KRISS 한국표준과학연구원 Korea Research Institute of Standards and Science

Progress Report of KRISS on DC, LF, RF and Magnetic Measurement (2023-2024)

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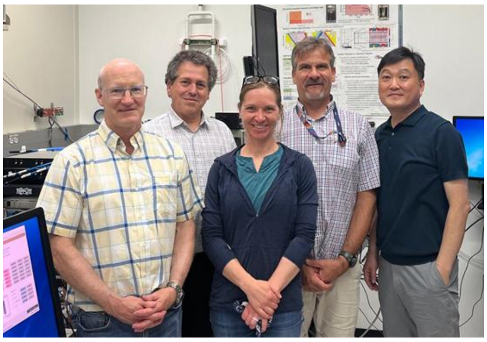
1. PJVS-based differential sampling of AC Voltage (Dr. Mun-Seog Kim and Ms. Hehree Cho)

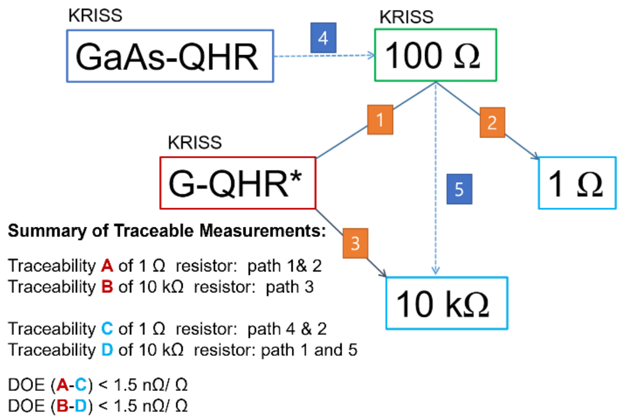
In 2023, KRISS participated in a pilot study for an international on-site comparison of AC voltages based on the Josephson standard to be conducted by the BIPM. For about three weeks at KRISS in Daejeon, comparisons were performed in the frequency range below 1.25 kHz using a KRISS-developed programmable Josephson voltage standard (PJVS) and differential sampling system. The study employed an AC source developed by CMI in the Czech Republic as the transfer standard, and comparisons were performed using two different samplers (NI PXI-5922 and Fluke 8588A). Then, in the summer of 2024, KRISS also participated in another BIPM pilot study at NIST in Boulder. This pilot study, involving BIPM, KRISS, and NIST, was the first to measure AC waveforms synthesized by a Josephson arbitrary wave synthesizer (JAWS) developed by NIST with the BIPM (KRISS and NIST-developed) measurement system. The measurements confirmed the reliability of the BIPM system, achieving a Type A uncertainty of 1 part in 10^9 for a 10 Hz sine wave at 2 V rms.

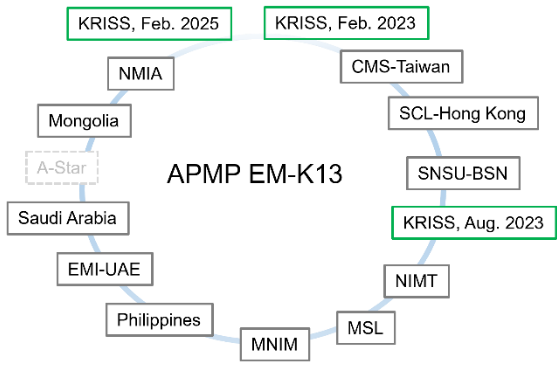
In 2025, KRISS will publish a paper titled “Effect of Sampler Characteristics in Differential Sampling Adopting a Programmable Josephson Voltage Standard” in the IEEE Transactions on Instrumentation and Measurement (accepted for publication), which reports on the effect of the filter functions of the NI PXI-5922 on the differential sampling based on a PJVS. This publication completes a series of three papers by KRISS and BIPM investigating the impact of samplers, including the Keysight 3458A (“Measurement configurations for differential sampling of AC waveforms based on a programmable Josephson voltage standard: effects of sampler bandwidth on the measurements”, Metrologia, vol. 57, no. 6, p. 065020, 2020) and Fluke 8588A (“Differential sampling of AC waveforms based on a programmable Josephson voltage standard using a high-precision sampler”, Metrologia, vol. 59, no. 1, p. 015006, 2022), on differential sampling.



2. Quantum Hall Resistance at KRISS (Dr. Dong-Hun Chae and Mr. Seong Su Shin)

KRISS provides the traceability of a key comparison (APMP.EM-K13) amongst the NMIs within the APMP. The two traveling 1 Ω and 10 kΩ resistance standards link to the SI value of the von Klitzing constant R_K (h/e^2) with a cryogenic current comparison (CCC) resistance bridge at KRISS. The Hall resistance plateau at $R_K/2$ for a filling factor of 2 is realized with a KRISS-made graphene Hall device. The 10 kΩ resistance standard was directly compared with the quantized Hall resistance (QHR). The measured value was confirmed through a ratio measurement of the 10 kΩ resistance standard to a precalibrated KRISS-owned 100 Ω resistance standard with the GaAs-based QHR standard [1] at 0.3 K and the CCC bridge [1]. The 1 Ω resistance value was determined via the 100 Ω resistance standard, which was determined in comparison with $R_K/2$ in the graphene device; two resistance ratio measurements of $(R_K/2)/R_{100\Omega}$ and $R_{100\Omega}/R_{1\Omega}$ were consecutively performed.



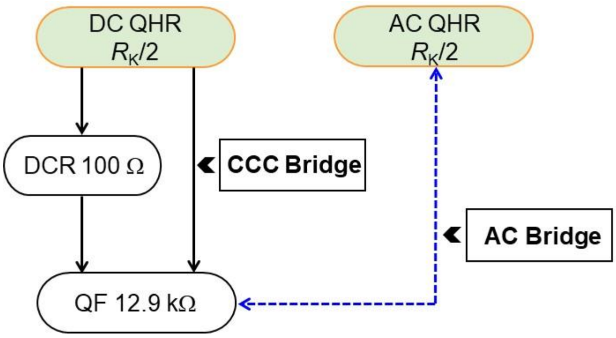


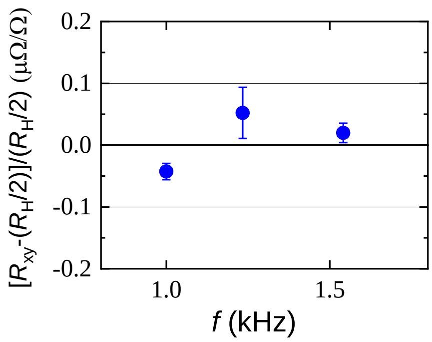
A KRISS-made graphene Hall device was employed to realize the QHR in liquid helium at a temperature of 4.2 K and a magnetic field of 10 T [2]. A current of 38.74 μA was applied for the realization. A dissipation of graphene device in the quantum Hall state was investigated by measuring the longitudinal resistance, which corresponds to a difference between the ordinary Hall resistance and a Hall resistance, measured in a diagonal Hall configuration as described in the Guideline [3]. The QHR in the graphene device was compared with the GaAs-based KRISS QHR standard via the 100 Ω resistance standard. The degree of equivalence is smaller than 1.5 nΩ/Ω [2].

A 12-bit CCC bridge was employed to measure resistance ratios as described in Ref. 1. Driven currents through 1 Ω, 100 Ω, 10 kΩ, and QHR are 50 mA, 0.5 mA, 50 μA, and 38.74 μA, respectively. The applied currents through two comparing resistors are reversed every 10 s to avoid an offset bridge voltage and its time drift. Employed turn ratios for resistance ratio measurements of $(R_K/2)/R_{10k\Omega}$, $(R_K/2)/R_{100\Omega}$, $R_{10k\Omega}/R_{100\Omega}$, and $R_{100\Omega}/R_{1\Omega}$ are 2056/1593, 4001/31, 4100/41, and 400/4, respectively. The resistance ratio was determined by the following bridge equation; $R_1/R_2 = (N_1 + kN_A)/N_2 \cdot (1 + \Delta U/\Delta(IR))$. For balancing, an auxiliary fractional effective turn (kN_A) was applied. Here, $\Delta(IR)$ is the voltage drop across a resistor, typically approximately 1 V. The voltage drop for the ratio measurement of $R_{100\Omega}/R_{1\Omega}$ is exceptionally 0.1 V. The bridge voltage difference (ΔU) was measured by a nanovoltmeter module in the bridge.

3. AC Quantum Hall Resistance in Graphene at KRISS (Dr. Dan Bee Kim, Dr. Dong-Hun Chae, Dr. Wan-Seop Kim, and Mr. Seong Su Shin)

The quantum Hall resistance (QHR) of a graphene device—fabricated at KRISS—was measured at AC using a digital impedance bridge. In order to verify the measurement, the degree of equivalence was confirmed between the DC and the AC QHR values using a quadri-filar resistor as a transfer standard. The 12.9 kΩ quadri-filar resistor was first calibrated against the QHR at DC using a cryogenic current comparator. Then, they were compared again at AC using a 4-terminal-pair digital bridge. The AC comparisons were done near 1 kHz, and the results showed that the measured AC QHR values agreed with the DC QHR value on the 10^{-8} level. Based on the successful results, further studies are being carried on, including the frequency extension and the capacitance calibration against the AC QHR.

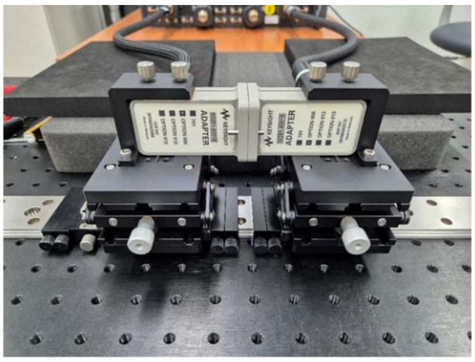




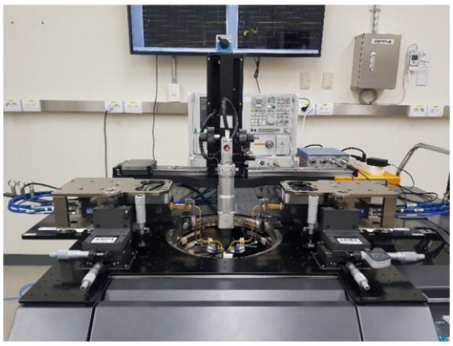
4. RF Impedance (Dr. Chi-Hyun Cho, Dr. Hyunji Koo, Dr. Tae-Weon Kang, and Dr. Jae-Yong Kwon)

Recently, we established waveguide impedance measurements from 50 GHz to 220 GHz and launched calibration services for V-, W-, D-, and G-bands. We are now in the process of re-establishing the impedance standards for X-, Ku-, K-, Ka-, and Q-bands. Additionally, we have started E-cal calibration services last year.
We are currently participating in the CIPM key comparison CCEM.RF-K5.d.CL (2.4mm coaxial impedance).

For on-wafer impedance, we are focusing on research aimed at solving the coupling problem between probes. Additionally, we are manufacturing an impedance calibrator on a silicon substrate to ensure measurement reliability in semiconductor chips. Last year, we conducted a measurement comparison with PTB, and the results show quite good agreement.



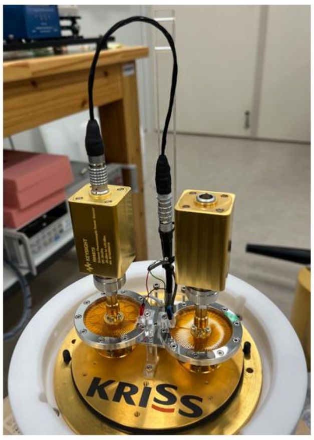
Waveguide measurement system

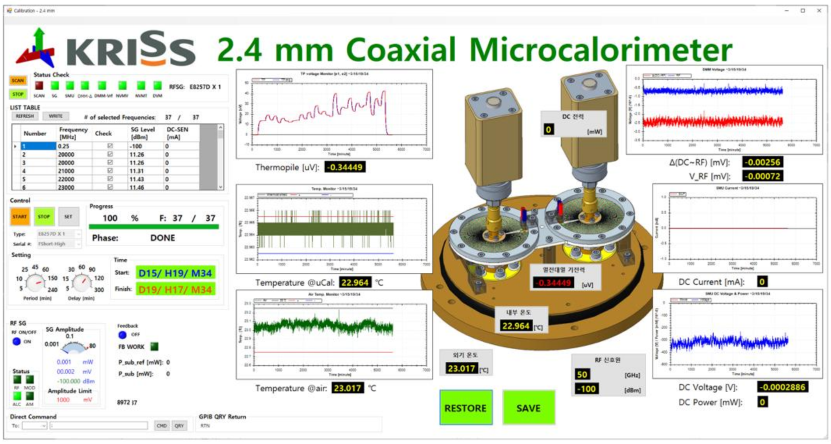


On wafer measurement system

5. RF power (Dr. Jae-Yong Kwon and Dr. Tae-Weon Kang)

We set up and have been evaluating KRISS 2.4 mm coaxial microcalorimeter (~ 50 GHz). The system will adopt
commercial thermoelectric power sensors as its transfer standards after feasibility test. We expect the microcalorimeter to replace several waveguide-band microcalorimeters below 50 GHz.



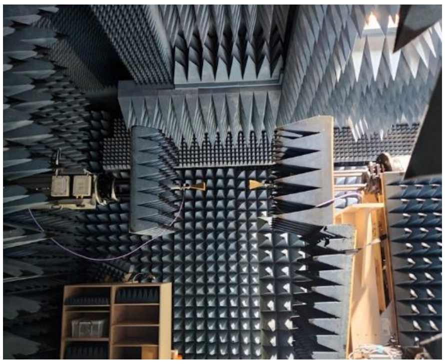


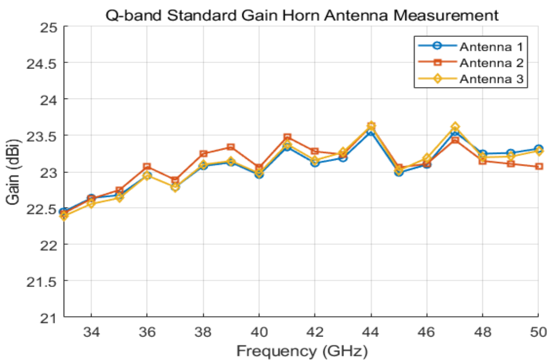
KRISS 2.4 mm coaxial microcalorimeter and its operation software

We have participated in the CIPM key comparison CCEM.RF-K28.W, RF power from 18 GHz to 26.5 GHz in rectangular waveguide and submitted the measurement report to the pilot laboratory.

6. Antenna (Jeong-Il Park and Dr. In-June Hwang)

We have developed a new measurement system for Q-band (33–50 GHz) antenna measurements. This system was built by replacing the outdated equipment in the near-field measurement chamber at KRISS with newly purchased equipment. To evaluate the performance of the new Q-band antenna measurement system, we measured the far-field gain of a standard gain horn antenna. We plan to confirm the accuracy and reliability of the Q-band antenna measurement system through uncertainty analysis. Through this equipment replacement and validation process, we aim to improve the accuracy of antenna measurements and contribute to future research, such as antenna inter-comparisons.



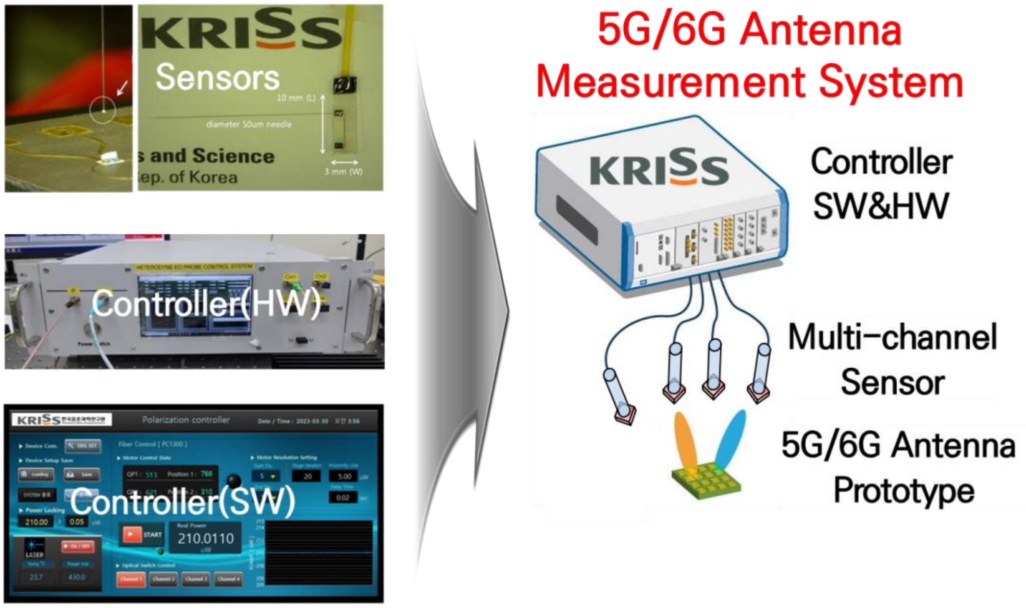


KRISS Q-band (33-50 GHz) antenna measurement system and measured far-field gain of standard gain horn antennas

7. EO(Electro-optic)-based 5G/6G Antenna Measurement System (Dr. Young-Pyo Hong and Dr. Dong-Joon Lee)

We developed 5G/6G (frequency range: 1~40 GHz) antenna measurement system based on a non-metallic sensor using an optical method. To evaluate antenna performance, the sensor is placed at a certain distance to measure the electromagnetic waves generated by the antenna. Previously, metallic sensors were used. This caused coupling effects due to the electromagnetic wave reflection properties of metal, resulting in distorted measurements. This problem was easily resolved by replacing them with non-metallic sensors the size of a grain of rice. Moreover, unlike previous measurements that required very large, fixed facilities such as anechoic chambers, the measurement equipment developed by KRISS is lightweight, similar in size and weight to a computer tower, making it portable and suitable for use in standard laboratories.

We have transferred this technology to East Photonics Co., Ltd., a company specializing in fiber optic communication and repeaters, for a royalty of KRW 300 million, and a signing ceremony was held on April 8, 2024.



5G/6G Antenna Measurement System developed by KRISS

References

[1] Gournay P, Rolland B, Chae D-H and Kim W-S 2020 On-site comparison of quantum hall effect resistance standards of the KRISS and the BIPM: ongoing key comparison BIPM.EM-K12 *Metrologia* **57** 01010

[2] Chae D-H, Kruskopf M, Kucera J *et al* 2022 Investigation of the stability of graphene devices for quantum resistance metrology at direct and alternating current *Meas. Sci. Technol.* **33** 065012

[3] Delahaye F and Jeckelmann B 2003 Revised technical guidelines for reliable DC measurements of the quantized Hall resistance *Metrologia* **40** 217–23