Current waveform synthesis by quantized single-electron pumping

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Electrical quantum metrology links the electrical units to fundamental constants of nature, namely the charge of the electron e and Planck's constant h. The success of quantum metrology is documented by the plans of the General Conference on Weights and Measures to redefine the international system of units (SI) based on fundamental constants. In electrical quantum metrology the two effects which have been successfully applied for many years are the Josephson effect for the generation of quantized voltages and the quantum Hall effect for quantized resistance. Recently, semiconductor-based single-electron pumps (SEP) have become subject of intense studies as they might allow the realization of a quantum standard of the electrical base unit ampere [1,2]. When operated at a pumping frequency f such single-electron pumps generate quantized currents $I = ef$. These pumps have so far demonstrated output currents above 100 pA with ppm uncertainty [3], and promise lower uncertainties based on theoretical analysis [3,4].

Initially, all electrical quantum standards have been operated in dc mode only. Later, Josephson quantized ac voltage generation was realized based on switchable binary arrays and on pulse-driven arrays enabling arbitrary waveform synthesis. Additionally, studies of the ac quantum Hall effect have recently paved the way to a quantum standard of electrical capacitance [5]. However, the generation of quantized ac current waveforms based on frequency-modulated single-electron pumping has not been considered yet.

We will present the results of a proof-of-principle experiment on the generation of ac modulated quantized currents using a semiconductor-based single-parameter SEP [2] with frequency-modulated pumping frequency. These pumps are driven by a single high frequency signal and can be used over a wide frequency range which allows for a robust implementation of modulation schemes. ac-modulated quantized current waveforms are generated by sinusoidal and sawtooth modulation of the pumping frequency f. In our experiments kHz modulation frequencies and peak currents up to 100 pA are realized. The modulation frequency in our experiment was only limited by our current measurement bandwidth and thus our detection ability; generation of ac currents at MHz frequencies is possible. More advanced modulation schemes based on pulse-driven SEPs in combination with parallelization [6] could in the future enable arbitrary quantized current waveform synthesis with nA peak amplitude with applications in metrology and on-chip signal generation.

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