A Bolometric Receiver for the LLAMA-QUBIC Project

HIRSAP Annual Meeting - November 2021

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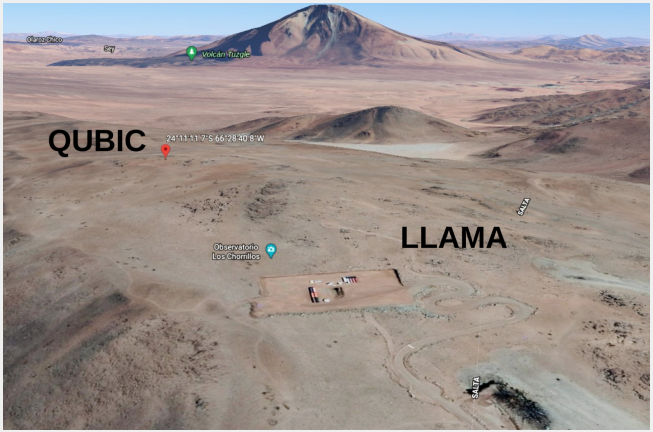
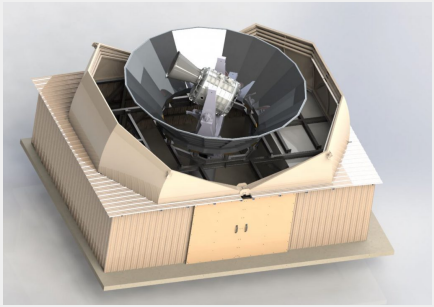
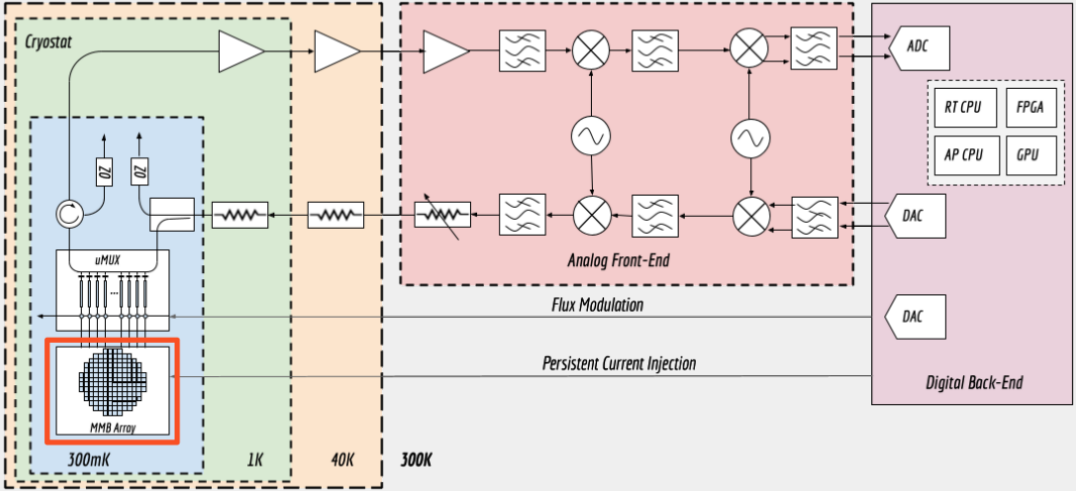
Karlsruher Institut für Technologie



Site: Alto Chorrillos near San Antonio de Los Cobres, Salta Province, Argentina.

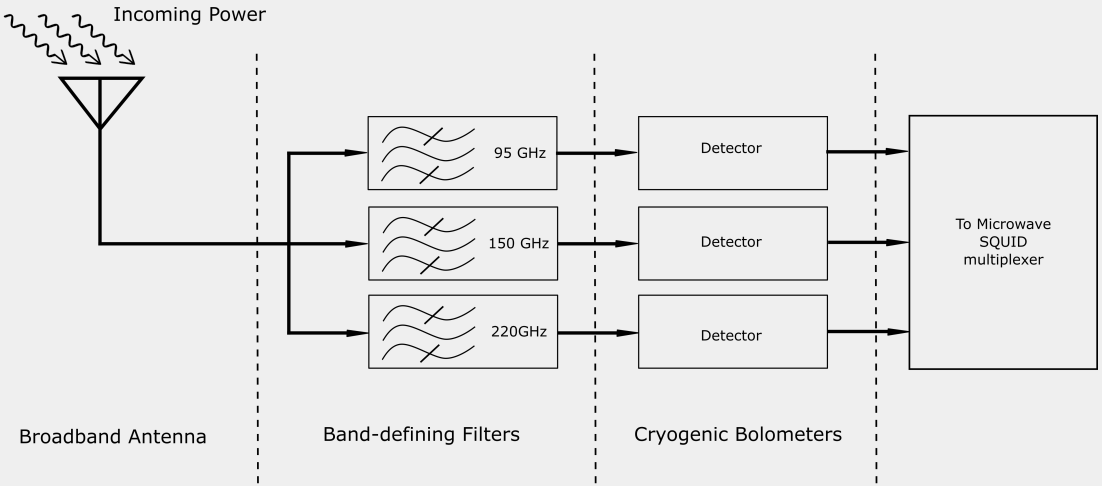


Introduction - Detector and Readout scheme in development



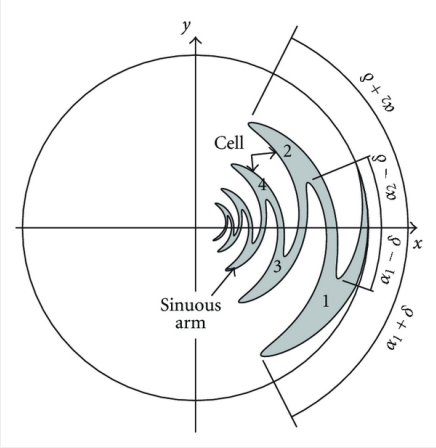
My thesis work is focused in the **MMB Detector Array**

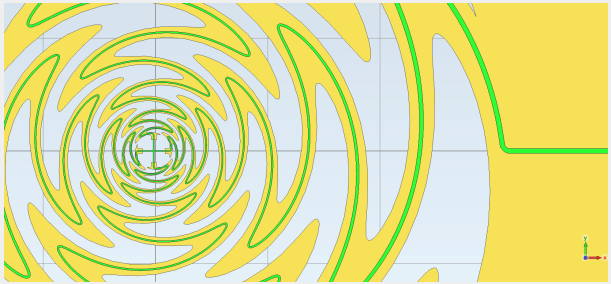
Antenna-Coupled Bolometer concept:



Sinuous Antenna - A Log-Periodic Planar Antenna

Frequency Range:
$80GHz \rightarrow 300GHz$!!!



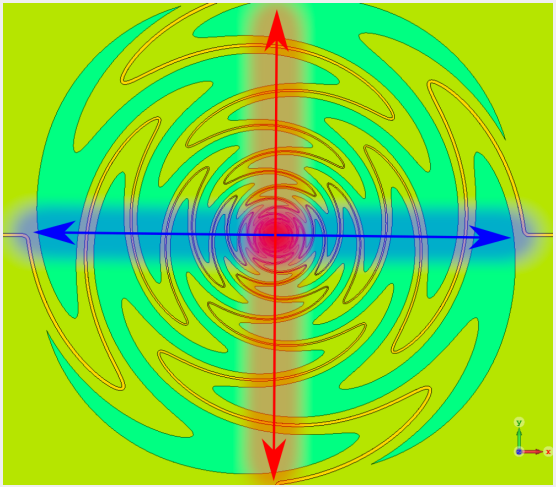


Key points:

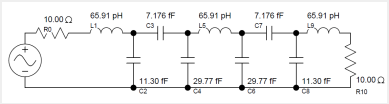
- Impedance Matching to the transmision line in the entire bandwidth.
- Radiation Lobe matching to the telescope optics.
- Size: $\approx 3mm$ in diameter.

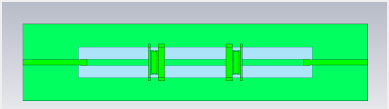
And it is polarization sensitive!

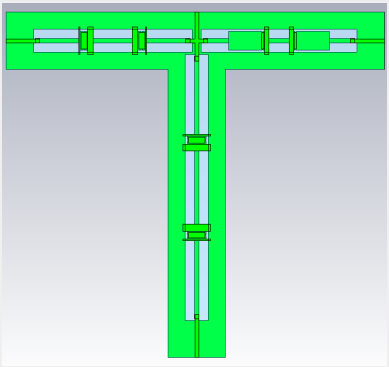
- Each pair of opposing arms act as independent polarized antennas.



Band-Defining Filter Design

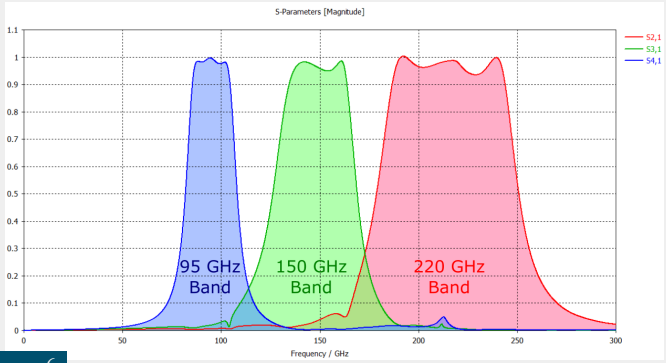




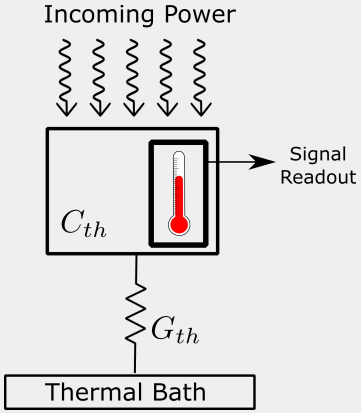


Key points:

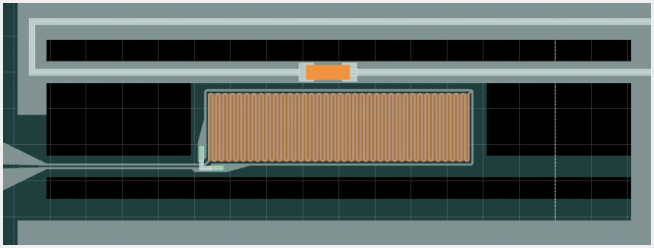
- Lumped element design was chosen.
- 3rd order Chevyshev passband filters were designed
- Electromagnetic Simulations were performed to optimize dimensions and geometries.



Bolometer Principle



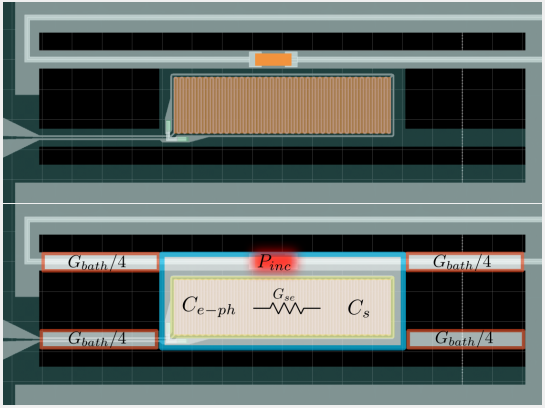
Physical Implementation



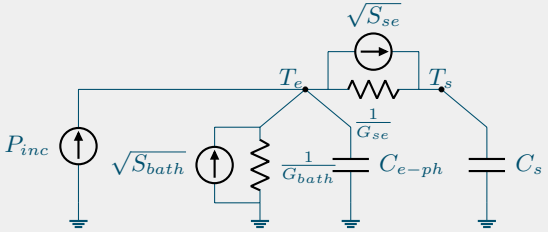
$$\Delta P \rightarrow \Delta T \rightarrow \Delta M \rightarrow \Delta \Phi$$

The use of a **temperature-dependent para-magnet** made of Erbium doped Gold **Au:Er** is being proposed as the thermometer of this device.

Physical Implementation



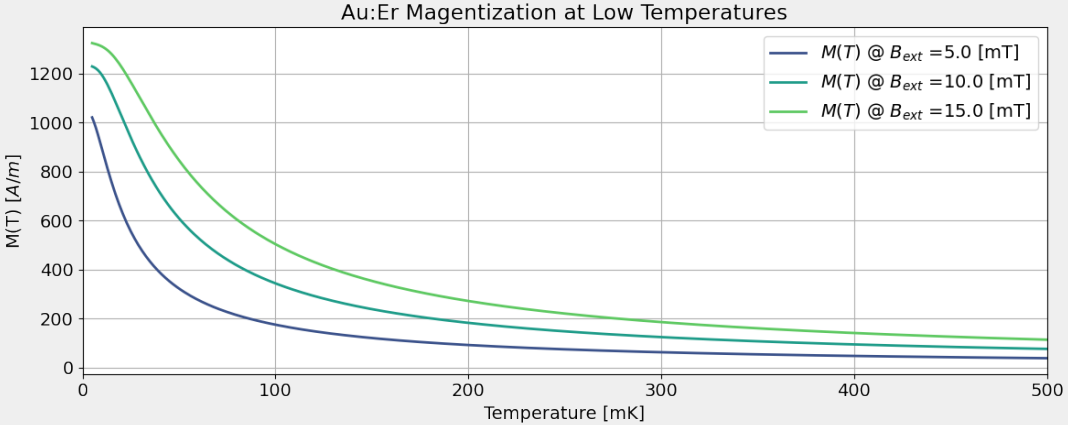
Thermal Model of the MMB



$$\mathfrak{R}_{MMB} = \frac{\partial \Phi}{\partial P} = \boxed{\frac{\partial T}{\partial P}} \cdot \frac{\partial \Phi}{\partial T}$$

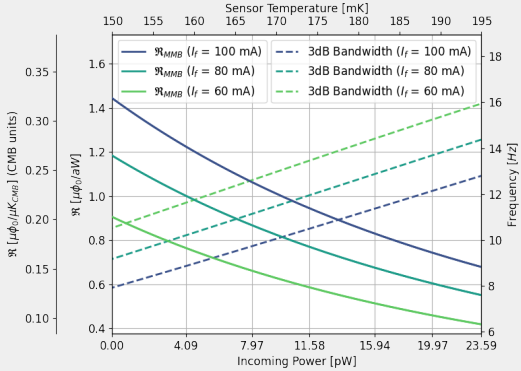
$$\frac{\partial T}{\partial P} = \underbrace{\frac{1}{G_{bath}}}_{\text{Thermal Gain}} \cdot \underbrace{\frac{1}{1 - \frac{C_{e-ph}C_s}{G_{bath}G_{se}} \cdot \omega^2 + \frac{C_s(G_{bath}+G_{se})+C_{e-ph}G_{se}}{G_{bath}G_{se}} \cdot i\omega}}_{\text{Frequency Response}}$$

Temperature-Dependent Magnetization

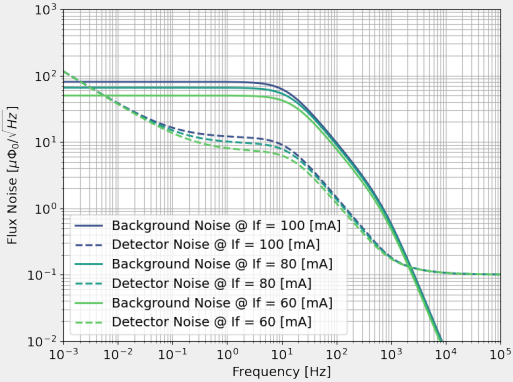


Magnetization of the Au:Er sample and signal readout are performed by the *superconducting pick-up coil* that lies underneath the sensor.

MMB Responsivity and Bandwidth



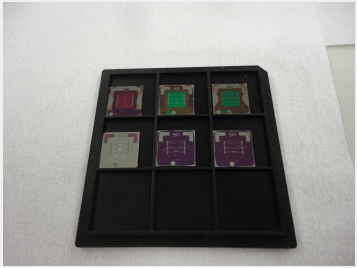
Background and Detector Noise

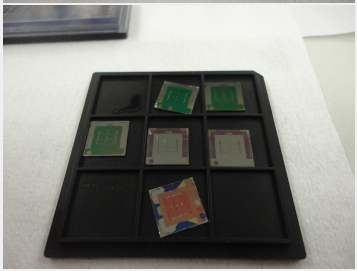


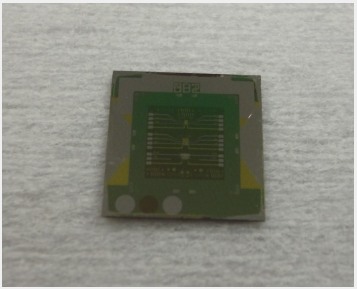
$$\mathfrak{R}_{MMB} = \frac{1}{G_{bath}} \cdot \left(\int_{V_s} \frac{\mu_0 G(\vec{r}/p)}{p} \cdot \frac{\partial M}{\partial T}\Big|_{|\vec{B}(\vec{r})|} \cdot d^3 r \right) \cdot \frac{k\sqrt{L_{in} L_s}}{L_m + L_{stray} + L_{in}}$$

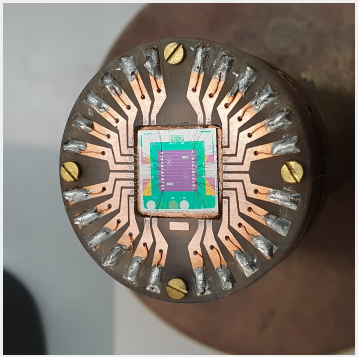
Ongoing Work

- Currently the first MMB prototypes are being developed at IMS.
- Individual optimization and testing of each involved structure must be performed.









Summary and Future Work

Summary:

- Antenna-coupled MMBs discussed so far are promising candidates as photon-limited bolometer detectors for CMB experiments.
- Metallic Magnetic based sensors seem to achieve required responsivity, bandwidth and SNR when used in bolometric applications.
- Microfabrication of these detectors is not straightforward and need multiple "inbetween" tests and optimizations to achieve reproducible and stable recipes.

Future Tasks:

- First measurements at 4K of the involved structures.
- Further optimization of the fabrication techniques will be carried out both at IMS and CNEA.
- The first bolometer prototypes will be fabricated and measured.
- The antenna and filter designs will be tested.

Courses, Lectures and Articles

Courses and Lectures:

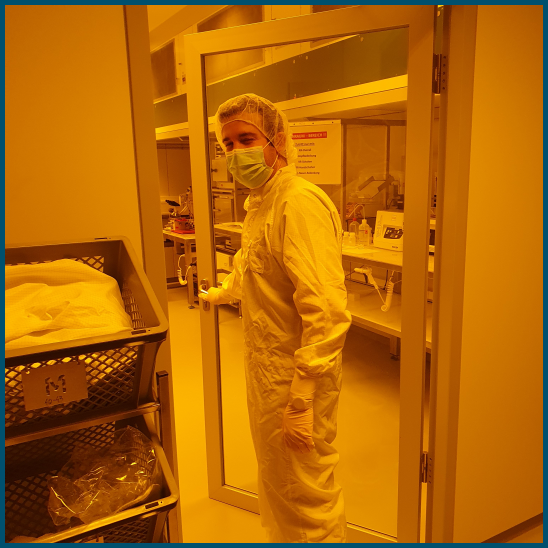
- Introduction to the Finite Element Method (UNSAM - 2020)
- School for Nanoscience and Nanotechnology (CNEA - 2021)
- Python programming (UNSAM - 2021, in course)
- Thin Films, Technology, Physics and Applications (KIT - 2021, in course)
- Single-photon Detectors (KIT - 2021, in course)

KSETA Courses:

- Statistical Methods in Data Analysis (March, 2021)
- Observational Cosmology (March, 2021)
- Introduction to Quantum Physics (October, 2021)
- Introduction to Quantum Cryogenic Detectors (October, 2021)

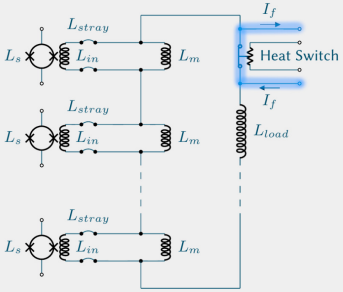
Article:

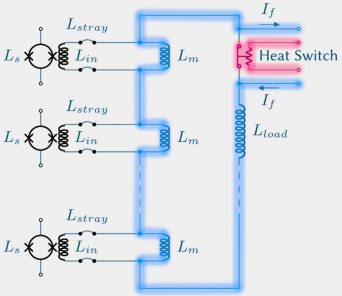
- Writing in progress.

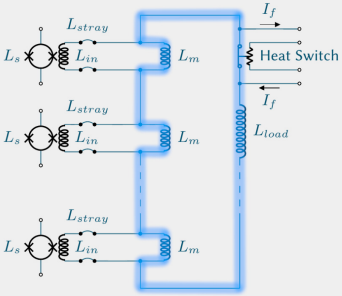


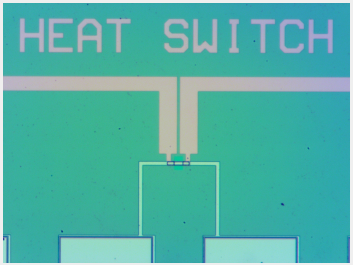
Thank you very much!
Questions??

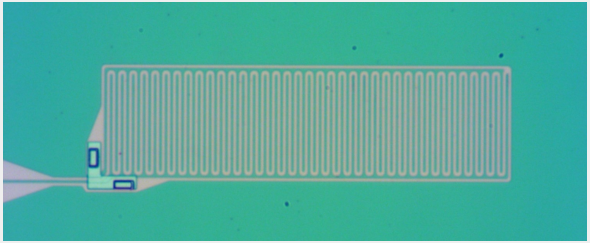
Persistent Current Injection Scheme





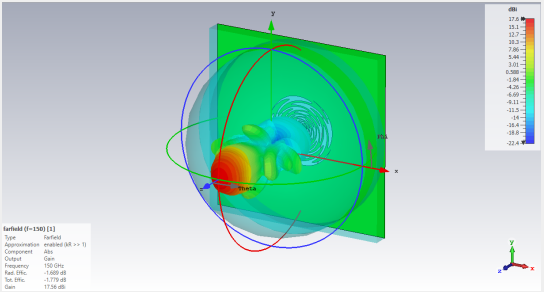


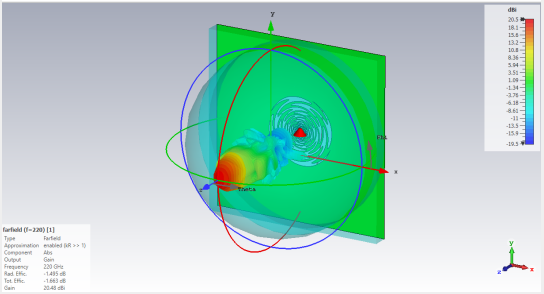




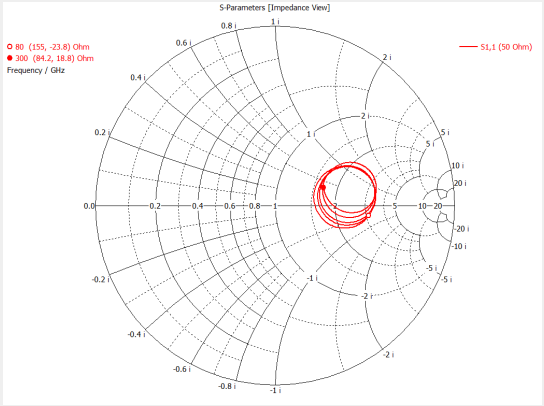
Fabrication and Characterization facilities at IMS

Antenna Impedance and radiation plots with high-K lenslets.



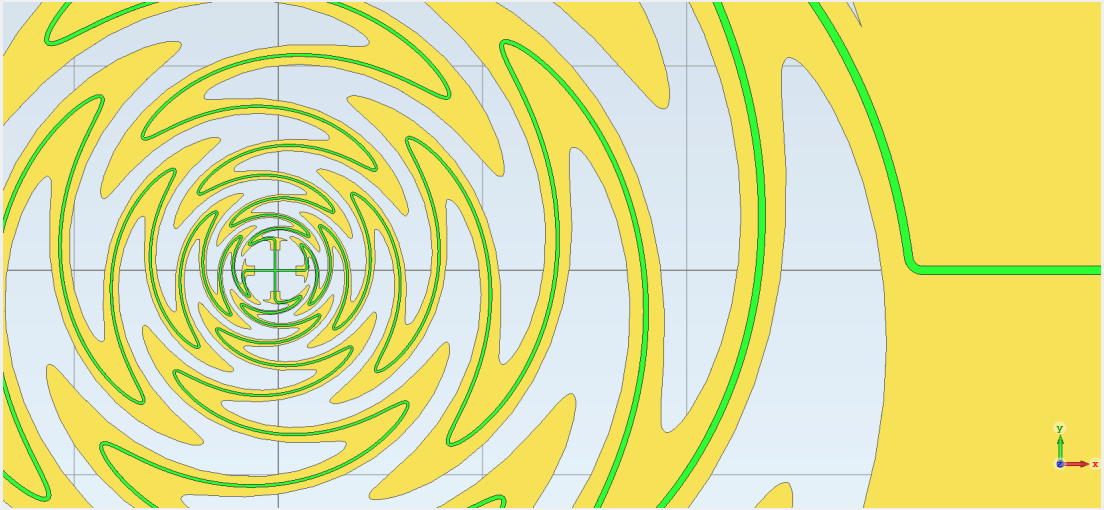


$$Z_{in} = \frac{\eta_0}{\sqrt{2} \cdot \sqrt{\frac{1+\epsilon_{r_{Si}}}{2}}} = 105.37\,\Omega$$



Impedance Matching

Impedance matching is performed by a microstrip line which is gradually weidend to follow a Dolph-Chevyshev impedance profile while travelling thorugh the antenna's arms.



Fabrication and Characterization of the first detector prototypes

Ongoing work is cenetered in the fabrication and characterization of the first bolometer prototypes.