International Topical Meeting on Microwave Photonics 10-12 September, 2003

Optical Single Sideband Modulation Using an Injection-Locked Semiconductor Laser as an Optical Filter

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Abstract: We propose a new technique of generating optical single sideband (SSB) signals using an injection-locked semiconductor laser (SL). The injection-locked SL acts as an optical filter which filters out the undesired mode from the double sideband signals. 30GHz optical SSB signals with our scheme are successfully generated.

I. Introduction

A simple approach to generate and transmit millimeter-wave (mm-wave) signals over fiber-optic links is intensity modulation with a high speed modulator [1-3]. This results in double sideband (DSB) signals in which two sidebands are separated by the desired mm-wave frequency from the optical carrier. As they propagate through dispersive optical fiber, two sideband signals experience disparate phase-shifts. Whenever the relative optical phase difference between two sidebands becomes π, the photo-detected signal powers at the desired mm-wave frequency are greatly suppressed.

Optical single sideband (SSB) modulation which can overcome dispersion induced power degradation has been an important research topic. Optical sideband filtering using a fiber Bragg grating filter is simple but requires a filter with very narrow optical passband and high reflectivity [4]. Dual electrode Mach-Zehnder electro-optic modulators can be utilized for optical SSB modulation, but its operation is sensitive to bias phase shifts [5].

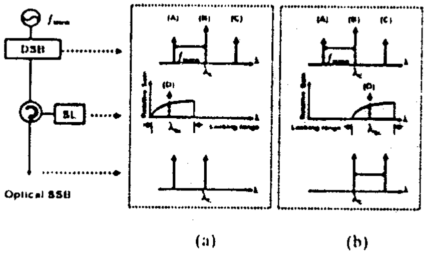


Fig. 1. Proposed scheme for optical single sideband. For (a), the mode at the shorter wavelength (A) is within locking range. For (b), two modes at the longer wavelength (B and C) are within locking range. SL: Semiconductor laser.

In this paper, we demonstrate a new technique of optical SSB modulation using an injection-locked semiconductor laser (SL) which filters out undesired modes from DSB signals. The filtering process is schematically shown in Fig. 1. DSB signals produced are injected into SL, whose locking characteristics are shown in the figure. The dotted arrow (D) represents the wavelength of the free-running (without any injection) SL. The shaded areas indicate the locking ranges under the strong locking condition and the gain that injected optical signals experience. This essentially represents the filtering characteristics of the injection-locked SL to the injected optical signals.

When one sideband (A) of the DSB signals is located within the locking range as shown in Fig. 1(a), this mode locks the SL and receives additional optical gain [6]. Other sidebands (B and C) outside the locking range are suppressed. Since mode (B) is sufficiently large to start with, two dominant modes are realized and optical SSB signals are generated.

When two DSB optical modes (B and C) are located within the locking range as shown in Fig. 1(b), both of them receive gain but the mode at the longer wavelength (C) gets larger optical gain [7]. Consequently, optical SSB signals are again generated. Since locking characteristics can be controlled by adjusting SL lasing wavelength and power, the desired filtering characteristics can be easily tuned so that only two modes are dominant after passing the SL.

II. Optical SSB Generation Experiments

In order to verify our scheme, experiments were first performed in which externally modulated DSBs were filtered with an injection-locked DFB laser diode (DFB-LD). The experimental setup is shown in Fig.2. The DSB modulation at 30GHz was done by modulating light from a tunable light source (TLS) with a 40GHz LN intensity modulator. The consequent optical spectrum is shown as input in Fig. 3, where each sideband is separated by 30 GHz from the optical carrier. The intensity-modulated light was injected into an unisolated DFB-LD biased at 12 mA near the threshold (≅ 11 mA) to ensure a wide locking range of about 35GHz. By controlling the temperature of the DFB-LD, its lasing wavelength was brought to the desired wavelength. As an example, temperature change of about 5 degrees was required between two conditions shown in Figs. 3(a) and 3(b). Whether the injection-locking is achieved or not was easily identified by observing the RF spectrum of photo-detected signals. A sharp peak at 30GHz was clearly observed when locking was achieved. Figs. 3(a) and 3(b) show the measured optical spectra of optical SSB signals with different locking characteristics: Fig. 3(a) is the case that one mode of DSB (A) is within the locking range, corresponding to Fig. 1(a), and Fig. 3(b) is the case that two modes of DSB (B and C) are within the locking range, corresponding to Fig. 1(b). In both cases, the desired sidebands for SSB are larger than unwanted sidebands by more than 20 dB.

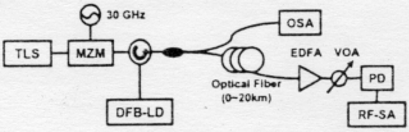
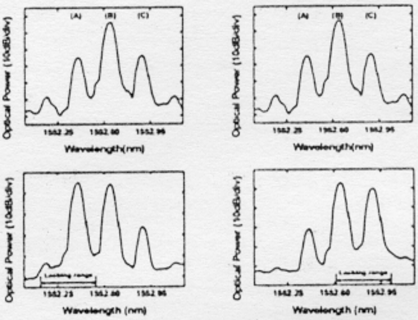


Fig. 2. Experimental set up. TLS: tunable light source, MZM: Mach-Zehnder intensity modulator, OSA: optical spectrum analyzer, EDFA: Erbium-doped fiber amplifier, VOA: variable optical attenuator, and RF-SA: RF-spectrum analyzer



(a) (b)

Fig. 3. Measured optical spectra for input DSB and output optical SSB for case that one mode of DSB at shorter wavelength (A) is within locking range (a) and for the case that two modes of DSB (B and C) are within locking range (b).

In order to investigate the effects of fiber chromatic dispersion on the generated SSB signals, photo-detected 30 GHz signal powers were measured as function of fiber transmission length and the results are shown in Fig. 4. For the compensation of the optical loss in fiber transmission, an Erbium-doped fiber amplifier and a variable optical attenuator were employed before PD as shown in Fig. 2. With DSB signals without passing through the DFB-LD, the signal powers were periodically suppressed as shown in Fig. 4 as expected. The solid line in the figure is obtained from curve-fitting the DSB signal power measurement results with theory [5]. On the contrary, SSB signals, whose optical spectra before launched into fiber are shown in Figs. 3(a) and 3(b), are not influenced by fiber dispersion as shown in Fig. 4.

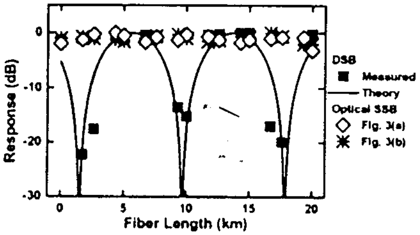


Fig. 4. Measured RF power versus fiber length.

As another demonstration, DSB signals were produced by a directly modulated DFB laser and filtering was performed with a Fabry-Perot laser diode (FP-LD) as shown in Fig. 5. The DSB optical spectrum and the resulting SSB spectra are shown in Fig. 6. Fig. 6 also shows FP modes that are not locked to the injected signals, but they are also greatly suppressed. As can be seen, SSB generation is successful. Since FP-LD has many modes that can be used for the filtering process, the wavelength range for this technique can be very wide. Fig. 7 shows RF spectrum correspondent to the optical SSB spectrum of Fig. 6(b) and SSB phase noise at the offset frequency of 100 kHz was – 92.17dBc/Hz.

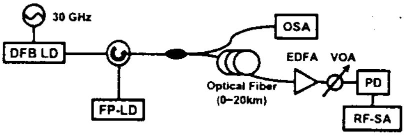
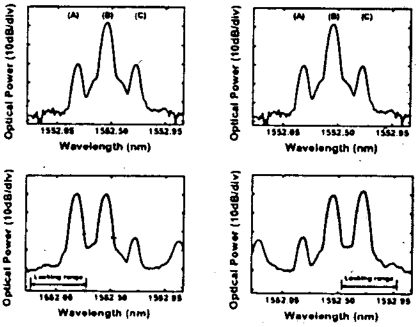


Fig. 5. Experimental set up for generation of optical single sideband. OSA: optical spectrum analyzer, EDFA: Erbium-doped fiber amplifier, VOA: variable optical attenuator, and RF-SA: RF-spectrum analyzer.



(a) (b)

Fig. 6. Measured optical spectra for input DSB and output SSB for the case that the sideband at the shorter wavelength (A) is within locking range (a) and for the case that the sideband at the longer wavelength (C) are within locking range (b).

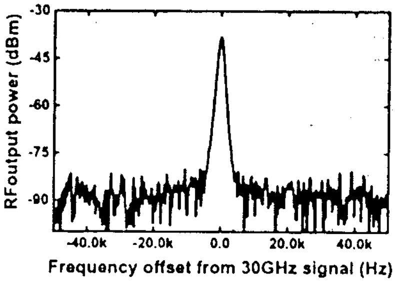


Fig. 7. Detected RF spectrum, RBW: 1 kHz and VBW: 1 kHz.

IV. Conclusion

We proposed a new technique of optical single sideband modulation using an injection-locked semiconductor laser as an optical filter. We successfully demonstrated generation of 30 GHz optical SSB signals using a DFB laser diode for externally modulated DSB signals and using a Fabry-Perot laser diode for directly modulated DSB signals. We also confirmed that these optical SSB signals were not influence by fiber dispersion. The proposed method has the benefit that it can be easily implemented by simple addition of a temperature-controlled laser.

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