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Edited by Masatoshi Kajita and Yasuhiro Koyama, National Institute of Information and Communications Technology

A1. Time and Frequency Standards and Time Transfer Technique

In Japan, the researches and developments on Time and Frequency (T&F) Standards and Time Transfer Techniques are mainly carried out in the National Institute of Information and Communications Technology (NICT) and National Metrology Institute of Japan (NMIJ).

NICT has developed a cesium atomic fountain primary frequency standard NICT-CsF1. [Circular T, Kumagai et al., 2008a, b]. The typical uncertainty was 1.5×10^{-15} including the uncertainty of the link. To improve the short-term stability of NICT-CsF1, the authors have introduced the cryogenic sapphire oscillator (CSO), which developed in the University of Western Australia. The stability improved by a factor of 3. And, to reduce the systematic uncertainty, the authors have started to develop our second atomic fountain (NICT-CsF2). So far, the authors have succeeded to observe 0.95 Hz Ramsey signal in NICT-CsF2.

NICT newly developed a Network Time Protocol (NTP) server with high-performance and started a public time service from 2007. The number of access was about fifteen million per day in 2007 and is more than one hundred million per day in 2010. A new protocol for high-speed network time transfer has been investigated by using this server. NICT also developed a GPS receiver with network for a remote calibration and time transfer [Machizawa et al. 2008] and reconstructed more convenient system [Iwama et al. 2010]. Then NICT transferred the technology of a GPS receiver to a commercial company.

NICT is regularly performing Two Way Satellite Time and Frequency Transfer (TWSTFT) between Germany (PTB) and Asian T&F institutes (KRISS, TL, NTSC, SPRING, and NMIJ), and calibrated their station delays for TL, KRISS and NMIJ. Obtained data by TWSTFT and GPS are reported to BIPM. The TWSTFT data for NICT/PTB link has been adopted for TAI link since April 2007 in place of GPS data. The number of participants of this Asia-Eu link sharply increased. At last 6 Asian and 2 European institutes (NICT, KRISS, NMIJ, TL, NTSC, NIM, PTB and OP) joined. After the link pause for half year due to the satellite malfunction, the link restarted by switching the satellite on October 2010. Causes of observed diurnal variation have been studied, especially compared before and after the switch. By the install of a relay station in Hawaii, the link between NICT and USNO was established by 2-hop connection on July 2010. The result shows good agreement with GPS PPP.

NICT developed a new TWSTFT modem using Dual Pseudo-random Noise (DPN) signal. NICT carried out TWSTFT experiments with DPN signal between NICT and TL, as well as confirmed that short (< 100 sec) and long (< 1 day) term stability of the DPN system were less than 50 ps and less than 200 ps respectively. DPN method was also adopted for QZSS narrow band bent pipe system, and used for time comparison between NICT Koganei and Okinawa earth stations. NICT developed GPS carrier phase time transfer software “concerto version 4”. The software can analyze both methods, PPP and single difference observations, and be used for the evaluation of DPN method. The results of DPN and GPS carrier phase were consistent within 100 ps per 1 day.

NICT developed an RF distribution system using optical fibers, which has an active phase-noise cancellation system. The system was evaluated in the JGN2plus optical fiber link which was an urban optical fiber link in Tokyo [Fujieda et al. 2009]. The transfer stability in the 10^{-18} level at an averaging time of 1 day was achieved in the 114-km frequency dissemination [Kumagai et al. 2009]. In addition, the transfer length was extended to 204 km by a cascaded system, which stability was still in the 10^{-17} level [Fujieda et al. 2010]. For direct comparison of optical clocks, an optical carrier transfer system has been developed, too. Two ^{87}Sr optical clocks were compared using a 60-km optical fiber link in the 10^{-16} frequency resolution. Its short term stability in the 10^{-15} level enabled us the real time detection of the frequency difference of 10 Hz.

NICT achieved pico-second order precision for two-way time and frequency comparison between the ground clock and the on-board atomic clock on ETS-8 satellite, which was launched in December 2006. Both code phase and carrier phase showed consistent result and capability to monitor the on-board atomic clock. [Takahashi et al. 2008]

NICT developed the time management system, which consists of on-board equipment and the ground segment of the Quasi-Zenith Satellite System (QZSS) which is a regional satellite navigation system in Japan. Its first satellite QZS-1 was successfully launched on September, 2010. Various experiments such as precise T&F comparison between the QZS-1 and UTC(NICT) and between two ground stations, on-board atomic clock monitoring, L-band calibration, are now been carrying out [Hama et al. 2009]

In NMIJ, following researches have been conducted. Primary Frequency Standards; NMIJ has made the calibration of the International Atomic Time (TAI) 18 times between 2007 and 2010 with the Cs atomic fountain frequency standard, NMIJ-F1 with a combined uncertainty of 3.9×10^{-15} [Circular T, Yanagimachi et al. 2008, Takamizawa et al. 2010]. NMIJ-F1 will be used as a reference oscillator for the evaluation of the optical lattice clocks in NMIJ, the development of our second fountain (NMIJ-F2), as well as used for the TAI contribution. The construction of NMIJ-F2 has been continued. A truncated atomic beam fountain was proposed and the proof of the principle experiments has been started, in order to achieve a low collisional frequency shift, high frequency stability and the uncertainty of the order of 10^{-16} [Takamizawa et al. 2010].

Ultra-stable microwave oscillator; NMIJ has been maintaining two cryogenic sapphire oscillators (CSOs) for use as a local oscillator of Cs atomic fountains and a reference oscillator for the evaluation of ultra-stable lasers in optical lattice clocks.

Time Keeping; Four cesium atomic clocks with high-performance beam tubes (Agilent 5071A) and four active hydrogen maser frequency standards are operated for time keeping in NMIJ. One of the hydrogen maser frequency standards has been used for the generation of UTC(NMIJ) since March 2006 to improve the short term stability of UTC(NMIJ).

Time and Frequency Transfer; In NMIJ, dual frequency carrier phase GPS receiver is one of the main international time and frequency transfer tools. In addition, 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 also studied in NMIJ as one of future precise time and frequency comparison systems [Amemiya et al. 2006, Amemiya et al. 2010a, Amemiya et al. 2010b].

Frequency Calibration Service; NMIJ and related organizations have been conducting to construct remote calibration systems for several metrology areas since 2001. Time and frequency division of NMIJ has been developing a frequency calibration system using GPS common-view method and Internet. NMIJ's remote frequency calibration service has been started since 2006 to the calibration laboratories. NMIJ has also started to develop the user equipment for the end users of the remote frequency calibration service [Imae et al. 2010]. A simple and cost effective frequency dissemination method also has been developed in NMIJ. In this method, optical fiber network service (INS-1500) is used for generating 10 MHz reference signal. Stability test results showed a good performance with an uncertainty of less than 1×10^{-12} at an averaging time of one day [Amemiya et al. 2008].

A2. Laser Stabilization and Frequency Measurement

The researches and developments in Japan on the stabilization of lasers and the optical frequency measurement are also mainly carried out in the National Institute of Information and Communications Technology (NICT) and National Metrology Institute of Japan (NMIJ), together with some very active universities.

NICT is developing a single Ca^+ ion trap optical frequency standard. Matsubara et al. have measured the absolute frequency of the $4s^2S_{1/2}$ - $3d^2D_{5/2}$ forbidden transition, and the frequency uncertainty is reduced down to 5 Hz [Matsubara et al., 2008 a,-c, 2009 a-b].

NICT is developing also an optical frequency standard based on the Sr $^1S_0$ – $^3P_0$ forbidden transition in a optical lattice. The frequency uncertainty is of the order of 0.2 Hz [Yamaguchi et al. 2010 a].

Li et al. developed clock lasers with linewidth narrower than 3 Hz [Li et al. 2008 1.-b, 2010 a]. Also the new system to transfer the stable laser frequencies to a distant place via optical fibers [Fujieda et al. 2009, Kumagai et al. 2008 c, 2009].

To measure the laser frequency, NICT has operated two optical frequency combs based on Ti:Sapphire laser with the uncertainty at 10^{-17} level [Nagano et al., 2009] and is developing fiber laser frequency combs. The fiber combs measure their relative frequency stability and estimate the stability as 5×10^{-13} and 1×10^{-15} at averaging time of 1 s and 500 s respectively.

The Allan variance of the ratio between Ca^+ - Sr transition frequencies was measured to be 3×10^{-16} with the measurement time 2000 sec..

Various time and frequency standards related researches have been conducted in NICT and some Universities, such as on atomic and molecular physics. Kajita has proposed an infrared frequency standard based on the vibrational transition frequencies of magnetically trapped XH and XLi molecules, and XH^+ molecular ions (X: even isotopes of group II atoms) [Kajita 2008 a,b, 2009 a-e, 2010a-b].

NMIJ is developing an ^{171}Yb optical lattice clock. They have succeeded in the first absolute frequency measurement of the $^1S_0$ – $^3P_0$ clock transition of ^{171}Yb with an uncertainty of 5.4×10^{-14} [Kohno et al. 2009]. Progress is under way to reduce the uncertainty by increasing the signal to noise ratio of the observed spectrum using the atom number normalization scheme. They have developed a fiber-comb-stabilized light source at 556 nm for magneto-optical trapping of ytterbium, which is necessary for obtaining ultracold ytterbium atoms trapped in an optical lattice [Yasuda et al. 2010]. NMIJ has also started a new project on Yb/Sr dual optical lattice clock project in 2009. They developed a compact light source for 1st stage cooling of Sr using a periodically poled lithium niobate waveguide [Akamatsu, et. al. 2010] and successfully magneto-optically trapped both species in the same chamber. NMIJ has developed advanced optical frequency combs based on erbium-doped fiber laser (fiber comb). Robustness, usability, and servo bandwidth has been improved. For example, NMIJ have established the national standard of length in Japan by using a fiber comb. On the other hand, a fiber comb with mHz-level relative linewidth was realized using an intra-cavity electro-optic modulator [Nakajima et al. 2010]. They utilized the narrow linewidth fiber comb to develop the light source for the clock transition of Yb and the 2nd stage cooling of Sr. In the clock laser system, the highly stabilized fiber 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. The clock laser at 578 nm for the Yb optical lattice clock has been phase locked to one of the comb modes. The authors have demonstrated spectroscopy of the clock transition in Yb atoms with the new clock laser system.

Katori group at University of Tokyo developed lattice clocks using ^{87}Sr and ^{88}Sr [Akatsuka et al. 2008]. Takamoto et al. discussed also the possibility to trap Sr atoms with a blue detuned laser [Takamoto et al. 2009]. Hachisu et al. started to develop an Hg optical lattice clock [Hachisu et al. 2008].

The frequency transfer between Katori group and NMIJ, that made possible to compare the Sr lattice clock and NMIJ-F1 [Hong et. Al. 2009]. In 2010, the direct frequency comparison between Sr lattice clocks in Katori group and NICT was performed.

A3. Realization of Electrical Units (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 Electricity and Magnetism division of National Metrology Institute of Japan (NMIJ), partly in collaboration with several other institutes in Advanced Industrial Science and Technology (AIST).

NMIJ has been developing a pulse-driven (10 mV, rms) and programmable (3 V, rms) Josephson arbitrary waveform synthesizers (JAWS) based on the over-damped Josephson junction arrays (JJAs). NMIJ has adopted pulse-tube-type mechanical cryocoolers and newly developed wide band chip carriers for this project. The cryocoolers have extremely low mechanical noise and the chip carriers are equipped with 20 or 32 coaxial inputs/outputs of which the outer conductor are electrically separated to suppress ground loop noise [Kaneko et al. 2010, Urano et al. 2009a, 2009b, Maruyama et al. 2009, Maruyama et al. 2010].

Devices of quantum Hall array resistance standard (QHARS) with a nominal value close to 10 kΩ on the i = 2 plateau have been developed on a GaAs/AlGaAs hetero-substrate. This QHARS device consists of just 266 Hall bar elements, and its nominal value has only 0.0342 ppm difference based on R_{K-90} from the integer value of 10^4. As a result of comparison measurement with the conventional Quantized Hall Resistance Standard via a 100-Ω standard resistor, the difference between the measured value and nominal value is less than the uncertainty level of 1.0×10^{-8}. We plan to fabricate and evaluate several types of QHARS devices and confirm the reliability of the devices [Oe et al., 2008, 2010a].

Stable standard resistors (1 Ω to 10 kΩ) are now being developed in collaboration with Alpha Electronics. 100-Ω standard resistors of which temperature coefficients are extremely low, less than 0.1 ppm/degree, and resistance values are greatly stable, less than 0.1 ppm/year have been successfully manufactured and in market. Resistors with other nominal values are also under development [Sakamoto, Y et al., 2010].

Capacitance standards from 10 pF to 1000 pF are established at NMIJ based on the Quantized Hall Resistance at dc with an ac/dc calculable resistor and a quadrature bridge [Nakamura et al., 2010]. NMIJ has planned to derive the capacitance values from the AC-QHR in the future. The new quadrature bridge to link capacitance to the AC-QHR is now being developed [Oe et al., 2010b]. Higher values of capacitance with dissipation factor from 0.01 μF to 10 μF are also established at NMIJ using a four-terminal-pair (4TP) impedance bridge with a 10:1 voltage ratio transformer.

NMIJ has 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. Estimations of the uncertainties of 1 mF are now in progress [Sakamoto, N et al., 2010].

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. Practical thin film multi-junction thermal converters (MJTC) have been also developed in collaboration with NIKKOHM Co. Ltd. Our device has the thermoelectric transfer difference of better than 0.2 μV/V and frequency characteristics of the ac-dc transfer differences were considerably improved in the range between 10 Hz and 1 MHz [Sasaki et al., 2010]. NMIJ has developed AC voltmeter calibration system by using a planar MJTC in the frequency range from 40 Hz to 100 kHz and at the voltage of 10 V [Amagai et al., 2010]. NMIJ has planned to extend the frequency range down to 5 Hz and the voltage range down to 1 V. Also, we have been developing a planar MJTC for improving low-frequency characteristics below 100 Hz and the long-term stability. Employing a new thermopile pattern, the stability of the planar MJTC has been improved.

NMIJ has developed a harmonic voltage and current measurement standard. The standard has been confirmed that it has the uncertainty level of 40 ppm – 80 ppm up to 50th harmonics by means of using AC calibrators as AC reference standards. The feasibility of a power measurement capability of the standard has also been confirmed that it has uncertainty level of 20 ppm in the comparison of a power meter between Japan Electric Meters Inspection Corporation (JEMIC) and NMIJ [Yamada et al., 2010].

NMIJ has developed a calibration system for the AC shunt standard of the current range from 1 A to 10 A and the frequency range from 50 Hz to 400 Hz [Kon et al., 2010].

A4. EM field, Power density and antenna Measurement

A dipole antenna is a simple linear antenna, and this result in the accuracy and high-selectivity of the field polarization. Since many electromagnetic compatibility /electromagnetic interference (EMC/EMI) measurements below 1 GHz are implemented on a ground plane, responses of the antenna employed in these measurements should contain the effect of the coupling with image. However, free space antenna factor (AF) is often used for the measurements even above the ground plane, and errors are introduced by few decibels especially at lower frequencies. To overcome this problem and considerable efforts in the measurements, a prediction method of the height-dependent AF and mismatch effects have been proposed [Morioka et al. 2010b]. Measurements in an anechoic chamber become common above 1 GHz. Some EMC test regulations require measurements in this frequency range. Since the measurement environment is quasi-free space, the free space AF of the antenna should be calibrated. The three-antenna method is applied and the calibration capability has been achieved to 0.4 dB (k=2) in the frequency range from 1 to 2 GHz [Morioka 2009a].

Although the field generation in an anechoic chamber has an advantage in the frequency band, that in a transverse electromagnetic (TEM) waveguide is still useful in terms of compactness. In addition to this, generating a strong field in the TEM waveguide requires an amplifier with significant lower gain compared with that in an anechoic chamber. Accordingly, it is reasonable to use a TEM cell at a lower frequency than the higher order mode cutoff frequency of the cell. For the use of a TEM cell as a standard field generator, the electromagnetic fields of the cell should be accurately evaluated. A method to measure electromagnetic fields in a TEM cell by using a passive scatterer has been proposed [Morioka 2009b]. Since the E-field of a TEM cell varies with respect to the location, probe responses to such a non-uniform E-field have been investigated [Morioka 2010a].

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) and a bi-conical antenna (from 30 MHz to 300 MHz) were evaluated for a metrology standard. A new method was proposed for evaluating a free-space antenna factor continuously through a wide frequency band. The method is based on a technique of a time-domain analysis and a pulse-compression technology for reducing the influence by the reflected waves from surrounding obstacles. The method was examined for calculating the free-space antenna factor of a log-periodic antenna and a bi-conical antenna widely used for EMI measurement [Kurokawa et al. 2009, 2010a].

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 about 10 cm and 60 cm in the frequency range from 9 kHz to 30 MHz since 2007. This calibration service was expanded in March in 2008. The target of the loop antenna’s diameter is 133 mm and the frequency range is from 20 Hz to 200 kHz. Basically they calibrate the standard loop antenna by the “3-Antenna Method” and the customer’s loop antennas by the “Reference Antenna Method”. They also studied and proposed another more simple reference calibration method for loop antenna [Ishii et al. 2009a].

The developments of calibration techniques for short monopole antennas were carrying out by AIST. They proposed "3-Antenna Method [Ishii et al. 2009b]" and "Reference Antenna Method [Ishii et al. 2010]" for short monopole antenna. 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. On the other hand, NICT and Aoyama Gakuin University are also developing the magnetic field sensor calibration system.

Calibration services for the gains of standard horn antennas are being performed from 1 GHz to 40 GHz at specified 21 frequency points using transfer method. An antenna gain calibration service for micro-wave standard gain horn antenna (1.7 GHz to 2.6 GHz) has been prepared using a planer near-field antenna measurement method. An antenna factor calibration service for ridged guide broadband horn antenna (1 GHz to 6 GHz) will be started from March 2011.

For expanding the frequency range of antenna gain standard, we have developed a calibration system for V-band (50 GHz to 75 GHz) millimeter-wave horn antenna using the three antenna extrapolation method. In the conventional extrapolation method, the multiple reflections between antennas are removed by the moving average method. To reduce the long measuring time caused by the moving average, the time-domain gating method was employed for removing multiple reflections [Ameya et al. 2010 a].

A novel method was proposed in antenna measurements [Hirose et al. 2010]. The method realizes antenna measurements in full 2-port calibration that requires only open-short-load calibration at each port without through calibration because of using the unknown thru algorithm. The residual systematic errors are completely equivalent to the conventional unknown thru method. No need to do through calibration is especially important in antenna measurements because we are released from the hard labor to mate cable connectors directly or to other cable connectors.

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 improve the EMI anechoic chamber performance above 1 GHz, we have proposed a new anechoic chamber evaluation technique using plane-wave spectrum for finding the reflection points in EMI anechoic room [Ameya et al. 2010 b]. The proposed method enables to obtain the intensity and the angle of arrival of reflection waves and facilitates improving performance of anechoic chambers.

Kurokawa et al. have developed an EMI measurement system using microwave photonic technologies. It has the function of a kind of directional findings for interferences in, for example, an anechoic EM chamber [Kurokawa et al. 2010 b]. The system can be used from 30 MHz to 6 GHz.

Capozzoli et al. have developed planar and spherical scanner systems for near- field antenna measurement using photonic sensors that are a few of grams in weight and a few of millimeters long. The systems are available about below 10 GHz. The authors have launched a collaborative research with Napoli Federico II University in Italy for the phase-less near-field antenna characterization using such photonic sensors as above mentioned [Capozzoli et al. 2009, 2010].

A5. Power, Attenuation and Impedance Measurement

In recent years, NMIJ has started to study and develop a new microwave power standard based on quantum electronics. The new microwave power standard is directly linked with frequency measurement via atomic Rabi frequency. The Rabi frequency of cesium atoms in a glass cell inserted in a WR-90 waveguide was measured. Then, the magnetic field strength of the microwave was estimated from the measured Rabi frequency in 2008 [Kinoshita et al., 2008a, 2008b, 2008c, 2009a, 2009b, 2009c, 2009d]. The magnetic field strength was converted into the microwave power using an analysis of the distribution of the electromagnetic field in the waveguide [Kinoshita et al., 2010a]. It was confirmed that the microwave power measured from the Rabi frequency is consistent with that measured by a calorimetric method within their uncertainties [Kinoshita et al., 2010b, 2010c]. Now, the authors are improving the uncertainty by developing a new glass cell.

In high precision attenuation measurements and standards, the mismatch is often the largest term contributing to the systematic uncertainty. To minimize this uncertainty a RF attenuation measurement technique, where the source and load do not have to be matched to the line impedance, was proposed [Widarta et al, 2008a, 2009a]. The technique based on the cancellation of the multiple reflected signals in the network by performing additional loss measurement steps to the device under test (DUT), which are fitted to quarter-wavelength (QW) lines. The QW lines reverse the directions of the vectors of the reflected signals, and then the effects of the mismatch are approximately canceled. This technique has the ability to measure attenuations of discrete frequencies at which the relative phase shift values of the lines to the frequencies are 90º. Improvement to the system was done, by introducing two low-reflective lines (airlines) where the phase shift values are already-known instead of the QW lines, in order to extend the capability to measure RF attenuation in broad continuous frequencies [Widarta et al, 2010]. A simple IF receiver system dedicated for working standard system of attenuation has been also developed by employing a calibrated resistive step-attenuator assembly at 30 MHz as an IF reference standard and a general-purpose receiver as a sensitive level detector [Widarta, 2008b].

NMIJ participated as a linking laboratory in the APMP comparison of attenuation at 60 MHz and 5 GHz (APMP.EM.RF-K19.CL) [Gao et al, 2010].

Calibration service for RF attenuation in the frequency range of 50 – 75 GHz (V-band) was started to meet the demands for accurate and traceable measurement in the industry. A new primary attenuation standard for the V-band was developed [Iida et. al. 2010]. Based on the IF substitution method, it employs an inductive voltage divider (IVD) working at 10 kHz as a reference standard. A highly stable IF signal is obtained for precision measurement using phase-lock technology on the frequency-converted local signal.

For the noise standard, an original cryogenic standard noise source with WR90 waveguide flange was constructed in the frequency range of 8-12 GHz [Iide et. al. 2008, 2009a]. The noise temperature and uncertainty of the noise source were evaluated by a sliding short method using a total-power radiometer. In order to expand the frequency range of the standard noise source, NMIJ was also developed a cryogenic 7-mm coaxial noise source and its evaluation method [Iida et. al. 2009b]. The noise temperature of the coaxial noise source was calibrated by using an auxiliary transmission line. The contribution of the noise generated from the transmission lines was estimated by the available power ratio of the transmission line and the radiometer measurements in particular conditions.

NMIJ has started the joint research project with National Physical Laboratory, UK. In the collaborative work, it is clear that the dimensional calibration capabilities of coaxial air line, i.e. 3.5 mm line size and 1.85 mm line size, were good agreement between both laboratories [Horibe et al., 2007, 2008c, 2010a]. Then NMIJ and NPL had been developed the verification method of phase measurements in the vector network analyzers (VNA) [Horibe et al., 2009a]. In addition, NMIJ and NPL developed a new concept of VNA calibration standards, i.e. 'Air Open' standards [Horibe, et. al., 2010e]. The NMIJ showed the calibration and measurement capabilities for air line dimensions of 1.0 mm line size [Horibe et al., 2008a, 2009a]. The evaluation infrastructure for the connector interface to estimate electrical characteristics of air line, then NMIJ shows a characteristic depends on the connector dimensions, i.e. male pin and female socket, [Horibe, 2008b]. The calibration services of the complex voltage reflection coefficients, in the frequency range of 9 kHz to 18 GHz, have been started for PC7 connector in 2010 [Horibe et al., 2009e, 2010b]. These calibration cervices are based on use of the originally-designed standard terminations in the range of 9 kHz to 10 MHz, then, the long length air lines as the impedance standards are calibrated using a dimensional measurement and electrical loss measurement [Horibe et al., 2010b]. In 2009, the development of the scattering parameter standard for the rectangular waveguide in the frequency range of 50 GHz to 330 GHz, have been started [Horibe et al., 2010c, 2010d. Subsequently, in 2010, the originally-designed waveguide flanges and calibration standard were developed and evaluated.

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