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Experiment on 60-GHz MMW transmission performance in an optical fiber and wireless system

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We experimentally investigate the transmission performance of 60-GHz signals over standard single-mode fiber (SSMF) and wireless links at different bit rates. Experimental results show that in a transmission of over 10-km SSMF and 1.3-m wireless link, bit rate reaches up to 5 Gb/s and bit error rate (BER) is less than 10^{-4}. The main limiting factor in such radio-over-fiber (ROF) systems is intersymbol interferences caused by the so-called walk-off effect when BER is below 10^{-8}. In addition, a transmission of over 20-km SSMF without chromatic dispersion compensation is briefly investigated. For a BER of 10^{-8}, the optical penalty is 2 dB.

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Because of its high bandwidth and attenuation of up to 15.5 dB/km, a 60-GHz millimeter-wave (MMW) is suitable for wide-band modulation and picocell architectures; owing to these features, it continues to attract increasing attention[1−3]. In recent years, chip design and manufacture techniques supporting 60-GHz band wireless have become more mature; various wireless standards for the 60-GHz band are being developed, and a draft standard has been written[4]. Hence, the time has come to prepare for the coming "60 GHz era." Radio-over-fiber (ROF) technology, which combines the limitless bandwidth of optical transmission and the flexibility of wireless transmission, is seen as capable of satisfying increasing bandwidth demands in wireless communication. It is especially suitable for picocell architectures for its simple structure in base stations. These years, many publications focusing on ROF operating at a 40-GHz MMW band have emerged to explore the details of system performance. Conversely, 60-GHz band technology is at the experimental stage and few publications have investigated its system performance. Most previous studies presented work on 60-GHz ROF systems focused on the physics layer of the optical link[5−9]. Some concentrated on 60-GHz MMW wireless transmission performance[2,3], but investigations on both optical fiber and wireless transmission performance are rare. The relationship between different wireless distances and system performance with 2.5 Gb/s at a 60-GHz band ROF system were studied in Ref. [10], and the low bit rate 60-GHz MMW transmission over an optical fiber and wireless line was presented in Refs. [11,12].

In this letter, we investigate the transmission performance at different data rates with a 60-GHz signal over standard single-mode fiber (SSMF) and a 1.3-m wireless line without chromatic dispersion compensation. In addition, a transmission of over 20-km SSMF without chromatic dispersion compensation is briefly investigated. Results show that for 10-km SSMF and a 1.3-m wireless line link, even when data rate reaches up to 5 Gb/s, the eye diagram remains very clear, and bit error rate (BER) is less than 10^{-4}. For a BER of 10^{-8}, the optical penalty is 2 dB over 20-km SSMF.

Figure 1 shows the experimental setup for a 60-GHz ROF system. At the transmitter, a distributed feedback laser generates the continuous wave (CW) at 1543.75 nm. It is modulated by the dual-arm Mach-Zehnder modulator (MZM) with 15-GHz radio frequency (RF) signals to generate the double sideband signal. The output of the dual-arm MZM is shown in Fig. 1(a). Then, a 50-GHz interleaver (IL) is used to filter the optical carrier; the 60-GHz MMW is shown in Fig. 1(b). After an erbium-doped fiber amplifier is used, a pseudo-random bit-sequence with a length of 2^{31}-1 drives the LN-MZM, and the direct current (DC) bias is 7.8 V. Figure 1(c) shows the 60-GHz MMW with 5-Gb/s non-return-to-zero (NRZ) signal. After 10-km SSMF transmission (the waveform is shown in Fig. 1(d)), a photoelectric detector (PD)

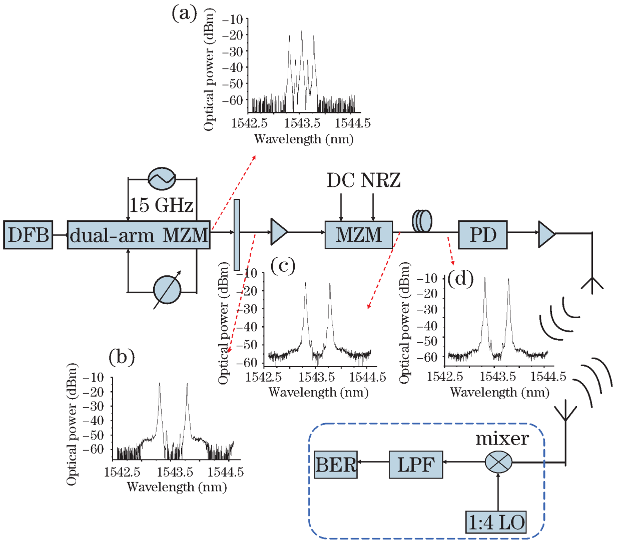

Fig. 1. Experimental setup. (a) Spectrum after dual-arm MZM; (b) Spectrum after IL; (c) spectrum of modulated 60-GHz MMW; (d) received spectrum after transmission over optical fiber.

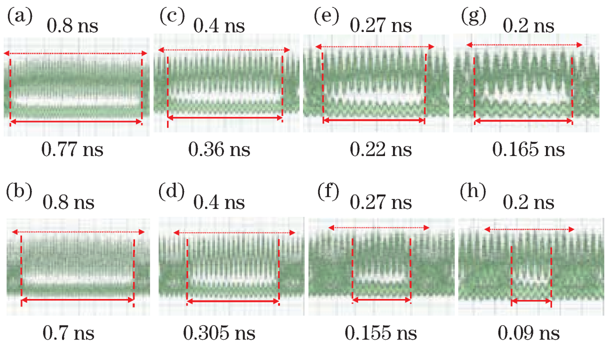

Fig. 2. Optical MMW eye diagrams of 1.25-, 2.5-, 3.75-, and 5-Gb/s signals before and after transmission over 10-km SSMF. (a) 1.25 Gb/s, B-T-B; (b) 1.25 Gb/s, 10-km SSMF; (c) 2.5 Gb/s, B-T-B; (d) 2.5 Gb/s, 10-km SSMF; (e) 3.75 Gb/s, B-T-B; (f) 3.75 Gb/s, 10-km SSMF; (g) 5.0 Gb/s, B-T-B; (h) 5.0 Gb/s, 10-km SSMF.

is used to transform the optical MMW signal to an electrical MMW signal in the receiver. The electrical MMW signal is amplified by the electrical amplifier before the signal is transmitted over the air via the antenna. After 1.3-m wireless transmission, the receiving antenna receives the MMW signals, and coherently demodulated by mixing the local oscillator (LO) signal at 60 GHz. The 60-GHz local oscillator (LO) signal is obtained using a 1:4 frequency multiplexer and a 15-GHz RF signal. The obtained baseband signal is sent to the measured BER after transmission at a low band filter.

Figure 2 shows the optical MMW eye diagrams (captured using an Agilent 86100C oscilloscope) of 1.25-, 2.5-, 3.75-, and 5-Gb/s signals before and after transmission over 10-km SSMF. In the case of back-to-back (B-T-B), Figs. 2(a), (c), (e), and (g) show that as bit rate increases from 1.25 to 5 Gb/s, the eye width decreases from 0.77 to 0.1655 ns. The pulse width narrows as bit rate increases; with increasing bit rate, the pulse width decreases and the decision time that the signal consumes is reduced. Because of the jitter in the digital system, the system becomes more sensitivity to the jitter, the bit rate increases, and the system error performance worsens. The optical MMW eye diagram of transmission over 10-km SSMF is shown in Figs. 2(b), (d), (f), and (h). Compared with the corresponding bit rate eye diagram of the B-T-B, the eye width depicted reflects a decrease. When the MMW are transmitted over the SSMF, the two sidebands are affected by the walk-off effect at different velocities, which expands the codes and intersymbol interference (ISI). When ISI exists, the received signal is distorted, so that the scan paths of the oscilloscopes do not completely coincide. Thus, the rising edges widen, and the eye width decreases. Once the optical length, radio frequency, and fiber dispersion are all determined, the time shift of the code edge becomes proportional to bit rate.

The eye diagrams of different bit rate signals over 10-km SSMF and 1.3-m wireless transmission are shown in Fig. 3. The duty cycle becomes smaller as bit rate increases, indicating worse system performance. The signal degradation is caused by edge broadening and the attenuation of signal electrical level. Both optical and wireless links introduce impairments and performance degradation. The edge broadening stems from the walk-off effect in fiber transmission, whereas attenuation is caused by power loss of the wireless link.

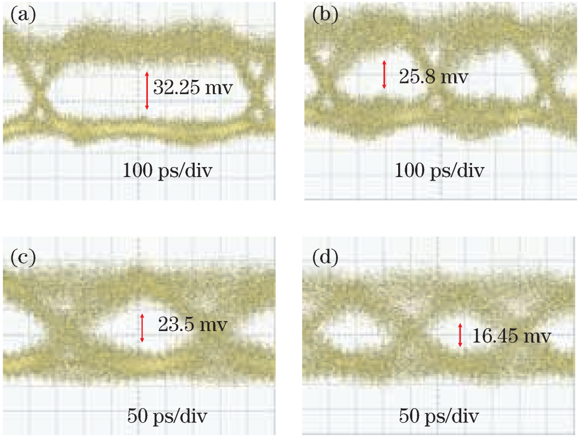

Fig. 3. Eye diagrams of different bit rate signals after transmission over 10-km SSMF and 1.3-m wireless line. (a) 1.25 Gb/s; (b) 2.5 Gb/s; (c) 3.75 Gb/s; (d) 5.0 Gb/s.

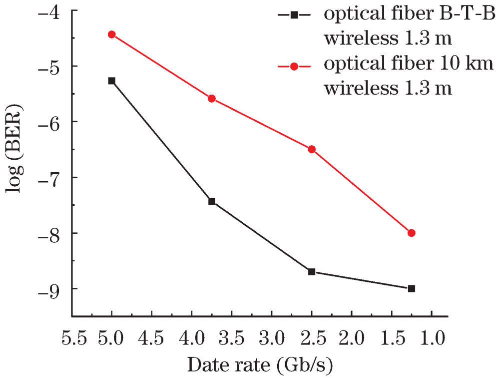

Fig. 4. Data rate-BER curve of 60-GHz MMW transmission over fiber and wireless line when received optical power is −15 dBm.

To analyze impairments from optical and wireless links, we measured the BER curves under different conditions. Figure 4 shows BER versus bit rate in the ROF system with a wireless link before and after fiber transmission. Because of the high absorption by oxygen, the main limiting factor of a 60-GHz MMW in wireless link is power attenuation. If signal power is given, the higher the data rate, the weaker the energy per bit, and the worse the signal quality. This can be deduced from the lower line in Fig. 4. System performance increases as bit rate decreases. We also find that performance slowly diminishes when bit rate is lower than 2.5 Gb/s. This bit rate suggests that as BER becomes lower than 10^{-8}, the main limitations in the wireless link are other impairments such as jitter, additional white noise, and distortion rather than attenuation. For fiber transmission, however, the interference (ISI) caused by fiber dispersion plays an important role in the limitations in a ROF system. The dashed line in Fig. 4 suggests that system performance is worse with fiber transmission. The penalty of fiber transmission is introduced from ISI caused by the walk-off effect. System performance clearly worsens as bit rate increases because the higher the bit rate, the

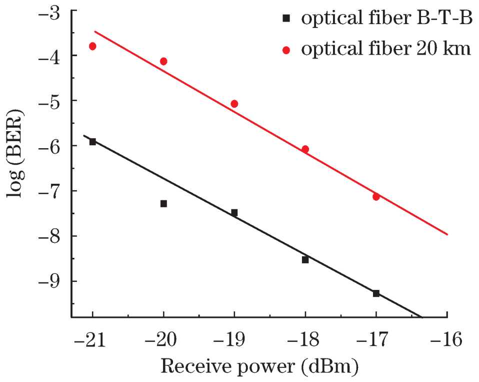

Fig. 5. BER curves of the 2.5-Gb/s signal before and after transmission over 20-km SSMF.

higher the sensitivity to ISI as caused by the fiber. The main limitation in such ROF systems is ISI when BER is below 10^{-8}. Figure 5 shows BER versus received power before and after 20-km SMF without a wireless link. The walk-off effect introduces a power penalty of 2 dB at a BER of 10^{-8} in the system, and the BER curves are smoother than those reflected in Fig. 4.

In conclusion, we experimentally investigate the transmission performance at different data rates of a 60-GHz signal over 10-km SSMF and 1.3-m wireless line without chromatic dispersion compensation. To compare performance, transmission over 20-km SSMF without chromatic dispersion compensation is briefly investigated. For 10-km SSMF and 1.3-m wireless line link, even when data rate achieves 5 Gb/s, the eye diagram remains very clear, and BER is less than 10^{-4}. When data rate is lower than 2.5 Gb/s and BER is below 10^{-8}, the trend of amplitude attenuation in the wireless link is flattened. The main limitations in the wireless link are other impairments such as jitter, additional white noise, and distortion rather than attenuation, and the main limitation in such ROF systems is ISI when BER is below 10^{-8}. In the 2.5-Gb/s 60-GHz signal transmission over 20-km SSMF without transmission over wireless lines, the optical penalty for a BER of 10^{-8} is 2 dB. This system can realize an efficient performing 60-GHz MMW at high speed transmissions over optical fiber and short-range wireless.

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References

1. J. A. Howarth, A. P. Lauterbach, M. J. Boers, L. M. Davis, A. Parker, J. Harrison, J. Rathmell, M. Batty, W. Cowley, C. Burnet, L. Hall, D. Abbott, and N. Weste, in *Proceedings of Tencon 2005-2005 IEEE Region 10 Conference* 1 (2005).
2. N. Pleros, K. Tsagkaris, and N. D.Tselikas, IEEE Commun. Lett. **12,** 852 (2008).
3. Y. Jiang, K. Li, J. Gao, and H. Harada, in *Proceedings of IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications* 1781 (2009).
4. IEEE standard 802.16-2004, IEEE Standard for Local and metropolitan area networks−Part 16: Air Interface for Fixed Broadband Wireless Access Systems. http://www.ieee802.org/16/pubs/80216-2004.html.
5. J. Ma, J. Yu, X. Xin, C. Yu, and L. Rao, Opt. Fiber Technol. **15,** 125 (2009).
6. H.-C. Chien, A. Chowdhury, Z. Jia, Y.-T. Hsueh, and G.-K. Chang, Opt. Express **17,** 3016 (2009).
7. Z. Jia, Y.-T. Hsueh, H.-C. Chien, A. Chowdhury, J. Yu, and G.-K. Chang, in *Proceedings of Opto-Electronics and Communications Conference, and the Australian Conference on Optical Fibre Technology* (2008).
8. Z. Jia, J. Yu, Y.-T. Hsueh, and G.-K. Chang, in *Proceedings of 34th European Conference on Optical Communication* Tu.3.F.5 (2008).
9. L. Liu, Z. Dong, Y. Pi, J. Lu, L. Chen, J. Yu, and S. Wen Chinese J. Lasers (in Chinese) **36,** 148 (2009).
10. Z. Dong, Z. Cao, L. Chen, and S. Wen, Chinese J. Lasers (in Chinese) **37,** 1018 (2010).
11. L. Noël, D. Wake, D. G. Moodie, D. D. Marcenac, L. D. Westbrook, and D. Nesset, IEEE Trans. Microwave Theory Tech. **45,** 1416 (1997).
12. T. Kuri, K. Kitayama, A. Stöohr, and Y. Ogawa, J. Lightwave Technol. **17,** 5 (1999).