100 GHz Ultra-wideband Wireless System for the Fiber to the Antenna Networks

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Abstract: We experimentally demonstrate an optical ultra-wideband (UWB) (75GHz-110GHz) fiber-to-the-antenna (FTTA) system using our developed W-band near-ballistic unitraveling-carrier photodiode (NBUTC-PD) based photonic transmitter (PT). 2.5Gb/s and 1.5Gb/s UWB-FTTA systems with 1,024 high split-ratio are demonstrated.

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1. Introduction

Fiber-to-the-home (FTTH) using passive optical network (PON) is considered as a promising and cost-effective access solution to distribute broadband services to end-users using passive optical splitters. People not only require high bandwidth FTTH network, but also demand mobile services [1]. Ultra-wideband (UWB) has been considered as one of the promising techniques for wireless communications. People also consider that UWB wireless signal can be a replacement for the high-definition (HD) video cables [2] in the near future. In the UWB-impulse radio (IR) system, each transmitted pulse occupies the whole UWB bandwidth. It is carrier-less and has a strong tolerance against multipath reflections. The UWB-IR system is particularly suitable for high data rate and short-range in-building applications. Using optical approach of fiber-to-the-antenna (FTTA) system to distribute UWB-IR signal can be cost-effective and achieving good quality signal when compared with electrical approach, since the optical approach can remove the high propagation loss and limited transmission distances when transmitting short electrical pulses in electrical cables. In the FTTA system, a head-end office (HE) generates the UWB signals, which are distributed over low-loss and low-cost optical fibers to a number of subscribers (different rooms in a building). At the subscriber ends, the received optical UWB signals are radiated via an optical pulse triggered photonic transmitter (PT) to broadcast the UWB signals to the UWB-ready devices. In this system, modulation and complex electronic processing can be performed in the head-end office, while signals are radiated in the low-cost remote antenna units (RAUs). Due to the high atmospheric attenuation at high frequency bands, the cost-effective FTTA system can support a large number of RAUs to provide good wireless service coverage.

Previous UWB systems support bit rates of up to 1 Gb/s at a few meters range [3], and extended range of 30 m by using multiple-input multiple-output (MIMO) technique [4]. Here, we demonstrated a 1.5 Gb/s-2.5 Gb/s UWM-IR FTTA system with a high split-ratio of 1,024, over 300 m of optical fiber. The optical UWB-IR wireless link is operated in the W-band (75 GHz - 110 GHz) using our developed near-ballistic unitraveling-carrier photodiode (NBUTC-PD) [5] based PT and a mode-locked laser with a 10 GHz repetition rate. Our scheme can be operated at a much higher data rate and without the need of radio-frequency (RF) mixer for the signal down-conversion at the receiver (Rx) when compared with other optical UWB communication links [6, 7].

2. Experiment and device structure

Figs. 1(a) and (b) show the experimental setups to evaluate the FTTA systems. Fig. 1(a) shows the first scenario in which the optical UWB-IR signal is broadcast and distributed to multiple RAUs through optical fibers and passive fiber splitter. A 10 GHz optical pulse train was generated by a commercial fiber mode-locked laser (MLL) (*Calmar Laser, PSL-10-2T*). The pulse train was then encoded by 1.5 Gb/s non-return-to-zero (NRZ) data, pseudo-random binary sequence 2^{15}-1, via a Mach-Zehnder modulator (MZM) (optical modulation). The electrical NRZ data was produced by a bit-error-rate tester (BERT). There was no need of synchronization between the MLL and the BERT. Inset of Fig. 1(a) shows the autocorrelator trace of the optical pulse after amplified by an erbium-doped fiber amplifier (EDFA) (saturation power of 27 dBm, noise figure of 5 dB). The pulse width was 2.22 ps (full-width half-maximum (FWHM)) and this had the Fourier-transformed frequency component around 100 GHz, which was suitable for our designed NBUTC-PD and antenna operating at W-band (75 – 110 GHz).

The optical UWB-IR signal was distributed over 300 m of optical fiber (250 m of standard single mode fiber (SMF) and 50 m of dispersion compensating fiber (DCF)). The dispersion parameter of the SMF and DCF are 17 ps/nm/km and -100 ps/nm/km respectively. A variable optical attenuator (VOA) was used to emulate the achievable split ratio of the FTTA system. We measured that error-free BER operation can be achieved when the attenuator was > 30 dB, which corresponded to a split-ratio of 1,024. After the fiber transmission, the UWB-IR signal was launched into the NBUTC-PD via a lens fiber at the RAU, where the signal was radiated in the air via a W-band horn antenna. At the Rx side, another W-band horn antenna was used to receive the wireless signal. The received signal was amplified by a W-band low noise amplifier (LAN), and then envelope-detected by a fast W-band power detector. The data was analyzed and BER measurements were performed. This scenario could emulate the case of downstream wireless signal broadcast from the HE to 1,024 RAUs, where the UWB-IR signal are then transmitted wirelessly to different devices.

Fig. 1(b) shows another scenario of the optical wireless link. In this scenario, the optical pulse generated by the MLL was first distributed to the NBUTC-PD. The NBUTC-PD was directly modulated by a 2.5 Gb/s data (PRBS: 2^{15}-1) via a bias-tee (bias modulation). This could emulate the case for the upstream connection where each end-user has a low power 10 GHz optical source and transmits the upstream signal using direction modulation (bias modulation) of the NBUTC-PD in their end-user devices.

The photograph of the NBUTC-PD based PT is shown in the inset of Fig. 1(a). The NBUTC-PD has an active area of 144 μm^2 connecting to a planar quasi-yagi antenna. Bond pads are used for flip-chip bonding process on a 100 μm thick aluminum-nitride (AlN) substrate for good thermal conduction. The optical signal is launched onto the active area of the NBUTC-PD via a lens fiber vertically. A W-band horn antenna is attached directly to the quasi-yagi antenna. A RF probe is used to bias and drive the PT in the case of direct modulation. In previous measurement under continuous wave (CW) operation [8], our developed NBUTC-PD can work efficiently with a maximum saturation current of about 30 mA. However, the average saturation current will decrease under optical pulse launching (experiment reported here, in which the NBUTC-PD is excited by UWB-IR signal). This is due the higher peak optical power will produce the space-charge screening effect and reduce the average saturation current. In the measured as shown in next section, the average saturation current is about 8 mA.

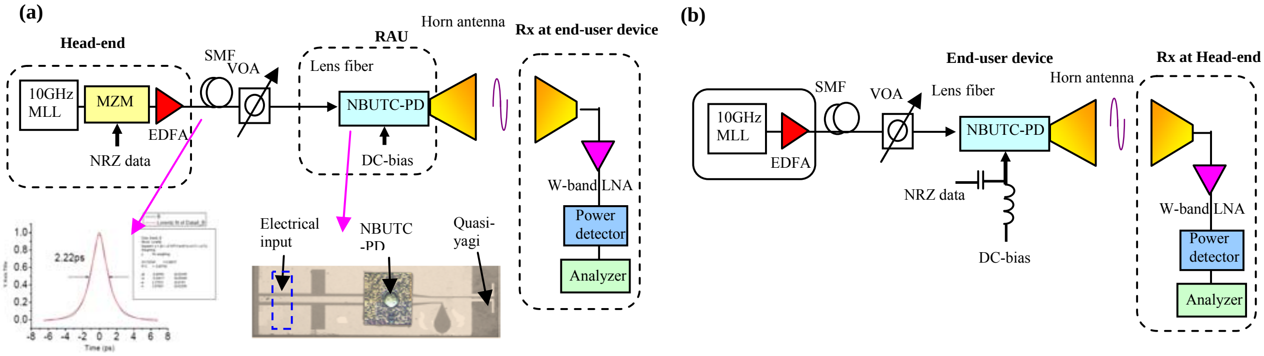

Fig. 1. Experimental setup of the UWB-IR FTTA system using (a) optical modulation and (b) bias modulation. MLL: mode-locked laser, MZM: Mach-Zehnder modulator, SMF: single mode fiber, EDFA: erbium doped fiber amplifier, VOA: variable optical attenuator. Insets: Autocorrelator trace of the optical pulse after amplified by an EDFA; and a photograph of our developed W-band NBUTC-PD used for the UWB-IR system.

3. Results and Discussion

First, we analyzed and characterized the operation frequency bands of the UWB-IR wireless signal emitted by the FTTA system using the NBUTC-PD, and the envelop-detected baseband signal at the Rx. The measured RF spectra at the Rx side in the FTTA system (using bias modulation) before and after the power detector are shown in our previous work [5]. We can observe a significant power envelop exists around 90-110 GHz. However, when the transmission distance increases (up to 250 m SMF), chromatic dispersion broadens the optical pulse-width and the photo-generated UWB power envelope at 90-110 GHz disappears. Hence 50 m DCF was used to dispersion compensate the fiber transmission link. Figs. 2(a), (b), and (c), shows the optical pulse-shape measured at back-to-back (BTB), 250 m SMF, and 250 m SMF together with 50 m DCF respectively. The measurement was performed by using a 50 GHz photodiode module (*Anritsu, MN4765A*) and a 50 GHz sampling scope. The system limited time resolution is around 12 ps. As can be observed in Fig. 2(b), after 250 m SMF fiber transmission, the FWHM pulse-width broadened from less than 12 ps (system limited) to over 15 ps. By using dispersion compensation, as shown in Fig. 2(c), the pulse-width is compressed to around system-limited time resolution as in the case of BTB.

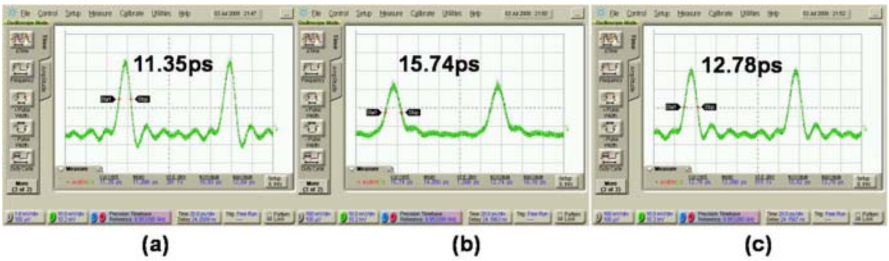

Fig. 2. The measured optical pulse by using 50 GHz photodiode at (a) BTB, (b) 250 m SMF, and (c) 250 m SMF and 50 m DCF.

Figs. 3(a) and (b) show the measured 1.5 Gb/s eye-diagrams of optical modulation (as shown in Fig. 1(a)) at BTB and 250 m SMF with 50 m DCF transmission, respectively. The antenna-to-antenna distance is fixed at around 20 cm. The clear eye-opening definitely indicates that DCF can significantly enhance the coverage of our demonstrated

FTTA network. Fig. 3(c) and (d) shows the measured 1.5 Gb/s eye-diagrams after > 30 dB attenuation of optical power with transmission of 250 m SMF and 50 m DCF by using optical modulation (Fig.1(a)) and bias modulation (Fig. 1(b)) respectively. The antenna-to-antenna transmission distance was 20 cm. We can clearly see that even under 1,024 split-ratio (>30dB attenuation), both modulation schemes can support clear eye-opening at 1.5 Gb/s.

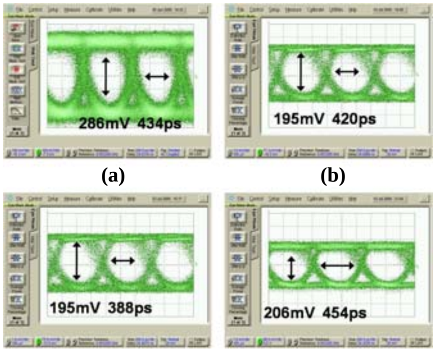

Fig. 3. Measured 1.5 Gb/s eye-diagrams at (a) BTB and optical modulation, (b) 250 m SMF + 50m DCF and optical modulation, (c) 250 m SMF + 50m DCF with 1,024 split-ratio and optical modulation and (d) 250 m SMF + 50m DCF with 1,024 split-ratio and bias modulation. The antenna-to-antenna transmission distance in (a) to (d) is the same as 20 cm.

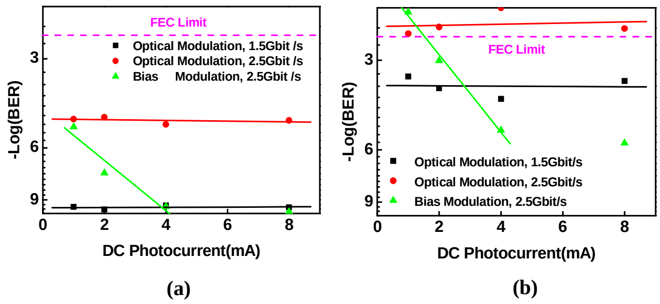

Fig. 4. Measured 1.5 or 2.5 Gb/s BER vs. photocurrent at the Rx by using optical modulation and bias modulation at antenna-to-antenna wireless transmission distances of (a) 20 cm and (b) 160 cm.

Finally, we evaluated the BER performance of the wireless transmission link of our UWB-IR FTTA system with different antenna-to-antenna wireless transmission distances. Figs. 4(a) and (b) shows the BER measurements of the UWB-IR FTTA systems (250 m SMF + 50 m DCF with 1,024 split-ratio) detected at the Rx by using optical modulation (Fig. 1(a)) and bias modulation (Fig. 1(b)) at antenna-to-antenna wireless transmission distances 20 cm and 160 cm respectively. From Fig. 4(a), we can observe that error-free transmission (BER < 10^{-9}) can be achieved at 2.5 Gb/s bias modulation and 1.5 Gb/s optical modulation. In Fig. 4(b), by increasing the photocurrent of device, 2.5 Gb/s bias modulation can be achieved at the BER below the forward-error-correction (FEC) level [9]. However, under such wireless transmission distance (160 cm), the measured 1.5 Gb/s and 2.5 Gb/s BER under optical modulation cannot be improved by increasing the photocurrent. This is due to the fact that the transmitted optical UWB-IR data, which occupies a large optical spectrum (1530nm to 1560nm), suffers significantly from the amplified spontaneous emission (ASE) noise by the EDFA during the fiber transmission. Hence, this produces a poorer signal quality when launched into the NBUTC-PD when compared with the case of bias modulation.

It is also worth to mention that in the wireless link, we are using the NRZ on-off keying (OOK) modulation. Due to the simple circuitry in the NRZ-OOK signal generation and detection, and lower power consumption of non-coherent detection at the Rx (can be envelop-detected), NRZ-OOK signal is also considered as one of the promising modulation formats for short range wireless applications. In the proposed scheme, local oscillators at the transmitter (Tx) and Rx are not required, and this means that the phase noise of local oscillator has no effect on the signal generation and detection performances. This can further reduce the cost of the RAU and Rx.

4. Conclusion

We have experimentally demonstrated an optical UWB–IR FTTA system for in-building applications using our developed NBUTC-PD based PT and a 10 GHz mode-locked laser. The UWB-IR wireless link was operated in the W-band (75 GHz to 110 GHz), having a peak RF power at about 100 GHz. Two scenarios of the FTTA system were evaluated, emulating the downstream and upstream FTTA systems. 2.5 Gb/s and 1.5 Gb/s UWB-IR FTTA systems having a high split-ratio of 1,024 and transmission over 300 m optical fiber were demonstrated using direct PT modulation and external optical modulation respectively.

5. References

[1] A. Chowdhury, et al, "Advanced system technologies and field demonstration for in-building optical-wireless network with integrated broadband services," J. Lightw. Technol., **27**, 1920, 2009.
[2] R. Llorente, et al, "Ultra-wideband radio signals distribution in FTTH networks," IEEE Photon. Technol. Lett., **20**, 945, 2008.
[3] T. Lunttila, et al, "Advanced coding schemes for a multi-band OFDM ultrawideband system towards 1 Gbps," in Proc. CCNC'06, Las Vegas, NV, 2006, 1, 553–557.
[4] Q. Zou, et al, "Performance analysis of multiband OFDM UWB communications with application to range improvement," IEEE Trans. Veh. Technol., **56**, 3864, 2007.
[5] F.-M. Kuo, et al, "Photonic Impulse-Radio Wireless 2.5Gbit/sec Data Transmission at W-Band Using Near-Ballistic Uni-Traveling-Carrier Photodiode (NBUTC-PD) Based Photonic Transmitter," IEEE Photonics Society Meeting, Paper ThW4, Belek-Antalya, Turkey, Oct., 2009.
[6] T. -A. Liu, et al, "Wireless audio and burst communication link with directly modulated THz photoconductive antenna," OE **13**, 10416, 2005.
[7] H. Togo, et al, "Gigabit impulse radio link using photonic signal-generation techniques," European Microwave Conference 2005, 1, 4-7.
[8] Y.-S. Wu, et al, "Dynamic Analysis of High-Power and High-Speed Near-Ballistic Unitraveling Carrier Photodiodes at W-Band," IEEE Photon. Technol. Lett., vol. 20, pp. 1160-1162, 2008.
[9] J. Cartledge, et al. "Electronic Signal Processing for Fiber-Optic Communication," IEEE LEOS NEWSLETTER, vol. 23, pp. 11, 2009.