Techniques of Measurement Standards for Terahertz Band

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After completing a doctoral course, joined the Communications Research Laboratory, Ministry of Posts and Telecommunications (currently NICT) in 2000. Since then, engaged in research on frequency standards, including primary frequency standard development and reference signal distribution using optical fiber. Ph.D. (Science).

As terahertz waves become practically applicable in communications, sensing techniques, and more, precise measurements of radio field strengths and frequencies is essential. NICT is engaged in R&D providing accurate standards with respect to radio field strengths and frequencies for terahertz wave measurements.

Why NICT measures terahertz waves

For the past 70 years, NICT has been offering a paid calibration service which articulates the relationships between the standard instruments maintained and managed by NICT, and the instruments used in inspections and maintenance checks required to obtain radio licenses in Japan. The calibration of RF power meters and frequency standard instruments, which are fundamental to determining the characteristics of radio waves, are the services into which NICT has poured the most energy. Meanwhile, in anticipation of an era where terahertz waves will be used extensively, NICT is pushing forward with R&D for techniques for the highly-accurate measurement of radio field strengths (for RF power), high-accuracy generation of terahertz frequencies, and more.*

Techniques for measuring radio field strengths

RF power meters are used to measure the strength of radio fields. NICT has offered an RF power meter calibration service, extending up to 0.11 THz (110 GHz), since 2007. Following in the footsteps of this service, in 2011 NICT began working with the National Institute of Advanced Industrial Science and Technology to research and develop a device known as a calorimeter, which can provide reference values for RF power for terahertz waves. NICT also began R&D into calibration services for calibrating RF power meters given by customers, so that they can use accurate values.

Thus far, we have developed power meter calibration devices like the one shown in Figure 1 and provided services for calibrating RF power meters up to 0.33 THz (330 GHz). As technologies which use radio waves become more advanced, the frequency range for our calibration service is expanding from lower to higher frequency bands; and although we are only just entering the terahertz band, after having no values to serve as standards, we have finally reached a milestone for reference values to measure the strengths of terahertz fields.

From now on, if we use power meters that have been calibrated correctly, we will be able to express the strength of terahertz fields as numerical values. For example, in research papers, it should be possible to take qualitative statements such as "we have developed a generator capable of emitting a stronger radio field than was traditionally possible" and express them quantitatively, e.g., "we have developed a generator capable of emitting a radio field at 0.484 mW ± 0.041 mW, an increase of 28 % over traditional techniques." One meter measured using a calibrated ruler is the same one meter throughout the world, so just as one can compare lengths from different locations. Similarly, we will be able to compare radio field strengths of the terahertz waves emit from the distant generators without needing to bring them to the same location.

Incidentally, an RF power meter measures the strength of radio waves propagating through a waveguide. An antenna is needed to measure the strength of the radio waves traveling through a space. The antenna can be thought of as a "converter" which enables the RF power meter to take a measurement by converting the radio waves traveling through the space into radio waves propagating through the waveguide. However, the conversion factor must be known at that time. To that end, we are researching and developing calibration for standard gain horn antennas, which serve as a reference for a variety of antennas; circular horn antennas, which show promise for use in IoT sensors for detecting obstructions; and more (Figure 2).

Techniques for measuring frequencies

NICT is a public institution which, in addition to the calibration services described earlier, also sets the national standard of frequency. Distributing the frequency standard based on the definition to real society is one of the institute's missions. The terahertz wave will likely be applied in more and more parts of our lives, and thus like the field strengths discussed above, terahertz frequencies will need to be measured with a high level of accuracy for frequency resources to be used effectively. In this section, we will introduce terahertz frequency measurement, as well as terahertz frequency reference generation and its measurement applications, based on an optical comb.

An optical comb, an ultrashort pulses laser whose oscillation modes have constant frequency intervals, is widely used for highly-accurate measurements of optical frequencies. Also, in terahertz frequency region, a combination of an optical comb and a photoconductive antenna enables direct frequency measurement of the terahertz wave. We have confirmed that, under certain conditions, the system we developed (Figure 3) is capable of measuring the absolute frequency of terahertz waves at the same level of accuracy as the national standard of frequency. Moreover, a terahertz frequency reference having the same accuracy as the national standard of frequency can be generated at any desired terahertz frequency by photomixing two arbitral oscillation modes extracted from an optical comb using the nonlinear effect of optical fibers. Combined with a superconducting frequency mixer (see pp. 8-9) highly-sensitive frequency measurement of terahertz waves is possible. We successfully demonstrated the frequency measurement of the remote terahertz wave (the narrow line width 3 THz quantum cascade laser discussed on pp. 4-5) at an optical fiber endpoint as shown in Figure 4.

In addition to measuring the absolute frequencies of terahertz waves, we are engaged in ongoing research for terahertz frequency standards in various areas. These include terahertz frequency reference transmission, which shows promise for application in remote calibration and frequency comparisons; the development of frequency standard based on quantum transitions in atoms/molecules, which can serve as an independent frequency reference in the terahertz band; and more.

Future prospects

Research & development is already underway for next-generation mobile communication systems aimed at Beyond 5G. Completely new services and applications using terahertz waves will likely begin appearing in the near future. NICT will continue to lead global R&D into techniques for precisely measuring radio field strengths and frequencies— the primitive measurand for using the terahertz band —and promote the spread of terahertz technologies throughout society through our calibration service.

＊ "Able to generate with a high level of accuracy" and "able to measure with a high level of accuracy" are synonymous, and which is made more accurate differs depending on physical quantities.

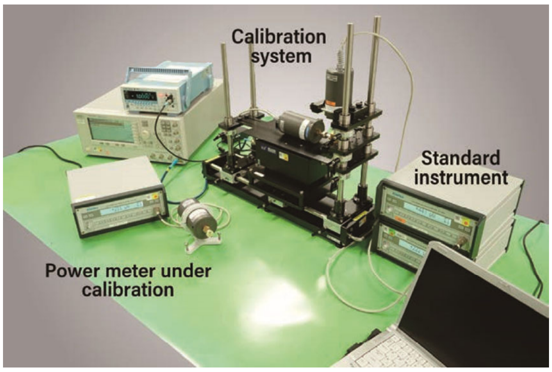

Figure 1　RF power meter calibration system
A calibration system of power meters for terahertz waves, owned by customers. The service is provided for individual frequency bands, based on the dimensions of the waveguide.

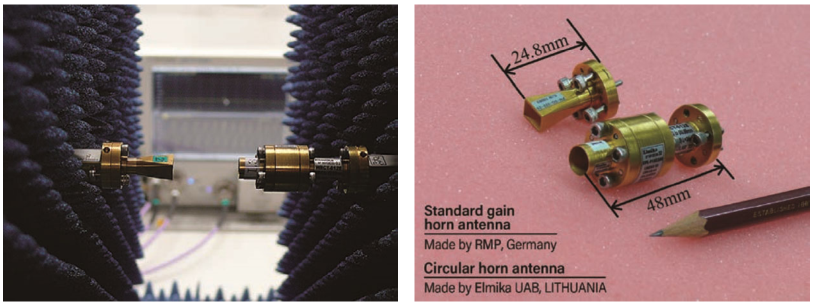

Figure 2　Research on antenna calibration
NICT is involved in R&D for determining the actual gain in antennas for measuring the strength of terahertz waves traveling through a space.

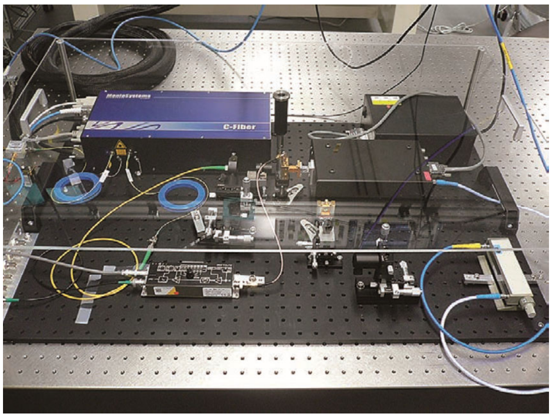

Figure 3　Terahertz frequency measurement system using an optical comb and a photoconductive antenna

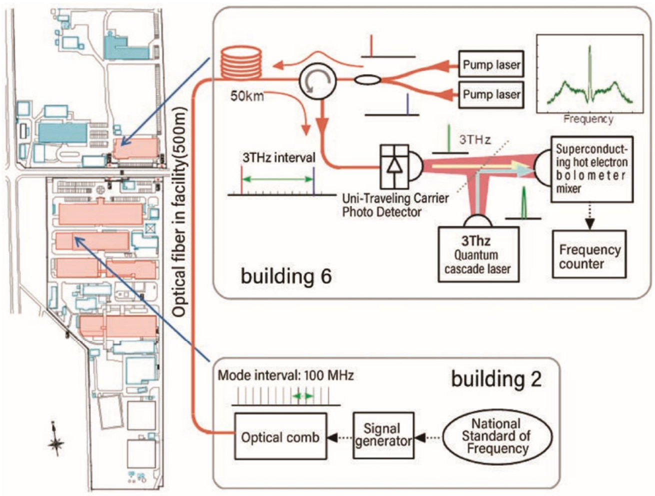

Figure 4　Terahertz frequency reference transfer and frequency measurement of the remote terahertz wave using an optical fiber link at the NICT site