Detector Array Readout with Traveling Wave AmplifieRS

The DARTWARS project

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DARTWARS

Detector Array Readout with Traveling Wave AmplifieRS

Project selected for the tematic call:
”Sviluppo di tecnologie quantistiche per i settori di fisica di interesse INFN”

DARTWARS: Detector Array Readout with Traveling Wave AmplifieRS

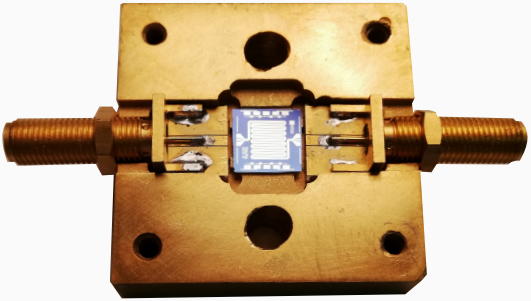
The principal objectives of DART WARS are

1. The practical development of high performing parametric amplifiers following two different promising approaches (KI-TWPA, TWJPA) and exploring new design solutions, new materials and advanced fabrication processes;

2. The read out demonstration of various detectors/components (TESs, MKIDs, microwave cavities and qubits) with improved performances due to a parametric amplification with a noise at the quantum level;

The technical goal is to achieve

- a gain value around 20 dB, comparable to HEMT;
- a high saturation power (around -50 dBm);
- quantum limited or nearly quantum limited noise (noise temperature < 600 mK)
- reduction of the gain ripple and yield improvement.



DARTWARS: working packages

- **WP1: Design and Simulation:**
  Leader: Sergio Pagano (INFN-SA)

  Improvement of the current traveling wave parametric amplifier (TWPA) designs with new geometries and layouts, supported by simulations
  Involved units: LNF, MIB, SA, INRiM.

- **WP2: Devices fabrication:**
  Leader: Emanuele Enrico (INRiM)

  Fabrication of the devices designed in WP1
  Involved units: LNF, LE, TIFPA, FBK, INRiM.

- **WP3: KI-TWPA Test and Characterization:**
  Leader: Andrea Vinante (INFN-TIFPA)

  Characterization of the KI-TWPA prototypes produced in WP2.
  Read-out demonstration with arrays of MKIDs and TESs detectors
  Involved units: LNF, LE, TIFPA, FBK, INRiM.

- **WP4: JTWPA test and Characterization**
  Leader: Claudi Gatti (INFN-LNF)

  Characterization of the JTWPA prototypes produced in WP2.
  Read out demonstration with arrays of microwave cavities
  Involved units: LE, LNF, SA, IBS-CAPP, INRiM.

- **WP5: Management and Communication**
  Leader: Andrea Giachero (INFN-MIB)

  Project Management Board (PMB),
  composed of the Project National Coordinator (RN),
  the Unit Local Coordinators (RL), and the leaders of all WPs
  Involved units: all

DARTWARS: funds allocated for 2022

	MISS [k€]		CON [k€]		INV [k€]		LIC-SW [k€]		APP [k€]		PERS [k€]		Total [k€]	
Unit	REQ	ALLOC	REQ	ALLOC	REQ	ALLOC	REQ	ALLOC	REQ	ALLOC	REQ	ALLOC	REQ	ALLOC
LE	5	4	10	6							30	30	45	40
LNF	3	3	29	20+15sj	12	0			15	5	25.5	25	94.5	48+20sj
MIB	5	4	12.5	7.5	59.5	50	2.5	0					79.5	61.5
SA	4	3	23	14			2.5	0			30	30	59.5	47
TIFPA	5	3	35	17+15sj	10	10							50	30+15sj
Total	**22.0**	**17.0**	**119.5**	**64.5+30sj**	**81.5**	**60.0**	**5.0**	**0**	**15.0**	**5.0**	**85.5**	**85.0**	328.5	226.5+35sj
Total	**22.0**	**17.0**	**119.5**	**94.5**	**81.5**	**60**	**5.0**	**0**	**15.0**	**5.0**	**85.5**	**85.0**	**328.5**	**261.5**

- 2022: Requested: 328.5 k€ , Funded: 261.5 k€ ⇒ -67 k€ (∼ 20%)
- 2021: Requested: 380.0 k€ , Funded: 245.0 k€ ⇒ -135 k€ (∼ 36%)

- CON/ALLOC @ LNF includes 15 k€+15 k€ sj for production at INRiM;
- CON/ALLOC @ TIFPA includes 15 k€+15 k€ sj for production at FBK;

DARTWARS: sub-judice funds

Unit	Rich. [k€]	Note Alla Richiesta	Commento
LNF	15	Device Production at INRiM	SJ ai risultati della prima ed alla definizione del nuovo disegno.
LNF	5	Contribution for addition Pulse Tube	SJ al reperimento della somma restante
TIFPA	15	Device Production at FBK	SJ ai risultati della prima ed alla definizione del nuovo disegno.
Totale	**35**		

- 2022: 35 k€ over the total of 261.5 k€ are sub-judice ($\sim$ 13%)
- 2021: 131 k€ over the total of 245.0 k€ were sub-judice ($\sim$ 47%) $\Rightarrow$ all released and used during 2021

- Half of the device production costs are sub-judice (30 k€ over 60 k€)
  this might complicate the buying order process with FBK and INRiM

DARTWARS: 2021 Milestones

M1 Kick-start meeting and report with project master and communication plans;
31-03-2021 100% ✓☺

M2 Public and Private project website on-line: dartwars@lists.infn.it
31-03-2021 100% ✓☺

M3 First Design of JTWPA and KI-TWPA, operating in different bands, and submission to the foundries
31-12-2021 JTWPA: 100% ✓☺ KI-TWPA: 50% –😐

M4 MIB: Setup and test of the experimental apparatus for the device characterization.
31-12-2021 Demonstration of optimal conditions for quantum-limited measurements.
50% –😐

M5 LE: Setup and test of the experimental apparatus for the device characterization.
31-12-2021 Demonstration of optimal conditions for quantum-limited measurements.
50% –😐

M6 LNF: Setup and test of the experimental apparatus for the device characterization
31-12-2021 Demonstration of optimal conditions for quantum-limited measurements
100% ✓☺

M7 SA: Demonstration of optimal conditions for testing the operation of developed device
31-12-2021 Demonstration of optimal conditions for quantum-limited measurements
50% –😐

M8 TIFPA: Setup and test of the experimental apparatus for the device characterization
31-12-2021 Demonstration of optimal conditions for quantum-limited measurements
50% –😐

DARTWARS: 2022 Milestones

M1 **31-03-2022**	First JTWPA prototypes produced;
M2 **31-03-2022**	First KI-TWPA prototypes produced
M3 **31-09-2021**	Characterization of the first JTWPA: noise, gain and bandwidth measurements
M4 **31-09-2021**	Characterization of the first KI-TWPA: noise, gain and bandwidth measurements
M5 **31-12-2021**	Improved design of JTWPA operating in different bandwidths
M6 **31-12-2021**	Improved design of KI-TWPA operating in different bandwidths

Conference in 2021

[1] **"Traveling wave parametric amplifiers"**, Andrea Giachero, invited presentation at the *Q@TN Workshop*, Trento, Italy, September 8, 2021;

[2] **"Development of quantum limited superconducting amplifiers for advanced detection"**, Sergio Pagano, oral presentation, on behalf of the DARTWARS collaboration, at the *15th European Conference on Applied Superconductivity (EUCAS2021)*, Virtual Conference, Moscow, Russia, September 5, 2021;

[3] **"Noise Figures of Merit of rf-SQUID-based Josephson Travelling Wave Parametric Amplifiers"**, Luca Fasolo, poster presentation, on behalf of the DARTWARS collaboration, at the *15th European Conference on Applied Superconductivity (EUCAS2021)*, Virtual Conference, Moscow, Russia, September 5, 2021;

[4] **"Detector Array Readout with Traveling Wave AmplifieRS"**, Andrea Giachero, poster presentation, on behalf of the DARTWARS collaboration, at the *19th International Workshop on Low Temperature Detectors (LTD19)*, Virtual Workshop, NIST, Boulder, Colorado, USA, July 19 - 29, 2021;

[5] **"Detector Array Readout with Traveling Wave AmplifieRS"**, Andrea Giachero, oral presentation, on behalf of the DARTWARS collaboration, at the *14th edition of the Workshop on Low Temperature Electronics (WOLTE-14)*, Virtual Workshop, Matera, Italy, April 12 - 15, 2021;

list continuously updated at dartwars.unimib.it/research/presentations

- **”Applied Superconductivity Conference 2022”**, Hawaii Convention Center, Honolulu, HI, USA, October 23 – October 28, 2022.
- **”15th Workshop on Low Temperature Electronics (WOLTE15)”**, to be held in Matera? In spring?
- others?

Pubblications in 2021

[1] **Microwave Quantum Radar using a Josephson Traveling Wave Parametric Amplifier**, P. Livreri *et al.*, arXiv:2111.03409 [quant-ph]

[2] **Detector Array Readout with Traveling Wave Amplifiers**, A. Giachero *et al.*, submitted to Journal of Low Temperature Physic, arXiv:2111.01512 [cond-mat.supr-con]

[3] **Development of quantum limited superconducting amplifiers for advanced detection**, S. Pagano *et al.*, submitted to IEEE Transactions on Applied Superconductivity

[4] **Bimodal Approach for Noise Figures of Merit Evaluation in Quantum-Limited Josephson Traveling Wave Parametric Amplifiers** L. Fasolo *et al.*, submitted to IEEE Transactions on Applied Superconductivity, arXiv:2109.14924 [cond-mat.supr-con]

[5] **Josephson Travelling Wave Parametric Amplifiers as Non-Classical Light Source for Microwave Quantum Illumination** L. Fasolo *et al.*, Measurement: Sensors 18 (2021) 100349, doi:10.1016/j.measen.2021.100349, arXiv:2106.00522 [quant-ph]

list continuously updated at dartwars.unimib.it/research/pubblications

- Collaboration mailing list: dartwars@lists.infn.it
- Project web page: dartwars.unimib.it
- Indico page: agenda.infn.it/category/1473/
- Google Drive: bit.ly/33y0ODS

DARTWARS is a quantum technologies project with the aim to boost the sensitivity of experiments based on low-noise superconducting detectors and qubits. This goal will be reached through the development of wideband superconducting amplifiers with noise at the quantum limit and the implementation of a quantum-limited read-out in different types of superconducting detectors and qubit.

Noise at the quantum limit (Heisenberg limit) over a large bandwidth is a fundamental requirement for challenging future applications, like neutrino mass measurement, next-generation x-ray observatory, CMB measurement, and dark matter and axion detection, in which INFN is deeply involved. The sensitivity and the bandwidth of microcalorimeter detectors such as Transition Edge Sensors (TESs) and Microwave Kinetic Inductance Detectors (MKIDs) using dissipative readout are limited by the noise temperature and bandwidth of the cryogenic amplifier. Likewise, resonant axion-detectors, such as haloscopes, must probe a range of frequencies of several GHz keeping the system noise to the lowest possible level. The need for a quantum-limited microwave amplifier with large bandwidth operating at millikelvin temperatures is also particularly felt in many quantum technology applications, for example, the rapid high-fidelity multiplexed readout of superconducting qubits. To this end, devices called traveling-wave parametric amplifiers (TWPAs) are currently being developed. The nonlinear element of TWPAs is provided by Josephson junctions or by the kinetic inductance of a high-resistivity superconductor.

The **DARTWARS** project is a research effort to improve the performance and reliability of these amplifiers with the study of new materials and with improved microwave and thermal engineering. The long-term goal is to demonstrate, for the first time, the readout with different sensors (TESs, MKIDs, microwave cavities, and qubits) opening the concrete possibility to increase the sensitivity of the next generation particle physics experiments.

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