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Generation of Optical Single Sideband Using a Semiconductor Laser under Modulated Light Injection

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A novel optical single-sideband (SSB) modulation technique using a semiconductor laser under modulated light injection is proposed. The transformation of double-sideband signals into optical SSB is realized using the optical filtering characteristics of a semiconductor laser under modulated light injection. It is experimentally shown that the resulting optical SSB signals do not suffer from fiber dispersion. [DOI: 10.1143/JJAP.42.L1064]

KEYWORDS: millimeter wave, fiber optic link, fiber dispersion, optical single sideband, semiconductor laser, optical injection locking

Millimeter-wave (mm-wave) wireless access systems have attracted attention in broadband radio services such as mobile communication, intelligent transportation system, and indoor wireless LAN, since the utilization of the mm-wave frequency ensures not only large transmission bandwidth but also reduced cell size and, thus, allows more subscribers and efficient frequency reuse.[1,2] For the delivery of mm-wave signals from a central office to remotely located base stations with antenna units, the fiber-optic technique is a powerful solution mainly because of optical fibers having low loss, large bandwidth and immunity to electromagnetic interference. A simple approach to transmitting mm-wave signals over fiber-optic links is to employ double-sideband (DSB) modulation using high-speed intensity modulators.[3,4]

DSB-modulated signals have two sidebands separated by the desired mm-wave frequency f_{mm} from the optical carrier in the optical spectrum. As they propagate through dispersive optical fibers, two sideband signals experience disparate phase shifts because they travel at different velocities owing to fiber chromatic dispersion. Whenever the relative phase difference between two sidebands becomes π, the photo-detected signal powers are greatly suppressed.[3]

In order to avoid dispersion-induced signal suppression, various single-sideband (SSB) modulation techniques have been demonstrated. Optical sideband filtering using a fiber Bragg grating is simple but requires a filter with a very narrow optical passband and a high reflectivity.[5] Optical SSB modulation based on all-optical Hilbert transformers overcomes the problem of a restricted operating bandwidth in the case of an electrical transformer, but is complex in implementation.[6] Dual-electrode Mach-Zehnder electro-optic modulators can be utilized for optical SSB modulation, but their operation is sensitive to bias phase shifts.[3]

In this paper, we propose a novel optical SSB generation scheme using a semiconductor laser (SL) under DSB-modulated light (DSB-ML) injection, where the SL acts as an optical filter. The experimental setup is illustrated in Fig. 1. Optical filtering using an SL is attractive because it can provide optical gain as well as filtering.

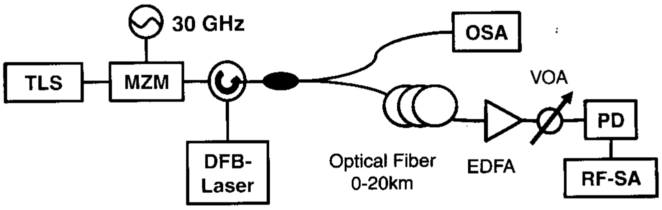
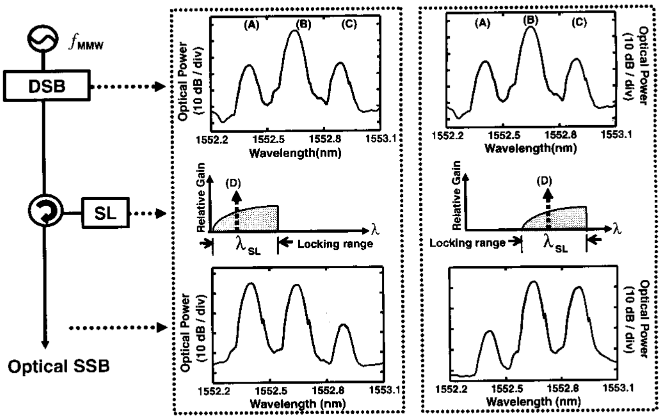


Fig. 1. Experimental setup. TLS: tunable light source, MZM: Mach-Zehnder intensity modulator, OSA: optical spectrum analyzer, EDFA: erbium-doped fiber amplifier, VOA: variable optical attenuator, and RF-SA: RF-spectrum analyzer.



(a) (b)

Fig. 2. Conceptual diagram and measured optical spectra for input DSB-modulated light and output SSB. (a) For the case in which one mode of DSB (A) at the shorter wavelength is within locking range. (b) For the case in which two modes of DSB (B and C) at the longer wavelength are within locking range. SL: semiconductor laser.

The conceptual diagram of the proposed scheme is described in Fig. 2. An SL under light injection transforms the input DSB-ML into SSB with gain and filtering characteristics. In Fig. 2, the free-running (without any injection) SL has the wavelength λ_{SL} represented by dotted arrows (D). The shaded areas represent the relative gain within the locking range that input optical signals will experience. When one sideband at the shorter wavelength of the DSB-ML (A) is located within the locking range as shown in Fig. 2(a), this sideband obtains the largest optical gain in the SL.[7] On the contrary, other DSB-ML modes (B and C) outside the locking range become suppressed, so that two optical modes (A and B) become dominant and optical SSB generation is achieved.

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When two (or even three) DSB-ML optical modes (B and C) are located within the locking range as shown in Fig. 2(b), both of them receive gain but the mode (C) at the longer wavelength receives the larger optical gain.[8] Consequently, the optical SSB generation is again achieved.

In order to verify our concept, experiments were performed with a setup shown in Fig. 1. The DSB modulation at 30 GHz was performed by modulating light from a tunable external cavity laser with a 40 GHz LN intensity modulator. The consequent optical spectrum of DSB-ML is shown as input in Fig. 2, where each sideband is separated by 30 GHz from the optical carrier. The intensity-modulated light was injected into an unisolated DFB-laser biased at 12 mA near the threshold (≅11 mA) to ensure a wide locking range.[7] By controlling the temperature of the SL, its lasing wavelength is brought to the desired mode of the input DSB-ML. As an example, a temperature change of about 5 degrees was required between the two conditions shown in Figs. 2(a) and 2(b). Whether or not the desired modes are located within the locking range was easily determined by the presence of a sharp peak at 30 GHz in the RF spectrum of the photodetected signals. Figures 2(a) and 2(b) show the measured output optical spectra of the resulting optical SSB signals. In both cases, the desired sidebands for SSB are larger than the unwanted sidebands by more than 20 dB.

In order to investigate the effects of fiber chromatic dispersion, photodetected 30 GHz signal powers were measured as a function of fiber transmission length, and the results are shown in Fig. 3. 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. 1. With the DSB-ML only, the signal powers were periodically and greatly suppressed in the RF spectrum as expected, which is represented by[3]

$$P_{\text{signal}} \propto \cos^2\left(\frac{\pi\lambda_{\text{ML}} D L f_{\text{mm}}^2}{c} + \arctan(\alpha)\right), \qquad (1)$$

where D represents the fiber dispersion, L the fiber length, λ_{ML} the center optical carrier wavelength, f_{mm} the electrical modulation frequency, and α the chirp of the modulator used. The solid line in the figure is obtained by curve-fitting the DSB-modulated signal power measurement results with eq. (1). On the contrary, the optically SSB modulated signals, whose optical spectra are shown in Figs. 2(a) and 2(b), are not influenced by fiber dispersion as shown in Fig. 3.

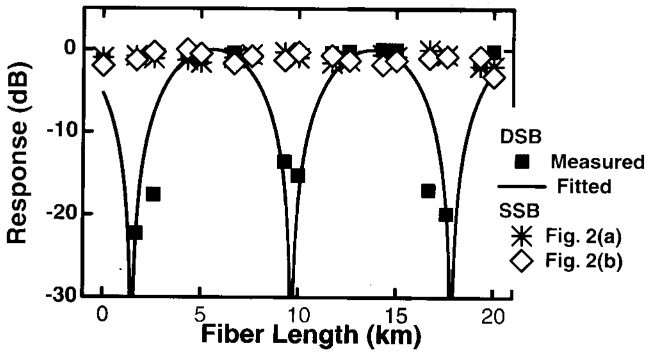

Fig. 3. Measured RF power versus fiber length.

A novel optical SSB modulation technique using a semiconductor laser under modulated light injection has been proposed. It has been successfully demonstrated that optical SSB generated by this scheme overcomes dispersion-induced power degradation. The proposed method has the advantage that it can be easily implemented by the simple installation of a temperature-controlled distributed feedback (DFB) laser.

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