



Commission A

2012-2014 Triennial Report

Chair: Dr. William A. Davis, United States

Vice Chair: Dr. Yasuhiro Koyama, Japan

1. In Memoriam and Concerns

There were no friends and colleagues from the URSI Commission A Community that have been reported to me as passing away during the triennium. However, our sympathies go out to those we have missed and others in the URSI community, such as Professor Karl J. Langenberg of the University of Kassel, Germany -- passed away on May 22 after a losing battle with cancer..

It is felt that a special concern and wishes for the best should be provided for those who are struggling with turmoil in their countries. It seems that so many countries have come to see bloodshed and all members living in those areas or having family in those areas are in our concerns and prayers.

2. Chair's Comments

General: I would like to thank the GASS conveners and reviewers, as well as all of those who submitted papers to make the 2014 GASS a success. My vice-chair Yasuhiro Koyama and my immediate past-chair Parmeswar Banerjee have provided much needed assistance and helpful advice. Dr. Koyama has been very helpful in the activities in the Pacific region, particularly with the 2013 AP-RASC.

One of my goals was to move Commission A to a more active role of assistance to other commissions in the concepts of measurement. There has been some move in this direction this triennium, in addition to continuing to support the classic areas of metrology in time and synchronization. A list of topics was developed for the 2014 GASS as:

- Universal Coordinated Time: The International Reference Time Scale and Possible Redefinition
- Time Scale
- Time and Frequency Transfer
- Metrology of Optical Frequencies and Optical-Dimensional Measuring Techniques
- Quantum-Based Metrology
- Education and Training in Metrology
- Recent Advances in Antenna Measurement Techniques
- Advances in sensor development and applications

- Global Navigation Systems (Overview of the timing techniques in the various satellite systems)
- Nonlinear Measurements and Characterization
- Mode-Stir Chambers
- Pulsars and the Application to Time Scales
- Bioeffects and medical applications
- EMC and EM metrology/pollution
- Interconnect and Packaging Evaluation
- Material Measurement and Characterization
- Microwave to submillimeter measurements/standards
- Noise Measurements and Standards
- Time domain metrology
- Techniques for Remote Sensing
- Measurements and Calibration in Propagation
- RFID
- Signal Enhancement for EM Metrology
- Scattering calibration
- References (bi-static)

Several of these areas overlap with other commissions with the potential for support in the concepts of measurements.

Funding: The URSI board provides to the Commission Chairs a sum of money at the start of each triennium, to be administered for the good of the community. During this triennium a sum of EUR 9000 was made available. Approximately EUR 1000 was spent in supporting various meetings. Support was provided to the past chair to assist in attending the GASS, and the remainder was requested for support of Young Scientists.

Mailing Lists: Commission A uses the electronic mailing list maintained by URSI and available at the Commission link on the URSI web site. The chair has tried to keep update information provided to URSI as well as send separate e-mails to a complementary list, particularly if attachments are desired for the transmission. It might be considered to develop a list for all members of Commission A who wish to be notified of events worldwide. An alternative would be to establish a Facebook page, but that may be limited in distribution due to the nature of the media. It is still an area to be considered for the next triennium.

Meetings: The Beijing GASS Program: Commission A has ~102 papers at the GASS. This includes 72 submitted directly and 30 in joint sessions. The submitted papers included one student paper and 19 Young Scientists. A panel session on “Education and Training in Metrology” is also planned. A new topic “Quantum-Based Metrology” was hoped to generate interest, but did not bring enough papers for a session. It is still a topic to watch for future growth and small sensor systems. Quantum systems was the topic of the Plenary session of the 2014 National Radio Science Meeting in Boulder, CO, USA – sponsored by Commission A in the USA.

One move that was tried for the 2014 GASS was to introduce open sessions, allowing individuals to submit general papers for consideration in open oral sessions. The other sessions were formed primarily from the invited papers requested by convenors. The future AP-RASC and AT-RASC have all open sessions and the larger list of topics was submitted for consideration at those meetings.

The Commission technically sponsored several other conferences and had sessions in some of these conferences, such as the 2013 ICEAA–IEEE APWC–EMS in Torino, Italy. Plans are also being made to participate in the 2015 AT-RASC.

The future might be worthy of establishing working groups in the areas of Time Scale and the need for a redefinition, as well as in the area of quantum-based metrology.

3. Vice-Chairs Comments

In the field of Time and Frequency Metrology, discussion about the redefinition of Coordinated Universal Time (UTC) have been an important issue and some important conferences were held. In

2012, Radiocommunications Assembly of ITU-R discussed the issue and deferred the decision until 2015. ITU-R requested member nations and scientific organizations including URSI to provide their opinions to ITU-R. ITU/BIPM Workshop Future of the International Time Scale held in 2013 was one of the important conferences for such discussions. In the next GASS, a special session about UTC will be organized. I think it's worth mentioning in the report of commission A.

The report provides the following information (reference list deleted) and is included because of the importance:

A1. Time and Frequency Standards and Time Transfer Technique

The researches and developments on Time and Frequency Standards and Time transfer in Japan are mainly carried out in National Institute of Information Technology (NICT) and National Metrology Institute of Japan (NMIJ).

-- In NICT, Kumagai et al. are going to upgrade NICT-CsF1 aiming the operation at the 10^{-16} level (currently operating with 1.4×10^{-15}). They are developing also the 2nd fountain (NICT-CsF2), with which a frequency stability of $3 \times 10^{-13} / \tau^{1/2}$ was obtained. They completed evaluations of most systematic frequency shifts and their uncertainties for CsF2 at the level below 5×10^{-16} .

A microwave frequency standard using the $^{171}\text{Yb}^+$ is under development at NICT. For this purpose, Shiga et al. constructed an experimental apparatus and the absolute frequency of the $^{171}\text{Yb}^+$ hyperfine transition was measured with 4×10^{-14} uncertainty. This apparatus is used to demonstrate a new measurement method using atomic phase lock.

The time difference between UTC (NICT) and UTC has been kept almost within +25ns to -19ns for the last 3 years. NICT has 29 Cs clocks and 7 H-masers. UTC (NICT) is generated by using 18 high-performance Cs clocks and 3 H-masers. Other Cs clocks are in operation at two LF stations and at Advanced ICT Research Institute of NICT. UTC (NICT) has been used as the reference for frequency calibration services

NICT was certified to be in accordance with the ISO/IEC 17025 for the frequency calibration system from National Institute of Technology and Evaluation (NITE) in March 2001. NITE provided an accreditation of ISO/IEC 17025 to NICT on 31 January 2003, and also provided an accreditation of ISO/IEC 17025 of the frequency remote calibration system and the time scale difference to NICT on 2 May 2006 and on 30 September 2011 respectively. BMC of carried in system was changed to 5×10^{-14} in April 2007. The measurement range of frequency calibration was expanded from 1 Hz to 100 MHz in September 2011. NICT received surveillance by NITE in February and renewed IAJapan certificate dated April 26, 2013 from NITE.

Fujieda et al. [Fujieda et.al. 2011] developed an all-optical link system for making remote comparisons of two distant ultra-stable optical clocks. An optical carrier transfer system based on a fiber interferometer was employed to compensate the phase noise accumulated during the propagation through a fiber link. Transfer stabilities of 2×10^{-15} at 1 s and 4×10^{-18} at 1 s were achieved in a 90-km link.

NICT has performed various experiments using Two-Way Satellite Time and Frequency Transfer (TWSTFT). Gotoh et al. [Gotoh et.al. 2011] have developed a new two-way time transfer modem to improve the time transfer precision of remote clock comparison. For the real-time digital signal processing stages implemented in software, they relied on a graphics processing unit (GPU) and performed two-way satellite time transfer experiments using these modems between Japan and Taiwan. The obtained results are consistent within 200 ps with respect to the results of GPS carrier phase time transfer. The first international TWSTFT experiment using a new software-defined modem with dual pseudo-random noise (DPN) codes were performed over a period of 6 months [Wen-Hung et al., 2012]. The results of DPN exhibit excellent performance, which is competitive with the GPS precise point positioning (PPP) technique in the short-term and consistent with the conventional TWSTFT. Time deviations of less than 75 ps are achieved for averaging times from 1 s to 1 d. Fujieda et al. [Fujieda et.al. 2012] started to implement a carrier-phase information to improve the short-term

stability of TWSTFT. The experiments in a domestic short baseline were performed. The short-term stability of 4×10^{-13} at 1 s was achieved.

NICT also performed direct time comparisons using the first Quasi-Zenith Satellite (QZS-1) in order to monitor the onboard clock as a part of the satellite navigation system [Nakamura et al., 2013]. The NICT system achieves a measurement precision of about 25 ps which is an order of magnitude better than the precision of the clock parameters obtained from the combined orbit and clock estimation.

A study via VLBI simulation for evaluating the potential of the time and frequency transfer was performed by assuming use of the next-generation VLBI technique, which is the “VGOS (VLBI2010 Global Observing System)” including the wide-band receiver and data acquisition system, small antenna, antenna slew speed improvement, and phase delay measurement. This simulation indicated that feasibility of the frequency stability with the VLBI measurement would be at the order of 10^{-16} at one-day interval [Hobiger 2011 a,b]. Further feasibility study campaign experiment was performed by using 11m antennas between Kashima-Koganei (100 km distance) on 19-23 Feb. 2012. Clock difference between two hydrogen masers at each site was compared with multi techniques: GPS, VLBI, and TWSTFT (code). It is notable that the increase of VLBI observation bandwidth from 500 MHz to 1 GHz improved the precision of clock comparison. This result encourages developing new wideband VLBI system [Sekido 2012 a,b 2013 a,b, Koyama 2012, 2013, Takefuji 2012 a,b,c, 2013]].

The development of the new wideband VLBI system for T&F transfer named 'Gala-V' has started since 2012 [Ichikawa 2011, Kondo 2012]. The system is designed in composition of transportable small diameter antenna pair and large diameter antenna. And its observation frequency range was selected so that coincides with that of the next generation international geodetic VLBI system (VGOS) for future joint observation with international VLBI stations [Ujihara 2011, 2012 a,b]. Wide frequency (6.4GHz - 15GHz) feed for cassegrain 34-m diameter antenna was originally designed and installed to Kashima 34m radio telescope in 2013. Test evaluation experiment with the Gala-V system is being planned in 2014.

In NMIJ, following researches have been conducted.

- Primary frequency standards at NMIJ: NMIJ has made the calibration of the International Atomic Time (TAI) 4 times between November 2010 and March 2011 with the Cs atomic fountain frequency standard, NMIJ-F1 with a combined uncertainty of 3.9×10^{-15} [Circular T, Takamizawa et al. 2010, Takamizawa et al. 2012]. However, the resonance frequencies of the microwave cavities were shifted out of the atomic resonance due to the huge earthquake. Moreover, the cesium source was exhausted. Therefore, we opened the vacuum chamber to replace the microwave cavities and supply a new cesium ampule. Here, the microwave cavities are parts of the vacuum chamber in the new version. Then, the ultrahigh vacuum has been obtained. Now we are making the optical setup again. In parallel, our second fountain NMIJ-F2 has been developed, aiming uncertainty of $< 1 \times 10^{-15}$ as an immediate goal [Takamizawa et al. 2010, Takamizawa et al. 2012, Takamizawa et al. 2013]. In addition, the large frequency corrections for the 2nd-order Zeeman shift, the blackbody radiation shift, and the collisional shift have been evaluated. Therefore, we are now in a position to compare NMIJ-F2 with TAI and the other primary frequency standards at the 1×10^{-15} level. Ultra-stable microwave oscillator: One of the two CSOs was modified with the addition of a low-vibration pulse-tube cryocooler to be employed as a local oscillator for the fountains. No liquid helium refills are needed for the cryocooled version of the CSOs. Phase noise standards: We have developed a phase noise standard [Watabe et al. 2012, Yanagimachi et al. 2013a, Yanagimachi et al. 2013b, Yanagimachi et al., 2013c].
- Time Keeping at NMIJ; All atomic clocks ran down due to power failure by the Great East Japan Earthquake in 2011. Since then NMIJ has been trying to recover the damaged equipment. At present four active hydrogen maser frequency standards and two cesium atomic clocks with high-performance beam tubes (Agilent 5071A) are operated for time keeping. Those atomic clocks are kept in individual chambers, whose temperatures are kept to within 0.2 deg C. One of the hydrogen masers is used as a source oscillator for the generation of UTC (NMIJ) to improve the short-term stability. UTC (NMIJ) is created by frequency-

steering the hydrogen maser output signal to UTC using a frequency stepper. Time and Frequency Transfer; In NMIJ, dual frequency carrier phase GPS receiver is one of the main international time and frequency transfer tools.

- NMIJ has the Two Way Satellite Time and Frequency Transfer (TWSTFT) facilities for Asia Pacific link and for Asia-European link. An optical fiber bidirectional frequency transfer system using Wavelength Division Multiplexing technology is studied as one of future precise time and frequency comparison systems. In addition, NMIJ started the research on a precise frequency comparison system using an optical carrier. Technical challenges and solutions for the system were investigated on the issues such as propagation delay limit, burst noise, interferometer noise and so on (Wada et al. 2014).
- Frequency Calibration Service at NMIJ; NMIJ has been providing the remote frequency calibration service using the GPS common-view method and Internet since 2006. The CMCs of the service are 1.1×10^{-13} (baseline: 50 km), 1.4×10^{-13} (baseline: 500 km) and 4.9×10^{-13} (baseline: 1,600 km) at an averaging time of one day. The number of users is 16 in 2014; it is on the rise year by year.

A2. Laser Stabilization and Frequency Measurement

The researches and developments on laser stabilization and frequency measurement in Japan are mainly carried out National Institute of Information Technology (NICT), National Metrology Institute of Japan (NMIJ) and RIKEN group.

In NICT, optical frequency standard using Sr atom and Ca^+ ion have been developed. Yamaguchi et al. developed the frequency standard based on the $^{87}\text{Sr } ^1\text{S}_0\text{-}^3\text{P}_0$ transition frequency, using atoms in an optical lattice [Yamaguchi 2012]. Matsubara et al. reduced the uncertainty of the absolute frequency of $^{40}\text{Ca}^+ ^2\text{S}_{1/2}\text{-}^2\text{D}_{5/2}$ transition down to 3×10^{-15} , and the ratio of the $^{40}\text{Ca}^+$ and Sr transition frequencies with the uncertainty of 2×10^{-15} [Matsubara 2012]. A new optical frequency standard based on the $^{115}\text{In}^+ ^1\text{S}_0\text{-}^3\text{P}_0$ transition frequency is under development to a higher accuracy than that of $^{40}\text{Ca}^+$. For this purpose, techniques for generating ion chains consisting of $^{115}\text{In}^+$ and $^{40}\text{Ca}^+$ have been developed [Hayasaka 2012].

A new frequency standard in THz (0.1-10 THz, wavelength 30 μm - 3 mm) domain has started in NICT. Ito et al. developed a THz frequency comb for the absolute THz frequency measurements. Its measurement accuracy has attained to 10^{-17} level around 0.3 THz [Ito 2013]. Nagano et al. demonstrate microwave synthesis from a continuous-wave THz oscillator [Nagano 2013]

Also some proposals for new frequency standards in the THz and Infrared area were given in NICT. Kajita et al. proposed the precise measurement of the vibrational transition frequencies of alkali earth - H^+ molecular ions eliminating the Stark shift induced by probe lasers. [Kajita et al. 2011 a, 2012 b]. They proposed also to measure the vibrational transition frequencies of alkali earth-alkali diatomic molecules trapped in an optical lattice [Kajita et al. 2011b, 2012 a, 2013].

NMIJ has developed an Yb optical lattice clock. In 2012, they demonstrated an improved frequency measurement of the $^1\text{S}_0 - ^3\text{P}_0$ clock transition in ^{171}Yb bound in the Stark-shift-free optical lattices with an uncertainty of 3.9×10^{-15} that is limited by UTC-NMIJ [Yasuda et al. 2012]. Consequently, the clock transition in Yb was selected as one of secondary representations of the second by the International Committee for Weights and Measures (CIPM). In order to evaluate the optical clocks that exceed the performance of the Cs fountain primary standards, one needs to measure the frequency ratio between optical clock transitions in the different types of the optical clocks. Therefore, at NMIJ, Sr optical lattice clock has also been developed and, furthermore, an Yb/Sr dual optical lattice clock project is now underway.

At NMIJ, optical frequency combs play an important role in their optical clock project. In the clock laser system, the highly stabilized fibre comb is able to transfer the linewidth and frequency stability from one laser frequency to another and it plays a role of an ultra-stable local oscillator for multi wavelengths. Using the linewidth transfer technique with high-speed controllable fibre-based frequency combs, cooling laser operated at 689 nm for Sr and clock lasers operated at 578 nm and 698

nm for Yb and Sr, respectively, are stabilised and successfully used for atomic spectroscopy [Akamatsu et al. 2012, Iwakuni et al. 2012, Inaba et al. 2013].

In order to reduce the effect of the thermal noise on the optical cavity that could give frequency stability limits for short averaging times, a long cavity would be one of attractive solutions. For the long cavity, a new spacer material with high specific rigidity would be required, because a long cavity would be sensitive to the seismic noise in laboratories. At NMIJ, they have developed an optical cavity with an ultralow expansion ceramic spacer and investigated the thermal properties of the ceramic [Hosaka et al. 2013].

Katori group at the University of Tokyo and RIKEN has been developing optical lattice clocks with Sr Hg atoms, and optical frequency transfer system using a telecom fiber link between these two sites.

In 2011, the University of Tokyo developed a scheme to compare two clocks with high stability by canceling out the laser noise. They succeeded to compare two clocks with the Allan deviation of $\sigma_y(\tau) = 4 \times 10^{-16} / \sqrt{\tau}$ and reached 1×10^{-17} with an averaging time of 2,000 s, which corresponds to the quantum projection noise limit of optical lattice clocks with 1,000 atoms [Takamoto et al. 2011].

Frequency comparison between two remote Sr optical lattice clocks operated in the University of Tokyo and NICT was performed via a phase-stabilized optical fiber link [Yamaguchi et al. 2011]. The frequency comparison of two remote clocks with their distance of 24 km measures the relative frequency difference to be $(1.0 \pm 7.3) \times 10^{-16}$ and the gravitational red shift of ≈ 2.6 Hz due to the height difference of 56 m.

Prof. Katori with theorists [Ovsianikov et al. 2013] discussed the multipolar and higher-order light shift for Sr atoms.

RIKEN has developed two cryogenic strontium (Sr) lattice clocks since 2011. Thus far, the accuracy of Sr lattice clocks has been limited by the uncertainty of ambient blackbody radiation shift. By installing a cryogenic chamber, they have succeeded to suppress the blackbody radiation and compare two cryogenic Sr lattice clocks with the uncertainty of 10^{-18} level [Ushijima et al. to be published].

Frequency transfer system between RIKEN and the University of Tokyo has been developed to compare remote cryogenic Sr lattice clocks at the uncertainty of 10^{-18} [Akatsuka et al. to be published]. The link stability is evaluated to be 1×10^{-17} at 1 s and reaches 1×10^{-18} at 100 s, which corresponds to the gravitational red shift for the height difference of 1 cm.

RIKEN is also developing a lattice clock with mercury (Hg) atoms. Hg atoms have one order of magnitude smaller sensitivity to the blackbody radiation than Sr and Yb atoms. This enables the accuracy at 10^{-18} even in a room temperature environment. They have succeeded in trapping Hg atoms in a magic optical lattice and precise spectroscopy of Hg clock transition, and started frequency comparison between Hg and Sr lattice clocks.

Sugiyama group at Kyoto University is developing single Yb⁺ ion clocks. They succeeded in single-ion spectroscopy of the ²S_{1/2}–²D_{5/2} transition in ¹⁷⁴Yb with a spectral width of 5 kHz [Imai et al. 2013]. They also study laser frequency stabilization to 6S–8S two-photon transitions in Cs in a gas cell in order to pursue high frequency-stability. They obtained a root Allan variance of 4.4×10^{-14} at an averaging time of 16 s [Uehara et al. 2012].

A3. Realization of Electrical Unit (DC & LF)

Research works and developments on dc and low frequency electrical standards, that is, standards for dc voltage, dc resistance, ac resistance, capacitance, inductance, ac/dc transfer etc., are implemented in the Electricity and Magnetism (EM) Division of National Metrology Institute of Japan (NMIJ), partly in collaboration with several other institutes in the Advanced Industrial Science and Technology (AIST). The EM division has two sections, the Applied Electrical Standards Section and

the Quantum Electrical Standards Section. The Applied Electrical Standards Section takes charge of the AC/DC transfer, the low value impedance and the power standards. The Quantum Electrical Standards Section covers the Josephson voltage, the quantum Hall resistance, and the high value impedance standards.

NMIJ has been studying a quantum-based Johnson noise thermometry in quest of world-record electronic measurement of Boltzmann's constant and absolute temperature measurement in collaboration with the Thermometry Section of NMIJ and the NIST (Boulder and Gaithersburg). A Josephson-junction chip dedicated for JNT and other components required for JNT measurement such as data acquisition system have been developed. Up to now, we have succeeded in measuring cross power spectra of a 100 ohm resistor at triple point of water temperature and a reference signal generated with the quantum voltage noise source (QVNS). We found, however, that there is some error in the cross spectra data obtained in our present system. We are now trying to improve our system and suppress the error (Urano et al., 2012, 2014)

A programmable Josephson voltage standard (PJVS) system has been optimized for AC waveform synthesis and adopted for sampling measurement using a calibrator and a thermal converter. Low-frequency characteristics of a thermal converter at below 10 Hz have been successfully evaluated using the sampling measurement. We are now trying to increase the voltage level from 3 V_{rms} to 10 V_{rms}, replacing the PJVS chip, in collaboration with CMS (Taiwan). Development of a calibration system for Zener voltage standards using a liquid-helium-free PJVS has been finalized. The system has been checked through direct and indirect comparisons with our conventional JVS (CJVS) system. A bilateral comparison of PJVS systems in NMIJ (Japan) and CMS (Taiwan) (APMP.EM.BIPM-K11.5) is now in progress with a support by KRISS (Korea). Another experiment for evaluating the linearity characteristics of commercial digital volt meters (DVMs) has been started using the system. Development of a high-stable and user-friendly DC voltage generator based on a rack-mount PJVS system with a small cryocooler is also in progress in the collaboration with the Nanoelectronics Research Institute (NeRI), AIST. (Kaneko et al., 2011, 2012a, Maruyama et al., 2014a, 2014b, 2014c, 2014d, Amagai et al., 2013, 2014a, Chen et al., 2014).

A compact and ultra-stable 100 Ω standard resistor is finished its development and development of resistors (1 Ω to 10 kΩ) with other decade values are in progress. This 100 Ω standard resistor of which temperature coefficients is extremely low, less than 0.1 ppm/K at room temperature, and resistance values are greatly stable, less than 0.1 ppm/year have been successfully manufactured and in market. The pressure coefficients are typically less than +0.01 (μΩ/Ω)/(-250 hPa) and the humidity coefficients of those resistors are immeasurable level (Kanko et al., 2012b, 2012c). Current coefficients are lower than measurement limit as well (Domae et al, 2013a). Trilateral comparison of four Alpha Electronics 100 Ω using QHR and CCC was carried out with KRISS (Korea) and NIST (USA). The calibrated values have been agreed within a few parts in 10⁻⁸ at a rough estimate. Detail data processing is now in progress (Kaneko et al., 2014b).

By using the fabrication technology of highly stable 100-Ω metal-foil resistor component, developed in collaboration between the NMIJ and Alpha Electronics Corp., 100-Ω standard resistors with a four-terminal-pair design, which enables ac measurements, have been fabricated. For the AC characteristics, the frequency dependence of the resistance and phase angle has been evaluated. (Domae et al, 2012a, 2013a, 2014)

NMIJ also developed a trial model of 1-kΩ metal-foil resistor with a four-terminal-pair design. The resistance and phase angle of the resistor were measured as a function of frequency. (Domae et al, 2014)

Conventional single Hall bar QHR devices have been fabricated and several devices have been provided for several NMIs.

Newly designed 10 kΩ quantum Hall array resistance standard devices also have been fabricated. This device consists of 16 Hall bars, and its nominal value has only 0.0342 ppm difference based on R_{K-90} from the integer value of 10⁴. We observed a clear 10 kΩ plateau, and the measured value agreed with its nominal value within a few ppb. (Oe et al, 2011, 2013)

Test devices of ac-QHR with on-chip double-shielding have been fabricated at NMIJ and their ac-characteristic was evaluated at PTB. (Kaneko et al., 2012e, 2013a)

A resistive voltage divider, which is constructed from a binary-segmented series array of QHR bars fabricated on one chip, named the 'QHR voltage divider', has been developed. From the preliminary tests, the results of the Hall resistance measurement showed large and well-defined plateaus, deviations from nominal voltage ratios were measured to be less than 1.4×10^{-6} , and the expanded uncertainty of the voltage ratio measurement was estimated to be less than 4.1×10^{-6} . (Domae et al, 2012b, 2012c)

One researcher of NMIJ had stayed at the NIST Gaithersburg for collaboration work on graphene. Shubnikov–de Haas (SdH) oscillation was observed in graphene synthesized on the Si-terminated surface of SiC. Carrier density in SiC graphene was successfully controlled with photochemical gating and QHE plateau ($i=2$) was observed. And QHE plateau was observed in graphene which made at the NIST Boulder with CVD technique and fabricated at Gaithersburg. (Shimamoto et al., 2012, 2013, Fukuyama et al., 2014).

The SINIS (Super/Insulator/Normal/Insulator/Super) turnstile devices for a single electron pumping have been fabricated. This device consists of a single pumping device and 14 parallel pumping devices. A measurement system has been also developed in a dilution refrigerator. At present, we succeeded to pump the current of 160pA (100 MHz) with the standard deviation of 1 part in 10^4 . Also to achieve metrological requirements, the influence of environments such as temperature, magnetic fields are studied. We also study different type of device, such as a tunable barrier-pumping device and small Josephson junction device (Kaneko, 2012d, 2013b, 2014a, Nakamura et al., 2014a, 2014b, Akiyama 2014c).

In order to maintain high reliability of the capacitance standard, NMIJ has been performing long-term monitoring of standard capacitors and of capacitance differences among a number of standard capacitors. After the massive earthquake on March 11, 2011, validation of calibration and measurement capabilities (CMCs) of the capacitance standard based on the analysis of these monitoring results was conducted (Domae et al, 2013b).

We have developed a capacitance-scaling bridge using a current comparator and an inductive voltage divider for calibrating 4TP-defined capacitance standards of 100 μ F. The expanded uncertainties of the capacitance and the dissipation factor of 100 μ F at 120 Hz are 11 μ F/F and 14 μ rad, respectively. The bridge was recently modified aiming to calibrate the standards of 1 mF. The expanded uncertainties of the capacitance and the dissipation factor of 1 mF at 120 Hz are 260 μ F/F and 270 μ rad, respectively (Sakamoto N. et al., 2010).

NMIJ has started a development of precision measuring techniques for diagnosis of the energy storage devices such as lithium-ion batteries (LIBs) and super-capacitors by using an impedance spectroscopy method. We have a plan to establish a metrology for evaluating the storage power devices. We have developed the impedance spectrum measurement system which is suitable for testing LIB cells using a frequency response analyzer and a potentio-/galvanostat. Results for LIBs of 18650-type in the range of 10 mHz - 10 kHz demonstrated that the impedance spectra for unused cells are clearly distinguished from those for used-up cells (Sakamoto N. et al., 2014).

NMIJ has provided ac-dc voltage difference transfer calibration of thermal converters in the voltage range from 10 mV to 1000 V and in the frequency range from 10 Hz to 1 MHz. A comparison system for ac-dc current difference transfer standards up to 5 A has been developed.

Practical thin film multi-junction thermal converters (MJTC) have been developed at NMIJ/AIST in collaboration with NIKKOHM Co. Ltd. A high-current thin-film multijunction thermal converter up to 200 mA for AC-DC current transfer standards has been developed (Fujiki et al., 2013, 2014).

A differential sampling measurement system using a 3 V RMS AC-programmable Josephson voltage standard (AC-PJVS) system has been developed, and AC-DC transfer differences of thermal voltage converters have been successfully characterized down to 1 Hz [Amagai et al., 2013]. To expand the voltage range from 3 V to 10 V for this technique, we are now developing a differential sampling system using a 10 V RMS AC-PJVS system, in collaboration through the Nanoelectronics Research Institute

(NeRI), AIST [Amagai et al., 2014a]. The low-frequency property of a single-junction thermal converter down to 1 Hz has been successfully simulated using an improved electro-thermal model [Amagai et al., 2012a, b, c, 2014b]. The long-term stability of our thin-film multijunction thermal converter has been improved by fabricating a new thermopile pattern. To further improve the sensitivity and low-frequency property, the thin-film multijunction thermal converter have been characterized under vacuum conditions, in collaboration with NIKKOHM Co. Ltd [Amagai et al., 2012d, 2014c, d]. The study on absolute measurements of Seebeck coefficient using an AC-DC measurement technique has started. At present, we have measured the Thomson coefficient of Pt thin-wire at room temperature [Amagai et al., 2014e, f]. With regard to a calibration service, we have provided a calibration service of AC voltmeters using a thermal converter in the frequency range from 4 Hz to 10 Hz, 40 Hz to 100 kHz at the RMS voltage of 1 V and 10 V.

NMIJ had developed a calibration system for non-sinusoidal voltage, current and power sources at 100 V/5 A of fundamental wave and at 10 V/ 3 A of higher harmonics in 2011. The extension of the range of the system is delayed because of the temporary transfer of the person in charge. (Yamada et al., 2012a).

Also, we developed an ac shunt calibration system at 5 amperes and 50 – 60 Hz. The system has been expanding up to 1 kHz at this moment. NMIJ has some plans for expanding up to 100 amperes and 10 kHz by 2015 according to requests from the industries which need power calibration and antenna calibration. To realize the expansion, the NMIJ ac current ratio standard has been re-checked and its calibration frequency has been expanded up to 4 kHz by improvement of its uncertainty estimation (Kon et al., 2011, 2012a, 2013c, 2014b, 2014d). In addition, the application systems of power measurement using shunt and IVD standards have been developed (Kon et al., 2012b, 2013a, 2013b, 2013d, 2014a, 2014c, 2014e).

Using the NMIJ standards of shunt and current transformer, an evaluation system for electronic current transformers (ECTs) accompanied by merging units (MUs) in accordance with IEC 61850 and IEC 60044-8 for automated substations has been developed. The system allows long-term evaluation of the ECT/MU of 80 and 256 samples/cycle. (Yamada et al., 2012b)

A4. EM Field, Power Density and Antenna Measurement

A dipole antenna has a simple linear structure and this improves the measurement accuracy. However, since an ordinary dipole antenna employed for the measurement is a half-wavelength dipole and the total length becomes approximately 5 m at the low end frequency of EMC measurements, a shortened dipole antenna is used for the measurement in an anechoic chamber. The antenna factor (AF) for a shortened dipole antenna is usually calibrated by the reference antenna method at a finite separation. To estimate uncertainty of the reference antenna method, the measured and calculated results are compared [Morioka et al. 2013].

The response of a field probe is calibrated by the well defined standard field. Such a field strength is generated in a transverse electromagnetic (TEM) waveguide sufficiently below the cutoff frequency of the waveguide. However, above the cutoff frequency the higher-order modes perturb the field distribution. For this frequency range a dipole antenna is employed to calibrate the E-field strength at a location in the anechoic chamber [Morioka 2011a]. Although the field generation in an anechoic chamber has an advantage in the frequency band, TEM waveguides are still useful in terms of compactness. For the use of a TEM cell as a standard field generator, the electromagnetic field distribution should be accurately evaluated. The response of a dipole-like probe against the non-uniform field distribution of the TEM cell is simulated and compared with the measured results [Morioka 2011 b].

A continuous antenna factor in a wide frequency range is convenient to be used and such a broadband antenna as a log-periodic antenna (from 300 MHz to 1 GHz), a bi-conical antenna (from 30 MHz to 300 MHz), and a bi-conical and log-periodic hybrid super broad band antenna (from 30 MHz to 1 GHz) were evaluated for a metrology standard [Kurokawa et al. 2012]. A new method was proposed for evaluating a far field gain and far field free-space antenna factor in the near distance. The method is based on a technique of a time-frequency analysis to determine the frequency

dependent antenna distance [Kurokawa et al. 2013]. The method was examined for calculating the free-space antenna factor of EMI broadband antennas.

The developments of calibration techniques for loop antennas were carrying out by AIST. AIST started to develop the calibration method since 2002. AIST has been providing a calibration service for small loop antennas whose diameters are 10 cm and 60 cm in the frequency range from 9 kHz to 30 MHz since 2007. The lowest frequency of loop antenna calibration service was expanded to 20 Hz for the loop antenna with 133 mm diameter in March in 2008. AIST and NICT are engaging to improve and simplify the loop antenna calibration since 2012.

The developments of calibration techniques for short monopole antennas were carrying out by AIST. There have been a number of measurement methods proposed for electrically short monopole antennas. A case in point is the equivalent capacitance substitution method, which is commonly used for monopole antenna measurements. On the other hand, we have proposed a near-field three-antenna method for electrically short monopole antennas. These two absolute measurement methods are of quite different origins. In light of this fact, a comparison is made between the two measurement methods by means of experiments and simulations, and the difference observed between the antenna factors is discussed [Ishii et al. 2011]. These studies are in progress.

AIST started to develop AC magnetic field strength standard since 2008. They will start the calibration service at 50 Hz, 55 Hz, and 60 Hz in 2011. The method depends on the “Standard Field Method” using a Helmholtz-coil [Ishii et al. 2012]. AC Magnetic field sensor calibration service has been expanded from 1 uT up to 150 uT at 50 Hz and 60 Hz, and the uncertainties were also improved [Ishii 2013]. This calibration service has been started since April 2013.

Calibration services for the gains of standard horn antennas are being performed from 1 GHz to 40 GHz specified 21 frequency points using transfer method. An antenna gain calibration service for standard gain horn antenna (1.7 GHz to 2.6 GHz, 18 GHz to 26.5 GHz, 50 GHz to 110 GHz) has been prepared using three antenna extrapolation method. An antenna factor calibration service for ridged guide broadband horn antenna (1 GHz to 6 GHz at 3 m) has been prepared. Far field antenna gain measurement method was proposed in antenna measurements using the amplitude center location in the Friis transmission formula from the Kern transmission formula using the phase centers of the antennas [Hirose et al. 2012, 2013]. An antenna pattern measurement system above 50 GHz using a photonic technology was proposed. This system can minimize the influence of waveguide components because an optical fiber is used as the mm-wave transmission line [Ameya et al. 2012].

In the EMC field, the frequency range of the EMI regulation is expanded from 1 GHz to 6 GHz in EU and Japan in 2010. To evaluate the EMI anechoic chamber performance above 1 GHz, we have proposed an optical feeding radiating antenna for site validation proficiency test of EMI anechoic room [Ameya et al. 2012 b].

A5. Power Attenuation and Impedance Measurements

NMIJ organized three international comparisons as the pilot laboratory. In the APMP.EM-RF.K8.CL regional metrology organization key comparison (KC) of RF power measurement, eleven countries participate in the KC. The KC started from June 2012 and finished its first rotation by 5 countries. The second rotation has been in operation and will finish August 2014. In the CCEM.RF-K5c.CL key comparison (KC) of scattering parameter measurement in 3.5 mm coaxial line (100 MHz to 33 GHz), nineteen countries participate in the KC. The KC started from June 2012 and finished its first rotation by 5 countries. The comparison will finish September 2015. In the APMC.EM.RF-S5.CL regional metrology organization supplementary comparison (SC) of characteristic impedance for coaxial lines, ten countries participate in the SC. The SC will be started from January 2014 and will finish November 2015.

The calibration services of the scattering parameter have been started for PC7 and Type-N 50 ohms connector in the frequency range of 9 kHz to 18 GHz, for Type-N 75 ohms connector in the frequency range of 9 kHz to 3 GHz, and for WM-1651 (WR-6) rectangular waveguide in the frequency range of 110 kHz to 330 GHz. These calibration services are based on use of the originally-designed standard terminations in the range of 9 kHz to 10 MHz, and then the long length air lines as the impedance

standards are calibrated using a dimensional measurement and electrical loss measurement. Subsequently, the dimensionally-derived scattering parameter calibration has been started. The development of the scattering parameter standard for the rectangular waveguide in the frequency range of 50 GHz to 1.1 THz, have been started.

NMIJ developed a new mm-wave power standard in the frequency range from 110 GHz to 170 GHz [Shimaoka, et. al, 2012a, 2013a]. It is an isothermal dry calorimeter, and has a WR-06 (WM-864) rectangular waveguide test port. Typical relative expanded uncertainties of a thermal power meter calibrated using the calorimeter range from 2.7 to 3.1%. NMIJ has been also developing two wideband waveguide calorimeters in the frequency range from 50 to 75 GHz and 75 to 110 GHz. We have reported a work concerning to their uncertainty evaluation [Shimaoka, et. al., 2013b]. Their measurement uncertainties have been under evaluation. NMIJ is developing a new microwave power standard based on the quantum effects. The measurement of a microwave power using the Rabi frequency of vapor-phased cesium (Cs) atoms which is proportional to the magnetic field strength of the microwave has been reported until 2010. Incidentally, the Rabi frequency was measured by an atomic candle method which is used for a stabilization and reference of microwave strength. Therefore, an optimization of the atomic candle is important for the atomic microwave power standard. NMIJ optimized the atomic candle signal [Kinoshita et. al., 2012b, 2013c]. This optimization contributed to understanding the accuracy and precision of the atomic microwave power standard. In addition, NMIJ has started to improve the glass cell containing Cs atoms to reduce the uncertainty of the atomic measurement of microwave power. The new cell enable to covert from the magnetic field strength to transmission power of the microwave without an electromagnetic simulation.

An accurate RF and microwave attenuation-measurement technique with a small mismatch uncertainty in broad continuous frequencies based on the loss measurements to the DUTs in four different phase networks was developed [Widarta, et.al. 2011a]. The four different phase-network configurations have been realized by introducing two known phase-shift values of airlines to the system. A practical technique to apply the mismatch loss correction in RF and microwave attenuation measurements of fixed attenuators as well as variable attenuators as devices under test has been also developed [Widarta, 2011b]. In the attenuation measurement, NMIJ developed a unique technique using step attenuator measurements for evaluation of the complex reflection coefficients of the source [Widarta, 2012c]. In order to measure high attenuation precisely, a newly double step attenuation measurement technique [Widarta, 2012d] and a broadband leakage investigation technique [Widarta, 2013d] has been developed. NMIJ has started to develop an attenuation standard based on the IF substitution method in the frequency range of 75 -110 GHz (W-band). NMIJ has adopted the IF stabilization technique using a phase-locked loop in order to expanding the frequency range of the attenuation measurement system into W-band with high stability. Basic performance of the system was evaluated and a good dynamic range over 60 dB was confirmed [Iida et al, 2013e].

NMIJ has been developing precision RF noise measurement techniques. A variable noise source using a rotary-vane attenuator was studied in the frequency range of 50 - 75 GHz [Iida et al, 2011c]. An experimental study for determining the resistivity and its temperature coefficient of a transmission line of a coaxial microwave noise source was performed [Iida et al, 2011d]. The uncertainty of a radiometer for RF and microwave noise temperature measurement was quantitatively evaluated [Iida et al, 2011e].

In recent years, NMIJ has started to study for accuracy evaluation of a terahertz spectroscopy. In the attenuation (or transmittance) measurement by a terahertz time-domain spectrometer (THz-TDS), it is important to evaluate its linearity. For validation of the THz-TDS, NMIJ developed a metalized-film attenuator (MFA) that can be used in both focused and collimated THz beam configurations [Iida et al, 2012e, 2012f, 2013f]. A method of power linearity evaluation by using the MFA has been proposed [Iida et al, 2011f, 2012g, 2013g, 2013h].

In the joint research project with the National Physical Laboratory, UK, NMIJ achieved the dimensional calibration capabilities of millimeter-wave coaxial line, i.e. 1.85 mm coaxial line, and waveguide, i.e. WM-864 waveguide size, and good agreement between both laboratories [Horibe et

al., 2010a, 2012i, 2012m, Shelton et. al. 2012r]. Then NMIJ had been developed the metrology standards in the both coaxial [Horibe et al., 2010b, 2011g, 2012k] and waveguide, uncertainty evaluation method of waveguide vector network analyzers (VNA) [Horibe et al., 2011h, 2012j, 2012n, 2012o, 2012p, 2013i] over 110 GHz up to 1.1 THz. In this research, NMIJ developed a new design of waveguide flange, connection clamp and VNA stage for establishing accurate and quick connection of waveguide standard devices and components [Horibe et al., 2011i, 2012l, 2013k, 2013m].

The calibration and testing methods of Artificial Main Network used in Electromagnetic compatibility testing has been developed using radio frequency impedance standards [Kishikawa et al., 2012q, 2013j, 2013n]. NMIJ has lunched to research material characterization and on-wafer measurement techniques in the frequency range between microwave and millimeter wave. In the collaborate work with the King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand, uncertainty evaluation method and uncertainty optimization technique have been developed for material characterization based on the transmission and reflection method. Further material characterization techniques, split cylinder, ring-down cavity [Kato 2013o] and free-space measurement methods, are being researched. In the on-wafer techniques, the method to achieve a metrological traceability has been established [Horibe 2013l].

4. Working Groups Reports

Several topics are becoming of importance internationally, either in coordinating standards or developing the area. The Chair recommends the creation of at least two working groups to include:

- Time Scale and the need for a redefinition
- Quantum-based metrology.

5. Sponsored meetings

Several meetings have been sponsored technical, with a small financial sponsorship in one case. These meetings include the following:

- “Foundations and Frontiers of Computer, Communications, Electrical Engineering: Commemorating 150 years of Maxwell’s Equations,” West Bengal, India on 9-10 January 2015
- “International Conference on Signal Processing and Integrated Networks (SPIN-2014),” 21-22 Feb 2014, Noida, India
- “ICEAA – IEEE APWC conference,” Aruba, August 3-9, 2014
- “ICEAA – IEEE APWC – EMS,” September 9 - 13, 2013 Torino, Italy
- “2013 Asia-Pacific Radio Science Conference (AP-RASC-13),” Taipei, Taiwan, September, 2013
- “RADIO 2014,” 7-10 April 2014, Mauritius
- “International Conference on Microwaves and Photonics (ICMAP 2013),” 13-15 December 2013, Dhanbad, India
- “URSI EMTS 2013,” Hiroshima, Japan, May 20-24, 2013
- “AES 2013, 2nd Advanced Electromagnetics Symposium,” Sharjah-Dubai, United Arab Emirates, 19-22 March, 2013
- “META’13, 4th International Conference on Metamaterials, Photonic Crystals and Plasmonics,” Sharjah-Dubai, United Arab Emirates, 18-22 March, 2013

COMMENTS:

The AP-RASC-13 conference participation was coordinated by the Vice Chair

The ICEAA–IEEE APWC–EMS conference participation was coordinated between George Uslenghi (URSI VP), Patrizia Tavella (Italy), and Bill Davis (Comm. A Chair). A large thanks to George and Patrizia for helping on this task. It was an enjoyable meeting.