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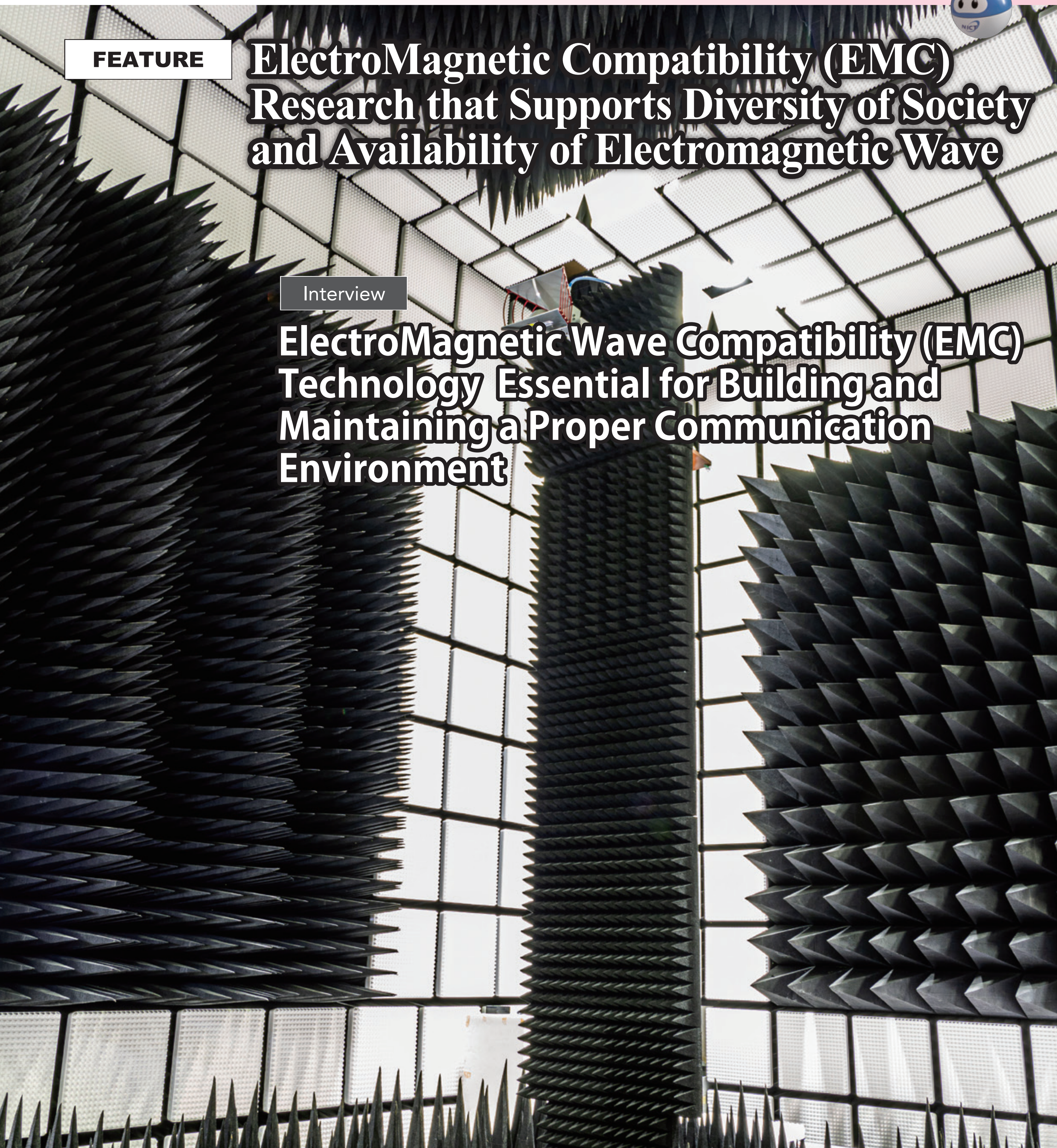
FEATURE

ElectroMagnetic Compatibility (EMC) Research that Supports Diversity of Society and Availability of Electromagnetic Wave

Interview

ElectroMagnetic Wave Compatibility (EMC) Technology Essential for Building and Maintaining a Proper Communication Environment



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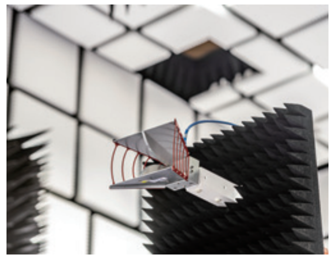


Cover Photo
Anechoic chamber
This experiment chamber is a space in which radio waves do not leak, reflect, or reverberate. This is achieved by installing radio-wave absorbers on the walls, floor and ceiling which are surrounded by metal. In the chamber, the radio wave environment is isolated from outside. Thus, during experiments, the radio waves do not leak to the outside and conversely the radio waves of smart phones and television broadcasts, etc., being used outside do not enter the chamber.
Shield surface dimensions:
length 12 m × width 7 m × height 6.8 m
Interior effective dimensions:
length 10 m × width 5 m × height 4.8 m

Photo Upper Left
Antenna used for electromagnetic noise measurement
This is one of the broadband antennas which has the ability to measure the electromagnetic noise of frequency from 1 GHz to 18 GHz. Generally, antennas used in communications and broadcasting are designed to drive only at the operating frequency, but antennas used in electromagnetic noise measurement are designed to be able to receive radio waves over a broad frequency band because they have to measure electromagnetic noise which is emitted at an unknown frequency.

Interview

ElectroMagnetic Wave Compatibility (EMC) Technology Essential for Building and Maintaining a Proper Communication Environment

GOTOH Kaoru
Director of Electromagnetic Compatibility Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After Completing a doctorate course in 2002, Dr. Gotoh worked as an Assistant Professor at Sugadaira Space Radio Observatory of University of Electro-Communication. Then she joined CRL(Currently NICT) in 2003. She has been engaging in research of EMC of communication systems. Ph.D.(Engineering).

Devices used in communication, such as smartphones, have become essential for our lives. Wireless communication is used not only for smartphones, but throughout modern society, and underpins our comfortable society as a whole. However, the intermingling of invisible radio waves in a complex manner raises the question of what impact radio waves have on other wireless communication and electronic devices, as well as on the human body.
In this interview, we asked Director Kaoru Gotoh of the Electromagnetic Compatibility Laboratory about the present state and future of electromagnetic compatibility (EMC) technology, which supports the safety and reliability of the radio wave use environment.

——What is EMC?

GOTOH The general public may not be familiar with the term, but "EMC" stands for "Electromagnetic Compatibility." This field of research was started to enable the compatibility and joint use of multiple devices by preventing the radio waves emitted from various electronic and electrical devices interfering with or jamming each other. Currently, the impact of radio waves on human beings is also part of the research conducted in the EMC field.

Many devices around us use radio waves to carry out communication, most notably smartphones and wireless local-area networks. At the same time, in addition to these communication devices, many other electrical and electronic devices exist. When unnecessary radio waves (electromagnetic noise) are radiated from those devices, they interfere with surrounding wireless communication and broadcasting, cutting out communication or distorting images on broadcasting screens, leading to a blackout.

This radio wave interference phenomena have been known about for a long time. I imagine many people have experienced the sound of static on an AM radio during a thunder storm, for example. Today, wireless communication and broadcasting technologies continue to evolve, with most having been digitalized, but even now, electromagnetic noise remains the archenemy of wireless communication. When temporal changes to the electrical current occur inside electrical and electronic devices, an electromagnetic field is created in the surrounding environment and becomes electromagnetic noise. Furthermore, focusing on wireless communication devices, which suffer interference from the electromagnetic noise, nowadays, one person often has multiple wireless communication devices, such as their smartphone, and the spatial density of radio wave use has become ex-

Interview

ElectroMagnetic Wave Compatibility (EMC) Technology Essential for Building and Maintaining a Proper Communication Environment

tremely high. Moreover, ever higher frequency bands are being used by these devices and bands are becoming broader to support communication involving large volumes of data, such as viewing 4K and 8K videos. At higher frequencies, the state of the electromagnetic radiation is affected by even slight changes in the position or orientation of devices. In addition, the radio wave use environment is becoming more complex, with, for example, the increasing prevalence of Internet of Things (IoT) devices, which continuously emit faint radio waves.

The Electromagnetic Compatibility Laboratory is engaged in a comprehensive range of activities in the face of such a complex electromagnetic environment, from R&D to contributions to Japanese and international standard-making, with the aim of realizing a safe and secure electromagnetic environment, where interference between different devices' electromagnetic waves devices is prevented, malfunctions due to electromagnetic noise are averted, and potential negative impacts on the human body due to radio waves are avoided.

Ever increasing importance of EMC Alongside the Transition to High-frequency Waves

── Please describe the structure of the Electromagnetic Compatibility Laboratory.

The Electromagnetic Compatibility Laboratory is composed of four research projects and one operations group.

The four research projects are the Radio Wave Exposure Level Monitoring Project, which measures and compiles data on radio wave exposure levels in a variety of everyday environments, the Project of the Wireless Communication Systems EMC, which researches methods for evaluating electromagnetic noise interference, the Calibration Technology Project, which conducts R&D on fundamental technologies and calibration systems for radio wave measurement, and the Biomedical EMC Project, which researches technologies for evaluating the impact of radio waves on living organisms.

The research content of each project may differ, but the shared objective across the whole Electromagnetic Compatibility Laboratory is to research how best to evaluate the impact of electromagnetic noise emitted from electrical and electronic devices and radio waves emitted from wireless communication devices on other devices and the human body, and to stipulate efficient and rational measures and rules for ensuring that electromagnetic waves do not have a negative impact on their surroundings.

There are two key concepts in EMC: "emission," which means the radiation of electromagnetic noise, and "immunity," which expresses the capacity of electrical and electronic devices to withstand electromagnetic noise. In emission, a limit is necessary for ensuring that no electromagnetic interference is caused to the surrounding wireless communication and broadcasting systems. In immunity, it is necessary to stipulate a test irradiation level of radio waves that can be used as a reference for ensuring that electrical and electronic devices do not malfunction. The fundamental aim of electromagnetic compatibility is to ensure that various electrical and electronic devices do not interfere with other devices and, at the same time, that they are resistant to interference by other devices, thereby realizing an electromagnetic environment in which these different devices can coexist.

The NICT Electromagnetic Compatibility Laboratory's mission is to contribute to the maintenance of good electromagnetic compatibility from a neutral and fair perspective and is engaged in rule-making for that purpose. We measure and evaluate the electromagnetic noise produced by a variety of electrical and electronic devices, develop limits for electromagnetic noise that are considered to be necessary to protect wireless communication and broadcasting and related measureme methods, and incorporate these limits and methods in the rules. Electrical and electronic devices are available internationally, so international standards for regulating the electromagnetic noise emitted from such devices are needed. The international standards are stipulated by an organization called the "Comité International Spécial des Perturbations Radioélectriques" (CISPR, the International Special Committee on Radio Interference), and many researchers from the Electromagnetic Compatibility Laboratory are also participating in the formulation of such standards.

── So the Electromagnetic Compatibility Laboratory conducts research aimed at solving problems in the complex electromagnetic environment?

GOTOH That's right. EMC is a research field that evaluates the mutual interference and negative impacts that are inevitably caused by the use of radio waves and seeks to prevent or reduce them by establishing rational standards. All knowledge concerning radio waves is necessary for that purpose. In addition to electromagnetism, radio wave engineering, antenna engineering, and measurement engineering, knowledge from fields such as communication engineering, chemistry, and physiology is necessary for deeply understanding all the objects exposed to radio waves. For that reason, our laboratory brings together researchers from a wide range of fields and can be said to facilitate an extremely broad range of highly stimulating research.

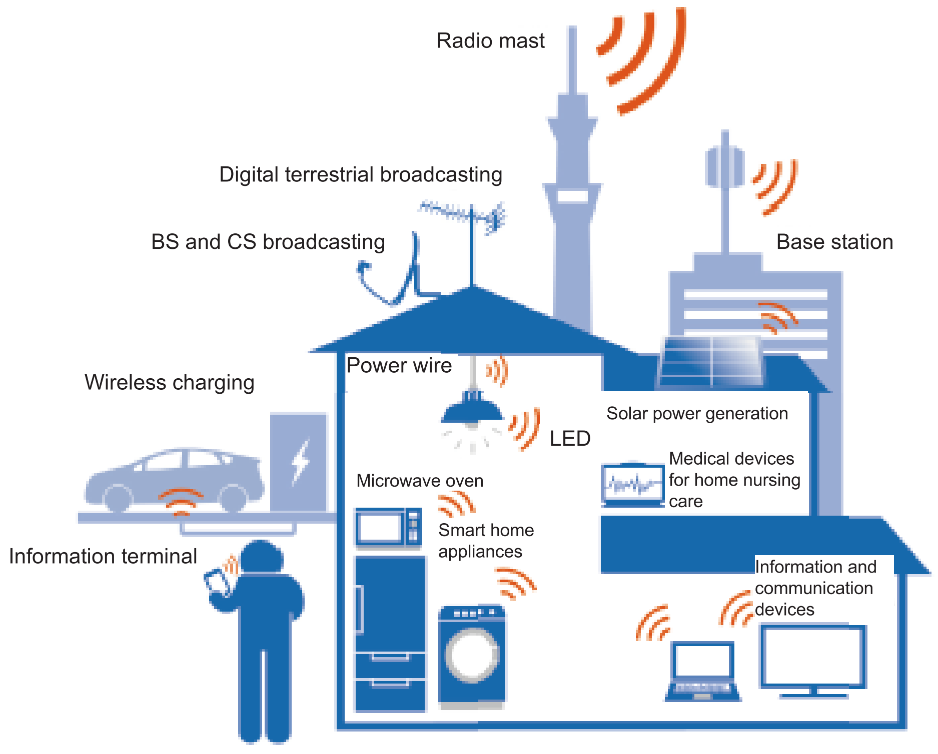
Furthermore, a key characteristic of EMC research in recent years has been the need to evaluate the extremely high frequencies of the sub-terahertz band and the terahertz band. This is because deliberation of the standards for Beyond 5G/6G is underway and these are the frequency bands being considered for Beyond 5G/6G use. What EMC research must focus on first is the development of technology to evaluate these frequencies' impacts on the human body. The Bio-EMC Project is driving the safe use of radio waves in the terahertz band by developing human body equivalent phantoms and computational human models to serve as subjects that simulate the electrical properties of the human body in the terahertz band in radio wave exposure experiments. It is also developing radio wave exposure equipment using gyrotrons and establishing systems to measure the temperature changes on the surface layer of the skin caused by radio wave exposure.

One more important EMC issue in the terahertz band is the development of calibration technology for radio frequency (RF) measurement instruments. A radio station license is required to emit radio waves from wireless equipment, and during the license application process, RF measurement instruments that are guaranteed to show the "correct values" for power, etc., must be used to measure the quality of the radio waves and conduct inspections. These "correct values" in the Radio Act are guaranteed by calibrations carried out by the Calibration Service Group in NICT's Electromagnetic Compatibility Laboratory and the results forms issued based on the calibrations.

Meanwhile, with Beyond 5G/6G R&D being actively conducted, most communication systems developers now start by installing an experimental test station to evaluate the system. RF measurement instruments calibrated for the Beyond 5G/6G frequency band are required for issuing the license for that experimental test station. Therefore, calibration systems for that frequency band must be completed even before the development of Beyond 5G/6G. Such work is fundamental for radio wave use and, if delayed, can result in a bottleneck in Japan's Beyond 5G/6G research. The Electromagnetic Compatibility Laboratory's research projects and operations group are therefore working together to develop calibration systems for up to one THz.

── Risk communication concerning the use of radio waves is also important, isn't it?

GOTOH As higher frequencies get used for mobile phones and so on, more people than before are feeling anxious about the use of electromagnetic waves. Our laboratory's Radio Waves Exposure Monitoring Project is obtaining and compiling radio wave exposure level data from a variety of environments and plans to publicly release the data. Moreover, it has commenced research into risk communication, namely, how to provide information based on these data and engage in two-way communication so as to accurately and effectively convey the actual situation. This is the latest initiative that our laboratory is engaged in. We believe that it is important for us, as a neutral, transparent, and reliable national research institute, to not only aim for safe radio wave use, as we have done previously, but also accurately communicate the facts based on scientific data.



EMC: Mutual interactions among communication systems, electronic equipment, and the human body

"Harmony" to be the Theme of EMC Going Forward

── What is your vision going forward?

GOTOH Firstly, in terms of the trends, as I stated earlier, radio wave use is moving toward the extremely high-frequency terahertz band. We must firmly respond to these developments. Our laboratory is particularly aware of the importance of anticipating future demands from society, while also taking into account the latest technology trends, so that we can take the lead in R&D, rather than merely responding to problems only after they arise, as has been the case in conventional EMC research.

Secondly, wireless communication devices and electrical and electronic devices are being used in increasingly spatially dense ways. For example, in factories and warehouses that use automated robots, malfunctions caused by radio wave interference are extremely dangerous and the economic losses can be large. We believe that the question of how to handle the EMC of robots and other technologies that are equipped with wireless communication functions and that operate and move autonomously is a major issue.

Finally, I would like to mention appropriate interfaces with people that are based on the effects of radio waves on people's intentions. It is human beings who engage in radio wave use, so I think that, even as AI technology advances at remarkable speeds throughout society, the research that I mentioned earlier on communicating the risks of radio waves, which concerns the invisible issue of how radio waves affect human beings' consciousness, will remain a difficult and longstanding challenge. Previously, in an article I submitted to a different journal, I wrote that "just as psychological harmony between people is valued in a mature society, perhaps electromagnetic harmony between objects will become important in a society with advanced science and technology." Since then, I have refined my thinking further and, going forward, I intend to promote R&D aimed at electromagnetic harmony not only among objects, but also with people.

── Thank you for your time today.

Monitoring of Radiofrequency Electromagnetic Field Exposure Levels

Measurement of radiofrequency electromagnetic fields in real environment

ONISHI Teruo

Research Manager, Electromagnetic Compatibility Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After working for several companies, he joined NICT in 2019. He has been engaging in research and development on monitoring of electromagnetic field exposure levels. Ph. D. (Engineering).

The environment around us is overflowing with a variety of equipment that uses radio waves. Radio waves from broadcasting, mobile telephones, wireless LANs, etc., are used within a scope that does not have any adverse health effects on the human body, based on the Japanese Radio Wave Protection Guidelines. On the other hand, there are also people who are made anxious by the fact they do not know how strong the radio waves are because they are invisible, even though they definitely exist in the environment around them. Therefore, we are conducting this research towards comprehensively clarifying the radiofrequency electromagnetic field (RF-EMF) environment, mainly in everyday life.

Background

On the subject of the safety of the equipment using radio waves around us, the 2018 report by the Working Group on Research Strategies concerning the Bioelectromagnetic Environment of the Ministry of Internal Affairs and Communications (MIC) discusses research concerning risk communication. It also calls for the strength of radio waves from a variety of generation sources to be measured comprehensively, for the data to be accumulated over the long term, and for information about RF-EMF exposure levels to be shared widely.

As the only public research institute in Japan specializing in the information and communications field, NICT began research into the acquisition, accumulation, and utilization of RF-EMF exposure level monitoring data from FY2019. This research aims to comprehensively clarify the RF-EMF environment, mainly in everyday life, and to present modes of risk communication that enable appropriate explanations and dialogue regarding the possible risks arising from the development and expansion of the use of radio waves. In this paper, we introduce monitoring of RF-EMF exposure levels.

Methodologies for Monitoring RF-EMF Exposure Levels

As shown in Figure 1, the monitoring methodologies for comprehensively ascertaining RF-EMF exposure levels can be broadly divided into spot measurement, long-term fixed-point measurement, mobile-type measurement in which individuals carry portable measuring devices, and measurement using a car equipped with measuring devices etc. With spot measurement, it is possible to take the measurements from any location, with the drawback that carrying out measurements over a broad scope is difficult from a human resources perspective. Long-term fixed-point measurement involves fixing a place to carry out long-term measurements continuously. On the other hand, with measurement using an Electric field (E-field) measurement equipment mounted car, it is possible to measure RF-EMF exposure levels over a broad area by driving around while carrying the measuring instruments, although it is not possible to measure temporal variations at each location. Furthermore, with the methodology of individuals carrying portable measuring devices, unlike with the above methodologies, it is possible to continuously observe the amount individuals are exposed to radio waves. This kind of measurement is also called micro-environment measurement. By combining these different methodologies, we can reduce bias in the data and acquire large-scale, detailed data on the RF-EMF exposure levels.

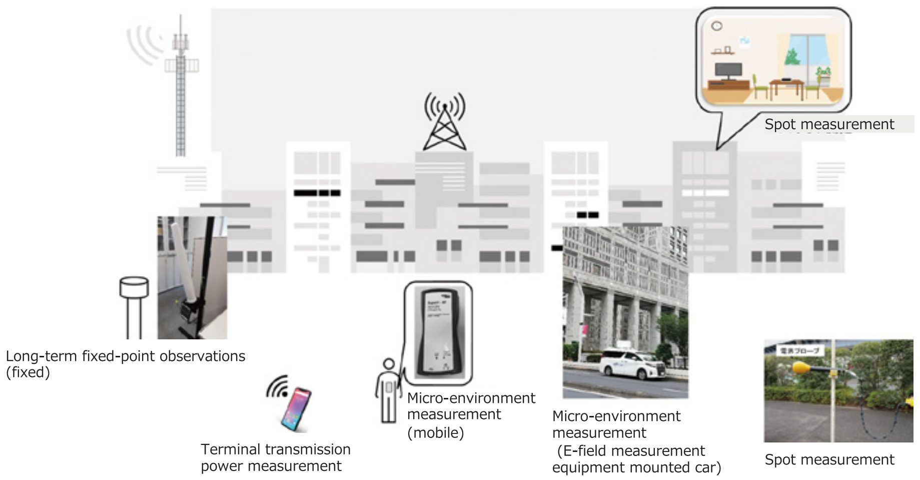


Figure 1 Overview of monitoring method

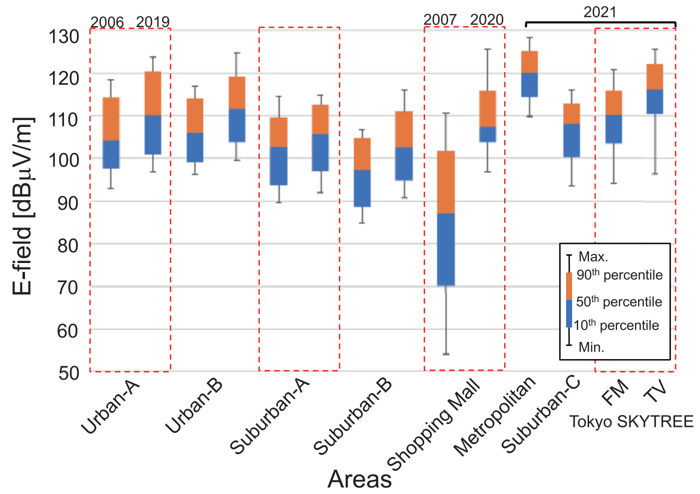


Figure 2 E-field strength from the mobile phone base stations and broadcast transmission towers

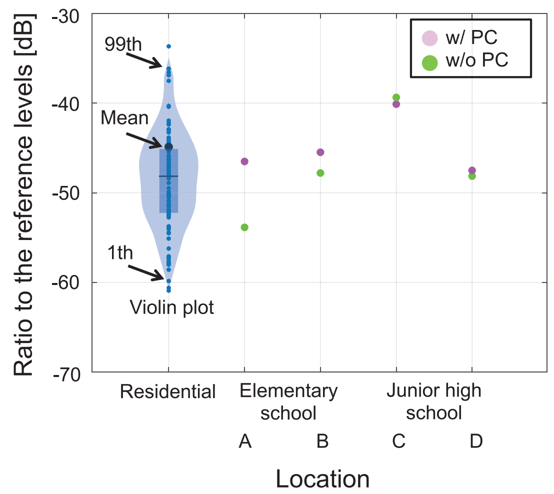


Figure 3 Measurement results inside residences and classrooms (compared to the Radio Wave Protection Guidelines)

Measurement Results (outdoors and underground shopping malls)

The results for the E-field strength [dBμV/m] for all these bands with respect to mobile phone base stations and broadcast transmission towers are shown in the box and whisker plot (Figure 2). Furthermore, we presented the urban-A/B, suburban-A/B, and shopping mall results for the sake of comparison with the results of past surveys by the MIC. The numbers stated on the graph show the fiscal years in which the measurements were taken. They are not displayed for urban-B and suburban-A/B, but these measurements were taken in the same fiscal year as urban-A. It was found that the median value of the E-field strength for metropolitan areas was the highest compared to the other measurement results. Furthermore, it can be seen that even in the vicinity of the broadcast transmission towers, the E-field strength level is about the same as metropolitan mobile phone base stations.

When comparing the past and present measurement results for urban-A/B and suburban-A/B, respectively, it was found that the current E-field strength is significantly higher than in the past for both urban areas and suburban areas. It is supposed that the E-field strength for shopping malls in the past was low due to the fact that mobile phone services at that time could not be used in some parts of shopping malls. It was revealed that although the level is rising overall, it is low with respect to the Radio Wave Protection Guidelines in all cases (approximately 1/10,000 or less).

Measurement Results (inside residences and classrooms)

Figure 3 shows the integrated ratio of the value of each frequency band and the Radio Wave Protection Guidelines value. It shows the maximum values found by integrating all of the frequency bands of the mobile phone and broadcasting and wireless LANs using the moving averages for every 6 minutes of 24 hours of data inside residences and 8 hours of classroom data with regard to the measurement results inside 48 residences and classrooms. The first column of the figure expresses the results from inside residences with a box and whisker plot and a violin plot, and the second and subsequent columns show the results at times when classes were using personal computers (PC) and at other times. It was found that the results inside both residences and classrooms are lower than the Radio Wave Protection Guidelines for the general environment, and that even when using PCs inside elementary and junior high school classrooms, the RF-EMF exposure levels were about the same as the average value inside residences.

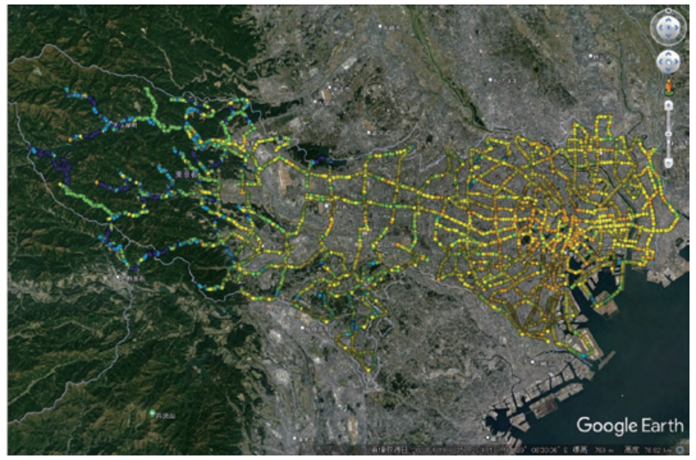


Figure 4 The E-field strength distribution of the Tokyo Metropolitan Area measured using the E-field measurement equipment mounted car

Measurement Results (E-field measurement equipment mounted car)

For the E-field measurement equipment mounted car, we installed two three-axis isotropic probes for 27 MHz to 3 GHz (low frequency use) and 420 MHz to 6 GHz (high frequency use) inside a radome on the roof of the vehicle (Figure 1). We carried out measurements in FY2021 over a total measurement distance of approximately 15,000 km within a radius of 100 km centered on Nihombashi, Tokyo. We selected general roads for the measurement routes excluding highways (mainly national routes) in order to comprehensively cover each municipality. Figure 4 shows an E-field strength map using the measurement results within the Tokyo Metropolitan Area, as an example. The E-field strength at each measurement spot is expressed with colors (with orange for the highest strength, followed by yellow, green, and blue), indicating that there is a difference in the E-field strength between the city center and suburban areas. In particular, it was found that in the city center, the strength is mostly 110 dBμV/m or higher whereas in suburban areas, it is 110 dBμV/m or less. Furthermore, when we investigated the relationship with population density, it was found that there is a proportional relationship between the E-field strength from mobile phone base stations and population density.

Future Prospects

We will continue to advance research to enable the radio wave environment in daily life to be comprehensively clarified and we will report the measurement results. Meanwhile, new wireless technologies are being developed and the environment around us is overflowing with a variety of products. Although it is impossible to measure all of them, we plan to use AI and other technologies to supplement our approach to the radio wave environment.

Establishing a Secure and Sustainable Electromagnetic Environment

Research and development of models to predict the aggregation effects of unwanted electromagnetic waves and the degradation of the electromagnetic environment

Ifong Wu
Senior Researcher
Electromagnetic Compatibility Laboratory,
Electromagnetic Standards Research Center,
Radio Research Institute

After receiving the D.E. degree in electrical engineering and electronics, Dr. Wu joined NICT in 2007, as a researcher. He has been engaged in research on the electromagnetic compatibility of radio communication systems. Dr. Eng.

In recent years, advanced wireless communication services, most notably the fifth-generation service (5G), have commenced. On the other hand, the characteristics of unwanted electromagnetic waves generated from electrical and electronic devices have also been changing. Specifically, with the proliferation of IoT (Internet of Things) devices and energy-conserving devices, the simultaneous usage of devices is expected to increase, leading to a rise in electromagnetic noise levels. Although numerous empirical studies have been conducted to measure and evaluate these electromagnetic noises, these studies have not fully elucidated their causes or underlying physical mechanisms. In pursuit of achieving coexistence between electrical and electronic devices and wireless communication, we are engaged in R&D aimed at understanding the potential conditions for such coexistence.

Background

The sustainable development of cyberspace, which is continuing to expand rapidly, greatly depends on the radio wave resources used in communication with smartphones, etc. Up until now, there has been active development of communication methods and devices aiming for the highly efficient use of radio wave resources. On the other hand, it must be noted that discussions from the perspective of "the degradation of the radio wave environment due to the increase in unwanted electromagnetic waves radiated from electrical and electronic devices" have been slightly lacking. In order to take action against degradation of the electromagnetic environment due to unwanted electromagnetic waves, it is essential to predict the extent of the impact that individual emissions regulations will have on the global environment, in the same way as for other environmental problems such as air and water pollution, warming, etc. However, the current situation is that there are almost no effective findings.

Currently, the limits of unwanted electromagnetic waves radiated from electrical and electronic devices are set to ensure that single products do not have an impact on nearby wireless receivers. However, these standards do not take into consideration the extent to which degradation of the electromagnetic environment of society overall has progressed due to the increase in the number of noise sources, or what kind of impact this has on the social infrastructure as a system using radio waves. Therefore, in the midst of the expansion and advancement of communication systems and electric and electronic devices, NICT is conducting R&D regarding the radiation of individual unwanted electromagnetic waves in order to establish models which predict the aggregation effects at the macroscopic scale and the impact on the electromagnetic environment, with the aim of establishing a secure and sustainable electromagnetic environment. To date, the generating mechanisms and properties of the unwanted electromagnetic waves caused by energy conserving devices which are expected to be widely adopted in general households (for example, LED lights, etc.) have been revealed through theory and actual measurements, including the impact when there are multiple adjacent noise sources (small-scale aggregation models). Furthermore, the amount of degradation of the electromagnetic environment in a situation in which multiple noise sources are distributed, such as a suburban residential environment, has been revealed using statistical techniques as the increase in the background noise in the wireless communication environment (large-scale aggregation models). In this paper, in order to develop methods for evaluating the unwanted electromagnetic waves radiated from individual electrical and electronic devices with the objective of the protection of wireless communication such as 5G, etc., we put the focus on the radiation properties of small-scale electromagnetic noise sources using a reverberation chamber (RC).* Furthermore, we introduce the establishment of an electromagnetic noise limit-setting model taking into consideration large-scale electromagnetic noise sources.

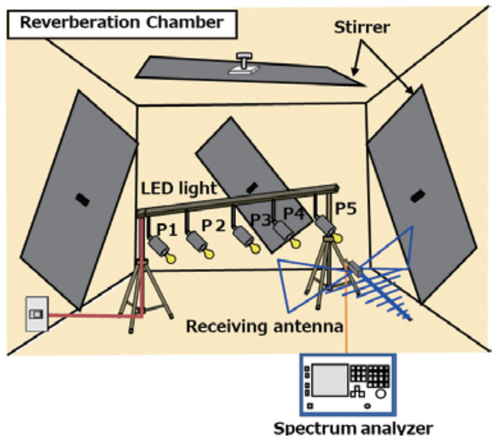


Figure 1 Schematic diagram of measurements for multiple electromagnetic noises using an RC

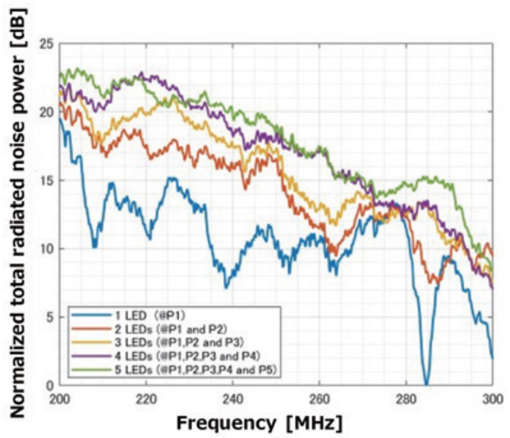


Figure 2 Variation in the total radiated noise power with changing the number of LED Lights

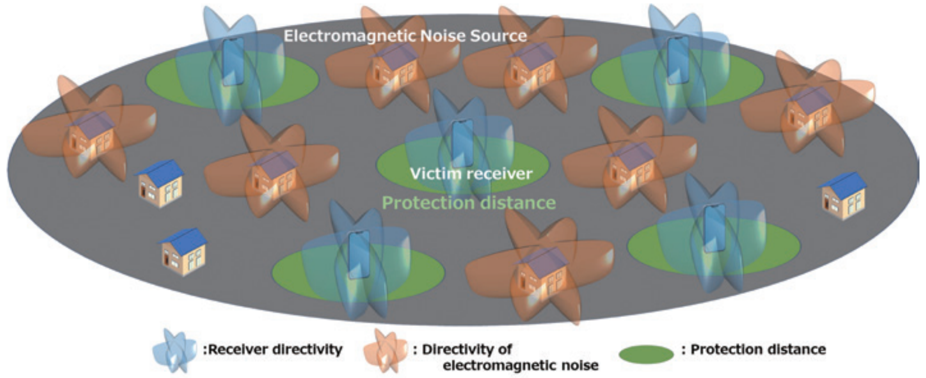


Figure 3 Interference model for radio protection from unintended electromagnetic noise

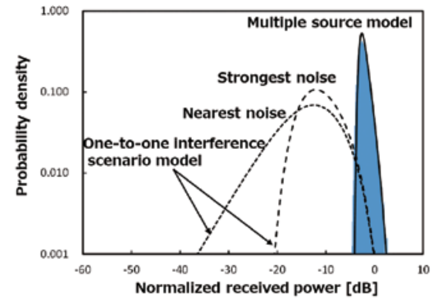


Figure 4 Example of a probability distribution of received electromagnetic noise power in the case that the electromagnetic noise sources are distributed within the distance of 100 m from a radio receiver, the protection distance is one meter, and the propagation coefficient (path loss factor) is one.
In interference models the directivity of the electromagnetic noise source (the radiation pattern representing the direction in which the noise is strongly radiated) is taken into consideration, so the electromagnetic noise source nearest the receiver is not necessarily the strongest source (the noise source which provides the strongest noise power to the receiver).

Evaluation of the Properties of Multiple Electromagnetic Noise Sources using an RC

Under the standards of the International Special Committee on Radio Interference (CISPR), limits are set for the electromagnetic noise radiated by individual products, which serves as the source of unwanted electromagnetic waves. However, there has been limited evaluation of radiated electromagnetic noise in an electromagnetic environment where multiple sources of unwanted electromagnetic waves are present simultaneously. In this article, we focus on evaluating electromagnetic noise using LED lights as the noise source, particularly when multiple LED lights are connected to the same power line, as shown in Figure 1, and present the results using an RC. Unlike an anechoic chamber, an RC enables simultaneous measurement of the total radiated electromagnetic noise power in all directions. As shown in Figure 2, we confirmed that the frequency spectrum of all of the radiated power from the LED lights is not necessarily in proportion to the number of LED lights. It is thought that this is because the arrangement of the LED lights changes the distribution of the noise current flowing along the power line, complicating the resonance of the noise current on the power line.

Limit-setting Models for Radio Protection Considering Multiple Electromagnetic Noise Sources

CISPR has defined radiated emission limits at a specified distance (=protection distance) from a noise source in order to protect the quality of radio reception in the presence of the noise. As shown in Figure 3, in a real environment, the intensity of the electromagnetic noise received by the victim receiver is not necessarily the largest; it depends on many random parameters including the radiation directivity of the electromagnetic noise, the distance to the electromagnetic noise source, propagation loss, the impact of obstacles and buildings in the propagation channel, etc. CISPR has developed limit-setting models using statistical techniques, but the current models assume one-to-one interference between an electromagnetic noise source and a victim receiver. Thus, they do not consider the aggregation effects of electromagnetic noise caused by multiple noise sources, as shown in Figure 3. NICT has established a 2D model to evaluate the impact that the increase in electromagnetic noise sources has on limit-setting with respect to protection of wireless communication, and we introduce the evaluation here. Figure 4 shows the probability distribution of noise power caused by the strongest noise source and that by all of the noise sources based on the general model we developed assuming densely distributed broadband electromagnetic noise sources. It is possible to set the limit based on an estimate of the electromagnetic noise intensity using the established model.

Future Prospects

In recent years, due to the latest information and communication technologies, namely the IoT and M2M (Machine to Machine), a smart community in which all devices connect to the Internet is being realized. However, when electromagnetic noise is generated from its constituent electrical and electronic devices, there is a possibility that the noise will interfere with the communication functions of the smart community itself. NICT aims to establish and maintain an appropriate electromagnetic environment and is advancing R&D into technologies to elucidate and evaluate the mechanisms behind the emission of electromagnetic noise in order to develop the communication technologies of the future and meet the demands of society. Furthermore, we are working on the development of technologies to prevent these problems in advance. In particular, in a situation in which multiple electrical and electronic devices (electromagnetic noise sources) and wireless communication terminals are intermingled as a consequence of the widespread adoption of 5G and the progress of R&D into Beyond 5G (the next-generation wireless communication system), we are also working on studies of electromagnetic noise evaluation technologies in order to prevent electromagnetic interference in advance.

Glossary

* Reverberation chamber (RC): as shown in Figure 1, an RC is an experimental facility equipped with rotating plates (stirrers) for scattering electromagnetic waves installed on the ceiling and walls of a room covered with metal walls. By placing a material with a conductive surface inside a metal enclosure, electromagnetic waves from the outside can be shielded, and electromagnetic waves generated by electrical and electronic devices can be reflected inside the enclosure to measure the electromagnetic radiation of the devices. The RC can also be used for emission testing, measuring the electromagnetic noise radiated from electrical and electronic devices.

Technology for Evaluating Radio Wave Exposure to the Human Body

NAGAOKA Tomoaki
Research Manager, Electromagnetic Compatibility Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After completing graduate school, he joined NICT in 2004. He has been engaging in research on bioelectromagnetic environment. Doctor of Medical Science.

In recent years, as a consequence of the rapid development of the use of radio waves, devices that emit radio waves are increasingly being used in our immediate environment. At the same time, interest in the health impacts on the human body from being exposed to those radio waves has become extremely high. In order to build a safe and secure radio wave use environment compatible with the upgrading of wireless communication technology, we have been conducting R&D into exposure evaluation (dosimetry) technology for revealing, through measurement or numerical simulation, what parts of the human body absorb radio waves and to what extent during the use of radio waves.

Background

As a consequence of the rapid progress and development of technologies that use radio waves, radio waves are being used in a variety of fields and it is predicted that the use of radio waves will continue to expand going forward, including becoming a part of many aspects of social life. At the same time, interest in the health impact of the radio waves emitted from such wide-ranging sources has also become high. It is known that the biological impact of radio waves differs depending on their frequency, with stimulatory effects generally being dominant on the low-frequency wave side below 100 kHz and heat effects due to the radio waves being absorbed by the body generally being dominant on the high-frequency wave side above 100 kHz. When thinking about the safety of radio waves, it is important to use measurement or calculation to accurately evaluate how many radio waves are absorbed by a human body that has been exposed to radio waves and which part of the human body absorbed them. We are conducting research on exposure evaluation to accurately evaluate the amount of radio waves absorbed by the human body. In particular, ethical and other constraints make it difficult to use experimental methods to evaluate the level of radio wave exposure inside the human body, so an effective approach is to conduct numerical simulation using a computational model that simulates the human body. We are advancing R&D on a computational human model that has the anatomical structure of a human body, a model that is necessary and essential for estimating the level of radio wave exposure to the human body with high accuracy, as well as R&D on measuring the electric constant of biological tissue, which is necessary for the numerical simulation of the electromagnetic field using the aforementioned computational human model. Furthermore, although it is not discussed here, we are also conducting research into conformity confirmation methods to check if the wireless communication terminals that are in actual use, such as smartphones, conform with the radio radiation protection guidelines.

Anatomically Realistic Computational Human Models

Since 2000, thanks to progress in medical diagnosis technology and enhancements in computer performance, it has become possible to precisely estimate the amount of radio wave exposure to the human body with electromagnetic field simulation using a high-definition computational human model that accurately simulates the human body. To date, we have developed various computational human models (adult males and females, pregnant women, children, etc.) based on medical images of human bodies that match the average body type of Japanese people, and have applied numerical simulation using these models to clarify that the protection levels of the guidelines formulated by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) are valid for protecting people from health impacts that are not desirable for the human body. In recent years, many of the computational human models for children that have been used in research to evaluate radio wave exposure have been problematic, such as being simply scaled-down versions of the computational human models for adults or not accurately modeling the standard body shape or internal tissue structure of children. We therefore developed the international reference computational human models for children (aged 1, 5, and 10 years) shown in Figure 1, the first in the world to have a body shape and anatomical structure that match the international reference values. The outcomes

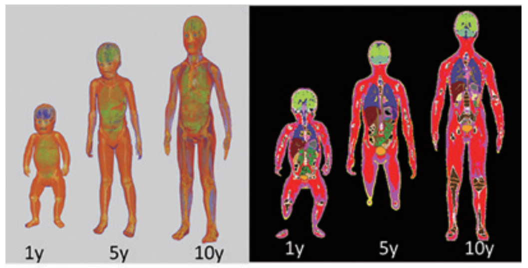


Figure 1 International reference computational human models for children

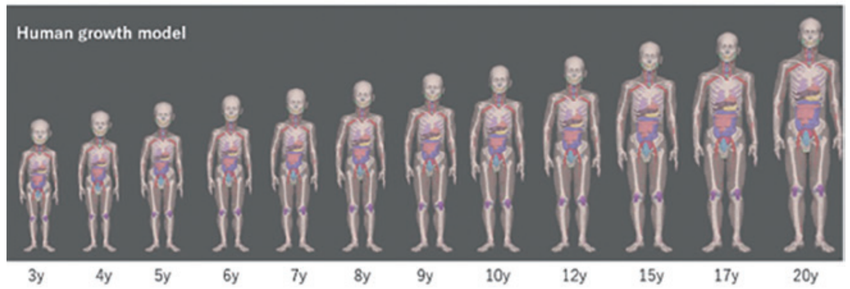


Figure 2 Growth and development model

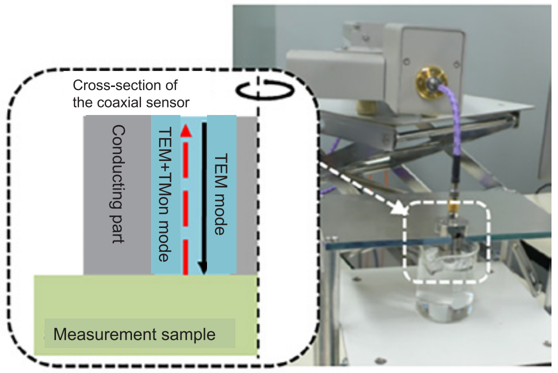


Figure 3 Measurement of the bioelectric constant using a coaxial sensor

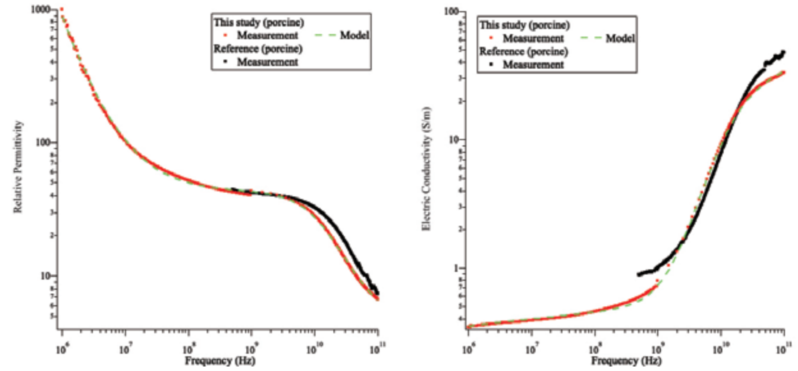


Figure 4 Measurements of the electric constant of the skin (dermis)

of evaluations of radio wave exposure using these international reference computational human models for children have been cited as the basis for the international guidelines published in 2020. Furthermore, using approaches that differ from conventional development methods for computational human models, we are working on the development of technologies for building a computational human model that simulates the growth and development of the human body as shown in Figure 2 and tailor-made computational human models matching the body shapes and internal tissue structures of individuals. We are making some of the computational human model data available free of charge for non-commercial research purposes or for a fee for commercial research (https://bioemc.net/bio/en/).

Electric Constant of Biological Tissue

It is thought that the human body is a dielectric body, and it is known that its electric constant changes depending on the tissue, internal organ, and frequency. Electric constant measurement using the tissue of the human body is not realistic from an ethical perspective, so tissue from, for example, mammalian experimental animals and livestock, which has a structure similar to the human body, is used in electric measurements as a substitute for human body tissue. Previously, an electric constant database for biological tissue published by a research group in the United Kingdom in 1996 was used in research into exposure evaluation using computational human models. This database comprises measurement data for approximately 40 types of biological tissue up to 20 GHz. Measurement data with respect to frequencies over 20 GHz, which are used in the fifth-generation mobile communication system (5G), are not included in this database. Biological tissue contains a lot of moisture, so it has a higher loss (larger conductivity) compared to the materials handled in the materials measurement field, such as those in antenna bases. Furthermore, most biological tissues, including the skin, the muscles, and the brain, are soft and difficult to shape accurately, so we use the free-space method, which is a method for estimating the electric constant of a sample by irradiating the sample with a uniform electromagnetic field from an antenna and detecting the reflected waves and permeated waves, and a measurement method whereby the mainstream coaxial sensor is used in the measurement of biological tissue with the coaxial line that is used in high-frequency wave measurement (Figure 3). We measured the electric constants of 58 types of biological tissue from 1 MHz to 100 GHz, including the millimeter wave band (Figure 4), built a large-scale electric constant database based on those measurement data, and have made it widely available (https://www2.nict.go.jp/cgi-bin/202303080003/public_html/index.py).

Future Prospects

Currently, 5G, which is being increasingly widely adopted, uses radio waves in the millimeter wave band. In the future, the use of even higher frequency bands is planned. Moreover, the use of the terahertz band in next-generation mobile communication systems (B5G/6G) is anticipated. The higher the frequency, the more the absorption of radio waves concentrates on the surface of the human body, so going forward, we hope to be able to continue to contribute to maintaining a safe and secure radio-wave-use environment in Japan and overseas by developing tissue models that accurately represent the skin and eyeballs, which are on the surface of the human body, in ultra-high-definition, and advancing R&D on technology for measuring the electric constants of these tissues and evaluating the radio wave exposure properties in these frequency bands with high accuracy, among other topics.

Electromagnetic Wave Measurement Technologies in the Millimeter Wave and Terahertz Band

Toward the realization of Beyond 5G

FUJII Katsumi

Research Manager
Electromagnetic Compatibility Laboratory,
Electromagnetic Standards Research Center,
Radio research Institute

After completing a doctoral course at university, Dr. FUJII worked at RIEC of Tohoku university as a research associate from 2001. Since 2006, he has been working for NICT. He has engaged in research of calibration methods for RF measurement instruments and the research of problems on electromagnetic compatibility (EMC). Ph. D. (Engineering).

Measuring radio waves accurately is essential technology for R&D in the electromagnetic environment. For example, even if we stipulate standards regarding the electromagnetic noise level emitted from electrical and electronic devices and the strength of the radio waves radiated from smartphones to the effect that they "shall be no stronger than a certain level," we cannot check whether the standards have been obeyed without measuring the strength of the radio waves accurately. Furthermore, it is necessary for radio equipment — not only for smartphones but also for television broadcasts and community wireless system for disaster prevention, etc.— to accurately measure the field strength and frequency of the radio waves radiated from radio equipment in order to avoid interfering with or jamming other radio equipment. We are conducting R&D into technologies for measuring radio waves accurately, technologies for calibrating measurement instruments and antennas, and other related technologies.

The Realization of Beyond 5G and the Use of Millimeter Wave and Terahertz Band Radio Waves

The next-generation mobile communication network (Beyond 5G), which is expected to be realized in about 2030, is aiming to further upgrade the communication functions of the current mobile communication network (5G). In order to realize super high speed and high-capacity communication surpassing 5G, the use of a frequency band called the millimeter wave and terahertz band is being considered. This is a higher frequency band than any previously used. We are promoting R&D into the radio waves in this millimeter wave and terahertz band.

Technologies for Manipulating Millimeter Waves and Terahertz Band

With the radio waves of the millimeter wave and terahertz band, which strongly exhibit the character of traveling in a straight line like light, a major research theme is technologies that can send out radio waves in a variety of directions or how to receive radio waves which only come from a specified direction. This is the exact opposite of conventional technologies, which absorb radio waves spreading in or around the surrounding environment, or signal processing technologies which extract the necessary information from inside radio waves coming from many directions, etc.

Therefore, we commenced research into technologies for controlling the way the radio waves are propagated and developed an Electromagnetic Scattering Sheet, which can be used in the 28 GHz band allocated for local 5G networks. With radio waves of the millimeter wave and terahertz band, which strongly tend to travel in a straight line, blind areas exist in which the radio waves do not arrive, and it is impossible to communicate in the areas separated from the routes the radio waves pass. However, when our Electromagnetic Scattering Sheet is put onto walls and ceilings, the radio waves that hit the Electromagnetic Scattering Sheet are scattered off in a variety of directions. Thus, we can reduce the blind areas in which communication is not possible and achieve a comfortable communication environment. Utilization of this technology in a variety of situations could be considered: for example, continuously sending data to the AMRs (autonomous mobile robots) and AGVs (automated guided vehicles) which are constantly moving in distribution centers and factories, sending radio waves to each hospital room from hospital corridors to ensure that communication with the computers containing electronic medical files is never interrupted, preventing communication being interrupted because people are in shadows in meeting rooms, etc. In our Electromagnetic Scattering Sheet, we have adopted a meta-material structure which is thin (only 0.8 mm thick), light, and does not require any power source. Just by simply pasting it on walls and ceilings it functions immediately, so it is easy to use. Currently, we are making improvements to convert it into a product, and we are conducting a series of demonstration experiments.

Technologies for Measuring Electromagnetic Noise

When communication in the millimeter wave and terahertz band is used, it is important to ensure that the surrounding environment does not obstruct the communication due to the electromagnetic noise emitted from a variety of devices in the surrounding environment, so it is necessary to measure the electromagnetic noise level accurately and evaluate its impact. Nonetheless, unlike the strong radio waves for communication, it is not easy to accurately measure weak radio waves like electromagnetic noise which are emitted unintentionally.

Currently, the International Special Committee on Radio Interference (CISPR) is carrying out studies aimed at the formulation of an international standard for methods to measure the electromagnetic noise level emitted from electrical and electronic devices in the 18 to 40 GHz band. In order to obtain the same results when measuring electromagnetic noise at all test sites in all countries, it is necessary for the measurement instruments, antennas, test sites (anechoic chambers), and competence of the measurers to satisfy fixed conditions. So, we are conducting research into antenna calibration methods and methods for evaluating the performance of anechoic chambers, and reporting the outcomes we obtain in CISPR meetings to promote their conversion into international standards.

Furthermore, we are currently conducting R&D into technologies that use optical fiber to transmit waveforms of electromagnetic noise received with antennas to measurement instruments without disturbing its waveforms.

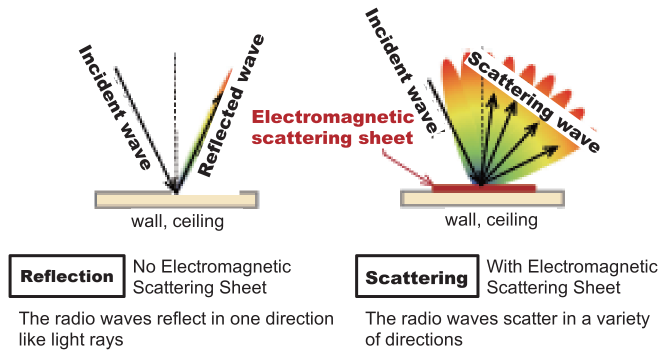


Figure1 Reflection and scattering of millimeter-/terahertz-wave

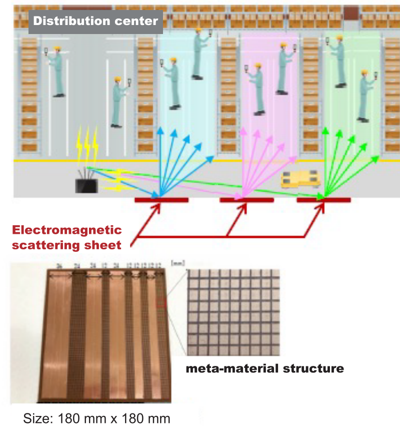
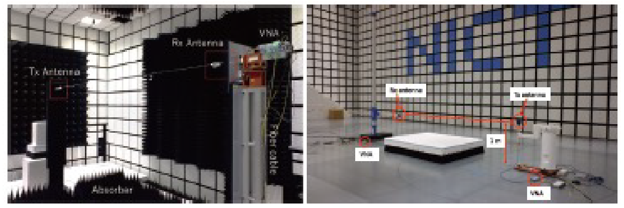


Figure2 Electromagnetic Scattering Sheet (prototype) and example of a use case (in a distribution center)



(a) antenna calibration method (b)validation method for anechoic chamber

Figure 3 Development of an 18 GHz to 40 GHz antenna calibration method and a validation method for anechoic chamber

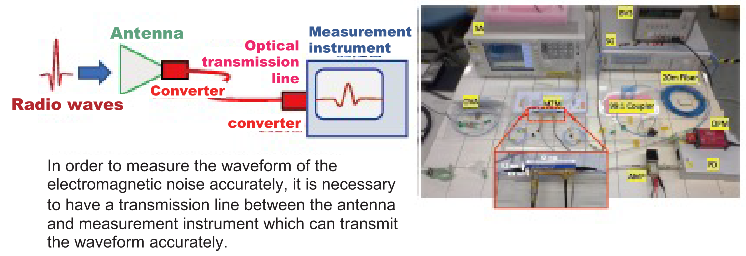


Figure 4 Development of a wide-band optical transmission line

Response to the Special System in the Terahertz Band within the Specific Experimental Test Station System

Before using our radio equipment to conduct experiments outdoors and in living rooms, we first have to measure the performance of the radio equipment and get a license from the Minister of Internal Affairs and Communications. In order to promote R&D for the realization of Beyond 5G, they established an application process to get a license for a radio station (a specific experimental test station) using 110 GHz to 1.1 THz had been stipulated in 2022, a world-first. To get licenses to conduct a variety of experiments outside and inside, it is now necessary to measure the RF power and frequency of radio waves emitted from radio equipment using measurement instruments with correction values confirmed by NICT or the measurement instrument manufacturer, and to make an application with the results of the measurements attached. We are conducting R&D into methods for deciding the correction values and methods for providing the decided correction values to the researchers making the license applications and the measurement instrument manufacturers. We are advancing preparations to be able to provide the correction factors up to 500 GHz in FY2024, up to 750 GHz in FY2025, and up to 1.1 THz in FY2026.

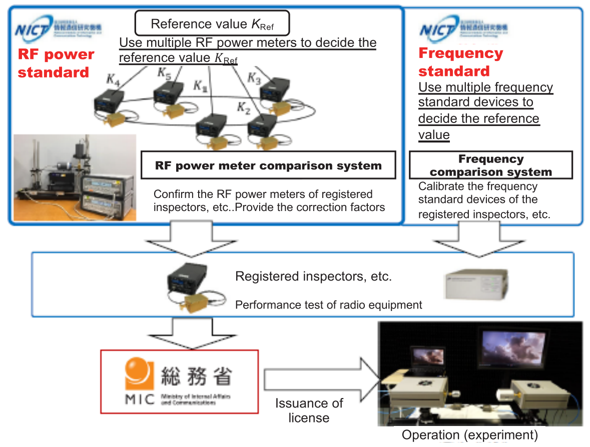


Figure 5 R&D for a service providing the correction factors of measurement instruments

Measures for Continuously Using Radio Waves

Radio waves are invisible, so both radio waves intentionally radiated for communication and electromagnetic noise emitted unintentionally are measured as electric signals using the technique of receiving them through antennas and using measurement instruments via cables. However, the measurement sites, measurement methods, and competences of the measurers are also necessary in order to measure radio waves accurately. Going forward, through R&D into electromagnetic wave measurement technologies which measure radio waves accurately, we will advance R&D into new communication systems, most notably Beyond 5G, R&D for protecting the electromagnetic environment, and R&D for calibration services providing the reference values necessary for license applications of radio stations.

Discover an Anechoic Chamber

Interviewee: **FUJII Katsumi**
Research Manager
Electromagnetic Environment Research Laboratory,
Electromagnetic Standard Research Center, Radio Research Institute

We visited an anechoic chamber for electromagnetic waves, a facility which plays an important role in electromagnetic compatibility research, and interviewed Research Manager Dr. FUJII who has conducted a large number of experiments to date.

● Is an anechoic chamber a test course for wireless devices?

Q: What kind of facility is an anechoic chamber? And what is it used for?

A: An anechoic chamber is a facility which prevents the incursion of electromagnetic waves from outside by covering the outside of a room with metal. It also prevents the reflection of electromagnetic waves inside the room by putting a material which absorbs electromagnetic waves on the six surfaces in the room, the floor, the ceiling, and the walls, enabling measurement of only the target radio waves under experiments (Figure 1). There are many anechoic chambers in NICT tailored to the targeted frequencies of the electromagnetic waves.

An anechoic chamber is a facility which tests the performance and properties of wireless devices and can be compared to a test course in automobile design. When designing and manufacturing a new automobile, the prototype vehicles are not driven on public roads immediately. Before that, they are driven on a test course with no impact on other cars or on people. This allows for confirmation that they meet expectations for the performance as designed, have satisfied the safety standards required by laws and regulations, etc. They are actually manufactured commercially and driven on public roads for the first time only after they have received the type certification of the supervisory agency. In the same way, wireless devices such as smart phones etc., are also tested regarding whether they have achieved the performance as designed, have an interference on other wireless devices, and satisfy safety standards regarding exposure on the human body, etc. They are launched on the market for the first time only after they have received the technical standards conformity certification, etc., of the Ministry of Internal Affairs and Communications. In other words, an anechoic chamber is a facility which is essential for the design, manufacturing, and sale of wireless devices.

The Electromagnetic Compatibility Laboratory is researching methods for measuring electromagnetic noise that is unintentionally emitted (for example, electromagnetic waves slightly leaking from personal computers). This is different from the measurement of radio waves radiated intentionally. We propose those results to international organizations such as the CISPR (International Special Committee on Radio Interference). If a measurement method is determined to be the international standard, then the same measurement results can be obtained anywhere throughout the world, encouraging international trade in wireless devices. We can conclude that this is a role that can only be played by NICT as a public organization.

Q: What kind of experiment are you conducting this time?

A: This time, we will measure the properties of this circularly polarized antenna called a spiral antenna (Figure 2). Circular polarized antennas are currently used in the sending and receiving of BS and CS broadcasts, but we believe that in the future, they will be broadly used in IoT devices and in millimeter-wave radars used for the automatic driving of automobiles, robots, etc. This is because with conventional linearly polarized antennas, there are specific conditions under which the radio waves that have struck the target stop being reflected. This means that the radar is not detected and in the worst-case scenario there is the possibility of a collision occurring. Conversely, that kind of danger can be eliminated with the radio waves radiated from circularly polarized antennas.

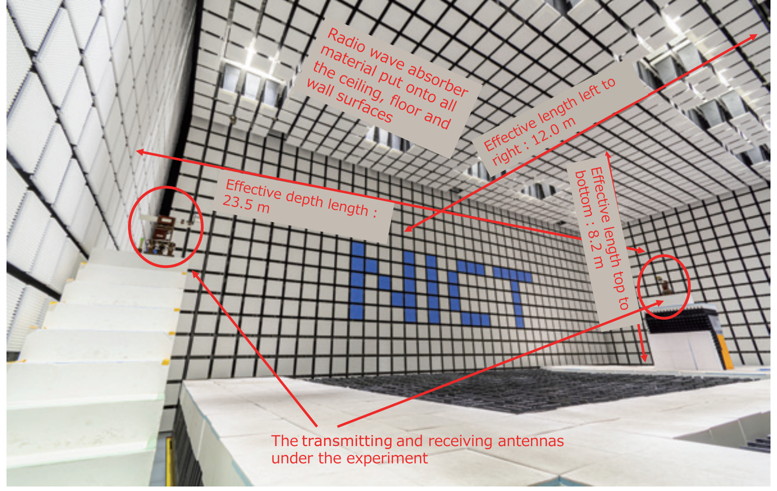


Figure 1　A view inside a large anechoic chamber

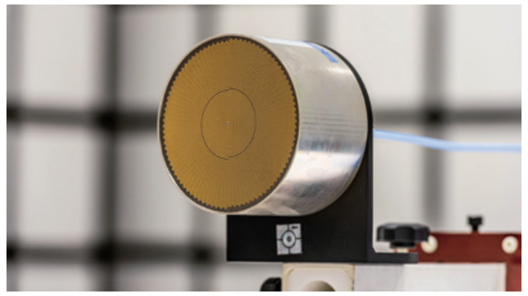


Figure 2　The spiral antenna under the experiment

Figure 3　A snapshot during an experiment

Q: How much time do experiments in an anechoic chamber take?

A: The period taken for one experiment is approximately one week. Laboratories in NICT other than the Electromagnetic Compatibility Laboratory also use the anechoic chamber for one week at a time. The most important part of an experiment is positioning the wireless devices and antennas to be measured. The higher the frequency to be measured, the higher the accuracy that is required for this.

Q: What kind of role will the anechoic chamber have going forward?

A: We think that wireless devices at even higher frequencies are necessary to realize more high-speed and high-capacity communications. In 2023, NICT newly opened an anechoic chamber for use with the terahertz waves which are planned to be used for wireless communications in Beyond 5G. We believe that the role of the anechoic chamber in the development of the wireless devices and electrical and electronic devices which enrich our lives will be extremely important going forward as well.

High-precision Measurement of the Temperature Distribution in a Biological Tissue-equivalent Phantom using a Fluorescent Probe that Changes Brightness Depending on the Temperature

YAMAZAKI Shota

Fixed term Researcher,
Electromagnetic Compatibility Laboratory,
Electromagnetic Standards Research Center, Radio Research Institute

● Biography

1987　Born in Aomori Prefecture
2015　Completed doctorate course on Agriculture at Tohoku University
2018　Joined RIKEN
2022　Joined NICT

● AWARDS

2023　Best Paper Award: ICETEC2023
2017　Best Young Researcher Award: Terahertz Science

Q&As

Q What is good about being a researcher?

A The fact that I can achieve "world-first" discoveries and perform technology development by working on cutting-edge research.

Q What advice would you like to pass on to people aspiring to be a researcher?

A If you continue as a researcher, your specialist field may change sometimes, but knowledge from different fields is often useful, and your experience will never go to waste.

Q How do you spend your free time?

A My hobby is going camping and fishing on my motorcycle. I often get new research ideas when I am having fun in nature.

Terahertz waves, located in the intermediate region between radio waves and light, are expected to be used for next-generation wireless communication called Beyond 5G. Terahertz waves have a property of being strongly absorbed by the surface of human bodies. However, little research has been done concerning the absorption and reflection characteristics of biological tissues in the terahertz region, and of the exposure characteristics on the human body in the region.

It is known that the energy of terahertz waves are almost absorbed at the thin region of the body's surface, at a depth of several hundred μm, and induce temperature increases. Therefore, when conducting exposure assessments of terahertz waves it is crucial to measure temperature changes in superficial tissues with high precision. However, it is difficult to precisely measure small temperature variations in the thin region of the body's surface with conventional methods. Therefore, I am conducting research and development of a technique that focuses on fluorescent probes emitting molecular-sized fluorescence, where brightness varies with temperature. Using this approach, I aim to achieve high-precision evaluations of temperature distribution within regions as small as several tens of micrometers.

Biological tissue-equivalent phantoms, commonly composed of water, agar, etc., are widely used for exposure assessment across a broad range of radio wave frequencies. To date, using the temperature-sensitive fluorescent probes as the material of biological tissue-equivalent phantoms, I have successfully visualized the internal temperature in three dimensions with a spatial resolution of 20 μm by acquiring fluorescence intensity through confocal laser microscopy. This result means that it is now possible to precisely measure the temperature changes of the surface layer, where the absorption of terahertz waves occurs.

Going forward, my plan is to enhance the accuracy of temperature measurements by focusing on improving spatial resolution. Additionally, I aim to advance research on the response characteristics of biological tissues to terahertz waves, including aspects such as absorption and reflection. Through this research, I hope to contribute to the elucidation of exposure characteristics of radiofrequency waves beyond 0.3 THz, where protection guidelines for radiofrequency exposure to the human body have not been established.

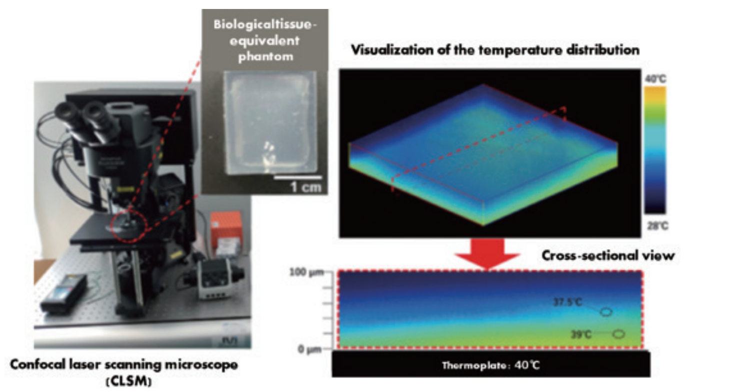


Figure　Example of using a thermoplate to heat a bioequivalent phantom using a temperature-sensitive fluorescent probe, and then measuring its internal temperature

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