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20-Gb/s QPSK W-band (75–110 GHz) wireless link in free space using radio-over-fiber technique

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Abstract: We demonstrate 20-Gb/s W-band wireless transmission in free space with a distance of 30 mm using optical signal generation. Optically synthesized QPSK signal and direct optical upconversion technique ease generation of W-band RoF signals for dual purpose of wireline and wireless transmission link. A W-band radio receiver with W-band frequency downconversion and digital signal processing will be applicable for any W-band radio detection.

Keywords: radio-over-fiber technique, quadrature-phase-shift-keying, wireless transmission

Classification: Fiber optics, Microwave photonics, Optical interconnection, Photonic signal processing, Photonic integration and systems

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1 Introduction

Recent digital-signal-processing-assisted coherent optical transmission technique with multi-level modulation is possible candidate for huge capacity transmission with high spectral efficiency. The capacity of optical transmission link is being increased rapidly greater than 1 Tb/s [1]. However, in commercial radio wireless link, the link speed would not achieve to 10 Gb/s. This capacity mismatch between optical link (wireline) and radio link (wireless) technologies causes the bottleneck in future wireline and wireless seamless networks. To meet the demand, high carrier frequency wireless link experiments have been reported with 12.5 Gb/s on-off keying with carrier of 300 GHz in free space, 20-Gb/s QPSK in the W-band under back to back condition, and 27 Gb/s OFDM-16-QAM in 60-GHz band with a distance of several meters [2, 3, 4].

Optical signal generation technique based on radio-over-fiber (RoF) technology will be applicable for high frequency wireless communication. Direct optical upconversion technique easily realizes the RoF signal in microwave frequency and 24 GHz bands as well as much higher frequency band [5, 6]. This is because the upconversion technique is based on combination of baseband and separated local oscillator (LO) signals. Moreover, the generated RoF signal would be available for dual purpose of wireline and wireless link.

In this paper, we demonstrate W-band (75–110 GHz) wireless link with RoF signal generation technique. Multi-level modulation for quadrature phase-shift keying (QPSK) signal achieved 20 Gb/s radio signal transmission with 30 mm distance in free space. Observed bit error rates (BERs) were much less than the forward error correction (FEC) limit of 2×10^{-3}. In our proposed system, RoF signal generation with direct optical upconversion technique is used to form W-band signals at the optical receiver side. The

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radio receiver consists of W-band waveguide components for downconverting to less than 30 GHz and digital signal processing for carrier recovery, IQ signal separation, equalization, and symbol decision.

2 Experimental setup

As shown in Fig. 1, our transmitter consisted of a frequency quadrupler and optical QPSK generator. The frequency quadrupler using a dual-parallel Mach-Zehnder modulator (DPMZM) can generate the forth order harmonics of the modulation signal fed to the electric input of the modulator [7]. High-extinction ratio operation of the DPMZM can effectually suppress the odd harmonics in the optical output. Thus, a two-tone optical signal whose frequency separation is four times the modulation frequency can be generated by using a fiber Bragg grating (FBG) filter whose reflection band covers the optical carrier. The frequency of the modulation signal fed to the DPMZM was 23.125 GHz, so that the frequency separation of the generated optical two-tone was 92.5 GHz. The two-tone signal was split by an optical arrayed waveguide grating (AWG) with a channel separation of 23 GHz through an erbium doped fiber amplifier (EDFA). The upper optical frequency component was used as the optical reference component of the RoF signal for the direct optical upconversion. The lower one was launched into a QPSK modulator connected to two-channel 10 Gb/s pulse pattern generator (PPG). The PPG generated pseudo random bit streams with a length of $2^{15} - 1$. The reference signal and the optically synthesized QPSK signal, combined by a 3-dB optical coupler, were fed to a uni-traveling carrier photodiode (UTC-PD) working as a W-band photo mixer through the EDFA [8]. A 24 dBi W-band horn antenna directly connected to the UTC-PD would transmit a W-band QPSK signal whose central frequency should be equal to that of the frequency separation of the two-tone signal generated by the frequency quadrupler. The RoF signal consisting of the reference and QPSK signal can be also used for digital baseband transmission. When the signal is fed to a photodetector that cannot respond to W-band signals, an optical coherent receiver would act as a baseband optical detector. To demonstrate the dual-

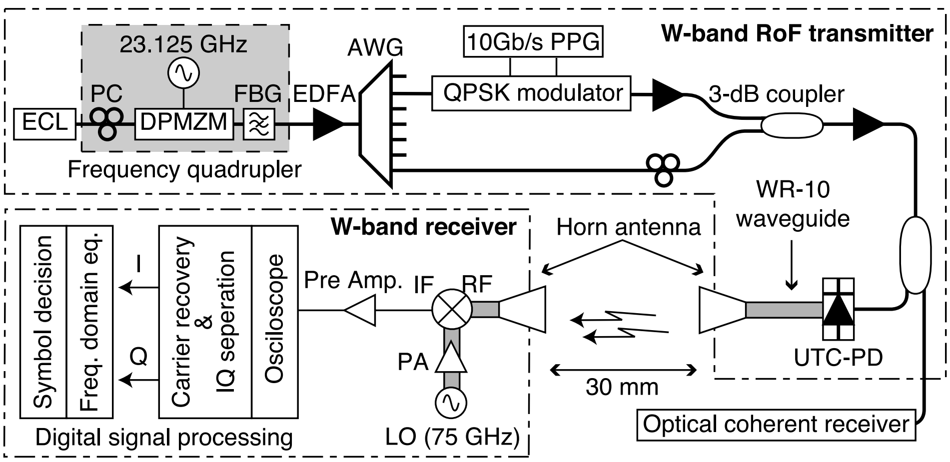

Fig. 1. Experimental setup.

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purpose capability, we used the optical coherent receiver with 1-nm band pass filter.

In a receiver side, we used combination of frequency downconversion and digital signal processing for the IQ signal detection. A conventional IQ mixer can provide the simplest setup, however, it is not easy to fabricate full-band IQ mixers in W-band due to its broad bandwidth of 35 GHz. Homodyne technique using a conventional mixer for downconversion to baseband eliminates IQ information. In order to avoid these issues, we used two-stage downconversion. First, a full-band double-balanced mixer in W-band downconverted the signal at the frequency from 82.5–102.5 GHz to 7.5–27.5 GHz for a main lobe of 10-Gbaud QPSK signal using an LO signal of 75 GHz. The modulation signal centered at 17.5 GHz with the bandwidth of 20 GHz was analog-to-digital converted by a real-time digital oscilloscope (LeCroy, SDA8Zi), whose bandwidth and sampling rate were 30 GHz and 80 GSa/s, respectively. For the phase detection, the digitized signal was multiplied with complex sinusoidal signal (i.e. $1 + j2\pi ft$: $f = 17.5$ GHz) after the carrier recovery process. Finally, I and Q components can be separated without using any electric full-band IQ mixers. Processing schemes such as frequency domain equalization and symbol decision can be applied for the I and Q components in the same manner as an optical digital coherent detection technique. We used another horn antenna as a receiver antenna. The distance between the antennas was 30 mm.

3 Demonstration

Optical spectrum measured at the UTC-PD input is shown in Fig. 2 (a). The optical reference component at the wavelength of 1551.9 nm and 10-Gbaud QPSK signals at the wavelength around 1552.7 nm were clearly observed with the separation of 92.5 GHz, which corresponds to about 0.8 nm in wavelength. Undesired harmonics and tones were largely suppressed by the high extinction-ratio operation of the DPMZM in the frequency quadrulper. These transmitted electrical spectrum was measured through the IF port of the mixer at the receiver side (Fig. 2 (b)). Note that this spectrum was gen-

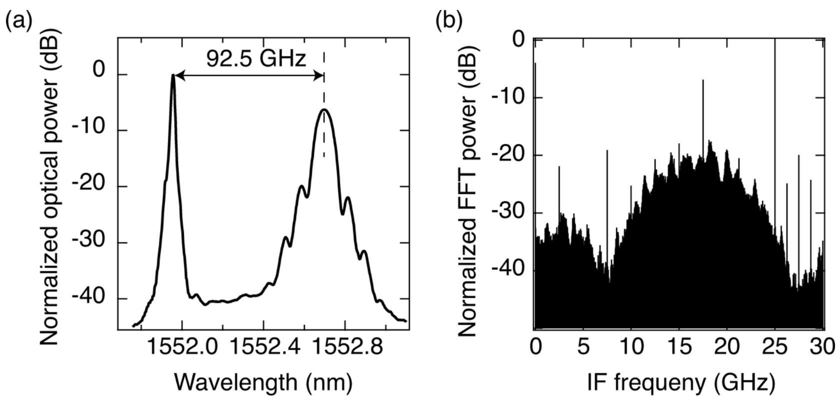

Fig. 2. Spectra of (a) optical RoF signal and (b) FFT-transformed IF signal of the receiver mixer.

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erated by a fast Fourier transform (FFT) processing with a time-series data observed by the real time oscilloscope. The main lobe of 10-Gbaud modulated signal centered at 17.5 GHz had some parasitic peaks, which could be generated in W-band components because there is no corresponding peak in the optical spectrum. Some spectrum distortions can be reflected by the frequency response of the W-band equipments. Periodic structure in the main lobe would be due to the interference between transmitted radio signals.

Observed constellation diagrams using the optical coherent receiver at the transmitter side and the electric receiver are shown in Fig. 3. The difference of symbol separation in optical and wireless signal could be caused by noise generated in the W-band electric components. Although the optical signal-to-noise ratio (SNR) was larger than 30 dB in the optical spectrum, the electrical SNR was less than 20 dB (Fig. 2). The distortion in the constellation diagrams was caused by the IQ imbalance of the optical QPSK modulator. The optimization of modulator bias would improve these distortions.

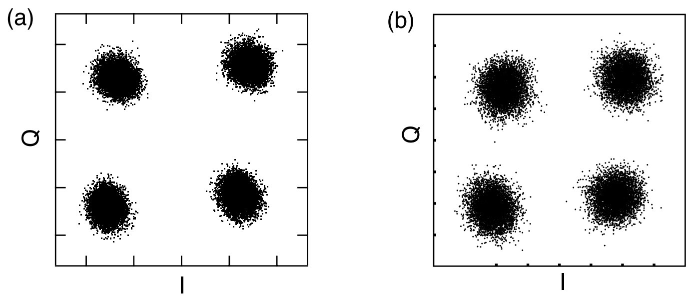

Fig. 3. Constellation diagrams of (a) optical QPSK signal and (b) received radio signal.

Figure 4 shows BERs in free space with the distance of 30 mm. The observed BERs are much less than the FEC limit of 2×10^{-3}. Thus, we deduce that the 18.7-Gb/s error-free wireless transmission with 7% FEC overhead

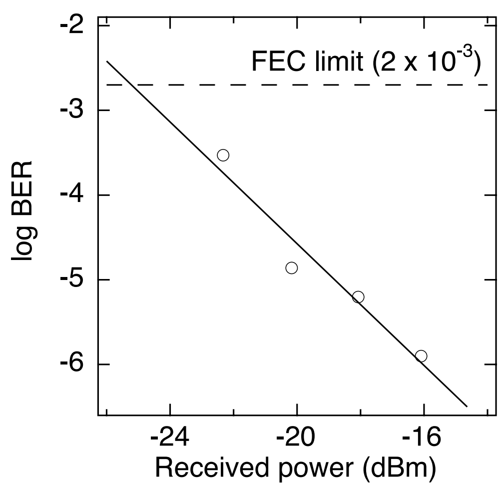

Fig. 4. Bit error rates dependence on received radio power.

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will be realized. The received power is estimated −25 dB when the BER is equal to the FEC limit. The transmission distance without any W-band amplifiers will be roughly estimated to be 100 mm under error free operation, assuming the transmission loss of 5 dB/km and the antenna gain of 24 dBi in the W-band. For application to wireless local area network (WLAN), a W-band amplifier will be required. The report on the fabrication of 5 W W-band amplifier will realize the W-band WLAN with the distance extension greater than 10 m [9].

4 Conclusion

We have successfully demonstrated 20-Gb/s W-band wireless transmission with the distance of 30 mm using optical signal generation. Combination of W-band RoF signal generation and digital signal processing with W-band electronics would realize W-band QPSK transmission. The RoF signal can be also demodulated by an optical coherent receiver designed for optical baseband transmission. Thus, technique will be applicable for future wireline and wireless seamless networks with the capacity greater than 10 Gb/s.

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