RF phase shifter using a distributed feedback laser in microwave transport systems

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Abstract: This work experimentally demonstrates the efficacy of a radio-frequency phase shifter using a distributed feedback laser in a microwave transport system. Phase shifts of about 101° are obtained at 8.75GHz. The proposed phase shifter can amplify microwave signals and thereby improve transmission performance. Additionally, a similar single sideband modulation can be generated by the phase shifter. Experimental results indicate that the proposed phase shifter can be used in future long-distance microwave transport systems and all optical inverters.

OCIS codes: (070.1170) Analog optical signal processing; (999.9999) Microwave photonics

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1. Introduction

Radio-over-fiber systems have garnered considerable attention due to their important applications, such as in wireless communication systems and phase-array antenna systems [1-4]. Radio-over-fiber systems facilitate flexible system design by linking central offices and remote antenna units via optical fiber. A simple and cost-efficient technique for transmitting microwave signals over fiber is to use an optical modulator based on double-sideband (DSB) modulation schemes [1]. However, when the double sideband signal propagates through dispersive optical fibers, two sideband signals experience different phase shifts, decreasing receiver sensitivity.

Phase shifters are major microwave components that have been extensively adopted in systems for communication, instrumentation, and measurement at microwave frequencies. The photonic elements in RF phase shifters have recently received attention due to their many advantages such as immunity to electromagnetic interference, optical distribution capability, excellent isolation, light weight, and small size [5-8]. The RF phase shifters that use semiconductor optoelectronic devices have become very attractive as a result of their inherent compactness, ease of integration with other devices, and low power consumption. Various approaches for constructing phase shifters in semiconductor optoelectronic devices have been developed, such as wavelength conversion in a distributed feedback (DFB) laser [9] and a vertical-cavity semiconductor optical amplifier [10]. Moreover, a commercial DFB laser in an external light-injection scheme for tunable optical delays has also been proven effective [11]. However, phase shifters and optical delays based on semiconductor devices in microwave transport systems have yet to be explored in detail.

This work experimentally demonstrates the effectiveness of a commercial DFB laser in an external light-injection scheme for an RF phase shifter. The tunable phase shift can be obtained by adjusting the wavelength detuning. Furthermore, the commercial DFB laser can amplify the microwave signal and thereby increase receiver sensitivity. Additionally, a similar single sideband modulation can be produced by the DFB laser. This single sideband modulation reduces RF fading problems resulting from fiber dispersion caused by double sideband modulation.

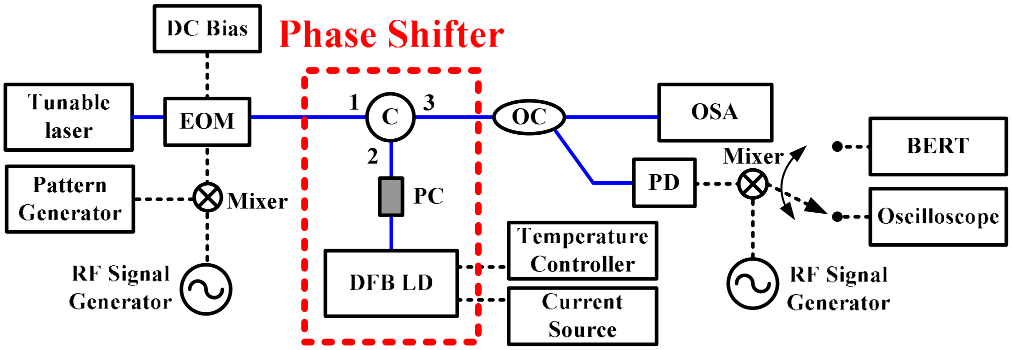

Fig. 1. Experiment setup (EOM: electro-optic modulator, C: optical circulator, OC: optical coupler, PC: polarization controller, DFB LD: distributed feedback laser, PD: photodetector, OSA: optical spectrum analyzer, BERT: bit error rate test)

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2. Experiment and results

Figure 1 presents the experimental setup for testing the feasibility of the proposed system. The 1.25 Gb/s data obtained from a pattern generator is mixed with an 8.75 GHz RF carrier. The 8.75 GHz 1.25 Gb/s binary phase-shift keying signal is fed into a single-electrode Mach-Zehnder modulator. Figure 2 shows the optical spectrum of the double-sideband signal. The generated optical signal is passed through an optical circulator, a polarization controller and a commercial DFB laser. Figure 3 shows the light-current characteristics and output spectrum of the DFB laser. The DFB laser driving current is 1.375 Ith (Ith: threshold current), and threshold current is approximately 8 mA. The light output by the DFB laser is guided through the same optical circulator. The output signal from port 3 of the circulator is then split into two paths, which are sent to an optical spectrum analyzer and a photodetector, respectively.

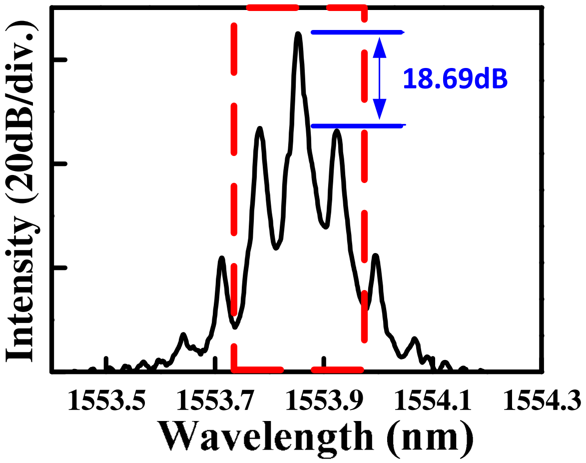

Fig. 2. Optical spectrum of a double-sideband signal.

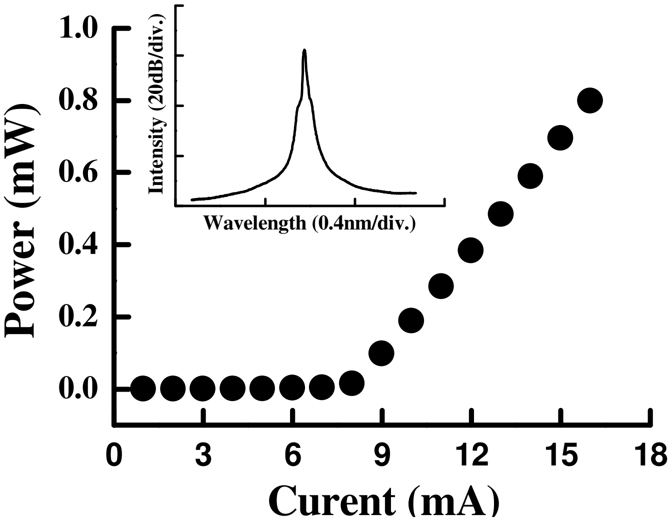

Fig. 3. Light-current characteristics and output spectrum of DFB laser.

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Figure 4 shows the measurements of time delay at the different wavelength detuning values ($\Delta\lambda = \lambda_{signal} - \lambda_{DFB}$ is the wavelength difference between the wavelength of optical microwave signal and the lasing wavelength of the DFB laser). The optical delay can be achieved to 32 ps delay. Moreover, the DFB laser is a narrow-band optical amplifier. The double sideband signal can be selectively amplified by the DFB laser. Thus, a single sideband spectrum can be obtained. Figure 5 shows the output spectra at wavelength detuning values of −0.04 and 0.01nm, respectively. The carrier-to-sideband ratio (ratio of carrier optical power to sideband optical power) can be controlled by adjusting wavelength detuning. The 8.75 GHz 1.25 Gb/s binary phase-shift keying signal is down converted using a mixer. Figure 6 shows the 1.25 Gb/s data pattern ("1010011000") at different wavelength detuning values. An inverted waveform was successfully obtained experimentally.

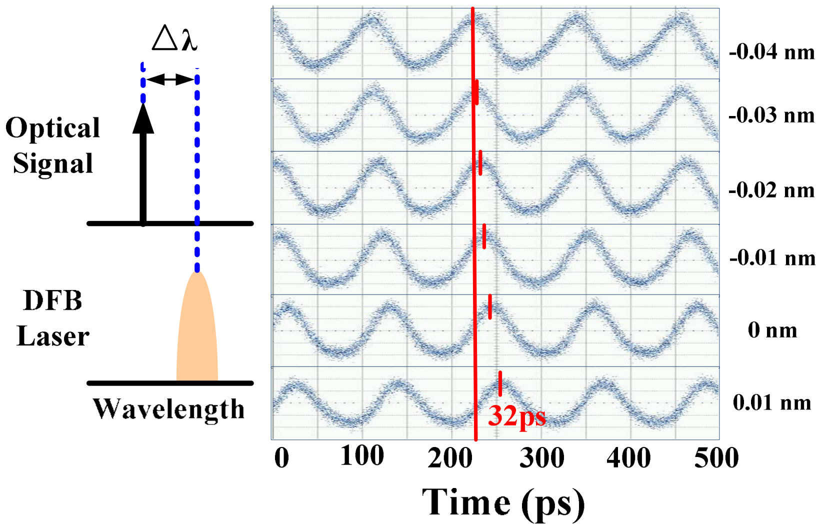
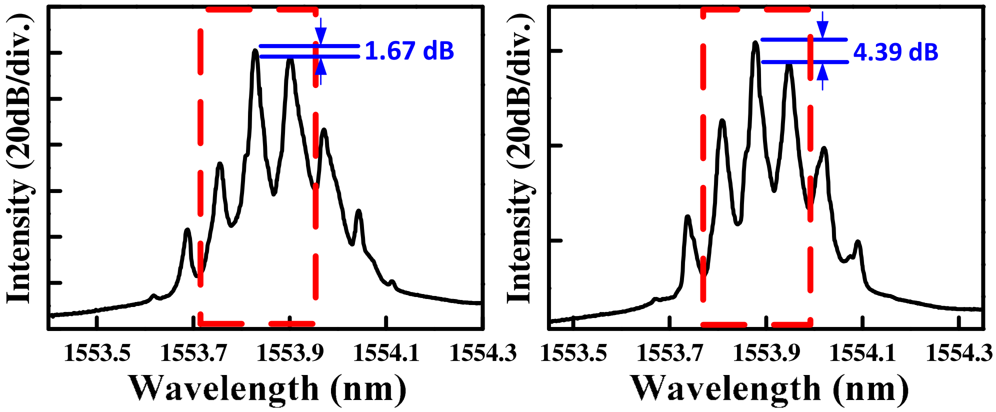


Fig. 4. Measured time delays at different wavelength detuning values



(a) (b)

Fig. 5. Output spectra at wavelength detuning values of (a) −0.04 nm and (b) 0.01 nm.

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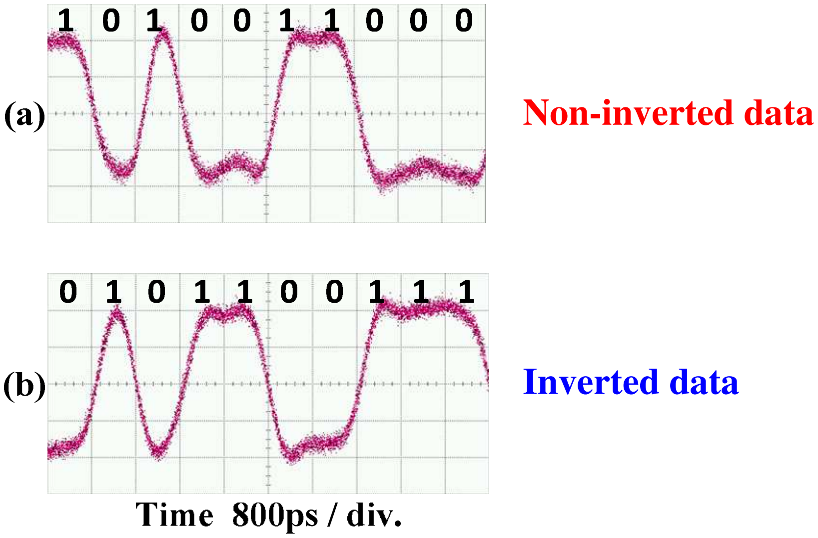

Fig. 6. The 1.25Gb/s data patterns at wavelength detuning values of (a) −0.04 and (b) 0.01 nm

Figure 7 plots the bit error rate (BER) as a function of received optical power for back-to-back and through DFB laser. Optical sensitivity can be improved by over 1.6 dB because the DFB laser amplifies the sideband signal and increases modulation depth. Measurements of BER demonstrate that the proposed phase shifter is suitable for use in microwave transport systems.

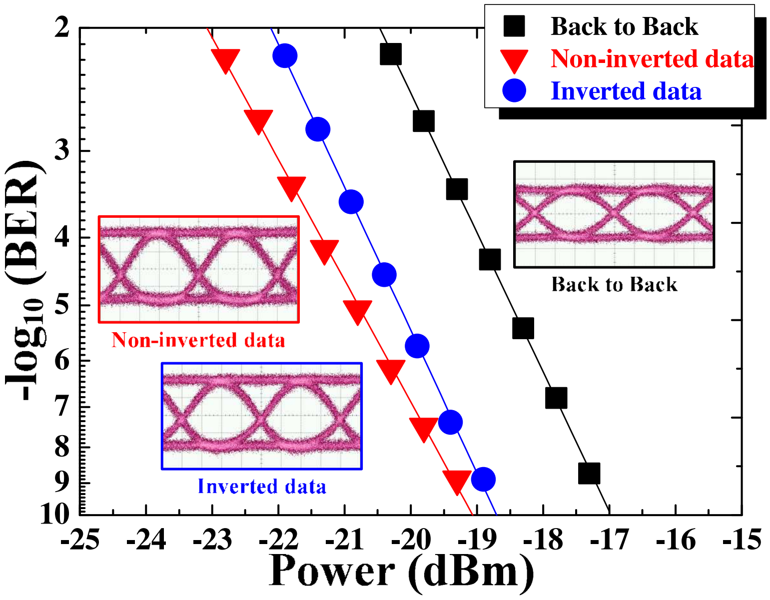

Fig. 7. Bit error rate (BER) as a function of the received optical power.

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3. Conclusion

This study experimentally demonstrated the efficacy of phase shifter using a DFB laser in a microwave transport system. The phase shifter for an 8.75 GHz 1.25 Gb/s binary phase-shift keying signal was demonstrated. Optical delay of 32 ps and phase shift of roughly 101° were achieved. The relationship between optical delay and wavelength detuning was studied. The phase shifter amplifies the microwave signal and increases receiver sensitivity. Moreover, this phase shifter can be utilized to generate a single sideband signal and invterted data.

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