Experimental Characterization of Extremely Broadband THz Impulse Radio Communication Systems

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Abstract— **We experimentally characterize a ultrabroadband terahertz (THz) impulse radio system with up to 10 GHz repetition rate. THz generation and radiation are realized in an antenna-integrated uni-traveling-carrier photodiode (UTC-PD), and THz reception is implemented based on photoconductive sampling by using a photoconductive antenna (PCA). We analyze the performance in terms of bandwidth and the features of the THz pulses. A 15 dB bandwidth of 1 THz confirms that this THz impulse system has a great potential of supporting ultrafast data rates, eventually for Terabit wireless communication era.**

I. INTRODUCTION

With the emerging of numerous modern applications and development of signal processing and transmission, there is an increasing interest in exploring ultrahigh capacity wireless communications. Actually, wireless data rates have doubled every eighteen months over the last three decades, and are quickly approaching to 100 Gbit/s [1], particularly driven by an increasing demand for much higher speed wireless communication anywhere, anytime. To support such fast wireless data dates at and above 100 Gbit/s, the radiation spectrum naturally falls into the THz (0.1-10 THz) range. So far a lot of efforts have been invested to develop high speed wireless communication systems, and most of them are operating in the millimeter-wave or sub-THz frequency region. For instance, 40 Gbit/s [2] and 50 Gbit/s [3] per channel wireless transmission in the W-band (75-110 GHz), 25 Gbit/s data transmission in 220 GHz band [4] and 24 Gbit/s data transmission in 300 GHz band [5] have been reported based on narrow band carrier modulation. Up to date, the fastest 100 Gbit/s data rates per wireless channel were demonstrated and realized by applying advanced modulation formats and signal processing techniques to improve the spectrum efficiency with carrier frequencies of 100 GHz [6] and 237.5 GHz [7], respectively. However, these narrowband frequency windows (< 100 GHz bandwidth) limit the highest achievable data rate according to Shannon's channel capacity theorem.

Alternatively, pulsed THz systems have been widely studied and used for THz spectroscopy. A conventional THz spectroscopic system employing photoconductive antennas (PCAs) for both THz emitter and receiver features an extremely broad bandwidth of a few THz, while typically operating at a low pulse repetition rate of 100 MHz [8]. Recently, such pulsed THz systems have attracted more research interests in developing high speed THz wireless communication because of its huge bandwidth [9]. So far, main efforts are however still focusing on analyzing THz propagation channel property [10] and shaping THz pulse [11] in a traditional THz spectroscopy system, due to the challenges associated with generation and detection of high repetition rate pulses.

In this paper, we characterize a 10 GHz repetition rate pulsed THz wireless communication system by combining an UTC-PD as THz emitter and a PCA based THz receiver. To our knowledge, this is the first time that a THz impulse radio system at such a high rate is experimentally implemented.

II. EXPERIMENTAL RESULTS

The experimental setup of our pulsed THz wireless communication system is shown in Fig. 1. In the system, 10 GHz optical pulses with 1.5 ps pulse width are first compressed in 200 m highly nonlinear fiber (HNLF) and dispersion-compensated in single mode fiber (SMF), in order to generate femtosecond (fs) optical pulses. The generated femtosecond pulses are then spitted into two paths for THz generation at a UTC-PD and coherent detection at a PCA. In the generation arm, a polarizer is used to maximize THz generation efficiency since the UTC-PD is polarization dependent, and a piece of dispersion compensation fiber (DCF) is used to compensate the link dispersion before illuminating the UTC-PD. Within the THz propagation channel, a pair of polymer THz lens is used to collimate THz radiation from the emitter antenna and focus THz signals into the PCA chip.

In the detection arm, in order to fulfill peak power requirement at the PCA (typically tens of mW average power for 100 MHz 100 fs pulses), the generated 10 GHz femtosecond pulses are down-sampled to 100 MHz by gating one of them every 100 pulses. The gating process is realized by modulating a programmed pattern at an intensity modulator, and the pattern generator is externally synchronized with the laser. The down-sampled 100 MHz optical pulses are then sent to the PCA. A delay line in the detection arm is used for scanning the THz pulses. The photocurrent in the PCA is first amplified by using a 40 kHz transimpendance amplifier with gain of 10^8 V/A, and then processed by a lock-in amplifier synchronized with an optical chopper.

The recorded THz train is presented in Fig.2 (a) when optical illumination power to the UTC-PD and the PCA are 10 dBm and 13 dBm, respectively. 100 ps time interval between two adjacent pulses confirms the success of generating and detecting THz signals at 10 GHz repetition

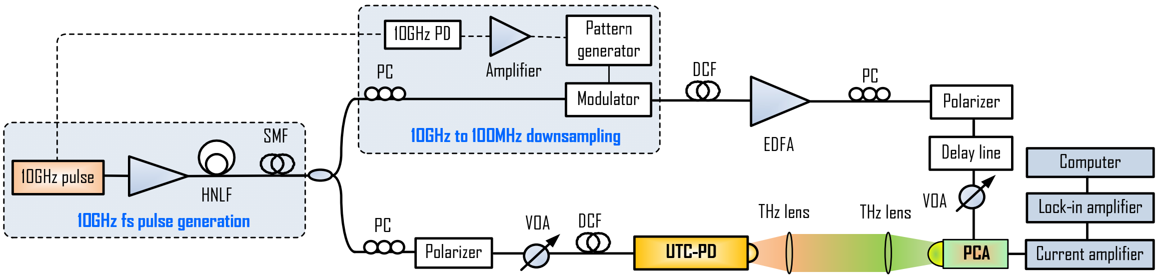

Fig.1. Experimental setup of 10 GHz pulsed THz wireless communication system. HNLF: highly nonlinear fiber, SMF: single mode fiber, PC: polarization controller, EDFA: Erbium-doped fiber amplifier, DCF: dispersion compensation fiber, VOA: variable optical attenuator, PD, photodiode.

rate. Looking at the details of a THz pulse enlarged in Fig. 2(b), we can observe that a THz pulse entirely lasts around 20 ps, while the width of monocycle-like swing is only 7 ps. In principle, when the UTC-PD is illuminated by a Gaussian pulse and the bow-tie antenna within the UTC-PD radiates a THz pulse, the THz field is the first-derivative of a Gaussian profile, namely monocycle. Broadening a THz pulse with a long time oscillation here is because this measurement combines frequency responses of both the UTC-PD and PCA. Although the photo-response of a PCA with defects is governed by its ultrafast trapping time (can be as low as 0.1ps), its long relaxation time (more than 100 ps) also contributes to this measurement at a system level. Besides that, we can also observe some echoes in Fig.2 (b), which degrades the signal-to-noise ratio. This is caused by the reflection between the Silicon lens and GaAs chip of the PCA. By applying Fourier transformation to the time traces, the THz frequency spectra are shown in Fig.2(c), with a 15 dB bandwidth of 1 THz. Such an extremely broadband system can apparently support ultrahigh speed wireless communication. Frequency attenuation in the 0.1 THz region in Fig.2(c) is mainly caused by the PCA cutoff frequency defined by the output aperture of PCA waveguides [12].

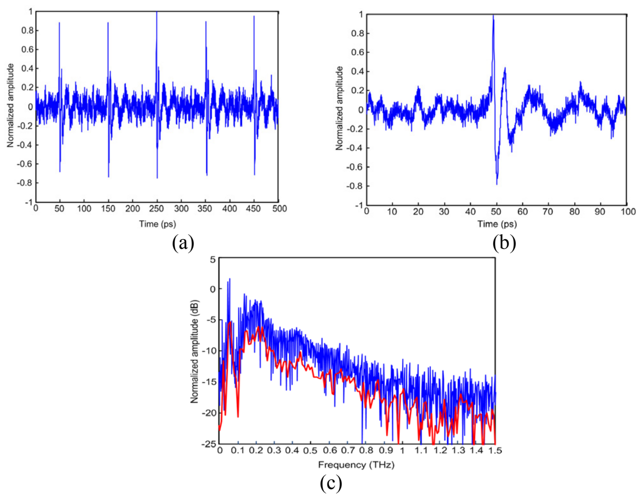

Fig. 2 (a) Received THz pulses train at a repetition rate of 10 GHz. (b) enlarged waveform of single THz pulse. (c) Fourier transformation of single THz pulse and 10 GHz THz pulse train.

III. Summary

An extremely broadband THz impulse radio system with up to 10 GHz pulse rate is successfully demonstrated. In the system, we use an UTC-PD for generating THz signals and a PCA for photoconductive sampling of THz signals. Pulse operation of 10 GHz repetition rate is well beyond conventional THz pulsed spectroscopic systems. The pulsed system with an extremely broad bandwidth of 1 THz at 15 dB can definitely be capable of carrying very high data rate, and hence has great potential for next generation ultrafast wireless communication.

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References

[1]. J. Federici and L. Moeller, Review of terahertz and subterahertz wireless communications, *J. Appl. Phys*., vol. 107, pp. 111101, June 2010.
[2]. A. Kanno, et al, 40 Gb/s W-band (75–110 GHz) 16-QAM radio-over-fiber signal generation and its wireless transmission, *Opt. Express*, vol. 19, B56-B63, 2011.
[3]. X. Pang, et al, 100 Gbit/s hybrid optical fiber-wireless link in the W-band (75–110 GHz), *Opt. Express*, vol.19, pp. 22944-22949, 2011.
[4]. A. Kallfass, et al, All active MMIC-based wireless communication at 220 GHz, *IEEE Trans. Microw. Theory Techn.*, vol. 1, no. 2, pp. 477-487, Nov. 2011.
[5]. C. Jastrow, et al, 300 GHz transmission system, *Electron. Lett*. vol. 44, no. 3, pp. 213-214, 2008.
[6]. X. Li, J. Yu, et al, A 400G optical wireless integration delivery system, *Opt. Express*, vol.21, pp.18812-18819, 2013.
[7]. D. L.-Diaz, et al, Wireless sub-THz communication system with high data rate, *Nature Photon*., vol. 7, pp. 977-981, Dec. 2013.
[8]. P. U. Jepsen, et al, Generation and detection of terahertz pulses from biased semiconductor antennas, *J. Opt. Soc. Am. B*, vol.13, pp. 2424-2436, 1996.
[9]. X. Yu, et al, The prospects of ultrabroadband THz wireless communications, *ICTON 2014*, paper Th.A3.3.
[10]. Y. Yang, et al, Understanding THz pulse transmission in the atmosphere, *IEEE Trans. THz Sci. Technol.*, vol.2, pp. 406–415, 2012.
[11]. J. Palací, A. Bockelt, B. Vidal, Terahertz radiation shaping based on optical spectrum modulation in the time domain, *Opt. Express*, vol. 20, pp. 23117-23125, 2012.
[12]. M C Schaafsma, et al, Enhanced terahertz extinction of single plasmonic antennas with conically tapered waveguides, *New J. Phys., vol.* 15, 015006, 2013.