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Broadband photon-assisted terahertz communication and sensing

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Abstract *We review our recent advance in terahertz communication and sensing. Based on photonics-aided scheme, wireless transmission of ~100Gb/s THz signal over hundreds of meters has been demonstrated. A communication capacity of 38.1Gbit/s and a radar range resolution of 1.58cm are simultaneously achieved in the terahertz band. ©2022 The Author(s)*

Introduction

The Terahertz-band (THz-band, i.e., 0.3THz to 10THz) are attracting extensive attention in interdisciplinary fields of electronics and photonics, which can offer hundreds of Gbps or even Tbps data capacity due to its huge available bandwidth. Photonics-aided THz technique can break the bottleneck of electronic devices and facilitates seamless integration with high-speed optical fiber access networks, which is expected to become an extremely promising application prospect for future 6G communication. The reported research on >100Gbps THz wireless transmission is summarized in detail in table 1 [1-6]. Photonics technology has exhibited great potential in the integration of sensing and communication system [9-18]. The reported research on photon-assisted integrated sensing and communication is summarized in detail in table 2. The integration of sensing and communication system in the THz frequency band is rarely reported.

In this paper, we summarized our recent research results in long distance and broadband real time THz communication [2,6,7,19-27] as well as THz sensing [13,14,17,18]. We demonstrate 124.8\56\32Gbit/s line rate photonics-aided THz signal wireless delivery over 104\200\400m distance [6]. We also show a real-time transparent fiber-THz-fiber 2×2 MIMO

Tab. 1: Reported research on >100 Gbps THz wireless transmission

Year	Carrier frequency (GHz)	Date rate (Gbps)	Distance (m)	Reference
2019	300	100	0.5	[1]
2019	**450**	**103.9**	**1.8**	**[2]**
2019	408	131	10.7	[3]
2020	350	106.2	26.8	[4]
2020	300	115	110	[5]
2022	**339**	**124.8**	**104**	**[6]**

Tab. 1: Reported research on photon-assisted integrated sensing and communication

Year	Carrier frequency (GHz)	Date rate (bps)	Range resolution for radar (cm)	Reference
2019	20	100M	No	[9]
2019	27	1.56G	30	[10]
2021	24	335.6M	7.5	[11]
2021	60	1G	1.8	[12]
2021	92	46.55G	1.02	[13]
2021	**104.5**	**32G**	**3**	**[14]**
2022	**24**	**6.4G**	**7.5**	**[15]**
2022	35	1G	3.5	[16]
2022	**78**	**78G**	**No**	**[17]**
2022	**340**	**38.1G**	**1.58**	**[18]**

transmission system based on photonic up-/down-conversion at 370GHz THz band for the first time [7,8]. The 103.125Gbps net rate DP-QPSK signal transmission over two spans of 20km SSMF and 1m wireless link under 15% SD-FEC is successfully achieved. In THz sensing, a target which is 40cm away from the reference position is successfully detected and a data rate of 32Gbit/s for communication is demonstrated [14]. A 38.1Gbit/s capacity for communication and a 1.58cm range resolution for radar is simultaneously achieved [18].

Long distance and broadband real time THz Communication

1) Long distance communication

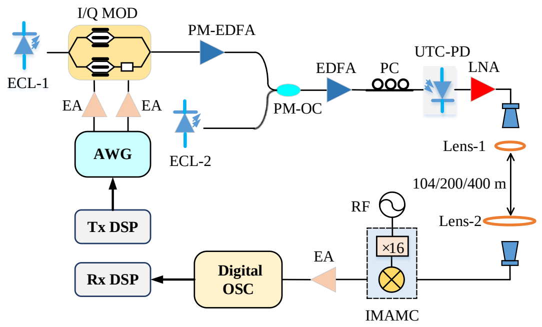

Fig.1: Experimental setup of THz signal wireless transmission system.

low-noise amplifier (LNA) with 25dB gain before delivered over 104/200/400m wireless distance. Since the THz receiving antenna has a very small aperture and the output signal from the transmitting antenna is divergent, it is difficult to realize long-distance wireless delivery under normal signal power. To solve this problem, we design a pair of PTFE lenses to focus the collimated THz beam to maximize the received power by the receiving antenna. The received THz signal is down-converted by an integrated mixer/amplifier/multiplier chain (IMAMC).

Thanks to the pair of PTFE lenses and advanced DSP, we have successfully achieved 124.8-Gbit/s line rate PS-256QAM signal wireless transmission over 104m distance at 339GHz based on photonics-aided scheme [6], and recently we have realized PS-64QAM\16QAM 56\32Gbit/s THz signal wireless transmission over 200\400m distance at 335GHz by using this same experimental setup.

2) Broadband and real time demonstration

In recent years, coherent optical detection technology has developed rapidly, and coherent products with a single-channel transmission rate of 800Gb/s have matured. Through the seamless integration of terahertz communication and coherent optical communication [19,20], we have achieved real-time transmission of 100Gb/s terahertz signals. After adopting advanced DSP and FEC, the bit error rate of terahertz signal can

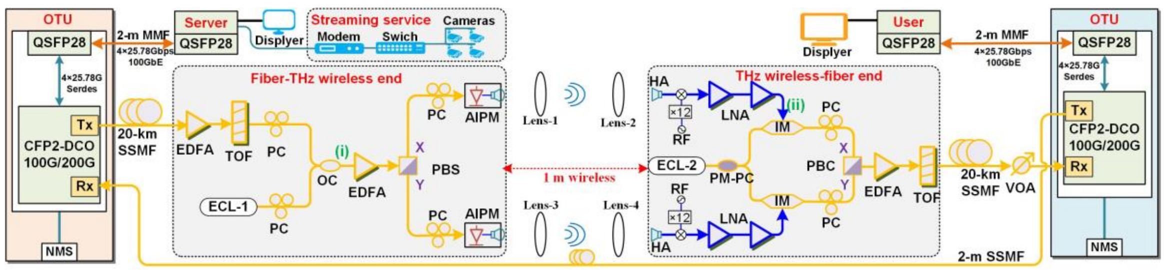

Fig. 2: Testbed setup of 100GbE real-time transparent fiber-THz-fiber transmission system.

In order to promote the practicality of THz communication, high-speed THz signal transmission distance over 100m is required. Recently, we have extended the transmission distance of broadband THz signals to 400m by using newly designed THz antennas, high-gain THz amplifiers and developed advanced DSP algorithms with probability shaping and Volterra nonlinear compensation. Fig. 1 depicts the experimental setup for photonics-aided THz transmission system [6]. The baseband electrical I/Q signals generated from AWG are boosted by two parallel EAs. The frequency space between the two ECLs is set as 339/335GHz. An EDFA is utilized to adjust the input power into the UTC-PD. The generated THz signal is amplified by a THz

be less than 10^{-12}, and the highest terahertz frequency can reach 400GHz.

Fig. 2 shows our real time 100GbE THz wireless transmission system [7, 8]. We build a 100GbE (103.125 Gbps) transmission platform including two displayers, two servers, and two optical transport units (OTUs). The optical baseband modulation polarization multiplexing signal is delivered over one span of 20km SSMF. A PBS is used to separate the X- and Y-polarization components of the combined lightwaves. In our demonstrated system, photonic heterodyning is utilized to generate ~370GHz THz wireless signal. Then, the THz signals are delivered over a 1m 2×2 MIMO wireless THz transmission link. At THz wireless-fiber end, for X and Y-polarization THz wireless signals, two identical THz receivers operating within 330 to 500GHz are driven by electronic LO sources to implement analog down conversion. Then, the down-converted X- and Y-polarization IF signals at 24GHz is boosted by two cascaded LNAs to drive two IMs, respectively. Then, the X- and Y-polarization are combined by a PBC and boosted by another EDFA. The obtained optical baseband signal is delivered over the second span of 20km SSMF, and then received by the CFP2-DCO module. Fig. 3 shows the BER performance at different frequency. This system can transmit stably with post-FEC BER<10^{-15}.

THz Integrated sensing and communication

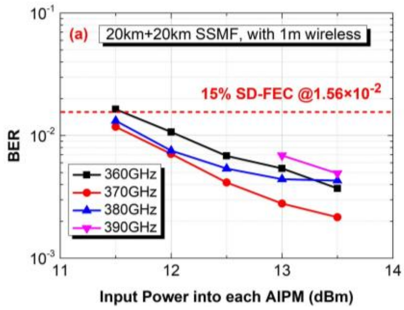

Fig. 3. BER (Before FEC) versus input power into each AIPM with fiber and wireless transmission.

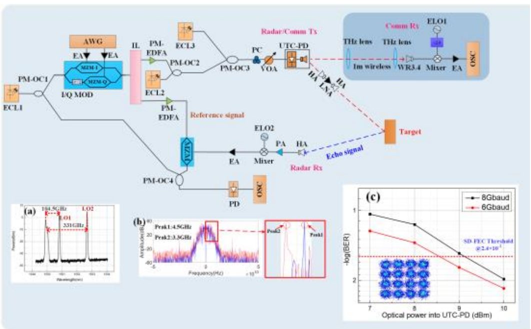

Fig.4: The experimental setup of the photonics-based THz data communication and radar sensing integrated system. (a) Optical spectrum after the PM-OC3. (b) Spectra of the de-chirped signal for 40cm away from the reference position, (c) BER versus input power for the 16QAM signal.

We have developed several multiplexing techniques to realize the integration of THz communication and sensing, and here are two solutions to achieve this function. The first scheme is realized by allocating different frequency band to each function [14]. The second scheme is obtained by using time division multiplexing in a signal frame for dual-function [18]. Both two schemes can realize high-resolution radar sensing and high-speed data communication. However, they also have operational issues such as spectral efficiency, power allocation and resolution.

Fig.4 shows the platform based on frequency multiplexing [14]. As can be seen from Fig.4 (b), the distance between the two positions is calculated to be 36cm, which is close to the practical value (40cm). At the same time, the experimental results also show that the rate of 32Gbit/s has been successfully transmitted over a 1m wireless link at 324GHz band. In this experiment we do not use THz LNA, the wireless transmission distance is limited to 1m.

Fig. 5 shows the principle based on time division multiplexing transmission OFDM signals and LFM signals [18]. Based on this scheme, we have realized the data rate of 38.1Gbit/s transmission over a 50m wireless link at a

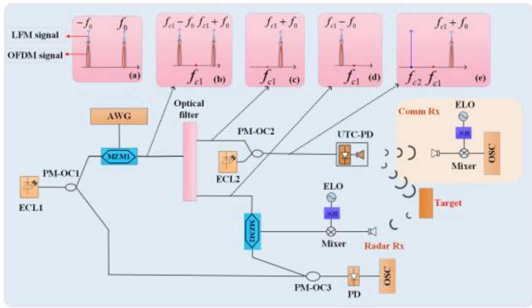

Fig.5: The principle the photonics-based THz high-resolution radar sensing and high-speed data communication integrated system.

340GHz band. Our experimental results show we can get the similar range resolution of THz sensing by using the two demonstrated schemes. The range resolution is around ~2cm.

Conclusions

We summarized our research results on THz communication and sensing based on photon-assisted techniques. In terms of long-distance terahertz transmission, we have achieved wireless transmission of 124.8\56\32Gbit/s line speed PS-256QAM\PS-64QAM\16QAM terahertz signals over a distance of 104\200\400m. For real-time terahertz communication, we also demonstrate a real-time transparent fiber-THz-fiber 2×2 MIMO transmission system for 100G THz signals. For the integration of terahertz communication and sensing, we have achieved a radar range resolution of 1.58cm and a communication capability of 38.1Gbit/s.

Acknowledgements

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