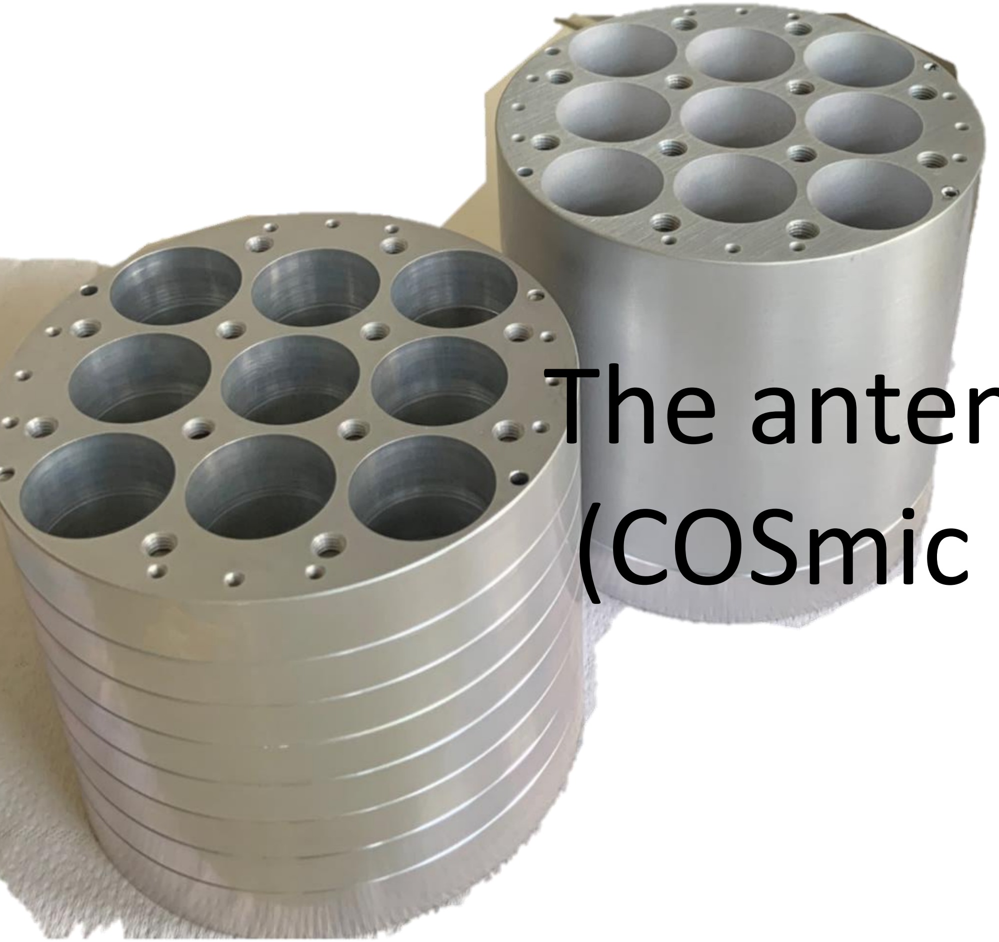


The antenna system of COSMO (COSmic Monopole Observer)

Elenia Manzan

Università degli Studi di Milano

The COSMO experiment

Aims at measuring the isotropic y-distortion of the CMB spectrum

The current state-of-the-art is $|y| < 1.5 \cdot 10^{-5}$, from COBE-FIRAS and TRIS

COSMO forecasted sensitivity: $|y| \sim 10^{-6}$

Site: Concordia station, Antarctica

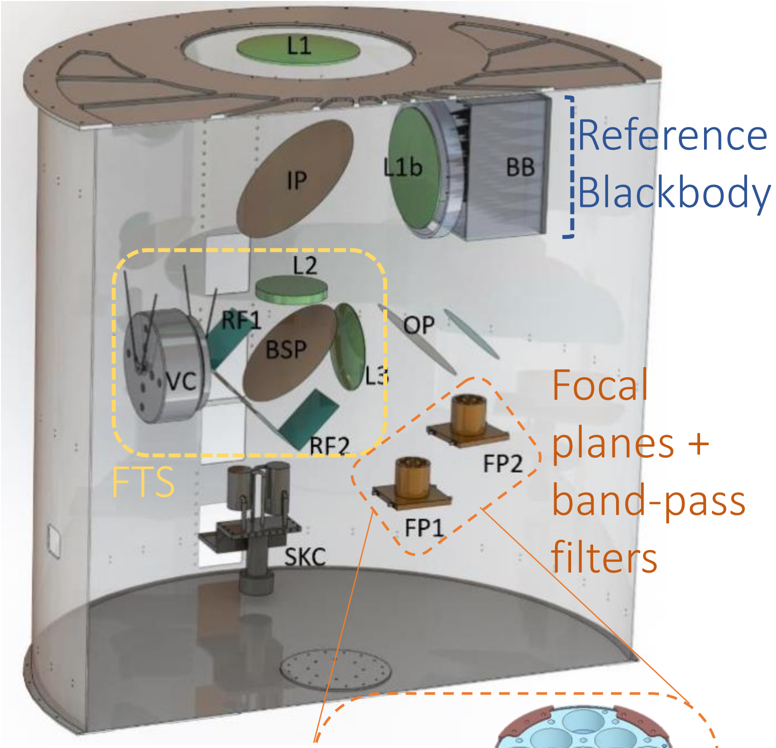
Image: COSMO collaboration

The COSMO experiment

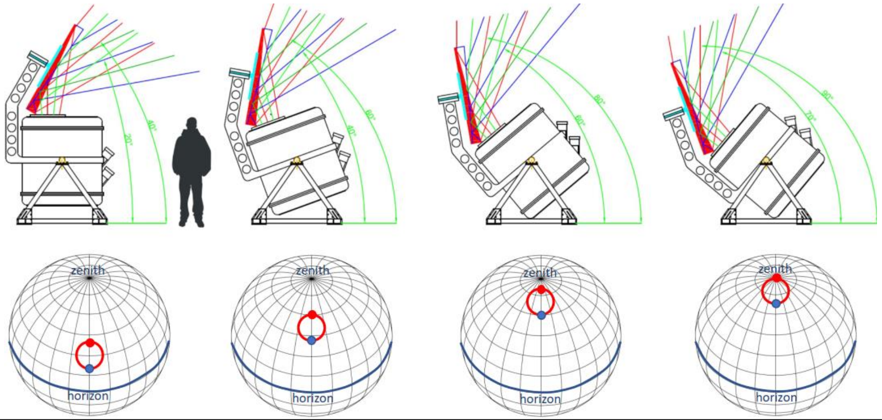
Differential, cryogenic Martin-Pupplett Fourier Transform Spectrometer (FTS)

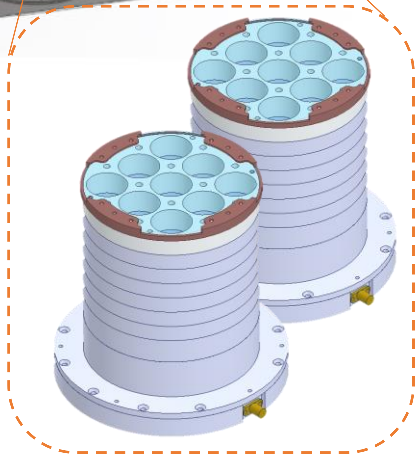
2 Focal planes: 18 multimoded feed-horns + KID bolometers

Band: 120-300 GHz (limited by the atmospheric window)



The cryostat can be tilted and a spinning wedge mirror performs fast sky scans

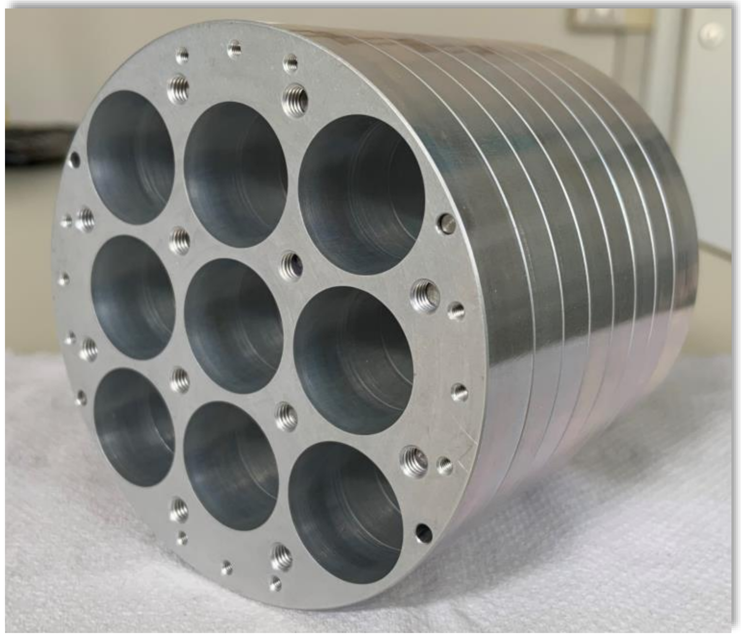


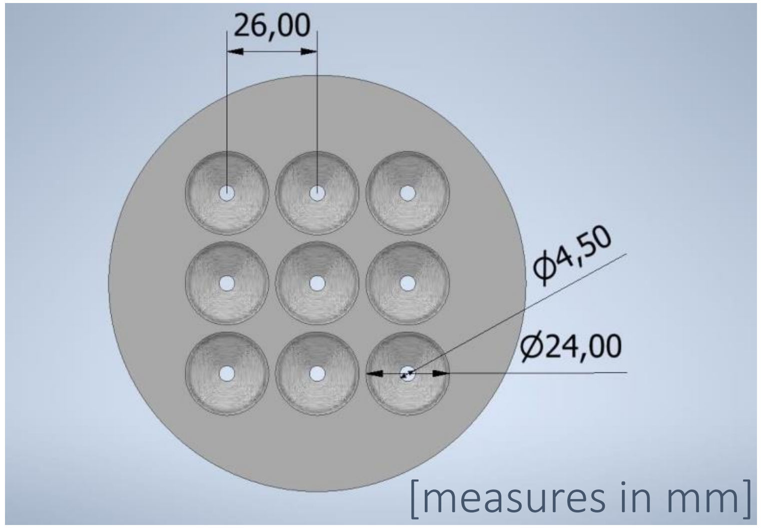


The antenna system

Overview of the antenna system

- Array 1 band: 120-180 GHz
- Array 2 band: 210-300 GHz
- Antennas: smooth-walled feed-horns
- Made in aluminum with CNC milling
- 3x3 feed-horn arrays
- Multimoded feed-horns instead of traditional single-mode horns





Multimode propagation principle

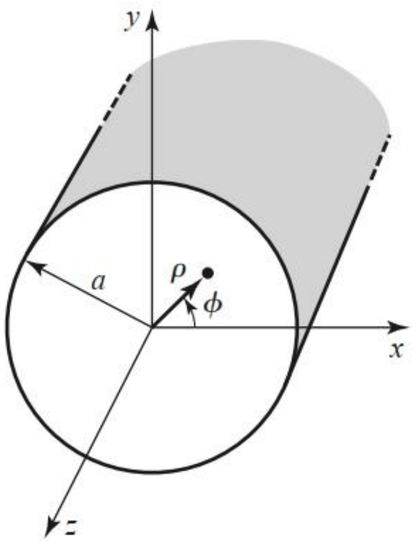
Single-mode antenna

Band	Waveguide diameter	# modes
120-180 GHz	1.47 mm	1
210-300 GHz	1 mm	1

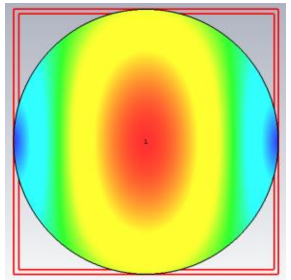
Multi-mode antenna

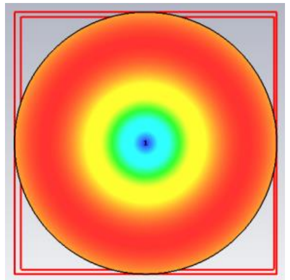
Band	Waveguide diameter	# modes
120-180 GHz	4.5 mm	From 10 to 19
210-300 GHz	4 mm	From 23 to 42

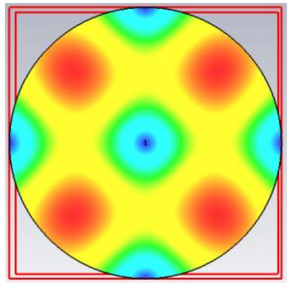
A hollow circular waveguide supports TE and TM mode propagation.

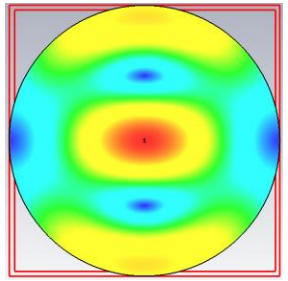


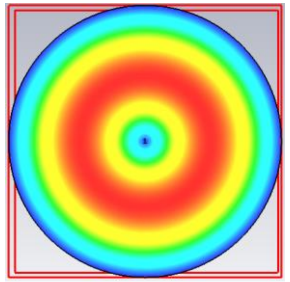
Cut-off frequency $\sim {}^{1}/_{a}$

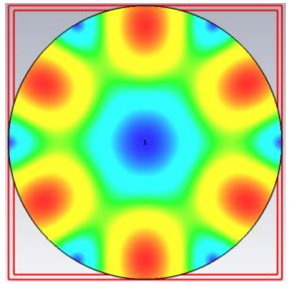

TE11

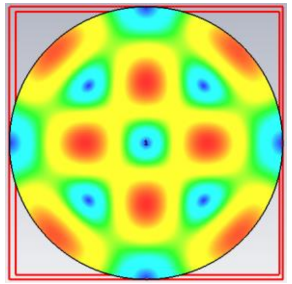

TM01

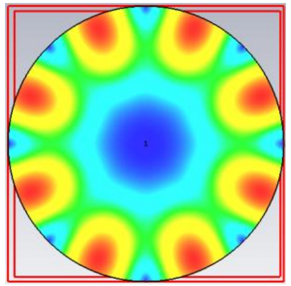

TE21

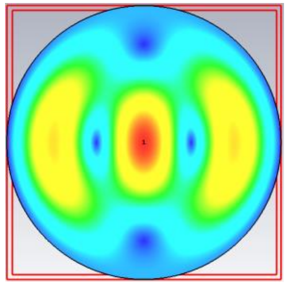

TM11

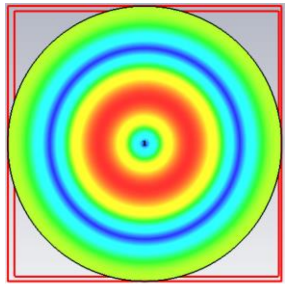

TE01


TE31


TM21


TE41

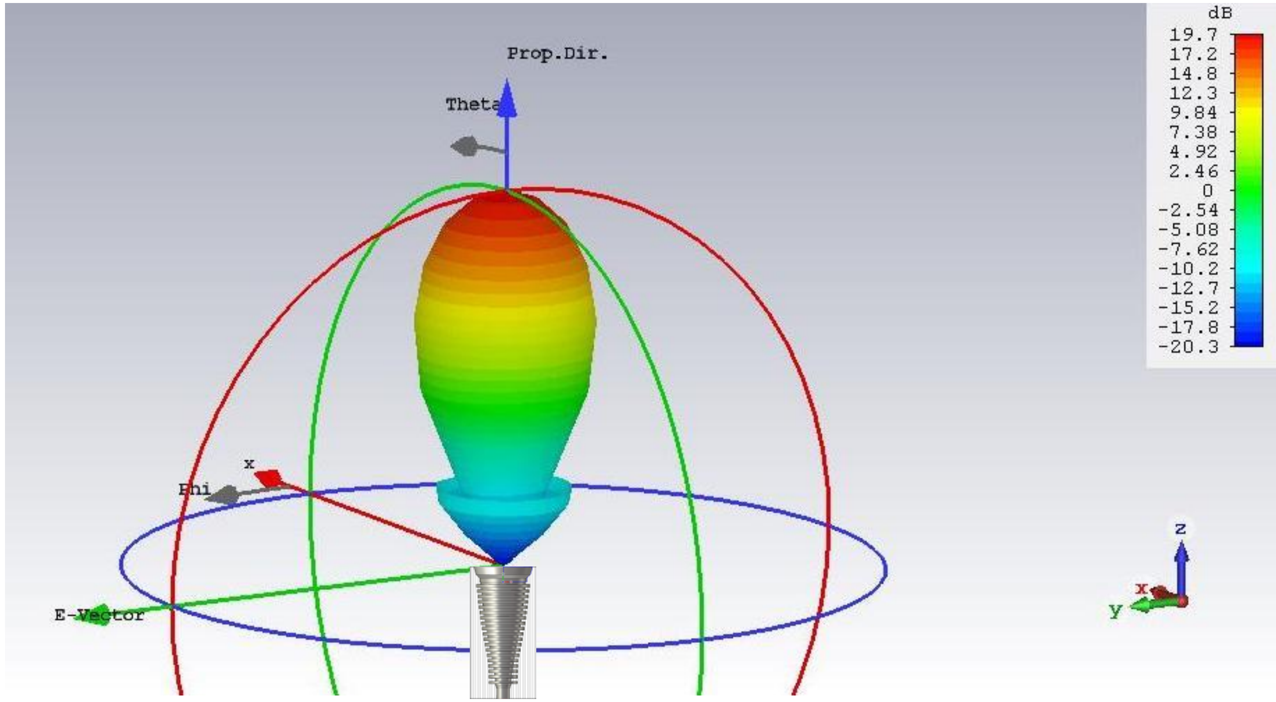

TE12


TM02

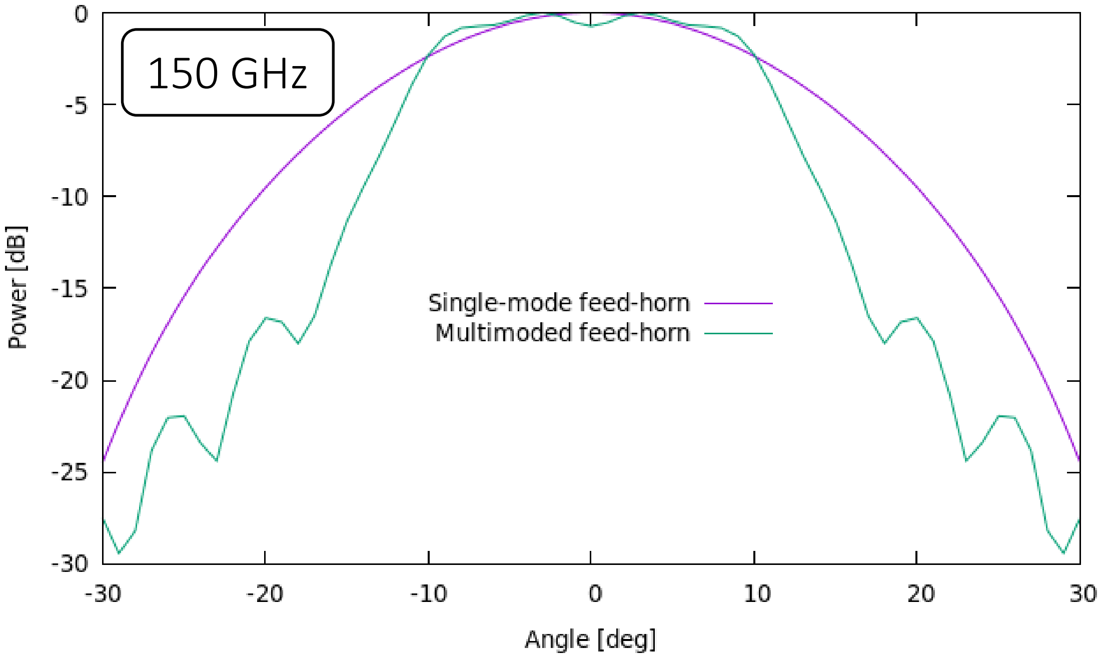
Multimode propagation advantages

- Multimoded receivers (antenna+detector) have a higher signal-to-noise level: $\frac{S}{N} \sim \sqrt{N_{modes}}$
- Multimoded antennas can illuminate the cryostat aperture (or telescope) more uniformly than single-mode ones.

The beam pattern $\mathrm{P}(\vartheta, \phi)$ describes the antenna performance, i.e. the angular distribution of emitted/received power in farfield condition.



Multimoded beam pattern are flatter than single-mode ones along the antenna axis.



The antenna design in details

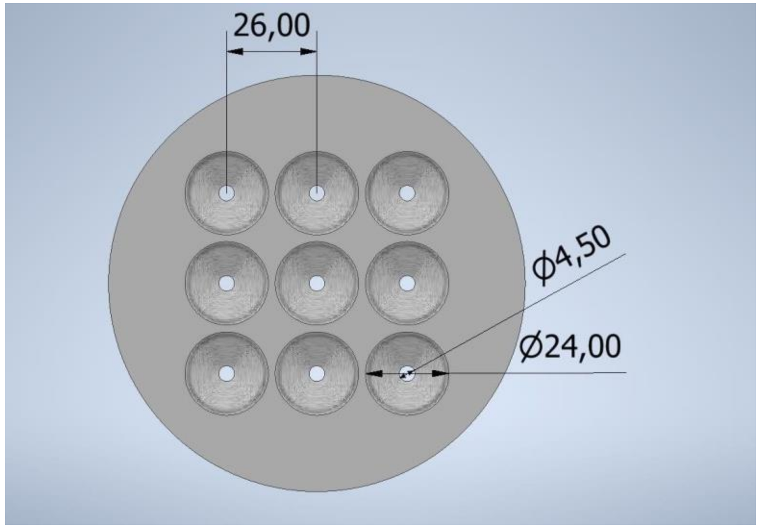
The antenna design is the best trade-off between

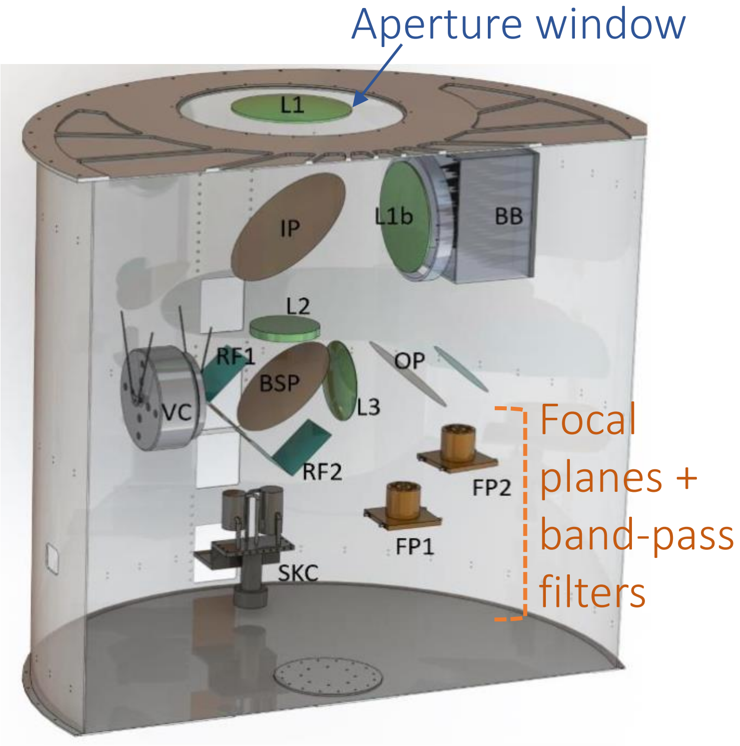
- The multimode requirement on the circular waveguide: fixed waveguide diameter

- The mechanical constraint on the antenna aperture: aperture $\leq$ 24 mm

- The optimization of the antenna directivity inside
  the cryostat aperture window, seen under a $\approx 17°$ angle (f/# 3.3)

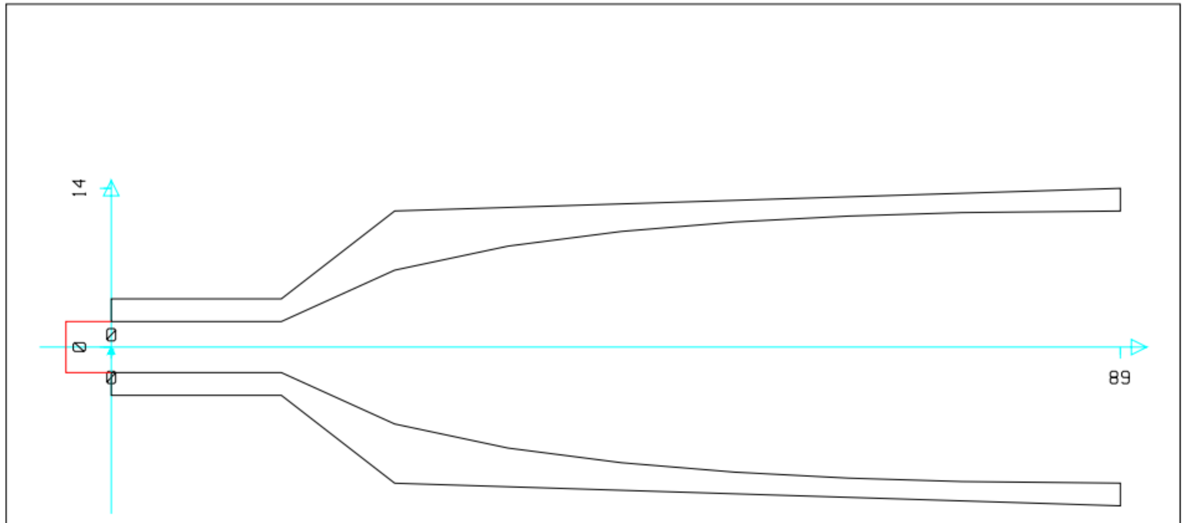
Band	Waveguide diameter
120-180 GHz	4.5 mm
210-300 GHz	4 mm



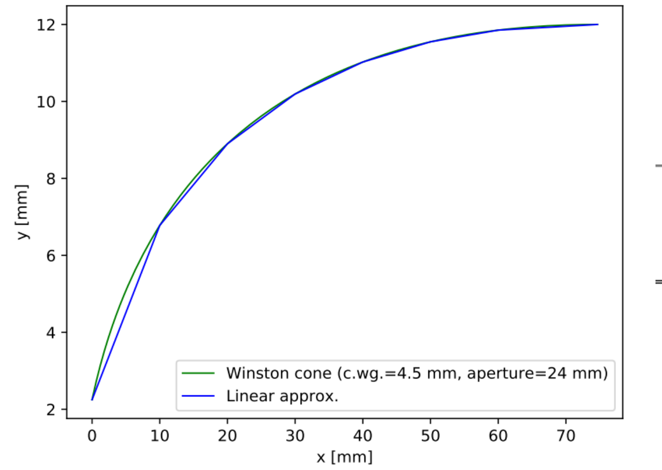


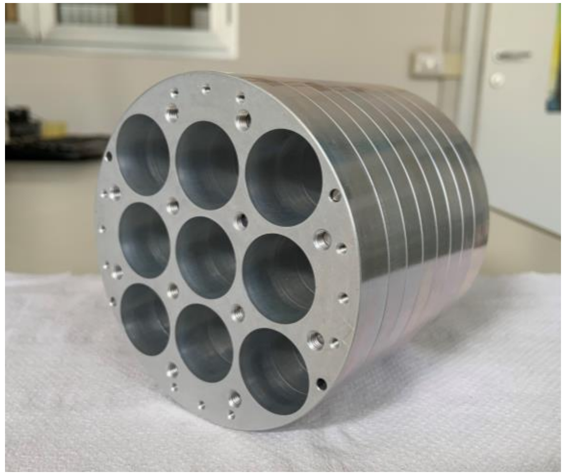
The low-frequency array

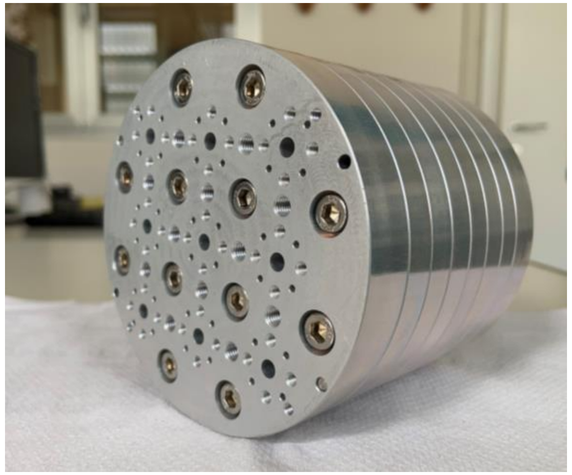
Profile: 4.5 mm circular waveguide + platelet Winston cone

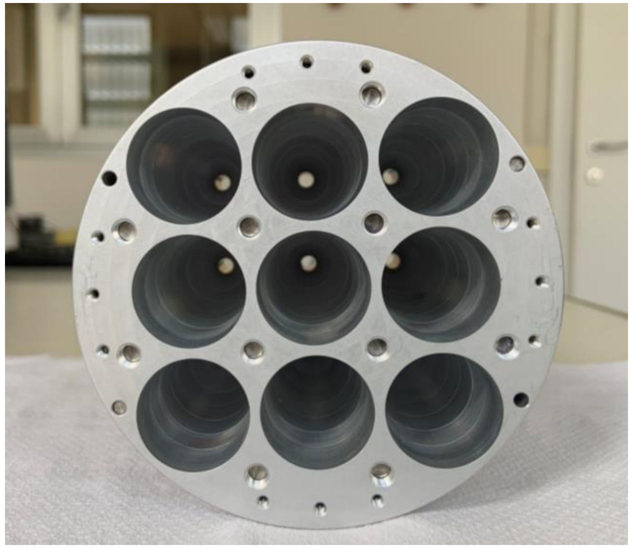


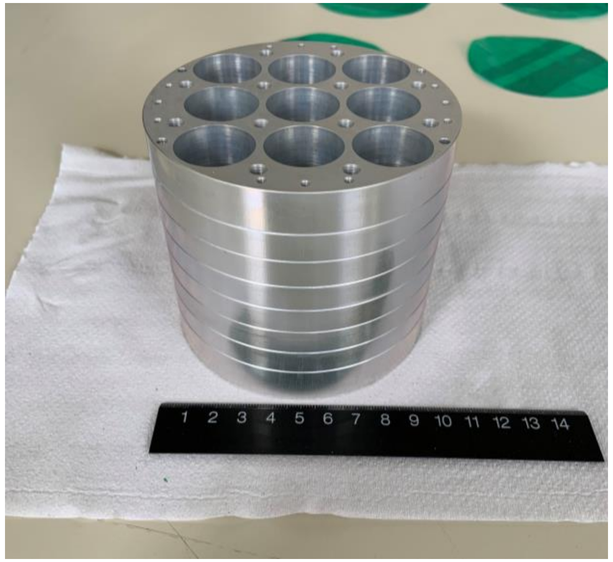
[measures in mm]





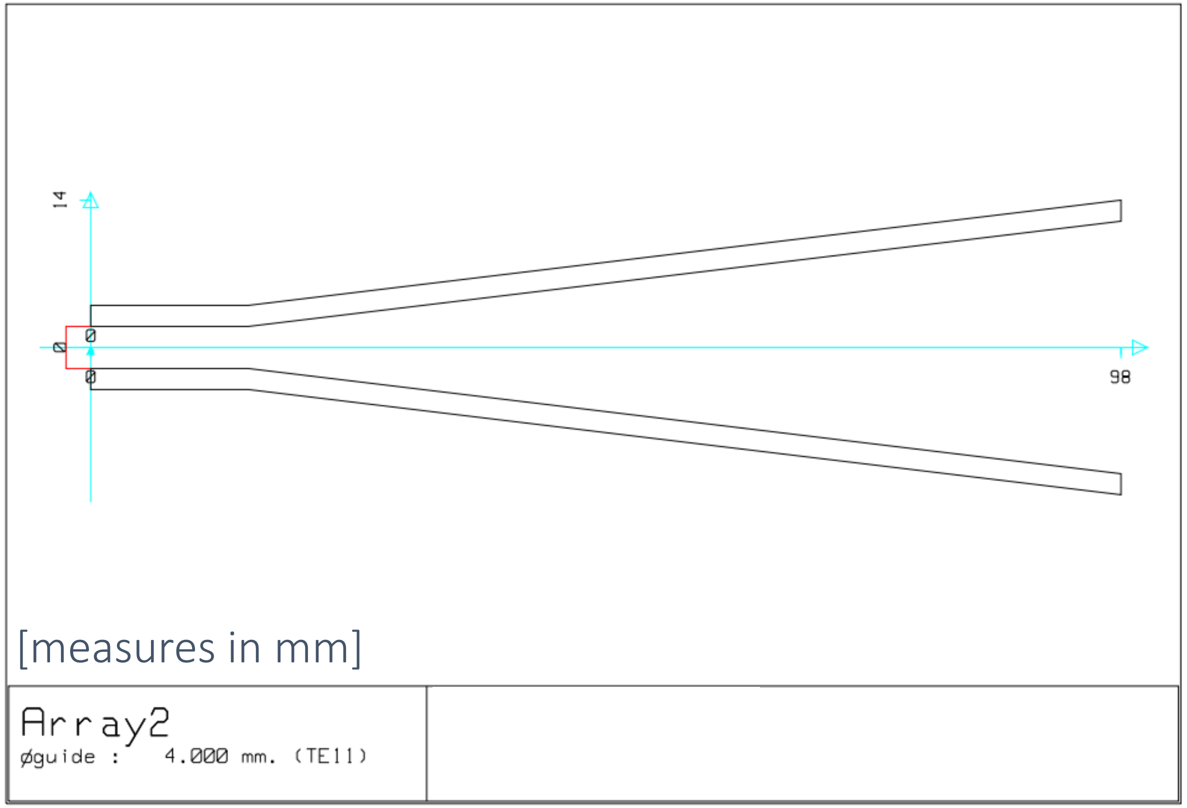




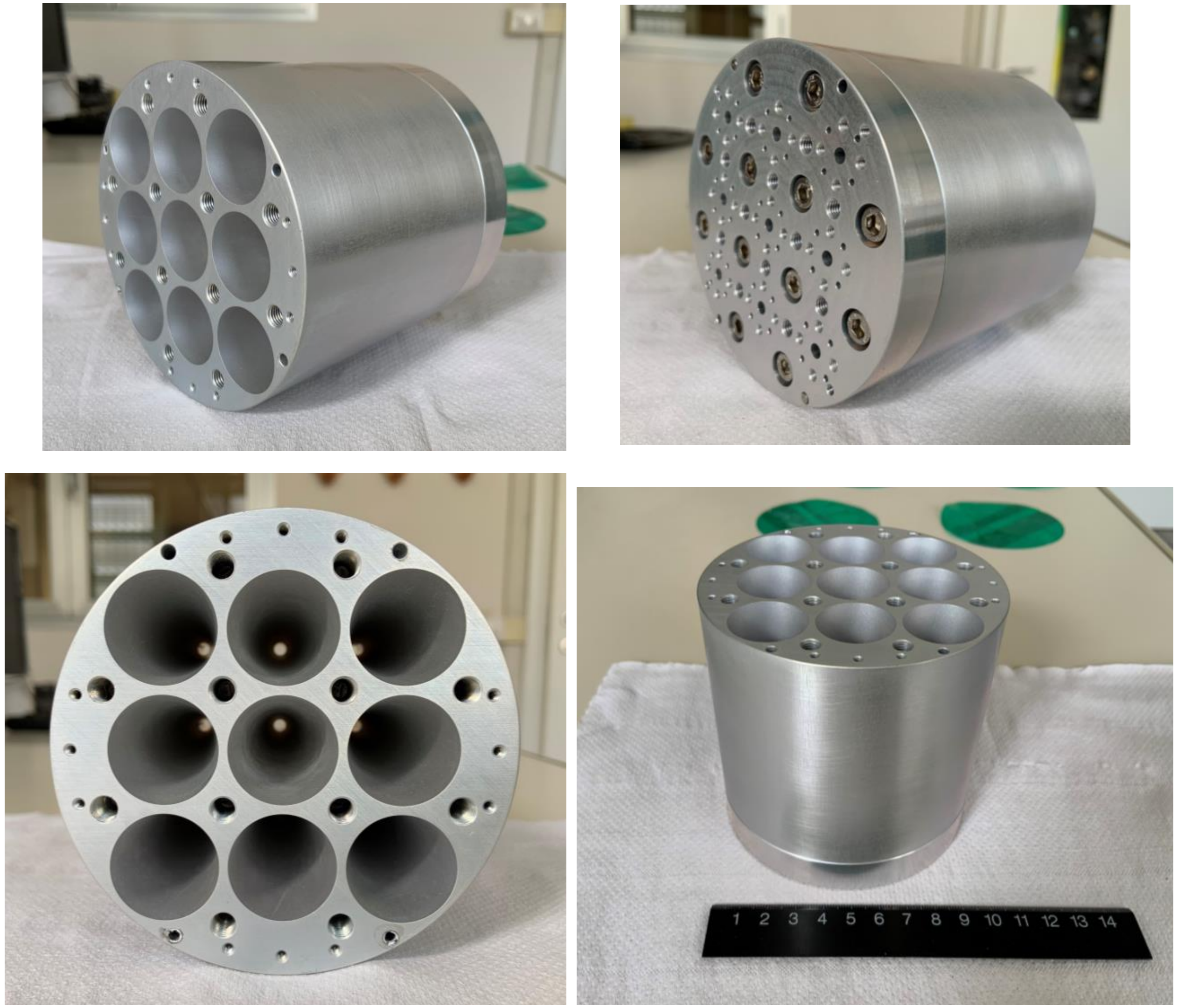


The high-frequency array

Profile: 4 mm circular waveguide + linear profile

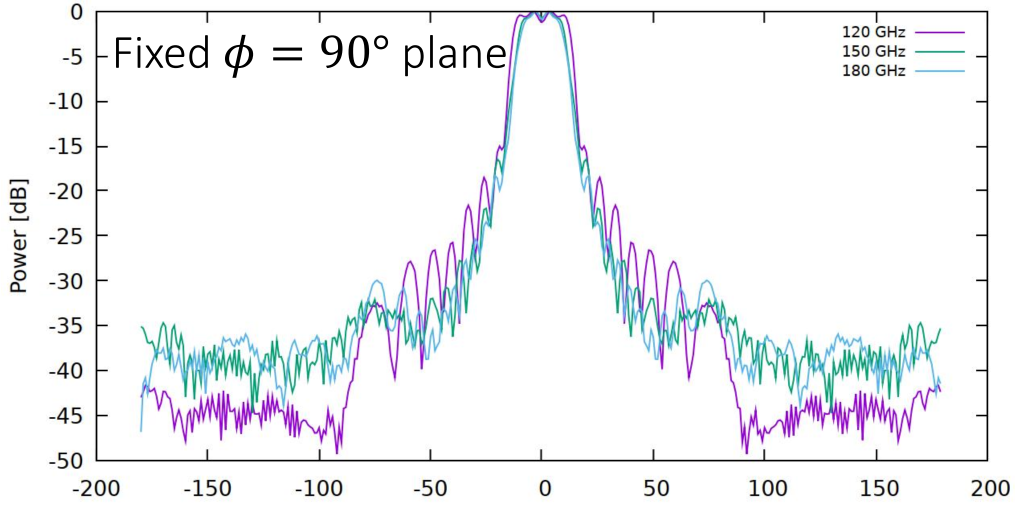


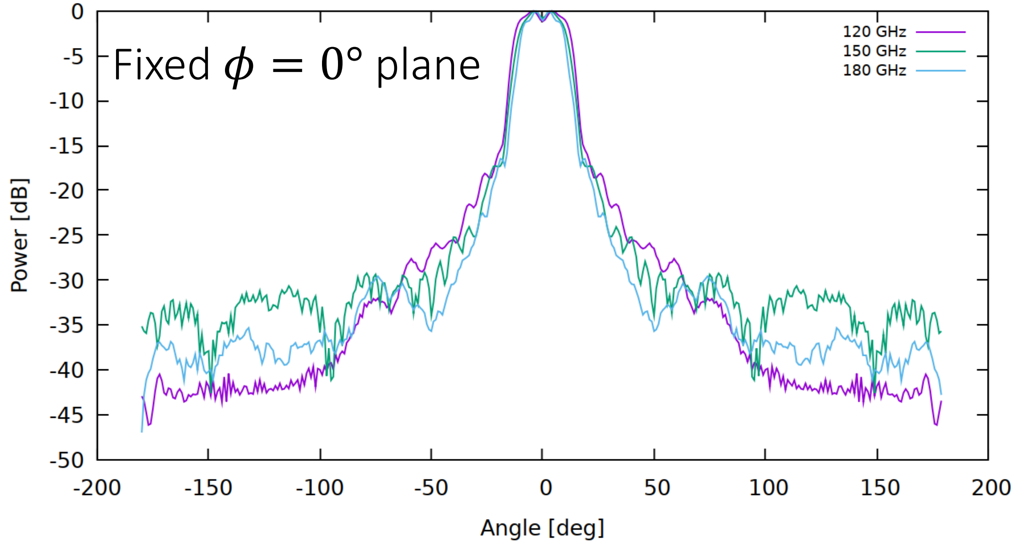
[measures in mm]



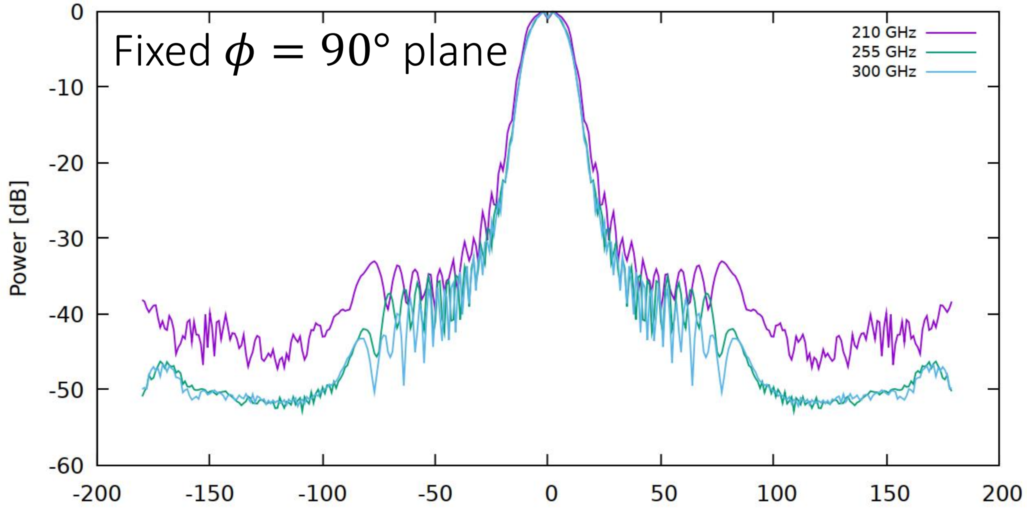
Forecasted broadband performance

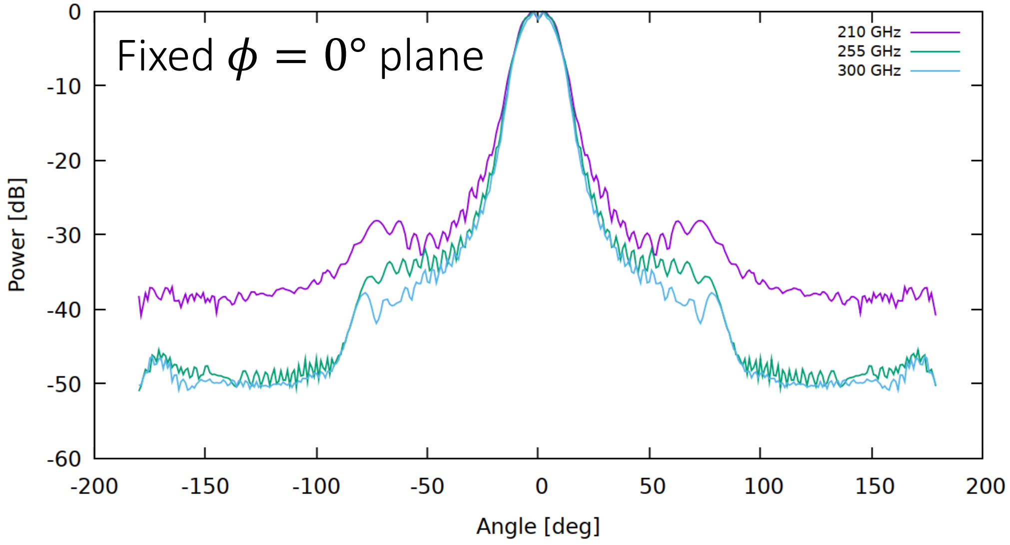
Low-frequency array





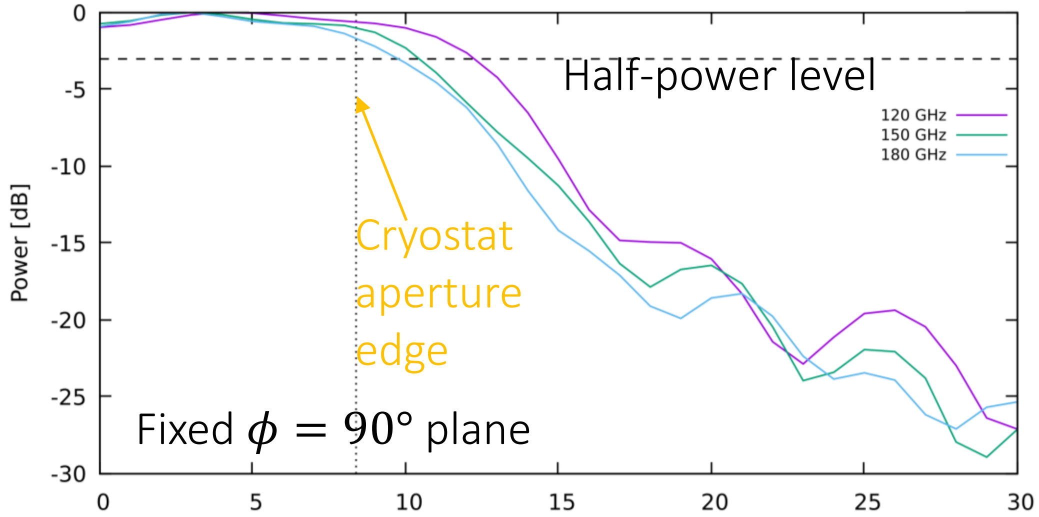
High-frequency array

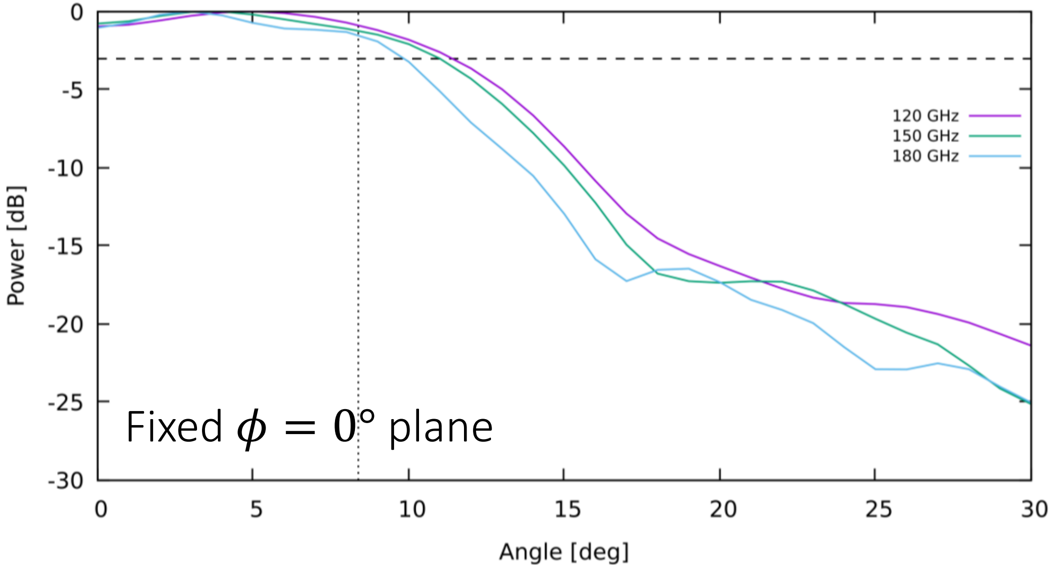




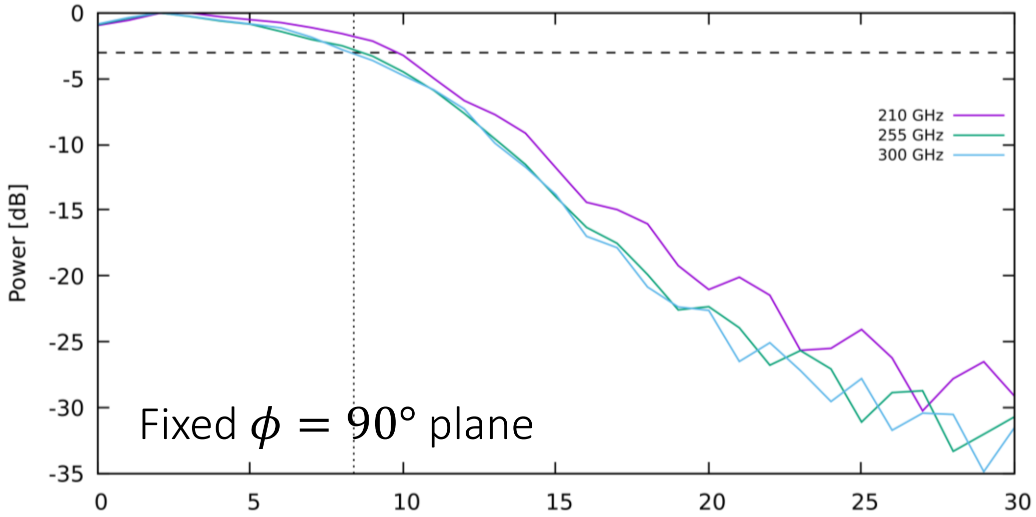
Forecasted broadband performance

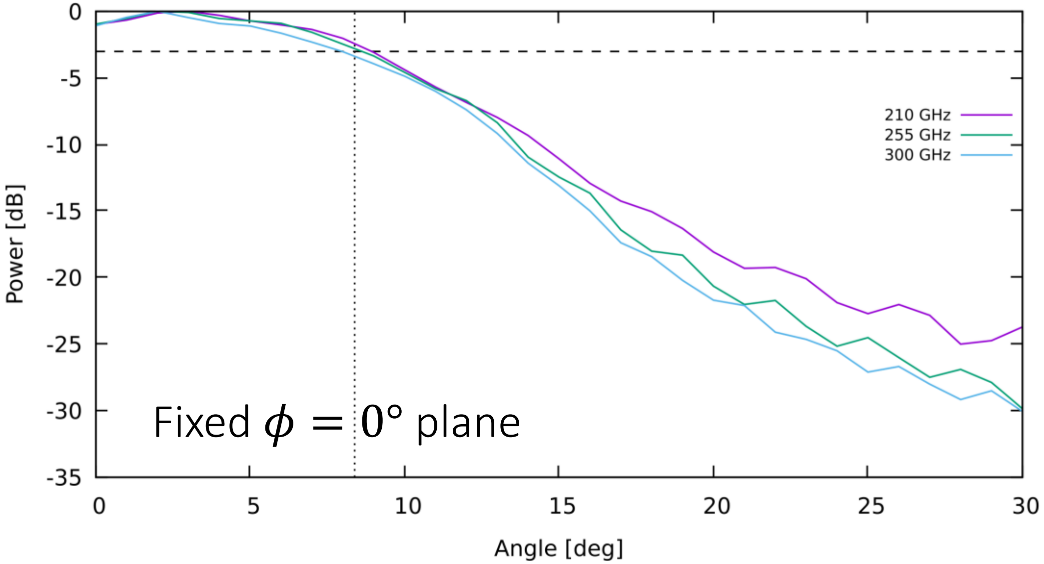
Low-frequency array





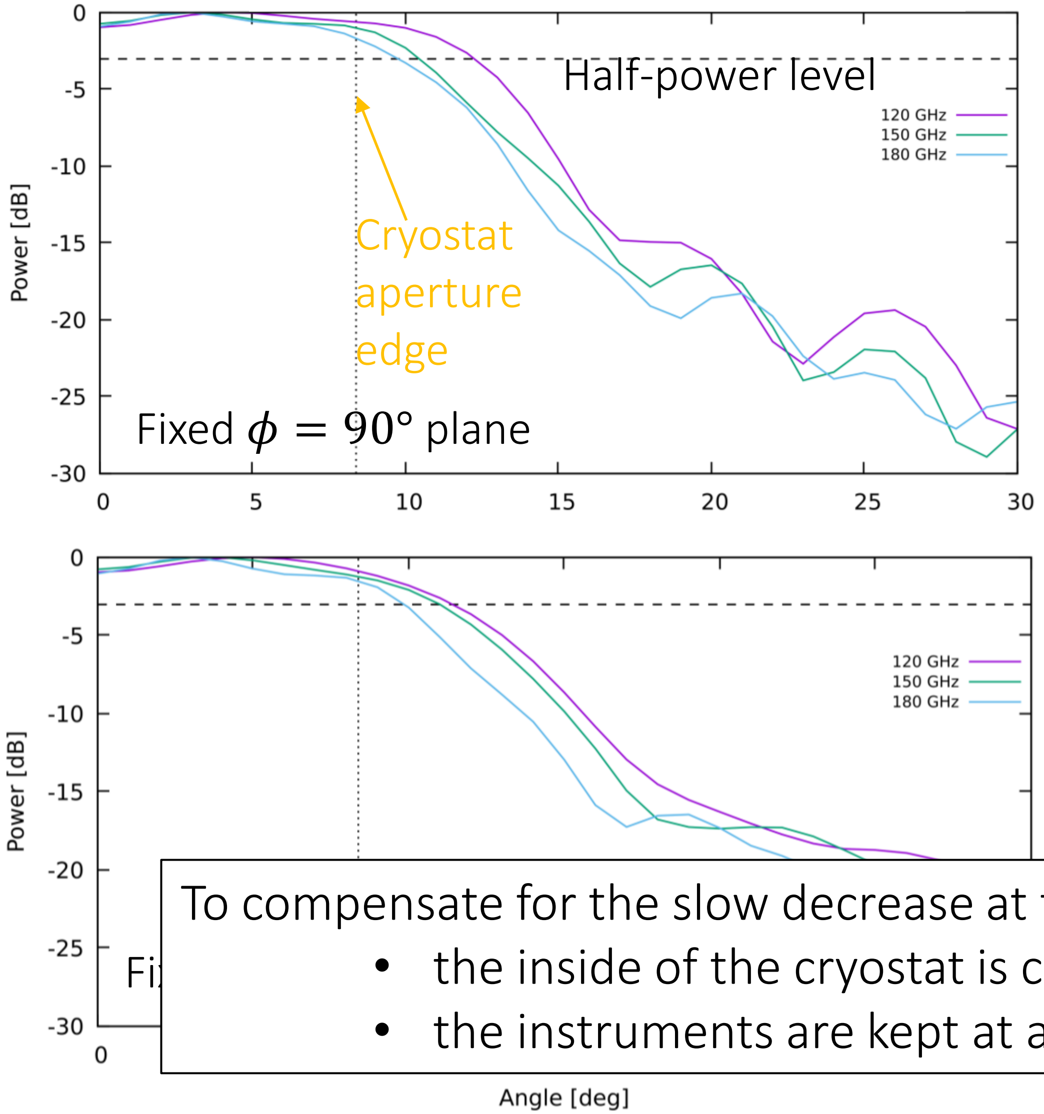
High-frequency array



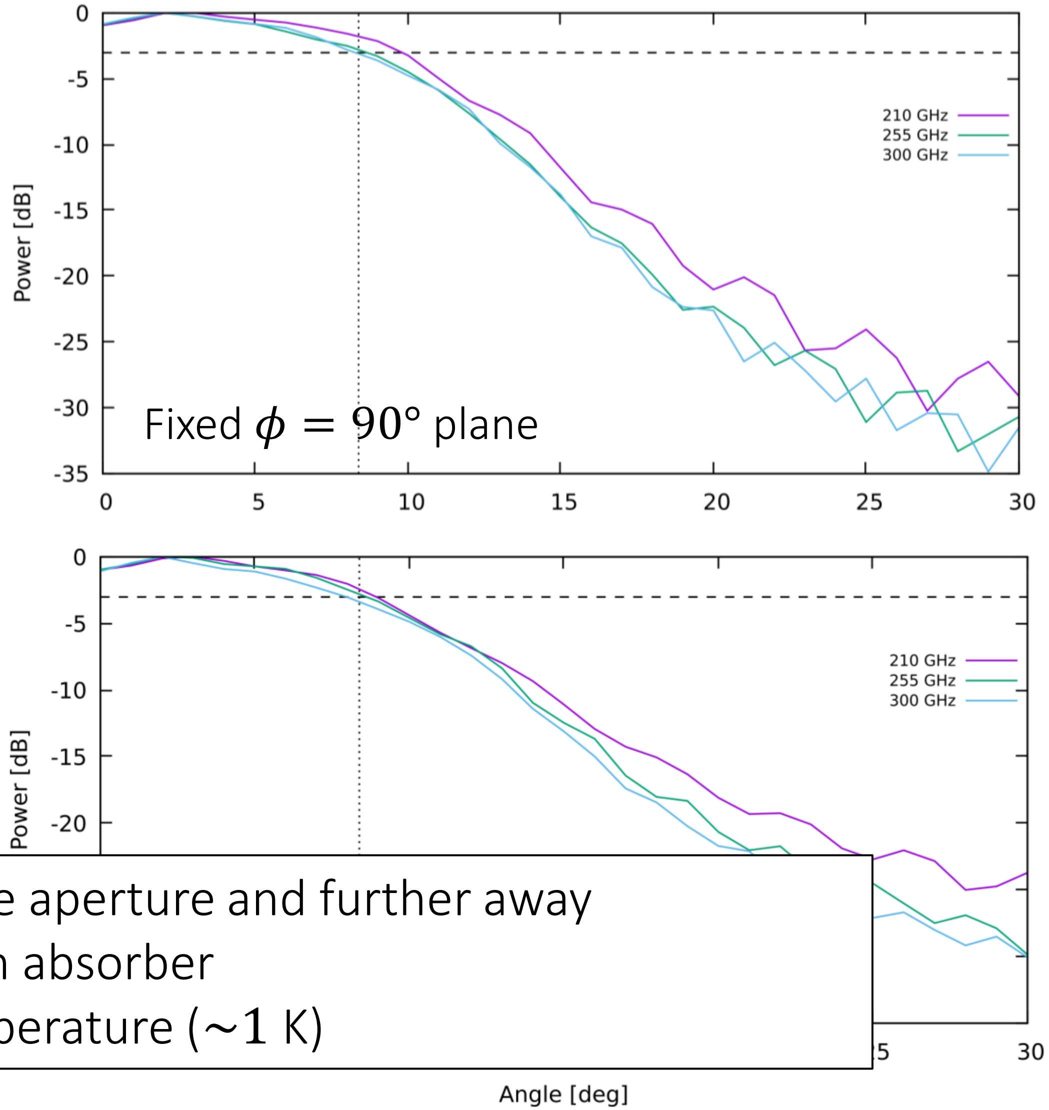


Forecasted broadband performance

Low-frequency array



High-frequency array



To compensate for the slow decrease at the edge of the aperture and further away

- the inside of the cryostat is covered with an absorber
- the instruments are kept at a very low temperature (~ 1 K)

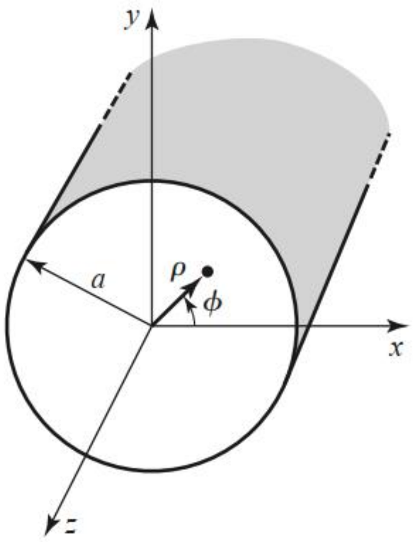
Summary

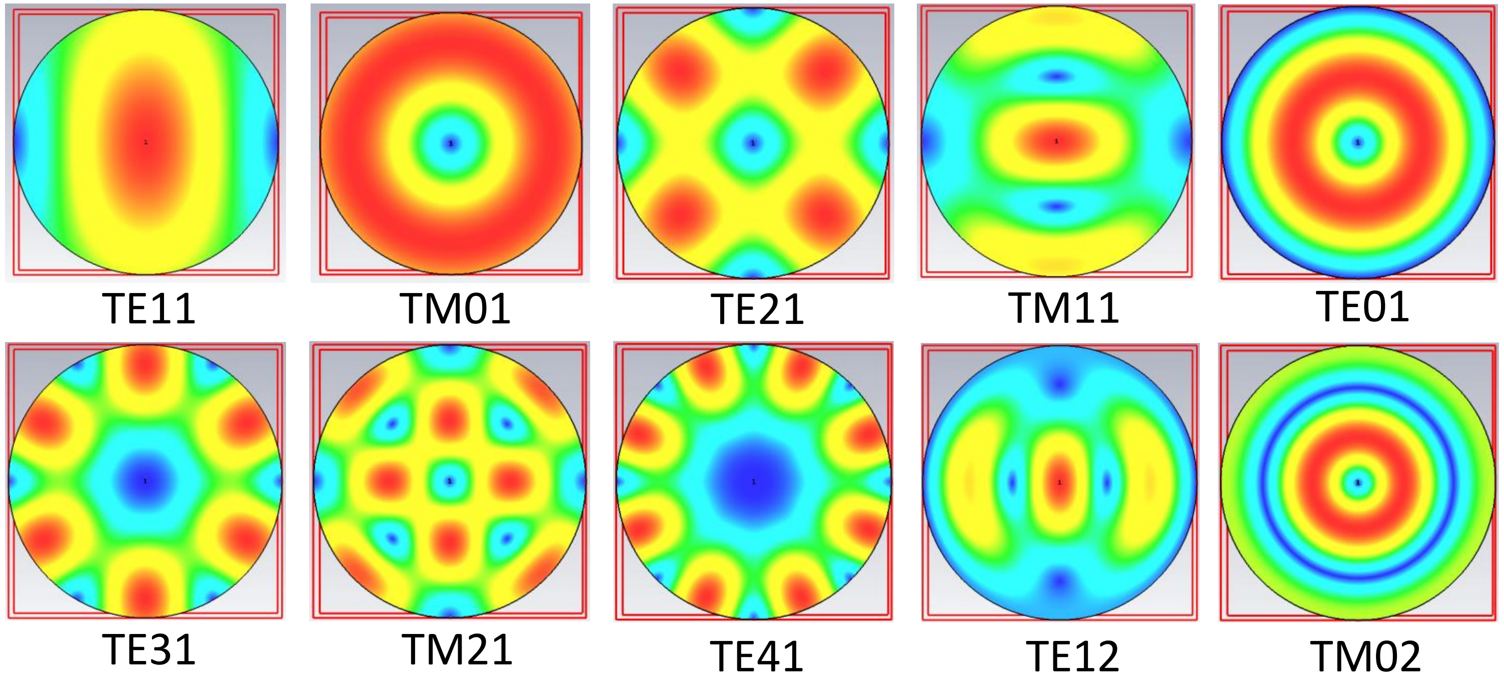
- The antenna system of COSMO consists of two arrays of nine smooth-walled feedhorns
- The 120-180 GHz array is made of platelet Winston cones
- The 210-300 GHz array is made of linear horns
- The feed-horns are multimoded
- The design is the best trade-off between mechanical and electromagnetic requirements, with side lobes below -15 dB and HPBW (Half Power Beamwidth) between $17°$ and $26°$
- The arrays are made in aluminum through CNC milling

Back-up slides

Multimode propagation principle

A hollow circular waveguide supports TE and TM mode propagation.





Solving the Helmholtz equation for a TE (or TM) wave and applying transverse boundary conditions shows that each mode $\mathrm{TE_{m,n}}/\mathrm{TM_{m,n}}$ has a cut-off frequency

$f_{c\,\mathrm{m,n}}^{\ \mathrm{TE}} = \frac{p'_{\mathrm{n,m}}}{2\pi a} c$, where $p'_{\mathrm{m,n}}$ is the *n*-th root of $J'_{\mathrm{m}}(x) = 0$

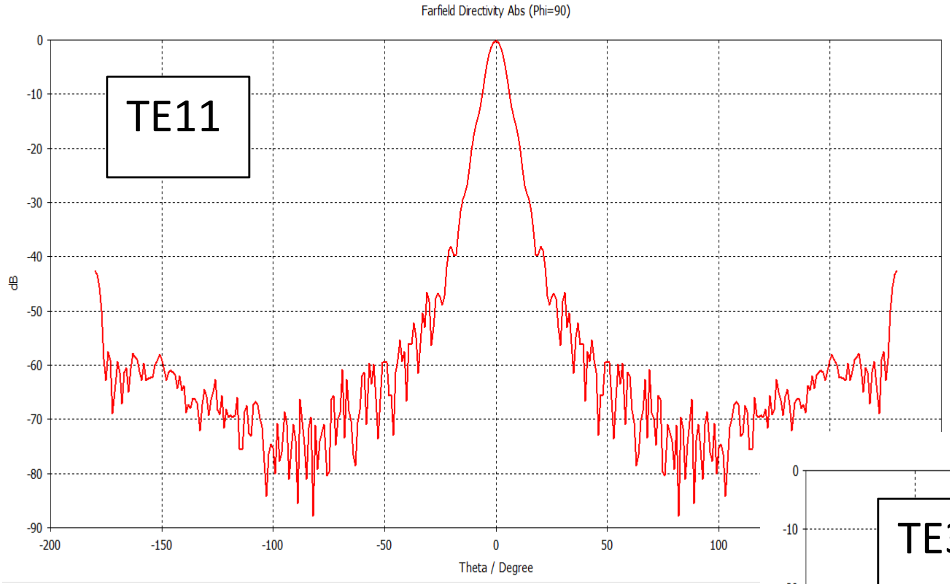
$f_{c\,\mathrm{m,n}}^{\ \mathrm{TM}} = \frac{p_{\mathrm{n,m}}}{2\pi a} c$, where $p_{\mathrm{m,n}}$ is the *n*-th root of $J_{\mathrm{m}}(x) = 0$

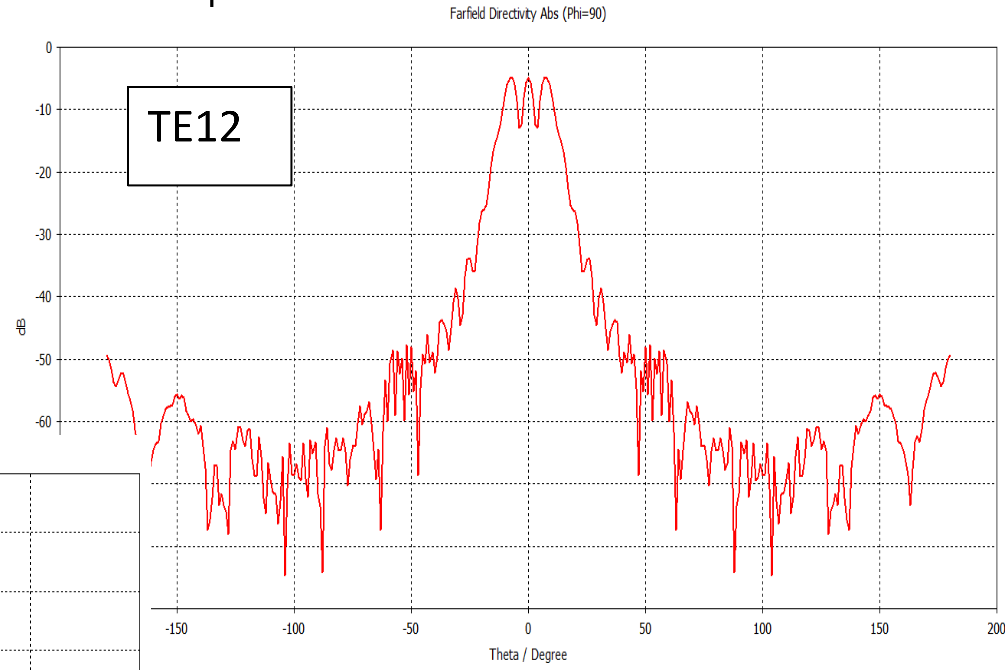
Bessel function

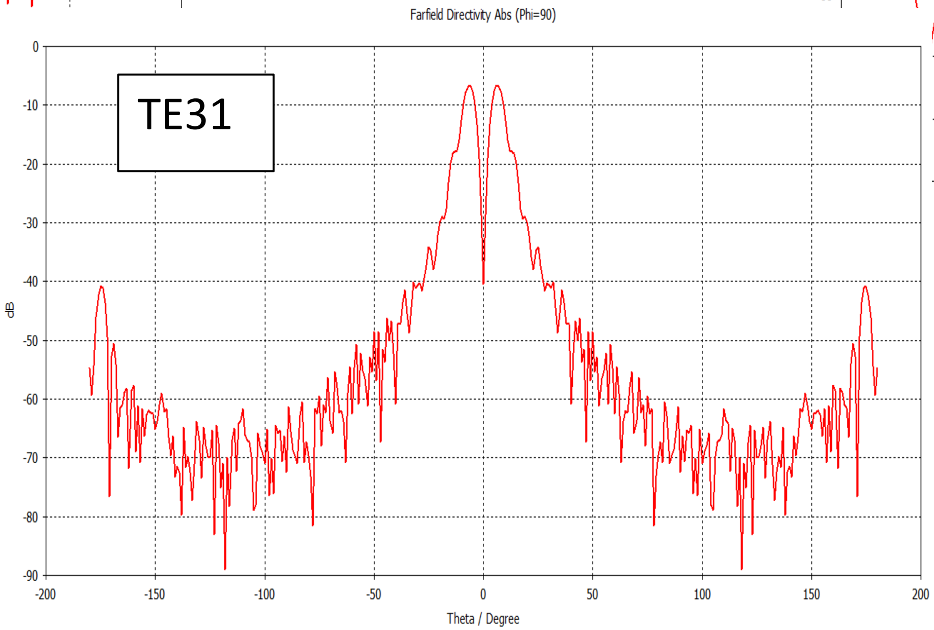
If $f < f_c$ the mode is evanescent
If $f > f_c$ the mode propagates

Individual mode beam pattern

Each mode has its own beam pattern. A few examples:



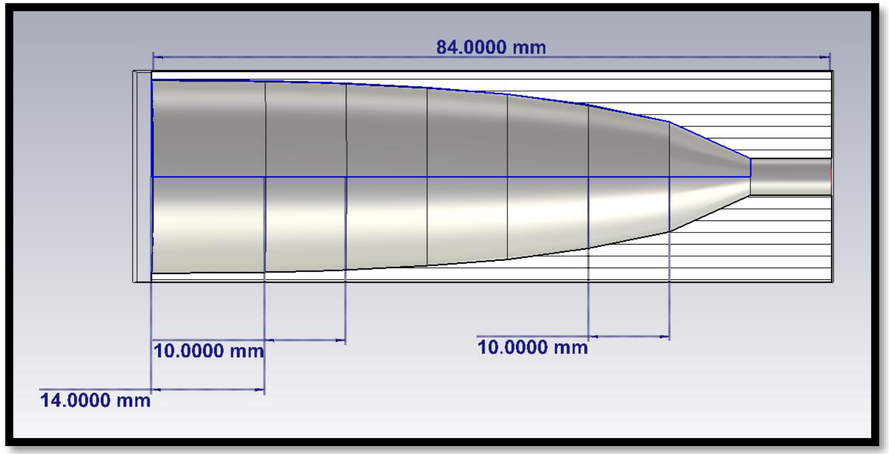


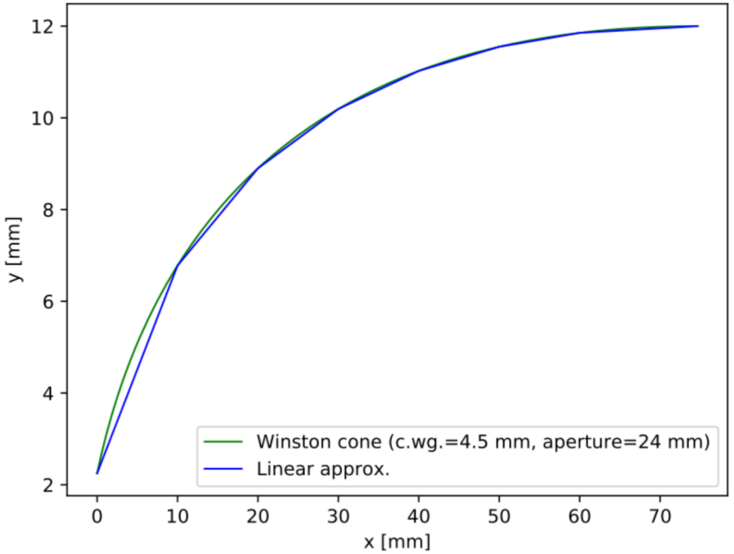


Some beams are symmetric w.r.t. the azimuthal angle ϕ, some are not.

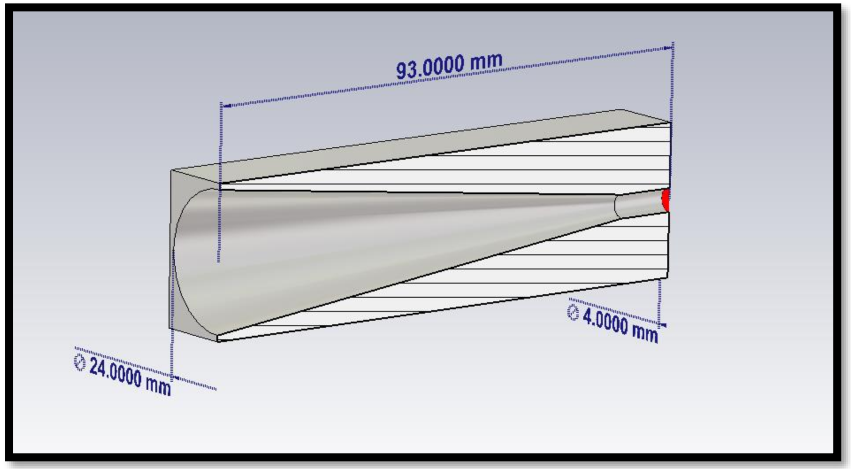
The COSMO antenna profiles

150 GHz array: platelet Winston cone



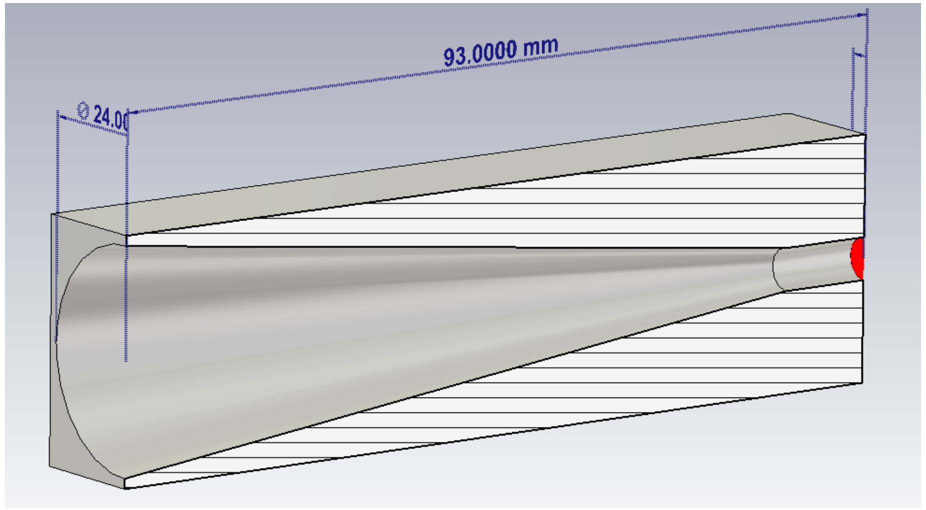


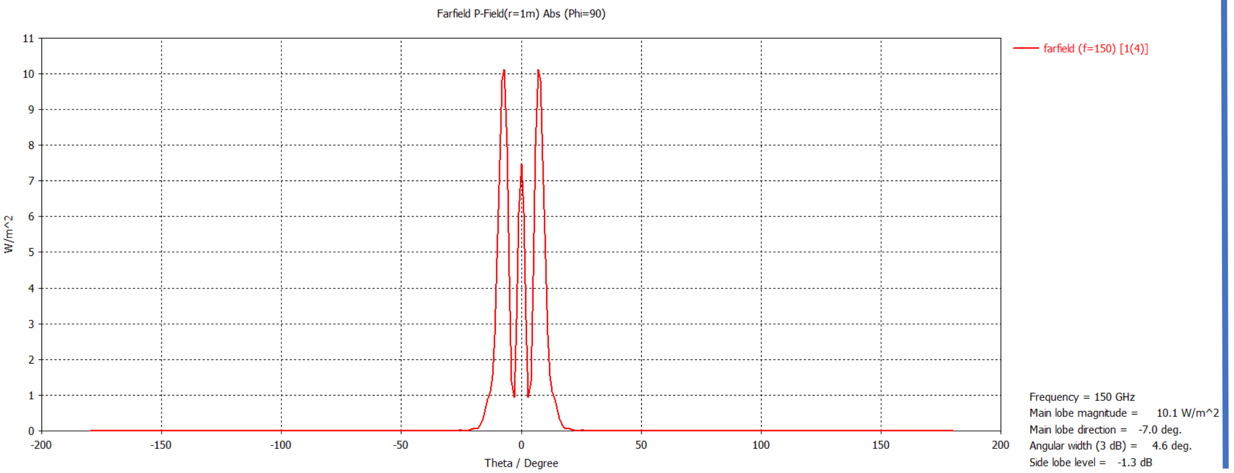
255 GHz array: linear horn



Mode modification

From this





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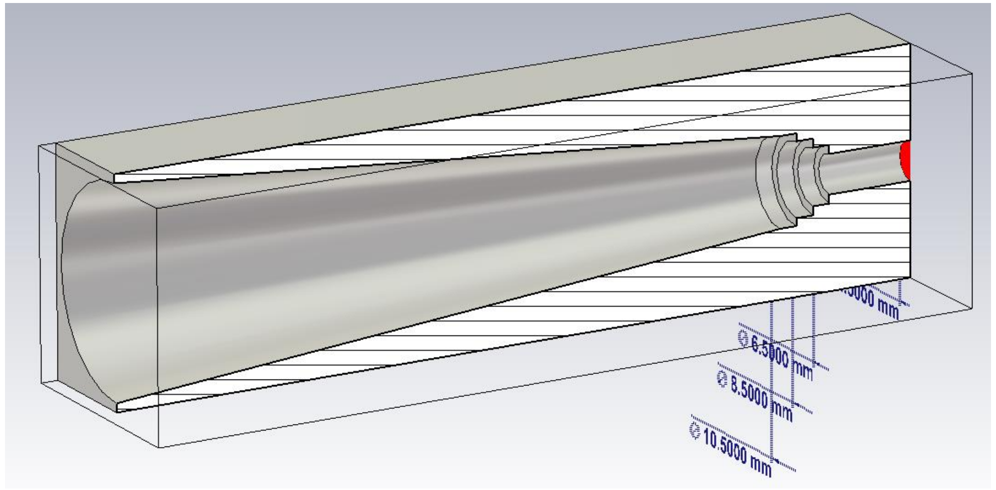
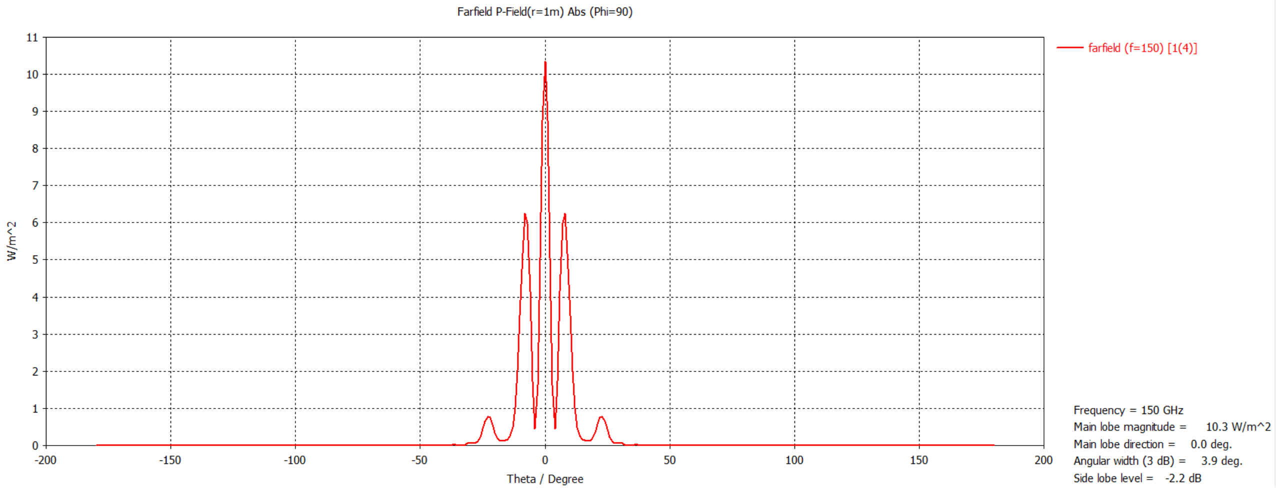




Do this but in a controlled fashion

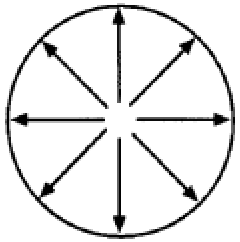
Mode conversion

Credit:

METHOD FOR CONVERSION OF WAVEGUIDE MODES, MODE-CONVERTING ARRANGEMENT AND ANTENNA ARRANGEMENT

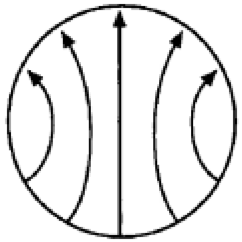
Inventor: **Ola Forslund**, Sundbyberg (SE)

From this



TM_{01}

To this



TE_{11}

What I want to do:

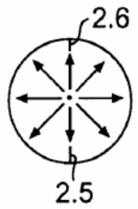


FIG. 5a

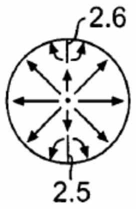
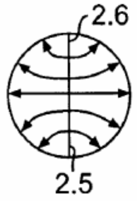
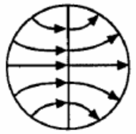


FIG. 5b





How I can do it:

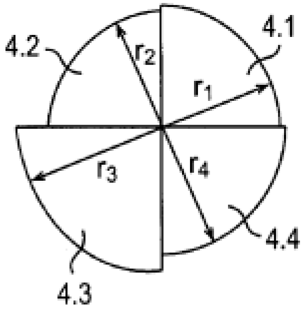


FIG. 2

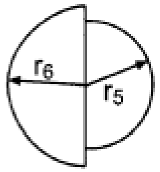


FIG. 6

Do this but for several modes