A novel OFDM-ROF system based on OCS and asymmetrical filtering technique

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A novel radio-over-fiber (ROF) system has been proposed and simulated, which is based on orthogonal frequency division multiplexing (OFDM) and asymmetrical filtering of optical carrier suppression (OCS) technique, so it can effectively suppress the fading effect caused by power periodic variation in traditional OCS system. Simulation results show that the 2.5 Gbit/s OFDM-modulated wideband wireless signal can be transmitted over 25 km single mode fiber (SMF) successfully.
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Radio-over-fiber (ROF) system is regarded as a promising technique with high efficiency for realizing future broadband wireless networks[1]. One of the key points of ROF system is the generation and transmission of optical millimetre-wave (mm-wave). A number of ROF system schemes have been proposed to generate high quality mm-wave and improve the performance of signal transmission. Due to double sideband (DSB) modulation is used to generate mm-wave in Refs.[2, 3], the fading effect severely limits the transmission distance and bit rate, because power periodic variation of DSB ROF signals is induced by dispersion, and DSB modulation is prone to time shifting of the codes and broadening of the optical carriers by dispersion. Fortunately, the problems of time shifting of the codes and broadening of the optical carriers can be solved by orthogonal frequency division multiplexing (OFDM) technique[4-7]. Since there are only two frequency components, single sideband (SSB) modulation can be used to mitigate the fading effect caused by power periodic variation of ROF signals. However, SSB system has high bandwidth requirement for components, because it can't use local oscillator (LO) to achieve doubling frequency for optical carriers. In Ref.[8], optical carrier suppression (OCS) technique is used to against the fading effect to a certain extant when the baseband signals is used to modulate optical carriers. And OCS can achieve doubling frequency for optical carriers simultaneously. However, when OFDM transmission signals are employed to avoid the time shifting of the codes and improve the bit rate, the problem of fading effect caused by power periodic variation still exists[9].

In this paper, a novel OFDM-ROF system based on OCS and asymmetrical filtering technique is proposed. The reasons of fading effect of traditional OFDM-ROF system based on OCS modulation are analyzed. The novel OFDM-ROF system can avoid the fading effect cased by power periodic variation, and it is simulated. The transmission performance of it is also discussed.

The architecture of the proposed novel ROF system is shown in Fig.1. A continuous wave is generated by a distributed feedback laser diode (DFB-LD), and then modulated by a dual-drive Mach-Zehnder modulator (MZM) and used to generate optical mm-wave. The electric OFDM signals are generated by the OFDM modulation and mixed with the RF signal from an LO by a mixer. The mixed OFDM signals are used to drive both the upper arm and the lower arm of the MZM. In order to realize the OCS modulation, a phase shift is imported at the lower arm of the MZM and the bias voltage of MZM is set at V_π. Before the optical mm-wave is generated, an optical filter is employed to suppress the extremely right loading signal. Finally, the optical mm-wave is delivered into standard single mode fiber (SSMF) link. In the optical network unit (ONU), the downstream mm-wave signals are directly detected by a PIN, and then electric mm-wave signals are broadcast by an antenna. In customer unit, after frequency conversion and OFDM demodulation, electric mm-wave signals are converted into the original data.

The architecture of the novel OFDM-ROF system based on OCS and asymmetrical filtering technique is similar to the traditional one. The main difference is that an optical filter is employed to remove the signal at frequency of $\omega_C+\omega_{RF}+\omega_{IF}$.

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The spectral analysis diagram of OFDM-ROF signals based on OCS and asymmetrical filtering technique is shown in Fig.2. Here, ω_C is the frequency of the center optical carrier, ω_{RF} is the frequency of the RF signal from an LO, and ω_{IF} is the intermediate frequency (IF) of the loading signals. The optical signal is given by

$$S_C(t)=E\{e^{j(\omega_C+\omega_{RF})t}+e^{j(\omega_C+\omega_{RF})t}+\alpha(t)[e^{j(\omega_C+\omega_{RF}-\omega_{IF})t}+e^{j(\omega_C-\omega_{RF}+\omega_{IF})t}+e^{j(\omega_C-\omega_{RF}-\omega_{IF})t}]\}\ ,\qquad(1)$$

where E is the light field intensity and $\alpha(t)$ is the useful transmitted signal. Given the effect of the dispersion in optical fiber transmission, the optical signals become

$$S_C^{'}(t)=E\{e^{j(\omega_C+\omega_{RF})t}+e^{j(\omega_C-\omega_{RF})t}+\alpha(t)e^{j(\omega_C-\omega_{RF}-\omega_{IF})t}\cdot e^{j\theta_1}\times\alpha(t)[e^{j(\omega_C+\omega_{RF}-\omega_{IF})t}+e^{j(\omega_C-\omega_{RF}+\omega_{IF})t}]\cdot e^{j\theta_2}\}\ ,\qquad(2)$$

where θ_1 is used to replace $\beta_2(\omega_{RF}+\omega_{IF})^2L/2$ and θ_2 is used to replace $\beta_2(\omega_{RF}-\omega_{IF})^2L/2$, β_2 is the second-order dispersion coefficient and L is transmission distance. The first-order dispersion and high-order dispersion are ignored. The second-order dispersion is regarded as the main one in this paper.

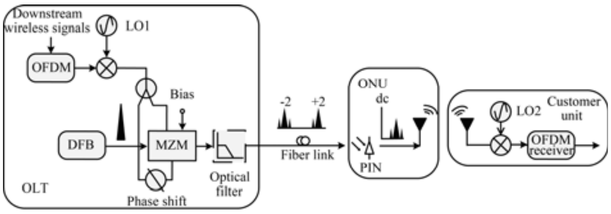


Fig.1 The proposed architecture of the OFDM-ROF system based on OCS and asymmetrical filtering technique

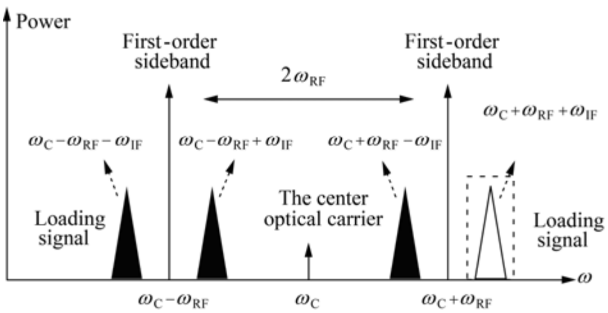


Fig.2 The spectral analysis diagram of OFDM-ROF signals based on OCS and asymmetrical filtering technique

Now, $e^{j\theta_1}$ and $e^{j\theta_2}$ respectively represent the influence of the dispersion of the signals at different frequencies. If the useless high-order and low-roder harmonic components are ignored, after a photodetector, the signal current can be expressed as follows:

$$I_{RF}\propto P_C(t)=|S_C^{'}(t)|^2\approx d_C+E^2\{2\alpha(t)\cos[(2\omega_{RF}+\omega_{IF})\text{-}\theta_1]+4\alpha(t)\cos\theta_2\cdot\cos[(2\omega_{RF}-\omega_{IF})t]\}\ ,\qquad(3)$$

where d_C is DC component. It can be seen that electric RF signal has the useful transmitted signal $\alpha(t)$ at both the frequencies of $2\omega_{RF}+\omega_{IF}$ and $2\omega_{RF}-\omega_{IF}$. The relationship between the power of the received electric signal after the photodetector and the amplitude attenuation factors is as follows:

$$P_{RF}\propto I_{RF}^2\propto\cos[(2\omega_{RF}+\omega_{IF})-\theta_1]\ ,\qquad(4)$$

$$P_{RF}\propto I_{RF}^2\propto\cos\theta_2\cdot\cos[(2\omega_{RF}-\omega_{IF})t]\ .\qquad(5)$$

Given the periodic variability of the amplitude attenuation factors in Eq.(5), the power of RF signal will show the characteristic of periodic variation. When the value of the amplitude attenuation factor $\cos\theta_2$ is close to zero, the power of the received electric signal will be too small to be used to demodulate original data. So the signal $\alpha(t)$ at the frequency of $2\omega_{RF}-\omega_{IF}$ still has the power periodic variation. However, the signal $\alpha(t)$ at the frequency of $2\omega_{RF}+\omega_{IF}$ doesn't have the problem, which can be used to recover the original data without the fading effect. The only problem is that the signal has the influence of phase, which can be offset by phase correction.

However, when a typical OCS modulation is employed, the signal current at the receiving end is expressed as follows:

$$I_{RF}\approx d_C+4E^2\alpha(t)\cos\theta_1\cdot\cos(2\omega_{RF}+\omega_{IF})t+4E^2\alpha(t)\cos\theta_2\cdot\cos(2\omega_{RF}-\omega_{IF})t\ .\qquad(6)$$

It means that the signals $\alpha(t)$ at the both frequencies of $2\omega_{RF}+\omega_{IF}$ and $2\omega_{RF}-\omega_{IF}$ will have the power periodic variation, because of the amplitude attenuation factors $\cos\theta_1$ and $\cos\theta_2$.

The proposed OFDM-ROF system based on OCS and asymmetrical filtering technique is also simulated. The DFB-LD at 1552.5 nm is employed to generate the continuous wave. For the purpose of modulating the OFDM signals to the lightwave and realizing the OCS modulation, the OFDM signals are mixed with 30 GHz RF signal, and 4QAM, 128 point IFFT and 1/16 cyclic prefix ratio are applied. Here, 2.5 GHz IF is employed in OFDM modulation to prevent frequency-band overlapping and system bit rate is 2.5 Gbit/s. The generated electrical OFDM signals are divided into two branches to drive the upper arm and the lower arm of the MZM, respectively. The phase shift is 90°and the bias voltage of MZM is set at V_π. One dual-drive MZM is used to modulate OCS optical mm-wave instead of using two MZMs to realize the same purpose. The bandwidth of the optical band-stop filter is 2 GHz and center frequency is $(193.1\times10^{12}+32.5\times10^9)$ Hz. Finally, the optical mm-wave is delivered into SMF link. The modulated optical mm-wave is shown in Fig.3. The main parameters of the SMF include 17 $ps\cdot nm^{-1}\cdot km^{-1}$ dispersion, 0.2 dB/km attenuation and $2.6e^{-20}$ m^2/W nonlinear index.

In the OUN, the optical 70 GHz PIN is used to beat and generate the 60 GHz electrical mm-wave signals.

Electrical mm-wave signals are transmitted to the customer units by an antenna. In the customer units, the right loading signals are unbroken and could be used to recover the original data. Here, 62.5 GHz de-conversion and OFDM demodulation are required so that customer could receive the original data.

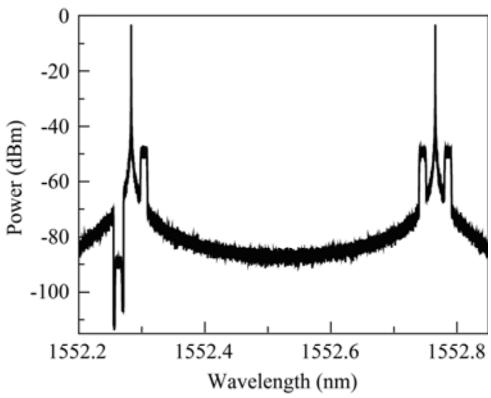


Fig.3 The modulated optical mm-wave

Due to the effect of different transmission distances, different 60 GHz electrical mm-wave signals are obtained. The different 60 GHz electrical mm-wave signals which are generated by traditional OFDM-ROF system based on OCS technique are shown in Fig.4(a)−(d). It is found that both the two sides of the loading signals are influenced by fading effect. The problem of the power periodic variation along with the change of the transmission distance could induce signal distortion and the failure of recovering original data.

The electrical mm-wave signals generated by the proposed OFDM-ROF system based on OCS and asymmetrical filtering technique are shown in Fig.4(e)−(h). Compared with the ones of traditional OFDM-ROF system based on OCS technique, only the left loading signals are influenced by fading effect. At the same time, the left distortion loading signals have the same waveforms with the ones of traditional OFDM-ROF system in different transmission distances. However, the right loading signals are not affected by the power periodic variation. So we can use the right loading signals to recover the original data.

In order to demonstrate the superiority of the proposed OFDM-ROF system based on OCS and asymmetrical filtering technique, we take the 25 km SSMF system for simulation. The 60 GHz mm-wave signals of 25 km SMF transmission without and with filtering technique are shown in Fig.4(c) and Fig.4(g), respectively. Obviously, both sides of the loading signals of the traditional system are seriously distorted, which are induced by fading effect. At the same time, the left loading signals of the proposed system are distorted, but the right loading signals are unbroken without power attenuation. Therefore, the right loading signals can be filtered out by an electric filter and then demodulated.

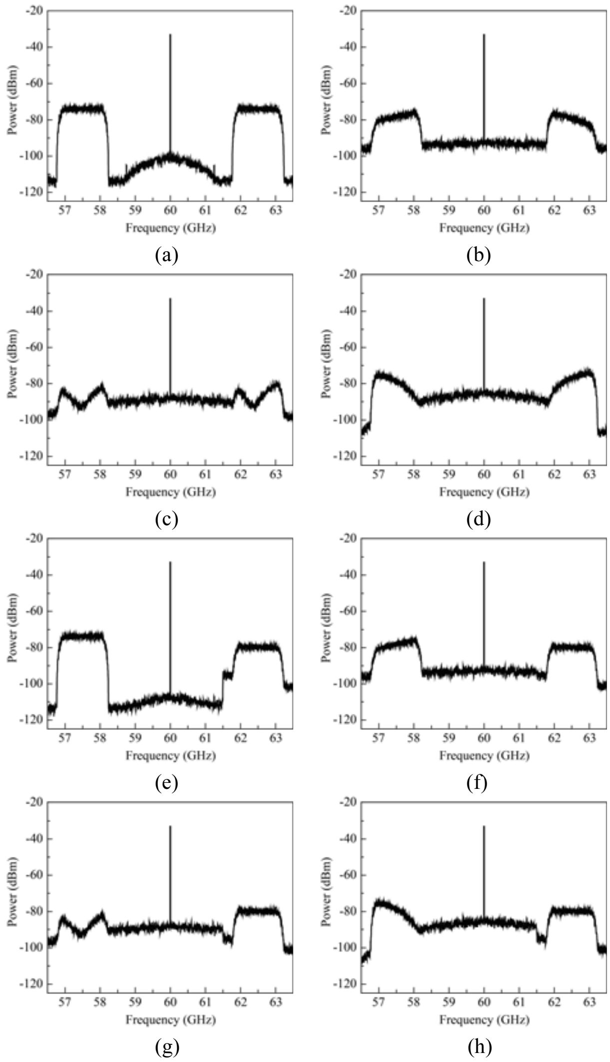
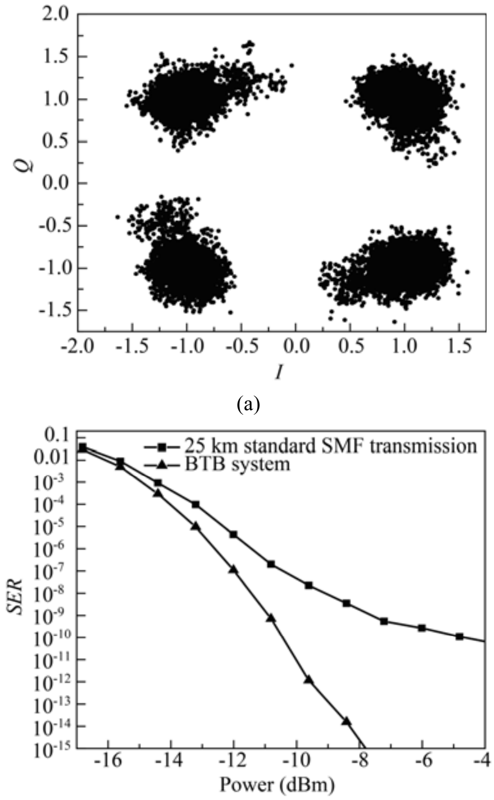


Fig.4 The 60 GHz mm-wave signals: (a) BTB without filtering technique; (b) 15 km SMF transmission without filtering technique; (c) 25 km SMF transmission without filtering technique; (d) 35 km SMF transmission without filtering technique; (e) BTB with filtering technique; (f) 15 km SMF transmission with filtering technique; (g) 25 km SMF transmission with filtering technique; (h) 35 km SMF transmission with filtering technique

The 25 km SMF transmission performance of the proposed OFDM-ROF system based on OCS and asymmetrical filtering technique is shown in Fig.5. The constellation of 25 km SMF transmission rotates slightly, but it is clear as a whole and does not affect the data demodulation. As shown in Fig.5(b), the power penalty is about 1 dB at symbol error rate (SER) of 10^{-6} over 25 km SSMF, which is an acceptable value for access network systems. However, in the traditional OFDM-ROF system based on OCS technique only, the constellation is disordered and the signals can barely be demodulated. Therefore, the proposed OFDM-ROF system based on OCS and asymmetrical filtering technique is superior to the traditional one and has acceptable performance for access networks.



(b)

Fig.5 25 km SMF transmission performance of the proposed OFDM-ROF system based on OCS and asymmetrical filtering technique: (a) Constellation; (b) SER vs. received power

In this paper, we have proposed a novel OFDM-ROF system based on OCS and asymmetrical filtering technique. By theory analysis and simulation, the reasons of the fading effect of the traditional OFDM-ROF system based on OCS are analyzed. An optical filter is employed to effectively eliminate the fading effect induced by the power periodic variation along with the change of the transmission distance. Simulation results show that the proposed system can generate and transmit 2.5 Gbit/s OFDM-modulated wideband wireless signals at 60 GHz and the power penalty is about 1 dB at the SER of 10^{-6} when 25 km standard SMF is employed. Thus, the proposed OFDM-ROF system is economical and reliable.

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