On-chip integration of a μMUX and MMB detector for QUBIC collaboration

HIRSAP Annual Meeting - November 2023

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Director (KIT)
Prof. Dr. Sebastian Kempf

Director (UNSAM)
Dr. Eng. Alejandro Almela

Outline

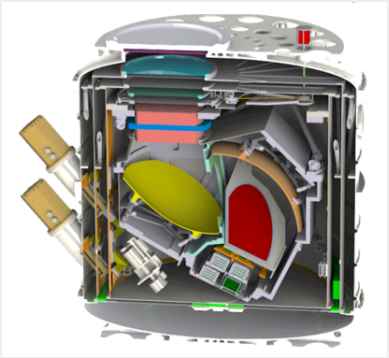
- Background: QUBIC
- Superconductor microwave resonators
- Tri-layer tests
- Preliminary results
- Future work

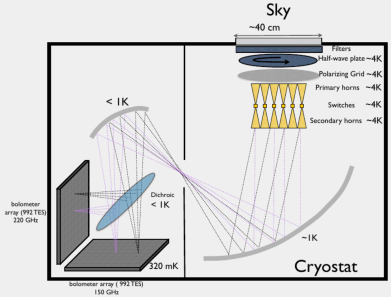
QUBIC Project

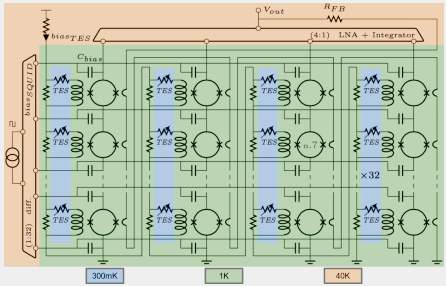
- (QUBIC: Q&U Bolometric Interferometer for Cosmology)
- Cosmology experiment: CMB (B-Modes).
- Proposal for the Focal Plane (ARG-GER).

October 2022: QUBIC deployed in Salta, Argentina, at the mountain site (4869 m a.s.l.)

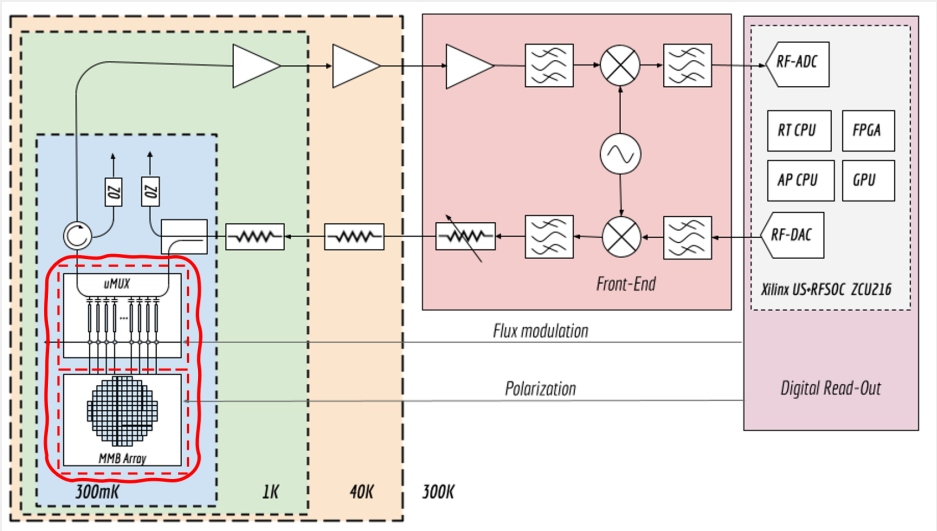
QUBIC Instrument





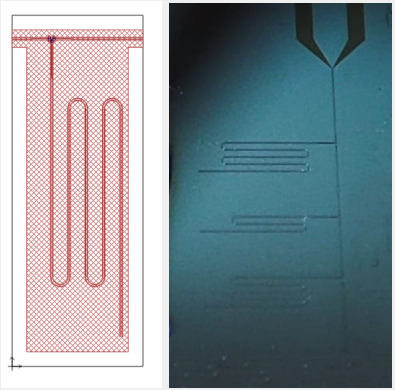


QUBIC Instrument: Focal Plane second version



My thesis work is focused on show the possibilities to combine the μmux SQUID Multiplexer with the MMB Detectors.*

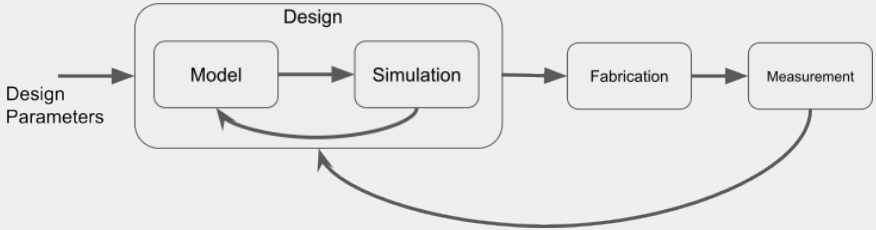
Superconductor Microwave Resonators (SMR)



First steps in optimisation of the superconductor microwave resonators

Quarter wave resonator:
Coplanar waveguide resonators
Frequency ranges: 4 to 8 GHz
Bandwidth: 200 kHz

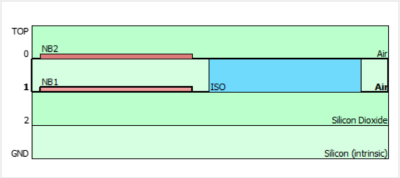
SMR: Tools

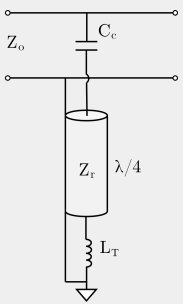


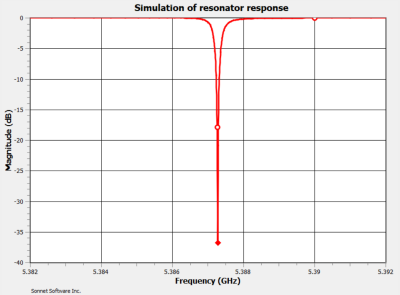
Development tools for resonators design.

Superconductor materials: Niobium, Aluminum.
Substrate materials: Silicon, Silicon dioxide.
Resonance frequency:

$$f_r' = \frac{f_r}{1 + 4 f_r C_c Z_r + 4 f_r L_{(\Phi)} / Z_r}$$

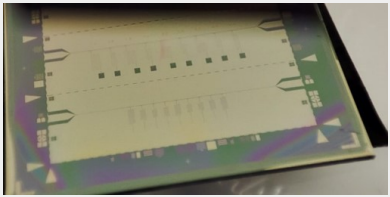


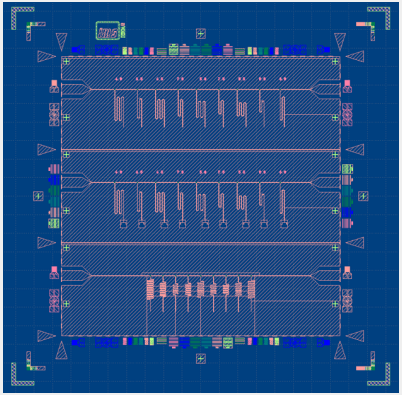




Niobium resonators fabrication at IMS (GER) by Eng. Nahuel Müller.

- 9 bare resonators
- Resonators with L_T
- Another geometry with different C_c.

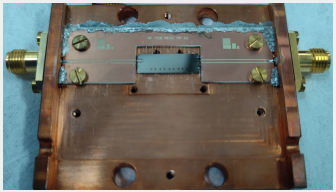


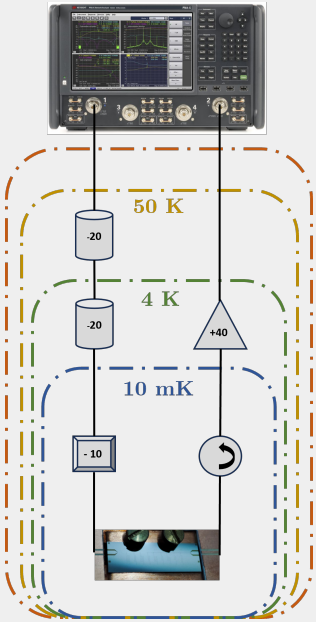


SMR: RF Setup

RF Setup for low temperature measurements (ARG).

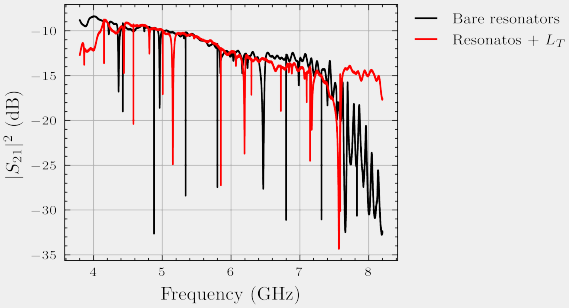
- Bluefors LD250.
  - Channel 1 $\approx$ 45 dB nominal attenuation
    LNA: LNF4_8C (3301H)
  - Channel 2 $\approx$ 55 dB nominal attenuation
    LNA: LNF4_8C (3464H)
- N5242B PNA-X Microwave Network Analyzer.

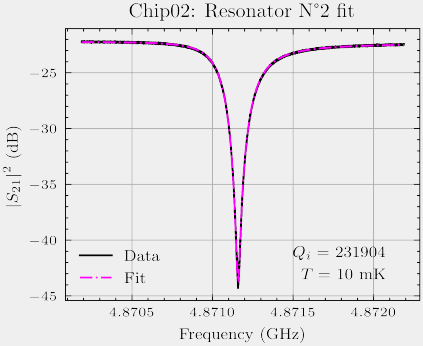




9 resonators design from 4 to 8 GHz

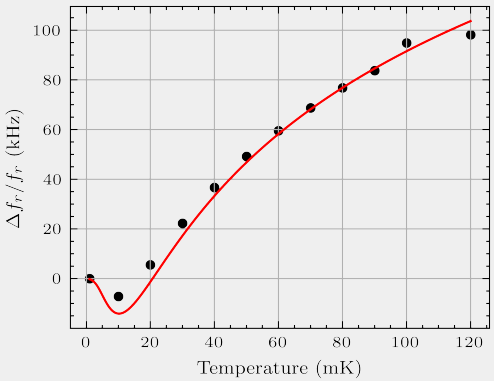
- Chip 01: Bare resonators.
- Chip 02: Resonators + L_T.

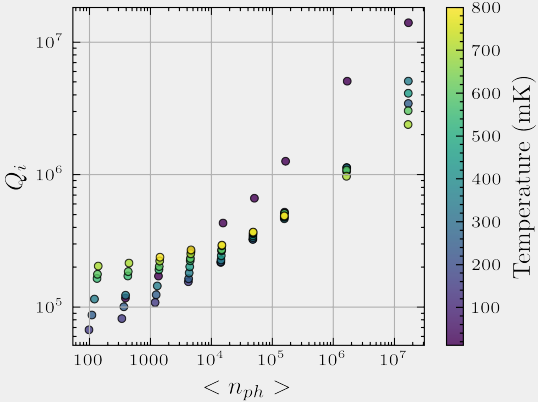




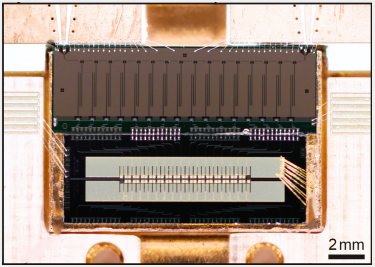
$$S_{21}(f) = ae^{i\alpha}e^{-2\pi i f\tau}\left[1 - \frac{(Q_l/|Q_c|)e^{i\phi}}{1 + 2iQ_l(f/f_r - 1)}\right]$$

SMR: Measurements

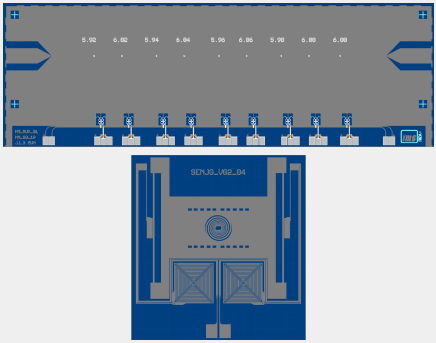




- Match between different fabrication process
- Higher thickness in the first Nb layer.
- High Ic for Detector coil.



D. Richter (2021)



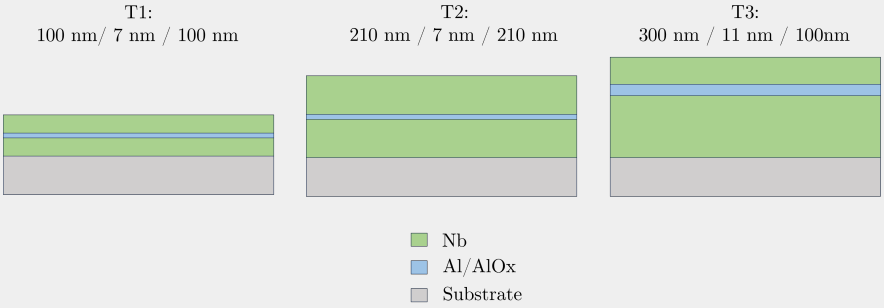
Eng. Nahuel Müller and Eng. Juan Geria

Ongoing work: Tri-layer tests

Description of the fabrication process currently used for umux development at IMS.
Tri-layer deposition (Nb: 100 nm / Al/AlOx: 7 nm / Nb: 100 nm).

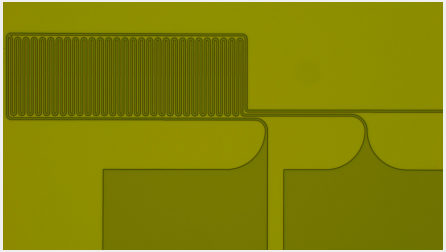
#	Name	Material	Thickness (nm)	Process
1	Bottom layer	Nb	100	Sputtering + dry etching
2	Tunnel barrier	Al - AlOx	7	Sputtering + wet etching
3	Top layer	Nb	100	Sputtering + dry etching
4	First isolation layer	SiO2	125	Sputtering + lift-off
5	Second isolation layer	SiO2	125	Sputtering + lift-off
6	Last connection layer	Nb	300	Sputtering + lift-off

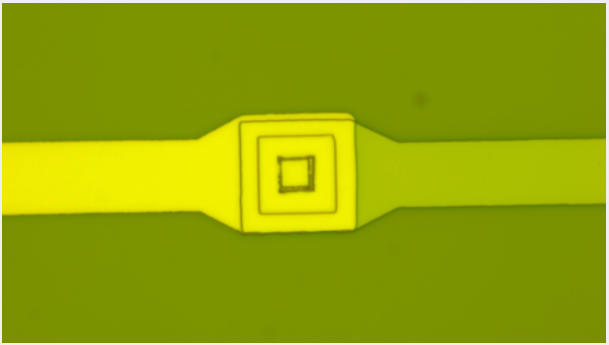
Ongoing work: Tri-layer tests



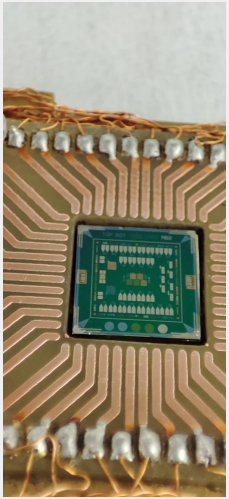
Functionality of the Josephson Junctions with a thicker Bottom layer of Nb.

Ongoing Work: Microfabrication

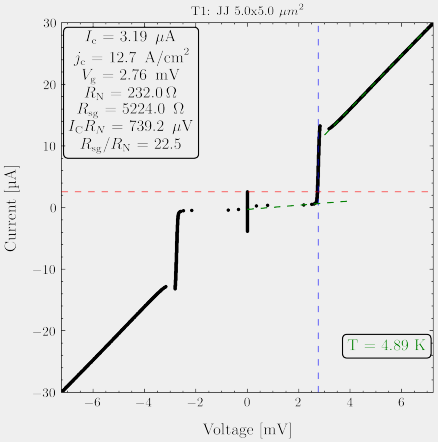


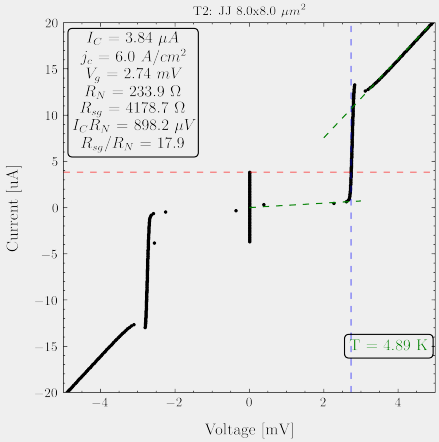


Ongoing Work: Cryogenic Measurements



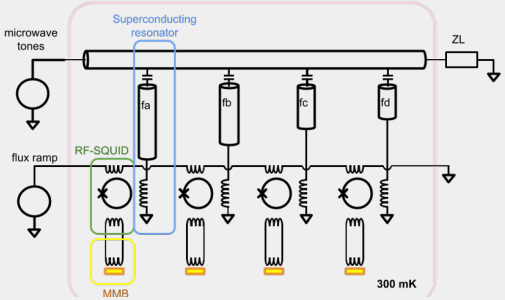
Preliminary results.

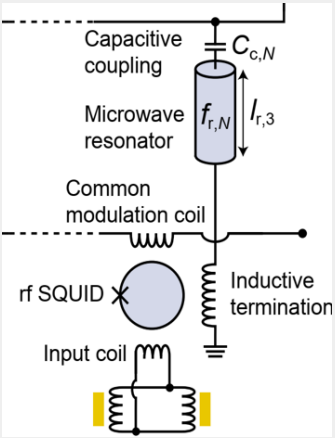




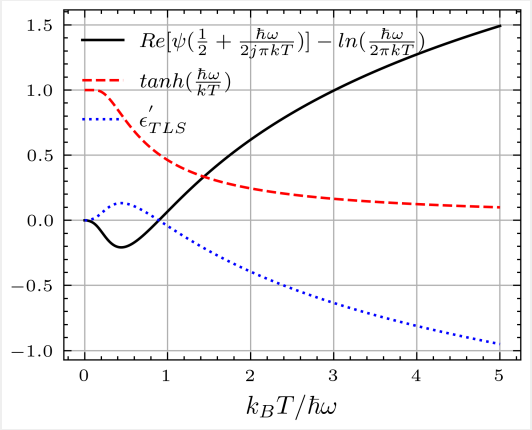
Gracias, Thanks, Danke :)

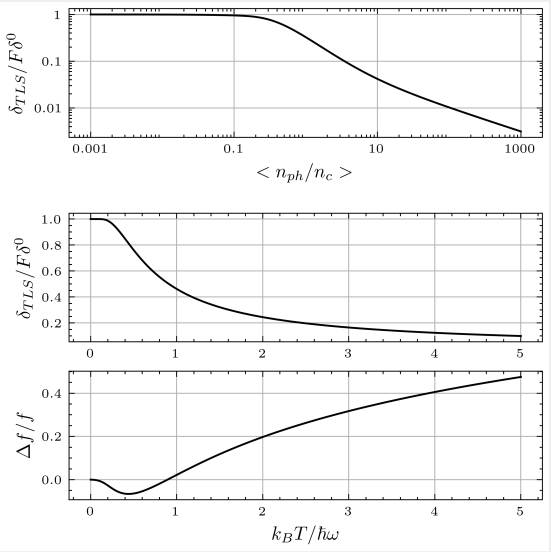
Back up


microwave tones
Superconducting resonator
ZL
fa
fb
fc
fd
flux ramp
RF-SQUID
MMB
300 mK

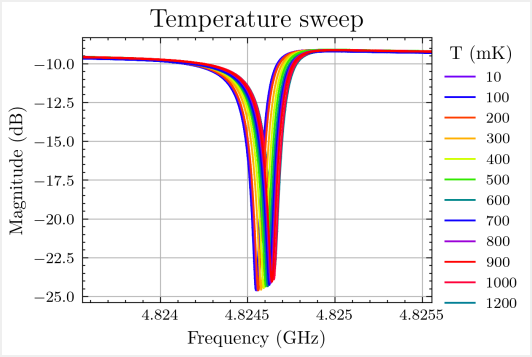

Capacitive coupling
$C_{c,N}$
Microwave resonator
$f_{r,N}$
$l_{r,3}$
Common modulation coil
rf SQUID
Inductive termination
Input coil

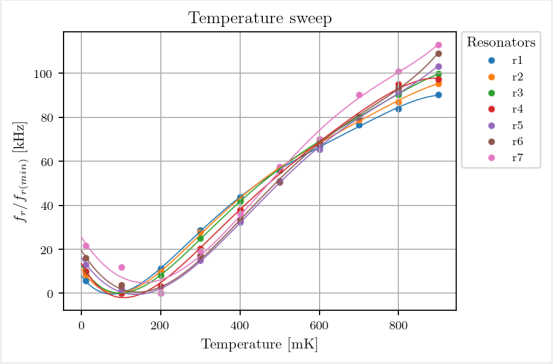
Back up


$Re[\psi(\frac{1}{2}+\frac{\hbar\omega}{2j\pi kT})]-ln(\frac{\hbar\omega}{2\pi kT})$
$tanh(\frac{\hbar\omega}{kT})$
ϵ'_{TLS}
$k_BT/\hbar\omega$

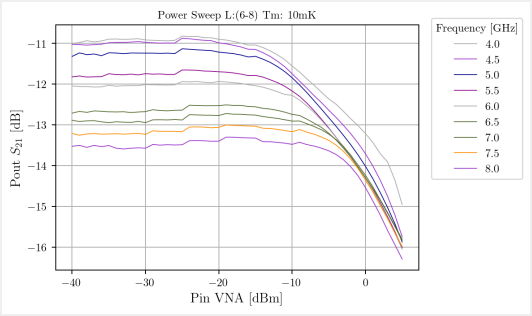

$\delta_{TLS}/F\delta^0$
$< n_{ph}/n_c >$
$\delta_{TLS}/F\delta^0$
$\Delta f/f$
$k_BT/\hbar\omega$

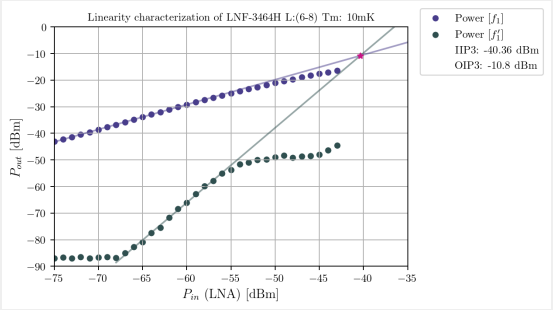
Back up

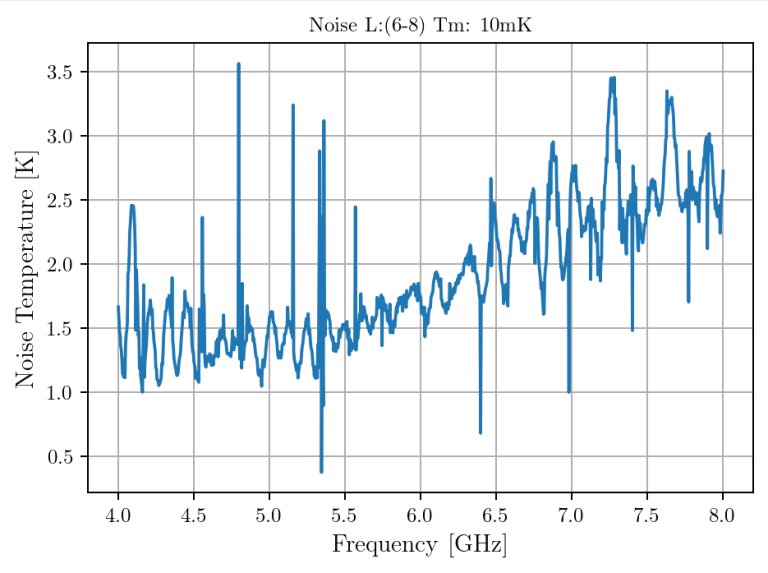

Temperature sweep
Magnitude (dB)
−10.0
−12.5
−15.0
−17.5
−20.0
−22.5
−25.0
4.824
4.8245
4.825
4.8255
Frequency (GHz)
T (mK)
10
100
200
300
400
500
600
700
800
900
1000
1200


Temperature sweep
$f_r/f_{r(min)}$ [kHz]
100
80
60
40
20
0
0
200
400
600
800
Temperature [mK]
Resonators
r1
r2
r3
r4
r5
r6
r7

Back up


Power Sweep L:(6-8) Tm: 10mK
Pout S_{21} [dB]
Pin VNA [dBm]
Frequency [GHz]
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0


Linearity characterization of LNF-3464H L:(6-8) Tm: 10mK
P_{out} [dBm]
P_{in} (LNA) [dBm]
Power [f_1]
Power [f_1']
IIP3: -40.36 dBm
OIP3: -10.8 dBm


Noise L:(6-8) Tm: 10mK
Noise Temperature [K]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
Frequency [GHz]