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Single-sideband modulated radio-over-fiber system based on phase-shifted superstructure fiber Bragg grating

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Abstract: A prototype for the typical optical single-sideband(SSB) modulated radio-over-fiber (ROF) system was presented by employing a phase-shifted superstructure Bragg grating. The grating has different transmission characteristics with different oblique angle. So, the different transmission peak could be obtained with different phase shift inserted into different positions. Then it was used in SSB modulation scheme as a filter. In the scheme, the lower sideband experiences higher attenuation due to the negative slope in reflectivity spectrum. Thus the conversion from dual-sideband(DSB) to single sideband with carrier(SSB+C) can be easily achieved by using only one phase-shifted superstructure fiber Bragg grating. Also, the optical carrier-to-sideband ratio(OCSR) can be optimized by using grating with different oblique angle. In this paper, the OCSR could be optimized from 33.02 dB to 1.31 dB and a 60 GHz millimeter-wave was detected after photodiode. What′s more, a min BER of 1.966e−44 with 30−km fiber length was implemented which means that only using one phase-shifted superstructure FBG can improve the link performance greatly.

Key words: radio over fiber; phase-shifted fiber Bragg grating; transmission spectrum; single-sideband modulation

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基于相移超结构光栅的 ROF 单边带调制系统

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摘　要：提出了一个利用相移超结构光栅构建的典型 ROF 单边带调制系统。改变倾斜角，光栅就会呈现不同的传播特性。将不同的相移插入光栅的不同位置就会得到不同的透射谱特性。因此该光栅可视为滤波器应用于单边带调制系统中。反射谱的负斜率特性使得低阶边带会经历更高的衰减。所以，仅仅使用一个相移超结构光栅就可以简单地实现双边带到载波单边带的转换。与此同时，还可以通过改变光栅的倾斜角优化光载波抑制比。在实验中，60 GHz 的毫米波信号产生的同时光载波抑制比也由 33.02 dB 优化到 1.31 dB，经过 30 km 光纤传输后的最小误码率可以达到 1.966e−44，所以仅仅通过一个相移超结构光栅就可以大大提高链路性能。

关键词：光载无线；　相移超结构光栅；　透射谱；　单边带调制

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0 Introduction

Radio over fiber(RoF) is a promising technology to realize the high-speed wireless or mobile communication systems [1-3]. In a RoF link, the mm-wave and microwave signals at the carrier frequency are delivered over a central station (CS) and several base stations(BSs). According to recent researches, mm–wave carrier generation methods include:(1) intensity modulation direct detection (IMDD)[4], (2) remote heterodyne detection[5], and (3) harmonic upconversion techniques [6]. IMDD is one of the simplest and cheapest approaches. However, due to the chromatic dispersion in fiber links, the converted RF signals will experience periodic dispersion-induced power fading corresponding to fiber length, which makes long-distance fiber transmission unpredictable. To solve this problem, the optical carrier suppression (OCS) and optical single-sideband with carrier(OSSB+C) schemes have been proposed [7-10]. In Ref.[7], fiber grating was first proposed to improve link performance. A narrow-band FBG was proposed to suppress optical carrier and improve receiver sensitivity. However, it suffers from poor OCSR tunability. In Ref. [8], an SBS–assisted filter based on PS–FBG was proposed to improve dynamic range, however, it suffers from complicated structures and the OCSR cannot reach 0dB.

In this work, we analyze and demonstrate an OSSB+C modulation RoF system using a phase-shifted superstructure FBG as a filter. This grating has wavelength selectivity of high quality, low insertion loss, and stable spectral characteristics. In our experiment, 7 identical phases are inserted into a 16–mm–long grating evenly. Then the grating is used in the RoF system. Only using one phase-shifted superstructure FBG can generate the OSSB+C signal and improve the link performance greatly.

1 Principle and discussion

The transmission spectrum of the phase-shifted superstructure FBG is shown in Fig.1. As can be seen, there are two transmission high peaks at the wavelengths of 1 547.8 and 1 548.2 nm. The first peak is with a transmission depth of 31.92 dB and the second peak is with a transmission depth of 74.41 dB. The spectra from 1 547.1 to 1 547.34 nm can be considered as flat. In this paper, we demonstrate a 16–mm–long grating with seven identical phases inserted in 1/8, 1/4, 3/8, 1/2, 5/8, 3/4, 7/8 of the grating. The main parameters are as follows: KL=16.0 mm, T=533 nm, N_{eff}=1.460, q=0.25p, m=0.000 8.

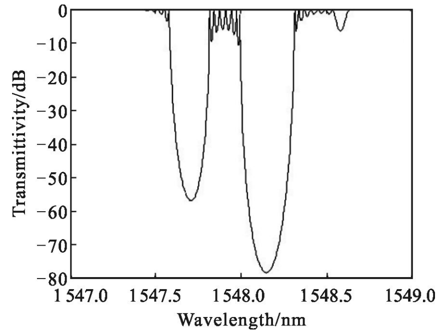

Fig.1 Spectra of phase-shifted superstructure FBG

Figure 2 shows the diagram of the RoF system by employing phase-shifted superstructure FBG. In the experiment, two peaks with 0.48–nm wavelength deviation are realized. Then, the grating is used in the single-sideband RoF system. The optical field at the output of MZM can be expressed as

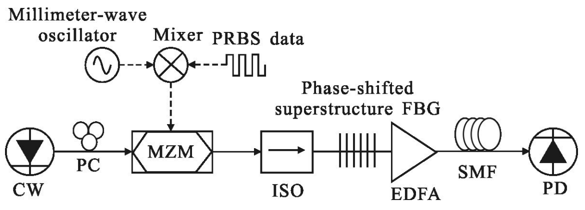

Fig.2 Schematic setup of the OSSB+C RoF system

$$E_{\mathrm{out}}=E_0\cos(\omega_0 t)\cos[m\cos(\omega_0 t)] \tag{1}$$

where E_0 and ω_0 denote the magnitude and angular frequency of optical electric field, $m=\pi V_m/V_\pi$ represents the modulation index of MZM, V_m, V_π denote modulation voltage and half wave switching voltage of the MZM. Then expand Eq.(1) with the Bessel functions. Eq.(1) becomes

$$E_{\mathrm{out}}(t)=E_0\exp(\mathrm{j}\omega_0t)[J_0(m)+2\sum_{n=1}^{\infty}(-1)^nJ_{2n}(m)\times \cos(2n(\omega_mt))] \quad (2)$$

For example, m equals to 1, the optical field at the output of the MZM can be simplified as

$$E_{\mathrm{ODSB}}(t)=-E_0J_2(m)\exp(\mathrm{j}\omega_0t+\mathrm{j}2\omega_mt)+E_0J_0(m)\exp(\mathrm{j}\omega_0t)-E_0J_2(m)\exp(\mathrm{j}\omega_0t-\mathrm{j}2\omega_mt) \quad (3)$$

The simulated spectrum of DSB is shown in Fig.3. The OCSR of signal can be calculated from the figure as

$$\mathrm{OCSR}=20\log_{10}\frac{\sum J_0(m)}{\sum J_2(m)}33.02\ \mathrm{dB} \quad (4)$$

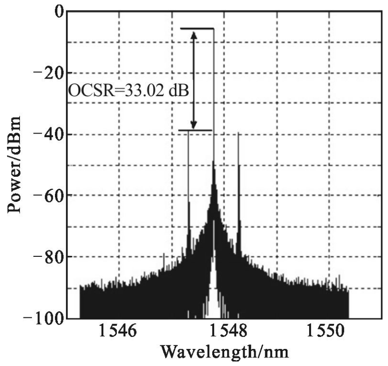

Fig.3 Simulated optical spectrum of ODSB

Then the optical field is transmitted by the phase-shifted superstructure FBG. Making sure that the peak with a 31.92 dB transmission depth is adjusted to the optical carrier and the peak with a 74.41 dB transmission depth is adjusted to lower sideband. The output signal can be regarded as OSSB+C modulation signal, the output signal from phase-shifted superstructure FBG can be concluded as

$$E_{\mathrm{OSSB}}(t)=[-a_1E_0J_2(m)\exp(\mathrm{j}\omega_0t+\mathrm{j}2\omega_mt)+a_2E_0J_0(m)\exp(\mathrm{j}\omega_0t)-a_3E_0J_2(m)\exp(\mathrm{j}\omega_0t-\mathrm{j}2\omega_mt)] \quad (5)$$

Where a_1, a_2 and a_3 denote the attenuation factor respectively. The OCSR is calculated as

$$\mathrm{OCSR}'=20\log_{10}\frac{\sum J_0(m)}{\sum J_2(m)}1.31\ \mathrm{dB} \quad (6)$$

The resulting spectrum can be seen in Fig.4. After being amplified by an erbium-doped optical fiber amplifier(EDFA), the OSSB+C signal is intensity modulated with 0.5 Gb/s pseudorandom binary sequence (PRBS) data and then transmitted through dispersive single-mode fiber. The transfer function of SMF can be concluded as

$$H(f)=\exp\left[-\mathrm{j}\pi D(\lambda_0)L\frac{\lambda_0^2(\upsilon-\upsilon_0)}{c}\right] \quad (7)$$

where $D(\lambda_0)$ denotes the dispersion coefficient, λ_0 represents operating wavelength, υ and υ_0 denote the frequency of sideband and carrier. The Fourier transform of Eq.(5) is multiplied by Eq.(7), the result can be expressed as

$$F[E_{\mathrm{OSSB}}'(t)]=[-a_1E_0J_2(m)\delta(\omega-\omega_0-2\omega_m)+a_2E_0J_0(m)\delta(\omega-\omega_0)-a_3E_0J_2(m)\delta(\omega-\omega_0+2\omega_m)]\cdot\exp\left[-\mathrm{j}\pi D(\lambda)L\frac{\lambda^2(\upsilon-\upsilon_c)}{c}\right] \quad (8)$$

Then Fourier inverse transform of Eq.(8) is done, the output signal is OSSB+C modulation signal in optical field, which can be concluded as

$$E_{\mathrm{OSSB}}'(t)=[-a_1E_0J_2(m)\exp(\mathrm{j}\omega_0t+\mathrm{j}2\omega_mt-\mathrm{j}D(\lambda)\lambda^2L\omega_m^2/\pi c)+a_2E_0J_0(m)\exp(\mathrm{j}\omega_0t)-a_3E_0J_2(m)\exp(\mathrm{j}\omega_0t-\mathrm{j}2\omega_mt-\mathrm{j}D(\lambda)\lambda^2L\omega_m^2/\pi c)] \quad (9)$$

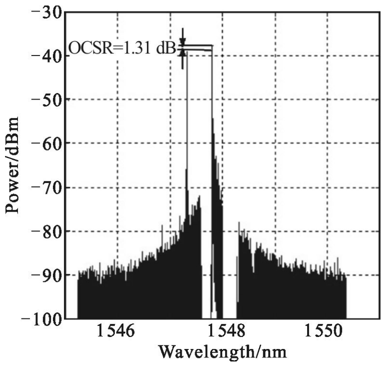

Fig.4 Simulated optical spectrum of OSSB

Figure 5 shows the spectrum of 60 GHz signal, the power of the signal can be calculated as

$$P_{mm}=2R^2E_0^4J_0^2(m)J_2^2(m)\{a_1^2a_2^2+a_2^2a_3^2+2a_1a_2^2a_3\cos[2D(\lambda)\lambda^2L\omega_m^2/\pi c]\} \quad (10)$$

If we don't use a phase-shifted superstructure FBG, the power of the 60 GHz signal is

$$P_{mm}'=2R^2E_0^4J_0^2(m)J_2^2(m)\{2+2\cos[2D(\lambda)\lambda^2L\omega_m^2/\pi c]\} \quad (11)$$

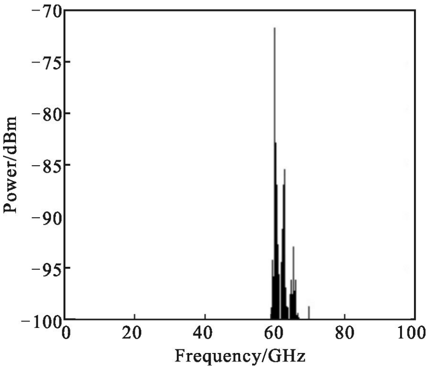

Fig.5 Spectrum of 60 GHz signal

The mm-wave signal power due to the fiber length is shown in Fig.6. When the L increases from 0 to 20 km, the millimeter-wave signal power fluctuates in periodism because of the fiber dispersion. Thus the fluctuation of the signal power can be significantly improved. As shown in Fig.7, when the fiber length is 20 km, the scheme with phase-shifted superstructure FBG is with higher receiving sensitivity of -5.2 dBm at BER of 10^{-9}, and the scheme with uniform FBG is with a lower receiving sensitivity of 1 dBm at BER of 10^{-9}, the receiving sensitivity increases 6.2 dB.

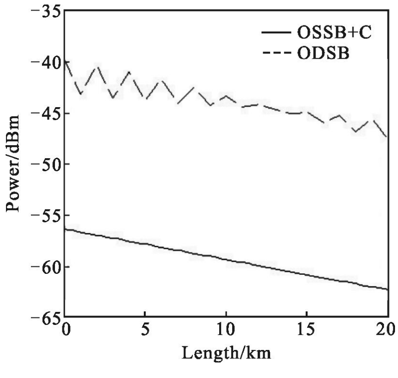

Fig.6 Millimeter-wave signal power due to fiber length

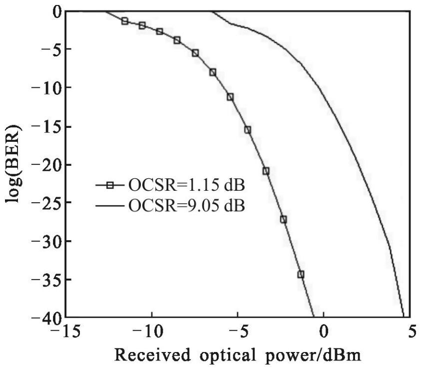

Fig.7 BER curves with different OCSR

2 Conclusion

In conclusion, we proposed an OSSB+C signal generation for a RoF system. We only employ a phase-shifted superstructure FBG as a filter to realize OSSB +C generation and CSR optimization simultaneously. Hence, the receiving sensitivity and the optical link performance can be consequently improved, which has been proved by a simulation. Finally, a 60 GHz millimeter-wave electrical signal is detected after the process of the photodiode.

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