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# NEWS LETTER

on Superconducting Electronics

S-PULSE
Shrink-Path of Ultra-Low Power Superconducting Electronics
www.S-PULSE.eu

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## EDITORIAL

*Superconducting Electronics is a developing field with currently allows to build quantum limited detectors in a wide range of the electromagnetic spectrum, as well as more and more complex digital circuits that can operate at clock frequencies of several tens of GHz with a very low power consumption for a wide range of applications: telecommunications, super-computing or detectors readout. In this frame, the EUROFLUX 2009 conference, that takes place on 20-23 September 2009, will be an excellent opportunity to gather participants from research centers, universities and industries in the beautiful city of Avignon in France, place of Popes' palace. If you work in the field of superconducting detectors and/or electronics, cryogeny, come to present your last achievements. If you are rather in the field of optics, photonics or semiconductors (high-speed FPGAs, low consumption electronics, SiGe,...), come and see the current state-of-the-art in Superconducting Electronics systems and the associated challenges. There are opportunities to seize to integrate several complementary technologies for developing more complex systems. More information at www.euroflux.org.*

## LOW POWER COMPUTING REQUIRES LOW OPERATION TEMPERATURE


by Dr. Thomas Ortlepp

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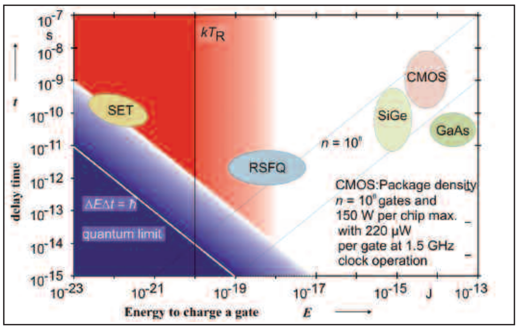
The very high integration density in semiconductor technology leads to an ultimate high power density. The power consumption of about 100 Watts on integrated circuits of typically 1 $cm^2$ causes serious problems leading to the necessity of large cooling fans. Today, this situation is limiting a further increase of the circuit density in CMOS technology [1]. Energy consumption per logic bit operation needs to be reduced as much as possible, to handle even higher integration densities. But the present switching energy of transistors in complex circuits with more than one billion transistors cannot be reduced any more, because a certain gap between the switching energy and the noise floor is required to avoid switching errors [2]. The only possibility is to reduce the operation temperature of the circuits, which will proportionally reduce the thermal noise. Lower operation temperatures offer a high potential to reduce the switching energy of semiconductor circuits by a factor of 10-100. The situation is even better for the material class of superconductors. The phenomenon of superconductivity is closely related to low temperatures. In the last 100 years, the research in low temperature physics was pushing the lowest temperature limit down to very low values of only a few millikelvins above the absolute zero point. The transition, where a normal conductor turns into a superconductor, takes place at the so called critical temperature. The research in material science had great success in finding new materials with higher and higher critical temperatures. There is a very popular hope, sometimes called the Holy Grail of Physics, to find a room temperature superconductor. Such a material will be for sure of great interest for some applications including magnetically levitated super-fast trains, efficient magnetic resonance imaging (MRI) systems, lossless power generators, transformers, and transmission lines, etc...

This situation is different in the field of electronics and highly integrated circuits. Devices are based on Josephson junctions with a very low switching energy and at the same time a very high speed. In the case of digital electronics, one can estimate that a superconducting




*Gate delay time versus gate energy [3]. The thermal noise limit is indicated by the kTR line, where RSFQ is the fastest technology with the lowest switching energy.*

circuit is about 10 times faster and consumes 10.000 times less energy than an equivalent CMOS circuit. The single bit switching energy of a Josephson junction is in the order of $10^{-18}$ Joule, which is about 10.000 times lower than state-of-the-art CMOS transistors. Such a low switching energy makes the junction also susceptible to thermal noise, but the typical operation temperature of liquid helium (4.2 Kelvins) provides enough margin to enable stable error-free operation [4]. A futher increase of the operation temperature, for example to 60 Kelvins, requires an increase of the switching energy, which makes them less attractive in comparison to CMOS technology. Especially in the case of high integration density, the increased power density will cause serious problems with proper cooling of the superconducting chip and leading to the same conflict mentioned at the beginning.

The reduction of power consumption of any computational system requires a reduction of the operation temperature to values below the boiling point of liquid Nitrogen. This general trend offers a strong impact for superconductive electronics since this temperature can now be obtained with compact cryocoolers. Nevertheless, a hypothetical room temperature superconductor with nice metallic properties cannot improve the operation temperature of superconductive electronics to temperatures above about 77 Kelvins.


**[1]** L. B. Kish. End of Moore's law: thermal (noise) death of integration in micro and nano electronics. Physics Letters A, vol. 305, pp. 144, 2002.

**[2]** K. Natori and N. Sano. "Scaling limit of digital circuits due to thermal noise", Journal of Applied Physics, vol. 83, pp. 5019, 1998

**[3]** International Technology Roadmap for Semiconductors, http://public.itrs.net/

**[4]** P. Bunyk, K. Likharev, D. Zinoviev, "RSFQ technology: physics and devices," Int. Journal of High Speed Electronics and Systems vol. 1, pp. 257, 2001





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