NEWS LETTER
on Superconducting Electronics

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

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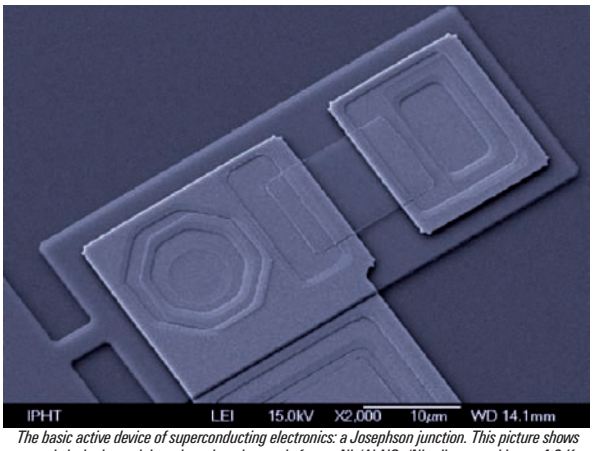
EDITORIAL

Superconducting Electronics is a scientific and technological field that is not widely spread and known in the Society. However, it plays a central but discrete role in several fields: many instruments that are used nowadays in advanced technologies, from computers to mobile phones, from GPS systems to game stations, deal with signals that are received by antennas - think about WiFi - and processed by sophisticated microprocessors, to be transformed in high-quality images, sounds or movies. In these systems that surround us, data are usually carried through voltages. A common standard is needed to compare their values with accuracy and develop the consumer electronics products we know. This standard is based on a superconducting device, the Josephson junction, which gives a direct and fundamental relation between a voltage and a frequency. This last quantity can be measured with high accuracy, so that voltages can be calibrated accordingly.



The basic active device of superconducting electronics: a Josephson junction. This picture shows a resistively-shunted Josephson junction made from a Nb/Al-AlOx/Nb trilayer, working at 4.2 K for high speed digital applications - Source: Fluxonics Foundry

Astronomy is another field that has always raised the interest of people. Its development is intimately connected to the one of ever more performant detectors. Do people know that many discoveries in the last decades, in the fields of radioastronomy or cosmology for instance, have used detectors based on **superconducting electronics**? The Herschel Space Observatory, a satellite of new generation developed by the European Space Agency to be launched in the coming months, will be using an instrument crowded with **superconducting electronics**, Josephson junctions again, to study the cold Universe and understand its origins. Are there other applications that can concern more directly citizens? Yes, there are. Think about Magnetic Resonance Imaging (MRI), magneto-encephalography or cardio-encephalography. These techniques have matured to a point that it is currently possible to distinguish the heart beat of a pregnant mother from the one of her fœtus; or to follow in real time the progression of an epileptic crisis through the magnetic signals emitted by the brain. The detector is again based on Josephson junctions, two junctions connected in parallel to be more exact. This small circuit is called a SQUID (Superconducting Quantum Interferometer Device), a beast that exhibits ultimate quantum-accurate magnetic sensitivity thanks to the wonderful properties of the quantum macroscopic nature of superconductivity.

Are you concerned by risks of Earthquakes, or tsunamis? Would you like to understand the way people were living in your area a few millenia ago? Or sound the Earth for environmental proposals? Scan airports to detect concealed weapons or explosives? There are answers. They already rely on the use of **superconducting electronics**.

So ... what else? What about making microprocessors that run 10 to 100 times faster than existing ones while consuming less? Or digitizing signals in the microwave frequency range to increase flexibility and performance of mobile phone and satellite communications? There are solutions based on **Superconducting Electronics**. Just add a resistor in parallel with the Josephson junction. You will get what you need: a digital device that can work ultimately above the 100 GHz frequency range. Based on a submicron technology that is simple with respect to semiconductor standards.

Then... where are the problems? Well... we are still waiting for room-temperature superconductors. It would ease our task. We are ready when they come up. Meanwhile, we still need to cool our systems at low temperatures. This is not a real issue, it is done routinely in hospitals, and in every environment that requires **superconducting electronics**. It adds a bit to the cost of the system but, on the other hand, it is not currently possible to achieve the ultimate performances of **superconducting electronics** with any other available technology.

What is the way to go then? It is straightforward: add **superconducting electronics** extensions to existing electronics systems if you want to achieve performances that cannot be obtained otherwise. And put some effort on interfaces between existing semiconductor or optical systems and superconducting ones to insure optimum compatibility.

Can you really interface technologies that are so different in their physical principles and conditions of operation? Sure, we can.

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PRESENTATION OF S-PULSE

>> S-PULSE, namely Shrink-Path of Ultra-Low Power **Superconducting Electronics**, is an action dedicated to push forward **Superconducting Electronics**. European activities in this field are currently coordinated by the non-profit Society FLUXONICS e.V. (http://www.fluxonics.org), a SCENET initiative (the former European Network for Superconductivity) that has been launched under the Sixth Framework Programme of the European Commission for a dynamic technology platform in **Superconducting Electronics**.

The aim of S-PULSE is to prepare **Superconducting Electronics** for the technology generation beyond the scaling limits of semiconductor electronics. S-PULSE is funded by the 7th Framework Programme of the European Commission on Research, Technological Development and Demonstration.
Scaling laws in CMOS (Complementary Metal Oxide Semiconductor) technology indicate that some concepts cannot be simply extrapolated to gain speed and performance for the future generation of electronic devices. New physical effects that have not been investigated thoroughly up to now, need to be taken into account in the future. **Superconducting Electronics** is one of the paths to be carried out.

Superconducting Electronics is based on a device that is commonly called a Josephson junction, from the name of the british physicist who received in 1973 the Nobel Prize *"for his theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena which are generally known as the Josephson effects"*. The Josephson junction is an active device that is used to perform several functions in **Superconducting Electronics**. It is the equivalent of the transistor used in semiconductor electronics.
The physics behind the Josephson effects, that is derived from the quantum macroscopic properties of superconductors, has a nature that is different from the one of semiconductors. For this reason, **Superconducting Electronics** never had a scaling law as in semiconductor electronics. Only quantum limits define the ultimate speed.

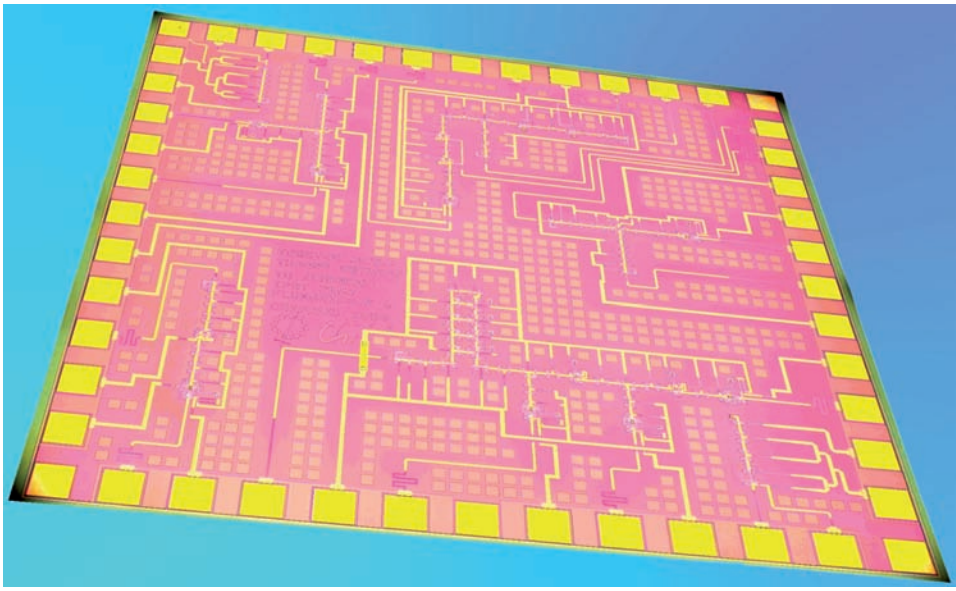
Moreover, the features of **Superconducting Electronics** rely on ***quantum accuracy***, which is a tremendous advantage over other technologies, whenever high linearities, dynamic ranges or absolute calibrations are required in electronic systems. Actually, every current electronic equipment in the world is ultimately calibrated with a **Superconducting Electronics** metrology device that is based on the Josephson effect.

Today **Superconducting Electronics** used in digital mode already demonstrated logic operation speed above 100 GHz with a typical power dissipation of 1 aJ (10^{-18} Joule) per logic operation with devices that have a feature size of 1 micrometer (1000 nm). This leaves a wide path to shrink dimensions and further increase performances. For comparison a Pentium-IV processor relies on a 65 nm technology, clocked below 4 GHz that dissipates about 2 10^{-16} Joule per logic operation.

As a major outcome of the FLUXONICS network, a circuit foundry, known as the FLUXONICS Foundry for **Superconducting Electronics** was established. A cell library is available and a first roadmap was drawn up in the field [(1)]. The S-PULSE project supports joint efforts of European academic and industrial groups in the field of superconducting technologies. The goal is to strengthen the vital link between research and development on one hand, and the industrial view on the other hand. It consists of bringing together industrial expectations and visionary extrapolation with the current status of technology, by intensifying the exchange of knowledge and ideas, taking charge of education, and winning public interest. To achieve these goals, the overall strategy of S-PULSE is to broaden the FLUXONICS network in the field of ultra-low power **superconducting electronics** down to the nano-scale domain. Consequently, the S-PULSE Support Action is expected to strengthen the competitiveness of the European nanoelectronics industry and to make **Superconducting Electronics** technologies available next to other technologies.

The S-Pulse projet comprises 15 members. It is coordinated by the Institute of Photonic Technology (IPHT) located in Jena, Germany. Other members are the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig (Germany), the University of Technology of Ilmenau (Germany), the University of Twente (Netherlands), the University of Chalmers (Sweden), the University of Birmingham (United Kingdom), the University of Cambridge (United Kingdom), the University of Karlsruhe (Germany), the University of Savoie (France), the National Research Council in Naples (Italy), the University of Stellenbosch (South Africa), the Commissariat à l'Energie Atomique in Grenoble (France), Thales Research and Technology (France), the Institute für Mikroelectronik- und Mechatronik-Systeme GmbH (IMMS) in Ilmenau (Germany) and Thales Alenia Space in Toulouse (France).

(1) H.J.M. ter Brake et al, "SCENET Roadmap for Superconductor Digital Electronics," Physica C, Vol. 439, Issue 1, pp. 1-42, 2006.



Rapid-Single-Flux-Quantum (RSFQ) circuit chip, designed and fabricated by the FLUXONICS Foundry. Size is 5mm x 5mm. Source: FLUXONICS Foundry.

by Nobuyuki Yoshikawa
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SUPERCONDUCTING DIGITAL ELECTRONICS RESEARCH ACTIVITIES IN JAPAN

Overview of the RSFQ large-scale reconfigurable datapath project

>> Three large projects on Rapid-Single-Flux-Quantum (RSFQ) digital electronics are currently being conducted in Japan.

• One research project, entitled "Large-scale reconfigurable data path (LSRDP) based on RSFQ circuits", is researching basic RSFQ technologies for future high-end supercomputers. Three universities (Yokohama National University, Nagoya University and Kyusyu University) and one research organization (Superconductivity Research Laboratory (SRL)) are participating in this six-year project, which commenced in 2006.

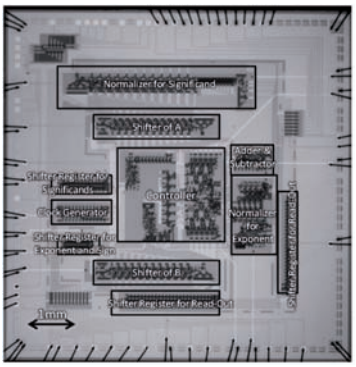
• Six universities are participating in another four-year research project, named "RSFQ integrated circuits based on localized electromagnetic waves". This project aims to discover new device materials, device physics, circuit technologies, and design methodologies to improve the fundamental performance of RSFQ circuits for future sub-terahertz integrated circuits.

• SRL is also participating in a project named "Development of next-generation high-efficiency network devices" that is being conducted by several optical communications companies. The main goal of this project is to develop a 160-Gps high-end router.

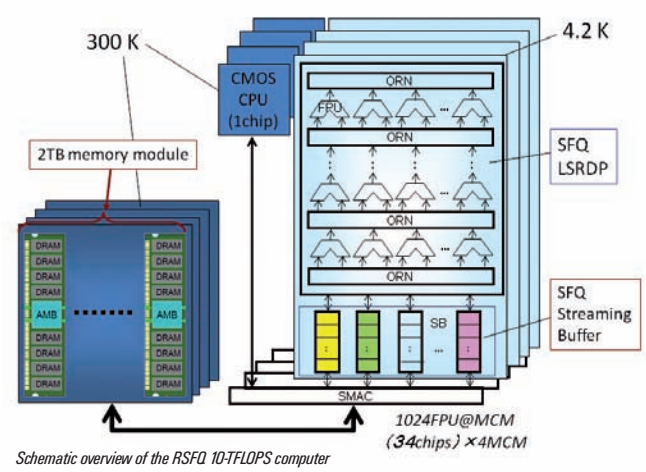
Due to space restrictions, this article focuses on reviewing the recent research activities of the RSFQ LSRDP project. The goal of the RSFQ LSRDP project is to establish fundamental technologies for RSFQ circuits including architecture, design and fabrication technologies for realizing desk-side computers with 10-TFLOPS performance (editor's note: 1 TFLOP corresponds to 10^{12} floating point operations per second). The RSFQ LSRDP is the main component of the system. It consists of a two-dimensional array of a large number of floating-point units (FPUs), which are connected to each other by operand routing networks (ORNs). Various kinds of numerical calculations can be directly mapped on the RSFQ LSRDP by reconfiguring the ORNs, in other words, by rearranging the connection of the network. The data streams propagate and are processed in the FPU array from the bottom to the top. The advantage of the RSFQ LSRDP system is its enormous computing performance with low-power consumption. This is impossible to achieve using conventional semiconductor circuits due to the high switching activity in the LSRDP system. Another advantage of the LSRDP system is that its memory bandwidth can be reduced because the FPUs communicate directly with each other without accessing the memory.

Up until now, several circuit components for the RSFQ LSRDP system have been successfully designed, implemented and tested by using the CONNECT cell library [2] and the SRL Nb 2.5 kA/cm^2 standard process [3]. Park et al. developed an RSFQ half-precision (16 bits) floating-point adder (FPA), which is the most complicated circuit component in the RSFQ LSRDP system [4]. Bit-serial architecture was employed to reduce the circuit size, where a bit-serial datapath was used for the significand and another one was used for the exponent. By optimizing the pipeline stage and the clocking scheme, a minimum data input interval of (n_f + 1) clocks was obtained, where n_f is the bit length of the significand. The FPA consists of 10224 Josephson junctions and has a circuit size of 5.9 mm × 5.7 mm. Its correct operation was successfully demonstrated at 20 GHz by using on-chip high-speed tests. It has a performance of 1.67 giga floating-point operations per second (GFLOPS). The total power consumption was estimated to be 3.5 mW.

Successful demonstration of a bit-serial half-precision floating-point multiplier (FPM) was also performed by Hara et al. [5]. The multiplier for the FPM was designed by using a regularly aligned pipeline structure, called systolic-array architecture. The RSFQ half-precision FPM was implemented by using 11044 junctions in a circuit of size 6.2 mm × 3.8 mm. On-chip high-speed tests revealed that the maximum operation frequency was about 32 GHz. This corresponds to a performance of 2.5 GFLOPS...



RSFQ half-precision floating-point adder (FPA) successfully demonstrated at 20 GHz. Circuit size is 5.9 mm × 5.7 mm. It consists of 10224 Josephson junctions. Performance is 1.67 GFLOPS. Total power consumption is 3.5 mW.



Schematic overview of the RSFQ 10-TFLOPS computer

[1] N. Takagi, et. al., "Proposal of a desk-side supercomputer with reconfigurable datapaths using rapid single-flux-quantum circuits," IEICE Trans. Electron., Vol. E91-C, No. 3, pp. 350-355, Mar. 2008.

[2] S. Yorozu, et. al., "A single flux quantum standard logic cell library," Physica C, vol. 378-381, pp. 1471-1474, Oct. 2002.

[3] S. Nagasawa et. al., "A 380 ps, 9.5 mW Josephson 4-Kbit RAM operated at a high bit," IEEE Trans. Appl. Supercond., vol. 5, pp. 2447-2452, Jun. 1995.

[4] H. Park et. al. "Design and Implementation of SFQ Half-Precision Floating-Point Adders," ASC2008, Chicago, USA, August 17-22, 4EB01.

[5] H. Hara et. al. "Design and Implementation of SFQ Half-Precision Floating-Point Multipliers," ASC2008, Chicago, USA, August 17-22, 2EZ03.

[6] M. Tanaka et. al. "A high-throughput single-flux-quantum floating-point serial divider using the signed-digit representation," ASC2008, Chicago, USA, August 17-22, 2EZ02.

[7] A. Fujimaki et. al., "Demonstration of an SFQ-Based Accelerator Prototype for a High-Performance Computer," ASC2008, Chicago, USA, August 17-22, 2EZ01.

[8] I. Kataeva et. al., "An Operand Routing Network for an SFQ Reconfigurable Data-Paths Processor," ASC2008, Chicago, USA, August 17-22, 2EZ07.

[9] S. Nagasawa et. al., "Reliability evaluation of Nb 10 kA/cm2 fabrication process for large-scale SFQ circuits," Physica C, vol. 426-431, pp. 1525-1532, 2005.

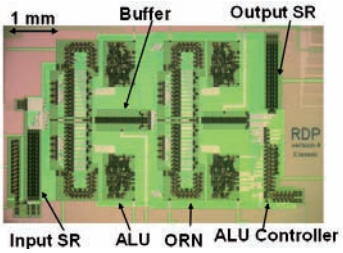
[10] H. Akaike et. al. "The effect of a DC power layer in a 10-Nb-layer device for SFQ LSIs," ASC2008, Chicago, USA, August 17-22, 2EPA03.

... Tanaka et al. proposed a bit-serial floating-point divider for RSFQ circuits [6]. They designed a high-throughput, low-latency divider based on systolic-array architecture. A 4-bit driver was implemented and its successful operation up to 19 GHz was demonstrated.

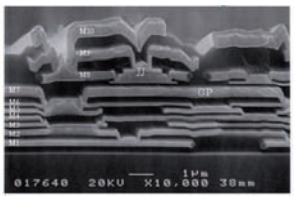
• Fujimaki et al. demonstrated reconfiguration of the data-path in a two-by-two RSFQ LSRDP prototype [7]. It consists of four arithmetic logic units (ALUs) and four shift registers, which are connected by four 4:3 ORNs (see picture).

• Kataeva et al. investigated the architecture of the ORN for the RSFQ LSRDP system [7]. They compared two different architectures for ORNs: an NDRO-based ORN and a crossbar-based ORN. This comparison revealed that the crossbar-based ORN had superior timing design and performance because of its regularity. They implemented a 1-to-2 crossbar-type ORN prototype and demonstrated its correct operation up to 36 GHz.

• All the above-mentioned circuit components have been implemented by using the SRL Nb 2.5 kA/cm^2 standard process. Recently, the SRL has developed a new 10-Nb-layer fabrication process with Jc = 10 kA/cm^2, called advanced process 1 (ADP1). Akaike et al. investigated the effect of magnetic fields from the large bias currents of DC power lines on the 10-Nb-layer structure and proposed a new device structure for large-scale Josephson ICs [10]. The last figure shows a cross section of the new 10-Nb-layer structure, called ADP2. In ADP2, active layers that contain Josephson junctions are fabricated on top of the multilayer structure, whereas the DC-power layer for bias current feeding is fabricated on the bottom of the multilayer structure. The advantage of ADP2 is that the effects of the bias current and ground return current are significantly reduced.



Two-by-two RSFQ "Large-Scale Reconfigurable Data Path" (LSRDP) prototype. Circuit area is 5.9 mm × 3.7 mm. LSRDP has 10839 Josephson junctions. Arithmetic Logic Units (ALUs) and Operand Routing Networks (ORNs) have maximum operation frequencies of 28 GHz and 23 GHz, respectively.



Cross-section of SRL Niobium advanced process 2 (ADP2) for Superconducting Digital Electronics.

SUPERCONDUCTING DIGITAL ELECTRONICS RESEARCH ACTIVITIES IN THE UNITED STATES OF AMERICA

Superconductor Analog-to-Digital Converters for Digital-RF Receivers

by Deep Gupta
Vice President, Research and Development, HYPRES Inc., U. S. A.

Ultrafast switching speed, natural quantization of magnetic flux and low noise of cryogenic superconductor circuits enable fast and accurate data conversion between the analog and digital domains. Since the turn of the century, HYPRES has been primarily focusing on building digital receivers, harnessing the potential of high-fidelity conversion of wideband radio frequency (RF) analog signals directly to the digital domain for subsequent processing in programmable hardware, firmware, and software. This is in contrast to the conventional narrowband approach of one or more stages of analog down-conversion. The central element of this digital-RF receiver is the analog-to-digital converter (ADC). Among the various flavors of ADCs being developed for RF applications, most prominent are oversampled low-pass phase-modulation-demodulation (LP PMD) and continuous-time bandpass delta-sigma (BPDS) ADCs.

The LP PMD ADC is a delta ADC, ideally suited for low frequency applications below 100 MHz. We demonstrated 90 dB signal-to-noise ratio over 10 MHz bandwidth with a 30-GHz sampling clock frequency. Three different paths are currently being pursued for extension of the LP PMD ADC dynamic range:

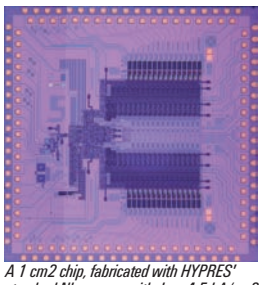
• a multi-rate design, allowing the ADC modulator to be sampled at a higher rate than the more complex on-chip digital decimation filter,

• a higher slew-rate modulator front end, called a quarter-rate quantizer (QRQ) coupled with additional synchronizer channels in the phase demodulator,

• and a multi-modulator ADC representing a subranging architecture.

With the multi-rate design, we have succeeded in increasing the ADC sampling frequency up to 50 GHz. The quarter-rate ADC quadruples the input slew-rate limit. With a corresponding increase in the number of synchronizer channels, up to 3.5 bits performance enhancement has been conceived, but not yet demonstrated. Preliminary modeling of subranging ADC promises even bigger enhancement in signal-to-noise ratio. Successful integration of low-jitter on-chip clock sources will be required to achieve the performance benefits associated with these advanced ADC architectures.

Bandpass delta-sigma ADCs employ one or more LC resonators in the feedback loop to achieve minimum quantization noise in the band of interest. We have designed and demonstrated a wide range of BPDS ADCs in various bands, ranging from 700-900 MHz for wireless communications to 20.2-21.2 GHz for Ka-band satellite communication (SATCOM). One of these ADCs integrated with a digital channelizing circuit comprising in-phase and quadrature digital mixers and filters was demonstrated to operate as part of a cryocooled receiver system. Integrated with a digital demodulator, we were able to demonstrate the superconductor digital-RF receiver (called ADR) with live satellite data and video communications. Currently, this SATCOM receiver prototype hosts in a modular cryopackage an X-band ADR chip clocked at 30 GHz. The X-band ADR chip, containing over 10,000 Josephson junctions, represents a class of the most complex rapid single flux quantum (RSFQ) circuits demonstrated to date. This year, HYPRES delivered two other system prototypes with a lowpass PMD ADC and a bandpass ADC for direct reception of Link-16 waveforms in the 960-1215 MHz band.



A 1 cm2 chip, fabricated with HYPRES' standard Nb process with Jc = 4.5 kA/cm2, contains a bandpass delta-sigma ADC, a digital channelizer, and output drivers.

A complete cryocooled digital-RF receiver system prototype, assembled in a standard 1.8-meter tall 0.5-meter wide equipment rack. Using the modular packaging approach, the system can currently host variety of chips, such as the one shown in the previous picture. The system includes a two-stage 4-K Gifford-McMahon cryocooler manufactured by Sumitomo, two sets of interface amplifiers for connecting chip outputs to an FPGA board (placed behind the vacuum enclosure, on the metal tray) for further digital processing and computer interface. The system also includes a current source and a temperature controller.

Superconducting Technology Highlight

Superconducting Electronics in Metrology: a platform for high-precision measurements

by Dr. Johannes Kohlmann
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Important applications of superconducting electronics exist in the field of metrology, i.e. in high-precision measurements. The most significant representative of a metrological application is the Josephson voltage standard. Superconductivity as a macroscopic quantum effect is an essential basis of this standard, which is nowadays used in many laboratories world-wide for precise voltage measurements. This article briefly describes the fundamentals and present applications as well as new developments for further applications.

When Brian D. Josephson was a student at Trinity College in Cambridge, UK, he theoretically explored the behaviour of weakly coupled superconductors. He predicted the flow of superconducting currents through a later on so-called Josephson junction in 1962. High-frequency components of these currents at finite voltages can be phase locked to an external microwave oscillator. This phase lock generates constant-voltage steps in the current-voltage characteristic of the Josephson junction, which forms the basis for all Josephson voltage standards. The exceptional behaviour of Josephson junctions was confirmed experimentally soon after its prediction. Josephson's discovery won him a share of the 1973 Nobel Prize for Physics.

A long time was needed from the discovery of the Josephson effect in 1962 to the realization of modern Josephson voltage standards. Josephson indeed mentioned the unique applicability of this effect for precise voltage measurements already in his first paper. Constant-voltage steps are generated by irradiation of microwaves on Josephson junctions. The values of these steps $U = n \cdot (h / 2e) \cdot f$ are determined by the frequency f of the external microwaves, the ratio of two fundamental constants (Planck's constant h and the elementary charge e), and an integer n for the order of the step. h / 2e denotes the flux quantum Φ_0. The voltage U is nothing more than the transfer rate of flux quanta across the Josephson junction which shows the quantum nature of the reference voltage. A single junction operated at 73 GHz generates a voltage of 150 µV for the first order constant-voltage step. As frequencies can be measured with highest precision by atomic clocks, Josephson junctions enable the generation of reference voltages at a level of highest precision, likewise.

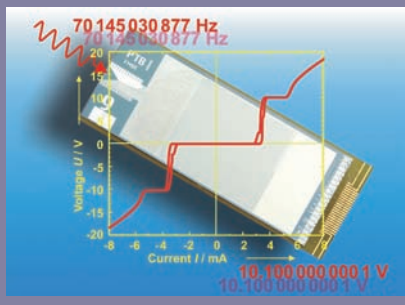
The first voltage standards based on this effect were already developed only just over 10 years after Josephson's discovery. These standards consisted of a single or of a few junctions and generated low voltages in the mV range. However, the realization of modern Josephson voltage standards for output voltages up to 10 V required further important developments. The technology for fabricating a very large number of junctions in thin film technology plays an essential role within these developments. Borrowed from progress achieved in semiconductor manufacturing, a reliable technology for fabrication of integrated superconducting circuits could be established in the 1980's based on Niobium as a superconductor. The first modern Josephson voltage standards were realized in a cooperative effort between PTB in Germany and NIST (formerly NBS) in the USA. These very large series arrays consist of up to 20,000 Josephson junctions and generate DC voltages of up to 10 V with a relative uncertainty of less than 10^{-10} (corresponding to 1 nV). They are fabricated in multilayer thin-film technology under clean room conditions. In spite of all technological challenges, these conventional Josephson voltage standards are a success story. Conventional Josephson voltage standards are nowadays routinely used by more than 50 laboratories world-wide for DC calibrations and related applications. Josephson voltage standards are meanwhile commercially available from two companies, one in Germany and another one in the USA.

The increasing demand, not only for DC voltages with fundamental precision, but also for highly precise AC voltages has stimulated several research programs to develop measurement tools based on Josephson series arrays to meet this requirement. Although conventional Josephson voltage standards are very successfully operated for DC applications, these circuits can not be used for AC voltage generation. This limitation is caused by the nature of the junctions and their current-voltage characteristics. The junctions of conventional Josephson voltage standards are called underdamped due to the analogy of a Josephson junction with a pendulum. Underdamping of the junction oscillator results in a hysteretic current-voltage characteristic and a complete overlap of the constant-voltage steps causing an extremely multi-valued reference voltage at the relevant bias current. This behaviour prevents a fast and specific switching between particular steps as it would be required for important technical applications of precision AC voltage metrology.

Therefore, so-called overdamped Josephson junctions have been increasingly investigated recently. Due to their non-hysteretic current-voltage characteristics, single-valued constant-voltage steps are generated by microwave irradiation. Suitable external bias electronics enable a switching between the different constant-voltage steps of the junctions rapidly. If the series arrays with N junctions are divided into segments containing numbers of junctions belonging e.g. to a binary sequence and the junctions are operated on the zero and first order steps, any number of junctions between –N and +N can be active at a given instant and add to the desired reference voltage. This new type of series arrays based on overdamped Josephson junctions is the main component in a programmable voltage standard. While conventional Josephson voltage standards are typically operated by microwaves in the frequency range around 70 GHz, programmable voltage standards are operated within two frequency ranges around 70 GHz and around 15 GHz, respectively, depending on the junction technology in use. 1-V circuits have been realized for both frequency ranges by a few research institutes and are successfully operated in several laboratories world-wide. These circuits contain 32,768 junctions for operation around 15 GHz and 8,192 junctions for operation around 70 GHz, respectively. Besides these 1-V circuits, first 10-V circuits have been developed and operated successfully at PTB (cf. figure). As the fabrication of 10-V series arrays is very complicated due to the enormous number of about 70,000 junctions, a simplified fabrication of these arrays as well as further improvements of their use for AC applications is the subject of current research.

An important question from the point of view of physics is the general validation of the Josephson effect, its so-called universality or independence of the details of the junctions. Experiments to answer this question are very sophisticated. Different researchers made these experiments by comparing the voltages generated by Josephson junctions made from different materials and being of different types. They did not measure any deviation down to voltage levels below 10^{-22} V, i.e. 0.000 ... (22 times 0 altogether) 1. These results imply that the output voltages for the junctions differ by no more than 3 parts in 10^{19}. Due to these measurements, the Josephson effect is expected to be one of the most accurate phenomena in physics at all.

In the field of metrology, i.e. in high-precision measurements, quantum phenomena have increasingly gained in importance in recent years. Reference of units to artefacts has been replaced by reference to fundamental constants. In electricity, we are in the fortunate position of having quantum standards for two of the most important electrical units. Nowadays, the unit of voltage, the volt, and the unit of resistance, the ohm, are reproduced by quantum standards based on the Josephson effect and the Quantum Hall effect, respectively. These quantum standards provide humans with uniform measuring capabilities independently from space and time, all over, and outside of the Earth.



The 10-V series array developed at PTB consists of 69,632 overdamped Josephson junctions, where the number of junctions follows a binary sequence. The area of each junction amounts to 12 µm x 30 µm. The size of the whole chip is approximately 10 mm x 24 mm. A constant-voltage step at the 10-V level is generated under microwave irradiation at 70 GHz.

Support of Friedrich-Immanuel Buchholz and Juergen Niemeyer is gratefully acknowledged

by Dr. Coenrad Fourie
Dr. Retief Gerber

Stellenbosch University
South Africa

STATUS OF SOFTWARE DEVELOPMENT IN SOUTH AFRICA

The NioCAD team of South Africa

overview of the NioCAD software suite

>> Retief Gerber and Dr. Coenrad Fourie from Stellenbosch University demonstrated NioCAD in Europe at the 5th FLUXONICS RSFQ Design Workshop in June 2008. The workshop, held at the Ilmenau University of Technology in Germany, marked the first time that the software – developed specifically for superconductive electronic circuit designers – was demonstrated to an international audience. The demonstration was a resounding success, and sparked lively debates among the audience, all of whom showed a clear interest in the results of the project.

The development of NioCAD, the brain child of Retief Gerber, Dr. Coenrad Fourie and Prof. Willem Perold, is currently funded by the South African National Research Foundation through its Innovation Fund. The development team is based in Stellenbosch, near Cape Town, South Africa, and at the time of the demonstration the project had already been funded for nearly a year and a half. A full-time staff of dedicated professional software developers and engineers, managed by Jan Pool, are employed to turn the idea of a one-stop design and verification tool for superconductive electronics designers into reality.

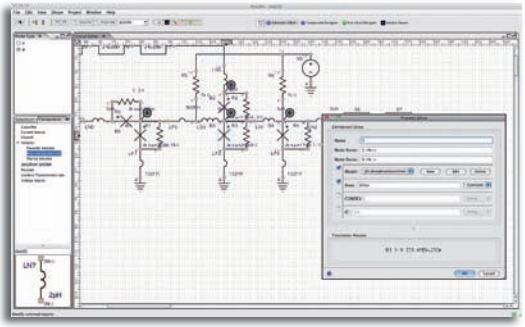
The NioCAD project aims at initially providing a single tool for digital, analogue and mixed-signal electronics design in the applied superconductivity community, as well as adjacent or related fields when the software matures. Developed by computer scientists and engineers, NioCAD will cater specifically to the needs of research scientists and development engineers. The NioCAD team is also involved in the European S-PULSE project, and through close ties with Dr. Thomas Ortlepp at Ilmenau University of Technology and a host of other contacts in Europe and the rest of the world, the software's functionality is always aligned with the requirements of academia and industry.

NioCAD also shares the ideals of the S-PULSE project, one of which is to standardise, automate and simplify superconductive circuit design to such an extent that students and engineers without advanced degrees in quantum electronics or applied superconductivity can design functional circuits and systems. In this way, NioCAD would like to help the migration of superconductive systems from the laboratory to industry.

Due to the diverse nature of research and development environments, NioCAD is developed to be platform independent and runs under Windows, Linux and Mac OS X. With an innovative built-in translation engine, NioCAD also supports a variety of popular free and commercial spice engines. On the technology side, NioCAD will be developed to support custom foundries, with specific support for the IPHT Jena foundry in Europe and the Hypres foundry in the USA.

At the RSFQ Design Workshop demonstration, Retief Gerber showed circuit schematic entry, simulation and performance calculation for RSFQ circuits. The NioCAD team is currently adding layout and extraction capabilities to the software. Following that, VHDL modelling support will be added. The first official release of NioCAD is scheduled for July 2009.

If you would like to know more about NioCAD, contact Coenrad Fourie at *coenrad@sun.ac.za*, or Retief Gerber at *hrgerber@sun.ac.za*. Comments and suggestions from the superconductive electronics community, as well as other fields of specialised electronics, are always welcome. You can also look out for us at applied superconductivity conferences and workshops.



example of a RSFQ circuit schematic with NioCAD

by Thierry Trollier
Alain Ravex

Air Liquide Advanced Technologies, Sassenage-France

CRYOGENICS ACTIVITIES DEDICATED TO SUPERCONDUCTING ELECTRONICS.

>> In the temperature range of 20-70K suitable for HTS applications, Air Liquide Advanced Technologies is developing high frequency (40-60Hz) pulse tube cryocooler systems. Those systems are producing a cooling capacity ranging from 0.3W @ 20K up to 6 W @ 70K. The developed pulse tube technology is highly efficient ultra reliable mono-stage or two-stages systems, currently supported by Earth observation and space exploration programs. They make use of a dual opposed pistons flexure bearing compressor connected to a non-moving part coaxial pulse tube cold head.

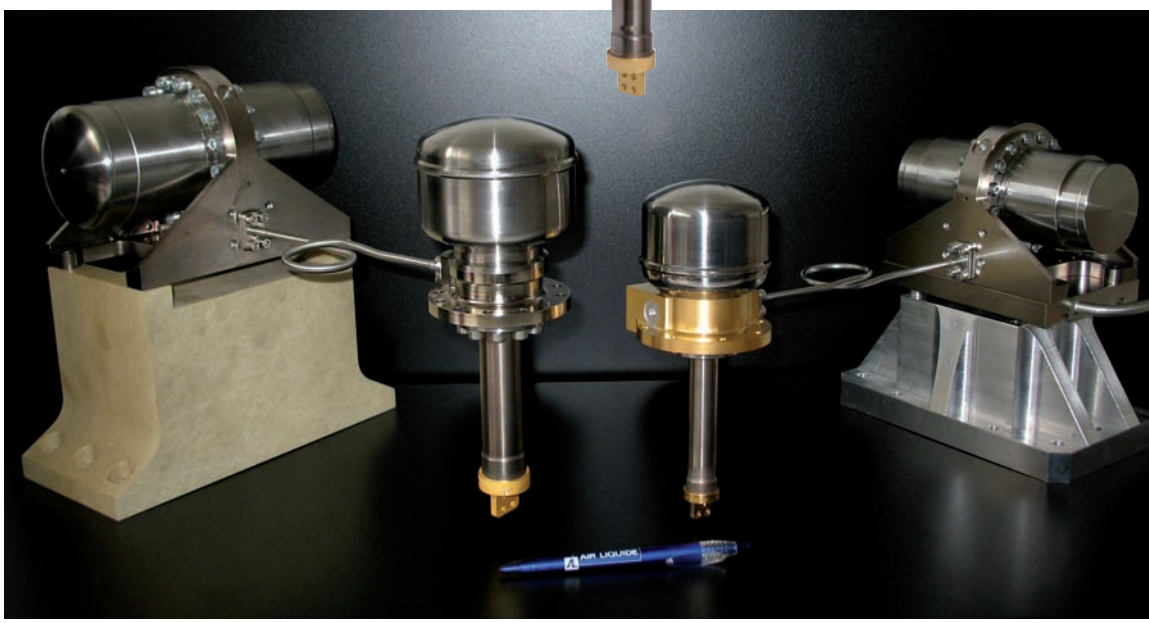
An illustration of this kind of pulse tube cooler is shown in the first picture. The Large Pulse Tube Cooler (LPTC) proposes high cooling capacity in the 40-80K range in a single stage architecture. It weighs 5.1 kg. A smaller version, Miniature Pulse Tube Cooler (MPTC) is also available as shown in the second picture. The MPTC weighs 2.8 kg.

Multistaging architectures (3 and even 4 stages) are developed in the US (Northrop Grumman Space Technologies and Lockheed Martin) in order to provide 4K for RSFQ.

For LTS applications, ranging from 4K to 8K, Air Liquide Advanced Technologies is using low frequency (1 to 2 Hz) pulse tube cryocooler technology. A basis of commercial available two-stage pulse tube cooler is used form CRYOMECH (Syracuse, NY, USA) on which patented (AL patent US 6,915,642) heat interceptors are placed to extract cooling power at intermediate temperature between 1st and 2nd stages. An illustration of the proposed modification is visible in the third picture.
Original Two stage Pulse Tube Cooler with intercepts can be considered for numerous applications (thermal screening, wire and coaxial lines thermalisation, subKelvin cooler precooling, cold electronics,...)

Large Pulse Tube Cooler – LPTC
Air Liquide Advanced Technologies

Two stage pulse tube cooler with heat interceptors
Air Liquide Advanced Technologies



LPTC (left) and MPTC (right) Pulse Tube Cooler family
Air Liquide Advanced Technologies

by Emanuela Esposito
Maurizio Russo

CNR Istituto Motori, Naples, Italy.

EUROFLUX2008 INTERNATIONAL CONFERENCE ON "SUPERCONDUCTING ELECTRONICS: FROM PHYSICS TO DEVICES" - NAPLES, SEPTEMBER 2008

>> This EUROFLUX2008 conference was an outcome of the Shrink-Path of Ultra-Low Power Superconducting Electronics (S-PULSE), a Support Action project of the 7th EU Program (Work Package 2: Training seminars, workshops and conferences). The conference was organized by the CNR Istituto di Cibernetica, and hosted by CNR Istituto Motori, Naples, Italy. Dr. Emanuela Esposito and Dr. Maurizio Russo were responsible for the scientific program.

The overall goal of S-PULSE is to prepare Superconducting Electronics (SE) technologies for the next generation of devices beyond the CMOS scaling limit. The action is to strengthen the vital link between research and development on the one hand and the industrial view on the other hand, bring together Industrial expectation and visionary extrapolation and current status of technology.
In particular, the aim of the conference was to disseminate the knowledge to interested industry and research laboratories in the three principal sub domains: Digital Electronics, Superconducting Sensors and Microwave Devices & Systems.
The main topics were: LTS and HTS junctions, SQUIDS and SQUIDS applications, Radiation Detectors at quantum limit, Digital Applications, Microwave devices and Metrology devices.
The conference was attended by 70 participants from different European countries, and from US, Japan and India.
Key-note speakers gave a review for a number of applications and evaluated the technical and the economical aspects of the already existing devices, prototypes, demonstrators or functional models and their potential for further progress. The conference social event consisted of a visit to Erculaneum excavation and a dinner in a Vesuviun villa, in a beautiful and fascinating setting.
The scientific program consisted of 3 full working days, with 36 oral presentation, 7 of those were 45 minutes talks, and 14 posters.
The talks of the first section dealt with the RSFQ digital applications, Anna Herr from Chalmers University (Sweden) gave a review on digital signal processing circuit design and packaging.
Juergen Niemeyer from PTB (Germany) presented the level of the presently available superconducting circuit technology which determines the limit and the quality of the reference voltage signal. He compared the advantages of the SINIS and the SNS technology and addressed to the last one to develop arrays of small junctions for circuit size reduction and with values of the characteristic voltage in the range of 100mV.
Hans-Georg Meyer from IPHT (Germany) presented a review on SQUID technology for geophysical application. He reported on successful tests of planar LTS SQUID gradiometers on a heliborne platform and showed that the system works stable and allows profile work without any constraints.
Vittorio Pizzella from Chieti University (Italy) presented a review on biomedical applications of SQUIDs. In particular, he presented study on brain functionality with magnetoencephalographic (MEG) instrumentation. A standard MEG system available at the moment features about 300 SQUIDs, each one able to sense the magnetic field in one location in space with a 2-3 fT/√Hz noise figure in the required bandwidth (dc-100Hz). He also addressed to a more challenging arrangement of combining MEG and MRI in one single apparatus. In this configuration the same SQUID sensor should be able to operate as a biomagnetic field detector and as a detector of the magnetic resonance free induction decay. In the same session, Andrei Matlashov from Los Alamos National Laboratory (USA) presented a multichannel Ultra Low Field Magnetic Resonance Imaging ULF MRI system compatible with MEG. He discussed different technical aspect of designing high resolution SQUID gradiometers that can be exposed to a 0.1 T range pulsed pre polarized field.
Stephan Friedrich from Lawrence Livermore National Laboratory (USA) reviewed on Superconducting Tunnel Junction (STJ) as X-ray detectors for Synchrotron Science. STJ detectors provide higher sensitivity for soft X-rays where conventional Ge detectors lack energy resolution and grating spectrometer lack detection efficiency. In the same session, Gabriel Zieger from the Institute of Photonic Technology (Germany) presented a fast scanning passive terahertz camera for security purposes using transition edge sensors bolometers. The camera can visualize hidden objects under clothing or inside packaging from a security distance of 5 meters with a lateral object resolution of about 1 cm. Konstantin Il'in from Karlsruhe University (Germany) presented results on the development of hot electron bolometer detectors based on thin NbN films, and on the study of the intrinsic and artificial proximity effect in such detectors.
For the microwave devices session, Alexey Ustinov from Karlsruhe University (Germany), reviewed on imaging the microwave properties of circuits and resonators.
Valery Ryazanov from the Russian Academy of Science (Russia) presented a digital circuit consisting of superconducting loops interrupted by Superconducting-Ferromagnetic-Superconducting pi-junctions. These junctions with high critical current density are suitable for Josephson digital and quantum electronics applications as a passive superconducting phase inverters.
Juergen Kunert from the Institute of Photonic Technology (Germany) provided an overview of the design and fabrication process and a demonstration of the established integrated framework of the FLUXONICS Foundry.
All the talks were extremely interesting and stimulating for the audience. All the presentations can be visualized on the web page of the project http://www.s-pulse.eu. The conference contributed to overlook the current status of technology and to exchange knowledge and ideas.
The EUROFLUX conference also supported the activities to prepare Superconducting Electronics for the next technology generation and to enable the transition from the present scientifically-oriented network towards a more industrially-guided activity.

Group picture of the EUROFLUX2008 conference Naples, September 2008

by H.J.M. ter Brake

University of Twente
Netherlands

FIRST TWENTE MICROCOOLING WORKSHOP UNIVERSITY OF TWENTE, ENSCHEDE, NL, APRIL 7-8, 2008

>> Within the frame of S-Pulse, three microcooling workshops will be organized by the University of Twente. The first workshop was held at the campus of the University of Twente on April 7 and 8, 2008. The objective of this first workshop was primarily to bring together the two communities working on cooling and on SE, and to exchange information on developments in the respective fields of research. During the first S-Pulse Twente Microcooling Workshop, 21 presentations were given on trends in Superconducting Electronics devices and in cooling. These trends were discussed in a quite general sense, not specifically focused on small-size devices. Targets on microcooling were defined in three temperature ranges: In addition, the **Superconducting Electronics** community strongly suggested cooler standardization as an important step in cost reduction. The idea is to have a relatively small number of standardized cooler units that can be coupled to reach the whole range of temperatures down to 4 K, in order to serve a wide variety of applications. This standard modular cooler approach may be applied to microcoolers as well as to cooling systems of about 0.1 W at 4 K for cooling digital electronics, D/A converters and voltage standard applications. The next S-Pulse Twente Microcooling Workshop will be organized in April 2009 again at the University of Twente, Enschede, NL. The objective of that workshop will be to discuss progress made with respect to the targets mentioned above.

example of a microcooler developed at the University of Twente, Netherlands.

Starting temperature	End temperature	Cooling power	Application
300 K	80 K	10 - 20 mW	small HTS SQUID
80 K	30 K	5 - 10 mW	simple HTS digital
50 K (or lower)	5 K	1 - 5 mW	LTS devices, new low-power RSFQ

by Thomas Orlepp

University of Technology Ilmenau, Germany

FIFTH FLUXONICS RSFQ DESIGN WORKSHOP UNIVERSITY OF TECHNOLOGY ILMENAU GERMANY – 29 JUNE - 02 JULY, 2008

Group picture of the fifth FLUXONICS RSFQ design workshop June 30th, Ilmenau, Germany

>> The FLUXONICS RSFQ design workshop was established directly after the foundation of FLUXONICS e.V. [1], and has been held every second year since the beginning. After the 4th workshop in 2007, this activity was included in the new European S-PULSE activity to support superconducting electronics (SE). The increasing number of participants clearly showed the growing interest in design and simulation aspects of superconducting electronics.

The 5th RSFQ design workshop took place in Ilmenau from June 30th to July 2nd 2008. Our objective with this workshop was to support investigation activities in the field of SE, the technology with the best potential for solving the bottlenecks already identified by ITRS [2], because of its high speed, quantum accuracy and size-independent very low power dissipation. All topics support the joint efforts of European academic and industrial groups in the superconducting technologies field. The workshop is focused on knowledge dissemination with particular attention to inspire industrial interest and to prepare related industry for application of RSFQ as a future electronic generation beyond the possibilities of semiconductor circuit technologies.

The modus operandi of this workshop includes a first part of a training course for integrated SE design. In addition to the lectures on design and testing, each participant is invited to contribute to the second part, where special research topics are discussed. The activity is to strengthen the vital link between research and development groups and to support education for all groups active in the field of RSFQ circuit design. We focus on training and knowledge dissemination to support the education of young scientists and to bridge the gap between SE and industrial areas of other electronics. The program of the three days 5th workshop was organised in six sessions:

1. Lectures on Superconductor Electronics
- Introduction of circuit design and test infrastructure
- Analysis of the decision making element

2. Device fabrication technologies
- FLUXONICS Foundry process at IPHT Jena [3]
- Self-shunted NbN Josephson junction technology

3. Design and Application of analogue-to-digital converters (ADC)
- Industrial needs
- system configuration of ADC with RSFQ digital circuits
- VHDL-AMS modelling

4. Advanced design aspects
- current recycling techniques
- advanced fabrication aspects
- frequency dependent damping
- flux trapping
- noise sensitive elements

5. High speed RSFQ-to-Semiconductor interface
- development of cryogenic amplifiers for high data rates
- superconducting output driver circuits [4]

Design framework for superconductive electronics
- new aspects in analogue circuit design
- presentation of the NioCAD project and demonstration of the EDA workbench

The first day of the workshop was dedicated to the education of young scientists on modern aspects of superconductor electronics design. International experts offered detailed information's in lecture like training courses. First realization aspects of ultra high-performance computing system where presented by Prof. Yoshikawa (Yokohama National University, Japan). This new architecture is based on grid computing with reconfigurable data paths and able to overcome present limitations of high data throughput. Because of the pulse driven nature in RSFQ technology, the gate delays and timing are a very important issue of complex digital systems. Prof. Anna Herr presented (via Skype) novel aspects of timing models for circuit simulations based on high level hardware descriptions languages.

The organizer of the workshop, Thomas Ortlepp, interacting via Skype for the talk of Anna Herr.

On the second day, an analysis of the application potential for superconducting analogue-to-digital converters (ADC) was done by industrial participants from Hypres Inc. (USA) and Thales Alenia Space (France). There is no clear goal for superconductor ADCs and no market pull, but e.g. the American military is interested and willing to pay for special instrumentation, rf-functional electronic radar and digital receiver systems for communication. The power budget in space applications makes such ADCs only interesting, if beam forming capabilities with many channels (e.g. 128 ADC chips) are cooled in a single system. The experts conclude on the fact, that superconductive ADCs are only a very small issue, but the capabilities of data processing at high speed on the same chip have a very promising future. The flux quantum counting principle of superconductor ADCs is the unique feature providing an ultra high linearity. Digital processing at high speed (sampling rates of 40 Gigasample and more) on the same chip can only be done in RSFQ technology.
The main outcome of the workshop was the identification of current demands in design automation for SE. The development of new design tools is always application driven and current bottle-necks were identified. The ultra high operation frequency of RSFQ circuits requires too bridge the gap to existing microwave and analogue design tools.

The participants clearly agree on the fact that all efforts in digital SE are today oriented on one mature technology: the niobium-based thin film process with Aluminium-oxide Josephson junctions. The fabrication and design capabilities of Japanese groups are very advanced and leading in the world. As stated in the ITRS semiconductor roadmap, RSFQ could become an important technology, if the correct market driver emerges. The cryogenic operation at 4 Kelvin limits the applications, but one has to focus on niche applications, for which this low operation temperature is not an issue.

[1] http://www.fluxonics.org

[2] ITRS http://www.itrs.net/Links/2004Update/2004_05_ERD.pdf

[3] http://www.fluxonics-foundry.de

[4] http://www4.tu-ilmenau.de/EI/ATE/kryo

The 5thFLUXONICS RSFQ design workshop had 25 participants including most of the European groups as well as 4 participants from outside Europe:

> Germany: TU Ilmenau (5), IPHT Jena (2), Uni Karlsruhe (2), IMMS Ilmenau and Erfurt (4), PTB Braunschweig (1),

> France: University of Savoie (1), CEA Grenoble (1), Thales Alenia Space (1), Thales R&D (2), ENST Paris (1)

> Sweden : U Chalmers (1+1 via Skype), South Africa: University of Stellenbosch (2),

> Japan: Yokohama National University (1),

> U.S.A.: Hypres Inc. (1)

by Juergen Kunert

IPHT, Jena, Germany.

FIRST S-PULSE TECHNOLOGY TRAINING WORKSHOP INSTITUTE OF PHOTONIC TECHNOLOGY (IPHT), JENA GERMANY – SEPTEMBER 10-11, 2008

Group picture of the first S-PULSE Technology Training Workshop, September 10-11, Jena, Germany

>> One of the major aims of the European S-PULSE project is the dissemination of knowledge about superconductor electronics. Therefore, the first S-PULSE Jena Technology Training Workshop for students and young scientists was held from September 10 to September 11, 2008 at the Institute of Photonic Technology (IPHT) in Jena, Germany. The IPHT is the circuit manufacturer of the FLUXONICS Foundry. More than twenty participants from South Africa, France, United Kingdom and Germany attended the workshop. In contrast to other S-PULSE workshops the lecture course was focused on education by the circuit makers.

During the first day the lessons started with information on the organization structure of the FLUXONICS Foundry, the basic principles of thin film technology and the characterization of microstructures. The main session was about the design rules of the FLUXONICS Foundry. It consisted of three lectures about the IPHT 3.5 micron RSFQ process, the circuit design and the circuit characterization. The first day was closed by a laboratory tour at the IPHT to get an impression on circuit assembling and circuit characterization. In the evening the discussion was pursued during a dinner in the restaurant "Haus im Sack" located in the historical part of Jena.

The second day started with a lesson on clean room environments followed by a clean room tour. In front of the production tools the workshop participants discussed with the circuit makers and got an idea on the RSFQ circuit fabrication.

In the afternoon our guests left Jena. The lessons enable the students and young scientists to develop new RSFQ circuits based on the design rules of the FLUXONICS Foundry. The next FLUXONICS Foundry run has started at the end of October 2008.

A visit of the clean room facility of the FLUXONICS Foundry at IPHT in Jena during the first S-PULSE Technology Training Workshop

Upcoming events

>> Workshop on experimental aspects of superconducting electronics Chambéry, France – April 6-8, 2009.
The first S-PULSE workshop about metrology will be held in spring 2009 at PTB (Physikalisch-Technische Bundesanstalt) in Braunschweig, Germany.. This workshop will deal with experimental considerations related to Superconducting Electronics: methods of measurements about analog and digital devices, interfaces with other technologies, with cryocoolers,... There is no registration fee. If you wish to attend and present your work in this area, you can register directly from S-PULSE website *www.s-pulse.eu* before March 6, 2009.

>> Metrology Workshop, Braunchweig, Germany.
The first S-PULSE workshop about metrology will be held in spring 2009 at PTB (Physikalisch-Technische Bundesanstalt) in Braunschweig, Germany. This workshop will deal with all aspects of metrology related to the use of Superconducting Electronics. More information will be available on S-PULSE website *www.s-pulse.eu* in due time.

>> SEFIRA days, Fréjus, France
The sixth edition of the French Superconducting days (SEFIRA days) related to Superconducting Electronics and Physics of Superconductors will be held in the beautiful city of Fréjus on the french Riviera from May 26th to May 28th, 2009. If you want to attend, present an oral talk or a poster, you can register directly from SEFIRA website *www.sefira.org.*

>> ISEC 2009 and Superconducting SFQ VLSI Workshop - Fukuoka, Japan
The International Superconducting Electronics Conference (ISEC 2009) will be held in Fukuoka, Japan during June 15-19, 2009, along with the Superconducting SFQ VLSI Workshop. Deadline for abstract submission is January 31, 2009. To know more, submit an abstract or register, go to *www.isec09.org*.

>> Cryogenics conference Tucson, USA
The Cryogenic Engineering Conference and the International Cryogenic Materials Conference (CEC/ICMC) will be held in Tucson, Arizona from June 28 to July 2nd, 2009. More information available at *www.cec-icmc.org*.

>> 6th Fluxonics design workshop Ilmenau, Germany
The 6th edition of the Fluxonics RSFQ design workshop will be held in Ilmenau, Germany, on July 27-29, 2009. More information available at *www.s-pulse.eu*.

>> EUCAS 2009 - Dresden, Germany
The European Conference on Applied Superconductivity (EUCAS) will be held in Dresden in Germany from September 13 to September 17, 2009. Deadline for abstract submission is March 15, 2009. More information is available at *www.eucas2009.eu*.

>> EUROFLUX2009 – Avignon
The second EUROFLUX conference, following the first edition that took place in Naples in September 2008, will take place in 2009 from September 20 to September 23, in the beautiful city of Avignon in France. The conference aim is to disseminate the knowledge to interested industry and research laboratories in the three principal sub-domains: digital electronics, superconducting sensors and microwave devices and systems. Topics are: LTS and HTS junctions, SQUIDs and SQUIDs applications (magnetometry), Radiation Detectors, Digital circuits and applications, Microwave devices (filters, SQUID amplifiers...), Metrology devices... Abstract submission and early registration starts on January 5, 2009. Abstract submission deadline is planned in June 2009. More information is available on the conference website: *www.fluxonics.org/euroflux2009*

>> ASC2010, Washington DC, USA
The next edition of the Applied Superconductivity Conference (ASC2010) will be held in Washington DC, USA in August 1-6, 2010. More information available at *www.ascinc.org*.

Announcements

Contributions to this newsletter

If you wish to write an article, mention an event or make an announcement about Superconducting Electronics in this Newsletter, please send the content in text or word format with separate files for pictures (with high resolution: 300 dpi minimum) at the following e-mail address, two months before publication: newsletter@s-pulse.eu. Next publications are planned for April 2009, September 2009, January 2010 and June 2010.

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