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Single-sideband modulated radio-over-fiber system based on long period fiber grating

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ABSTRACT

We present a prototype for optical single-sideband (SSB) modulated radio-over-fiber (RoF) system by employing a long period fiber grating (LPFG). A LPFG with 13.78 nm base width of transmission spectrum and 0–23.2 dB of transmission depth was designed by using commercial software. Then it is used in RoF SSB modulation scheme. In the scheme, a Mach–Zehnder modulator modulates the light wave with millimeter-wave driving signals to realize optical double-sideband (ODSB) modulation, the generated ODSB modulation signals pass through a LPFG. Due to the negative slope in transmission spectrum, the lower sideband experiences higher attenuation than the upper sideband. Thus the conversion from ODSB to optical single sideband with carrier (OSSB + C) can be easily achieved by using only one LPFG. Also, the carrier to sideband ratio (CSR) can be reduced by using a LPFG, results show the CSR can be decreased from 12.49 dB to 1.1 dB.

1. Introduction

The two major development trends of communication are broadband and wireless, the existing wireless communication system cannot carry the high-speed multimedia services signals because of the limited bandwidth. How to realize the high-speed wireless access? One of the solutions is RoF [1], where the millimeter-wave and microwave signals at the carrier frequency are delivered over an optical network from central station (CS) to base stations (BSs). According to recent researches, millimeter-wave carrier generation methods include: (1) intensity modulation direct detection (IMDD) [2,3]; (2) remote heterodyne detection [4,5]; and (3) harmonic upconversion techniques [6]. IMDD is one of the simplest and most cost-effective approaches. However, the chromatic dispersion of single mode fiber (SMF) has different influence between the lower sideband and the upper sideband, which cause the signals to fade corresponding to fiber length [2]. For this reason, other schemes, such as OSSB + C [7] and optical carrier suppression (OCS) [8] have been presented. Recent studies have shown that the OSSB + C and the OCS can be realized by employing the external modulator and filtering technologies. The OSSB + C modulation is usually implemented by filtering technologies because of the external modulator with extinction ratio and complexity limit. Because the radio-frequency (RF) driving signals are typically weakly modulated onto the optical carrier with very low modulation efficiency, the power of the optically modulated millimeter-wave sideband is much lower than that of the optical carrier (CSR is much higher than 0 dB). The performance of fiber link can be significantly improved when the optical signal is transmitted at the optimum CSR of 0 dB [9]. There are some technologies such as fiber grating [7,10,11] and optical attenuation [12] which can be used to improve the performance of fiber link.

In this letter, we demonstrate a prototype for OSSB + C modulation RoF system by employing a LPFG as a filter. Firstly a LPFG with 13.78 nm base width of transmission spectrum and 0–23.2 dB of transmission depth was designed by using a commercial software. Then the LPFG was used in the radio over fiber system. Only using one LPFG can descent the CSR and realize the OSSB + C modulation. In the simulation, receiving sensitivity of −23.5 dBm at bit error rate (BER) of 10^{-9} with 20 km fiber length is implemented.

2. Principle and discussion

The schematic setup is shown in Fig. 1. A tunable laser (TL) services as the optical source. Lightwave signals which are coupled into a Mach–Zehnder modulator (MZM) are first modulated by a millimeter-wave driving signals with the frequency of 30 GHz. The MZM is biased in its maximum transmission point.

The optical field at the output of MZM can be expressed as

$$E_{\text{out}}(t) = E_{\text{in}}(t)[\exp(j\pi \frac{V_s}{\sqrt{2}V_\pi}\cos(\omega_s t)) + \exp(-j\pi \frac{V_s}{\sqrt{2}V_\pi}\cos(\omega_s t))] \quad (1)$$

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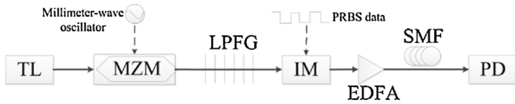

Fig. 1. Schematic setup of the OSSB + C RoF system.

where $E_{in}(t)$ denotes the input optical field with a amplitude of E_0 and angular frequency of ω_0, V_s and ω_s are amplitude and angular frequency of the millimeter-wave signals. V_π represents the half wave switching voltage of the MZM. We expand Eq. (1) with the Bessel functions. Eq. (1) becomes

$$E_{out}(t) = E_0 \exp(j\omega_0 t) \times [J_0(m) + 2\sum_{n=1}^{\infty}(-1)^n J_{2n}(m)\cos(2n\omega_s t)] \quad (2)$$

where $J_n(.)$ presents the Bessel function of first kind of order n, and $m = \pi V_s/\sqrt{2}V_\pi$ denotes the modulation index of MZM. To realize weak modulation, m should be set as a small value, for example m equals to 1.2, the corresponding values of $J_0(m)$, $J_2(m)$, and $J_4(m)$ are 0.6711, 0.1593, and 0.0050. Hence, sideband with order higher than $J_2(m)$ can be neglected. Therefore, the optical field at the output of the MZM can be simplified as

$$E_{ODSB}(t) = -E_0 J_2(m)\exp(j\omega_0 t + j2\omega_s t) + E_0 J_0(m)\exp(j\omega_0 t) - E_0 J_2(m)\exp(j\omega_0 t - j2\omega_s t) \quad (3)$$

Eq. (3) shows that the output field presents an ODSB signal with lower sideband, upper sideband, and carrier. The CSR of signal can be calculated as

$$CSR = 20\log_{10}\left[\frac{J_0(m)}{J_2(m)}\right] \approx 12.49\,\text{dB} \quad (4)$$

LPFG is fabricated with metal mask instead of phase mask, the metal mask is more cheaper than phase mask and more easy to fabricated. In addition, LPFG has no back reflected light, the back reflected light is not considered when LPFG is used in communication system. In the scheme, we make use of the coupled-mode theory and a single mode fiber which have three layer including core, cladding, and the third layer to design a LPFG. The key parameters of LPFG are listed in Table 1. The transmission spectrum is presented in Fig. 2.

As can be seen in Fig. 2, the LPFG is with a negative slope from 1553.44 nm to 1559.47 nm and transmission depth from 0 to 23.2 dB.

In order to verify our scheme, simulations are implemented by a Matlab program and commercial simulation software. In the scheme, the TL is operated at the wavelength of 1558.9 nm and power of 0 dBm. The millimeter-wave oscillator is operated at the frequency of 30 GHz. Then the frequency span between sideband and optical carrier is 60 GHz. The spectrum of ODSB signal is shown in Fig. 3. Then the ODSB signal pass through the LPFG, upper sideband, optical carrier, and lower sideband experience different attenuation, the corresponding attenuation is −19.00 dB, −30.39 dB, and −34.26 dB. The optical field at the output of LPFG can be expressed as

$$E_{OSSB+C}(t) = -\alpha_1 E_0 J_2(m)\exp(j\omega_0 t + j2\omega_s t) + \alpha_2 E_0 J_0(m)\exp(j\omega_0 t) - \alpha_3 E_0 J_2(m)\exp(j\omega_0 t - j2\omega_s t) \quad (5)$$

where α_1, α_2, and α_3 denote the attenuation factor. Fig. 4 is the spectrum of the output optical signal. As can be seen in Fig. 4, the lower sideband experiences the largest attenuation, the intensity difference between upper sideband and lower sideband is approximately 15.26 dB. Hence, the output optical signal can be approximately considered as OSSB + C and the optical CSR can be calculated as

$$CSR = 20\log_{10}\left[\frac{\alpha_1 J_0(m)}{\alpha_2 J_2(m)}\right] \approx 1.1\,\text{dB} \quad (6)$$

Table 1
Parameters value of LPFG.

Parameter	Value
Fiber core radius	4.15 μm
Fiber Cladding radius	58.35 μm
The third layer radius	20 μm
Core index	1.44921
Cladding index	1.44403
The third layer index	1
Period	630 μm
The number of period	100
Index modulation	0.000225

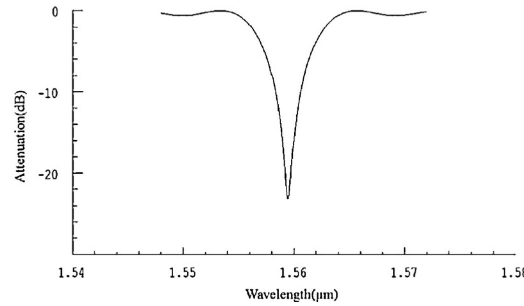

Fig. 2. Spectra of LPFG.

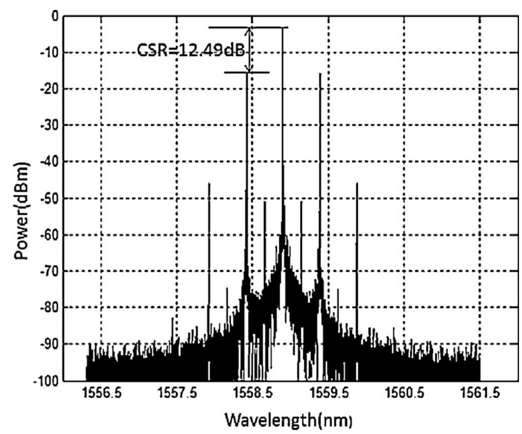

Fig. 3. Spectra of DSB signals.

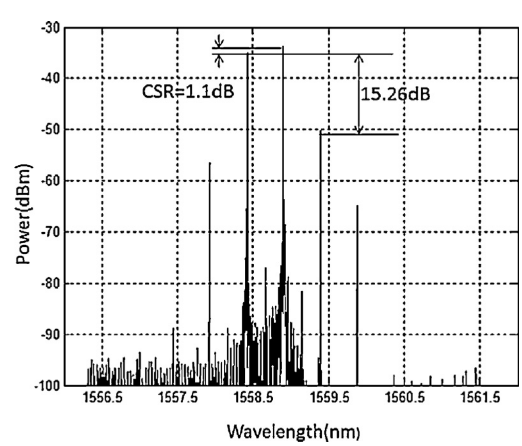

Fig. 4. Spectra of OSSB + C signals.