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New developments for the programmable quantum current generator

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Summary:

This paper describes the latest improvements of the programmable quantum current generator. Here we focus on the fabrication of the new cryogenic current comparator, which will allow implementing the triple connection between the quantum Hall resistance standard and the programmable Josephson voltage standard, necessary step to reduce the correction on the generated current from few parts in 10^7 to few parts in 10^{10}. Other on-going developments towards a laboratory dedicated to a new ampere traceability are also introduced.

Keywords: Current measurements, metrology, quantum standards, cryogenic current comparator.

Introduction

The first implementation of the PQCG demonstrated that the ampere could be realized from the elementary charge, e, with a 10^{-8} relative uncertainty in the mA range down to the µA range [1]. The high accuracy is obtained by applying Ohm's law in a circuit connecting directly a quantum Hall resistance standard (QHRS) and a programmable Josephson voltage standard (PJVS) with a multiple connection scheme and by amplifying the quantized current with a cryogenic current comparator (CCC). Our next goal is to develop a more compact and even more accurate version of the PQCG in a dedicated laboratory. We already demonstrated noise improvements of the set-up and reported in a comparison with the Ultrastable Low-Noise Current Amplifier (ULCA) from PTB at 50 µA [2]. An important target is the development of a new CCC, which allows implementing the triple connection of the QHRS to the PJVS in order to reduce to a negligible value the cable correction, which was amounting to a few 10^{-7} in the double connection scheme previously implemented. Hence the goal is to generate a quantum current simply given by Gn_Jef_J , where G is the gain of the CCC, and n_J and f_J are the number of Josephson junctions and the Josephson frequency respectively. This important step will not only reduce the Type B uncertainty budget to a few parts in 10^9 but also results into a significant simplification of the system by avoiding the measurement of the cable resistances. After a detailed description of the new CCC, we will give some details about the other on-going developments towards a more compact version of the PQCG and we will discuss the advantage to use the PQCG to calibrate resistances.

Design of the new CCC

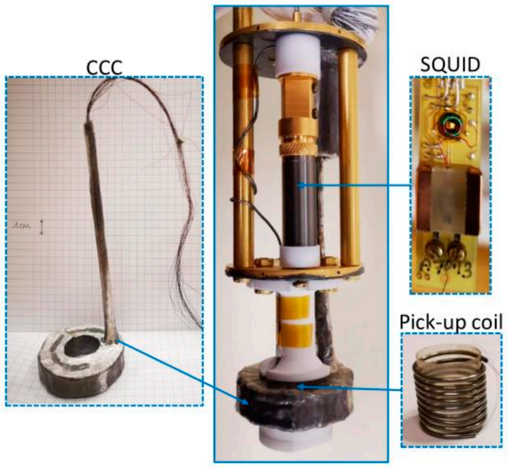

Fig.1: CCC mounted in the cryoprobe.

The new CCC is based on an architecture similar to the one presented in [3] but with 5 additional windings. The total number of turns is 8789. The CCC is made of 20 windings of 1, 1, 1, 2, 2, 16, 16, 16, 32, 64, 128, 128, 160, 160, 465, 465, 1600, 1600, 2065 and 2065 turns. The triple connection will be possible for the windings of 1, 2, 16, 128, 160, 465 and 1600 turns. The possibility to connect the circuit containing the PJVS and the QHRS to three windings of 465 turns will allow enhancing in an optimum way the signal-to-noise ratio while preventing the Johnson-Nyquist noise of the QHRS at 1.3 K from becoming the dominant contribution [2]. The windings were glued with a two-component epoxy adhesive. Each winding is made of insulated 80-µm-diameter Cu clad NbTi superconducting wire. We used 150-µm-thick Pb foils and Pb/Sn/Bi superconducting solder with a low melting temperature to realize the toroidal shielding around the windings. To prevent flux leakage, the toroidal shield is made of three electrically insulated turns corresponding to two overlap turns. The inner and outer diameter of the toroidal shield are 19 mm and 47 mm respectively. The chimney is about 125 mm high. The CCC is fixed by a nut on a screw made of machinable glass ceramic (Macor) at the bottom of the cryogenic probe. The CCC is enclosed in a first 0.5-mm-thick Pb superconducting cylindrical screen with an inner diameter of 57 mm and a height of 83 mm. The lead foil is maintained mechanically into a gold plated brass cylinder. Based on the geometries of the CCC and of the superconducting shield, the calculated effective inductance of the CCC is 14.5 nH.

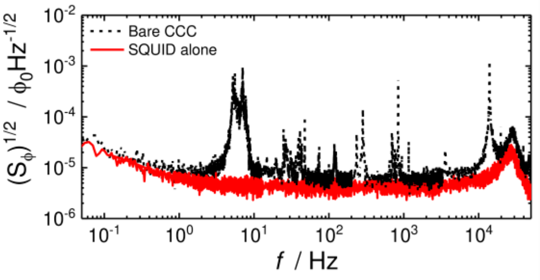

Fig.2: Noise spectrum of the bare CCC and the SQUID alone.

Fig.1 shows the mounting of the CCC into a cryoprobe, which was designed to reduce the mechanical vibrations leading to electrical noise in measurements. It is equipped with a Quantum Design Inc. DC SQUID, which has a white noise level of 3 $\mu\phi_0\mathrm{Hz}^{-1/2}$, where ϕ_0 is the superconducting flux quantum, and a 1/*f* corner frequency f_c = 0.3 Hz. The SQUID is placed in a separate superconducting Nb shield. It is coupled to the CCC via a superconducting flux transformer composed of a wire wound sensing coil placed as close as possible to the inner surface of the CCC. The coil is made of a 100-µm diameter NbTi wire inserted in a lead tube to increase the effective radius of the wire. The coupling is obtained with a sensing coil of N_p = 9 turns, leading to a measured sensitivity of 8 µA.turns/ϕ_0. Forty copper alloy wires with a stainless steel shield are connected to the CCC wires on a PTFE plate in the helium bath. Two concentric magnetic shields are added: a Pb superconducting shield enclosing the SQUID and the CCC stages and a Cryoperm shield surrounding the whole. The expected overall magnetic attenuation is about 202 dB. The noise spectrum of the CCC and of the SQUID alone are presented in Fig.2. The base noise level of the CCC amounts only to 7 $\mu\phi_0\mathrm{Hz}^{-1/2}$, slightly above the base SQUID level, which proves the shielding efficiency. At frequencies below f_c, one can observe the dominant contribution of the 1/*f* SQUID noise.

Other developments and conclusion

The developments for the new version of the PQCG are done in a new laboratory dedicated to the metrology of the ampere. Two pits 3 m apart are dedicated to the QHRS on one side and to the CCC or two PJVS systems on the other side. The latter hosts a cryogenic system based on a pulse tube refrigerator, which has been shielded with a 3 mm pure iron screen reducing the magnetic field to less than 20 µT when the QHRS is operated at 10 T. A new external voltage controlled current source has been developed delivering currents from the nA range to the mA range.

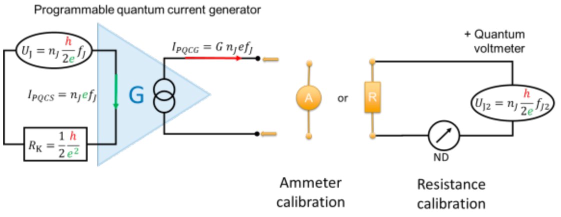

Fig.3: Calibration set-up for the calibration of currents or resistances using the PQCG.

One of our objectives is to investigate the possibility of using the PQCG for the direct calibration of resistances in conjunction with a quantum voltmeter (PJVS associated with a voltage null detector) as described by the sketch of Fig.3. We expect reaching relative uncertainties down to a few 10^{-9} in a more flexible way than with resistance comparison bridges: no need of transfer resistance, wide range of resistance values from 1 Ω to 1 GΩ, more flexibility on the value of the measurement current, reduction of the effect of the current leakage owing to the low impedance of the PJVS. Hence, the PQCG realizing the ampere would constitute the skeleton of a future quantum calibrator.

References

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