

Millimeter-wave Photonic Techniques For Radio-over-Fiber Systems

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Abstract— we proposed a 60 GHz multiband-orthogonal frequency-division-multiplexing (MB-OFDM) system using millimeter-wave (MMW) photonic techniques. A simple optical modulation scheme is developed to generate 60 GHz carrier by the sixth-harmonic term of local oscillator (LO) frequency. We have experimentally demonstrated that the wireless MMW photonic MB-OFDM system can transmit data at up to the rate of 480 Mbps and the maximum wireless-transmission distance can reach 3 m.

Keywords— 60 GHz, millimetre-wave photonic, MB-OFDM, RoF, optical modulation

I. INTRODUCTION

Recently with the fast development and wide application of wireless communication, people have strong requirements on the field of internet TV, high definition TV and real-time video transmission. It is a great challenge for data rate and quality of wireless transmission. The Federal Communication Commission (FCC) allocated 3 bands for general unlicensed use in the field of Industrial, Scientific and Medical (ISM) in 1985, which is the most popular communication frequency band of 2.4/5.8 GHz [1-2]. For the demands of digital electronic message service (DEMS), the FCC set standard of band on 24 GHz (24.25-24.45, 25.05-25.25 GHz) and opened the band of 22-29 GHz in 1997. Generally the band of millimeter-wave is from 30 GHz to 300 GHz, which have a bandwidth of 270 GHz. In 2001, a 60 GHz unlicensed band was proposed by the FCC, which has since draw considerable interest for different applications [3]. It can solve the problem of the insufficient of wireless communication band. In IEEE 802.15.3c, the whole band of 60 GHz standard is divided into 4 channels, with 2160 MHz bandwidth for each channel, 240 MHz front-end protection band and 120 MHz back-end protection band [4-5]. In this study, we proposed a 60 GHz photonic millimeter-wave MB-OFDM radio-over-fiber system. The system structure is based on simultaneous MB-OFDM signal and RF modulation at the sixth-harmonic term of the

local oscillator frequency of an optical carrier. The paper is organized as follows. In section II, the introduction of radio-over-fiber (RoF) technique is shown. The content of Part A in section III is the structure of MMW photonic MB-OFDM RoF system. The experimental results are depicted in Part B. For the last Part of this section, we illustrate the system performances. Some conclusions are drawn in section IV.

II. RADIO-OVER-FIBER TECHNIQUE

Much interest is attracted by the RoF technique because of its potential to provide higher bandwidth and data-rate services for different applications, such as real-time video transmission, mobile communication, wireless networks and medical image transmission. Both high total capacity and single-channel bit rate will be strong requirements for the next generation optical transmission systems and networks [6].

Some literatures have been reported about the major techniques of optical modulation. In 2001, Martinez etc. proposed the scheme to get the RF signal at twice frequency in the photoelectric conversion, using the technique of optical frequency multiplication (OFM) [7]. Two years later in 2003, Hirata etc. used optical time-division multiplexing (OTDM) to generate 60 GHz optical pulse train (OPT), while loading a 30 GHz signal to the mode-locked laser diode (ML-LD) [8]. A 60 GHz wireless RoF system was proposed in 2010, which has 3 configurations separately based on tandem single-sideband (TSSB) modulation, single-sideband-carrier-suppressed (SSB-CS) modulation and all-optical up-conversion technique. Among the 3 configurations, the TSSB modulation is the simplest but has the disadvantages of system high cost and that peak to average power ratio (PAPR) is too high to lead to signal distortion. Comparing with TSSB modulation, SSB-CS modulation can solve the problem of PAPR, but the modulation needs two Mach-Zehnder modulators (MZM) to drive, which increases system complexity. The system using the technique of all-optical up-conversion has high conversion efficiency but a complex system structure [9].

In summary, we proposed a simple system architecture, using a single MZM to make the LO frequency at the sixth

-sixth-harmonic term of an optical carrier. In this system, carrier frequency can be modulated to the band of 60 GHz while the LO frequency is only 10.8 GHz.

III.60 GHz MMW PHOTONIC ROF SYSTEM

A. System Structure

In this study, we proposed a 60 GHz millimeter-wave photonic MB-OFDM RoF system. Fig. 1 shows the diagram of the system. The system consists of a MMW photonic communication module, a 60 GHz communication up-conversion module, a pair of wireless RF antennas and a 60 GHz communication down-conversion module.

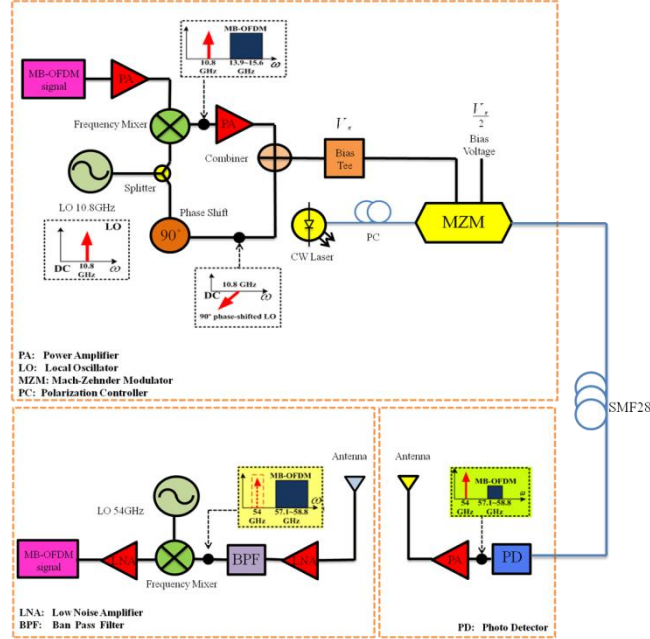


Figure 1. System structure

We select the MB-OFDM signals ranging from 3.1 GHz to 4.8 GHz (band group 1) as the baseband data. A local oscillator (LO) is located to generate a 10.8 GHz carrier signal. Via a frequency mixer, the carrier signal is mixed with the baseband data which have been amplified by a power amplifier (PA). The mixed signal is combined with another 90° phase-shifted LO signal, to drive the single port of the MZM. The proposed configuration is based on the use of a dual-electrode MZM which has some features as follow: 1) simultaneous baseband data and RF modulation at the sixth-harmonic term of the LO frequency of an optical carrier and 2) mitigated the carrier suppression effect caused by the fiber chromatic dispersion. To achieve the effect of 5 times the LO frequency on the optical carrier, a voltage is provided by a bias-tee to control the bias voltage of the MZM. A photo detector (PD) is set to convert the optical signals to electric signals.

For wireless RF transmitting, a pair of antennas is placed. From the Friis transmission equation, it can be believed that the transmission path loss increases with the square of the carrier frequency. It is a great challenge for wireless

transmitting on the band of 60 GHz, so that an enough gain should be improved to contend with the path loss. Therefore, we select a pair of directional antenna which can achieve a gain over 25 dB on 60 GHz band.

At the end of receiver, the down-conversion module plays the role of downing the transmission frequency from the band of 60 GHz to the MB-OFDM baseband which is from 3.1GHz to 4.8 GHz. Placed close to the RF antennas, the low noise amplifier (LNA) is to compensate the transmitting path loss and a band pass filter (BPF) can filter other harmonics off.

B. Experimental Results

Currently OFM technique mainly depends on the PD's feature of photo-electric conversion [10]. The two optical field of carrier can be expressed as follow:

$$E_1 = E_{01} \cos(\omega_1 t), E_2 = E_{02} \cos(\omega_2 t) \quad (1)$$

The current which is detected by PD can be expressed as follow:

$$I_{PD} = R(E_1 + E_2)^2 \quad (2)$$

, R is the PD response, taking E_1 and E_2 into (1), we can get:

$$I_{PD} = RE_{01}E_{02} + RE_{01}E_{02}[\cos(\omega_1 + \omega_2)t] + \dots \quad (3)$$

In (3), $RE_{01}E_{02}[\cos(\omega_1 - \omega_2)t]$ is RF signal part, which frequency is $\omega_1 - \omega_2$, and else is DC part or signal with higher frequency.

We can observe that the RF signal loaded into MZM interfere with each other and generate multiple harmonics. These harmonics have a serious relationship with the LO frequency. Frequency difference of central carrier and harmonic can reach the effect of frequency multiplication.

AMkr	A	1550.340 0 nm	B	1551.779 0 nm	B.A	1.439 0 nm
Lmkr	C		D		C.D	

Res: 0.03nm VBW: 10Hz Sm: Off Smpg: 501pt Intvl: Off SwpAvg: 50 []

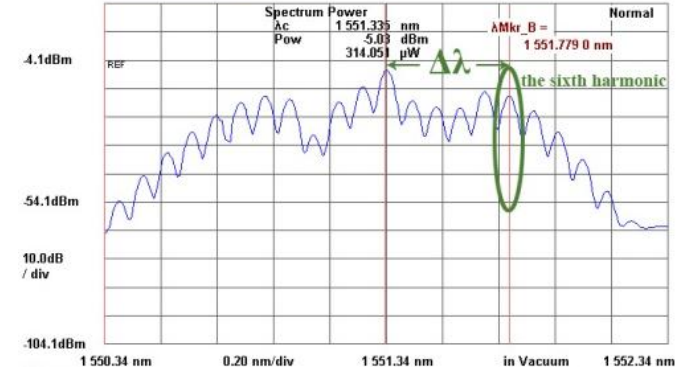


Figure 2. Spectrum of LO frequency multiplication on optical carrier

We use the PD to verify the correction of frequency multiplication modulation. Showing in the optical spectrum, we can get the central wavelength of each harmonic. Via the speed of light formula:

$$C = f \times \lambda \quad (4)$$

we can derive the relationship between the frequency difference and wavelength difference:

$$\Delta f = \frac{c}{\lambda_c^2} \Delta \lambda \quad (5)$$

According the testing record showing in Table 1, the wavelength of the sixth harmonic is 1551.789 nm. Therefore, we can take the parameters into (5) and get the calculating

result of that we can achieve the 60 GHz band by 5 times the LO frequency of only 10.8 GHz.

A modulation optical spectrum is showed in Fig.2. Modulated in the system, we observe the LO frequency at the second, third, fourth, fifth, sixth and other higher-frequency harmonics. We filter off the harmonics which frequency is higher than the sixth harmonic's because that the powers of these harmonics are too low to be detected by PD.

TABLE 1. WAVELENGTH OF OPTICAL CARRIER HARMONIC

Harmonic	Wavelength (nm)	$\Delta\lambda$ (nm)	Δf (GHz)
Center	1551.360		
2 nd term	1551.4473	0.0873	10.88
3 rd term	1551.5289	0.1689	21.05
4 th term	1551.6207	0.2607	32.50
5 th term	1551.7023	0.3423	42.67
6 th term	1551.7890	0.4290	53.48

C. System Performances

To illustrate performances of the system, we use a spectrum analyser to receive the spectra of MB-OFDM signals transmitted in the system.

The MB-OFDM, which frequency band is from 3.1 GHz to 10.6 GHz, is divided into 14 sub-bands with the bandwidth of 528 MHz each band. It also defines 7 time-frequency codes (TFC), including 4 modes which transmit signals in hopping-frequency and other 3 modes for transmitting in a fixed-frequency. As an example showed in Fig.3, the MB-OFDM signal, operating on the band group 1 (from sub-band 1 to sub-band 3), is transmitted using a hopping frequency as the sequence of f1, f3, f2, f1, f3, f2 ... (TFC3).

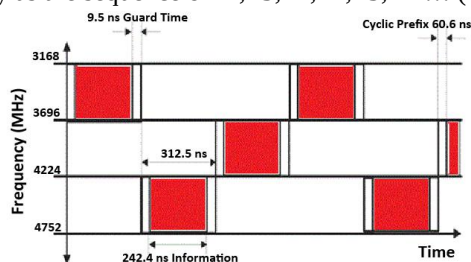


Figure 3. MB-OFDM signals transmitted in TFC3

We tested the system using different TFCs. The testing results can be showed in the Fig.4 to Fig.7. We can observe the spectra of MB-OFDM signals transmitted by 60GHz millimetre-wave photonic RoF system.

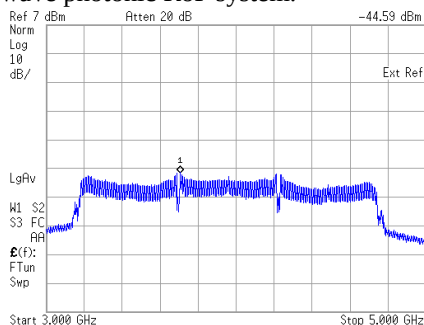


Figure 4. Spectra of MB-OFDM signals transmitted in TFC1

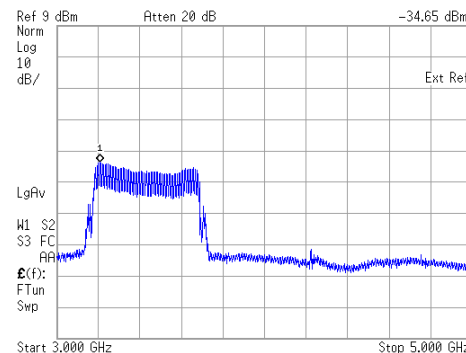


Figure 5. Spectra of MB-OFDM signals transmitted in TFC5

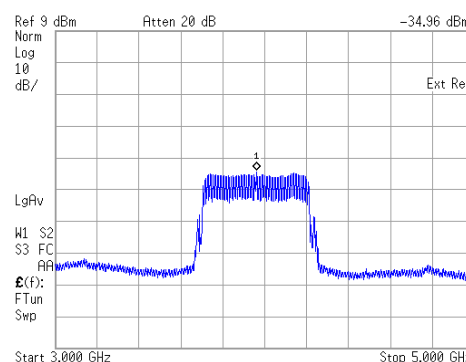


Figure 6. Spectra of MB-OFDM signals transmitted in TFC6

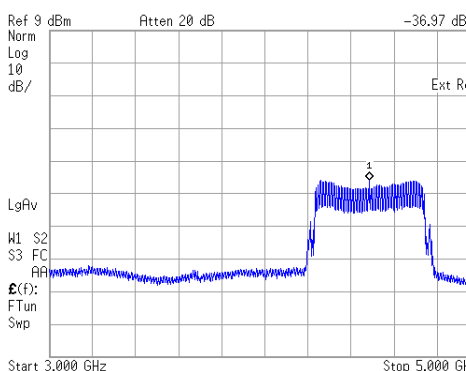


Figure 7. Spectra of MB-OFDM signals transmitted in TFC7

A series data rates of 53.3, 80, 106, 160, 200, 320, 400 and 480 Mbps have been defined in MB-OFDM standard. We use the different data rates up to 480 Mbps to test the system. We can receive the spectra of MB-OFDM signals, which are transmitted in the system, at the baseband of 3.1 GHz to 4.8 GHz. In the experimental environment, the spectra of received signals can be observed correctly at the maximum wireless-transmission distance of 3 m, beyond which the MB-OFDM signals transmitted will be distorted.

IV. CONCLUSIONS

We proposed a 60 GHz MMW photonic MB-OFDM RoF system based on the use of a dual-electrode MZM. In the

system, a new optical modulation scheme by the sixth-harmonic term of the LO frequency on optical carrier has been proposed and verified, we can achieve the LO frequency multiplication to 60 GHz band only at the LO frequency of 10.8 GHz. Comparing with conventional system, we proposed the configuration of optical modulation scheme to achieve 5 times the LO frequency, and drive the dual-electrode MZM with a single channel RF signal. The new optical modulation has several advantages of enhancing the efficiency of optical carrier frequency multiplication, simplifying the system structure and reducing the system cost and complexity. Testing the system, we achieved 60 GHz MMW photonic MB-OFDM wireless RoF transmission at data rate up to 480 Mbps, and the maximum wireless transmission distance can reach 3 m. For future applications, the optical modulation and the system can be used in the fields which have strong requirement of long distance, wireless, high data rate and bandwidth communications, such as some real-time video transmission, industrial bus and medical devices.

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