

## Report on the Activities in Electricity and Magnetism within National Institute of Metrology, China

### RESEARCH PROGRESS

#### DC&LF

##### 1. Joule Balance

The development of the joule balance method to measure the Planck constant, in support of the redefinition of the kilogram, has been going on at the National Institute of Metrology of China (NIM) since 2007. By the end of 2014, the relative standard uncertainty of the Planck constant measurement result with NIM-1 is reduced to  $2.6 \times 10^{-6}$  and has reach its limit.

To make contribution for the final redefinition of kilogram, the uncertainty has to be less than 0.05ppm. But for NIM-1, there are three aspects that limit its uncertainty to  $10^{-6}$  level. The first is its big size and it cannot be put into a vacuum chamber. The length measurement will be limited to  $10^{-6}$  level in air environment. The 2<sup>nd</sup> limitation lays on the resolution and short time repeatability of the balance. The 3<sup>rd</sup> one is the self heating of the coils with currents.

Thus since early 2013, NIM has started the design and construction of the new generation Joule balance NIM-2 to decrease all the big uncertainty sources in the NIM-1 version, an uncertainty at  $10^{-7}$  level could be expected. At present, all the electrical parts, mechanical parts, and laser system have been ready and will be mounted by the middle of 2015.

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##### 2. Programmable Josephson Voltage

Based on Josephson Effect, at NIM we have developed 1V and 10V conventional Josephson voltage standard (JVS), continuously programmable Josephson voltage standard (PJVS). A comparison of the JVS of the BIPM and the NIM was carried out in Nov. 2013. And some research and applications on the precision measurement of magnetic flux and mutual inductance, microvolt Josephson voltage standard, differential sampling of the ACJVS have been done and some progress have been obtained.

1) Within the framework of CIPM MRA key comparisons, a comparison of the Josephson voltage standards of the BIPM and the NIM was carried out in November 2013 at the level of 10 V. For this exercise, options A and B of the BIPM.EM-K10.b comparison protocol were applied. Option B required the BIPM to provide a reference voltage for measurement by NIM using its Josephson standard with its own measuring device. Option A required NIM to provide a reference voltage for measurement by the BIPM using its analogue detector and associated measurement loop. The final results were in good agreement within the combined relative standard uncertainty of 9.2 parts in  $10^{11}$  for the nominal voltage of 10 V.

2) We continue researching on the improvement of magnetic flux measurement and focus on the precision measurement of the mutual inductance with the flux measurement system we built two years ago. A mutual inductance measurement method which is based on the programmable Josephson system at NIM is used to

measure the mutual inductors we designed. Experimental results show that the type A uncertainty of the measurement of mutual inductances of 341 mH and 577 mH is less than 2 ppm, which demonstrates the feasibility and reliability of the flux and mutual inductance measurement method we proposed.

3) A new record of magnetic flux measurement of 1 Wb with the type A uncertainty of less than 1 ppm was achieved, which is an improvement over the result that was achieved with our previous magnetic flux measurement circuit with Josephson system. The flux difference measured between the rectangular pulse synthesized with the Josephson system and the flux under test (around 1 Wb) is less than 4 mWb, which significantly reduces the impact of the flux meter reading error on the measurement results.

4) Now we continue developing of the differential sampling system based on the programmable Josephson voltage standard. Both of the Agilent 3458A multimeter and the NI PXI-5922 dual channel digitizer are tried to use as a digitizer in our sampling experiments. We aim to use this differential sampling system to measure the ac voltage with the amplitude at one volt level and the frequency up to 60 Hz, which is provide by a calibrator or a DAC, with the uncertainty of several ppm by the end of this year.

5) An automated microvolt Josephson voltage set-up was developed at NIM. It is based on two programmable Josephson SINIS arrays, and can be used to calibrate the lower ranges of nanovoltmeters for low level DC measurements. A low noise bias source developed at NIM has been used and the step flatness of the arrays was verified carefully. The preliminary results of the measurements set at 3  $\mu$ V show that the difference between the measured values and the theoretical value is 0.03 nV with the uncertainty ( $k = 1$ ) of 0.10 nV.

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### **3. Calculable Capacitance**

A new type calculable capacitor has been built at NIM in cooperation with NMIA, from which the SI unit of capacitance of 1 pF was reproduced within an uncertainty of 20 parts in  $10^9$ .

1) A simplified reproducing approach was adopted.

The classical approach through substitution measurement between the special-manufactured small-value capacitors and the calculable capacitor was not applied. In the adopted approach the huge integral number of the fringe was determined by the original horizontal calculable capacitor at NIM built in 1970s. The decimal number was then determined by the new vertical calculable capacitor system.

2) The distinctive workings are included in the installation and adjustment.

On the basis of the four main bars with non-cylindricity reaching  $\pm 25$  nm, which were carefully grinded by Mr. G.W.Small of NMIA in several years, the installation and adjustment were completed by adopting the mechanical and optical approaches. Some distinctive approaches were used to satisfy the practical mechanical processing level. The positions of the four main bars were adjusted with

the capacitive sensor technology to reach the level of  $10^{-9}$  firstly. Mr. J.R. Fiander of NIMA visited and assisted NIM to adjust again down to the level of  $10^{-10}$ , including a new skew factor.

### 3) Many experiments are undertaken

Reproducing SI unit of the fixed standard capacitor of 1 pF, linearity and stability of the whole system, disseminations to 10, 100, 1000, 10000 pF, transferring the capacitance unit to the resistance, and measurement of the fine structure constant.

### 4) Uncertainty estimated

The influence factors are analyzed; their scales were measured, calculated, obtained through the model experiments. The published works (NMIA, NIST, PTB, NPL, PEL, etc.) are referred and compared. Some of these influence factors, such as “Voltage influence” and “Frequency influence” were overestimated.

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## 4. High Voltage and Current

### 1) Development of LVE-TSVT for AC HV ratio

We developed a new type of two-stage voltage transformer (TSVT) with toroidally-wound ring cores excited by low voltage, which is called LVE-TSVT. Three TSVTs, 10kV, 35kV and  $110/\sqrt{3}$  kV, were developed based on this scheme. The ratio errors and phase displacements of these TSVTs are all less than  $-3.2 \times 10^{-6}$  and  $-1.1 \times 10^{-6}$  rad respectively at reference voltage. Comparative measurements with a high voltage capacitive divider and current comparator illustrate that, in the range of 20% to 120% rated voltage, variations of no-load errors of TSVTs are as follows,  $2 \sim 4 \times 10^{-6}$  of the ratio errors and  $2 \times 10^{-6}$  rad phase displacements, these reach class 0.0005 to class 0.001.

### 2) Voltage coefficient measurement of HV capacitor

We developed a new method to calibrate the capacitance voltage dependence and dissipation voltage dependence of the HV capacitor, by connecting two transformers in series (the primary and secondary winding respectively). We carried out contrast measurements with this serial summation method and the traditional tilting method on a 200kV capacitive voltage divider, and the results of these two methods coincide well.

### 3) High DC measurement technology

In order to measure high direct current accurately, we had developed a series of direct current comparators, which are up to 6 kA, and they are self-calibrated by the series-parallel method. This year, a full-optical current sensor for 450 kA on site calibration is developed and verified. This optical sensor was calibrated in the lab with accuracy 0.2% and was tested on site with uncertainty 0.5%

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## 5. AC power standard

1) The establishment of the new ac power standard at frequency ranges from 400 Hz to 100 kHz has been activated to cover the current ranges from 1 A to 100 A and voltage ranges from 10 V to 300 V.

2) A time constant standard with coaxial structure design has been proposed and calibrated against a mutual inductance at 100 kHz. The time constant standard is used as the reference to determine the phase angle errors of the high accurate current shunts. A new measurement setup, based on the use of the voltage divider technique, has also been developed to extend the current ranges to 100 A by comparing with the time constant standard.

3) A self-calibrated Resistive Voltage Divider (RVD) in parallel and in series structure has been built to reduce the measuring voltage down to the voltage applied to the digital sampling system. A self-calibrated Inductive Voltage Divider (IVD) and cascaded structure IVDs have also been designed and calibrated in a step-up procedure. Two different type voltage dividers have been inter-compared and shown well agreement in phase angle errors at frequency ranges up to 100 kHz.

4) A new measurement setup to compare two shunt-TVC combinations at common ground has been proposed and given an oral report on this CPEM2014 in Rio de Janeiro. This setup is based on the use of Binary Inductive Current Divider (BICD) to generated two currents with known relationship and reduces the current leakage influence when two shunt-TVC combinations compared in series connection.

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## 6. Quantum Device

Single quantum Hall device was measured by DCC with 1 k $\Omega$  transfer standard resistance with resistance deviation with  $R_k/2$  was  $10^{-7}$  because of the low current of 38  $\mu$ A. Quantum Hall array devices of 1 k $\Omega$  and 10 k $\Omega$  were fabricated and measured on PPMS and the deviation from decade value was  $10^{-5}$ . These array devices will be accurately calibrated by CCC.

For the Josephson junction array devices, we are in the process of making small scale Nb/Nb<sub>x</sub>Si<sub>1-x</sub>/Nb arrays with 500~1000 junctions. We improved the chip testing system. Observed good DC IV curves in a Josephson junction array with 1000 junctions, also observed Shapiro steps in a Josephson junction array with 500 junctions.

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## RF& MICROWAVE

### 7. Antenna

The final evaluation of NIM's new open area test site (OATS) is finished. To validate our OATS performance, 24 pairs of calculable dipole antennas have been designed and manufactured to cover 24MHz to 1000 MHz. Using 24 pairs resonant calculable dipole antennas to validate the site performance, for horizontal

polarization, deviation of measured and theoretical site insertion loss is less than 0.26 dB, and for vertical polarization, the deviation is less than 0.34dB The results of comparison between NIM,NPL and ETS show our OATS performance is the best.

A project, cooperated with National Physical Laboratory, is under way to develop a measurement facility for the antenna gain and cross-polarization measurement in our Second Experiment Base. It is based on the three antenna extrapolation test method, and the expanded uncertainty of the gain for the standard gain horn antennas will be from 0.4 dB to 0.05 dB over 250 MHz to 110 GHz. The facilities are installing in the chamber. Measurement capability below 50GHz will be provided by November.

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## **8. Information Technology Metrology**

NIM is starting a new project to establish national standards and quantity traceability system for new generation of information technology, one of China strategic emerging industries.

There are 8 tasks to develop measurement techniques and traceable methods for information source, information channel, information network and information display. This project involves various kinds of wireless communication systems. Calibration technologies for different kinds of antennas, such as smart antenna, need to be developed.

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Project 2: Calibration Method Research of RF Parameters for RFID

This project focuses on the RF parameters and channels in a RFID System. An 800MHz~1000MHz measurement system has been set up with 3 environments simulation.

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## **9. Microwave parameters**

Project 1: millimetre wave attenuation standard

Millimeter wave attenuation standards cover 50-75 GHz and 75-110GHz are being developed at NIM. The whole standard will be finished by October. The dynamic range is nearly 100 dB.

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Project 2: Power

This project focuses on waveguide primary power standard to cover 50-75 GHz with the similar microcalorimeter design of recently developed 33-50 GHz power standard. A 110-170 GHz power standard research is carrying on with calorimeter method.

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Project 3: Scattering parameters

Broad band scattering parameters standard is being developed and will be completed by October. It covers 100 kHz -110GHz with coaxial. Rectangular waveguide part will cover 50 GHz -110GHz.

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## **COMPARISONS**

### **Participate in comparisons**

#### **1. APMP.EM-K12 10 mA and 5 A currents**

The CCEM-K12 comparison of the ac-dc transfer standards has been finished during 2005 to 2007 with three APMP participants. The APMP TCEM decided to activate a follow-up APMP comparison to link more APMP members to the CCEM key comparison and agree that NMC would be the pilot laboratory of this comparison. The traveling standards of this comparison are Planar Multi-junction Thermal Converter manufactured by IPHT for current 10 mA, Germany and precision current shunt from Fluke A40B-5A for current 5 A. NIM is one of the APMP member participating this comparison and has received the traveling standards recently. Comparison work is ongoing and will be done at the end of September.

#### **2. APMP.EM APMP EM RF-K8 RF Power within 18GHz**

NIM is one of the APMP member participating this comparison and has done the comparison work. The comparison data will be sent to pilot lab after the internal review.

### **CMCs simplification**

The CMCs simplification of NIM has passed the intra-review of APMP.

The CMCs simplification of NIM started on March 2014 and ended on September 2014. The simplification was dedicated only on a cleaning up of the CMC tables and on extending the use of matrices, and new entries or improved entries was not allowed. Great efforts have been spent in the use of matrices and increase uncertainty values or to reduce the scope of CMC entries, or to delete CMC entries, etc.

In addition to, NIM has reviewed 12 NMIs simplification on Part 8 “High voltage and current”. In the review, NMIs have also corrected the misprints and editorial typos, to increase uncertainty values or to reduce the scope of CMC entries, or to delete CMC entries, etc.