A ROF downstream link with optical mm-wave generation using optical phase modulator for providing broadband optical-wireless access service

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***Abstract*—**we have experimentally demonstrated a ROF downstream link with optical mm-wave generation using optical phase modulator and optical filtering for providing broadband optical-wireless access service for the first time. We extend the transmission distance limited by fiber dispersion using a novel scheme.

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I. INTRODUCTION

There is a strong interest in providing broadband wireless access services in the emerging optical-wireless networks. Optical millimeter (mm)-wave generation is a key technique in this optical-wireless access networks. Recently, a few new methods for generating optical mm-waves generation are reported [1-10]. Optical external intensity modulators can be used to generate high frequency mm waves. However, a control electrical circuit is needed to optimize the DC bias added on the external intensity modulator in order to obtain high quality mm-wave signals. An optical phase modulator does not need a DC bias, so it does not suffer from the DC bias-drifting problem if it can be used to generate optical mm waves. Ref. 11 theoretically anticipated that an external phase modulator followed by an optical notch filter could be utilized to produce optical mm waves. However, due to the multiple sidebands created by a deep modulation index, the mm wave generated by this method suffered from large fiber dispersion, and the transmission distance was limited to a few kilometres; otherwise, dispersion compensation is necessary. Dispersion compensation would add the cost for the ROF systems; moreover, it could reduce the flexibility of dynamic system because the transmission distances to the customer units in access networks may not be fixed. In this paper, we have experimentally demonstrated a ROF down-stream link with optical mm-wave generation based on phase modulation and optical filtering scheme for the first time, and the dispersion limitation is overcome by this novel and low-cost technique.

II. EXPERIMENTAL SETUP AND RESULTS

The experiment setup for optical millimeter wave generation and transmission is shown in Fig. 1. A CW lightwave was generated by a distributed feedback laser-diode (DFB-LD) at 1549.5 nm. The optical mm wave was generated using a phase modulator and a fiber Bragg grating (FBG) filter. The $LiNbO_3$ phase modulator was driven by a 20GHz RF sinusoidal wave with a RF voltage of 6V, and the optical spectrum and the waveform are shown as inset (i) and (ii) in Fig.1, respectively. The half-wave voltage of the phase modulator is 11V. Since the driving voltage is smaller than half-wave voltage of the phase modulator, the second order sideband is 25dB lower than the first order sideband; therefore the second order sidebands do not largely affect the transmission of the optical mm wave in SMF fibers. An FBG was used to suppress the optical carrier and convert the modulated lightwave to optical mm wave [11]. The transmission spectrum of the FBG filter is shown in Fig. 2. The FBG filter has a 3-dB reflection bandwidth of 0.2nm and reflection ratio larger than 50dB at the reflection peak wavelength. The resulting waveform detected by a high-speed receiver, and the corresponding optical spectrum, are shown as inset (iii) and (iv) in Fig. 1, respectively. It can be seen that the mm wave was successfully generated after passing the FBG filter. The carrier suppression ratio is larger than 25dB, and the repetition frequency of the optical mm wave is 40GHz. Then, the optical mm wave was modulated by a LN-MZM driven by 2.5Gbit/s pseudo-random bit sequence electrical signal with a word length of 2^{31}-1. Thus, the 2.5Gbit/s signals are carried by the 40GHz mm wave. The eye diagram of the optical mm wave signal is shown as inset (v) in Fig. 1. The generated millimeter optical wave was amplified by an erbium doped fiber amplifier (EDFA) to reach a power of 5dBm before it was transmitted over SMF fibers of various lengths. Fig. 3 shows the eye diagrams at different distances. For a pure dual-mode millimeter wave, Ref.1 has shown that the RF power of the optical millimeter wave after transmission over 60km still maintains even if the carrier frequency is as high as 60GHz. The pulse-width of the 2.5Gbit/s signal carried by the optical millimeter wave is approximately 400ps. The two peaks with a wavelength spacing of 0.32nm will have a walk-off time of 400ps caused by fiber dispersion after the millimeter wave is transmitted over 74km SMF with a dispersion of 17ps/nm/km, which means full eye closure. While considering the limited rise and fall time of the optical receiver and the electrical amplifier, the maximum transmission distance is shorter than 74km. Fig. 3 clearly shows this procedure caused by the fiber dispersion. The non-flat amplitude of the optical carrier at 40GHz shown in Fig. 3 (b) is caused by fiber dispersion of the second sidebands. Ref.1 and 3 reveal that fiber dispersion causes the amplitude fluctuation of the carrier but the RF power at 40GHz does not disappear when the carrier is a dual-mode lightwave. Fig. 3 (d) shows that the eye is almost closed after the optical millimeter wave is transmitted over 60km. At the receiver, the millimeter wave was filtered by a tunable optical filter (TOF1) with a bandwidth of 0.5nm before it was pre-amplified by an EDFA with a small-signal gain of 30dB, then it was filtered by TOF2 with a bandwidth of 0.5nm before the O/E conversion via a PIN PD with a 3dB bandwidth of 60GHz. The receiver is the same as that used in Ref. [5, 6]. The converted electrical signal was amplified by an electrical amplifier (EA) with a bandwidth of 10GHz centered at 40GHz. An electrical LO signal at 40GHz was generated by using a frequency multiplier from 10 to 40GHz. We used the electrical LO signal and a mixer to down-convert the electrical millimeter-wave signal. After the down conversion, the 2.5Gbit/s signal was detected by a BER tester, and their eye diagrams after transmissions are shown in Fig. 4. The measured BER curves are provided in Fig. 5. For a BER of 10^{-9}, the receiver sensitivity is -37.1dBm. The power penalty after 20-km transmission can be neglected. At 40-km distance, the power penalty is 2dB. The power penalty increases significantly when it is transmitted over 50km, and there appear an error-floor of 10^{-6} after it is transmitted over 60km. The down-converted eye diagrams after transmission over 20, 40, 50 and 60km are shown in Fig. 5, respectively. The eye is still open and clear even at the 50-km distance.

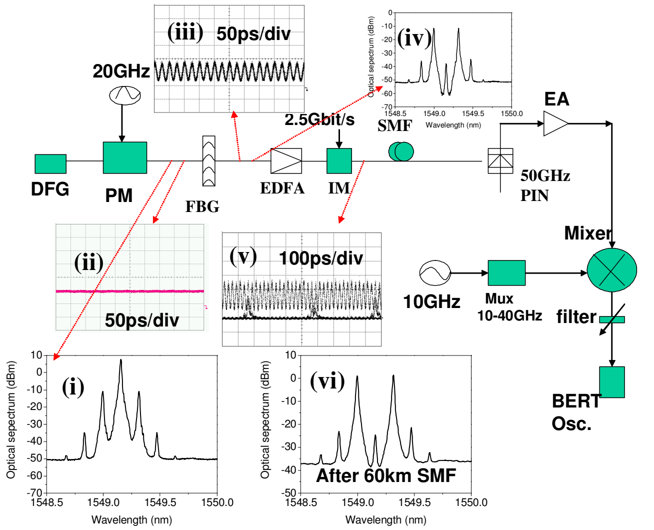

Fig.1. Experimental setup for optical millimeter-wave generation by using OCS modulation scheme. The resolution for all optical spectra is 0.01nm in this paper.

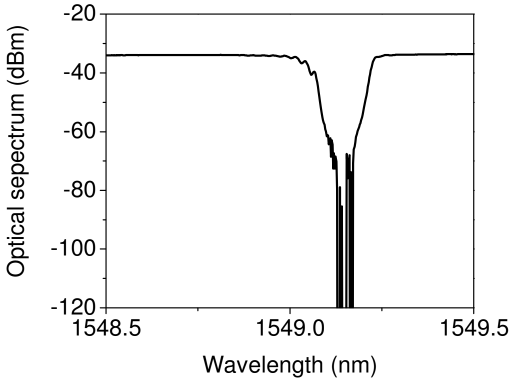

Fig. 2. Transmission spectrum of the FBG filter

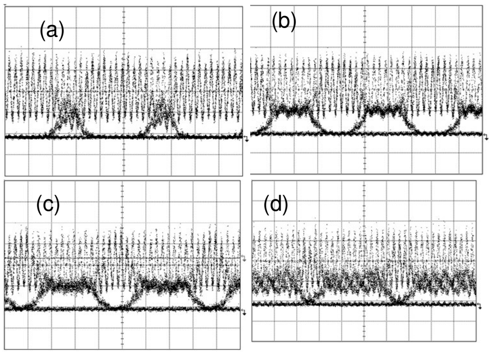

Fig. 3. Optical eye diagrams after the optical millimeter wave transmission over (i) 20km, (ii) 40km, (iii) 50km, and (iv) 60km SMF (100ps/div).

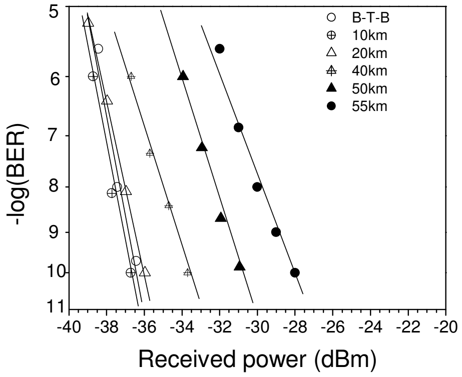

Fig. 4. BER curves and eye diagrams: (i) after 10km, (ii) after 50km.

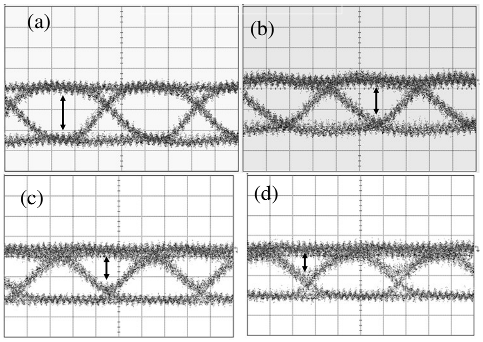

Fig. 5. Optical eye diagrams (100ps/div) after down-conversion at the receiver after transmission over SMF (a) 20km, (b) 40km, (c) 50km, (d) 60km.

III. DISCUSSION

Ref. 11 shows that the optical-mm wave generated by the optical phase modulator with subsequently filtering cannot be sent over long distance in SMF due to fiber dispersion. However, our experimental results show that this mm-wave source can be transmitted over 40km with a power penalty of only 2dB; and over 50km without error-floor. In our experiment, we used an RF amplifier with a maximum output of 7V, and the optical sidebands are only up to second order as shown as inset (ii) in Fig. 1. Otherwise the high order sidebands would suffer from severe dispersion due to the large wavelength span between the high order sidebands. In our experiment only small second-order sidebands were generated, therefore the fiber dispersion effect can be greatly reduced. After detected by a 60GHz PIN PD, the electrical signal was amplified by a RF band-pass amplifier. There is no any gain for the signal components at 20GHz; therefore, the 20GHz components cannot interfere with the RF components at 40GHz. Due to the above two reasons, a relatively long transmission distance was achieved.

IV. CONCLUSION

We have experimentally demonstrated, for the first time to the best of our knowledge, a ROF downstream link with optical mm-wave generation using a phase modulator and optical filtering. Since we used a relatively small modulation RF signal, the power of the multiple sidebands of the optical mm-wave is reduced. The power penalty of 2.5Gbit/s broadband signal through transmission over 40km is only 2dB, and there is no error-floor at a BER of 10^{-9} at 55-km distance; hence the dispersion compensation is unnecessary in this optical-wireless access network. As a result, the flexibility of the system is increased. This scheme has good stability by eliminating DC-bias drafting problem; hence it can simplify the configuration of the optical-wireless access network.

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