



Bolometer for CMB

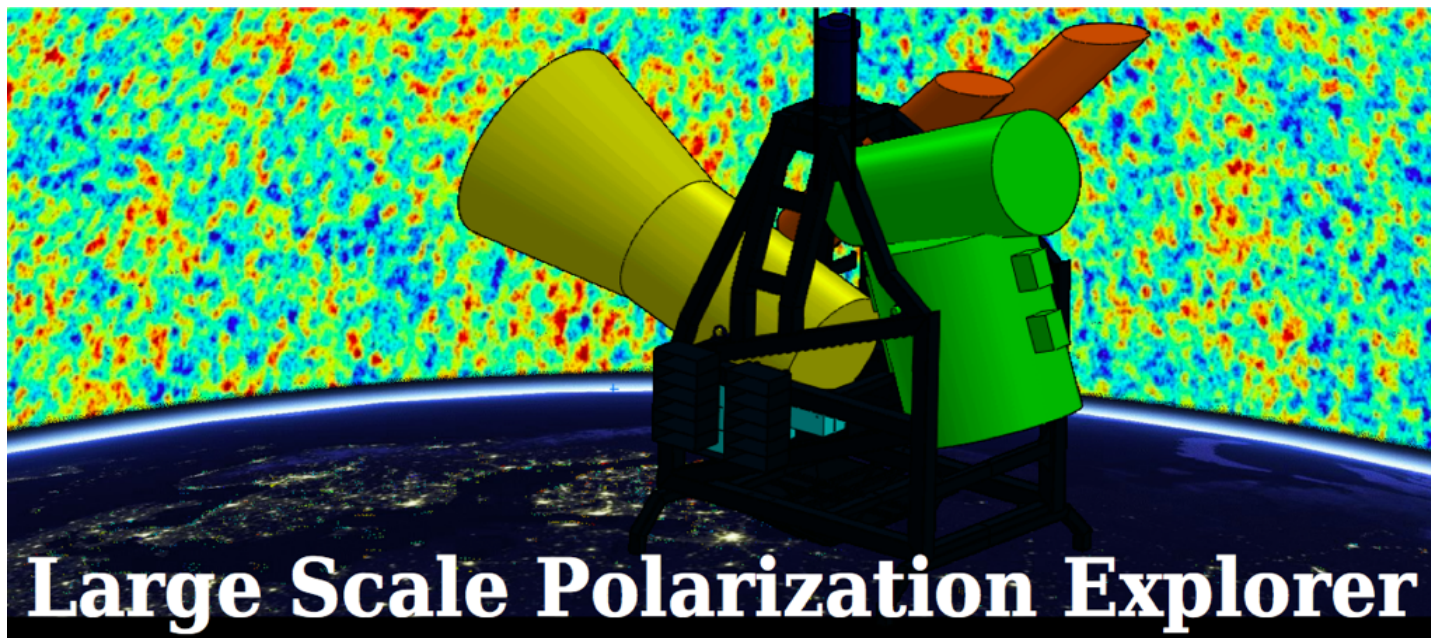
Flavio Gatti

Università e INFN, Genova

Overview

1. CMB TES Bolometers and Performance
2. Status of the Art
3. TES Bolometers and Readout chain for LSPE
4. Future developments
5. Sub-THz/THz detection with Qdot/QPC

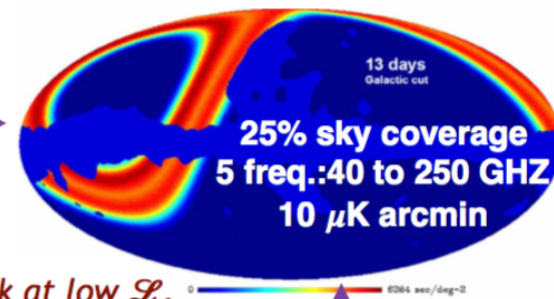
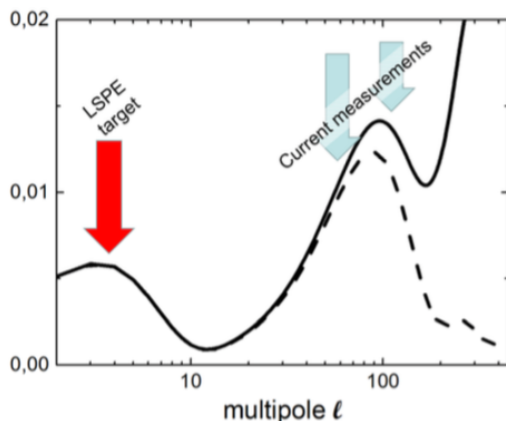
Forewords



Large Scale Polarization Explorer

1. First TES Spiderweb Bolometers developed within ASI project “Sviluppi Tecnologici nel Millimetrico per missioni di polarizzazione” (2010-12) within the call on new instruments
2. They were proposed as baseline detectors for LSPE (ASI-Uni. La Sapienza) as contribution of INFN (Bolometers-SQUID Readout-FDM electronics)
3. New future developments within the Progetto Premiale ASI-INFN on CMB with Balloon Born Telescopes

Ballon borne CMB HF-telescope in polar stratospheric trajectory and LF-Telescope at Tenerife



Search for the B mode peak at low ℓ .

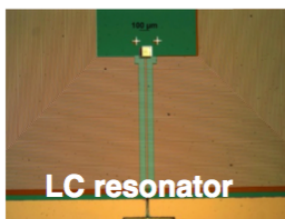
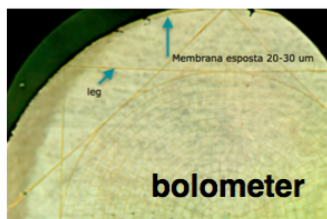
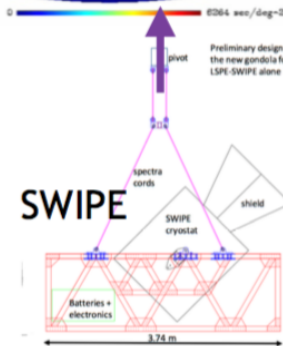
Sensitivity on the parameter $r \rightarrow 0.03$.

New Experiment Configuration and Flight Schedule

- Flight scheduled by ASI in the winter 2018–19
- Low frequency telescope (STRIP) ground based at Tenerife
- High Frequency telescope (SWIPE) will fly alone

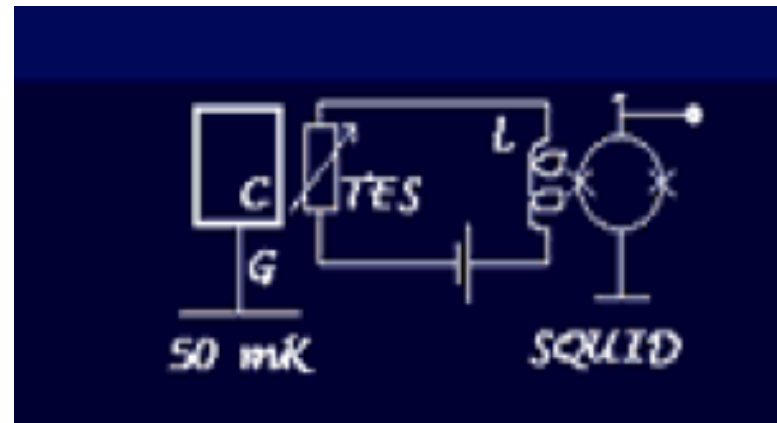
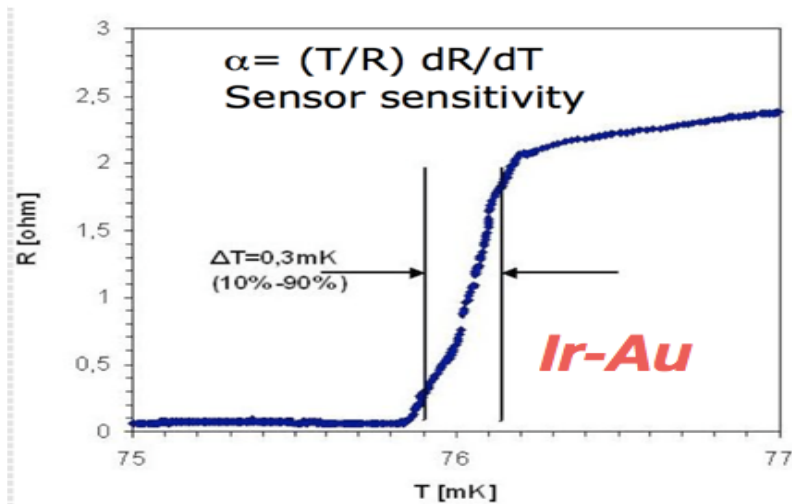
Hardware status

- Horn designed and prototype ready
- New bolometer under production
- SQUID selected, LNA 4th prototype tested
- LC resonator and FDM electronics prototype tested

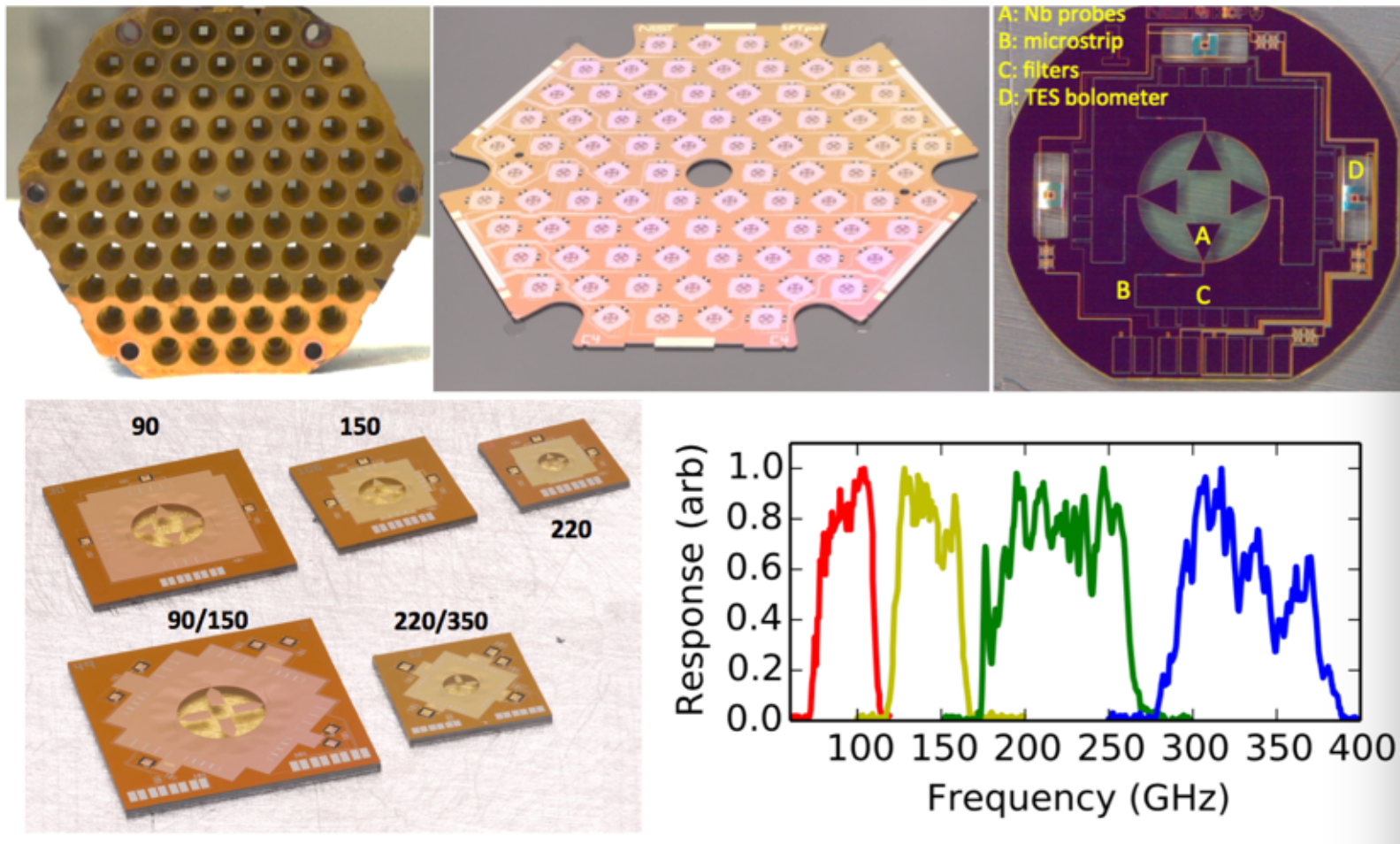


TES

- Superconducting film operated in the s/c to normal transition
- SQUID as best matching current amplifier
- Low T \rightarrow Low Noise Equivalent Power to input and narrow transitions
- Multiplexing schemes TDM and FDM are suitable



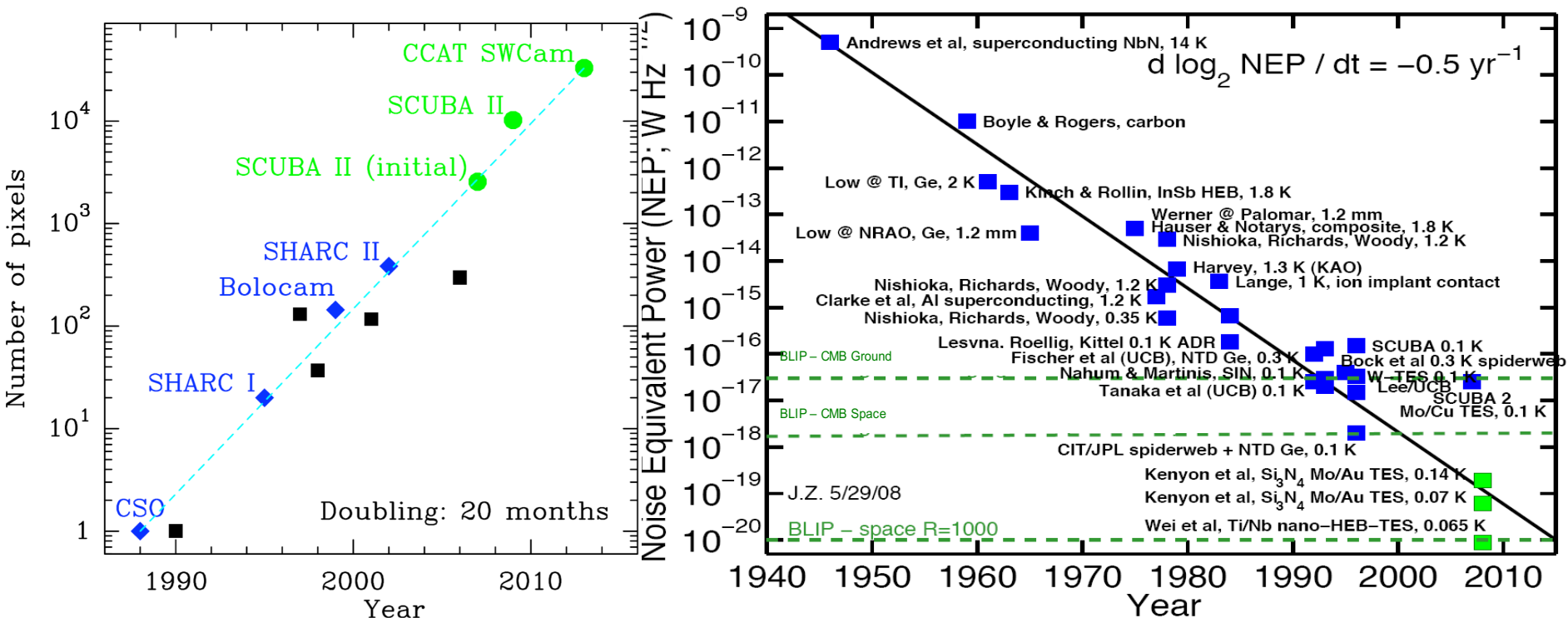
Status of the Art



A. Lee, UCB, "Workshop CMB from Space" Tokyo 12 Dec 15

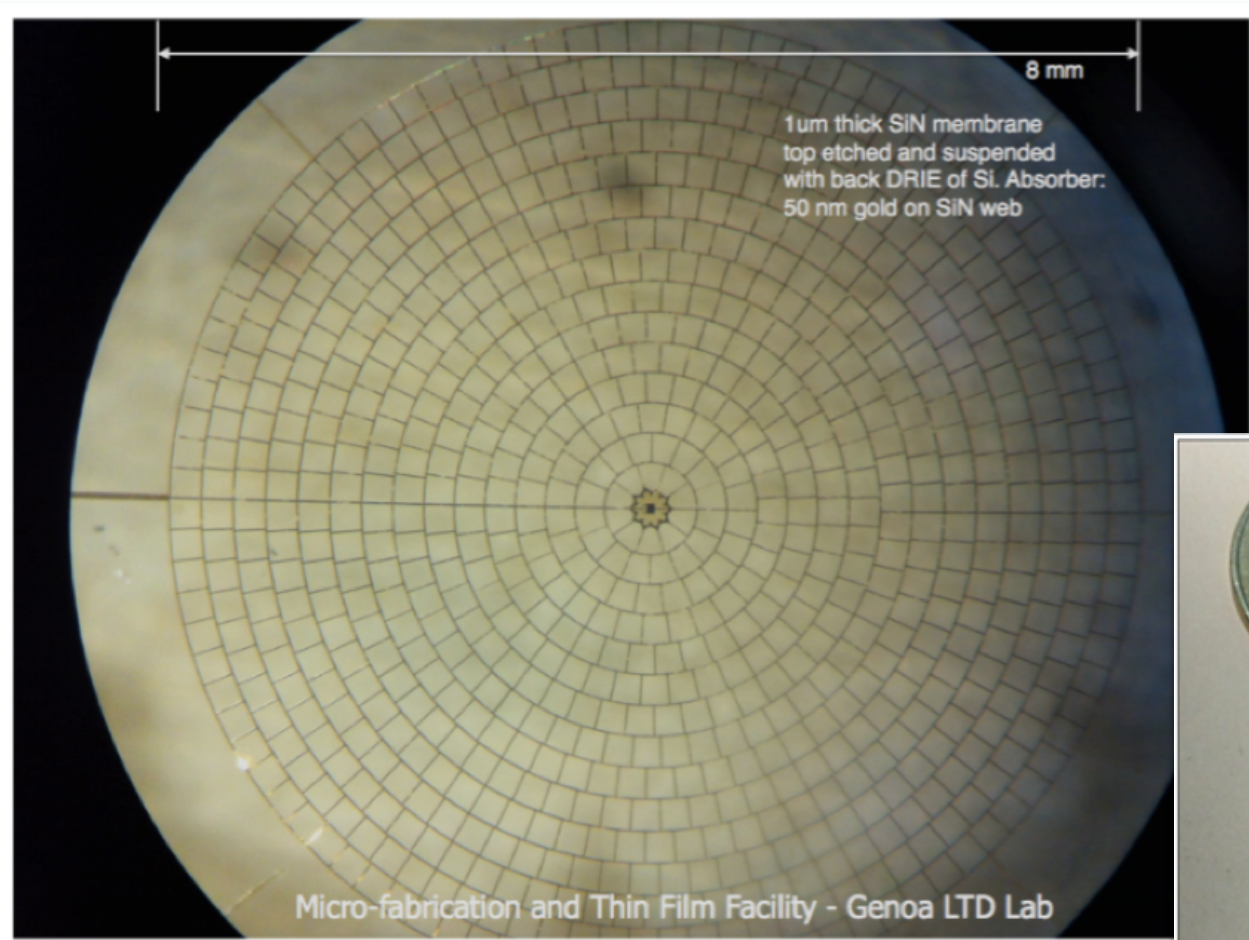
Status of the art

- Array size: doubling time = 20 months
- NEP challenge: improves of about a factor 10 each 10 years

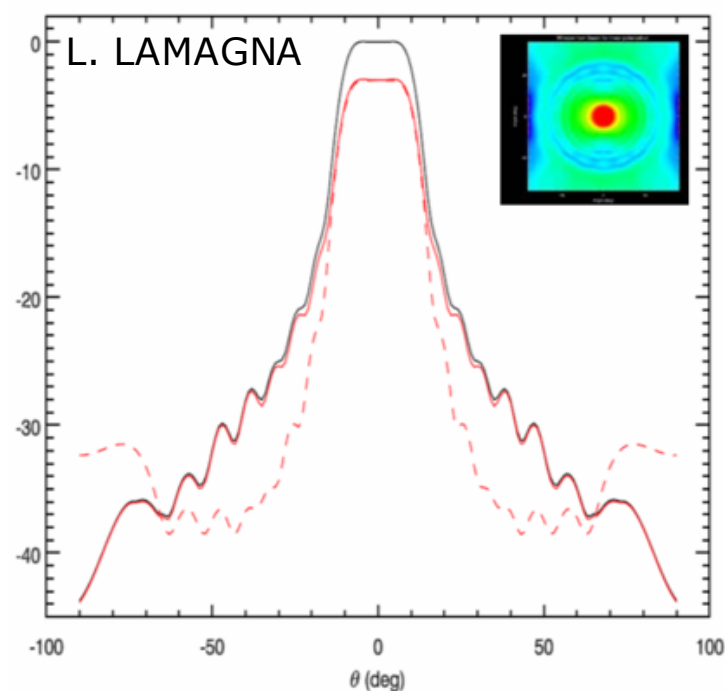
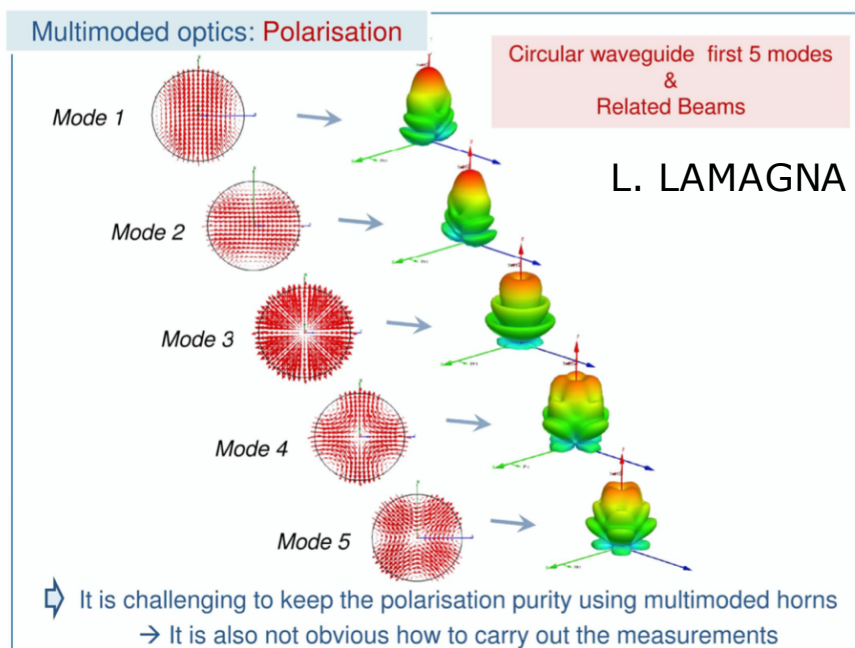


TES Large Area Bolometer for LSPE

Bolometers: starting point (Genova)



- LSPE based on Multi-Mode detection: Bolometers must couple with several tens of cavity modes (P.de Bernardis)
- This is the motivations of a such large area
- Expected performance of comparable experiment with 10^3 single mode detector
- Top flat beam is within the required angular resolution of LSPE



Fabrication Process @ Genova

Full fabrication in the Genova Facilities

Fabrication Process 1: metals deposition

Negative Photolithography, e-beam metal evaporation, Lift-off process

Starting from a silicon wafer covered with:

- $0.5\ \mu\text{m}\ \text{SiO}_2$
- $1\ \mu\text{m}\ \text{Si}_3\text{N}_4$

TES:
Ti 5 nm
Au 4 nm
Ti 38 nm

TES wiring:
Al or Ti/Al/Ti multilayer

Au absorber deposition
(a Ti sticking layer is necessary)



Fabrication Process 2: Etching

Reactive Ion Etching used to cut silicon and silicon nitride

Positive photolithography
and RIE $\text{CF}_4 + \text{O}_2$ etching



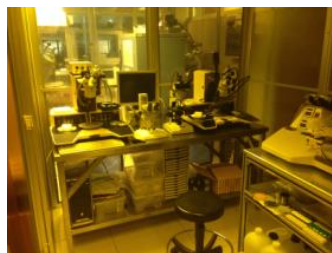
deposition of Aluminum
hard mask on backside
with lift-off process

RIE back wafer etching with
 $\text{SF}_6 + \text{O}_2$ and suspension of
spider web structure

Endpoint detection by optical plasma analysis

Fab and Test Facility in Genova

1. Fab Facility with Thin Film growth system (PVD, RF/DC Sputtering, PLD)
2. Optical micro-lithography
3. Micromachining (RIE/ICP)
4. Low T fridges with SQUID for testing
5. "Flexible" for fast prototyping not very well suited for large production



Clean room for litho and thin films evaporation system facilities

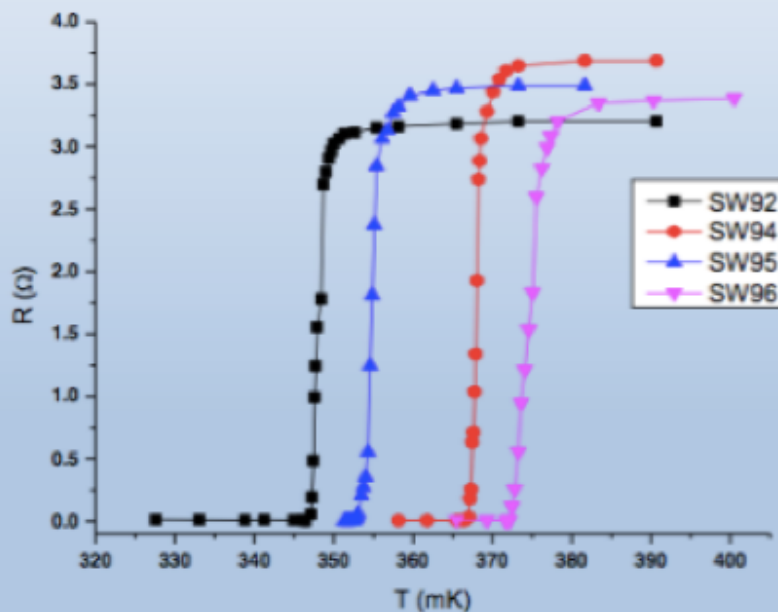


Test facilities
(3 dilution fridgew)



TES performance test

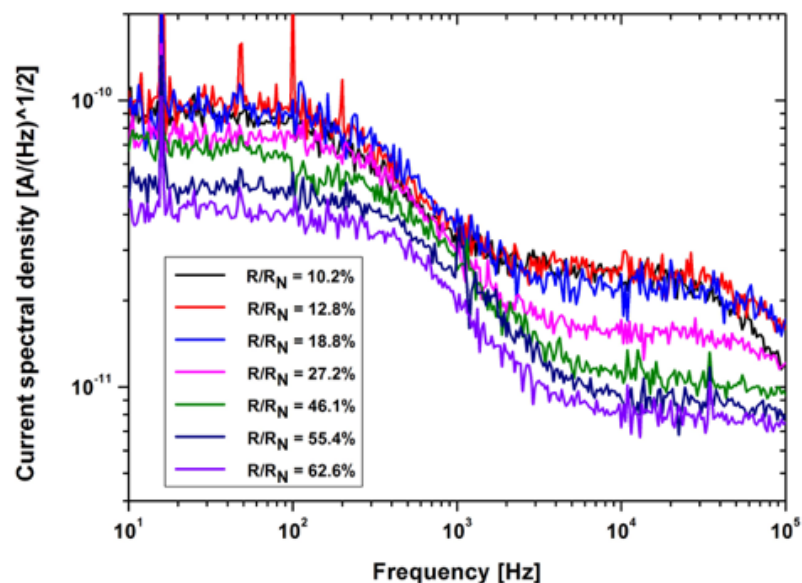
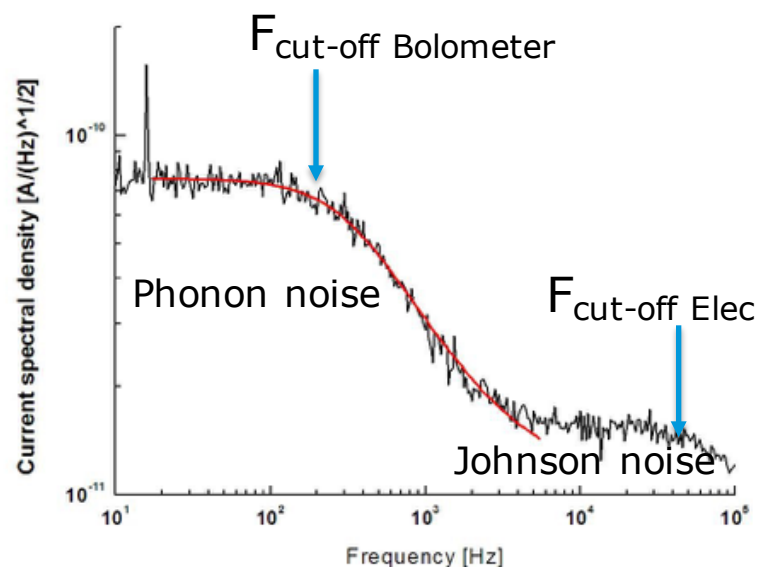
- Bilayer TES Ti-Au studied for covering 0.3 -0.4 K
- Larger temperature range requirements (0.5K): Investigations on Ti and Mo films proximized with gold



	Ti (nm)	Au (nm)	Ti (nm)
SW92	5.0	4.4	37.2
SW94	5.0	4.4	38.0
SW95	5.0	3.8	37.2
SW96	5.0	3.8	38.0

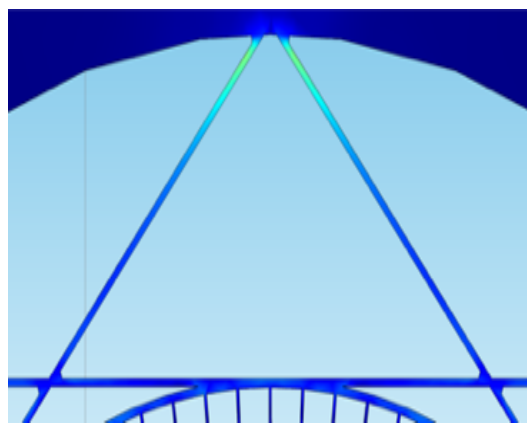
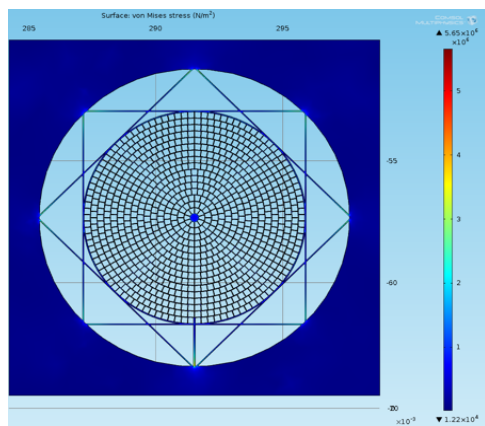
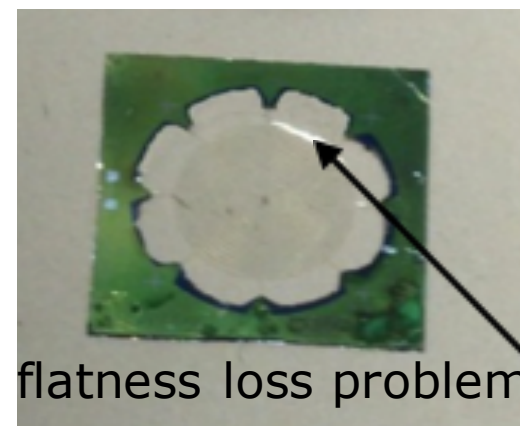
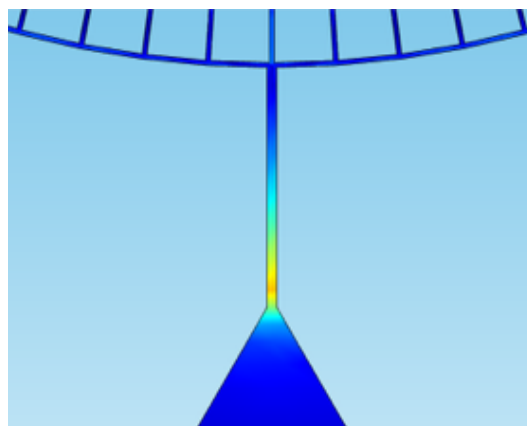
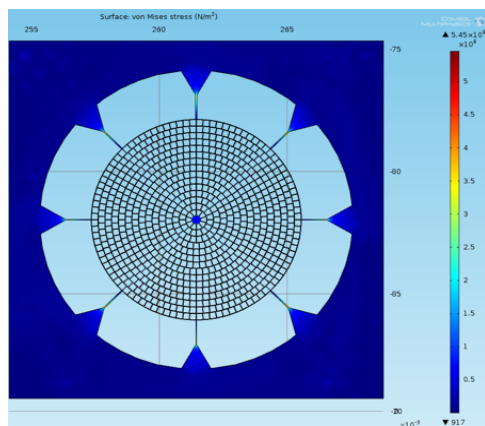
TES Performance tests

1. Bolometer in isothermal box at low T (no external EM radiation)
2. TES at several operating points (R/R_n)
3. Current Noise as composition of [phonon noise x bolometer gain] and Johnson noise; SQUID noise at 1×10^{-12} A/Hz.



Design Review and upgrade

- Largest spiderweb bolometers even built: Metal film-SiN stress release \rightarrow wavy shape at the edges
- Reduction of von Mises stress at the supporting beam \rightarrow more than a factor 3



Design Review and upgrade

1. TES: TiAu, MoAu

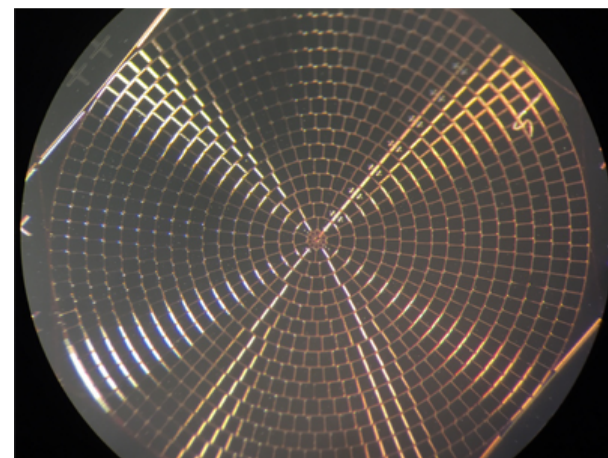
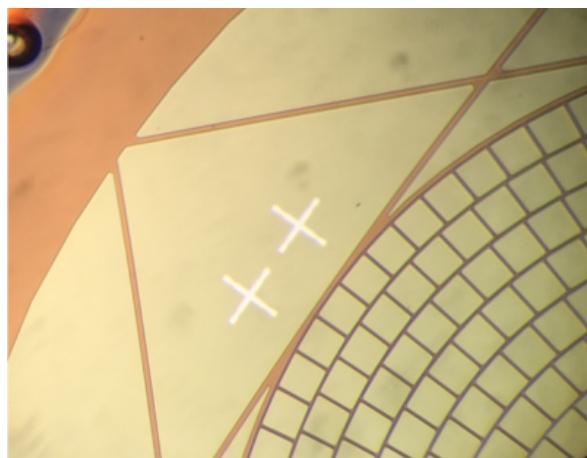
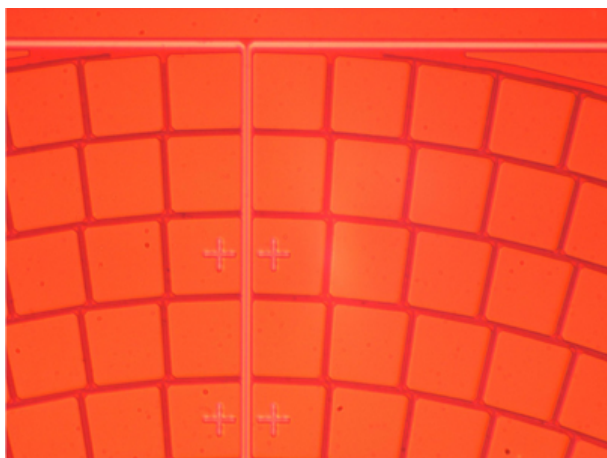
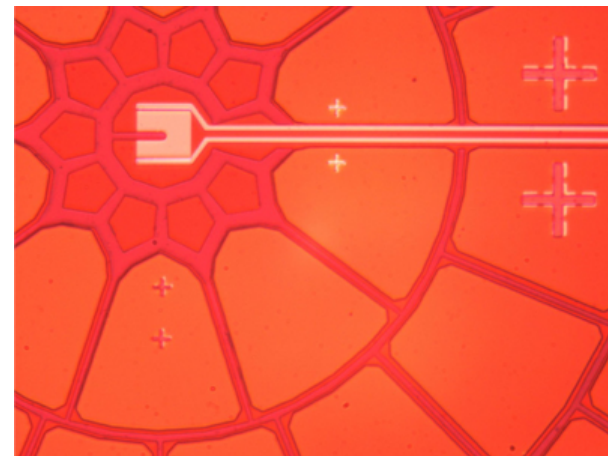
Ti: $T_c(0.4-0.6 \text{ K})$ depends process T profile (issue fixed)

MoAu: unsatisfactory results

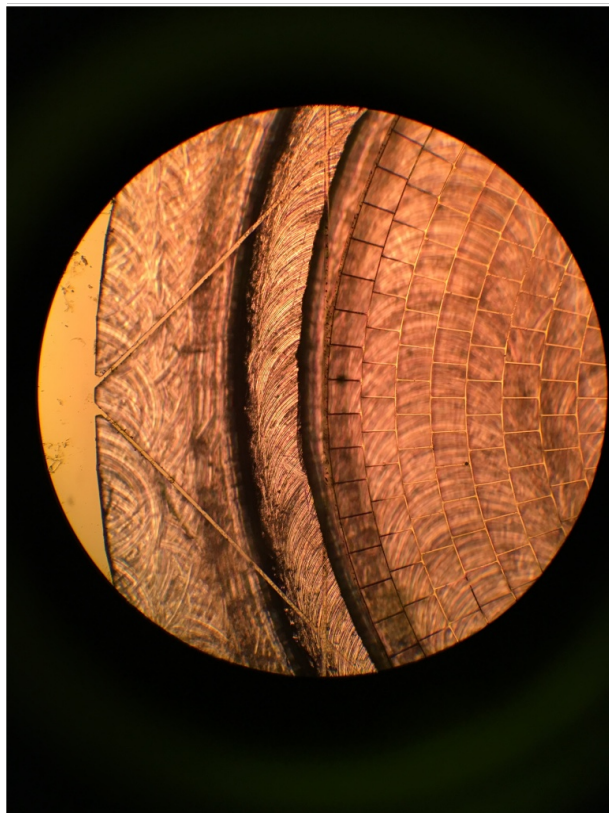
1. New Wiring: Nb better than Al

2. New mechanical structure (wavy almost negligible)

3. Fabrication and micro-etching recently switched to RIE-ICP for BOSH process



1. New Bolometer mounted in the cavity

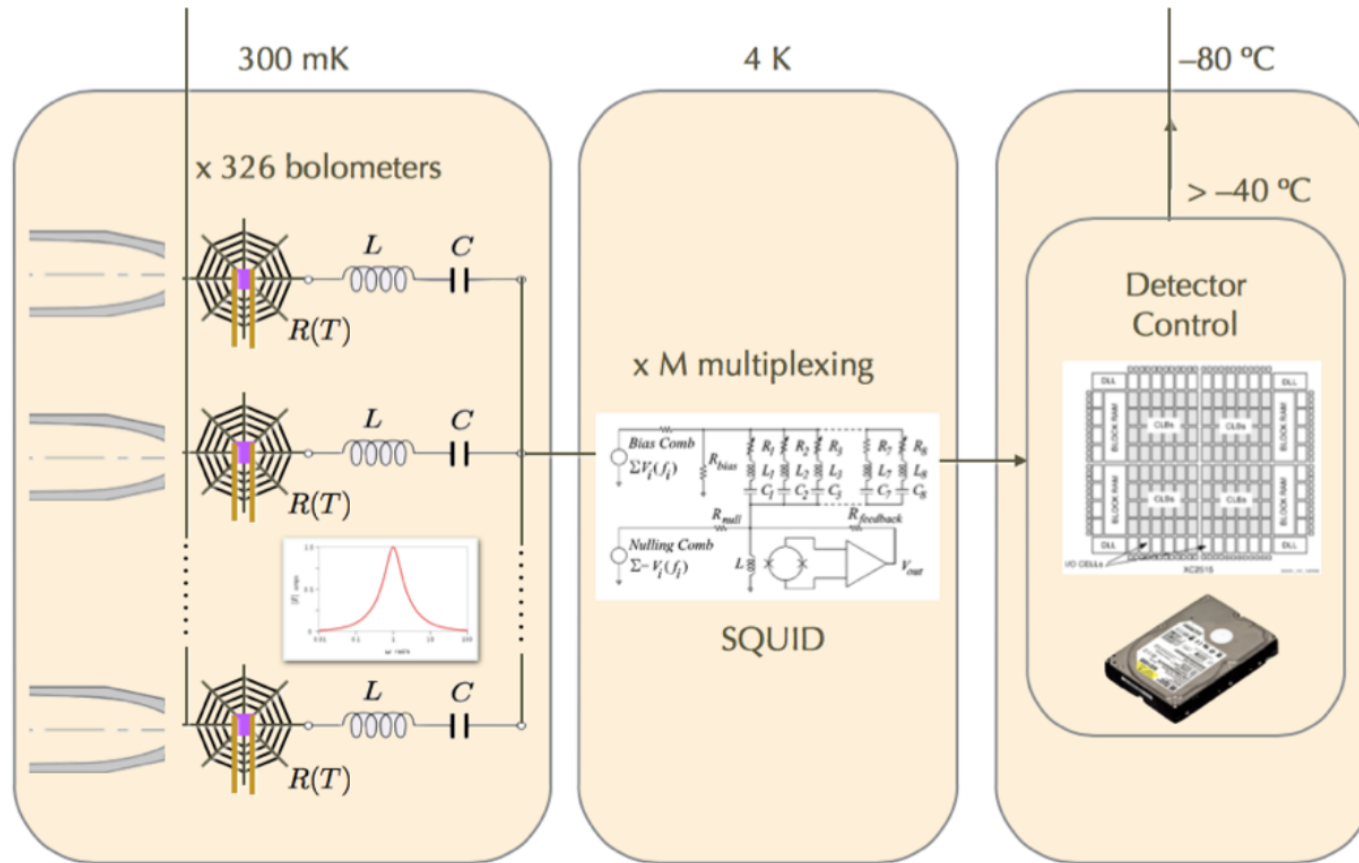


2. Horn and Focal Plane (P. De Bernardis)



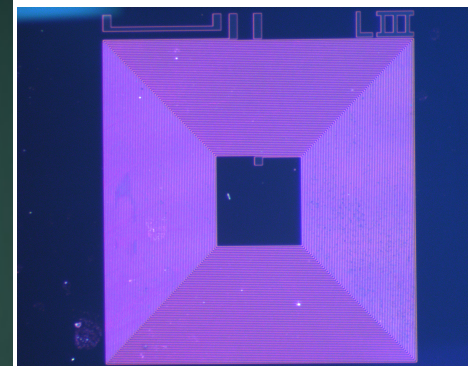
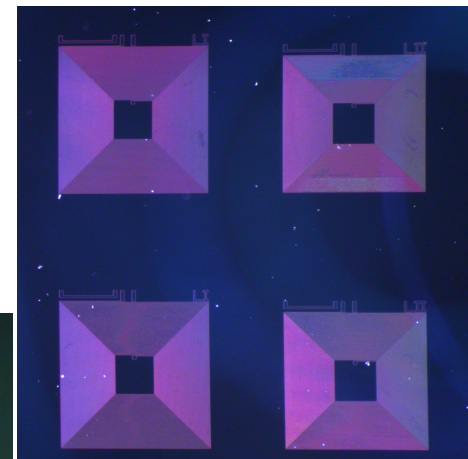
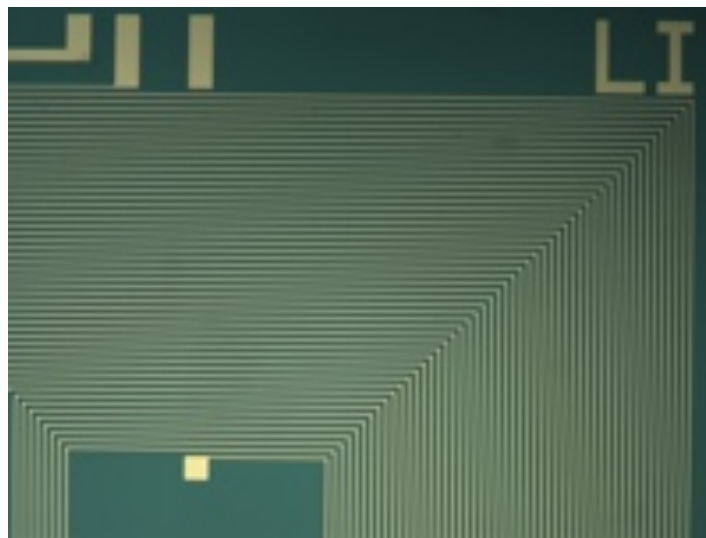
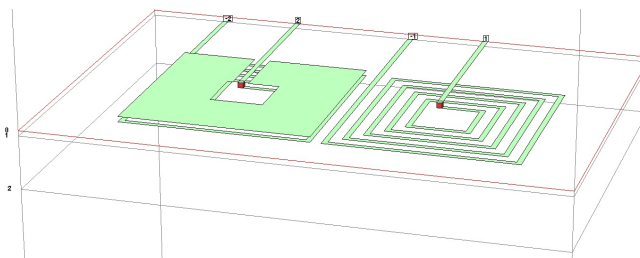
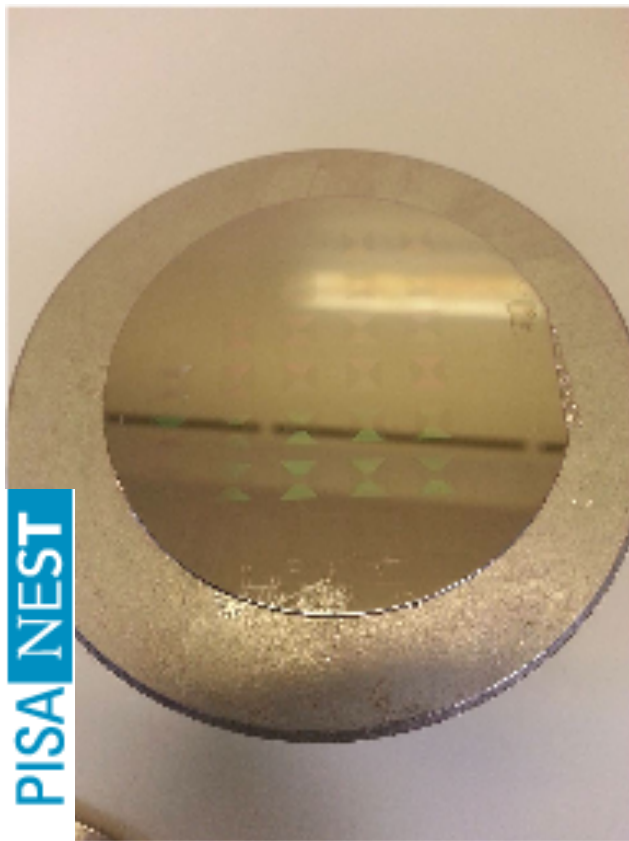
Frequency Division Multiplexing

FDM electronics by INFN-PISA – Giovanni Signorelli



Custom LC circuits for FDM resonators

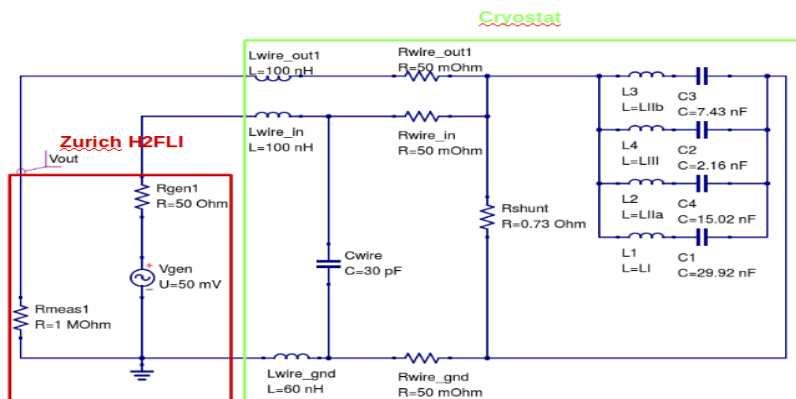
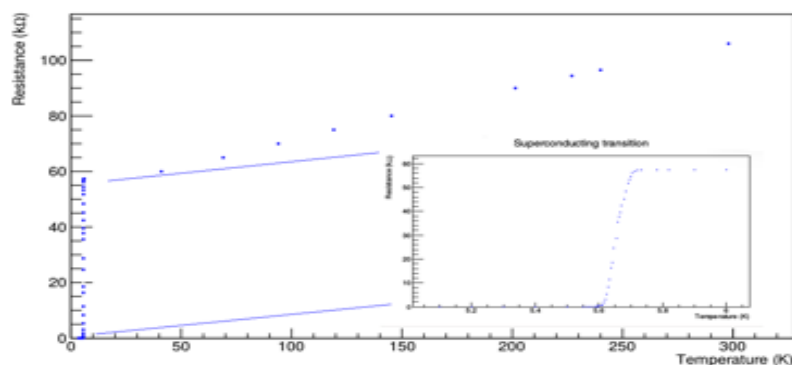
- Niobium inductors produced on 2" Si wafer
- Designed, simulated and tested at INFN Pisa- Fabricated at CNR-NANO PISA and INFN PISA



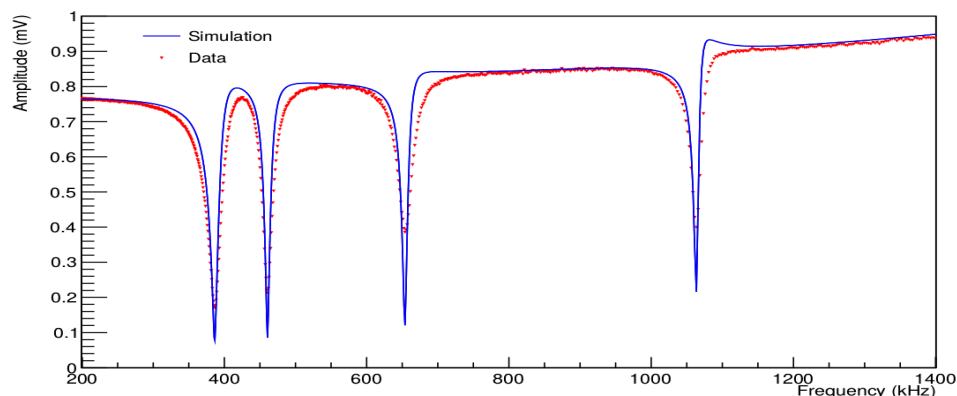
Custom LC circuits for FDM resonators

- Pack 16 carriers in 0.2 -2 MHz frequency band for the LSPE bolometers
- Nb quality test: $T_c=5.6$ K , $RRR=2$
- 4-resonator test at 4.2: amplitude and phase (data vs simulation)

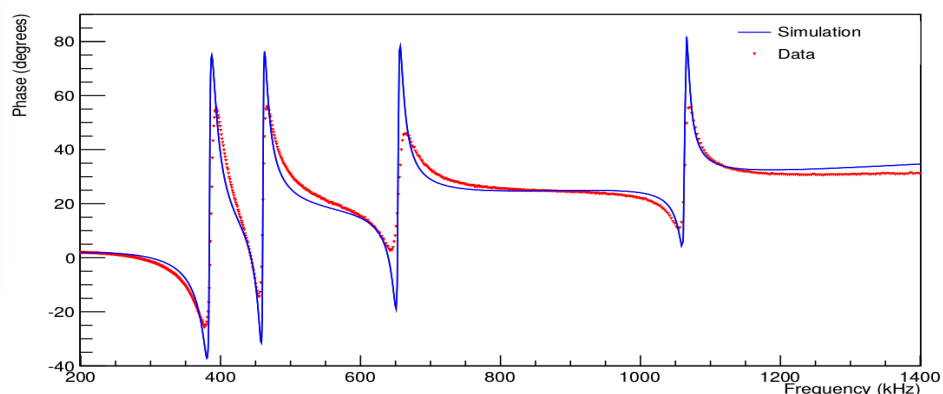
Superconducting transition



FDM - Data vs Simulation

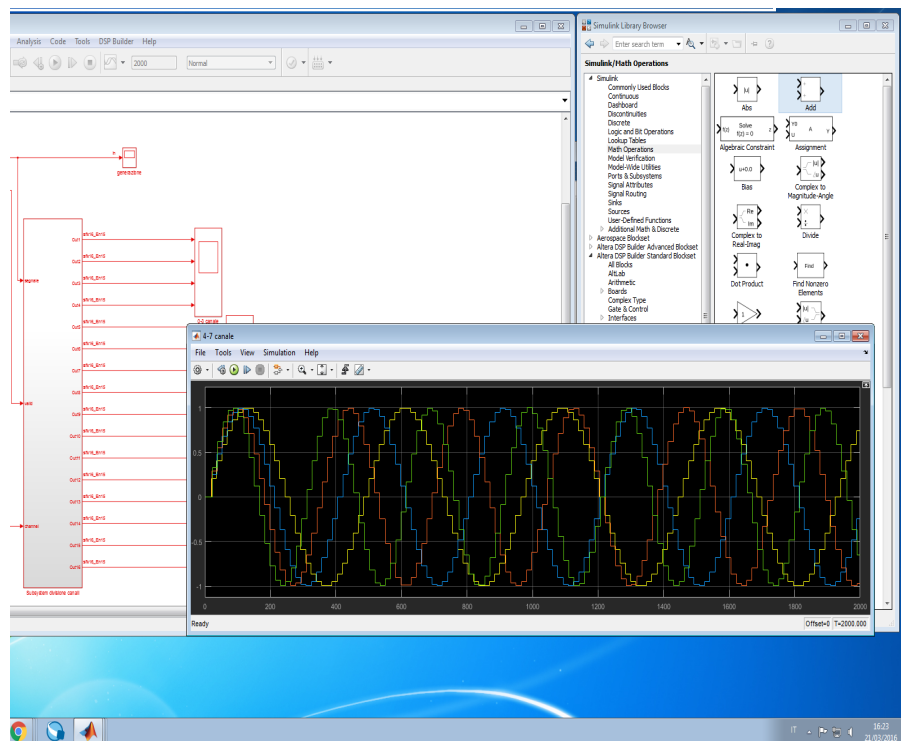
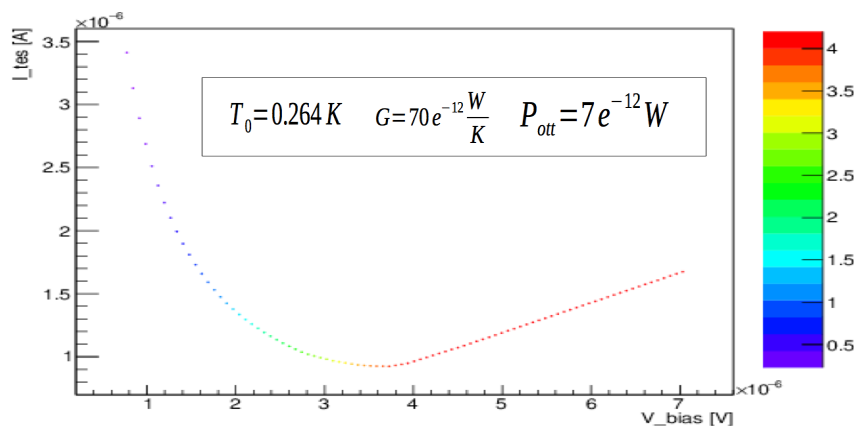


FDM - Data vs Simulation



Custom LC circuits for FDM resonators

- FPGA controls the carrier frequencies generation and de-MUX
- Provide operating set-point tuning of TES bolometers
- Firmware test done with Altera CycloneV FPGA for DAC/Carrier gen.
- Foreseen migration to MicroSemi SmartFusion2



Future Developments

1. Goals:

- a. Antenna Coupled Bolometers
- b. High Multiplicity GHz FDM (developed for the HOLMES project-INFN by NIST)

2. R&D:

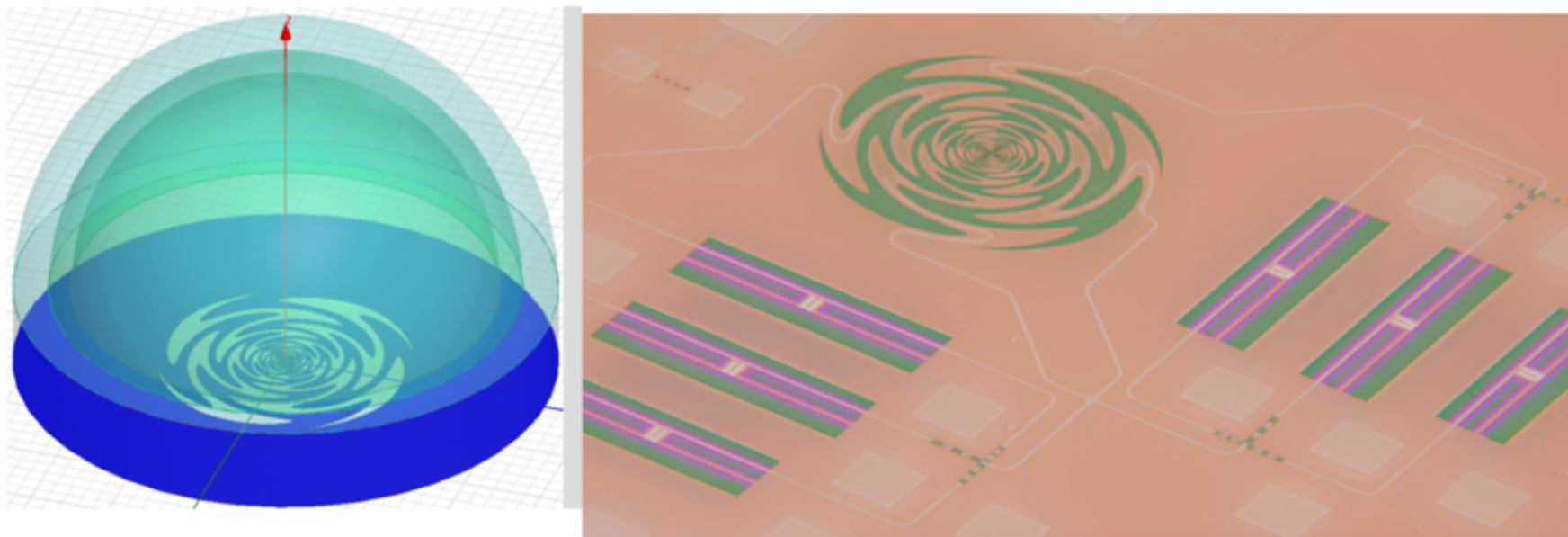
- a. Planar Antennas (multicrystalline and polarization saving)
- b. HF Striplines and Filters
- c. Small TES bolometer (10^{-2} μm)
- d. High multiplicity FDM (several 10^{10})

3. Teaming up with Uni. Trento - TIFPA and FBK

- a. Antenna design
- b. HF striplines and Filters (FBK)
- c. Large scale production (FBK)

Future Developments

A snapshot of the possible future development for the Italian CMB community: multiband and polarization sensitive antenna coupled bolometers



A. Lee, UCB, "Workshop CMB from Space" Tokyo 12 Dec 15

THz detectors: my experience within TERA EYE



Integrated project for SMEs



$$\omega^2 = \frac{2\pi e^2 n_s}{m^* \epsilon R}$$

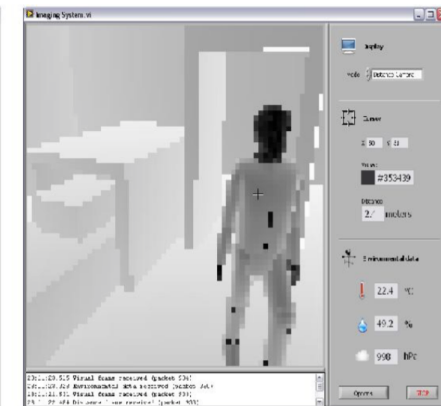
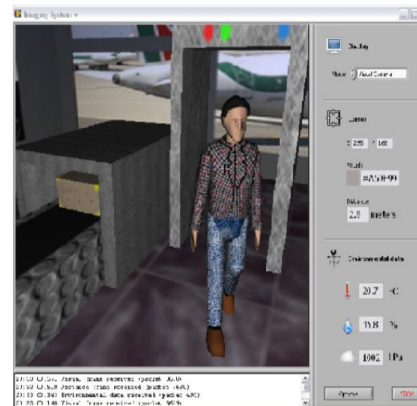
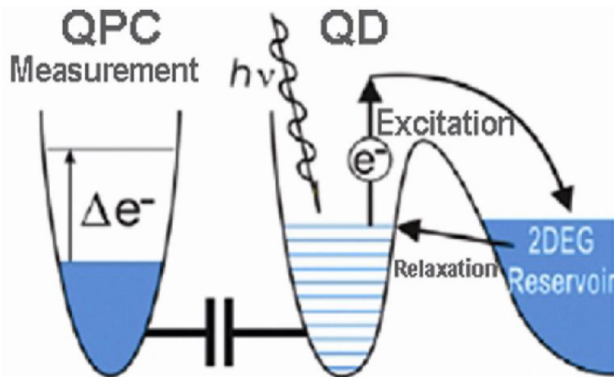


Figure 1.10 – Resulting image of passive spectroscopy.

THz detectors: my experience within TERA-EYE

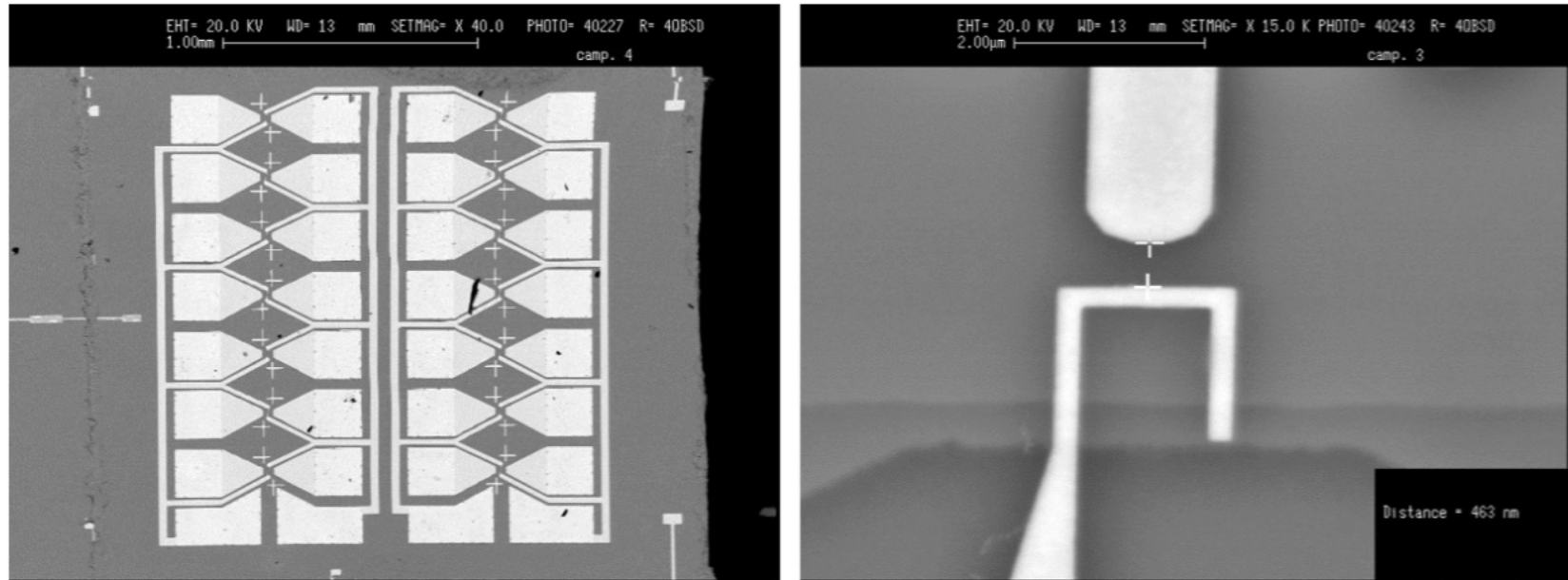
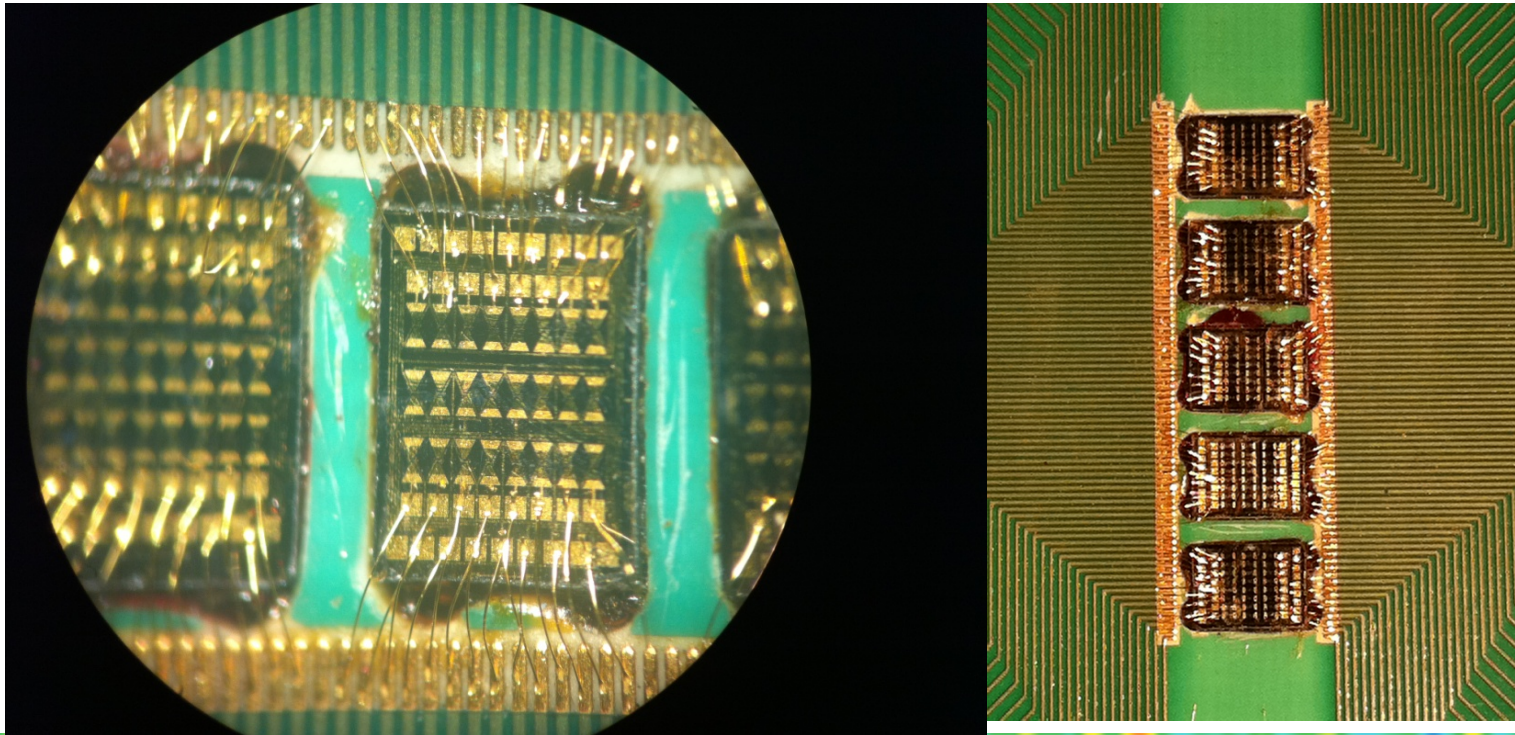


Figure 3.5 – On the left the whole array of sensor is presented, on the right the picture of one mesoscopic sensor in which gates define the point contact and the coupled dot. The image has been acquired with Scanning Electron Microscopy courtesy of Cristina Bernini, SPIN-CNR sez. Genova.

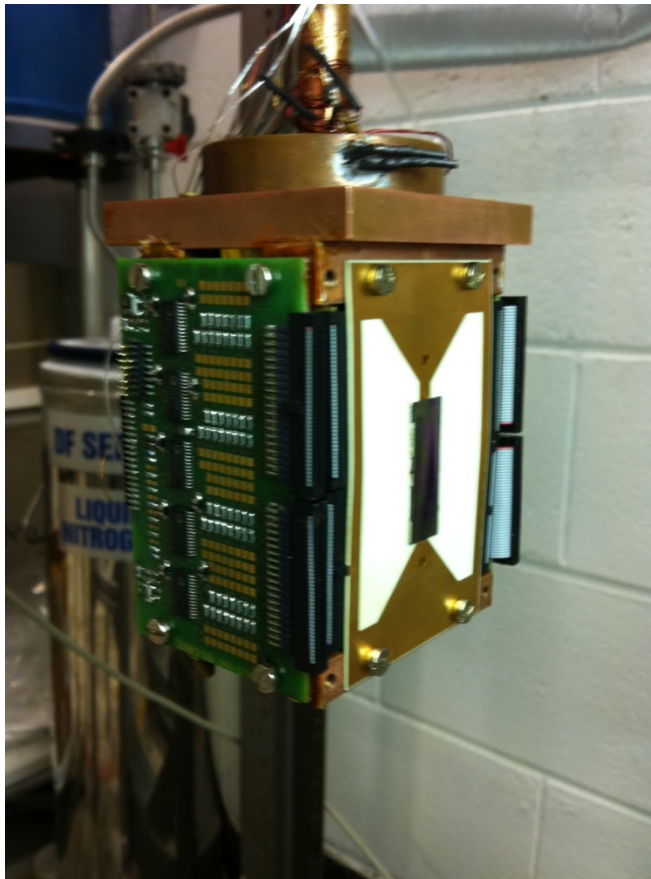
THz detectors: my experience within TERA-EYE

1. QPC detector Array (Fab.: Chalmers, Des.: Royal Holl. Univ. Lond., VTT, UniGenova)



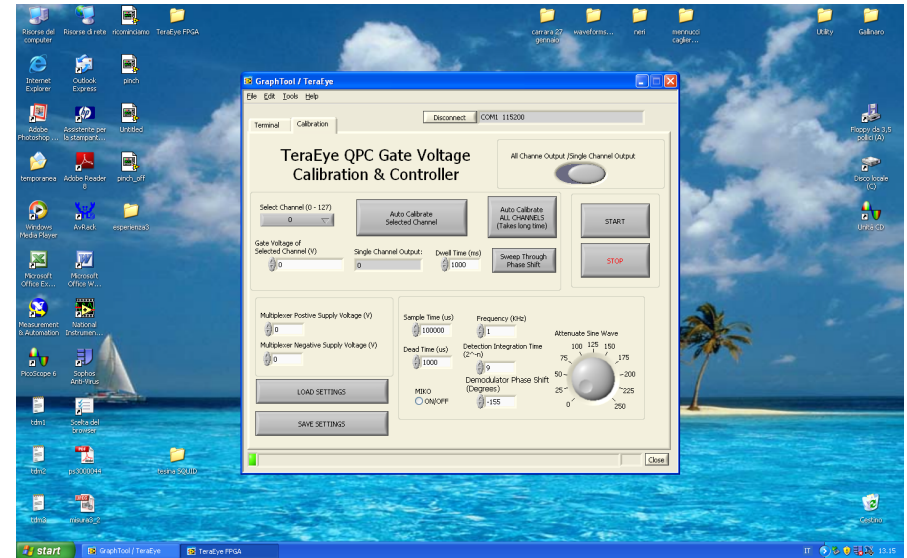
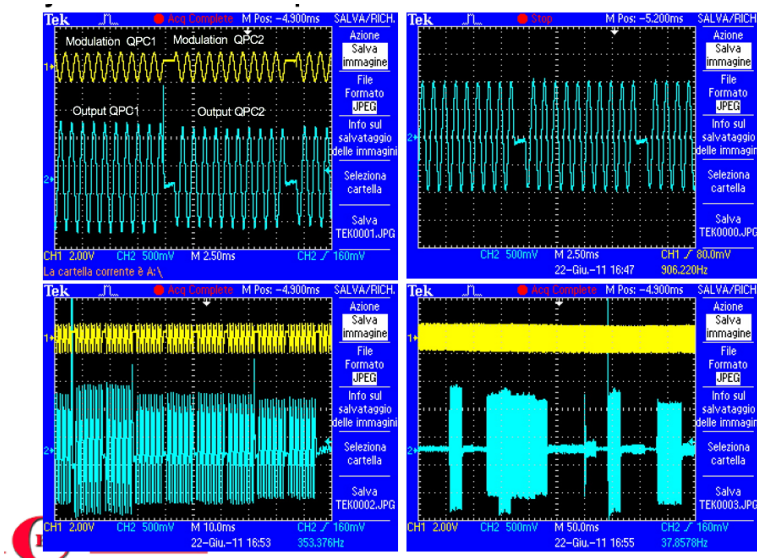
THz detectors: my experience within TERA-EYE

1. 1.5 K detector CMOS-TDM mux electronics (UniGe, VTT) and THz Fresnel lens (Un. Savoy)



THz detectors: my experience within TERA EYE

1. The Camera started and operated but not in passive mode
2. The only images taken were obtained with THz irradiation



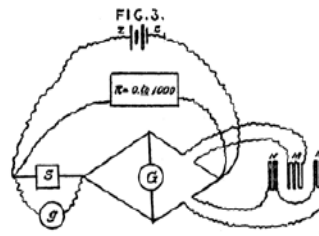
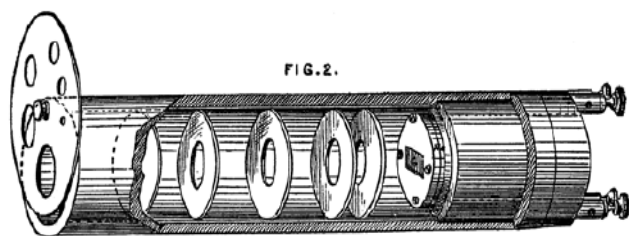
~~CONCLUSIONS~~ my experience within TERA-EYE

1. Almost 3 decades expertise in Low Temperature Detectors in INFN and 2 decades in TES detectors.
2. Presently a INFN groups are committed for providing the full detector-electronic chain (300 bolometers channels) for LSPE.
3. We hope for a successful ballon mission in the winter 2018-19.
4. Involvement in future projects is under the INFN plans.
5. Teaming up with Uni.Trento-TIFPA and FBK could allow:
 - a. Expertise exchange and design/fab. capability improvement
 - b. Large array productions
6. Nano-devices (TES or Qdot) should have sensitivity for single photon in sub THz and THz range.

Back up slide

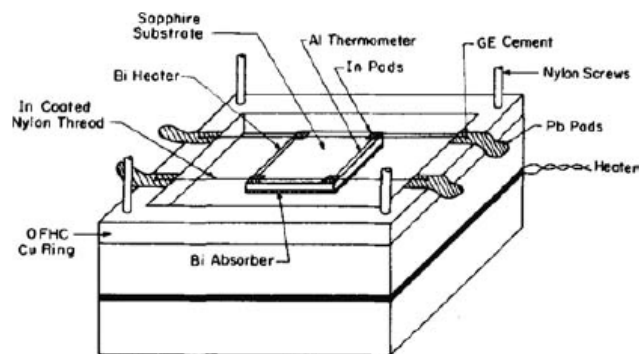
History

S. Langley, "The Bolometer," *Nature*, vol. 25, p. 14, 1881.



Clarcke et al. 1977

NEP $10^{-13} - 10^{-12}$ W/Hz



A Superconducting Bolometer as a High Sensitivity Detector for Molecular Beams

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Gruppo Nazionale di Struttura della Materia del C.N.R.
(Z. Naturforsch. 21 a, 1850-1851 [1969]; received 31 July 1969)

The construction, operation and calibration of a superconducting bolometer is reported. Operated as a molecular beam detector the bolometer has, for Argon, a maximum sensitivity of $7 \cdot 10^6$ molecules sec^{-1} corresponding to a N.E.P. of $3 \cdot 10^{-13}$ Watt Hz^{-1} .

The use of a liquid He cooled Ge infrared detector as a high sensitivity bolometer detector for molecular beams has been recently reported¹ and its usefulness in molecular scattering experiments has been shown^{2,3}.

The present note is intended to report on the construction, operation and calibration of a superconducting bolometer which, operated as a molecular beam detector, showed an order of magnitude improvement in signal to noise ratio compared with the previously used Ge bolometer.

A superconducting bolometer has been reported, almost ten years ago, by MARTIN and BLOOR⁴ which showed a noise equivalent power (N.E.P.) of about $3 \cdot 10^{-12}$ Watt Hz^{-1} (reflection coefficient $\alpha \approx 0.1$) with a time constant of about $50 \cdot 10^{-3}$ sec. The sensitive element was an evaporated tin film maintained at a fixed temperature, to within 10^{-3} °K, in its superconducting transition (around 3.7 °K). In this condition the film has a very large temperature coefficient of

resistance that can be used to transduce a chopped power input to a voltage output which may then be integrated with standard techniques.

Up to the present time the superconducting bolometer has not been widely adopted in infrared spectroscopy for two main reasons. The first is the difficulty of thermo-regulating the sensitive element within 10^{-3} °K, and the second is the extreme delicacy of its construction.

Taking into account that the N.E.P. of Martin and Bloor's bolometer was reported to be limited by the electronics available at that time, we undertook the development of a superconducting bolometer with the aim of solving the mechanical ruggedness problem by relaxing the requirement that the film, when operating, should be homogeneous in temperature.

Indeed the possibility of a superconducting thin film acting as a non isothermal bolometer is qualitatively quite obvious and has also been quantitatively discussed theoretically in the literature by FRANZEN⁵.

A superconducting bolometer of the non isothermal kind has also been reported by V.A. KONOVDCHENKO et al. at the 11th Low Temperature Conference (St. Andrews 1968). With respect to this point it should be noted, however, that it is not clear whether or not a non isothermal bolometer can be operated only in the way described by FRANZEN⁵. Indeed the transition curves obtained by us (see Fig. 1) were of the kind expected for a non isothermal element. Two types of operations are then possible: namely in the region a or in the region b. Region b corresponds to the type described by Franzen. If sufficient thermal stability is available one can operate in region a which, in our opinion, corresponds to a different non isothermal kind of opera-

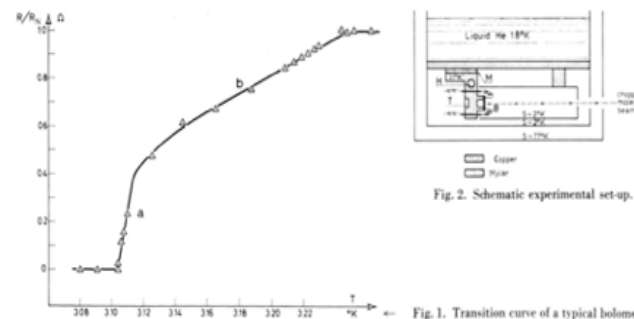


Fig. 2. Schematic experimental set-up.

Fig. 1. Transition curve of a typical bolometer.

Reprint requests to Dr. G. SCOLES, Istituto di Fisica Sperimentale dell'Università di Genova, Viale Benedetto XV, 5, I-16132 Genova, Italy.

¹ M. CAVALLINI, G. GALLINARO, and G. SCOLES, Z. Naturforsch. 22a, 413 [1967].

² P. CANTINI, M. CAVALLINI, M. G. DONDI, and G. SCOLES, Phys. Letters 27 A, 284 [1968].

³ M. G. DONDI, G. SCOLES, F. TORELLIO, and H. PAULY, J. Chem. Phys. 51, 392 [1969].

⁴ D. H. MARTIN and D. BLOOR, Cryogenics 1, 159 [1961].

⁵ W. FRANZEN, J. Opt. Soc. Am. 53, 596 [1963].