Activities on DC&LF&RF at NIM in recent two years

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DC&LF

The progress of the NIM-2 joule balance

Since 2023, the following improvements have been performed for the NIM-2 joule balance.

- The improvement of the alignment
- The construction of the vacuum mass transfer apparatus
- The new programmable current source

An automatic alignment system by measuring the parasitic displacements and then minimizing the initial position and posture offsets has been built as shown in Fig.1.1 With this automatic alignment technique, the adjustment for minimizing the parasitic displacements or the forces can be performed in several minutes. Fig.1.2 show the performance of the alignment system. When the automatic adjustment is turned on, it can be finished in several minutes, which is suitable for the integration measurements in joule balance.

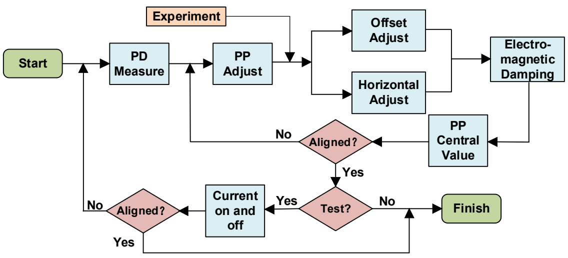

Fig. 1.1 The automatic alignment system

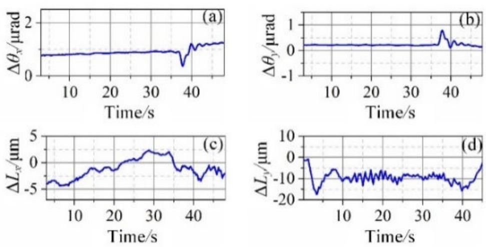

Fig. 1.2 The alignment process

At present, the mass was calibrated in the vacuum chamber of NIM-2 and transferred to other laboratory in air. But in some cases, there is a requirement that the mass is calibrated in vacuum and transferred in vacuum. It can avoid the effect from absorption and dust in air, etc. A vacuum to vacuum mass transfer apparatus has been designed and in construction as shown in Fig.1.3. With this apparatus, the mass can be taken out of the NIM-2 or put the mass into the NIM-2 in the vacuum status. The transfer apparatus includes a small chamber, and two parts. One is called inner part used in the chamber of NIM-2, the other is called outer part and used in the small chamber as shown in Fig.1.4. The inner part pick up the mass from the mass pan of NIM-2 and deliver it to the outer part. Then the outer part put the mass in a small vacuum container. There is a valve between the vacuum chamber of NIM-2 and the small vacuum chamber of transfer apparatus. Before taking the mass from the NIM-2. The valve is closed and the outer chamber will be pumped to vacuum. Then the valve is open and the transfer can be started.

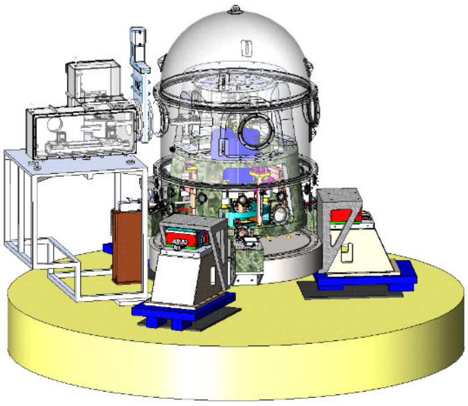

Fig. 1.3 The mass transfer apparatus

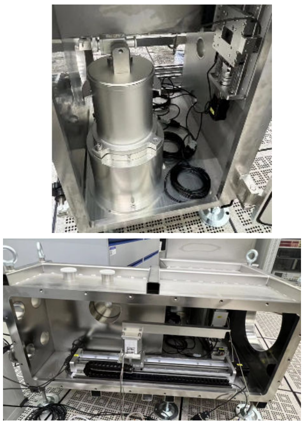

Fig. 1.4 The mass transfer apparatus in construction

A programmable current source with higher resolution is under developing. A structure of current summation rather than voltage summation is used to to get high dynamic range. Two 20-bits DACs are used to output the reference voltage for the current source. One is use for the main voltage reference and the other is attenuated 1000 times to be the fine adjustment of the voltage reference. A Micro-controller Unit (MCU) controls two DACs. Opto-couplers are used to isolate the between digital circuit and analog circuit and avoid the crosstalk.

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Quantum Device – 3 V PJVS device based on non-logic scheme

We demonstrate a new kind of programmable logic for the representation of an integer using for the programmable Josephson arrays. It is different from normal binary logic or ternary logic. It can enable the number of junctions in each bit to be a variable integer value. So missing junctions due to superconducting short circuits can be tolerated under this logic. We also find that this logic can have nearly the same segmentation efficiency with the ternary logic. And the completeness of this logic is proved using the recursive method in mathematics. While the first and second bits are not tolerant to missing junctions, bits beyond these can tolerate one to hundreds of missing junctions. We name this logic with non-integer multiples sequence logic (NIMS). Finally a 3 V programmable Josephson junction array device using this logic for PJVS application is realized.

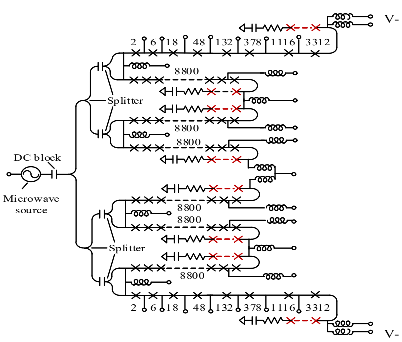

Fig. 2.1 Design of NIM PJVS.

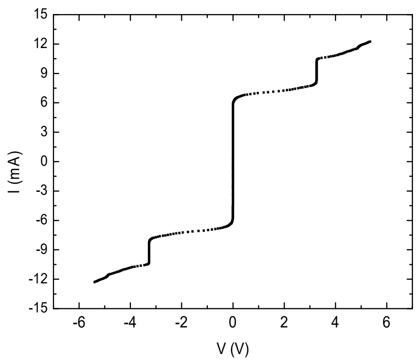

Fig. 2.2 3V NIMS PJVS

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Programmable Josephson Voltage Standard

A portable Programmable Josephson Voltage Standard (PJVS) system operating on a commercially available Gifford–McMahon (G-M) cryocooler has been designed and developed at NIM. Several approaches are researched to greatly reduce the magnetic fields and electromagnetic noise in the vicinity of the Josephson junction array (JJA) chip. Especially, an enclosure of very low magnetic field region was created for the JJA chip by fabricating two concentrically spaced magnetic shields from high permeability permalloys. The multiplying effect of successive shields provides substantially greater attenuation of magnetic fields and prevents saturation of the shield as compared to the former single magnetic shield. The NIST fabricated 10 volt Josephson array chip was mounted and tested in the domestic cryostat. The minimum quantum voltage step of 23 sub-arrays is 1.12 mA. The thermal behavior of the domestic 2 volt Josephson junction array has also been evaluated and researched base on this PJVS system.

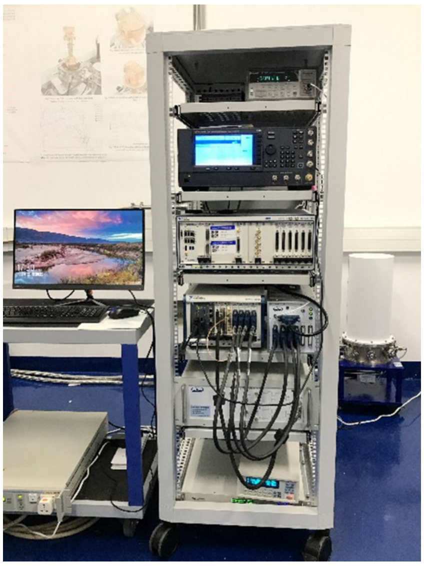

Fig.3.1 the Cryocooled PJVS system

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Based on the differential frequency Josephson array, the NIM group, working on Josephson voltage standard, has establish a special type of DC voltage standard with the quantum voltage output from 100 nV to 10 V, which extend the minimum quantum voltages at the level of dozens of microvolt (μV). Therefore it is capable of fulfilling the requirement of the low level DC measurement. Using the improved low-voltage Josephson standard, shown as in the Fig. 2.3, we have developed some services in Electricity and Magnetism, mainly on low value for DC voltage sources and very low values for DC voltage meters. According with that, three new entries of service item were applied for recognized Calibration and Measurement Capabilities (CMCs). And all of them have passed the peer review on site at NIM in Sep. 2023, preparing for approval to be included in the BIPM key comparison database.

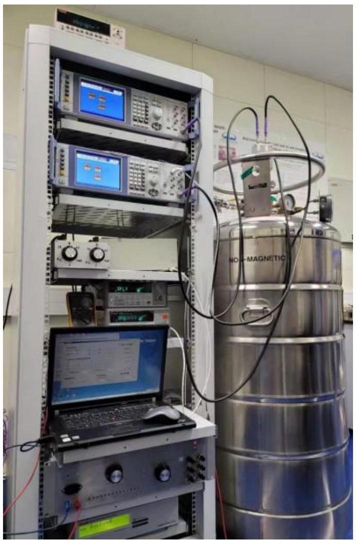

Fig. 3.2 The improved low-voltage Josephson standard developed at NIM based on the differential frequency Josephson array

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Josephson Arbitrary Waveform Synthesizer

In 2024, we conducted an indirect comparison of quantum voltages produced by Josephson arbitrary waveform synthesizers (JAWSs) using switching circuits and digital-to-analog converters (ADCs). Two chips manufactured by the National Institute of Standards and Technology (NIST) are placed in the first cryostat. A chip containing 8000 Josephson junctions manufactured by the NIM is placed in the second cryostat. The 3D design of the cryostat is shown in Fig. 4.1(a). The digitizer sampling waveform produced by quantum voltage sources, as shown in Fig. 4.1(b). The discrete Fourier transform and amplitude ratio are calculated. Results show that the deviation between two quantum voltages is less than 7e-8 within 1kHz. A comparison between the JAWS and a programmable Josephson voltage standard (PJVS) is also being conducted. We plan to join the international comparison of AC voltages in recent years.

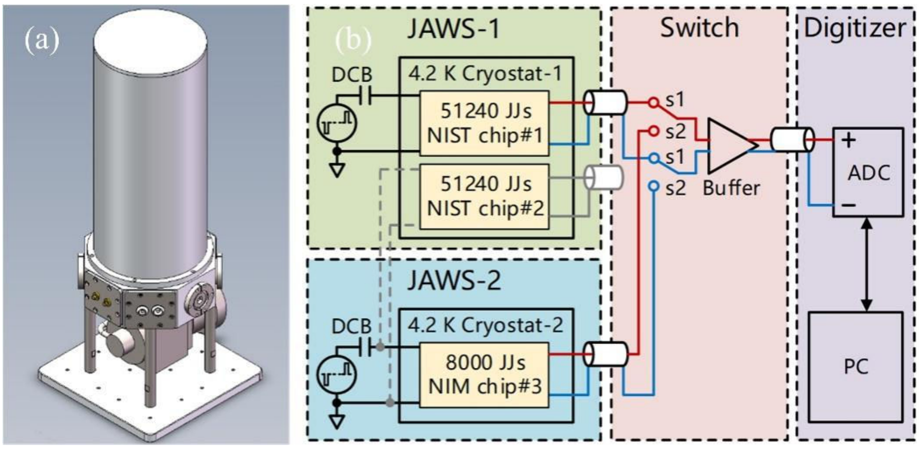

Fig. 4.1 (a) design of the cryostat (b) structure for JAWS comparison.

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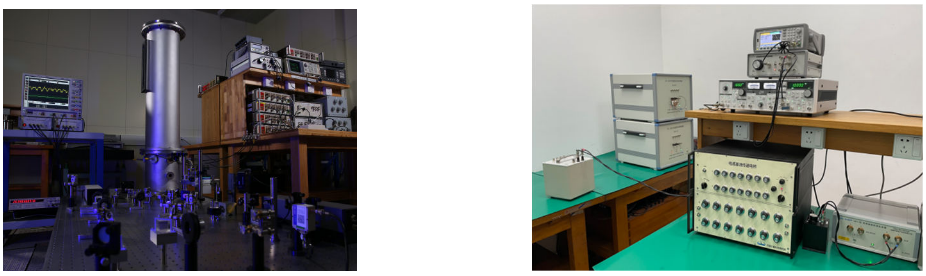
The establishment of new impedance traceability system at NIM

The new vertical calculable cross-capacitor (VCCC) with the unique electrical compensation approach shown in Fig. 5.1(a), which can reproduce the capacitance unit with the standard uncertainty of 0.01 μF/F, has passed the examination of NIM's superior department of the State Administration for Market Regulation, China and been authorized to become the new national capacitance standard since March 2023. In the same time, the new national inductance standard traced to the capacitance and ac resistance standards by one improved Maxwell-Wayne bridge shown in Fig. 5.1(b), which can reproduce the inductance unit with the standard uncertainty of 2 μH/H has also been authorized. The new impedance traceability system traced to new VCCC has been established at NIM.



(a) The new national capacitance standard (b) The new national inductance standard

Fig. 5.1 The new national capacitance and inductance standards established at NIM

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Development of two new 10 mH active simulated inductors for key comparison

The key comparison CCEM-K3, inductance at 10 mH and 1 kHz is joint piloted by a supporting group comprising PTB, NIM and NMIA. The comparison is now hold by the issue of transportation method of the traditional artefacts which provided by PTB for the traditional inductance standards have thermal statistic hysteresis. The main issue whether or not the traditional artefacts should be shipped under temperature control is still under investigating.

NIM proposed a supplementary option for the CCEM-K3 artefacts: a new type active simulated inductor aimed to achieve high stability of inductor endurable for transportation shown in Fig. 6.1. The standard inductance cells are thermostabilized at 30 ℃. And their inductance values are proved to be stable from the changing of the environment temperature from 20 ℃ to 25 ℃. There is no thermal statistic hysteresis found through power off and short-distance transport test verification. The initial investigating results carried out by NIM show very good stability of the new active simulated inductors. The results are shown in Fig. 6.2.

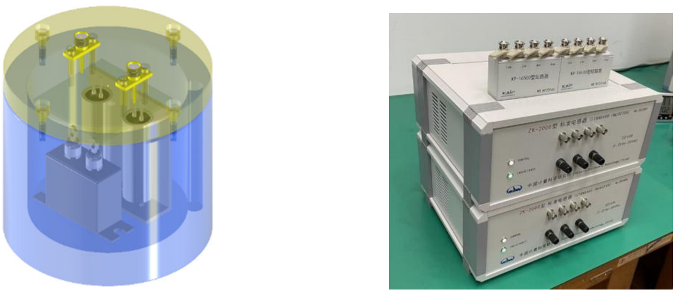

Fig. 6.1 The new type active simulated inductance standards proposed by NIM

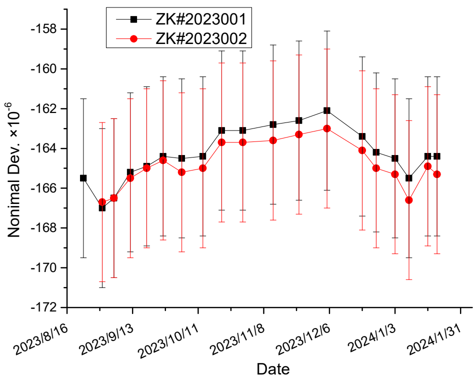

Fig. 6.2 The investigation of two new simulated inductance standards stability

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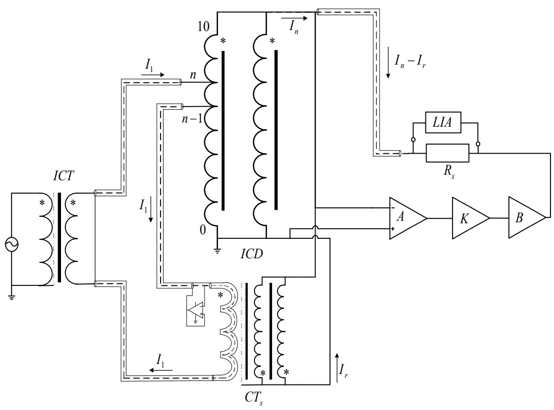
Development and self-calibration of the inductive current divider

A set of two-stage inductive current divider with (ICD) ratio of 10:1 has been developed to cover the current ranges up to 10 A and frequencies ranges from 50 Hz to 1 kHz. A method of self-calibration of the ratio and phase angle errors of the ICD have also been proposed. This method is based on the use of reference current increment calibration principle. The self-calibration principle is shown in Fig. 7.1 and the picture of the measurement setup is shown in Fig. 7.2. The ratio errors and phase angle errors of this two-stage inductive current divider is measured at the frequencies with ranges from 50 Hz to 1 kHz. The experimental results show that ratio and phase angel errors of each section of the ICD are less than 5×10^{-7}. The uncertainty of the ratio errors ICD is less than 5×10^{-8} A/A and the uncertainty of the phase angle errors is less than 1×10^{-7} rad at 50 Hz. The measurement uncertainty of ratio errors of the ICD is less than 1×10^{-7} A/A, and the measurement uncertainty of phase angle errors is less than 2×10^{-7} rad at 1 kHz.



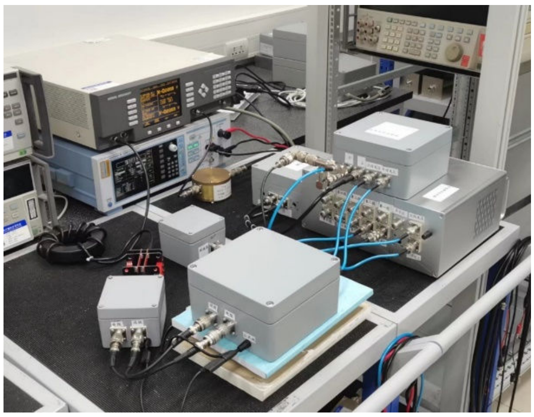


Fig. 7.1 Self-calibration principle of the ICD

Fig. 7.2 Picture of this measurement setup

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Bilateral Comparison of Voltage Dependence of High-Voltage Standard Capacitors

NIM and NMIA carried out a comparison program, which included low-voltage capacitance, the voltage dependence of high-voltage capacitance and the dielectric dissipation factor (DDF) at 50 Hz. The travelling standards included a low-voltage standard capacitor, a dissipation factor standard and a 100 kV compressed-gas capacitor. The capacitance and DDF of the standard capacitor, measured by the two institutes, agreed within 2 μF/F and 2×10^{-6}, respectively, at 50 Hz and 500 V. DDF measurements at nominal values of 0.00000, 0.0001 and 0.001 agreed within 6×10^{-6} at 50 Hz and 10 kV. The capacitance change of a 100 kV compressed-gas capacitor measured by the two institutes agreed within 2 μF/F over the voltage range from 10 kV to 100 kV.

The success of the program proved comparisons using a re-filled high-voltage compressed gas capacitor and a low-voltage standard capacitor can be conveniently used to validate the complete traceability chain of the measurement of high-voltage capacitance at 50 Hz. The program also proved that DDF measurements with different implementations of traceability chain via capacitance and resistance would agree well within the uncertainties required by industrial measurements and a commercial DDF standard that has undergone international air travel would be sufficiently stable.

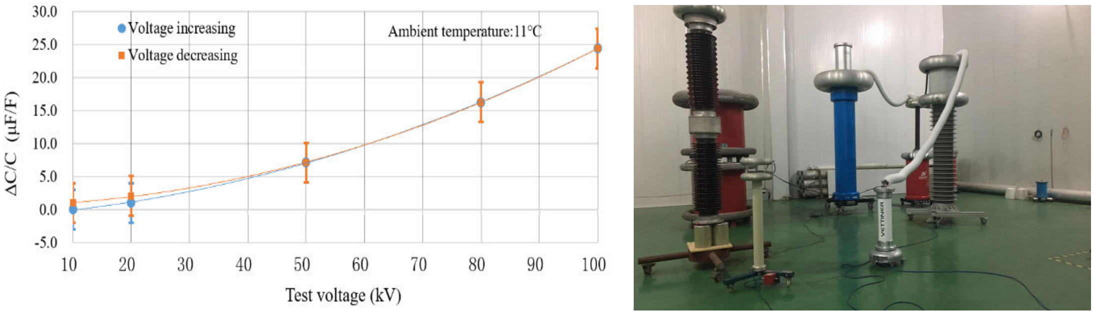

Fig. 8.1 Relative capacitance change of HV capacitor (CG100) measured by NIM

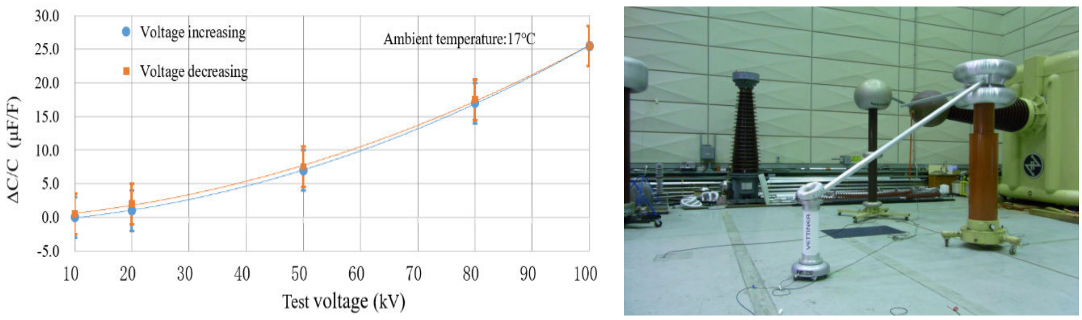

Fig. 8.2 Relative capacitance change of HV capacitor (CG100) measured by NMIA

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1200 kV Lightning Impulse Voltage Measuring System

A 1200kV lightning impulse voltage measuring system using the resistive divider was developed and attended the measurement campaign in the Netherlands last year. The comparison results are published in ISH 2023 conference this year. 9 labs provided their LI measuring standards covering 400 kV to 3600 kV, and A three-week measurement campaign was carried out at the high voltage laboratory at TU Delft in October 2022 to compare the linear extension with uncertainties. The test voltage non-linearity of NIM measuring system (R1200A) is found to be less than 0.5%, which provides proof for the determination of measurement uncertainties.

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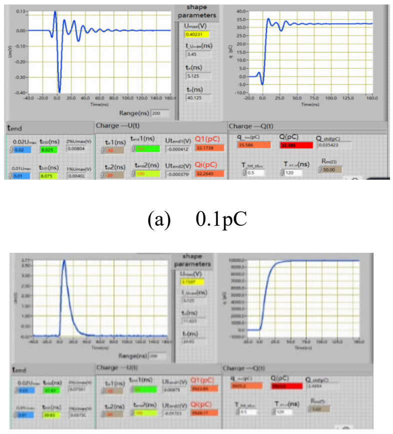
EURAMET_EM_S36: Comparison of partial discharge (PD) calibrators

The comparison of partial discharge (PD) calibrators from 0.1 pC to 10 nC（EURAMET_EM_S36）is piloted by RISE. The comparison is undergoing. According to the schedule for comparison participants given in the technical protocol document, the comparison experiment for NIM was in Apr. 2023, our comparison data sheet has been sent to the pilot laboratory in August, and the final report will be sent next month. Four PD Calibrators were selected as travelling standards as shown in Fig. 10.1. The voltage impulse and their integration charge curves are shown in Fig. 10.2.

Fig. 10.1 Travelling standard



(a) 0.1pC

(b) 10nC

Fig. 10.2 voltage impulses and integration charge curves

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EV charging station calibration

NIM has built a traceability chains and calibration capabilities both for ac and dc fast charging station. This was based on some projects related to development of EVSE calibrator, standard setup, and verification regulations. The traceability chains covers the calibrators for on-site verification of EVSE, working standard setup, and DC and AC energy primary standards based on JVS. Development of calibration and traceability system of High-power super EVSE up to 1500 V and 800 A has been completed. We focus on the draft and verify testing on the OIML Recommendation on EVSE and dc energy meter, and try to explore the possibility of simplify the testing procedures for EVSEs with CPA meters. We are investigating the online evaluation of the measurement performance of large-scale EVSEs based on big data analysis of the charging data, BMS data and total energy meters data.

Fig. 11.1 Super Charging Calibrator with liquid cooling

Fig.11.2 Calibration Setup

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RF & MICROWAVE

I Topics and contacts

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The E-field strength comparison between NIM and Brazil	linhy@nim.ac.cn
CIPM Key Comparison CCEM.RF-K27.W in “RF power from 50GHz to 75GHz in rectangular waveguide”	cuixh@nim.ac.cn
CIPM Key Comparison CCEM.RF-K28.W in “RF power from 18GHz to 26.5GHz in rectangular waveguide”	cuixh@nim.ac.cn
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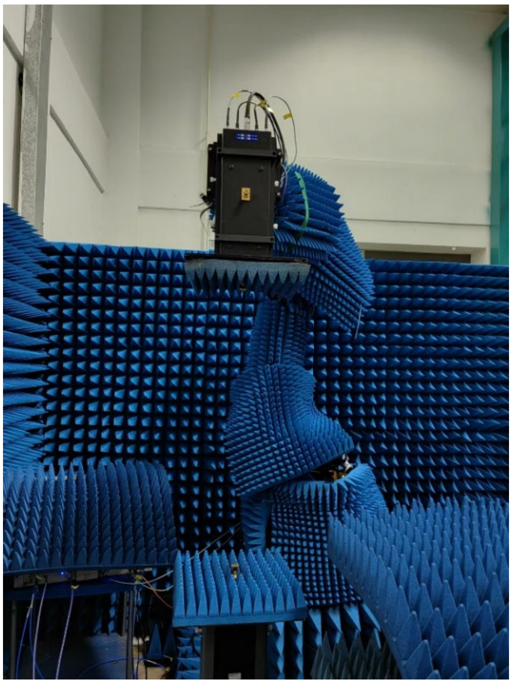
Improved electro-optic modulation chip for electro-optic sampling system	chenhe@nim.ac.cn zhaokj@nim.ac.cn
Spherical Near-Field Antenna Measurement for Over-the-Air Testing (OTA)	siwk@nim.ac.cn
Waveform Metrology for EVM Measurement and OTA Test	zhangyichi@nim.ac.cn
Digital Calibration Certificate (DCC) for RF power traceability	liuxiaomeng@nim.ac.cn

2 Report

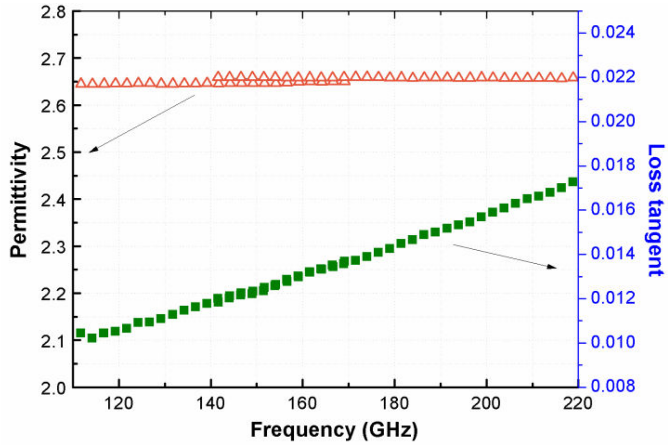
Terahertz Antenna calibration

In 2023, a novel antenna measurement system using an industrial robot is set up to carried out the extrapolation technique to get the infinite gain of the standard gain horn (SGH) antenna up to 220GHz. By accurately positioning the robot arm which carries the paired antenna, while the SGH to be calibrated is measured. An extrapolation range for antenna gain measurement is achieved in a flexible way at millimeter-wave and Terahertz frequency range from 18GHz to 220GHz.For the SGH infinite true gain, a typical expended uncertainty (*k*=2) of 0.5dB@220GHz could be achieved.

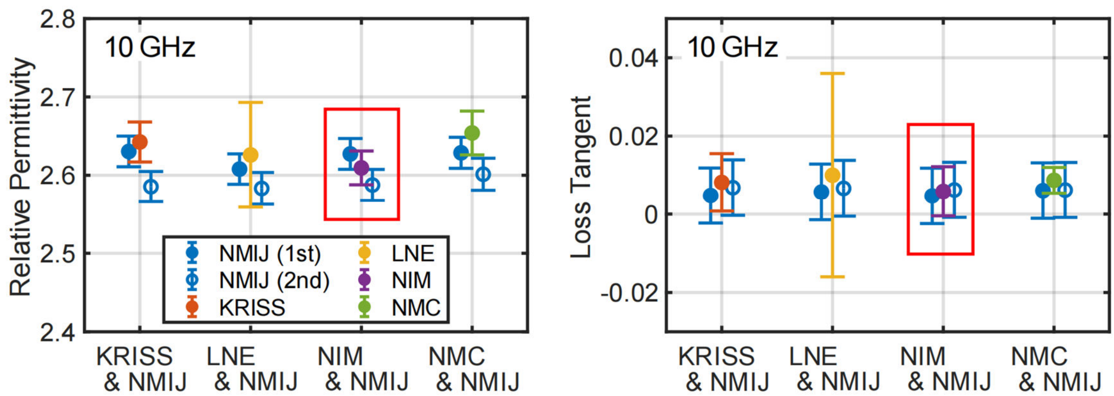


THz dielectric properties of low-loss materials

In 2023, a THz quasi-optical Fabry-Perot open resonator was designed and fabricated in NIM. The apparatus can precisely measure the complex permittivity of the dielectric materials in a wide frequency range of (110~220) GHz. Owing to its high Q factor, the open resonator is especially suitable for the characterization of low-loss materials. In compatibility, this resonator has two operating modes, including the double-concave geometry and the plano-concave geometry, which satisfy the measurement requirements for both the thin film and thick sample.



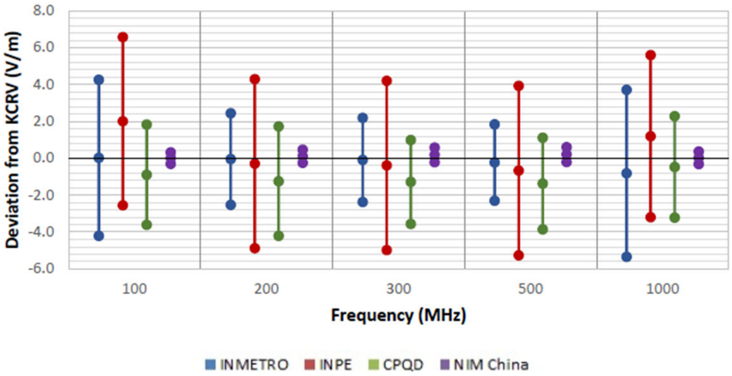
This year, the final comparison report on the CCEM pilot study of dielectric material measurement was completed to verify the equivalence of permittivity measurements between NMIs. The measurement results obtained from NIM and other laboratories are consistent within the ranges of uncertainties for both relative permittivity and loss tangent.



The E-field strength comparison between NIM and Brazil

In 2023, INMETRO (National Institute of Metrology, Quality and Technology, Brazil) conducted an E-field strength comparison between China and Brazil with four labs participated in: INMETRO, INPE (National Institute of Space Research, Brazil), CNPQ (Research and Development Center Telecommunications, Brazil) and NIM of China. The quantity to be measured is the E-field strength (unit: V/m) and the frequency range is from 80 MHz to 2200 MHz using GTEM cell as the E-field generator for all the four labs. The travelling standards are ETS HI 6105 and STT RF06M which is a special designed E-field probe from 0.5 MHz to 2 GHz with the size of 11 mm×10 mm. In this comparison NIM gets good results and the values agree with KCRV very well.

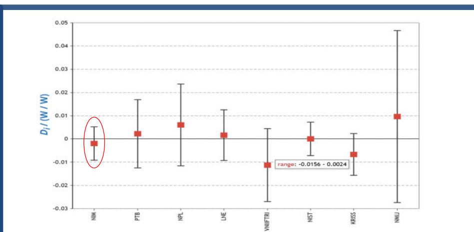
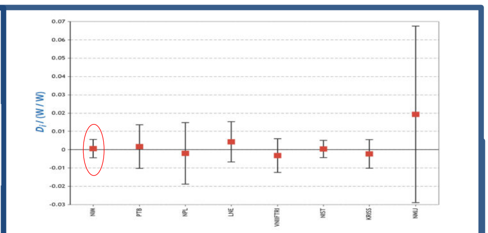
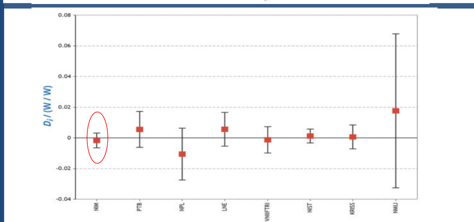
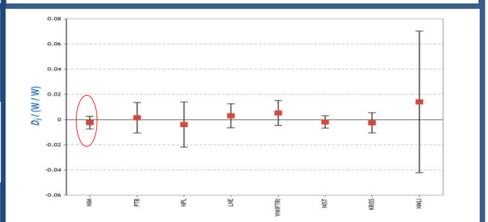
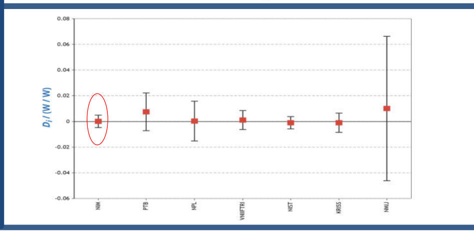
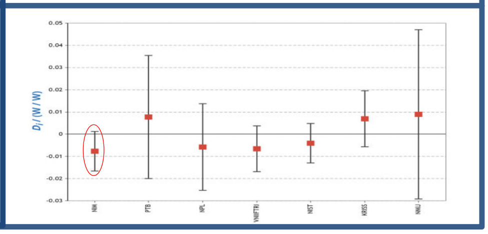
STT RF06M



Deviation from KCRV for E-field = 20 V/m using RF06M

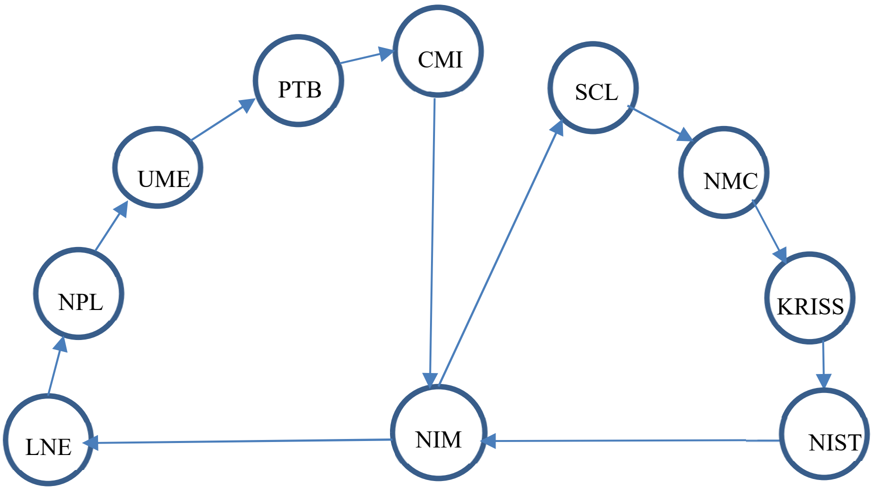
CIPM Key Comparison CCEM.RF-K27.W in “RF power from 50GHz to 75GHz in rectangular waveguide”

In 2023, this year, the final report of CIPM Key Comparison CCEM.RF-K27.W in “RF power from 50GHz to 75GHz in rectangular waveguide” was completed (Xiaohai Cui et al 2023 Metrologia 60 01001). In this comparison, effective efficiency and calibration factor of two waveguide thermistor mounts were determined by eight National Metrology Institutions (NMIs). The results were evaluated at six frequency points by determining the KCRV for both effective efficiency and calibration factor of the first travelling standard (PTB-1, SN 140). The reported results were related to the KCRV by calculating the Degrees of Equivalence and their expanded uncertainties. The difference between the effective efficiency of the travelling standard measured by NIM and the international key comparison reference value (KCRV) is 0.0002 (70GHz), which is the minimum value in the measurement results of the reference laboratory, and the expanded uncertainty is 0.0048 (k=2)

5		5	
6		6	
7		7	

CIPM Key Comparison CCEM.RF-K28.W in “RF power from 18GHz to 26.5GHz in rectangular waveguide”

A CIPM key comparison CCEM.RF-K28.W in “RF power from 18 GHz to 26.5 GHz in rectangular waveguide” is in progress among the NMIs in 2023 and 2024. NIM is the pilot laboratory and another 9 National Metrology Institutes (NMIs) have joined the comparison including LNE, NPL, PTB, CMI, UME, SCL, NMC, KRISS and NIST. Two WR-42 thermistor mounts are provided by NIM as the travelling standards and the effective efficiency and calibration factor of the travelling standard are measured at 18GHz, 21GHz, 24GHz and 26.5GHz respectively. This comparison holds significant importance for verifying existing calibration systems, demonstrating high-precision measurement capabilities, and establishing equivalence in RF power measurements within this frequency range.

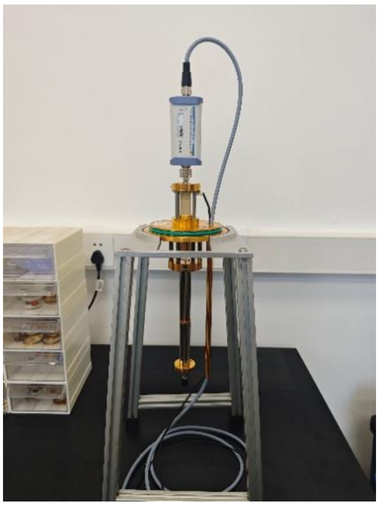


Microwave & Pulse High Power

In 2024, NIM has designed and established a microwave high-power flow calorimeter and a pulse high-power flow calorimeter. Microwave high-power flow calorimeter covers frequency range from 10MHz to 18GHz, and power range from 1W TO 150W. Pulse high power flow calorimeter is capable of calibrating pulse high power sensor with peak power of 50kW (with duty cycle 1%~2%). Automatic power meter is designed for both calorimeters, to detect thermal equilibrium and record measurement results with dramatic efficiency. Thermal control unit and correction factors are implemented in calorimeters as well to improve measurement stability. Calorimeters are widely used in calibration of high power sensor in fields of semiconductor manufacturing and medical service.

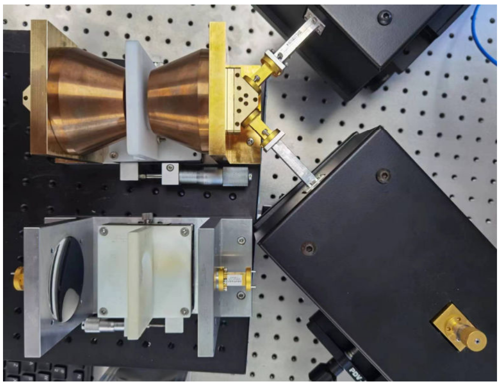
NIM 1.85 mm coaxial microcalorimeter

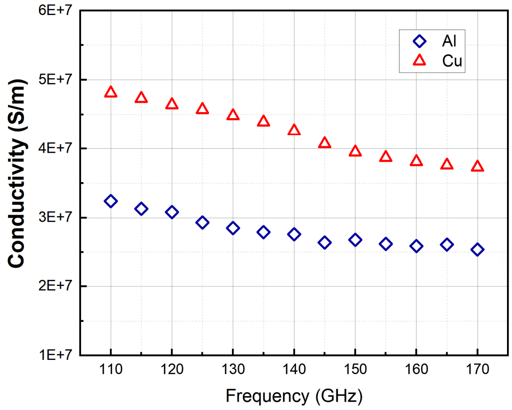
In 2024, NIM designed a new microwave coaxial 1.85mm power standard. The coaxial 1.85mm microcalorimeter covers the frequency range of 10MHz~67GHz. Currently, the coaxial 1.85mm power standard is designed to calibrate power sensors in the frequency range of 10MHz~67GHz with a power range of 1mw~10mw. In addition, we remodeled the power sensor to insert connectors and DIP switches between the absorption sensing element and the digital circuitry. The DIP switch is used to disconnect the absorption sensing element from the digital circuit, and the output voltage of the absorption sensing element can be measured directly through the connector, which reduces the influence of the digital circuit part of the power sensor in the calorimetric process.



Millimeter-wave Characterization for Dielectric Substrates and Conductors

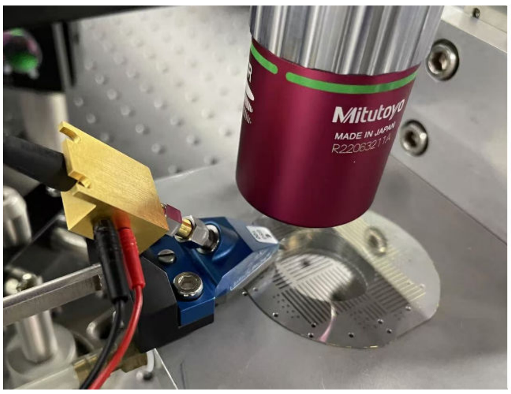
In 2024, a broadband waveguide-coupled FPOR was developed to accurately measure the complex permittivity of low-loss substrates and the reflection loss of metal samples in110-220 GHz. Compared with the conventional FPORs, the proposed resonator can simultaneously operates in the D-band and G-band. The position and the size of the feeding holes on the spherical mirrors are carefully considered. A fairly high Q-factor, larger than on hundred of thousands, is achieved, which ensures the high sensitivity and accuracy of the measurements. In addition, The resonator can be switched from the double-concave mode to plano-concave mode easily. As a result, it can realize the measurement of multi-parameters, including permittivity，loss tangent，reflection loss and conductivity.

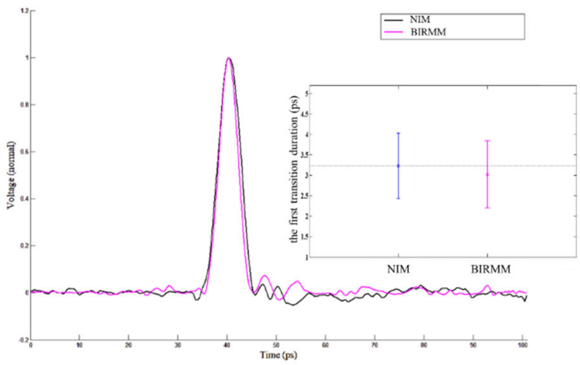




Improved electro-optic modulation chip for electro-optic sampling system

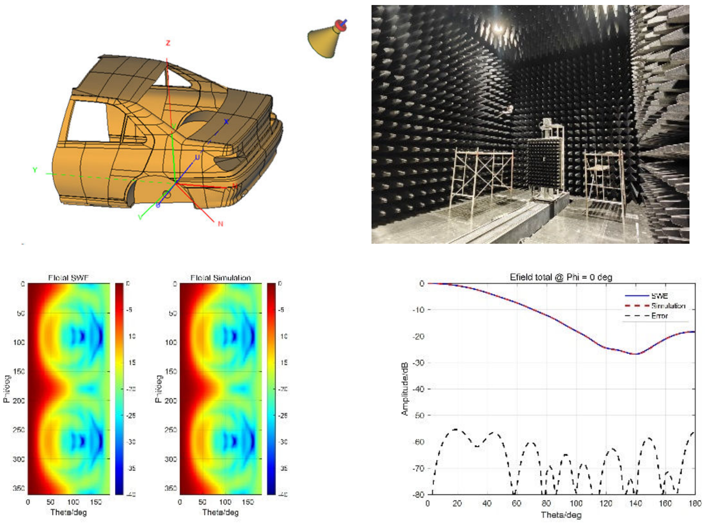
In 2024, a broadband electro-optic modulation chip was developed to accurately measure photodetectors response characteristics. 3dB bandwidth of the CPW is more than 190 GHz. With improved bandwidth chip, measured photodetector time domain response has smaller risetime and pulse width (FWHM). A comparison in the pulse waveform parameters standard between NIM and BIRMM was held. The device under test is a photodiode (PD) with a nominal bandwidth of 100 GHz (Finisar XPDV4121R). A good agreement is obtained on time domain response and the first transition duration (10%-90%). The risetime is less than 3.5ps.





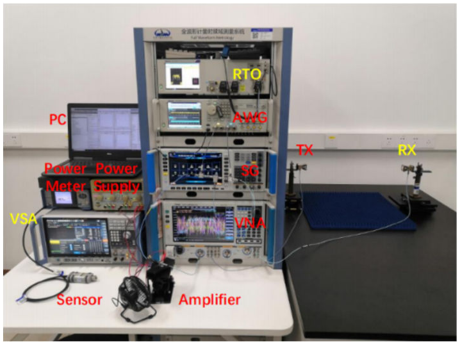
Spherical Near-Field Antenna Measurement for Over-the-Air Testing (OTA)

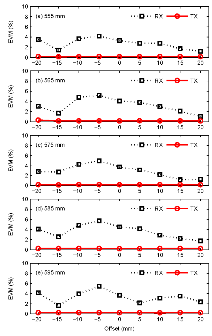
In 2024, as the convergence of modern smart connected vehicles and 5G wireless communication technology advances, there is a surge in the number of on-vehicle antennas and wireless sensors, presenting new challenges for antenna testing technologies. Leveraging its extensive experience in antenna over-the-air testing, the National Institute of Metrology (NIM) has established a spherical near-field testing facility with a frequency range from 0.2 to 40GHz. This facility is capable of providing comprehensive testing and metrological services for a variety of antennas, from standard horns to intricate phased arrays and metasurface antennas. Addressing industry concerns regarding the testing of vehicle-integrated antennas, NIM has developed dual-polarized broadband near-field testing probes designed for large-scale targets and has delved into the intricacies of antenna off-axis measurements and phaseless measurement theories. NIM holds exclusive intellectual property rights over the hardware and software used, which are independently developed rather than procured from external sources. In the future, NIM is committed to offering technical support and facilitating the commercialization of these advancements to clients worldwide, with a focus on sustained evolution in the domain of spherical near-field measurement.

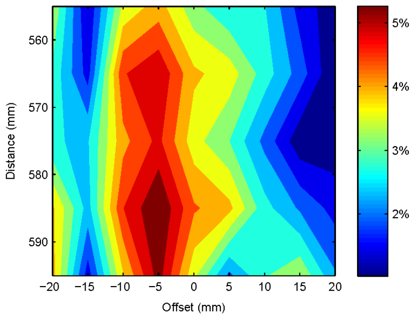


Waveform Metrology for EVM Measurement and OTA Test

In 2024, a frequency-domain approach for waveform metrology of millimeter-wave digitally-modulated signals was developed, which was based on characterization of magnitude and phase spectra with swept-frequency measurements using a vector network analyzer. Pre-distortion according to the frequency-domain measurement is applied to lower the error vector magnitude (EVM). In this way, low-EVM test signal with uncertainties can be used to not only verify the RF performance of commercial instruments, bur also evaluate the over-the-air (OTA) behavior of antenna systems.







Digital Calibration Certificate (DCC) for RF power traceability

In 2024,NIM has conducted research on applying DCC technology to RF power traceability. Based on the standardized DCC format and the traceability requirements for power meters, NIM designed a DCC structure for power meters, generated DCC using calibration data, and embedded them into their self-developed terahertz power meter. The THz power meter can recognize DCCs and automatically correct measurement results based on the calibration data. The digitalization of RF power metrology systems enhances the operational efficiency and measurement accuracy.