Laboratory Report

of

National Metrology Institute of Japan (NMIJ/AIST)

and Japan Electric Meters Inspection Corporation (JEMIC)

2013-2015

At NMIJ/AIST, there are two divisions in the electrical standards area. One is the Electricity and Magnetism (EM) Division and the other is the Electromagnetic Waves Division. The former covers low frequency electrical standards and the latter high frequency and electromagnetic field standards.
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 high value impedance and the power standards. The Quantum Electrical Standards Section covers the Josephson voltage, the quantum Hall resistance, and the low value impedance standards.
The Electromagnetic Waves Division has also two sections, the Radio-Frequency Section and the Electromagnetic Fields Section. The Radio-Frequency Section takes charge of RF power, voltage, noise, attenuation and impedance (S-parameter) standards. The Electromagnetic Fields Section covers antenna properties, electric field and magnetic field standards.
One topic this year is that our old helium liquefier, which was also damaged partially, has been replaced, and the new system has started its operation in March 2014.

1. Josephson Voltage

Johnson noise thermometry 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 (Contact: Chiharu Urano, c-urano@aist.go.jp).

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. Recently, the PJVS chip was replaced to new one, which is composed of 524 288 junctions. We have succeeded in synthesizing AC waveforms with an rms amplitude of 10 V using the new chip and an improved bias control circuit. We investigated the uncertainty sources of an AC sampling measurement for a commercial calibrator using the PJVS system, in collaboration with CMS (Taiwan). The uncertainty was estimated to be approximately 1 uV/V for nominal 10 Vrms amplitude. A calibration system for Zener voltage standards using a liquid-helium-free PJVS has been developed. The system has 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). The PJVS system is capable for calibrating not only Zener voltage standards but also the linearity characteristics of digital voltmeters. 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 (Contact: Michitaka Maruyama, m-maruyama@aist.go.jp).

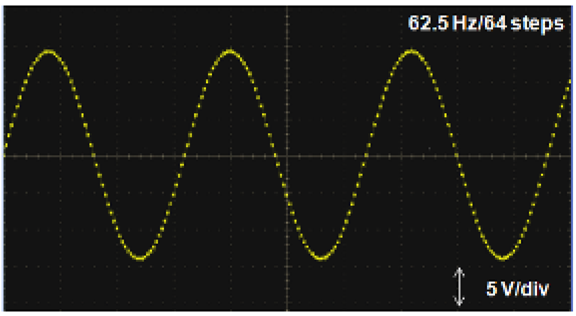



Fig. AC-PJVS system with compact cooler (left) and synthesized AC waveform (right).

2. Resistance

Development of compact and ultra-stable 10 Ω and 100 Ω standard resistors has been finished, and resistors (1 Ω to 10 kΩ) with other decade values are in progress of evaluation and development. Trilateral comparison of four 100 Ω of this kind using

QHR and CCC has been carried out between KRISS (Korea), NIST (USA) and NMIJ (Japan). Two of the resistors have been transported in hand-carried luggage and the other two by normal air freight. Resistance values as well as other characteristics have been carefully evaluated before and after the transportation to the national metrology institutes. No noticeable difference between the two transportation methods has been detected within a standard uncertainty of 0.01 μΩ/Ω. Other characteristics, the drift rate: about 0.05 (μΩ/Ω)/year or less, temperature coefficient: about 0.02 (μΩ/Ω)/◦C or less, and power coefficient: negligible, have also been reported. It is demonstrated that this excellent performance is suitable for utilization in national metrology institutes and international comparisons.

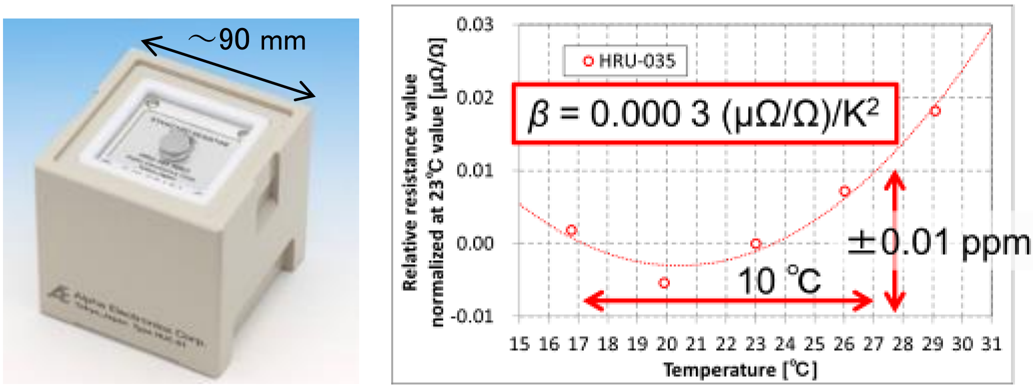


Fig. Picture and temperature-resistance curve of developed 100-Ω standard resistor.

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.

(IEEE Transactions on Instrumentation and Measurement, Vol. 62, No.6 (2013) 1755)

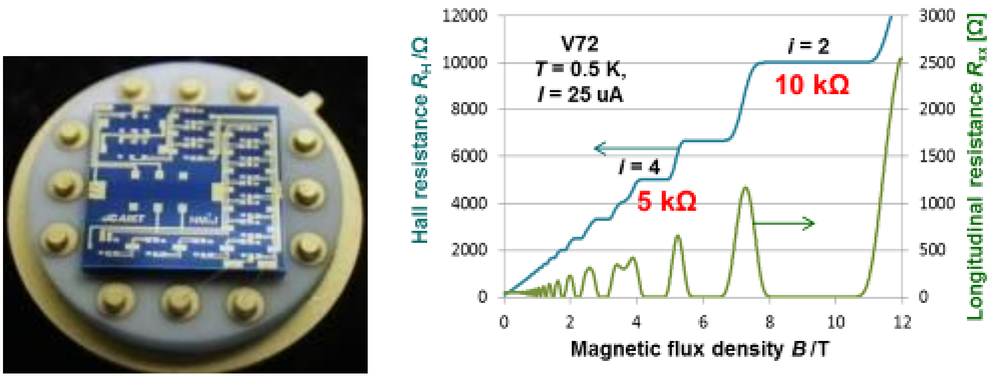


Fig. Picture and Hall and longitudinal resistance curve of 10-kΩ array device.

Test devices of ac-QHR with on-chip double-shielding have been fabricated at NMIJ and their ac-characteristic was evaluated at PTB.
(IEEE Transactions on Instrumentation and Measurement, Vol. 62, No.6 (2013) 1743)
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 R_{H} 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}.
(Measurement Science and Technology Vol. 23, No.12, 2012)
One researcher of NMIJ has 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 photo-chemical gating. And QHE plateau was observed in graphene which made at the NIST Boulder with CVD technique and fabricated at Gaithersburg. (Contact: Nobu-hisa Kaneko, nobuhisa.kaneko@aist.go.jp and Yasuhiro Fukuyama, y.fukuyama@aist.go.jp).

3. DC Current (single electron pumping)

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 16pA (100 MHz) with the standard deviation of 1part in 10^4. Also to achieve metrological requirements, the influence of environments such as temperature, magnetic fields are studied (Physica C, 504, 93 (2014)). We also arrange the eleven SINIS turnstiles in parallel and succeeded to increase pumping current .
We also study different type of device, such as a tunable barrier pumping device and small Josephson junction device.
(Contact: Shuji Nakamura, shuji.nakamura@aist.go.jp)

4. LF-Impedance

By using the fabrication technology of highly stable 100-Ω metal-foil resistor component, developed in collaboration between the Alpha Electronics Corp., JEMIC and NMIJ, two types of 1-kΩ standard resistors with a four-terminal-pair design which enables ac measurements have been fabricated. Key characteristics: drift rate, first-order temperature coefficient at 23 °C, frequency dependence of the resistance in the frequency range from 400 Hz to 2 kHz, and time constant have been evaluated.

(Accepted to *IEEE Transactions on Instrumentation and Measurement*, Article DOI: 10.1109/TIM.2015.2398955).

(Contact: Atsushi Domae, domae-atsushi@aist.go.jp).

Fig. 1. Photograph of the developed 1-kΩ metal-foil resistor

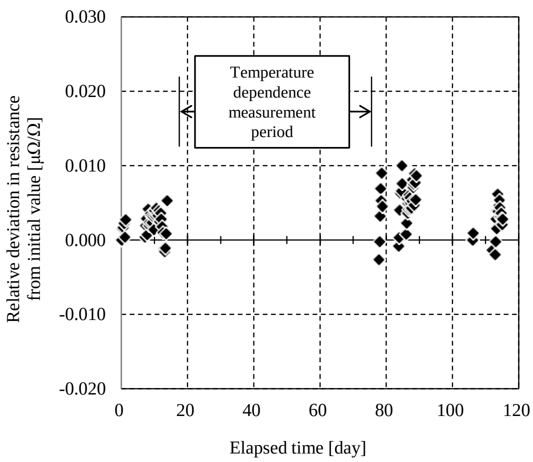


Fig. 2. DC resistance monitoring results of the metal-foil resistors of 1 kΩ over 115 days. DC resistance monitoring results of the s/n: 1 resistor.

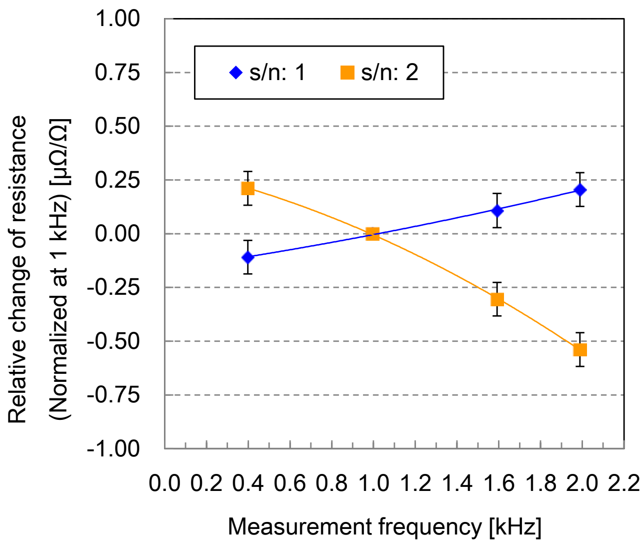


Fig. 3. Frequency dependence of the resistance (nominal value of 1 kΩ), plotted as the relative change in the resistance normalized to the value at 1 kHz. The solid line represents quadratic approximation curve.

NMIJ has started a development of precision measuring techniques for diagnosis of the energy storage devices such as lithium-ion batteries and super-capacitors by using an impedance spectroscopy method. We have a plan to establish a metrology for evaluating the storage power devices. Preliminary impedance measurements for lithium-ion battery cells in the range of 10 mHz – 10 kHz demonstrated that the impedance value for unused cells is clearly distinguished from that for used-up cells. Impedance spectra for the unused cells which are obtained under 100 mΩ indicate that the evaluations of the uncertainties should be required for detecting a faint sign or a symptom of degradations of storage devices. We have developed an electrochemical impedance measurement system and have evaluated the type-A uncertainty for the impedance spectra which was estimated to be less than 0.2 mΩ.

(Contact: Norihiko Sakamoto, n-sakamoto@aist.go.jp).

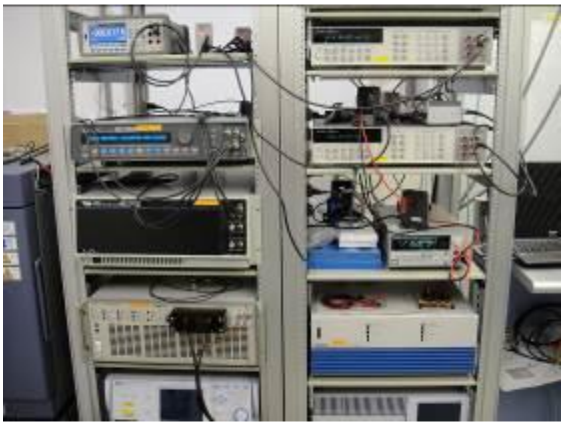


Fig. 1 Photograph of the electrochemical impedance measurement system developed using the Frequency Response Analyzer and the Potentio-Galvano Stat.

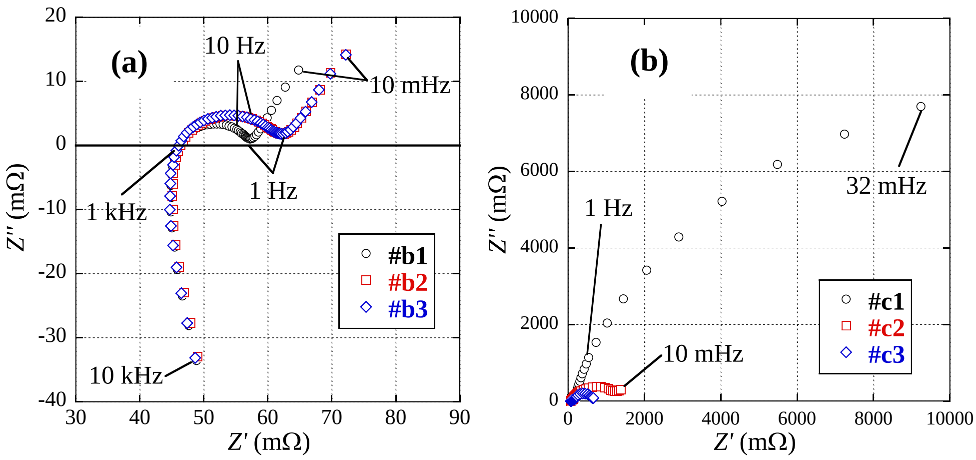


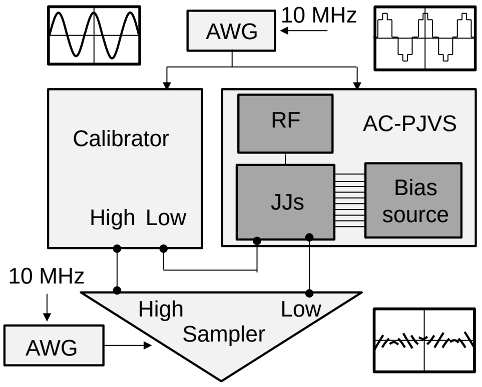
Fig. 2 Nyquist plot of the impedance spectra for the 18650-type lithium-ion batteries: (a) the unused samples and (b) used-up samples. Obvious change in impedance spectra was observed with the progression of the charge/discharge cycle.

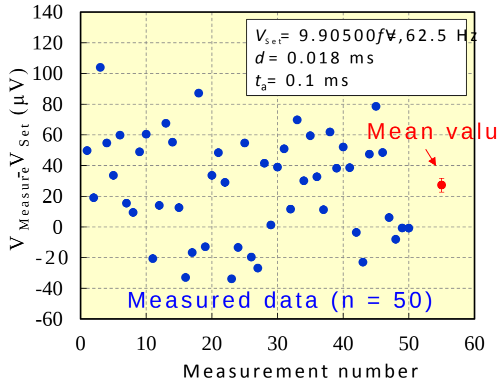
5. AC/DC transfer

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. We have been participating in APMP Comparison for " APMP.EM-K12" of AC/DC current transfer difference.

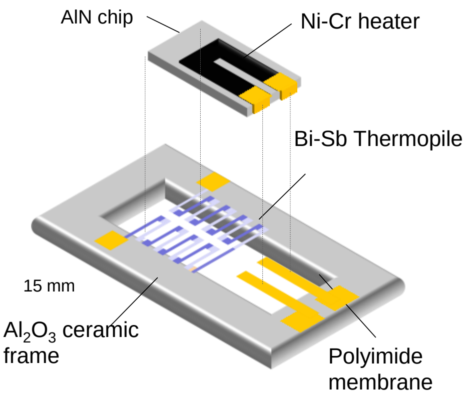
Practical thin film multi-junction thermal converters (MJTC) have been developed at NMIJ/AIST in collaboration with NIKKOHM Co. Ltd. We have introduced a new thermopile pattern to improve the performance of our thin film MJTC. (Contact: Hiroyuki Fujiki, h-fujiki@aist.go.jp).

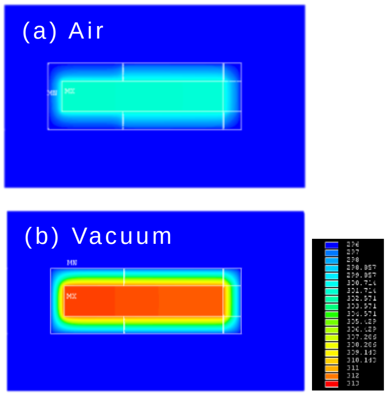
Toward a low-frequency AC voltage standard down to 10 Hz, a differential sampling measurement system using an AC-programmable Josephson voltage standard (AC-PJVS) system has been developed. A relative Type B uncertainty of 1 part in 10^6 was achieved with the technique when measuring a 10 Vrms sine wave generated by a commercial AC source at 62.5 Hz.



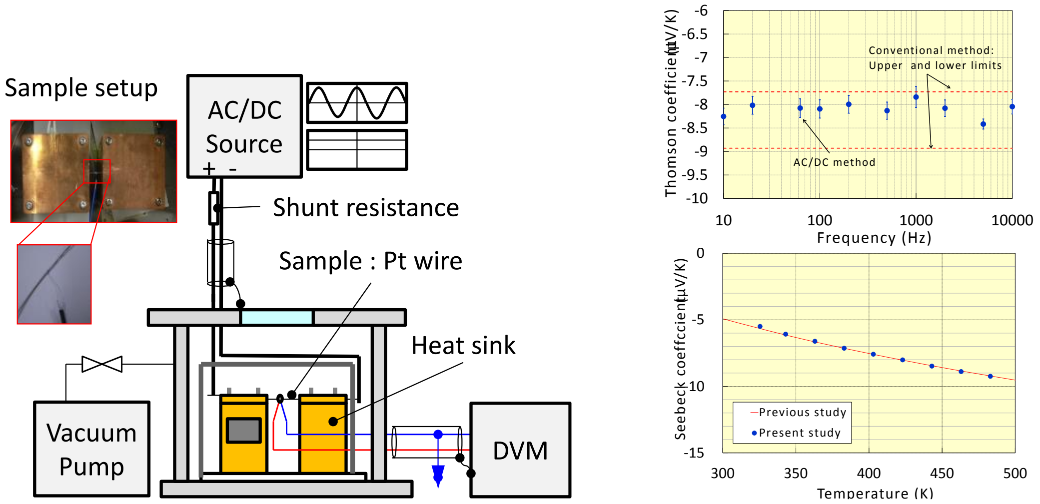


Also, a thin-film multijunction thermal converter with low-frequency application have been developed in collaboration with NIKKOHM Co. Ltd. We have succeeded in improving low-frequency properties of AC–DC transfer differences and enhancing the sensitivity by operating in vacuum chamber. With regard to a regular calibration service, we have started 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 10 V, and we have newly extended the voltage down to 1 V.





We have launched a new project toward high-temperature Seebeck coefficient metrology that is the most fundamental physical property in the research field of thermoelectric energy conversion. Absolute Seebeck coefficient can be determined from measured Thomson coefficient. So far we have succeeded in proof-of-principle experiments of Thomson coefficient measurements using AC-DC transfer measurement technique.



(Contact: Yasutaka Amagai, y-amagai@aist.go.jp).

6. Power (NMIJ)

6.1. Power at NMIJ (harmonics, etc)

NMIJ developed a nonsinusoidal power measurement standard for calibrating power sources designed to calibrate power analyzers, for voltage up to 100 V and current up to 5 amperes and frequencies up to 3125 Hz (corresponding to 50 harmonics of the fundamental of 62.5 Hz). This system will be improved for voltage up to 230 V because of power analyzer calibration needs. To realize this, introduction of a resistive voltage divider will be considered instead of inductive voltage divider.We developed an ac shunt calibration system using a current-bridge method at 5 amperes and 50 – 60 Hz. The system has been expanding up to 1 kHz at this moment. Also, a comparison of the calibration results obtained using the current-bridge method with the results using DC-resistance and AC–DC-difference methods was performed to verify the system. These comparison results showed that the current-bridge-based system performs well with small measurement uncertainties for both the AC resistance and phase angle of the AC shunts up to 1 kHz. NMIJ has some plans for expanding up to 100 amperes and 10 kHz by 2015 according to requests from the industries who 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. Development of the ac current ratio standard up to 10 kHz and 100 amperes is in progress.

An electronic current transformer (ECT) calibration system meeting with 80 and 256 samples per period, using the NMIJ standards of shunt and current transformer, has been developedin accordance with IEC 61850 and IEC 60044-8 for automated substations (Contact: Tatsuji Yamada, yamada.79@aist.go.jp).

6.2. Power at JEMIC (mains)

The primary standard of AC power measures voltage U, current I and phase θ, and then the active power is calculated by $UI\cos\theta$. In the same way, the reactive power can be determined by using sine instead of cosine. Until the last peer-review conducted in March 2014, the primary standard produced only active power/energy, while the reactive power/energy was derived from the secondary active power standard and the quadrature phase. After the review, we have started direct calibration services of the active/reactive power and energy with the smaller uncertainties.

JEMIC has been participating in APMP Key Comparison for "APMP.EM-K5.1" of AC power and energy. (Contact: Jun KAWAGOE, kawagoe@jemic.go.jp)

7. RF-power

The development of a WR-06 waveguide calorimeter completed (a collaborative research with National Institute of Information and Communication Technology of Japan.), and its calibration service started from 2014.

The evaluation of a WR-15 calorimeter finished. A calibration service of 2.4 mm coaxial power meter at 50 GHz, 1 mW using the WR-10 calorimeter started. WR-10 calorimeter is under evaluation.

A collaborative research work for an RF power standard under the frequency of 10 MHz was performed with NMIT (Thailand) from March to June 2014. NMIJ and NMIT have been preparing for a new collaborative project of an RF power standard at NMIT.

(Contact: Kazuhiro Shimaoka, kazuhiro-shimaoka@aist.go.jp, Moto Kinoshita, moto-kinoshita@aist.go.jp)

8. RF-Attenuation

NMIJ has successfully established a RF attenuation standard system in the frequency range of 33 GHz to 50 GHz (Q-band), and started the calibration service from April 2014. The system is built by using the simple intermediate frequency (IF) receiver technique using a resistive step attenuators operated at 30 MHz, as an IF attenuation reference standard and a general-purpose receiver, as a level detector. By increasing the IF to 30 MHz, the noise effects caused by higher RF signals, such as the Q-band, can be kept small. This condition also allows us to use a general-purpose receiver as a sensitive level detector that facilitates the automation and long-term maintenance to the system. Traceability of the system then is ensured by performing periodic calibration to the IF attenuator reference standard at 30 MHz using the NMIJ attenuation standard system based on the voltage ratio of the IVD at 1 kHz.

NMIJ took the initiative to organize a CIPM Key Comparison of attenuation at 18 GHz, 26.5 GHz and 40 GHz using a step attenuator. This comparison has been registered in the KCDB under the identifier CCEM.RF-K26. First measurement by NMIJ as a pilot laboratory has been completed, and the traveling standard now began to be circulated to the participants. 18 laboratories (countries) declared to participate.

NMIJ also provided a reference value; attenuation of 10 dB to 100 dB in the frequency range of 10 MHz to 18 GHz, for the recent proficiency testing of the accredited laboratory under the Japan Calibration Service System (JCSS).

(Contact: Anton Widarta, anton-widarta@aist.go.jp)

The calibration service for a waveguide variable attenuator in W-band (75 GHz to 110 GHz) has been started. We have developed an attenuation measurement system in W-band based on the IF substitution method using a two-stage inductive voltage divider as a reference standard. This service was conducted in cooperation with National Institute of Information and Communication Technology of Japan.

(Contact: Hitoshi Iida, h-iida@aist.go.jp)

9. RF-Impedance

NMIJ has developed RF impedance standard in the frequency range from 9 kHz to 170 GHz in the coaxial lines and rectangular waveguides. The primary standard is an original load device. The characteristics of this device are calculated from dimension and insertion loss for evaluation. NMIJ started an S-parameter calibration service for PC3.5 in the frequency range from 9 kHz to 33 GHz. NMIJ is developing S-parameter calibration system from 10 MHz to 40 GHz in 2.92 mm coaxial line and from 50 GHz to 110 GHz in V- and W-band waveguides. To verify millimeter S-parameter measurement technique, the verification devices and verification method for WR-3(WM-864) waveguide has been developed.

NMIJ has also proposed the calibration and testing method for Artificial-Main-Network / Line Impedance Stabilization Network (AMN/LISN) used in electromagnetic compatibility (EMC) testing.

Furthermore, NMIJ as a pilot laboratory is managing the CCEM key comparison (CCEM.RF-K5c.CL: S-parameter for PC3.5 in the range from 50 MHz to 33 GHz), the APMP supplemental comparison (APMP.EM.RF-S5.CL: Dimensionally-derived characteristic impedance for PC7, PC2.4 and PC1.85) and will start the bilateral comparison between NMIJ, Japan and MSL, New Zealand (APMP.EM.RF-S6.CL: S-parameter for Type-N, 50 ohms, in the range from 50 GHz to 18 GHz).

(Contact: Masahiro Horibe, masahiro-horibe@aist.go.jp, Ryoko. Kishikawa, ryoko-kishikawa@aist.go.jp)

10. Antennas, electric field, and magnetic field

A calibration service for the free-space antenna factor on loop antenna has been kept in the frequency range of 20 Hz to 30 MHz. The measurements of APMP supplementary comparison CCEM.RF-S21.F (KRISS, NMIA and NMIJ) was finished at November 2013. The report of Draft A is written in NMIJ. AC Magnetic field sensor calibration service has been expanded from 1 uT up to 150 uT at 50 Hz and 60 Hz.

(Contact: Masanori Ishii, masanori-ishii@aist.go.jp)

The calibration of the dipole antenna factor above a ground plane from 30 MHz to 1 GHz with the specific conditions (horizontal polarization and 2.0 m from the ground surface) is available. The free space dipole antenna factor in an anechoic chamber from 1 GHz to 2 GHz is also available.

(Contact: Takehiro Morioka, t-morioka@aist.go.jp)

The free space antenna factor calibration service for broadband antenna for Biconical antenna (30 MHz to 300 MHz) and Log periodic dipole array antenna (300 MHz to 1000 MHz) has been started using our original three antenna calibration method. The free space antenna factor calibration service for super broadband antenna (30 MHz to 1000 MHz) will be started soon.
(Contact: Satoru Kurokawa, satoru-kurokawa@aist.go.jp, Masanobu Hirose, masa-hirose@aist.go.jp)

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 gain calibration service for ridged guide broadband horn antenna (1 GHz to 6 GHz) is available.
(Contact: Masanobu Hirose, masa-hirose@aist.go.jp)

The peer-review of calibration service for standard gain horn antenna for V-band (50 GHz to 75 GHz) and W-band (75 GHz to 110 GHz) has been conducted in October 2014.
The calibration system of monostatic Radar Cross Section (RCS) for a trihedral corner reflector in W-band has been developed. The RCS calibration range is 3 dBsm to 12 dBsm at 75 GHz and 6 dBsm to 15 dBsm at 110 GHz. This RCS range corresponds to the reflector size L ranging from 75 mm to 125 mm. The expanded uncertainty of RCS was estimated to between 0.90 dB and 1.32 dB. This RCS calibration service will be started from April 2015.
(Contact: Michitaka Ameya, m.ameya@aist.go.jp)

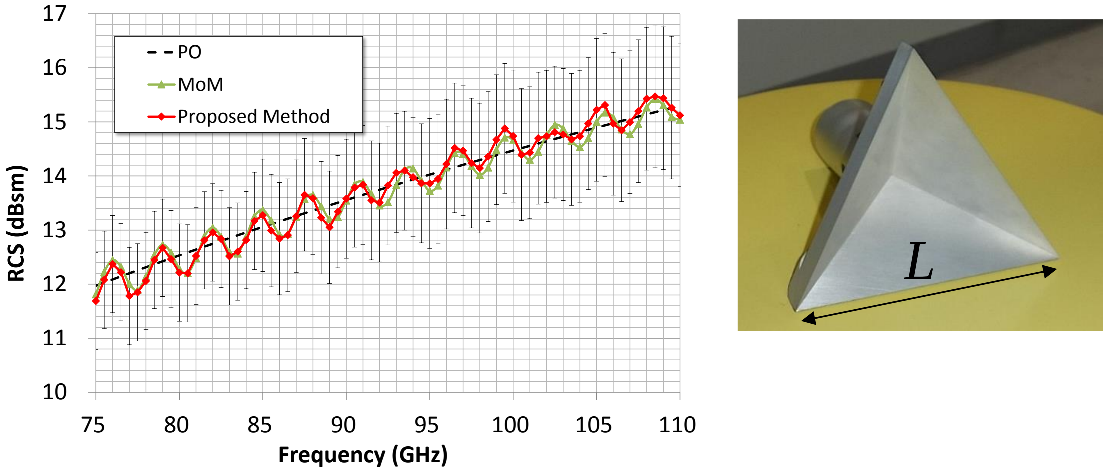


Fig. RCS calibration results in W-band and an example of a trihedral corner reflector

The E-field transfer probe calibration from 20 MHz to 2 GHz in a G-TEM cell is available. The correction factor of a probe under calibration is provided when the probe output is 10 V/m. A TEM cell is employed as the standard E-field generator at low frequencies and the free space dipole antenna factor is used for the standard field generation in the anechoic chamber above 900 MHz. An optical E-field probe is employed to transfer the standard E-field strength into the G-TEM cell.
(Contact: Takehiro Morioka, t-morioka@aist.go.jp)

11. Application of optical technology

We 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. Using another type of photonic sensor, we have developed a photonic balun transformer for receiving the signal from balanced type of antennas about below 2 GHz. We continue 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.
(Contact: Masanobu Hirose, masa-hirose@aist.go.jp, Satoru Kurokawa, satoru-kurokawa@aist.go.jp, Michitaka Ameya, m.ameya@aist.go.jp)

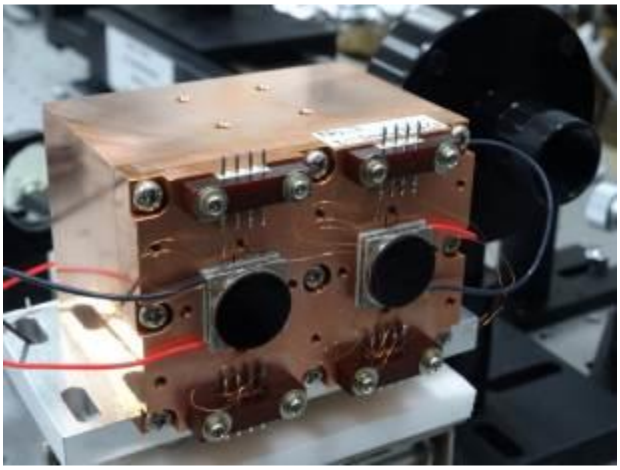
We have developed an extended port usable attached to a RF network analyzer by microwave photonic technologies. It has a function of optical signal transmission and two-way conversion of E-O and O-E. Because the extend port is available being directly connected to antenna terminals and fed by only optical fibers without any batteries, it

does not affect the antenna characteristics and will become an ideal tool for antenna measurements.
(Contact: Masanobu Hirose, masa-hirose@aist.go.jp, Satoru Kurokawa, satoru-kurokawa@aist.go.jp)

We 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. The system can be used from 30 MHz to 18 GHz.
(Contact: Satoru Kurokawa, satoru-kurokawa@aist.go.jp, Michitaka Ameya, m.ameya@aist.go.jp)

12. Terahertz Metrology

NMIJ has been studying for measuring absolute power of a terahertz beam in free space. A terahertz calorimeter was experimentally demonstrated at room temperature. We have succeeded in calorimetric measurement of the absolute power at 1 THz at sub-microwatt level.
(Contact: Hitoshi Iida, h-iida@aist.go.jp)



13. Material characterization

NMIJ is now researching and developing material characterization, i.e. dielectric permittivity measurements, at the microwave frequency. NMIJ has originally developed dielectric permittivity analysis with uncertainty optimization in the transmission/reflection measurement method for coaxial and waveguide lines. In the millimeter-wave frequency range, two types of free space measurement systems have been designed and installed. They are now being optimized and estimated the measurement uncertainty from 50 GHz to 330 GHz.

Furthermore, NMIJ as a pilot laboratory, switched from NIST, will start the Pilot study for dielectric permittivity measurement proposed by NIST as a former pilot laboratory in it. NMIJ is now considering and selecting the transfer material standards in the comparison.

(Contact: Masahiro Horibe, masahiro-horibe@aist.go.jp, Yuto Kato, y-katou@aist.go.jp)