Progress Report to CCEM

(The 33th meeting of the CCEM, March 2023)

Electrical and magnetic measurements

Submitted by G. Gubler, VNIIM (St. Petersburg, Russia)
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DC and AC voltage (VNIIM, St. Petersburg, Russia)

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The primary voltage standard of VNIIM based on Josephson effect consists of the laboratory-made devices that can use 1 V and 10 V SIS and SINIS.

VNIIM has 10 V transportable Josephson standard for a key comparison of DC national voltage standards.

VNIIM carried out improvement of the primary voltage standard by introducing an automated installation based on a programmable 10 V array. The output voltage of new standard spans from 1 mV to 10 V. Now it is possible to carry out automatic calibration of both DC voltmeters and calibrators. Research is underway to use this system for calibrate AC voltage calibrators. Research is continued of pulse driven JVS system.

VNIIM maintains and develops the State primary AC voltage standard consisting of:

- special primary standard for the unit of electrical voltage in the frequency range from 10 to $3 \cdot 10^7$ Hz at voltage from 0.1 to 1000 V;

- special primary standard for the unit of electrical voltage in the frequency range from $3 \cdot 10^7$ to $2 \cdot 10^9$ Hz at voltage from 0.1 to 10 V.

Publications

A.S. Katkov. Ways to implement the new international system of units. *World of measurements*, No. 2 (192), 2021, pp. 16-21 (in Russian).

A. S. Katkov, A. N. Petrovskaya, G. B. Gubler, and V. I. Shevtsov. Prospects for the application of voltage quantum measures based on the Josephson effect for the improvement of volt standards. *Measurement Techniques*, Vol. 65, No. 7, 2022, pp. 493-499. DOI 10.1007/s11018-023-02109-9.

DC current

VNIIM maintains and develops the state primary standard of DC current in the range of $1 \cdot 10^{-16}$ A to 1 A. VNIIM uses a unique transportable standard of DC current in the range of $1 \cdot 10^{-15}$ A to $1 \cdot 10^{-9}$ A.

DC Voltage electrostatic field

VNIIM maintains and develops the State standard for the unit of the electrostatic field. The range of the electrostatic field in free space is up to ± 1000 kV/m. The range of electrostatic potential is ± 30 kV. Relative uncertainty of reproduction set point electrostatic field strength is 1.5%. The standard allows to calibrate the potential meters of a charged surface in the range of ± 50 kV. Relative uncertainty of charged surface potential is 0.6%.

AC current

VNIIM maintains and develops the State Primary AC current Standard in the frequency range of 20 Hz to $1 \cdot 10^6$ Hz. It consists of a unique set of thermo-converters that directly convert the AC current up to 20 A. AC current shunts parameters is used in the range up to 100 A at frequencies up to 100 kHz.

LF power

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New reference multifunctional system with digital inputs/outputs via IEC 61850-9-2 protocol was created. It provides traceability for reference instruments with only digital inputs/outputs via IEC 61850-9-2 (meters, power quality analyzers and calibrators, phasor measurement units, calibrators).

Comparisons

VNIIM has been participating in the following comparisons:

AC power at 50/60 Hz: APMP.EM-K5.1;

Ongoing comparisons

AC power at 50/60 Hz: CCEM-K5.

Magnetic measurements (VNIIM, St. Petersburg, Russia)

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In 2021, work began on expanding the upper limit of the range of reproduction and measurement of magnetic induction of a constant field of GET 12-2021 to $1 \cdot 10^{-8}$ - 1.5 T (currently $1 \cdot 10^{-8}$ - $1 \cdot 10^{-3}$ T), which will allow for the first time to create a single standard that allows metrological support of measurements of magnetic induction of a constant field from "hypogeomagnetic" up to "strong" fields.

In addition, work is underway to modernize the reference helium-cesium magnetometer EGM, which is a key element of the state primary standard of units of magnetic quantities GET 12-2021. The development and replacement of electronic and hardware equipment of the reference magnetometer is being carried out, software is being created, research is being conducted on the introduction of alternative form factors of the device sensor and optical pumping methods.

Magnetic measurements (VNIIM-UNIIM, Ekaterinburg, Russia)

(A. Ahmeev, lab262@uniim.ru)

In 2022, work began on improving the State primary standard of units of magnetic loss power, magnetic induction of a constant magnetic field in the range from 0.1 to 2.5 T and magnetic flux in the range from $1 \cdot 10^{-5}$ to $3 \cdot 10^{-2}$ Wb GET 198 in order to expand the measurement capabilities in the field of reproduction and transmission of dynamic magnetic characteristics of samples of magnetic materials.

As a part of the performance of the work:

- structural scheme of the facility for the reproduction and transmission of the unit of magnetic induction in alternating magnetic fields is developed;
- equipment is selected and its composition is justified;

Ongoing Comparisons:

COOMET.EM-S26 Supplementary comparison of national standard instruments in the field of magnetic flux density and magnetic flux measurements by sensing coils. Pilot laboratory VNIIM-UNIIM

High AC and DC current (VNIIM-UNIIM, Ekaterinburg, Russia)

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In 2022, work was completed to improve the state primary standard of units of electric current conversion coefficients GET 152. As a result of the improvement, the measuring capabilities of the primary standard when reproducing and transmitting units of the coefficient and angle of the scale conversion of sinusoidal current have expanded by a frequency range from 40 to 2500 Hz, and when reproducing and transmitting units of the scale conversion of direct current, the range of primary currents has increased to 10 000 A.

During the execution of the work:

- a reference installation of sinusoidal current in the frequency range from 40 to 2500 Hz has been created;

- a reference DC installation has been created in the range of primary currents up to 10000 A;

- the created installations are included in the primary standard.

Ongoing Comparisons:

COOMET.EM-S25 Supplementary Comparison of Instrument Current Transformers (CTs)

Participants: VNIIM-UNIIM – pilot laboratory, BelGIM (Belarussian State Institute of Metrology, Republic of Belarus), UzNIM («Uzbek National Institute of Metrology» State Institution, Republic of Uzbekistan), GEOSTM (LEPL Georgian National Agency of Standards and Metrology, Georgia), SASO-NMCC (SASO-NMCC National Measurements and Calibration Center, Kingdom of Saudi Arabia).

COOMET № 855/RU/22 Pilot comparisons in the field of high DC current measurements

Participants: VNIIM-UNIIM – pilot laboratory, BelGIM (Belarussian State Institute of Metrology, Republic of Belarus).

High AC and DC voltage

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VNIIMS is a centre of the national standards in the field of measurements of high and ultra high voltages.

VNIIMS continued to perform modernization in the field of HV metrology.

Some works had been finished before 2021 and the results were included to the brief reports of VNIIMS for the previous Meetings of CCEM.

The process of upgrading the equipment for HV measurements is being continued by now:

1) From 2018 to 2021 specialists of VNIIMS carried out works in terms of modernization and improved State primary special standard for the unit of DC electrical voltage – volt – in the range of ± (1...500) kV (SPS 181-2022) and has been approved, including a reference complex developed in the course of improvement based on a new component base (low-voltage thermostable reference sources of integrated design) in the range from 1 kV to 100 kV of both polarities.

2) From 2020 to 2022 specialists of VNIIMS carried out works in terms of improvement of State primary special standard of units of ratio error and phase displacement of AC voltage of power frequency in the range of $0{,}1/\sqrt{3}\ldots750/\sqrt{3}$ kV and units of the electric capacitance and tangent of the loss angle (tan δ) at AC voltage of power frequency in the range from 1 to 500 kV (SPS 175-2019) in order to expand its functionality, providing reproduction and transmission of units of ratio error and phase displacement to digital electronic voltage transformers, as well as analog and digital low-power voltage transformers (sensors) – LPVT. To the present moment, SPS 175, including a reference complex developed in the course of improvement, is approved.

3) This year improvement of the State Primary special standard of the units of electric voltage of standardized lightning and switching impulses in the range from 1 to 1000 kV (SPS 204-2012) in order to expand the functionality of SPS 204 in terms of meeting the needs of industry in the field of reproduction and transmission of the units of electric voltage of standardized lightning and switching impulses in the range from 50 to 2000 V has begun.

Ongoing Comparisons (2020-2023):

1) COOMET 821/RU-a/20 Pilot comparisons of DC high voltage measuring reference instruments in the voltage range ± (1…100) kV (SPS 181-2022)

Participants: VNIIMS – pilot laboratory, BelGIM (Republic of Belarus), NIM (National Institute of Metrology) (People's Republic of China).

Measurements under the comparisons are finished. Protocol (report) of comparisons in progress (results of comparisons between VNIIMS and BelGIM are being agreed; NIM is given

a postponement in providing the measurement results to the pilot laboratory by TC 1.3 COOMET «Electricity and magnetism» in connection with COVID restrictions in China).

2) COOMET 862/RU/22 Pilot comparisons of reference instruments measuring AC high voltage above 1 kV when transmitting units of ratio error and phase displacement to analogue low-power voltage sensors (transformers - LPVT) (SPS 175-2019)

Participants: VNIIMS – pilot laboratory, BelGIM (Republic of Belarus), interested NMIs of COOMET member-countries.

Research within the framework of comparisons with BelGIM is being performed, looking for interested participants of the comparisons.

Publications

Kiselev V.V., Grishin M.V., " Experience in testing the first domestic digital electronic voltage measuring transformers on the Pokkels effect". Digital substation. 2020. No. 13 S. 40 (in Russian).

Kiselev V.V., Grishin M.V., "Metrological support of digital measuring instruments". Collection of articles edited by Academician of the Russian Academy of Sciences V.V. Okrepilov, III International Forum Metrological Support of Innovative Technologies, 2021 St. Petersburg (in Russian).

Grishin M.V., "Analysis of the characteristics of electronic digital measuring voltage transformers". Legislative and Applied Metrology, 2022, issue 4, p. 39. (in Russian).

Kiselev V.V., Rogozhin S.Yu., Gromochkova E.V., Voinov V.N., Dubrovskaya T.A., "Improvement of the state primary special standard of DC voltage in the range from 1 to 100 kV using a differential measurement method based on microelectronic components operating on the principle of the Zener effect" Legislative and Applied Metrology, 2022, issue 4, p. 3-8 (in Russian).

Pulsed high voltage and current (VNIIOFI, Moscow, Russia)

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In 2021, VNIIOFI completed pilot comparisons of standards of pulsed electric and magnetic fields units (pulse rise time from 20 ps to 10 ns) within COOMET (project 682/RU/16). The participants of the comparisons are VNIIOFI (Russia), KRISS (Republic of Korea), Tsinghua University (PRC). Comparisons were carried out using a strip line measuring transducer as a transfer measurement device. The transfer device was calibrated in the standard facilities of the participants, which are monocone systems, excited by step pulse voltage generators. The rise time of the excitation generator pulses ranged from 10 to 200 ps. The calculated amplitude of the electric field strength pulses ranged from 1 V/m to 60 V/m. As a result of the project, the equivalence of these comparisons was established, the methodology for performing measurements was tested, and the validity of using a transfer device in the form of a strip sensor was shown.

VNIIOFI continues the upgrade of the National primary standard of the lightning discharge pulse current unit GET 202-2012, which began in 2021. The upgraded standard will be used to calibrate measuring instruments for electrostatic discharge current. To reproduce current pulses, solid-state high-voltage pulse generators are used, working on terminals with a measuring instrument and then to a matched load of 50 ohms. Reference coaxial shunts have been developed to control reproducible pulses and transmit units. The expected range of reproduction of a unit of pulsed current is from 1 A to 100 kA, the minimum duration of the pulse rise time is 1 ns, the expanded uncertainty of reproduction of a unit (k=2) is not more than 5%.

Publications

Dolmatov T.V., Bukin V.V., Garnov S.V., Gerasimchuk O.A., Popovsky Yu.Yu., Neustruev V.V., Sakharov K.Yu., Mikheev O.V. Ultra-wideband Electric Field Measurement System Using CDTE-based Dielectric Fiber Tip Sensor. Doklady of Russian Academy of Sciences. Physics, Technics. 2022. N. 1. V. 503. P. 8-12.

Sukhov, A.V., Sakharov, K.Y., Zolotarevsky, Y.M. et al. A Study of High Transient Voltage Unit Realization Uncertainty. Meas Tech 63, 823–827 (2021). https://doi.org/10.1007/s11018-021-01859-8.

RF power (VNIIFTRI, Moscow, Russia)

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In 2021, measures were taken to improve the State Primary Standard of the unit of power of electromagnetic oscillations GET 167-2021 in order to improve its technical characteristics in terms of increasing the accuracy of measurements and expanding the frequency range from 37.5 to 118.1 GHz. The basis for reproducing the power unit in GET 167-2021 is the method of replacing microwave power with DC power. Substitution is implemented in a bolometric wattmeter consisting of a system of automatic replacement of microwave power with DC power and a set of bolometric converters. In GET 167-2021, a bolometric method for comparing DC power and electromagnetic oscillation power is used as providing the highest accuracy.

The achievement of the set goals became possible due to the implementation of the following scientific results obtained for the first time: original calorimetric bolometric power converters were developed; the value of the non-excluded systematic error of the standard was clarified due to the influence of nonequivalence of substitution in calorimetric converters.

VNIIFTRI has been participating in the CCEM.RF-K27 Key comparisons of power standards in the frequency range from 50 to 75 GHz.

Publications

A.V. Koudelny, I.M. Malai, A.I. Matveev, V.A. Perepelkin, I.P. Chirkov. The state primary standard of the unit of power of electromagnetic oscillations in the frequency range 37.5–118.1 GHz GET 167-2021 // Measuring equipment. 2022. № 6. C. 3-8

Key comparison CCEM.RF-K27.W of RF power from 50 GHz to 75 GHz in rectangular waveguide/ Electromagnetic Wave Metrology Group // January 2023 - Metrologia 60(1A):01001. - doi.org/10.1088/0026-1394/60/1A/01001

RF noise (VNIIFTRI, Moscow, Russia)

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In 2021, the State Primary Standard of the unit of Spectral power density of noise radio emission in the frequency range from 0.002 to 178.3 GHz GET 21-2021 was approved. As primary reference measures, low-temperature noise generators were introduced into the GET 21-2021. The designed and manufactured primary reference measures were investigated: two coaxial low–temperature noise generators in the frequency ranges 0.002–4.0 GHz, 4.0-12.05 GHz and three waveguide low-temperature noise generators in the frequency ranges 12.05–17.44 GHz, 17.44–25.86 GHz, 25.86–37.5 GHz.

Publications

State primary standard units of spectral power density of noise radio emission in the frequency range from 0.002 to 178.3 GHz GET 21-2021, Measuring Technology No. 12, 2022. - doi.org/10.32446/0368-1025it.2022-12-3-9

Reflection coefficient in waveguide (VNIIFTRI, Moscow, Russia)

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In the period from 2019 to 2022, a set of equipment was developed for measurements of the highest accuracy reflection coefficient in the frequency range up to 178.4 GHz in waveguide paths. Sets of reference measures λ/4, λ/8, 3λ/8 are developed in sections of the waveguide path 90,0×45,0; 72,0×34,0; 58,0×25,0; 48,0×24,0; 40,0×20,0; 35,0×15,0; 28,5×12,6; 23,0×10,0; 17,0×8,0; 16,0×8,0; 11,0×5,5; 7,2×3,4; 5,2×2,6; 3,6×1,8; 2,4×1,2; 1,6×0,8; WR-340; WR-284; WR-229; WR-187; WR-159; WR-137; WR-112; WR-102; WR-90; WR-75; WR-62; WR-51; WR-42; WR-34; WR-28; WR-22; WR-19; WR-15; WR-12; WR-10; WR-8; WR-6. Research is underway on the equipment.

Publications

Bondarenko A.S., Borovkov A.S., Malay I.M., Semyonov V.A.. Methodology for determining the error of reproducing the unit of the complex reflection coefficient in waveguide paths. Measurement Techniques, 2022, vol. 64, no. 11, pp. 922–927. DOI: 10.1007/s11018-022-02022-7

Bondarenko A.S., Borovkov A.S., Semenov V.A., Guba V.G. Methodology for determining the measurement error of complex reflection and transmission coefficients using vector circuit analyzers in waveguide paths // XII All–Russian seminar on radiophysics of millimeter and submillimeter waves, Nizhny Novgorod, February 28 – March 4, 2022 - Nizhny Novgorod: IPF RAS. – 2022. – p. 128.

Antenna gain, antenna pattern (VNIIFTRI, Moscow, Russia)

In 2022 measurement system development for precision measurements of antenna characteristics was completed. The new system includes an extrapolation range and a compact range. The equipment provides measurements of antenna parameters in the frequency range from 1 to 50 GHz.

Frequency deviation (VNIIFTRI, Moscow, Russia)

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In 2021, the upgrade of the State Primary Standard GET 166-2020 was completed. A direct digital signal synthesis method has been implemented to reproduce the frequency deviation unit. This method is devoid of a number of sources of errors in measuring frequency deviation and allows you to significantly expand the ranges of carrier and modulating frequencies, as well as increase the maximum reproducible value of the frequency deviation unit by 10 times without increasing the non-excluded systematic error. The Primary Standard includes modern measuring instruments based on digital signal analysis - a signal analyzer and a digital storage oscilloscope, which allow transmitting a unit of frequency deviation to reference measuring instruments and significantly expand the capabilities of the primary standard.

The expanded uncertainty of reproducing a frequency deviation unit within (0.02...0.05) % ($p = 0.95$, $k = 2$).

Publications

Kaminsky O. V., Mylnikov A. V., Mogilev I. V., Tishchenko V. A. The state primary standard of the frequency deviation unit GET 166-2020. *Measurement Techniques.* 2022, vol. 65, no. 4, pp. 227–232. https://doi.org/10.1007/s11018-022-02073-w

Mogilev, I.V., Mylnikov, A.V., The primary standard of frequency deviation. New opportunities and perspectives. *Measurment Techniques,* 2019, vol. 62, pp. 1–6. https://doi.org/10.1007/s11018-019-01577-2