A Cost-effective Multi-gigabit 60-GHz Wireless over Optical Fiber Access System Based on a Novel Frequency Quintupling Technique

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***Abstract*—We propose and demonstrate a cost-effective wireless over optical fiber access system using frequency quintupling technique. A 2.5-Gb/s OOK signal at 60-GHz is successfully transmitted through 30-km SSMF and 10-ft air link without dispersion compensation.**

I. INTRODUCTION

THE ever-increasing video-based interactive and multimedia services are demanding large bandwidths and high data rates in wireless access network. Multi-gigabit wireless transmission using the 60-GHz millimeter-wave (MMW) band, with 7-9 GHz unlicensed bandwidth, is considered to be a promising candidate that realizes very high throughput (VHT) local area networks (LANs) or wireless personal area networks (WPAN) [1]. Recently, several industrial consortium and IEEE standardization efforts have been carried out, such as IEEE 802.15.3c, ECMA, and Wireless-HD [2], to promote the global use of multi-gigabit 60-GHz wireless technology. However, due to high atmospheric and large free space propagation loss of the 60-GHz MMW signal, the effective wireless access coverage is limited to tens of meters [3]. Thanks to the huge bandwidth and low transmission loss of optical fibers, radio-over-fiber (RoF) technology is considered to be an attractive solution to increase capacity and mobility as well as to reduce overall cost in wireless access networks [4]. A 60-GHz RoF system was demonstrated in Ref. [5], however, 30-GHz optical and electrical devices were used, which increased the cost of the system. In Ref. [6], critical phase control was required to generate the 60-GHz MMW signal and a third modulator was used to load data, resulting in a complex and unstable system.

In this work, we propose and experimentally demonstrate a 60-GHz wireless over optical fiber system with a cost-effective structure. Two cascaded single-drive Mach-Zehnder modulators (MZMs) are used to realize frequency quintupling and data loading, where high-frequency devices and phase control are not required in the central station (CS). A 2.5-Gb/s on-off-keying (OOK) signal at 60-GHz MMW is generated using only 12-GHz radio frequency (RF) clock source and low-speed modulators. After transmission, at the base station (BS), the RoF signal is detected by a high-speed photo-detector (PD) and broadcast to the end users through antennas. Down-conversion is realized through envelope detection (ED), eliminating the 60-GHz local oscillator (LO) and critical phase control circuit.

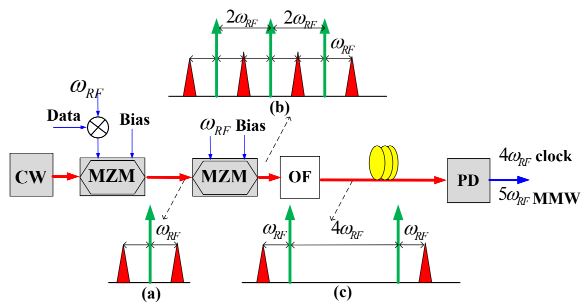

Fig. 1. Schematic diagram of the proposed RoF system using frequency quintupling technique. CW: continual wave; OF: optical filter; PD: photo-detector.

II. PROPOSAL AND ARCHITECH

The schematic diagram of the proposed RoF system using frequency quintupling is shown in Fig. 1. A baseband data is mixed by a sinusoidal clock with a frequency of ω_{RF} to generate an electrical subcarrier multiplexing (SCM) signal. A continual wave (CW) light is input to the first MZM, which is biased at the push-and-pull of the transmission curve and driven by the generated SCM signal. The output of the MZM has three bands: the un-modulated central band and modulated side bands, as shown in Fig. 1(a). The three-band signal is up-converted by a second MZM, which is biased at the peak of the transmission curve and driven by another clock with the same frequency. It is noted that no phase control is needed between the two RF clocks, enabling a simple and stable generator. Fig. 1(b) illustrates the output of the second MZM and an optical filter is used to select the wanted components, which contains two un-modulated carriers with a frequency space of $4\omega_{RF}$ and two modulated carriers, as depicted in Fig. 1(c). After transmission, the signal is detected by a high-speed PD, where a clock with a frequency of $4\omega_{RF}$ is obtained through the beating of the two un-modulated carriers and an MMW signal with a frequency of $5\omega_{RF}$ is realized by the beating of the modulated and un-modulated carriers.

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III. EXPERIMENTAL SETUP AND RESULTS

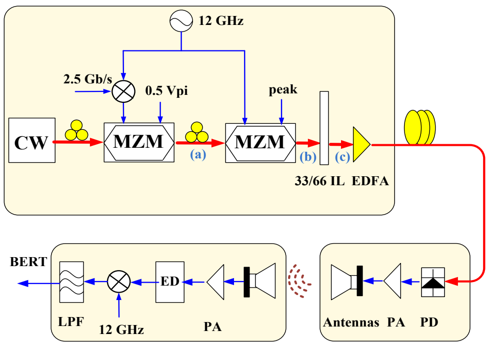

Fig. 2. Experimental setup of the proposed RoF system. CW: continual wave OF: optical filter; PD: photo-detector.

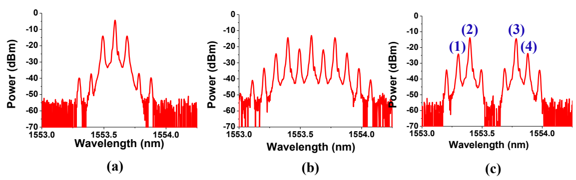

Fig. 3. Optical spectra taken at different positions as indicated in Fig. 2.

We perform an experiment to verify the feasibility of the proposed scheme with a setup shown in Fig. 2. In the central station (CS), a CW light originated from a tunable laser with a wavelength of 1553.6 nm is fed into a single-drive MZM. A 2.5-Gbit/s pseudo-random bit sequence (PRBS) stream with a word length of 2^{31}-1 is mixed with a 12-GHz RF clock. The output of the mixer is amplified and used to drive the MZM, which is biased at the push-and-pull of the transmission curve. An optical SCM signal (Fig. 3(a)) is obtained at the output of the MZM, which is fed into a second single-drive MZM. The optical SCM signal is up-converted by the second MZM with a V_π (half-wave voltage) of 6.7 V, which is biased at the peak of the transmission curve and driven by an amplified 12-GHz RF clock with a 10-V peak-to-peak voltage. The spectrum of the up-converted signal is shown in Fig. 3(b), whose unwanted bands are filtered by a 33/66 GHz interlevel. After the interlevel, we achieve a four-tone signal (Fig. 3(c)), where tone-1 and tone-4 are modulated carriers, and tone-2 and tone-3 are un-modulated carriers. The frequency space between tone-1 and tone-3 is 60 GHz; and between tone-2 and tone-3 is 48 GHz. The optical signal is amplified by an erbium-doped fiber amplifier (EDFA) to reach a power of 6 dBm and then transmitted to the BS through 30-km standard single mode fiber (SSMF).

At the BS, a high-speed PD (u2t XPDV 2020R) is used to detect the coming signal, whose spectrum is illustrated in Fig. 3(c). The beating of the un-modulated tone-2 and tone-3 generates a 48-GHz RF clock and a 60-GHz OOK MMW signal is obtained through the beating of tone-1 and tone-3 (tone-2 and tone-4). The electrical spectrum of the output of the PD is depicted in Fig. 4(a), which is input to

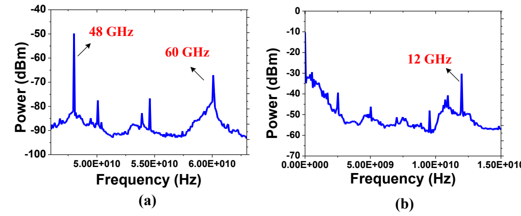

Fig. 4. (a) The spectrum of the received wireless signal, (b) the spectrum of the down-converted signal after the envelope detector.

a power amplifier (Narda West NW 06-0023). A pair of rectangular horn antennas (Ducommun ARH-1525-62) with a gain of 25 dBi at the range of 45-75 GHz are employed to broadcast and receive the wireless signal. After transmission over 10-ft wireless link, at user terminal, the wireless signal (including 48-GHz RF clock and 60-GHz OOK MMW signal) is input into an envelope detector, where down-conversion is realized through the beating of the 48-GHz clock and 60-GHz OOK signal. The spectra before and after the envelope detector are shown in Fig. 4(a) and (b).

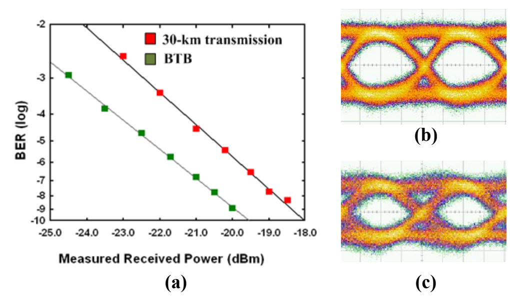

Fig. 5. (a) BER performance of the 2.5-Gb/s OOK signal, (b) the eye diagram before transmission, (c) the eye diagram after 30-km SSMF transmission.

At the output of the envelope detector, an intermediate frequency-OOK (IF-OOK) signal at 12-GHz is obtained, which is down-converted to baseband through a 12-GHz clock. The eye diagrams of the baseband OOK signals before and after transmission are shown in Fig. 5(b) and (c), respectively. The bit-error-rate (BER) measurement results are shown in Fig. 5(a) and error-free performance is achieved with 1.5-dB power penalty after 30-km SMF and 10-ft air-link transmission.

IV. CONCLUSION

We propose and experimentally demonstrated a novel wireless over fiber system using frequency quintupling technique. A 2.5-Gb/s 60-GHz MMW signal is generated using only 12-GHz RF clock and modulators. Error-free performance is achieved after 30-km SMF and 10-ft air link transmission. The experimental results verify that our proposal is a potential candidate for the next generation high-speed wireless over optical fiber access system.

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