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THz Photonics-Wireless Transmission of 160 Gbit/s Bitrate

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Abstract: *We present a record bitrate wireless transmission in the THz band above 300 GHz by successfully demonstrating a 160 Gbit/s photonics wireless link operating in the 300-500 GHz band based on a single THz emitter.*

Keywords: *THz photonics, RF photonics, THz communications.*

I. INTRODUCTION

The demand of wireless data rates have grown explosively in the past decades, mobile data traffic is forecasted to increase 10-fold between 2014 and 2019 by Cisco, reaching 24.2 exabytes per month by 2019 [1]. To be capable of accommodating the ever increasing traffic in the access networks, wireless links in the future are highly desired to operate at a data rate of well beyond 100 Gbit/s, eventually up to Tbit/s. 100 Gbit/s Ethernet (100GbE) was already established in 2009, and indeed, optical fiber communication systems have been technically demonstrated with a capability of delivering several tens of Tbit/s. Therefore wireless links which are transparently, seamlessly compatible with the existing high capacity optical network infrastructure, will be beneficial and appreciated for last-mile wireless access. In addition to backhauling mobile data streams, ultrafast wireless communication technologies are also expected to significantly benefit many other bandwidth-hungry applications, such as wireless transmission of ultrahigh definition video, wireless transfer of large volume data, ultrafast intra/inter-chip data exchange, fast restoration of wired connections in disaster areas, and so on.

Recently, a lot of efforts have been contributed to develop photonics-aided high-speed wireless communication systems. 100 Gbit/s and beyond wireless connections have been achieved in the sub-THz band (200-300 GHz) [2][3] and in the W-band (75-110 GHz) incorporating optical polarization division multiplexing (PDM) [4] and spatial multiple-input-multiple-output (MIMO) techniques [5]. To move further, the THz band (300 GHz-10 THz) between the millimeter-wave and infrared radiation has been considered as the 'Next Frontier' to meet the eventual bitrate target of Tbit/s [6][7], due to its much larger frequency bandwidth comparing to the millimeter-wave band or sub-THz band, as well as less atmospheric disturbances compared to optical wireless links.

Up to date, significant progress on the development of THz photonics-wireless communication systems have been also achieved, for instance, tens of Gbit/s transmission have been enabled [9]-[13] by using ultra-broadband uni-travelling carrier photodiodes (UTC-PDs) [8] as photo-mixing emitters and Schottky diodes as electronic receivers. We have recently contributed to this development by demonstrating 60 Gbit/s Nyquist-QPSK wireless transmission at 400 GHz using a UTC-PD and a Schottky receiver [14], representing the highest reported bitrate in the frequency band above 300 GHz. However, the capacity potential of THz wireless systems has not been achieved yet. The use of free running lasers for heterodyne photo-mixing in the UTC-PD in the previous work [14] intrinsically leads to a THz beat-note with high phase noise, which seriously degrades the performance of spectrally efficient modulation formats requiring highly pure THz carriers.

In this paper, we significantly reduce the THz phase noise by creating a coherent optical frequency comb and compensating phase decorrelation of photo-mixing tones induced by the optical path difference. This scheme not only enables generation of high quality THz carriers, but also allows exploitation of large THz bandwidth in the 300-500 GHz band for communication, and up to 160 Gbit/s bitrate wireless transmission is successfully demonstrated. To the best of our knowledge, this is a new record in the THz band above 300 GHz, which pushes THz communication bitrate beyond 100 Gbit/s.

II. EXPERIMENTAL SETUP

The experimental configuration is shown in Fig. 1. We first optically create a frequency comb based on two concatenated phase modulators (PMs), both of which are driven by an amplified 25 GHz sinusoidal signal. An optical tunable delay line in-between is used to match the phase of the two-stage modulation, in order to improve the signal-to-noise ratio (SNR) of the optical tones in the comb used for the 300-500 GHz carrier generation. Subsequently, a programmable wavelength selective switch (WSS, Finisar 4000S) is employed to separate one optical comb line, to be used as an optical local oscillator (LO), from 8 other comb lines, to be used for optical baseband modulation. The LO line and the 8 data lines are 300-500 GHz apart, and the WSS additionally performs the equalization of the comb lines. The digital baseband data signal is generated from an arbitrary waveform generator (AWG) and modulated onto the lightwave at an in-phase (I) and quadrature (Q) modulator. In the experiment, we modulate a Nyquist quadrature phase shift keying (QPSK) PRBS 2^7-1 signal and perform Nyquist pulse shaping in the AWG by applying a square root raised cosine filter with 0.1 roll-off factor. The even-order and the odd-order channels after the IQ modulator are de-correlated by using a second WSS and a fiber delay line. With respect to the optical LO, we compensate the path by using a piece of matched fiber, since the path difference between the optical LO and the 8 data lines de-correlates their phases.

The LO and the 8 data lines are eventually directed on to the UTC-PD based THz photo-mixing emitter, generating 8 carrier frequencies centered around 400 GHz with 25 GHz spacing. The UTC-PD has an extremely fast photo-response and high responsivity (DC responsivity of 0.15 A/W here). Before launching into the UTC-PD, the optical signals are polarized to minimize the polarization dependency of the UTC-PD. In the free space path, a pair of THz lenses is used to collimate the THz beam, in order to reduce the free space propagation loss in a 50 cm line-of-sight (LOS) communication link. At the receiver side, a 12-order harmonic THz Schottky mixer operating in the frequency range of 300-500 GHz is used to down-convert the received THz signal into an intermediate frequency (IF) signal. The mixer is driven by a 31-36 GHz tunable electrical LO signal. The IF output is amplified by a chain of electrical amplifiers with 42 dB gain, and is finally demodulated and analyzed in a broadband real time sampling oscilloscope (63 GHz Keysight DSOZ634A Infiniium).

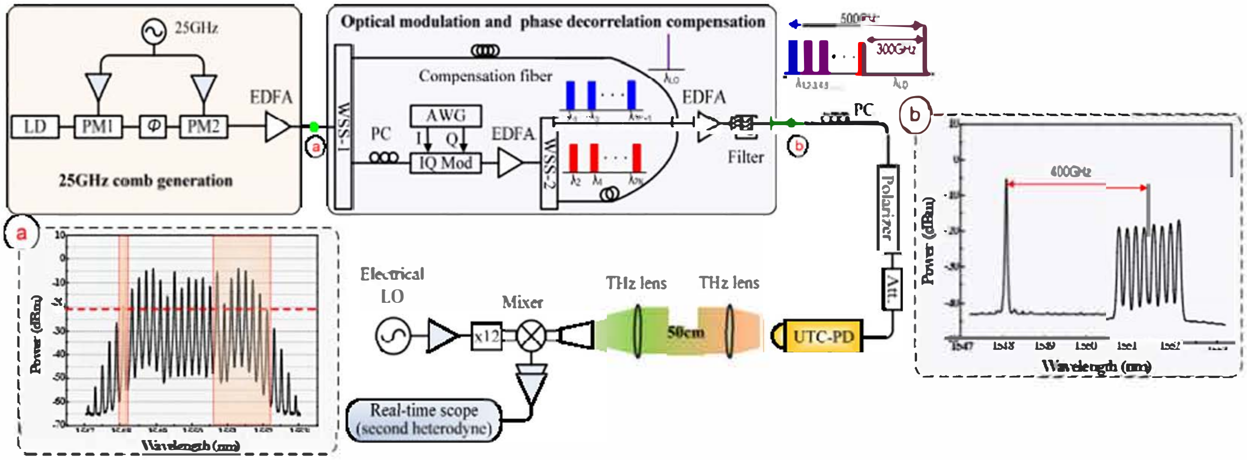


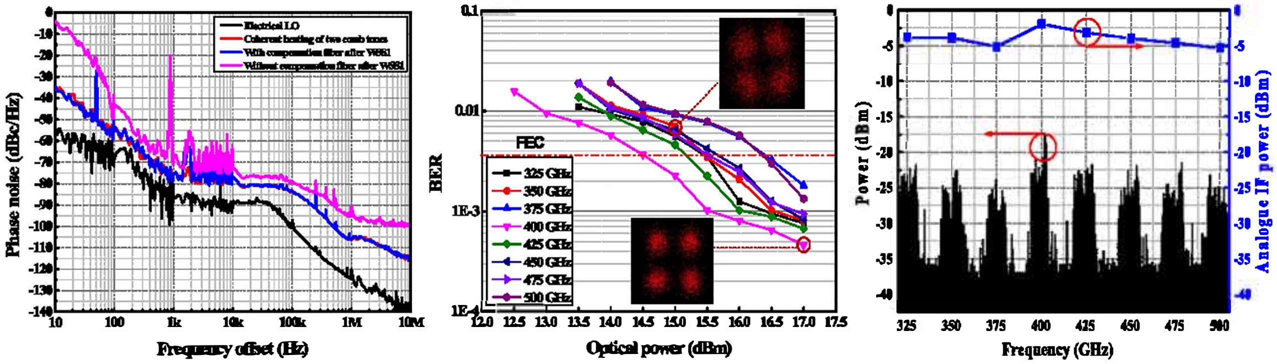
Fig. 1. Experimental configuration of the 300-500 GHz photonics-wireless communication link. PM: phase modulator, WSS: wavelength selectable switch, AWG: arbitrary waveform generator, LO: local oscillator, Att.: attenuator, UTC-PD: uni-travelling carrier photodiode. a) Generated optical frequency comb spectrum. b) WSS-prepared 8-channel centered 400 GHz with 25 GHz spacing before the UTC-PD.

III. EXPERIMENTAL RESULTS

The 25 GHz spaced optical frequency comb is shown in the inserted spectrum in Fig. 1(a). The comb extends beyond 5 nm and the desired optical tones (in shaded regions) for heterodyne generation of 300-500 GHz carriers present more than 40 dB carrier-to-noise ratio, which is mainly limited by the 25 GHz modulation index. The data modulated 8 channels are used with the LO to generate the THz signal around 400 GHz, as seen in Fig. 2(c). We measure the phase noise performance of the THz carriers after wireless propagation, as shown in Fig. 2(a). Compared to an electrical sinusoidal signal from a synthesizer, photo-mixing of two coherent tones directly from the comb generates a THz carrier (350 GHz in Fig.2(a)) with 10 dB higher phase noise at 10 kHz offset frequency. This is because the photo-mixing of the two phase-correlated harmonic tones, originating from the same laser, adds their individual phase noise. When the LO path after WSS1 is not compensated, the phase noise of the generated THz carrier is much worse due to phase de-correlation. When compensating the path difference with a piece of 49.5 m fiber, the same phase noise performance as for coherent beating can be achieved.

The combined optical spectrum before the UTC-PD is illustrated in Fig. 1(b). 8 tones from the 25 GHz comb occupy 200 GHz overall operation bandwidth. Photo-mixing of these 8 tones with the LO wavelength in the UTC-PD correspondingly generates the 8-channel 25 GHz spaced THz signals with a center frequency of around 400 GHz. The data modulation is 10 Gbaud Nyquist QPSK per channel, resulting in an aggregated bit rate of 160 Gbit/s. The baud rate is less than half of the channel spacing, for the sake of reducing interference from the neighbor channel in the down-conversion in the demonstration.

We measure bit error rate (BER) performance for all the 8 channels after 50 cm wireless transmission, as shown in Fig. 2(b). It can be seen that all channels have achieved a BER performance below the hard decision forward error correction limit (FEC, BER 3.8e-3 with 7% overhead). The BER performance is evaluated from the error-vector magnitude (EVM) of the processed constellations. For illustration purposes, two constellation diagrams corresponding to BER of 4e-4 and 7e-3 are also displayed. We observe that the BER performance of the 8 channels is approximately classified into 3 clusters: The 400 GHz channel is the best, the 375 GHz and 500 GHz channels are the worst, the 325-, 350-, 425- and 450 GHz channels are in-between, and the penalty between clusters is about 1 dB. This penalty can be explained by the unflat conversion loss of the Schottky mixer based receiver, as shown in Fig. 2(c). The receiver conversion loss fluctuates over the 300-500 GHz frequency range, 375 GHz and 500 GHz bands exhibit the largest conversion loss and 400 GHz lest, which comply well with the BER performance observation. Here the conversion loss is investigated by measuring the down-converted analogue IF power at 6 GHz without modulation and it is also reflected in the 8-channel electrical spectrum in Fig. 2(c).



(a) (b) (c)

Fig. 2. (a) phase noise performance comparison of generated 350 GHz carriers in different regimes, (b) measured BER performance after 50 cm wireless transmission for 8 channels in 300-500 GHz band, (c) 8-channel electrical spectrum and frequency dependent conversion loss of the receiver.

IV. CONCLUSIONS

We have experimentally demonstrated an ultrafast THz wireless link in the 300-500 GHz band by using a single UTC-PD. By significantly improving the purity of generated THz carriers, the record 160 Gbit/s bitrate above 300 GHz band has been successfully achieved. This achievement reveals the potential of THz communication links accommodating beyond 100 Gbit/s bitrates, for bringing high capacity in optical networks to ultrafast wireless access applications.

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REFERENCES

[1] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.pdf.
[2] S. Koenig, et al, "Wireless sub-THz communication system with high data rate," *Nature Photonics*, vol. 7, pp. 977-981, 2013.
[3] H. Shams, et al, "100 Gb/s multicarrier THz wireless transmission system with high frequency stability based on a gain-switched laser comb source," *IEEE Photonics J.*, vol. 7, no. 3, pp. 1-11, 2015.
[4] X. Pang, et al, "100Gbps hybrid optical fiber-wireless link in the W-band (75-110 GHz)", *Optics Express,* vol. 19, pp. 24944-24949, 2011.
[5] X. Li, et al, "A 400G optical wireless integration delivery system," *Optics Express*, vol. 21, no. 16, pp. 18812-18819, 2013.
[6] I. F. Akyildiz, et al, "Terahertz band: next frontier for wireless communications," *J. Physical Communication*, vol.12, pp. 16-32, 2014.
[7] X. Yu, et al, "The prospects of ultra-broadband THz wireless communications," *2014 International Conference on Transparent Optical Networks (ICTON) 2014*, Paper Th.A3.3.
[8] T. Ishibashi, et al., "Uni-traveling-carrier photodiodes for terahertz applications," *IEEE J. Select. Topics in Quantum Electron.*, vol. 20, no. 6, pp. 79-88, 2014.
[9] H.-J. Song, et al, "24Gbps data transmission in 300GHz band for future thz communications," *Electron. Lett.*, vol. 48, pp. 953-954, 2012.
[10] T. Nagatsuma, et al, "Terahertz wireless communications based on photonics technologies," *Optics Express,* vol. 21, no. 20, pp. 23736-23747, 2013.
[11] T. Nagatsuma, et al, "Enabling technologies for real-time 50Gbit/s wireless transmission at 300GHz," *2015 ACM NANOCOM,* Boston.
[12] G. Ducournau, et al, "Ultrawide-bandwidth single-channel 0.4-THz wireless link combining broadband quasi-optic photomixer and coherent detection," *IEEE Transactions on THz Science and Technology,* vol. 4, pp. 328-337, 2014.
[13] G. Ducournau, et al, "32Gbps QPSK transmission at 385GHz using coherent fibre-optic technologies and THz double heterodyne detection," *Electronics Letters*, vol. 51, no. 12, pp. 915-917, 2015.
[14] X. Yu, R. Asif, M. Piels, D. Zibar, M. Galili, T. Morioka, P. U. Jepsen, L. K. Oxenløwe, "60Gbit/s 400GHz Wireless Transmission," *Photonics in Switching 2015*, Postdeadline paper PDP1, 2015.