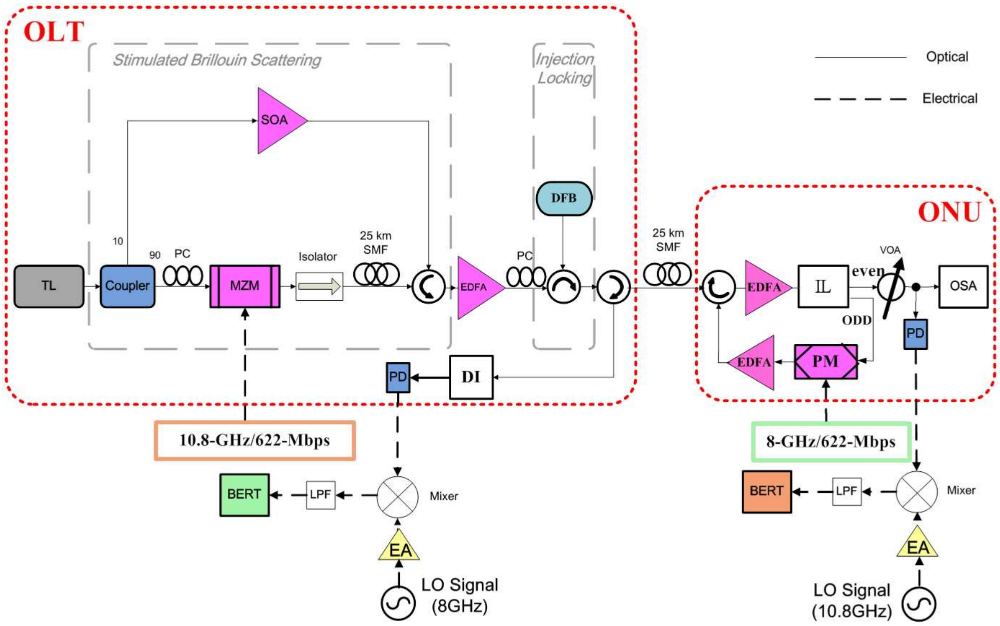

Figure 1: Experimental setup for bidirectional ROF transport system based on SBS effect and DFB laser injection.

up-conversion data signal, and the resulting microwave data signal is supplied to the MZM. TL output signal launches into a 10 : 90 coupler. The 90% light is modulated by the microwave data signal at 10.8 GHz via a MZM with insertion loss about 7 dB. The remaining 10% light is amplified by a SOA acts as feedback light for enhanced OSSB modulation. The modulated signal is launched into a 25-km SMF and interacted with the feedback light from the optical circulator (OC). After 25-km SMF transmission, output signal is using injection locked technology by a DFB laser to enhance OSSB modulation. The output OSSB signal goes into an EDFA to amplify for another 25-km SMF transmission. After fiber transmission, optical signal goes into an EDFA to amplify and then separates two parts by an optical interleaver (IL). For even part optical signal measures the optical spectrum by an optical spectrum analyzer (OSA). On the other hand, photo-detector (PD) transforms optical signal to electrical one, then performs down-conversion to base band via a mixer for bit error rate (BER) test Odd part optical signal reuses as uplink light carrier. A 622 Mb/s NRZ PRBS signal mixed with 8 GHz to generate uplink data signal is modulated by PM modulator. The modulated light signal goes into an EDFA to amplify for 25-km SMF transmission. Uplink light signal feeds into delay interferometer (DI) to transfer the phase modulated signal into intensity modulated one. Optical signal goes into receiver to perform O/E convert for BER test.

3. RESULTS AND DISCUSSIONS

Figure 2 is the optical spectrum using DFB laser injection locked. We observe the right sideband is larger 2.33 dB than left sideband because we utilize SBS effect and DFB laser injection locked to enhance the right sideband power. Because of using the SBS effect in fiber, the output spectrum for right sideband of modulated signal is amplified and left sideband is attenuated as well. The optical spectrum is likely optical SSB format. The DFB laser injection locked can double enhance the right sideband of optical spectrum and then the SBPR can be increased.

Figure 3 is the optical spectrum for downlink optical signal in even channel after optical signal passes through IL. We observe the optical signal is OSSB modulation and SBPR is > 15 dB.

Figure 4 shows the optical spectrum for uplink optical signal in odd channel after optical signal is modulated by PM modulator. The transmitting light is successfully remodulated with 622 Mbps/8 GHz RF signal for uplink transmission.

The measured BER curves as a function of the received optical power is plotted in Fig. 5 The received optical power levels at the BER of 10^{-9} are -23.3 dBm (back-to-back), -22.3 dBm (upstream) and -20.5 dBm (downstream). Power penalties about 1 dB (upstream) and 2.8 dB (downstream) for the fiber link are observed at BER test for 25-km SMF transmission.

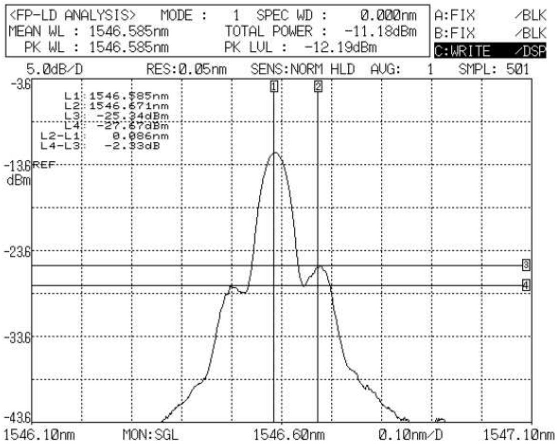

Figure 2: Optical spectrum after DFB laser injection locked.

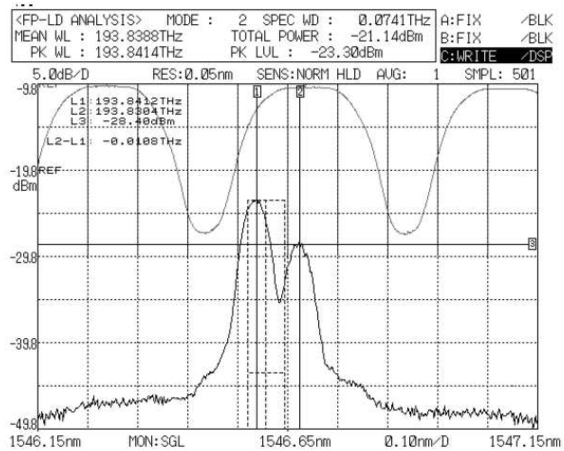

Figure 3: Optical spectrum for downlink in even channel passed through IL.

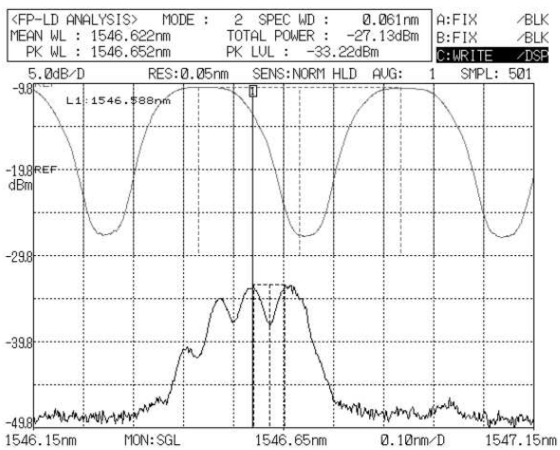

Figure 4: Optical spectrum for uplink transmission in back of PM modulator.

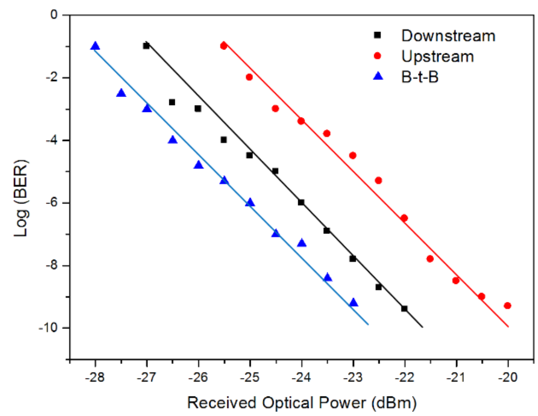

Figure 5: Measured BER curves as a function of the received optical power.

The BER is given by

$$\mathrm{BER} = \frac{1}{2} erfc\left(\sqrt{\frac{\mathrm{SNR}}{2}}\right) \tag{1}$$

where SNR is systems' signal-to-noise ratio. External light injection will reduce the threshold current of DFB laser, thus increase the optical output power of DFB. Moreover, SBS effect in fiber and injection locked technology can increase the output lower sideband power and suppress the noise distortion in which leading to SNR increment. The SNR value improves will lead to better BER performances.

4. CONCLUSION

We propose a bidirectional transmission system based on SBS effect and DFB laser injection locked to achieve OSSB modulation in fiber. Two kinds of technologies fall on frequency band approximately nearby 10.8 GHz to enhance OSSB signal. First step we drive 10.8 GHz RF signal into the modulator and then used SBS effect to enhance right sideband Second step based on injection-locked DFB laser to achieve OSSB modulation for downlink transmission. For uplink transport, we reuse transmitting light to carry signal by phase modulation to avoid signals interference. Using the proposed scheme, the 622 Mbps/10.8 GHz RF signals for downlink and 622 Mbps/8 GHz RF signals for uplink are successfully transmitted over a 25-km SMF link, we can observe the sideband power ratio (SBPR) > 15 dB and system's power penalty is < 2.8 dB. The results show good performances are achieved in our purposed bidirectional ROF transport system.

REFERENCES

1. Chi, H. and J. Yao, "Frequency quadrupling and upconversion in a radio over fiber link," *Journal of Lightwave Tech.*, Vol. 26, 2706–2711, 2008.
2. Lee, U. S., H. D. Jung, and S. Kook, "Optical single sideband signal generation using phase modulation of semiconductor optical amplifier," *IEEE Photon Tech. Lett.*, Vol. 16, 1373–1375, 2004.
3. Blais, S. R. and J. Yao, "Optical single sideband modulation using an ultranarrowual-transmission-band fiber bragg grating," *IEEE Photon Tech. Lett.*, Vol. 18, 2230–2232, 2006.
4. Sung, H. K., E. K. Lau, and M. C. Wu, "Optical single sideband modulation using strong optical injection-locked semiconductor lasers," *IEEE Photon Tech. Lett.*, Vol. 19, 1005–1007, 2007.