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A Radio-Over-Fiber System with a Novel Scheme for Optical Local Oscillator and mm-Wave Distribution

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Abstract: This study proposes a novel scheme for realizing a cost-effective Base Station (BS) by using optical Local Oscillator (LO) and millimeter (mm)-wave signal distribution in a Radio-Over-Fiber (ROF) system. In the Central Station (CS), the optical LO and mm-wave signals were obtained via the Four-Wave Mixing (FWM) process in a Semiconductor Optical Amplifier (SOA). A 100/200 GHz optical interleaver was used to separate the optical LO and mm-wave signal in the BS and simplify the complexity of the filtering configuration. The 40 GHz optical LO and mm-wave distribution has been experimentally demonstrated in ROF systems by using the proposed scheme. The power penalty for downlink 40 GHz mm-wave signal was less than 1 dB.

Key words: Radio-over-fiber, local oscillator, semiconductor optical amplifier, four wave mixing

INTRODUCTION

Radio-Over-Fiber (ROF) is a promising technique for providing high-speed access to future broadband wireless communication networks (Cooper, 1990; Koonen *et al*., 2008; Wake *et al*., 2010). The millimeter (mm)-wave is considered as a potential wireless carrier for future ROF systems with high bandwidth and low spectral congestion. With regard to the high atmospheric attenuation in the mm-wave band, the Base Station (BS) cell has a small coverage, and thus, minimizing its cost is necessary (Pleros *et al*., 2009; Sauer *et al*., 2007). Therefore, a number of ROF design techniques have been proposed and investigated to develop cost-effective BSs. For example, the optical mm-wave generation technique in the Central Station (CS) simplifies the configuration of the BS (Xiao and Yu, 2012; Chen *et al*., 2006; Huang *et al*., 2008; Yu *et al*., 2010; Shi *et al*., 2011). However, the electrical Local Oscillator (LO) for demodulating downlink mm-wave signals poses as a cost-constraint in the BS as the mm-wave carrier frequency increases. Four-wave mixing (FWM) in a SOA is independent of the modulation format and thus, it can be used to generate optical mm-wave signals (Li *et al*., 2009; Lu *et al*., 2009; Wang *et al*., 2009; Zhang *et al*., 2011). A design for realizing 60 GHz optical LO and mm-wave signal generation and distribution via the FWM effect in a SOA has been proposed. Such system can generate optical LO and mm-wave signals in the CS and allow the BSs to share them, thereby simplifying the BSs configuration further. However, the optical LO and mm-wave signals must be separated twice, and thus, two-peak fiber Bragg gratings (FBGs) were necessary. The use of two-peak FBGs increased system complexity (Mo *et al*., 2009).

In this study, a novel scheme was proposed to realize optical LO carrier and mm-wave distribution and to simplify the BS configuration. Instead of using two-peak FBGs, a 100/200 GHz optical interleaver (IL) was used to separate the optical LO and mm-wave signals. In our scheme, the optical LO and mm-wave signals were separated in the CS only once, thereby reducing system complexity. By this scheme, the power penalty for downlink 40 GHz mm-wave signal was less than 1 dB over 20 km Single-Mode Fibers (SMFs) transmission.

PRINCIPLE

Figure 1 shows the principal diagram of the 40 GHz optical LO and mm-wave signals distribution. In the CS, the optical carrier was generated from a Continuous-Wave Laser (CW1). An intensity modulator (IM1) and a cascaded optical filter were used to generate two optical first-order sidebands with 40 GHz frequency space, in which the even-order sidebands and the optical carrier were suppressed. Two optical first-order sidebands, which had parallel polarization directions, were used as pumps. Another optical carrier from a continuous-wave lightwave (CW2) with modulated baseband signal was used as an optical signal. The pumps and an optical signal were in the odd and even channels of the

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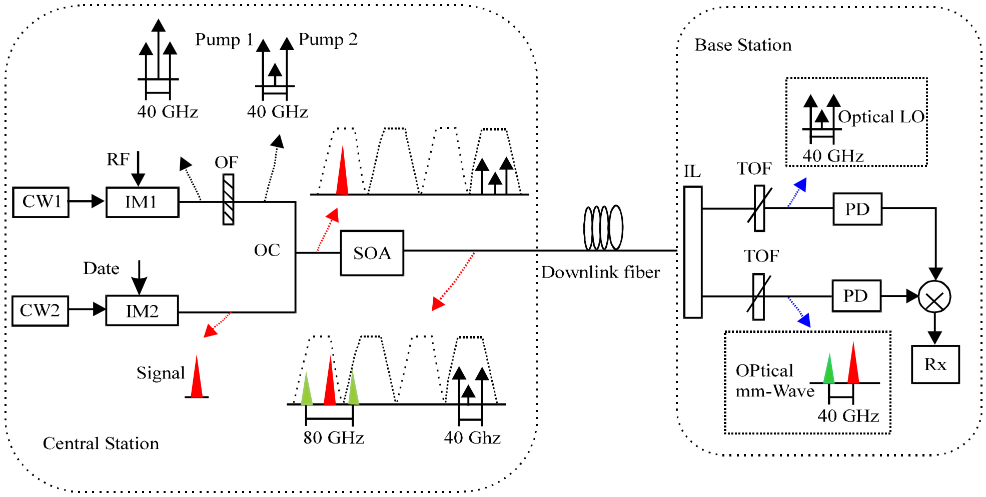

Fig. 1: Principal diagram of the optical LO and mm-wave signals distribution, IM: Intensity modulator, OF: Optical filter, OC: Optical coupler, SOA: Semiconductor optical amplifier, TOF: Tunable optical filter, IL: Interleaver, PD: Photodiode, Rx: Receiver

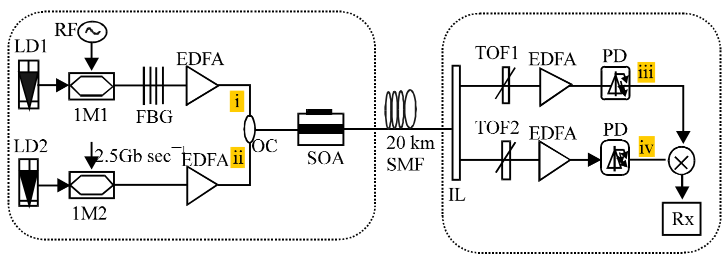

Fig. 2: Experimental setup of proposed new scheme IM: Intensity modulator. FBG: Fiber Bragg grating. OC: Optical coupler. SOA: Semiconductor optical amplifier. EDFA: Erbium-doped optical fiber amplifier, TOF: Tunable optical filter. PD: Photodiode. Rx: Receiver

100/200 GHz IL, respectively. These signals were applied to a SOA by using an Optical Coupler (OC). Two new converted optical signals with frequency space of 80 GHz were obtained after the FWM process in the SOA. Thereafter, all optical signals were transmitted to the BS over optical fibers. After all optical signals passed through the IL, the incoming signals are separated into two branches: one is two pumps without modulating data used as 40 GHz optical LO and the other is like single-sideband (SSB) optical signal, which contains origin optical signal and a converted signal, used as 40 GHz optical mm-wave signal. Two tunable optical filters (TOFs) were used to eliminate the other unwanted optical sidebands. Therefore, electrical 40 GHz LO and mm-wave signals can be produced by beating the two pumps and SSB signals, respectively. Moreover, electrical LO and mm-wave signals could be sent by an electrical mixer to retrieve the baseband data.

EXPERIMENT SETUP AND RESULTS

Figure 2 shows the experimental setup for the optical distribution of 40 GHz optical LO and mm-wave signals. In the CS, a CW lightwave from a distributed feedback laser diode (LD1) at 1543.8 nm was modulated using an intensity modulator (IM1) driven by a 20 GHz RF signal with a DC bias voltage of 0.5 v_π. Half-wave voltage (v_π) of IM1 was 7.4 V. Figure 3a shows two first-order sidebands with 40 GHz frequency spacing. After using a FBG, the carrier suppression became greater than 30 dB. Therefore, the remaining two first-order sidebands with the same polarization direction and locked phase acted as dual-pump signals, as shown in Fig. 3b. Another lightwave at 1539.8 nm from LD2 was modulated via an IM2 driven by a 2.5 Gb sec^{-1} NRZ electrical signal. To provide a high FWM efficiency, two erbium-dopes fiber amplifiers (EDFAs) were used to optimize the powers of

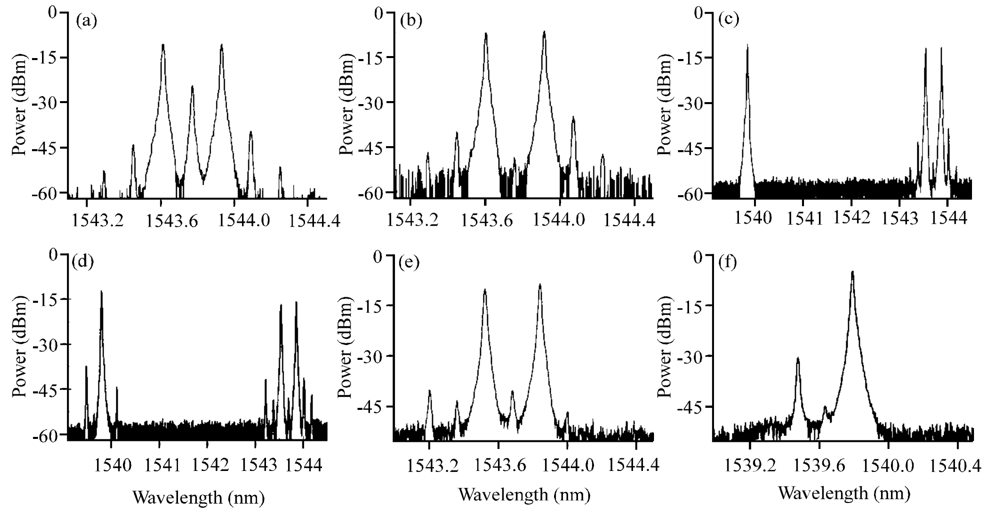

Fig. 3(a-f): The optical spectra were measured at different positions in Fig. 2 (a) After the IM1, (b) After the FBG (c) After the OC (d) After the SOA, (e) After TOF 1 and (f) After TOF 2

the pumps and signal. The optical power of the two pumps and the signal before the SOA were measured to be 8.6 and 10.2 dBm at points (i) and (ii) in Fig. 2, respectively. These optical signals were combined and launched into the SOA by using an OC. The SOA input power was 8.9 dBm and its corresponding optical spectrum is shown in Fig. 3c. The SOA has a 3 dB gain bandwidth of 68 nm, a small signal fiber-to-fiber gain of 28 dB at 1552 nm, a polarization sensitivity of less than 1 dB and a noise figure of 6 dB at 1553 nm. The two converted signals were created from a 2.5 Gb sec^{-1} NRZ origin signal after applying FWM in the SOA, as shown in Fig. 3d. Then, the total optical signal was transmitted to the BS over 20 km SMFs.

In the BS, a 100/200 GHz spaced IL was employed to separate the two pumps and optical signals. Figure 3e and f show, respectively the remaining two pumps and the SSB signal after using a TOF with 3 dB bandwidth of 1 nm to remove the accumulated Amplified Spontaneous Emission (ASE) noise and suppress the unwanted FWM tones. The two pumps and the SSB signals with 40 GHz frequency spacing were found to be stable and the Optical Signal-to-Noise Ratio (OSNR) of the converted signal remained greater than 20 dB. The electrical LO signal was generated by beating the two pumps. Figure 4a and b show the waveform of the optical LO signals before and after transmission, respectively, over 20 km SMFs measured at point (iii) in Fig. 2. The adjacent peaks have a spacing of 25 psec, corresponding to a 40 GHz repetitive frequency. The mm-wave signal was

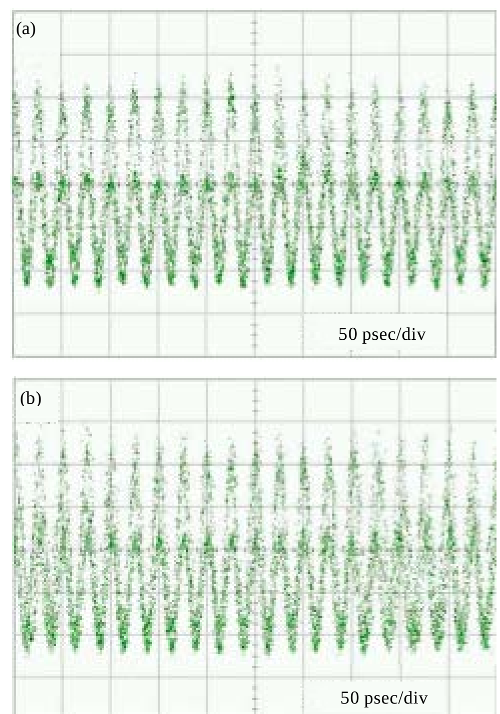

Fig. 4(a-b): The waveform of 40 GHz optical LO with different SMF transmission distances (a) 0 km and (b) 20 km

show the eye diagrams of the optical mm-wave signals before and after transmission, respectively, over 20 km SMFs measured at point (iv) in Fig. 2. From the figure, it

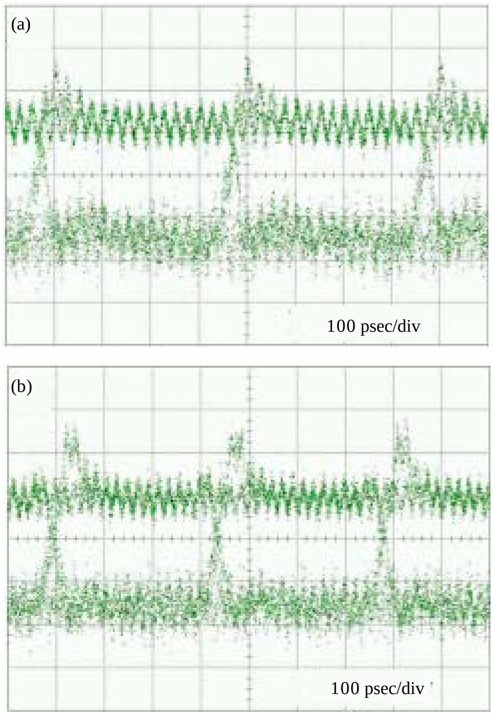

Fig. 5(a-b): Eye diagrams of the 40 GHz optical mm-wave signal with different SMF transmission distances (a) 0 km and (b) 20 km

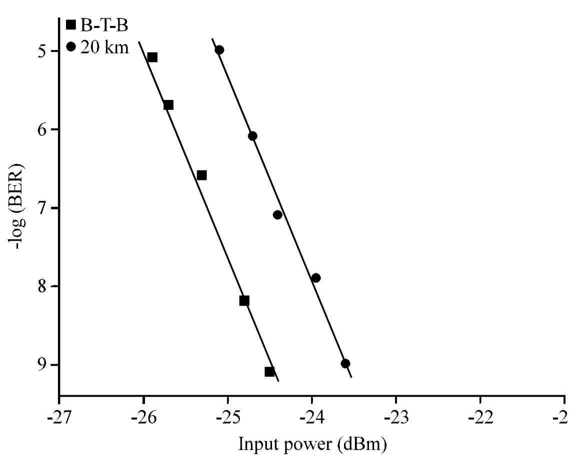

Fig. 6: BER curves of downlink 40 GHz mm-wave signal

generated by beating the SSB signal. Figure 5a and b can be seen that the 2.5 Gb sec^{-1} signal is carried by a 40 GHz optical mm-wave. A mixer was used to down-convert the downlink electrical mm-wave signal. Fig. 6 shows the measured Bit Error Ratio (BER) results. The power penalty for the downlink 40 GHz mm-wave signal was less than 1 dB after passing through the 20 km SMFs transmission.

CONCLUSION

In this study, a novel design was proposed to simplify the filtering requirements and realize the optical LO and mm-wave distribution in a 40 GHz ROF system. System complexity was reduced using the proposed design, further simplifying the BS configuration. The experimental results showed that the eye diagrams of 40 GHz optical mm-wave signal and the waveform of optical LO remained clear after 20 km transmission. The converted downstream mm-wave signals exhibited power penalty of less than 1 dB.

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