Antenna Technologies for Terahertz Communications

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Abstract — This paper describes several antenna technologies, which have been employed in our terahertz (THz) wireless communications research since around 2000, and discuss issues on antennas for the future of THz communications.

Index Terms — Terahertz, communication, antenna.

1. Introduction

Since the first demonstration of the wireless link using a carrier frequencies of over 100 GHz in 2000 [1], terahertz (THz) communications have been studied intensively towards a data rate of over 100 Gbit/s [2]. Currently, there are lots of reports and publications on 300-GHz-band wireless communications enabled by both photonic and electronic technologies. This is because carrier frequencies above 275 GHz have not yet been allocated at active services, and the frequency range 275-450 GHz is planned to be identified as frequency bands for use in the land mobile and fixed services applications at the World Radio Conference (WRC) in 2019. One of the greatest challenges in THz communications research is an antenna technology that can handle such a broad frequency range efficiently. This paper first reviews several antennas, which we deployed in demonstrations of THz wireless links for short and long distance applications, and then point out issues we faced to clarify the future direction of THz antenna technologies.

2. Antennas for THz Link Demonstrators

Table 1 summarized various types of antennas, which were used for THz wireless links at 120-GHz and 300-GHz bands. The first 120-GHz link was enabled by planar dipole and slot-ring antennas integrated with a photodiode and a Schottky-barrier diode for the transmitter [1, 3] and the receiver [4], respectively, for short distance (0.5~1 m) demonstration. The data rate of 10 Gbit/s was the highest among any radio links. Then, Gaussian-optic lens antenna with a diameter of 375 mm was introduced to increase a link distance. Photodiodes and diode detectors were packaged into hollow waveguides to use a horn antenna as a feeder [5]. For our outdoor-field trials, light-weight Cassegrain antennas with a diameter of 450 mm was used [6], and they finally enabled a successful transmission of real-time broadcasting video signals, and a record-transmission distance of 5.8 km at 10 Gbit/s.

In late 2000’s, 300-GHz-band research was initiated to further increase the data rate firstly by using a pair of 50-mm diameter dielectric lens and horn antenna for up-to 2-m transmission-distance experiment [7]. 48-dBi gain was achieved with a 100-mm diameter lens to allow 20-m indoor transmission experiments [8].

To achieve a high antenna gain with smaller size, waveguide slot array antennas were introduced to both 120-GHz and 300-GHz bands [9], and most recently Si-MEMS process was developed for 300-GHz-band antennas, which require more precise control of hollow waveguide fabrication [10]. This type of array antenna structure with massive slot apertures exhibits quite a useful property for close-proximity and/or near-field communications. A standing-wave effect can be mitigated with the slot array antenna, which offers a stable transmission even when the transmitter and receiver are placed close together [11]. We studied ultra-broadband antennas by making a taper-slot structure on a polymeric substrate with low dielectric

<table>
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<td>Antenna type</td>
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<tr>
<td>Planar dipole/slot ring on Si with Si lens</td>
<td>120 GHz</td>
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<td>Horn and dielectric lens (375 mm diameter)</td>
<td>120 GHz</td>
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<td>Dielectric rod antenna (40) array</td>
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constant, and demonstrated a dual-band operation at 120 GHz and 300 GHz [12]. We examined to increase the antenna gain by 8-array antennas. ~3-dB increase in the gain was achieved though it was theoretically ~6 dB. This was due to unexpected loss in metal conductors.

For outdoor long-distance experiment in 300-GHz band, a reflector antenna was developed because of its low loss, broad bandwidth, and high gain, and a real-time 100-m transmission was demonstrated at a data rate up to 50 Gbit/s [14].

We have been developing all electronic transceiver ICs using THz resonant-tunneling diodes (RTDs). Broadband bow-tie antennas were monolithically integrated with RTDs on InP substrate, and Si lens was attached to the backside of the substrate to effectively increase the gain of planar antennas [15].

As a different approach for antennas used in THz communications, dielectric/non-metallic antennas have recently been investigated in 300-GHz band together with ultra-low loss dielectric waveguides made of photonic crystal slabs on Si substrate [16]. >20-dBi-gain with a bandwidth of over 100 GHz was confirmed experimentally as designed with 40 rod antenna arrays, and successfully applied to 10-Gbit/s transmission [17].

3. Discussion and Conclusion

In our research on THz antennas together with several transmitter/receiver technologies for over a decade, large bandwidth and high gain should be simultaneously satisfied for most cases. This is because we have to utilize much wider bandwidth than ever used, and compensate a huge free-space propagation loss, which increases with a frequency.

One of the efficient ways to increase the antenna gain is to form an array as verified in Ref. [9], where a sophisticated hollow waveguide structure minimizes an interconnection loss of THz signals. However, in general, as we experienced a loss of metal interconnection when we formed an array of taper-slot antennas at 300 GHz [13], a low-loss interconnection technology for massive antenna feeding is an important issue. Dielectric waveguides are promising for low-loss THz interconnections, and array antennas with dielectric materials would become a solution, as described in Ref. [17].

With such high-gain antennas, a beam steering function is necessary for most practical applications. Future important challenge in THz antenna technologies is an efficient beam-forming antenna with large RF bandwidth, where photonics technologies can be deployed [2].

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