COMMISSION A : Electromagnetic Metrology
(November 2010 - October 2013)

Edited by Mitsuru Musha (University of Electro-communications) and Yasuhiro Koyama (National Institute of Information and Communications Technology)

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 x 10^{-15}). They are developing also the 2nd fountain (NICT-CsF2), with which a frequency stability of 3 x 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 x 10^{-16}.

A microwave frequency standard using the $^{171}Yb^{+}$ is under development at NICT. For this purpose, Shiga et al. constructed an experimental apparatus and the absolute frequency of the $^{171}Yb^{+}$ hyperfine transition was measured with 4 x 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 +25 ns to -19 ns 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 x 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 11-m 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 (6.4 GHz – 15 GHz) feed for cassegrain 34-m diameter antenna was originally designed and installed to Kashima 34-m 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 $< 1\times10^{-15}$ 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..

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 $^{87}Sr\ ^1S_0$-$^3P_0$ transition frequency, using atoms in an optical lattice [Yamaguchi, 2012]. Matsubara et al. reduced the uncertainty of the absolute frequency of $^{40}Ca^{+}\ ^2S_{1/2}$-$^2D_{5/2}$ transition down to 3 x 10^{-15}, and the ratio of the $^{40}Ca^{+}$ and Sr transition frequencies with the uncertainty of 2 x 10^{-15} [Matsubara, 2012]. A new optical frequency standard based on the $^{115}In^{+}\ ^1S_0$-$^3P_0$ transition frequency is under development to a higher accuracy than that of $^{40}Ca^{+}$. For this purpose, techniques for generating ion chains consisting of $^{115}In^{+}$ and $^{40}Ca^{+}$ 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 $^1S_0 - {}^3P_0$ 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 [Ovsiannikov 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 ^{174}Yb 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 x 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].

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 Vrms to 10 Vrms, 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 being 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, Amagai et al., 2013,].

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.

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].

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 $R_{K\text{-}90}$ from the integer value of 10^4. 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].

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].

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 μF. The expanded uncertainties of the capacitance and the dissipation factor of 100 μF at 120 Hz are 11 μF/F and 14 μrad, 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 μF/F and 270 μrad, respectively [Sakamoto 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.

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].

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). 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]. 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., 2012]. The study on absolute measurements of Seebeck coefficient using an AC-DC measurement technique has started. 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 10Hz, 40 Hz to 100 kHz at the RMS voltage of 1V and10 V.

NMIJ had developed a calibration system for non-sinusoidal voltage, current and power sources at 100V/5A 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]. In addition, the application systems of power measurement using shunt and IVD standards have been developed [Kon et al., 2012b, 2013a, 2013b, 2013d].

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 broad-band 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 launched 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].

[References]

Akamatsu, D., Nakajima, Y., Inaba, H., Hosaka, K., Yasuda, M., Onae, A., and Hong, F.-L. [2012], "Narrow linewidth laser system realized by linewidth transfer using a fiber-based frequency comb for the magneto-optical trapping of strontium," Opt. Exp. **20**, Issue 14, pp. 16010-16016.

Amagai Y. and Y. Nakamura [2012a], "Numerical Analysis of Low-Frequency Properties in Single-Junction Thermal Converters," IEEJ Trans. Electrical and Electronic Engineering, **7**-1, pp.350-354.

Amagai Y. and Y. Nakamura [2012b], "Development of Low-Frequency AC Voltage Measurement System Using Single-Junction Thermal Converter," IEEJ Trans. Fundamentals and Materials, **132**-3, pp.214-219.

Amagai Y. and Y. Nakamura [2012c], "Improved Measurement of AC-DC Transfer Difference Using a Low-Drift Single-Junction Thermal Converter," IEEE Trans. Instrum. Meas., **61**-3, pp.786-790.

Amagai Y., H. Fujiki, K. Shimizume, and S. Hidaka [2012d], "Improved Stability of a Thin-Film Multijunction Thermal Converter," IEEJ Trans. Fundamentals and Materials, **132**-11, pp.1011-1017, (in Japanese).

Amagai Y., M. Maruyama and H. Fujiki [2013], "Low-Frequency Characterization in Thermal Converters Using AC-Programmable Josephson Voltage Standard System," IEEE Trans. Instrum. Meas., **62**-6, pp.1621-1626.

Ameya M. and S. Kurokawa [2012a], "Antenna Pattern Measurement Using Nested Mach-Zehnder Optical Modulator and Uni-traveling Carrier Photodiode in Millimeter Wave," in 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp.638-639, Washington, USA, July.

Ameya M., S. Kurokawa, M. Hirose [2012b], "Antenna Pattern Measurement Using Nested Mach-Zehnder Optical Modulator and Uni-traveling Carrier Photodiode in Millimeter Wave," in in 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp.638-639, Washington, USA, July.

Ameya M., S. Kurokawa, M. Hirose [2012c], "Pseudo EMI Measurement Using VNA and Optical Feeding Antenna for Site Performance Comparison among Public Testing Laboratories in Kanto-area in Japan," in Proc. ISAP2012, pp.638-639, Nagoya, Japan, Dec.

Circular T 275, 276, 277, 278, published by BIPM in 2010 and 2011.

Domae A., T. Oe, M. Kumagai, M. Zama, N. Kaneko [2012a], "Characterization of 100-Ω metal-foil resistor for AC measurements," 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp. 578-579.

Domae A., T. Oe, K. Matsuhiro, S. Kiryu, N. Kaneko [2012b], "Evaluation of a voltage divider based on quantized Hall resistance arrays," 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp. 368-369.

Domae A., T. Oe, K. Matsuhiro, S. Kiryu, N. Kaneko [2012c], "Development of a one-chip quantized Hall resistance voltage divider," Measurement Science and Technology, **23**-12, pp.4008-4012.

Domae A., T. Oe, M. Kumagai, M. Zama, N. Kaneko [2013a], "Characterization of 100-Ω Metal Foil Standard Resistors," IEEE Trans. Instrum. Meas., **62**-6, pp.1776-1782.

Domae A., N. Sakamoto, N. Kaneko [2013b], "Validation for Capacitance National Standard Based on Long-term Monitoring Results of Standard Capacitors," IEEJ Transactions on Electrical and Electronic Engineering, **8**-2, pp. 111-115.

Fujieda M., Kumagai M., Nagano S., Yamaguchi A., Hachisu H., Ido T. [2011], "All-optical link for direct comparison of distant optical clocks," Opt Exp., **19** (17):16498-507. doi: 10.1364/OE.19.016498, Aug.

Fujieda M., Gotoh T., Nakagawa F., Tabuchi R., Aida M., Amagai J. [2012], "Carrier-phase-based two-way satellite time and frequency transfer," IEEE Trans Ultrason. Ferroelectr. Freq. Control, **59** (12):2625-30. doi: 10.1109/TUFFC.2012.2503, Dec.

Fujiki H [2013], "Development of Thin-Film Multijunction ThermalCurrent Converters With Increased Rated Current," IEEE Trans. Instrum. Meas., **62**, No. 6, pp.1853–1858.

Gotoh T., Amagai J., Fujieda M., and Aida M. [2011], "Development of a GPU based two-way time transfer modem", IEEE Trans. Instrum. Meas., DOI:10.1109/TIM.2010.2091313, Aug.

Hayasaka K. [2012], "Synthesis of two-species ion chains for a new optical frequency standard with an indium ion," Appl. Phys. **B107**, 965-970.

Hirose M., S. Kurokawa [2012], "Relation Between Phase Center and Amplitude Center of Antenna By Kern Transmission Formula,'' in Proc. ISAP2012, pp.0351-0351, Oct.

Hobiger T. et al. [2011a], "On the feasibility to utilize space-geodetic techniques for advanced time and frequency transfer," BIPM Workshop on Development of advanced time and frequency transfer techniques.

Hobiger T., et al. [2011b], "VLBI analysis with c5++ - status quo and outlook," Proceedings of the 20th EVGA.

Horibe M., Shida M. and Kishikawa R. [2010a], "Complete Characterization of Rectangular Waveguide Measurement Standards for Vector Network Analyzer in the range of Millimeter and Sub-millimeter wave frequencies," The 76th ARFTG Microwave Measurement Symposium digests.

Horibe M, Ridler N., Salter M. and Eio C. [2010b], "Characterization and Verification of Coaxial Open-circuit Primary Standards for Millimeter-wave Vector Network Analyzer Calibration," The 76th ARFTG Microwave Measurement Symposium digests.

Horibe M., Ridler N., and Salter M. [2011g], "New Calibration Technique for Coaxial Network Analyzer Reflection Measurements at Millimeter-wave Frequencies," 77th ARFTG conference digests.

Horibe M., and Kishikawa R. [2011h], “Evaluation of Complex Residual Error in Vector Network Analyzer Measurement System in the Range of Millimeter-wave and Submillimeter-wave frequencies,” 77th ARFTG conference digests.

Horibe M., and Noda K. [2011i], “Modification of Waveguide Flange Design for Millimeter and Submillimeter-wave measurements,” 77th ARFTG conference digests.

Horibe M., and Ridler N. [2012i], “Comparison Between NPL and NMIJ of Diameter and Scattering Parameter Measurements of Precision 1.85 mm Coaxial Air Lines,” IEEE Trans. Instrum. Meas.

Horibe M. and Kishikawa R. [2012j], “Establishment of S-parameter Standards of Rectangular Waveguide at Millimeter-wave and THz Frequencies,” PIERS2012 digests.

Horibe M. and Kishikawa R. [2012k], “Accurate Measurement Standards and Calibration Techniques for S-parameter Measurements in Coaxial Line System at Millimeter Wave Frequency,” PIERS2012 digests.

Horibe M. and Kishiakwa R. [2012l], “Performance of New Design of Waveguide Flange for Measurements at Frequencies from 800 GHz to 1.05 THz,” 79th ARFTG conference digests.

Horibe M. Ridler N. and Wilson A. [2012m], “Traceability via Precision Dimensional Measurements of WM-864 (WR-03) Waveguide Standard Shims Including Comparison between NPL and NMIJ,” 79th ARFTG conference digests.

Horibe M., and Kishikawa R. [2012n], “Traceability to National Standards for S-parameter Measurements in Waveguide at 1.1 THz,” 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests.

Horibe M., and Kishikawa R. [2012o], “Confidence of Waveguide VNA Measurement in the Frequency Range of W-band and D-band,” IRMMW-THz2012 conference digests.

Horibe H. and Kishikawa R. [2012p], “Characterization of Quarter Wavelength Line as Measurement Standard for Scattering Parameter in the Frequency Range of W-band and D-band,” IRMMW-THz3012 conference digests.

Horibe M. and Kishikawa R. [2013i], “Metrological Traceability in Waveguide S-parameter Measurements at 1.0 THz band,” IEEE Trans. Instrum. Meas., **62**-6, pp.1814-1820.

Horibe M., and Kishikawa R. [2013k], “Comparing Accuracy of Waveguide VNA Measurement Calibrated by TRL Calibration Using Different Length of Line Standard in Terahertz Band,” ARFTG conference digests.

Horibe M. [2013l], “Metrological Traceability Challenge for On-Wafer S-parameter Measurement at Microwave and Millimeter-wave length,” AP-RASC2013 Conference digests.

Horibe M. and Kishikawa R. [2013m], “Investigations of Capability of Connection Repeatability for Waveguide with Different Size Apertures,” 81st ARFTG conference digests.

Hosaka, K., Inaba, H., Akamatsu, D., Yasuda, M., Sugawara, J., Onae, A., and Hong, F.-L. [2013], “A Fabry-Perot Etalon with an Ultralow Expansion Ceramic Spacer,” Jpn. J. Appl. Phy., **52**, pp. 032402.

Ichikawa R., et al. [2011], “Precise Frequency Transfer Experiments using VLBI and other Techniques,” The XXX General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS 2011).

Iida H., T. Inaba, Y. Shimada and K. Komiyama [2011c], “Uncertainty of a Millimeter-Wave Variable Noise Source using a Variable Attenuator,” IEEJ Trans. Fundamentals and Materials, **131**, no. 4, pp. 302-303 (in Japanese).

Iida H., T. Inaba, Y. Shimada and K. Komiyama [2011d], “A Study on the Estimation of Noise Temperature of a Microwave Standard Noise Source,” IEEJ Trans. Fundamentals and Materials, **131**, no. 4, pp. 300-301 (in Japanese).

Iida H., Y. Shimada and K. Komiyama [2011e], “Evaluation of Type B Uncertainty of a Radiometer for RF and Microwave Noise Temperature Measurement,” IEEJ Trans. Fundamentals and Materials, **131**, no. 4, pp. 231-238 (in Japanese).

Iida H., Y. Shimada, M. Kinoshita, H. Kuroda, K. Kitagishi and Y. Izutani [2011f], “Power Linearity Measurement in Terahertz Time-Domain Spectroscopy using Metalized Film Attenuators,” Jpn. J. Appl. Phys. **50**, no. 12, 128004.

Iida H., M. Kinoshita, Y. Shimada, H. Kuroda, K. Kitagishi, and Y. Izutani [2012e], “Comparison of transmittance measurement between high-resistivity float-zone silicon and metalized-film attenuators in focused-beam THz-TDS,” Tech. Dig. of the 7th Asia-Pacific Microw. Photon. Conf., PB-1.

Iida H., M. Kinoshita, Y. Shimada, H. Kuroda, K. Kitagishi, and Y. Izutani [2012f], “Experimental investigation of a metalized-film attenuator for validation of terahertz time-domain spectroscopy,” The 37th Int’l Conf. on Infrared, Millimeter and Terahertz Waves, Thu-Pos-47.

Iida H., M. Kinoshita, Y. Shimada, H. Kuroda, K. Kitagishi, and Y. Izutani [2012g], “Linearity evaluation of THz-TDS system by a step attenuator using metalized films,” 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp. 660-661.

Iida H. and K. Fujii [2013e], “Basic Study for Development of Attenuation Standard in W-band,” Ext. Abstr. 74th Autumn Meet., Japan Society of Applied Physics, 16a-C8-2 (in Japanese).

Iida H., M. Kinoshita and Y. Shimada [2013f], “Measurement of optical properties of a metalized-film attenuator at terahertz frequencies using a time-domain spectrometer,” Int’l Workshop on Optical Terahertz Science and Technology Ext. Abstr., pp. 339-339.

Iida H., M. Kinoshita, Y. Shimada, H. Kuroda, K. Kitagishi, and Y. Izutani [2013g], “Validation of power linearity in terahertz time-domain spectroscopy using a programmable step attenuator,” IEEE Trans. Instrum. Meas., **62**, no. 2, pp. 1801-1806.

Iida H., M. Kinoshita and Y. Shimada [2013h], "Improvement of transmission characteristics of a THz step attenuator," The 38th Int'l Conf. on Infrared, Millimeter and Terahertz Waves, Mo-P1-35.

Imai Y., Sugiyama K., Nishi T., Higashitani S., Momiyama T., and Kitano K. [2013], "Single-ion spectroscopy of the $^2S_{1/2}$—$^2D_{5/2}$ clock transitions in Yb^+ towards search for temporal variation of the fine structure constant," Abstract of the 12th Asia Pacific Physics Conference (APPC12), B3-PWe-21, Makuhari (Japan), p.927, July.

Inaba, H., Hosaka, K., Yasuda, M., Nakajima, Y., Iwakuni, K., Akamatsu, D., Okubo, S., Kohno, T., Onae, A., Hong, F.-L. [2013], "Spectroscopy of ^{171}Yb in an optical lattice based on laser linewidth transfer using a narrow linewidth frequency comb," Opt. Exp., **21**, pp.7891-7896.

Ishii M., S. Kurokawa, and Y. Shimada [2011], "Comparison between three-antenna method and equivalent capacitance substitution method for calibrating electrically short monopole antenna," Proceedings of 2011 IEEE International Symposium on Electromagnetic Compatibility (Long Beach), pp. 101 – 106, Aug.

Ishii M., S. Kurokawa, Y. Shimada [2012], "AC Magnetic Field Standard for Magnetometer Calibrations at NMIJ," in Proc. CPEM2012, pp. 488-499, Washington, USA, July.

M. Ishii, R. Ketzler, M. Albrecht, S. Kurokawa [2013], Y. Shimada, "Improvement of Formula and Uncertainty of the Reference Magnetic Field for AC Magnetometer Calibration," IEEE Trans. Instrum. Meas., vol. 62, no. 6, pp. 1443-1449, June.

Ito H., S. Nagano, M. Kumagai, M. Kajita, and Y. Hanado [2013], "Terahertz Frequency Counter with a Fractional Frequency Uncertainty at the 10^{-17} Level," Appl. Phys. Express **6**, 102202 1-3.

Iwakuni, K., Inaba, H., Nakajima, Y., Kobayashi, T., Hosaka, K., Onae, A., and Hong, F.-L. [2012], "Narrow linewidth comb realized with a mode-locked fiber laser using an intra-cavity waveguide electro-optic modulator for high-speed control," Optics Express, **20**, pp.13769.

Kajita M., M. Abe, M. Hada, and Y. Moriwaki [2011 a], "Estimated accuracies of pure XH^+ (X: even isotopes of group II atoms) vibrational transition frequencies: Toward the test of the variance in m_p/m_e," J. Phys. B: At. Mol. Opt. Phys. **44**, 025402 1-7.

Kajita M., G. Gopakumar, M. Abe, and M. Hada [2011 b], "Elimination of the Stark shift from the vibrational transition frequency of optically trapped ^{174}Yb ^{6}Li molecules," Phys. Rev. A **84**, 022507 1-6.

Kajita M., G. Gopakumar, M. Abe, and M. Hada [2012 a], "Accuracy estimations of overtone vibrational transition frequencies of optically trapped ^{174}Yb^{6}Li molecules," Phys. Rev. A **85**, 062519 1-8.

Kajita M. and M. Abe [2012 b], "Frequency uncertainty estimation for the $^{40}CaH^+$ vibrational transition frequencies observed by Raman excitation," J. Phys. B: At. Mol. Opt. Phys.**45,** 185401 1-5.

Kajita M., G. Gopakumar, M. Abe, and M. Hada [2013], "Sensitivity of vibrational spectroscopy of optically trapped ^{88}Sr^{6}Li and ^{40}Ca^{6}Li molecules to variations in m_p/m_e," J. Phys. B: At. Mol. Opt. Phys. **46,** 025001, 1-5.

Kaneko N., M. Maruyama, and C. Urano [2011], "Current Status of Josephson Arbitrary Waveform Synthesis at NMIJ/AIST," IEICE Trans. Electron., **E94-C** No.3, pp.273-279.

Kaneko N., M. Maruyama, and C. Urano and S. Kiryu [2012a], "Review of Josephson Waveform Synthesis and Possibility of New Operation Method by Multibit Delta-Sigma Modulation and Thermometer Code for Its Further Advancement," Jpn. J. Appl. Phys. **51**, pp.010116(7).

Kaneko N., T. Oe, A. Domae, T. Abe, M. Kumagai, and M. Zama [2012b], "Development of High-Stability Metal-foil Standard Resistors for DC and AC Measurements," Proceedings of the NCSLI 2012 Workshop & Symposium.

Kaneko N., T. Oe, A. Domae, T. Abe, M. Kumagai, and M. Zama [2012c], "Development of High-Stability Metal-Foil Resistors for DC and AC Measurements," NCSLI Measure J. Meas. Sci., **7**, no. 4, pp. 34-40.

Kaneko N., A. Domae, T. Oe, J. Schurr, F. J. Ahlers, and S. Kiryu [2012e], "Investigation of On-chip Double-shieled QHR Device in AC Regime," CPEM2012 Digest, pp.193-194.

Kaneko N., A. Domae, T. Oe, J. Schurr, F. J. Ahlers, and S. Kiryu [2013a], "First attempt to develop an on-chip double-shielded QHR device for use in ac measurements," IEEE Trans. Instrum. Meas., **62**, pp.1743-1748.

Kaneko N. [2013b], "Progress of Electrical Standards and the future Revision of the International System of Units," Measurement Standards and Metrology Management, **63** No.1, pp.6-11.

Kato Y. Ameya M., Horibe M. and Kurokawa S. [2013o], "A Proposal of a New Permittivity Measurement Method for Low-Loss Materials", Proceedings of European Microwave Week 2013, pp.1287-1290.

Kinoshita M., K. Shimaoka, Y. Shimada [2012b], "Optimization of the Atomic Candle Signal Used for Microwave Power Standard Based on the Rabi Frequency," 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digest, pp. 114-115.

Kinoshita M., K. Shimaoka, Y. Shimada [2013c], "Optimization of the Atomic Candle Signal for the Precise Measurement of Microwave Power," IEEE Transactions on Instrumentation and Measurement, volume **62**, Issue 6, pp. 1807-1813.

Kishikawa R. and Horibe M. [2012q], "Development of S-parameter Standard for Coaxial 3.5 mm Connectors in the Frequency Range from 10 MHz to 100 MHz," 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests.

Kishikawa R., and Horibe M. [2013j], "Establishment of S-parameter Traceability for 3.5 mm Coaxial Lines from 10 MHz to 100 MHz," IEEE Tans. Instrum. Meas.

Kishikawa R. and Horibe M. [2013n], “Metrological Standard of S-parameter for 2.92 mm Coaxial Lines,” AP-RASC Conference Digests.

Kon S., and T. Yamada [2011], “Uncertainty Evaluations of an AC Shunt Calibration System with a Load Effect Reduction Circuit,” IEEE Trans. Instrum. Meas., **60**, No.7, pp.2286-2291.

Kon S., and T. Yamada [2012a], “Development of an Extremely Precise Buffer Amplifier for AC Shunt Standards at Audio Frequencies,” *Electrical Engineering in Japan*, **178**, No.4, pp.24-31.

Kon S., and T. Yamada [2012b], “Uncertainty Estimations of an Evaluation System for a High Accuracy and Wideband Transconductance Amplifier,” CPEM2012 Digest, pp.482-483.

Kon S., Y. Kasai, M. Murakawa and T. Higuchi [2013a], “Visualization System for Electrical Power Consumption and its Evaluation,” IEEJ Transactions on Electrical and Electronic Engineering, **7**, S1, pp.14-18.

Kon S. and T. Yamada [2013b], “Frequency Characterizations of Voltage and Current Transducers for Evaluation of Phasor Measurement Units,” The 10th IEEE International Conference on Power Electronics and Drive Systems conference proceedings, pp.989-991.

Kon S., and T. Yamada [2013c], “Expansion of the frequency range of ac shunt calibration system and its verification,” SICE annual conference 2013 conference proceedings, pp.1671-1672.

Kon S., and T. Yamada [2013d], “Characterization of high-accuracy, wideband transconductance amplifiers up to 100 kHz,” IEEE Trans. Instrum. Meas., (accepted).

Kondo, T., et al. [2012], “VLBI Application for Time and Frequency Transfer, and Comparison with Other Techniques,” Shanghai Astronomical Observatory "New Technologies in Astronomy” Symposium.

Koyama, Y. [2012], “The Use of Very Long Baseline Interferometry for Time and Frequency

Metrology," MAPAN, **27**, pp. 23-30.

Koyama, Y., et al. [2013], "Remote Frequency Comparison with Very Long Baseline Interferometry," 2013 Asia-Pacific Radio Science Conference (AP-RASC2013).

Kurokawa S., M. Hirose, M. Ameya [2012], "Three antenna method for a hybrid broad band antenna using time domain and pulse compression technique," in 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp.634-635, Washington, USA, July.

Kurokawa S., M. Hirose, M. Ameya [2013], "Far Field Gain Estimation Method for Japanese Broadband Antenna Standard Using Time-frequency Analysis," in Proc. Piers2013, pp.838-842, Stockholm, Sweden, Aug.

Matsubara K., H. Hachisu, Y. Li, S. Nagano, C. Locke, A. Nogami, M. Kajita, K. Hayasaka, T. Ido, and M. Hosokawa [2012], "Direct comparison of a Ca+ single-ion clock against a Sr lattice clock to verify the absolute frequency measurement," Opt. Exp. **20**, 22034.

Morioka T. [2011a], "Tracing E-field probe responses to the dipole antenna factor," in Proc. IEEE Int. Symp. Electromagn. Compat., pp. 1-5, Long Beach, CA., USA, Aug.

Morioka T. [2011b], "Response of a short dipole probe to a non-uniform E-field of a TEM cell," IEEE Trans. Instrum. Meas., vol. 60, no. 7, pp. 2709-2714, July.

Morioka T., M. Yamanaka, and K.Hirawsawa [2013], "Shortened dipole antenna factors by the reference antenna method at a finite separation," in Proc. IEEE Int. Symp. Electromagn. Compat., pp. 439-444, Denver, CO., USA, Aug.

Nagano S., H. Ito, M. Kumagai, M. Kajita, and Y. Hanado [2013], "Microwave synthesis from a continuous-wave terahertz oscillator using a photocarrier terahertz frequency comb," Optics Letters, **38**, 12, pp.2137 -2139.

Nakamura M., Takahashi Y., Amagai J., Gotoh T., Fujieda M., Tabuchi R., Hama S., Yahagi Y., Takahashi T. and Horiuchi S. [2013], “Time Comparison Experiments Between the QZS-1 and its Time Management Station,” NAVIGATION, Journal of the Institute of Navigation, **60**, No. 4, 319-324, DOI: 10.1002/navi.46, Dec.

Ovsiannikov, V. D., V. G. Pal’chikov, A. V. Taichenachev, V. I. Yudin and H. Katori [2013], “Multipole, nonlinear, and anharmonic uncertainties of clocks of Sr atoms in an optical lattice,” Phys. Rev. A **88**, pp. 013405.

Oe T., K. Matsuhiro, T. Itatani, S. Gorwadkar, S. Kiryu, and N. Kaneko [2011], “Improvement of yield ratio of ohmic contact to GaAs/AlGaAsheterostructure by application of SiO_2 protective layer,” *Phys. Status Solidi C*, **9**, No.2, pp. 270-273.

Oe T., K. Matsuhiro, T. Itatani, S. Gorwadkar, S. Kiryu, and N. Kaneko [2013], “New Design of Quantized Hall Resistance Array Device,” IEEE Trans. Instrum. Meas., **62**-6, pp.1755-1759.

Sakamoto N. and Y. Nakamura [2010], “Calibration Method for Large Capacitances Using a Current Comparator with an Inductive Voltage Divider,” 2010 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp.412-413.

Sekido, M., et al. [2012a], “Research on VLBI application for Time and Frequency Transfer in NICT,” IVS VLBI2010 Workshop on Technical Specifications.

Sekido, M. [2012b], “VLBI Application for Time and Frequency Transfer,, and Comparison with Other Techniques,” IAU XXXVIII General Assembly, Beijing.

Sekido M., et al. [2013a], “Development of Wide Band Very Long Baseline Interferometry System for Time and Frequency Comparison on Intercontinental Distance,” NICT Workshop on Optical Frequency Standards --Recent Progress and Future Prospect.

Sekido, M., et al. [2013b], “Development of wideband VLBI system "Gala-V",” The 2nd International VLBI Technology Workshop.

Shelton D, Salter M, Ridler N. and Horibe M. [2012r], “Characterizing Artifact Standards for

Use with Coaxial Vector Network Analyzers at Millimeter-wave Frequencies," 80th ARFTG conference.

Shimamoto S., Y. Naito, Y. Fukuyama, S. Kiryu and N. Kaneko [2012], "Native Graphene Oxides at Graphene Edges," 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp.518-519.

Shimamoto S., Y. Naito, Y. Fukuyama, S. Kiryu and N. Kaneko [2013], "Native Graphene Oxides at Graphene Edges," IEEE Trans. Instrum. Meas., **62**, pp.1461-1466.

Shimaoka K., M. Kinoshita, K. Fujii, and T. Tosaka [2012a], "Design of a broadband calorimeter for mm-wave power standard in the frequency range from 110 GHz to 170 GHz," 2012 37th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), 10.1109/IRMMW-THz.2012.6380247.

Shimaoka K., M. Kinoshita, K. Fujii, and T. Tosaka [2013a], "Calibration of mm-wave power meters using a broadband calorimeter in the frequency range from 110 GHz to 170 GHz," 2013 38th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), 10.1109/IRMMW-THz.2013.6665712.

Shimaoka K., M. Kinoshita, and T. Inoue [2013b], "A Broadband Waveguide Calorimeter in the Frequency Range from 50 GHz to 110 GHz," IEEE Trans. Instrum. Meas. **62**, No. 6, pp. 1828 – 1833.

Takamizawa A., S. Yanagimachi, Y. Shirakawa, K. Watabe, K. Hagimoto, and T. Ikegami [2010], "Cesium Atomic Fountain Clocks at NMIJ," Proc. 42nd Annual Precise Time and Time Interval (PTTI) Meeting, pp. 321-328.

Takamizawa A., S. Yanagimachi, T. Tanabe, K. Hagimoto, and T. Ikegami T. [2012], "Development of cesium atomic fountains at NMIJ," International Conference on Atomic Physics (ICAP), Th-019.

Takamizawa A., S. Yanagimachi, T. Tanabe, K. Hagimoto, and T. Ikegami [2013], "Development of the Atomic Fountain Primary Frequency Standard, NMIJ-F2," Asia-Pacific Radio Science Conference (AP-RASC), A2-3.

Takamoto M., T. Takano and H. Katori [2011], "Frequency comparison of optical lattice clocks beyond the Dick limit," Nat. Photon. **5**, pp. 288-292.

Takefuji K., et al. [2012 a], "High-order sampling technique for geodetic VLBI and the future," Proceedings of 11th European VLBI Network（EVN symposium, PoS (11th EVN Symposium) 113.

Takefuji K., et al. [2012 b], "Study of an RF Direct Sampling Technique for Geodetic VLBI," IVS 2012 General Meeting Proceedings "Launching the Next-Generation IVS Network" Edited by Dirk Behrend and Karen D. Baver, NASA/CP-2012-217504, pp. 71-75, December.

Takefuji, K., et al. [2012 c], "The Gala-V, our unique solution for the VLBI2010," 1st International VLBI Technology Workshop.

Takefuji, K., et al. [2013], "Evaluation of the RF Direct sampler Galas in the VLBI2010 era," The 2nd International VLBI Technology Workshop.

Tseng W.-H, Y. Huang, T. Gotoh, T. Hobiger, M. Fujieda, M. Aida, T. Li, S. Lin, H. Lin, K. Feng [2012], "First international two-way satellite time and frequency transfer experiment employing dual pseudo-random noise codes," IEEE transactions on ultrasonics, ferroelectrics, and frequency control, **59** (3): 531-8. DOI:10.1109/TUFFC.2012.2224, March.

Uehara T., Sugiyama K., and Kitano M. [2012], "Frequency stabilization of laser diode to the 6S-8S two-photon transitions in cesium atoms in a vapor cell placed in and external cavity," Digest of the 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, Washington (USA), July 2012, pp. 268-269.

Ujihara, H., et al. [2011], "Development of Multimode Horns and Wideband Feed for Radio Telescopes," The XXX General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS 2011).

Ujihara, H., et al. [2012 a], "Development of Wide Band Feeds," IVS VLBI2010 Workshop on Technical Specifications.

Ujihara H., et al. [2012 b], "Development of Wide Band Feed," IVS 2012 General Meeting Proceedings "Launching the Next-Generation IVS Network" Edited by Dirk Behrend and Karen D. Baver, NASA/CP-2012-217504, pp. 57-60, December.

Urano C., Y. Fukuyama, N. Kaneko, M. Maruyama, T. Oe, A. Domae, K. Yamazawa, J. Tamba, H. Yamamori, and S. Kiryu [2012], "Development of Thermodynamic Temperature Measurement Technique Based on Quantum Standards at NMIJ/AIST," 2010 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp.48-49.

Watabe K., S. Yanagimachi, T. Ikegami, H. Iida, and Y. Shimada [2012], "Signal with Flat Phase Noise Using a Carrier and the Power Spectral Density of White Noise for Phase Noise Standards," Jpn. J. Appl. Phys. **51**, 018002.

Widarta, A., Endo, M., and Kawakami, T. [2011a], "Attenuation Measurement Technique With a Small Mismatch Uncertainty Using Phase Characteristics of Multiple Reflected Signals," IEEE Trans. Instrum. Meas., **IM-60**, No.7, pp. 2715-2719.

Widarta A. [2011b], "Mismatch Uncertainty Evaluation in Precision RF Attenuation Measurement," IEEJ Trans. FM. **131**, No.4, pp. 283-287, (*in Japanese*).

Widarta, A. [2012c], "Determination of RF Source Reflection Coefficients Using Step Attenuator Measurement Technique," 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp. 98-99, July.

Widarta, A. [2012d], "Double Step Attenuation Measurement Technique for High Attenuation of Variable Attenuators," 2012 Conference on Precision Electromagnetic Measurements (CPEM) Digests, pp. 30-31, July.

Widarta, A. [2013d], "Investigation of Leakage in Broadband RF and Microwave Attenuation

Measurement Systems," 2013 International Conference on Electromagnetics in Advanced Applications (ICEAA'13 15th Edition including EMS), pp.1356-1357, Sept.

Yamada T., S. Kon [2012a], "Uncertainty Estimation and Performance Evaluation of A Non-sinusoidal Power Measurement Standard," IEEJ Trans. Fundam. Mater. **132**, No.3, pp.251-256.

Yamada T., S. Kon, N. Hashimoto, T. Yamaguchi, K. Yazawa, R. Kondo, and K. Kurosawa [2012b], "ECT Evaluation by an Error Measurement System According to IEC 60044-8 and 61850-9-2," IEEE Trans. Power Del. **27**, No.3, pp.1377-1384.

Yamaguchi A., M. Fujieda, M. Kumagai, H. Hachisu, S. Nagano, Y. Li, T. Ido, T. Takano, M. Takamoto and H. Katori [2011], "Direct Comparison of Distant Optical Lattice Clocks at the 10^{-16} Uncertainty," App. Phys. Exp. **4**, pp. 082203.

Yamaguchi A., N. Shiga, S. Nagano, Y. Li, H. Ishijima, H. Hachisu, M. Kumagai, and T. Ido [2012], "Stability Transfer between Two Clock Lasers Operating at Different Wavelengths for Absolute Frequency Measurement of Clock Transition in ^{87}Sr," Appl. Phys. Exp. **5**, 022701.

Yanagimachi S., K. Watabe, T. Ikegami, H. Iida, and Y. Shimada [2013a], "Uncertainty Evaluation of -100 dBc/Hz Flat Phase Noise Standard at 10 MHz," IEEE Trans. Instrum. Meas. **62**, pp.1545.

Yanagimachi S., K. Hagimoto, and T. Ikegami [2013b], "Analysis of Truncation Error for Dual-Mixer-Time-Difference Measurement System Using Discrete Fourier Transformation," Jpn. J. Appl. Phys. **52**, 036601.

Yanagimachi S., A. Takamizawa, T. Tanabe, K. Hagimoto, T. Ikegami [2013c], "Dual-Mixer Time-Difference Measurement System using Discrete Fourier Transformation," Proc. European Frequency and Time Forum, pp. 310-313.

Yasuda, M., Inaba, H., Kohno, T., Tanabe, T., Nakajima, Y., Hosaka, K., Akamatsu, D., Onae, A. [2012], Suzuyama, T., Amemiya, M., and Hong, F.-L., "Improved Absolute Frequency

Measurement of the ^{171}Yb Optical Lattice Clock towards a Candidate for the Redefinition of the Second," Appl. Phys. Exp. **5**, pp. 102401.