SUPERCONDUCTING DIGITAL CIRCUITS FOR SUB KELVIN APPLICATIONS

PICO-GROUP

LOW TEMPERATURE LABORATORY

Thermal isolation and transport are important issues in microsensors and microelectronics. Most of the important low temperature applications, such as quantum computing and thermal radiation detection are very sensitive to overheating. At sub-kelvin temperatures, when thermal conductivity of materials decreases significantly and electron–phonon interaction is very weak, even a tiny power leads to significant overheating. Often the excess power dissipation of the on-chip read-out electronics can heat the systems to the limit where the benefits arising from the low temperature are lost and the device operation degrades. This problem occurs for instance in a novel qubit (quantum bit) read-out scheme where Rapid Single Flux Quantum (RSFQ) electronics are used as a classical interface to multi-qubit circuits of Josepson-junction qubits. RSFQ elements are a family of widely studied and well-developed Josephson digital circuits. The significant advantage of RSFQ electronics is their very high operating frequency (up to 500 GHz). Although the RSFQ circuits have been investigated for many years, one of the implied "design objectives" of these investigations was the possibility to increase rather than decrease operating temperature, and many of the suggested approaches can not be immediately utilized at sub kelvin temperatures. New temperature range sets new design priorities, with overheating becoming a more important issue than the operation speed and miniaturization.

RECENT RESULTS

In cooperation with our partners from Stony Brook University and partners within the European project "RSFQubit" we participate in development of new generation of RSFQ logic aimed for control of quantum devices and sensitive sensors at sub Kelvin temperatures. The central problem in interfacing RSFQ components with low temperature circuits is the relatively high power consumption in the RSFQ elements due to their high critical current. We have investigated the overheating problem theoretically and experimentally and suggested possible solutions of this problem through changes in the thermal design of SFQ circuits [A.M. Savin, J.P. Pekola, D.V. Averin, and V.K. Semenov, Thermal budget of superconducting digital circuits at sub-Kelvin temperatures, cond-mat/0509318. S. Intiso, J. Pekola, A. Savin, Y. Devyatov, A. Kidiyarova-Shevchenko, RSFQ circuits for low noise mK operation, ISEC'05 Ext. Abs., accepted for publication in Supercond. Science and Techn.]. The direct way to transfer RSFQ circuit design to the sub-kelvin temperature range based on reduction of all currents, including critical currents of Josephson junctions and dc bias currents. With this scaling, the existing technology can be used as such and most of the existing SFQ logic elements can be adopted with some modifications. We carried out such scaling for several basic SFQcircuits and demonstrated their operation at sub-kelvin temperatures.

(a) (b)

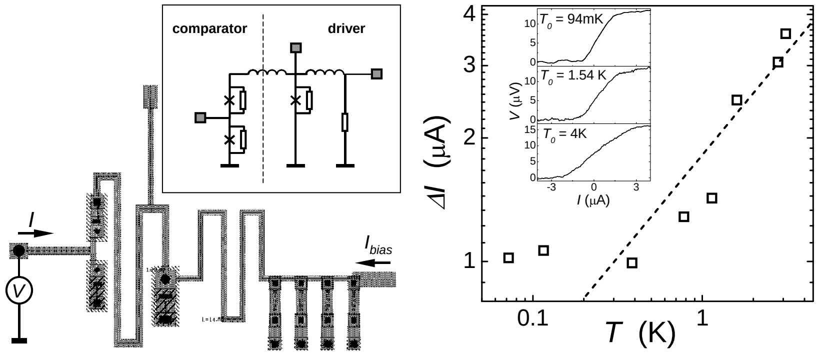

Figure 1: (a) Layout and equivalent circuit of an RSFQ comparator. (b) Temperature dependence of the width of the comparator gray zone. Squares and dashed line are experimental data and theoretical prediction for thermal limit, respectively.

CONTACT PICO group http://ltl.tkk.fi/PICO/

Prof. Jukka Pekola (jukka.pekola@tkk.fi) +358-9-4514913