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An improved radio-over-fiber communication system based on optical carrier suppression

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An improved radio-over-fiber (ROF) system based on optical carrier suppression modulation (OCS) is presented. In this ROF system, through adopting frequency down-conversion of the down-sideband, a millimeter (mm) wave emitted signal, whose frequency is higher than twice of the radio frequency (RF) which is used to drive the dual-arm $LiNbO_3$ Mach-Zehnder intensity modulator (DLN-MZI) in OCS, can be obtained at the base station. Meantime, self-mixing technique has been used to realize frequency down-conversion of the up-stream link, and then the base station can be further simplified due to that the local oscillation (LO) is not necessary. For 2.5 Gb/s down-link data stream, the transmission characteristics of this system have been investigated. The results show that the effect of the fiber chromatic is not serious, after transmission over 140 Km single-mode fiber, the eye diagram is still open and the power penalty is about 0.86 dBm.

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Keywords: Optical wireless communication, Radio-over-fiber (ROF), Optical carrier suppression modulation, Optical mm-wave

1. Introduction

The radio-over-fiber (ROF) is a promising technique for providing wireless broadband services [1-10]. As one of the key techniques in the ROF system, the generation of the optical millimeter (mm) wave has attracted many interests in recent years, and many schemes have been proposed to generate optical mm-wave. Among these schemes, optical external modulation has been proven to be a simple and effective approach. Through adopting different optical external modulation methods such as double sideband (DSB), single sideband (SSB) and optical carrier suppression (OCS) [1-2], different format mm-waves can be obtained.

In the ROF system, the baseband signal can be loaded into the system by the subcarrier modulation technique. In this way, the baseband signal is modulated onto one (or both) of the central optical carrier and two sidebands [6]. The reported results showed that the transmission performance can be improved if the baseband signal is only modulated onto one of the two sidebands based on OCS [4]. This method helps to avoid both the periodical fading of optical mm-wave power and the code distortion caused by the chromatic dispersion.

In this paper, we propose an improved ROF system based on OCS. Through adopting frequency down-conversion and the self-mixing technique, the required RF driving frequency for generating a fixed frequency optical mm-wave can be decreased and the base station can also be simplified. For 2.5 Gb/s down-link baseband signal, after transmission over 140Km single-mode fiber, the eye diagram is not deteriorated obviously and the power penalty is about 0.86 dBm.

2. Systematical setup and theory

Fig. 1 is the schematic of the improved ROF system. In central office, a dual-arm $LiNbO_3$ Mach-Zehnder intensity modulator (DLN-MZI) is used to modulate a continuous-wave (CW) light wave generated by a distributed feedback laser diode (DFB-LD). The optical mm-wave output from DLN-MZI mainly consists of two first-order sidebands (named upper and lower sideband) due to optical carrier suppression (OCS) technique, and the upper sideband and lower sideband are separated by an optical interleaver (IL). The upper sideband is modulated by the down-link digital data stream, while the lower sideband is frequency-down-converted by an optical frequency converter. The upper sideband with carrying signal, together with the frequency down-converted lower sideband, inject into single-mode fiber by an optical coupler (OC). At the base station, optical mm-wave is divided into two parts, where one part is used to generate electrical mm-wave by a photodetector (PD) and the other part is used as the optical carrier of the up-link stream through filtering the upper-sideband. The electrical mm-wave is broadcast by an antenna. The received up-link data from the antenna are down-converted through self-mixing technique to obtain baseband up-link data, which is used to drive an intensity modulator (IM) to generate an optical up-link data before it is transmitted to the central office via the fiber.

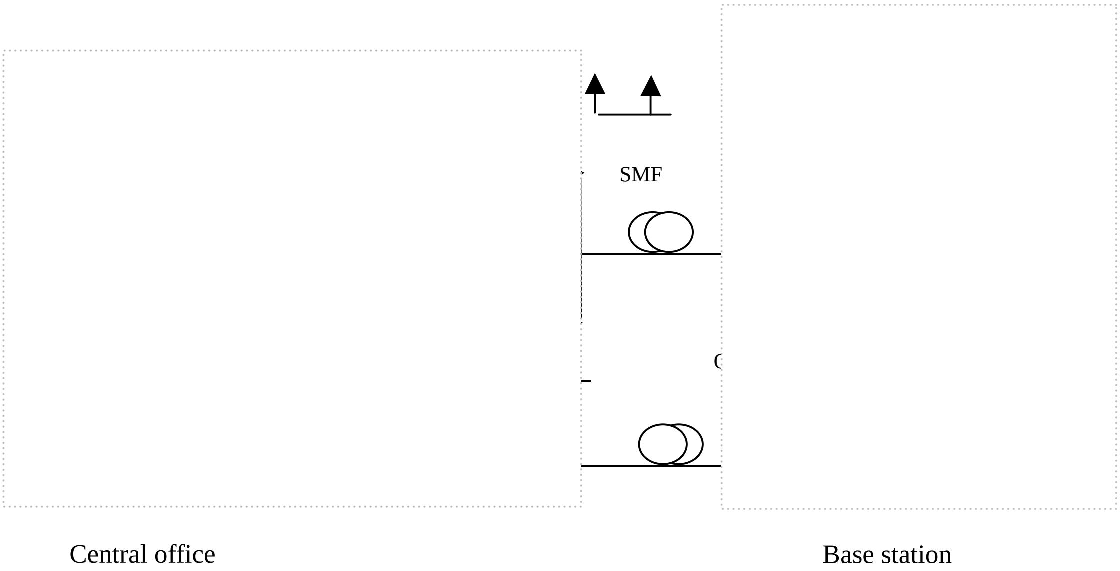

Fig. 1. Schematic of the improved ROF system based on OCS. DLN-MZI: Dual-arm LiNbO$_3$ Mach-Zehnder intensity modulator; IL: Optical interleaver; IM: Intensity modulator; FDC: Frequency-down convertor; OC: Optical coupler; SMF: Single-mode fiber; OF: Optical filter.

For optical wireless communication system, the influences of fiber chromatic on the optical mm-wave in the down-link must be considered. The amplitude of modulated optical signal output from DLN-MZI can be expressed as:

$$E(t)=A_c[a_{-1}\cos(\omega_c-\omega_m)t+a_0\cos\omega_c t+a_{+1}\cos(\omega_c+\omega_m)t] \quad (1)$$

where A_c and ω_c are the amplitude and frequency of the input CW light wave, respectively, a_0 and $a_{\pm 1}$ are the relative amplitude of optical carrier and two first-order sidebands generated by modulation, respectively, ω_m is the frequency of the radio frequency (RF) driving signal. In the right side of Eq. (1), the term including a_0 can be ignored due to OCS modulation technique.

After the upper sideband is modulated by the baseband signal and the lower sideband is frequency-down-converted, the optical field coupling into the single-mode fiber is:

$$E(t)\approx A_c[a_{-1}\cos(\omega_c-\omega_m-\omega_0)t+A(t)a_{+1}\cos(\omega_c+\omega_m)t] \quad (2)$$

where ω_0 is the down-converted frequency of the lower sideband, and $A(t)$ is the down-link data stream.

After neglecting the loss and the nonlinearity of the fiber, the amplitude of optical field at distance z can be described by

$$\begin{aligned}E_2(z,t)&=a_{-1}A_c\cos[(\omega_c-\omega_m-\omega_0)t-\beta(\omega_c-\omega_m-\omega_0)z]\\&\quad+a_{+1}A_cA(t-\frac{\beta(\omega_c+\omega_m)}{\omega_c+\omega_m}z)\cos[(\omega_c+\omega_m)t-\beta(\omega_c+\omega_m)z]\\&=A_{-1}\cos[(\omega_c-\omega_m-\omega_0)t-\beta(\omega_c-\omega_m-\omega_0)z]\\&\quad+A_{+1}\cos[(\omega_c+\omega_m)t-\beta(\omega_c+\omega_m)z]\end{aligned} \quad (3)$$

where $\beta(\omega)$ is the transmission constant. Here, we define $A_{+1}=a_{+1}A_cA(t-\beta(\omega_c+\omega_m)/(\omega_c+\omega_m)z)$ and $A_{-1}=a_{-1}A_c$ for simplification. Then photocurrent detected by PD can be mathematically expressed as

$$I_2(t)=\mu\left|E_2(z,t)\right|^2 \quad (4)$$

where μ characterizes the converted efficiency of O/E, and the optical component is neglected due to that the PD can not response the optical frequency. The Taylor's expansion of $\beta(\omega)$ is

$$\beta(\omega_c\pm\omega_m)=\beta(\omega_c)\pm\omega_m\beta^{'}(\omega_c)+\frac{1}{2}\omega_m^2\beta^{''}(\omega_c)+\cdots \quad (5)$$

and the photocurrent becomes

$$I_2(t)\approx\frac{1}{2}\mu(A_{+1}^2+A_{-1}^2)+\mu A_{+1}A_{-1}\cos[(2\omega_m+\omega_0)(t-\beta^{'}(\omega_c)z)] \quad (6)$$

Thus, the electrical mm-wave signal with frequency $2\omega_m+\omega_0$ can be obtained at the base station when a radio frequency signal with ω_m is used to drive DLN-MZI in the central office.

In traditional ROF systems, in order to realize the frequency down-conversion of the high-frequency mm-wave received from the antenna, a local oscillator (LO) is usually necessary at the base station. In this improved system, the LO is not needed by adopting self-mixing technique. Assumed that the high-frequency signal received from the antenna is $s(t)=A(t)\cos(\omega_m t)$, the signal after self-mixing can be expressed as:

$$s^{'}(t)=s(t)\cdot s(t)=A^2(t)\cos^2\omega_m t=\frac{1}{2}A^2(t)[1-\cos(2\omega_m t)] \quad (7)$$

For the digital data stream, the value of $A(t)$ is 0 or 1, and then the signal after self-mixing can be expressed as:

$$s'(t) = \frac{1}{2}A(t)[1-\cos(2\omega_m t)] \qquad (8)$$

After passing through a low pass filter, the baseband up-link signal can be obtained.

3. Results and discussion

During the simulations, we use the optical communication simulation software optisystem3.0 and matlab7.5.

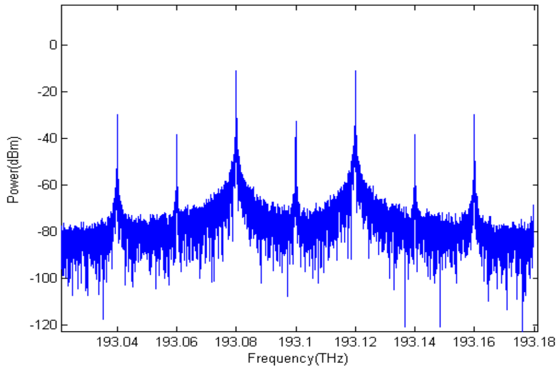

Fig. 2. Optical spectrum output from DLN-MZI.

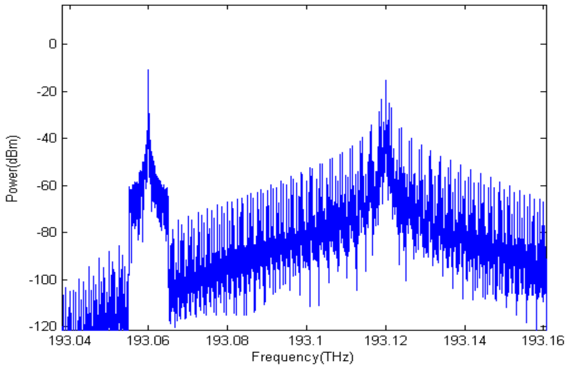

Fig. 3. Optical spectrum after optical coupler.

A distributed-feedback (DFB) laser is used to generate a CW with 193.1THz central frequency and 1mw power. The CW light wave is OCS modulated by a dual-arm LN-MZI driven by two complementary 20 GHz RF signals. Fig. 2 is the spectrum of the obtained optical mm-wave. The frequency difference between the two sidebands is 40 GHz and the carrier suppression ratio is more than 20 dB. After passing an optical interleaver, the two sidebands are separated. The upper sideband is modulated with 2.5 Gb/s down-link baseband data, while the lower sideband is 20 GHz frequency-down-converted. The modulated upper sideband and down-converted lower sideband are simultaneously injected into single-mode fiber through an optical coupler, and the optical spectrum after the optical coupler is given in Fig. 3. As shown in this diagram, the two sidebands have a 60 GHz frequency difference, and the upper sideband carries the data signal but the lower sideband does not. At the base station, the optical mm-wave is divided into two parts. One part is converted into 60 GHz electrical mm-wave by a PD and the other passes through an optical filter to extract the lower sideband which is used as optical carrier for the up-link data.

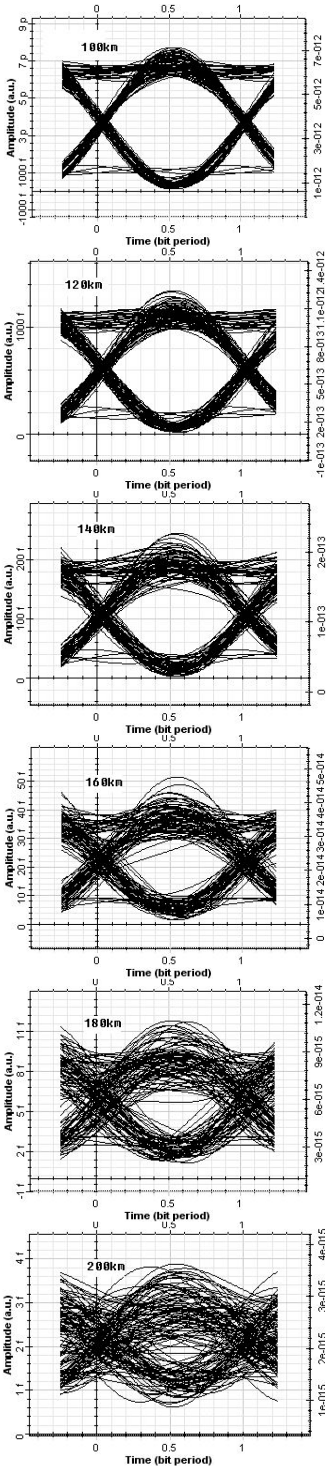

Fig. 4. Eye diagrams of baseband signal after transmission over different length fiber.

Fig. 4 is the eye diagrams of the baseband signal after transmission over different length single-mode fiber. It should be pointed out that self-mixing technique has been used during signal demodulated process. From this diagram, one can see that the signal transmission quality deteriorates slowly with the increase of the transmission distance. The eye diagram is still open even for transmission over 140 km single-mode fiber, but fully closes when the transmission distance reaches 200 km.

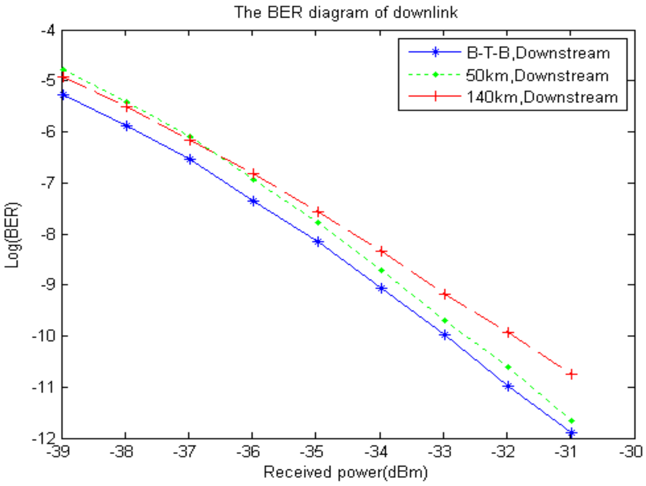

Fig. 5. Dependence of BER on the received power for back-to-back (B-T-B), 50 km and 140 km transmission distances, respectively.

Finally, we examine the dependence of the bit error rate (BER) on the received power. Fig. 5 is the simulated results for back-to-back (B-T-B), 50 km and 140 km transmission distances, respectively. For 10^{-9} BER, the optical power penalty is 0.35 dBm after transmission over 50 km and is about 0.86 dBm after transmission over 140 km.

5. Conclusions

In conclusion, we propose an improved ROF system based on OCS. Based on this ROF system, mm-wave with 60 GHz has been obtained by adopting the frequency down-conversion when the dual-arm $LiNbO_3$ Mach-Zehnder intensity modulator is driven by 20 GHz RF signal. The base station is simplified because the local oscillation can be discarded by introducing self-mixing technique. Furthermore, the transmission performance of this improved system has been investigated, and the results show that for 2.5 Gb/s baseband data stream, the clean eye diagram can be obtained after transmission over 140 Km single-mode fiber. Additionally, the BER performance is evaluated. The power penalty after transmission over 50 km is 0.35 dBm, and power penalty after transmission over 140 km is 0.86 dBm.

Acknowledgements

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