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All optical up-converted signal generation with high dispersion tolerance using frequency quadrupling technique for radio over fiber system

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ABSTRACT

A novel all optical up-converted signal generation scheme with optical single-sideband (OSSB) technique for radio over fiber (RoF) application is presented and experimentally demonstrated using low-bandwidth devices. The OSSB signal is generated by one low-bandwidth intensity $LiNbO_3$ Mach-Zehnder modulator (LN-MZM) under frequency quadrupling modulation scheme and one low-bandwidth LN-MZM under double sideband carrier suppressed modulation (DSB-CS) scheme. The proposed all OSSB generation scheme is capable of high tolerance of fiber chromatic dispersion induced power fading (DIPF) effect. Benefiting from this novel OSSB generation scheme, a 26 GHz radio frequency (RF) signal up-conversion is realized successfully when one sideband of the optical LO signal is reused as the optical carrier for intermediate frequency (IF) signal modulation. The received vector signal transmission over long distance single-mode fiber (SMF) shows negligible DIPF effect with the error vector magnitude (EVM) of 15.7% rms. In addition, a spurious free dynamic range (SFDR) of the OSSB up-converting system is measured up to 81 dB $Hz^{2/3}$. The experiment results indicate that the proposed system may find potential applications in future wireless communication networks, especially in microcellular personal communication system (MPCS).

1. Introduction

Radio over fiber (RoF) technique is considered as one of the most promising candidate that satisfies the ever-increasing bandwidth demand of next generation wireless networks and convenient service for all kinds of end users [1–4]. In such wireless access systems, the cost-effective generation and distribution of high frequency mm-wave signals over long distance optical fiber are the key technology to achieve successful deployment of RoF applications. Several approaches to generate high-frequency RF signals have been reported using low bandwidth devices [5–10]. According to these articles, the up-converted signal generation could be realized by using the non-linearity of the external modulator [5,6], by utilizing the cascaded single-electrode Mach-Zehnder modulator (SE-MZM) with double-sideband suppressed-carrier (DSB-SC) modulated scheme [7], by employing the nonlinear behavior of the photodetector [8] or by exploiting the inherent nonlinearity of the fiber and the semiconductor optical amplifier (SOA) [9,10]. These techniques make the RoF system not only to avoid the implementation of high frequency RF mixers, but also operate in the favorable high-frequency range with improved dispersion tolerance and reduced installation cost at the same time.

However, with the increasing of microwave frequency, the well-known dispersion induced power fading (DIPF) has become a limiting factor of the system performance. Due to DIPF effect, the received RF signal power after intensity-modulation and direct-detection (IMDD) shows sine-like fluctuation which will eventually limit the available transmission distance [11]. Utilizing OSSB signal transmission in RoF system is one of the effective methods to overcome the DIPF problem. In recent years, various kinds of OSSB RF signal generation approaches have been reported [12–15]. Usually, the OSSB signal generation could be achieved by utilizing a dual-electrode MZM biased at the quadrature point [12], cascaded polarization modulators (PolMs) by controlling the polarization direction [13], cross phase modulation of SOA [14]. The OSSB generation utilizing fiber stimulated Brillion scattering is reported in Ref. [15] with only one sideband being amplified and the other being suppressed. Moreover, OSSB generation in combination with up-conversion technique has become an interest

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research topic in recent years. Quite a few OSSB up-conversion schemes are proposed for RoF applications [16–18]. A quasi OSSB generation and up-conversion approach utilizing the cross gain modulation (XGM) in a nonlinear SOA is demonstrated [16]. Afterwards, an OSSB up-conversion technique employing cross polarization effect of SOA with carrier suppressed scheme is realized [17]. Carrier generation and signal up-conversion was also achieved by using fiber stimulated Brillouin scattering with optical injection locking [18].

In this paper, a simultaneous all-optical SSB up-conversion system utilizing low bandwidth modulators in associate with fiber Bragg gratings (FBGs) is demonstrated. One obvious advantage of the proposed system is that the local oscillator (LO) frequency only requires a quarter of the RF carrier frequency and the up-converted OSSB signal shows the significant capability of long distance SMF transmission with negligible DIPF due to one sideband beating in the photodetection [12]. Thus, a high-frequency RF signal generation and a low-frequency LO transmission are achieved with improved dispersion tolerance compared to conventional double-sideband (DSB) modulation scheme.

2. Operational principle

The operational principle of the proposed OSSB signal generation and up-conversion scheme is illustrated in Fig. 1.

In the central station (CS), an optical carrier from a distributed feedback laser diode (DFB-LD) is first launched into LN-MZM-i driven by LO (f_{LO}) signal. The electrical field of optical carrier can be represented as

$$E_{in}(t) = E_c \exp(j\omega_c t) \tag{1}$$

where ω_c is the angular frequency of the optical carrier, E_c is electrical field amplitude. The electrical field of the generated optical LO signal at the output of LN-MZM-i can be expressed as

$$\begin{aligned} E_{out}(t) \propto\ & E_c e^{j\omega_c t} J_0(\beta_1)\cos\left(\frac{\varphi_0}{2}\right) \\ & + E_c e^{j\omega_c t}\cos\frac{\varphi_0}{2}\left\{2\sum_{m=1}^{\infty}(-1)^m J_{2m}(\beta_1)\cos\left[2m\omega_{LO}t\right]\right\} \\ & - E_c e^{j\omega_c t}\sin\frac{\varphi_0}{2}\left\{2\sum_{k=1}^{\infty}(-1)^k J_{2k-1}(\beta_1)\cos\left[2(k-1)\omega_{LO}t\right]\right\} \end{aligned} \tag{2}$$

where φ_0 is a constant phase produced by dc-bias of modulator, V_π is the half-wave voltage of LN-MZM-i, ω_{LO} is the angular frequency of the LO signal, J_{2m} and J_{2k-1} are the Bessel function, $\beta_1 = (V_{LO}/V_{\pi-MZM-i})\cdot(\pi/2)$ is the phase modulation index, V_{LO} is the amplitude of LO signal. From Eq. (2), if the LN-MZM-i is under maximum point modulation scheme with $\varphi_0 = 0$, all the odd-order sidebands associated with the term $\sin(\varphi_0/2)$ are suppressed. When the higher order optical sidebands are neglected and the insertion loss of the MZM is assumed to be zero, the resulting optical signal can be written as

$$\begin{aligned} E_{out}(t) =\ & E_c e^{j\omega_c t} J_0(\beta_1)\cos\left(\frac{\varphi_0}{2}\right) \\ & - E_c\cos\frac{\varphi_0}{2}J_2(\beta_1)\left\{e^{j(\omega_c t+2\omega_{LO}t)} + e^{j(\omega_c t-2\omega_{LO}t)}\right\} \end{aligned} \tag{3}$$

As can be seen from Eq. (3), it is found that there are three main optical components left, separated by twice of the electrical LO frequency to each other, as shown in Fig. 1(i) (Node A).

The signal generated at the output of LN-MZM-i is then launched into FBG-i via an optical circulator. The FBG-i directs the center component (ω_c) and lower sideband (LSB, $\omega_c - 2\omega_{LO}$) component for downlink transmission (node C). The upper sideband component (USB, $\omega_c + 2\omega_{LO}$) is sent to the MZM-ii for IF signal modulation (node B). This USB component first pass through an erbium-doped fiber amplifier (EDFA) for amplification and then to an MZM which is modulated by the DSB-CS modulation scheme. Besides, the MZM-ii is driven by IF signal carrying vector data. With the DSB-CS modulation scheme, only the even-order optical sidebands are reserved. If we neglect the higher order optical sidebands, the resultant optical IF signal at the output of LN-MZM-ii can be written as Eq. (4)

$$E_{outC}(t) \approx \alpha E_c J_2(\beta_1)\cdot J_1(\beta_2)\left[e^{j(\omega_c+2\omega_{LO}+\omega_{IF})t} + e^{j(\omega_c+2\omega_{LO}-\omega_{IF})t}\right] \tag{4}$$

where $\beta_2 = (V_{IF}/V_{\pi-MZM-ii})\cdot(\pi/2)$ represents the modulation index of modulator, V_{IF} denotes the IF signal amplitude, α is a constant that representing the intrinsic gain of the system, $V_{\pi-MZM-ii}$ denotes the half-wave voltage of MZM-ii.

According to Eq. (4), the generated optical IF carrier consists of two sidebands carrying IF signal. The signal with the other components at node C is applied to an optical coupler. The signal from the coupler then passes through an optical filter (OF) in which the optical carrier $E_c J_0(\beta_1)e^{j\omega_c t}$ is filtered out. At node D, the electrical field of the optical signal becomes

$$\begin{aligned} E_{outD}(t) \approx\ & -E_c J_2(\beta_1)e^{j(\omega_c-2\omega_{LO})t} \\ & + C J_2(\beta_1)J_1(\beta_2)\left[e^{j(\omega_c+2\omega_{LO}+\omega_{IF})t} + e^{j(\omega_c+2\omega_{LO}-\omega_{IF})t}\right] \end{aligned} \tag{5}$$

where C represents the insertion loss of optical system. As can be found in Eq. (5), there is only one beat component for the generated RF signal. This signal is then transmitted to BS through fiber. Due to the fiber chromatic dispersion, an extra phase shift will be introduced to all the existent sidebands. After transmission, the optical signal in BS can be written as

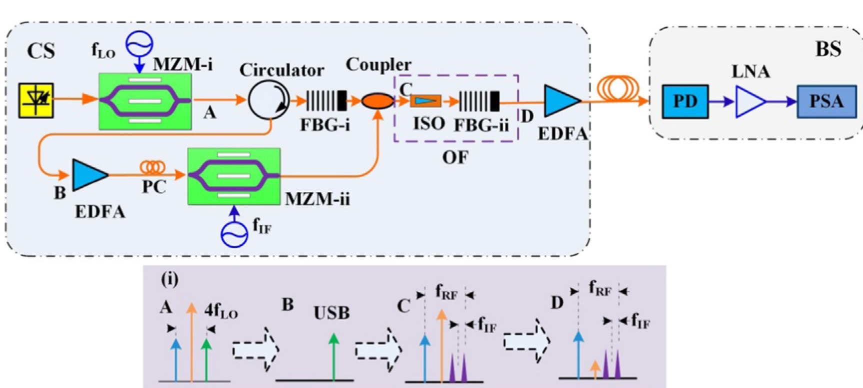

Fig. 1. Principal diagram of the OSSB signal upconversion (PSA: RF spectrum analyzer; PC: polarization controller; LNA: low noise amplifier; ISO: optical isolator).