Terahertz Communications: Past, Present and Future

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***Abstract*—It has been about 15 years, since the first demonstration of terahertz (THz) communications using both impulse and continuous waves. To meet an ever-increasing demand for the speed of wireless communications, THz communications have recently gained lots of interest and expectation. This paper overviews a latest trend of THz communications research, and discusses the future perspective with respect to technologies, applications and standardization.**

In the history of wireless communications technologies initiated by G. Marconi in early 20th century, we have been exploring higher and higher carrier frequencies to enhance a speed and/or a channel capacity. Now, the demand for much greater data rate of wireless technologies is ever increasing in accordance with a rapid advancement of mobile networks and rich contents handled by networks, computers, etc. The prospective data rate for wireless communications in the marketplace will be 100 Gbit/s within ten years. Against this background, researchers have recently been seeking a use of radio waves whose frequency is over 275 GHz for ultrahigh-speed wireless links, since the frequency bands from 275 GHz to 3000 GHz are not yet allocated for specific active services in the world, and there is a possibility to employ extremely large bandwidths for ultra-broadband wireless communications. The terahertz (THz) communications will promise a data rate of over 100 Gbit/s using low-cost and/or energy-efficient modulation schemes like ASK and QPSK because of their ultra-broad bandwidths [1-4].

The origin of THz communications is traceable back to 1999~2000. In 1999, Lee *et al*. demonstrated an "impulse" radio scheme using a photoconductive switch triggered by a mode-locked Ti: Sapphire laser [5]. Then, this work was applied to audio-signal transmission with indirect [6] and direct [7] modulation methods. In contrast, Nagatsuma *et al.* demonstrated a photonic generation of "continuous" sub-terahertz waves at 120 GHz using a photodiode triggered by a mode-locked diode laser, and applied it to a video-signal transmission in 2000 [8]. The data rate was immediately increased to 10 Gbit/s, which was a breakthrough in the speed of wireless communications in 2002 [9].

The 120-GHz band wireless link has been evolved with progress of semiconductor electronics technologies in particular by using InP-HEMT transistor technologies with respect to transmission distance, stability, size, cost and ease of use [10]. On January 30, 2014, Ministry of Internal Affairs and Communications (MIC) of Japan officially revised the radio regulations to allocate the band from 116 GHz to 134 GHz to the 120-GHz band wireless link for broadcasting services. This is the first industrial allocations of over-100-GHz carrier frequencies. The data rate has been upgraded to 20 Gbit/s with use of QPSK modulation scheme [11].

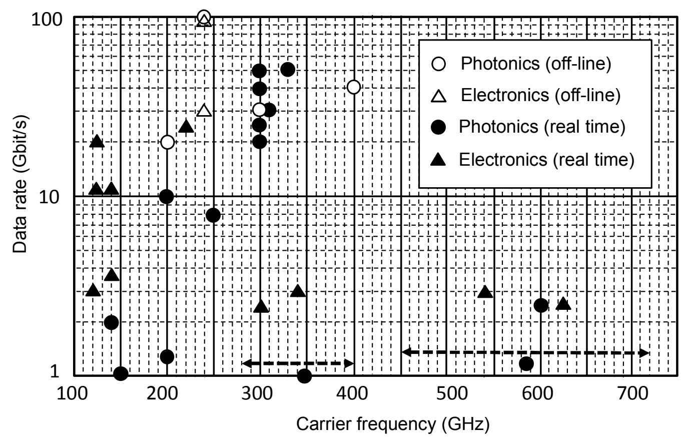

Fig. 1. Carrier frequency vs. data rate obtained for THz wireless link systems with real-time transmission (solid circle/triangle) and with off-line digital signal processing (open circle/triangle). Dotted lines show are extremely wide-bandwidth operation at 1- to 1.6-Gbit/s data rate.

One of the noticeable trends in THz communications is an increase of carrier frequencies up to 700 GHz in order to achieve higher data rates. Figure 1 summarizes the data rate achieved with different carrier frequencies. Both photonics-based and electronics-based approaches have been studied; highest data rate are 50 Gbit/s with a single channel and 100 Gbit/s with a multi-value modulation scheme [12-14].

Si-CMOS and SiGe HBT technologies have placed a great impact in THz communications research [15, 16]. Compound semiconductor devices such as GaAs, InP, and GaN, will continue to play a key in 300-GHz to 1000-GHz band technologies. There have also been various emerging technologies to enable new function [17] and system integration [18-20] in the THz region. By fully accommodating the THz bands from 100 GHz to 1000 GHz, the data rate of over 1 Tbit/s should be feasible in the future.

The effort on standardization and spectrum regulation issues has been initiated and led by Kürner *et al*. [21, 22] by considering use cases, channel/propagation models, interference effects with other services such as, for example, radio astronomy and earth observation, enabling technologies, etc. Potential applications include wireless local area networks, wireless personal area networks, near-field communications such as kiosk downloading, wireless connections in data centers, device-to-device communications, wireless backhauling, etc. [21]

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