Demonstration of Real-time 125.516 Gbit/s Transparent Fiber-THz-Fiber Link Transmission at 360 GHz ~ 430 GHz based on Photonic Down-Conversion

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Abstract: The first real-time transparent fiber-THz-fiber 2 × 2 MIMO transmission system with a record line rate of 125.516 Gbit/s and net data rate of 103.125 Gbit/s is demonstrated at 360 GHz-430GHz based on photonic down-conversion.
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1. Introduction

The Terahertz-band (THz-band, 0.1THz to 10THz) are attracting extensive attention in the interdisciplinary fields of electronics and photonics, which can provide hundreds of Gbit/s or even Tbit/s data capacity due to its huge available bandwidth [1]. The fiber-THz wireless-fiber transmission system integrates large-capacity long-distance advantages of fiber-optics transmission link and THz wireless transmission link, and therefore it has the great potential for future 6G communications [2]. Recent years, high-speed mm-wave and THz-wave signal generation, modulation, and detection enabled by integrated photonics technology effectively promote the seamless integration of wireless and fiber-optic networks. A series of >100 Gbti/s fiber-wireless integration transmission have been experimentally demonstrated at Q-, V, W-, or D-band based on offline digital signal processing (DSP) [3-6]. The transparent Optical-THz-Optical link providing line-rates up to 240 and 190 Gbit/s over distances from 5 to 115m at 230GHz is demonstrated using a plasmonic modulator with a low noise built-in amplification [7]. The transparent fiber-radio-fiber bridge at 101 GHz is demonstrated using optical modulator and direct photonic down-conversion [8]. These research works are based on off-line DSP. The real-time transmission of a 34-GBd PDM-QPSK signal over two fiber links by an electronic THz wireless link at 300 GHz has been demonstrated [9]. However, the >100 Gbti/s real-time fiber-THz-fiber link transmission beyond 350 GHz based on photonics has not yet been reported.

In this paper, we propose and experimentally demonstrate a real-time photonics-aided transparent fiber-THz-fiber link 2 × 2 MIMO transmission system based on photonic down-conversion at 360GHz~430 GHz. The 31.379 GBaud (125.516 Gbit/s) DP-QPSK signal providing 103.125 Gbit/s net capacity is successfully transmitted over two spans of 20 km SSMF and 1 m wireless distance under 15% soft-decision forward-error-correction (SD-FEC) for pre-FEC BER threshold of 1.56×10^{-2}. To the best of our knowledge, this is the first time to realize >100 Gbti/s real-time transparent fiber-THz-fiber link transmission.

2. Experimental setup

Figure.1 gives the experimental setup of our real-time transparent fiber-THz-fiber link transmission 2 × 2 MIMO system over two spans of 20 km SSMF and 1 m wireless distance based on photonic down-conversion. The optical baseband signals are processed by two commercial real-time digital coherent CFP2 modules. These modules are based on DP-QPSK modulation, polarization diversity intradyne detection and advanced electronic link equalization. Its photo is given by Fig. 1(a). In our experiment, the 31.379 GBaud DP-QPSK modulated optical baseband signal at 15% SD-FEC limit with a PRBS length of 2^{31} is generated by setting the module through network management system (NMS). The optical signal carrier frequency is 193.5 THz, and the optical power is 3 dBm. Then, the optical baseband modulation signal is delivered over one span of 20 km SSMF with 17-ps/km/nm chromatic dispersion (CD) at 1550nm. At the fiber-THz wireless-fiber end, an EDFA is used to compensate for the fiber transmission loss, and a pass-band tunable optical filter (TOF) is utilized to suppress the out-of-band amplified spontaneous emission (ASE) noise. ECL-1 is used as an LO and free-running with <100-kHz linewidth. In our demonstrated system, we utilize photonic remote heterodyning to generate THz-wave wireless signal, located within the frequency range from 360 GHz to 430 GHz. The optical signal with 9 dBm optical power and ECL-1 with 12 dBm optical power are combined by an OC and then amplified by an EDFA to drive antenna-integrated photomixer modules (AIPMs). Fig. 2(i) gives the 370 GHz optical spectrum. The PBS-1 can separate the X- and Y-polarization components of the combined lightwaves. Two parallel AIPMs, each with a typical output power of -28 dBm and an operating frequency range from 300 GHz to 2500 GHz, up-convert X- and Y-polarization baseband signals to two THz-wave wireless signals. The AIPMs used in our experiment is polarization sensitive, and hence we use four PCs to adjust the polarization direction to get the maximal output from each AIPMs. The photo of fiber-THz wireless end is given by Fig. 1(b).

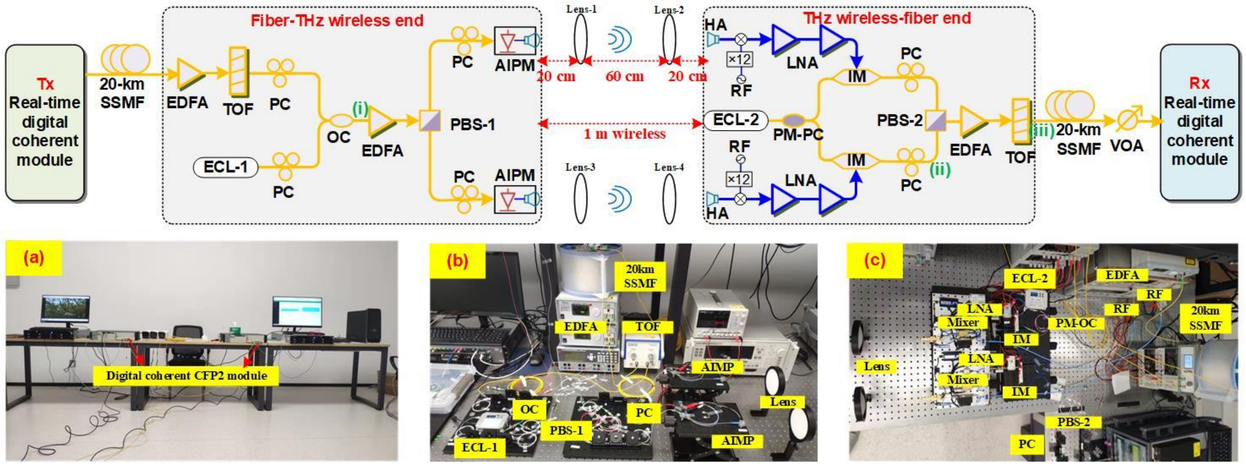

Fig.1. Experimental setup of real-time transparent fiber-THz-fiber link transmission system. Photos of: (a) Digital coherent transceiver module; (b) Fiber-THz wireless end; (c)THz wireless-fiber end.

Then, the THz-wave signals are delivered over a 1m 2 × 2 MIMO wireless THz-wave transmission link. Two pairs of lens are used to focus the THz-wave wireless signal to maximize the received wireless power. Lens 1-4 are identical, and each of them has 10-cm diameter and 20-cm focal length. At the THz wireless-fiber end, THz-wave wireless signals are received with two parallel 26-dBi HAs. For X and Y-polarization signal, two identical THz mixer/amplifier/multiplier chains are used, each integrating a mixer, an amplifier, and a ×12 frequency multiplier, operating within 330GHz to 500GHz. Then, the down-converted X- and Y-polarization intermediate-frequency (IF) signals at 24GHz is boosted by two cascaded electrical amplifiers with 3-dB bandwidth of 47 GHz to drive Intensity-modulators (IMs). ECL-2 is split by a polarization-maintaining OC (PM-OC) into two branches as the optical carrier input of the two IMs. Each IM is DC-biased at the optical-carrier-suppression (OCS) point with 3-dB bandwidth of 40 GHz. Fig. 2(ii) shows the spectrum after IM. X- and Y-polarization are combined by a PBS-2 and then boosted by an EDFA. Another TOF is used to suppress the upper sideband and the central optical carrier as well as the ASE noise, only leaving DP-QPSK modulated lower sideband. Fig. 2(iii) gives the spectrum after IM. Then, the optical baseband signal is delivered over the second span of 20 km SSMF, and then received by the commercial real-time digital coherent CFP2 module. A variable optical attenuator (VOA) is used to measure OSNR of the receiver module. The photo of THz wireless-fiber end is given by Fig. 1(c).

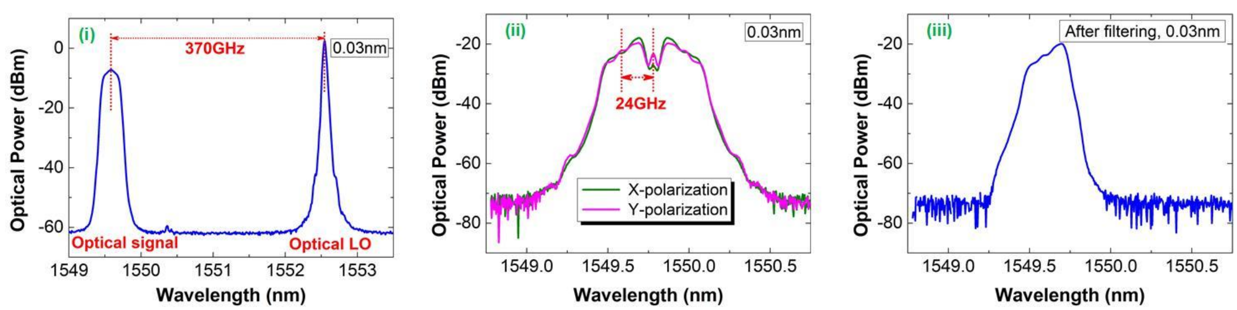

Fig. 2. Measured optical spectrum at 0.03-nm resolution after: (a) Optical coupler; (b) Intensity-modulator; (c) Tunable optical filter.

3. Results and discussion

We first measure the performance of our real-time transparent fiber-THz-fiber link transmission system at back-to-back (BtB) case, i.e., without fiber and wireless distance transmission. The optical signal carrier frequency is constant. We adjust the center wavelength of ECL-1 to generate THz-wave wireless signals within the frequency range varying from 360 GHz to 430 GHz. Fig. 3(a) shows the measured optical spectrum for 360GHz~430GHz at 0.03-nm resolution. Fig. 3 (b) gives the measured BER versus the ECL-2 to optical signal frequency spacing at 370 GHz with 10.5 dBm input power into each AIPM at BtB case. We can find that there is 5 GHz frequency drift at the

BER of 1×10^{-4}. When the frequency spacing between optical signal and ECL-2 is 24 GHz, the transmission system has the best BER performance. Fig. 3(c) shows the BER versus input power into each AIPM within 360 GHz to 430 GHz at BtB case without fiber and wireless transmission. THz-wave carrier frequency within 360 GHz to 430 GHz at BtB case can be successfully real-time transmitted. The best BER performance is at 370 GHz and 380 GHz. This digital coherent CFP2 module can support 15% SD-FEC for pre-FEC BER threshold of 1.56×10^{-2}. Therefore, 31.379 GBaud (125.516 Gbit/s) DP-QPSK signal can provide 103.125 Gbit/s net capacity for 100GbE client.

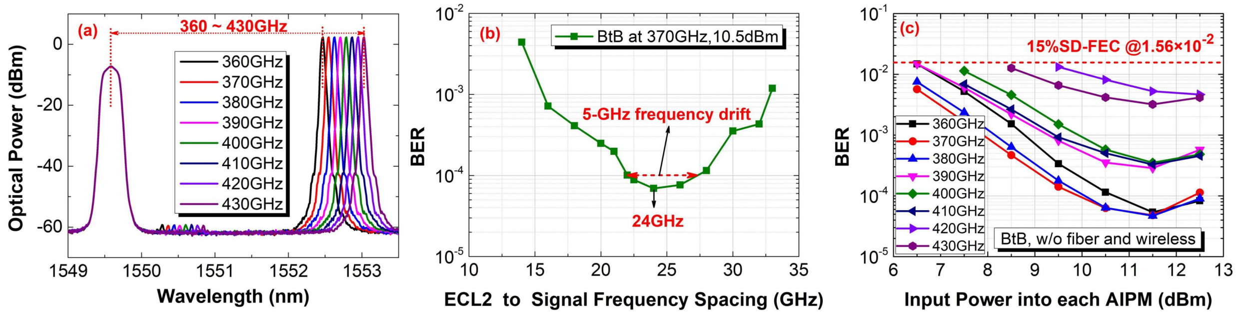

Fig. 3. (a) Measured optical spectrum for 360GHz~430GHz; (b) BER versus ECL-2 to signal frequency spacing; (c) BER versus input power into each AIPM at BtB case without fiber and wireless transmission.

Fig. 4(a) gives the BER versus input power into each AIPM over two spans of 20 km SSMF and 1 m wireless distance. THz-wave carrier frequency within 360 GHz to 390 GHz can be successfully real-time transmitted at 15% SD-FEC threshold. The best BER performance is at 370 GHz. Finally, we evaluate the OSNR of module versus THz-wave carrier frequency at different case. The OSNR budget at 370 GHz for BtB case and fiber & wireless case is 5.3 and 1.7, respectively, as shown in Fig. 4(b). Fig. 4(c) shows the photo of 1m wireless link.

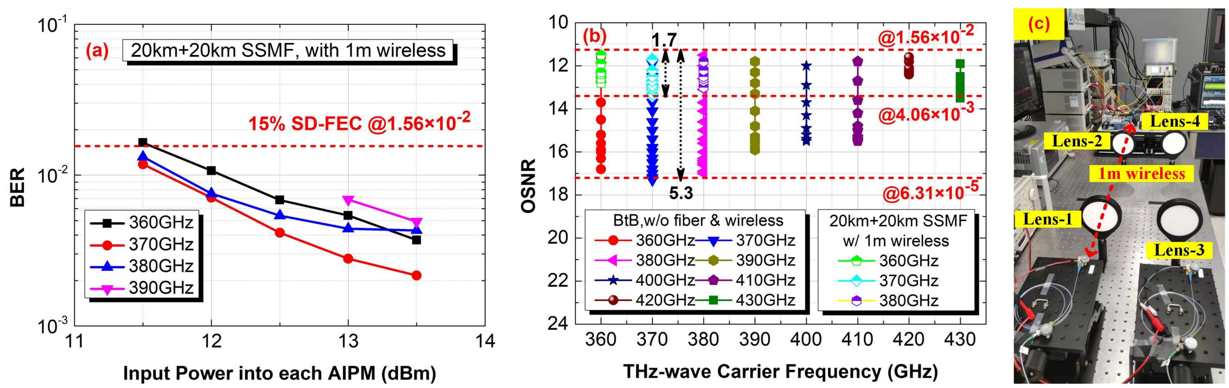

Fig. 4. (a) BER versus input power into each AIPM with fiber and wireless transmission; (b)OSNR versus THz-wave carrier frequency at different case; (c) Photo of 1m wireless link.

4. Conclusions

To the best of our knowledge, we have experimentally demonstrated the first real-time 103.125 Gbit/s net capacity transparent fiber-THz-fiber link transmission system based on photonic down-conversion within 360GHz~430 GHz over two spans of 20 km SSMF and 1 m wireless distance under 15% SD-FEC. It is the first time to realize >100 Gbit/s real-time transparent fiber-THz-fiber link transmission. This system is promising for transparent fiber-THz-fiber link transmission system in back- and front-haul links of B5G and 6G. *This work was partially supported by National Natural Science Foundation of China (62101121, 62101126).*

5. References

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