# Dual-frequency receiving systems with cold-electron bolometers

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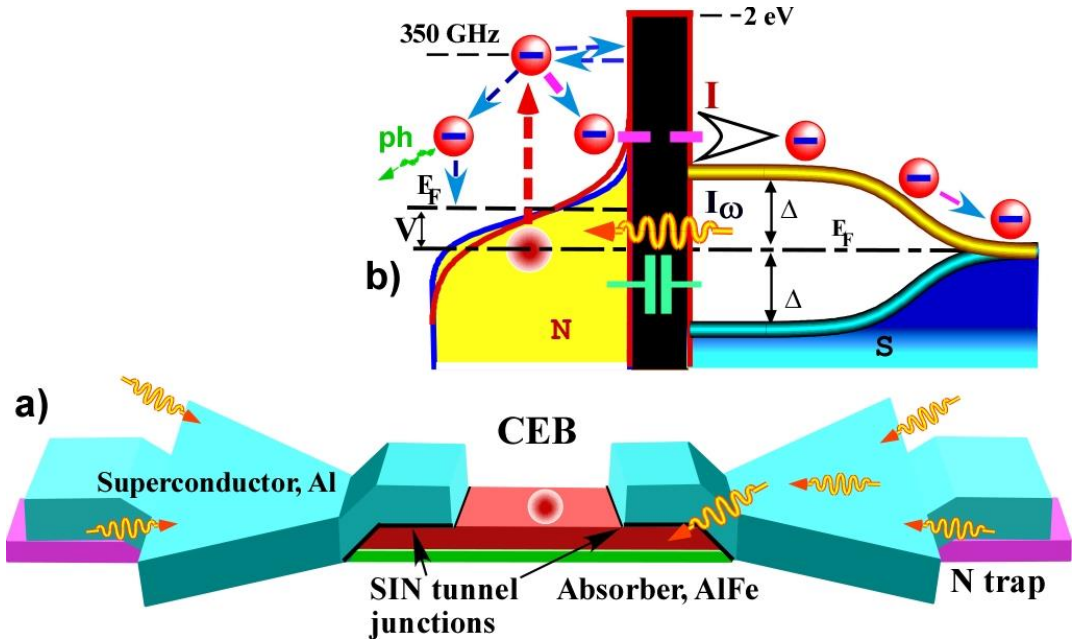
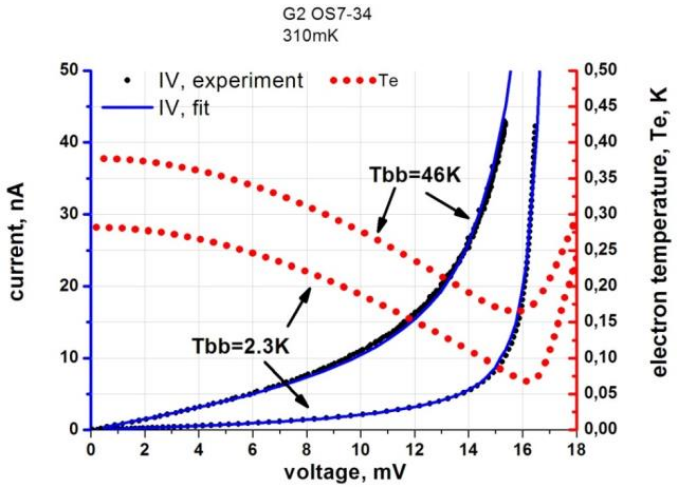
# Cold-electron bolometer. Electron cooling.

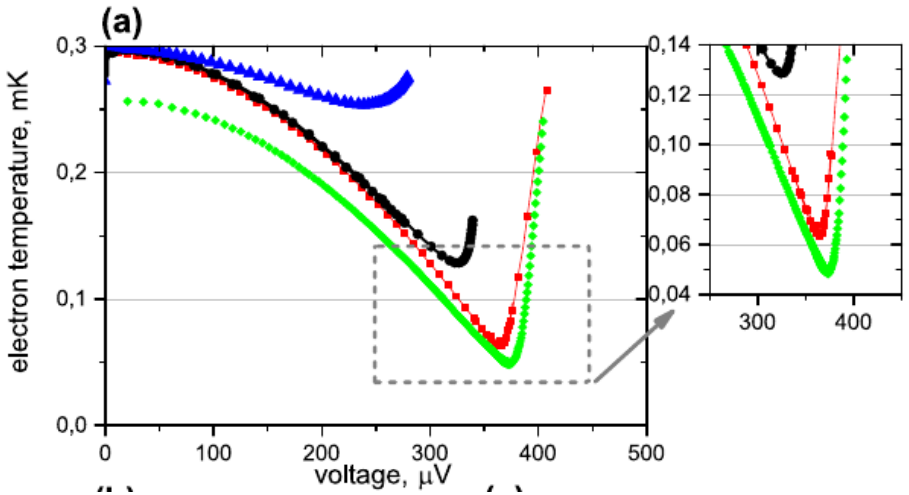
## Cold-electron bolometer (CEB)




## IV curve and electron cooling




(L.S. Kuzmin et al., Communications Physics, 2019)

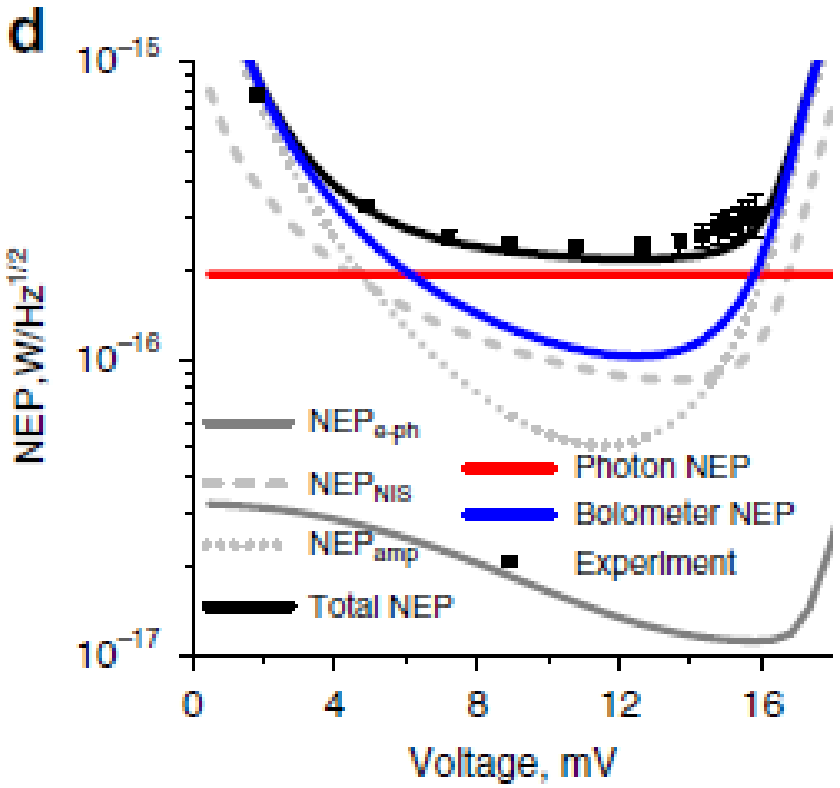


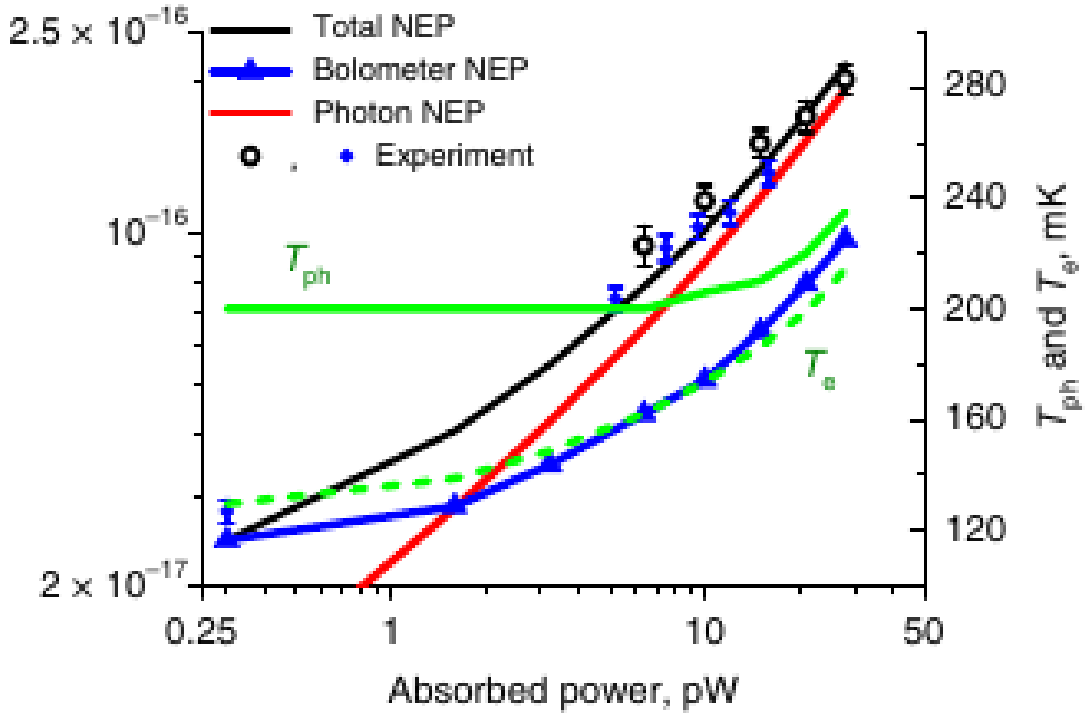

(A.V. Gordeeva et al., Scientific Reports, 2020)

## Advantages of CEB

1. High responsivity
2. Low noise
3. Immunity to cosmic particles

# Noise equivalent power (NEP)




$$NEP_{ph}^2 = P_0 hf + \frac{P_0^2}{\delta f}$$

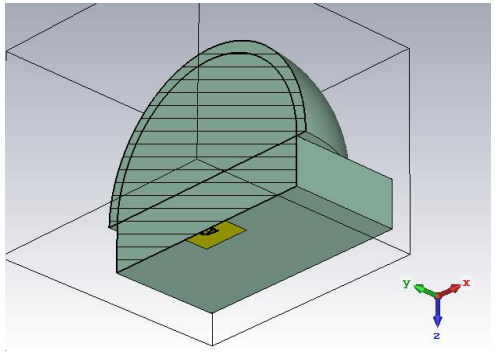
(L.S. Kuzmin et al., Communications Physics, 2019)

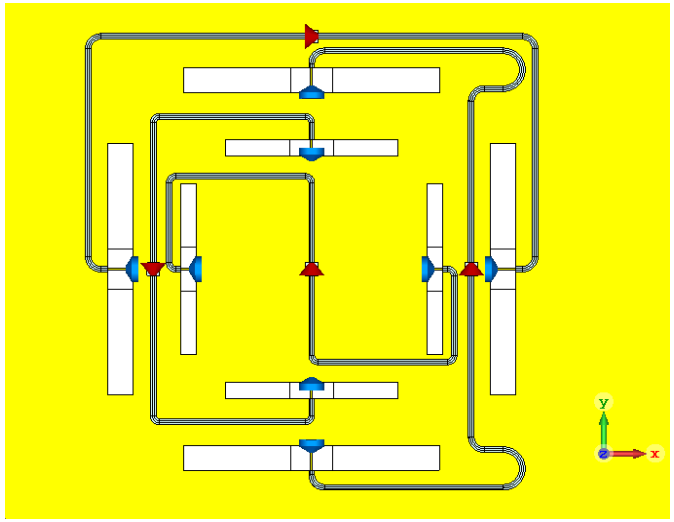
# Dual frequency receiving system for COrE mission

Requirements

| Parameter | Value |
|---|---|
| Beam ellipticity | <5% |
| Beam FWHM | ~20° |
| Sidelobes | <-20 dB |
| Polarization resolution! | |
| Cross polarization | <-30 dB |
| Operating frequencies | 75, 105, (135, 165, 195, …) |
| FWHM | 20% |

Antenna system design

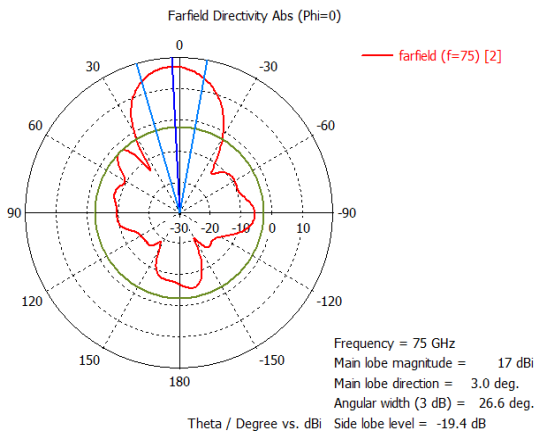


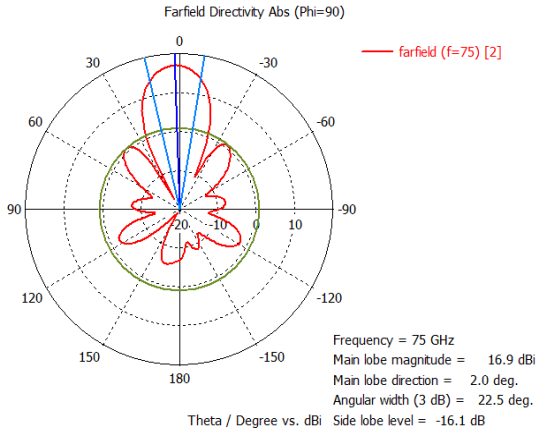


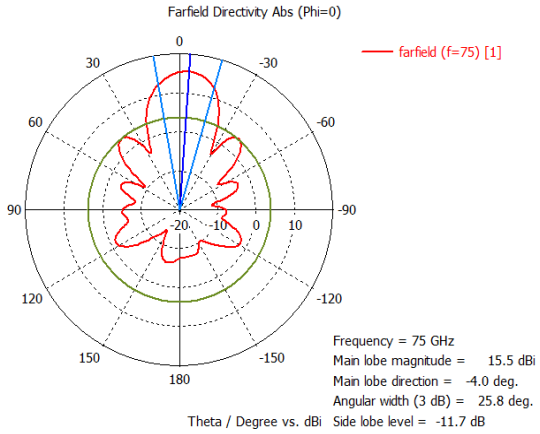
Paired slot antennas - for each polarization

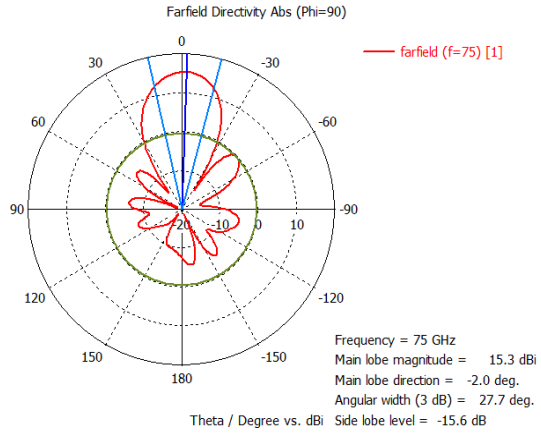
# Dual frequency receiving system for COrE mission — radiation pattern modeling

## 75 GHz channel

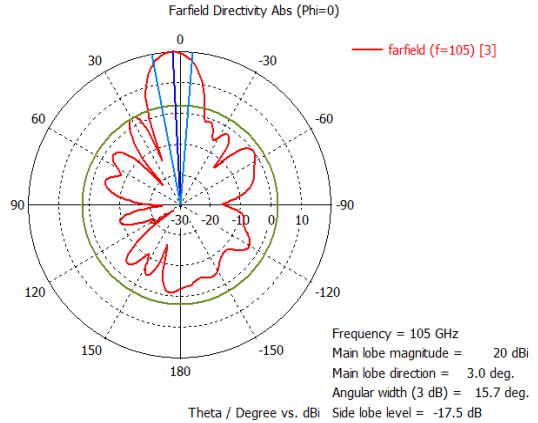


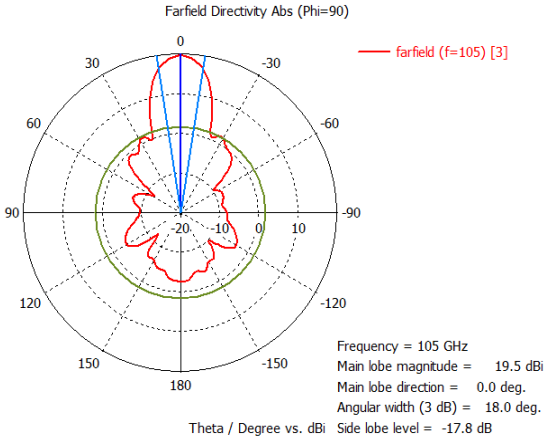



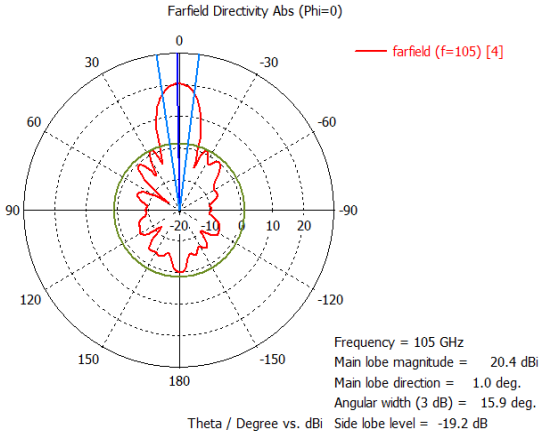



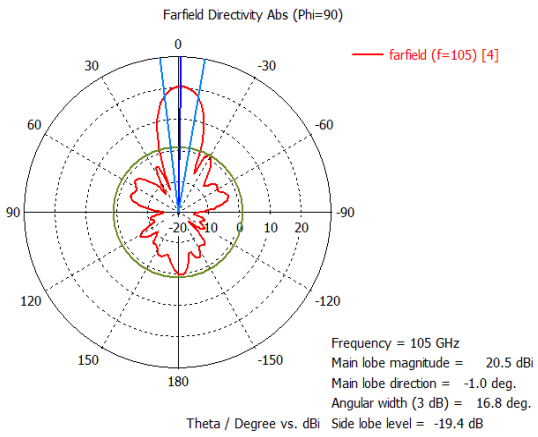




## 105 GHz channel



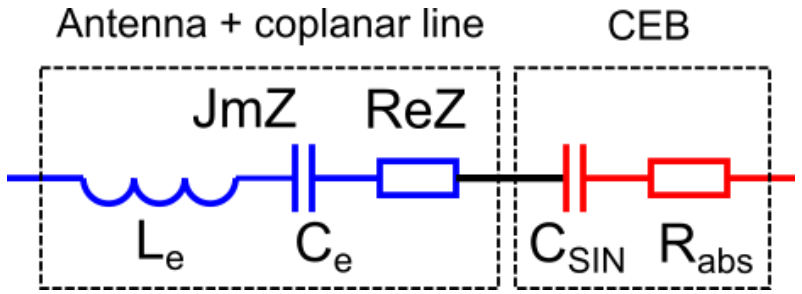
# Dual frequency receiving system for COrE mission — radiation pattern modeling

Radiation pattern characteristics

| Channel, GHz | 75 | | | | 105 | | | |
|---|---|---|---|---|---|---|---|---|
| Polarization | Horizontal | | Vertical | | Horizontal | | Vertical | |
| Section, ° | 0 | 90 | 0 | 90 | 0 | 90 | 0 | 90 |
| Main lobe direction, ° | 3 | 2 | 4 | 2 | 3 | 0 | 1 | 1 |
| Main lobe magnitude, dBi | 17 | 16.9 | 15.5 | 15.3 | 20 | 19.5 | 20.4 | 20.5 |
| Angular width, ° | 26.6 | 22.5 | 25.8 | 27.7 | 15.7 | 18.0 | 15.9 | 16.8 |
| Beam ellipticity, % | 8.3 | | 3.6 | | 6.8 | | 2.8 | |

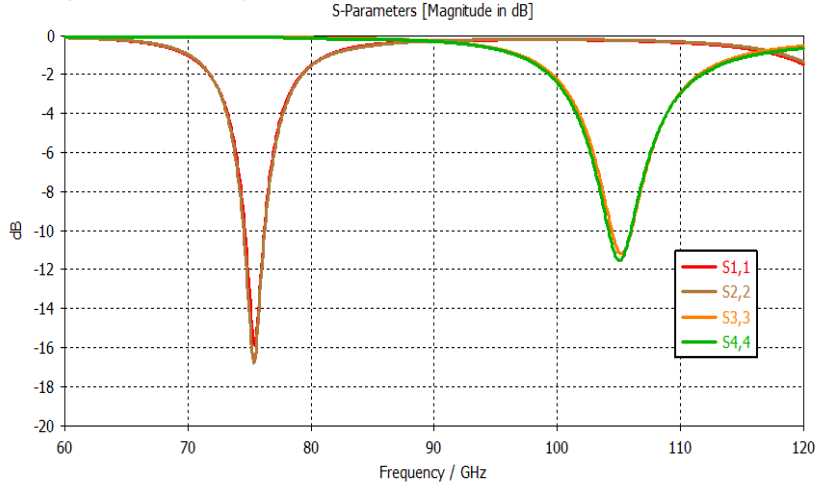
# Dual frequency receiving system for COrE mission — frequency response modeling

Equivalent circuit of the receiving cell with CEB



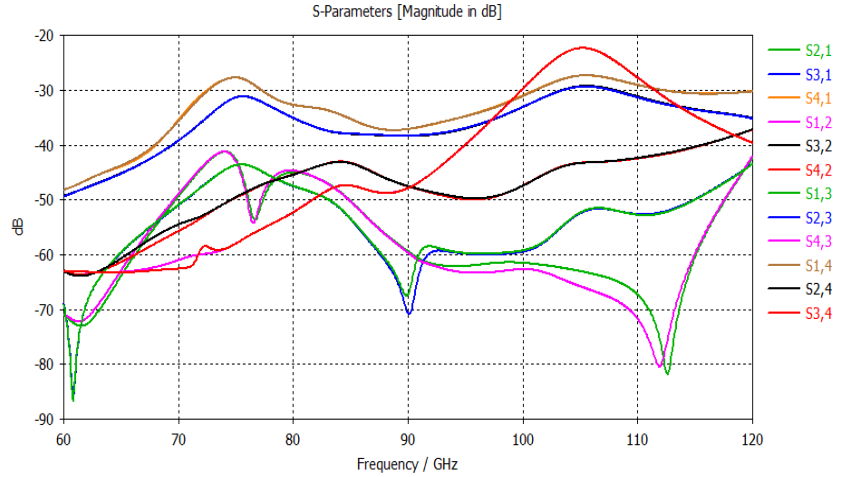

$$R_{abs} = \mathrm{Re}\, Z(f_0), C_{SIN} = \frac{1}{2\pi f_0 \,\mathrm{Im}\, Z(f_0)}$$

Frequency response of two frequency channels (diagonal components of the S matrix)




FWHM less than 20%

Crosstalks (nondiagonal components of the S matrix)

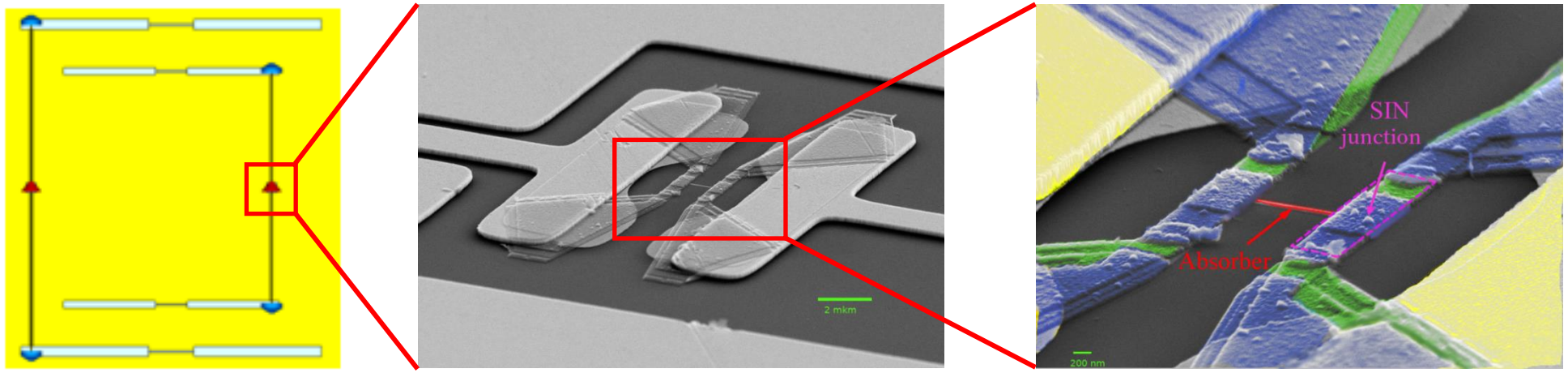



Crosstalks smaller than -20 dB

# Dual frequency receiving system for COrE mission - experiment

For the first step we consider the antenna for one polarization

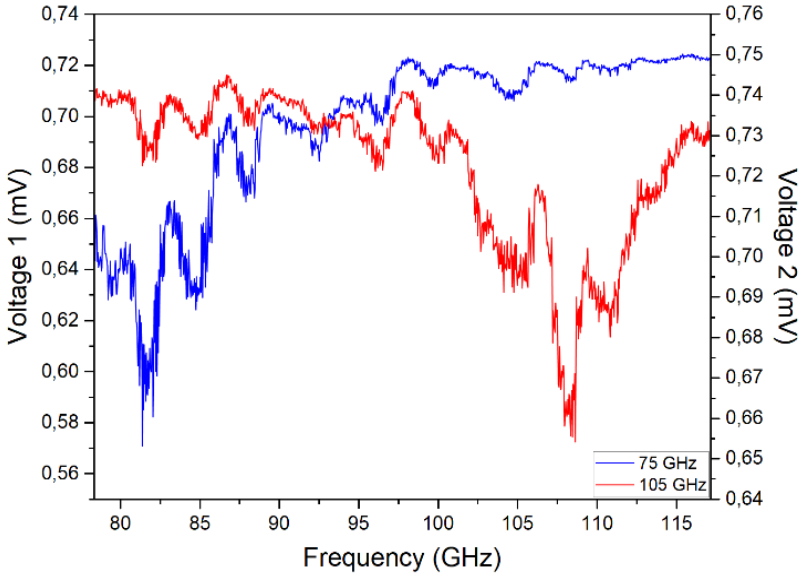
SEM images of the CEB inserted into a cut of the coplanar line



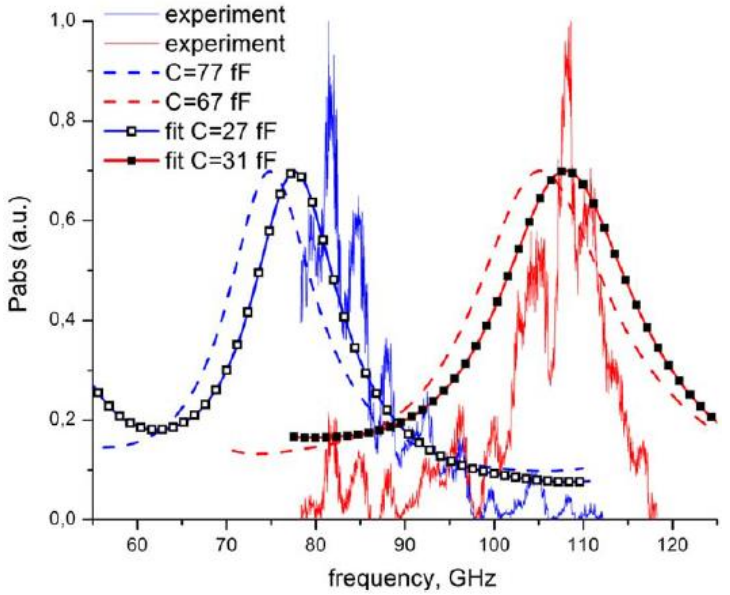
# Dual frequency receiving system for COrE mission - experiment

Irradiation from BWT through cryostat windows with proper attenuation

"Raw" responce




Fitting theory to experiment

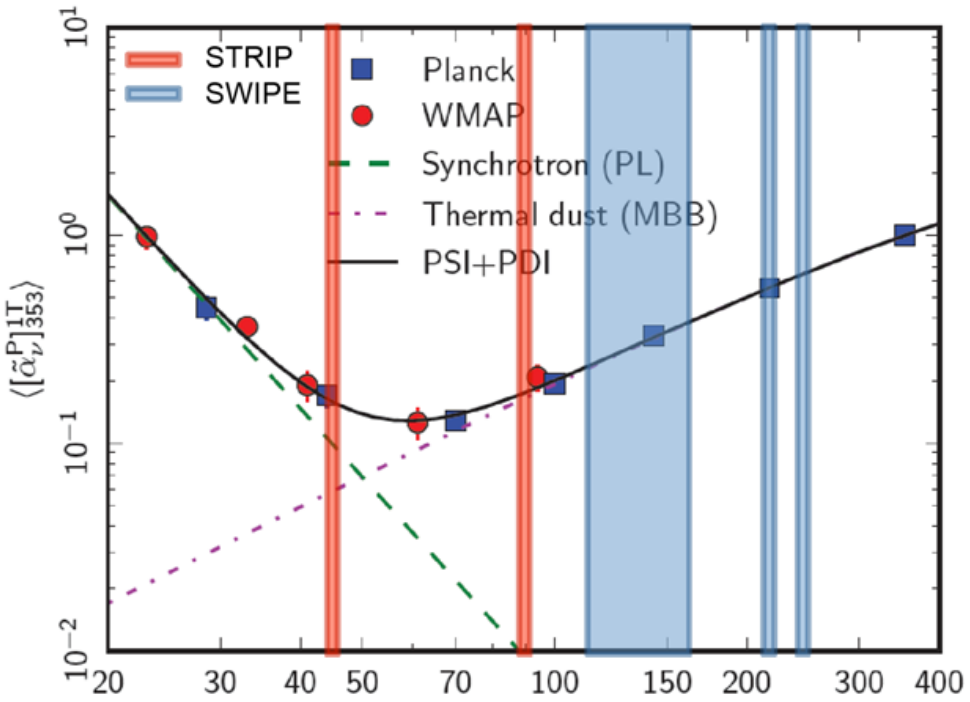



Standing waves due to reflections from cryostat screens

# Dual frequency receiving system for COrE mission

L.S. Kuzmin, A.V. Blagodatkin, A.S. Mukhin, D.A. Pimanov, V.O. Zbrozhek, A.V. Gordeeva, A.L. Pankratov, and A.V. Chiginev, Multichroic seashell antenna with internal filters by resonant slots and cold-electron bolometers, Superconductor Science and Technology, 33 (2019), doi: 10.1088/1361-6668/aafeba (open access) (IF 2.861);

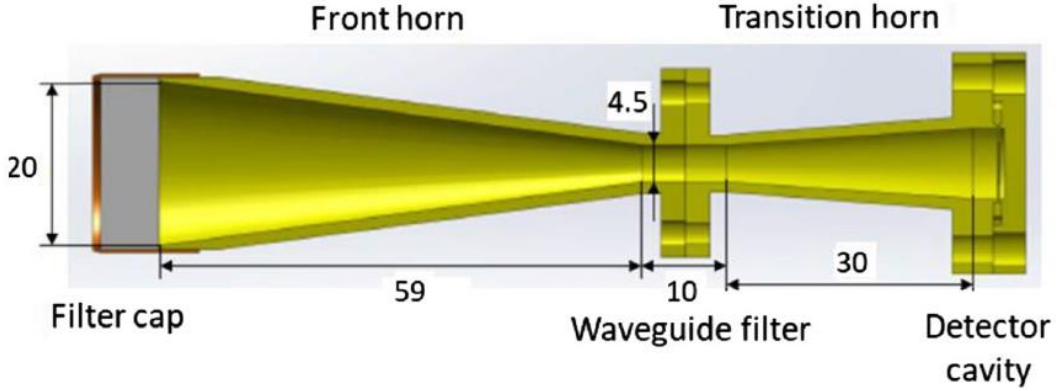
# A project of the balloon radiotelescope LSPE-SWIPE – requirements to the receiving system




(P. de Bernardis, Università La Sapienza, Roma, Italy for the LSPE collaboration)

**Table 1** LSPE instrumental parameters

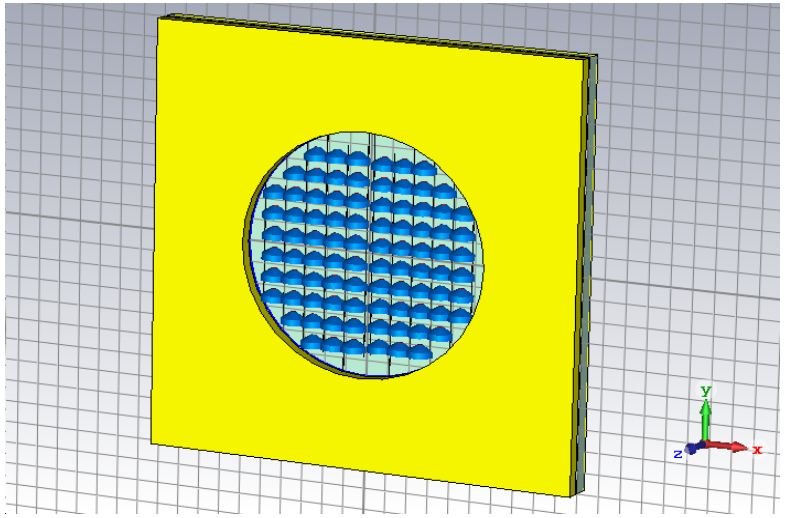
| Instrument | STRIP | | SWIPE | | |
|---|---|---|---|---|---|
| Site | Tenerife | | balloon | | |
| Freq (GHz) | 43 | 90 | 145 | 210 | 240 |
| Bandwidth | 16% | 8% | 30% | 20% | 10% |
| Angular resolution FWHM (arcmin) | 20 | 10 | 85 | | |
| Detectors technology | HEMT | | TES multimoded | | |
| Number of detectors $N_{det}$ | 49 | 6 | 110 | 108 | 108 |
| Detector NET ($\mu K_{CMB}\sqrt{s}$) | 460 | 1247 | 12.7 | 15.7 | 30.9 |
| Mission duration | 2 years | | 15 days | | |
| Duty cycle | 35% | | 90% | | |
| Sky coverage $f_{sky}$ | 37% | | 38% | | |
| Map sensitivity $\sigma_{Q,U}$ ($\mu K_{CMB}$ · arcmin) | 104 | 809 | 12 | 14 | 29 |
| Noise power spectrum $(\mathcal{N}_\ell^{E,B})^{1/2}$ ($\mu K_{CMB}$ · arcmin) | 171 | 1330 | 19 | 24 | 47 |



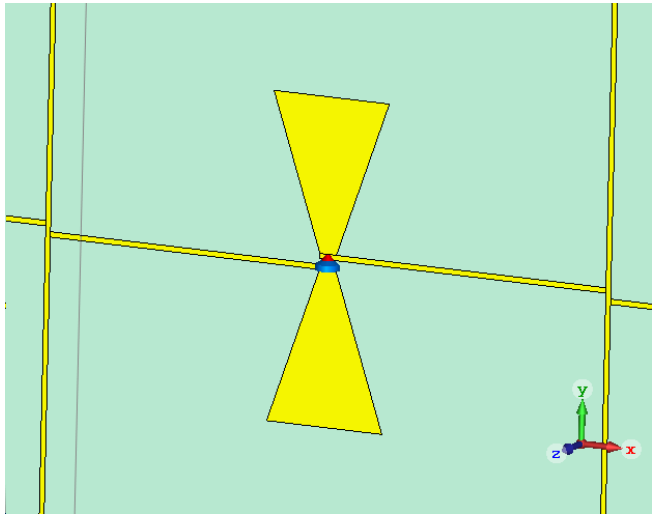

(L. Lamagna et al. // Journal of Low Temperature Physics, 2020)

# Dual frequency receiving system for auxiliary frequency channels for LSPE project - modeling

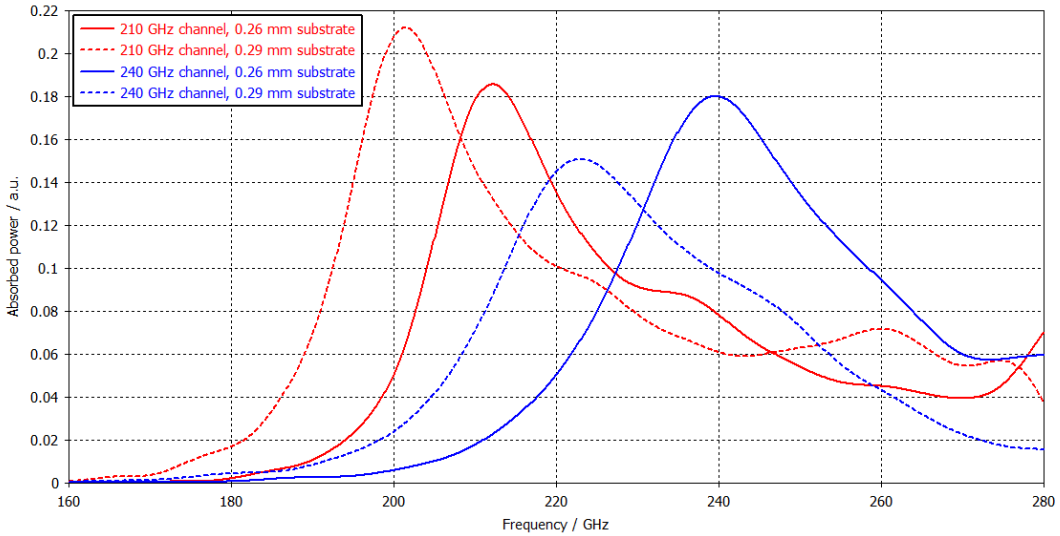
Matrix of receiving cells




Receiving cell – a dipole bowtie antenna + CEB



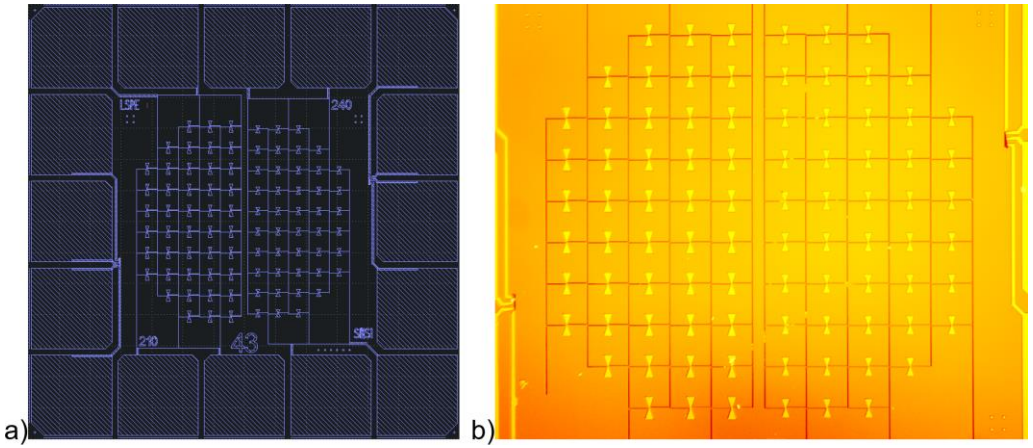

Frequency response of the receiving system



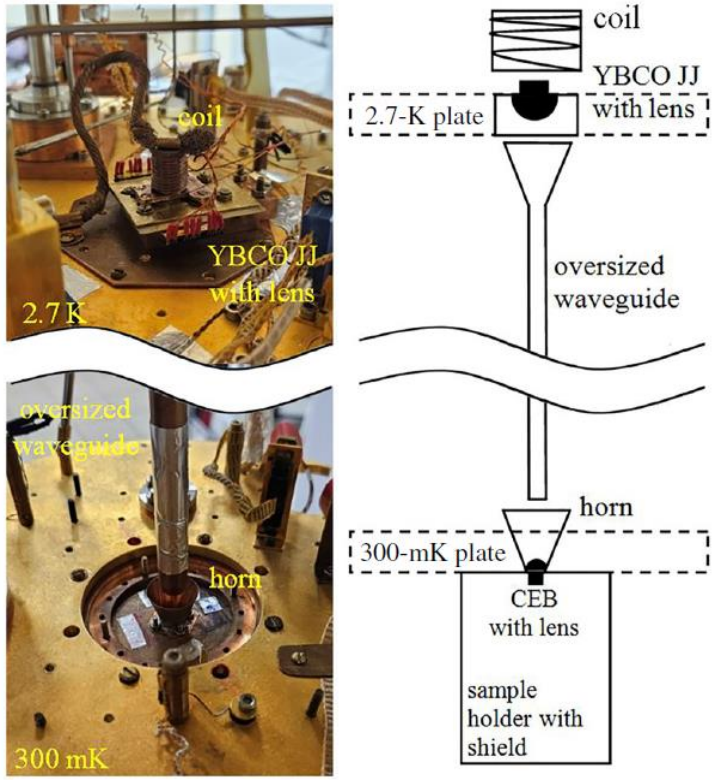

Receiving cells are connected in parallel to match with the SQUID readout

# Dual frequency receiving system for 210 and 240 GHz – samples and measurements

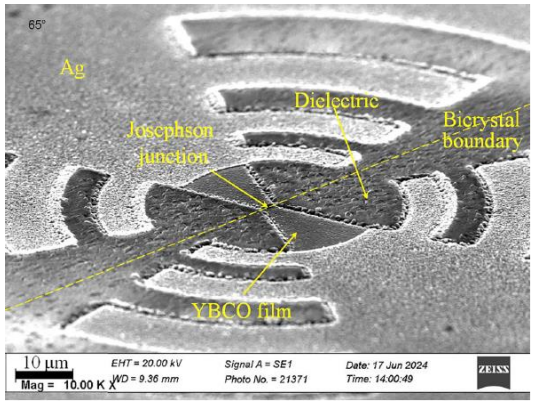
Design of the sample (a) and optical image (b) of the receiving system



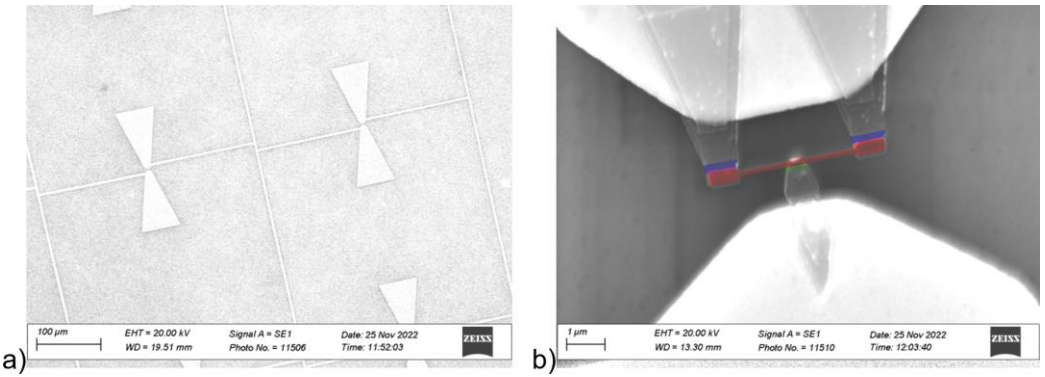

Setup of the experiment



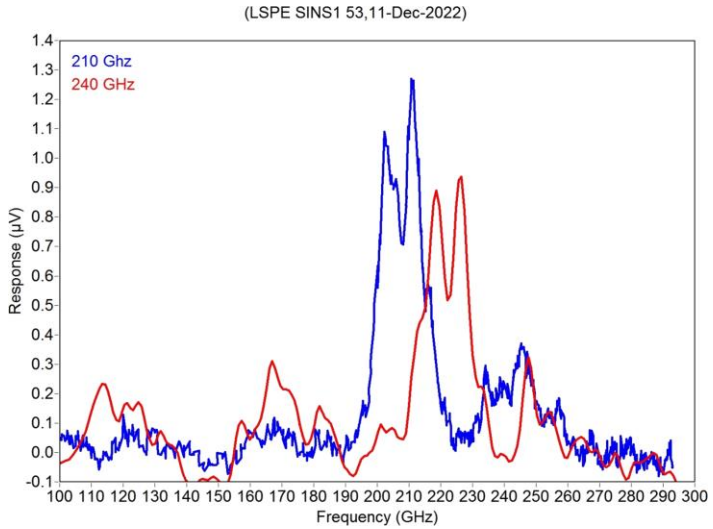

STM image of the YBCO flux-flow oscillator




SEM images of the dipole bowtie antennas (a) and cold-electron bolometers (b)




Measurements of the frequency response




(L.S. Revin et al., Beilstein Journal of Nanotechnology, 2024)