SAPIENZA
UNIVERSITÀ DI ROMA

INFN Istituto Nazionale di Fisica Nucleare

CNR IFN Istituto di Fotonica e Nanotecnologie

Lumped Element Kinetic Inductance Detectors for the W Band

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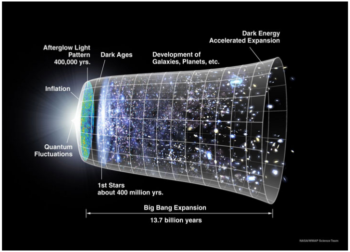
Roma
22nd September 2015

Cosmic Microwave Background

- The Cosmic Microwave Background (CMB) is the oldest light in the Universe, dating to the epoch of Recombination (about 380 000 years after the Big Bang).
- All the information encoded in the map of the CMB are contained in the angular power spectrum



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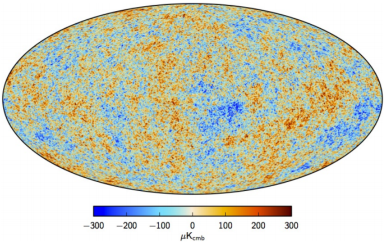
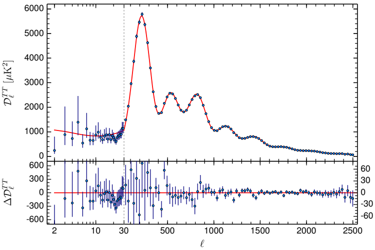
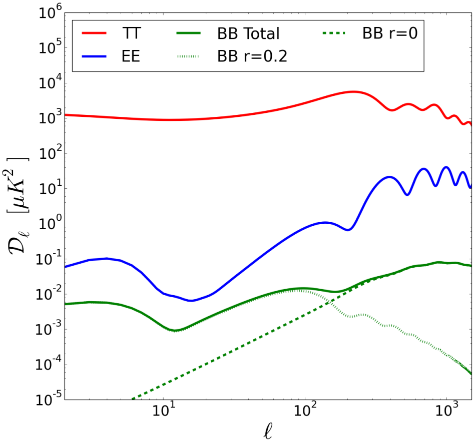




Cosmic Microwave Background

- CMB polarization measurements are of special interest because they would bring important confirmation to the theory of inflation and gravitational waves.
- Planck spider-web bolometers were able to measure the E modes, but not the B modes.
- Low Temperature spider-web bolometers work in BLIP condition, so such a gain has to arise from larger focal planes, with arrays of thousands of independent detectors $\Rightarrow$ MULTIPLEXING.



Thanks to Luca Pagano

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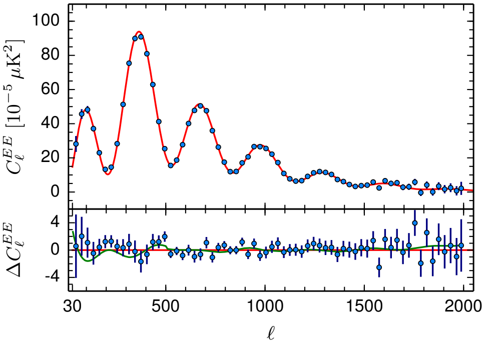

Planck Collaboration 2015,
Planck 2015 results. XIII.

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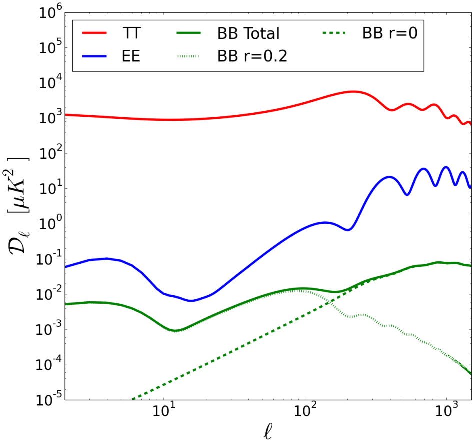

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The W Band

Why the W Band?

- The W-band lies at an interesting transition between frequencies where Galactic emission is dominated by free-free and synchrotron, and frequencies where is dominated by dust.
- In this band, the atmosphere is quite transparent, and then we can perform ground-based observations, avoiding the costs, complications and size limitations of balloon-borne and space-based missions.

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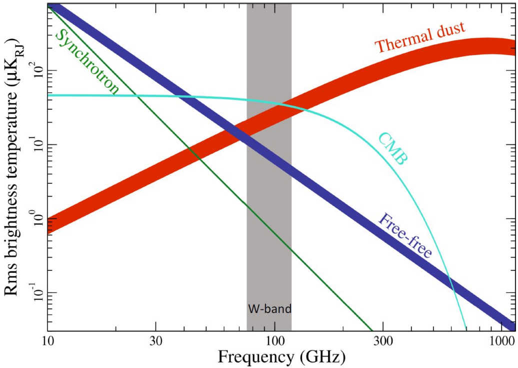

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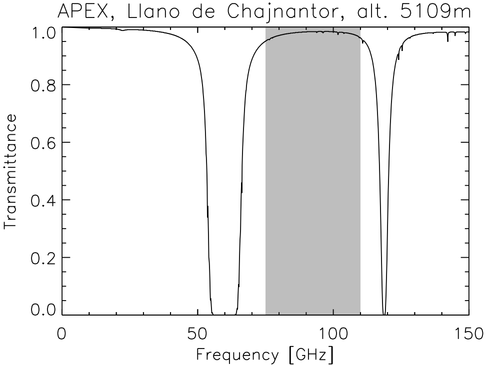
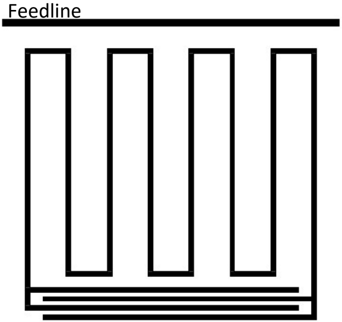
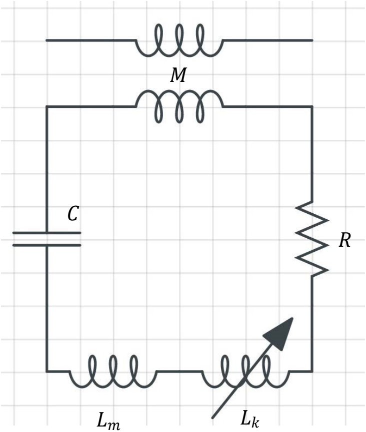


What KIDs are





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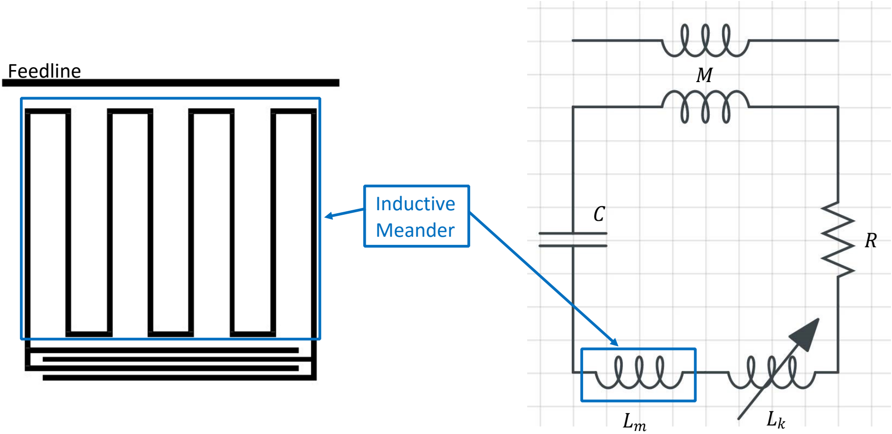

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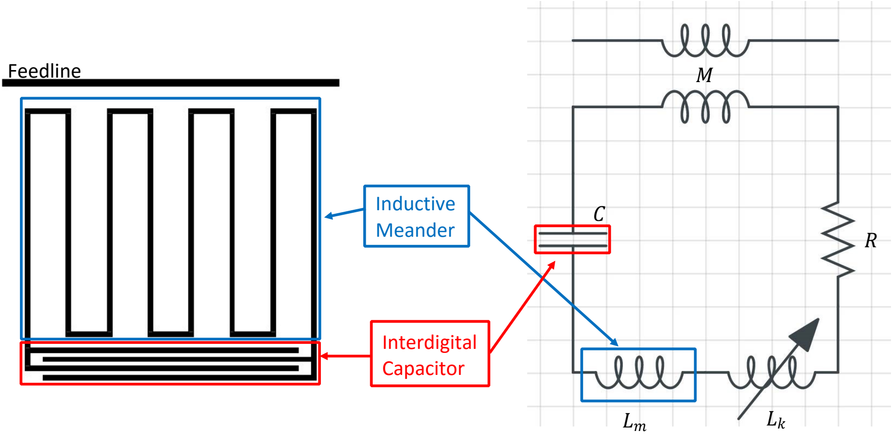

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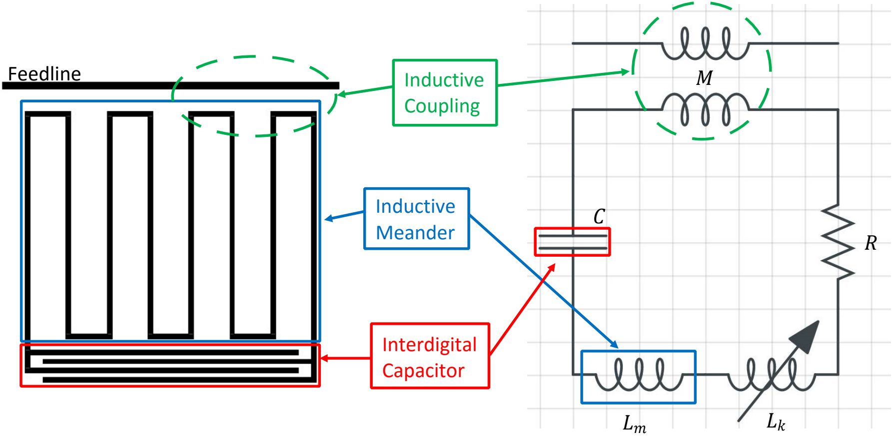

How KIDs work

Which are the effects of incoming radiation?

- A Kinetic Inductance Detector works on the principle that incident photons, with enough energy to break Cooper pairs ($h\nu > 2\Delta$), change the surface impedance of a superconductor (Z_s).
- In particular, the photons absorbed in the superconductor break the Cooper pairs producing quasi-particles (n_{qp}), and the rise in quasi-particle density results in a change of the kinetic inductance (L_k).
- This change can be accurately measured using a thin film superconducting resonant circuit, and sensing the change in amplitude and in phase of a microwave signal transmitted through the resonator.

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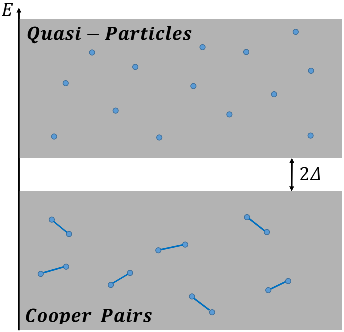

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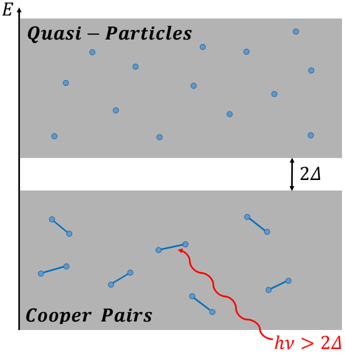

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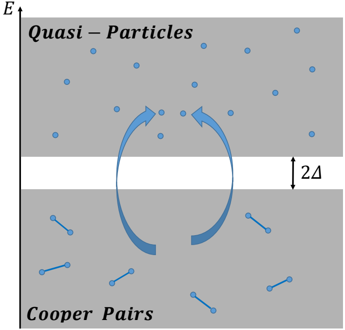
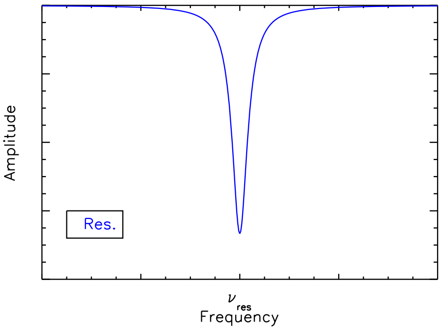
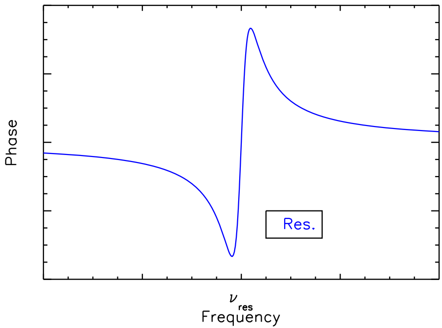


How KIDs work

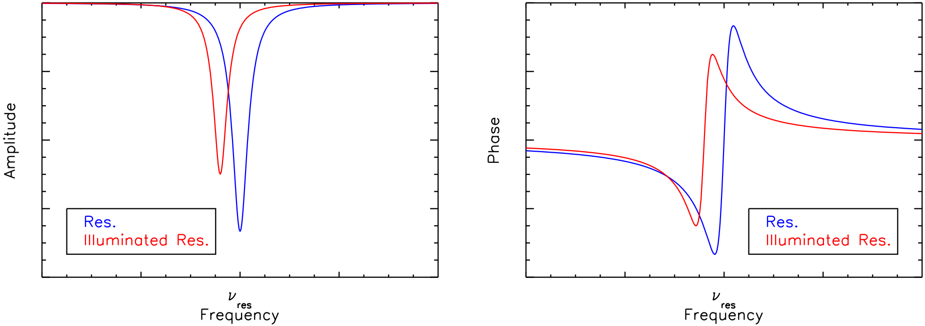
When photons, with $h\nu_\gamma > 2\Delta$, hit the KID . . .





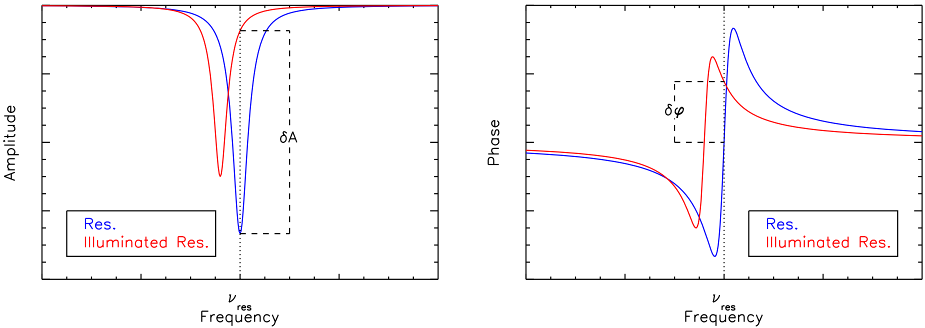
How KIDs work

$$\ldots n_{qp} \uparrow \quad \Rightarrow \quad \begin{cases} L_k \uparrow \\ R_s \uparrow \end{cases} \quad \Rightarrow \quad \begin{cases} \nu_{res} \propto 1/\sqrt{LC} \downarrow \\ Q \propto \frac{1}{R_s}\sqrt{\frac{L}{C}} \downarrow \end{cases} \quad \ldots$$



How KIDs work

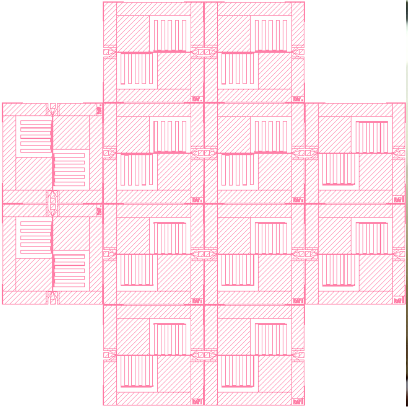
$$\ldots \quad \frac{\delta\varphi}{dN_{qp}} = \text{responsivity.}$$



Fabrication

Our prototypes are fabricated at the Istituto di fotonica e nanotecnologie (IFN), of the Consiglio Nazionale delle Ricerche (CNR).

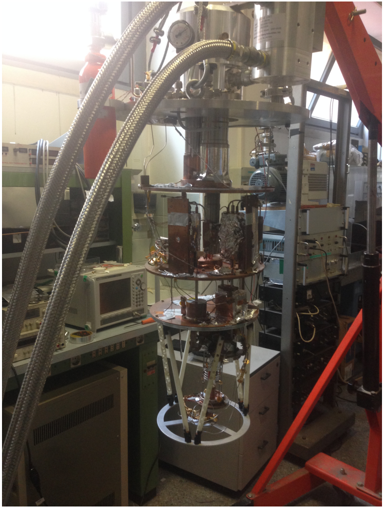
CNR IFN
Istituto di Fotonica e Nanotecnologie



Experimental Setup

The experimental setup is composed of

- the cryogenic system, necessary to reach the optimum working temperature;
- the optical system, necessary to remove the non interesting radiation and to focus the interesting radiation on the detectors;
- the data acquisition system, with which we can investigate the electrical and the optical characteristics of the resonators;
- the thermometers and the control unit, with which we can read the temperature and power the heaters.



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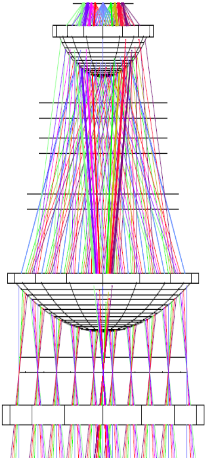

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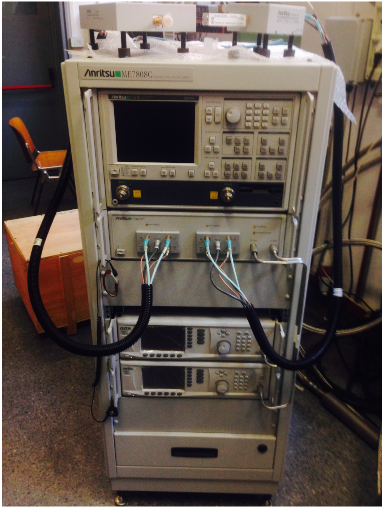

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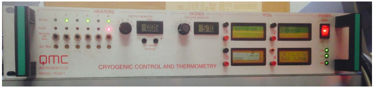

FULL | BRIEF | CONTROL | MESSAGES | RECYCLE | SERVICE

Full Dewar Readout

Channels	Ch.1	Ch.2	Ch.3	Ch.4	Ch.5	Ch.6	Ch.7	Ch.8
Diodes A	66.71 K	6.729 K	6.782 K	63.73 K	4.086 K	4.640 K	42.28 K	3.601 K
RTD 1–4	3.405 K	3.143 K	2.456 K	2.471 K				
Channels	Ch.1 (V)	Ch.2 (V)	Ch.3 (V)	Ch.4 (V)	Ch.5 (V)	Ch.6 (V)	Ch.7 (V)	Ch.8 (V)
Diodes A	1.045	1.612	1.608	1.050	1.750	1.726	1.088	1.795
Channels	V1 (μV)	V1q (μV)	I1 (nA)	R1 (Ω)	V2 (μV)	V2q (μV)	I2 (nA)	R2 (Ω)
RTD 1–2	33.750	0.350	9.9750	3.3752k	34.725	1.450	7.4700	3.4755k
Channels	V3 (μV)	V3q (μV)	I3 (nA)	R3 (Ω)	V4 (μV)	V4q (μV)	I4 (nA)	R4 (Ω)
RTD 3–4	22.875	1.050	998.75	22.899	37.500	2.550	9.8025	3.7587k

Heater Control

Heater	Set V	Status
CP4He	7.00	Ok
HS4He	0.00	Ok
CP3He	7.00	Ok
HS3He	0.00	Ok
FP HSCP	0.00	Ok
MDR Still	0.00	Ok

Update Reset Save

Settings

Measurements

- We measured the critical temperature to know if our detectors work in the W-band:

$$h\nu = 2\Delta \approx 3.5 k_B T_c \ ;$$

- we performed electrical tests in order to find the resonance frequency and the quality factors of our detectors;
- we performed optical tests in order to measure the responsivity and the noise.

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Critical Temperature

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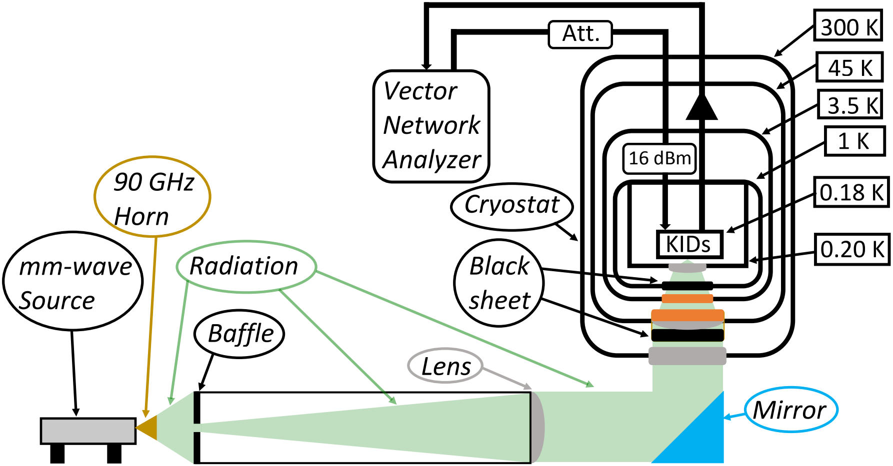
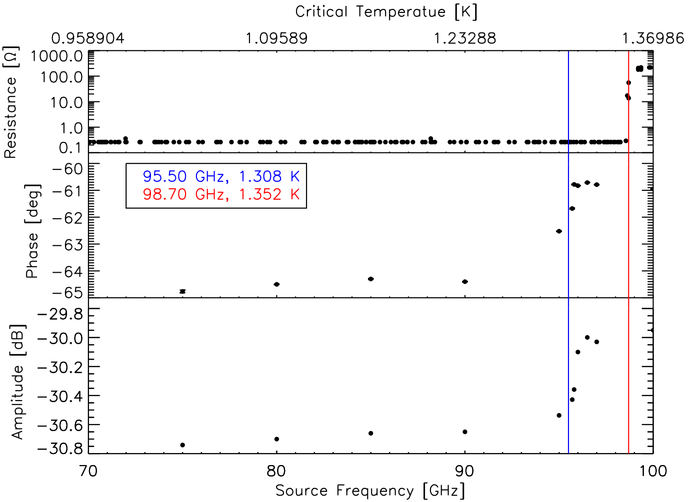
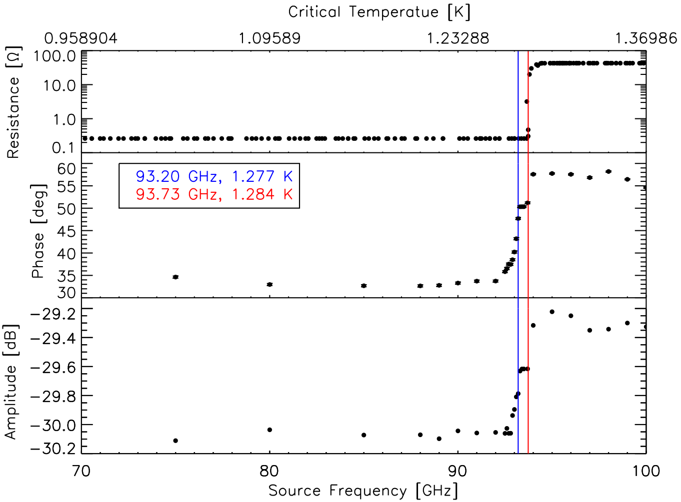


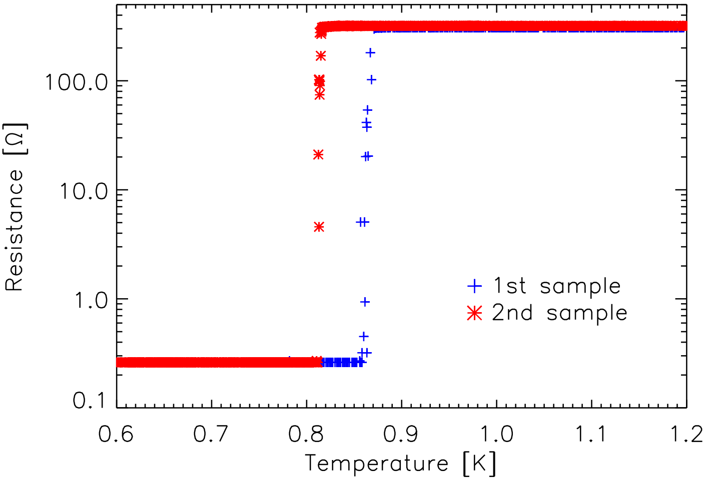
Critical Temperature: Al 40 nm



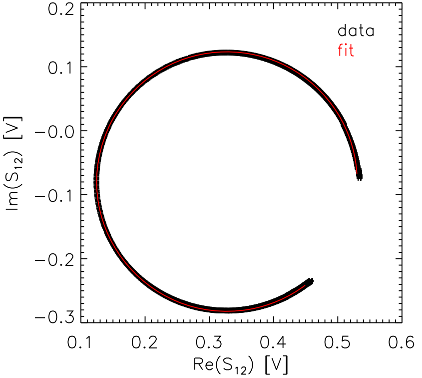
Critical Temperature: Al 80 nm



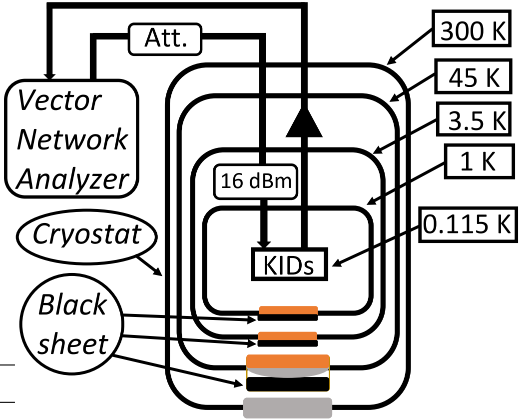
Critical Temperature: 10 nm Ti + 25 nm Al



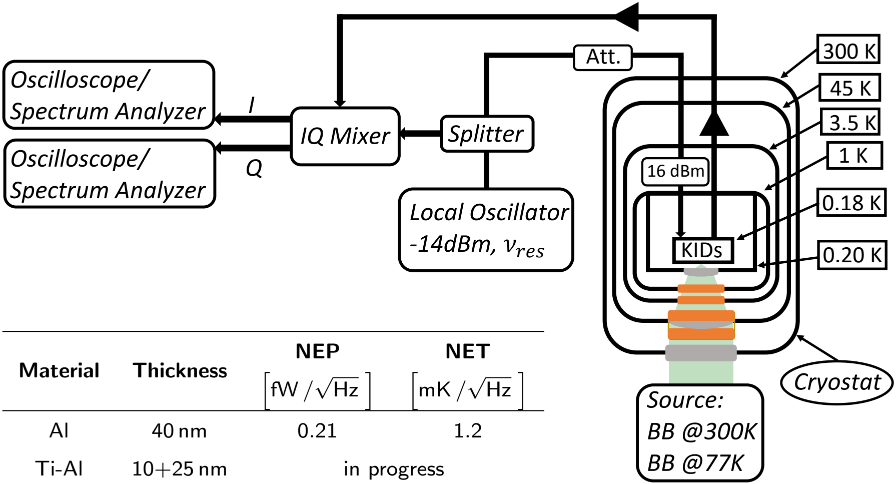
Electrical Test



Material	Thickness	Q_i	Q_e
Al	40 nm	82 958	26 447
Ti-Al	10+25 nm	28 632	22 144



Optical Test

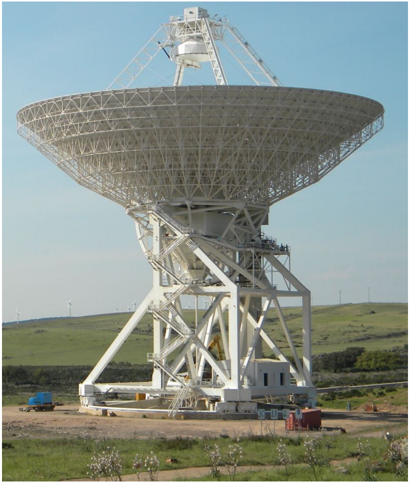


Material	Thickness	NEP $\left[\mathrm{fW}/\sqrt{\mathrm{Hz}}\right]$	NET $\left[\mathrm{mK}/\sqrt{\mathrm{Hz}}\right]$
Al	40 nm	0.21	1.2
Ti-Al	10+25 nm	in progress	

Sardinia Radio Telescope

Cruciani et al., PoS TIPP2014 (2014) 129

- We have studied the possibility to integrate an array in the focal plane of the 64 m−Sardinia Radio Telescope (SRT).
- In order to define the main requirements of the detectors, it is necessary to characterize the background on the devices and the consequent Noise Equivalent Power (NEP).
- We estimated the background emission in a band between 80 and 100 GHz considering different contributions:
  - the atmosphere,
  - the mirrors,
  - the optical window of the experiment and the CMB.



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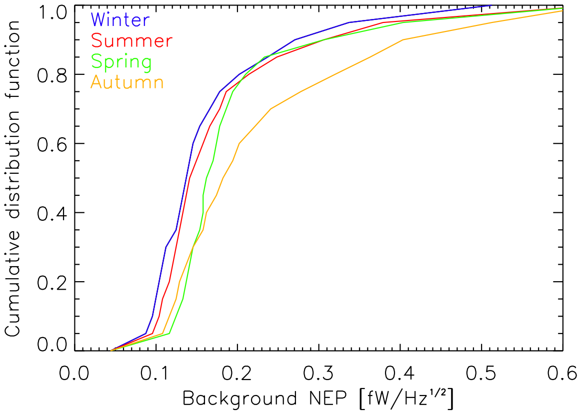
Cruciani et al., PoS TIPP2014 (2014) 129



The main requirement is that the detector should have NEP $\sim 0.1\,\mathrm{fW}/\sqrt{\mathrm{Hz}}$.

Conclusions

- Our purposes are to design, fabricate and test LEKIDs able to work in the W-Band ($75 \div 110\,\text{GHz}$).
- We tested prototype with different Al thickness (40 and 80 nm): these are not suitable to cover the whole W-band.
- The use of Ti-Al bi-layer allows us to cover frequencies greater than 60 GHz.
- We are now performing the optical characterization of Ti-Al LEKID.
- In the same time, we are developing LEKIDs for the D-Band ($110 \div 170\,\text{GHz}$).

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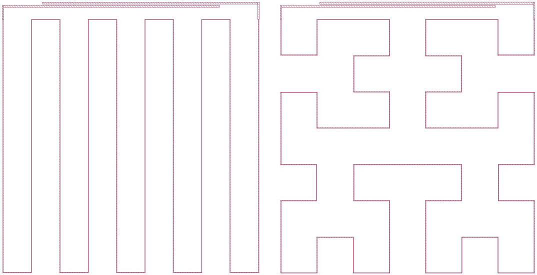

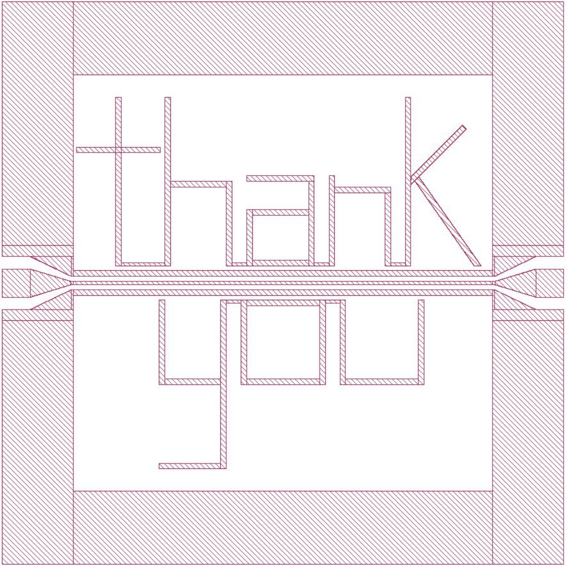
thank
you