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A novel radio-over-fiber system with dual millimeter-wave signals generated simultaneously

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ABSTRACT

A novel radio-over-fiber (RoF) system with V-band and W-band millimeter-wave (MMW) signals is proposed. We begin our simulation by first utilizing a 20 GHz local oscillator (LO) to drive a dual-parallel Mach-Zehnder modulator (DP-MZM) and generate two quadruple-frequency-interval coherent optical carriers. And then we use a dual-drive Mach-Zehnder modulator (DD-MZM) to load signal data and realize an optical single side-band (OSSB) modulation. Following these transmitted signals, we add a 50 km single-mode fiber (SMF) for signal transmission and a photonics detector (PD) for signal self-heterodyning detection. Thanking to the mitigated chromatic dispersion (CD) effect of OSSB signals, the eye opening in the eye diagram is observed even after the transmission over 50 km of the SFM spool. The power penalties of the generated V-band 60 GHz and the W-band 100 GHz MMWs at a 10^{-9} bit-error-rate (BER) are 1.7 dB and 2.5 dB, respectively.

1. Introduction

With the explosive increase of the communication services, low-frequency communication bands (MHz to several GHz) are becoming more and more crowded. To solve this problem, attention is turning to MMW bands (tens of GHz to hundreds of GHz) as they provide faster data transmission rates and lager communication capacities than low-frequency bands. In the future communication system, 60 GHz technology can find applications in high speed wireless local area networks and wireless personal area networks, thanks to the unlicensed spectral band of 7 GHz from 57 to 64 GHz that is available in most countries [1,2]. 100 GHz finds uses in various applications including broadband wireless communication, radars, and millimeter-wave imaging [3,4]. However, it is difficult to generate such high-frequency MMW signals using electrical methods. Furthermore, there are large losses when these high-frequency MMWs are broadcasted in the air, so they cannot be transmitted over long distances. In this regard, the RoF system has been proposed as a possible next generation broadband internet access technology as it can provide truly broadband access to end user units while warranting the mobility [5–7].

Many methods which use RoF system to generate MMW have been reported. Some researchers use optical-heterodyning to beat two optical carriers which come from two independent lasers [8,9]. However, this requires an optical phase-lock loop (OPLL), increasing the complexity and cost of the system. Compared with this method, it is simpler and more cost-effective to use self-heterodyning to beat two coherent optical carriers in a PD to generate MMW signals. Owing to the CD effect in optical fibers, there will be a bit walk-off effect in the generated MMW if the baseband signal is all modulated onto the two coherent optical carriers. To avoid this effect mentioned above, the baseband signal ought to be only modulated onto

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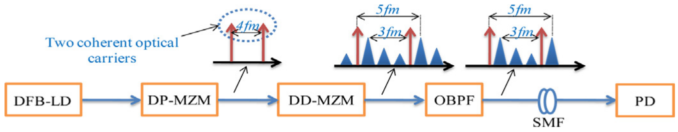

Fig. 1. The proposed scheme to generate millimeter-waves (DFB-LD: distributed feedback laser diode; f_m: the frequency of the local oscillator; DP-MZM: dual-parallel Mach-Zehnder modulator; DD-MZM: dual-drive Mach-Zehnder modulator; OBPF: optical band-pass filter; SMF: single-mode fiber; PD: photonics detector).

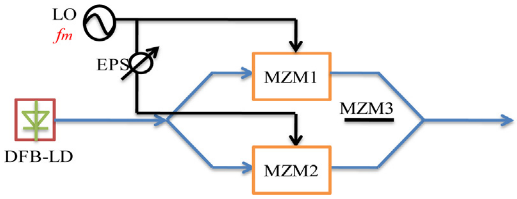

Fig. 2. Diagram of dual-parallel Mach Zehnder modulator (DFB-LD: distributed feedback laser diode; LO: local oscillator; EPS: electrical phase shifter; MZM: Mach-Zehnder modulator).

one optical carrier to realize an OSSB modulation [10–12]. In Refs. [13,14], a generation of 2.9 Gb/s 60 GHz MMW using a DP-MZM and an OBPF to realize an OSSB modulation has been reported. No complex devices are needed in these methods. However, the frequency of the generated MMW is maximally 2 times the frequency of the LO. In Refs. [15,16], methods only using a DP-MZM to generate a 2.5 Gb/s 60 GHz MMW have been reported. The authors propose a novel formula derivation and only modulate the baseband signal onto the +6 order optical sideband. Excepting the −6 order optical sideband, all other sidebands and the central optical carrier are eliminated. Although an OBPF is not used in the proposed system, the system uses too many electrical mixers (EMs) and electrical splitters (ESs). Thus, it may have a large noise figure (NF) and insertion loss (IL) in real deployment. In Refs. [17–19], methods using either a wavelength division multiplexing de-multiplexer (WDM DEMUX) or a wavelength selective switch (WSS) to realize an OSSB modulation has been proposed. Two coherent optical carriers without data are first generated through the use of external modulators. Then, the proposed systems separate the two coherent optical carriers into two branches by employing WDM DEMUX or WSS, and only modulate the baseband data onto one optical carrier. This allows flexible generation of MMWs by changing the interval of the two coherent optical carriers. However, there will be an extra time delay and polarization variations between the two coherent optical carriers.

Fig. 1 is the proposed scheme to generate MMWs in our paper. A DP-MZM is first employed to generate two coherent optical carriers, the interval of which is 4 times the frequency of the LO. After that, the two coherent optical carriers are sent into a DD-MZM to realize an OSSB modulation at the same time. By using an OBPF, the central optical carriers and +1 order optical sidebands are filtered out. After SMF transmission and self-heterodyning in a PD, a 60 GHz and a 100 GHz MMW can be generated simultaneously when the frequency of the LO is 20 GHz. In our proposed RoF system, no complex devices are used and optical signals are transmitted in an identical optical path all the time. So, the structure is simple and there are no extra time delay and polarization variations between the optical signals. Furthermore, two MMWs can be generated simultaneously in our proposed scheme. Given the high financial cost of optical devices, our scheme is efficient and the cost of a RoF system can be halved.

This paper is organized as follows: The principles of the proposed technique are described in Section 2. Section 3 shows the simulation setup, discussions, and results. Finally, conclusions are presented in Section 4.

2. Principles

2.1. Two coherent optical carriers' generation based on a DP-MZM

A diagram of the two coherent optical carriers' generation is shown in Fig. 2. A continuous wavelength (CW) emitted from a distributed feedback laser diode (DFB-LD), is injected into a commercial DP-MZM. The power splitting ratios of the Y-junctions of MZ-3 are supposed equals to 3 dB. MZM 1 and MZM 2 are biased at the maximum transmission bias point (MATAP) and the bias voltage of the MZM 3 is applied at 0 V. The outputs of the MZM 1 and MZM 2 can be written as follows, respectively:

$$E_{MZM1}(t) = 0.5E_0 \sum_{n=-\infty}^{n=+\infty} J_n(m)\cos\left(n\pi/2\right)\exp\left\{j\left[(\omega_0 + n\omega_m)t + n\pi/2\right]\right\} \tag{1}$$

$$E_{MZM2}(t) = 0.5E_0 \sum_{n=-\infty}^{n=+\infty} J_n(m)\cos\left(n\pi/2\right)\exp\left\{j\left[(\omega_0 + n\omega_m)t + n\pi/2 + n\theta\right]\right\} \tag{2}$$