Traceable low-current measurements towards the realisation of the ampere in the new SI

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Summary

This work is focused on DC low current measurements in the frame of the new International System of Units (SI). All the units of new SI, that will be implemented starting from the 20 May 2019, are based on fundamental constants of nature. The new definition of the ampere is based on the assignment of an exact value to the elementary charge e. Single-electron devices are a possible realization of this new definition due to their ability to transfer an integer number of charges in a controlled way.

Transresistance amplifiers are commonly employed to measure the current produced by single-electron devices, which is usually below the nanoampere level. In this dissertation two amplifiers are investigated: the commercial FEMTO DDPCA-300 and the advanced Ultrastable Low-noise Current Amplifier (ULCA).

The FEMTO DDPCA-300, embedded in a simple temperature control system, achieves a resolution around 15 times better than the uncontrolled case. The amplifier gain is calibrated by using a set-up which employs the capacitance-charging method, achieving an accuracy of the order of 10^{-5}. The set-up is especially design and built for the calibration of transresistance amplifiers with currents in the range from 100 fA to 100 pA.

On the other hand, the resolution of the ULCA can be enhanced by a factor of around four by shielding it in a Mu-metal box. By using a 14 bit cryogenic current comparator (CCC), the overall transresistance gain of the ULCA can be calibrated with a relative uncertainty in the 10^{-8} range.

The final part of this dissertation is dedicated to the work done in the measurement of a single-electron pump, based on GaAs/AlGaAs heterostructure, generating a nominal current of 100 pA. New features of the experimental set-up are introduced in order to perform a high accuracy measurement. The outcome of a 16 hours measurement is presented: the current produced by the pump is measured with a preliminary accuracy of 9×10^{-8}. This result, which is beyond the state of the art, is a big step towards the adoption of single-electron pumps as quantum current standards.