Optimization of LEKIDs for NIKA: a dual band kinetic inductance camera for the IRAM 30 m telescope

Lumped Element KID Array

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Antenna coupled quarter wavelength KID Array

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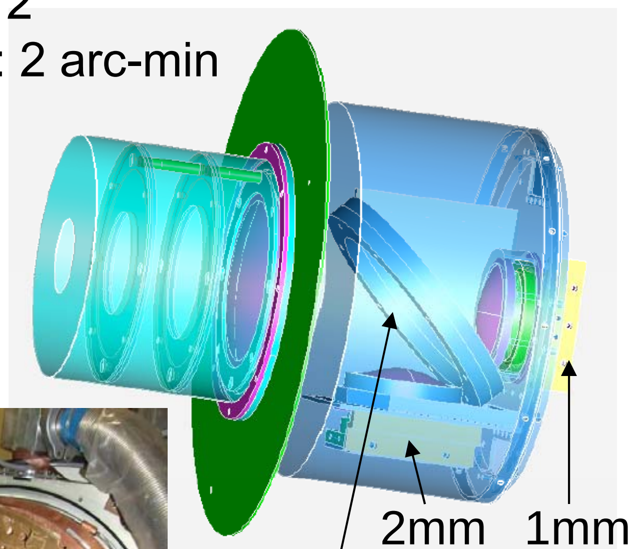
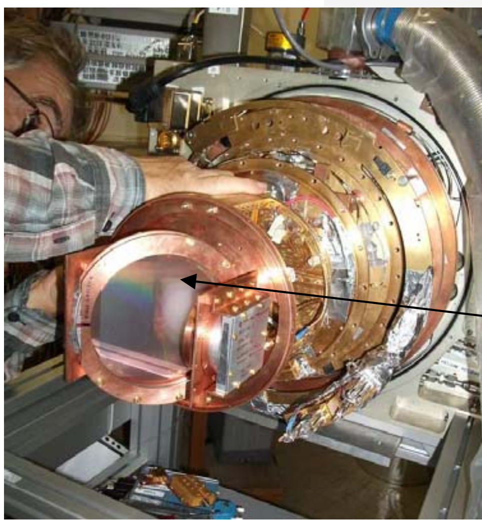
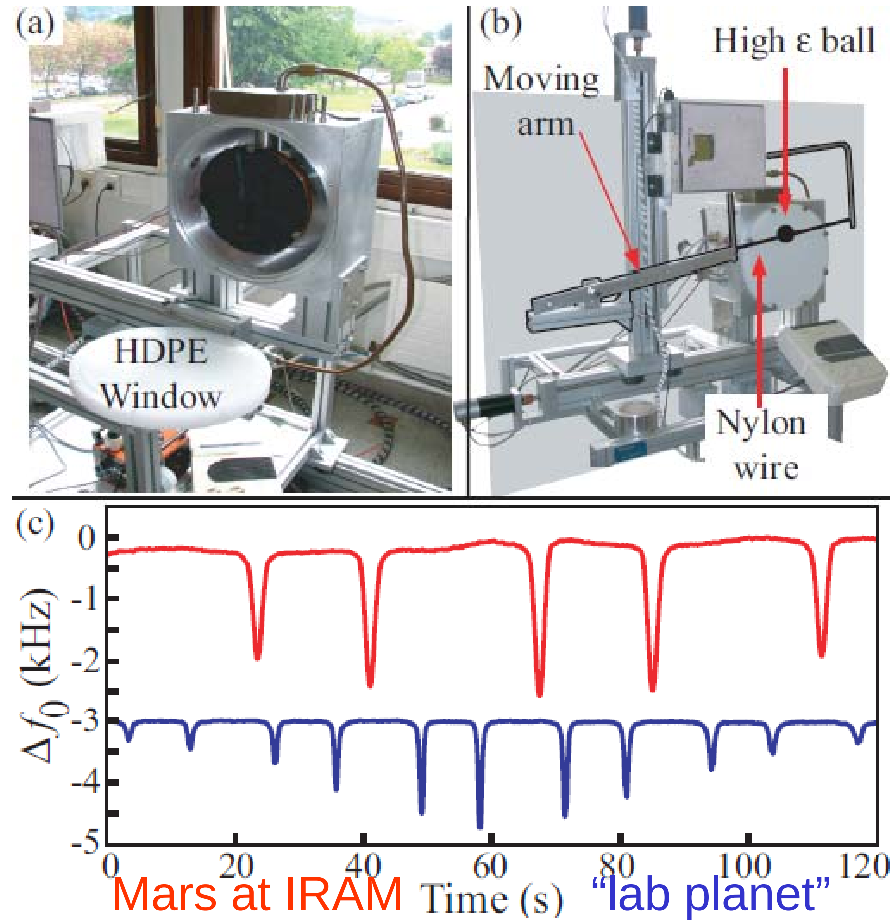
The NIKA2 camera and sky simulator

H3H4 cryogen free dilution fridge
Bands : 1.25 and 2.05 mm
Pixels : 132 x 2
Field-of-view : 2 arc-min
T_{base} = 60mK



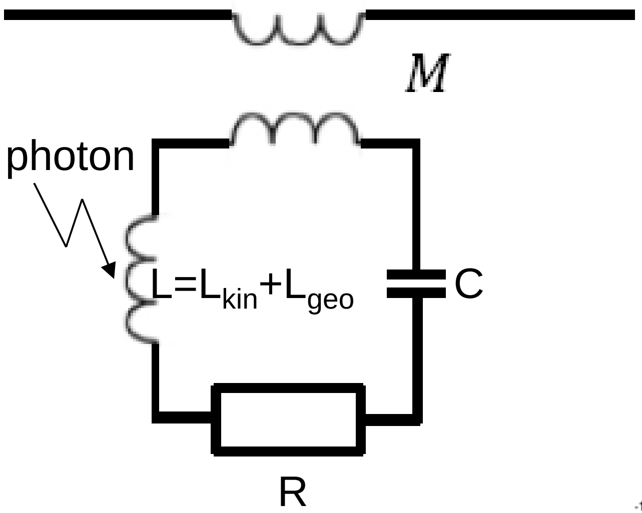


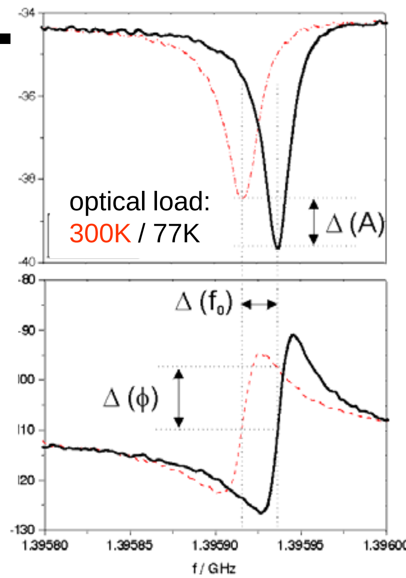
Pulse tube cryostat with black body
Temperature range: 50 – 300 K



A. Bideaud, PhD thesis, 2010

The NIKA 2-mm LEKID array

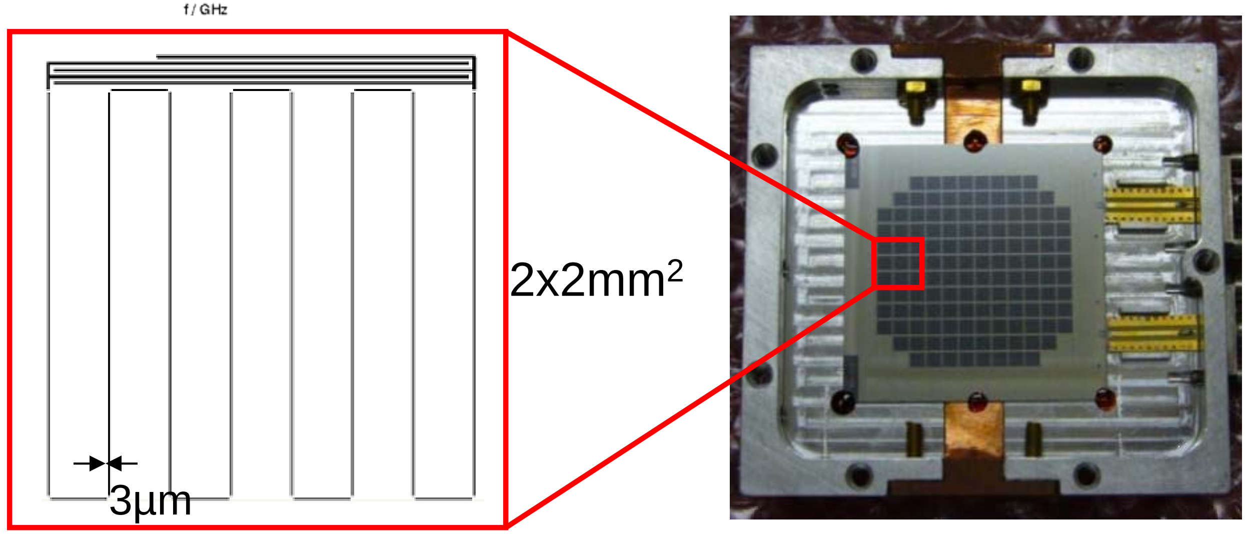




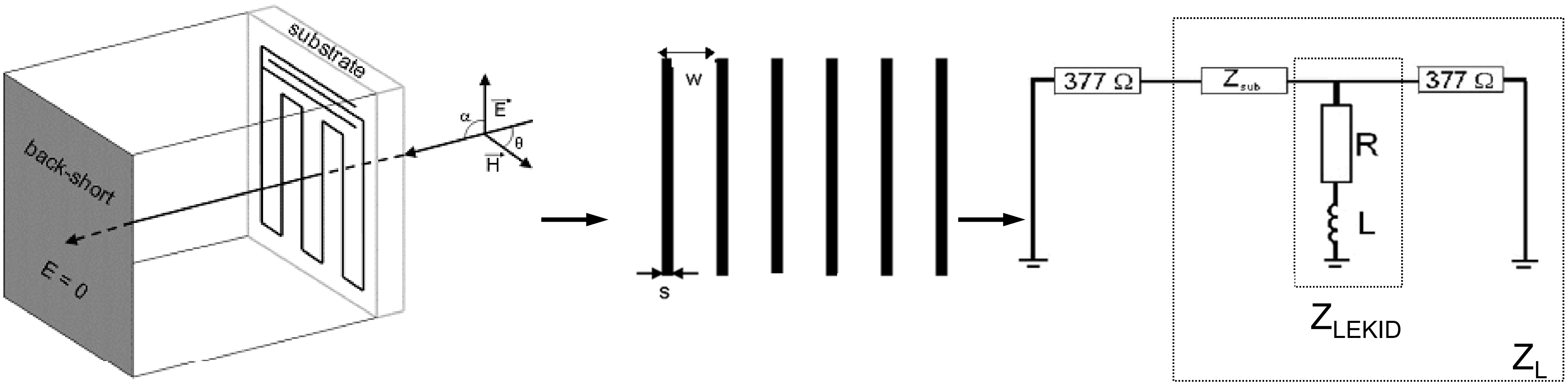
Lumped Element KIDs (Doyle, PhD thesis, 2008)

- discrete capacity and inductance
- constant and high current density in inductive part
- frequency tuning by changing the finger length
- direct absorption area
- matching to free space impedance
  → optimizing the optical efficiency

- Material: aluminum
- Thickness: 20 nm
- Substrate: high resistive silicon
- number of pixels: 132
- sample holder: aluminum
- not visible: back-short



Optical coupling of LEKIDs



$$Z_{substrate} = \frac{Z_{FS}}{\sqrt{\varepsilon_r}} = \frac{120\,\pi\Omega}{\sqrt{\varepsilon_r}}$$

$$Z_{LEKID} = R + j\omega L = \frac{R_{sheet}}{s/w} + j\frac{w}{\lambda}\ln\csc\left(\frac{2w}{\pi s}\right)Z_0$$

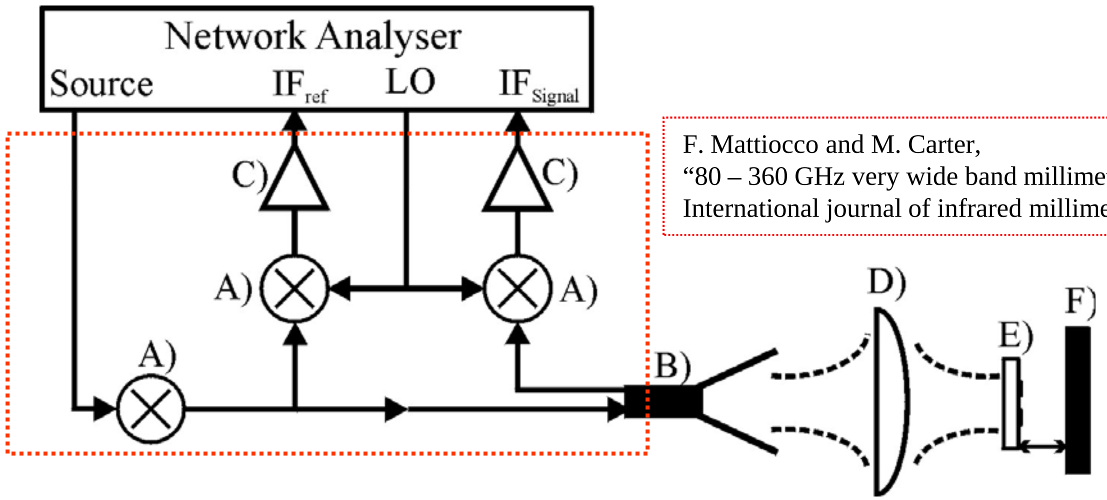
Ulrich, Infrared physics, vol. 7, pp. 37-57, 1967
Marcuvitz, Microwave Handbook

$$|\underline{S}|_{11} = \frac{|Z_L - Z_0|}{|Z_L + Z_0|}$$

$$absorption = 1 - |\underline{S}_{11}|^2$$

Reflection measurements at room temperature

Assumptions:
- detection = absorption
- el. properties are comparable to cryogenic case (150 GHz > 90 GHz gap frequency of aluminum)
- resistivity can be adapted by RRR factor



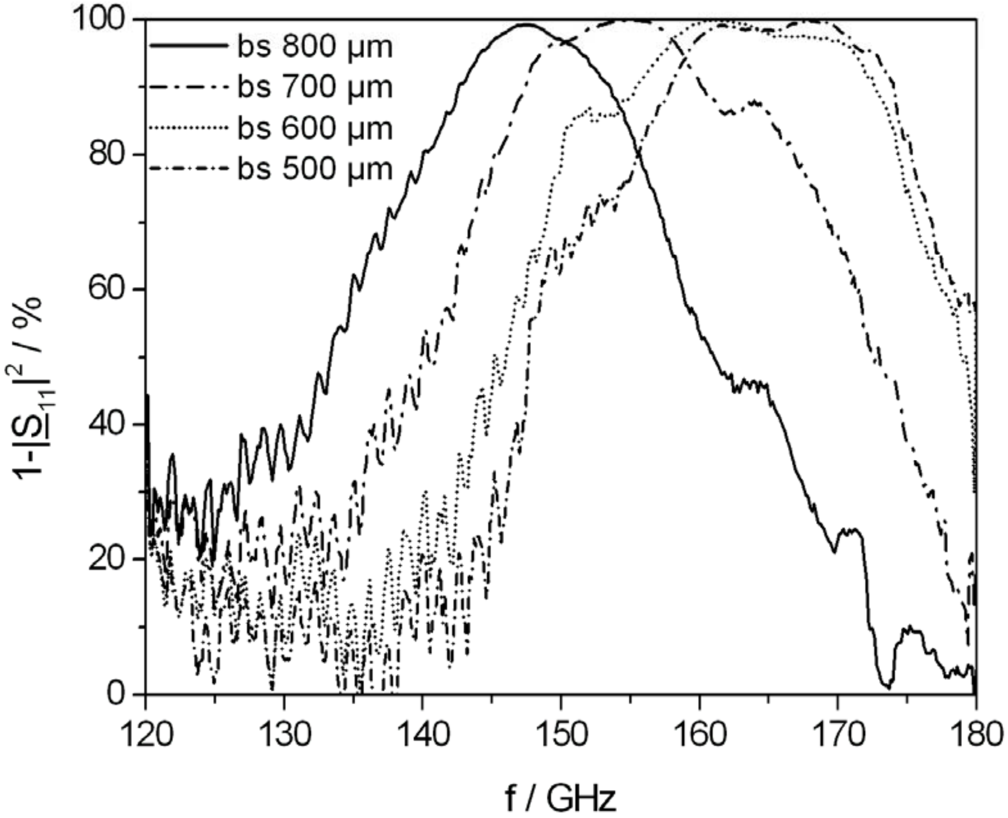
F. Mattiocco and M. Carter,
"80 – 360 GHz very wide band millimeter wave network analyzer",
International journal of infrared millimeter waves, Vol. 16, No. 12, 1995.

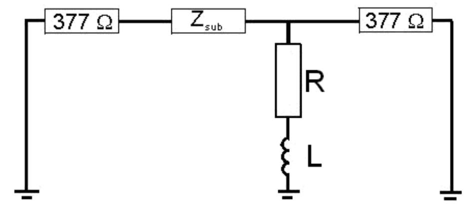
- frequency band: 120 – 180 GHz
- only one polarization measurable
- only first mode measurable
- side lobes are not considered
- radiation in different polarizations are not considered

A) Harmonic mixer
B) Corrugated feed horn
C) Amplifier
D) Corrugated lens
E) Sample
F) Back-short

Reflection measurement results

Back-short dependence of optical coupling





- 40 nm aluminum film

→ R_{sheet} = 1.3 ohm
→ R = 90 ohm with s/w=(69)^-1
→ L = 200 pH

This corresponds to a 25 nm aluminum film at a temperature just above $T_{C,al}$ = 1.2 K

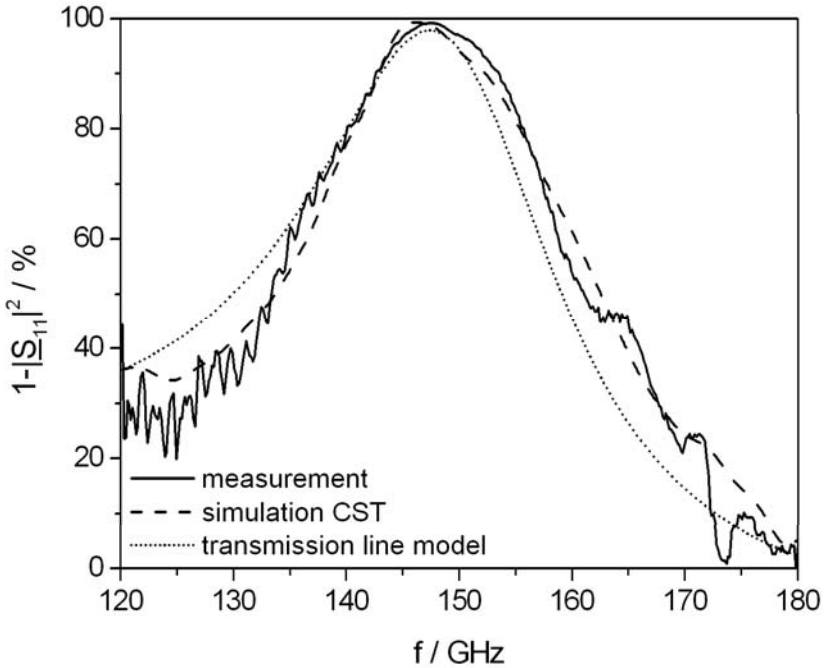
- 300 µm high resistivity substrate

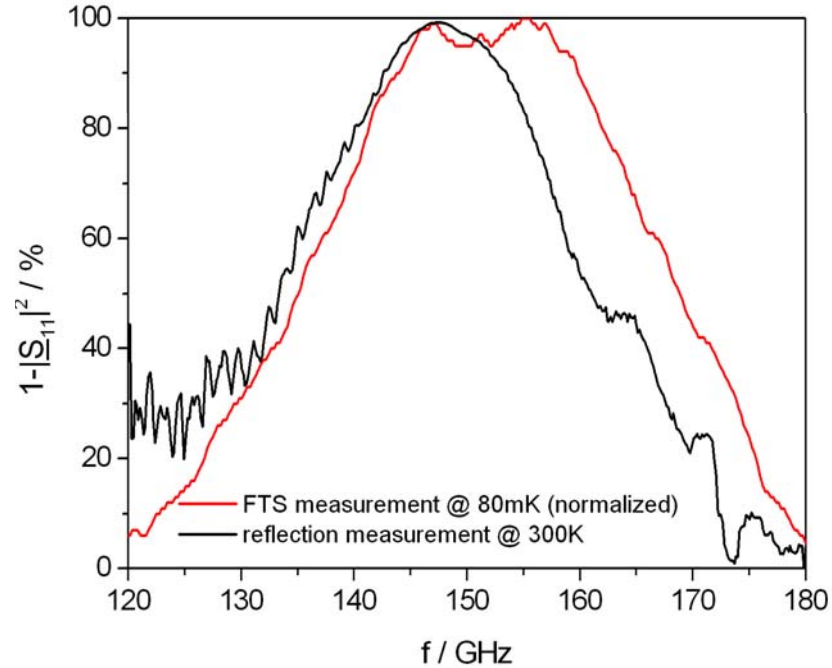
Measurement and simulation

Comparison of reflection measurement, simulation and transmission line model

Comparison of reflection measurement and FTS measurement at 100 mK in camera

A. Bideaud, thesis, 2010
A. Monfardini et al, ApJ, 2011



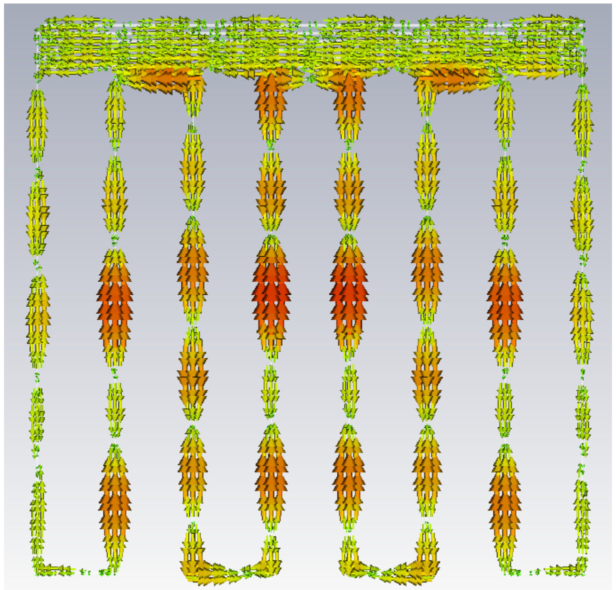


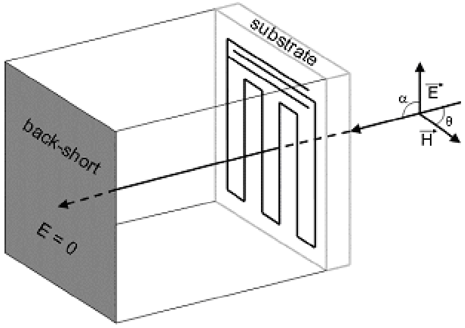
Simulation of current distribution in LEKIDs

Excited current distribution from absorbed mm-wave at 150 GHz

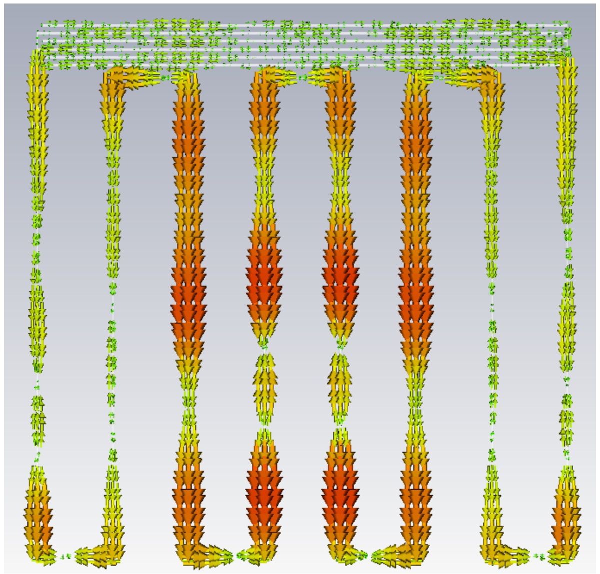
(This is not the current distribution due to the coupled energy from the transmission line at ~1.5 GHz when the resonators is on resonance !)

Phase: 0 deg





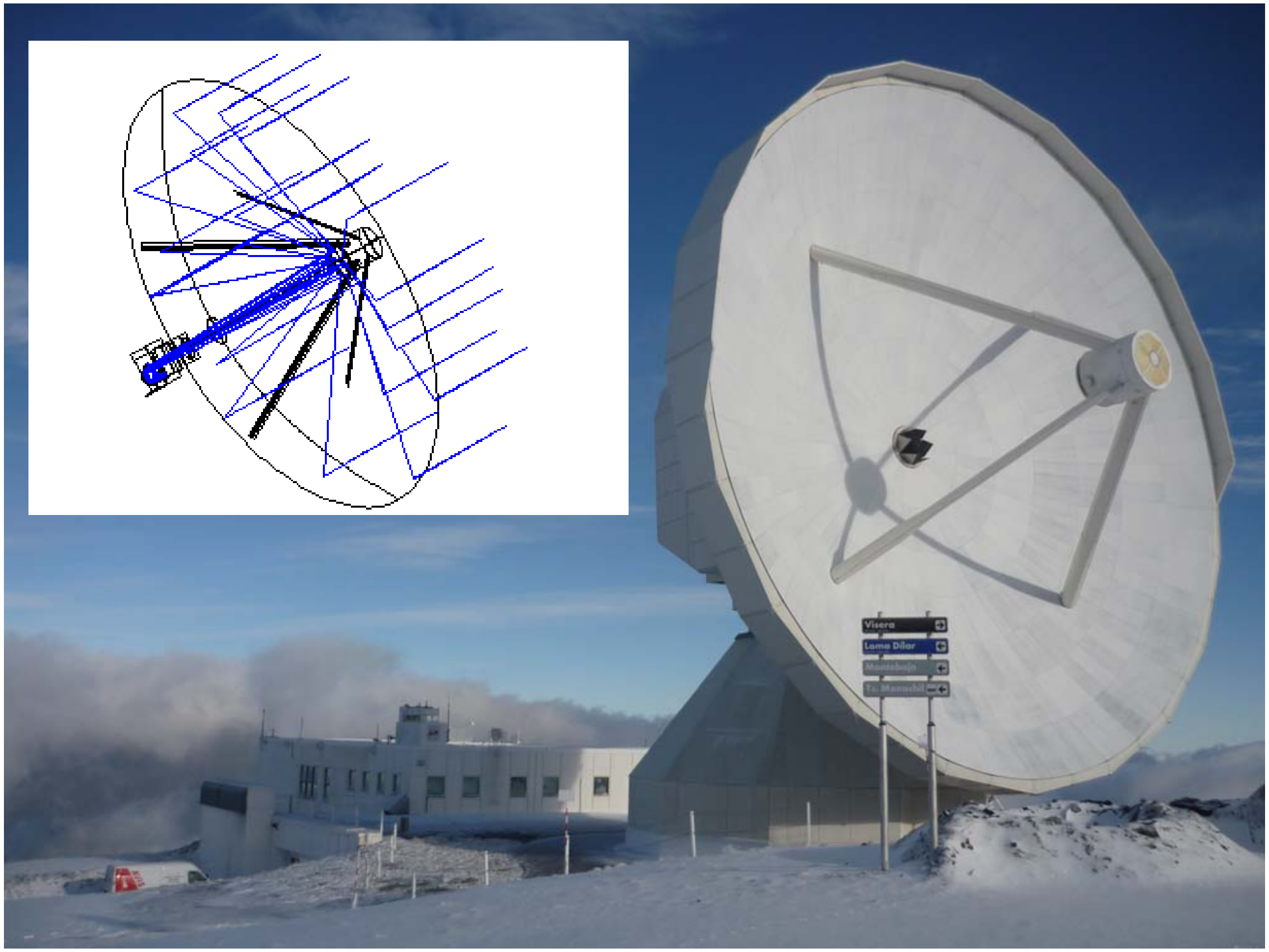
Phase: 90 deg



Current distribution varies with the phase of the incoming mm-wave

Current in strips that are orthogonal to the el. field vector is small
→ Error due to radiation in different polarizations is small

The IRAM 30m telescope at Pico Veleta, Spain

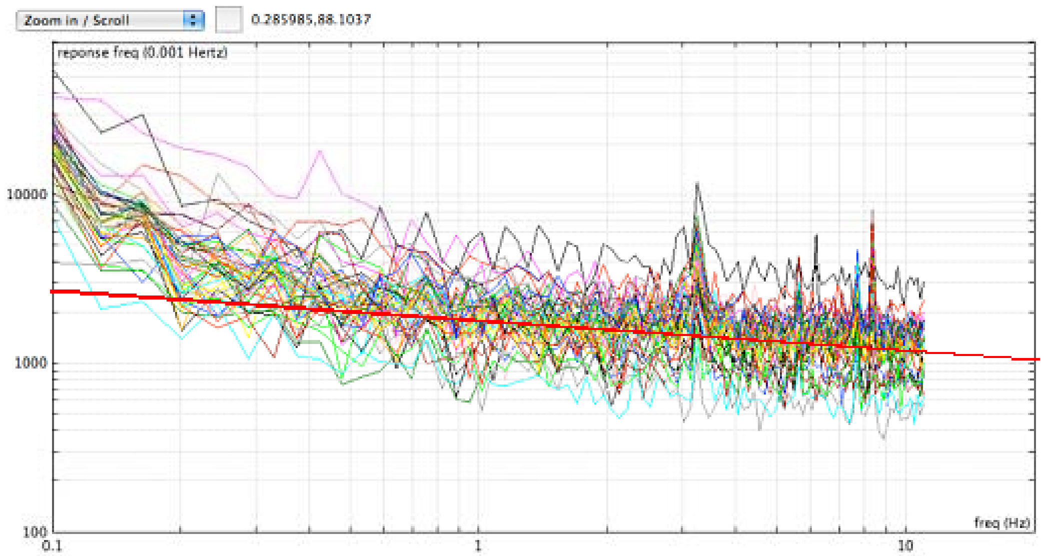


- Sierra Nevada, Spain
- altitude: 2900 m
- primary dish: ∅ 30 m
- secondary dish: ∅ 2 m

Working Bands:

3mm (100 GHz)
2.05mm (146 GHz)
1.25mm (240 GHz)
0.87mm (345 GHz)

2nd test run at the IRAM 30 m telescope October 2010



Phase noise spectrum of LEKIDs at the 2mm band

- Phase noise relatively flat (under excellent sky conditions) ~ 1 / $f^{0.15}$

- avg. NEP = $2.3 \cdot 10^{-16}$ W/√Hz @ 1 Hz per pix

- NEFD = 37 mJy*$s^{0.5}$ per pix

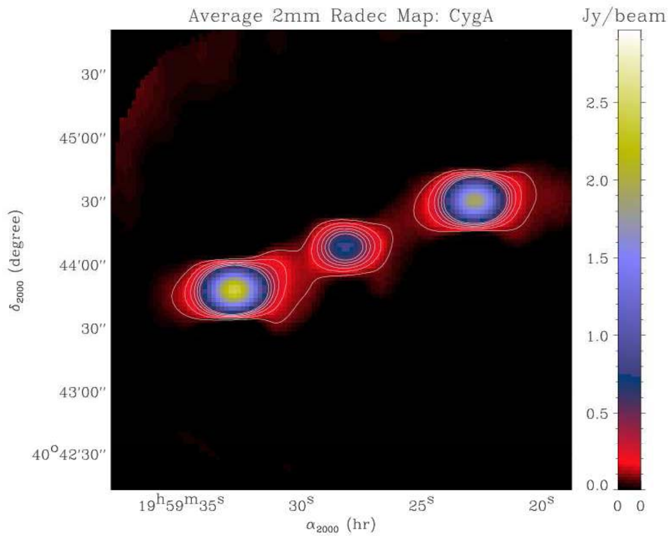
- Problems due to pixel cross-talk

- Photometry error ~ 20 %

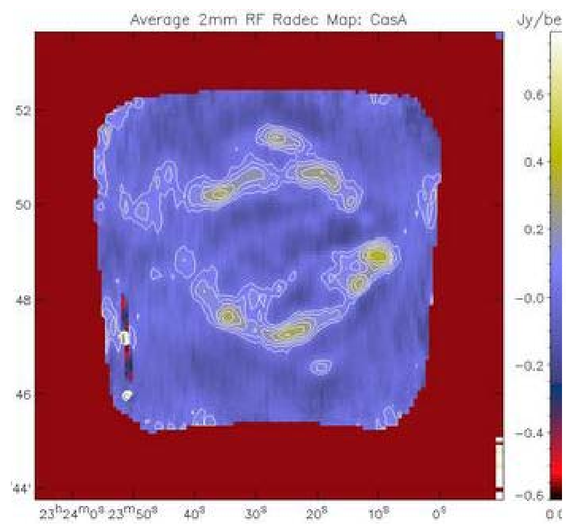
Monfardini et al, "A dual-band mm-wave KID camera for the IRAM 30 m telescope", ApJ, 194, 24 2011

Observed sources at 2 mm with LEKIDs

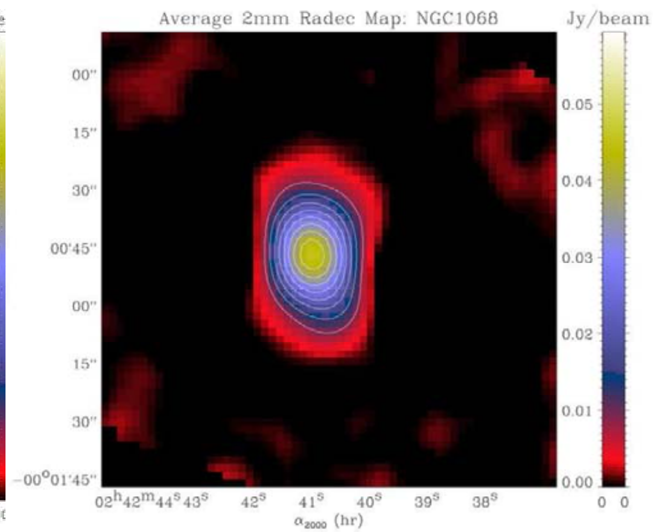
CygA



CasA



NGC 1068



Integration time: 2200 sec
Max. 2,47 Jy/beam

Max. 600 mJy/beam

Integration time: 1260 sec
Max. 66 mJy/beam

Monfardini et al, "A dual-band mm-wave KID camera for the IRAM 30 m telescope", ApJ, 194, 24 2011

LEKID geometry for 2 polarizations

- constant filling-factor over the whole direct detection area
- reasonable filling factor for optimal optical coupling
- symmetrical geometry:
  - same optical coupling for horizontal and vertical orientation
  - symmetrical current distribution

Hilbert curve

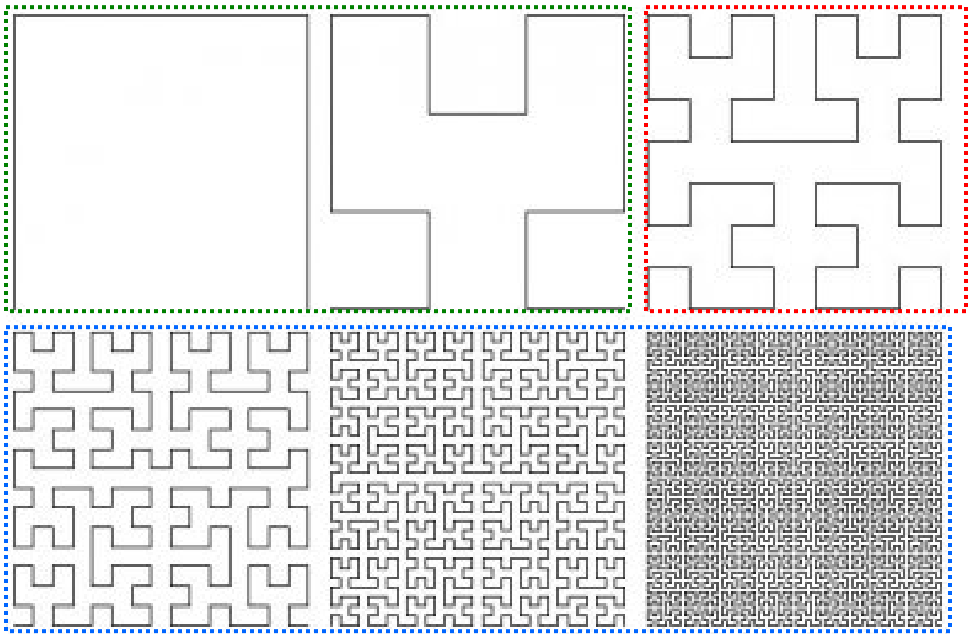
filling factor too low:
→ Z_{LEKID} too high

↑

for aluminum

↓

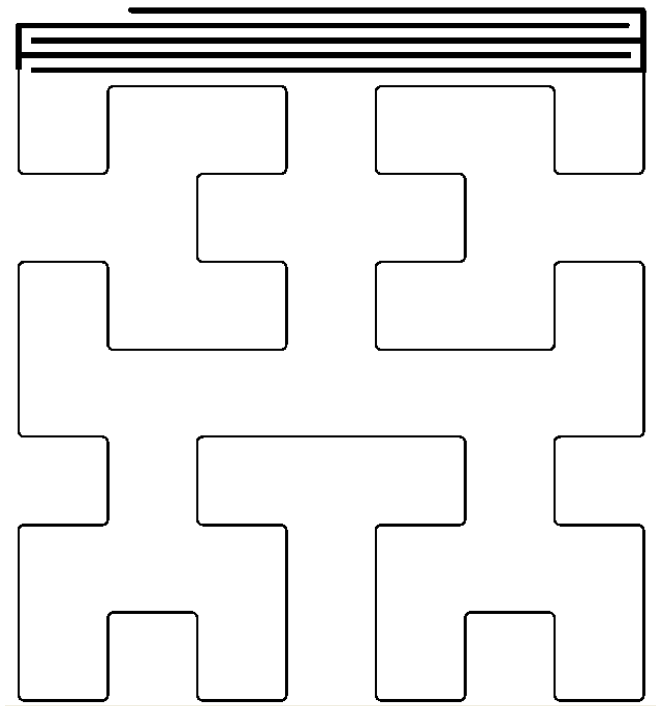
filling factor too high:
→ Z_{LEKID} too low



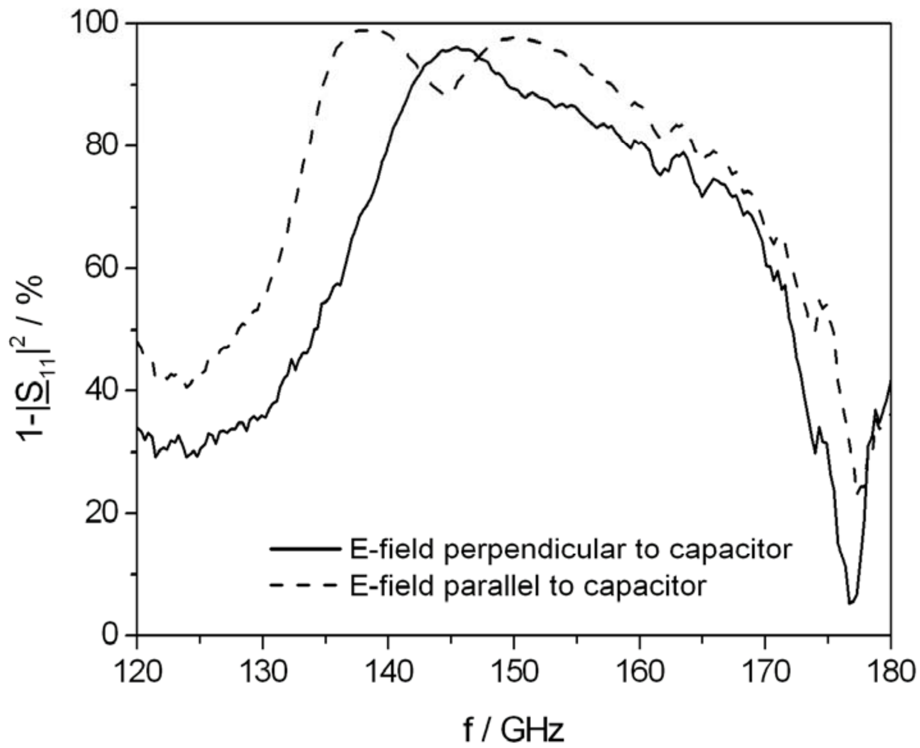
reasonable filling factor possible for 150 GHz:
→ Z_{LEKID} can be optimized

LEKID geometry for 2 polarizations

Hilbert curve 3rd order



Reflection measurement of Hilbert LEKID

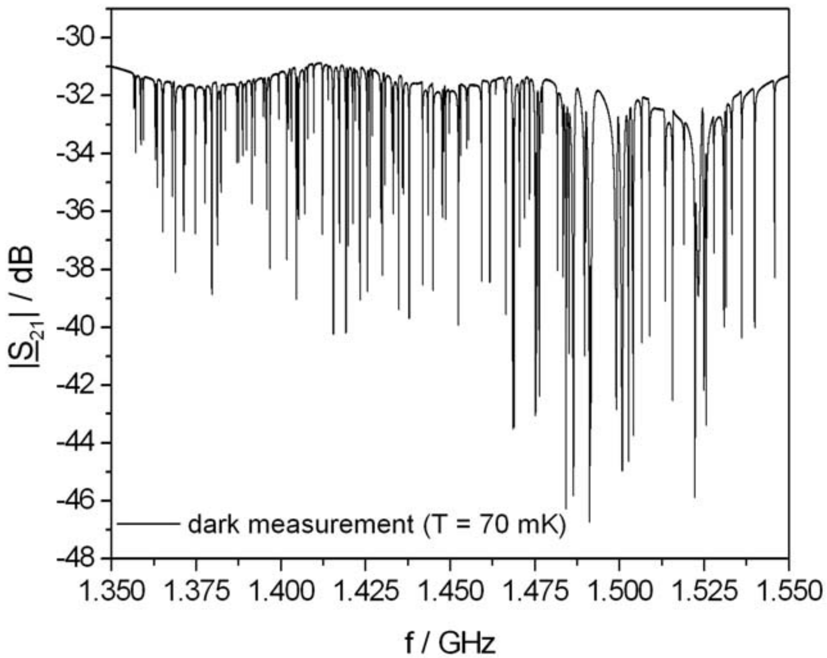


- same filling-factor as meander geometry (assuming similar absorption in interrupted lines)
- same coupling to feed line

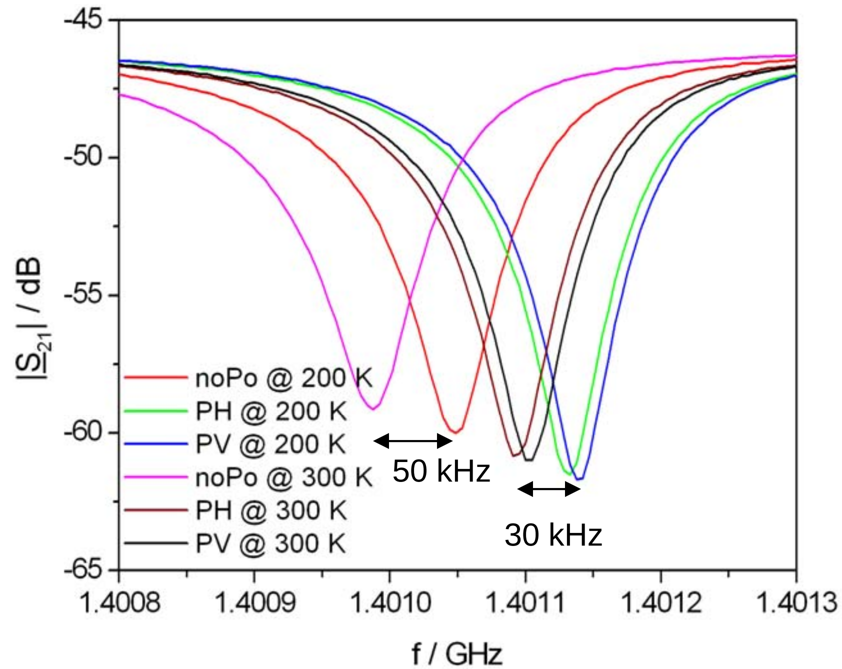
- almost identical absorption for both polarizations

Low temperature measurements of Hilbert LEKIDs

VNA scan of 132 pixel array

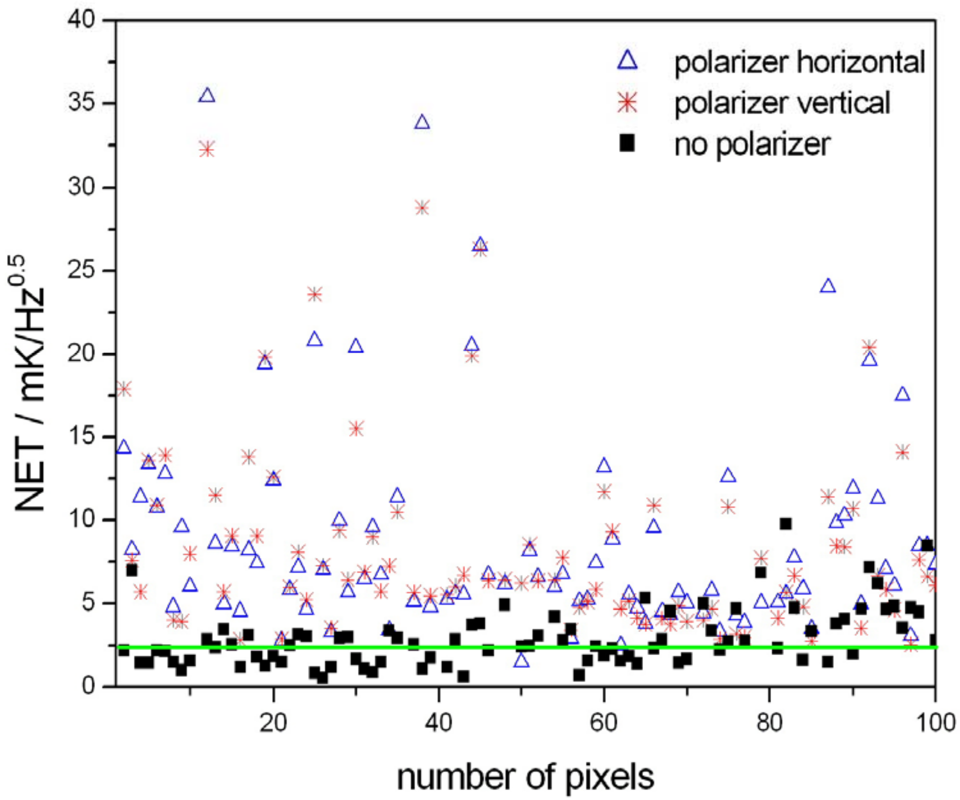


Optical response (load 200 and 300 K)
(using polarizer in front of cryostat in
vertical (PV) and horizontal position (PH))



Response for both polarizations identical

Sensitivity of a 20 nm Al Hilbert LEKID array



Noise equivalent temperature:

$$NET = \frac{\Delta T}{S / N} \quad [K/Hz^{0.5}]$$

Noise equivalent power:

$$NEP = \frac{P}{S / N} \quad [W/Hz^{0.5}]$$

(ΔT = 5K, P = 5pW)

- Average sensitivity: NET = 2.5 mK/Hz$^{0.5}$ per pix (factor 2-3 from IRAM specifications)

best pixels: NET = 0.8 mK/Hz$^{0.5}$ per pix

TiN LEKIDs

H. G. Leduc, et al., “Titanium nitride films for ultrasensitive microresonator detectors”, Appl. Phys. Lett. 97, (2010)

JPL film, $T_c \approx 1.4$ K

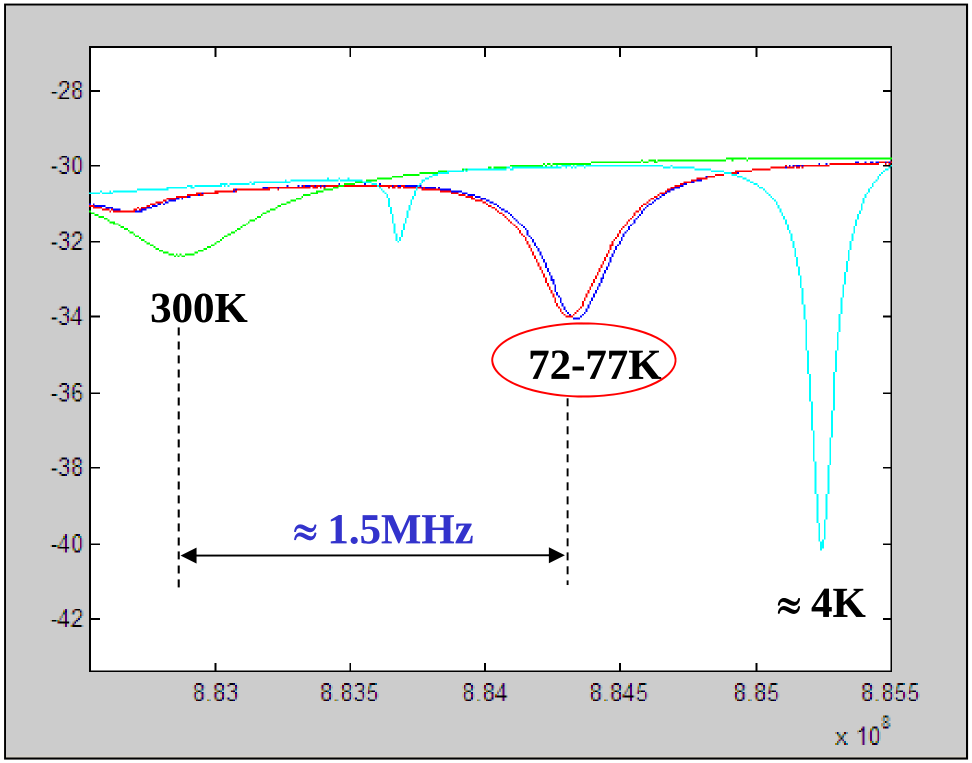
Thickness ≈ 50 nm

LEKID design and measurement: Institute Néel/IRAM

Huge responsivity :

6 kHz / K ≈ 6 · $\text{LEKID}_{Al=20nm}$

$L_{kin}(\text{TiN}) \approx 20 * L_{kin}(\text{Al})$



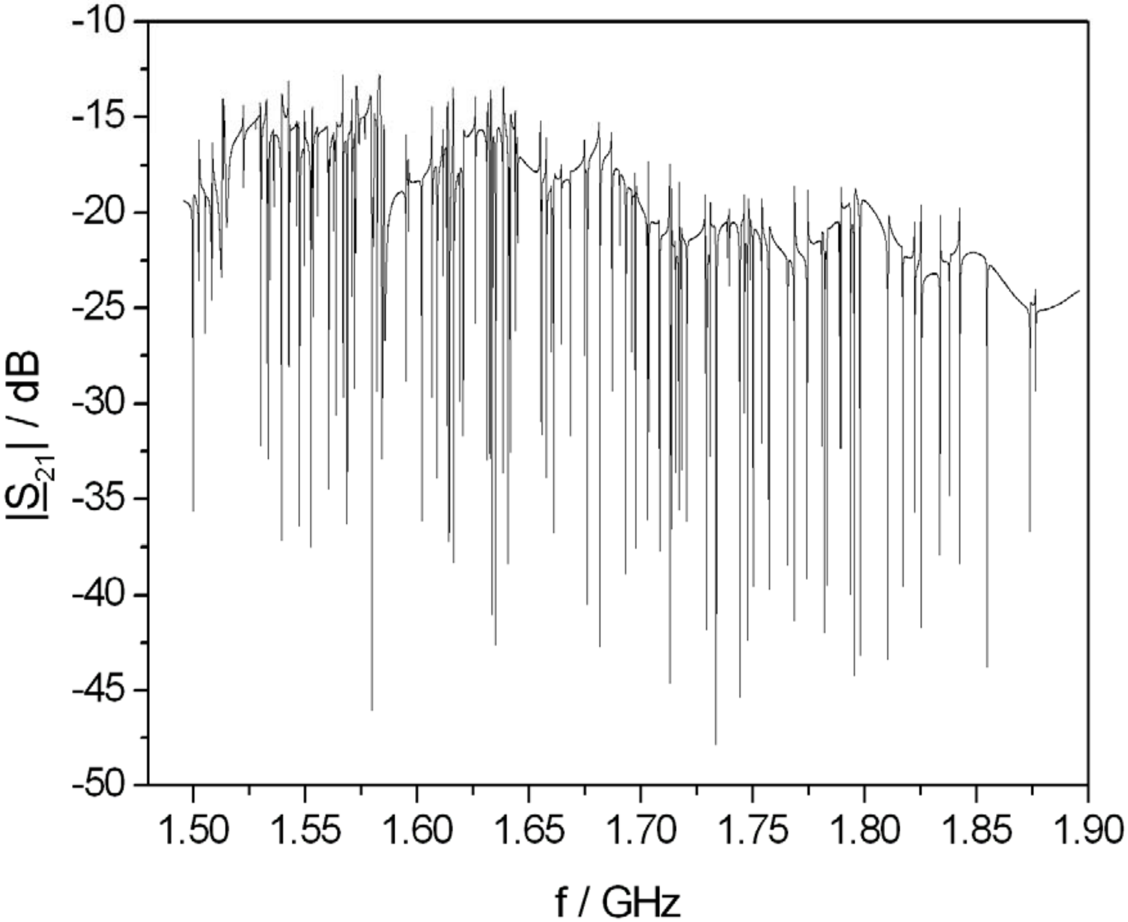
Under lower loading (≈ 1 pW/pix) → **$NEP^{1Hz}_{opt} \approx 2 \cdot 10^{-17}$ W/Hz$^{0.5}$**

IN PROGRESS:

- New SiGe Caltech amplifier
- LEKID design and film thickness has to be optimised for NIKA loading

TiN LEKIDs made at IRAM

60 nm TiN film @ T = 60 mK, Tc = 2.1 K



Conclusion

- Reflection measurement setup to optimize the optical coupling at room temperature as alternative to cryogenic measurements

- Good agreement between reflection measurements, transmission line model, simulation and FTS measurement

- Successful telescope run in October 2010 (competitive with existing instruments)

- Two polarization geometry shows promising results

- Factor gained in NET compared to meander structure ~ 1.5

- Best pixels showed NET = 0.8 mK/Hz^0.5 → new record for LEKIDs at 2 mm

- TiN promising material for future LEKIDs

Outlook

- developing arrays for 1 mm
- Optimize the optical coupling by simulations and measurements for 1 mm
- cross-talk issues
- investigation in TiN LEKIDs

- 3rd telescope run foreseen in October 2011 with LEKID arrays at 1 and 2 mm.