NICT NEWS

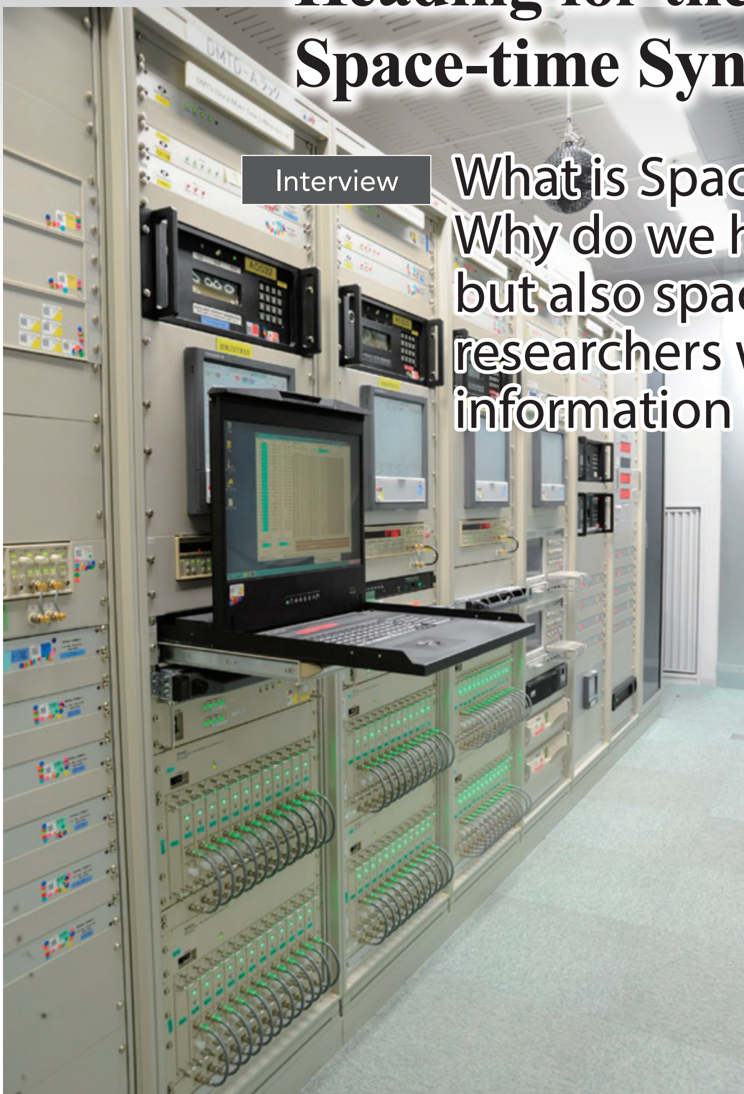
National Institute of Information and Communications Technology

No.4 2022

Vol.494

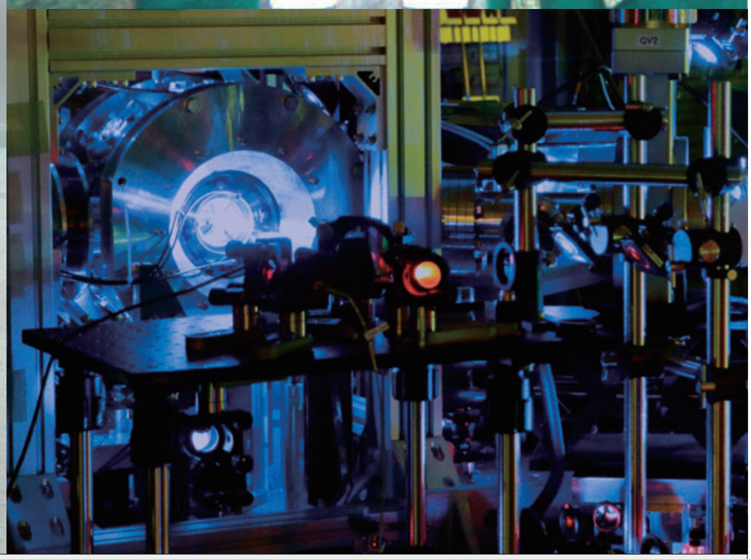
FEATURE

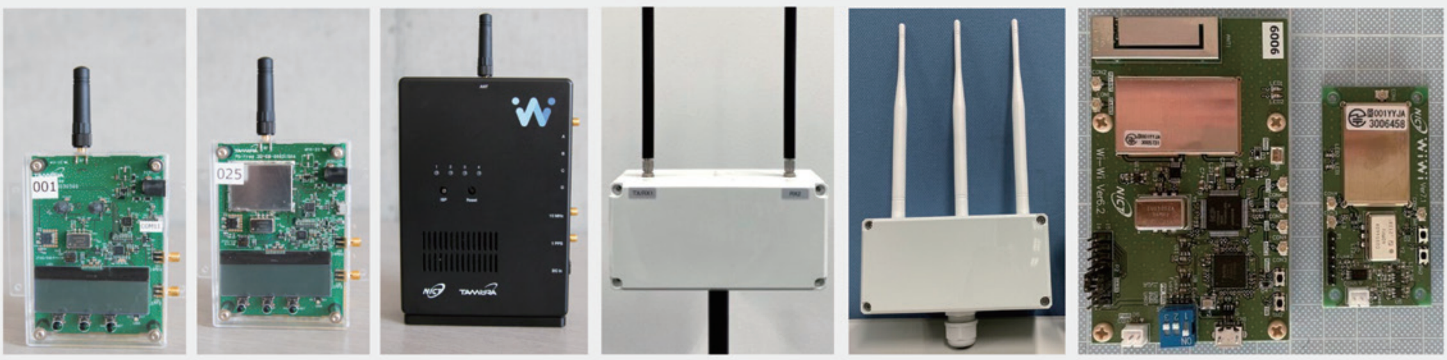
Space-time Standards Technology: Heading for the Decentralization and Space-time Synchronization



Interview

What is Space-time? Why do we handle not only time, but also space? Interview with the researchers who generate time information that governs modern society





CONTENTS

National Institute of
Information and Communications Technology

NICT NEWS 2022 No.4 Vol.494

Cover Photo: Technologies developed in Space-Time Standards Laboratory to generate highly accurate time and frequencies and to deliver them to the public

Left
Japan Standard Time generation system that collects atomic clock signals and generates time signals
(Top Right) Ultra-compact oscillator using acoustic wave elements to realize miniaturization of atomic clocks

Middle Right
Strontium optical lattice clock

Bottom
Wi-Wi (Wireless two-way interferometry) modules ver. 1-7, enabling the capture of space and time (space-time synchronization)

Photo Upper Left:
Application of the space-time synchronization technology as a sensor
Over the approximately 4.3 km between NICT headquarters (near) and Sky Tower West Tokyo (far), water vapor along the path causes an elongation of the radio propagation path by about 1.5 m. Using Wi-Wi (wireless two-way interferometry) to communicate over this distance, we can detect changes in elongation within a precision of 2 cm.

FEATURE

Space-time Standards Technology: Heading for the Decentralization and Space-time Synchronization

Interview

TOPICS

INFORMATION

The New NICT PR Movie "A Future with N" released!

In July 2022, NICT's New PR Movie "A Future with N" has released.

The AI character "N" explains four focusing technologies, Beyond 5G , Simultaneous AI Interpretation, Quantum Cryptography and Cybersecurity.
Please watch the future made by NICT.

https://www.youtube.com/watch?v=YOenAWHhRIA&list=PLBwwDuSrrNU1GuFPOguE5WrZvKzje1eZN

Interview

What is Space-time?
Why do we handle not only time, but also space?
Interview with the researchers who generate time information that governs modern society

Accurate time is essential in modern society. A delay of a few minutes may be acceptable when people are meeting up with each other. However, in the future, vast numbers of machines will be communicating with each other, and if, for example, a self-driving car is equipped with an improperly set clock, then it might collide with another car. In anticipation of such prospects, in the near future, even more precise time will be realized through optical lattice clocks and other devices that are now under development. The definition of the second will also be realized more accurately.

From daily life to science and technology, time dominates our lives and society. In this interview, we will introduce the Space-Time Standards Laboratory, which generates and disseminates Japan Standard Time (JST).

IDO Tetsuya

Director, Space-Time Standard Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After completing a doctoral course and serving as Researcher at JST-ERATO, Research Associate at JILA (NIST/University of Colorado), and as a JST-PERSTO Researcher, Then he joined NICT in 2006. After his doctoral course, he has been engaged in laser cooling of Sr atoms and its application for optical lattice clocks, also precise measurement technology. Ph.D. (Engineering).

MATSUBARA Kensuke

Group Leader, also Research Manager
Japan Standard Time Group, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After completing graduate school, he joined the Communications Research Laboratory (CRL, currently NICT) in 2001. He has been engaged in research on single-ion optical clocks, high-precision frequency provision by standard radio waves and operation of Japan Standard Time, etc. Ph.D. (Science).

SHIGA Nobuyasu

Planning Manager, North-America Collaboration Center, Global Alliance Department
Senior Researcher, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After completing doctorial course, he worked as a post doctorial researcher at the university. He joined NICT in 2008. He had been engaged in optical lattice clocks and ion trap atomic clock, then he moved to research of wireless time synchronization technology (Wi-Wi), and application of Space-Time synchronization. Ph. D. (Physics).

HARA Motoaki

Senior Researcher, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After receiving Ph.D. in engineering, he Joined Fujitsu Laboratories Ltd. He became an associate professor at the Graduate School of Tohoku University in 2013. Then he joined NICT in 2016. He has been engineering in devise development by applying semiconductor microfabrication. Ph.D.(Engineering).

What is the Space-Time Standards Laboratory?

IDO The Space-Time Standards Laboratory is the laboratory that generates and disseminates JST. This is the core mission of NICT. We also develop technologies for that purpose. Our mission is to continue providing society with a stable and uninterrupted supply of the frequencies that are the basis of JST. Additionally, by advancing these activities further and developing and presenting new technologies, we seek to pioneer never-before-seen ways of using time.

When we say "time," we aren’t just talking about having good precision. Users also shouldn't have to spend too much money to receive accurate time.

With that in mind, our laboratory has envisioned a future as shown in Figure 1, whereby we not only provide the public with time and frequency standards in a format and at precisions that meet the needs of users at different layers, but also develop technologies that utilize time and frequencies for the positioning. In order to service according to the required accuracy, it is first necessary to generate accurate time, which is the responsibility of the Japanese Standard Time Group in the laboratory.

MATSUBARA It is primarily important for JST to provide an accurate standard time that

Interview

What is Space-time? Why do we handle not only time, but also space? Interview with the researchers who generate time information that governs modern society

is used with confidence and that is also disseminated without interruption. By achieving it at a high level, we can also demonstrate Japan's advanced scientific ability to the world, which we believe will create trust in the technology in Japan. Currently, Coordinated Universal Time (UTC), which is the world's universal time standard, is determined in Paris at the International Bureau of Weights and Measures (BIPM) by averaging the times indicated by atomic clocks operated by metrology institutes around the world. How accurately a country can maintain its standard time compared to UTC is a representation of its technological capabilities relevant to time and frequency, and, over the past year, JST has been maintained within a maximum of 8 nanoseconds from UTC. To give you an idea of how short a time span it is, in 8 nanoseconds even light can only travel 2.4 meters. However, such nanosecond-scale precision is not always necessary in everyday life. NICT disseminates standard time via several methods, including telephone lines and NTP (Network Time Protocol). For example, in the low frequency standard radio wave method, the time is transmitted with an error of less than 100 nanoseconds, which is a completely negligible level when received and used with a radio-controlled clock. On the other hand, extremely high accuracy is required in cutting-edge science. The strontium optical lattice clock operated by NICT is accurate to within one second over the course of several hundred million years. Applying such clocks, among others, we are generating and disseminating time that can be used for a variety of needs, including those of the future.

IDO In addition to creating a basis for accurate time and frequency, the technologies to deliver it to the people with as little loss of accuracy as possible are also extremely important. Furthermore, if we measure the time it takes for a radio wave to propagate between us, we also know the distance between us, and then we can work out each other's positions by exchanging time information. Time synchronization is also related to space, which is why we are conducting research based on the term "space-time synchronization."

SHIGA I think that everyone is already familiar with time synchronization. It’s what we do when we set clocks. What, then, does "space synchronization" mean? This refers to having many machines that, although spatially separated, are aware of each other's positions. In this case, there is a close and inseparable relationship between accurate time synchronization and the technologies to accurately measure position.

For example, if everyone were to try to set the time by using a wall clock as a reference clock, strictly speaking, it is not possible for everyone to set the time completely identical, because each person's distance from the wall clock is different. These differences in distance result in slight differences in how long it takes for the visual information of the time indicated by the wall clock to reach each person's eyes. Therefore, in order to accurately synchronize time between two people who are separated from each other, it is necessary to have a clear understanding of their positional relationship in space. Thus, accurate time synchronization and space synchronization are in fact the two sides of a coin, and it is space-time synchronization that realizes both of them at the same time.

In the present day, we hardly feel any delay even during an online call or meeting with someone overseas, but this is because in human communication we don't notice delays of up to a few milliseconds.

If we can increase precision to the nanosecond and picosecond range by using the technologies that our lab is studying, then we will be able to greatly expand what is possible for machines. We would be able to realize collaboration far exceeding the processing speed of the human brain, which would then enable autonomous driving, as just one example. By linking together machines at ultra-high speeds, it will be possible to manage the movements of groups of machines at quantities and densities beyond normal human control.

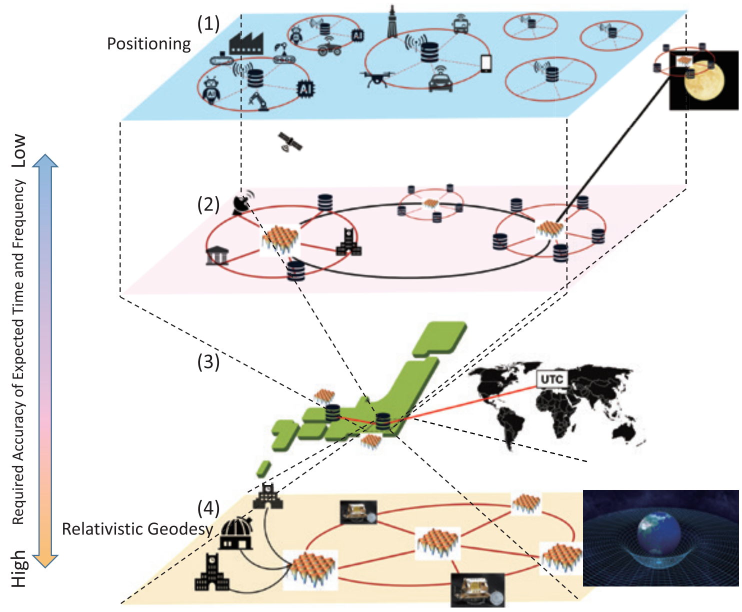
Dr. Hara, you are also doing research on space-time synchronization, right?

HARA I am researching the miniaturization of atomic clocks by embedding them in chips, and I envision every machine and device containing a high-precision clock. In the future, all devices will be connected by information. With that being the case, multiple machines must be able to move and work as one. If all machines contain high-precision clocks, they will be able to determine their exact location and time, and take action based on independent decisions. In this way, rather than humans controlling the machines, the machines will be able to cooperate with each other to actively and intelligently respond to humans.

Maybe this is what the evolution of smartphones will look like? If all smartphones and IoT devices were connected and synchronized in time, then both time and space (location) will be shared by everyone.

The research on optical lattice clocks, which is aimed at greater precision, is also interest-

Figure 1 Vision of Time and Frequency Social Infrastructure in the Future
(1) to (4) show examples of supply layers for applications that use time and space.
(1) Mobile networks originating from an edge server. The disseminated time standard is also used for positioning and other spatial understanding.
(2) A metropolitan area network with interconnected optical atomic clocks. From here, time and frequency are disseminated to edge servers, etc., according to their required accuracy.
(3) Robust and resilient standard time and UTC are created in cooperation with NICT and Japan and overseas research institutes.
(4) Unexplored areas, such as the development of ultra-high precision atomic clocks and the development of fundamental science. It is also expected that this ultimate precision will be used for relativistic geodesy.



ing. How are things going in that area?

IDO Around 2030, the General Conference on Weights and Measures will discuss the possibility of changing the definition of the second to that of an optical clock, and we are producing research results that will contribute to the realization of this change. Additionally, we are working to ensure that, even if the definition of the second changes, we will be able to generate seconds by ourselves in a corresponding manner and disseminate them as standard time. Currently, the Japan Standard Time Service Group has already begun to reflect in standard time the exact one second period ticked by an optical lattice clock.

MATSUBARA Through a demonstration of relativistic effects with optical lattice clocks between NICT and the University of Tokyo Hongo campus (2011) and also higher precision experiments at the Tokyo Skytree (2020), optical lattice clocks have shown us that time ticks differently for different gravitational potentials (altitude difference of several tens of meters). Until now, we thought that there was only a single "correct" time and that we could share it, but now we may be creating a society in which it is natural to have multiple times. I think that research on precise time will lead to changes in how time is used in this new era.

HARA I think that the latest information infrastructure of the information terminals we use will also be able to receive high-precision time information from optical lattice clocks. This will improve the accuracy of the time we can handle by five digits of precision, significantly raising the level of coordination between terminals. Until now, IoT devices have mainly handled information as sensors, but going forward they will handle images and videos in real time. Furthermore, this data will be processed "while moving" through space, as in autonomous driving. Highly precise time synchronization is indispensable for meeting the demand for parallel processing of such large volumes of data by multiple devices, and we believe that the practical applications of optical lattice clocks will have important impacts.

SHIGA Imagine robots working together, and you can imagine the direction that information and communication will take in the future. The current logistics will change its form to the smooth flow of people, goods, and services in three and four dimensions. This is only possible when space-time synchronization is achieved.

HARA For example, consider a bus in a public transportation system. Right now, passengers gather according to the bus schedule, and, if the bus is late, the passengers wait for the delay, but if a passenger is late, the bus will go without waiting for that passenger. Recently there have been apps that show bus delays and bus locations, but, if synchronized clocks are also built into the systems that handle passenger information, it will be possible for buses to track passenger delays and locations, allowing buses to adjust accordingly and maximize the effectiveness of their services. This effect will become even more pronounced as buses become unmanned through autonomous driving and they are optimally controlled over the network.

The important point here is not that bus and passenger clocks are set to prevent late arrivals, but that a system synchronized to a level beyond that of a human's cognitive level can consider the needs and behaviors of passengers to enable the more flexible and efficient operation of public transportation. And, conversely, humans will no longer be tied to clocks.

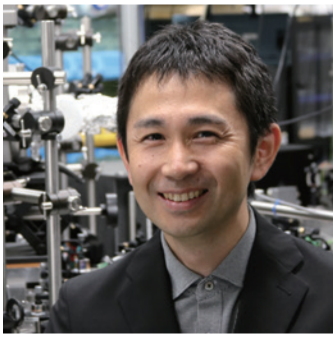
Finally, could you summarize the goals of the Space-Time Standards Laboratory?

IDO Using optical lattice clocks, etc., to improve the precision of time remains one of our major goals. On the other hand, time information is one of the most important social infrastructures. Our Kobe Sub-station and long-wave standard frequency transmission stations use decentralized technologies so that, even if one location is damaged due to a disaster, we will be able to generate and disseminate a robust and resilient standard time that never stops.

We will create a new value by providing technology to generate accurate and stable time and frequency and also providing methods to receive the benefit of such high-quality signal. The shape of system relevant to time would change from a concentration to decentralization, and finally space-time synchronization will be realized.

Standard Time Ticks by the Light of an Optical Lattice Clock

Optical references replace microwave references as the basis of time



HACHISU Hidekazu

Senior Researcher, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After earning his doctorate and working as a JST-CREST Post-Doctoral Fellow, he has been with NICT since 2010, where he has been involved in the research of optical frequency standards, especially optical lattice clocks. Ph.D. (Engineering).

Nils Nemitz (left)

Senior Researcher, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After gaining an interest in high resolution spectroscopy during his doctoral thesis, Nils studied microwave clocks at PTB in Germany and optical lattice clocks at RIKEN before joining NICT in 2017. He now works on the frequency combs and data evaluation that connect optical clocks to UTC. Dr. rer. nat. (Physics).

ITO Hiroyuki (right)

Senior Researcher, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

He joined NICT in 1999. His research interests include atomic clocks, precise frequency measurements and time and frequency standards. Ph.D. (Science).

Calibrating the rate of Coordinated Universal Time UTC has long been the responsibility of microwave frequency standards around the world. Their measurements have kept the progression of global time in agreement with the duration of the second as defined in the International System of Units. But new, optical standards based on precise laser spectroscopy of atoms have appeared in recent years, and several such optical clocks also started calibrating the rate of UTC, including a strontium optical lattice clock at NICT. The same clock has now become a reference standard contributing to a greater accuracy of Japan Standard Time. These activities at the Space-Time Standards laboratory fulfill important goals for a redefinition of the second.

Standard Time

The International Bureau of Weights and Measures (BIPM) collects time information recorded for more than 450 atomic clocks operated by institutions around the world to calculate a robust Free Atomic Timescale EAL from their weighted average (Figure 1). A smaller number of highly accurate primary frequency standards [1] then evaluate the rate of this timescale relative to the definition of the second in the International System of Units. BIPM uses the results to obtain a monthly correction value and determine the International Atomic Time (TAI). Finally, a varying number of leap seconds is added to maintain agreement with Earth's rotation. This provides the Coordinated Universal Time UTC, which serves as the international standard and progresses at the same rate as TAI.

But the BIPM results do not directly create a real-world timescale signal since they are only available with a delay of up to 40 days and for only one point every five days. Each participating institute therefore generates its own continuous timescale signal UTC(*k*), where *k* designates the institute. UTC(NICT) is generated using a hydrogen-maser atomic clock as a source oscillator with excellent short-term stability. Its rate is then adjusted by 18 long-term stable commercial cesium atomic clocks. NICT distributes UTC(NICT)+9 h as Japan Standard Time (JST) in various ways.

Optical clocks

In an atomic clock, the oscillations of electromagnetic waves absorbed or emitted by the atom are counted like the swings of a pendulum might be in another kind of clock. According to the current definition, 9 192 631 770 such oscillations in a cesium clock make up the duration of one second. Just like a finely marked ruler helps measure length more precisely, the second can be determined

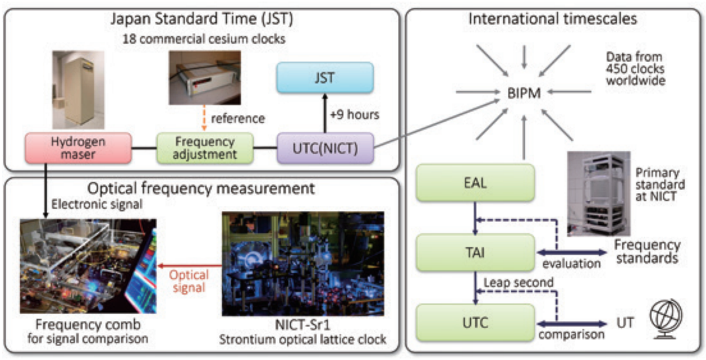


Figure 1
Schematic overview of time standards. (Left side:) With the help of an optical frequency comb, the frequency of a hydrogen maser is determined by the optical lattice clock NICT-Sr1. The same maser contributes to the generation of UTC(NICT), which is evaluated monthly against UTC calculated by BIPM (right side).

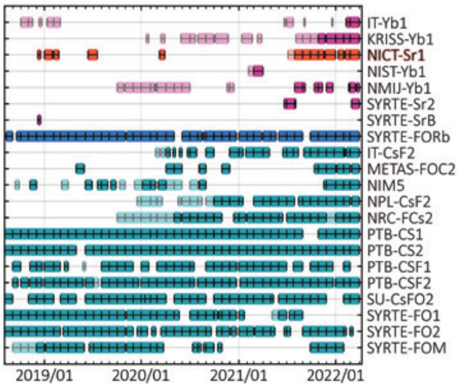


Figure 2 TAI rate calibrations by frequency standards since August 2018. NICT-Sr1 is highlighted in orange, other optical standards are shown in pink. Blue indicates a microwave secondary frequency standard, while the primary standards are shown in green. Pale colors indicate "delayed" calibrations that were not submitted on-time for the monthly calculation.

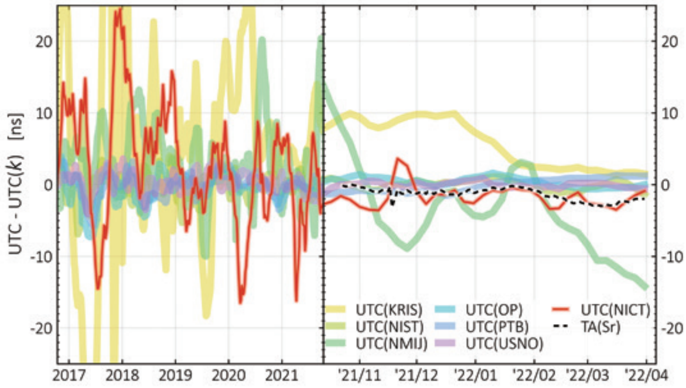


Figure 3 Time difference between UTC and the UTC(k) of various institutions. UTC(NICT) is shown in red, and the dotted line shows the time difference between UTC and TA(Sr).

more precisely by a high frequency. This is an advantage of optical clocks [2], which use light at frequencies more than 10 000 times larger than that of the cesium clock.

Optical clocks have improved rapidly in recent years and are now far more accurate than the cesium primary frequency standards. Consequently, the Consultative Committee for Time and Frequency (CCTF) of the International Committee for Weights and Measures (CIPM) is discussing criteria for redefining the definition of the second to make use of optical transitions in atoms. One such criterion is that every month, more than three optical clocks should calibrate the rate of international time with an uncertainty of less than 2×10^{-16}.

Contributions of NICT's optical lattice clock to international time

Before any clock may contribute to the calibration of TAI, it is reviewed by an international working group of researchers in the field of time and frequency measurement. Among the frequency standards that are recognized as suitable, clocks that use atoms other than cesium are called secondary frequency standards. Using strontium atoms, the optical lattice clock NICT-Sr1 developed at NICT became the second optical secondary frequency standard worldwide in November 2018, following the strontium optical lattice clock of the Observatoire de Paris.

Primary and secondary frequency standards submit their rate evaluations to BIPM for the determination of the calibration value over the preceding month. As an example, the best accuracy in the calculation for December will be achieved if the frequency standards report their results for the month during the first days of January, before the calculations are performed. The Observatoire de Paris and NICT were the first institutes to submit such "on-time" reports following their measurements in December 2018 [3]. Although its contributions initially were irregular, NICT-Sr1 was virtually the only optical standard that reported on-time over the following two and a half years. Since then, optical on-time reports have become more common (Figure 2), and for November 2021 a record number of 16 atomic clocks contributed to TAI calibration, including three optical clocks [4]. Such world-wide cooperation makes international time more robust.

One month after this, NICT-Sr1 submitted an extended report for December 2021 that reduced the uncertainty of the satellite frequency comparison as much as possible to reach a reporting uncertainty of 1.9×10^{-16}. This is the highest-ever precision, and an important milestone towards a redefinition of the SI second that offers a significant improvement in the frequency accuracy of TAI and UTC.

Contributions of NICT's optical lattice clock to Japan Standard Time

Besides improving the calculated timescale of UTC, optical clocks can also provide more accuracy for time signals generated in real-time. For five months in 2016, NICT generated the world's first high-precision time signal TA(Sr) based on an optical clock, by evaluating and correcting the frequency of a hydrogen maser with NICT-Sr1 [5]. In 2021, the generation of TA(Sr) was restarted using a similar method, and this time it was included as a source in the generation of the UTC(NICT) signal.

The time difference of UTC(NICT) from UTC, calculated after the fact by BIPM, previously reached up to 20 nanoseconds (Figure 3). Including the measurements of NICT-Sr1 reduced this difference to only a few ns. Japan Standard Time is the first national timescale that includes an optical clock as a standard for the duration of one second. Such a regular contribution of optical clocks to UTC(k) is another condition considered in the decision to redefine the second.

Future Prospects

NICT continues to lead in the adoption of optical clocks and works to apply them to maintain and improve the accuracy of both UTC and Japan Standard Time. Our efforts play an important role in demonstrating that the time has come for a redefinition of the second based on such highly accurate optical frequency standards.

We also aim to contribute to geodesy [6] and basic science, such as the search for dark matter, by making high-precision time signals available anytime, anywhere, to anyone.

Glossary

*1 Primary or secondary frequency standard: An atomic clock that has been assessed by an international working group of the Consultative Committee for Time and Frequency and found to be capable of contributing to the calibration of TAI. Primary frequency standards probe cesium atoms according to the definition of the SI second, while secondary frequency standards are based on different atoms.

*2 Optical clock: An atomic clock that is based on optical transitions with frequencies of several hundred terahertz. Optical clocks are usually constructed as either optical lattice clocks or single-ion clocks:
Hidekazu Hachisu, "Next Generation Frequency Standard by Laser Light" NICT NEWS 2019 No. 3

*3 NICT Press Release, https://www.nict.go.jp/en/press/2019/03/04-1.html

*4 BIPM, "Record number of frequency standards contribute to International Atomic Time" https://www.bipm.org/en/-/2021-12-21-record-tai

*5 NICT Press Release, https://www.nict.go.jp/en/press/2018/03/20-1.html

*6 Page 10 of this issue of NICT NEWS

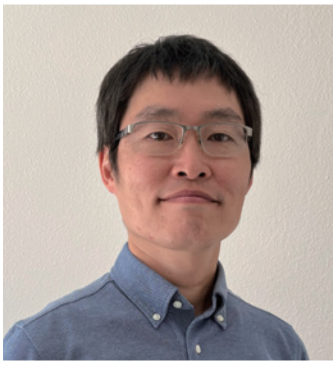
Synergy of Things via Space-time Synchronization

Transformation from "Internet of Things" to "Synergy of Things"

YASUDA Satoshi

Researcher,
Space-Time Standard Laboratory,
Electromagnetic Standards Research Center,
Radio Research Institute

He joined NICT in 2008 after 2 postdoc positions in Alaska and NIST Boulder. He contributed to Strontium optical lattice atomic clock experiment and constructed Ytterbium ion atomic clocks. He then proceeded to develop Wireless two-way Interferometry (Wi-Wi) technology and have been working on the research and development of "Space-Time synchronization." Ph.D.(Science).



SHIGA Nobuyasu

Senior Researcher,
Space-Time Standard Laboratory,
Electromagnetic Standards Research Center,
Radio Research Institute

He joined NICT in 2014 after a researcher at Shizuoka University and a system engineer at a private company. He then proceeded to develop Wireless two-way Interferometry (Wi-Wi) technology and have been working on the research and development of "Space-Time synchronization." Ph.D.(Physics).

Today the implementation of 5G is proceeding at a rapid pace in the field of information and communications. At the same time, research and development is being advanced around the world on Beyond 5G technologies. In the Beyond 5G era, we will probably see social issues being solved by many robots that are highly coordinated in terms of time and position. We call the technology used to coordinate the time and position of various devices as space-time synchronization technology and is an area where R&D is ongoing. Our aim is to ensure that as collaboration among machines and devices advances, so too does collaboration among people.

Background

In robot anime, there are scenes in which a group of robots will transform to become one large integrated robot with greater functions and powers. Unfortunately, more than 50 years have passed since such robot anime first appeared, and still no-one has been able to create a transforming, combinable robot. One reason for this is that the technologies to combine multiple robots in time and space are still relatively undeveloped. In recent years, it has become possible to automatically coordinate time on smartphones and personal computers linked via the internet to within a millisecond. Although precision to a few milliseconds is a time-scale that is not perceptible to humans, if the clocks of machines could be synchronized to within a microseconds, this would significantly boost the efficiency of communications. The three Key Performance Indicators of 5G communications are high capacity, low latency, and massive connectivity. The current level of time synchronization accuracy, which is a few milliseconds, is now beginning to hinder efficiency, meaning that further improvement of the time synchronization accuracy is needed to further enhance communication efficiency in the future.

Global navigation satellite systems (GNSS) such as GPS are the most convenient and common means of precise time synchronization of mobile objects. However, given that any overdependence on GNSS in Beyond 5G mechanisms could result in system vulnerabilities at times of disaster, a key global challenge is to develop new time synchronization and positioning technologies in order to establish resilient communications. If time synchronization precision could be improved to the picosecond range (1 trillionth of a second), it would enable positioning measurements using radio waves with an accuracy in the millimeter range (Figure 1).

Introduction to Wi-Wi

It is against this backdrop that we have worked to develop wireless two-way interferometry (Wi-Wi) technology. Wi-Wi is based on two-way satellite time and frequency transfer technology (TWSTFT) used to compare Japan Standard Time (JST) with Coordinated Universal Time (UTC) (Figure 2). Wi-Wi simultaneously measures the time difference and the time it takes for a signal to reach its destination (propagation time) by sharing time information via satellite, and it is possible to achieve measurements accurate to the picosecond. We have developed a technology to incorporate this protocol into wireless communications systems in order to align the clocks of these systems to the picosecond level.

Wi-Wi is used in clock comparison and time propagation measurements, and it is also possible in principle to measure the distance between antennas by multiplying the propagation time by the speed of light. To date, we have verified that positioning measurement is possible in environments where there is little radio wave reflection, such as in anechoic chambers or fields outdoors.

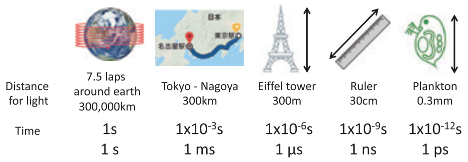


Figure 1 Timescale and distance travelled by light

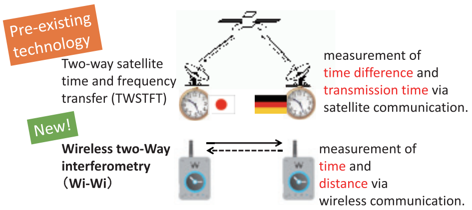


Figure 2 Two-way satellite time and frequency transfer technologies and wireless two-way interferometry technologies

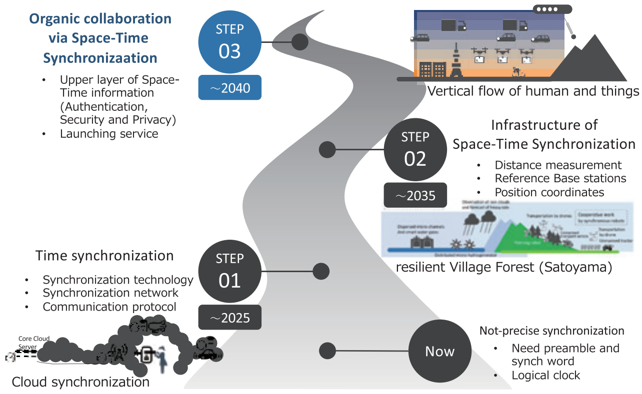


Figure 4 Roadmap of Space-Time synchronization technology

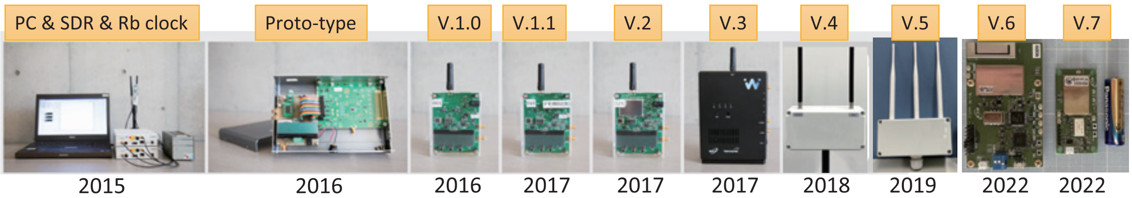


Figure 3 Chronology of Wi-Wi module

Wi-Wi module development

Since 2015, after verifying the principles of Wi-Wi using measurement devices, we have worked to develop a Wi-Wi module with Wi-Wi functionality for commercial-use communication devices.

This Wi-Wi communications module is IEEE802.15.4g -compliant and uses a 920 MHz bandwidth. Although still only a prototype, it conforms to technical standards and can be used by anyone, anywhere. Communications range is projected to be around 200 m, with a time synchronization precision to 30 nanoseconds and synchronization jitter of 20 picoseconds. While the module-2 was the size of a postcard, the module-6 has been miniaturized to the size of the business card, in addition to which performance improvements continue to be made, including enhancing time synchronization precision from 1 microsecond to 30 nanoseconds.

The development of this Wi-Wi module and research into its possible applications is being conducted jointly with Tohoku University, The University of Tokyo, Hiroshima University, and Nihon Dempa Kogyo Co., Ltd., with support from New Energy and Industrial Technology Development Organization (NEDO)'s Project for Research and Development of Enhanced Infrastructures for Post 5G Information Communication Systems. Based on the premise that time synchronization technology is available, this research project aims to build an efficient wireless communication technology and use it to control a group of robots. By realizing Wi-Wi time synchronization, we have developed low-latency, massive connectivity, and noise-resistant wireless communication protocols, all of which boast unprecedented performance. Using the Wi-Wi module as a communications radio wave environment measuring sensor, we are also starting research to survey the communications environment using robots.

Outlook for development of space-time synchronization technologies

Our goal is for people, things and information to interact with each other in an orderly and three-dimensional way by around 2040. It is for this reason that we are working to develop space-time synchronization infrastructure in specific regions and make collaborative work operations by groups of autonomous robots commercially viable, with a target year of around 2035. This will make it possible to engage in forestry management operations in mountainous regions with only few staff. To realize space-time synchronization, it is first necessary to develop infrastructure. In addition to progressing R&D aimed at completing time synchronization core technologies by around 2025, implementation tests are also underway (Figure 4), but R&D alone will be insufficient to realize this vision. In parallel, it is necessary to also engage in collaboration with business, as well as to work towards international standardization and development of legislation. Since 2016, we have been exploring means of collaborating with business, and the importance of time synchronization has gradually been recognized. The Standardization Promotion Office and the Space-Time Standards Laboratory are working together towards the international standardization of space-time synchronization, and in addition to space-time synchronization being included as a 6G future technology trend at the Working Party 5D (WP 5D) within the ITU Radiocommunications Sector (ITU-R), preparations are being made to include it in the 3rd Generation Partnership Project (3GPP) Release 19. Activities for implementation in Japan alone will not be sufficient, and international collaboration will also be necessary in the future. We are making preparations for international collaboration, aiming to engage in joint research with research institutions, universities and businesses, starting with those in the United States.

Conclusion

We are working to develop technologies that will significantly enhance and advance the synchronization of time and space on devices. This research is necessary because, in order to make the leap from "robots being linked" to "robots in synch," the precision of time synchronization must be improved. Our aim is to facilitate collaboration among people by realizing collaboration among machines, and we are also implementing measures to make these technologies available to use in parallel with ongoing R&D.

Distributed Time Synchronization using Miniaturized Atomic Clocks and Future Vision

YANO Yuichiro

Researcher,
Space-Time Standard Laboratory,
Electromagnetic Standards Research Center,
Radio Research Institute

After completing doctorial course, he became JSPS research fellow. Then he joined NICT in 2016. He has been engaging in research of small atomic clock and its applications. Ph.D.(Engineering).

HARA Motoaki

Senior Researcher,
Space-Time Standard Laboratory,
Electromagnetic Standards Research Center,
Radio Research Institute

After receiving Ph.D. in engineering, he Joined Fujitsu Laboratories Ltd. He became an associate professor at the Graduate School of Tohoku University in 2013. Then he joined NICT in 2016. He has been engineering in devise development by applying semiconductor microfabrication. Ph.D.(Engineering).

Progress is being made in the miniaturization of atomic clocks based on microwave quantum transitions as the frequency standard. Atomic clocks are likely to become more common once they can be made small enough to be installed in smartphones. From the perspective of time dissemination, this article introduces how the spread of atomic clocks could change our lives, current activities using miniaturized atomic clocks, and a vision for the future.

From Centralized to Decentralized Management of Time Synchronization

When setting the time on a terminal, the easiest method is to set it to the same time as the reference clock. The same concept applies to the current time dissemination system, in which terminals are in a subordinate relationship, under a centralized management system in which the time on the reference clock is shared across the entire network. While this system is easy to manage, it is vulnerable to failures in the reference clock or the transmission pathways for time information. For example, currently, time synchronization using the Global Navigation Satellite System (GNSS) is widely used, but this system could be subject to malicious attacks such as jamming or spoofing, or the threat of natural disasters caused by solar wind. According to calculations made in the U.S., it has been reported that if GNSS were to be rendered unusable, this would lead to daily economic losses of US$1 billion (approximately 128 billion yen). The Japan Standard Time Generation System used to set time in Japan achieves high accuracy and reliability through a decentralized management system involving multiple independent atomic clocks. At NICT, approximately 18 commercial atomic clocks are used, with the time of each being aggregated and calculated to achieve both high accuracy and high resistance to defects. In anticipation of the wider use of atomic clocks, we are advancing R&D into highly precise and reliable distributed management of time synchronization for Beyond 5G.

R&D into Miniaturized Atomic Clocks and NICT Activities

From the 2000s, great advances were made in semiconductor laser performance, resulting in the emergence in 2011 of a miniaturized atomic clock with a size of 17 cc and 125 mW power consumption. R&D is continuing today in Japan, as well as the U.S., China, Europe and Israel, among other countries and regions. NICT has worked with academia and industry to conduct R&D into miniaturization and power saving of core components. For example, using a thin film bulk acoustic resonator, we newly developed an oscillation circuit (Figure 1) that oscillates directly in the GHz band (transition frequency of atoms), demonstrating that it is possible to approximately halve the abovementioned size and power consumption. Further R&D into components will continue with the aim of achieving an atomic clock that is simultaneously miniaturized, inexpensive, and power-saving.

Distributed time synchronization using miniaturized atomic clocks

Maximizing the “strength in numbers” of miniaturized atomic clocks, which are antici-

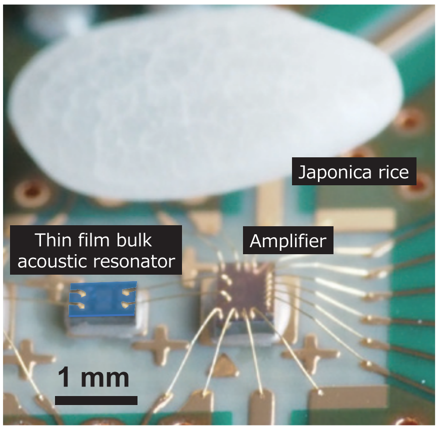


Figure1 Oscillator using piezoelectric thin-film resonator

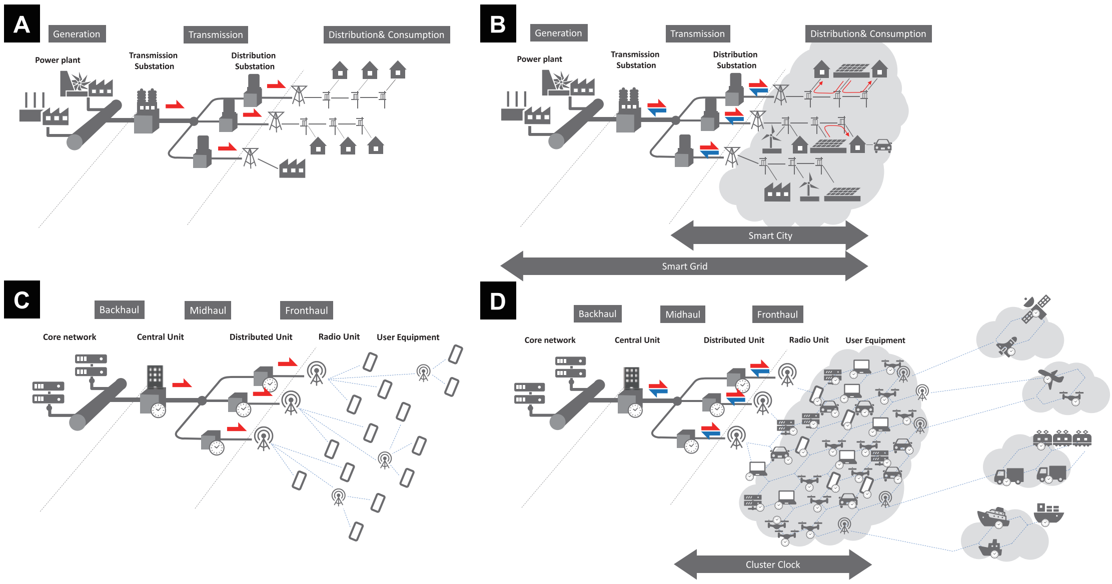


Figure2 Conceptual diagram of electric power systems transitioning from centralized to decentralized systems (A, B) and time synchronized systems (C, D)

Table1 Similarities between smart grids and distributed time synchronized networks

Smart grid	Distributed time synchronization
Distributed power sources, such as solar/wind, etc.	Small atomic clocks
System to aggregate power information from distributed power sources, minimize transmission losses and transmit power	System to aggregate time information from atomic clocks, minimize propagation errors and distribute time
Improved power supply stability	Improved time dissemination stability
Consumer	User wishing to know time and frequency
Supplier	User owning an atomic clock

pated to become more widespread in the future, NICT is conducting research and development into time synchronization networks with enhanced accuracy and reliability. We call this a cluster clock system, as multiple atomic clocks keep time cooperatively. In this research, we began from a numerical network analysis, simulating the generation of atomic clock time. We have recently implemented verification experiments using three miniaturized atomic clocks that are actually the size of a matchbox. These experiments have shown that using a cluster clock can be up to 1.6 times more stable than using a single clock in isolation. In the future, even greater accuracy and reliability can be expected through the use of more atomic clocks and more sophisticated calculation algorithms for aggregation.

Future image of decentralized time synchronization infrastructure

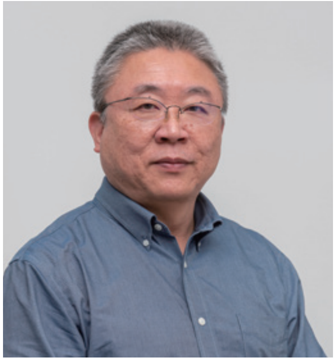
In terms of the future for decentralized time synchronization using cluster clocks, it is likely that smart grid-related initiatives will provide a reference, as they are already at the forefront of the transition from centralized (Figure 2-A) to decentralized (Figure 2-B) systems. In smart grids, the aim is for decentralized power sources such as solar and wind power to be efficiently controlled using IT, thereby providing a stable power supply. Furthermore, in comparison to conventional centralized power networks, it can be expected that these decentralized networks will ensure a stable power supply, even if one power station were to go offline in the event of a disaster, etc. Just as power can be bundled from multiple dispersed power sources to realize a stable supply, the time generated by multiple atomic clocks could be similarly bundled to form a shared stable time source. In the same way that power infrastructure is moving from centralized to decentralized power sources, as atomic clocks become more widespread, we believe that there will be a natural shift from centralized (Figure 2-C) to decentralized (Figure 2-D) time synchronization infrastructure. Similarities between the types of relationships involved in smart grids and distributed time synchronization are summarized in Table 1.

Although energy has a market price and can be monetized, it is still not certain whether time and frequency information could be converted into something of monetary value. If such monetization were not possible, then no sustainable infrastructure could be created, as doing so would not be to the advantage of any supplier of atomic clock time information or businesses maintaining decentralized synchronized systems. However, Intelligent Transport Systems (ITS) and Cyber-Physical Systems (CPS) require both highly accurate time information, coupled with safety and reliability. The global COVID-19 pandemic has also escalated demand for high-trust services based on highly reliable time information, including electronic signatures, supply chains, electronic seals, and time stamps. It is therefore likely that the value of highly accurate and reliable time information will increase, resulting in the establishment of a system that provides information in exchange for a fee.

Future Prospects

The SDGs call for the realization of high-quality, highly reliable, and sustainable infrastructure. Time and frequency information is part of the information that underpins our data-driven society. What is more, time infrastructure of the future must not only be extremely accurate, but also satisfy various other requirements, including being safe, reliable, energy-saving and economical. In order to realize sustainable time synchronization infrastructure, it is imperative to work together with many stakeholders to advance research activities.

Optical Atomic Clocks and Geodesy



ICHIKAWA Ryuichi

Research Manager
Space-Time Standard Laboratory,
Electromagnetic Standards Research Center,
Radio Research Institute

After earning his Ph.D. in science, he joined the Communications Research Laboratory (now NICT) in 1995, where he has researched crustal deformation monitoring using VLBI and GPS, spacecraft tracking using VLBI, technologies for a compact VLBI system, and GNSS time & frequency transfer. Ph.D.(Science).

"Geodesy" may be an unfamiliar word to many people. Simply put, it is *the study of the earth's shape, size, rotation, and gravity, and their changes over time.* In more familiar terms, it is an essential field for the creation of accurate maps and for navigation systems in cars and smartphones. NICT has been researching and developing an optical frequency standard (optical atomic clock) as a clock with unprecedentedly high precision. Although this may at first appear to be a completely separate field from geodesy, this article will show how closely related they are.

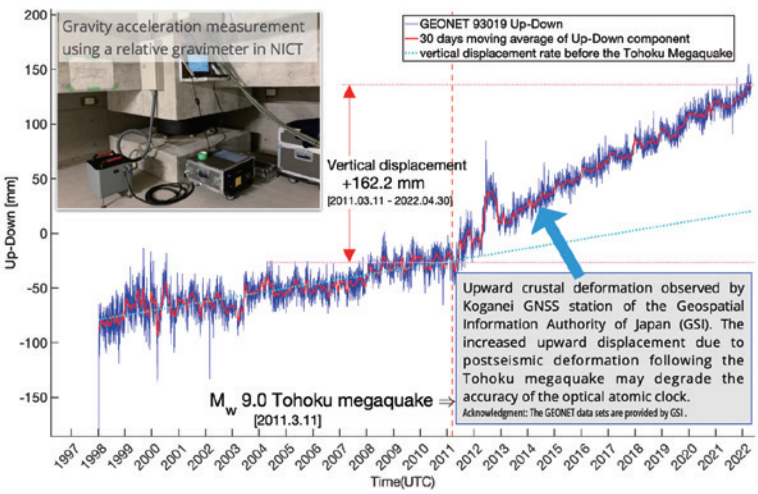
The frequency accuracy of optical atomic clocks has dramatically increased over the past 15 years, improving by more than two orders of magnitude from 16 digits of precision to 18 or even 19 digits of precision. However, because the measurements of their absolute frequency are based on the older cesium frequency standards that define the second, improvements to the uncertainty of these frequencies have mostly leveled off at 16 digits of precision. After numerous experimental results, the absolute frequency for a Sr (strontium) optical lattice clock has only been obtained as $\boldsymbol{\nu(^{87}Sr) = 429\ 228\ 004\ 229\ 872.99\ Hz}$, as of April 2022, and the true performance of optical atomic clocks cannot be fully utilized. Since around 2015 researchers from around the world therefore began to consider a *redefinition of the second* that uses optical atomic clocks.

It has long been known that with any change in the elevation of a clock's location, its frequency changes, too. *Chronometric leveling*, a height measurement method that utilizes this phenomenon, was proposed around 40 years ago. However, in order to detect a 1-cm change in elevation, it is necessary to detect frequency changes at 18 digits of precision, and the accuracy of clocks at that time could, at best, measure elevation changes of approximately 2 m. This is a far cry from conventional leveling, which can measure with an uncertainty of less than 1 cm over distances up to 10 km.

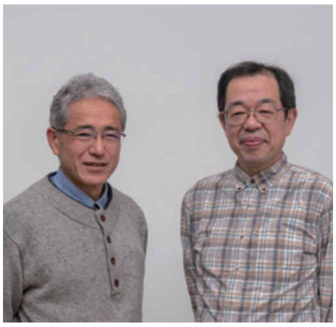
Since then, the development of optical atomic clocks has progressed, and in 2020, RIKEN and collaborating institutes obtained results with 18 digits of precision between portable Sr optical lattice clocks that were installed on the observation deck of the Tokyo Skytree and on the ground. In terms of elevation differences, this provides centimeter-level precision. It shows that chronometric leveling can now be realized with the same level of accuracy as conventional leveling, and that in the future it will be possible to take real-time elevation difference measurements regardless of distance.

Recently, such research has become known internationally as *relativistic geodesy*, and the application of optical atomic clocks to the determination of global height standards is being actively discussed. On the other hand, the *redefinition of the second* requires the stable operation of optical atomic clocks, and so it is important to understand frequency changes caused by solid-earth tides ranging from 10 to 20 cm in amplitude, oceanic tidal loading, crustal deformations due to earthquakes, and ground movements due to groundwater changes (Figure). NICT, in collaboration with partners including the Geospatial Information Authority of Japan (GSI), the National Institute of Polar Research (NIPR), the National Institute of Advanced Industrial Science and Technology (AIST), and several universities, has begun observations and data analysis to evaluate how these effects interact with optical atomic clocks. We believe that the optical atomic clocks developed by NICT can greatly contribute to future geodetic applications.

Figure Time series of upward displacement obtained by GEONET GNSS measurement at NICT headquarters. The inset photo shows the relative gravity measurement. (GEONET data sets are provided by GSI.)



Time and Frequency Transfer Technique for Realizing Definition of the SI Second



SEKIDO Mamoru

Research Manager, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

He joined in the Communications Research Laboratory (currently NICT) in 1991. He has carrier in research field of geodesy and astrometry with very long baseline interferometry. He is engaged in time and frequency calibration service and TWSTFT since 2021. Ph.D.

GOTOH Tadahiro

Senior Researcher, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

He joined in the Radio Research Laboratory (currently NICT) in 1985. He has engaged in the research of satellite time transfer. Ph.D.(Engineering).

In order to determine Coordinated Universal Time (UTC), based on the definition of the second, it is necessary to compare the times of atomic clocks that are maintained and operated by metrology instiutes around the world with a high degree of accuracy. As for methods to measure time differences between distant atomic clocks on Earth, there are two: one is receiving Global Navigation Satellite System (GNSS) signals at each end, and the other is bidirectionally comparing exchanged timing signals generated by the atomic clocks with each other via communication satellites. The latter is called Two-way Satellite Time and Frequency Transfer (TWSTFT).

The GNSS time comparison method requires only receivers and antennas, and time comparisons can be made simply by receiving GNSS satellite signals (Figure 1). The majority of national metrology institutes contributing to UTC use this method because it enables time and frequency comparisons over long distances at a relatively low cost. Due to the Earth's atmosphere and water vapor, the propagation time of electromagnetic signals from a satellite to a receiver is subject to additional delays relative to that in a vacuum. In order to make highly accurate comparisons with the GNSS time comparison technique, it requires not just expertise in time and frequency, but also a wide range of knowledge on space geodesy, such as satellite orbits, Earth deformation, and atmospheric propagation characteristics.

Figure 1 GNSS antennas installed on the roof of the NICT Headquarters building No. 2. They are used for international comparisons and for decentralized generation of JST.

On the other hand, the TWSTFT method exchanges signals simultaneously and bidirectionally between the atomic clocks being compared (atomic clock – satellite – atomic clock), so time and frequency comparison can be achieved by a simple difference of one-way signal travel time, by which propagation delay is canceled out. Although it requires transmission equipment for sending signals to geostationary satellites, and costs for renting communication satellite transponders and for operating Earth stations, etc., the TWSTFT method is expected to provide a more accurate performance comparison than the GNSS method. By operating the two methods in parallel, it is possible to compare their results and accuracies for maintenance and improvement of the performance of each. NICT uses this comparison technology to contribute to UTC, as well as for the decentralization of Japan Standard Time (JST) and its stable operation.

Figure 2 SRS modem developed by NICT, capable of time comparison with 17 digits of precision by using the carrier phase in addition to the conventional way using modulation code phase.

The current definition of the SI second is based on microwaves emitted by cesium atoms, but there are plans to change the definition in the near future to a more accurate one that uses the oscillation frequency of light emitted by atoms. Although conventional time comparison technologies have sufficient accuracy for microwave frequency standards, comparisons of optical atomic clocks require the development of more accurate comparison methods, and NICT has been developing next generation technologies for that.

Conventionally, the TWSTFT technique uses the propagation time of the modulated wave signal, but its precision is limited by the bandwidth of the satellite transponder. To solve this problem, NICT has developed a next-generation TWSTFT modem (SRS modem) that enables 17 digits of precision by measuring the carrier phase of the bidirectional satellite signal (Figure 2). The SRS modem can achieve an order of magnitude higher accuracy than conventional modems. Regular operations utilizing this modem have already started with Taiwan (TL) and South Korea (KRISS). This modem also plays a role in supporting operations for JST, such as for the decentralized generation of JST. Additionally, NICT has received inquiries from France and Germany about trial introductions of the modem, and NICT will contribute to the international metrological community with this technology.

Recent Topics on Dissemination of Japan Standard Time

MATSUBARA Kensuke

Group Leader, also Research Manager, Japan Standard Time Service Group, Space-Time Standards Laboratory, Electromagnetic Standards Research Center, Radio Research Institute

After completing graduate school, he joined the Communications Research Laboratory (CRL, currently NICT) in 2001. He has been engaged in research on single-ion optical clocks, high-precision frequency provision by standard radio waves and operation of Japan Standard Time, etc. Ph.D. (Science).

NICT is in charge of operations to generate, maintain and disseminate Japan Standard Time (JST). In terms of time generation and maintenance, NICT is introducing optical clocks and time and frequency transfer as showcased in the various articles of this issue, and is continuing to make efforts to improve dissemination in response to communication network and societal needs. This article describes recent topics on dissemination of JST.

Methods of disseminating JST include standard radio waves, telephone lines, and telecommunications networks. For standard radio wave dissemination, both Ohtakadoya-yama LF Standard Time and Frequency Transmission Station (Fukushima Prefecture; est. 1999) and Hagane-yama LF Standard Time and Frequency Transmission Station (Saga Prefecture Fukuoka Prefecture; est. 2001) continue to transmit low frequency standard radio waves in a stable manner after more than 20 years in operation.

In terms of telephone line dissemination, we are transitioning to Hikari Telephone JJY. Since 1995, Telephone JJY has been used to disseminate JST broadly to society, including individuals, but the expansion of IP lines has made it difficult to maintain stable accuracy. Hikari Telephone JJY was developed jointly with the private sector and can supply time with high accuracy and speed using fiberoptic lines. It went into official operation in 2019. After making explanations to frequent users such as broadcasters and other industry groups, we announced that the existing Telephone JJY service would be discontinued at the end of March 2024. We have since been encouraging users to switch to Hikari Telephone JJY, and in March 2022, the number of monthly accesses to the Hikari Telephone JJY service exceeded the Telephone JJY service for the first time, with more than 120,000 accesses (Figure). Further publicity activities are being planned to realize a full transition to Hikari Telephone JJY.

In terms of time dissemination using telecommunications networks, we provide services using Network Time Protocol (NTP) and the time information providing service for Time Business. Use of NICT's public NTP service, has been increasing rapidly since 2018 to reach a current maximum of more than 9 billion accesses / day. Many of these are from overseas and we are responding with redundant operation using multiple lines and systems. Looking to further improve the availability of time dissemination, we plan to install a system in central Tokyo with enhanced countermeasures against anomalies such as power outages.

NICT also participated in the digital timestamp system, which is the purpose of the time information providing service for Time Business. This timestamp system was officially introduced in Japan in 2005. Subsequently, NICT led initiatives to propose a system of time dissemination and auditing that could be easily adapted to various national conditions and has since been standardized internationally. In April 2021, the Japanese regulations for the accreditation of digital timestamp operations by the Minister of Internal Affairs and Communications were published. These regulations designate UTC (NICT), which is the basis for JST, as the time source for authentication, and we will continue to engage in the steady provision of time information providing services.

In parallel with the above activities, we are advancing continuity plans to ensure that even if Tokyo area were to suffer a major natural disaster, time dissemination services could still be provided. The Kobe Sub-station, which has been in operation since 2018, is a JST station used in conjunction with NICT HQ. It is capable of generating JST and is equipped with facilities for disseminating time via Hikari Telephone JJY and public NTP and for monitoring the standard time and frequency transmission stations. Training and updates to operational manuals are conducted annually to ensure that in the event of a natural disaster, HQ functions for JST could swiftly be shifted to the Kobe Sub-station. These measures help to ensure the stable and uninterrupted dissemination of JST.

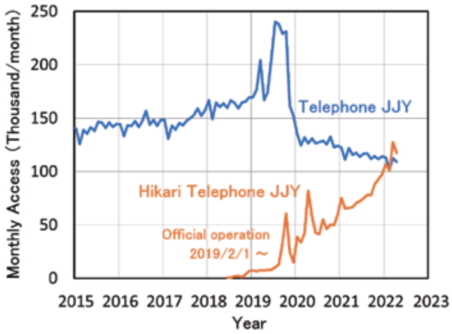
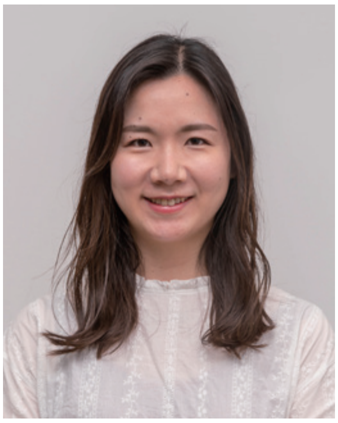


Figure No. of Accesses Using Telephone JJY/Hikari Telephone JJY (2015/1-2022/4)

Towards the Development of Trapped Multi-Ion Optical Clocks that Apply Quantum Technologies



Ami Shinjo-Kihara

**Researcher,
Space-Time Standards Laboratory,
Electromagnetic Standards Research Center,
Radio Research Institute,
Ph.D.(Science).**

Biography

1991	Born in Fukui Prefecture, then later moved to Tokyo
2014	Graduated from Department of Physics, Faculty of Science, Gakushuin University
2019	Completed doctoral program at Department of Physics, Faculty and Graduate School of Science, Gakushuin University
2021	Joined NICT after working as a specially appointed assistant professor at Osaka University Graduate School of Engineering Science

Awards, etc.

2018	45th Young Scientist Presentation Award
2021	Outstanding Paper Presentation Award by the Electronics, Information and Systems Society of the Institute of Electrical Engineers of Japan

Q&As

Q What are you interested in other than research?

A I've been working out quite a bit since my doctoral course, and now I'm training at home while watching YouTube. Even before teleworking, I worked out to raise my heart rate and to make my body feel more awake.

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

A Research often doesn't go well and may be disappointing, but, no matter what happens, I hope that you take it positively and enjoy the present.

Q How do you spend your time on holidays?

A I work out, go on walks near my house with my husband, and cook make-ahead meals. When I find seasonal or unusual vegetables, I just start experimenting with them instead of looking up how best to cook them.

The current definition of the second is based on the resonance frequency of the microwave transition of cesium atoms, but the use of optical clocks based on the optical transition of cold atoms is being considered as a future standard.

In an indium ion optical clock, the electric field from an arrangement of electrodes confines a single indium ion in a vacuum. The ion is laser-cooled to approximately 1/100,000 of a degree Kelvin, then irradiated by a laser that resonates with a transition within a very narrow frequency range. Stabilized to maintain this resonance, the laser's frequency is used as a reference. Indium is not easily affected by external electric or magnetic fields, so it is possible to capture multiple ions at the same time, and as such is a candidate ion species for multi-ion optical clocks where high frequency stability is expected and for when performing quantum information manipulation with quantum correlations between multiple ions.

Indium ions are characterized by the relatively low temperatures that they can reach when directly cooled via a laser, but it is difficult to trap a single indium ion by itself. Therefore, the indium ion optical clock currently being developed at the Space-Time Standards Laboratory uses a method called "sympathetic cooling," in which a single calcium ion, which can be trapped independently, is first trapped and cooled, and then the indium ion is placed in the same trap and cooled by repeatedly exchanging energy with the calcium ion. In sympathetic cooling, the closer the masses of the two types of ions are, the more efficiently they can be cooled.

Therefore, in the indium ion optical clock that I am developing, sympathetic cooling is performed with ytterbium ions, which are close to indium in terms of mass. By creating conditions that facilitate ion cooling, I am aiming to realize an ion optical clock that utilizes the abovementioned quantum entanglement state of multiple ions.

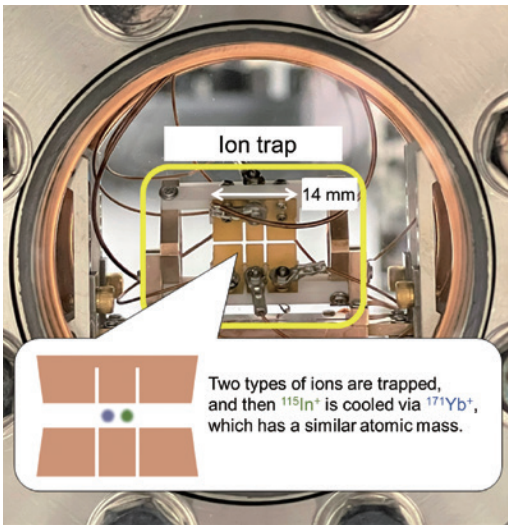


Figure Ion trap electrodes installed in a vacuum chamber. Ions are trapped in the 1-mm space between the electrodes and then restricted to a diameter of approximately 0.1 mm by irradiating the ions with a laser.

The Maejima Hisoka Award was established in memory of Mr. Maejima, one of the founders of Japan's telecommunications industry, and to pass on and promote his spirit. The award is presented to those who have made an outstanding contribution to the advancement of the information and communications industry (including postal services) or the broadcasting industry. One group and one person of NICT researchers received this award in FY2022.

For research conducted at universities and research institutes, the Ichimura Prize in Science is presented to a researcher or research group that has contributed to advancing an academic field and whose research has the potential for practical applications. This year, NICT received an Ichimura Prize in Science.

* The affiliations and positions are those at the time of winning the awards.

Awards

Tsushinbunka Association The 67th MAEJIMA Hisoka Awards

Group Award Social Deployment Group of Space Weather Information, NICT

● Awarded for: **Development of Social Uses for Space Weather Information**

From left, Dr.TAIRA, Director General Radio Research Institute, Dr.ISHII, Director General, Radio Propagation Research Center, Dr.KUBO, Group Leader, Forecast Service Group

Photo by SUGIYAMA Hiroshi, REAA

●Date: April 7, 2022

●Abstract: The "Space Weather User's Council" was established to directly discuss with users the effects of solar activity on radio wave use, etc., and to stimulate discussions. It has also made significant contributions to the actual use of space weather observation services by developing observations, models, and applications to provide information needed by society, and by building a 24-hour monitoring system for space weather.

●Receiver's comment: Thank you very much for selecting us to receive the MAEJIMA Hisoka Award. Space weather forecasting requires cross sectional knowledge of each area from the sun to the earth. We feel that this joint award is truly the result of the combined efforts of people in space weather forecasting, and we will continue striving to provide the information that society needs.

Promotion Award YOSHIDA Yuki,

Senior Researtcher, Optical Access Technology Laboratory, Photonic ICT Research Center, Network Research Institute

● Awarded for: **Research and development of new signal processing technology for low-cost, low-power, and ultra-high-speed optical transmissions**

Photo by SUGIYAMA Hiroshi, REAA

●Date: April 7, 2022

●Abstract: YOSHIDA Yuki has developed a digital signal processing technique for retrieving the phase information of high-speed optical signal from intensity-only measurements without using complex coherent receivers. He was the first to demonstrate the computational coherent detection of a optical phase-modulated signal only by using a photodetector array. He is highly expected to make further contributions in the acceleration of the digital transformation of society in the future.

●Receiver's comment: I have been working on a signal processing technique that makes the optical coherent transmission technology used in the core/submarine networks applicable to the edge networks close to us. I would also like to express my deep gratitude to everyone inside and outside NICT for supporting my research. I will continue striving for further performance enhancement and practical deployment.

Ichimura Foundation for New Technology The 54th Ichimura Prize in Science for Distinguished Achievement

HIGASHIWAKI Masataka,

Director, Green ICT Device Laboratory, Koganei Frontier Research Center, Advanced ICT Research Institute

● Awarded for: **Pioneering research and development of gallium oxide devices**

Dr. HIGASHIWAKI, third person from left

●Date: April 15, 2022

●Abstract: Starting with the world first demonstration 1of gallium oxide (Ga_2O_3) transistor operation, HIGASHIWAKI Masataka has developed numerous device processes and epitaxial growth technologies, which has led to the realization of new milestone devices and to demonstrations of superior device characteristics. Furthermore, he has continued to play a leading role in the field of Ga_2O_3 devices and materials with outstanding research achievements and industrialization activities, such as contributing to the establishment of Ga_2O_3 startups through the transfer of various research and development results and technologies.

●Receiver's comment: It is a great honor for me to receive the prestigious Ichimura Prize in Science. I am very pleased that my activities in Ga_2O_3 device research and development have been recognized, and, at the same time, I feel the weight of that responsibility. Taking this award as encouragement, I will continue working towards the practical application and industrialization of Ga_2O_3 devices.

NICT NEWS 2022 No.4 Vol.494
Published by Public Relations Department, National Institute of Information and Communications Technology
Issue date: Jul. 2022 (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/
@NICT_Publicity #NICT
ISSN 2187-4050 (Online)