NICT NEWS

National Institute of Information and Communications Technology

No.2 2023
Vol.498

FEATURE

Antennas Lead Innovative Researches in NICT

Interview

History and Future of NICT Wireless Communication Technology through Antennas

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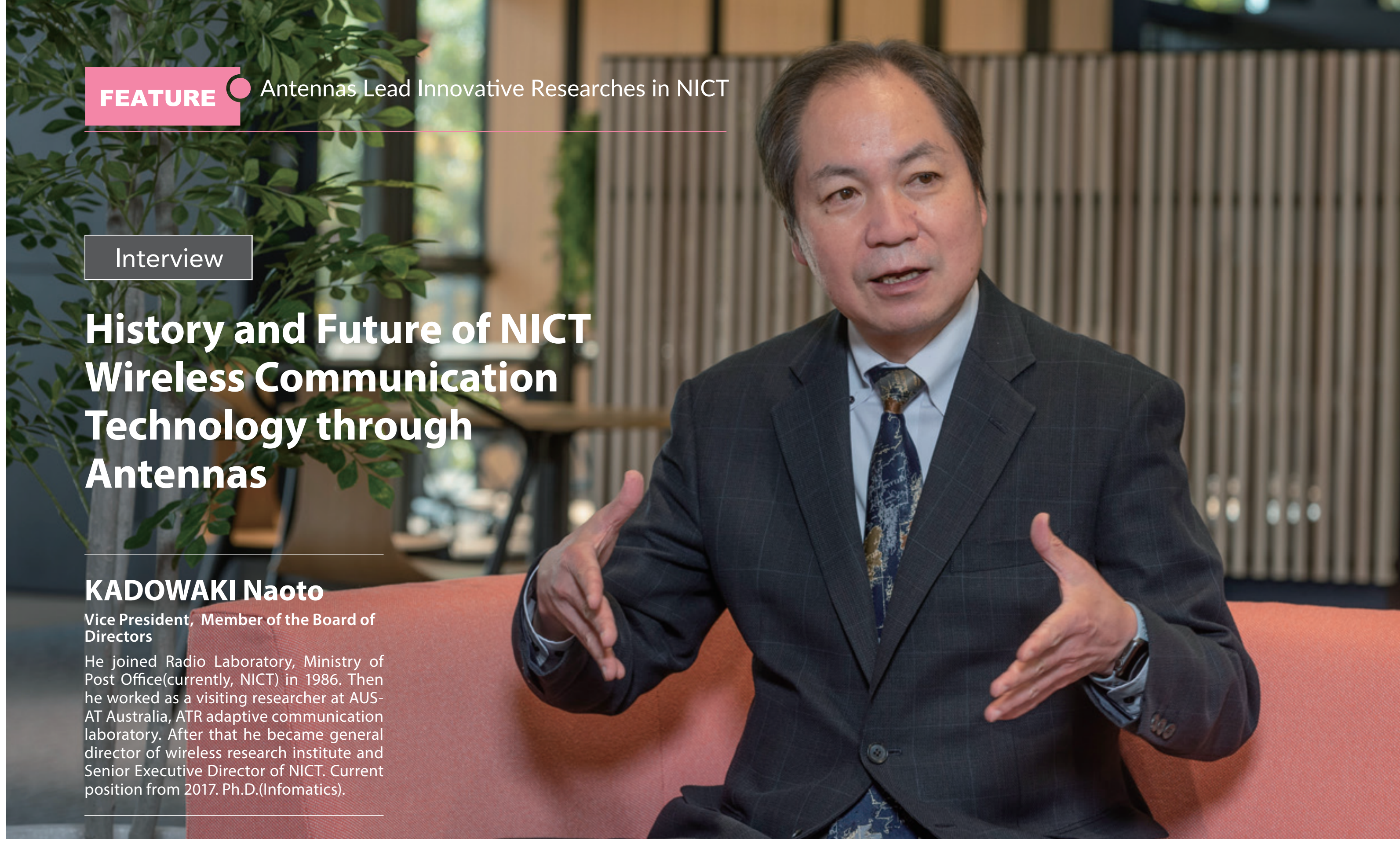
National Institute of Information and Communications Technology

Cover Photo
Large to ultra-small antennas used and developed at NICT
(For more information, refer to the corresponding articles in this special issue)

Photo Upper Left
(Top) left:HiRAS-2 right:HiRAS-3 Center:F10.7(2.8GHz)Observation Antenna
HiRAS was a dynamic spectrometer located at the Hiraiso Solar Observatory that continuously received solar radio waves across a wide bandwidth of 25 MHz to 2.5 GHz using three antennas. It also observed the distribution and temporal variations of their intensity. HiRAS-2 was designed to operate within 70 to 500 MHz, while HiRAS-3 operated between 500 MHz to 2.5 GHz.
(Photo by TAKIZAWA Osamu)

(Bottom) HiRAS-1
This antenna was responsible for receiving the lowest frequency range of 25 to 70 MHz for HiRAS. Its wide bandwidth coverage utilized two orthogonal log-periodic (deformed approximation self-complementary) antennas to independently receive both left and right circularly polarized components. The sunrise from January 1, 2015, the 100th anniversary of the Hiraiso Solar Observatory, can be seen in the background.
(Photo by ISHIJIMA Hiroshi)



Interview

History and Future of NICT Wireless Communication Technology through Antennas

KADOWAKI Naoto
Vice President, Member of the Board of Directors

He joined Radio Laboratory, Ministry of Post Office(currently, NICT) in 1986. Then he worked as a visiting researcher at AUSAT Australia, ATR adaptive communication laboratory. After that he became general director of wireless research institute and Senior Executive Director of NICT. Current position from 2017. Ph.D.(Infomatics).

It has been just over a century since Italian inventor Guglielmo Marconi invented wireless communications in the late 19th century. Incredible progress has been made in the meantime. The 1964 Tokyo Summer Olympics marked the premiere of satellite relays, and in the latter half of the 20th century we witnessed the advent of high-speed, high-capacity optical communication. In the present century, research on Terahertz-band radio waves has progressed, aiming to attain yet higher speeds. In addition, optical satellite communication experiments are being conducted, and progress toward high-speed communication with the Moon and Mars is underway. Antennas constitute an integral aspect of these methods.

In this article, we spoke with NICT Vice President KADOWAKI Naoto, who has been fostering research on antennas at NICT.

——What types of antennas do we commonly encounter in our daily lives?

KADOWAKI The most familiar would be those in smartphones. Despite their small size, smartphones house multiple antennas for stable transmission and reception of radio waves. A smartphone likely contains seven or more for GPS, Bluetooth, and other functions.

Some of the latest 5G devices also feature built-in antennas in the 28 GHz millimeter wave band. Flat antennas called microstrip antennas, consisting of small slits between metal plates, transmit and receive these high-frequency radio waves. NICT has a history of developing cutting-edge technology, including high-frequency antennas.

NICT's History of Antenna Research and Development

——When did NICT first start working on antennas?

KADOWAKI Marconi pioneered wireless communications in 1895. However, by 1896 the Ministry of Telecommunications' Electricity Testing Station (established in 1891) had started experimenting with wireless telegraphy. That Ministry is now known as the Ministry of Internal Affairs and Communications, and so NICT's history of antenna R&D can be traced back to these early experiments.

These experiments led to full-scale research on wireless communications. In 1917, NICT developed a dual-frequency resonating antenna, enabling simultaneous transmission and reception at different frequencies. This technology was revolutionary at the time.

——There are so many different antenna types.

KADOWAKI Some of the smallest antennas are in smartphones, which I mentioned earlier, while the largest are parabolic antennas. They are used for satellite communication and capturing weak radio waves from the sun and space. Antennas are also used for remote sensing.

For example, the broadside array antenna installed at the Hiraiso Radio Observatory (now Hitachinaka City, Ibaraki Prefecture) in 1952 was operated by NICT's predecessor, the Radio Research Laboratories, which fell under the Ministry of Posts and Telecommunications. This antenna, a vertical dipole on a flat reflector, observed 200 MHz radio waves from the sun. It aimed to study changes in solar activity by observing the intensity of the sun's radio waves. It was the precursor to NICT's current space weather forecasting efforts. In 1967, the broadside array was replaced by a larger parabolic antenna for full-scale observations.

Interview

History and Future of NICT Wireless Communication Technology through Antennas

—— Didn't it also operate the satellite relays for the Tokyo Olympics?

KADOWAKI The 1964 Tokyo Olympics were broadcast worldwide using two parabolic antennas: a 30-meter diameter receiver at the Kashima Branch (now the Kashima Space Technology Center in Kashima City, Ibaraki Prefecture) and a temporary 10-meter diameter transmitter.

The broadcast was via the U.S. Syncom 3 geostationary satellite, and it marked the start of the satellite communications era.

Although it is gone now, in 1975, a facility with two 13-meter diameter parabolic antennas was built for experimenting with the Communications Satellite (CS) and Broadcasting Satellite (BS) for experimental purposes. The various experiments conducted with Japan's first medium-capacity experimental communications satellite Sakura (launched 1977) and test broadcasting satellite Yuri (launched 1978), paved the way for present-day BS and CS broadcasting.

The higher frequencies of the 30 GHz and 20 GHz Ka-band were used for CS parabolic antennas. This band is currently used as a main spectrum for broadband services in satellite communications, but it was a very advanced technology 50 years ago.

A VLBI (Very-Long-Baseline Interferometry) antenna was also installed at Kashima for space observations. In 1968, a 26-meter diameter antenna was installed and was initially used for satellite communication experiments with transmitting and receiving capabilities. The first Japan-US VLBI experiment was conducted in 1983. Later, in 1988, an even larger parabolic antenna with a diameter of 34 meters was installed. VLBI simultaneously receives radio waves from stars at two distant points on Earth and precisely measures their distance based on phase differences. NICT introduced VLBI to Japan, and has since collaborated with groups such as the National Astronomical Observatory of Japan, the Geospatial Information Authority of Japan, the JAXA Institute of Space and Astronautical Science, and the National Institute of Polar Research to advance radio astronomy, geodesy, and deep-space navigation technologies.

Higher frequencies gradually began to be used for communications, with research into optical satellite communications starting in the 1980s. A 1.5-meter diameter optical communication antenna installed in 1988 can still be seen at NICT headquarters in Koganei, Tokyo. This antenna was used for experiments with Engineering Test Satellite Kiku-6 (ETS-VI), launched in 1994.

The Current Status of Antenna Research

——What antenna-related technologies is NICT developing?

KADOWAKI One technology under development is an aircraft onboard communications antenna for high-speed Internet access via Ka-band satellites. It is a flat array antenna with electronic beam scanning. The beam can be electronically redirected to track the satellite, but it has no mechanical moving parts, making it suitable for aircraft subject to vibration and heavy loads. The aperture can also be enlarged for better performance without protruding.

A prototype will be demonstrated on Kiku-9 (ETS-9), set to launch in 2025.

Another development is antennas for communication at high frequencies (140 GHz and 300 GHz) in the terahertz band. These antennas are horn-type, with a small aperture (1.36 x 1.36 mm) and length (1.79 mm). They are highly directional but have the potential to achieve transmission speeds of 100 Gbps or higher for Beyond 5G/6G by arranging several of them in a row and processing them electronically.

Collaboration with External Parties

——That could have a substantial economic impact if put to practical use.

Kadowaki: Yes. But it would be difficult to achieve this alone, so NICT is thinking of forming a consortium with manufacturers and universities. Given the intense overseas competition, collaboration is crucial.

——You could say that telecommunications have always involved international collaboration, like with satellite communications.

KADOWAKI As an example of my involvement, in 1997, we conducted a high-data-rate satellite communications experiment between Japan and the United States using Intelsat and NASA's Advanced Communications Technology Satellite (ACTS). This experiment confirmed that a 45 Mbps HDTV signal could be edited in close to real-time across multiple lines using an IP connection between Sony Pictures in Los Angeles and Sony's studios in Tokyo. The process of sending video footage shot on location to the studio via a high-data-rate satellite link, editing it, and then sending it back to the field is known as remote post-production. It has become a widely used filming technique and allows for a more efficient shooting process, as filmmakers can review the edited footage and only re-shoot what is necessary.

In addition, the National Library of Medicine in Maryland, USA, has digital information on the human body referred to as "Visible Human." We had a professor from Sapporo Medical University access this library from Japan to experiment with transmitting high-resolution human body scans.

We have also been providing space weather forecast data from around Japan to the International Civil Aviation Organization (ICAO) in collaboration with countries such as Australia, Canada, France, and others.

We are also constructing a 7.3-meter diameter parabolic antenna in Kashima to receive radio signals from US solar observation satellites.

Future Research and Development using Antennas

——What do you expect for the future of antennas?

KADOWAKI A future with ultra-high-speed communications using high-frequency radio waves is coming, that is, a future even surpassing Beyond 5G/6G. The devices we carry, such as smartphones, must be compact and lightweight. This constraint means fine antenna technologies are crucial. Additionally, even smaller IoT devices will be utilized for communication and sensing across the globe. So, low-energy antenna designs will be needed for these devices.

Automated driving will also become widespread. Since cars move, communication must be maintained to prevent accidents. Therefore, highly reliable antennas and systems are needed for simultaneous networked control of all vehicles.

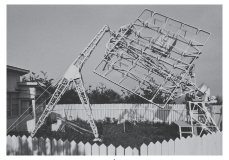
——How might the manned Artemis moon mission shape antenna development?

KADOWAKI The mission involves a gateway space station orbiting the moon and a permanent lunar base. But beyond that, future goals include manned exploration of Mars. A future where the Moon and Mars are connected to Earth through ultra-high-speed Internet is near. Antennas, as crucial components in wireless communication networks, are critical for transmitting and receiving radio waves, a shared resource among all humanity.

We aim to drive progress by developing new era-appropriate antennas and international collaboration in antenna research and development.

HISTORY AND FUTURE
wireless communication technology

START PROJECT → 1952 → 1964 → 1975 → 1983 → 1988 → 2021 → 2023.3

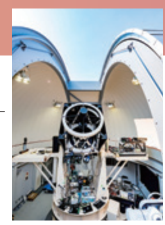


●Broadside antenna

●Two 13-meter diameter parabolic antennas were used for communication satellite and broadcasting satellite experiments

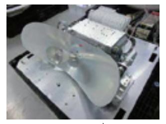
●10-meter and 30-meter parabolic antennas transmitted the Tokyo Olympics around the world

●26-meter aperture antenna for Japan-U.S. VLBI experiment



●1.5-meter aperture antenna for optical satellite communications

●Communication antenna for aircraft mounting



●Horn-type antenna Aperture: 1.36 x 1.36 mm, Length: 1.79 mm

●34-meter aperture VLBI antenna

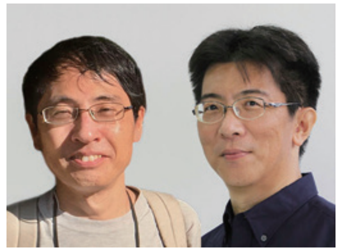
Multi Parameter Phased Array Weather Radar

Realization of high speed, high density, and polarization observation

KAWAMURA Seiji

Director of Remote Sensing Laboratory, Radio Propagation Research Center, Radio Research Institute,

After completing his doctorate, he served at Communications Research Laboratory (currently NICT) as a postdoctoral fellow for the- Japan Society for the Promotion of Science(JSPS), and then joined NICT in 2006. He is engaged in the research of radar remote sensing. Ph.D. (Informatics).



HANADO Hiroshi (left)

Research Manager, Remote Sensing Laboratory, Radio Propagation Research Center, Radio Research Institute

In 1989, after completing a master's course, joined the Ministry of Posts and Telecommunications Communications Research Laboratory (currently NICT). His research interests include microwave remote sensing, especially precipitation radar.

SATOH Shinsuke (right)

Chief Senior Researcher, Remote Sensing Laboratory, Radio Propagation Research Center, Radio Research Institute

After completing a doctoral course, he joined Communications Research Laboratory (currently NICT) in 1995. He is engaged in the research on satellite born precipitation radar, bistatic polarization radar, and now phased array weather radar. Doctor of Science.

Single-polarized phased array weather radar utilizes 128 slotted waveguide antennas for high-speed, high-density observations, a departure from traditional weather radars that rely on parabolic antennas. Even more on the cutting edge is the multi parameter phased array weather radar, which uses a large number of dual-polarized patch antennas for polarization observations. This article examines these advancements in radar technologies, focusing on the antennas.

Differences from Conventional Radar

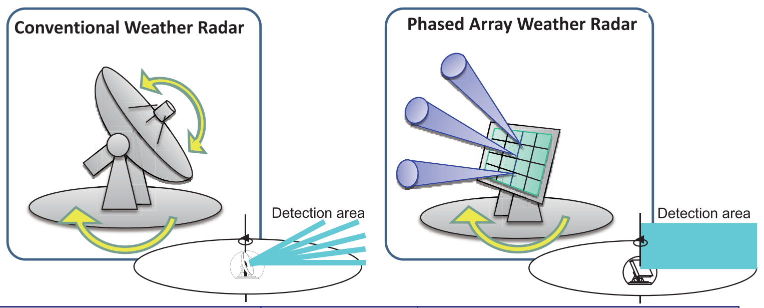
In recent years, there have been an increasing number of disasters caused by severe rainfall, such as localized downpours and linear rainbands. These disasters are characterized by rapidly developing cumulonimbus clouds and can cause significant damage. Therefore, early detection of these clouds is crucial for disaster prevention and mitigation efforts. To meet this need, the National Institute of Information and Communications Technology (NICT) is developing phased-array weather radar technology, which offers faster and denser observations than traditional weather radar systems.

The comparison between the two radar types can be seen in Figure 1. Traditional radar systems utilize a parabolic antenna that rotates a narrow beam in the azimuth direction and then slightly adjusts its angle of elevation before rotating once more. A set of spatial observations captures a dozen or so elevation cross sections and takes approximately five minutes. Phased array weather radar, on the other hand, leverages phased array technology that electronically swings the beam, as well as digital beamforming technology that forms multiple beams simultaneously after reception through phase synthesis, to observe high-density vertical profiles for over 100 elevation angles almost instantaneously, without any movement of the antenna in the elevation direction. Furthermore, fast three-dimensional observations can be achieved with a single 30-second rotation in the azimuth direction.

Single Polarized Phased Array Weather Radar (PAWR)

In 2012, the first Phased Array Weather Radar (PAWR) began operating from the roof of Osaka University's Suita Campus. Figure 2 shows a photograph of the antenna. The square antenna, measuring approximately 2 meters in all directions, comprises 128 oblong slotted waveguide antennas. Of these, the lower 24 antennas are shared by 24 transmitters and receivers, while the remaining 104 antennas are connected to 104 receivers. The beam width in the azimuth direction is roughly 1.2 degrees due to a waveguide measuring approximately 2 meters. During transmission, the lower 24 antennas quickly scann a fan beam electronically in the elevation direction. However, during reception, all 128 antennas simultaneously produce multiple sharp beams of around 1.2 degrees, matching the azimuth direction, with digital beamforming. This technique allows for the instantaneous observation of a high-density vertical profile of more than 100 elevation angles without moving the antenna in the elevation direction. In 2014, similar PAWRs were installed at the Advanced ICT Research Institute in Kobe and the Okinawa Electromagnetic Technology Center in Onna Village.

However, this PAWR is single polarized (horizontal polarization only) and lacks the multi parameter (MP) functionality that has become prevalent in recent years. Raindrops exhibit different scattering and propagation characteristics for horizontally and vertically polarized waves because the larger they become, the more they encounter air resistance and become flattened horizontally. Polarization observation functionality, which enables more accurate observations of rain, is becoming increasingly common among conventional (parabolic) weather radars, such as the Ministry of Land, Infrastructure, Transport and Tourism’s X-MP. While PAWR had significant advantages in observation speed and spatial density (approximately 10 times greater than conventional radars), it lacked this capability.



Conventional Weather Radar		Phased Array Weather Radar
Parabolic dish antenna (2 m diameter) with mechanical EL and AZ scanning	Antenna	Flat antenna (128 elements slot array) with electronic EL scanning and mechanical AZ scanning
5 minutes for 3D scan (15 EL angles) 1 minutes for a rain map (3 EL angles)	Observation cycle	30-60 seconds for 3D scan (100 EL angles)
80 km in radius	Observation range	60-80 km in radius

Figure 1 Comparison between the two radar types

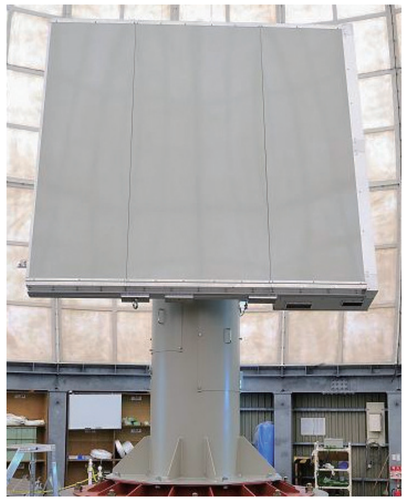


Figure 2 Phased Array Weather Radar (PAWR)

Figure 3 Multi Parameter Phased Array Weather Radar (MP-PAWR)

Figure 4 Installation of MP-PAWR antenna (December 12, 2022)

Multi Parameter Phased Array Weather Radar (MP-PAWR)

The Multi Parameter Phased Array Weather Radar (MP-PAWR) was developed to add polarization observation capabilities to PAWR. The development of dual-polarized patch antennas was facilitated through the "Research and Development of Cooperative Radar Systems for Effective Utilization of Frequency Resources," which was conducted between 2012 and 2014 by spectrum use fee fund research by MIC. MP-PAWR was created as part of the "Enhancement of Social Resiliency against Natural Disasters" program (early warning for torrential rainfall/tornado), which was implemented by the Council for Science, Technology and Innovation (CSTI) Cross-ministerial Strategic Innovation Promotion Program (SIP) between 2014 and 2018. It has been in use at Saitama University in Saitama City, since 2018.

Figure 3 is a photo of the MP-PAWR antenna. Separate antennas perform transmission and reception. The upper octagonal structure in the photo serves as the receiving antenna, while the lower rectangular structure functions as the transmitting antenna. The system comprises 5760 dual-polarized patch antennas for reception and 960 for transmission, arranged in a two-dimensional layout. Despite modifying the antenna system through shared polarization, the beamforming method remains consistent with PAWR. Integrating a phased array and digital beamforming technology enables high-density observations at over 100 elevation angles and high-speed data collection.

Future Prospects

MP-PAWR is poised to become the standard for X-band weather radars. Currently, only one MP-PAWR is operating at Saitama University. However, supplementary funding for FY2021 means that PAWRs at Osaka University and the Advanced ICT Research Institute in Kobe will be upgraded to MP-PAWRs by the end of FY2022. Figure 4 depicts the upgrade to the MP-PAWR antenna at Osaka University's Suita Campus on December 12, 2022. A new MP-PAWR antenna was installed, topped with a new radome.

With its advanced functionality, MP-PAWR generates roughly 100 times more data than traditional radars, with 10 times higher temporal resolution and 10 times higher spatial resolution. To effectively use the vast amount of remote sensing data generated, the Ministry of Internal Affairs and Communications has commissioned a three-year research project in FY2022 titled "Research and Development of Advanced Technologies for a User-Adaptive Remote Sensing Data Platform.” The project aims to create a platform that uses AI-based data compression and restoration to provide optimized data to users.

Two MP-PAWRs will become operational in Kansai (Suita and Kobe) in FY2023. These two radars' observation areas overlap with the Expo 2025 Osaka, Kansai, Japan site. Therefore, consideration is given to using their data for the event. We will continue conducting research and development to further advance the deployment of MP-PAWR and data utilization.

R & D of Active Electronically Steered Array for Aircraft

Aiming to Realize Stress-free In-flight Internet

OKURA Takuya

Researcher, Space Communications Systems Laboratory, Wireless Networks Research Center, Network Research Institute,

After completing a doctoral course, He joined NICT in 2017. He has engaged in research and development related to antennas for non-terrestrial networks. Doctor of Engineering.

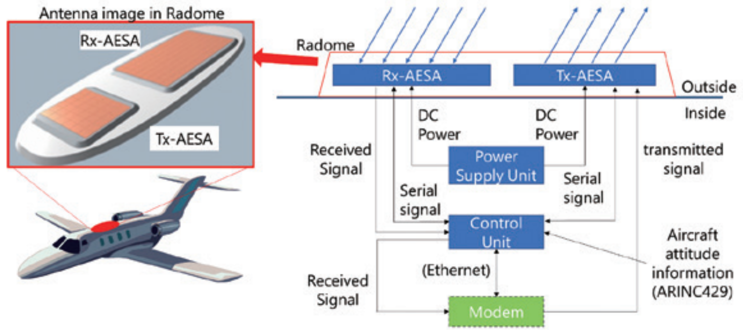


Figure 1 Overview of AESA for Aircraft

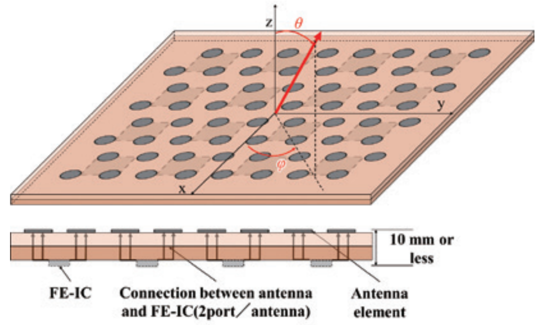


Figure 2 Array antenna element arrangement and cross-sectional structure

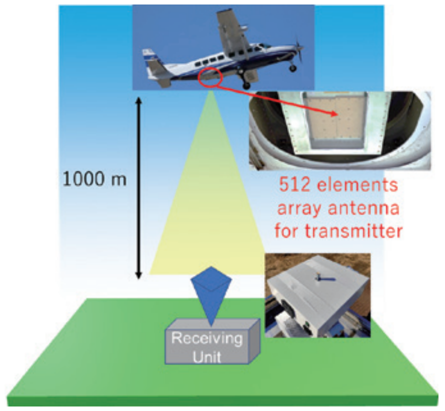


Figure 3 Image of a flight test of a 512-element array on the transmitter side

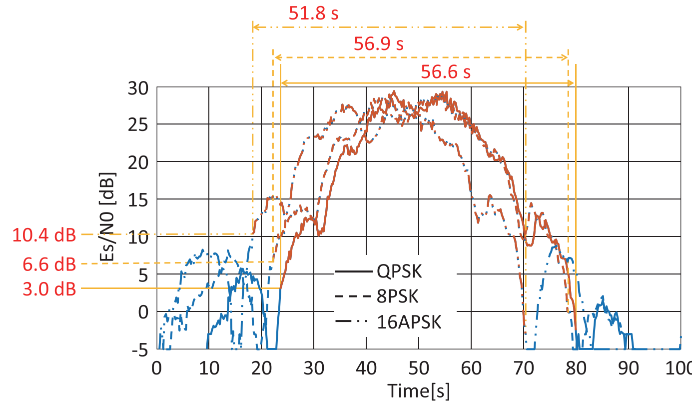


Figure 4 Results of modulated wave communication measurements

Non-Terrestrial Networks (NTN) encompass various communication technologies, including satellites in geostationary orbit, medium and low earth orbit satellites, high-altitude platform stations (HAPS), unmanned aircraft, and more. They offer broad coverage and robustness against disasters. NICT is pioneering research into developing Active Electronically Steered Array (AESA) antenna technology for mobile applications within NTNs. This technology can dynamically adjust to changing satellite orbits and operating conditions, with advanced beam scanning and formation capabilities that surpass traditional mechanical driven antenna systems.

Background

In-flight Wi-Fi access is growing in popularity, fueled by the widespread use of smartphones and tablets. According to the research report "Prospects for In-Flight Entertainment and Connectivity," published in September 2019 by Euroconsult, an independent consulting firm specializing in artificial satellites, satellite communication, and earth observation, the number of commercial aircraft providing In-flight Wi-fi service used Ka-band communication satellites will increase about nine-fold over the next decade, as the number of in-service aircraft jumps from 8,200 in 2018 to over 20,500. To enhance antenna functionality and meet this demand, NICT is developing an AESA solution that can be used in the Ka-band with good mountability in an aircraft, a scalable aperture size and wide-area beam scanning capabilities.

Development Outline of AESA Antenna for Aircraft

NICT is developing AESA technology for use on aircraft, aiming to improve frequency utilization efficiency by over 30% through multi-level modulation schemes. The AESA antenna is shown in Figure 1. It features separate transmitter and receiver configurations, with the antenna located in a radome exterior to the aircraft, and the power unit, control unit, and modem housed within the aircraft. AESA antennas operate in the Ka-band (29.5-30.0 GHz for the transmitter and 19.7-20.2 GHz for the receiver) using 8 Phase Shift Keying (8PSK) or higher modulation. The antenna's performance targets, Equivalent Isotopically Radiated Power (EIRP) and Gain-to-Noise-Temperature ratio (G/T), were set to establish connections with existing communications satellites utilizing 8PSK. In addition, its design adheres to Resolution 156 from the 2015 World Radiocommunication Conference (WRC-15) held by the International Telecommunication Union Radiocommunication Sector (ITU-R) for off-axis EIRP on the transmitter side. Figure 2 displays the antenna's element arrangement, cross-sectional structure, and defined scanning angles. Its basic structure is uniform for both transmitter and receiver. It uses a patch antenna element arranged in a triangular pattern, with spacing of the elements determined to prevent grating lobes within the desired frequency band and beam scanning angle. The scanning angle is 0 to 360 degrees in the φ direction and -65 to +65 degrees in the θ direction. A single Front-End IC (FE-IC) controls four antenna elements, providing antenna excitation amplitude and phase control, switching between left and right-handed circular polarizations, and beam scanning. The multilayer substrate and high-density mounting technologies allow for a substrate thickness of 10 mm or less from the antenna element through to the FE-IC. This four-year project was launched in 2017 as part of the commissioned research of the "Research and development on narrow band technology using active electronically steered array antenna that can be mounted on small aircrafts" (JPJ000254) by the Ministry of Internal Affairs and Communications, Japan. 16-element array and 64-element sub-array prototypes on the transmitter and receiver sides were evaluated as part of basic studies. Final-year experiments used an aircraft-mounted 512-element array for the transmitter side.

Evaluation Experiments using Aircraft

Figure 3 shows a fabricated 512-element array antenna for the transmitter installed on a small single-engine aircraft fuselage for evaluation experiments. The aircraft flew at 1,000 m above ground level over the receiving device. Performance was evaluated in terms of radiation pattern, tracking, and modulated wave communication. The results and details of the evaluation of modulated wave communication are presented below. The antenna's communication performance was tested using the Quadrature Phase Shift Keying (QPSK), 8PSK, and 16 Amplitude Phase Shift Keying (16APSK) modulation schemes with a satellite communication modem. Preliminary measurements of QPSK, 8PSK, and 16APSK symbol rates and occupied bandwidths in an anechoic chamber with the information rate set at 50 Mbps showed an improvement in frequency utilization efficiency of approximately 33% for 8PSK and 50% for 16APSK, compared to QPSK. The flight tests aimed to confirm if the antenna improves frequency utilization efficiency by verifying whether the communication performance is unchanged when the modulation method is changed. During the test, the beam was controlled to track the receiving device. The modem's energy per bit to noise density ratio (Es/N0) was monitored over time, along with its communication status, while flying in a straight line over the receiving device .

Figure 4 shows the Es/N0 results over time. The aircraft flew directly over the receiving device for approximately 40 to 50 seconds. The red lines indicate that the modem's communication availability lasted about 25 seconds both before and after passing over it. The required Es/N0 values for communication are 3.0 dB for QPSK, 6.6 dB for 8PSK, and 10.4 dB for 16APSK, respectively. However, the communication availability times are similar: 56.6 s for QPSK, 56.9 s for 8PSK, and 51.8 s for 16APSK. These results indicate that the antenna offers equivalent performance for 8PSK and QPSK and improves frequency utilization efficiency by approximately 33%. The results also suggest it can handle multi-level modulation beyond 8PSK, as seen in the 16APSK results, meaning it contributes to the effective use of frequency resources.

Future Prospects

AESA is a versatile technology for the beyond-5G era, as its flat design and lack of mechanical drive allow for it to be used on aircraft, NTNs, and ground platforms. Future development will be focused on reducing power consumption and increasing heat efficiency to increase its scope of use.

The Entrance of Radio Wave: Small/Planar Antennas for Wireless Communication Systems

Keren LI

**Senior Researcher,
Wireless Systems Laboratory,
Wireless Networks Research Center,
Network Research Institute /
Senior Researcher,
Terahertz Laboratory,
Terahertz Technology Research Center ,
Beyond 5G Research and Development Promotion Unit**

After received the Ph.D. degree, Dr. Keren Li became a Research Associate/ Lecture/Associate Professor of the University of Electro-communications since April 1991 to 1997. He jointed Communications Research Laboratory (CRL, now renamed as NICT: National Institute of Information and Communications Technology), in April 1997, and became a senior researcher. His research interests include electromagnetic theory, microwave engineering, wireless communications (UWB radio system and millimeter-wave/THz-wave wireless communication systems), optical communications and photonic devices, microwave photonics, and antennas.

Antennas are vital for transmitting or receiving radio (or electromagnetic) waves effectively. When German physicist Heinrich Hertz first discovered and demonstrated radio waves in 1888, he was already performing experiments using antennas. Radio waves have numerous applications, such as in radio astronomy and television. However, wireless communication systems, particularly cell phones, are widely available and closely linked to our daily lives. In a wireless system, the role of the antenna is to emit and receive radio waves. They both transmit radio waves, which are propagated through space, and receive them as signals. Therefore, the quality or efficiency of an antenna directly affects the wireless communication system's quality. Various antennas have been developed to ensure optimal communication, according to the operating frequency (or wavelength) of the radio waves and the type of wireless communication system. To use a biological analogy, antennas are as varied as sense organs in animals. Antenna researchers work to develop an antenna that can efficiently transmit and receive radio signals for the target radio frequency and system without distortion. Wireless communication systems research involves selecting the appropriate antenna for the frequency and system. Although there are numerous types of antennas, this article focuses on the technology and applications of two: compact multi-band antennas used in cellphones and millimeter-wave planar antennas.

Compact Multi-Band Antennas for Cellphones

Nowadays, cellphone antennas are typically internal and, therefore, not directly visible. However, they are the most commonly encountered antenna in most people's day-to-day lives. Since cell phones are so small, antenna miniaturization is crucial.

However, today's cell phones also require multiple communication bands (frequencies), including GPS and Bluetooth/Wi-Fi. Recent 5G-enabled cell phones can also use millimeter-wave, such as 28 GHz band. Antennas that support these multiple radio waves are needed, but cell phones lack the space for multiple antennas. Multi-band antennas operating on multiple frequencies with a single antenna were developed to address this issue. Figure 1 shows a photograph of 2- and 3-band antennas developed by NICT around 2004. The three-band antenna supports 800-900-MHz, GPS, and 2-GHz bands with a single antenna. This multi-band antenna has characteristics almost the same as a monopole antenna while also maintaining the features of a small space-saving antenna. It can also be easily adjusted to multiple frequency bands. As an aside, NICT was successful in patenting this technology. Later, antennas that could handle even more bands were developed.

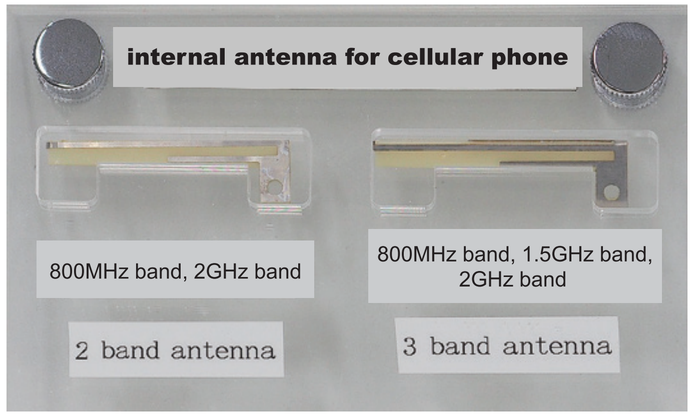
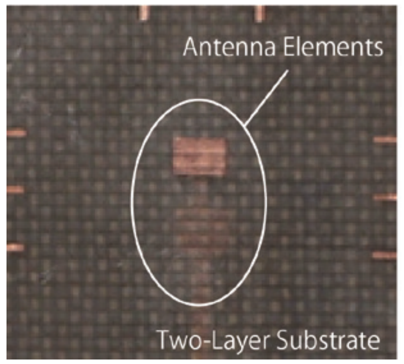
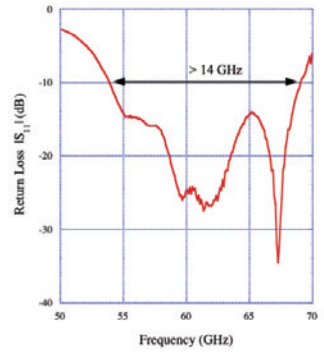


Figure 1
An internal multi-band antenna for a cellphone (2- and 3-band antenna) (At the time when the technology was transferred, the company provided some samples for evaluation purposes)



(a) Planar antenna structure



(b) Reflection characteristics and operating bandwidth of the antenna

Figure 2 60 GHz wideband planar antenna

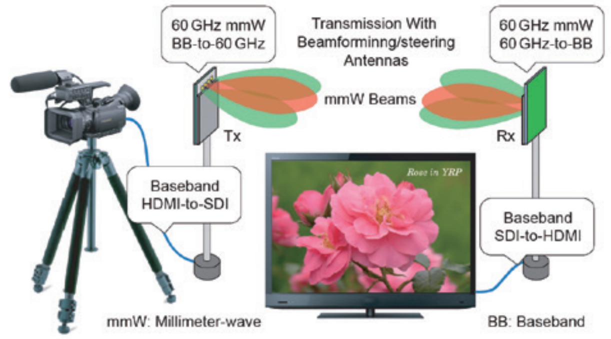


Figure 3 Experiment involving a non-line of sight high-speed wireless video transmission system using a 60-GHz wideband beam-forming antenna

To disseminate the results of our research on high-frequency circuit components to industry, we transferred the technology behind these multi-band small antennas to the company formerly known as Nissin Parts Co. Ltd. As a result, this technology was adopted in the latest multi-functional cellphones, and several million units were shipped.

Despite the advantages of this technology, there are several technical challenges in moving from single-band to multi-band antennas. For instance, it is essential to figure out how to operate multiple bands simultaneously in an integrated structure, achieve impedance matching in each band without losing too much radiation efficiency, and make the matching circuit have high impedance so that the effects the bands have on each other are minimal.

As is generally the case with small antennas, their radiation characteristics depend not only on the antenna itself but also on the surrounding environment. Therefore, antenna development is not just about developing the antenna's structure. In the case of a cellphone, the radiation characteristics must be evaluated, and the center frequency and impedance matching must be adjusted after the phone is assembled in the housing. These are crucial challenges and are yet to be resolved.

Applications of 60 GHz Millimeter-Wave Wideband Planar Antennas

NICT has been researching and developing millimeter wave wireless communication systems for decades, using the 60-GHz band as an example, as part of frequency resource development. Several millimeter-wave antennas have been developed, including new structures for wideband planar antennas that offer excellent antenna characteristics. Planar antennas are widely used in the millimeter wave and terahertz wave bands due to their crucial role in connecting and integrating the antenna with semiconductor devices and circuit modules. These antennas are lightweight, compact, and have good affinity with the semiconductor devices that make up the RF signal source and receiver, making them easy to connect and integrate. However, planar antennas have drawbacks such as narrow operating bandwidth and high losses in the feeding circuit when assembled in antenna arrays. To solve these shortcomings, NICT proposed a new planar antenna structure that broadens the bandwidth and achieves a certain level of efficiency and gain. Figure 2a shows a millimeter-wave wideband planar antenna developed specifically for the 60 GHz frequency band. This antenna boasts impressive features, including a compact form factor of less than 1 cm square and a thickness of only 0.5 mm. Moreover, it offers an operating bandwidth of over 14 GHz, with a maximum gain of 9 dBi. This single antenna can cover all currently standardized, unlicensed 60-GHz bands globally, as shown in Figure 2b. In addition, a wideband beam-forming antenna in the 60 GHz band has also been developed. Figure 3 shows an experimental concept of high-speed wireless video transmission using this beam-forming antenna. The experiment utilized the antenna's beam-forming functionality, which enabled a communication speed of 3.5 Gbps, even in a non-line of sight environment with obstructions.

Future Prospects

Researching and developing single antennas is no longer sufficient in the current era, as needs are becoming increasingly multi-functional, requiring higher frequencies (such as millimeter wave and terahertz wave) and beam-forming functions, as exemplified by Beyond 5G (B5G) / 6G. Therefore, future research will not only aim to discover new antenna structures suitable for the systems they're used in and the pursuit of antenna characteristics such as operating bandwidth, efficiency, and gain, but also focus on creating more innovative antennas by integrating them with semiconductor devices and circuits while incorporating functionality from these systems. In response to the high frequencies used in B5G / 6G, we have successfully developed a terahertz wideband planar antenna in the 300 GHz band. In addition, we have also demonstrated an array antenna with an area of a few millimeters square, an operating bandwidth of 70 GHz or higher, and a maximum gain of 10 dBi. This antenna is expected to see practical use in terahertz-wave wireless communication systems. In addition, next-generation wireless communication systems are expected to combine radio and light waves (i.e., wireless and wired communications). As such, photonic antennas, which we pioneered and researched over 20 years ago, and which integrate optical devices and antennas, are expected to be in the spotlight again.

Operation and Maintenance of Japan Standard Time LF Transmission Station

MORIKAWA Masaki

**Research Engineer,
Japan Standard Time Group,
Space-Time Standards Laboratory,
Electromagnetic Standards Research Center, Radio Research Institute**

After completing a master course, he joined NICT in 2021. He has been engaged in operation and maintenance of Japan Standard Time. Certificate Class-1 Land Radio Engineer

NICT is responsible for determining standard frequency and generating, maintaining, and supplying Japan Standard Time. In Japan, two transmission stations, one in the east and one in the west, operate 24/7 to provide standard radio waves with time information across the country. One typical example of their use is radio-controlled clocks, which rely on standard radio waves to display time accurately. This article presents an overview of the maintenance and operation of longwave standard time and frequency transmission stations.

What are Longwave Band Standard Radio Waves?

Longwave band standard radio waves (call sign JJY) are a national standard NICT-determined frequency provided for nationwide use. Currently, these radio waves are transmitted on two frequencies, 40 kHz and 60 kHz. They are amplitude-modulated and superimposed with Japan Standard Time (JST) information. One example of their use is with radio clocks, a common household item in Japan, which use them to synchronize the time.

In 1999, the Ohtakadoya-yama Standard Time and Frequency Transmission Station (40 kHz) was established in Fukushima Prefecture (Figure 1). In 2001, the Hagane-yama Standard Time and Frequency Transmission Station (60 kHz) was established on the border of Fukuoka and Saga Prefectures (Figure 2) to extend the reception area and provide a seamless supply. NICT has provided these radio waves to Japanese society for over 20 years.

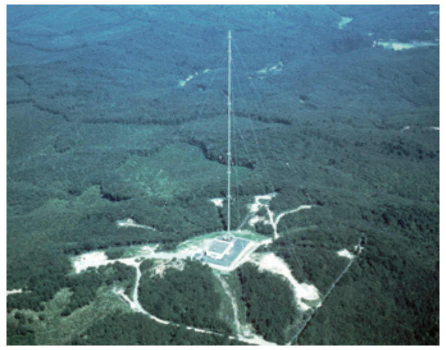


Figure 1 Panoramic view of the Ohtakadoya-yama Standard Time and Frequency Transmission Station

Figure 2 Panoramic view of the Hagane-yama Standard Time and Frequency Transmission Station

Overview of Transmission Stations

Each station has an atomic clock room, a time signal control room, an impedance-matching transformer room, a transmitter room, and an antenna. The atomic clock room houses a minimum of three cesium atomic clocks in a temperature- and humidity-controlled and electromagnetically shielded environment. The time signal control room uses positioning satellites and satellite communications to fine-tune the frequency and maintain an error of fewer than 100 nanoseconds between the output of the atomic clocks and Japan Standard Time. Its output serves as the basis for signal generation. The transmitter room features two transmitters with a rated output of 50 kW in a redundant configuration to ensure stable transmission. The transmitter's power amplification is achieved using 48 MOSFET amplifier modules. In case of a failure due to lightning damage or other issues, only the faulty module board needs to be replaced, ensuring quick repairs.

Each station's buildings and antennas are situated near mountain tops, with a 250-meter-high omnidirectional umbrella antenna located on Ohtakadoya-yama (790 meters above sea level) and a 200-meter-high antenna located on Hagane-yama (900 meters above sea level) (Figure 3). Being in elevated positions, these stations frequently require maintenance due to lightning strikes and snow. When visiting the transmission station, one can observe the colossal antenna towers from the ground. There are 360 copper wires embedded in the earth at one-degree angle intervals over a 150-meter radius around the base of the antennas. Use of these copper wires, known as radial grounding, enhances the radiation efficiency of the radio waves.

Station Maintenance

Our transmission stations are maintained based around three primary perspectives. Firstly, since they serve as the foundation of the Japanese Standard Time system, maintenance involves fine-tuning of the atomic instruments and frequencies. Secondly, the stations' buildings and associated facilities require maintenance, including replacing aircraft warning lights (explained below) or disaster recovery. The final perspective relates to their functionality as radio and standard frequency stations under the Radio Act.

Multiple employees are on hand to monitor and control the stations' signals and facilities around the clock, using remote monitoring via a dedicated line. Operating these transmitters requires a first-class Technical Radio Operator for On-The-Ground Services certification. In early September and late October (respectively), the 40 kHz station and 60 kHz station undergo inspections and maintenance. This ten-day process involves intensive inspection and repair of transmission facilities, station buildings, and antennas, requiring daytime outages and having to undergo radio station inspections to ensure the quality of the transmitted radio waves.

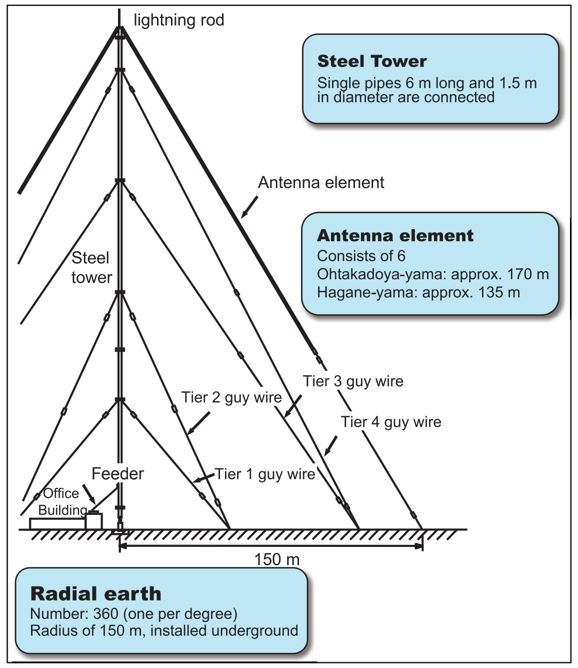


Figure 3 Overview of antenna

Conversion to High-Intensity LED Aircraft Warning Lights

From November 2021 to February of the following year, the aging aircraft warning lights at the Ohtakadoya-yama Transmission Station were upgraded to LEDs. The lights previously had xenon bulbs, which required annual replacements, a process that involves climbing the tower. The newly installed LED types eliminate the need for annual replacement and reduce power consumption by more than 70%.

However, completing this upgrade was challenging; it was not as simple as changing the bulbs. The work could only be carried out during the daytime to avoid interfering with radio clocks, which typically synchronize the time at night. Workers had to climb up and down a ladder in the tower, which was over 250 meters high. The climb takes more than an hour each way, but the work had to be completed in a limited time frame. Additionally, freezing temperatures at the summit, poor weather conditions, and wind speeds exceeding 10 m/s resulted in work being suspended. These circumstances prolonged the construction period and required additional outage dates. Inspecting these lights to ensure their correct functioning is another one of our essential roles. This photo was taken while waiting for sunset amongst the snowy mountains. We were confirming that the lights would change intensity according to changes in the sky's brightness (Figure 4).

Figure 4 Aircraft warning light test (Ohtakadoya-yama Transmission Station)

Recovery from Landslide During Typhoon No. 14

In mid-September 2022, Typhoon No. 14 caused severe damage to the 5-km-long private road managed by NICT, which connects the foot of the mountain to the Hagane-yama Transmission Station, stopping people and vehicles from passing (Figures 5 and 6).

This caused several slopes to collapse and parts of the road to cave in, resulting in a commercial power outage after power lines were cut. However, the station's dedicated power generator was activated immediately, ensuring that transmission was uninterrupted. Thanks to the hard work of the power company, the outage was resolved two days later, and transmission continued.

Although the station building and antenna were not severely damaged, the road damage impacted shifts for several weeks, requiring workers to walk part of the way. However, temporary restoration work was completed quickly. In addition, thanks to the cooperation of various specialized contractors, the local government, related organizations, and NICT-related departments, the station's periodic inspection was completed in December, two months after it had been postponed due to the disaster.

Figure 5 Hagane-yama Transmission Station Road cave-in caused by typhoon

Figure 6 Landslide at Hagane-yama Transmission Station caused by typhoon

Conclusion

Standard radio waves have been transmitted in Japan for over 80 years, dating back to the shortwave band era. The stations are commonly referred to as radio wave lighthouses, providing accurate time throughout Japan. NICT is committed to providing stable and uninterrupted time and frequency transmissions while also exploring innovative ways to meet the changing needs of the times and maintain this vital service.

Dawn of Radio Telescope in Japan

Radio Astronomy in Japan started as Observation of Solar Noise

TAKIZAWA Osamu

Senior Expert, NICT Knowledge Hub

After completing master course, he joined the Radio Research Laboratory, M.P.T. (now NICT) in 1987. He has researched speech recognition, secret sharing scheme using natural language text, ICT for disaster management and mitigation, and so on. Since 2021 he has engaged in survey of history of research institution related to ICT. He also holds the post of director of Radio Wave Management and Manufacturing Office. He is also visiting professor of the Advanced Support Center for Science Teachers of Tokyo Gakugei University. Ph.D.(Engineering).

Karl Guthe Jansky, a communications engineer at Bell Telephone Laboratories in the United States, was the first to notice the radio waves arriving from a galaxy in 1931. However, the discovery of incoming radio waves from the sun, the most familiar celestial body, was delayed due to difficulty distinguishing them from radio waves generated in the atmosphere by sunlight. It was only during World War II, when antennas with strong directivity at higher frequencies than the VHF band began being used for radio surveillance and radar, that they were discovered.

Radio telescopes, which aim to receive radio waves arriving from celestial bodies, were created with cooperation between communications engineers and astronomers. Initially, astronomers, who had only been trained in optical observation, did not understand the importance of observing space using radio waves. By comparison, communications engineers, including Jansky, regarded radio waves as noise that would impact the quality of radio communications and so needed to investigate them. Therefore, the first radio telescopes were produced from the relationship between communications engineers, who insisted on their need and led their development, and astronomers, who used them.

The First Radio Telescope to be Operated at Tokyo Astronomical Observatory (September 1949)

In September 1949, the Tokyo Astronomical Observatory (the predecessor of the National Astronomical Observatory of Japan) installed the first solar noise observation instrument, that was the first radio telescope in Japan (Figure 1). Kenichi Maeda, the director of the Ministry of Education's Physical Institute for Radio Waves (the predecessor to NICT; located in Koganei, Tokyo), was responsible for creating and installing the device. He enlisted Yusuke Hagiwara, the director of the Tokyo Astronomical Observatory, to help with the project[1]. Kin'nosuke Kawakami and Hiroshi Akima from the Electrical Communication Laboratory (another predecessor of NICT) were also involved[2]. The instrument consisted of a 200-MHz receiver and a 4-×-4 dipole antenna with a reflector, with the mount for tracking the diurnal motion adapted from the mount of an optical telescope used by the Tokyo Astronomical Observatory for other observations[1]. According to Kawakami and Akima, the instrument was the first in Japan to experimentally confirm solar noise. They said they carried out both the installation and start-up of observations[2].

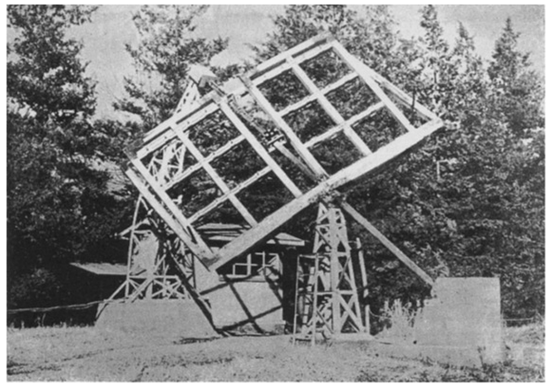


Figure 1 The 200-MHz-band solar noise observation antenna installed by Kawakami and Akima at the Tokyo Astronomical Observatory (Photo courtesy of the National Astronomical Observatory of Japan)

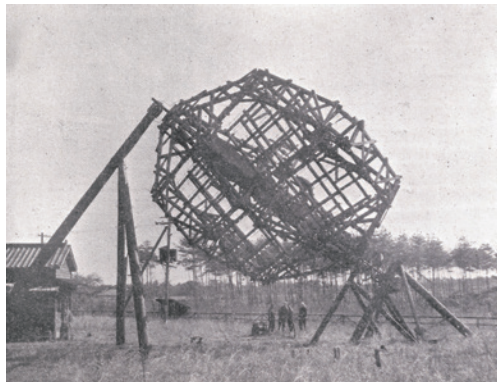
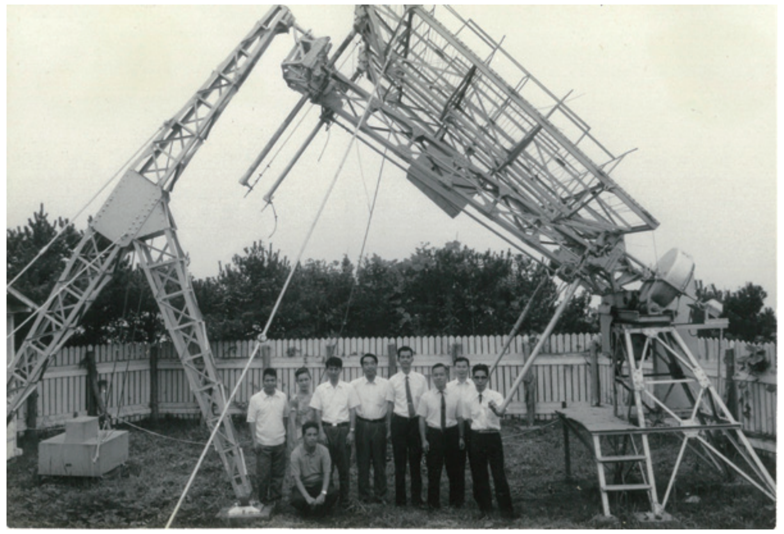
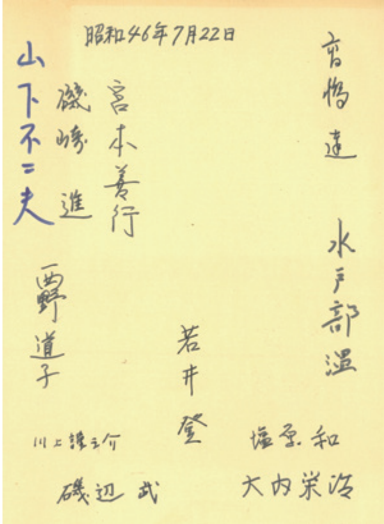


Figure 2 The Solar Noise Observation Antenna at the Electrical Communication Laboratory's Ooi Radiowave Observatory[2].



July 23, 1971.

Figure 3 Commemorative meeting honoring the completion of the 200-MHz-Band Solar Radio Antenna Mission at Hiraiso Radiowave Observatory



Writing by member

Solar Noise Observation Antenna Installed at the Electrical Communication Laboratory (July 1949)

In the July 1949 issue of The Monthly Journal of the Electrical Communication Laboratory (now NTT Technical Review), an article was published about the completion of solar noise observation antennas at the Ooi Radiowave Observatory at the Electrical Communication Laboratory in Fujimino City, Saitama Prefecture. It was completed two months earlier than the installation at the Tokyo Astronomical Observatory [3]. This antenna (Figure 2) had an effective area four times larger than the Tokyo Astronomical Observatory antenna (8 × 8). It was installed for the purpose of studying celestial noise in the VHF band and warning of the Dellinger effect. Kawakami and Akima used this antenna to conduct continuous observations of solar noise (daytime) and galactic noise (nighttime) over about one month, starting in February 1950. The frequency used in these observations was 61.2 MHz. Reference [2] shows a two-wave solar noise graph comparing the results of simultaneous reception in the 200-MHz band by the aforementioned Tokyo Astronomical Observatory antenna.

Solar Radio Wave Observation Antenna Installed at the Hiraiso Radiowave Observatory (construction completed in March 1952, observations commenced in September 1952)

As the first solar noise observation antennas were being established in Japan, the Electrical Communication Laboratory focused on practical research for the telegraph and telephone services. It later created a separate department for public research observations, such as ionospheric observations, which ultimately became NICT. Since the Ooi Radiowave Observatory remained at the Electrical Communication Laboratory, new 200-MHz-band, 4-×-6 dipole antenna was installed at the Hiraiso Radiowave Observatory. It became apparent during this time that solar radio waves, in addition to creating noise in radio communication channels, contained vital information about solar activity, such as the Dellinger effect, which could interfere with shortwave communications. As a result, routine observations of solar radio waves began using this antenna to provide data for radio warnings, which predicted and announced disturbances in radio waves.

The Hiraiso Radiowave Observatory eventually developed higher-performance observation equipment that could observe higher frequencies and a wider range of frequencies. As a result, the former antenna was removed in mid-January 1972. A group photo was taken of the founding members of the solar radio observation team in front of the antenna before its removal (Figure 3), including Kin'nosuke Kawakami on the far right.

Hiraiso's Achievements Eternalized

Space weather forecasts eventually replaced radio warnings. The Hiraiso Radiowave Observatory ended its 102-year history in 2016 with the unmanned NICT Hiraiso Solar Observatory as its last facility. A plaque was installed at the new Minohamagakuen Station on the Hitachinaka Seaside Railway Minato Line inaugurated in 2021 to commemorate the facility's many achievements, including the aforementioned antenna (Figure 4). In a referrence [2] Kawakami and Akima, pioneers of Japanese radio telescope, noted as follows! "Observations of solar and galactic noise have provided valuable insights into the structure and properties of celestial objects, ultimately leading to the development of the new scientific discipline called radio astronomy".

Figure 4 The plaque for the Hiraiso Solar Observatory installed at Minohamagakuen Station in December 2022 (Photo by TOMITA Fumihiko)

Today, this plaque stands as a testament to the vital role that communication engineers from NICT played in the birth of radio astronomy in Japan.

Special thanks are due to Professor Masao Saito of the National Astronomical Observatory of Japan (NAOJ) for sharing his knowledge and materials on the early history of radio telescopes.

Reference

[1] "The First Radio Telescope," Astronomical Heritage: Pioneering Japanese Astronomers, pp. 96-99, Nikkei Science Supplementary No. 245, Nikkei Science Inc. 2021.

[2] Kin'nosuke Kawakami and Hiroshi Akima, "About Cosmic Noise (Mainly Regarding the Results of Observing Solar Noise)," Denpa Shiryoshu, no.1, pp.153-172, Central Radiowave Observatory of the Radio Regulatory Commission, March 1951. (in Japanese) https://doi.org/10.24812/nictkenkyuhoukoku.CRWO.D.1_153

[3] "A Giant Antenna that Follows the Sun Constructed at Ooi Radiowave Observatory," The Monthly Journal of the Electrical Communication Laboratory, vol.2, p.343, Electrical Communication Laboratory, Ministry of Telecommunications, July 1949. (in Japanese) https://dl.ndl.go.jp/info:ndljp/pid/2321791/37

HAGIMOTO Kazuo, Principal Researcher, and NAKAZAWA Masataka, Distinguished Professor at Tohoku University, Announced as 2023 Japan Prize Laureates.

The Japan Prize recognizes scientists and engineers worldwide who have made groundbreaking and exceptional advancements in science and technology, ultimately contributing to the betterment of humanity by promoting peace and prosperity. The awards ceremony will be held on Thursday, April 13 in 2023.

- Fields: **Electronics, information, communications**
- Award Recipients: **Dr. NAKAZAWA Masataka, Distinguished Professor (DP) / Specially Appointed Professor, Tohoku University**
  HAGIMOTO Kazuo, Principal Researcher, National Institute of Information and Communications Technology
- Achievement: **Outstanding contributions to advancing high-capacity, long-distance optical fiber networks through developing semiconductor-laser pumped optical amplifiers.**

HAGIMOTO Kazuo, Principal Researcher

Research Summary and Note of Acceptance

We are honored to be recognized for creating a compact and highly efficient erbium-doped fiber amplifier—which utilizes cutting-edge semiconductor pumping technologies—and the repeated transmission technology it is used in. It is with great pride that we observe Japan's pioneering efforts in introducing and operating this technology across various organizations, from basic structures to standardization and from devices to equipment and measuring instruments. Japan's leadership has enabled this technology to gain widespread acceptance and recognition as a crucial piece towards building a globally connected broadband society.

NICT NEWS 2023 No.2 Vol.498
Published by Public Relations Department, National Institute of Information and Communications Technology
Issue date: Mar. 2023 (bimonthly)
4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan
TEL: +81-42-327-5392 FAX: +81-42-327-7587
URL: https://www.nict.go.jp/en/
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ISSN 2187-4050 (Online)