Superconducting Computing: An Energy-efficient Quantum-based Technology for Supercomputers

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***Abstract*— The prediction of the quantum tunneling of a current between two superconductors through a thin barrier, even if there is no drop in voltage, was made in 1962 by Brian Josephson [1]; it is known as the dc Josephson effect. When there is a voltage drop, the current oscillates at a frequency proportional to the drop in voltage, the so-called ac Josephson effect. For both effects the current through the Josephson junction—the device made of two superconductors separated by a thin barrier—depends on the magnetic field. This last property has led to the invention of the Superconducting Quantum Interference Device, the SQUID, proposed two years later by Robert Jaklevic, John J. Lambe, James Mercereau and Arnold Silver [2]. Since then, Josephson junctions and SQUIDs have become the non-linear devices most widely used for superconducting electronics. They can be found either as quantum-accurate ultrasensitive magnetic field sensors, as direct or heterodyne quantum-limited detectors of faint electromagnetic signals from radiofrequencies to X-rays, in Single-Flux-Quantum (SFQ) and Adiabatic Quantum Flux Parametron (AQFP) binary logics to process signals with high energy-efficiency, or as qubits to process information in a pure quantum way. Most of quantum-based applications mentioned above have been proven with low- and high-Tc superconducting materials. Nevertheless, to date, only low-Tc superconducting materials, often niobium and sometimes aluminum, are used to design complex circuits, in particular for digital circuits because the technology of fabrication with low-Tc materials is more mature. Today, fabrication processes are planarized and reach industry standards [3], they are about to overcome the threshold of 1 million devices/cm^2 [4]. Such an integration level, reached for superconducting binary logics, is still 3 orders of magnitude lower than the record with semiconductor electronics with a density of integration reaching nearly 3 billion transistors/cm^2 in 2016. But already 3 orders of magnitude higher than the most complex qubit-based circuits developed in Canada [5]. On the other hand, the energy-efficiency and speed of superconducting circuits, either based on binary or quantum computing, do not depend directly on the size of devices, though a higher integration will allow more functionalities. Consequently, superconducting computing is seen as a viable alternative to the limitations associated to current semiconductor technologies, either because the same number of operations can be done faster and with much less energy with superconducting binary logics for big systems like supercomputers, or because the method to solve a given problem is done in a totally different and more efficient way with quantum-based computation. This talk will present the state-of-the-art of semiconductor and superconductor technologies for supercomputing and will assess the expectations of superconducting electronics to develop heavy-duty computing from a system point of view, based on the physical limitations and engineering limits of each technology.**

References

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