Experimental Realization of a Differential Radio-Frequency Single-Electron Transistor

J.F. Schneiderman*, P. Delsing[†,‡], M.D. Shaw*, H.M. Bozler*, and P.M. Echternach[‡]

[‡]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA*
**University of Southern California, Dept of Physics and Astronomy, Los Angeles, CA 90089-0484, USA*
[†]*Chalmers University of Technology, Microtechnology and Nanoscience, MC2, 412 96 Göteborg, Sweden*

Abstract. We have fabricated and characterized a new type of electrometer that couples two parallel single-electron transistors (SETs) to a radio-frequency tank circuit for use as a differential RF-SET. We demonstrate operation of this device in summing, differential, and single-SET operation modes. In differential mode, the device is sensitive to uncorrelated input signals while screening out correlated ones.

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The single-electron transistor[1,2] (SET) is widely used as an extremely sensitive electrometer, having found a niche in a number of applications involving ultra-sensitive measurements. Unfortunately, background charge fluctuations[3] have been a problem plaguing single electron devices since their inception. Such charges are thought to be a primary cause of the 1/f noise that limits the resolution of precision charge measurements. Over time, a number of important technological improvements have been made to the SET, such as radio-frequency operation[4]. The RF-SET is operated at sufficiently high frequencies for the 1/f noise level to be substantially lowered.

In this letter, we report the experimental demonstration of a differential RF-SET (DRFSET) consisting of two parallel SETs acting as the dissipative element of a single resonant LC circuit. Each SET has a separate transfer function which reflects the change in its conductance as a voltage is applied to its respective gate. To achieve differential readout, the SETs are biased so that their responses are of opposite sign. In this mode, when a fluctuation in charge couples to both SET islands, the conductance change of one island will be opposite in sign to that of the other, leading to a cancellation of the change in the conductance of the parallel SETs. In other words, the DRFSET is insensitive to collective fluctuations in charge affecting both SET islands together. This mode of operation also allows for a strong differential readout since increasing the charge coupled to one SET while decreasing the charge coupled to the other will produce a correlated and reinforced change in conductance of the parallel SETs, and hence a large change in the dissipation of the LC tank circuit for readout.

Other modes of DRFSET operation are also possible, depending on where each SET is biased on its transfer function (see Figure 1). The simplest mode of operation is to bias one SET at an insensitive part of its transfer function and the other at its highest sensitivity. This "single-SET" mode is useful for characterization of the separate SETs. Finally, one can operate the DRFSET in a "common" or summing mode which is closer to the usual RF-SET setup. Summing mode is made possible by biasing each SET island so that the signs of their respective responses are the same. Both SETs will then respond in the same way to an overall change in charge on their respective islands. DRFSETs were fabricated using a standard double-angle shadow mask evaporation technique[2]. Operation in the RF mode is achieved by sending an RF signal to an LC tank circuit for which the parallel SETs act as the dissipative element[4].

We have measured the voltage of the reflected signal as a function of both gate voltages with the SETs biased at the double-Josephson-quasiparticle (dJQP) peak[5,6]. Figure 1 shows the results of such a measurement, and indicates gate voltage values appropriate for each mode of operation. Regions where the slope of the curve is large represent operating points of high SET sensitivity. At point **a**, for example, the reflected signal is essentially independent of the voltage on gate 1, but depends strongly on gate voltage 2, and thus represents a point where only SET2 is sensitive (single-SET mode). Similarly, at point **b** only SET1 is sensitive. At points **c** (summing mode) both SETs are sensitive and biased on the same slope, so an increase in both gate voltages yields a net sum change in the reflected RF signal.

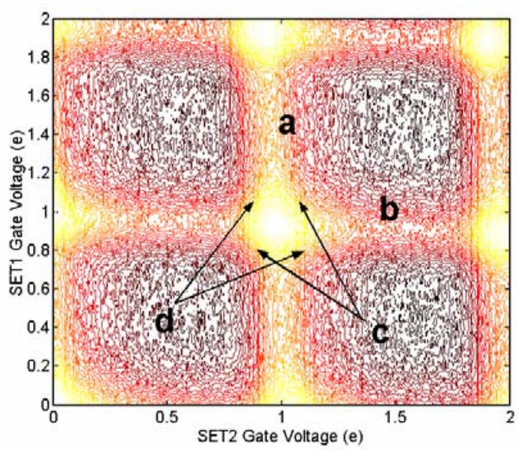

FIGURE 1. Coefficient of reflected power as a function of both SET gate voltages.

Finally, at points **d** (differential mode), where the SETs are biased on opposite slopes, an increase in both gate voltages results in an opposing change in the conductance of each SET, tending to cancel out the change in reflected power from the overall device. However, a change in each gate voltage in opposite directions will yield a reinforced change in the overall reflected power.

To demonstrate operation of the DRFSET, we applied small amplitude ($0.01e_{PP}$) low-frequency signals to each of the SET gates, and a third signal to both. Each signal had a unique and coprime frequency to avoid self-mixing or mixing with harmonic and subharmonic modes. We applied 9- and 11-Hz signals to SET1 and SET2 respectively, and a 13-Hz "common-mode" signal. By varying the DC offset levels of the 9- and 11-Hz signals, we could vary the operating point of the DRFSET, changing between summing, differential, and single-SET modes. We examined the reflected signal from the DRFSET using a spectrum analyzer, as shown in Figure 2. In Figures 2a and 2b, the SETs are biased in single-SET mode. For Figure 2a, The strong 11-Hz peak and absence of the 9-Hz one indicates SET1 is completely insensitive and SET2 is at maximum sensitivity. The opposite configuration in which SET1 is sensitive and SET2 is totally insensitive is evident in Figure 2b.

Figure 2c shows operation of the DRFSET in summing mode and 2d demonstrates differential mode. Observe the peak corresponding to the 13-Hz common mode signal is pronounced while in summing mode, whereas operation in differential mode causes this signal to be suppressed below the 1/f noise floor. To ensure the DRFSET was insensitive to correlated input signals for all frequencies up to several hundred Hz, we applied a white noise signal to both gates. The differential mode showed an average reduction in the correlated noise of 9.8±0.2 dB. The DRFSET operated in differential mode is thus insensitive to common mode signals, and therefore has the advantage of being immune to correlated noise.

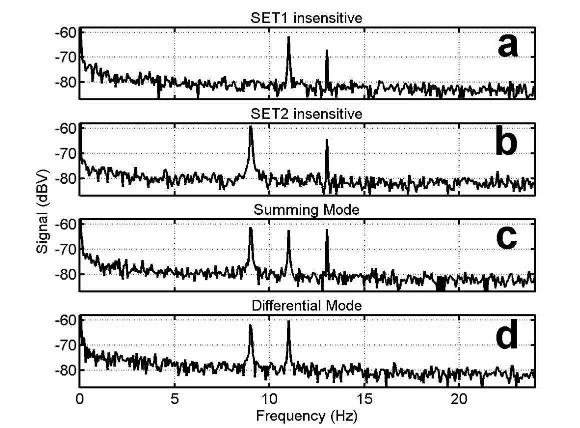

FIGURE 2. DRFSET readout spectra. Graphs a-d correspond to the four modes of operation indicated in Figure 1.

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