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# Advances in Photonics Assisted Terahertz Wireless Communication System

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***Abstract*—In this paper, the latest research progress of photonics-assisted terahertz wireless communication is summarized, and THz signal generation technologies, multi-dimensional multiplexing techniques, THz signal detection technologies for photonics-assisted terahertz wireless communication are briefly introduced. In addition, this paper also discusses a future perspective with respect to enabling device technologies and applications.**

***Keywords- photonics assisted THz signal generation; heterodyne detection; wireless communication***

## I. Introduction

With the exponential growth of user data traffic, the future social and industrial information interaction will put forward greater bandwidth, higher speed, and more diversified communication capabilities and business requirements for communication networks. The explosive growth of wireless transmission traffic prompted academia to explore new bands in the radio spectrum to meet the growing bandwidth demand. The terahertz band (0.1 THz–10 THz) with massive spectrum resources is recognized as a promising candidate for future B5G/6G communications, which provides important support for the development of B5G/6G communication in the future [1]. However, the THz signal wireless signals at such high bit rates cannot be generated by only bandwidth-limited electronic devices. Photonics-assisted THz signal generation technologies can effectively overcome the limitation of bandwidth-insufficient electrical devices, and simultaneously realize ultra-wideband and large-capacity data transmission [2].

There have been numerous publications since early 2010, which report wireless transmission experiments using photonics-assisted THz signal generation technology [3-15]. In Fig. 1 we summarize some state-of-the-art reports, experimentally achieved by transmission experiments at carrier frequencies beyond 100 GHz. In 2012, NTT achieved 24Gb/s real-time wireless data transmission using UTC-PD at 300GHz band, with a transmission distance of 0.5m [3]. Multi-dimensional multiplexing techniques is used to meet the needs of high bandwidth and large capacity in THz band. In 2019, Li X et al. propose and experimentally demonstrate a 2×2 multiple-input multiple-output (MIMO) wireless THz signal signal transmission system, which realizes 6×20 Gb/s six-channel polarization division multiplexing quadrature phase shift keying (PDM-QPSK) at 375-500 GHz [7]. In 2020, Yu X et al. successfully demonstrate 600 Gb/s wireless transmission by modulating 2 channels (30 GHz per channel) in the 320-380 GHz band, which employing THz orthogonal polarization dual-antenna, PS-64QAM-OFDM modulation and advanced nonlinear-digital reception techniques [9]. Furthermore, it is interesting to further investigate how to increase the wireless transmission distance, while maintaining its relatively large wireless transmission capacity. KIT demonstrate wireless THz transmission of 16QAM signals using a Schottky barrier diode (SBD) receiver in combination with generalized Kramers-Kronig signal processing, which realizes net data rate of 110 Gb/s over a transmission distance of 110 m by using THz amplifier [11-12].

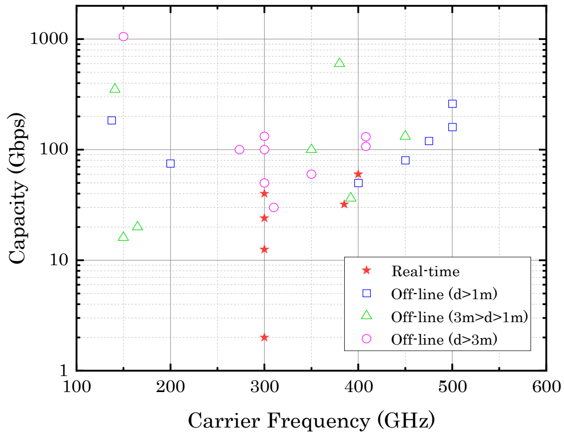


Figure 1. Carrier frequency vs. Capacity obtained for photonics-assisted THz wireless communications systems

This paper summarized a latest advance in photonics-assisted THz wireless communication research, and also review the THz signal generation technologies, multi-dimensional multiplexing techniques, THz signal detection technologies for photonics-assisted terahertz wireless communication. In addition, the future application cases and prospects of photonics-assisted THz wireless communication are discussed.

## II. THz Signal Generation Technology

A simple and cost-effective photonics assisted THz signal generation scheme is one of the key technologies to realize high-speed THz wireless communication. Currently, researchers mainly use heterodyne beating of two continuous-wavelength (CW) light-waves scheme, optical frequency comb (OFC) scheme, frequency doubling of high-order sidebands scheme to generate THz signal, as shown in Fig. 2.

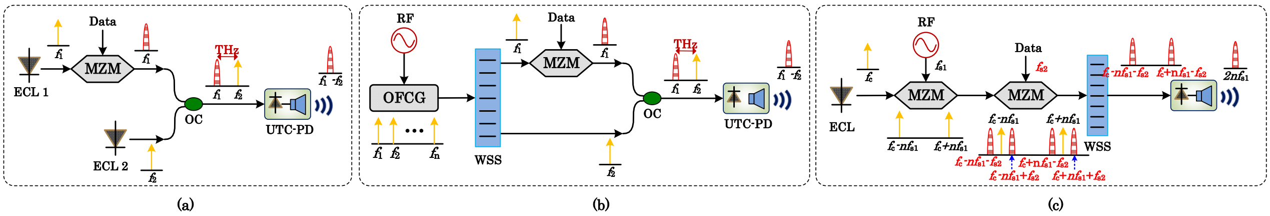


Figure 2. THz signal generation technology

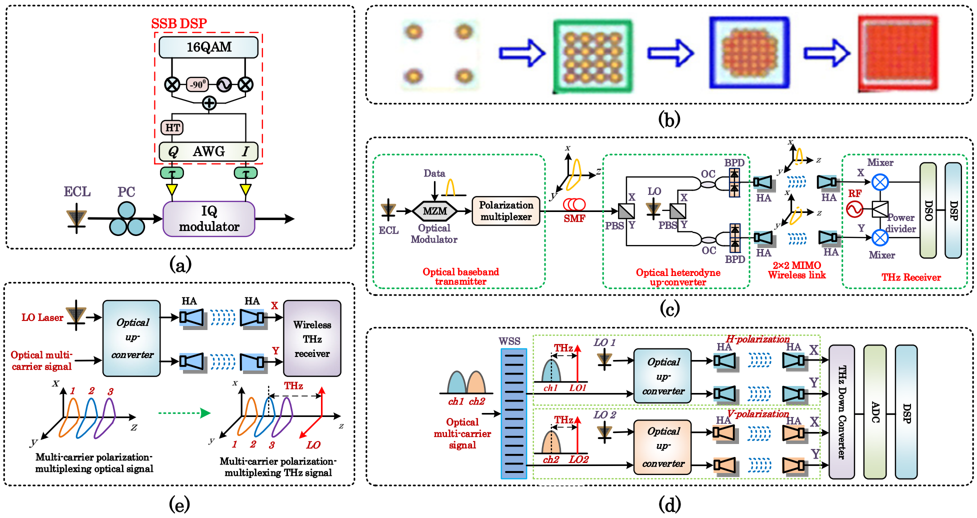


Figure 3. Various kinds of multi-dimensional multiplexing techniques; (a) single sideband modulation; (b) advanced multi-level modulation; (c) optical PDM combined with MIMO reception; (d) antenna polarization multiplexing; (e) multi-carrier modulation

### *A. Heterodyne Beating of Two CW lightwaves*

Heterodyne beating of two CW light-waves scheme is a simple and common method to generate THz signal, which two CW lights generated from two free running lasers, and then heterodyne beating at PD. The scheme structure is shown in Fig. 2 (a). This method can generate the THz signal with a tunable carrier frequency and a relatively high signal-to-noise ratio (SNR). However, the characteristics of the two free running lasers will cause the carrier frequency and phase drift. Therefore, the generated THz signal by this method has an unstable carrier frequency and large phase noise, which seriously affects the performance of the THz communication system.

### *B. Optical Frequency Comb*

Fig. 2 shows the structure of OFC scheme. In this method, we need to use an optical filter to select two combs with a certain frequency spacing from the OFC. Then we modulate one selected combs while keeping the other unmodulated, before they are heterodyne beat in a PD. The phase noise of the THz signal generated by this scheme is relatively small, but its SNR is also relatively small.

### *C. Frequency Boubling of High-order Sidebands*

The structure of frequency doubling of high-order sidebands scheme is shown in Fig. 2 (c). THz signal generated by beating the two high-order sidebands of the modulated signal. This scheme can use low-frequency radio frequency drive signals to generate high-frequency THz signals through photonics frequency doubling, thereby greatly reducing the bandwidth requirements of the transmitter for electronic and optical devices. However, the optical power from a single laser source is shared by multiple subcarriers, so the generated THz signal has a relatively low SNR.

## III. MULTI-DIMENSIONAL MULTIPLEXING TECHNIQUES

In order to increase the wireless transmission capacity, researchers used multi-dimensional multiplexing techniques, including single sideband modulation, advanced multi-level modulation, optical PDM combined with MIMO reception, and antenna polarization multiplexing, multi-carrier modulation, as shown in Fig. 3. These techniques effectively reduce the bandwidth requirements of the system, improve the spectral efficiency, and overcome the limitation of insufficient bandwidth of optical and electrical equipment.

By suppressing one of the redundant sidebands, the single sideband modulation can improve the spectral efficiency and the tolerance of dispersion. The advanced multi-level modulation, the larger the bit number per symbol and the lower the required signal baud rate. But at the same time, a higher receiver sensitivity is also required with the increase of modulation order. Therefore, there is a tradeoff between optimal vector modulation and overall system

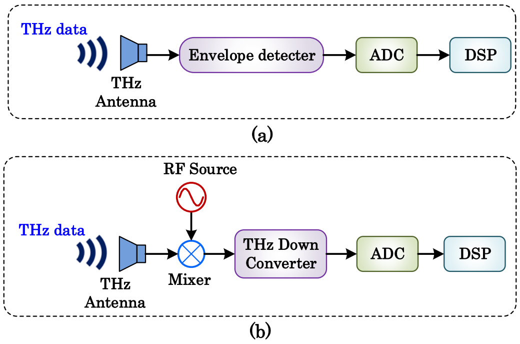


Figure 4. THz signal detection technology

performance. For PDM and MIMO technology, on the one hand, two polarization states are used to increase the system capacity at a certain baud rate, and on the other hand, polarization crosstalk is introduced, which needs to be eliminated by DSP at the receiver. Antenna multiplexing is to improve the system capacity by using two polarization states of the antenna, but it also needs to use DSP in the receiver to eliminate crosstalk. The multi-carrier modulation including electrical multi-carrier modulation and optical multi-carrier modulation. The electrical multi-carrier modulation, such as electrical OFDM, is robust to fiber CD and PMD. The optical multi-carrier modulation, such as optical OFDM and Nyquist WDM. Adopting multi-carrier modulation technique can reduce the signal baud rate and bandwidth requirement for optical and wireless devices. Moreover, multi-carrier modulation technique has a better tolerance to the spectrum fading effect gives the possibility for optical sub-carrier optimization.

## IV. THZ SIGNAL DETECTION TECHNOLOGY

THz signals can be detect by direct or heterodyne detection. The structure of the direct detection scheme is shown in Fig. 4 (a). Received the THz signal is down-converted to the baseband signal by an envelope detector. The direct detection scheme is simple, low-cost and phase noise insensitive. But this scheme cannot detect the vector signal carried by the THz but only intensity modulation signal. Fig. 4 (b) shows the structure of the heterodyne detection scheme, which consists of a RF LO and a mixer. Received the THz signal combines with the RF LO signal in the mixer to achieve the THz signal down-conversion. The heterodyne detection scheme requires an additional RF source and mixer resulting in a high cost, but the system has a high receiver sensitivity. This detection scheme can be used to detect both intensity modulation signal and vector signal, and the offline DSP algorithm can be used to compensate for the noise in the received signal.

## I. RECENT AND FUTURE PROSPECTS

The photonics-assisted THz communication system has many advantages, such as wide frequency spectrum, high speed, good directivity, and excellent ability of security. It is considered as the next breakthrough point to revolutionize the communication technology, and has great research significance and wide application prospects. However, there is still a long way to go toward real-world applications of photonics-assisted THz communication system, and there are many limitations and challenges to overcome. For example, THz channel model, THz devices, photon-assisted terahertz communication and sensing integration technology, optical and THz fusion communication system. These technological breakthroughs will pave the way to push THz into the center stage of the information era.

## ACKNOWLEDGMENT

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