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Fundamental Metrology by Counting Single Flux and Single Charge Quanta with Superconducting Circuits

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Transferring single flux quanta across a Josephson junction at an exactly determined rate has made highly precise voltage measurements possible. Making use of self-shunted Nb-based SINIS junctions, programmable fast-switching DC voltage standards with output voltages of up to 10 V were produced. This development is now extended from fundamental DC measurements to the precise determination of AC voltages with arbitrary waveforms. Integrated RSFQ circuits will help to replace expensive semiconductor devices for frequency control and signal coding. Easy-to-handle AC and inexpensive quantum voltmeters of fundamental accuracy would be of interest to industry.

In analogy to the development in the flux regime, metallic nano-circuits comprising small-area tunnel junctions and providing the coherent transport of single electrons might play an important role in quantum current metrology. By precise counting of single charges these circuits allow prototypes of quantum standards for electric current and capacitance to be realized. Replacing single electron devices by single Cooper pair circuits, the charge transfer rates and thus the quantum currents could be significantly increased. Recently, the principles of the gate-controlled transfer of individual Cooper pairs in superconducting Al devices in different electromagnetic environments were demonstrated. The characteristics of these quantum coherent circuits can be improved by replacing the small aluminum tunnel junctions by niobium junctions. Due to the higher value of the superconducting energy gap ($\Delta_{Nb} \approx 7\Delta_{Al}$), the characteristic energy and the frequency scales for Nb devices are substantially extended as compared to Al devices. Although the fabrication of small Nb junctions presents a real challenge, the Nb-based metrological devices will be faster and more accurate in operation. Moreover, the Nb-based Cooper pair electrometer could be coupled to an Nb single Cooper pair qubit which can be beneficial for both, the stability of the qubit and its readout with a large signal-to-noise ratio.