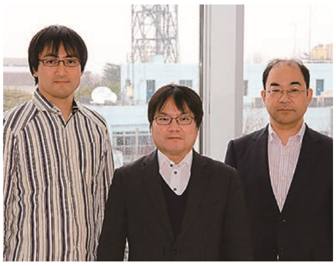
R&D on Terahertz-wave Testbed Platform

Toward Beyond 5G communication systems



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Terahertz waves, which have higher frequencies than millimeter waves, are being explored for use in future wireless systems (e.g., Beyond 5G). In addition to increasing transmission capacity, using higher frequencies is expected to provide more precise radiolocation systems, better physical security using narrower beams, and more. NICT has been developing a testbed platform for communications, measurement, and imaging applications in terahertz-wave bands. This article will introduce technologies for evaluating terahertz-wave transmission systems, as well as signal generation technologies for Beyond 5G and further.

Building a terahertz-wave transmission infrastructure

With the start of 5G mobile wireless services, the frequencies used in wireless systems continue to move away from the traditional microwave bands, toward millimeter wave bands. Broader bandwidth in higher frequencies is available, which in turn makes it possible to achieve transmission capacity exceeding 10 Gbps. Further improvements in communication capacities are expected through the use of the higher-frequency radio waves, such as terahertz waves. Technologies for transmitting and receiving high-frequency radio signals are thus being developed rapidly. To evaluate the transmitters and receivers being researched and developed in parallel, it is, of course, necessary to verify whether or not high-frequency terahertz-wave systems themselves can be used. NICT has, therefore, been developing terahertz-wave testbed platform technologies for verifying terahertz-wave systems experimentally (Figure 1). This article gives an overview of the testbed technologies and introduces efforts underway toward attaining even higher frequencies.

Developing testbed platform technologies in terahertz-wave bands

The available frequency band of terahertz waves is more than ten times broader that of microwaves. Traditional transceivers and signal processing techniques, therefore, cannot be applied as-is. Signal propagation loss over air also rises in proportion to the square of the frequency, which means that new amplifiers, antennas, and the other components must be designed and developed. NICT is developing the terahertz-wave platform technology, including wideband signal generation, transmission, and reception based on high-speed fiber-optic technologies. The optical technology has an extremely broad bandwidth,

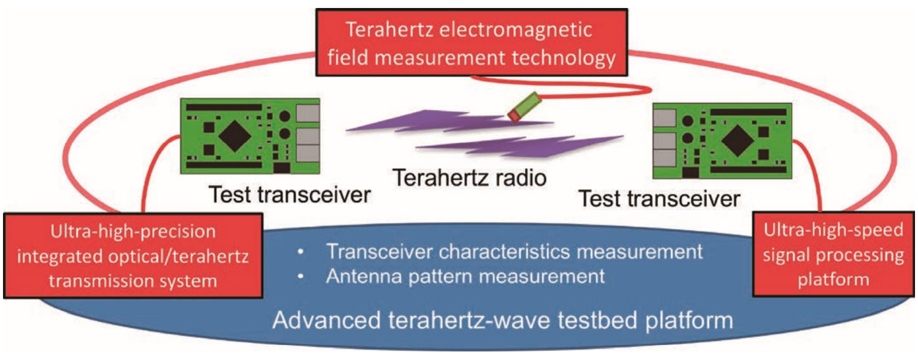

Figure 1 Overview of terahertz-wave testbed platform

and thus generated frequencies can be tuned and provide 100 Gbps-class high-capacity signals. Techniques for generating terahertz waves using optical frequency comb technology are being developed to ensure high-frequency stability. Meanwhile, radio signal transmissions in the 300 GHz and 600 GHz bands have been demonstrated through radio over fiber technology, which integrates fiber-optic communication systems with wireless communication technologies (Figure 2). NICT is also working on narrow-beam radio systems to both transmit and receive signals efficiently by suppressing transmission loss and optimize the irradiation areas to secure physical-link security. Employing the testbed platform based on optical technology is not only useful in developing and evaluating the 300 GHz-band systems expected to be used in the future but also contributes to research in advanced radio systems aimed at even higher frequencies and broader bandwidths.

Pushing the limits of radio wave use

Radio Regulations defines 3 THz as an upper limit for radio waves. In the ultra-high-frequency band of 2–3 THz, even simple generation and detection of signals is a difficult process, which has thus far limited applications to radio astronomy, spectroscopic measurement, and so on. The atmospheric absorption baseline is extremely high –100 dB/km– and molecular motion in the air produces many sharp absorption lines; however, there are several relatively low-loss windows with bandwidths of around 100 GHz. In other words, these ultra-high-frequency bands may be applicable in ultra-high-speed and broad-bandwidth communication, if used at short ranges. NICT is researching proprietary technologies such as terahertz-band semiconductor lasers, superconducting detectors, and more. Integrating these technologies will enable wireless communication systems that make use of extremely high frequencies exceeding 2 THz.

Figure 3 shows a terahertz-wave communication system currently being developed at a frequency greater than 1 THz. The transmitter is based on optical technologies, while the receiving system employs a superconductive electronic device. An optical frequency comb generator is used for signal generation. The signals of two terahertz frequency-separated components extracted from an optical frequency comb signal are data-modulated and input to a uni-traveling-carrier photodiode (UTC-PD) to generate the modulated signal in the terahertz bands. This method makes it possible to provide high stability and flexibility in terms of the terahertz wave frequency.

A heterodyne technique employing a high-sensitivity hot-electron bolometer mixer (HEBM) is used for the receiver system (see pp. 8–9). The local oscillator (LO) for frequency down-conversion in the receiver is a terahertz quantum cascade laser (THz-QCL). A terahertz-wave-band phase-locked loop (PLL) circuit was developed to stabilize the frequency, and finally, communication. Terahertz waves from the THz-QCL were received by a superlattice mixer (SLM) and compared with a microwave reference signal to obtain an error signal. The error signal was fed back into the system to stabilize the linewidth of the THz-QCL of approximately several MHz to less than 1 Hz (see pp. 6–7).

The HEBM receives the modulated signal in the terahertz bands from the transmitter, and the signal converted to the microwave band through integration with the frequency-stabilized THz-QCL is demodulated with a vector signal analyzer (VSA). This makes it possible to verify terahertz-wave radio systems in environments similar to traditional wireless communication even at extreme frequencies of several THz.

Future prospects

As millimeter waves continue to take on a primary role over microwaves in the 5G era, the demand for terahertz radio systems, which can realize even more advanced communications, radar, location measurement, and more, will continue to increase. However, a testbed platform for testing, evaluating, and providing feedback for terahertz radio systems is essential for exploring practical applicability for services. Developing the testbed platform technology based on optical technology has also enabled terahertz radio system verification, which goes beyond radio waves. The testbed platform technology is expected to be very useful in verifying new terahertz-wave systems in the future.

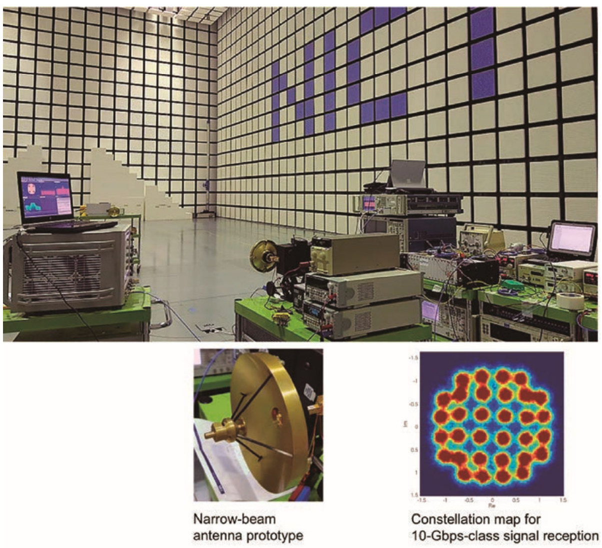

Figure 2 High-speed terahertz communication experiment using integrated optical/terahertz platform technology

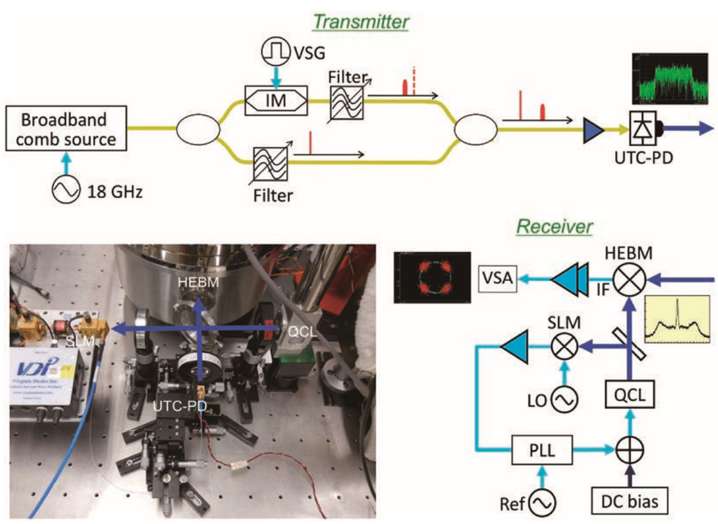

Figure 3 Overview of extreme-high-frequency terahertz communication system