# Extreme Bandwidth Wireless Communications Using Terahertz Waves

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***Abstract***

*There has been an increasing interest in the use of terahertz electro-magnetic waves at frequencies of >275 GHz with extremely large bandwidth for ultrahigh-speed wireless communications. This paper reviews our recent challenges towards 100-Gbit/s wireless communications using terahertz waves.*

## 1. INTRODUCTION

Demand has been increasing for higher data rate in wireless access systems in order to keep up with the remarkable speed-up of fiber-optic networks. 10-Gbit/s data rate is an urgent need for the wireless transmission of 10-Gigabit Ethernet (10GbE) signals, and multiplexed uncompressed high-definition television (HDTV) signals. In the future, 20, 40, and 100 Gbit/s will be required for the wireless technologies, which can transmit Super Hi-Vision (SHV)/Ultra High Definition (UHD) TV data, having 16 times the resolution of HDTV (at least 24 Gbit/s), OC-768/STM-256 data (43 Gbit/s), and 100GbE (100 Gbit/s). In addition to these access network applications, there has also been a need in close proximity wireless transfer of large amount of data, for example, between mobile terminals and storage devices. Such a near-field data transfer technology will possibly evolve to wireless interconnections in devices and equipments.

Towards 100-Gbit/s wireless, several promising approaches can be considered; 1) multi-value modulation with existing millimeter waves such as 60 GHz, 2) free-space optical link possibly with WDM technologies, and 3) use of terahertz carrier frequency with simple modulation format like ASK and PSK.

In particular, the use of millimeter and terahertz waves at frequencies above 275 GHz has attracted a great deal of interest for wireless communications [1]. This is mainly because that these frequency spectra have not yet been allocated to specific applications and thus we can possibly make use of extreme bandwidth for high-speed communications [1-6]. As the first step for the exploration of these electromagnetic waves, 300-500-GHz range is considered to be realistic since enabling semiconductor electronic and photonic devices operating at this frequency range have recently started to be in our hands. From the viewpoint of atmospheric attenuation of electro-magnetic waves, 500 GHz is nearly an upper limit in “last-one-mile” applications.

Utilization of full 300-500 GHz bands could be classified into two ways as shown in Fig. 1. One is to use extremely large bandwidth of over 40 GHz in a single channel. For example, >40-GHz and >70-GHz DSB bandwidths are required for the transmission of SHV and OC-768 data, respectively, in the case of ASK modulation format. The other use is to allocate multiple channels of giga-bit signals such as Gigabit Ethernet (1 Gbit/s) and HDTV (1.5 Gbit/s). 80 channels of HDTV signals can be allocated in 300-500 GHz bands.

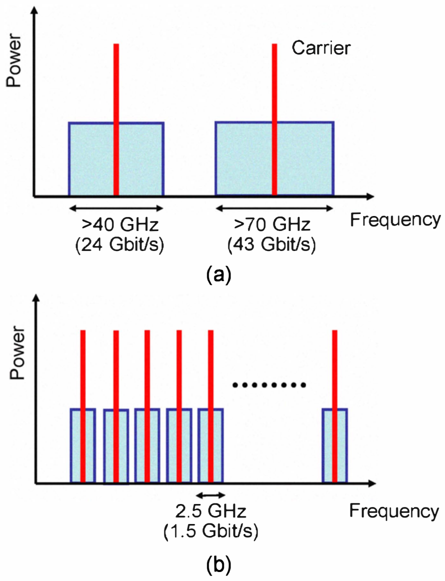


**Fig. 1.** Possible utilization of 300-500 GHz bands. (a) Ultra-broadband channel. (b) Multiple giga-bit channels.

## 2. EXPERIMENTAL SYSTEM

In order to first examine the wireless link using 300-500-GHz carrier frequencies, we have adopted the use of “photonics” as enabling technologies because of wide bandwidth in the signal generation and modulation [5, 6]. Figure 2 shows a block diagram of the short-distance (~0.5 m) wireless link

using a photonics-based transmitter. First, an optical THz-wave signal is generated by heterodyning the two wavelengths of light from the wavelength-tunable light sources. The optical signal is digitally modulated by the optical intensity modulator driven by the pulse pattern generator (PPG). Finally, the optical signal is converted to an electrical signal by a Uni-Traveling-Carrier-Photodiode (UTC-PD) [7, 8], and it is emitted to the free space via a horn antenna with a gain of 25 dBi. The emitted terahertz wave is well collimated by a 2-inch-diameter Teflon lens. Main features of this photonic approach are that carrier frequency is widely tunable, and that the modulation frequency can be increased to at least 40 Gbit/s.

The receiver consists of the Schottky barrier diode (SBD) followed by a low-noise pre-amplifier and a limiting amplifier. The envelope detection is performed by the SBD for the ASK (OOK) modulation.

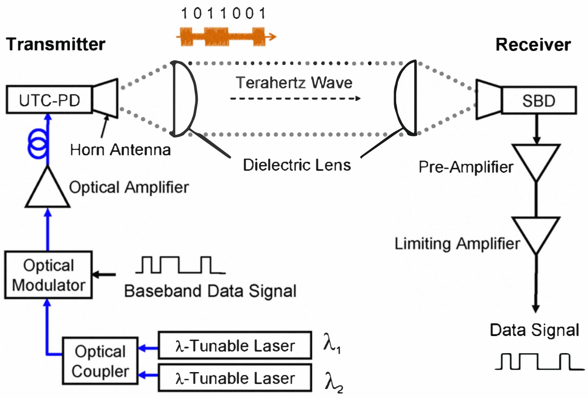


**Fig. 2.** Block diagram of the wireless link using photonics-based terahertz-wave transmitter. UTC-PD: Uni-Traveling-Carrier-Photodiode. SBD: Schottky-Barrier-Diode.

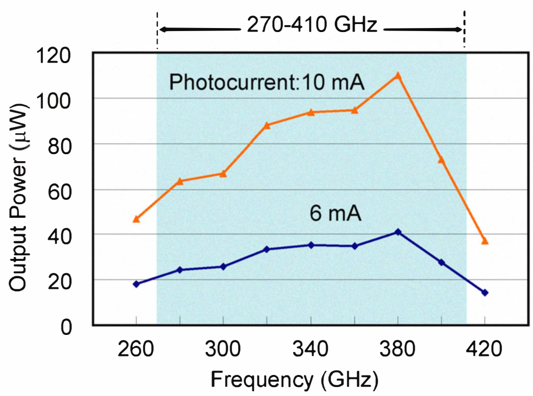


**Fig. 3.** Frequency dependence of the output power from the UTC-PD at different photocurrents.

The frequency dependence of the output power from the UTC-PD module is shown in Fig. 3. The 3-dB bandwidth is 140 GHz (from 270 to 410 GHz). The peak output power was 110 µW at 380 GHz for a photocurrent of 10 mA with a bias voltage of 1.1 V. The output power could be further increased to over 400 µW with increasing the photocurrent up to 20 mA [7]. The SBD detector has almost the same bandwidth of over 100 GHz.

## 3. EXPERIMENTAL RESULTS

Figure 4 shows bit-error-rate (BER) characteristics at 12.5 Gbit/s with a carrier frequency of 300 GHz. Horizontal axis is a photocurrent of the transmitter. An error-free transmission at 12.5 Gbit/s has been achieved with 4-mA current, which corresponds to the transmitter output of around 10 µW. Currently, the upper limits in the bit rate of PPG and BER tester are 14 Gbit/s and 12.5 Gbit/s, respectively.

Figure 5 shows the eye diagram at 14 Gbit/s. Although the BER could not be measured, an error-free transmission was confirmed from the clear eye opening.

Since the bandwidth of both the transmitter and receiver exceeds 100 GHz and the available output power from the transmitter is over 10 times higher than the case of 12.5 Gbit/s, the bit rate of 20-40 Gbit/s can be anticipated. Leading-edge photonic component technologies such as 100-Gbit/s optical modulators [9] and 1-THz photodiodes [8] together with terahertz SBDs [10] and 100-Gbit/s electronic devices will promise 100-Gbit/s wireless transmission.

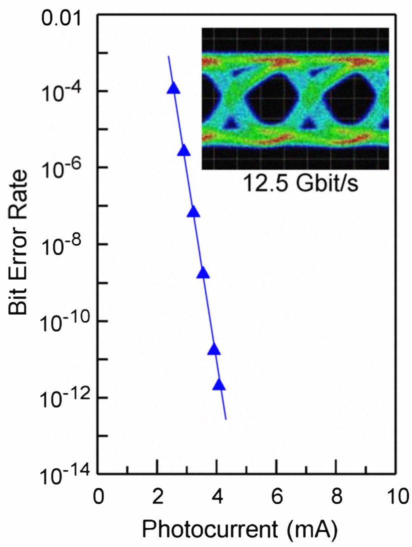


**Fig. 4.** BER characteristics at 12.5 Gbit/s.

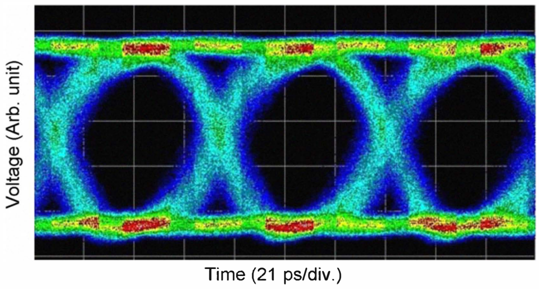


**Fig. 5.** Eye diagram at 14 Gbit/s.

Figure 6 shows a series of eye diagrams for different carrier frequencies at a bit rate of 1 Gbit/s, measured before the limiting amplifier in order to see waveform deterioration more clearly. Eye patterns were clean, which ensures an error-free transmission from 280 GHz to 400 GHz. Very small change in the eye opening is mainly due to the carrier frequency dependence of the responsivity of the Schottky barrier diode (SBD). The SBD responsivity is highest at around 300 GHz and decreases when the carrier frequency increases up to 400 GHz.

From the above results, the concept on the possible utilization of 300-400 GHz bands for multi-channel giga-bit link (Fig. 1(b)) has been confirmed.

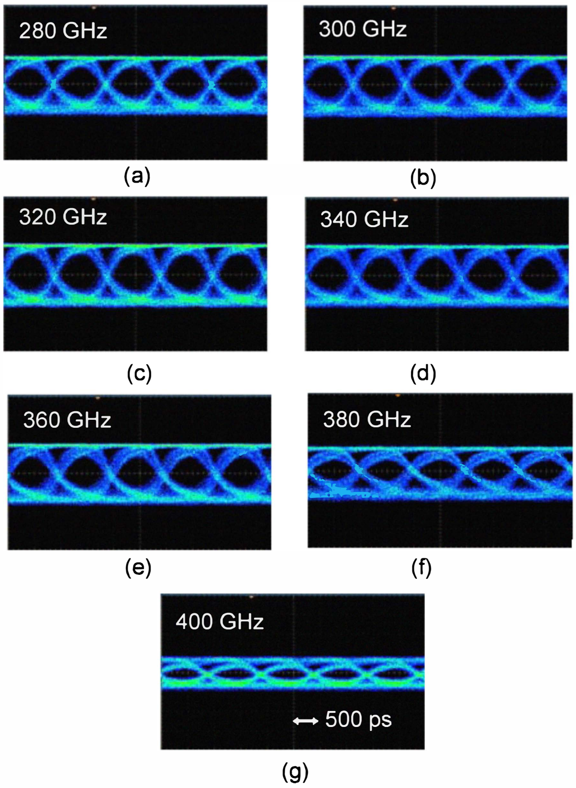


**Fig. 6.** Eye diagrams at a bit rate of 1 Gbit/s with carrier frequencies from 280 GHz to 400 GHz.

## 4. CONCLUSION

Utilization of frequency region over 275 GHz for wireless communications has attracted a worldwide attention. In order to demonstrate possible applications, we have developed a wireless link using photonics-based transmitter with high-power broadband photodiodes operating at 300-400 GHz bands. An error-free transmission up to 14 Gbit/s has been obtained at 300 GHz with a transmitter power of 10 μW. In addition, 1-Gbit/s transmission has been demonstrated over an ultra-wide carrier frequency range from 280 GHz to 400 GHz.

Future work addresses higher bit-rate transmission by increasing of the video bandwidth of the receiver circuit. Photonics-based approach should be a carrying vehicle for the exploration of undeveloped frequency regions. In the near future, semiconductor electronics technology, in particular, silicon LSI technology could be introduced in 300-400 GHz bands for compact and cost-effective wireless communication systems.

## 5. ACKNOWLEDGEMENT


The authors wish to thank H.-J. Song, K. Ajito, N. Kukutsu, A. Hirata, Y. Kado, A. Wakatsuki, Y. Muramoto, I. Ogawa and N. Shigekawa for their valuable discussion and support, and T. Takada, Y. Fujimoto and M. Kawamura for their help in the experiments. Part of this work was supported by The Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (A), 20246062, 2008.


## 6. REFERENCES


[1] http://www.ieee802.org/15/pub/TG3c.html.

[2] R. Piesiewicz *et al*., *IEEE Journal Selected Topics in Quantum Electronics*, vol. 14, pp. 421-430 (2008).

[3] C. Jastrow et al., Electron. Lett., vol. 44, no. 3. pp. 213-214 (2008).

[4] C. Jastrow *et al*., *Tech. Dig. 2008 Infrared, Millimeter and Terahertz Waves (IRMMW-THz 2008)*, M3A3.1342 (2008).

[5] T. Nagatsuma *et al*., *Tech. Dig. IEEE International Topical Meeting on Microwave Photonics (MWP)2009*, Th.2.3, Valencia (2009).

[6] H.-J. Song *et al*., *Tech. Dig. IEEE International Topical Meeting on Microwave Photonics (MWP)2010,* WE3-2, Montreal (2010).

[7] A. Wakatsuki *et al*., *Tech. Dig. 2008 Infrared, Millimeter and Terahertz Waves (IRMMW-THz 2008)*, M4K2.1199 (2008).

[8] T. Nagatsuma *et al.*, *Laser & Photonics Review*, vol. 3, no. 1-2, pp.123-137 (2009).

[9] Jan H. Wülbern *et al*., *Opt. Express*, vol. 17, pp. 304-313 (2009).

[10] http://www.virginiadiodes.com/