Gigabit Transmission in 60-GHz-Band Using Optical Frequency Up-Conversion by Semiconductor Optical Amplifier and Photodiode Configuration

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Abstract — **We demonstrate error-free 1.244-Gbit/s ASK data transmission based on remote frequency up-conversion technique in 60-GHz-band radio-on-fiber systems. For frequency up-conversion, 63-GHz optical heterodyne LO signals are cross-gain modulated by another optical baseband signal in SOA, and up-converted signals are generated after photodetection. The dependence of BER characteristics on the power and wavelength of optical baseband signals and the power of optical LO signals is also investigated.**

Index Terms — **Millimeter-Wave Frequency Conversion, Optical Mixers, Semiconductor Optical Amplifier, Millimeter-Wave Radio Communication, Radio-on-Fiber Systems, Microwave Photonics.**

I. INTRODUCTION

Broadband wireless communications operating in 60-GHz-band have been actively investigated because they provide large bandwidth, high directivity, and high frequency reusability. Most of all, the large bandwidth of 60-GHz signals is very attractive for future wireless backbone networks, and indoor broadband multimedia services and wireless LAN applications [1]-[2]. However, the cost to realize 60-GHz-band systems is still very high, and Radio-on-Fiber (RoF) systems can be a possible solution which can provide simple base station designs, centralization of expensive equipment, and long-distance data transmission with low loss fiber [3]-[5]. In addition, the wide bandwidth characteristics of optical components are very useful for 60-GHz-band systems. We have previously demonstrated a RoF system architecture based on the remote frequency up-conversion technique using the cross-gain modulation of a semiconductor optical amplifier (SOA) [7]-[8]. In this scheme, optical heterodyne local oscillator (LO) signals are cross-gain modulated by another optical signal containing data. After photodetection of these optical signals at the remote base stations, frequency up-converted data signals are generated, and then transmitted to mobile terminals. This optical mixing technique has high conversion efficiency characteristics with wide operating wavelength range, and LO frequency is not limited by SOA gain modulation bandwidth. In addition, very simple bi-directional RoF systems based on remote frequency conversion can be realized by combining the frequency down-conversion technique using an electroabsorption modulator [9]-[10]. We also presented calculated bandwidth of our up-converter in [8], but experimental verification and data transmission results have not been presented in 60-GHz-band yet.

In this paper, we experimentally demonstrate error-free 1.244-Gbit/s ASK data transmission using SOA frequency up-conversion method to show the wide bandwidth mixing operation at 63GHz. For frequency up-conversion, 63-GHz optical heterodyne LO signals and 1.244-Gbit/s optical baseband signals are used. In addition, the dependence of bit-error rate (BER) characteristics on optical IF power and wavelength as well as optical LO signal power is investigated.

II. OPERATION PRINCIPLE

Fig. 1 schematically shows the operation of SOA-PD frequency up-conversion for ASK data transmission. Optical LO signals at λ_{LO} are generated by the optical heterodyne method resulting in two optical sidebands separated by f_{LO}. When optical LO signals along with optical signals at λ_{data} carrying baseband data are injected into the SOA, two sidebands of optical heterodyne LO signals are cross-gain modulated by the baseband data signals at λ_{data}, and frequency up-converted data signals at f_{LO} are created by the signal beating process in a photodiode. This frequency up-conversion scheme has high conversion efficiency due to SOA gain, and the LO frequency is limited only by the photodetector frequency response. Therefore, it is very useful for systems requiring high frequency operation. Details of the frequency up-conversion characteristics are well explained in [7] and [8].

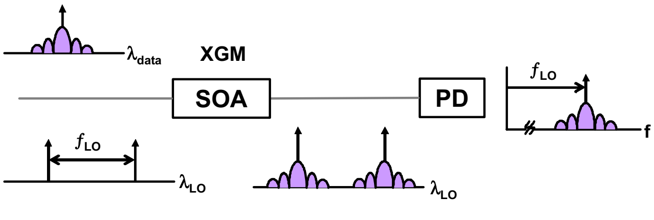

Fig. 1. Schematic for optical frequency up-conversion of baseband data signals using SOA cross-gain modulation and photodetection

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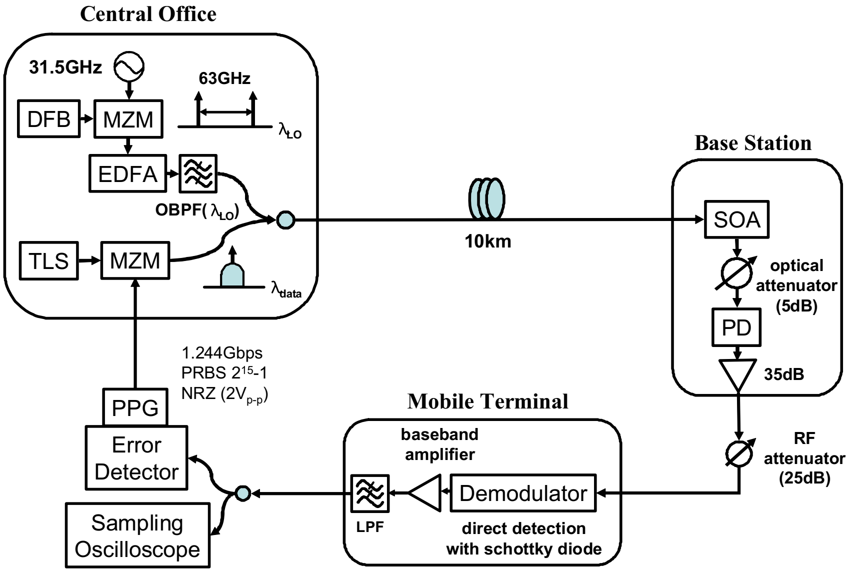


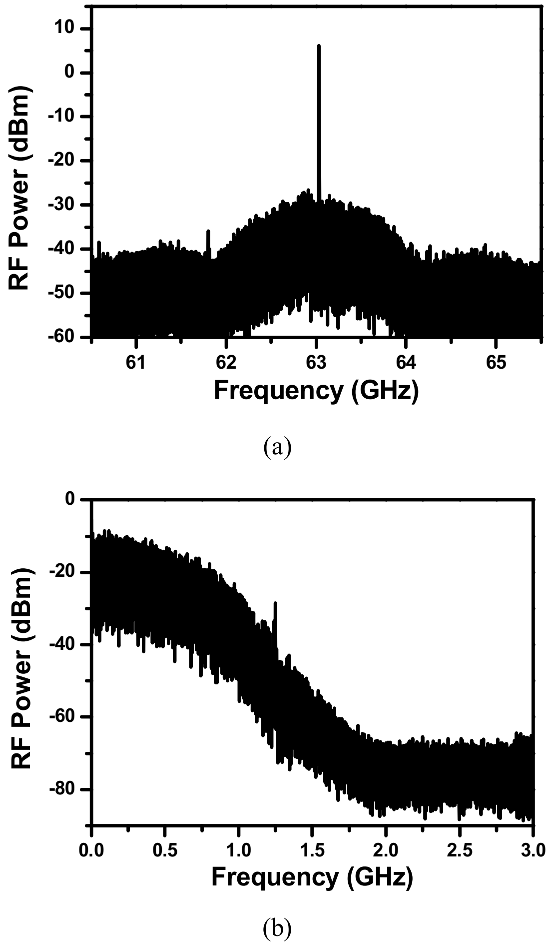
Fig. 2. Experimental setup for 1.244-Gbit/s ASK data transmission in 60-GHz-band remote up-conversion Radio-on-Fiber systems. DFB : Distributed Feedback Laser, MZM : Mach-Zehnder Modulator, EDFA : Erbium-Doped Fiber Amplifier, TLS : Tunable Laser Source, OBPF : Optical BandPass Filter, PD : Photodiode, PPG : Pulse Pattern Generator, LPF : Low Pass Filter.

III. EXPERIMENTAL SETUP AND RESULTS

To apply the frequency up-conversion method in 60-GHz-band RoF systems, the experimental setup shown in Fig. 2 was used. 63-GHz optical heterodyne LO signals were generated by the double-sideband-with-suppressed-carrier method for which a 40-GHz Mach-Zehnder modulator biased at the minimum transmission point was modulated by 31.5-GHz RF signals [6]. The wavelength of optical LO signals was 1553.3-nm. For the optical baseband data signals, another Mach-Zehnder modulator biased at the maximum modulation efficiency point was modulated by 1.244-Gbit/s non-return-to zero (NRZ) pseudo-random bit sequence having the pattern length of 2^{15}-1 baseband data supplied from a pulse pattern generator. The amplitude of electrical baseband data signals was 2-V peak-to-peak. These two optical signals were combined by a 3-dB optical coupler, and transmitted to the base station via 10-km optical fiber.

At the base station, the optical signals were injected into the SOA-PD frequency up-converter, and frequency up-converted ASK data at 63-GHz were generated from the 60-GHz PD. The SOA was biased at 150-mA, which gave 25-dB optical gain and 8-dBm output saturation power. A 5-dB optical attenuator was inserted between the SOA and the PD to avoid unwanted data saturation at the PD. Fig. 3(a) shows the RF spectrum of 1.244-Gbit/s ASK data at 63-GHz after frequency up-conversion. In this measurement, the optical LO power before SOA was -13-dBm, and the optical IF power and wavelength before SOA was -13-dBm and 1550-nm, respectively. This spectrum was obtained after 50-dB electrical amplification to overcome low measurement sensitivity at 60-GHz-band, and this was not the actual input signal to the demodulator. As shown in the figure, baseband data signals are successfully up-converted to 63-GHz, however, a very high signal peak coming from the optical LO signal detection appears at 63-GHz, which can saturate electrical amplifiers and limit output data signal power. Balanced mixing of baseband data to intermediate frequency band, or carrier-suppressed ASK modulation techniques can mitigate this problem. However, we did not use such techniques in this experiment for simplicity.

To demodulate data signals, a 63-GHz direct conversion ASK demodulator based on a Schottky diode was used. The data signal was attenuated by a 25-dB RF attenuator since the demodulator has a maximum power limit of -30-dBm. Fig. 3(b) shows the RF spectrum of 1.244-Gbit/s baseband data demodulated from the optically up-converted ASK data. After baseband amplification and additional low pass filtering of data signals, demodulated data signals were analyzed by a sampling oscilloscope for eye diagram, and an error detector for BER. Fig. 4 shows the eye diagram of demodulated 1.244-Gbit/s data signals. Very clear eye-opening was observed as shown in the figure.

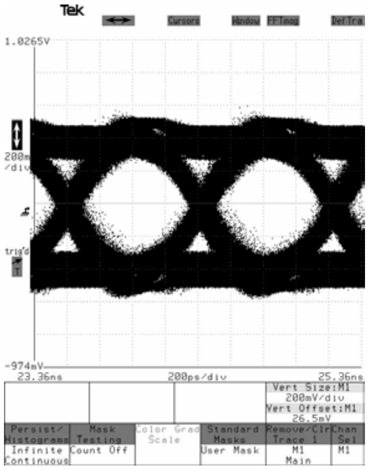


(a)

(b)

Fig. 3. RF spectrum of frequency up-converted 1.244-Gbit/s data signals at 63-GHz (a), and demodulated data signals (b)

As a first step, BER was measured as a function of optical baseband signal powers before SOA. As shown in Fig. 2, the SOA-PD frequency up-converter is placed at the remote base station, and input optical data signal power before SOA is an important parameter determining frequency conversion efficiency. Therefore, the SOA input data signal power is more critical than the optical power before PD. Moreover, because the optical input power to the SOA is high enough to saturate SOA gain, the output power of SOA does not change very much. Fig. 5 shows the measured BERs as a function of SOA input data signal power at several different optical baseband wavelengths varying from 1530-nm to 1570-nm. For this measurement, the optical heterodyne LO signal power before SOA was fixed at -13-dBm. As can be seen in the figure, the BER decreases as the baseband optical signal power increases. The reason for BER decrease is that the increased optical data signal power can improve cross-gain modulation efficiency in SOA, which results in the improvement of frequency up-conversion efficiency as explained in [7]-[8]. From 1550-nm to 1570-nm, the power penalty for 10^{-9} BER is less than 1-dB. However, the power penalty for the 1530-nm wavelength signal is about 9-dB. The SOA used in our experiment has gain peak at around 1550-nm when it is not saturated. Since the SOA gain peak is shifted to longer wavelength due to the carrier depletion when SOA gain is saturated, frequency up-conversion efficiency is higher for longer wavelength signals beyond 1550-nm [8, 11]. For 1530-nm and 1540-nm signals, the power penalty is mainly due to the low frequency up-conversion efficiency. Nevertheless, error-free data transmission is accomplished for a wide range of data wavelengths proving that WDM data transmission is possible with our scheme. It is believed that with further optimization of baseband modulation and demodulation, and RoF system design, the required baseband optical power can be much reduced.



Vert Size:M1
200mV/div
Vert Offset:M1
26.5mV

Infinite Continuous
Count Off
User Mask
M1 Main
M1

Fig. 4. Eye diagram of demodulated 1.244-Gbit/s ASK data signals.

The dependence of BER on optical LO power was also measured. The optical data signal power was fixed at -13-dBm, and the data wavelength was 1550-nm. Fig. 6 shows the results of optical LO power dependence. As the optical LO power increases, the BER is decreased. The reason for this improvement is that the high optical LO power results in high frequency up-conversion efficiency [7]-[8].

IV. Conclusion

We experimentally demonstrated error-free 1.244-Gbit/s ASK data transmission based on the SOA-PD frequency up-conversion scheme in 60-GHz-band RoF downlink. For frequency up-conversion, 63-GHz optical heterodyne LO signals were cross-gain modulated by 1.244-Gbit/s NRZ optical baseband signals, and frequency up-converted 63-GHz ASK data signals were generated after photodetection. We also measured BERs as functions of the optical power and wavelength of baseband optical signals and the optical LO signal power. The BER performance improves as the power of optical baseband signals and optical LO signals increases because of the increased frequency up-conversion efficiency. The error-free data transmission was achieved for a wide range of baseband data wavelengths. With these, we verified that our frequency up-conversion technique has enough bandwidth for gigabit data transmission at 60-GHz-band for a wide range of data wavelengths.

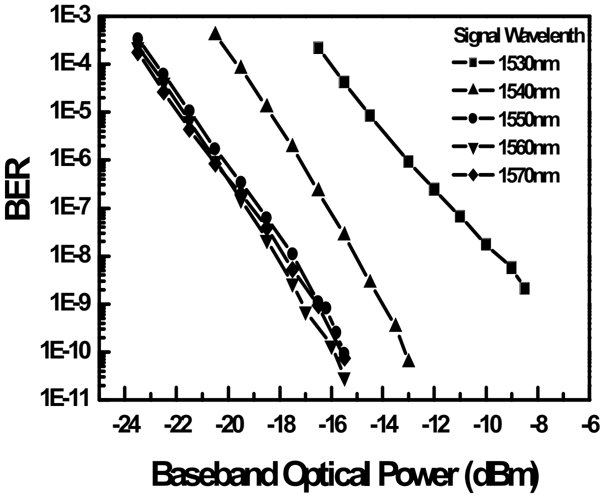


Fig. 5. The dependence of BER performance on SOA input baseband optical signal power. The baseband signal wavelength is changed from 1530-nm to 1570-nm.

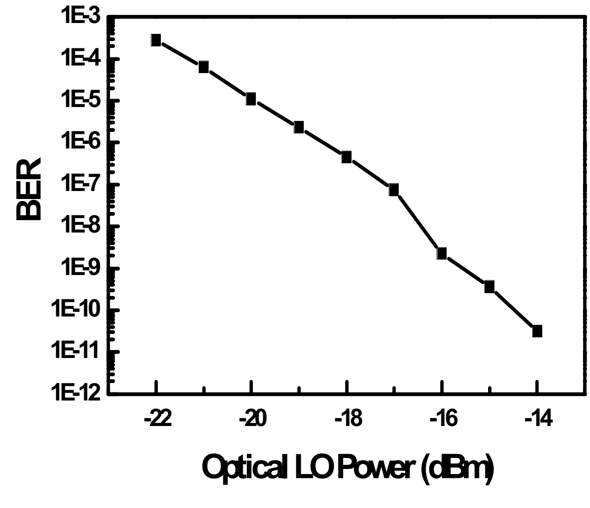


Fig. 6. The dependence of BER performance on SOA input LO signal power.

ACKNOWLEDGEMENT

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