Recent Progress in Digital Superconducting Electronics

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Abstract - Significant advancements in digital superconducting electronics are fueled by the recent emphasis on energy efficiency due to the extreme power requirements for the next generation high-end computers and by difficulties in removal of dissipated power in conventional electronic circuits and systems. This gives an edge to fast and low-power superconducting electronics as compared to other circuit technologies. In order to reach the energy efficiency levels relevant to high-end computing systems, new generations of single flux quantum (SFQ) circuits are quickly progressing from simple demonstrations to higher complexity circuits. In these new circuit approaches, the higher energy efficiency is achieved by significantly reducing and even completely eliminating the static power dissipation related to a resistor–based power distribution network in conventional RSFQ circuits. Both dc- and ac-power SFQ circuits are being developed. The ultimately low power dissipation even below the thermodynamic limit can be achieved in physically and logically reversible circuits. New circuit results will be reviewed. The necessary and critical component in any practical computing system is a random access memory (RAM). It has to have a high capacity, be energy-efficient and compatible to energy efficient SFQ digital circuits. This is being solved by a hybridization of traditional Josephson junctions (JJs) with ferromagnetic elements ranging from cryogenic metal spintronic elements to magnetic Josephson junctions. New results in cryogenic magnetic memories will be reviewed. Realizing integrated circuit complexities will not be possible without adequate design tools capable of handling JJs alongside with new elements of superconducting electronics brought by hybridization of superconductivity and magnetism, such spin-torque and spin-orbit magnetic elements, magnetic JJs, nanowire devices, and superconducting ferromagnetic transistors. Progress in design tools and new requirements and challenges will be reviewed. High-complexity, high-yield fabrication processes are being now developed capable of yielding complex energy-efficient SFQ circuits. Moreover, the new fabrication process should also be able to integrate the SFQ circuits with new magnetic and nanowire elements on a single chip. This requires the development of the integrated SFQ-Memory process by solving different process requirements for JJs and magnetic and nanowire elements. Recent results for new fabrication processes will be discussed.

Keywords (Index Terms) – Digital electronics, single flux quantum, SFQ, random access memory, RAM, hybrid RAM, spintronics, magnetic Josephson junction, spin-torque, spin-orbit, cryogenic memory, ferromagnetic transistor, high-yield fabrication.