IEEE 17th Workshop on Low Temperature Electronics

WOLTE 2026

1-5 JUNE 2026 | GIARDINI NAXOS, SICILY, ITALY

WOLTE 2026
CONFERENCE PROGRAM

Please visit our website for more information!

2026.ieee-wolte.org

SPONSORS & ORGANIZERS

IEEE

IEEE CSC Council on Superconductivity

Table of Contents

Monday, 1 June 2026 6

Keynote: Scalable Superconducting Quantum Computer with Tileable Qubit Architecture 6

Building a superconducting quantum computer 7

Raising the Operation Temperature of Superconducting Qubits 8

Toward Scalable All-Silicon Superconducting-Photonic Integration on SOI 9

Stacked Josephson junctions for quantum circuit applications 10

Unconventional Josephson junctions for superconducting quantum hardware 11

Flux-tunable transmon based on superconductor-semiconductor junctions 12

Direct Comparison of Cryogenic Split C-V and Hall Effect Mobilities 13

Phase-modulation control techniques for superconducting transmons 14

A Three-Transmon-Shared-SQUID Architecture For Analog Quantum Simulations 15

Chip-based digital readout of a superconducting qubit 16

Programmable Josephson Metasurfaces for Scalable Cryogenic Control of Superconducting Qubits 17

Low-Power Qubit Control Based Using Kinetic Fluxons 18

Doppler-induced Frequency Shift of Microwave Pulses 19

Wireless Excitation of a Superconductive Resonator in a Dilution Refrigerator 20

Superconducting Control for Scaled Quantum Systems 21

RQL Scalable mK Micro-controller for a Quantum Processor 22

Status update on FLUXONICS Foundry fabrication technologies: Mixed-signal CJ2 and future processes for quantum circuits 23

Tuesday, 2 June 2026 24

Keynote: Cryogenic Electronics and Architectures for Scalable Quantum Technologies 24

CryoCMOS for the Ultimate Cold: Millikelvin Applications and Perspectives for Quantum Computing 25

Cryogenic CMOS Circuits for Frequency-Multiplexed Qubit Control and Fast Readout 26

CryoCMOS RF multiplexer for superconducting qubit control, Readout and Flux Biasing at Millikelvin Temperatures with Picowatt Power Consumption 27

A Cryo-CMOS Phase-Locked Loop for Quantum Computing and Sensing 28

Cryogenic Measurements and Model Extension for a 28-nm Bulk CMOS Technology 29

Deep Cryogenic Operation of Single-Level and Stacked Nanowire and Nanosheet SOI MOSFETs for Quantum Computing 30
Temperature-Dependent Characterization of a Flash-Based FPGA 31
CryoCMOS Paving the Way to Scalable SET Based Logical Circuit 32
Superconducting Accelerator for Area-Efficient Quantum State Discrimination at 4K 33
Keynote: Superconducting Spintronics for Racetrack Memory 34
Prototypes of a vortex-based memory cell supporting wordline and bitline operation with non-destructive readout 35
Low Subthreshold Swing Cryo-CMOS for Ultra-Low-Power Cryo Electronics 36
Engineering Quantum Hardware on Silicon: From Low-Loss Circuits to Cryogenic Logic 37
Electrostatic Control of Superconductivity in Top-gated KTO3-2DEG Devices: Realization of Superconducting Field-effect Transistors 38
Increase of critical current in wafer-scale CVD graphene-based Josephson field-effect transistors by process optimization 39
Wafer scale superconducting transistor technology for ultrasensitive bolometers 40
Wednesday, 3 June 2026 41
Keynote: Quantum Sensing of Cosmological Signals 41
Nanoscale YBCO Devices for Quantum Sensors and Detectors 42
Ultra-Wide, High-Current Superconducting Nanowire Single Photon Detectors 43
Characterization of Light Detectors for Cryogenic Calorimeters 44
Superconductor Nanostripe Single-Photon Detectors with Cryogenic Readout Enabling Photon Number and Energy Resolution 45
High-Efficiency Superconducting PNR-Detector Arrays for Quantum Applications 46
Photoelectric detection of single microwave photons in a granular aluminum high-impedance quantum circuit 47
Recent progress in quantum sensors for high frequency gravitational wave detection 48
Methods of RF Calibration at Cryogenic Temperatures 49
Electrical noise of metrology-grade quantum Hall effect devices 50
Investigation of SQUID-based Noise Thermometry for low Temperatures 51
TiN Inductors for Thermometry and Readout to Enable Monolithic Integration of Silicon Quantum Processors 52

Thursday, 4 June 2026 53

Keynote: Giving Supercurrents a Greater Sense of Direction 53

Periodic Phase Slips and Nonreciprocal Supercurrents in Tubular Superconductors.......... 54

Magnetotransport Signatures of Spin-Orbit Coupling in High- Temperature Cuprate Superconductors 55

The possible trivial role of spin-orbit coupling in planar Josephson junctions 56

Unconventional gap structure in kagome superconductor integrated with a microwave circuit 57

Perfect spin nonreciprocity in gated superconducting altermagnetic heterostructures 58

Interface-driven triplet proximity effects and electronic transport in spin-orbit coupled superconductor/ferromagnet hybrids 59

Reentrant Superconductivity in a de Gennes spin valve 60

Phase dynamics and dissipation in tunnel ferromagnetic Josephson junctions 61

Dynamically Induced Anisotropy in Ferromagnet in Superconductor Ferromagnet Heterostructures Rhiannon Adela Fletcher-Stones *University of Cambridge, United Kingdom*. 62

Dzyaloshinskii-Moriya Interactions Mediated by Cooper Pairs 63

Gating all-Silicon Josephson junctions 64

Dynamical Slowing-down in Far-from-equilibrium Superconductivity Melting 65

High-Q Ta-based microwave resonators for quantum applications 66

High-Q Ta Superconducting Resonators on W-buffered Si Substrates 67

Towards a perfect field-free Josephson diode 68

Scanning SQUID Imaging of Trapped Vortices in Active Flux-Management Circuits 69

Vortex and Moat Coupling to SFQ and AQFP Circuits – Circuit Theory, Models and Validation .. 70

Ginzburg-Landau theory in application: Towards numerical modeling of integrated superconducting circuits 71

Friday, 5 June 2026 72

Keynote: Superconducting transition-edge sensors for applications in space astrophysics, fusion plasma and particle physics 72

A TES based large area anticoincidence detector with silicon absorber, the newAthena CryoAC microcalorimeter 73

Background Mitigation in a TES for Direct Dark Matter Searches 74

Tailoring Josephson Nonlinearity in an rf-SQUID for Superconducting Microwave Amplification 75

Cryogenic in situ Up-conversion and Down-conversion of Qubit Signals Using a Superconducting Nonlinear Kinetic Inductance Transmission Line 76

Kinetic Inductance Traveling Wave Parametric Amplifier for Practical Readout Applications 77

Generating Single Mode Squeezing with a Double-Pumped Traveling Wave Parametric Amplifier 78

Real-Time Readout of Large KID Arrays for the BULLKID-DM Experiment 79

Strongly Directional Amplification with a Kinetic Inductance Traveling Wave Parametric Amplifier 80

Strongly Nonlinear Regime of Josephson Transmission lines 81

Model-Independent Added-Noise Measurement in Cryogenic Microwave Amplifiers 82

Posters 83

1. Behavioral and Physics-Based Modeling of Josephson Field-Effect Transistors (JoFETs) 83

2. Low-Noise Performance of a Si JFET Fully Differential Amplifier at Low Temperatures 84

3. Development of KICS microwave multiplexing for the HOLMES+ experiment 85

4. Effect of Aging on the Superconducting Transition of Ti/Au TES Bolometers arrays 86

5. Millikelvin Digitization of Calorimetric Qubit Readout for Low-latency Feedback 87

6. Low-Temperature Microwave Characterisation of Titanium Nitride Coplanar Waveguide Resonators 88

7. Ta/MgO/Ta Josephson Junctions on Si Substrates by Room-Temperature Sputtering 89

8. Cryogenic Characterization of Inkjet-Printed Microwave Transducers 90

9. Low-temperature electrical characterization of carbon-black printed resistors 91

10. Flexible I-V Characterization System for Power Switch Devices in Room and Cryogenic Temperatures 92

11. Dynamic Beam Steering via DC-Biased Josephson Inductance in a Superconducting 30 GHz Phased Array 93

12. Nonlinear Spectral Filtering and Photonic Transport 94

13. Modelling, extraction, and calibration of layouts for the FLUXONICS cross-type Josephson junction process 95

14. Phase-induced switching of ferromagnetic insulators in Josephson spin valves 96

15. Superconducting Exchange Coupling in a FI/S/FM system 97
16. Retrapping diode effects in magnetic Josephson junctions 98
17. Competing Non-Coplanar Magnetic States in Cubic Mn_3Ge Kagome Antiferromagnets 99
18. Supercurrents in Lateral S/F/S Josephson Junctions Incorporating NbTiN and Ni Grown by Atomic Layer Deposition 100
19. POVM-Based Rigorous Evaluation of Photon-Number-Resolving Capability for Optical Quantum Computing 101
20. High-speed Superconducting Nanowire Single Photon Detector readout using RSFQ 102
21. A Hybrid Superconducting Architecture for Physically Embodied Active Inference: Classical and Quantum Operating Regimes of a Coupled JPO Array 103
22. Advancing Superconducting ADC Decimation Filters: Power Efficiency and Noise Robustness for Cryogenic Computing 104
23. An integrated low noise multi-loop SQUID magnetometer with asymmetric shunt resistors 105
24. Evolution and Air Instability of Se based 2D Materials used in Quantum Technologies 106
25. Low Temperature VNA-based Characterization of SAW and BAW Resonators.................. 107
26. Design and Simulation of Dual-Frequency Microfluidic Microwave Sensors 108
27. Development of KICS microwave multiplexing for the HOLMES+ experiment 109
28. A Compact Microwave Switching Platform for In-Situ Calibration up to 20 GHz 110
29. Superconducting Microwave Cavities for High-Sensitivity Axion Haloscopes 111
30. Josephson Coupling Through a Magnetic Racetrack 112

Monday, 1 June 2026

Keynote: Scalable Superconducting Quantum Computer with Tileable Qubit Architecture

Shuhei Tamate

RIKEN Center for Quantum Computing, Japan

Building a superconducting quantum computer

Giovanna Tancredi
Chalmers University of Technology, Sweden

Superconducting circuits are among the leading platforms for building scalable quantum computers, offering a promising path toward practical quantum information processing.

In my talk, I will discuss the building blocks of a superconducting-based quantum computer discussing the challenges that needs to be overcome. Lastly, I will present recent results and performances of the 25-qubit processor, currently in operation at Chalmers.

Raising the Operation Temperature of Superconducting Qubits

Vladimir Manucharyan
EPFL, Lausanne, Switzerland

The operation of superconducting qubits at the base temperature (around 10-20 mK) of dilution refrigerators heavily restricts the density of qubits per chip in quantum processors due to the limited cooling power. Since the cooling power scales quadratically with temperature, even a modest temperature increase would significantly up the cryogenics ceiling on the total number of qubits on a single chip. In conventional circuit QED, the requirement for 10-20 mK operating temperatures comes from the need to minimize the thermal occupation of the readout resonator. In theory, the thermal occupation can be suppressed exponentially with the mode frequency, which motivates reading out warmerd up qubits with higher frequency signals. We report a successful demonstration of this idea: regular superconducting transmon qubits are cooled down in a 21-GHz cavity and showed marginal degradation of the single-qubit gate fidelity, at the level of 0.9998-0.9999, all the way up to 100 mK temperature. Our experiment opens a new path to accelerate the scaling of superconducting processors.

Toward Scalable All-Silicon Superconducting-Photonic Integration on SOI

A. van Waveren [1], D. Débarre[1], D. Ricciarelli[2], G. Calogero[2], G. Hallais[1], C. Ramos[1], A. la Magna[2], F. Chiodi[1]
[1]Centre de Nanosciences et de Nanotechnologies, 91120, Palaiseau, France [2]CNR-IMM, 95121 Catania, Italy

The reproducibility and scalability associated to the CMOS industry have led to a large increase in the use of silicon for other applications as well, most notably the surge of silicon integrated photonics during the past decade. However, it is less well-known that this material cannot only host electronic and photonic circuits, but also becomes superconducting when hyper doped with Boron above 1 at.%.[1] We are currently working on building all-Si devices that combine superconductivity with integrated photonics to directly link quantum circuits to fast, low noise optical waveguides.

Achieving the concentration required for superconductivity in silicon-on-insulator (SOI) used for photonic circuits poses multiple challenges, as they can only be obtained via an out-ofequilibrium processes. Nanosecond laser doping, that induces an ultra-fast liquid-phase epitaxy enables boron incorporation far above the solubility limit (up to 8 at.% in bulk silicon.[2]) The reduced heat dissipation through the 1-3 µm thick buried oxide (BOX) compared to bulk silicon leads to a large reduction of the recrystallization velocity from 4 m/s to 2 m/s and thus to a lower charge carrier concentration. Additionally, the higher thermal budget enhances dopant diffusion, leading to unwanted deactivation of the boron.

By combining experiments and simulations, we investigated the influence of the silicon and BOX thicknesses (notably Si/SiO2 = 220/2000, 700/3000 and 88/145 nm) on recrystallization dynamics and electrical properties. It was shown that the silicon thickness is the dominant factor for the melting threshold, whereas the BOX thickness strongly impacts the thermal budget, leading to dopant deactivation. As a result, both the total stack and the chosen laser energy determine the final recrystallization velocity. For the 700/3000 nm SOI reducing the layer thickness from 250 to 80 nm lowers the thermal budget and hence improves the layer quality, leading to a doubling of the charge carrier concentration. This enables superconductivity with a critical temperature of 0.5 K and, to our best knowledge, constitutes the first demonstration of superconductivity on photonics-compatible SOI.

For SOI with thinner BOX layers, typical substrates for microelectronics applications such as FD-SOI MOSFET, the thermal confinement is smaller, and high dopant activation is systematically achieved. Furthermore, it has been shown that implantation followed by nanosecond laser annealing can reach similar active concentrations as in-situ doping [3], allowing the implementation of superconducting devices on 'microelectronics' SOI with CMOS compatible techniques. These results indicate a promising potential for the industrial fabrication of hybrid circuits combining integrated photonics and superconductive silicon.

References

1. E. Bustarret et al., Nature 444, 465–468 (2006).
2. L. Desvignes et al., pre-print at arXiv:2603.06383 (2026)
3. Y. Baron et al., APL Mater. 12, 121101 (2024).

Stacked Josephson junctions for quantum circuit applications

Alex Kreuzer[1], Hossam Tohamy[1], Hannes Rotzinger[1,2], Alexey V. Ustinov[1,2]

[1] *Physics Institute, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany*
[2] *Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany*

Low-loss inductors are essential components in various superconducting circuits, such as qubits or digital electronics. We explore a novel way of making superconducting quantum circuits by going off-plane from the substrate, namely by stacking Josephson tunnel junctions vertically. This approach allows for fabricating very compact inductors needed in many quantum circuit applications. Other potential advantages are, for example, the reduced stray capacitance of the junction array to the ground, which moves the array resonance modes up in frequency thus avoiding the unwanted resonances in the operation band of the circuit.

Our implementation of compact inductors [1] employs multiple layers of aluminum separated by Josephson tunnel barriers. Individual stacks are connected by suspended superconducting bridges, which are free of additional dielectric materials and therefore should not contribute significantly to losses. We developed a fabrication process of stacked Al/AlO_x/Al junctions and used it for making quarton-type flux qubits. We present implementation details, fabrication results, and device characterization data. Measurement results of the fabricated qubit circuits will be presented.

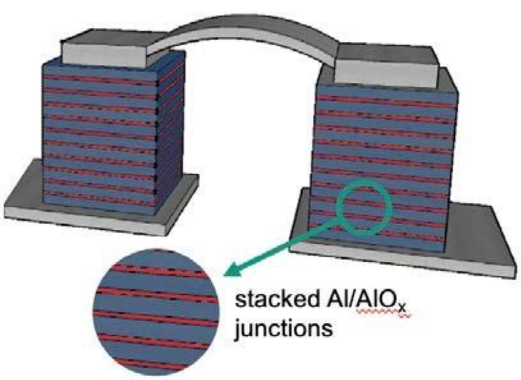


Fig. 1: *Schematics of an array of stacked Josephson junctions with airbridge connecting the top of two stacks (dimensions are not to scale.).*

References

1. Kreuzer, T. Krumrey, H. Tohamy, A. Ionita, H. Rotzinger, and A.V. Ustinov, e-print arXiv:2503.11437 (2025); to appear in Phys. Rev. Applied (2026).

Unconventional Josephson junctions for superconducting quantum hardware

D. Massarotti[1], R. Satariano[2], R. Ferraiuolo[3], H. G. Ahmad[2], F. Calloni[2], C. Cosenza[2], G. Serpico[2], D. Gatta[2], E. Raja[2], L. Parlato[2], G. Ausanio[2], A. Vettoliere[4], C. Granata[4], D. Montemurro[2], A. Bruno[3], G. P. Pepe[2], F. Tafuri[2]

[1] *Università di Napoli Federico II, Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione, Napoli, Italy*
[2] *Università di Napoli Federico II, Dipartimento di Fisica "E. Pancini", Napoli, Italy*
[3] *QuantWare, 2628 XG Delft, The Netherlands*
[4] *Consiglio Nazionale delle Ricerche, ISASI, Via Campi Flegrei 34, Pozzuoli, Italy*

Progress in material science and nanofabrication gives opportunities to create unique hybrid Josephson junctions (JJs) and novel designs of superconducting circuits, thus providing advanced functionalities in superconducting quantum technologies and promoting alternative layouts for superconducting quantum computing devices.

We will report on special properties of hybrid tunnel-ferromagnetic JJs [1-3], comprising both an insulating barrier and a ferromagnetic material. The capability to have low dissipative and high-quality tunnel ferromagnetic JJs [1-2, 4-5], also employing Al-based technology [6-8], have promoted the notion of a novel type of superconducting qubit: the ferro-transmon [9]. This type of device allows for an innovative protocol for the tuning of the qubit frequency by means of magnetic field pulses, which is not susceptible to specific noise sources in a transmon configuration.

Moreover, this kind of architecture offers novel experimental tools to probe the rich phenomenology of superconductor/ferromagnet interfaces [5] and to develop a set of quantum hardware components, ranging from amplifiers to couplers in a superconducting quantum processor, thus providing a relevant example of how unconventional materials can be used to realize functional devices.

References

1. D. Massarotti et al. Nat. Commun. **6**, 7376 (2015).
2. H. G. Ahmad et al., Phys. Rev. Applied **13**, 014017 (2020).
3. H. G. Ahmad et al. Comms. Phys. **5**, 2 (2022).
4. R. Satariano et al. Phys. Rev. B **103,** 224521 (2021).
5. R. Satariano et al. Communications Materials **5**, 67 (2024).
6. A. Vettoliere et al. Appl. Phys. Letter. **120**, 262601 (2022).
7. H. G. Ahmad et al., Appl. Phys. Letter. **124**, 232601 (2024).
8. R. Satariano et al. Appl. Phys. Lett. **127**, 252601 (2025)
9. H. G. Ahmad et al., Phys. Rev. B **105**, 214522 (2022).

Flux-tunable transmon based on superconductor-semiconductor junctions

Maxim G. Vavilov
Department of Physics, University of Wisconsin-Madison, Madison, WI 53706, USA
April 30, 2026

Abstract

We present a theoretical study of flux-tunable superconducting qubits based on interference effects in wide superconductor-semiconductor Josephson junctions. This approach accounts for two distinct device architectures: ballistic junctions threaded by magnetic flux [1] and splitjunction devices where flux is applied through a SQUID loop [2]. The common underlying phenomenon is the influence of magnetic flux on the interference of higher-order harmonics of the supercurrent. We investigate this flux effect in both ballistic junctions and split-junction devices and demonstrate that significantly enhanced anharmonicity can be routinely achieved without an increase in sensitivity to offset charge noise. Microscopic tight-binding simulations confirm that this enhancement persists even in the presence of inhomogeneous electrostatic potentials and disorder. We verify that such intrinsically large anharmonicity enables these devices to be driven coherently with short gate times without the need for complex pulse shaping. These results establish a robust framework for flux control in superconducting circuits, providing an operating point where anharmonicity and charge-noise protection are optimally balanced. Highresolution spectroscopy of device transitions as a function of flux also serves as an accurate tool for extracting fine details of the current-phase relation, providing insights into junction physics that are typically inaccessible through standard transport measurements.

References [1] L. Ma, et al. “Anharmonicity and Charge-Noise Sensitivity of Fraunhofer Qubit.” arXiv preprint arXiv:2603.06830 (2026). [2] S. Liu, et al. “Strongly anharmonic flux-tunable transmon based on InAs-Al 2D heterostructure.” Nature Communications 17, 740 (2026).

Direct Comparison of Cryogenic Split C-V and Hall Effect Mobilities

Giselle A. Elbaz

Quobly, France

Direct Comparison of Cryogenic Split C-V and Hall Effect Mobilities in Si-based Quantum Computing Platforms

Effective carrier mobility (μ_{eff}) is widely used to evaluate material and interface quality in MOSFETs. [1] This metric is particularly crucial to Si-based qubit and cryoelectronic technologies alike, as the Si lowtemperature mobility is limited by surface roughness [1] and a single defect can impair qubit performance. [2] At the industrial scale, μ_{eff} is typically estimated by combining drain current (I_{DS}) and gate-to-channel capacitance (C_{GC}). This estimation often neglects contributions to I_{DS} from access resistance or interface traps and is highly sensitive to the model chosen for the carrier density (N_{inv}). Split C-V (Fig.1 top), which calculates N_{inv} from the integral of C_{GC}–V_{GC}, generally improves μ_{eff} extractions but can still be subject to error; surface potential fluctuations and surface energy quantization effects can modify C_{GC}–V_{GC} and propagate to μ_{eff}. [3] The latter is particularly prevalent in thin gate oxides (t_{ox} < 2nm), [3] such as those found in commercial 28nm FD-SOI and 22FDX™ platforms, both of which are currently being explored for Si spin qubit development. [4] In comparison, the Hall Effect directly measures mobility (μ_{Hall}) as a function of N_{inv} (Fig.1 bottom) and is less susceptible to the above-listed errors. However, this method has significantly more design and setup constraints, is time-consuming, and is thus not easily scalable to the wafer level. Accurate C_{GC}–V_{GC} of Hall bars can be difficult to acquire and so comparisons of the two methods are typically performed with μ_{eff} of MOSFETs and μ_{Hall} of Hall bars. [5] In this study we present, for the first time, Split C-V and Hall Effect mobilities both collected on 28nm FD-SOI Hall bars. We provide waferlevel MOSFET statistical analysis to establish baseline device variability. We then show that, on the dielevel, both methods produce similar behavior as a function of temperature and back-bias (V_B). We further compare these results to simple MOSFETs integrated on the same wafers and show that, at low temperatures, Split C-V on MOSFETs can reproduce μ_{Hall} even at low N_{inv}. Implications for wafer-level screening in the quantum computing space, as well as benchmarking to similar 22FDX™ MOSFETs, are discussed.

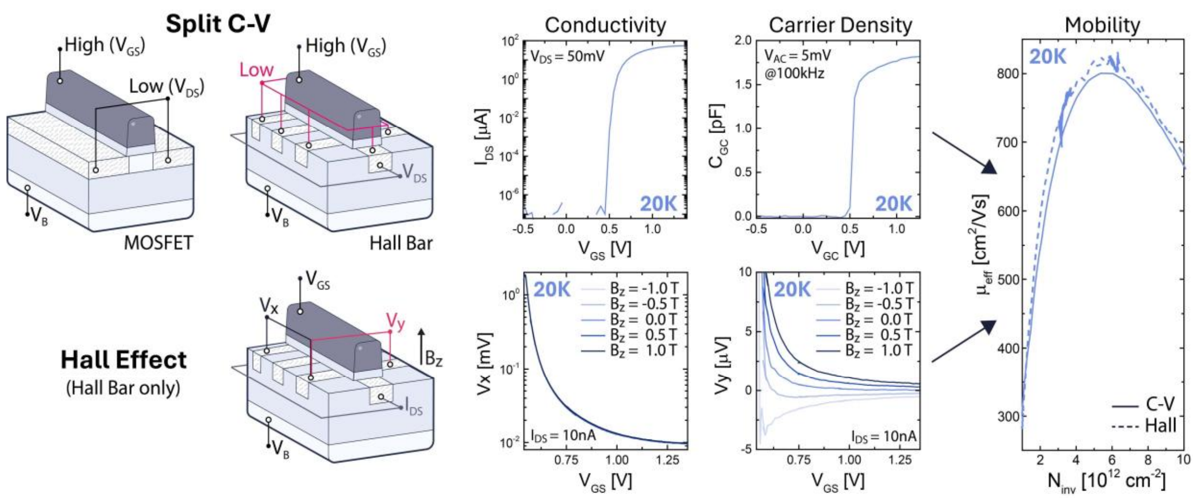


Fig. 1: Comparison between Split C-V (top) and Hall Effect (bottom) devices & methodologies at 20K.

References

1. S. Takagi, A. Toriumi, M. Iwase, H. Tango, IEEE Trans. on Elec. Dev. 41, (1994)
2. B. Martinez, Y. M. Niquet, Phys. Rev. Appl. 17, (2022)
3. (a) J. R. Hauser, IEEE Trans. on Elec. Dev. 43, (1996); (b) J. R. Hauser, K. Ahmed, AIP Conf. Proc. 449, (1998)
4. (a) G. A. Elbaz, P.L. Julliard, M. Cassé, H. Niebojewski, B. Bertrand, G. Roussely, V. Labracherie, M. Vinet, B. Cardoso Paz, T. Meunier, SISPAD 2025 (2025); (b) G. A. Elbaz, J. Pelloux-Prayer, K. Gruel, P. Torresani, R. Lethiecq, P.L. Julliard, C. Suarez-Segovia, F. Arnaud, E. Nowak, T. Meunier, B. Cardoso Paz, SSE 229 (2025)
5. G. A. Elbaz, M. Cassé, V. Labracherie, G. Roussely, B. Bertrand, H. Niebojewski, M. Vinet, F. Balestro, M. Urdampilleta, T. Meunier, B. Cardoso Paz, ESSDERC 2023, 53 (2023)

Phase-modulation control techniques for superconducting transmons

Gheorghe Sorin Paraoanu[1]
[1]Department of Applied Physics, Aalto University, FI-00076, Espoo, Finland

Standard control techniques of superconducting qubits typically rely on resonant Rabi microwave pulses; however, operations such as population transfer can be also realized by changing the frequency of the system [1]. Here I will present several results that demonstrate high-fidelity control of the first two or three levels of a transmon device. We have constructed single-qubit X/Y pulses that achieve frequency robustness of the order of 10 MHz around the qubit frequency and are tolerant to amplitude errors of the order of 20% [2]. Two-photon driving is also possible, and in this case, we have put in evidence the doubling of the Landau-Zener velocity and the exact cancellation of the ac Stark shift. Moreover, we can utilize the framework of neural ordinary differential equations (Neural ODEs) to create pulses with fidelity greater than 99.9% that are robust to 20 MHz detunings. Finally, I will mention the applications of these control methods to dark photon and axion detectors.

References

1. M.P. Silveri et al., Rep. Prog. Phys. 80, 056002 (2017)
2. M. Kuzmanovic et al., Phys. Rev. Research 6, 013188 (2024)
3. I. Björkman et al., Phys. Rev. Lett. 134, 060602 (2025)
4. M. Kuzmanović et al., arXiv:2505.02054

A Three-Transmon-Shared-SQUID Architecture For Analog Quantum Simulations

A. Cattaneo[1,2], D. Labranca[1,2], G. Peng[4], A. Schang[4], Z. Shi[4], Cindy X.C. Yang[4], A. Nucciotti[1,2,3], A. Giachero[1,2,3], C.M. Wilson[4]

[1] Department of Physics - University of Milano-Bicocca - Piazza della Scienza 3, 20126, Milan - Italy

[2] INFN - Milano-Bicocca - Piazza della Scienza 3, 20126, Milan - Italy

[3] Bicocca Quantum Technologies (BiQuTe) Centre - Piazza della Scienza 3, 20126, Milan - Italy

[4] Institute for Quantum Computing and Department of Electrical & Computer Engineering, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada

While universal quantum computers remain under development, analog quantum simulators (AQS) offer a powerful alternative for studying complex many-body systems in condensed matter, chemistry and high-energy physics. Unlike the digital paradigm, AQS realize the target Hamiltonian directly at the hardware level, demanding architectures tailored to the interactions of interest [1]. In superconducting circuits, parametric drives provide a particularly flexible tool: by modulating flux-sensitive elements, qubit interactions can be engineered and activated on demand, with programmable coupling strengths and phases [2].

In our work, we propose a three-transmon architecture in which the qubits share a common asymmetric SQUID: the result is a current-coupling causing strong hybridization between the circuit modes. This enables parametrically activated interactions far more powerful than those of conventional capacitive schemes. By construction, this design provides all-to-all connectivity and flexibility on the type of interaction. The large mode coupling ensures that even three-body processes reach interaction rates well above the weak regime typical of traditional implementations.

Modeling such systems accurately require numerical approaches, for which we rely on a tensor-network method implemented using the TeNPy library [3]. Finite-element electromagnetic simulations in Ansys HFSS supported the circuit model and guide the device design. A first prototype has been fabricated at the Quantum Nanofabrication and Characterization Facility (QNFCF) of the University of Waterloo and is currently undergoing cryogenic characterization.

This architecture finds direct application in the simulation of collective neutrino flavor oscillations in dense astrophysical environments [4], where all-to-all connectivity and many-body couplings are essential. Similarly, real-time simulations of lattice gauge theories, recently explored with a capacitive coupling scheme based on analogous principles [5], is another natural application.

Acknowledgements

This work is supported by the Mitacs Globalink Research Award Program, the Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant, and by QUART&T, a project funded by the Italian Institute of Nuclear Physics (INFN) within the Technological and Interdisciplinary Research Commission (CSN5) and the Theoretical Physics Commission (CSN4).

References

[1] T. H. Johnson, S. R. Clark, and D. Jaksch. What is a quantum simulator? *EPJ Quantum Technol.*, 1(10), 2014.

[2] X. Y. Jin, K. Cicak, Z. Parrott, S. Kotler, F. Lecocq, J. Teufel, J. Aumentado, E. Kapit, and R. W. Simmonds. Fast, tunable, high fidelity cZ-gates between superconducting qubits with parametric microwave control of ZZ-coupling. 5 2023.

[3] Hauschild et al. Tensor network python (tenpy) version 1. *SciPost Physics Codebases*, November 2024.

[4] Benjamin Hall, Alessandro Roggero, Alessandro Baroni, and Joseph Carlson. Simulation of collective neutrino oscillations on a quantum computer. *Phys. Rev. D*, 104:063009, Sep 2021.

[5] J. H. Busnaina, Z. Shi, Jesu´s M. Alcaine-Cuervo, Cindy X. Yang, I. Nsanzineza, E. Rico, and C. M. Wilson. Native three-body interactions in a superconducting lattice gauge quantum simulator. *Phys. Rev. B*, 112:134514, Oct 2025.

Chip-based digital readout of a superconducting qubit

L. Di Palma[1], S. Phiri[1], K. Manivannan[1], J. Walter[1], M. Renzullo[1], M. Yu[1], D. Yohannes[1], C. Checkley[1], O. Mukhanov[1], SJ. Han[1]

[1] *SEEQC inc., 10523, Elmsford (New York), USA*

Fast, high-fidelity, and scalable qubit readout is a key requirement for realizing fault-tolerant quantum computers (QCs) and fully harnessing their disruptive computational potential. Current experimental approaches to superconducting qubit readout rely on microwave components distributed between room and cryogenic temperatures, imposing significant technological and economic challenges to scalability. Developing a fast, high-fidelity, chip-integrated readout scheme operable entirely within the cryogenic environment is therefore essential to minimize system footprint and enable low-latency quantum operations.

In this work, we demonstrate high-fidelity SFQ on-chip digital readout of superconducting qubits using the Josephson Digital Phase Detector (JDPD) [1]. The JDPD's potential energy landscape exhibits a distinctive transition from a single-well to a double-well configuration when the system is properly flux-excited. This property enables direct digitization, at the millikelvin stage, of the phase sign of a coherent GHz-frequency input tone that encodes the qubit state information.

The JDPD readout architecture can be implemented in both flip-chip [2] and split-chip configurations, where the JDPD chip and the Quantum Processing Unit (QPU) are placed in close proximity and interconnected via PCB wires. This approach enables seamless integration of the JDPD with any QPU without design modifications. Moreover, the same implementation supports on-chip multiplexed qubit readout, allowing multiple qubits to be measured in parallel with minimal additional hardware overhead. The split-chip configuration has been experimentally tested with a commercial QPU, achieving single-qubit readout fidelities exceeding 99% with a fast detection speed, primarily limited by the ring-up time of the qubit resonators.

References

[1] Di Palma et al., Phys. Rev. Appl., 19(6), 2023

[2] Jordan C., et al. " A quantum computer controlled by superconducting digital electronics at millikelvin temperature ", https://doi.org/10.1038/s41928-026-01576-6.

Programmable Josephson Metasurfaces for Scalable Cryogenic Control of Superconducting Qubits

Mustafa Bakr
Department of Physics, University of Oxford, U.K.

Scaling superconducting quantum processors to the million-qubit regime demands a fundamental reduction in control wiring, thermal load, and cryogenic component count [1]. Several cryogenic control technologies have advanced rapidly toward this goa from CryoCMOS controllers [2, 3] to SFQ digital logic [4]. However, challenge remains unaddressed by digital cryogenic controllers: the analogue microwave functions currently implemented by discrete cryogenic components still require individually wired hardware that scales linearly with qubit count.

We present a programmable two-dimensional Josephson junction metasurface architecture that addresses this complementary set of functions by operating as an analogue microwave field processor directly at millikelvin temperatures [5]. By applying spatiotemporal flux modulation to a 2D SQUID array, the metasurface generates multiple microwave tones with independently controllable frequency, amplitude, phase, and spatial direction. The same device simultaneously provides analogue waveform synthesis, parametric amplification, nonreciprocal signal routing, and programmable qubit-qubit coupling through engineered parametric sidebands; unifying functions currently distributed across separate travelling-wave amplifiers, circulators, couplers, and room-temperature electronics.

References

[1] S. Krinner et al. EPJ Quantum Technol. 6, 2 (2019).
[2] D. L. Underwood et al., PRX Quantum 5, 010326 (2024).
[3] arXiv:2603.16608 (2026).
[4] C. Jordan et al. Nat. Electron. (2026).
[5] M. Bakr, arXiv:2411.01345 (2024).

Low-Power Qubit Control Based Using Kinetic Fluxons

Joao F. Barbosa[1], David McAllister[2], Oleg A. Mukhanov[2]
[1]SEEQC.UK, Zip, London, UK
[2]SEEQC, 10523, Elmsford, USA

Current superconducting quantum computing processors require multiple control signals per qubit generated with room temperature electronics and delivered over long and expensive high-quality coaxial cables which dominate the cryostat heat load, cause signal distortions and crosstalk. This fundamental scaling problems can be addressed with implementing qubit control and readout using low power superconducting electronics deployed inside of the cryostat next to quantum processors. One of the objectives is to ensure the cryogenic control energy dissipation would be significantly lower that the heat load associated with the signal delivery over the cables.

The successful realizations of qubit control using superconducting single-flux quantum (SFQ) circuits were demonstrated with ~nW of power per qubit dissipated at the millikelvin stage [1]. Minimization of the power dissipation further would allow scaling to higher qubit count for a given heat capacity. Conventional SFQ circuits, such as ERSFQ, RQL, etc. are built with artificially introduced losses in form of resistive shunts of Josephson junctions for controllable handling of individual quanta of magnetic flux (fluxons). As a result, a constant injection of external energy is needed to enable sustainable fluxon propagation.

We found a way to significantly reduce the circuit power dissipation by using kinetic energy of the fluxons ballistically moving throughout a circuit. The losses are minimized by using unshunted underdamped Josephson junctions. To preserve full control on fluxons, the data processing circuits are unbiased. To compensate for the eventual loss of kinetic energy and assure sustainable ballistic fluxon propagation, an on-demand injection of external energy is done via the quantized phase sources [2]. This has allowed a reduction of power dissipation by at least an order of magnitude per qubit compared to the standard energy-efficient SFQ logics while increasing circuit operation margins and yield.

References

1. J. Bernhardt, C. Jordan, et al. *Nature Electronics* 9, 287-294 (2026).
2. F. Lupo, O. Mukhanov, M Arzeo, PCT/US24/44937 patent application (2023).

Doppler-induced Frequency Shift of Microwave Pulses

Enrico Bogoni[1, 2], Felix Ahrens[1], Renato Mezzena[3, 4], Andrea Vinante[5, 1], Nicolò Crescini[1], Alessandro Irace[1, 2], Andrea Giachero[2, 6, 7], Gianluca Rastelli[8], Iacopo Carusotto[8], and Federica Mantegazzini[1, 4].

[1]Fondazione Bruno Kessler (FBK), 38123, Trento, Italy

[2]Department of Physics, University of Milano-Bicocca, 20126, Milano, Italy

[3]Department of Physics, University of Trento, 38123, Trento, Italy

[4]TIFPA - INFN, Trento, 38123, Italy

[5]CNR-IFN, 38123, Trento, Italy

[6]INFN - Milano Bicocca, 20126 Milano, Italy

[7]Bicocca Quantum Technologies (BiQuTe) Centre, 20126 Milano, Italy

[8]Pitaevskii BEC Center, CNR-INO and Department of Physics, University of Trento, 38123 Trento, Italy

In superconducting electronics, the ability to control the frequency of microwave wave packets is crucial for several applications, such as the operation of superconducting quantum processors and the readout of superconducting sensors.

We introduce a novel approach to frequency conversion of microwave signals, leveraging the Doppler effect on a non-linear superconducting transmission line.

A moving current step dynamically separates a high-kinetic-inductance transmission line into regions with different phase velocities. As a result, a dynamic Doppler effect is induced on a counterpropagating microwave pulse, shifting its frequency.

In contrast to conventional approaches based on frequency-mixing, our Doppler-induced frequency-conversion method avoids spurious mixing products, is continuously tunable by a quasi-dc current amplitude, and allows to imprint arbitrary patterns on the instantaneous frequency profile of temporally long wave packets.
With the current setup we achieved frequency shifts up to 3.7%, i.e. 150 MHz at a carrier frequency of 4 GHz, while fully preserving the wave packets temporal shape. This limit can be readily overcome by engineering transmission lines that allow for larger phase-velocity changes and/or by cascading multiple devices, in principle enabling an unlimited amount of frequency shifting.

Wireless Excitation of a Superconductive Resonator in a Dilution Refrigerator

Kristopher Barr,[1*] Mingyan Zhong,[2] Euan Parry,[1] Manoj Stanley,[3] Qusay Al-Taai,[2] Paniz Foshat,[2] Kaveh Delfanazari,[2] Martin Weides,[2] Nick M. Ridler,[3] Chong Li,[2] Alessandro Rossi,1,3

[1]Dept. of Physics, SUPA, University of Strathclyde, G4 0NG, Glasgow, United Kingdom

[2]James Watt School of Engineering, University of Glasgow, G12 8QQ, Glasgow, United Kingdom

[3]National Physical Laboratory, TW11 0LW, Teddington, United Kingdom

**k.barr@strath.ac.uk*

Condensed-matter quantum computing platforms often necessitate sub-kelvin environments for high-fidelity operation. As these systems scale, the “wiring bottleneck”, where increasing interconnect density introduces prohibitive thermal loads, remains a primary barrier to large-scale integration [1]. One possible solution is offered by classical cryo-CMOS electronics used to control the quantum system [2], but this is currently limited by the cooling power of dilution refrigerators. To mitigate these constraints, intracryostat wireless signal communications could offer a scalable alternative by reducing physical interconnects [3,4].

Here, we experimentally implement a multistage wireless routing architecture within a dilution refrigerator, shown in Fig. 1. This wireless link employs a metalens based on double split-ring resonators in tandem with patch antennas. We employ a NbN superconductive resonator as a testbed system (DUT) to assess the performance of the wireless link for excitation at mK temperature.

Our benchmarking includes comparative measurements between wired and wireless configurations. These reveal high consistency in the intrinsic fundamental resonator parameters. However, analysis of the coupling quality factor identifies secondary coupling pathways inherent to the wireless environment, likely originating from cavity modes. These provide critical insights into isolation requirements for quantum devices operating at the mixing chamber stage. This work demonstrates the viability of wireless interconnects for low-temperature electronics and provides a framework for integrating wireless signal delivery into future cryogenic quantum hardware.

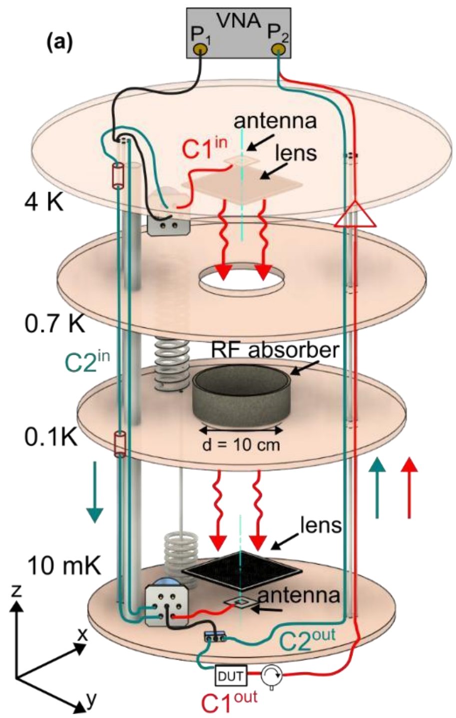


Fig. 1: *Schematic of wireless routing architecture. Antenna and metalens transmit collimated signal from 4 K.*

References

1. Brennan JC, Barbosa J, Li C, et al. Classical interfaces for controlling cryogenic quantum computing technologies. APL Quantum. 2025;2(4):041501.
2. Charbon E, Babaie M, Vladimirescu A, Sebastiano F. Cryogenic CMOS Circuits and Systems: Challenges and Opportunities in Designing the Electronic Interface for Quantum Processors. IEEE Microwave Magazine. 2021;22(1):60-78.
3. Wang J, Harris I, Ibrahim M, Englund D, Han R. A wireless terahertz cryogenic interconnect that minimizes heat-to-information transfer. Nat Electron. 2025;8(5):426-436.
4. Bandara et al., ‘28 GHz Wireless Channel Characterization for a Quantum Computer Cryostat at 4 Kelvin’, Jan. 23, 2026, arXiv: arXiv:2510.16962.

Superconducting Control for Scaled Quantum Systems

Joel Strand[1]
[1]Northrop Grumman, 21090, Linthicum, USA

At Northrop Grumman, we are defining possible at the bleeding edge of superconducting digital and quantum technology. Dual-Rail Qubits (DRQs) are a powerful unit cell for quantum applications, largely due to the inherent erasure detection capability. Superconducting electronics for the control of qubits in the mK environment hold the promise to reduce I/O to warmspace while producing high-fidelity quantum gates. In this work, a dual-rail superconducting qubit comprising two superconducting qubits coupled by a tunable coupler which is actuated by a proximal superconducting digital-to-analog converter (DAC) is presented. The DAC is controlled using Reciprocal Quantum Logic (RQL); a low-power superconducting digital logic family developed at Northrop Grumman. The DACs and qubits are on two separate chips which are bump bonded to form an assembly; flux control for the coupler is provided across the chip-to-chip gap. We will provide an overview of RQL and describe how we use it to perform microwave-free universal control of superconducting dual-rail qubits.

RQL Scalable mK Micro-controller for a Quantum Processor

Aaron Lee, Northrop Grumman
The MDA Quantum Computing Team, Northrop Grumman

Reciprocal Quantum Logic (RQL) is Ideal for cryogenic digital control circuits and is fabricated in Northrop Grumman's Microelectronics Center fabrication facility: Advanced Technology Laboratories (ATL). Northrop Grumman has over 15 years of maturing RQL fabrication to achieve a 13-metal layer stack. NGSC's process showed significant improvement in flux trapping performance across many releases and fully enables 1.5M junctions on 10mm chips. RQL leverages the most sophisticated superconducting automated place-and-route and is able to close 5M junction designs on 20mm die in < 2 weeks. Significant application of RQL is in quantum control to enable scaling to large system sizes. NGSC has demonstrated a standalone digital only qubit classical command generator on 5mm die with > 2dB of margin. Extending classical command generator to large array only requires 8 lines with total power of 3 uW. Northrop Grumman's RQL-controlled architecture enables rapid scaling of a quantum processor.

Status update on FLUXONICS Foundry fabrication technologies: Mixed-signal CJ2 and future processes for quantum circuits

R. Stolz[1,2,3], L. Kaczmarek[1], S. Mechold[1], J. Kunert[1,2], M. Schmelz[1], E. Mutsenik[1], G. Oelsner[1].

[1]*Leibniz Institute of Photonic Technology, 07745, Jena, Germany*

[2]*FLUXONICS - The European Foundry for Superconducting Electronics e.V., 38116, Braunschweig Germany*

[3]*TU Ilmenau, 98693, Ilmenau, Germany*

Superconducting circuits are a key technology for scalable quantum computers. Whilst industry giants such as Google, IBM and Rigetti are pushing the boundaries of performance, access to these technologies is also essential for research institutes and SMEs to develop niche applications and innovative readout concepts incl. those of sensor and detector arrays. The FLUXONICS Foundry bridges this gap: as a European center for superconducting electronics, it lowers barriers to access superconducting circuitry, promotes academic training, and provides the necessary manufacturing infrastructure for Europe.

To cope with recent developments, we advanced our fabrication technologies for mixed-signal analog and digital circuits and are currently extending services into processes for quantum circuits. Within this talk, we will provide an overview on available FLUXONICS Foundry fabrication technologies, their detailed characteristics as well as access opportunities. Results on example circuits fabricated in our mixed-signal CJ2 process, like Adiabatic Quantum Flux Parametron (AQFP), are presented. Moreover, detailed information on Al-based fabrication technologies featuring wafer-scale Manhattan-type Josephson junction technology and implementation of 3D integration technologies is given as well as future research directions are discussed.

Tuesday, 2 June 2026

Keynote: Cryogenic Electronics and Architectures for Scalable Quantum Technologies

David Reilly
The University of Sydney, AUS

CryoCMOS for the Ultimate Cold: Millikelvin Applications and Perspectives for Quantum Computing

A. Potočnik[1], Liam Fallik[1,2], Rohith Acharya[1], Sriram Balamurali[1], Alican Caglar[1], A.M. Vadiraj[1], M. Mongillo[1], Jan Craninckx[1], Alex Grill[1], Danny Wan[1] and K. De Greve[1,2,3]
[1]Imec, Kapeldreef 75, Leuven, B-3001, Belgium,
[2]Department of Electrical Engineering (ESAT), KU Leuven, Leuven, B-3000, Belgium
[3]Proximus Chair in Quantum Science and Technology, Department of Electrical Engineering (ESAT), KU Leuven, Leuven, B-3000, Belgium

Scaling quantum computers to millions of qubits remains a major challenge. Cryogenic CMOS (cryoCMOS) technology offers a promising route to improve scalability by reducing the number of DC and RF cables between room temperature and cryogenic stages, lowering latency, and mitigating the rapidly increasing power demands of control electronics at scale [1]. While several demonstrations have shown cryoCMOS control electronics for quantum computing operating at 4 K, extensive cryogenic hardware is still required to interface with quantum devices at millikelvin temperatures, which limits aggressive scaling. In this talk, I will present imec's latest activities on cryoCMOS, ranging from device fundamentals and technology optimization to ultra-low-power signal multiplexing applications targeting operation at millikelvin temperatures [2]. I will conclude with a discussion of future perspectives and remaining challenges for integrating cryoCMOS control and readout electronics directly at the coldest stages of large-scale quantum systems.

References

1. A. Potocnik et al., Nat. Electron. 8, 3 (2025).
2. L. Fallik et al., arXiv 2603.16608 (2026).

Cryogenic CMOS Circuits for Frequency-Multiplexed Qubit Control and Fast Readout

Hiroshi Fuketa, Ippei Akita, Hanpei Koike, and Takahiro Mori
National Institute of Advanced Industrial Science and Technology (AIST),
305-8568, Tsukuba, Japan

Quantum computers have gained considerable interest because of their potential to outperform classical computers in solving certain classes of problems. Quantum bits (qubits) are the fundamental units of information in quantum computers, and this study focuses on superconducting qubits and silicon spin qubits. In existing quantum computer systems, these qubits are placed inside a cryogenic refrigerator, whereas qubit control and readout electronics operate at room temperature outside the refrigerator. According to [1], quantum computers capable of solving practical problems require more than one million qubits with error correction. Realizing such a large-scale quantum computer system entails overcoming several key challenges: (1) Heat inflow through the cables connecting room-temperature electronics to qubits can overwhelm the cooling capacity of the refrigerator, as number of cables increases proportionally with the number of qubits. (2) Fast qubit readout is essential, since readout operations are performed in every error-correction cycle.

In this talk, we present circuit techniques based on cryogenic CMOS (cryo-CMOS) that address the interconnect complexity problem and enable fast qubit readout. Cryo-CMOS is a circuit design technique that allows chips fabricated using commercially available CMOS processes to operate at cryogenic temperatures.

First, we introduce a cryo-CMOS microwave signal selector for frequency-multiplexed qubit control [2,3]. The proposed signal selector consists of two injection-locked oscillators that can extract a specified frequency tone for qubit control from a multi-tone microwave signal. Experimental results demonstrate that the proposed circuit reduces the number of required cables by a factor of 18, while consuming only 1/30 of the power compared with conventional systems.

Second, we introduce a cryo-CMOS current readout circuit for silicon spin qubits [4,5]. The proposed circuit integrates a current integrator with a correlated double sampling circuit, allowing spin-state readout through a charge-sensing mechanism. We show that the proposed circuit enables a 100-fold faster readout compared with conventional readout systems that rely on room-temperature electronics.

Acknowledgment
This study was partly based on results obtained from a project, JPNP16007, commissioned by the New Energy and Industrial Technology Development Organization (NEDO), and MEXT Q-LEAP Grant Number JPMXS0118069228

References
1. M. Mohseni et al., e-print arXiv preprint, arXiv:2411.10406 (2024).
2. H. Fuketa et al., IEEE Journal of Solid-State Circuits, vol. 61, pp. 1526-1537 (2026).
3. H. Fuketa et al., IEEE Symposium on VLSI Technology and Circuits (2025), pp. 1-3.
4. H. Fuketa et al., IEEE Transactions on Circuits and Systems-I: Regular Papers, vol. 70, pp. 5220-5228 (2023).
5. H. Fuketa et al., IEEE Symposium on VLSI Technology and Circuits (2022), pp. 234-235.

CryoCMOS RF multiplexer for superconducting qubit control, Readout and Flux Biasing at Millikelvin Temperatures with Picowatt Power Consumption

Liam Fallik; Sriram Balamurali; Alican Caglar; Rohith Acharya; Jacques Van Damme; Tsvetan Ivanov; Shana Massar; Ruben Asanovski; A M Vadiraj; Massimo Mongillo; Jan Craninckx; Alexander Grill; Danny Wan; Anton Potocnik; Kristiaan De Greve

IMEC, KU Leuven, Belgium

Large-scale cryogenic quantum systems are constrained by an input–output bottleneck between room-temperature electronics and millikelvin stages, particularly in superconducting qubit platforms. This bottleneck is most acute for output lines, where bulky and expensive microwave components limit scalability. A promising approach to alleviate it is to multiplex signals directly at the qubit plane. We demonstrate a cryogenic CMOS (cryoCMOS) RF multiplexer operating at 10 millikelvin with record-low static power consumption of 200 pW. The device provides < 2 dB insertion loss and > 30 dB isolation across DC-8 GHz. Direct connection to transmon qubits marginally affects coherence times in the range of 100 µs, enabling multiplexing of readout, flux and, in principle, XY drive lines. This work introduces cryoCMOS multiplexers as valuable tools for scalable, high-throughput cryogenic characterization and testing, and advances co-integrated quantum-classical control for future large-scale quantum processors.

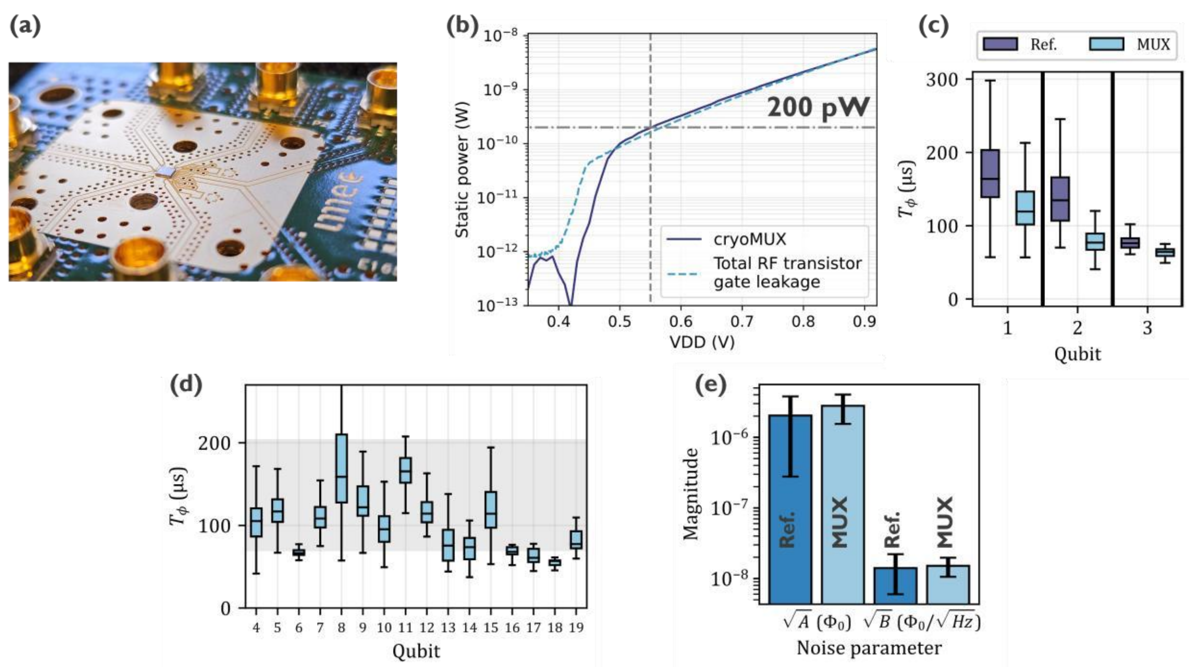


Fig. 1: *CryoCMOS multiplexers for scalable superconducting qubit control, readout and flux biasing at 10mK. (a) Photograph of the multiplexer die. (b) Static power consumption as a function of supply voltage. The light-blue dashed line represents the cumulative gate leakage current of all transistors that are active simultaneously. (c) Dephasing times of superconducting Transmon qubits directly interfaced by the multiplexer at their input (MUX), compared to reference qubit measurements (Ref.) (d) Dephasing times of qubits with multiplexed readout. (e) Noise parameters extracted from flux-dependent coherence time measurements with the Transmon flux bias line interfaced by the multiplexer and compared to reference measurements, using a noise model comprising of a low-frequency 1/f component and a high-frequency white component, i.e.* $S_\phi(\omega) = \frac{A}{|\omega|} + B$.

A Cryo-CMOS Phase-Locked Loop for Quantum Computing and Sensing

Batuhan Keskin[1], Baris Can Efe[1], Halil Kerim Yildirim[1], Gregor G Taylor[1], Edoardo Charbon[1]. 1 Advanced Quantum Architecture Laboratory (AQUA), École polytechnique fédérale de Lausanne (EPFL), Neuchâtel, Switzerland

The demand for cryogenic electronics continues to increase year-by-year [1-2], as research into quantum computation and sensing rapidly advances. Moving control and readout electronics for quantum systems to the cold domain is therefore a priority to permit system scaling [3]. To that end, we present the design and characterization of a phase-locked loop (PLL) designed for operation at 4 K. We benchmark the performance at both room temperature and cryogenic temperatures and observe a decrease in both the power consumption and phase noise at lower temperatures. At 3.1 mW, the PLL demonstrates ~20% lower power consumption at 4 K than at 300 K with a center frequency of 1.44 GHz, while phase noise is measured at -130 dBc/Hz at 1 MHz offset, down 10 dBc/Hz from room temperature. Output frequency is from 800 MHz to 1.44 GHz and has 6 evenly separated phases which will support time-interleaved structures for digital circuit applications. These circuits can be applied to qubit control and readout, and to control of superconducting sensors and electronics. The design was fabricated using the TSMC 65 nm technology node; the total area is 0.074 mm2, which includes a phase frequency detector, charge pump, VCO, and a loop filter.

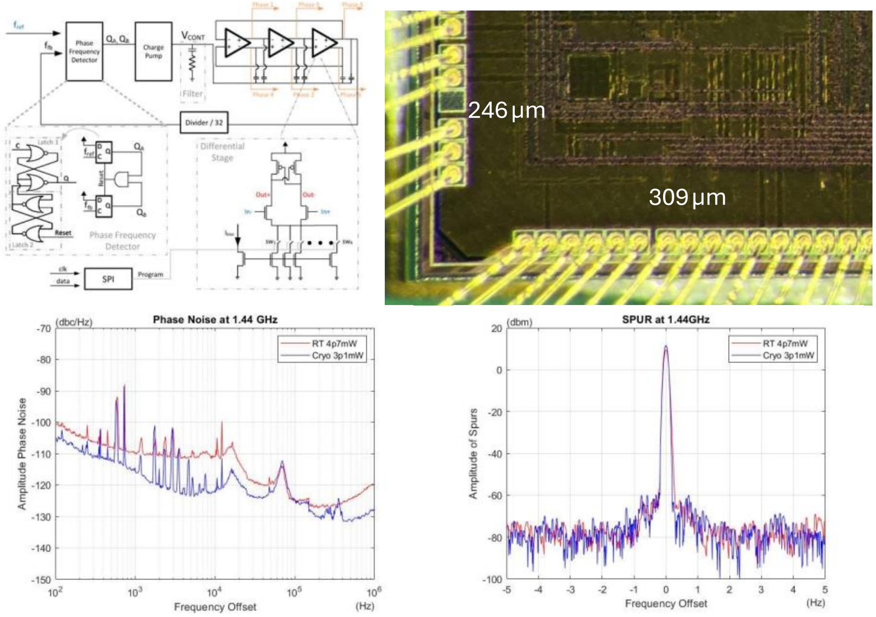


Fig. 1: Architecture of the PLL and Comparison of Phase Noise between 300 K and 4 K.

References

1. Charbon, Edoardo, et al. "Cryo-CMOS for quantum computing." 2016 IEEE international electron devices meeting (IEDM). IEEE, 2016.
2. Saligram, Rakshith, Arijit Raychowdhury, and Suman Datta. "The future is frozen: cryogenic CMOS for high-performance computing." Chip 3.1 (2024): 100082.
3. Reilly, D. J. "Challenges in scaling-up the control interface of a quantum computer." 2019 IEEE International Electron Devices Meeting (IEDM). IEEE, 2019.

Cryogenic Measurements and Model Extension for a 28-nm Bulk CMOS Technology

L. Castellani[1], P. Chava[2], M. Da Rocha Rolo.[1], D. Nielinger[2], S. Van Waasen[2,3]
[1]*INFN-Torino, Torino, Italy*
[2]*Forschungszentrum Juelich, Juelich, Germany*
[3]*University of Duisburg-Essen, Duisburg, Germany*

A DC-cryogenic characterization of a commercial 28-nm bulk CMOS technology was accomplished in a joint work between Forschungszentrum Juelich and INFN Torino, comprising thermal states from room temperature down to 8K. A forward body biasing (FBB) technique is tested on selected pMOS devices of this technology, in order to mitigate the cryogenic threshold-voltage increase.
An extension methodology for the foundry BSIM-BULK room temperature model, which allows to simulate transistors at fixed cryogenic temperature points, is presented; it is based on the inclusion of additive parameters in the model files, extracted through the multiple fitting of measured transfer currents, and does not require a physics-based cryogenic model.

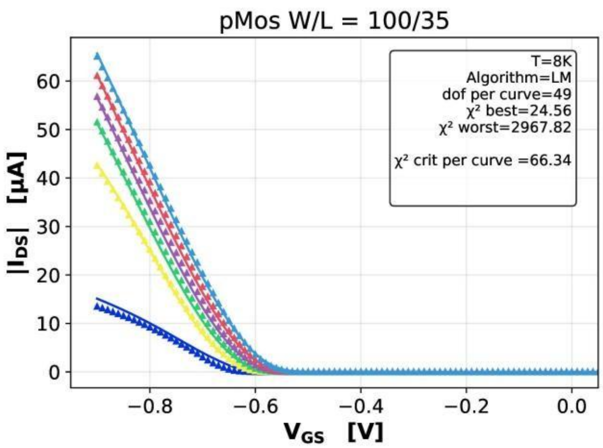


Fig. 1: *Model extension test on an example pMOS device at 8 K. Solid lines are simulated data, triangles measured data. Differently colored curves indicate different drain-source voltages.*

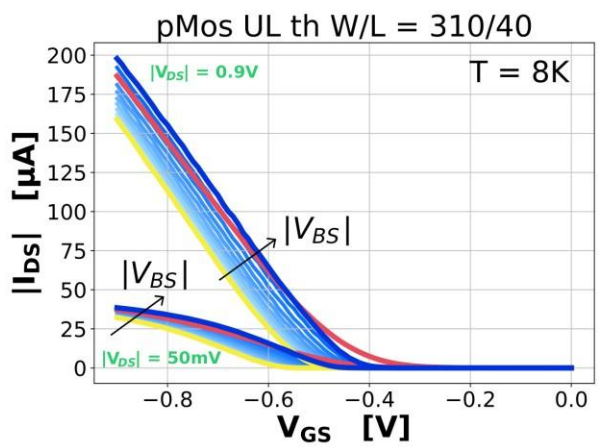


Fig. 1: *Forward Body-Biasing technique tested on an example pMOS device at 8K.*

Deep Cryogenic Operation of Single-Level and Stacked Nanowire and Nanosheet SOI MOSFETs for Quantum Computing

Michelly de Souza1, Jaime Calçade Rodrigues1, Flavio Enrico Bergasmaschi2, Vinicius Rodrigues Prates1, Sylvain Barraud2, Mikaël Cassé2, Marcelo Antonio Pavanello1

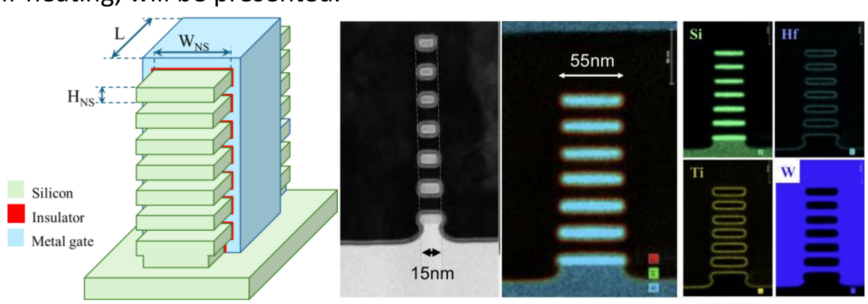
1Centro Universitario FEI, São Bernardo do Campo – SP, Brasil

2Univ. Grenoble Alpes, CEA, Leti, F-38000 Grenoble, France

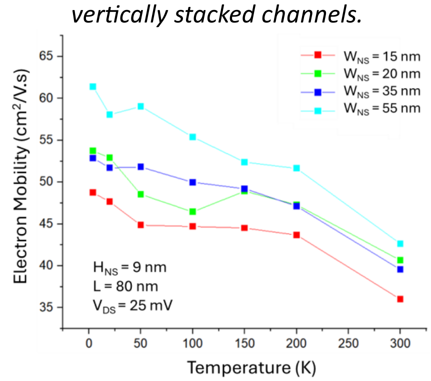
The aggressive scaling of MOSFET dimensions triggered the search for alternative solutions for the traditional planar transistors for future technological nodes. Also, the advent of Quantum Computing raised interest in the cryogenic operation of ultimate MOSFETs for interface circuits between Qubits and electronic systems. Three-dimensional MOSFETs operating with fully depleted (FD) silicon fabricated in Silicon-On-Insulator (SOI) substrates are among the technological solutions being widely investigated.

Triple-gate Ω-shaped MOSFETs with fin height and width of similar dimensions, in the order of 10-15nm, commonly referred to as nanowires (NWs) in the literature, are promising contenders. One key challenge in scaling down transistors is achieving high drive current density per footprint while simultaneously preserving the excellent electrostatics of nanometer-scale MuGFETs, which is crucial for mitigating short-channel effects. To address these scaling limitations, vertically stacked nanosheet transistors have attracted considerable attention. By layering multiple channels on top of each other, it allows for a significant increase in the current level per unit area, without sacrificing the electrostatic integrity inherently provided by nanometric MuGFETs. The experimental demonstration of seven-level stacked gate-all-around (GAA) nanosheet transistors achieved significant performance enhancements in both digital and analog applications, surpassing single-level transistors with similar structural characteristics. Moreover, due to their nanometer-scale channels, quantum transport can be observed in aggressively scaled nanowires at cryogenic temperatures.

In this scenario, this talk will present and discuss the operation of nanowire transistors, both single-level and stacked with up to seven levels, when exposed to cryogenic temperatures down to 4 K. Peculiarities of these devices while operating in the cryogenic regime, such as transconductance oscillations indicating carrier confinement and self-heating, will be presented.



Schematic three-dimensional representation, TEM and EDS spectroscopy images of nanosheet transistors with seven vertically stacked channels.



Extracted carrier mobility of seven-level stacked nanosheet SOI transistors down to 4K.

Temperature-Dependent Characterization of a Flash-Based FPGA

Jules Ludwig[1,2], Yves-Bérubé Lauzière[2], Mathieu Juan[2], Marc-André Tetrault[2]
[1] *Faculté de génie, J1K 2R1, Sherbrooke, Canada*
[2] *Institut Quantique, J1K 2R1, Sherbrooke, Canada*

The rapid development of superconducting quantum processors is driving an increasing demand for control and readout electronics capable of operating with low latency, high precision, and strong scalability. However, conventional architectures, in which most of the electronics remains at room temperature, are increasingly limited by interconnect complexity, the thermal load imposed on the cryostat, and the delays introduced by links between different thermal stages. In this context, moving part of the electronics closer to the quantum processor emerges as a particularly promising approach.

The literature has primarily focused on the characterization of SRAM based FPGAs, which are generally more power hungry. In this work, we investigate Flash based FPGAs, known for their energy efficiency and their ability to retain configuration at low temperature. This property enables their operation without active reconfiguration in a cryogenic environment and allows characterization over a wide temperature range from 300 K to 1.5 K, which is traditionally difficult to achieve with SRAM based FPGAs due to their higher self-heating and more complex configuration mechanisms.

Our results show that critical building blocks such as PLLs and embedded memory operate reliably across the entire temperature range. Combinational elements, particularly LUTs, exhibit performance improvements of up to 18 percent, which translate, at the system level, into an increase in maximum operating frequency ranging from 14 percent to 35 percent, depending on the balance between logic and routing.

Measurements were performed using embedded test structures, including ring oscillators and synchronous timing architectures, enabling the separation of logic and routing contributions. In addition, power measurements reveal a decrease in core logic consumption at low temperature, despite distinct behaviors across other power domains. These results pave the way for faster feedback algorithms in cryogenic environments. By combining the intrinsic performance gains enabled by cryogenic operation with the drastic reduction in interconnect length and therefore latency achieved by placing the FPGA closer to the quantum processor, this approach enables significantly faster in situ feedback systems compared to their room temperature counterparts. These findings confirm the potential of Flash based FPGAs as an efficient platform for real time cryogenic control of quantum processors.

CryoCMOS Paving the Way to Scalable SET Based Logical Circuit

Dante Regiani Freitas[1,†], Antoine Faurie[1,†], Brian Martinez[1],
Jean-Baptiste Casanova[2], Baptiste Jadot[1], and Franck Badets[1]
[1]Univ. Grenoble Alpes, CEA, LETI, F-38000 Grenoble, France
[2] Univ. Grenoble Alpes, CEA, LIST, F-38000 Grenoble, France
[†] These authors contributed equally to this work

Single Electron Transistors (SETs) hold the promise to reduce power consumption of electronic circuits achieving energy-delay products (EDP) 10,000 times lower than typical CMOS counterparts. Their working principle relies on trapping single electrons inside a quantum dot which brings one of their main challenges: random background charges which drastically shift their voltage operating points [1]. It is thus necessary to individually tune each device which, if done through external connections, would be costly in a cryogenic environment and not scalable due to fan-out congestion. Consequently, a co-integrated CryoCMOS biasing circuit for spin qubits such as [2], which uses a Sample and Hold approach (S&H) and time multiplexing, is proposed to tackle this bottleneck. This work aims to show the feasibility of a subset of primary logical structures – an inverter and an AND gate [3] – paving the way to co-integrated scalable CMOS and SET-based logical circuits. In addition, the use of a MOS-SET hybrid circuit [4] for the amplification of the SETs' signals up to CMOS logic levels is explored. Fig. 1 shows the simulation results done for a GF FD22X test chip (currently under fabrication) with monolithically co-integrated CryoCMOS biasing circuitry, and SET-based structures, which were simulated with MIB model [5] fitted to experimental data in the same technology [6].

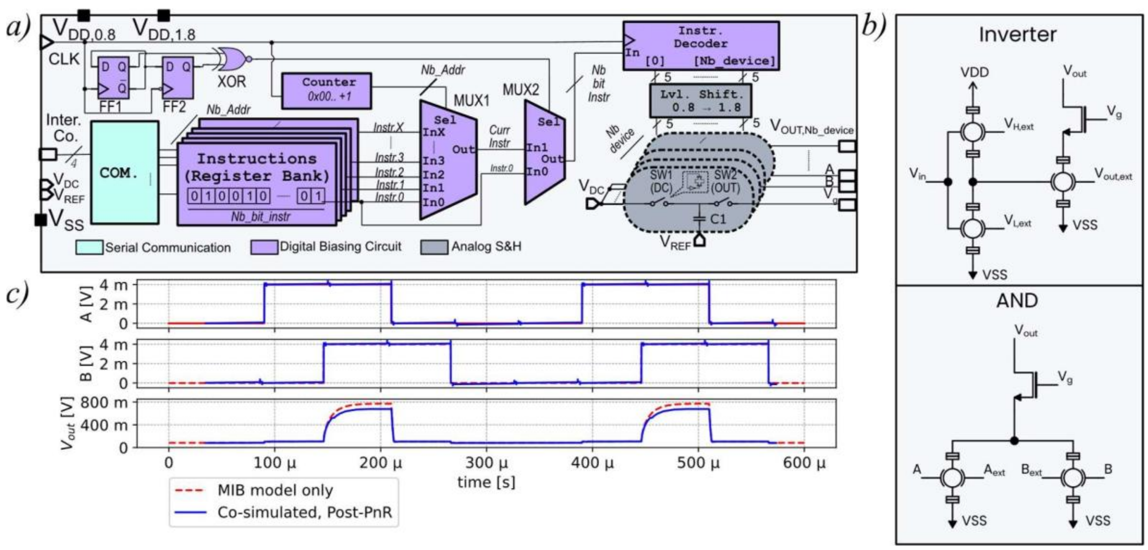


Fig. 1: a) Block diagram of the CryoCMOS biasing controller circuits
b) Co-integrated hybrid MOS-SET circuits c) Simulation results for SET AND gate operation

References

1. C. Wasshuber, Computational Single-Electronics, (Springer-Verlag Wien, New York, 2001).
2. S. J. Pauka et al., Nat. Electron., vol. 4, no. 1, Art. no. 1, (2021).
3. R. H. Chen et al., Appl. Phys. Lett., vol. 68, no. 14, pp. 1954-1956, (1996).
4. H. Inokawa et al., Appl. Phys. Lett., vol. 79, no. 22, pp. 3618-3620, (2001).
5. S. Mahapatra et al., IEEE Electron Device Letters, vol. 23, no. 6, pp. 366-368, (2002).
6. Q. Schmidt et al., 2024 ESSERC, pp. 157-160, (2024).

Superconducting Accelerator for Area-Efficient Quantum State Discrimination at 4K

Patricia Gonzalez-Guerrero[1], Meriam Gay Bautista-Jurney[1], Neel Vora[2], Yilun Xu[2], Kasra Nowrouzi[2], Anastasiia Butko[1]

[1]*Applied Math & Computational Research Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA*

[2]*Accelerator Technology & Applied Physics Division, Lawrence Berkeley National Laboratory,* Berkeley, CA, USA

Tight integration between Quantum Processing Units (QPUs) and Classical Electronic Circuits (CECs) is essential for the scalability of quantum computing [1]. Current CEC solutions, which rely on room-temperature components such as FPGAs, CPUs, and GPUs, face significant hurdles related to thermal load, spatial constraints, and mechanical complexity. Superconducting electronics offer a compelling alternative, enabling operation above 50 GHz and extremely low switching energy in cryogenic environments. We introduce a novel machine-learning-based superconducting hardware accelerator designed for qubit state discrimination at 4K. Our design directly tackles the critical challenge of low area density in superconducting circuits by employing a biologically inspired data representation, yielding computing units with a minimal footprint. This proposed superconducting ML accelerator achieves a 12X speedup and requires 20X less area than current state-of-the-art systems, utilizing fewer than 17k Josephson Junctions (JJs) for its computing elements.

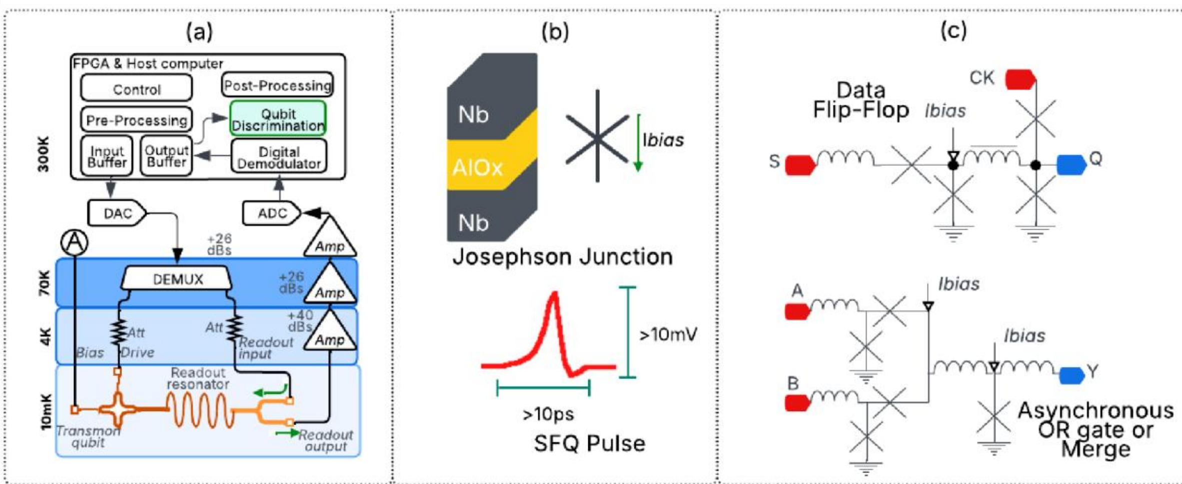


Fig. 1: *(a) Readout and control system for a Transmon Qubit. Highlighted the quantum state discrimination block. (b) Top, Josephson Junction (JJ). Bottom, Single Flux Quantum Pulse. (c) Example of circuits built with JJs [2]*

References

[1] P. Krantz, et.al., "A quantum engineer's guide to superconducting qubits," doi:10.1063/1.5089550

[2] Gonzalez-Guerrero, et.al., "Cryogenic hardware accelerator for Quantum State Discrimination at 4K," https://doi.org/10.21203/rs.3.rs-7661185/v1

Keynote: Superconducting Spintronics for Racetrack Memory

Stuart S.P. Parkin
Max Planck Institute of Microstructure Physics, Halle (Saale), Germany
stuart.parkin@mpi-halle.mpg.de

Superconducting spintronics is a highly interesting area of research which allows, for example, for the formation of unconventional superconducting states via proximity induced superconductivity in certain magnetic materials. We have shown that Josephson junctions fabricated from conventional s-wave superconductors that have barriers formed from an intrinsic noncollinear antiferromagnet1 or from magnetic multilayers designed to have magnetic layers with orthogonal magnetizations2 show very high supercurrent critical densities that are indicative of the formation of triplet supercurrents. Another highly interesting finding is the observation of a Josephson Diode effect (JDE)3-5 in both lateral and vertical Josephson junctions where the barrier is formed from a material that breaks both time reversal symmetry and inversion symmetry. The simplest case is perhaps that of the pure metal platinum that is magnetized at one surface by proximity to an insulating ferromagnet in a direction perpendicular to the supercurrent that is created by niobium electrodes at the opposing surface6. We find large asymmetries in the supercurrent critical density that increase with decreasing temperature below that of the superconducting ordering temperature of niobium. A more exotic case is where the barrier in lateral Josephson junctions is formed from a type II Dirac semi-metal, NiTe23. The superconducting critical current density shows large asymmetries for current flowing in opposite directions of up to 80% in the presence of small magnetic fields transverse to the supercurrent direction. The barriers can extend to almost a micron in extent and yet still allow for the passage of supercurrents. Similar results are found for barriers formed from PtTe24. Vertical junctions formed from WTe2 also show a diode-like behavior in the presence of a magnetic field but only when the field is along a direction perpendicular to a mirror plane in the orthorhombic crystal structure of this unusual van der Waals material5. The JDE could form a novel device for reading magnetic nanoscopic objects at ultralow temperatures. Triplet supercurrents that carry spin angular momentum could potentially be used to manipulate magnetization. Together these two superconducting spintronic effects are highly interesting for potential applications in cryogenic logic and memory that could support quantum computing systems. One of the most interesting applications is for a novel cryogenic form of racetrack memory7*.

References

1. Jeon, K.-R. *et al.* Long-range supercurrents through a chiral non-collinear antiferromagnet in lateral Josephson junctions. *Nat. Mater.* **20**, 1358–1363 (2021). https://doi.org/10.1038/s41563-021-01061-9
2. Kindiak, I., Mishra, S. S., Migliorini, A., Pal, B. & Parkin, S. S. P. Reduced decay in Josephson coupling across ferromagnetic junctions with spin–orbit coupling layers. *Appl. Phys. Lett.* **125**, 082601 (2024). https://doi.org/10.1063/5.0214835
3. Pal, B. *et al.* Josephson diode effect from Cooper pair momentum in a topological semimetal. *Nat. Phys.* **18**, 1228–1233 (2022). https://doi.org/10.1038/s41567-022-01699-5
4. Sivakumar, P. K. *et al.* Long-range Phase Coherence and Second Order ϕ_0-Josephson Effect in a Dirac Semimetal 1T-PtTe2 *Comm. Phys.* **7**, 354 (2024). https://doi.org/10.1038/s42005-024-01825-0
5. Kim, J.-K. *et al.* Intrinsic supercurrent non-reciprocity coupled to the crystal structure of a van der Waals Josephson barrier. *Nat. Commun.* **15**, 1120 (2024).
6. Jeon, K.-R. *et al.* Zero-field polarity-reversible Josephson supercurrent diodes enabled by a proximity-magnetized Pt barrier. *Nat. Mater.* **21**, 1008–1013 (2022).
7. Jeon, J.-C., Migliorini, A., Yoon, J., Jeong, J. & Parkin, S. S. P. Multi-core memristor from electrically readable nanoscopic racetracks. *Science* **386**, 315–322 (2024). https://doi.org/10.1126/science.adh3419

Prototypes of a vortex-based memory cell supporting wordline and bitline operation with non-destructive readout

Aiste Skog1, Taras Golod1, Vladimir M. Krasnov.1

1Department of Physics, Stockholm University, SE-10691, Stockholm, Sweden

Scalable random-access memory (RAM) is a bottleneck in development of modern superconducting computing. In this work, we experimentally demonstrate the operation of a ~2.5 x 2.5μm memory cell based on controlled trapping and erasure of Abrikosov vortices (AV) in a niobium sheet. Vortices are induced with current pulses and conscious geometry of the cell facilitates deterministic AV dynamics. Switching between vortex/vortex-free states and readout is possible in wordline (WL) and bitline (BL) directions. To read the state, voltage over two Josephson junctions is measured, where additional voltage induced in response to the magnetic field of the AV indicates the vortex state. Proposed design is scalable for two-dimensional arrays and allows random access of the cells, comparable to the WL/BL-based addressing in semiconductor DRAM chips. Furthermore, readout is non-destructive because current needed to write or erase an AV substantially exceeds the critical current of the Josephson junctions. Nevertheless, with several hundred μs long pulses, current amplitudes needed for control of AV dynamics were below 1mA, showing low power per operation. We conclude that the demonstrated prototype is a sufficient unit cell with adequate benchmark specifications for construction of dense two-dimensional structures, significantly furthering the development towards realization of cryogenic RAM.

Low Subthreshold Swing Cryo-CMOS for Ultra-Low-Power Cryo Electronics

N. Yurttagül, M. Kainlauri, J. Toivonen, S. Khadka, A. Kanniainen, C. Lauvitel, M. Prunnila, and J. S. Lehtinen

SemiQon Technologies, Tietotie 3, 02150 Espoo, Finland

Several quantum computing modalities and, in general, scalable cryo-systems need cryogenic classical circuitry for various tasks. CMOS has been utilized here under name cryo-CMOS, but here critical bottleneck, especially at sub-1 K temperatures, is cryo-CMOS circuitry power dissipation, which should remain within the limited cooling power of dilution refrigerators (µW–mW range below 1 K). This constraint fundamentally links system scalability to the switching efficiency of MOSFET devices, particularly their subthreshold characteristics. In conventional MOSFETs and CMOS, subthreshold swing (SS) does not follow thermionic transport characteristics at low temperatures, preventing efficient voltage and power scaling to levels that would be needed for complex circuits.

We have demonstrated cryogenically optimized fully depleted silicon-on-insulator (FD-SOI) MOSFETs engineered specifically for operation at millikelvin temperatures. The devices show record low subthreshold swing of 0.3 mV/dec (@ ~400 mK), significantly below previously reported values for different cryo-CMOS technologies. This result represents a major advance toward overcoming the long-standing power dissipation barrier in cryo-CMOS. The achieved subthreshold slope approaches the thermionic limit at millikelvin temperatures and enables aggressive supply voltage scaling while maintaining high on-off current ratios. Importantly, the improved switching behavior is obtained without sacrificing other transistor performance metrics. The measured devices exhibit enhanced carrier mobility, reduced gate leakage, and stable threshold voltage behavior enabled by the FD-SOI architecture, which provides improved electrostatic control and mitigates variability at low temperatures.

The reduced SS directly translates into lower operating voltages and reduced dynamic power consumption, while suppressed leakage currents minimize static losses. Combined with cryogenic benefits such as reduced interconnect delays and improved charge retention, these MOSFETs enable a new regime of ultra-energy-efficient cryo-CMOS circuits. Experimental observations confirm low-noise operation and compatibility with sensitive quantum device environments.

The scalability of cryo-CMOS architectures incorporating these transistors can be enhanced tremendously. Our analysis shows that power dissipation per control channel can be reduced sufficiently to support large-scale integration, e.g., potentially enabling control of millions of qubits within realistic cryogenic power budgets. This paves the way for hierarchical control architectures, local memory integration, and multiplexing strategies essential for large scale quantum computing. Beyond quantum computing, the demonstrated technology is relevant for other applications requiring ultra-low-temperature electronics, including space systems and high-performance computing in extreme environments.

In conclusion, we establish millikelvin-optimized MOSFETs as a key enabling technology for next-generation cryo-CMOS. By achieving unprecedented subthreshold performance at 420 mK, this work provides a viable pathway toward large-scale, monolithically integrated quantum-classical systems. The results close a critical gap between device physics and system requirements, bringing practical, scalable quantum processors significantly closer to realization.

Engineering Quantum Hardware on Silicon: From Low-Loss Circuits to Cryogenic Logic

Kaveh Delfanazari
Electronics and Nanoscale Engineering Division, James Watt School of Engineering, University of Glasgow, Glasgow, UK

Advancing large-scale quantum computing demands hardware platforms that simultaneously deliver long coherence times, scalability, and compatibility with established semiconductor manufacturing [1]. In this talk, I present a silicon-centric approach to low-temperature electronics that unifies superconducting circuits with semiconductor-compatible technology. We investigate niobium nitride (NbN) coplanar waveguide resonators monolithically integrated with Si/SiGe quantum wells, forming a hybrid architecture tailored for scalable quantum electronic hardware [2]. Using temperature-dependent microwave spectroscopy in the single-photon regime, we systematically quantify resonance frequency shifts and quality factor degradation to disentangle dominant loss channels. Our analysis reveals the interplay between two-level systems, quasiparticles, and scattering processes, and directly correlates these mechanisms with wafer properties and fabrication pathways. The resulting devices exhibit reproducible low-loss performance and operational stability over multi-year timescales, underscoring their suitability for robust quantum systems. Building on this foundation, I further explore emerging cryogenic device paradigms that extend silicon electronics into the cryogenic logic. In particular, I highlight the Josephson junction field-effect transistor (JJFET) as a compelling candidate for ultralow-power, phase-coherent logic operating at millikelvin temperatures [3]. By integrating superconducting contacts within semiconductor channels, JJFETs bridge classical semiconductor architectures and quantum circuits, enabling new modalities for cryogenic control and signal processing. I will compare silicon-based implementations with III–V platforms, emphasizing the advantages of silicon in terms of manufacturability, integration density, and long-term reliability.

References

1. K. Delfanazari, *Nat. Photon.* 19, 1163–1177 (2025)
2. P. Foshat et. al., *arXiv:*2509.26363
3. Y. Xiong, K. Delfanazari, *APL Engineering Physics* 1, 011503 (2026)
4. Y. Xiong, K. Delfanazari, et al., in preparation

Electrostatic Control of Superconductivity in Top-gated KTO3-2DEG Devices: Realization of Superconducting Field-effect Transistors

Vladimir Pirogov[1], Soumyajit Mandal[1], Marko Kuveždić[2], Hugo Witt[1,2], Isabella Boventer[2], Manuel Bibes[2], Nicolas Bergeal[1]

[1]*Laboratoire de Physique et d'Étude des Matériaux, ESPCI Paris, Université PSL, CNRS, Sorbonne Université, 75005 Paris, France*

[2]*Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, 91767 Palaiseau, France*

Semiconducting field-effect transistors (FETs) are indispensable components of modern electronics. One of their primary functions is to operate as switches, where the logic state is controlled by a gate voltage that modulates the charge carrier density and, consequently, the electrical resistance of the channel. However, as device integration scales up, increasing power dissipation and associated thermal management challenges have become critical concerns. In this context, superconducting FETs have attracted growing interest due to their ability to provide a superconducting, and thus virtually loss-free, on-state in the drain–source channel, along with the capability to sustain high current densities.

Two-dimensional electron gases (2DEGs) formed at the interfaces of artificial oxide heterostructures have attracted significant attention for enabling field-effect control of both superconductivity and Rashba spin–orbit coupling (SOC). After decades of extensive research on $LaAlO_3/SrTiO_3$ interface systems, a major breakthrough was achieved with the discovery of superconductivity in (111)-oriented $KTaO_3$ heterostructures. These systems exhibit critical temperatures as high as 2.2 K—nearly an order of magnitude higher than those of $SrTiO_3$-based interfaces. Moreover, the presence of heavy tantalum atoms leads to significantly enhanced spin–orbit coupling, positioning $KTaO_3$ as a highly promising platform for the exploration of topological superconductivity. In this work, we report the first demonstration of local electrostatic control of superconductivity in a two-dimensional electron gas (2DEG) at the $KTaO_3(111)/AlO_x$ interface, using top gates in which HfO_2 serves as the gate dielectric. Unlike conventional back-gate approaches that modulate the system globally, this top-gate architecture enables spatially resolved tuning of superconducting properties, an essential capability for the development of scalable quantum circuits.

Our work demonstrates robust and reproducible control of superconductivity through the combined use of top and back gates, enabling access to both underdoped and overdoped regimes within a single device. By systematically mapping the gate-voltage–temperature space, we construct a detailed phase diagram that reveals a quantum critical point separating the superconducting and insulating phases. The device operates as a gate-tunable superconducting transistor, allowing reversible control of the superconductor–insulator transition (SIT). To evaluate its dynamic response, finite-frequency square-wave signals were applied to the top gate across the SIT, with operation sustained up to a few kilohertz and performance primarily limited by the external circuitry. These results highlight the potential for further optimization and pave the way for the development of high-speed superconducting FETs.

Increase of critical current in wafer-scale CVD graphene-based Josephson field-effect transistors by process optimization

Markus Lehtisalo[1], Shanuka Gamaethige[2], Andrey Generalov[1], Heorhii Bohuslavskyi[1], Klaara Viisanen[1], Kari Stadius[2], and Jussi Ryynänen[2]
[1] VTT Technical Research Centre of Finland, 02150, Espoo, Finland
[2]Department of Electronics and Nanoengineering, Aalto University, 02150, Espoo, Finland

The Josephson Field Effect Transistor (JoFET) is a widely pursued and desired building block for future cryogenic electronic circuits. It offers the possibility to realize analog and digital cryogenic circuits operational down to millikelvin temperatures and, thanks to its dissipationless nature, JoFET circuits can consume only a fraction of the power required by, e.g., CMOS circuits. A scalable technology to produce JoFETs is essential for the development of novel and energy-efficient superconducting electronics. Recently, we reported progress in manufacturing reproducible JoFETs using gated Al-graphene-Al junctions on wafer scale. [1] An optical image of an example wafer is shown in Fig. 1.a.

One of the most important figures of merit for successfully fabricating integrated circuits with superconductors and JoFETs is the critical current of the JoFETs. A higher critical current gives a higher Josephson energy. This directly allows for less sensitivity to thermal noise and hence fewer phase slips. A higher critical current also gives a lower inductance and higher possible operating frequency [2], as well as better fan-out, meaning more gates driven with a given gate. This allows for more versatile integrated circuits. The critical current depends e.g. on the contact resistance and the transparency of the contacts. [3] Here, we report results from an optimized process, giving an increase of 300% to 500% in the critical current of JoFETs of identical width and length as corresponding devices fabricated with a previous process, as shown in Fig. 1.b. The improved process requires minimal changes in the fabrication and does not reduce the yield of JoFETs.

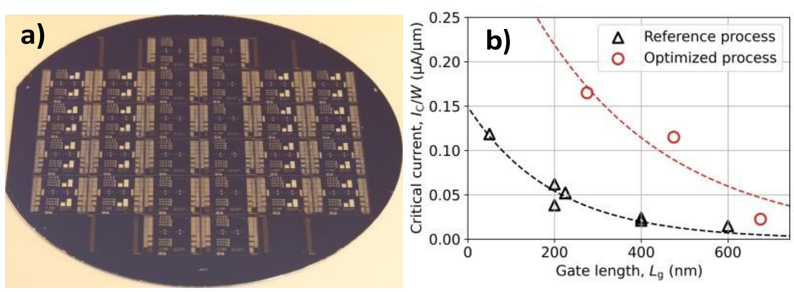


Fig. 1: *(a) 150 mm wafer of JoFETs. (b) Normalized critical current as a function of the gate length, for the reference process and the optimized process.*

References

1. Generalov, A. *et al*. 2024 *Appl. Phys. Lett.* **125**, 012602.
2. Tinkham, M. (1996). Introduction to Superconductivity (2nd ed.). McGraw-Hill.
3. Delin, K. and Kleinsasser, A. 1996 *Supercond. Sci. Technol.* **9** 227.

Wafer scale superconducting transistor technology for ultrasensitive bolometers

Andrey Generalov[1], Ashish Panigrahi[2], Richa Mitra[1], Jian Ma[2], Yefei Yin[2], Shiling Yu[2], Qiming Chen[2], Klaara Viisanen[1], Markus Lehtisalo[1], Mikko Möttönen[1,2], and Heorhii Bohuslavskyi.[1]

[1] VTT Technical Research Centre of Finland, 02150, Espoo, Finland

[2] QCD Labs, QTF Centre of Excellence, Aalto University, 00076, Aalto, Finland

The versatile Josephson field-effect transistor (JoFET) fabrication platform developed at VTT [1] allows for manufacturing of various building blocks of the superconducting integrated circuits. The Al – graphene – Al junction used in JoFETs acts as a sensitive thermometer for the thermal detectors due to its low heat capacity and weak electron-phonon coupling, as demonstrated in [2]. Furthermore, it can be integrated with superconducting resonators on the same wafer and subsequently used for the superconducting qubit readout [3]. We present a cryogenic microwave bolometer fabricated on wafer-scale with the feasibility of integration with qubits and allowing for scalability of multi-qubit systems readout. The fabricated, diced, packaged, and bonded bolometer chip is shown on Fig. 1 (a). The change in resonance frequency of the thermometer element of the bolometer is shown on Fig. 1 (b) versus incident power, indicating the bolometer sensitivity down to -135 dBm power level.

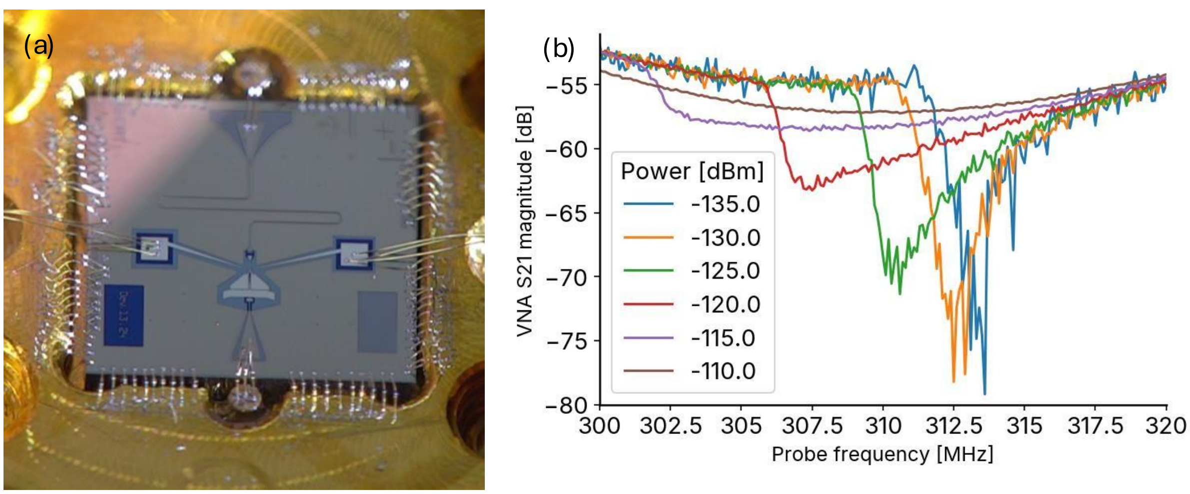


Fig. 1: (a) A diced and packaged chip of a microwave bolometer. (b) The S21 parameters of the bolometer at various incident powers.

In conclusion, we have demonstrated the feasibility of manufacturing the CVD graphene based superconducting bolometers on wafer scale and present their performance.

References

[1] A.A. Generalov *et al.*, Appl. Phys. Lett. **125**, 012602 (2024).

[2] R. Kokkoniemi *et al.*, Nature **586**, 47 (2020).

[3] Gunyhó *et al.*, Nat Electron **7**, 288–298 (2024).

Wednesday, 3 June 2026

Keynote: Quantum Sensing of Cosmological Signals

Takis Kontos

Institute of Astrophysics-FORTH, Greece

In this talk, I will present how quantum technologies can be used in order to probe cosmological signals. I will first present how quantum sensing techniques can be used to probe axion dark matter. I will then show how one can extend these ideas to radioastronomical signals. I will show first proof of principle experiments on 21-cm signals. The extension to the problem of detecting 21-cm signals of the Cosmic Dawn or the Epoch of Reionization in the early Universe will be discussed.

Nanoscale YBCO Devices for Quantum Sensors and Detectors

Thilo Bauch[1], Alessia Garibaldi[1], Núria Alcalde Herraiz[1], Edoardo Trabaldo[1], Alexei Kalaboukhov[1], R. Arpaia[1], Dag Winkler[1], Floriana Lombardi[1], Justin F. Schneiderman[2]

[1]*Quantum Device Physics Laboratory, Department of Microtechnology and Nanoscience, Chalmer University of Technology: Kemivägen 9, Göteborg, 41296, Sweden*

[2]*Institute of Neuroscience and Physiology, Sahlgrenska Academy, The University of Gothenburg: Box 430, Gothenburg,40530, Sweden*

Recent advances in nano-patterning of high critical-temperature (high-Tc) superconductors have enabled simpler, more versatile, and highly sensitive quantum devices, such as SQUID magnetometers, THz mixers, and single photon detectors. Conventional approaches using bicrystal and step-edge Josephson junctions, developed in the 1980s and 1990s, rely on complex epitaxy and multilayer structures that limit performance and design flexibility. Our nanoscale Dayem bridges [1] and novel grooved Dayem-bridge (GDB) [2] process addresses these limitations, offering an effective alternative.

We present SQUID magnetometers based on GDBs that match or exceed the low-noise performance of conventional SQUIDs at moderate temperatures (~77 K). This enables applications like magnetoencephalography (MEG) with sensor placement within 1 mm of the scalp, capturing stronger neuromagnetic signals and improving imaging resolution [3].

Additionally, we demonstrate THz harmonic frequency mixing using a YBCO nanobridge with cross section 70 × 50 nm² integrated with a spiral broadband antenna. At 1.2 THz (x12 mixing), with ~1 µW input and operating at 77 K and 60 K, the device achieved a 20 dB SNR at 1 Hz bandwidth. These results highlight the suitability of nanowire-based devices for high-frequency detection.

Finally, we report dark count observation in ultra-thin (10 nm) YBCO nanowire single photon detectors below 20K [4]. The high critical current density leads to hysterestic current voltage characteristics (IVCs), enabling bistable switching and revealing fluctuation induced dark pulses. This marks a milestone toward developing YBCO based quantum detectors for high temperature operation.

References

1. Nawaz S., et al., *Microwave Response of Superconducting YBa2Cu3O7 Nanowire Bridges Sustaining the Critical Depairing Current: Evidence of Josephson-like Behavior,* Phys. Rev. Lett. 110, 167004 (2013).
2. Trabaldo E., et al., *Grooved Dayem Nanobridges as Building Blocks of High-Performance YBa2Cu3O7−δSQUID Magnetometers,* Nano letters **19**, 1902 (2019).
3. Pfeiffer C., et al., A 7-Channel High-Tc SQUID-Based On-Scalp MEG System, IEEE Transactions on Biomedical Engineering **67**, 1483 (2020).
4. Ejrnaes M., et al., *Observation of dark pulses in 10nm thick YBCO nanostrips presenting hysteretic current voltage characteristics*, Supercond. Sci. Technol. **30**, 12LT02 (2017).

Ultra-Wide, High-Current Superconducting Nanowire Single Photon Detectors

Eli Mueller[1,2], Kristen M. Parzuchowski[1,3], Bakhrom G. Oripov[1,3], Ravin A. Chowdhury[1,3],
Dileep V. Reddy[1,3], Benedikt Hampel[1,3], Martin J. Stevens[1], Adam N. McCaughan[1]
[1]National Institute of Standards and Technology, 80305, Boulder, United States
[2]University of Colorado Denver, 80204, Denver, United States
[3]University of Colorado Boulder, 80309, Boulder, United States

Superconducting nanowire single-photon detectors (SNSPDs) are a leading platform for photon-counting applications in quantum photonics and photon-starved imaging. In this talk, I will present recent advances from our group in SNSPD technology, including demonstrations of high-efficiency detectors [1], extension of sensitivity into the mid-infrared [2], and the development of a 400-kpixel SNSPD camera [3]. I will then focus on our recent work aimed at moving beyond the conventional nanowire paradigm by developing ultra-wide wire SNSPDs [4]. We demonstrate a 50 μm-wide SNSPD with unity internal detection efficiency for 1550 nm-wavelength photons (Fig. 1(a)). In addition, these ultra-wide SNSPDs operate at currents orders of magnitude higher than traditional nanowire detectors. Our approach is based on current-biased superconducting "rails" placed on either side of the detector, as shown in Fig. 1(b), which redistribute current across its width. This work opens new opportunities for applications requiring extremely large active-area detector arrays, such as biomedical imaging and deep space optical communication. Further, the high current-carrying capacity of our ultrawide SNSPDs enable new detector readout methodologies requiring high operating currents.

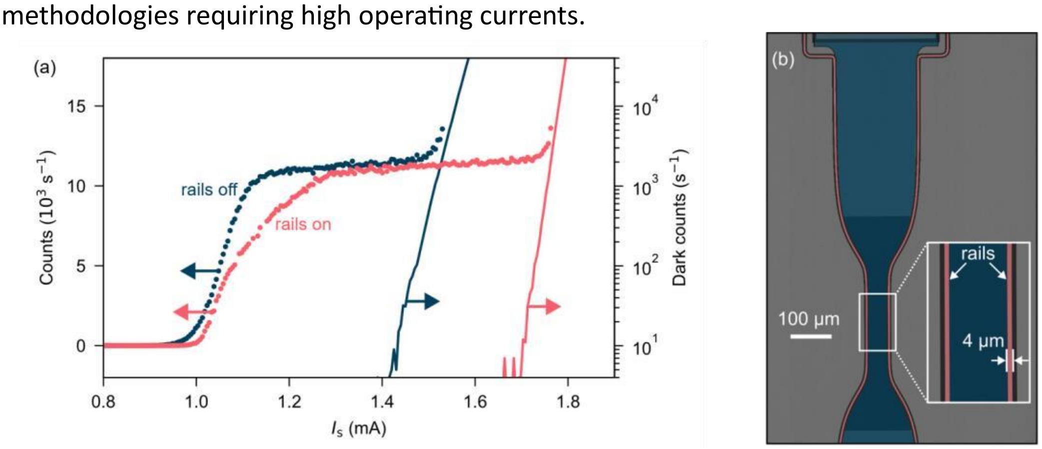


Fig. 1: *(a)Photon count rate at 1550 nm-wavelength (data points) and dark count rate (lines) as a function of bias current I_s for rails off (dark blue) and rails on (pink) for a 50 μm-wide SNSPD. (b) False-color SEM image of a 50 μm-wide SNSPD (dark blue) with adjacent rails (pink).*

References

1. Dileep V. Reddy, et al., Optica **7**, 1649-1653 (2020).
2. B. Hampel et al., e-print arXiv:2511.20868 (2025).
3. B. G. Oripov, et al., Nature **622**, 730–734 (2023).
4. K. Parzuchowski et al., e-print arXiv:2601.15971 (2026).

Characterization of Light Detectors for Cryogenic Calorimeters

Paolo Carniti[1,2], Claudio Gotti[1,2], Gianluigi Pessina[1,2], Davide Trotta.[1,2]

[1]INFN Milano-Bicocca, 20126, Milano, Italy
[2]University of Milano-Bicocca, 20126, Milano, Italy

The development of next-generation cryogenic experiments such as BINGO, CROSS, CUPID and TINY necessitates advanced light detection systems to achieve effective particle discrimination. These experiments rely on the simultaneous detection of heat and light signals to distinguish between alpha and beta particles [1]. To optimize the signal-to-noise ratio, silicon or germanium light detectors are biased using the Neganov-Trofimov-Luke effect, where the work done by the electric field on the generated drift charges enhances the signal. However, practical limitations emerge when the applied potential (< 200 V) induces leakage current. Even at the scale of hundreds of fW, this power dissipation heats the detector, leading to significant performance degradation.

This work presents the design of a specialized instrument developed to facilitate the systematic study of these detectors. The primary objective is to provide a dual-purpose system capable of both characterizing light detectors, by determining their operational voltage ranges and evaluating leakage current safety limits, and biasing during the detectors during experimental runs. This integrated approach allows for the continuous monitoring of performance shifts and ageing effects throughout the experiment's lifecycle.

The custom-designed board features 24 independent channels and includes daisy-chaining capabilities to expand the total channel count for large-scale experimental arrays and for mass production characterization. Control is managed through an FTDI 4232 module, which serves as a bridge between the host computer's USB port and I2C-controlled I/O expanders to actuate onboard switches. These switches are used to remotely select which detector is being characterized and to assign to each detector a specific polarization voltage from three available high-voltage options.

Achieving the necessary measurement sensitivity requires a two-fold approach. First, the PCB layout utilizes actively driven guard terminations to shield signal traces, enabling the SMU to resolve picoampere-scale currents. Complementing this, standard MOS-based switches are integrated such that their leakage current is shunted to the guard terminal during characterization, preventing interference with the primary signal. This study evaluated two different techniques for the characterization of the detectors. The first approach uses the SMU's high-side current measurement capability, allowing it to supply the bias while simultaneously measuring the resulting current. Alternatively, a low-side technique was implemented where an external high-voltage supply biases the detector while the SMU monitors the return current at a virtual ground. These methods were validated through high-value resistor testing and detector-free board characterization. With the most optimized configuration, this technique yielded baseline leakage currents below 10 pA at 200 V.

References

[1] A. Armatol et al., "A CUPID Li2100MoO4 scintillating bolometer tested in the CROSS underground facility," J. Instrum., vol. 16, no. 02, p. P02037, Feb. 2021, doi: 10.1088/17480221/16/02/P02037.

Superconductor Nanostripe Single-Photon Detectors with Cryogenic Readout Enabling Photon Number and Energy Resolution

Quang Nguyen,[1] Ivan Komissarov,[1] Amir J. Salim,[2] and Oleg A. Mukhanov,[2] and Roman Sobolewski[1]

[1]*University of Rochester, Rochester, NY 14627, USA*

[2]*Seeqc, Inc., Elmsford, NY 10523, USA*

Superconductor nanostripe single-photon detectors (SNSPDs) [1] are currently the most popular research-class single-photon detectors, since they exhibit near-unit quantum efficiency, up to gigahertz count rates, picosecond jitter, sub-hertz dark counts, and a relatively high operating temperature (2-4 K). However, single-pixel meander-type SNSPDs typically operate in a threshold mode as simple photon counters and implementing advanced functionalities is challenging. We present here a concept of cryogenic either semiconductor-analog or superconductor-digital readout circuitry that enables photon number and/or photon energy resolution detection of SNSPDs, making them not just photon counters but true photon sensors. The approach is based on the fact that the total resistance of a hotspot or hotspots, in case of a number of photons absorbed by an SNSPD, is directly dependent on the energy deposited by the photon(s) and results in a variation of the SNSPD output signal. A low-noise cryogenic high-electron-mobility transistor with a very high input resistance enables to obtain information on the energy of photons incident on a meander-type SNSPD, as well as demonstrates the photon-number-resolving capability [2]. Digitally-assisted SNSPDs with a Josephson-junction–based single-flux quantum (SFQ) digital circuitry also provide a photon-number resolving capability for applications in such fields of quantum measurement and quantum metrology. Using the LTSpice simulation environment, we have analyzed the dependence of the SNSPD photoresponse pulse risetime on the number of absorbed photons [3]. We have found that SNSPDs with large-area meanders, equivalently, high kinetic inductances are particularly well suited for photon-number-resolution applications. For photon absorption events involving up to five photons, the resulting SFQ output timing difference is approximately 10 ps for an SNSPD with the kinetic inductance of 100 nH and increases to about 40 ps for the kinetic inductance of 500 nH. These timing differences are readily resolvable by the SFQ circuitry with current fabrication rules. The merge of SNSPDs with the SFQ circuitry is a natural choice, since they are both superconductor-based cryogenic technologies and can be relatively easily integrated via, e.g., flip-chip technology.

This work was funded by the Center for Emerging and Innovative Sciences at the University of Rochester, a New York State Center for Advanced Technology funded by the Empire State Development Division of Science, Technology and Innovation. Additional funding came from the National Science Foundation under the Expedition project: Design and Integration of Superconducting Computation for Ventures beyond Exascale Realization, grant #2124453.

References

1. G. N. Goltsman, O. Okunev, G. Chulkova, A. Lipatov, A. Semenov, K. Smirnov, B. Voronov, A. Dzardanov, C. Williams, R. Sobolewski. Appl. Phys. Lett., **79** 705 (2001).
2. J. Kitaygorsky, W. Słysz, R. Shouten, S. Dorenbos, E. Reiger, V. Zwiller, and R. Sobolewski, Physica C **532** 33 (2017).
3. Q. Nguyen, I. Komissarov, and R. Sobolewski, Proc. of 38th Int. Symposium on Superconductivity, Nagasaki, Japan (2025).

High-Efficiency Superconducting PNR-Detector Arrays for Quantum Applications

F. Malnati[1,2,] , M. Malerba[1], E. Monticone[1] and M. Rajteri[1]
[1]*Istituto Nazionale di Ricerca Metrologica (INRiM), 10135, Turin, Italy*
[2]*Politecnico di Torino – Department of Applied Science and Technology, 10129, Turin, Italy*

Transition-Edge Sensors (TESs) are among the most advanced technologies for photonnumber-resolving detection in quantum optics, combining near-unity detection efficiency, ultra-low dark count rates, and high energy resolution. At INRiM, we have demonstrated state-of-the-art performance across several key TES metrics, including a dark count rate (DCR) of ~10^{-4} Hz [1], a resolving power of ~4 [2], detection efficiencies above 80% in Au/Ti TES devices with anti-reflection coating (ARC) [3], and count rates exceeding 1 MHz in Ti/Au TES devices with Au banks [2], fiber-coupled to single-mode optical systems.

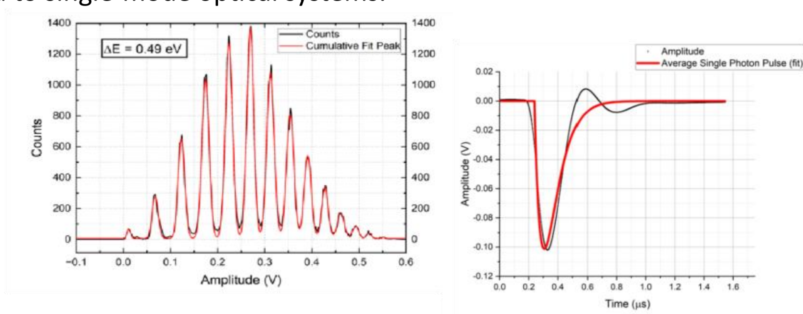


Fig. 1: ***.*** *Left: Amplitude histogram from 50k waveform acquisitions with a 690 nm pulsed laser, showing an energy resolution of 0.49 eV for an Au/Ti TES with anti-reflection coating (ARC).*
Right: Average single-photon pulse for a Ti/Au TES with Au banks. The response time was evaluated to be 68 ns from the fit.

As quantum technologies evolve, many protocols increasingly rely on the simultaneous detection of photons across multiple spatial and temporal modes. This drives the need for scalable detector platforms. Transitioning from single-pixel devices to arrays of optical TESs is therefore a crucial step toward enabling high-throughput, multi-channel quantum measurements while maintaining the outstanding performance of individual sensors.In this contribution, we report recent progress toward the realization of high-efficiency optical TES arrays optimized for quantum applications. We present advancements in the experimental infrastructure for multi-detector operation, including the adoption of electron-beam lithography (EBL) for fabricating miniaturized TES devices, the development of the Precise Optical Line-up And Reference Imaging System (POLARIS)—a hexapod-based platform enabling high-precision fiber alignment to detector arrays—and initial studies on the uniformity of detector response across array elements. Preliminary results indicate encouraging energy resolution and operational stability, supporting the viability of TES arrays as a scalable solution for next-generation quantum photonic experiments.

References

[1] L. Manenti et al., Phys. Rev. Applied **22**, 024051 (2024).
[2] C. Pepe, Ph.D. dissertation, Politecnico di Torino, (2024).
[3] F. Malnati et al., IEEE TAS (accepted, doi: 10.1109/TASC.2026.3676549) (2026)

Photoelectric detection of single microwave photons in a granular aluminum high-impedance quantum circuit

J. Basset[1], O. Stanisavljevic[1], J. Gabelli[1], M. Aprili[1] and J. Estève[1].
[1]*Université Paris-Saclay, CNRS, Laboratoire de Physique des Solides, 91405 Orsay, France.*

We demonstrate a single microwave photon detector based on photoassisted quasiparticle tunneling events that poison a superconducting island. Our method relies on continuously monitoring the island's charge parity using microwave readout of the parity. We achieve 10% detection efficiency with sub 50 ns time resolution and short dead time ($\sim$ 1 μs), for microwave photons at 10 GHz. The detector consists of three junctions connected to a superconducting island, which together carry out photoelectric conversion and charge readout. The enhanced light–matter coupling, crucial to photoelectric conversion, is provided by a granular aluminum-based high-impedance microwave cavity. The time resolved detection of itinerant microwave photon opens up perspectives in quantum sensing, microwave quantum optics, readout of superconducting qubits and mesoscopic physics.

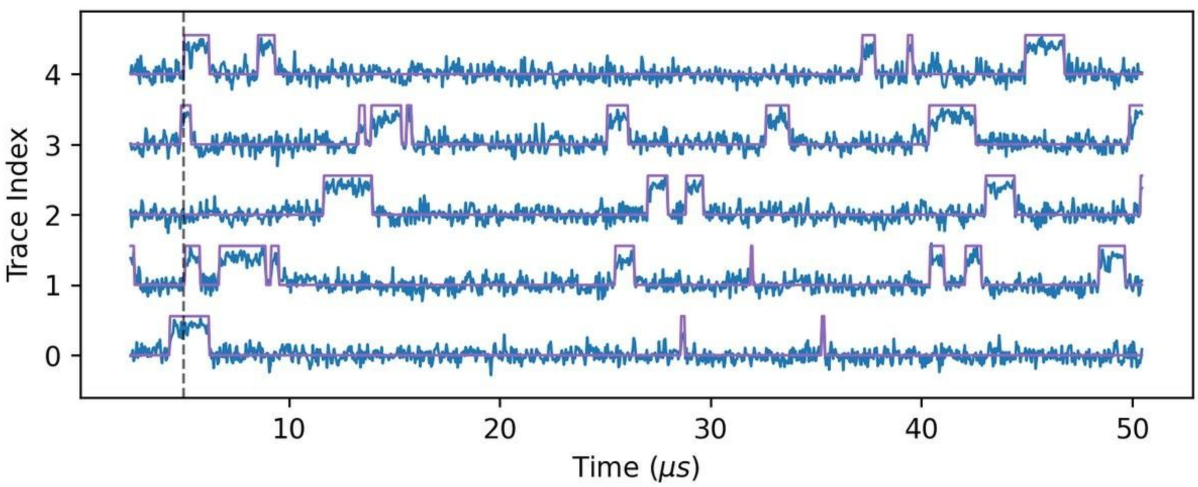


Fig. 1: *Time domain measurements of the microwave reflection coefficient of a cavity coupled to a superconducting island whose parity is altered by photo-assisted tunneling of quasiparticles due to 10 GHz microwave photons.*

References

1. O. Stanisavljevic et al., Phys. Rev. Letters **133**, 036702 (2024).
2. J. Basset et al., e-print arXiv:2511.17470 (2025)

Recent progress in quantum sensors for high frequency gravitational wave detection

A. D'Elia[1,], F. Chiarello[1,2], D. Di Gioacchino[1], C. Gatti[1], C. Ligi[1], G. Maccarrone[1], F. Mattioli[1,2], A. Rettaroli[1], J. Rezvani[1,3], S. Tocci[1]

1 INFN, Laboratori Nazionali di Frascati, Frascati, via Enrico Fermi 54, Roma 00044, Italy

2 IFN-CNR, Via del Fosso del Cavaliere 100, 00133 Roma Italy,

3 Physics Division, School of Science and Technology, Università di Camerino, Via Madonna delle Carceri 9, 62032 Camerino, Italy

Single-photon detection in the microwave domain is one of the main technological bottlenecks for a new generation of fundamental-physics experiments, including high frequency gravitational wave searches such as the GravNet project [1]. In this context, quantum technologies based on superconducting circuits offer a promising route to overcome the limits of conventional linear detection schemes [2,3]. This contribution will present recent progress in the development of single-photon detectors operating in the microwave regime, with particular emphasis on architectures based on superconducting qubits coupled to high-quality-factor cavities. I will discuss how quantum non-demolition (QND) measurement protocols enable direct access to the intracavity photon number, bypassing the standard quantum limit that constrains amplitude- and phase-based measurements. The talk will focus on detector architectures designed to operate under conditions relevant for GravNet, including high magnetic fields and ultralow temperatures (~10 mK). Finally, I will outline expected performance targets and possible experimental roadmaps for the integration of these detectors into large-scale experiments such as GravNet, highlighting their potential impact on the sensitivity to extremely weak signals

References

1. D. Amaral et al. Global detector network to search for high-frequency gravitational waves (GravNet): conceptual design Arxiv 10.48550/arXiv.2603.24645 march 2026
2. R. Moretti et al. Transmon Qubit Modeling and Characterization for Dark Matter Search IEEE Transactions on Quantum Engineering 2026
3. A. Rettaroli et al. Novel two-qubit microwave photon detector for fundamental physics applications, NIMA 2025

[1] e-mail: alessandro.delia@lnf.infn.it

Methods of RF Calibration at Cryogenic Temperatures

Jeremy Thomas[1], Lafe Spietz[1], Elyse McEntee Wei[1,2], Peter Hopkins[1], Paul Dresselhaus[1], Dylan Williams[1], and Samuel Benz.[1]

[1]National Institute of Standards and Technology, Boulder, CO, USA [2]Dept. of Physics, Colorado School of Mines, Golden, CO, USA

Cryogenic RF calibration is essential for characterizing devices used in quantum computing, superconducting voltage sources, and high-performance communications. However, precise S-parameter characterization is often hindered by thermal gradients and the inherent signal attenuation in cooled systems. To address these challenges, NIST is developing advanced measurement techniques to achieve accurate microwave characterization across a broad temperature range, from 77 K and 4 K down to millikelvin temperatures in dilution refrigerators.

I will review NIST measurements from three primary methods: (1) On-chip Wafer Probing: Utilizing a superconductor-based Through-Reflect-Line (TRL) calibration kit co-located with devices under test to significantly reduce systematic errors at any cryogenic stage; (2) Cryogenic RF MEMS Switches: featuring a controller and switches that allow for in situ electronic calibration and reconfigurable signal routing; and (3) Multi-Impedance State Lines (MISL): A specialized approach that enables probe-free and switch-free calibration by leveraging varying impedance states to maintain high fidelity in superconducting coplanar waveguides.

The NIST results for these three RF calibration techniques demonstrate their usefulness in achieving direct, in situ characterization of on-chip standards and devices. These techniques represent a significant shift from traditional electromechanical fixture-based methods toward comprehensive, in-situ RF calibration for a variety of applications that require lowtemperature electronics.

References

1. E. M. Wei, "On-Wafer Vector-Network-Analyzer Measurements at mK Temperatures," IEEE J. Microwaves, vol. 3, 2023.
2. L. F. Spietz et al., "Cryogenic RF MEMs Switch with Electronic Calibration Capability," IEEE J. Microwaves, vol. 6, 2026.
3. L. F. Spietz et al., "MEMSDuino: An Arduino-Based MEMS Switch Controller," NIST Tech. Note 2335, 2025.
4. J. N. Thomas et al., "Cryogenic On-chip In Situ S-parameter Calibration using Superconducting Coplanar Waveguides," IEEE Trans. Micro. Theory Tech., 2025.N. P. Author1, Phys. Rev. A **70**, 013603 (2004).

Electrical noise of metrology-grade quantum Hall effect devices

Luca Callegaro[1], Alessandro Cultrera[1], Vincenzo D'Elia[1],
Emanuele Enrico[1], Martina Marzano[1], Juan Medved[1,2] *1*
INRIM – Istituto Nazionale di Ricerca Metrologica, 10135 Torino, Italy 2
Politecnico di Torino, Dipartimento di Elettronica, 10129 Torino, Italy

Low-frequency excess noise is a sensitive probe of dissipation mechanisms in quantum Hall effect (QHE) devices, providing a diagnostic of the onset of resistance quantization [1,2]. We performed measurements of voltage noise spectra on QHE devices excited by a dc current I, versus magnetic induction B, in a dry cryostat environment. The experimental setup [3,4] enables the synchronous acquisition of voltage fluctuations at different device terminals, allowing both power (PSD) and cross-power (CSD) spectral densities to be estimated, and correlated noise components investigated.

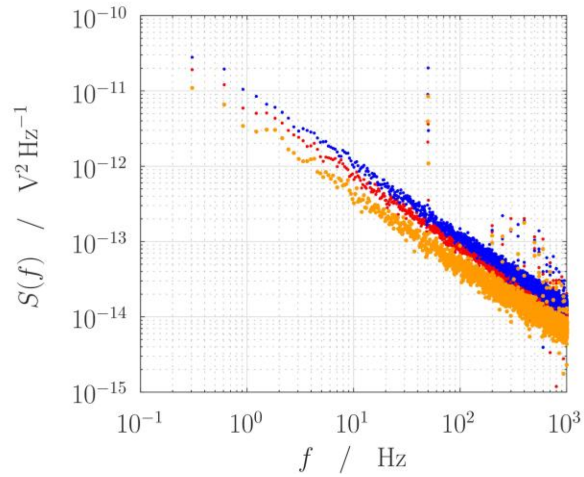


Fig. 1: *Voltage noise spectra of a graphene QHE device.* B = 0.7 T, T = 3.6 K, I = 10 µA. *PSD of (●) the longitudinal voltage* V_{xx}*; (●) the Hall voltage* V_H*; (●)* V_{xx}-V_H *CSD.*

Fig. 1 shows an example of measurements on a metrology-grade epitaxial graphene QHE device [5] designed for the realization of the ohm. The noise is strongly dependent on B; at low fields the noise spectra are dominated by $1/f$ noise, which is strongly suppressed above the quantization threshold. The evolution of the flicker noise magnitude with B can be compared with the longitudinal resistance R_{xx}, the standard indicator of the approach to quantization. The results demonstrate the technical feasibility of low-frequency excess noise measurements on QHE devices in a dry cryostat and support noise as a complementary diagnostic tool for assessing dissipation mechanisms at the edge of quantization in quantum resistance standards.

The project 23FUN07 QuAHMET has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

References

1. J. Schurr, F. Ahlers, and L. Callegaro, IEEE Trans. Instr. Meas. **62**, 1574 (2013).
2. C.-C. Kalmbach *et al.*, Phys. Rev. B **94** 205430 (2016).
3. M. Marzano *et al.*, Meas. Sci. Technol. **30**, 035102 (2019).
4. A. Cultrera *et al*., Appl. Phys. Lett. 093504 (2018).
5. Y. Yin *et al*., Phys. Rev. Appl. **23**, 014025 (2025).

Investigation of SQUID-based Noise Thermometry for low Temperatures

Xiaolong Xu[1, *], Yuxiao Guo[1], Xu Li[2], Wenxiang Guo[3], Yu Wang[4], Peike Shangguan[4], Shijian Wang[1], Guihong Zou[5], Jian Chen[1], Xueshen Wang[1], Bo Gao[3], Junyun Li[5], Jinjin Li.[1,*]

1 National Institute of Metrology (NIM), 100029 Beijing, China

2 QuantumCTek Co., Ltd, 230088 Heifei, China

3 State Key Laboratory of Cryogenic Science and Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, 100190 Beijing, China

4 Department of Modern Physics, University of Science and Technology of China, 230026 Hefei, China

5 University of Science & Technology of China, 201315 Shanghai, China

SQUID-based noise thermometry has demonstrated sufficient reliability and accuracy for practical use in the temperature range of 10 mK to 4 K. This paper presents the development of two compact noise thermometry systems: a current-sensing noise thermometer (CSNT) and a magnetic-field fluctuation thermometer (MFFT). Both thermometers operate on the Nyquist relation, exhibiting linear response characteristics, and function in a relative primary mode. Temperature calibration is achieved using a superconducting reference device (SRD) traceable to the Provisional Low-Temperature Scale of 2000 (PLTS-2000 at LNE-Cnam). Experimental results demonstrate that the time required to achieve approximately 1% measurement precision is independent of temperature.

Keywords: SQUID, noise thermometry, current-sensing noise thermometer, magnetic-field fluctuation thermometer, low-temperature measurement, PLTS-2000

TiN Inductors for Thermometry and Readout to Enable Monolithic Integration of Silicon Quantum Processors

M. de Kruijf[1], G. R. Ridgard[1], T. H. Swift[1], G. Aizpurua-Iraola[1,2], J. Drayne[1], G. M. Noah[1], K. Türe[1], F. Olivieri[1], A. Gomez-Saiz[1,3], J. J. L. Morton[1,4], M. F. Gonzalez-Zalba[1,4,5]
[1]Quantum Motion, 9 Sterling Way, London, N7 9HJ, United Kingdom
[2]CIC nanoGUNE Consolider, Tolosa Hiribidea 76, E-20018 Donostia-San Sebastian, Spain
[3]Department of Electrical and Electronic Engineering, Imperial College London, London SW7 2AZ, United Kingdom
[4] London Centre for Nanotechnology, UCL, London, WC1H 0AH, United Kingdom
[5] IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain

Building a utility-scale quantum computer requires scalable control and readout electronics to interface with qubits. Many qubit modalities operate at deep-cryogenic temperatures and are attempting to integrate electronics monolithically or as part of a 3D package to avoid wiring and latency bottlenecks. The proximity of the electronic elements to the qubits introduces footprint and thermal constraints. Here we address two important aspects of this, footprint of the readout architecture and mK-resolution thermometry.

First, we present a time-resolved thermometry technique with millikelvin sensitivity and sub-microsecond temporal resolution based on TiN kinetic inductance resonators integrated in an industrially manufactured CMOS process. Local heaters are used for pulsed heating sequences of controlled, local power dissipation. This information is then used to extract the system's thermal response time and separate electron and phonon contributions to the thermal conductance, across a range of operating temperatures. We observe frequency-dependent deviations of the cycle-averaged temperature from the DC limit, highlighting the role of transient, non-equilibrium thermal dynamics in these systems. Furthermore, we use these superinductor-based resonators to demonstrate an integrated radio-frequency single-electron transistor (rfSET) [1]. The integrated nature of the rfSET resonator reduces system parasitics and yields a sensitivity improvement of more than two orders of magnitude over the prior state-of-the-art, combined with a 10,000-fold area reduction compared to off-chip LC resonators.

In addition, we present a novel solution to the heat equation, which is used to extract cryogenic substrate thermal conductivity and chip-to-cold-plate thermal boundary resistance as a function of temperature. We have used on-chip thermometry data as a function of distance, heater power and bath temperature (from 300 mK to 4K) to extract these properties. We then compare the model results to an industry standard 3D FEM thermal solver (Ansys ICEPAK). From both we can generate 3D thermal maps of the chip. Our results show TiN could be a key element in building a utility-scale silicon-based quantum processor.

References

1. Swift, T. H., Olivieri, F., Aizpurua-Iraola, G., Kirkman, J., Noah, G. M., de Kruijf, M., ... & Gonzalez-Zalba, M. F. (2025). A superinductor in a deep sub-micron integrated circuit. *arXiv preprint arXiv:2507.13202*.

Thursday, 4 June 2026

Keynote: Giving Supercurrents a Greater Sense of Direction

Jason Robinson

Cambridge University, Cambridge, UK

A diode is a one-way valve for electrical currents. In the superconducting analogue, supercurrents preferentially flow in one direction along a wire or across a Josephson junction. This non-reciprocal flow, known as the superconducting diode effect (SDE), has been demonstrated in superconducting films, wires and Josephson junctions [1–3], and is attractive for low-dissipation superconducting electronics and as a probe of unconventional superconducting states. The central challenge is to identify what causes the non-reciprocity and to control it. Intrinsic SDEs are expected when both inversion and time-reversal symmetries are broken. For example, through structural asymmetry and spin–orbit coupling in conjunction with a magnetic exchange field in wires and Josephson junctions, which can generate finite-momentum Cooper pairs and direction-dependent de-pairing currents [1–3]. However, similar diode-like behaviour can arise from device-level or extrinsic effects, including vortex motion [4], geometric asymmetry [5], and magnetochiral contributions [6,7]. Distinguishing these mechanisms is essential if SDEs are to be understood and controlled. In this talk, I will present my groups experimental work on SDEs in wires in which common extrinsic origins of non-reciprocal supercurrents can be ruled out. By establishing a well-controlled platform for superconducting diode behaviour in superconducting wires with interfacial spin-orbit coupling, we are able to generate diode efficiencies that exceed 70% with engineered layer thicknesses. The results are key towards the development of low energy superconducting spintronic and spin-orbitronic devices.

References

[1] M. Nadeem *et al*., **Nat. Rev. Phys. 5**, 558 (2023).
[2] F. Ando *et al*., **Nature 584**, 373 (2020).
[3] M. Amundsen, J. Linder, J. W. A. Robinson, I. Žutić, N. Banerjee, **Rev. Mod. Phys. 96**, 021003 (2024).
[4] A. Gutfreund *et al*., **Nat. Commun. 14**, 1630 (2023).
[5] Y. Hou et al., **Phys. Rev. Lett. 131**, 027001 (2023).
[6] B. Pal et al., **Nat. Phys. 18**, 1228 (2022).
[7] H. F. Legg et al., **Phys. Rev. B 106**, 104501 (2022).

Periodic Phase Slips and Nonreciprocal Supercurrents in Tubular Superconductors

Axel J.M. Deenen[1], Dirk Grundler.[1,2]
[1]Institute of Materials (IMX), Laboratory of Nanoscale Magnetic Materials and Magnonics (LMGN), Ecole Polytechniaue Fédérale de Lausanne (EPFL), 1015, Lausanne, Switzerland [2]Institute of Electrical and Micro Engineering (IEM), EPFL, 1015, Lausanne, Switzerland

Advances in atomic layer deposition (ALD) enable the creation of three-dimensional (3D) nanodevices needed in modern microelectronics and integrated circuits based on semiconductors [1]. ALD processes for 3D superconducting electronics and 3D spintronics are under development [2,3]. In the latter case, ALD-growth of the $Ni_{80}Fe_{20}$ alloy and elemental Ni has recently enabled the experimental exploration of magneto-chiral effects in straight and spiral tubular ferromagnets, respectively [4,5]. In the spirals a magnon diode effect was evidenced [5]. We have implemented the time-dependent Ginzburg-Landau formalism in a finite-element-method simulation framework and explored numerically the vortex expansion in current-biased superconductor/normal metal interfaces exposed to a tilted magnetic field [6] as well as effects in 3D tubular superconductors attributed to curvature and torsion [7,8]. In a straight type-II superconductor tube with a nanoconstriction resembling a diabolo we investigated phase slips–discrete 2π jumps in the phase of the superconducting order parameter. Subjected to a longitudinal direct current (DC) the system stabilized periodic phase slips, resulting in voltage oscillations in the microwave frequency regime [7]. An additional AC frequency modulation generated frequency combs which depended characteristically on the interaction between moving vortices and phase slips. In spiral tubes with homogeneous diameter the helical geometry led to magnetic-field-induced screening currents which induced inequivalent critical currents for opposite polarities (superconducting diode) [8]. The diode efficiency reached a maximum when one current direction first nucleated vortices, revealing a chirality-controlled crossover between screening- and vortexdominated nonreciprocity. These results established mesoscopic geometric chirality as a robust mechanism for supercurrent rectification in an achiral superconductor. Our findings stimulate novel functionalities in superconducting electronics provided by ALD-inspired nanodevices entering the third dimension on a chip. The simulations have been performed using the facilities of the Scientific IT and Application Support Center of EPFL. We acknowledge support by the SNSF via project 10000845.

References

1. I. Hwang, M. Choe, D. Jeonab, and I.-H. Baek, J. Mater. Chem. C **12**, 18167 (2024).
2. G. K. Deyu, M. Wenskat, I. González Díaz-Palacio, R. H. Blick, R. Zierold, and W. Hillert, Mater. Horiz. **12**, 5594 (2025).
3. M. C. Giordano, S. E. Steinvall, S. Watanabe, A. Fontcuberta Morral, and D. Grundler, Nanoscale **13**, 13451 (2021).
4. M. C. Giordano, M. Hamdi, A. Mucchietto, and D. Grundler, Phys. Rev. Mater. **7**, 024405 (2023).
5. M. Xu, A. J. M. Deenen, H. Guo, P. Morales-Fernández, S. Wintz, E. Zhakina, M. Weigand, C. Donnelly, and D. Grundler, Nat. Nanotechn. **21**, 58 (2026).
6. M. F. L. Roinard-Chauvet, A. J. M. Deenen, and D. Grundler, Phys. Rev. Res. (in press).
7. A. J. M. Deenen and D. Grundler, ACS Nanoscience Au **5**, 362 (2025).
8. A. J. M. Deenen and D. Grundler, Nano Lett., DOI: 10.1021/acs.nanolett.5c06341.

Magnetotransport Signatures of Spin-Orbit Coupling in High- Temperature Cuprate Superconductors

A. Barrera, H. Li, T. Gunkel, J. Alcalà, S. Damerio, C.O. Avci, A. Palau
Insititut de Ciència de Materials de Barcelona, ICMAB-CSIC, Campus de la UAB 08193 Bellaterra, Spain

Spin transport in superconductors offers a compelling platform to merge the dissipationless nature of superconductivity with the functional promise of spin-based electronics. A significant challenge in achieving spin polarisation in conventional superconductors stems from the singlet state of Cooper pairs, which exhibit no net spin. The generation of spin-polarised carriers, quasiparticles, or triplet pairs in superconductors has predominantly been realised in hybrid superconductor/ferromagnet systems through proximity-induced spin polarisation. Historically, cuprate superconductors have been characterised by strong electronic correlations but negligible spin-orbit coupling. In this study, we observe a large in-plane angle-dependent magnetoresistance and a pronounced planar Hall effect arising near the superconducting phase transition in the prototypical high-temperature cuprate superconductor $YBa_2Cu_3O_{7-x}$ without using a proximity ferromagnet. These effects - unusual in centrosymmetric cuprates - may arise from spin-polarised quasiparticle transport potentially mediated by strong spin-orbit coupling. By systematically tuning magnetic field strength, orientation, temperature, and doping, we identify transport signatures that are consistent with spin-orbit-driven phenomena. Our findings suggest the presence of a previously underappreciated spin-orbit landscape in cuprates, which may provide the basis for exploring spintronic functionalities in high-temperature superconductors.

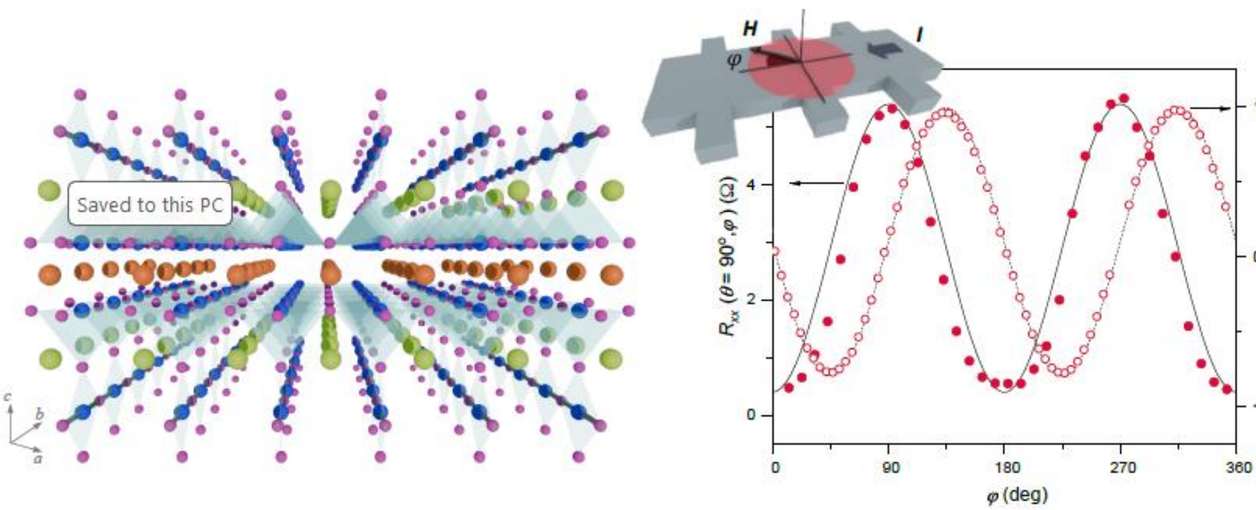


Fig. 1: *Anomalous angle-dependent magnetoresistance and planar Hall effect in High-Temperature YBCO films*

References

1. Barrera et al. arXiv:2505.10984 (2025)

The possible trivial role of spin-orbit coupling in planar Josephson junctions

Remko Fermin[1,2], Junyi Zhao[1], Jason Robinson[1]
[1]Department of Materials Science & Metallurgy, University of Cambridge, 27 Charles Babbage Road, CB3 0FS Cambridge, United Kingdom
[2]MESA+ Lab, University of Twente, Hallenweg 23, 7522 NH Enschede, The Netherlands

The relativistic coupling between spin and orbital momentum (spin-orbit coupling) is one of the most profound effects of quantum mechanics, and plays a central role in functional properties of superconducting electronics. Prominent among these are the Josephson diode effect — a Josephson junction featuring a nonreciprocal critical current: $I^+c \neq I^-c$ — and the generation of a finite magnetization due to the spin Hall effect. Despite the undeniable potential of spin-orbit coupling in applications and explaining the unconventional properties of superconducting electronics, the right control experiments needed to distinguish the role of spin-orbit coupling from trivial effects are often overlooked.

Here we show that shifts in the magnetic interference pattern and Josephson diode effect --- before attributed to the presence of a Rashba spin-orbit coupling in the weak link --- can be reproduced in planar Josephson junctions formed between an s-wave superconductor and a non-relativistic copper weak link.
Firstly, we find a sweep-direction-dependent shift in the Ic(B)-pattern, which occurs universally independently of the weak link material, junction geometry or layer thickness. This effect is only suppressed by reducing the uniformity of the junction morphology.

Secondly, we find that these Cu-junctions reproduce a Josephson diode behavior that mimics what is expected of a high spin-orbit coupling junction; in particular the field angle dependence.
Our results warrant caution when attributing unconventional features to spin-orbit coupling and need to be considered as additional factor when interpreting the characteristics of superconducting electronics.

Unconventional gap structure in kagome superconductor integrated with a microwave circuit

Yejin Lee[1], Haolin Jin[1], Sushmita Chandra[1], Berit H. Goodge[1], Edouard Lesne[1], Francesco Tafuri[2], Davide Massarotti[2], Golam Haider[3], Kornelius Nielsch[3], Bernd Büchner[3],
Claudia Felser[1], Debanjan Chowdhury[4], Nicola Poccia[2,3], Uri Vool[1]

[1]*Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany*

[2]*University of Naples Federico II, Naple, Italy*

[3]*Leibniz Institute for Solid State and Materials Research, 01069, Dresden, Germany*

[4]*Department of Physics, Cornell University, Ithaca NY 14853, United States*

Unconventional superconductivity is a hallmark of exotic quantum matter, with a growing diversity of newly discovered classes, and determination of pairing mechanism is essential for understanding underlying physics. Van der Waals (vdW) kagome superconductors provide a prominent platform for emergent phenomena exhibiting electronic correlations and nontrivial band topology, yet its microscopic origin remains elusive. The superconducting gap structure can be probed by the electrodynamic response of the material. However, in thin vdW flakes such measurements are inapplicable due to their small volume and delicate nature. Superconducting microwave resonators provide a highly sensitive and coherent platform, probing electrodynamic response, with versatile design to incorporate various materials and geometries. Here, we integrate vdW flakes with microwave circuits, enabling non-invasive measurements of superfluid response via contactless coupling that preserves crystalline integrity. We mitigate parasitic two-level systems that often cause dissipation in microwave circuits, leading to suppression of their contribution via geometric optimization and allowing isolation of the intrinsic material response. The temperature dependent superfluid density reveals a linear-in-T behavior at the millikelvin regime, consistent with a nodal gap structure. This approach demonstrates a microwave resonator platform for investigating complex correlated materials and advancing quantum device technologies.

Perfect spin nonreciprocity in gated superconducting altermagnetic heterostructures

Pei-Hao Fu[1], Luca Chirolli[1], Jorge Cayao.[2]
[1]*Department of Physics and Astronomy, University of Florence, I-50019 Sesto Fiorentino, Italy*
[2]*Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden*

We consider a superconducting altermagnet heterostructure and demonstrate that the interplay between altermagnetism and a selective filter of transverse momentum channels enables perfect nonreciprocal spin-polarized currents. We demonstrate that this nonreciprocity manifests in both local and nonlocal spin currents, signaling the emergence of directionally selective local and nonlocal spin behaviors. We show that the selective filter of transverse momentum channels is realized by gating a finite normal region between the superconducting altermagnet and the metallic reservoir, which then directionally selects transport channels that match the momentum-dependent spin-split superconducting altermagnetic states, allowing for nonreciprocal spin-polarized currents. We discover that the local and nonlocal spin nonreciprocity features a highly tunable polarity and nearly perfect quality factors, respectively, which is achieved by means of gate voltages and by varying the length of the finite region. Moreover, we find that local and nonlocal charge currents also develop a nonreciprocal behavior, whose quality factors can also reach perfect values. In all cases, the spin and charge currents are sensitive to variations of the altermagnetic field, a functional dependence that can be exploited to identify the type of altermagnetism. Our findings put forward an electrically controllable route towards nonreciprocal superconducting spintronic devices based on altermagnets.

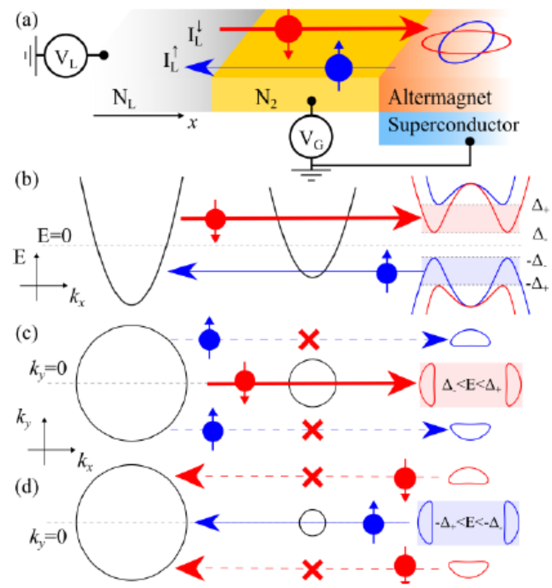


Fig. 1: *Junction geometry, energy dispersions and contours, and sketch of the spin nonreciprocity.*

References

[1] P.-H. Fu, J.-F. Liu, L. Chirolli, J. Cayao, arXiv:2604.20312 (2026).
[2] P.-H. Fu, Q. Lv, Y. Xu, J. Cayao, J. Liu, and X.-L. Yu, npj Quantum Mater. 10, 111 (2025).

Interface-driven triplet proximity effects and electronic transport in spin-orbit coupled superconductor/ferromagnet hybrids

Dr Niladri Banerjee[1]

[1]Department of Physics, Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom.
Superconductor/ferromagnet (S/F) hybrids, especially with spin-orbit coupling, provide an excellent platform to study several interesting phenomena ranging from spin triplet to topological superconductivity and the diode effect. These discoveries provide a platform for a wide range of applications in quantum technologies, some of which we have just started to explore [1].

In this talk, I will discuss recent theoretical and experimental progress in S/F structures which incorporate spin-orbit coupling in the context of spin triplet superconductivity. I will highlight our recent work where interface modification leads to a large triplet proximity effect [2] and some results on transport properties of these hybrid structures.

References:

1. Spin-orbit effects in superconducting hybrid structures, M. Amundsen *et al., Reviews of Modern Physics* 96, 021003, 2024
2. Enhanced controllable triplet proximity effect in superconducting spin–orbit coupled spin valves with modified superconductor/ferromagnet interfaces, A. T. Bregazzi *et al.*, *Appl. Phys. Lett.* 124, 162602 (2024)

Reentrant Superconductivity in a de Gennes spin valve

Pawan Kumar Verma and Avradeep Pal
MEMS department, IIT- Bombay, Mumbai- India

In superconductor (S)/ ferromagnetic (F) systems, re-entrant superconductivity is manifested in the form of 0–π phase transitions. This phenomenon has been observed in (S/F) bilayers [1] and S/F/S Josephson junctions [2], where re-entrance has generally been measured through ferromagnetic thickness-dependent transition temperature oscillations [1] and thickness [3] or temperature-dependent critical current oscillations [4], respectively.

In this work, we demonstrate reentrant superconductivity in de Gennes spin valves. We show that in FI/S/FI trilayers [5-6], the re-entrant state only appears at a specific magnetic configuration when one magnetic layer is saturated, while the other is close to its switching field and hence exhibits a multi-domain structure. Our work adds a novel dimension to the general body of literature on re-entrant superconductivity.

References:

1) V. I. Zdravkov et al, Reentrant superconductivity in Nb/$Cu_{1-x}Ni_x$ Bilayers *Phys. Rev. Lett.* ***97**, 057004* (2006)

2) Frank, C.E., Lewin, S.K., Saucedo Salas, G. *et al.* Orphan high field superconductivity in non-superconducting uranium ditelluride. *Nat Commun* **15**, 3378 (2024).

3) Robinson, J. W. A. et al., Critical Current Oscillations in Strong Ferromagnetic 0-π Junctions, *Phys. Rev. Lett*. **97**, 177003 (2006)

4) Ryazanov, V. V. *et al.,* Coupling of Two Superconductors through a Ferromagnet: Evidence for a π Junction, Phys. Rev. Lett. **86**, 2427 (2001)

5) Zhu, Y., Pal, A., Blamire, M. *et al.* Superconducting exchange coupling between ferromagnets. *Nature Mater* **16**, 195–199 (2017).

6) Bhakat, S., Samanta, S., Mahapatra, S. *et al.* Bistable and absolute switching driven by superconducting exchange coupling. *Nat Commun* **16**, 9609 (2025).

Phase dynamics and dissipation in tunnel ferromagnetic Josephson junctions

F. Calloni[1], R. Satariano [1], R. Ferraiuolo [2], H.G. Ahmad[1], D. Gatta[1], E. Raja[1], R. Vydyasagar[1], G. Santo[1], G. Serpico[1], D. Montemurro[1], N. Poccia[1,4], A. Vettoliere[3], G. Ausanio[1], C. Granata[3], L. Parlato[1], G.P. Pepe[1], A. Bruno[2], F. Tafuri[1], D. Massarotti[5].

[1] Dipartimento di Fisica ”Ettore Pancini”, Università degli Studi di Napoli ”Federico II”, 80126, Napoli, Italy

[2] QuantWare, 2628 XG, Delft, The Netherlands

[3] Consiglio Nazionale delle Ricerche-ISASI, I-80078, Pozzuoli, Italy

[4] Leibniz Institute for Solid State and Materials Research Dresden, (IFW Dresden), Dresden, 01069, Germany.

[5] Dipartimento di Ingegneria Elettrica e delle Tecnologie dell’Informazione, Università degli Studi di Napoli Federico II, Napoli, I-80125, IT.

Magnetic Josephson junctions (MJJs) are key structures in the field of superconducting spintronics [1,2] and recently have attracted consider able attention as building blocks for both quantum and classical superconducting circuits [3,4]. In this panorama, ferromagnetic tunnel Josephson junctions aim to combine the inherently low dissipation of tunnel junctions with the intrinsic memory behavior of magnetic layers. In this work, we present a comprehensive study of the phase dynamics and dissipation of ferromagnetic tunnel Josephson junctions based on Superconductor-Insulator-thin superconductor Ferromagnet-Superconductor (SIsFS) multilayers. We perform a comparative analysis of the electrodynamic properties of junctions featuring different ferromagnetic interlayers— Ni80 Fe20 (Permalloy: Py) and diluted Py thin films—and different superconducting electrodes (Nb and Al) [5,6]. We show a strong consistency between the parameters extracted from the Tunnel Junction Microscopic Model (TJM) fitting of current-voltage characteristics and those independently estimated from Switching Current Distribution (SCD) measurements, as reported in a work currently under review [7]. By scaling the lateral dimensions down to the submicrometric regime, we demonstrate that Al-based devices exhibit parameters, e.g. Josephson energy and charging energy, comparable to those of state-of-the-art superconducting qubits. Moreover, clear signatures of quantum phase diffusion, consistent with SIS Josephson junction employed in standard transmon qubit, have been observed [8]. These results validate the potential of these devices as building blocks for both scalable superconducting quantum hardware and high-speed classical digital circuits, and represent the first step for bridging the gap between magnetic functionality and quantum coherence.

References

[1] A. I. Buzdin. superconductor-ferromagnet tures. Proximity effects in heterostruc Reviews of Modern Physics, 77(3):935–976, September 2005.

[2] Jacob Linder and Jason W. A. Robinson. Superconducting spintronics. Nature Physics, 11(4):307–315, 2015.

[3] Norman O. Birge and Nathan Satchell. Ferro magnetic materials for Josephson π junctions. APL Materials, 12(4):041105, 04 2024.

[4] S. Kim, L. V. Abdurakhimov, D. Pham, et al. Superconducting flux qubit with ferromagnetic Josephson π-junction operating at zero magnetic field. Communications Materials, 5:216, 2024.

[5] R. Satariano, A.F. Volkov, and H.G. et al. Ahmad. Nanoscale spin ordering and spin screening effects in tunnel ferromagnetic Josephson junctions. Communications Mate rials, 5(67), 2024.

[6] Antonio Vettoliere, Roberta Satariano, Raf faella Ferraiuolo, Luigi Di Palma, Hal ima Giovanna Ahmad, Giovanni Ausanio, Giovanni Piero Pepe, Francesco Tafuri, Davide Massarotti, Domenico Montemurro, Carmine Granata, and Loredana Parlato. High-quality ferromagnetic Josephson junc tions based on aluminum electrodes. Nano materials, 12(23):4155, 2022.

[7] F. Calloni, R. Satariano, R. Ferraiuolo, H. G. Ahmad, D. Gatta, E. Raja, G. Santo, G. Serpico, V. Reddithota, D. Montemurro, N. Poccia, A. Vettoliere, G. Ausanio, C. Granata, L. Parlato, G. P. Pepe, A. Bruno, F. Tafuri, and D. Massarotti, "Phase dynamics and dissipation in tunnel ferromagnetic Josephson junctions," under review, 2026.

[8] R. Satariano, R. Ferraiuolo, F. Calloni, H. G. Ahmad, D. Gatta, F. Tafuri, A. Bruno, and D. Massarotti. Submicrometer tunnel fer romagnetic Josephson junctions with trans mon energy scale. Applied Physics Letters, 127(25):252601, 12 2025.

Dynamically Induced Anisotropy in Ferromagnet in Superconductor Ferromagnet Heterostructures

Rhiannon Adela Fletcher-Stones
University of Cambridge, United Kingdom

Superconductivity-induced torques in ferromagnets offer a promising route for ultra-low-power magnetic memory. Ferromagnetic resonance (FMR) studies of superconductor-ferromagnet heterostructures show increased magnetic anisotropy below the superconducting transition temperature (Tc), yet the mechanism remains poorly understood [1]. We investigate FMR shifts in symmetric superconductor/ferromagnet/superconductor (S/F/S) trilayers using systematic thickness- and angle-dependent measurements. The resonance field shift below Tc is unique to symmetric trilayers, independent of applied field and excitation frequency, and scales with both superconducting and ferromagnetic layer thickness. Insertion of a thin insulating spacer suppresses the effect entirely, confirming electrical contact is essential. This phenomenon has generated conflicting theoretical interpretations, from static Meissner screening to dynamical electromagnetic backaction [2,3,4]. Recent Cu spacer experiments reveal the effect decays over the superconducting coherence length, proving purely electromagnetic models insufficient. Our findings demonstrate that direct contact with superconducting correlations is crucial, ruling out purely electromagnetic origins and indicating proximity-induced mechanisms at the S/F interface.

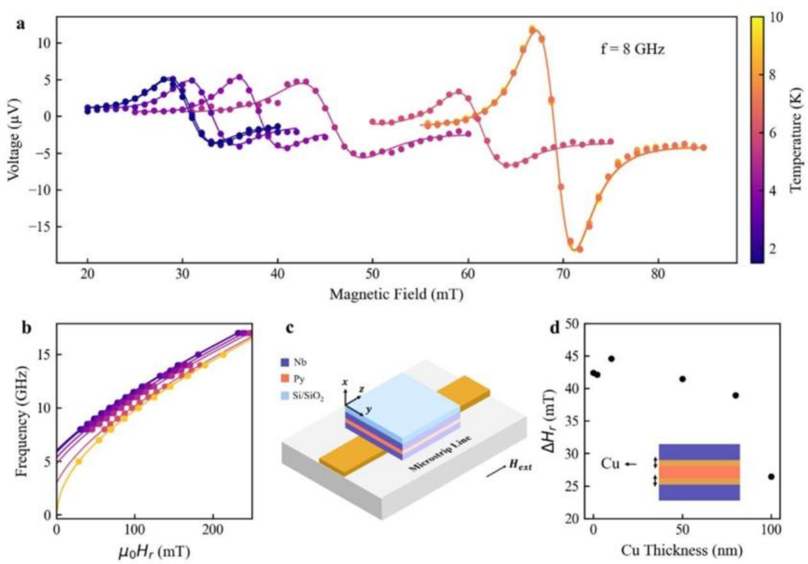


Fig. 1: Shift of ferromagnetic resonance field below transition of superconductor of Nb(80nm)/Py(20nm)/Nb(80nm) (a) Temperature-dependent FMR spectra at 8 GHz showing shift to lower fields with decreasing temperature. (b) Kittel. (c) Schematic of investigated sample structure. (d) The change in the shift from 10K to 2K with different thicknesses of Cu showing decrease around 60nm.

References

1. I. A. Golovchanskiy et al., Phys. Rev. Applied 14, 024086 (2020).
2. M. Silaev, Phys. Rev. B 106, 224509 (2022).
3. X.-H. Zhou and T. Yu, Phys. Rev. B 108, 144414 (2023).
4. S. V. Mironov and A. I. Buzdin, Appl. Phys. Lett. 119, 102601 (2021)

Dzyaloshinskii-Moriya Interactions Mediated by Cooper Pairs

Jabir Ali Ouassou[1], Takehito Yokoyama[2], Jacob Linder.[3]
[1]*Department of Computer Science, Electrical Engineering and Mathematical Sciences, Western Norway University of Applied Sciences, NO-5528 Haugesund, Norway.*
[2]*Department of Physics, Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan.*
[3]*Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway.*

Interacting impurity spins adsorbed on surfaces have been suggested as basic components for applications in quantum computation and spintronics. Due to the RKKY interaction, such spins usually prefer to align either in parallel or antiparallel depending on separation distance. However, the situation becomes more complex in materials with spin–orbit coupling, where noncollinear spin configurations can become possible due to an emergent DMI term in the RKKY interaction between the spins [1].

We show analytically and numerically that in superconducting systems, *DMI can arise even without spin–orbit coupling* [2–3]. More precisely, while DMI can emerge in *p*-wave triplet superconductors under special circumstances [2], it is most robustly realized in mixedparity superconductors where *s*-wave singlet and *p*-wave triplet Cooper pairs coexist [3]. This is interesting for several reasons. Firstly, the rich dependence of the RKKY interactions on the symmetries of the superconducting order parameter can be used as a probe to classify superconducting materials [2]. Secondly, we have proposed a way that DMI can be tuned *in situ* using the phase difference over a Josephson junction (see Fig. 1). Finally, this has some intriguing consequences due to the rich phenomenology of DMI, and may enable phenomena such as geometric frustration or emergent spin textures for spin impurities in superconductors.

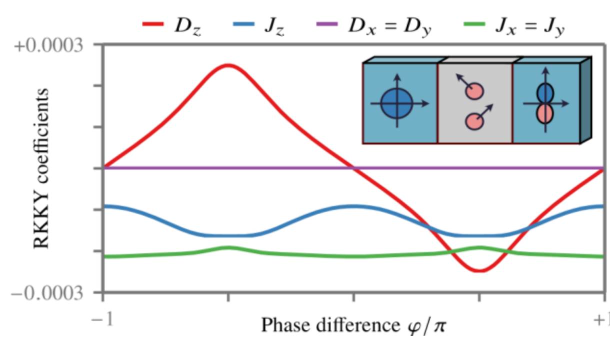


Fig. 1: *This figure is adapted from Ref. 3, and describes a Josephson junction between an s-wave singlet and p-wave triplet superconductor, which creates an effective mixed-parity state in the interlayer. The strength of the DMI coefficients D_n vs. conventional RKKY coefficients J_n depends strongly on the phase difference, permitting in situ control over a noncollinear spin ground state.*

References

1. H. Imamura, P. Bruno, Y. Utsumi. Phys. Rev. B 69, 121303 (2004).
2. J.A. Ouassou, T. Yokoyama, J. Linder. Phys. Rev. B 109, 174506 (2024).
3. J.A. Ouassou, T. Yokoyama, J. Linder. Phys. Rev. B 111, L060504 (2025).

Gating all-Silicon Josephson junctions

A. van Waveren[1], L. Desvignes[1], A. Chepelianskii[2], Y. Sun[2], J. Bourçois[3], G. Hallais[1], F. Lefloch[4], J. Labar[5], D. Débarre[1], F. Chiodi[1]

[1] *C2N, Université Paris-Saclay, CNRS, 91120 Palaiseau, France.*

[2] *LPS, Université Paris-Saclay, CNRS, 91405 Orsay, France.*

[3] *ICJLab, Université Paris-Saclay, CNRS/IN2P3, Orsay, 91405, France.* [4] *Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-PHELIQS, 38000 Grenoble, France* [5] *Thin Film Physics Laboratory, HUN-REN Centre for Energy Research, H-1121 Budapest, Hungary.*

[4]

Since the discovery of BCS superconductivity in silicon by nanosecond laser ultra-doping with boron, theoretical and experimental works have endeavored to understand what triggers and controls the superconducting phase. Indeed, superconducting Si has great potential to develop a cryogenic electronics with the advantages of large-scale integration and high reproducibility. Through the optimization of the nanosecond laser temporal profile, we achieved an excellent control of both the electrical and structural properties of ultra-doped Si thin layers, with the state of the art maximum carrier concentration of 8 at.%, in monocrystalline epilayers with few defects, 100% dopant activation up to and above the solubility limit, and a vertically homogeneous doping profile [1-3]. The control and improvement of the active doping is directly reflected in the control of the superconducting critical temperature T_c, increased by 30% in this optimized setup, and whose dependence with doping can be modelled within BCS frame [3]. Furthermore, we demonstrated that superconductivity is not only controlled by doping, but also by the lattice deformation. Thus, it is possible to tune up to 50% T_c by modifying by 1% the lattice parameter, as shown through nanosecond laser incorporation of Ge up to 20 at.% [4].
Mastering and understanding the materials properties has brought to the development of allsilicon devices, such as superconducting microwave resonators [5], SQUIDs, and Josephson junctions [6]. A key asset to for the latter is the excellent, epitaxial, transparent interface between superconducting Si and semiconducting Si, that we have characterized at sub-K temperatures as a function of the semiconductor doping. An optimized transparency leading to sizeable supercurrents, we have realized reproducible all-silicon Josephson junctions with critical currents $I_c \sim 10\mu A$, which can be strongly modulated via a gate voltage ($\delta Ic/Ic \sim 80\%$), paving the way for a silicon-based quantum circuits platform.

References

1. L. Desvignes, et al., e-print arXiv:2603.06383 (2026)
2. G. Hallais, et al., Semicond. Sci.Tech. 38, 034003 (2023)
3. L. Desvignes. PhD thesis, Université Paris Saclay (2023)
4. S. Nath, et al., Phys. Status Solidi A, 221: 2400313 (2024) 5. P. Bonnet, et al., Phys. Rev. Applied 17, 034057 (2022)
5. 6. F. Chiodi, et al., Phys. Rev. B 96, 024503 (2017).

Dynamical Slowing-down in Far-from-equilibrium Superconductivity Melting

Guillermo Nava Antonio [1], Théo Courtois [2], Corentin Pfaff [2], KM Shivangi Shukla [1], Asle Sudbø [3], Stéphane Mangin [2,4], Thomas Hauet[2], and Chiara Ciccarelli[1,3]

[1]*University of Cambridge, CB3 0HE, Cambridge, United Kingdom*

[2]*Université de Lorraine, F-54506, Nancy, France*

[3]*Norwegian University of Science and Technology, 7034, Trondheim, Norway*

[4]*Tohoku University, 980-8577, Sendai, Japan*

The excitation of a superconductor with a femtosecond optical pulse produces a strongly outof-equilibrium state characterized by a dynamical reduction of the superconducting gap. The investigation of such photo-induced dynamics has contributed to elucidating the electronic structure of BCS and unconventional superconductors [1]. At the same time, the understanding of the intrinsic energy and time scales that govern the evolution of superconductors following "fast" perturbations is relevant for the development of novel superconducting circuits [2], quantum sensors [3], high-performance radiation detectors [4], and superconductor-based optoelectronic devices [5].

In this work, we use optical pump-THz probe (OPTP) spectroscopy to chart the picosecond superconductivity melting in NbN thin films. Our experiments reveal a pronounced lengthening of the melting time (τ_s) when the absorbed optical energy is just enough to fully destroy the condensate (see Fig. 1). Assisted by time-dependent Ginzburg-Landau simulations, we interpret this effect as a non-equilibrium analog of critical slowing-down on a time scale comparable to that of superconducting fluctuations. Near equilibrium, critical slowing-down is a hallmark of universal behavior in continuous phase transitions. Out of equilibrium, universality remains significantly less understood [6]. Thus, our work provides valuable evidence that certain concepts of universality are valid in the non-equilibrium regime. From a practical perspective, this study establishes OPTP spectroscopy as a powerful tool to study superconducting dynamics driven by extreme

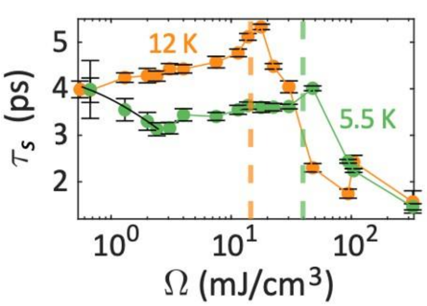


Fig. 1: *Superconductivity melting time* perturbations. *as a function of optical fluence.*

References

[1] J. Demsar, J. Low Temp. Phys. **201**, 676 (2020).

[2] P. Brookes, et al., Sci. Adv. **7**, eabe9492 (2021).

[3] S. Danilin, N. Nugent, and M. Weides, New J. Phys. **26**, (2024).

[4] A. Shurakov, Y. Lobanov, and G. Goltsman, Supercond. Sci. Technol. **29**, 023001 (2016).

[5] J. M. Shainline et al., Phys. Rev. Appl. **7**, 034013 (2017). [6] A. Polkovnikov et al., Rev. Mod. Phys. **83**, 863 (2011).

High-Q Ta-based microwave resonators for quantum applications

Sergio Pagano[1,2,3], Carlo Barone[1,2,3], Mikhail Lisitskiy[5], Muhammad Shoaib[4], Valentina Di Meo[5], Alessandro Mauro[1,2], Mariagorizia Pia Trippa[1], Giovanni Carapella[1,2]

[1]Dipartimento di Fisica "E.R. Caianiello" - Università di Salerno, 84084 Fisciano (SA), Italy
[2]Gruppo Collegato Salerno, Istituto Nazionale di Fisica Nucleare, 84084 Fisciano (SA), Italy [3]Istituto Superconduttori, Materiali Innovativi e Dispositivi - SPIN CNR, 84084 Fisciano (SA), Italy
[4]Dipartimento di Matematica e Fisica – Università della Campania "Luigi Vanvitelli", 81100 Caserta, Italy
[5]Istituto Superconduttori, Materiali Innovativi e Dispositivi - SPIN CNR, 80078 Pozzuoli (NA), Italy

This work aims at the development of thin-film superconducting resonators for applications in quantum technologies, with the goal of achieving high quality factors in the few-photon regime. Non-traditional materials, such as tantalum, are employed for the design and fabrication of the resonator structures. Several λ/4 coplanar resonators have been designed and simulated in the 4–8 GHz frequency range.

A number of test chips have been fabricated using single-crystal C-plane sapphire substrates, see Fig.1 (Left). Samples include both a single 200 nm Ta layer and a 20/200 nm Nb/Ta bilayer. The Ta, Al and Nb thin films were fabricated in a high-vacuum system equipped with DC magnetron sputtering sources and at room temperature. The resonator geometry was defined by reactive ion etching in a CF_4/O_2 plasma mixture. The superconducting devices were characterized in a 300 mK ^{3}He cryostat equipped with microwave feed lines with an 18 GHz bandwidth. The RF measurement setup includes cryogenic attenuators to limit the photon number in the cavity, a circulator, a cryogenic and a room-temperature low-noise amplifier to isolate and amplify the output signal. The resonator frequency response was measured using a 26 GHz vector network analyzer.

Measurements of the intrinsic quality factor as a function of input power—corresponding to different photon numbers in the cavity—show that resonators based on the Nb/Ta bilayer achieve quality factors up to 10^6, even after several months of storage in air, see Fig. 1 (Right). This result is particularly noteworthy given the significant degradation typically observed in Al- and Ta-based resonators due to surface oxidation under ambient conditions.

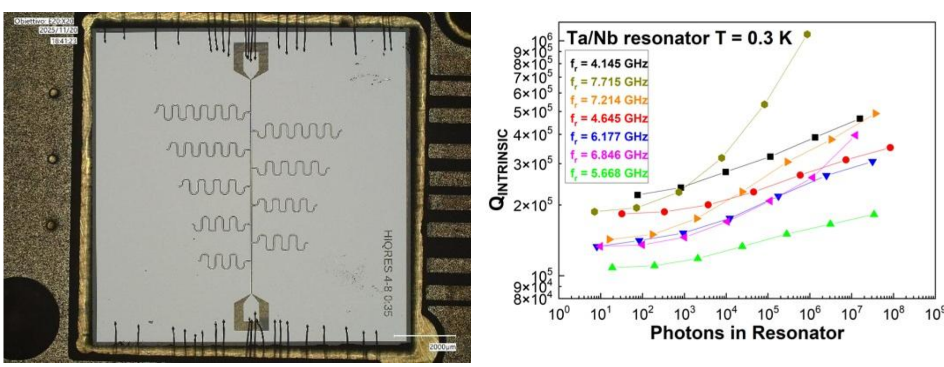


Fig. 1: *(Left) Ta resonator chips consisting on a coplanar transmission line capacitively coupled to nine λ/4 coplanar resonators with frequencies spanning from 4 to 8 GHz in 0.5 GHz steps. (Right) Measured intrinsic quality factor of the different resonators in a Nb/Ta bilayer sample at T = 0.3 K.*

High-Q Ta Superconducting Resonators on W-buffered Si Substrates

Min-Jui Lin[1], Shih-Yun Chen[2], Ian Huang[2], Bing-Lien Chen[3]
Shih-Yuan Chen[2], and Jiun-Yun Li[1,3,4,5]
[1]*Graduate Institute of Electronics Engineering, National Taiwan University, Taipei, Taiwan*
[2]*Graduate Institute of Communication Engineering, National Taiwan University, Taipei, Taiwan*
[3]*Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan*
[4]*Graduate School of Advanced Technology, National Taiwan University, Taipei, Taiwan*
[5]*Taiwan Semiconductor Research Institute, National Institutes of Applied Research, Hsinchu, Taiwan*

Tantalum (Ta) has been demonstrated as a promising material for improving the lifetime of superconducting qubits [1] due to the reduced microwave loss. To achieve ⍰-Ta phase for a higher critical temperature (~ 4 K), high-temperature sputtering is typically used or a few nanometers niobium (Nb) thin buffer layer is deposited as a seed layer [2]. While ⍰-Ta can be grown on Si substrates, the high-temperature step could induce the formation of amorphous silicides at the Ta/Si interface, potentially leading to additional microwave loss and noise to degrade the qubit performance [3]. In this work, we use Tungsten (W), widely used in CMOS technology, as a buffer layer to achieve ⍰-Ta on Si without heating substrates during the Ta sputtering steps. Phase compositions of Ta are characterized by GIXRD and TEM. GIXRD shows that 20-nm Ta exhibits ⍰-phase on 10-nm W, whereas 200-nm Ta is ⍰-phase on both 2-nm and 10-nm W buffers. Critical temperature and upper critical field of the superconducting Ta/W films are characterized through Hall measurements (Fig. 1(a)). We also fabricated coplanar waveguide resonators using the Ta/W stacks and demonstrated internal quality factor (Q_i) between 10^6 ~ 10^7 at 10 mK (Fig. 1(b)). Our results present low-loss Ta resonators fabricated at room temperature using CMOS-compatible W buffer layers, showing great potential for the development of superconducting qubit circuits with lower thermal budget and CMOS compatibility.

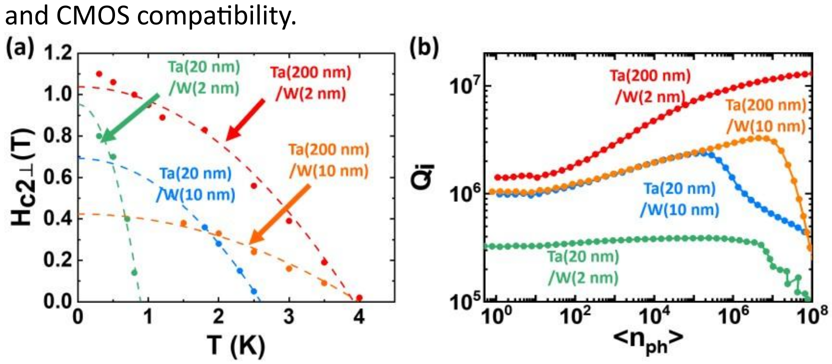


Fig. 1: *(a) Phase diagrams of upper critical field and temperature. (b) Internal quality factor (Qi) vs. average photon number <n_{ph}> at 10 mK.*

Acknowledgement

This work was supported by the Higher Education Sprout Projects (115L890303) at National Taiwan University, the Center of Data Intelligence: Technologies, Applications, and Systems, National Taiwan University (114L900903), and the National Science and Technology Council (NSTC) of Taiwan under the Grants of 115-2119-M-002-002-.

Reference

[1] A. P. M. Place et al., Nat Commun 12, 1779 (2021). [2] Yoshiro Urade et al., APL Mater. 12, 021132 (2024). [3] D. P. Lozano et al., Mater. Quantum. Technol. 4 025801 (2024).

Towards a perfect field-free Josephson diode

V. M. Krasnov, R. Hovhannisyan, T. Golod.
Department of Physics, Stockholm University, AlbaNova University Center SE-10691 Stockholm, Sweden

Superconducting electronics offer significant advantages in speed and power efficiency for next-generation computing and communication systems. However, their practical deployment is limited by the absence of simple, efficient, and scalable superconducting counterparts to key semiconductor components.

Here we will demonstrate diodes based on multi-terminal planar Josephson junctions fabricated from a conventional niobium superconductor. The nonreciprocity in these diodes arises from the self-field effect induced by the geometrical asymmetry of the junction [1]. By deliberate tuning of the junction parameters, we achieved effectively infinite nonreciprocity (within experimental resolution), characterized by a complete suppression of the superconducting critical current in one direction while maintaining a significant current in the opposite direction. We show that the multi-terminal junction structure enables both the reconfiguration of the diode characteristics through changes in the bias configuration and the generation of a local magnetic field using one of the junction electrodes as a control line, thereby eliminating the need for an external magnetic field for diode operation [2,3].

Finally, we will discuss the significance of the race for a perfect superconducting diode and its possible applications in electronics and telecommunication.

References

1. V. M. Krasnov, V. A. Oboznov and N. F. Pedersen, Fluxon dynamics in long Josephson junctions in the presence of a temperature gradient or spatial nonuniformity. Phys. Rev. B **55**, 14486 1997.
2. T. Golod and V. M. Krasnov, Demonstration of a superconducting diode-with-memory, operational at zero magnetic field with switchable nonreciprocity. Nature Commun. **13**, 3658 (2022).
3. R. Hovhannisyan, A. Loftian, T. Golod and V. M. Krasnov, Demonstration of an optical microwave rectification by a superconducting diode with near 100% efficiency, ArXiv:2508.21696.

Scanning SQUID Imaging of Trapped Vortices in Active Flux-Management Circuits

Ilya Sochnikov[1], Brenna Petrelli[1], Jonah Britton[1], Joshua Bedard[1]
Kyle Jackman[2,3], Lieze Schindler[2,3], Johannes Delport[2,3], Tessa Hall[2,3], Coenrad Fourie[2,3]
Daniel Yohannes[4], Oleg Mukhanov[4]
[1]Physics Department, University of Connecticut, Storrs CT, USA 06269
[2]SUN Magnetics, 15 De Beer Street, Stellenbosch 7600, South Africa
[3]Department of E&E Engineering, Stellenbosch University, Banhoek Road, Stellenbosch, South Africa
[4]SeeQC, 150 Clearbrook Rd., Elmsford NY, USA 10523

Trapped magnetic flux is a long-standing problem in superconducting digital and quantum circuits. Solutions like moat structures and extreme magnetic shielding have been in use. However, active flux management is desired due to the limitations of the above methods. Here, we report scanning SQUID imaging results showing flux management using a network of pulsed electric lines in the test superconducting circuits. We observe the effect of flux sweeping in areas with control lines as well as sweeping of vortices into moats (traps). This method of active flux management can potentially be expanded to larger and more sophisticated digital and quantum chips.

This material is based upon work supported by the Army Research Office and the Army Contracting Command under Contract No. W911NF-24-C-0093.

Vortex and Moat Coupling to SFQ and AQFP Circuits – Circuit Theory, Models and Validation

Coenrad J. Fourie[1,2]
[1]*Stellenbosch University, 7600, Stellenbosch, South Africa*
[2]*SUN Magnetics, 7600, Stellenbosch, South Africa*

Superconducting thin films in integrated circuits trap magnetic flux as pinned vortices or fluxons in engineered moats during cooldown.

We have previously shown how deviation of SQUID critical current can be measured in response to trapped flux, and that simulation models can be extracted from layouts to match the experimental measurements with high accuracy. The operating margins of RSFQ and AQFP circuit layouts in response to trapped flux can then be determined with high confidence through electrical simulation of extracted compact circuit models. We show measurements and simulation results for the ac and dc operating margins of AQFP circuits that shift and narrow in response to trapped flux. However, the electrical simulation method deprives the circuit designer of a deep understanding of why certain layouts are more susceptible to deterioration of margins than others. Here, we present a circuit theory description of the coupling of trapped flux to the inductors in SQUID-based circuits. We derive analytical models to find critical current deviation directly from layout-extracted inductance parameters and show how this provides insight into layout strategies such as moat size and position, symmetry and skyplane shielding. Experimental measurements for verification are also discussed.

Ginzburg-Landau theory in application: Towards numerical modeling of integrated superconducting circuits

Leonardo R. Cadorim[1], Milorad V. Milosevic[1]
[1]*COMMIT, Department of Physics, University of Antwerp, Groennmborgerlaan 171, B-2020, Antwerp, Belgium*

Superconducting microelectronics offer a promising alternative to CMOS technology, as they are theoretically capable of dissipation-free operation with ultrafast sub-nanosecond switching speeds[1]. Over the past decade, continued industrial and academic research has advanced superconducting digital technologies, though their maturity and scalability still lag behind conventional semiconductor platforms[2]. Critical issues such as unintended flux trapping and localized thermal runaway (crosstalk) severely degrade device performance and integration density. Overcoming these bottlenecks requires a profound understanding of the transient, non-linear quantum phenomena that dictate macroscopic circuit behavior. In this context, Time-Dependent Ginzburg-Landau (TDGL) theory[3] serves as a uniquely powerful predictive tool for modern superconducting circuit design. Unlike standard lumped-element circuit models (like SPICE), TDGL captures the intricate spatiotemporal evolution of the superconducting order parameter. We will discuss how this framework (coupled to external circuit dynamics) enables the direct modeling of microscopic processes in real integrated circuits designs, directly addressing issues like geometry-dependent flux pinning and localized Joule heating. To illustrate the capability of this approach, we investigated a shunted superconducting wirelet neuron[4]. Utilizing coupled TDGL-circuit simulations, we map the dynamical phase diagram of the device, showing the voltage spikes driven by the periodic formation and relaxation of hot spots and unveil a parameter region of “Neuron death”, due to the stabilization of phase-slip lines. Guided by these theoretical insights, we propose a minimal neuromorphic design where the voltage spike frequencies of superconducting nanowires, configured with different resistive shunts, are used to process information[5]. By feeding input signals into these wirelets, the intrinsic physics of the devices transforms the data into complex, highly non-linear temporal spike trains. These distinct, frequency-encoded feature maps are then linearly combined via a trained synaptic weight matrix to perform inference. We demonstrate experimentally that a network of just three such wirelets, operating in the TDGL-predicted regime, achieves 92.9% classification accuracy on the MNIST dataset with an exceptional energy efficiency of less than 0.5 pJ per synaptic event. Ultimately, this work establishes TDGL simulations as an indispensable framework for bridging fundamental condensed matter physics with the engineering of functional, robust, and scalable superconducting electronics.

References

1. D.S. Holmes *et. al.*, IEEE Trans. Appl. Supercond. **23**. 1701610 (2013).
2. S. K. Tolpygo, Low Temp. Phys. **42**. 361 (2016).
3. M.V. Milosevic and R. Geurts, Phys. C: Supercond. Appl. **470**, 791 (2010).
4. E. Toomey *et. al.*, Front. Neurosci., **13**. 933 (2019).
5. L.R. Cadorim *et. al.*, e-print arXiv:2602.14330 (2026).

Friday, 5 June 2026

Keynote: Superconducting transition-edge sensors for applications in space astrophysics, fusion plasma and particle physics

Luciano Gottardi
SRON, Space Research Organisation Netherlands, Niels Bohrweg 4,
2333 CA Leiden,
The Netherlands

Low temperature X-ray instrument based on large arrays of superconducting transition edge sensors (TESs) microcalorimeters are the key technology for future space-based X-ray observatories such as the ESA-led mission newAthena and are becoming popular in ground-based experiments in the fields of laboratory astrophysics, plasma physics, particle physics and material analysis.

Thanks to the sharp superconducting-to-normal transition a TES can detector very small temperature changes at low temperature. TES based X-ray microcalorimeter are non-dispersive spectrometers, which provide an exquisite resolving power ($E/\Delta E > 3000$) over a wideband energy range, from 100 eV up to 15 keV or more, along with almost 100% quantum efficiency, imaging capability and very low background.

To read out an array of thousands of pixels in a satellite-based instrument, a sophisticated focal plane assembly and multiplexing schemes, such as Time Division Multiplexing (TDM) or Frequency Division Multiplexing (FDM) are required. These read-out schemes make use of Superconducting QUantum Interference Devices (SQUIDs) as very low noise, low power consumption current amplifiers.

The high resolution cryogenic imaging spectrometer located in the focal plane of newAthena, the X-ray Integral Field Unit (X-IFU), is equipped with a large array of TES microcalorimeters and SQUID-based superconducting multiplexing read-out.

In preparation for mission adoption, a space-flight compatible model of the Focal Plane Assembly (FPA) of the X-IFU, known as the Demonstration Model (DM), has been designed and manufactured at SRON through a collaborative effort with European and American partners. The DM is equipped with four TDM channels, each containing 34 pixels, and operates with TDM timing settings that align with the baselined 48-pixel operation. Additionally, SRON has recently initiated a program to enhance the technological readiness of a fully European detector chain, utilizing SRON full-fledged TES array and FDM as a backup for X-IFU.

In this contribution, we will review the TES microcalorimeters and readout technology and investigate the the challenges of the implementation of the detection chain into the X-IFU Focal Plane Assembly (FPA). Simultaneously, to fully demonstrate the spectroscopic capabilities of SRON TES technology, we have recently utilized our FDM-based X-ray instrument in a hot plasma laboratory to study highly charged ions and their excited states. We have conducted extensive studies on iron, argon, nickel, and sulphur to support astrophysical observations. The results of this ongoing effort will also be presented.

Finally, we will explore the potential use of large arrays of TES-based X-ray photon detectors in studying hot plasma for nuclear fusion research, material analysis, and the direct detection of solar axions.

A TES based large area anticoincidence detector with silicon absorber, the newAthena CryoAC microcalorimeter

*Lorenzo Ferrari Barusso[1,3], Federico Bianco[7], Edvige Celasco[2], Matteo De Gerone[3], Flavio Gatti[2,3], Farwa Shaukat[2], Manuela Rigano[2], Matteo D'Andrea[4], Giacomo Gorla[4], Claudio Macculi[4], Luigi Piro[4], Andrea Argan[5], Gabriele Minervini[5], Guido Torrioli[6].

1 INAF OAB, Genova, 16146 Italy

2 Università di Genova, Genova, 16146 Italy

3 INFN Genova, Genova, 16146, Italy

4 INAF IAPS, Roma, 00133, Italy

5 INAF HQ, 00133, Italy

6 CNR IFN, Roma, 00133, Italy

7 Università La Sapienza, Roma, 00185, Italy

The Cryogenic Anti-Coincidence detector (CryoAC) is a critical component of the Athena X-ray Integral Field Unit (X-IFU) [1,2], in order to fully exploit the instrument performance in the pursuit of high-resolution X-ray spectroscopy with Transition Edge Sensor (TES) detectors. The detector aims to identify and veto non-X-ray events, allowing measurement of faint or distant X-ray sources that will be submerged by background events. In this configuration, the CryoAC serves to mitigate the impact of cosmic ray-induced events reducing the count per second of almost two order of magnitude on the spectrometer TES detectors [3], which compromises the sensitivity of X-ray measurements.

The Anticoincidence detector need to detects event with a threshold below 6 keV and low power dissipation (<10 nW/pixel). Plus it needs to be fast with a rise time below 15 µs and a thermal decay time under 2.5 ms. We developed two different kinds of detector exploiting athermal phonons collection [4,5] to reach fast responses and pure microcalorimeters [6,7] adding also spectroscopic capabilities reaching 170 eV at 6 keV. Our goal is to provide a comprehensive overview of the CryoAC configuration tested giving advantages and disadvantages for a 500 µm thick and cm^2 area silicon absorber anticoincidence detector and the results we obtained applicable on different applications.

References

1) P. Peille *et al. Exp Astron* **59**, 18 (2025). https://doi.org/10.1007/s10686-025-09984-w
2) D. Barret *et al. Exp Astron* **55**, 373–426 (2023). https://doi.org/10.1007/s10686-022-09880-7
3) S. Lotti *et al.* Astrophys. J. **909**, 111 (2021) https://doi.org/10.3847/1538-4357/abd94c
4) M. D'Andrea *et al. J Low Temp Phys* **214**, 164–172 (2024). https://doi.org/10.1007/s10909-023-03034-5
5) M. D'Andrea *et al. J Low Temp Phys* **209**, 433–440 (2022). https://doi.org/10.1007/s10909-022-02786-w
6) M. D'Andrea *et al. J Low Temp Phys* **214**, 164–172 (2024). https://doi.org/10.1007/s10909-023-03034-5
7) L. Ferrari Barusso *et al*. *IEEE T A S* **35**, 5, 1-4 (2025) https://doi.org/10.1109/TASC.2024.3518459

Keywords: Cryogenics, Superconducting detectors, TES, X-rays, particle detector, space instrumentation.

Background Mitigation in a TES for Direct Dark Matter Searches

Jose Alejandro Rubiera Gimeno; Katharina-Sophie Isleif; Friederike Januschek; Axel Lindner; Manuel Meyer; Christina Schwemmbauer; Elmeri Rivasto; Gulden Othman; Ruth Magdalena Jacobs

Helmut-Schmidt-Universität (HSU), Germany & Deutsches Elektronen-Synchrotron (DESY), Germany

Transition Edge Sensors (TES) are widely employed in the field of quantum sensing due to their exceptional energy resolution and sensitivity to single quanta of energy. When operated in the superconducting transition at millikelvin temperatures, the absorption of a single photon produces a measurable change in resistance. TESs are an ideal tool for quantum optics, rare-event searches, and the detection of low-energy deposits.

In this work, we employ tungsten TES devices, sensor provided by NIST and packaged by PTB, for direct dark matter detection, probing sub-MeV dark matter via dark matter-electron and dark matter-nucleon scattering, and sub-eV dark matter via electron absorption. For such rare-event searches, the achievable sensitivity is strongly limited by background-induced signals, requiring a detailed understanding and control of background sources.

To address this, we have developed a simulation framework combining Geant4-based background simulations with detector response modeling to better understand the observed background rates, including contributions from environmental radioactivity and cosmic rays. The results of these simulations allow the identification of the dominant contribution in the current detector configuration. Radionuclides in materials close to the sensor are found to be a major source of background. Based on these insights, alternative detector module designs have been developed to mitigate background sources.

A new TES module optimized for low background has been developed and characterized, followed by a dedicated direct dark matter measurement campaign exceeding 400 hours. First results show a reduction of the raw background rate by up to two orders of magnitude compared to the previous configuration.

Tailoring Josephson Nonlinearity in an rf-SQUID for Superconducting Microwave Amplification

Claudio Guarcello [1,2], Alessandro Bruno [3], Ahmet Mert Bozkurt[4], Giovanni Filatrella[5], Carlo Barone[1,2,6], Sergio Pagano[1,2,6]

[1] *University of Salerno, Physics Department, Salerno, Italy*

[2] *Istituto Nazionale di Fisica Nucleare, Gruppo Collegato di Salerno, Salerno, Italy*

[3] *QuantWare, 2628 XG, Delft, The Netherlands*

[4] *QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands*

[5] *University of Sannio, Science and Technology Department, Benevento, Italy* [6] *C.N.R. SPIN Institute, Salerno Unity, Salerno, Italy*

Building on our recent studies of Josephson traveling-wave parametric amplifiers with engineered current-phase relations, higher-harmonic effects, and resonant phase matching [1– 3], we present a theoretical investigation of tailored Josephson nonlinearity in a singlejunction rf-SQUID for superconducting microwave amplification. We show that suitable shaping of the effective Josephson nonlinearity and operating point enables a controllable small-signal response within realistic circuit constraints. We further discuss how this concept can be interfaced with a transmission-line environment, with emphasis on stability, inductive loading, and impedance matching. These results outline a promising route toward compact nonlinear building blocks for cryogenic microwave electronics and provide a framework for future developments in parametric amplification and quantum readout.

References

1. C. Guarcello, *et al*., Chaos, Solitons and Fractals **189**, 115598 (2024).
2. C. Guarcello, *et al*., Appl. Phys. Lett. **126**, 162602 (2025).
3. C. Guarcello, *et al*., IEEE Trans. Appl. Supercond. **36**, 1700405 (2026).

Cryogenic in situ Up-conversion and Down-conversion of Qubit Signals Using a Superconducting Nonlinear Kinetic Inductance Transmission Line

Adam Sirois[1], Manuel Castellanos-Beltran[1], Michael Vissers[1], Grant Giesbrecht[1,2], Taylor Barton[2], Peter Hopkins[1], Paul Dresselhaus[1]

[1]NIST

[2]University of Colorado

Superconducting qubits and their readout resonators operate in the (4-8) GHz range. Generating and measuring control and readout signals for these circuits can require state-of-the-art, costly, room temperature electronics. In this work we demonstrate using nonlinear transmission lines operating in the cryostat to up-convert and down-convert microwave control and readout pulses. Our transmission line consists of a 10-nanometer thick NbTiN 44 mm long meandered microstrip dc sputtered directly on a silicon substrate and is mounted to the 1 kelvin or 4 kelvin stages of a dilution refrigerator.

To demonstrate the up-conversion processes we used the nonlinear microstrip to separately generate 2nd ($2f = f_{qubit}$) and 3rd ($3f = f_{qubit}$) harmonics of Gaussian modulated control pulses for a 5 GHz qubit and qualified the performance of the technique with randomized benchmarking. The doubled signals produced errors-per-gate of 3.5×10^{-3}, consistent with rates obtained from driving the qubit directly on resonance. The tripled signals' error-per-gate yielded an error rate of 7.6×10^{-3}. Improvements to dielectric loss and impedance engineered lines will be discussed as ways to improve the error rate achieved as well as extending the operation to higher frequencies.

The inverse case of down-converting qubit resonator readout was demonstrated two ways as well. First, by applying a pump near half of the resonator's frequency the device generates an idler at low frequency. Second, with dc current applied to the converter in addition to a detuned pump from the resonator, a readout signal at the difference frequency between the two is produced. Again, converting to megahertz frequencies is possible.

We will also discuss how these devices could be integrated into a large-scale quantum system and how that may simplify operations and hardware. Additionally, signals for qubits or resonators that operate above the 4 GHz to 8 GHz band can be generated inside the cryostat and thereby avoid cabling losses inherent in coaxial lines with dielectrics.

Kinetic Inductance Traveling Wave Parametric Amplifier for Practical Readout Applications

Andrea Giachero; Corwin Shiu; Michael Visser; Pietro Campana; Logan Howe; Maya Erickson; Jordan Wheeler; Paul Szypryt; Douglas Bennett; Angelo Nucciotti; Jason Austermann; Johannes Hubmayr; Joel Ullom
University of Milano-Bicocca, Italy
University of Colorado, Boulder, USA

Increasing the size and complexity of detector arrays and quantum systems requires highly multiplexed readout architectures and amplifier chains operating near the quantum limit (QL) of added noise. Kinetic Inductance Traveling-Wave Parametric Amplifiers (KTWPAs) exploit the nonlinear kinetic inductance of superconducting films, notably niobium titanium nitride (NbTiN), to achieve high gain, broad bandwidth, large compression power, and near-quantum-limited noise performance.

Three-wave mixing (3WM) KTWPAs realized at NIST using 10 nm-thick NbTiN films in an inverted microstrip geometry exhibit kinetic inductances of ~30 pH/sq [1] and added noise close to the quantum limit, with gains exceeding 25 dB [2]. Their enhanced kinetic inductance enables significantly lower pump power (–45 dBm) and bias current (<1 mA) compared to conventional devices based on thicker (20–30 nm) NbTiN films (7–10 pH/sq). This results in reduced power dissipation, lower backaction due to pump leakage, and a compact footprint, shrinking the transmission line length to ~8 cm.

This platform enables further developments, including bandwidth-tailored designs, built-in isolation using reverse pump, apodized nonlinearity for ripple reduction, ultra-high kinetic inductance (~100 pH/sq), and on-chip integration of bias tees and directional couplers [3]. We present the current state of the art and outline steps toward practical deployment.

Acknowledgement
This work was supported by NIST (Innovations in Measurement Science), NASA (Grant NNH18ZDA001N-APRA), DOE (Grants 89243020SSC000058 and DE-SC0026061), the EU H2020-MSCA DARTWARS project (Grant 101027746), and Italian PNRR MUR projects NQSTI (PE0000023) and ICSC (CN00000013).

References

[1] A. Giachero et al., IEEE Trans. Appl. Supercond. 33 (2023) 5, 1700905
[2] L. Howe, A. Giachero et al., Phys. Rev. Applied 25, 044027
[3] L. Howe, A. Giachero et al., IEEE Trans.Appl.Supercond. 35 (2025) 5, 1701107

Generating Single Mode Squeezing with a Double-Pumped Traveling Wave Parametric Amplifier

A. Levochkina[1], K. Petrovnin[1], J. Wang[1], I. Harju[1] and G. S. Paraoanu[1]
[1]QTF Centre of Excellence, Department of Applied Physics, Aalto University, 00076, Espoo, Finland

Single-mode squeezing of the electromagnetic vacuum is a key resource for mode-selective noise reduction in quantum measurement and continuous-variable quantum technologies [1]. Josephson Parametric Amplifiers (JPAs) and Traveling Wave Parametric Amplifiers (TWPAs) operating in the three-wave mixing regime are widely used to generate single-mode squeezed states [2]. However, extending this capability to four-wave mixing is non-trivial, particularly in the degenerate regime where the signal, idler, and pump frequencies coincide. Recent work [3] demonstrated that degenerate four-wave mixing can be achieved in a TWPA using a double-pump scheme, where appropriately detuned pumps enable phase-sensitive amplification while suppressing pump at the signal frequency. In this work, we investigate this mechanism in a flux-tunable SNAIL (Superconducting Nonlinear Asymmetric Inductive Element)-based TWPA with alternating flux polarity between adjacent unit cells, as reported in [4]. Compared to Ref. [3], our device provides an additional control parameter, magnetic flux, allowing in-situ tuning of the phase-matching conditions. We experimentally investigate two representative flux bias points, zero applied flux and half a flux quantum. At both bias points, we observe noise suppression below the vacuum level, consistent with single-mode squeezing produced via degenerate four-wave mixing. These findings demonstrate the feasibility of double-pumped four-wave mixing in a flux-tunable TWPA.

References

1. A. Wallraff, et al, Nature 431, 162 (2004).
2. A. L. Grimsmo and A. Blais, npj Quantum Information 3, 20 (2017).
3. J. Y. Qiu, et al, Nature Physics, 19, 706–713 (2023).
4. A. Yu. Levochkina, et al, Supercond. Sci. Technol., 37 115021 (2024).

Real-Time Readout of Large KID Arrays for the BULLKID-DM Experiment

D. Quaranta[1],[2] on behalf of the BULLKID-DM Collaboration
[1]Physics Department, Sapienza University of Rome, 00185, Rome, Italy [2]INFN - Sezione di Rome, 00185, Rome, Italy

The BULLKID-DM experiment will search for hypothetical WIMP-like Dark Matter particles with mass below 1 GeV and cross-section with nucleons smaller than 10^{-41} cm^2 [1]. It will use superconducting Kinetic Inductance Detectors (KIDs) in the 0.7-1 GHz range, operated below 30 mK, to detect phonons produced by the Dark Matter particles in the scattering with a silicon target. The intrinsic multiplexability of the KID technology inspired a target design consisting of a 16 layer stack of silicon wafer with 100 mm diameter for a total mass of 800 g. Each wafer is diced to obtain a grid of 145 voxels with dimensions 5.4 x 5.4 x 5 mm^3, each coupled to a different KID resonator and frequency-multiplexed onto a single readout feedline. This fully active design unlocks spatial reconstruction of the interaction voxel, which enables vetoing of multiple interactions, and also allows volume fiducialization in a solid state target, both crucial features for efficient background rejection.

The unprecedented number of detectors used by BULLKID-DM requires a dedicated Data Acquisition (DAQ) system with custom firmware for online data processing [2]. It is based on the Software-Defined Radio (SDR) concept, performing tone comb generation, frequency demultiplexing and triggering in the digital domain. The system is built around the ZCU216 evaluation board, featuring 16-channel RF-ADCs and RF-DACs, operated at 2.5 GHz and 10 GHz, respectively. A custom front-end board contains the hardware devoted to signal conditioning, such as balun transformers, amplifiers, and two stages of low-pass aliasing filters for each readout line.

The Programmable Logic (PL) on the System-on-Chip contains custom modules, tailored to the experiment's data acquisition routine. The Vector Network Analyzer (VNA) module allows for scanning the entire resonator array to identify the position of each resonator. The Comb Generation module generates the frequency comb, containing the tones used to bias the KIDs. On the RX side, a Frequency Demultiplexing stage based on a polyphase filter bank separates the signal coming from each of the sensors. The data stream of each sensor can then be triggered by the Trigger module using multiple modes as simple differentiation, moving average or a Finite Impulse Response (FIR) filter.

The contribution will introduce the BULLKID-DM experiment and how the physics requirements shaped the design of the readout system. An overview of the firmware will be given, together with the results from the first characterization campaign of the board, performed to assess the system intrinsic noise level and the performance in simultaneous readout of multiple KID arrays.

References

1. A. Cruciani et al., Appl. Phys. Lett. 121, 213504 (2022).
2. T. Muscheid et al., IEEE Trans. Appl. Supercond. 36, 2500907 (2026).

Strongly Directional Amplification with a Kinetic Inductance Traveling Wave Parametric Amplifier

Pietro Campana; Logan Howe; Andrea Giachero; Corwin Shiu; Michael Visser; Maya Erickson; Jordan Wheeler; Paul Szypryt; Douglas Bennett; Angelo Nucciotti; Jason Austermann; Johannes Hubmayr; Joel Ullom

University of Milano Bicocca, Italy

INFN Milano-Bicocca, Italy

Parametric amplifiers achieve near-quantum-limited (nQL) noise performance but lack the directionality of semiconductor amplifiers. Without reverse isolation, backward traveling radiation from higher-temperature stages and reflections degrade nQL operation, requiring bulky, lossy, and field-sensitive commercial components between the amplifier and the quantum devices being measured.

Frequency conversion in traveling wave parametric amplifiers (TWPAs) offers a path towards integrated isolation for scalable quantum systems. Here we demonstrate directional operation in a 3WM KI-TWPA using an additional reverse-traveling pump to engage frequency conversion. The device provides more than 25 dB of forward gain across 5–10 GHz with simultaneous backward isolation exceeding 10 dB over approximately 1 GHz. The attenuation band is tunable across the amplification bandwidth by adjusting the reverse pump frequency, without degrading forward gain, provided the isolation pump remains outside the amplification band.

Device behavior is reproduced using an extended coupled mode equations (CME) framework with an iterative treatment of boundary reflections that accurately captures gain ripple. The validated framework serves as a design tool for next-generation devices targeting broader isolation bandwidth. Devices from the same fabrication run, operated in gain-only configuration with circulators, demonstrate added noise below 1.5 quanta, establishing a baseline for future directional implementations.

Strongly Nonlinear Regime of Josephson Transmission lines

A. A. Kopasov,[1] A. S. Averkin,[1] I. E. Pologov,[1] M. V. Fistul,[1] and A. Karpov[1]
[1]National University of Science and Technology "MISIS", 119049 Moscow, Russia

We present experimental and theoretical studies of the off-resonant and strongly nonlinear regime of Josephson transmission lines (JTLs) with galvanically-coupled nonlinear elements. Transition from the weakly to the strongly nonlinear regime of a JTL induced by increasing the input power of the pump is probed via the two-tone spectroscopy. Measurements of the phase of the transmission coefficient for a weak probe signal reveal a large increase and pronounced oscillations in the phase length variation as a function of the microwave power of the pump. Experimental observations are explained on the basis of the developed theoretical approach suitable for the description of the nonlinear response of strongly driven JTLs. Using the derived nonlinear wave equation, we show that the behavior of the phase length variation is associated with the oscillatory dependence of the Josephson inductances on the microwave power. It is demonstrated that the dissipation induced propagation losses are increased in the strongly nonlinear regime and also lead to smearing out the phase length oscillations. The developed theoretical analysis is in a good agreement with experimental observations.

Model-Independent Added-Noise Measurement in Cryogenic Microwave Amplifiers

Andrea Celotto[1,3], Alessandro Alocco[1,3], Bernardo Galvano[2,3], Luca Fasolo[3], Emanuele Palumbo[1,3], Luca Callegaro[3], Luca Oberto[3], Patrizia Livreri[2], and Emanuele Enrico[3]
[1] *Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy*
[2] *Department of Engineering, University of Palermo, Palermo, Italy* [3] *Istituto Nazionale di Ricerca Metrologica (INRiM), Torino, Italy*

Cryogenic microwave amplifiers are essential for the readout of superconducting qubits and other solid-state quantum devices, where near-quantum-limited operation is required to preserve weak microwave signals [1,4]. Their characterization remains challenging because gain and added noise must be referred to the amplifier input through a complex cryogenic measurement chain. Existing calibration methods often place the noise reference in series with the device under test or rely on on/off gain estimates [2]. While effective in some regimes, these approaches can introduce systematic errors when the internal noise-transfer mechanism departs from an ideal parametric-amplifier model.

Here we present a model-independent calibration protocol based on a Variable Temperature Stage (VTS), used as a tunable thermal noise source in parallel with the device under test. Unlike earlier matched variable-temperature sources, typically combined with heuristic gain extraction [3], our approach combines the VTS with in situ calibrated S-parameters and Plancknoise spectroscopy of the readout chain, enabling retrieval of gain and input-referred added noise without assuming a specific internal amplifier model. The proposed architecture offers a practical route toward traceable, standardized noise benchmarking of cryogenic microwave amplifiers.

References

1) A. Clerk, M. H. Devoret, S. M. Girvin, F. Marquardt, and R. J. Schoelkopf, Rev. Mod. Phys. 82, 1155 (2010).
2) M. Malnou, T. F. Q. Larson, J. D. Teufel, F. Lecocq, and J. Aumentado, Rev. Sci. Instrum. 95, 034703 (2024).
3) S. Simbierowicz, V. Vesterinen, J. Milem, A. Lintunen, M. Oksanen, L. Roschier, L. Gronberg, J. Hassel, D.
4) Gunnarsson, and R. E. Lake, Rev. Sci. Instrum. 92, 034708 (2021).
5) M. Esposito, A. Ranadive, L. Planat, and N. Roch, Appl. Phys. Lett. 119, 120501 (2021).

Posters

1. Behavioral and Physics-Based Modeling of Josephson Field-Effect Transistors (JoFETs)

Shanuka Gamaethige[1], Markus Lehtisalo[2], Heorhii Bohuslavskyi[2], Kari Stadius[1], Klaara Viisanen[2], Jussi Ryynänen[1], and Andrey Generalov[2]
[1]*Aalto University, 02150, Espoo, Finland*
[2] *VTT Technical Research Centre Finland, 02044, Espoo, Finland*

The Josephson Field Effect Transistor (JoFET) is a versatile building block for ultra-low-power and high-energy-efficiency classical and quantum electronics. In a JoFET, the superconducting current is controlled by electrostatic gate voltage. Among various material platforms, graphenechannel JoFETs have emerged as promising candidates for superconducting hybrid integration owing to their gate-tunable transport properties [1], [2] and compatibility with scalable device fabrication [3].
Accurate modeling of JoFETs is essential for circuit-level design and understanding the physical mechanisms governing device operation [4]. We report two complementary modeling approaches for a graphene channel JoFETs. These models have been implemented in commercial and open-source circuit simulators, namely Keysight ADS and Ngspice. Behavioral model provides a compact empirical description of the nonlinear current–voltage (I–V) characteristics by representing the gate-dependent superconducting region through a simple power-law relation. Enables easy first-level simulation of JoFET integrated circuits.

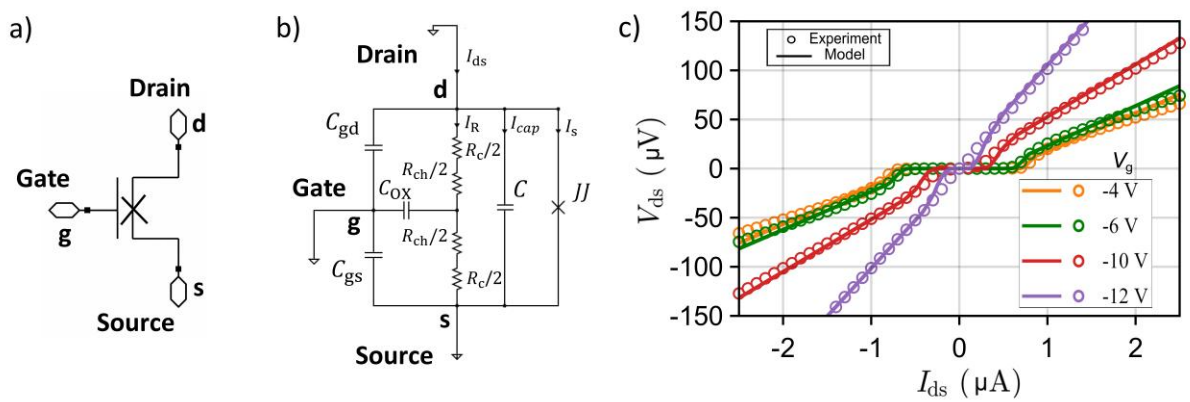


Fig. 1: *(a) JoFET symbol. (b) RCSJ equivalent circuit description. (c) Current-voltage characteristics of the JoFET at various gate voltages, comparing Verilog-A simulation results with measured data.*

Physics-based model links JoFET behavior to electronic transport in the graphene channel, capturing gate-voltage dependence of both normal-state resistance and critical current. Using this approach, a Verilog-A model was implemented in Keysight ADS to reproduce the I-V characteristics across varying gate voltages. Fig. 1(a) illustrates the JoFET symbol, including the drain (d), source (s), and gate (g) terminals. The equivalent circuit of the proposed model, comprising the Josephson element along with its associated RCSJ components, is presented in Fig. 1(b). As shown in Fig. 1(c), the model exhibits good agreement with the experimental data.

References

[1] F. Wen *et al.*, IEEE Trans. Electron Devices 70, 013603 (2019).
[2] G. Butseraen et al., Nat. Nanotechnol. 17, 1153–1158 (2022).
[3] A. A. Generalov et al., Appl. Phys. Lett. 125, 1 (2024). [4] L. Olausson et al., Appl. Phys. Lett. 22, (2024).

2. Low-Noise Performance of a Si JFET Fully Differential Amplifier at Low Temperatures

Julius Mumme[1], Marion Reineke[1], Meinhard Schilling[1], Benedikt Hampel.[1]
[1]*Technische Universität Braunschweig, 38106 Braunschweig, Germany*

Cryogenic experiments frequently rely on low-noise amplification for sensor readout. Integrating a preamplifier onto the first stage of a cryocooler provides a practical way to lower its operating temperature, thereby significantly reducing the noise floor with minimal infrastructural overhead.

In this work, a dc coupled ultra-low noise fully differential amplifier [1] is optimized for the measurement of Josephson junction current-voltage (IV) characteristics and characterized over the temperature range of 60 K – 300 K. It employs the matched silicon JFET JFE2140 as input stage for a composite amplifier in a current feedback topology with a gain of 650. The amplifier consumes 1 W of power and can easily be cooled by the first stage of a pulse tube cryocooler without compromising the second stage temperature. The JFE2140 shows increased transconductance when cooled to 120 K, and a degradation of both transfer characteristics and noise performance below 100 K due to charge carrier freeze-out and strong self-heating effects, which agree with literature [2]–[4].

The amplifier achieves its lowest noise at an operating temperature of 120 K. Its differential input-referred white noise is reduced from 0.7 nV/√Hz at room temperature to 0.4 nV/√Hz at 120 K (Fig. 1), which is explained by reduced thermal noise and increased JFET transconductance. The bandwidth is increased from 660 kHz to 1.16 MHz, and the common mode rejection ratio (CMRR) is degraded from 80 dB to 50 dB. Within the 120 K – 300 K range, the amplifier shows good differential mode stability with an input offset voltage drift of 80 µV and a gain variation of 0.26 %. These results make the design a suitable candidate for fast Josephson junction IV characteristic sweeping.

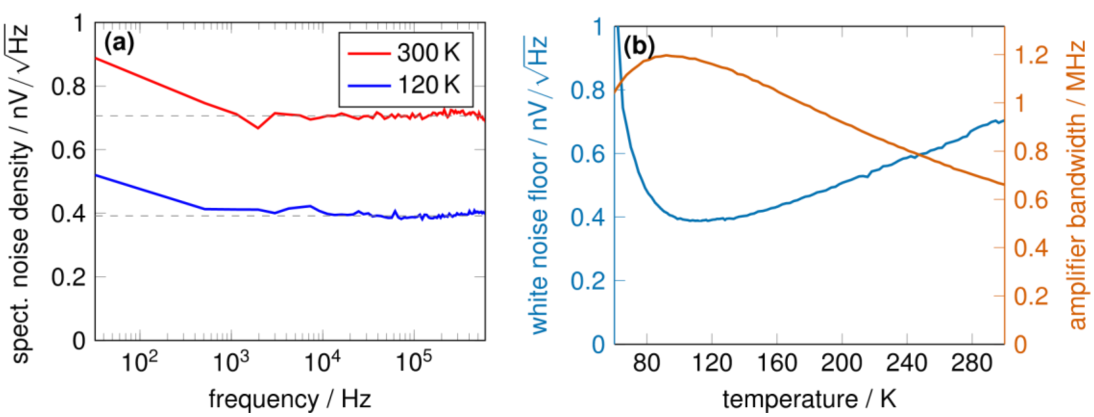


Fig. 1: *(a) Amplifier differential input-referred noise voltage density spectrum; white noise floor marked with dashed line, (b) white noise floor and bandwidth vs. temperature.*

References
1. E. M. Spinelli and M. A. Haberman, IEEE Trans. Instrum. Meas., **73**, 2007508 (2024).
2. S. S. Sesnic and G. R. Craig, IEEE Trans. Electron Devices, **19**, 933 (1972).
3. W. Nawrocki, Czech J. Phys., **46**, 2747 (1996).
4. R. T. Goldberg et al., Electrochem. Soc. Proc., **95-9**, 428 (1995).

3. Development of KICS microwave multiplexing for the HOLMES+ experiment

Enrico Bogoni[1, 2, 3], Sara Gamba[2, 4], Pietro Campana[2, 4], Felix Ahrens[1, 3], Matteo Borghesi[2, 4], Rodolfo Carobene[2, 4], Alessandro Cattaneo[2, 4], Hervè Atsè Corti[2, 4], Nicolò Crescini[1, 3], Marco Faverzani[2, 4], Elena Ferri[4], Andrea Giachero[2, 4], Marco Gobbo[2, 4], Alessandro Irace[2, 1, 3], Danilo Labranca[2, 4], Federica Mantegazzini[1, 3], Benno Margesin[1, 3], Renato Mezzena[5, 3], Roberto Moretti[2, 4], Angelo Nucciotti[2, 4], Luca Origo[4], P. Szypryt[6], J.N. Ullom[6], and Andrea Vinante[7, 1].

[1]Fondazione Bruno Kessler (FBK), 38123, Trento, Italy

[2]Dipartimento di Fisica, University of Milano-Bicocca, 20126 Milano, Italy

[3]TIFPA - INFN, Trento, 38123, Italy

[4] INFN - Milano Bicocca, 20126 Milano, Italy

[5]Department of Physics, University of Trento, 38123, Trento, Italy

[6]National Institute of Standards and Technology (NIST), 80305 Boulder, Colorado, USA

[7]CNR-IFN, 38123, Trento, Italy

The HOLMES experiment investigates the electron neutrino mass by studying the end point of the electron-capture decay spectrum of 163Ho. The detector technology is based on transition edge sensors (TESs) microcalorimeters.

During the first phase of the experiment, the simultaneous readout of multiple detectors was performed via microwave SQUID multiplexing (µMUX). However, the high cost per detector of this multiplexing technology limits neutrino mass measurements below 0.1 eV.

In the next phase, HOLMES+, the multiplexed readout will instead be performed with kinetic inductance current sensors (KICSs) [1]. A KICS consists of a lumped element tunable resonator whose inductance is mainly governed by the kinetic inductance of the superconducting material. Thus, its resonance frequency can be modulated upon a current signal, thanks to the current-sensitivity of the kinetic inductance. This novel multiplexing technology brings several advantages if compared to the µMUX approach, including ease of microfabrication, with a single lithographic layer, high yield and low costs, as well as a potentially higher multiplexing factor and temporal resolution. This will increase the number of points on the signal rising slope, allowing the distinction of signals pile-up.

In this contribution, we report our recent results in the development of KICS based on thin NbTiN films. We discuss the design and simulation of the first prototypes, with several KICSs coupled to a common transmission line, and we show their successful operation at cryogenic temperatures. We demonstrate the insertion of a persistent current in the circuit to fix an optimal working point, as well as the expected frequency response of the devices upon a current signal, achieving the detection of a test gaussian-shaped pulse.

References

1. Paul Szypryt, Douglas A. Bennett, Ian Fogarty Florang, Joseph W. Fowler, Andrea Giachero, Ruslan Hummatov, Adriana E. Lita, John A. B. Mates, SaeWoo Nam, Galen C. O'Neil, Daniel S. Swetz, Joel N. Ullom, Michael R. Vissers, Jordan Wheeler, and Jiansong Gao. Kinetic inductance current sensor for visible to nearinfrared wavelength transition-edge sensor readout. Communications Engineering, 3(1), nov 6 2024.

4. Effect of Aging on the Superconducting Transition of Ti/Au TES Bolometers arrays

F. Shaukat[1,2] , E. Celasco[1,2], L. Ferrari Barusso[1,2], P. Manfrinetti[3], D. Odino[1], L. Repetto[1], D. Yohannes[4], J. Vivalda [4] and F. Gatti[1,2]

[1]*Dipartimento di Fisica, Università degli Studi di Genova, 16146 Genova, Italy* [2]*Istituto Nazionale Fisica Nucleare, Sezione di Genova, 16146 Genova, Italy* [3]*Dipartimento di Chimica, Università degli Studi di Genova, 16146 Genova, Italy.*

[4]*SEEQC, Inc., 150 Clearbrook Road, Elmsford, New York, 10523, USA*

Ti/Au-based transition-edge-sensor (TES) bolometers are an important part of the Large-Scale Polarization Explorer (LSPE) project, aimed at measuring the B-mode polarization of the cosmic microwave background, one of the strongest signatures of inflation in the early universe. For this purpose, Ti/Au TES bolometers on SiN suspended membrane, of 8 mm diameter, were prepared in the Low Temperature Detector Laboratory in Genoa, where a transition temperature of about 500 mK was achieved, according to the project requirement.

Since LSPE requires around 300 bolometers, a collaboration was established with the See-QC company. An array of spiderwebs were fabricated, confirming a Tc of 500mK. However, considering the sensitive nature of Ti and the importance of long-term stability for the full project, it became necessary to investigate whether aging could affect the transition temperature and find a Tc stabilization over time.

To address this, three Ti/Au samples were prepared on Si/SiO/SiN substrates. The deposited structure consisted of a tri-layer with a very thin Ti adhesion layer. The samples were then annealed at 150∘C for different durations and under different environments, namely air and vacuum, to accelerate the possible aging effect. Using the Arrhenius equation, the equivalent aging time at room temperature. In this way, annealing times of 17 h, 24 h, and 34h at 150 ∘C correspond to about 5.2, 7.3, and 10.4 years at room temperature, respectively.

Low-temperature measurements still showed a clear superconducting transition after annealing. From the Sigmoidal fitting of the R-T curves, the as-deposited sample showed a transition temperature of about 559 mK, while the sample annealed for 17 h in vacuum showed a transition of 507 mK, and the sample annealed for 17 h in air showed a transition of 490 mK.

These results confirm the good quality of the film showing that the annealing condition shift the Tc, in an as expected range. We are still working on annealing parameters with the aim to find a stabilisation conditions of the Tc, versus time, a fundamental step for space applications.

5. Millikelvin Digitization of Calorimetric Qubit Readout for Low-latency Feedback

Siddhi Khaire[1], Suman Kundu[1], Aashish Sah[1], Qi-Ming Chen[1], Wei Qiu[1], Maaria Tiiri[1],
Emma Mykkänen[2], Mikko Möttönen[1,2]
[1]QCD Labs, QTF Centre of Excellence, Department of Applied Physics, Aalto University, P.O. Box 13500, Espoo, FIN-00076, Finland
[2]QTF Centre of Excellence, VTT Technical Research Centre of Finland Ltd., P.O. Box 1000, 02044 VTT, Finland.

Realization of large-scale superconducting quantum architectures requires mitigation of the feedback latency and thermal dissipation associated with room-temperature signal routing. Additionally, high fidelity readout is critical for successful digitization and subsequent control of the quantum processor. Although parametric amplifiers remain the standard for high-fidelity readout, their integration into large-scale architectures is hindered by significant pump-power requirements and physical size. Recently [1,2], ultrasensitive thermal detectors based on superconductor–normal-conductor–superconductor (SNS) junctions have emerged as a highly promising, low-power alternative, offering fast, high-fidelity single-shot readout of superconducting qubits while operating at a fraction of the power of traditional quantum-limited amplifiers. However, to enable autonomous feedback via such calorimeter sensors, the readout signals must be digitized and processed at the millikelvin stage. To address this, we propose the integration of a Josephson Digital Phase Detector (JDPD) [3] with calorimetric readout to achieve low-latency, cryogenic signal digitization. Such a framework facilitates further signal processing through platforms such as single flux quantum (SFQ) logic, thereby facilitating closed-loop operation at millikelvin temperatures. This architecture minimizes feedback latency and thermal overhead, providing a pathway toward autonomous readout and real-time control, a critical requirement for the operation of scalable, fault-tolerant quantum processors.

References

1) A. Gunyhó, S. Kundu, J. Ma, et al., Nat. Electron. 7, 288–298 (2024).
2) A. Gunyhó, K. Kohvakka, Q. Chen, et al., Nat. Electron. (to be published, 2026).
3) L. Di Palma, A. Miano, P. Mastrovito, et al., Phys. Rev. Applied 19, 064025 (2023).

6. Low-Temperature Microwave Characterisation of Titanium Nitride Coplanar Waveguide Resonators

Samane Kalhor, Shima Poorgholam-Khanjari, Paniz Foshat, Hua Feng, Martin Weides, Kaveh Delfanazari*
Electronics and Nanoscale Engineering Division, James Watt School of Engineering, University of Glasgow, Glasgow, UK
E-mail: Kaveh.Delfanazari@glasgow.ac.uk

Titanium nitride (TiN), as a high kinetic inductance superconductor, enables high-quality resonators and provides a new platform for superconducting nanobridge electronics [1,2]. Additionally, it has been shown that replacing aluminium with TiN in transmons can improve qubit coherence times [3]. Here, we report superconducting microwave coplanar waveguide (CPW) resonators based on TiN on a silicon substrate and investigate their characteristics at millikelvin temperatures, from the high-power regime to the low-power regime. We fabricated an array of superconducting TiN microwave resonators using standard e-beam lithography followed by dry etching. Our circuit includes three resonators, each with a width of 4 µm and a gap of 2 µm, capacitively coupled to a single common transmission line. The resonator length was chosen to achieve a fundamental mode frequency in the range of 3 to 8 GHz [4-7].

We observed that the internal quality factor (Q_i) decreases from $Q_i = 1.6 \times 10^5$ at high photon number, at a base temperature of T = 54 mK, with decreasing power (photon number $\langle n_{ph} \rangle$) for resonance frequency of f_r=3.07 GHz. Moreover, we study Q_i and frequency tuning of the CPW resonators over a temperature range from 54 mK to 1.1 K to characterise the quasiparticle (qp) density in TiN. This investigation paves the way towards engineering superconducting resonators for low-loss quantum computing architectures.

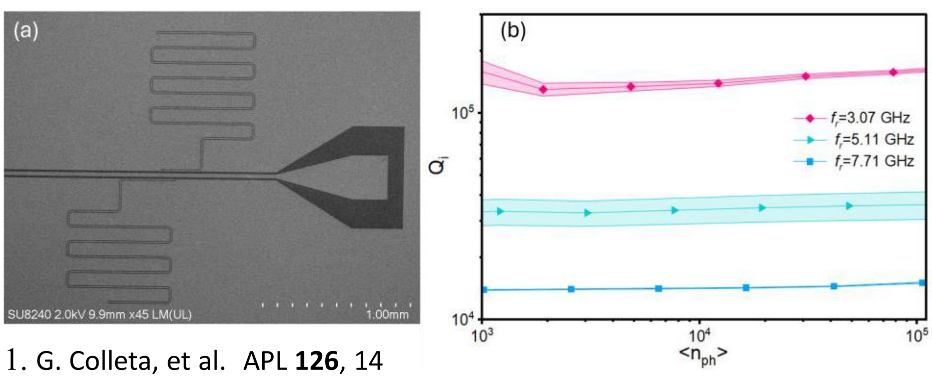


Fig. 1: *(a) SEM image of superconducting TiN chip with three CPW resonators coupled to a transmission line. (b) The internal quality factor (Q_i) of the CPW resonator for three different resonances of circuits as a function of photon number*

References

1. G. Colleta, et al. APL **126**, 14 (2025) p. 142601
2. G. Colleta, et al. *arXiv preprint arXiv:2603.20757* (2026).
3. J. B. Chang, et al, APL **103**, (2013) p. 012602
4. S. Poorgholam-Khanjari, et al. Scientific Reports **15**, 1 (2025). p. 27113
5. S**.** Poorgholam-Khanjari, et al. ACS Appl. Mater. Interfaces, **18** (2026). p. 3007−3013
6. P. Foshat, et al. IEEE Transactions on Quantum Engineering, **6** (2025) p. 3102608
7. P. Foshat, et al. *IEEE Transactions on Applied Superconductivity* **35**, 3 (2025) p. 1-16

7. Ta/MgO/Ta Josephson Junctions on Si Substrates by Room-Temperature Sputtering

Min-Jui Lin[1], Wei-Che Hsu[1], and Jiun-Yun Li[1,2,3,4]
[1]*Graduate Institute of Electronics Engineering, National Taiwan University, Taipei, Taiwan*
[2]*Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan*
[3]*Graduate School of Advanced Technology, National Taiwan University, Taipei, Taiwan*
[4]*Taiwan Semiconductor Research Institute, National Institutes of Applied Research, Hsinchu, Taiwan*

Superconducting qubits are typically fabricated using Al/AlO_x/Al Josephson junctions by shadow- or double-angle-evaporation. While this approach has led to high-fidelity qubits, the step of double-angle evaporation is not compatible with state-of-the-art CMOS technology, which could limit device yields and reproducibility for wafer-scale processing [1]. In this work, we demonstrate a CMOS-compatible process to fabricate Ta/MgO/Ta Josephson junctions using standard CMOS manufacturing steps. This tri-layer structure includes a thin W buffer layer, ⍰-Ta electrodes, and an ultrathin MgO film as a tunneling barrier by room-temperature sputtering onto Si substrates using an 8”-cluster UHV magnetron sputter. A high-quality cross-sectional TEM images of the Ta/MgO/Ta stack with good crystallinity is shown in Fig. 1(a). We etched the Ta/MgO/Ta stacks to form mesas and utilized in-situ O_2 plasma to passivate the stack sidewall for the isolation of the top and bottom Ta electrodes. I-V characteristics of the device shows a clear zero-voltage supercurrent and an overdamped Josephson-junction characteristic (Fig. 1(b)), which show great promises to integrate with Ta cavity to manufacture superconducting qubits by the standard CMOS technology.

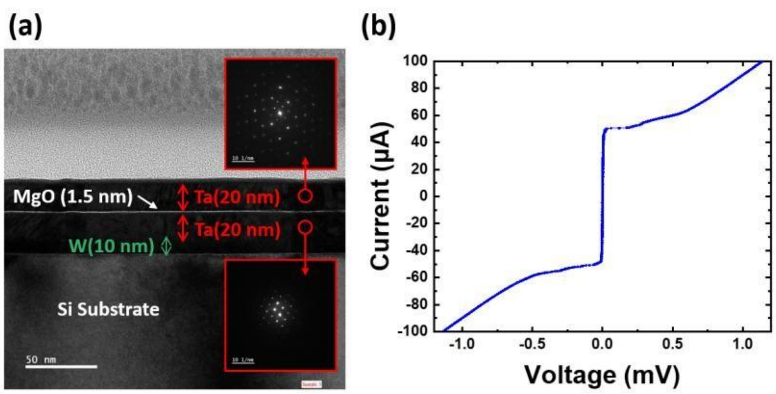


Fig. 1: *(a) A cross-sectional TEM image of the structure Ta/MgO/Ta/W/Si. Inset: SAED patterns taken from both Ta layers. (b) I-V characteristics of the Ta/MgO/Ta Josephson junction measured at 20 mK.*

Acknowledgement

This work was supported by the Ministry of Education (MOE) of Taiwan through the Higher Education Sprout Projects (115L890303) at National Taiwan University, the Center of Data Intelligence: Technologies, Applications, and Systems, National Taiwan University (114L900903), and the National Science and Technology Council (NSTC) of Taiwan under the Grants of 115-2119-M-002-002-.

Reference

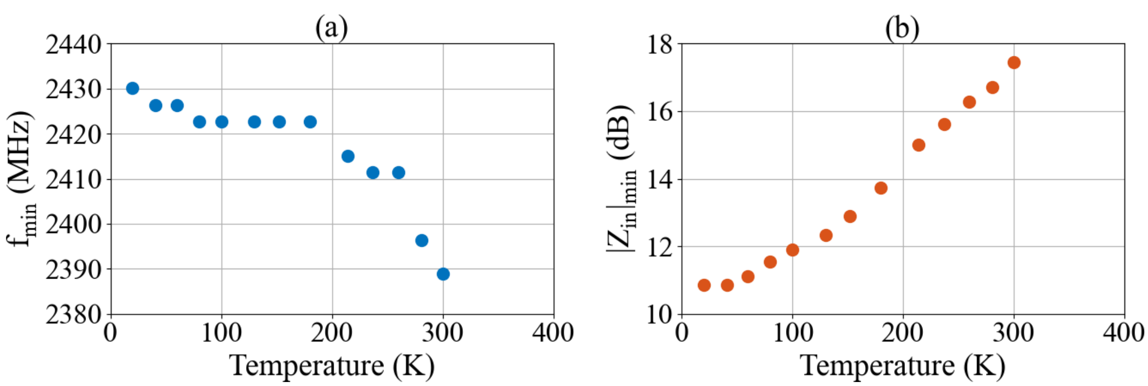
[1] J. Verjauw et al., npj Quantum Inf 8, 93 (2022).

8. Cryogenic Characterization of Inkjet-Printed Microwave Transducers

Laura Arruzzoli[1], Giovanni Gugliandolo[2], Mariangela Latino[3], Giovanni Crupi[1], Nicola Donato[2]
[1]BIOMORF Department, University of Messina, 98125, Messina, Italy [2]Engineering Department, University of Messina, 98166, Messina, Italy [3]CNR-IPCF, 98166, Messina, Italy

Integrating low-cost microwave transducers into cryogenic systems is a significant advancement for enhanced sensing and deep-cold electronics [1]. Despite the growing adoption of inkjet printing for the rapid prototyping of microwave devices, a knowledge gap exists regarding the electrical behavior of printed conductive structures when subjected to cryogenic temperatures [2]. This study investigates the characterization of an inkjet-printed single-port IDC, tracking its behavior from room temperature (300 K) down to 20 K. The device was fabricated by depositing the ACI FS0142 flexible silver ink onto an FR4 substrate, using the Voltera V-One® printer. The measurement setup included a CTI-Cryogenics closed-loop cryogenic unit, a Varian vacuum system, and an Agilent 8753ES vector network analyzer (VNA). In Fig.1, the input impedance Z_{in} was analyzed to evaluate the position and the amplitude of the dip close to 2.4 GHz.

Fig. 1: *Influence of temperature variation at 2.4 GHz resonance: a) resonance frequency and b) peak amplitude as functions of the temperature range from 20 K to 300 K.*



The observed upward shift in the resonance frequency and the simultaneous decrease in peak amplitude at 20 K are due to the thermoelectrodynamic response of the device's constituent materials (i.e., the conductive ink and the substrate). These results represent a promising starting point for further investigations into inkjet-printed microwave transducers.

References

1. Gugliandolo, G.; Naishadham, K.; Crupi, G.; Campobello, G.; Donato, N. Microwave transducers for gas sensing: A challenging and promising new frontier. IEEE Instrum. Meas. Mag. 2022, 25, 42–51.
2. S. L. Merilampi, J. Virkki, L. Ukkonen, and L. Sydänheimo, "Testing the effects of temperature and humidity on printed passive UHF RFID tags on paper substrate," *Int. J. Electron.*, vol. 101, pp. 711–730, 2014.

9. Low-temperature electrical characterization of carbon-black printed resistors

Laura Arruzzoli[1], Mariangela Latino[2], Federico Randazzo[1], Giovanni Gugliandolo[3], Alessandro Pistone[3], Antonino Quattrocchi[3], Giovanni Crupi[1], Nicola Donato[3] [1]*BIOMORF Department, University of Messina, 98125, Messina, Italy*

[2]*CNR-IPCF, 98166, Messina, Italy*

[3]*Engineering Department, University of Messina, 98166, Messina, Italy*

Additive manufacturing applications are increasing in the market even in cryogenics related contexts [1-3], in such a frame it is important to evaluate the performance of prototypes and materials that in the past were developed using more expensive fabrication techniques. This paper reports the electrical characterization as a function of temperature of a carbon black resistor fabricated by printing a serpentine-shaped resistive track using a commercial ink (i.e., the ACI SC1502) on Kapton substrate with a Voltera Nova® printer. The characterization procedure was performed in a temperature range spanning from 300 K down to 10 K by means of a test fixture and a vacuum chamber equipped with a closed loop cryogenic system (CTI Cryogenics) and a Keithley 2400 Source Measurement Unit. The I-V tests were performed in a voltage range spanning from -5 V to 5 V to evaluate the electrical resistance and the possible presence of hysteresis behavior.

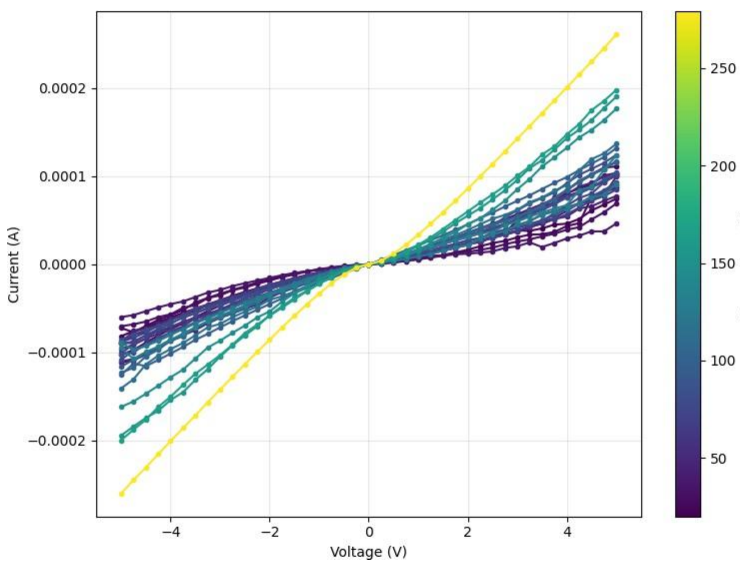


Fig. 1: *I-V traces vs. temperature of a carbon black resistor.*

In Fig.1, the I-V traces as a function of temperature are reported, showing a semiconductive behavior of the resistor, with resistance values ranging from about 20 k⍰ to 110 k⍰. No hysteresis effects were observed during the cyclic I-V tests, demonstrating high material stability and the reliability of the printed resistors, even under extreme thermal stress.

References

1. W Stautner et al., IOP Conf. Series: Materials Science and Engineering 278 (2017) 012134.
2. O Rehme and C Weidermann IOP Conf. Series: Materials Science and Engineering 1301 (2024) 012047.
3. I. Mellouki et al., Infrared Physics & Technology, Vol. 50, Iss. 1, (2007), Pages 58-62.

10. Flexible I-V Characterization System for Power Switch Devices in Room and Cryogenic Temperatures

Mateus C. Costa[1], Marília de M. A. N. e Silva[1], Gabriel A. G. Pinhão[1], André Lucas F. N. de Souza[1], Bruno W. França[1], and Guilherme G. Sotelo[1] *1*

Department of Electrical Engineering, Federal Fluminense University (UFF), R. Passo da Pátria, 156 - Sala 347, Bloco E - São Domingos, 24210-240, Niterói, RJ, Brazil

The advancement of space exploration, green aviation, and superconducting systems demands highly efficient low-temperature power electronics [1]-[3]. Designing reliable converters for these environments requires a deep understanding of device-level electrical behavior under thermal stress. To address this, this work presents a flexible, cost-effective I-V characterization system, serving as an accessible alternative to commercial curve tracers, allowing the evaluation of power semiconductors from 300 K down to cryogenic temperatures. Automated via an adaptable PyVISA and NI-VISA algorithm [4], the setup ensures precise instrument control and data acquisition.

This system enabled a comprehensive comparison of discrete Si MOSFETs, SiC MOSFETs, and IGBTs, assessing on-state resistance, threshold voltage, and forward voltage drop. The results highlight fundamental differences in low-temperature carrier transport [5][6]. Unipolar devices (Si and SiC MOSFETs) show enhanced performance due to increased channel mobility, significantly reducing on-state resistance before severe carrier freeze-out. However, IGBTs exhibit limitations, notably increased forward voltage drops linked to incomplete ionization and bipolar freeze-out.

By detailing the development of this flexible and cost-effective measurement setup, this study presents a highly accessible alternative to expensive commercial curve tracers. This approach directly benefits academic laboratories and R&D facilities seeking to perform advanced cryogenic semiconductor characterization without prohibitive equipment costs.

References

1. J. Presley, J. Pet. Technol. 76, 30 (2024).
2. M. Menicou, et al., IOP Conf. Ser.: Earth Environ. Sci. 1558, 012009 (2025).
3. E. Nilsson et al., IEEE Trans. Appl. Supercond. 34, 1 (2024).
4. Grecco et al., Journal of Open-Source Software, 8(84), 5304 (2023).
5. P. Pathak, D. Deb, D. Nath et al., J. Electron. Mater. 53, 1142 (2024).
6. A. Elwakeel et al., IEEE Access, 1 (2023).

11. Dynamic Beam Steering via DC-Biased Josephson Inductance in a Superconducting 30 GHz Phased Array

Ilan Kurtser[1], Eldad Holdengreber[2], Shmuel E Schacham[1], Eliyahu Farber[1,3]
[1]Department of Electrical & Electronics Engineering, Ariel University, ISRAEL
[2]Department of Mechanical Engineering & Mechatronics, Ariel University, ISRAEL
[3]Department of Physics, Ariel University, ISRAEL

To mitigate insertion loss in quantum sensing RF front ends, this paper introduces a steerable, superconducting 2x2 phased array operating at 30 GHz and 77 K. By embedding series arrays of Josephson Junctions at the antenna feeds, continuous, low-loss phase shifting is achieved purely via DC current bias. This replaces lossy RF phase-shifting networks with simplified DC control lines, leveraging the tenable kinetic inductance of the junctions while maintaining a non-dissipative, zero-voltage superconducting state.
Physical feasibility is evaluated using full-wave 3D simulations in Ansys HFSS. Translating required RF reactances into quantum control states, we demonstrate that 30° and 60°
progressive phase shifts, corresponding to estimated DC biases of $I_{bias} \approx 0.45 I_c$ and $I_{bias} \approx 0.72\ I_c$, successfully steer the main beam by 10° and 20° in azimuth. These results confirm that localized junction tuning improves cryogenic system sensitivity. Further analysis should provide details regarding DC bias routing and RF choke integration.

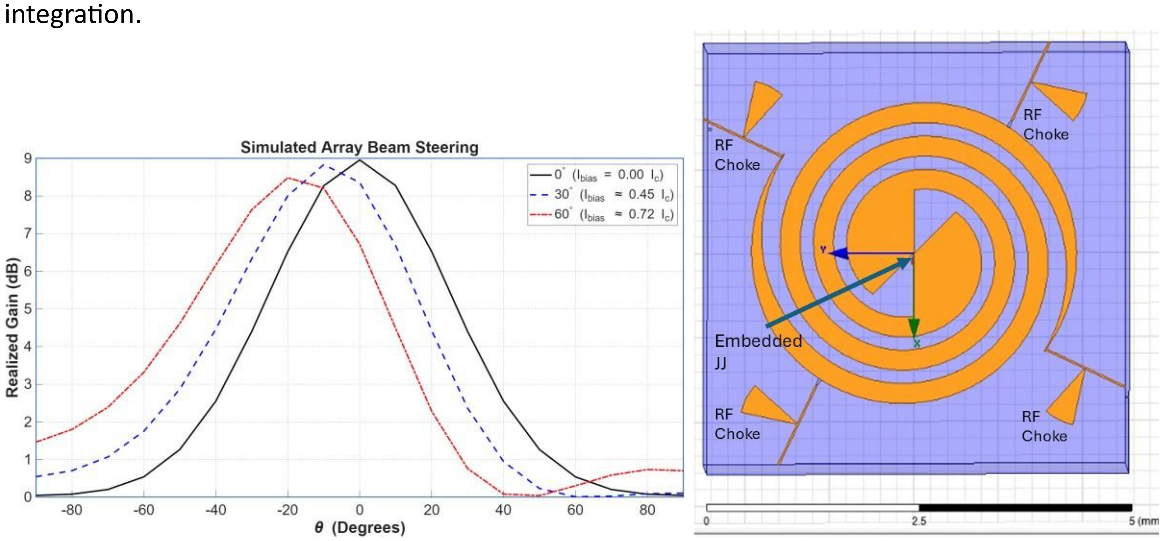


Fig. 1a: *Simulated realized gain of the 30 GHz 2x2 superconducting array. Beam steering of* $\sim 10^\circ$ *and* $\sim 20^\circ$ *is demonstrated by applying 30° and 60° progressive phase shifts along the X-axis. The legend indicates the corresponding estimated DC bias current fractions* I_{bias}/I_c *required to tune the embedded series Josephson inductance to achieve the necessary localized RF phase delay without resistive dissipation (Left).*
Fig. 1b: *Layout of the 30 GHz spiral antenna unit cell. The series Josephson Junction array is embedded at the central feed for localized phase tuning. DC bias current is supplied via corner routing lines equipped with radial stubs acting as RF chokes to isolate the 30 GHz signal from the control circuitry. (Right)*

12. Nonlinear Spectral Filtering and Photonic Transport

From Defect Taxonomy to Reflection-Kernel Cavity–Waveguide Design

Krzysztof Pomorski; John Dusch
University of New Mexico, USA

We present a consolidated spectral-flow manuscript joining nonlinear Lambert–W spectral filtering, defect taxonomy, and photonic cavity–waveguide design. The central object is the nonlinear spectral interrogation operator

$$F_\tau(H) = \frac{W_0(\mathrm{i}\tau H/\hbar)}{\mathrm{i}\tau H/\hbar},$$

interpreted as a defect-sensitive functional calculus probe. The updated theory is organized by defect class: branch-zero defects are detected by branchwise contrast and ridge extraction; minimum-gap defects are detected by normalized pairwise separation and minimum-line ex-traction; exceptional-point defects are detected by two-dimensional defect fields and curvature concentration. We then reinterpret the same extraction logic for cavity–quantum-dot–waveguide transport, where a physical control parameter plays the role of a nonlinear photonic interrogation variable and reflected-path kernels provide a geometric mechanism for directional response.

13. Modelling, extraction, and calibration of layouts for the FLUXONICS cross-type Josephson junction process

Coenrad J. Fourie[1,2,4], Kyle Jackman[2,4], Lieze Schindler[1,2,4], Matthias Schmelz[3], Jürgen Kunert[3,4] and Ronny Stolz[3,4]

[1]*Stellenbosch University, 7600, Stellenbosch, South Africa*

[2]*SUN Magnetics, 7600, Stellenbosch, South Africa*

[3]*Leibniz Institute of Photonic Technology, 07745, Jena, Germany*

[4]*FLUXONICS - The European Foundry for Superconducting Electronics e.V., 38116, Braunschweig Germany*

The performance requirements of superconducting qubits and superconducting quantum interference devices (SQUIDs) in millikelvin applications, while retaining compatibility with superconducting digital control circuits, necessitate fabrication processes that provide high quality Josephson junctions. These junctions must be placeable anywhere on a chip, must be easy to define in layout, and must support the operation of SQUIDs, digital and mixed-signal circuits. A cross-type junction process that meets all these requirements was developed by Leibniz IPHT Jena.

For circuit and system design and verification, physical parameter extraction from device and circuit layouts is essential. We show how the modelling infrastructure in InductEx has been expanded to process cross-type junctions directly from layout artwork, and how calibration on experimental circuits verify the modelling techniques. Applicability to more generic cross-type junction processes is also discussed. Finally, application to full circuit extraction at scale is shown.

14. Phase-induced switching of ferromagnetic insulators in Josephson spin valves

A. A. Mazanik[1], C.-H. Huang[2], Miguel A. Cazalilla[3,4], and F. S. Bergeret[1,3] 1
Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU,
E-20018, Donostia-San Sebastián, Spain 2
Department of Physics and Nanoscience Center, University of Jyväskylä, P.O. Box 35 (YFL)
FI-40014, University of Jyväskylä, Finland 3
Donostia International Physics Center (DIPC), 20018, Donostia-San Sebastian, Spain 4
Ikerbasque, Basque Foundation for Science, 48013, Bilbao, Spain

We study the Josephson effect in junctions composed of two ferromagnetic insulator/diffusive superconductor bilayers separated by an insulating barrier. By computing the free energy of the system, we identify two distinct contributions: (i) The work performed by a current source to create a supercurrent through the junction, and (ii) an antiferromagnetic coupling between ferromagnetic insulators, mediated by the superconducting condensate across the insulating barrier. The competition between these contributions allows for switching between parallel and antiparallel configurations of the magnetizations of the ferromagnetic insulators. We explicitly show that the switching occurs at finite temperatures and for superconducting phase differences satisfying $\pi/2<\phi<3\pi/2$. Importantly, this effect can be realized in ferromagnetic insulators with sufficiently large easy-plane anisotropy energy. Using realistic junction parameters, we demonstrate that the switching can be controlled by phase bias and triggered by half–flux-quantum voltage pulses or external magnetic field pulses on the microsecond timescale. These results provide a route towards controllable Josephson-based superconducting memory devices based on EuS/Al heterostructures.

References

1. A. A. Mazanik, C.-H. Huang, M. A. Cazalilla, and F. S. Bergeret, Phys. Rev. B 113 6, L060507 (2026).

15. Superconducting Exchange Coupling in a FI/S/FM system

Subhashree Subhasmita Dash[1] and Avradeep Pal[1]
[1] *Quantum Materials & devices laboratory, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology, Bombay, Powai, Maharashtra – 400076.*

Superconducting Exchange coupling (SEC) is a distinct feature of de Gennes superconducting Spin valves with a thin superconductor ($d_S << \xi$) sandwiched between two Ferromagnetic Insulators (FI)[1-4]. For observation of this phenomenon FIs are imperative as it prevents diffusion of the cooper pairs. Hence, reflection of cooper pairs from the S/FI interfaces is understood to be the driving force for the occurrence of SEC. This work demonstrates another aspect of this phenomenon, in a system where a thin superconductor is sandwiched between a ferromagnetic metal (FM) and a FI layer, thus allowing partial dissipation of cooper pairs. We show that such a system exhibits a weak manifestation of SEC effect and leads to temperature dependent strongly hysteretic superconductivity.

References:

1. P. G. de Gennes, Phys. Lett. 23, 10 (1966).
2. Y. Zhu, A. Pal, M. G. Blamire, and Z. H. Barber, Nat. Mater. 16, 195 (2017).
3. B. Dutta, S. Bhakat, P. Banerjee, and A. Pal, Phys. Rev. Appl. 24, 044053 (2025).
4. S. Bhakat, S. Samanta, S. Mahapatra, and A. Pal, Nat. Commun. 16, 9609 (2025).

16. Retrapping diode effects in magnetic Josephson junctions

Abhijith Sharma[1] and Avradeep Pal[1]

[1]*Quantum Materials and devices laboratory, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology, Bombay*

A recent experiment has shown that asymmetry in quasiparticle tunnelling conductance caused by Yu–Shiba–Rusinov states of magnetic Josephson junctions can break inversion symmetry, leading to non-reciprocity in retrapping currents [1, 2]. In this work we try to generalize this phenomenon through controlled experiments where we study two kinds magnetic tunnelling Josephson junctions-one with a symmetrical differential tunnelling conductance (Nb/Co/AlO_x/Nb), and the other with asymmetric differential tunnelling conductance (NbN/GdN/NbN, due to asymmetric exchange fields at the top and bottom NbN layers) [3, 4]. We demonstrate that at zero applied magnetic field, while the former lacks retrapping nonreciprocity the latter exhibits a pronounced retrapping reciprocity. Our results indicate that the observed effect can possibly be generalized to be arising from symmetry breaking in the dissipative component of the RCSJ model [1, 2].

References:

1. Trahms, Martina, et al. "Diode effect in Josephson junctions with a single magnetic atom." *Nature* 615.7953 (2023): 628-633.
2. Steiner, Jacob F., et al. "Diode effects in current-biased Josephson junctions." *Physical Review Letters* 130.17 (2023): 177002.
3. Bergeret, F. Sebastian, Alvise Verso, and Anatoly F. Volkov. "Spin-polarized Josephson and quasiparticle currents in superconducting spin-filter tunnel junctions." *Physical Review B—Condensed Matter and Materials Physics* 86.6 (2012): 060506.
4. Hao, X., J. S. Moodera, and R. Meservey. "Thin-film superconductor in an exchange field." *Physical review letters* 67.10 (1991): 1342.

17. Competing Non-Coplanar Magnetic States in Cubic Mn_3Ge Kagome Antiferromagnets

Xiaodong Hu[1], Amar Fakhredine[2], Roger Guzman[3], Martin Frentrup[1], Jinan Shi[3], Giulio I. Lampronti[1], Nadia Stelmashenko[1], Wu Zhou[3], Mehmet Egilmez[4], Grzegorz P. Mazur[5], Mario Cuoco[6], Carmine Autieri[2,6], Jason W. A. Robinson[1]

[1] Department of Materials Science & Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge, United Kingdom.

[2] International Research Centre Magtop, Institute of Physics, Polish Academy of Sciences, Aleja Lotników 32/46, Warsaw, Poland.

[3] School of Physical Sciences, University of Chinese Academy of Sciences, Huairou District, Beijing, 100049, China.

[4] Department of Physics, American University of Sharjah, University City, Sharjah, 26666, United Arab Emirates.

[5] Department of Materials, University of Oxford, Parks Road, Oxford, OX1 3PH, United Kingdom.

[6] SPIN-CNR, UOS Salerno Fisciano (SA), IT-84084, Italy.

Non-collinear Kagome antiferromagnets offer a promising platform for Berry-curvature-driven electronic transport and antiferromagnetic spintronic devices [1]. In this work, we investigate an unconventional cubic phase of Mn_3Ge, which exhibits reduced magnetic anisotropy compared with conventional hexagonal Mn_3Ge and enables access to non-coplanar spin configurations under standard laboratory magnetic fields.
Magnetotransport measurements reveal a tunable anomalous Hall response with magnetic-field-induced sign reversal and hump-like features, indicating the presence of competing magnetic states. These observations suggest that field-driven transitions between stable and metastable non-coplanar spin configurations can strongly modify Berry curvature and electronic transport in antiferromagnets.

Our results establish cubic Mn_3Ge as an experimentally accessible platform for studying non-coplanar magnetism, metastability, and Berry-curvature engineering in frustrated Kagome systems. This work provides new insight into controlling electrical responses in antiferromagnetic materials for low-temperature spintronic and electronic devices.

References

1. Rimmler, B.H., Pal, B., Parkin, S.S.P.: Non-collinear antiferromagnetic spintronics. Nature Reviews Materials 10(2), 109–127 (2025).

18. Supercurrents in Lateral S/F/S Josephson Junctions Incorporating NbTiN and Ni Grown by Atomic Layer Deposition

Ferdinand Posva[1], Dirk Grundler[1,2]

[1] *Institute of Materials (IMX), School of Engineering (STI), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne 1015, Switzerland*

[2]*Institute of Electrical and Micro Engineering, STI, EPFL*

Superspintronics exploits spin-polarized supercurrents generated by the superconducting proximity effect in superconductor/ferromagnet (S/F) hybrids, enabling dissipationless spin transport and energy-efficient computing. NbTiN, with its large superconducting gap, and Ni, which shows the highest I_cR_n, long decay length, and strong supercurrent transport among elemental ferromagnets [1], form a promising materials platform.

We optimized atomic layer deposition (ALD) of 30-nm Ni films with excellent ferromagnetic and electrical properties, including pronounced anisotropic magnetoresistance at 300 K [2] and low cryogenic resistivity (ρ_{2K} = 1µΩcm) After Ar-plasma removal of the native oxide, NbTiN was deposited to form lateral NbTiN/Ni/NbTiN junctions. We compare two devices in which the Ni weak link was defined either by dry etching (S1, t_{NbTiN} = 50 nm, T_c = 10.7 K) or lift-off (S2, t_{NbTiN} = 20 nm, T_c = 9.8 K). For S1, a superconducting transition occurs at T^* = 7.1 K for a 70±3 nm weak link (Fig. 1A), with a maximum critical current I_C = 89 µA. At 2K, hysteretic features in the Fraunhofer pattern are consistent with discrete magnetization-reversal steps in Ni (Fig. 1B). Although S2 shows a resistive IV curve (R(2K) = 6.2 Ω), its 50-nm-long weak link still exhibits phase-sensitive transport with a field-modulated differential resistance (Fig. 1C). Combined with the conformal coating ALD, our approach provides a scalable route to free-form S/F hybrids on curved nanotemplates and enables systematic studies of curvature effects on supercurrent transport in 3D S/F/S geometries [3].

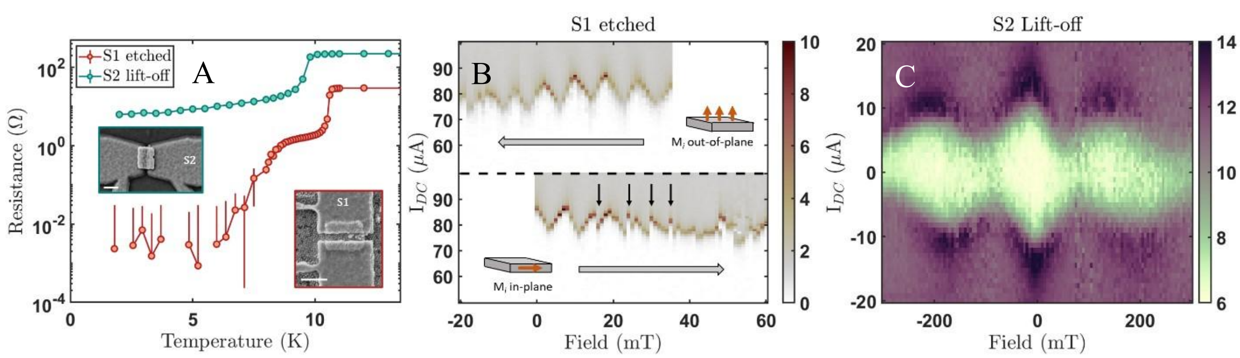


Fig.1 *(A) Resistance of the junctions. The insets show SEM pictures of the samples. The scale bars represent 300 nm. (B) Fraunhofer pattern with features (black arrows) attributed to magnetization reversal. The colorbar indicates dVdI values in Ohm. The field is applied out-of-plane. Sweeping direction is indicated by the grey arrows. (C) Field-induced modulation of the normal resistance. The colorbar indicates dVdI values in Ohm.*

References

[1] N.O. Birge *et al.*, APL Materials, 12(4), 041105 (2024).
[2] M. C. Giordano *et al.*, ACS Applied Materials & Interfaces 12(36), 40443 (2020)
[3] A. J. Skarpeid *et al.*, Journal of Physics: Condensed Matter 36(23), 235302 (2024)

19. POVM-Based Rigorous Evaluation of Photon-Number-Resolving Capability for Optical Quantum Computing

Tetsuya Tsuruta[1], Akio Yoshizawa[1] and Daiji Fukuda[1]
[1]National Institute of Advanced Industrial Science and Technology1, Tsukuba, Japan

Photonic quantum computing has emerged as a leading platform for fault-tolerant quantum information processing, with architectures based on Gottesman-Kitaev-Preskill (GKP) qubits representing one of the most promising near-term pathways [1]. A critical enabling technology for these architectures is a photon-number-resolving (PNR) detector capable of true single-shot operation, without reliance on post-processing [2] or mutiplexing. Despite rapid advances in detector technologies, a rigorous and operationally meaningful framework for quantifying single-shot photon-number identification performance has remained lacking [3].

Here we propose and experimentally demonstrate a confusion-matrix-based evaluation framework that faithfully captures photon-number misidentification arising from finite energy resolution. Using a Ti/Au bilayer transition-edge sensor (TES; Ti 20 nm / Au 10 nm, 12 µm × 12 µm) with a system detection efficiency of 99.0 % at 1550 nm, we reconstruct the positive operator-valued measure (POVM) via maximum-likelihood estimation and obtain a *post-processing fidelity* F_{A} = 99.2 % for photon numbers from 1 to 16. We then introduce a *confusion matrix* constructed directly from the experimentally measured full width at half maximum (FWHM) of the TES response, explicitly accounting for photon-number misidentification under single-shot threshold detection. This yields a *resolution-aware fidelity* F_{B} = 96.6 % over the same photon number range. We argue that F_{B} represents the operationally relevant figure of merit for quantum computing applications and propose it as a new standard for benchmarking PNR detectors. Applying this framework to a systematic comparison with previously reported PNR detectors, we show that our TES achieves the highest single-shot fidelity margin above the fault-tolerance threshold required for GKP qubit generation [4], establishing it as one of the most suitable detector platforms currently available for optical quantum computing.

References

1. N. Konno et al., "Propagating Gottesman-Kitaev-Preskill states encoded in an optical oscillator," Science 383, 289–293 (2024).
2. S. Bartolucci et al., "Fusion-based quantum computation," Nat. Commun. 14, 912 (2023).
3. M. Endo et al., "Quantum detector tomography of a superconducting nanostrip photon-number-resolving detector," Opt. Express 29, 11728 (2021).
4. K. Fukui et al., "High-Threshold Fault-Tolerant Quantum Computation with Analog Quantum Error Correction," *Phys. Rev. X* **8**, 021054 (2018).

20. High-speed Superconducting Nanowire Single Photon Detector readout using RSFQ

David Busse[1], Jorge Andrés Carballo Santana[1], Kai Müller.[1]
[1]QEC Technical University Munich, 85748, Munich, Germany

We developed an SFQ-based readout approach for parallel operation of Superconducting Nanowire Single Photon Detectors (SNSPDs). The system combines multiple nanowires into a single high-speed detector while maintaining channel separation at the readout level.

SNSPDs offer state-of-the-art single-photon detection performance and are suitable for quantum applications such as QKD and photonic quantum computing. Scaling to higher count rates requires multiplexing approaches that preserve timing performance while reducing wiring complexity. This allows smaller individual nanowires with lower timing jitter and dead times, while keeping the high efficiency by combining an ensemble of wires. In our work, we demonstrate the parallel readout of two SNSPDs designed for direct fiber coupling using a superconducting digital circuit. The implemented readout is inherently crosstalk-free and allows the operation of up to four detectors. Each detector operates at a count rate above 25 kHz and reaches saturation, indicating a high internal quantum efficiency. This results in a logical detector with a two-fold increase in count rate with losses below 3%. We measure a timing jitter of 81.5 ps for the SFQ-based readout scheme.

The presented approach is compatible with multi-pixel SNSPD designs and provides a solution towards high-count-rate detection systems suitable for small-form-factor cryostats.

21. A Hybrid Superconducting Architecture for Physically Embodied Active Inference: Classical and Quantum Operating Regimes of a Coupled JPO Array

G. Finnegan
Cybernetic Instruments Ltd, London, N16 7UR, United Kingdom

We propose a hybrid superconducting architecture in which active inference [1] is implemented directly in cryogenic hardware across two operating regimes. The system comprises a Josephson Parametric Oscillator (JPO) resonator array coupled to an Adiabatic Quantum-FluxParametron (AQFP) logic fabric [2], with a SQUID-based flux-counting ADC providing environmental input referenced to Φ_0 and photonic cryogenic interconnects providing galvanic isolation between temperature stages.

In the classical regime, the JPO array operates above the parametric threshold at 4.2 K. Each resonator self-oscillates; quantum vacuum fluctuations seed phase selection at bifurcation [3]. Nonlinear inter-resonator coupling produces Kuramoto-like phase synchronisation whose collective configuration encodes a distributed latent state. A designed Q-factor hierarchy provides intrinsic temporal filtering: high-Q resonators encode slowly varying context; low-Q resonators track rapid transients. Learned coupling strengths, stored as persistent superconducting bias currents updated by the AQFP fabric, constitute the trainable parameters of the generative model. The AQFP fabric provides GHz-clocked deterministic logic for feature extraction, prediction-error accumulation, parameter-update primitives, and action formatting, while the effective closed-loop rate is set by the sensory and readout bandwidths.

In the quantum regime, the same array operates below threshold at millikelvin temperatures, where a 5 GHz mode has thermal occupancy ranging from approximately 4×10^{-11} at 10 mK to 8×10^{-3} at 50 mK, with n_th ≈ 6×10^{-6} at 20 mK.. Bath-mediated two-mode squeezing between resonator pairs encodes prior precision and prediction-error geometry in the quadrature correlations of the quantum state. Engineered Lindblad dissipators define taskdependent steady-state priors, while driven dissipative evolution provides a physical analogue of gradient flow on variational free energy. Homodyne readout aligned to the squeezed quadrature provides prediction-error signals at sensitivities below the standard quantum limit. The parametric threshold provides a control parameter, enabling dynamic selection between classical phase-locking and quantum-correlated inference per task.

We identify a structural correspondence between the bias tone in analogue magnetic tape, the AC excitation clock in AQFP logic, and the encoding of priors in active inference: in each case, a sustained oscillation prepares a physical substrate for information-bearing interaction without itself specifying the output. The demonstration platform, an autonomous musical instrument coupled via photonic interconnects to a room-temperature analogue signal chain, provides a real-time test of dynamic criticality maintenance near the Kuramoto synchronisation transition. The architecture generalises to coupled dynamical systems requiring continuous state estimation and low-latency adaptive control, including cryogenic signal processing at the quantum limit.

References

[1] K. Friston, "The free-energy principle: a unified brain theory?" Nature Reviews Neuroscience, vol. 11, pp. 127-138, 2010.
[2] N. Takeuchi et al., "Adiabatic quantum-flux-parametron: a tutorial review," IEICE Trans. Electron., vol. E105C, pp. 251-263, 2022.
[3] Z. Wang et al., "Josephson parametric oscillators for quantum information," Applied Physics Letters, vol. 117, 2020.

22. Advancing Superconducting ADC Decimation Filters: Power Efficiency and Noise Robustness for Cryogenic Computing

Patricia Gonzalez-Guerrero[1], Panagiotis Zarkos[2], Carl Grace[2], George Michelogiannakis[1]
[1]Computing Sciences, Lawrence Berkeley National Laboratory, Berkeley, CA, USA [2]Physical Sciences, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Superconducting Analog-to-Digital Converters (S-ADCs) are a pivotal technology for enabling high-fidelity readout and control in deep-cryogenic environments, such as those required for quantum computing and transition-edge sensor (TES) arrays [1-2]. However, the practical deployment of these converters is challenged by the high power consumption and noise sensitivity of their digital decimation filters. Our work examines the robustness and efficiency of oversampling phase-modulation-demodulation S-ADCs. Noise analysis reveals that while front-end quantizers remain relatively resilient, the digital decimation filter, specifically the moving average and downsampler blocks, serves as the primary bottleneck for reliability. Performance degradation in these components becomes significant at error probabilities as low as 10^{-7}, indicating a critical need for fault-tolerant architectures to ensure circuit stability.

To address the power constraints inherent in 100 mK cryostat stages, we present novel parallelized decimation strategies. By segmenting the decimation operation into parallel stages, such as the Parallel Cascaded Integrator-Comb (P-CIC) filter, active power dissipation can be reduced by up to 76% compared to traditional single-stage designs. This architecture leverages frequency scaling to lower the operating rate of follow-on blocks, effectively bringing the power budget within the 40µW limit of modern millikelvin refrigerators. Furthermore, prefiltering reference phases relaxes the timing requirements for phase recombination, enabling higher resolution without a proportional increase in sampling speed. These advancements in power efficiency and noise-aware design facilitate the transition toward scalable, in-cryostat digitization for next-generation superconducting systems.

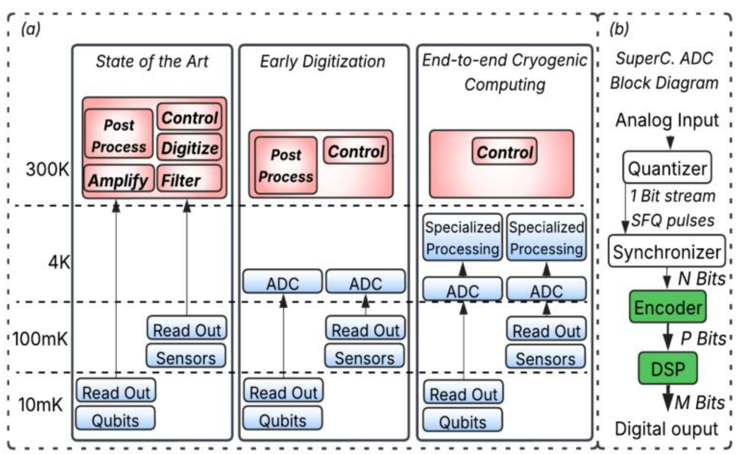


Fig. 1: Block diagrams contrasting state-of-the-art configurations for qubits and superconducting sensors with promising approaches to address scalability challenges. (b) Block diagram of a typical superconducting ADC [3].

References

[1] S. Rylov et al., 1995 IEEE Trans. on Applied Superconductivity. doi: 10.1109/77.403035 [2] O. Mukhanov et al., 2001 Supercond. Sci. Technol. doi: 10.1088/0953-2048/14/12/318 González-Guerrero et al., 2026 LASCAS.

23. An integrated low noise multi-loop SQUID magnetometer with asymmetric shunt resistors

Yuxiao Guo[1], Xiaolong Xu[1], Shijian Wang[1], Xueshen Wang[1], Jian Chen[1] and Jinjin Li[1]

[1] *National Institute of Metrology, 100029, Beijing, CHINA*

The direct-current superconducting quantum interference device (DC-SQUID) stands as the most sensitive magnetic flux transducer currently available, boasting an energy resolution close to the quantum limit of approximately $\hbar$ [1]. It has found extensive utilization across a variety of applications, including biomagnetic sensing [2] and geomagnetic field detection [3]. We introduce a novel integrated multi-loop SQUID magnetometer incorporating asymmetric shunt resistors. This configuration yields a high voltage-to-flux ratio of approximately $V_\Phi \approx 300$ µV/Φ_0 at a voltage swing near 40 µV, comparable to that achieved via Additional Positive Feedback (APF), while retaining the intrinsic simplicity and tunability of conventional SQUID architectures. Through a systematic analysis of performance variations with the Stewart-McCumber parameter β_C, we identify an optimal operating point at $\beta_C \sim 0.4$, at which the device exhibits a magnetic flux noise of 2.9 µΦ_0/√Hz and a corresponding magnetic field noise of 8.7 fT/√Hz on a compact 3×3 mm^2 chip. The proposed design concurrently delivers low magnetic field noise, high integration density, and fine spatial resolution, rendering it well-suited for readout applications across a wide range of ultra-sensitive scientific instruments.

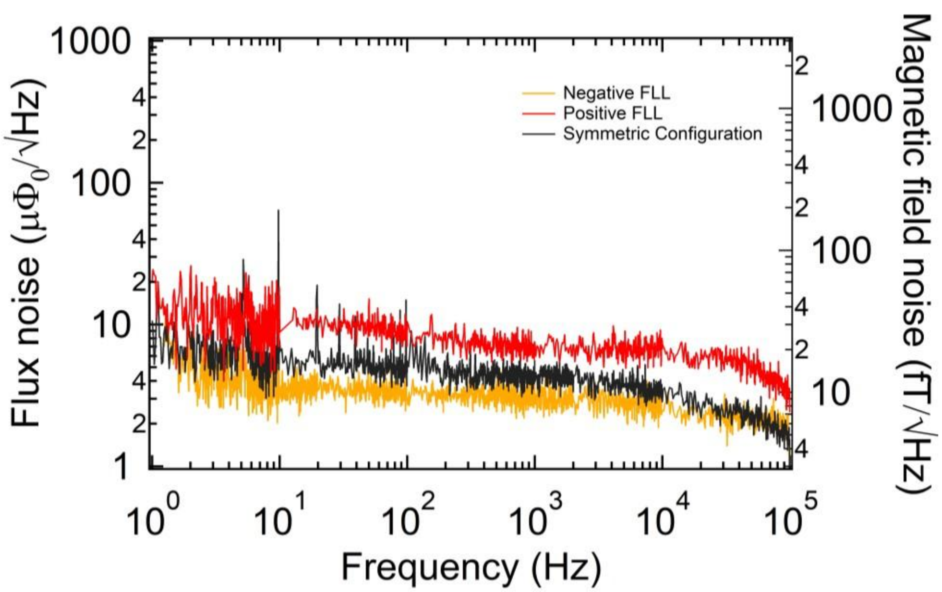


Fig. 1: *Flux noise spectra of Asymmetric and Symmetric SQUIDs in with negative and positive FLL working model.*

References

1. J. Clarke and A. I. Braginski, *The SQUID handbook: Applications of SQUIDs and SQUID systems*. John Wiley & Sons, 2006.

2. J. Clarke, Y.-H. Lee, and J. Schneiderman, *Supercond. Sci. Technol,* vol. 31, no. 8, p. 080201, 2018.

R. Stolz *et al.*, *Superconductor Science and Technology,* vol. 34, no. 3, p. 033001, 2021

24. Evolution and Air Instability of Se based 2D Materials used in Quantum Technologies

Hazel Neill[1], J.C. Seamus Davis[2], Paul K. Hurley[1,3], Farzan Gity[1]

[1] *Tyndall National Institute, University College Cork, Lee Maltings, Dyke Parade, Cork, T12 R5CP, Ireland*

[2] *School of Physics, University College Cork, Cork, Ireland*

[3] *School of Chemistry, University College Cork, Cork, Ireland*

2D materials including transition metal mono- and dichalcogenides (TMDs), have a wide range of applications, including those related to superconductivity and low-temperature electronics. Some of the benefits of 2D materials, is that they allow for a higher T_c such as the case with FeSe [1] and have fine tuneable properties, especially in terms of thickness. This study looks at the air sensitivity of three selenide-based 2D materials, $NbSe_2$, WSe_2 and Cu_x-$TiSe_2$ (x = 0.06, 0.08 or 0.09), two of which are known for their cryogenic applications which includes Josephson Junctions (JJs). [2,3] The substitution of 2D materials such as these in place of the conventional $Al/Al_2O_3/Al$ JJs may enable the increase in T_c improving scalability. The evolution of these TMDs was evaluated under a controlled, continuous exposure to air over a limited period of time to observe if any morphological or chemical changes occurred. This study demonstrates the spontaneous formation of Se-rich protrusions and nanowires on the edges and site defects across the materials within this timeframe similar to other Se based 2D materials used in transistors. [4]

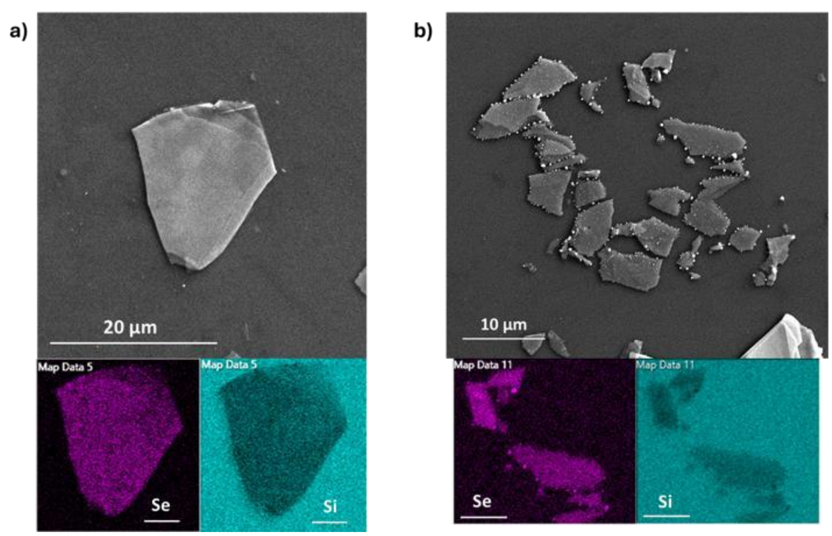


Fig. 1: *SEM and EDX images of an $NbSe_2$ flake* ***a)*** *freshly exfoliated and* ***b)*** *>6-month aged. The scale bar in the EDX maps is 5µm.*

References

1. JF. Ge et al., Nat. Mater. 14, 285-9 (2015).
2. X. Yuan et al., Appl. Phys. Lett, 124, 132602 (2024)
3. J. Ma et al., Com. Phys. 8, 125 (2025)
4. K. Intonti and H. Neill et al., Mater. Today Adv. 28, 100654 (2025)

25. Low Temperature VNA-based Characterization of SAW and BAW Resonators

Giovanni Gugliandolo[1], Antonino Quattrocchi[1], Mariangela Latino[2], Pier Paolo Capra[3] Andrea Sosso[3], Nicola Donato[1]

[1]Engineering Department, University of Messina, 98166, Messina, Italy
[2]National Research Council, Institute for Chemical-Physical Processes, 98158 Messina, Italy
[3]National Metrology Institute of Italy (INRiM), 10135, Torino, Italy

This work presents a low-temperature VNA-based characterization of acoustic resonators, with focus on surface acoustic wave (SAW) and bulk acoustic wave (BAW) devices. Acoustic resonators are key components in RF filters, oscillators, sensors, and low-noise communication systems, and their behavior under cryogenic conditions is relevant for aerospace, radio-astronomy, quantum technologies, and harsh-environment sensing [1] [2]. The experimental activity was carried out in a vacuum cryogenic setup, allowing measurements from room temperature (i.e., 300 K) down to 20 K. Scattering parameters were acquired after SOLT calibration using a VNA, and the temperature evolution of the resonance characteristics was analyzed. For the SAW device, a commercial two-port resonator with nominal resonance at 423.2 MHz was investigated, showing a clear temperature-dependent shift of the resonance frequency and variations in the transmission response. Similar analyses are in progress on a BAW resonator with a 10 MHz nominal frequency value.

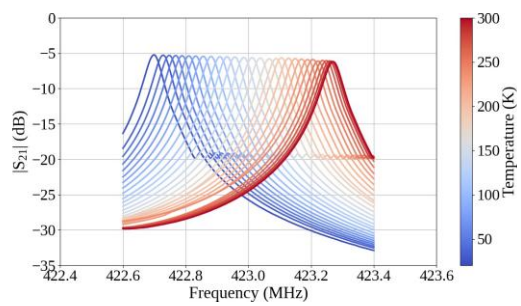


Fig. 1: Temperature-dependent $|S_{21}|$ response of the SAW resonator measured through VNA.

A complete analysis will be carried out by extracting the resonance parameters of both devices as a function of temperature, including resonance frequency, insertion loss, and quality factor, thereby providing useful information for the selection of acoustic resonators intended for low-temperature RF systems.

References

1. Kohler, Michael C., et al. "Temperature and Strain Sensing Characteristics of a 128° YX–Cut LiNbO3 Rayleigh–Mode SAW Sensor from Room to Cryogenic Temperatures." IEEE Sensors Journal (2025).
2. Ju, Shuai, et al. "Langasite cryogenic pressure sensor for space shuttle fuel tank monitoring." ASME Aerospace Structures, Structural Dynamics, and Materials Conference. Vol. 88759. American Society of Mechanical Engineers (2025).

26. Design and Simulation of Dual-Frequency Microfluidic Microwave Sensors

Xiaochuan Wang[1,2], Giovanni Gugliandolo[3], Giovanni Crupi[4], Nicola Donato[3], Xiue Bao[1,2]

[1]School of Integrated Circuits and Electronics, Beijing Institute of Technology (BIT), 100081 Beijing, China

[2]Tangshan Research Institute of BIT, 063000 Tangshan, China [3]Engineering Department, University of Messina, 98166 Messina, Italy [4]BIOMORF Department, University of Messina, 98125 Messina, Italy

Cryogenic liquids are widely used in extreme-environment technologies, where their dielectric properties are critical for system design, calibration, and safety. However, microwave-band dielectric data for cryogenic liquids remain scarce, limiting the development of cryogenic microwave sensing technologies. To address this challenge, this paper presents a dual-band microwave microfluidic sensor [1] based on a rhombic CSRR-loaded [2] microstrip transmission line for dielectric characterization of cryogenic liquids. Optimized with bent grooves on all four sides, the structure significantly enhances electric field confinement, forming two stable, spurious-free resonant peaks at 2.35 GHz and 7.85 GHz, providing a reliable foundation for non-invasive, high-sensitivity detection of cryogenic fluids. Simulation results based on the S_{21} transmission coefficient, shown in Fig. 1, demonstrate clear dual-band responses of the sensor to variations in the dielectric constants of typical cryogenic liquids. Due to the lack of direct measured data in the high-frequency microwave band, this work adopts dielectric constant values measured in the low-frequency band from literature as simulation inputs, including liquid helium, liquid nitrogen [3], and liquid hydrogen. The simulation results show that as the dielectric constant of the liquid increases, the two resonant peaks exhibit regular opposing shifts: the low-frequency resonant peak moves toward higher frequencies, while the high-frequency resonant peak shifts toward lower frequencies. Compared with the limitations of conventional sensors in cryogenic scenarios, this compact and robust design shows good application potential for on-site dielectric measurement of cryogenic fluids such as liquid helium, nitrogen, and hydrogen, and provides a reference for the optimization of subsequent cryogenic dielectric sensing schemes and high-frequency dielectric property measurement research.

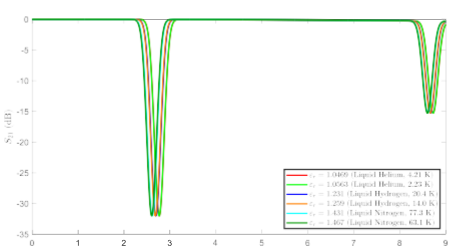


Fig. 1: *Transmission coefficient*

References

[1]. X. Han, K. Liu and S. Zhang, "High-Sensitivity Dual-Band Microfluidic Microwave Sensor for Liquid Dielectric Characterization," *IEEE Sensors Journal*, vol. 24, no. 22, pp. 36689-36697, 15 Nov.15, 2024.

[2]. X. Han et al., "Highly Integrated Improved Hexagonal CSRR-Based Fluid Sensor for Complex Dielectric Parameter Detection," *IEEE Sensors Journal*, vol. 24, no. 13, pp. 20559-20570, 1 July1, 2024.

[3]. K. N. Mathes, "Dielectric Properties of Cryogenic Liquids," in *IEEE* Transactions on Electrical Insulation, vol. EI-2, no. 1, pp. 24-32, April 1967.

27. Development of KICS microwave multiplexing for the HOLMES+ experiment

Enrico Bogoni[1, 2, 3], Sara Gamba[2, 4], Pietro Campana[2, 4], Felix Ahrens[1, 3], Matteo Borghesi[2, 4], Rodolfo Carobene[2, 4], Alessandro Cattaneo[2, 4], Hervè Atsè Corti[2, 4], Nicolò Crescini[1, 3], Marco Faverzani[2, 4], Elena Ferri[4], Andrea Giachero[2, 4], Marco Gobbo[2, 4], Alessandro Irace[2, 1, 3], Danilo Labranca[2, 4], Federica Mantegazzini[1, 3], Benno Margesin[1, 3], Renato Mezzena[5, 3], Roberto Moretti[2, 4], Angelo Nucciotti[2, 4], Luca Origo[4], P. Szypryt[6], J.N. Ullom[6], and Andrea Vinante[7, 1].

[1]Fondazione Bruno Kessler (FBK), 38123, Trento, Italy
[2]Dipartimento di Fisica, University of Milano-Bicocca, 20126 Milano, Italy
[3]TIFPA - INFN, Trento, 38123, Italy
[4] INFN - Milano Bicocca, 20126 Milano, Italy
[5]Department of Physics, University of Trento, 38123, Trento, Italy
[6]National Institute of Standards and Technology (NIST), 80305 Boulder, Colorado, USA
[7]CNR-IFN, 38123, Trento, Italy

The HOLMES experiment investigates the electron neutrino mass by studying the end point of the electron-capture decay spectrum of 163Ho. The detector technology is based on transition edge sensors (TESs) microcalorimeters.

During the first phase of the experiment, the simultaneous readout of multiple detectors was performed via microwave SQUID multiplexing (µMUX). However, the high cost per detector of this multiplexing technology limits neutrino mass measurements below 0.1 eV.

In the next phase, HOLMES+, the multiplexed readout will instead be performed with kinetic inductance current sensors (KICSs) [1]. A KICS consists of a lumped element tunable resonator whose inductance is mainly governed by the kinetic inductance of the superconducting material. Thus, its resonance frequency can be modulated upon a current signal, thanks to the current-sensitivity of the kinetic inductance. This novel multiplexing technology brings several advantages if compared to the µMUX approach, including ease of microfabrication, with a single lithographic layer, high yield and low costs, as well as a potentially higher multiplexing factor and temporal resolution. This will increase the number of points on the signal rising slope, allowing the distinction of signals pile-up.

In this contribution, we report our recent results in the development of KICS based on thin NbTiN films. We discuss the design and simulation of the first prototypes, with several KICSs coupled to a common transmission line, and we show their successful operation at cryogenic temperatures. We demonstrate the insertion of a persistent current in the circuit to fix an optimal working point, as well as the expected frequency response of the devices upon a current signal, achieving the detection of a test gaussian-shaped pulse.

References

1. Paul Szypryt, Douglas A. Bennett, Ian Fogarty Florang, Joseph W. Fowler, Andrea Giachero, Ruslan Hummatov, Adriana E. Lita, John A. B. Mates, SaeWoo Nam,

   Galen C. O'Neil, Daniel S. Swetz, Joel N. Ullom, Michael R. Vissers, Jordan Wheeler, and Jiansong Gao. Kinetic inductance current sensor for visible to nearinfrared wavelength transition-edge sensor readout. Communications Engineering, 3(1), nov 6 2024.

28. A Compact Microwave Switching Platform for In-Situ Calibration up to 20 GHz

Edoardo Boretti[1], Fabrizio Cologgi[1], Andrea Alimenti[1], Alessandro Magalotti[1], Nicola Pompeo[1], Kostiantyn Torokhtii[1], Enrico Silva[1]

,[1]*Dept. of Industrial, Electronic and Mechanical Engineering, Roma Tre University, 00146, Roma, Italy*

Accurate microwave calibration at cryogenic temperatures remains a key challenge for the characterization of low-temperature electronic systems [1]. To address this issue, we developed a compact high-frequency switching platform based on the Menlo Micro MM5130 RF MEMS SP4T [2] switch, specifically designed for operation in cryogenic environments and for in-situ calibration of microwave lines up to 20 GHz, in small diameter cryostats. A dedicated grounded coplanar waveguide PCB was designed using a stack-up based on a 0.17 mm RO4350B. This configuration enabled the realization of a 50 Ω transmission line with 0.25 mm center conductor width and 0.10 mm gap, precisely matching the switch landing pads and minimizing discontinuities at the RF interface. Particular care was devoted to layout optimization, connector transition design, and grounding strategy in order to suppress parasitic reflections and ensure broadband impedance matching. Gate actuation electronics were also developed using a PA78 high-voltage operational amplifier, providing the required ~90 V gate bias and appropriate slew rate for reliable switch operation. Room-temperature preliminary characterization shows return loss consistently better than −10 dB up to 20 GHz, in agreement with manufacturer specifications. The proposed architecture is intended as a cryogenic calibration module, where the common input line is sequentially routed to four ports connected to Open, Short, Load standards and to the device under test. In this application, path-to-path repeatability is critical: first measurements show transmission differences among ports below 1.5 dB, indicating promising channel uniformity. A detailed uncertainty analysis of the resulting cryogenic calibration procedure will be presented to assess applicability, performance limits, and prospects of this approach for low-temperature microwave electronics.

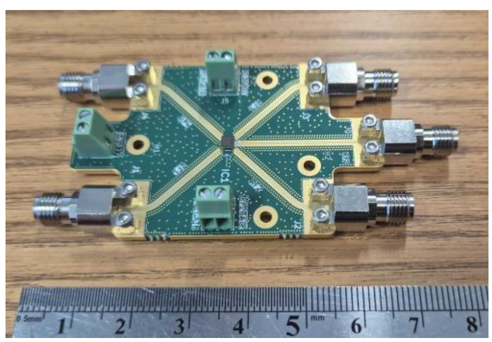


Fig. 1: *3D model of the designed calibration board.*

References

1. Arakawa, T., & Kon, S. (2023). Calibrated two-port microwave measurement up to 26.5 GHz for wide temperature range from 4 to 300 K. IEEE Transactions on Instrumentation and Measurement, 72, 1-8.
2. Menlo Microsystems, *MM5130—DC to 26 GHz High Power RF Switch Datasheet*, ver. 2.9, Nov. 3, 2025.

29. Superconducting Microwave Cavities for High-Sensitivity Axion Haloscopes

Alessandro Magalotti[1,2], Andrea Alimenti[1,2], Nicola Pompeo[1,2], Kostiantyn Torokhtii[1], Enrico Silva[1,2]

[1]Deptartment of Industrial, Electronic and Mechanical Engineering, Roma Tre University, 00146, Roma, Italy[2]National Institute for Nuclear Physics, Roma Tre Section, 00146, Rome, Italy

Axions are among the most compelling candidates for cold dark matter and are currently investigated through several experimental approaches, including resonant microwave cavities known as haloscopes [1]. In these experiments, axions are converted into microwave photons in the presence of static magnetic fields *B*. Since the expected signal power is extremely weak and scales with the cavity quality factor *Q*, improving detectors performance is essential to enhance both SNR$\propto B^2Q$ and scan rate $\propto B^4Q$ [1,2]. Conventional copper cavities are limited by ohmic losses, while superconducting cavities provide a promising route toward higher *Q*-factors, although their microwave losses are dominated by vortex motion dissipation. The impact of superconducting coatings on the haloscopes figure of merits is discussed through microwave studies of vortex dynamics at large *B*. Different materials, including NbTi, Nb_3Sn, $YBa_2Cu_3O_{7-\delta}$, and $FeSe_{0.5}Te_{0.5}$, were characterized exploiting a high sensitivity dielectric loaded resonator [3]. The superconductors performances are then compared in terms of achievable cavity quality factor under realistic operating conditions, as depicted in Fig.1a [3]. The benchmark used geometry, depicted in Fig.1b, follows standard haloscope cavity design, which has been electromagnetically simulated to calculate geometrical factors and field distributions [3]. The results show that superconducting cavities can outperform copper cavities, enhancing the scan rate. $YBa_2Cu_3O_{7-\delta}$ and $FeSe_{0.5}Te_{0.5}$ emerge as promising candidates for high-field haloscopes. The present calculation considers anisotropy, vortices elasticity, flux flow resistivity, pinning constant, penetration and coherence lengths [3].

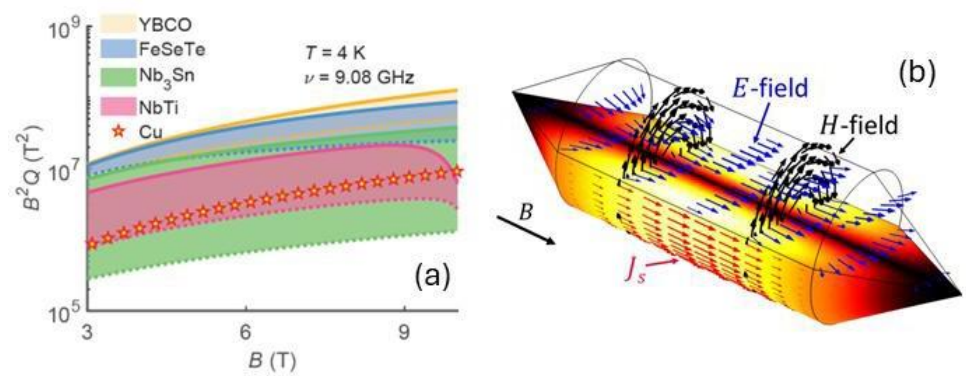


Figure 1: (a) Haloscope figure of merit B^2Q, proportional to the expected signal power. (b) Electromagnetic simulation of the haloscope excited with the TM010 mode.

Acknowledgements

This work was partially supported by MIUR-PRIN Project IronMOON Grant No. 2022BPJL2L, and INFN-CSN5 'SuperMAD'.

References

1. Semertzidis, Y. K. et al., Sci. Adv., 8, 8, 2022.
2. Braine, T et al., Phys. Rev. Lett., *124*, 101303, 2020.
3. Alimenti, A et al., *Instruments*, *6*, 1, 2021.

30. Josephson Coupling Through a Magnetic Racetrack

A. A. Mazanik[1,*] and F. S. Bergeret[1,2]

[1]Centro de Física de Materiales (CFM-MPC), Centro Mixto CSIC-UPV/EHU, E-20018 Donostia-San Sebastián, Spain

[2]Donostia International Physics Center (DIPC), 20018 Donostia-San Sebastián, Spain

We investigate the Josephson coupling between two superconducting electrodes connected by a ferromagnetic racetrack hosting a Bloch-like domain wall (DW). We show that the interplay between superconductivity and the DW leads to highly non-trivial spatial distributions of the supercurrent, including the formation of current loops and a strong sensitivity to the DW position and orientation. We further demonstrate that the Josephson critical current I_c can be efficiently controlled by the DW position along the racetrack, exhibiting pronounced variations and tunable 0–π transitions. These results provide clear design principles for superconducting racetrack devices and establish domain walls as a viable control element for readout schemes in racetrack memory architectures. This talk is based on the work [1].

References

1. A. A. Mazanik and F. S. Bergeret, e-print arXiv:2604.12742 (2026), https://arxiv.org/pdf/2604.12742.