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A full-duplex 100-GHz radio-over-fiber communication system based on frequency quadrupling

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ABSTRACT

We have experimentally demonstrated an effectively full-duplex radio-over-fiber (ROF) system, which only used a single light source at central station (CS). Frequency quadrupling modulation scheme was employed to generating 100-GHz optical millimeter wave (mm-wave) for downlink transmission while the central optical carrier was reused at base station (BS) for uplink connection. Using this proposed system design, 2.5-Gb/s OOK data was successfully transmitted over 10-km dispersion shifted fiber (DSF) and 3-m wireless link for downstream channel with about 3.5-dB power penalty, and 2.5-Gb/s OOK data was transmitted over 50-km standard single-mode fiber (SMF) for upstream channel with power penalty less than 0.5-dB.This system shows good performance in long distance transmission and provides an efficient solution for high frequency mm-wave communication.

1. Introduction

With the emergence of mobile online games and ultra-high definition videos, wireless data traffics have drastically increased over the last few years. However, traditional wireless communication is hard to provide ultra-high transmission rate for the scarcity of spectral resources. Radio-over-fiber (ROF) technology [1], combining the high-bandwidth of communication and the flexibility of wireless communication, is an effective solution not only for increasing the capacity and mobility of communication systems, but also for reducing the cost of mobile networks [2]. To meet the high transmission rate of optical communication, it is necessary to improve the frequency of wireless carrier even to mm-wave band [2,3]. Among several mm-wave frequency bands of interest, the W-band (75–110 GHz) has relatively lower atmospheric propagation loss and broader transmission window, and attracts great interest of researchers [4–11]. It's believed that W-band can attract more attentions in future wireless communication systems. In ROF system, the frequency of RF signals selection and generation, bidirectional transmission simultaneously for the uplink and downlink, and the optimal design of the overall architecture are the key of its applications. There is a long way to go to generating high-quality mm-wave and reducing significantly the cost of a ROF system.

Recently, several technologies have been proposed for optical mm-wave generation, including direct-modulation, external optical

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modulation and optical heterodyning [12–27]. Affected by chirp and nonlinear effect, the direct-modulation method is only applicable for low-frequency ROF communication system. The optical heterodyning is strongly dependent on the coherence of light sources, which cause that the system is complex and the cost is high. Among them, the external optical modulation is a simple and effective method for high-frequency mm-wave generation, but the frequency-multiply technology is the key point for its ability to generate high-quality optical mm-wave. Meanwhile, how to minimizing the cost of the overall system and optimizing uplink connection together with downlink is also key problem to be solved in ROF systems [28,29]. Many cost-efficiency ROF system schemes have been reported, such as, the wavelength reusing scheme, in which a single light source is shared by downlink and uplink simultaneously [30–32]. Therefore, the wavelength reusing scheme has been widely used for data bidirectional transmission and reducing the cost of BS. And the full-duplex ROF system using external optical modulation to generate high-frequency mm-wave RF signals has captured great attentions of researchers.

In this paper, an efficiency full-duplex 100-GHz ROF system has been proposed and experimentally demonstrated. The scheme of frequency quadrupling has been employed to generating optical mm-wave for downstream by using only one external modulator, which not only reduced the cost of CS, but also ensured the high quality of the mm-wave generated by beating two sidebands. At the BS, an interleaver was used to separating the central optical carrier and the optical mm-wave signal. Then the reused optical carrier was modulated with the upstream signals. In the experiment, 2.5-Gb/s data was successfully transmitted over 10-km DSF and 3-m wireless link for downstream channel with about 3.5-dB power penalty, and 2.5-Gb/s data was transmitted over 50-km standard SMF for upstream channel with power penalty less than 0.5-dB. Since we have combined the wavelength reusing technique with frequency quadrupling technique to constructing a full-duplex 100-GHz ROF communication system, which not only provide a solution for high frequency mm-wave generation, but also available for data bidirectional transmission with only a single light source, shows great application potential in cost-efficiency ROF communication system.

2. Principle

The schematic diagram of full-duplex 100-GHz ROF system is shown in Fig. 1. The electrical field of the continuous wave (CW) lightwave from a distributed feed-back laser diode (DFB-LD) can be represented by $E_{\rm in}(t) = E_0 \exp(j\omega_0 t)$. Here, E_0 and ω_0 are the amplitude and angle frequency of lightwave, respectively. Then, the lightwave is modulated by the $LiNbO_3$ Mach-Zehnder Modulator (LN-MZM), which is driven by

RF sinusoidal clocks $V_{\rm RF1}(t) = V_{\rm m}\cos(\omega_{\rm m}t)$ and $V_{\rm RF2}(t) = V_{\rm m}\cos(\omega_{\rm m}t + \theta)$. Here, $V_{\rm m}$ and $\omega_{\rm m}$ are the amplitude voltage and angle frequency of the local oscillator, respectively. And θ is the relative phase of the clocks between two arms. According to Refs. [33–35], the output field after the LN-MZM can be written as

$$E_{out1}(t) = \frac{E_{\rm in}(t)}{10^{\frac{\alpha}{20}}}\left\{\gamma\exp\left[j\pi\frac{V_{RF2}}{V_\pi} + j\pi\frac{V_{bias2}}{V_\pi}\right] + (1-\gamma)\exp\left[j\pi\frac{V_{RF1}}{V_\pi} + j\pi\frac{V_{bias1}}{V_\pi}\right]\right\} \tag{1}$$

Here, α is the insertion loss of the modulator. γ is the power splitting ratio of the two arms of the modulator. V_π is the half-wave voltage of the modulator. For a perfect LN-MZM, the power splitting ratio is approximately 0.5 and the insertion loss is almost 0. By adjusting the direct current bias voltage V_{bias1} or V_{bias2} and the relative phase θ of the clocks between the two arms, the optical mm-wave can be got. From Eq. (1), with the V_{bias2} is set to 0, the output field can be simplified as

$$E_{out1}(t) = \frac{E_0}{2}\left\{\cos\left[\omega_0 t + \frac{\pi V_m}{V_\pi}\cos(\omega_{\rm m}t + \theta)\right] + \cos\left[\omega_0 t + \frac{\pi V_m}{V_\pi}\cos\omega_{\rm m}t + \frac{\pi V_{bias1}}{V_\pi}\right]\right\} \tag{2}$$

We set the phase modulation index $\chi = \pi V_m/V_\pi$, and the constant phase shift $\varphi = \pi V_{bias1}/V_\pi$, which is induced by direct current

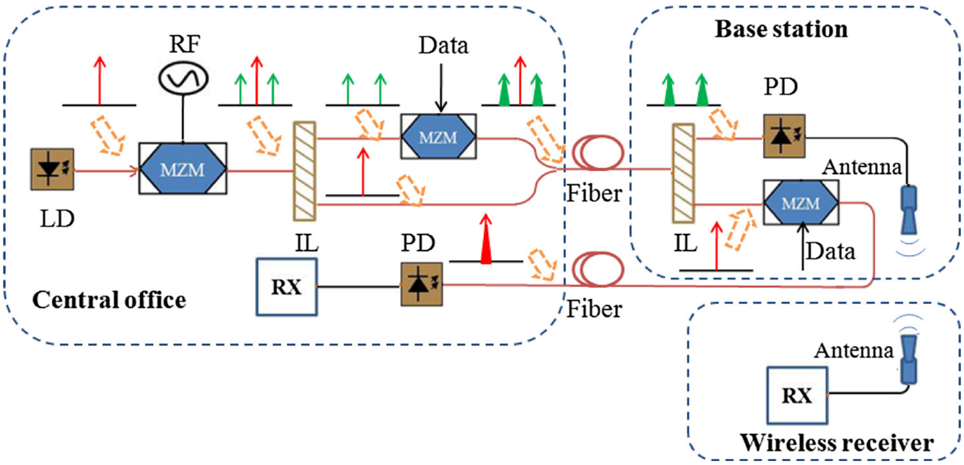

Fig. 1. Schematic diagram of a full-duplex 100-GHz ROF system based on frequency quadrupling and reuse.