Terahertz Wireless Communication Link at 300 GHz

Ho-Jin Song, Katsuhiro Ajito, Atsushi Wakatsuki, Yoshifumi Muramoto, Naoya Kukutsu, and Yuichi Kado

NTT Corporation
3-1 Morinosato-Wakamiya, Atsugi, Kanagawa, Japan
hjsong@aecl.ntt.co.jp

Tadao Nagatsuma

Graduate School of Engineering Science
Osaka University
1-3 Machikaneyama, Toyonaka, Osaka, Japan

***Abstract*—We present a terahertz wave wireless link operating at 300 GHz which has a potential for use in ultra fast future wireless services in short range. Terahertz wave was generated and modulated with photonic technologies in the transmitter, allowing us to use radio on fiber system concept as well. For the receiver, we used a Schottky barrier diode detector integrated with a planar antenna. With the link, error free data transmission at 12.5 Gbps was experimentally demonstrated. Taking the performance margin of the transmitter and receiver into consideration, we believe that even up to 20-Gbps data can be transmitted.**

I. INTRODUCTION

As the demand for high-definition digital video and related multimedia services increases, so does the need for multi-gigabit data capacity not only for wired access networks but also for wireless environments in order to subscribe to those digital services [1]. To do so, in many wireless communication systems at microwave frequencies, the data capacity have been improved by increasing the spectral efficiency with advanced modulation schemes and signal processing technologies. But, still multi-gigabit data rate is challenging issue because of the essential limitation, narrow bandwidth. Recently, multi-gigabit data rate radio systems have been demonstrated at millimeter-wave frequencies where we can use much larger spectral resources easily. In 60-GHz ISM band, small and compact radio transceivers have been commercialized for delivering uncompressed high definition digital video signal between home video appliances [2], and 15-Gbps 16 QAM transceiver has been also successfully demonstrated with a commercially available standard CMOS technology [3]. In 120-GHz band has been developed a fixed wireless access system which can transmit up to 10 Gbps, equivalent to 6 channels of uncompressed HDTV signal over several kilometer long distance [4-5]. Thanks to wide bandwidth, even ASK modulation allows us to handle 10 Gbps.

In these trends, terahertz waves have been attracting great interest for ultra fast wireless communication link. Especially frequency band at over 275 GHz, where isn't being allocated to specific uses yet, is being considered for a possible use for future wireless system providing data rate of more than 10 Gbps. To implement the wireless system operating at such a high frequency, photonic technologies are advantageous against electronic approaches because of its inherent broadband nature. Not only can photonic technologies generate a high frequency carrier signal, but also handle extremely broadband data signal. Though experimental demonstration of analogue video-signal transmission at 300 GHz has been reported [6], they couldn't fully utilize the advantage of the wide bandwidth because of the limitation of electronic approaches for data modulation. We presented terahertz wireless links at 250 and 300~400 GHz using photonic technologies for transmitters and the maximum data rate of 8 and 2 Gbps per a single channel were presented respectively [7-8]. Though photonic technologies in the transmitter helped to improve the data rate, taking the carrier frequency into consideration the links should provide higher data capacity.

In this work, we experimentally demonstrate the data rate of 12.5 Gbps at 300 GHz band with a transmitter based on photonic technologies and a newly designed Schottky barrier diode receiver module, and explain a possible application concept of the terahertz wireless link as well. Since the receiver provides much wider baseband bandwidth (video bandwidth) than those used in the previous works and the transmitter has enough power margins, we believe that up to 20-Gbps rate would be feasible with the link.

II. IMAGE OF TERAHERTZ WIRELESS COMMUNICATION LINK WITH RADIO-ON-FIBER CONCEPT

Although providing extremely wide bandwidth, the terahertz wave has very high path loss in air due to its short wavelength and high absorption coefficient of atmosphere. In practical case, we will experience significant signal loss even in waveguide structures. Moreover available output power is lower than that in lower frequency bands, in general. These characteristics would limit coverage range of the terahertz wireless system within order of tens meter or less. Therefore

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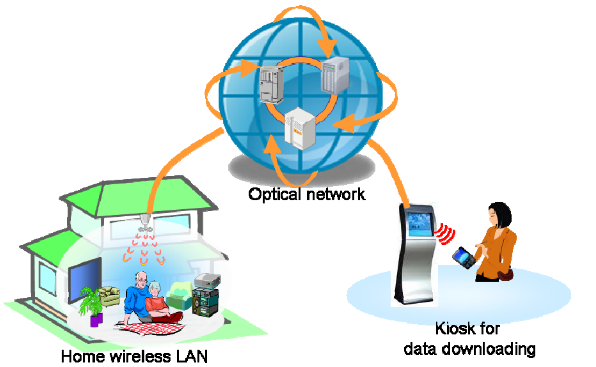


Fig.1 Image of terahertz wave wireless communication system incorporating with radio on fiber network

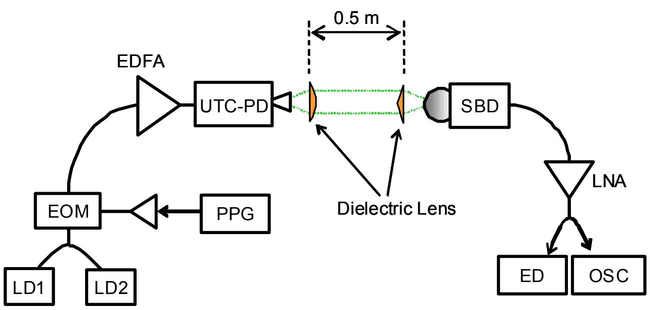
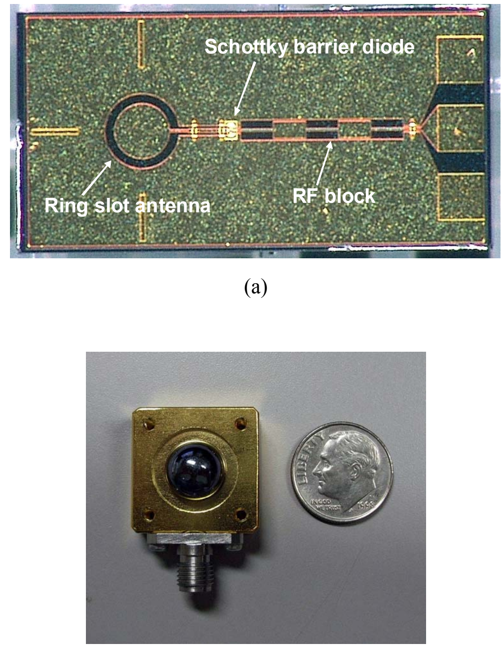


Fig. 2 Experiment setup (LD: laser diode, EOM: Electro-optic modulator, PPG: pulse pattern generator EDFA: Erbium doped fiber amplifier, UTC-PD: Uni-travelling photodiode, SBD: Schottky barrier diode, LNA: low noise amplifier, ED: error detector, OSC: Oscilloscope)

terahertz wireless communication links will be available only for short range. In the meantime, photonic technologies for generating and modulating terahertz waves are the most efficient and easiest ways because of its inherent broadband nature, and allow us to deliver photonic terahertz waves over long distance using optic-fibers, which is unimaginable with an electric approach. It implies that radio on fiber configuration can also be used for terahertz wireless communication systems.

Using these features, such as short range wireless link, and feasibility of incorporating with radio on fiber network, we can image possible terahertz wireless communication systems as shown in Fig. 1. One is a home wireless LAN system which provides multi-gigabit data capacity and thereby allows users to consume high quality multimedia services with a high mobility freedom in home. The other would be a kiosk for downloading huge size of data files such as HD video in just a second. Let image that you can download a Blu-ray movie (approximately 25 GB) to your memory card embedded in smart phones just in 20 ~ 5 second at 10 ~ 40 Gbps data rate, respectively, and you even don't need to take your phones out of your bags or pockets. It can be one image of the future [9].



(a)

(b)

Fig. 3. (a) top view of the Schottky barrier diode detector integrated with an ring slot antenna and (b) receiver module with a Silicon lens

III. Experiment and Results

Fig. 2 shows the experiment setup for the terahertz wave wireless link. In the transmitter, the carrier signal at 300 GHz was generated and modulated with photonic technologies. For simple setup, two free-running laser sources were used. The intensity of the lightwave from the lasers was modulated with an electro-optic modulator by random data patterns to implement the ASK modulation. The uni-travelling photodiode (UTC-PD) module used in this work has a WR-3 rectangular waveguide for output and can maximally produce approximately 500 μW at 300 GHz with 20-mA photocurrent. You can find more details about the device in [10]. In this experiment, we didn't insert any fiber spool between the electro-optic modulator and UTC-PD for simulating the radio on fiber network. The output terahertz wave at 300 GHz was radiated via a waveguide horn antenna with the gain of approximately 25 dBi, which is followed by a dielectric lens to increase the directivity of the radiated beam by around 15 dB. Since the lasers for generating the carrier signal are free-running devices, the 300-GHz carrier signal is also free-running signal with quite large linewidth of approximately a couple of ten MHz. However, since the linewidth is much smaller than the overall bandwidth of the modulated signal and the envelop detection with the SBD receiver was used for data recovery, this poor frequency purity of the carrier signal would not cause a large degradation of link performance.

For the receiver, Schottky barrier diode (SBD) detector was fabricated on the same epi-layers as the UTC-PD [11],

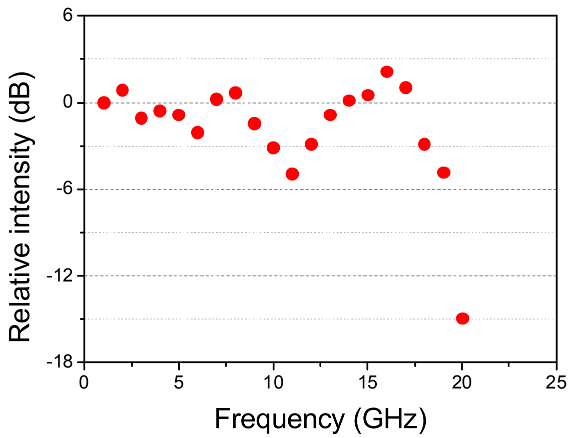


Fig. 4 Baseband signal bandwidth (video bandwidth) of the receiver module.

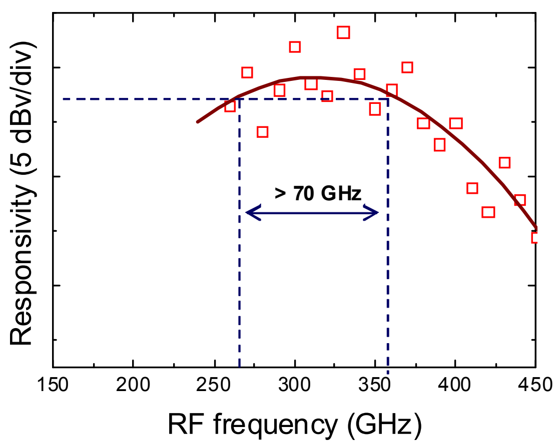
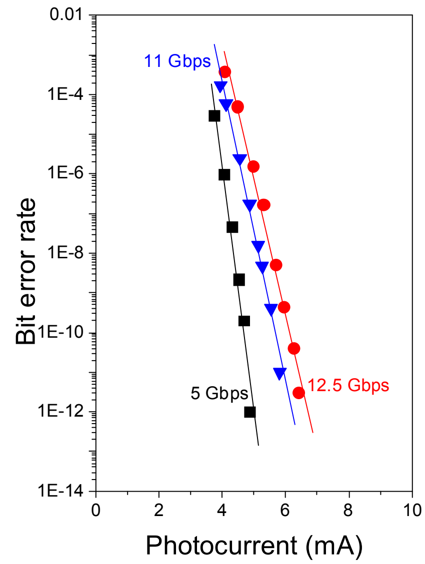
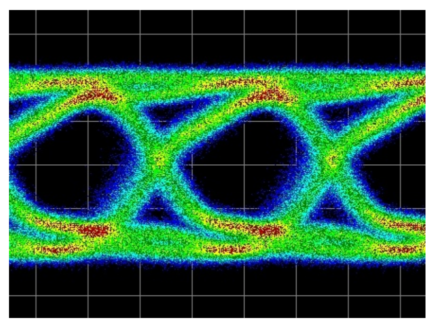


Fig. 5 Relative responsivity of the receiver with respect to the RF frequency (scatter: measured data, solid line: fitted curve)



(a)



(b)

Fig. 6 (a) measured bit error rate for several data rates and (b) eye-diagram for 12.5 Gbps

and Fig. 3(a) shows a top view of the fabricated detector. In the detector, a planar ring slot antenna fed by a coplanar waveguide line was monolithically integrated with the SBD. Since in the previous work, maximum data rate was limited by the baseband signal bandwidth of the receiver, we focused to solve this limitation in the new design. To do that, we designed the impedance matching between the antenna and SBD as shortly as possible and located the RF-blocking low pass filter at output port in series with the antenna. The fabricated detector chip was mound on a silicon lens to increase the directivity of the receiver and packaged as shown in Fig. 3(b). The dielectric lens used in the transmitter side was also used for the receiver. Antenna gain of the receiver including the dielectric lens is estimated to be approximately 34 dBi, according to full 3D electromagnetic simulation. Fig. 4 shows the measured baseband signal bandwidth characteristics of the receiver module. As can be seen, 3-dB bandwidth with a 50-ohm load is around 10 GHz, which is two times wider than previous version. According to EM simulation, the frequency deep at around 12 GHz should be related to the packaging and the intrinsic baseband signal bandwidth of the detector chip would reach up to 17 GHz. Fig. 5 shows the normalized responsivity of the receiver with respect to the RF frequency. Measured data shows a little large fluctuation, but it must be due to the wave reflection between the transmitter and receiver because of short link distance. As can be seen, the center frequency of the receiver shifted a little to higher frequency than the design (300 GHz). Though it is clearly defined because of large deviation of the measured data, 3-dB bandwidth of responsivity is expected to be as wide as 70 GHz or more. Since there is no RF filter to define a noise bandwidth of the system, so should this RF bandwidth of the receiver do.

For wireless link test, pseudo random data with a sequence length of 2^{21}-1 was carried on the intensity of the 300-GHz signal and was transmitted over a 0.5-m distance to the receiver. Fig. 6(a) shows the measured bit error rates (BERs) for several data rates with respect to the photocurrent of the UTC-PD, which is directly related to the output power from the transmitter. As can be seen, up to 12.5-Gbps data was successfully transmitted with no error (BER $< 10^{-12}$). For the error free transmission, we just need average power of around 60 μW at the UTC-PD output (approximately 6.5-mA

photocurrent). Fig. 6(b) shows the eye-diagram for 12.5 Gbps data rate, which opens clearly. In this experiment, we couldn't drive the link at further higher rate and extend the link distance because of the limitation of instruments, BER tester, and the experiment space issue. However, since the UTC-PD can produce approximately 9-dB higher power and optical modulator can handle up to 40-Gbps data, it should be possible to transmit data at higher data rate over longer link distance. In addition, the receiver has wide enough bandwidth for higher data rate in both of the RF and baseband, and therefore we believe that the current link can transmit data at up to 20-Gbps or even at faster rate with no error.

IV. SUMMARY

In this report, we present a terahertz wave wireless link operating at 300 GHz which has a potential for use in ultra fast future wireless services in short range. In the transmitter photonic technologies are used for generating and modulating the terahertz waves. For the receiver, a Schottky barrier diode was integrated with a planar antenna on the InP substrate, and assembled with the high resistive silicon lens, resulting in 19-dBi directivity. Using the system, 12.5-Gbps data stream was successfully transmitted over 50-cm long distance with no error. Taking the performance margin of the transmitter and receiver into consideration, we believe that even up to 20-Gbps data can be transmitted.

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