2022 Activities on DCLF & RF at NIM

National Institute of Metrology, China

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DCLF

Pulse-driven Josephson Arbitrary Waveform Synthesizer

A cryo-cooled Josephson arbitrary waveform synthesizer (JAWS) has been developed at the National Institute of Metrology (NIM). The JAWS is capable of synthesizing ac voltages of 2 Vrms with the compensation method and 0.5 Vrms with the zero compensation method. When producing large voltages, the JAWS requires compensation signals to ensure that the Josephson junctions (JJs) work in the quantum state. A compensation signal source (CSS) integrated with multiple compensation channels, a sweep channel and summing amplifiers are developed at NIM for simplification. In 2023, several experiments will be conducted at NIM to validate the accuracy of the ac voltages and expand application areas of the JAWS. Firstly, we will compare the JAWS with PJVS through differential sampling from 60 Hz to 100 kHz. Secondly, a direct comparison of two or three JAWS will be performed. Finally, we will calibrate ac voltages above 100 V with the JAWS.

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Programmable Josephson Voltage Standard

A portable AC Programmable Josephson Voltage Standard (PJVS) system operating on a commercially available Gifford–McMahon (G-M) cryocooler has been designed and developed at NIM. The NIST-fabricated 2 volt Josephson array chip was mounted and tested in the domestic cryostat. The minimum quantum voltage step of 14 subarrays is 1.1 mA. This cyrocooled PJVS system was able to perform ac voltage calibration of the calibrators with satisfactory accuracy. The type A uncertainty of less than 3 parts in 10^{-7} was achieved with the differential sampling technique when measuring a 1 V rms sine wave generated by a calibrator at 53 Hz.

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Quantum Device - SQUID

Series SQUID Array and two stage SQUID chips were designed and fabricated as current meters. Both are fabricated based on a SNEAP process developed in NIM Lab. A series SQUID Array, designed with a first-order series gradiometer, the open-loop transfer coefficient is about $2mV/\Phi_0$ and the white flux noise is as low as 0.4 $m\Phi_0/\sqrt{Hz}$ at 4.2 K. The two-stage SQUID consists of a front-end low noise second-order parallel gradiometric SQUID at the input stage and a series SQUID Array at the output stage, the overall open-loop transfer coefficient of this two stage SQUID current sensor is about 1 mV/Φ_0 and the overall white noise is about 0.9 $m\Phi_0/\sqrt{Hz}$ at 4.2 K.

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The progress of the NIM-2 joule balance

Since 2021, the NIM-2 joule balance's alignment theory has been improved. It attempted to normalize and simplify the alignment process and proposed a method to automatically minimize the parasitic horizontal forces and torques of the suspended coil in the NIM-2 joule balance. Based on several flexure hinges, this alignment process was performed in vacuum and the parasitic horizontal forces and torques were significantly reduced using our automatic alignment system. In order to restrain the hysteresis and nonlinearity during the posture adjustment of the suspended coil, a controlling method based on the fuzzy model (Fuzzy Model Predictive Control, FMPC) has been proposed for a predictive control. This method can decompose the original complex system into multiple subsystems according to the system characteristics, and establish discrete state space control models for the subsystems based on MPC. Based on the above improvements, the measurement uncertainty from the misalignment were reduced from 4.5×10^{-8} to 1.7×10^{-8} in comparison with the alignment results before. During the September 2021 to March 2022, the NIM has participated in the second key comparison of kilogram realizations (CCM.M-K8.2021) piloted by the BIPM with its NIM-2 joule balance.

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Development of the Dissemination System of AC Resistance

A new four terminal-pair (4TP) resistance bridge has been developed for the precision measurement of ac resistance and time constant by means of two sets of 4TP quadrifilar reversed resistor (QR) of 10 kΩ with known frequency dependence. The whole dissemination system can be traced to the NIM's new vertical calculable cross-capacitor with unique electrical compensation approach and the quantum hall resistance standard, which can realize the value transfer between 1 Ω to 1 MΩ in the frequency range from 400 Hz to 10 kHz with expanded uncertainties between 0.05 μΩ/Ω and 8 μΩ/Ω.

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Development of the capacitance and dissipation factor bridge

A four-terminal-pair (4TP) capacitance and dissipation factor bridge is developed to achieve accurate measurement of capacitance's dissipation factor at NIM. The four-terminal-pair IVD bridge is simplified by meeting the required 4TP definition conditions of the compared capacitance high ports with two precision voltage followers. The techniques are also adopted in the 4TP AC resistance bridge at NIM. Specifications: capacitance range: 1 pF~10 μF, frequency range: 100 Hz~10 kHz; dissipation factor measurement uncertainties $5\times10^{-7}\sim1\times10^{-5}$ (k=2).

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Bilateral Comparison of Voltage Dependence of High-Voltage Standard Capacitors

A comparison of the voltage dependence of high-voltage standard capacitors was performed between the National Institute of Metrology China (NIM) and the National Measurement Institute, Australia (NMIA) in the period between June 2019 and May 2021, with a 100 kV high-voltage compressed gas capacitor provided by NIM as the travelling standard. The capacitance changes measured by the two institutes agreed within 2 μF/F over the voltage range from 10 kV to 100 kV, which demonstrated excellent equivalence of the measurements.

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APMP.EM-S15: Supplementary comparison of four-terminal- -pair capacitance

In 2022, the final report of the comparison was approved and published in KCDB. The comparison of four-terminal-pair 1 pF, 10 pF, 100 pF and 1000 pF capacitance at frequencies of 10 kHz, 100 kHz, 1 MHz and 10 MHz aims to provide participating laboratories with the opportunity to compare capacitance in the extended frequency range, and to gain experience and knowledge in this field. The participants include NIM, NPLI and NIMT in which NIM is the pilot laboratory.

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CCEM-K3: Comparison of Inductance at 10 mH and 1 kHz

The new key comparison CCEM-K3, inductance at 10 mH and 1 kHz, has just started with eleven participating laboratories and a supporting group comprising PTB, NIM and NMIA. In the supporting group, NIM is responsible for logistics, including liaising with NMIs on schedules, artefact movements and participant report submission. PTB suggests an airworthy temperature-controlled enclosures for the artifacts shipment. The expense of hiring and transporting a thermally controlled container may not be warranted for all participants. The main issue whether or not the artefacts should be shipped under temperature control is still under inverstigating. The draft of CCEM-K3 Protocol has been prepared by NMIA.

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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 Research Institutes of Sweden. The comparison is undergoing. According to the schedule for comparison participants given in the technical protocol document, the comparison work for NIM will be held in Apr. 2023. At NIM, the experiments to evaluate the uncertainty components that may be applicable to different methods are studied, and new partial discharge(PD) calibrators of NIM, less than 1 pC and greater than 1 nC are developed.

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Millivolt AC Voltage Measurement with AC-DC Transfer Method

The millivolt ac voltage is traced to dc voltage standard using voltage divider technology. A resistive voltage divider (RVD) with serial-parallel connection structure is designed. The ac-dc difference of ratio error of the RVD is measured with ac-dc transfer at wide-band frequencies. The upper part of the RVD contains 7 resistors in serial connection and the lower part contains 9 resistors in parallel. The resistors are all 100 Ω. The input voltage of the RVD is 19.2 V and the output is 0.3 V. The ac-dc difference of the PMJTC with range resistor is calibrated with a step-up procedure. The ac-dc difference of ratio error of the 64:1 RVD is within 100 μV/V at frequencies from 50 Hz to 1 MHz. The voltage dependence of ratio error of the RVD is calibrated using self-calibrated IVD as reference standard and can be ignored. The ac-dc difference of Fluke 792A at millivolt voltage down to 10 mV has been measured with the RVD and within 200 μV/V at frequency ranges from 50 Hz to 1 MHz.

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CCEM-K13: Comparison of power harmonics with three waveforms

The comparison is pilot by NIM, measurement start in 2018. All three waveforms of CCEM-K13 are stored in the travelling standard and only these stored waveforms shall be measured in the CCEM-K13. The comparison, involving eight laboratories, has experienced serious delays due to several device failures and Covid-19. The circulation of the travelling standard has restarted, it was sent from Beijing on 2 Sep. and arrived at RISE on 7 Sep. 2022. VNIIM agreed to withdraw from CCEM-K13 to enable the comparison to continue. VNIIM will participate in a subsequent bilateral comparison when CCEM-K13 is finalized and as soon as the situation allows.

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1200 kV Lightning Impulse Voltage Measuring System

In 2020, NIM signed a letter of agreement with EURAMET research project Future Energy, and took part in its research task on the linearity extension of the lightning impulse voltage. A 1200 kV lightning impulse voltage measuring system is developed and attends the comparison at TU Delft in the Netherlands this October. There are 7 participants in the measurement campaign. NIM expects to extend the lightning impulse voltage from 700 kV to 1200 kV to support UHV. Recently the comparison test has been completed.

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COOMET 821/RU-a/20: ±100 kV DC Voltage Measuring System Comparison

From 2021, NIM, VNIIMS and BelGIM had been involved in a comparison on DC voltage measuring systems within the range of ±(1~100) kV (COOMET 821/RU-a/20). The comparison tests have been finished.

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RF& MICROWAVE

RF&MW Power

A coaxial calorimeter system for low frequency (9 kHz~10 MHz) is designed and fabricated by NIM, working as a standard for coaxial power sensor calibration. The symmetrical twin line structure adopted by the calorimeter can effectively resist the influence of temperature drift since it is very sensitive to temperature changes. The operation frequency of the thermistor power sensor is usually not lower than 10 MHz, so the low frequency calorimeter uses the commercial thermocouple power sensor as the transfer standard, with small mismatch error. The expanded measurement uncertainty is better than 0.25%.

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The Dielectric Properties Measurement of Materials

NIM has developed the measurement systems for characterizing the complex permittivity of materials at the range of (1~110) GHz. A broadband measurement setup based on the free space method and focusing lens horns was proposed, which can operate from 18 GHz to 110 GHz. Both the GRL and TRL two-port calibration methods were investigated and the measurement uncertainties were analyzed. For accurate loss tangent measurements of low loss materials at millimeter-wave frequencies, a Fabry-Perot quasi-optical open resonator was fabricated, which can operate at (20~110) GHz. The standard uncertainty of the real part of permittivity was about 0.4%. Moreover, The in-situ dielectric properties of the semiconductor substrate up to 110 GHz were measured by using a wafer probing station equipped with on-wafer probes and frequency extenders. The multi-line TRL calibration technique was used to correct the impedance mismatch of the system.

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Ultrafast pulse waveform generation and measurement

Ultrafast pulse waveform is generated based on GaAs chip. Photoconductive switch is embedded into co-planar wave guide (CPW). CPW was evaporated onto low-temperature GaAs. Low-temperature GaAs was grown onto GaAs wafer. Rise time (10%-90%) of such ultra-fast pulse waveform is 7.0 ps. From 1 GHz to 110 GHz, the CPW transmission coefficient attenuation is less than 1 dB and reflection coefficients are less than -20 dB. Based on the electro-optic sampling (EOS) system and GaAs chip mentioned above, ultra-fast pulse waveform generated by 100 GHz photodiode (PD) was measured. Rise time (10%-90%) of such ultra-fast pulse waveform is 5.3 ps.

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Antenna Metrology

Antenna key parameter calibrations capability including gain, antenna factor, radiation pattern, port reflection and port isolation are updated from 9 kHz to 110 GHz for standard antennas. Site verification of the microwave chamber are set up and the quite zone experimental verification methods are invested referring the compact range, the far field range, the OTA and the reverberation chamber up to 40 GHz. A reverberation chamber with dimensions of 16 m×13 m×7 m designed by NIM has been built in Tianjin for road vehicle EMC testing.

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The achievement transformation of electric field strength metrology technology

In order to fulfil the demand for electric field strength metrology technology from other metrology institutions, NIM has carried out the achievement transformation based on their accumulation on the aspect of electric field strength metrology over the years. Now NIM has provided a whole electric field probe calibration system designed according to the requirements of IEEE 1309-2013 for a domestic customer. The frequency range of the system is from 10 kHz to 18 GHz while the electric field strength is from 10 V/m to 100 V/m and the uncertainty is from U=1.0 dB to U=1.4 dB (k=2). NIM provided hardwares (including TEM cell, GTEM cell, anechoic chamber, and supporting mechanical devices), software (automatic control and data processing), technical report (including uncertainty evaluation) and other services for the customer. In addition, the above hardwares and software are all designed or developed by NIM specifically for this project instead of purchased from other companies. In the future, NIM has the plan to provide this achievement transformation not only for domestic customers but also for foreign customers.

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Waveform Metrology

A frequency-domain measurement approach for millimeter-wave digitally-modulated signals was proposed by the NIM in 2020, which was based on characterization of magnitude and phase spectra with swept-frequency measurements rather than the time-domain waveform by an oscilloscope. As a further development of this previous work, the measurement techniques are applied to characterize the frequency-modulation continuous-wave (FMCW) signals in 2022, where a maximum FMCW bandwidth of 2 GHz is experimentally accomplished oriented to the 24 GHz and 60 GHz automotive radar applications. The characterized FMCW signal can be used as a reference signal to calibrate commercial vector signal analyzers (VSA) and real-time oscilloscope (RTO), so that the performance and accuracy of their FMCW analysis results can be evaluated.

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