Antennas

Jamie Leech

Recommended books:

"The Tools of Radio Astronomy", Kristen Rohlfs

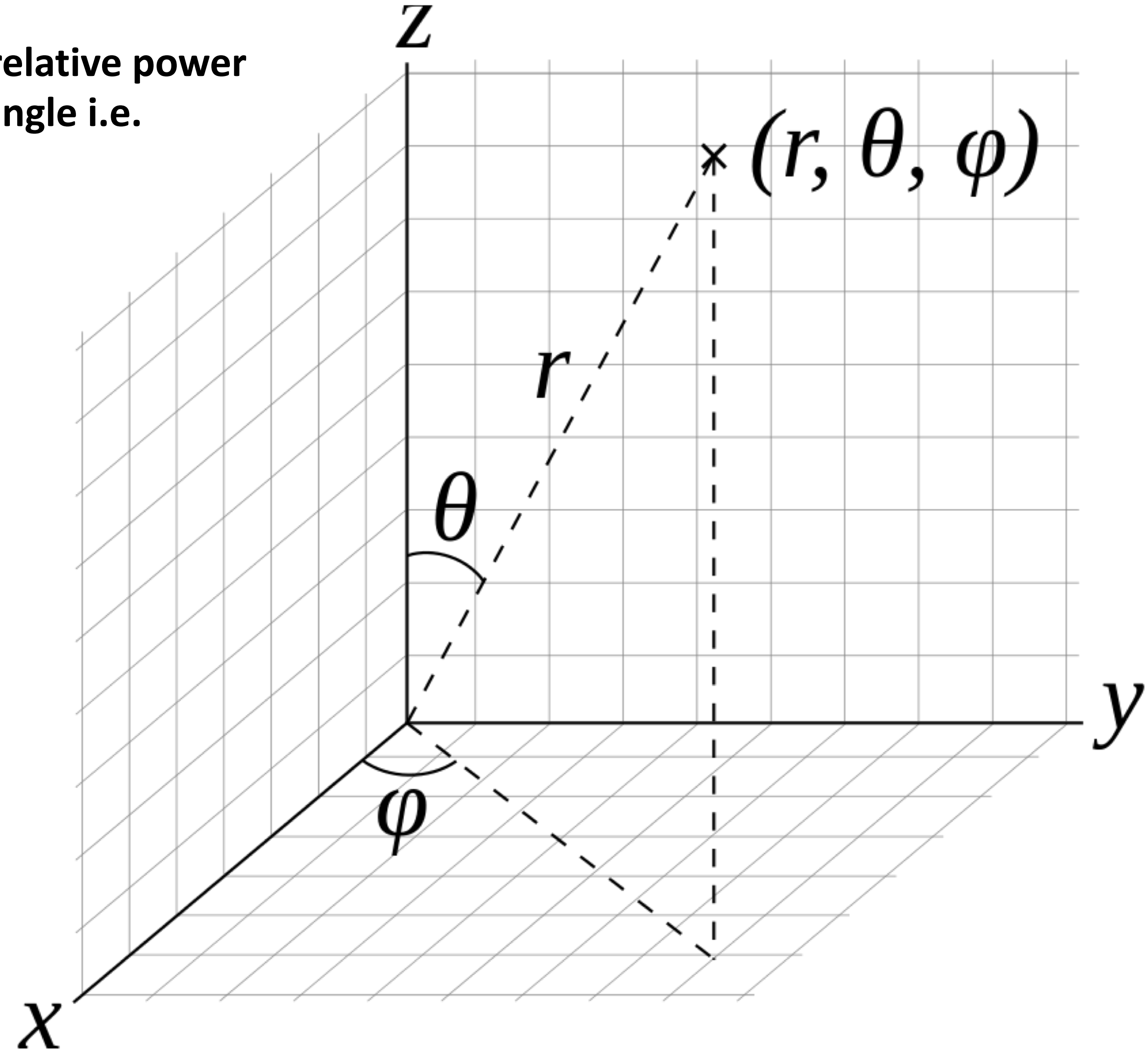
"Radio Astronomy" J.D. Kraus

"An Introduction to Radio Astronomy" Bernard F. Burke and Francis Graham-Smith

Spherical co-ordinates

Beam pattern is relative power as a function of angle i.e.

$P(\theta,\phi)$

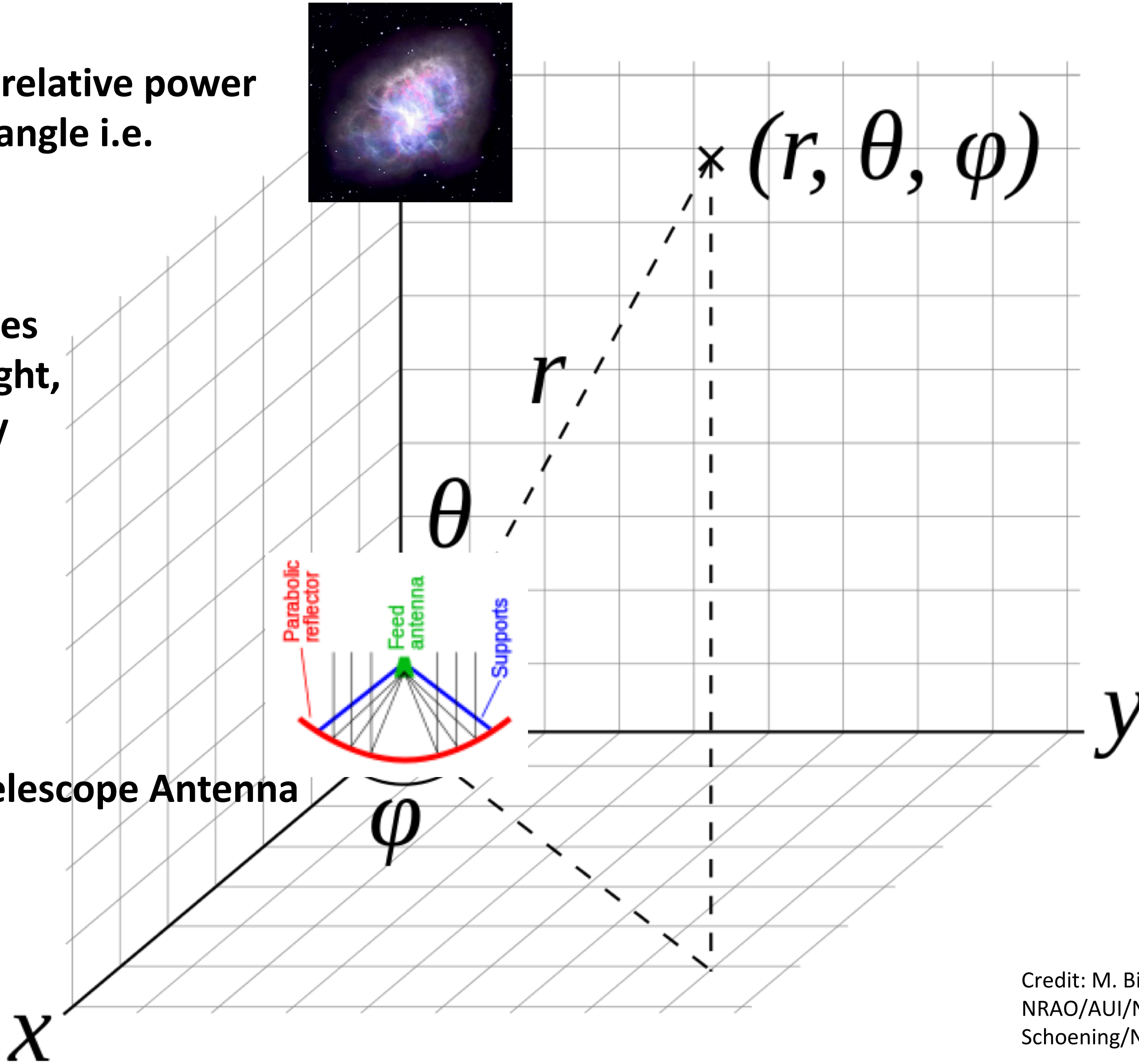


Concept of a beam pattern

Beam pattern is relative power as a function of angle i.e.

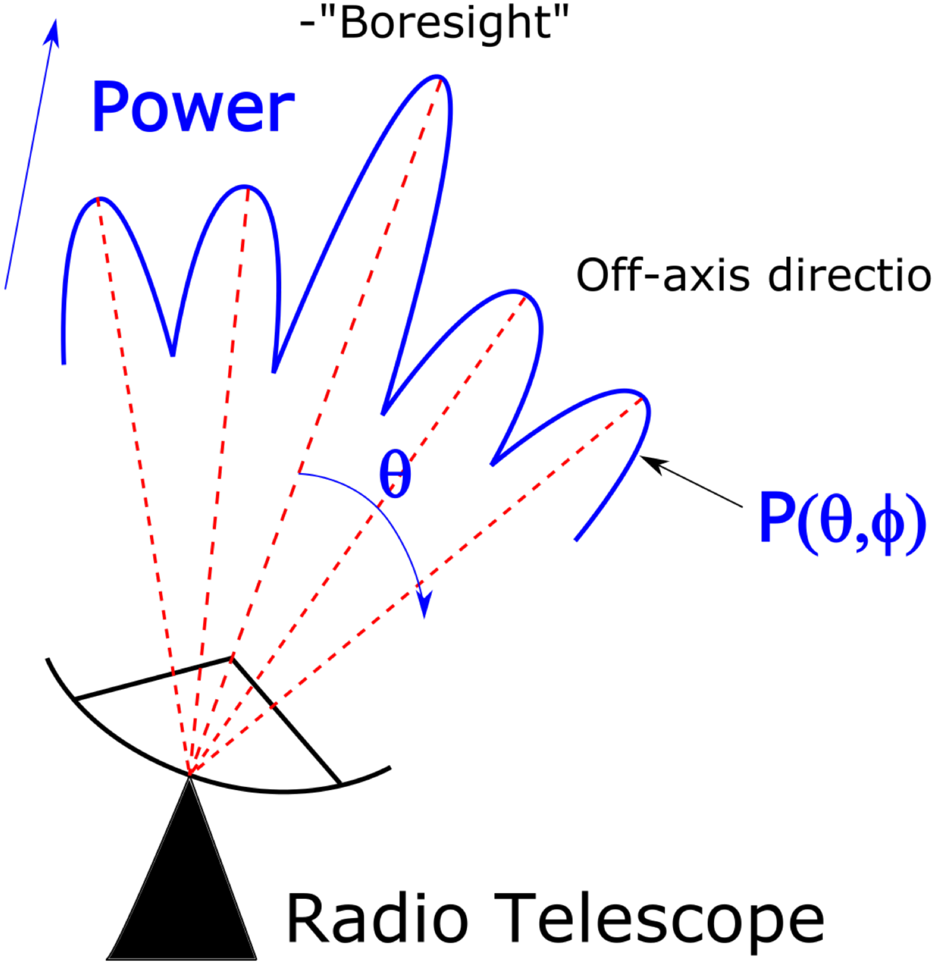
P(θ,ϕ)

Response decreases away from boresight, but NOT smoothly (monotonically).



Credit: M. Bietenholz, T. Burchell NRAO/AUI/NSF; B. Schoening/NOAO/AURA/NSF

Concept of a beam pattern



Aside: Decibels (dB)

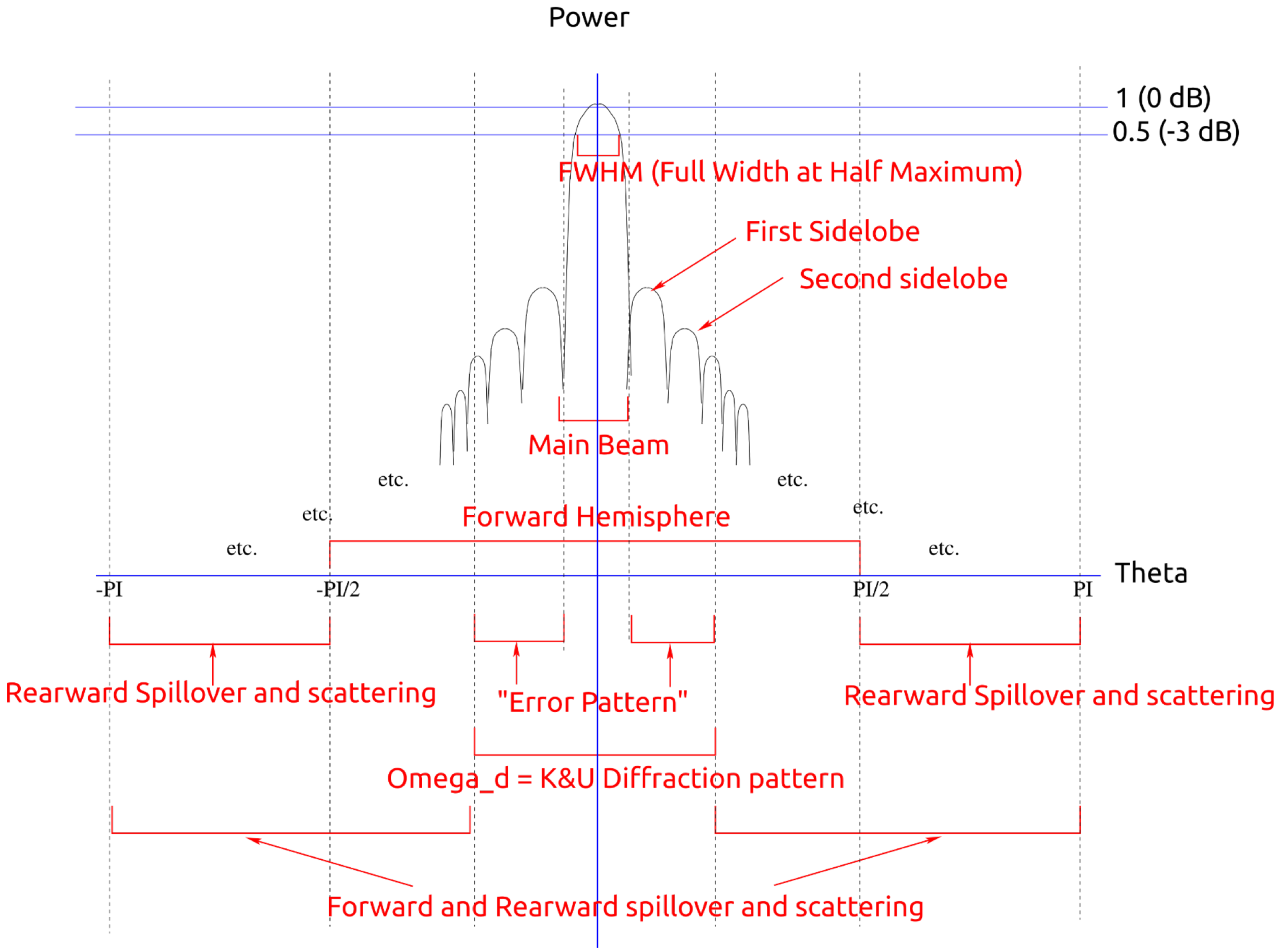
(dB) A logarithmic way of expressing relative powers:

$P(dB) = 10 \log_{10} (P/P_0)$

where P_0 is some reference power. P_0 is chosen to be some convenient power level e.g. the centre of the beam pattern.

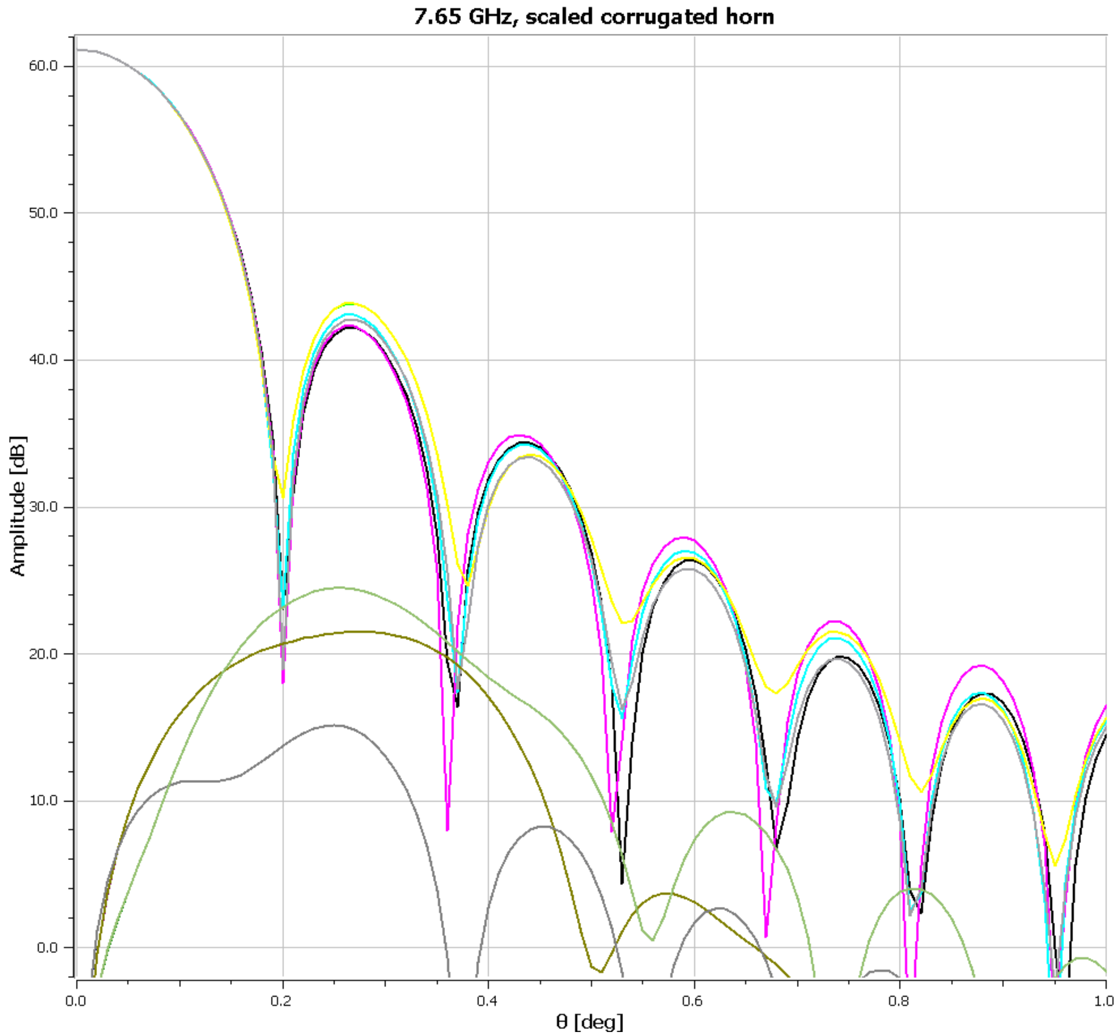
Useful dB values:
½ =~ -3 dB
1/10 = -10 dB
1/100 = -20 dB
1/1000 = -30 dB
Power axis of beam patterns almost always in shown dB.

Concept of a beam pattern



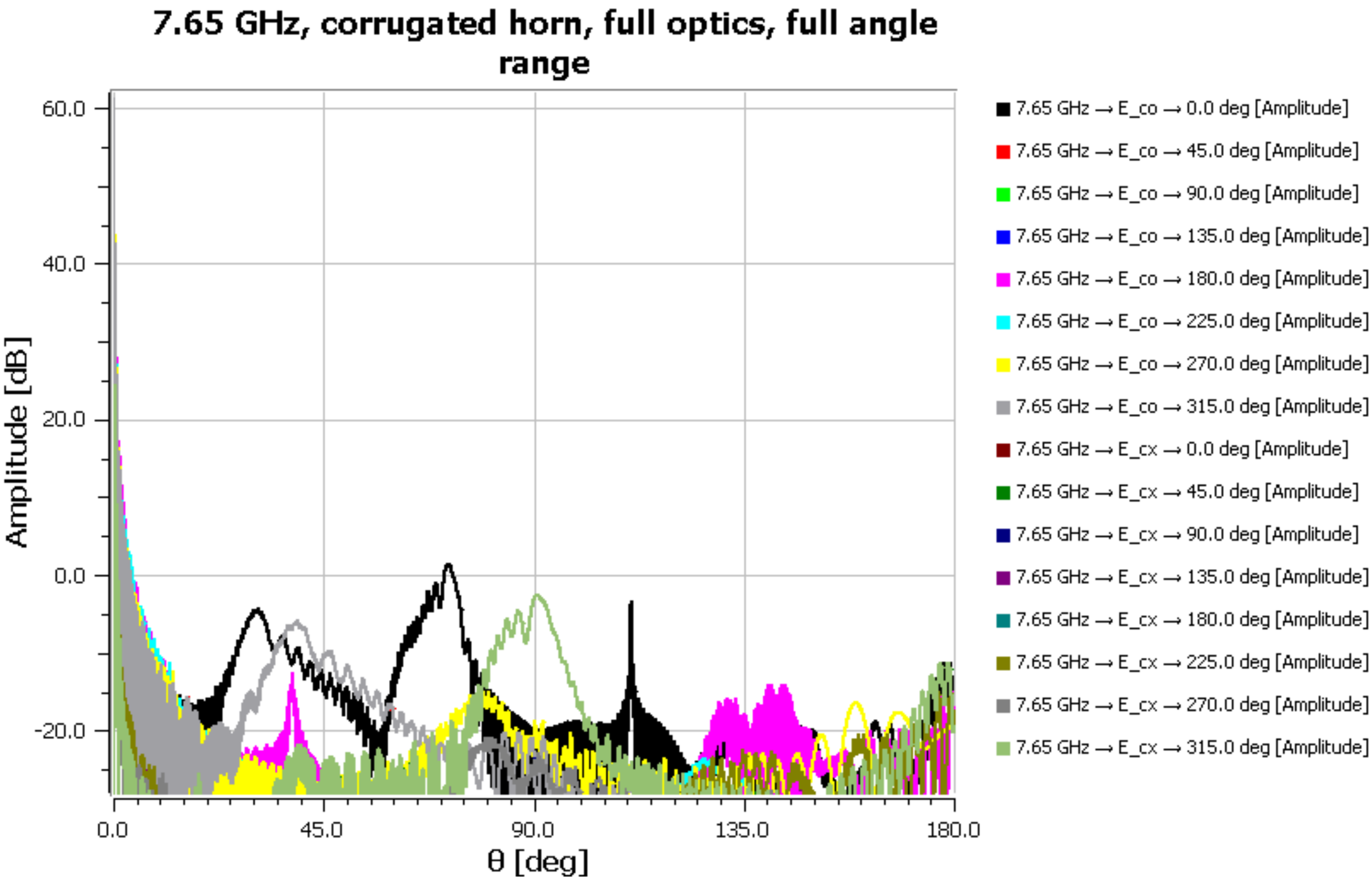
Band 5 beam pattern

Near main beam (theta less than 1 degree)



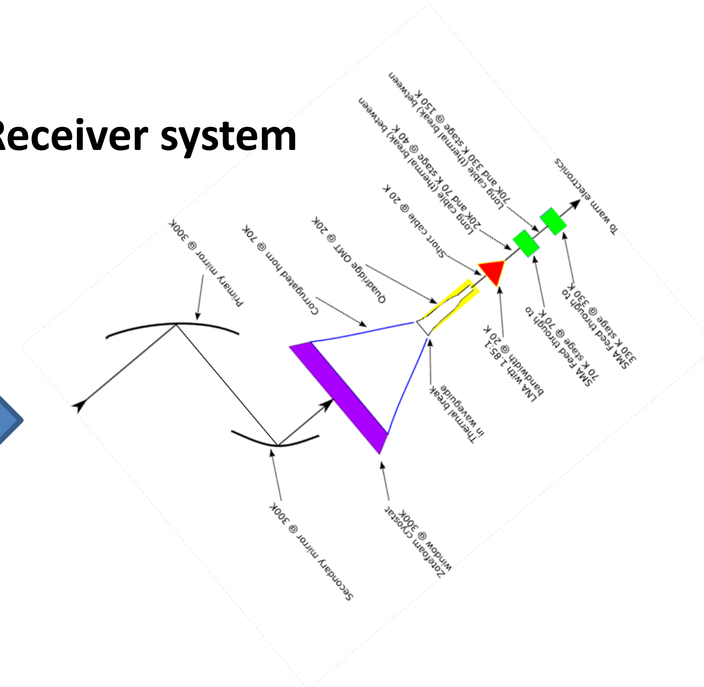
Band 5 beam pattern

Entire pattern (theta from 0 to 180)

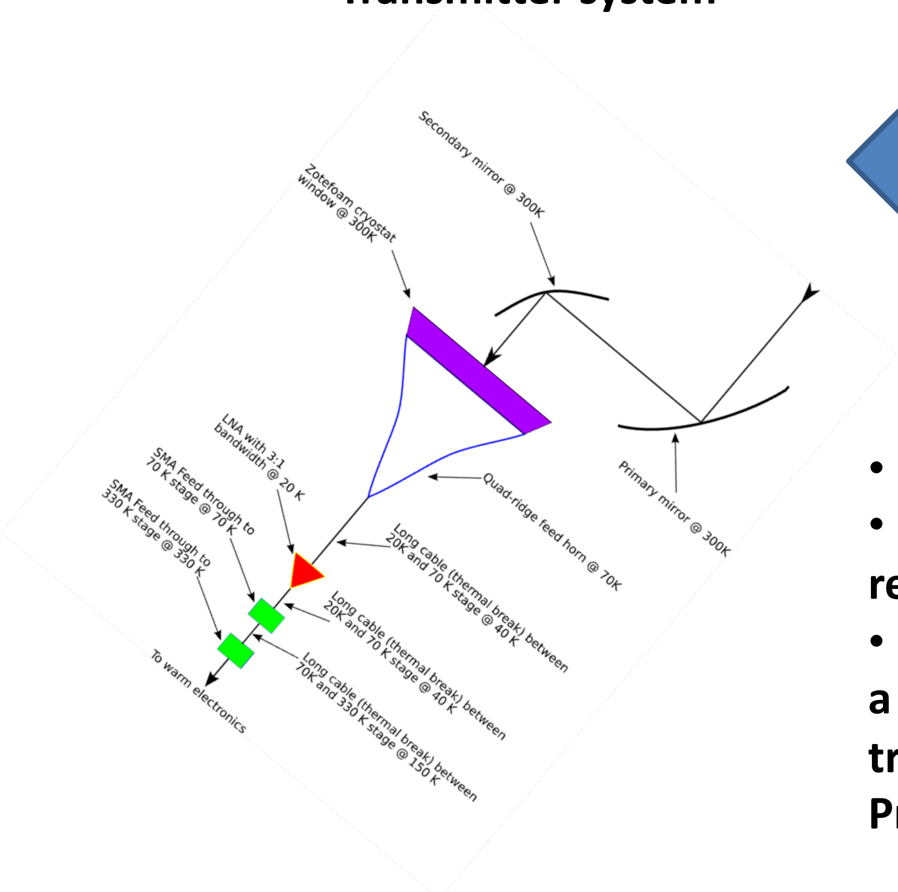


Reciprocity theorem

Receiver system



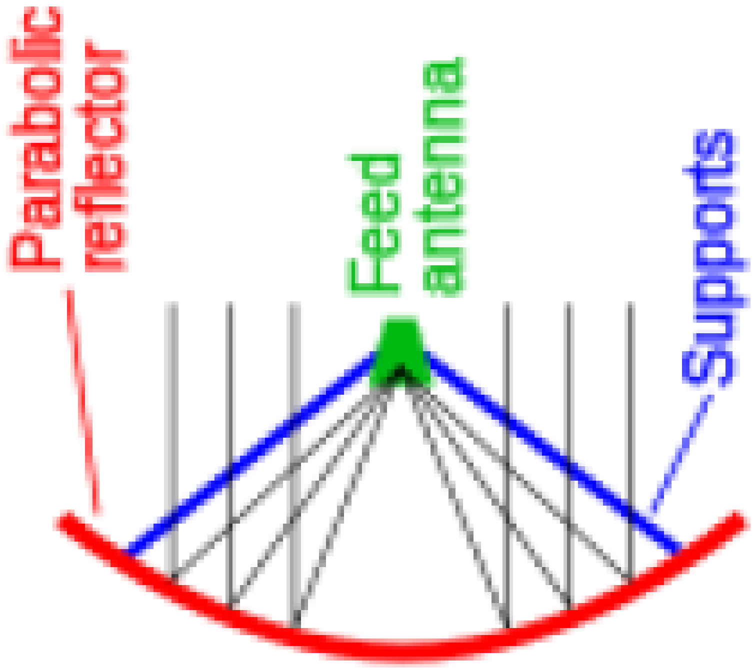
Transmitter system



- **Reciprocity theorem:**
- **The physics is exactly the same if the receiver and transmitter are interchanged.**
- **For this reason, we often talk about a radio telescope antenna as if it were transmitting the signal, rather than receiving it. Proof from Maxwell's Equations see e.g. Rohlfs.**

Types of dish antenna used in radio astronomy

The Parabolic antenna



Focal ratio – f-Number = F/D where F = focal length and D = diameter

The Parabolic antenna

Various form of parabolic reflectors

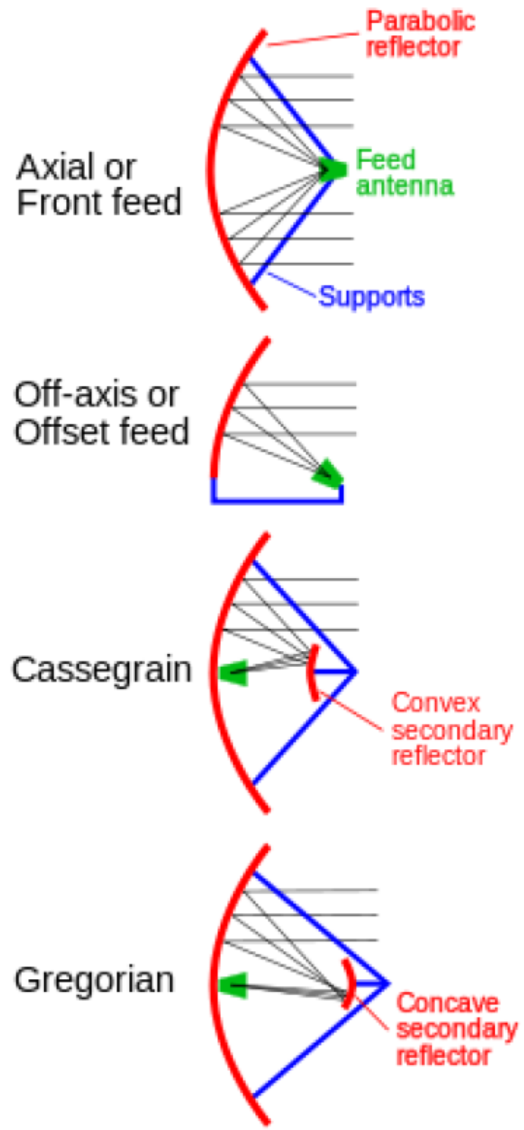
The axial or front fed feed is the mosst basic, and is known as a ***prime focus feed.***

The most common use of the off-axis feed is for DSTV saellite reception. It has a clear aperture with no blockage loss .

The ***Cassegrain feed*** is widely used for radio telescopes and large satellite communication antennas. The secondary reflector is ***hyperboloidal*** in shape, and is below the primary focus. It generally has high efficiency, and low spillover towards the ground.

The ***Gregorian feed*** is similar to the Cassegrain, but the secondary, which is ***ellipsoidal*** in shape, lies above the prime focus. Similar advantages to the Cassegrain, but additiional one is that prime focus is accesible without removing the secondary reflector.

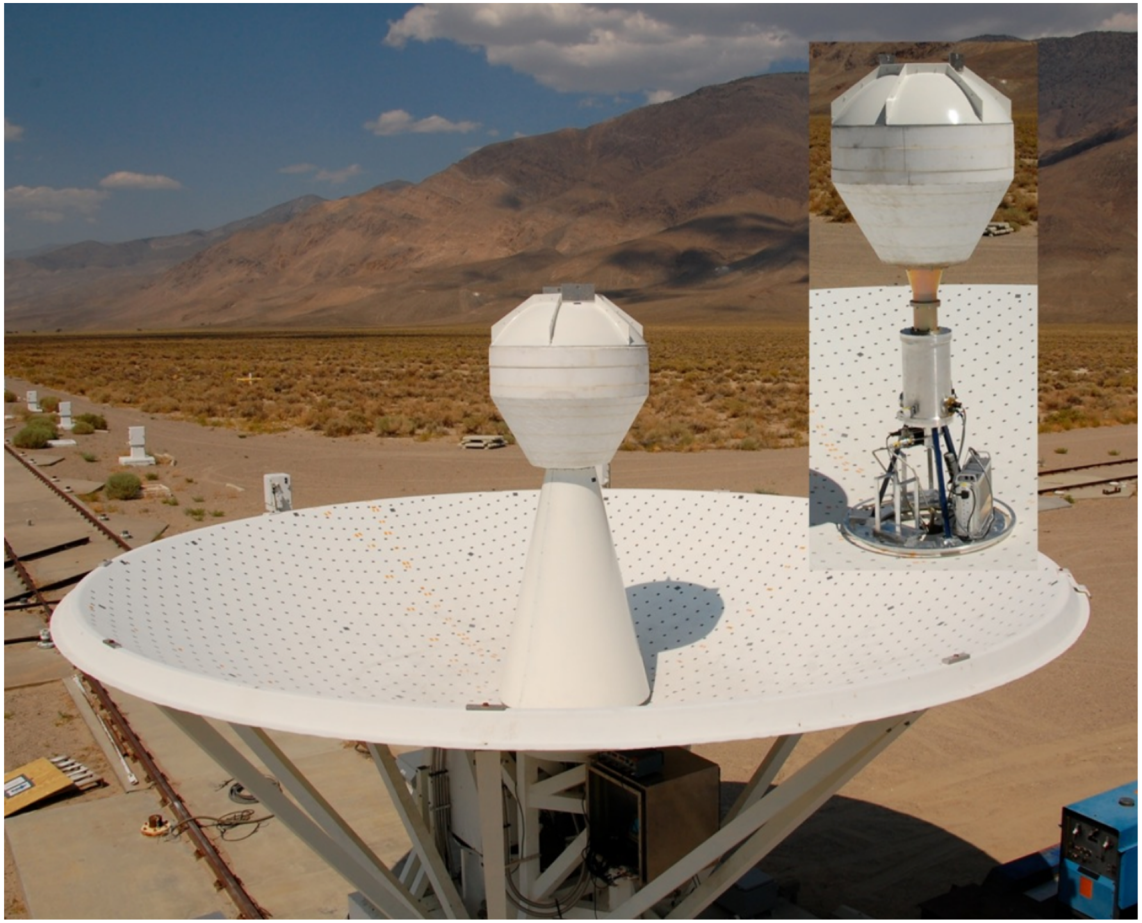
Both have the advantage that there is far more space available at the secondary focus than there is at the prime focus. This allows for multiple receivers to be permenently mounted.



On-axis Gregorian optics e.g

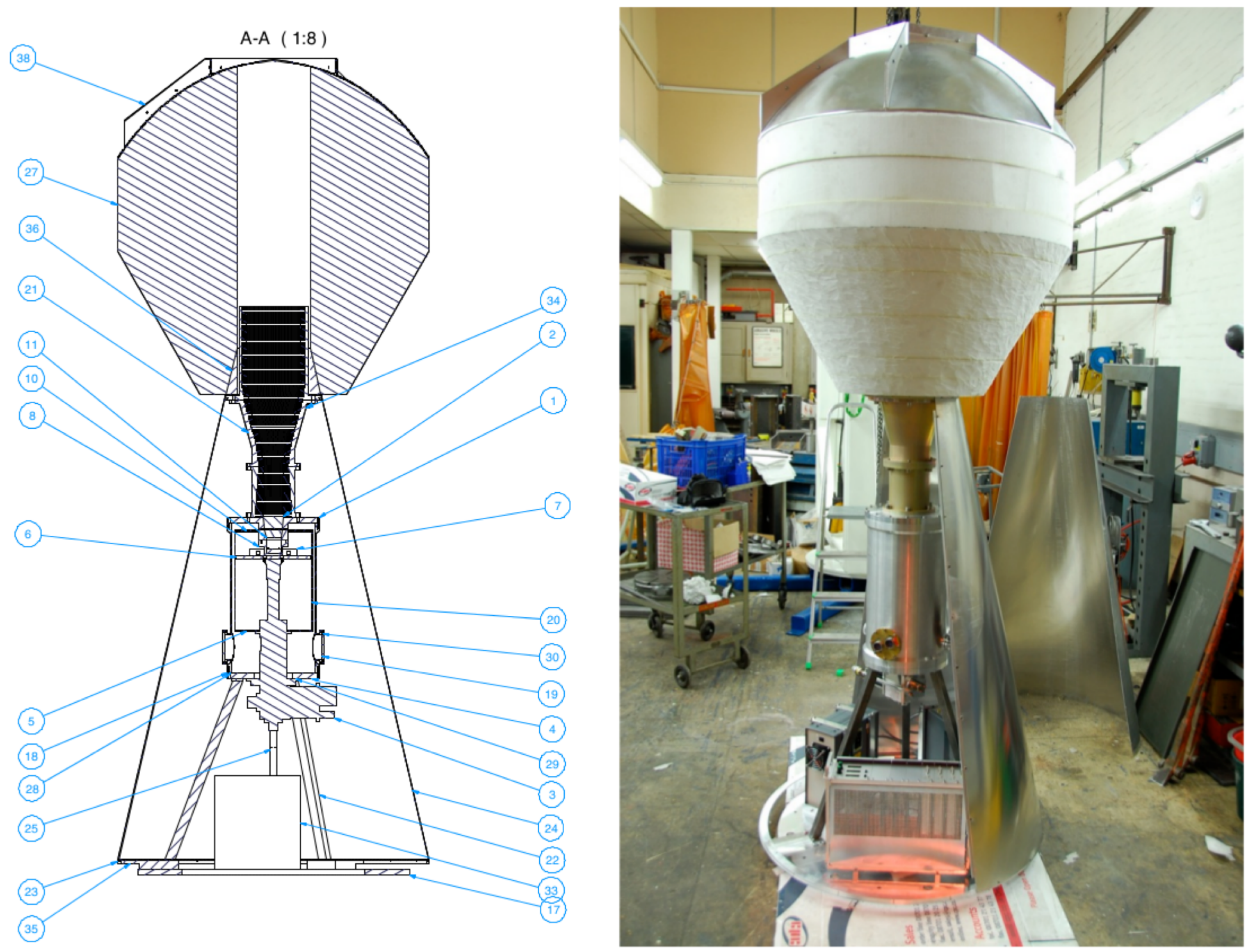
CBASS - North

- Cryostat and secondary on the dish



CBASS North

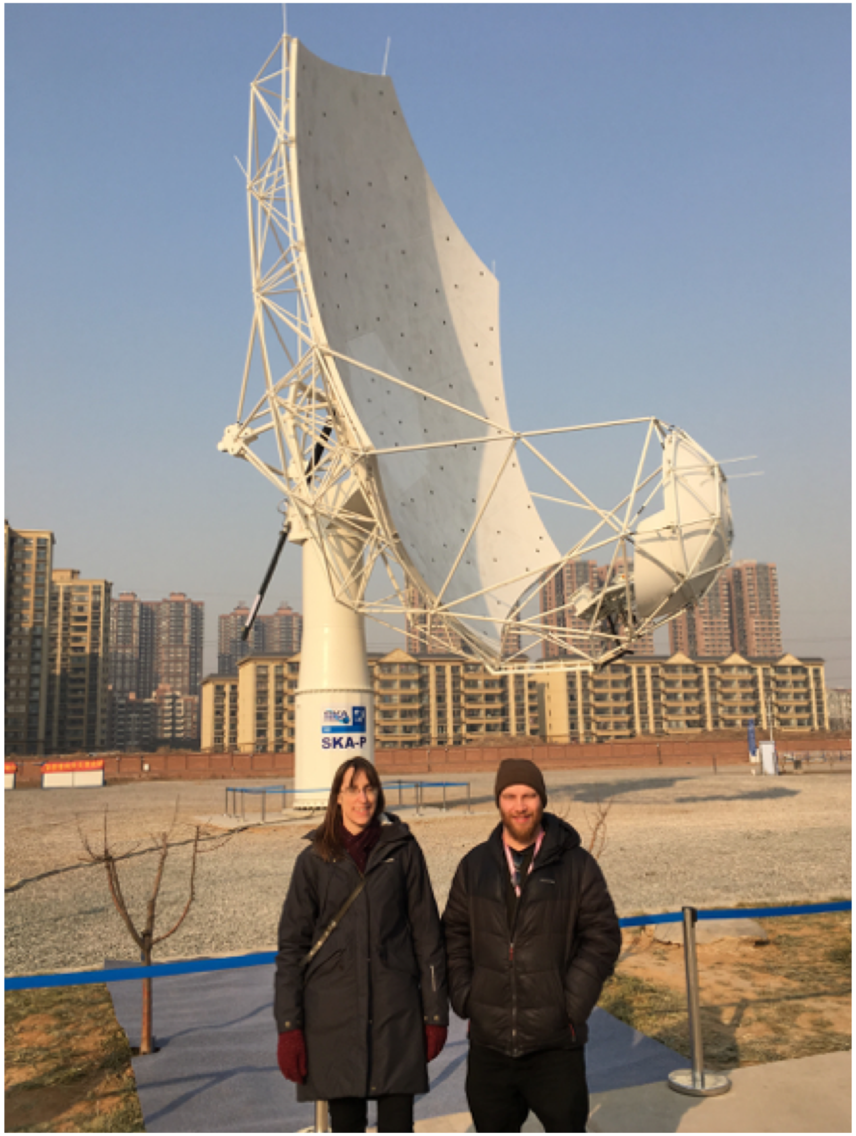
- Cryostat, horn and secondary assembly



(a) (b)

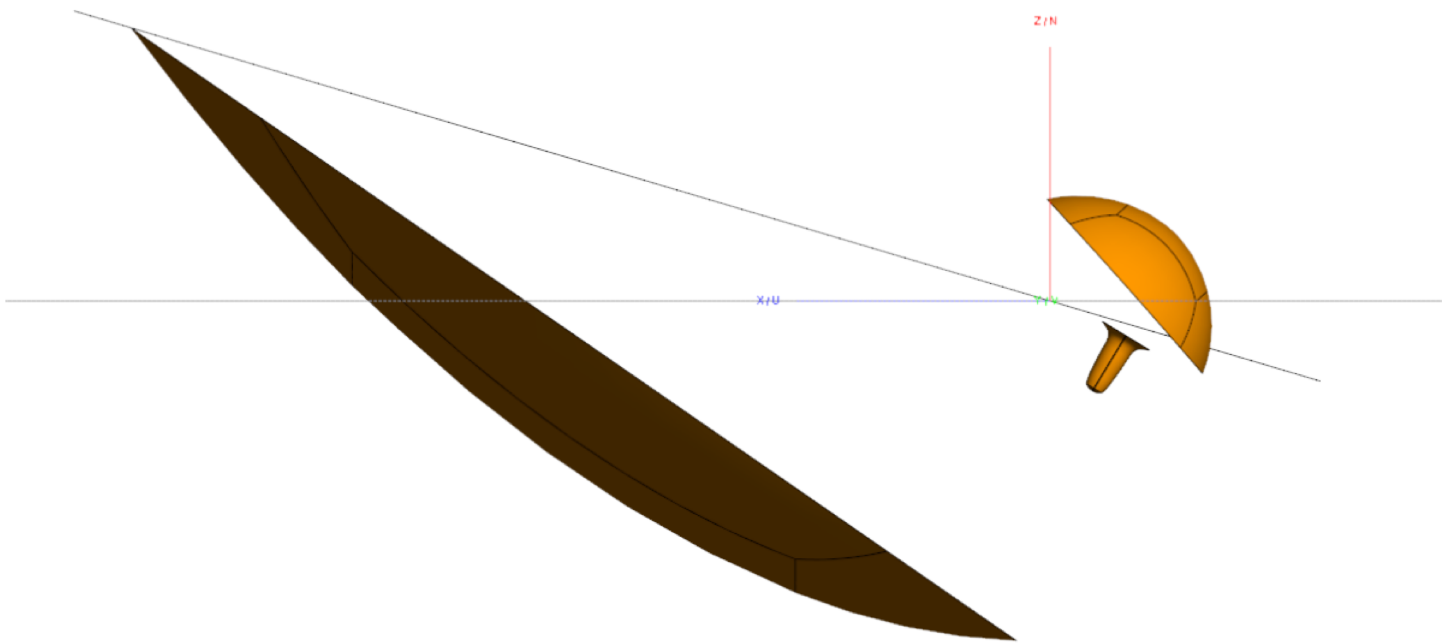
Off-axis Gregorian optics example: SKA-MID Dish

SKA DISH Off axis Gregorian

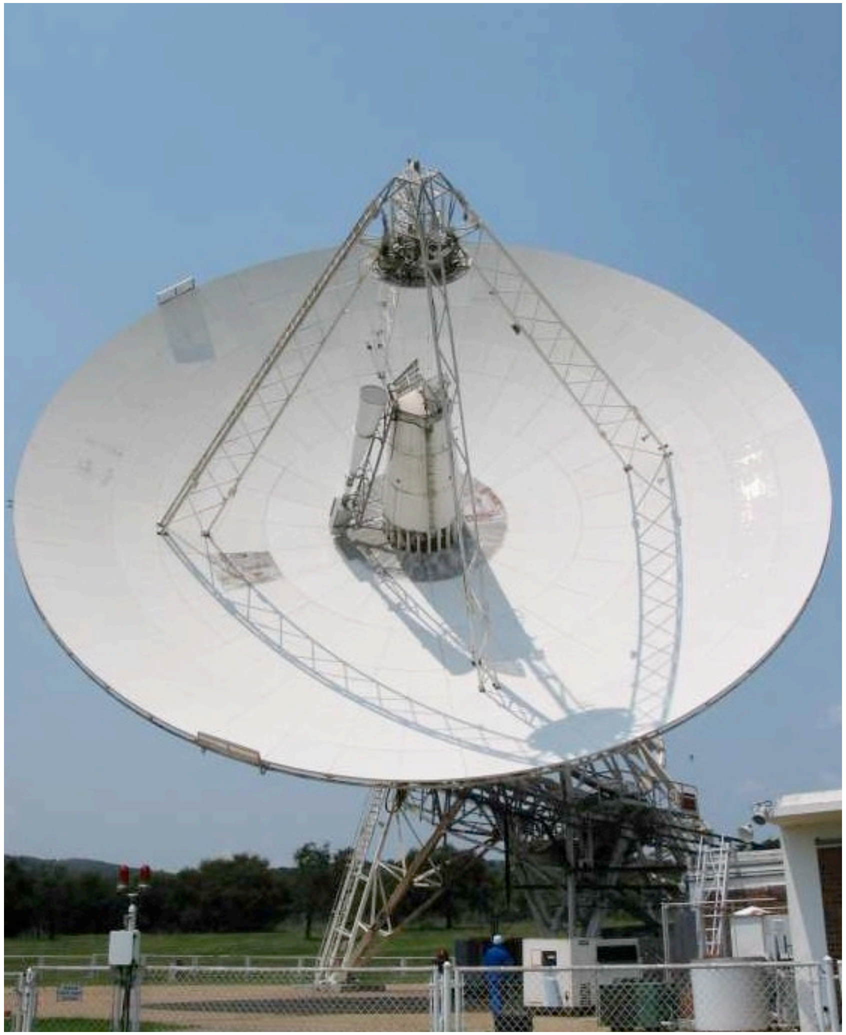


SKA DISH Off axis Gregorian

Advantage: reduces blockage – clear path to primary mirror.



Cassegrain Example: HartRAO 26m



Antenna “illumination”

- Far-field beam pattern as Fourier Transform of antenna illumination

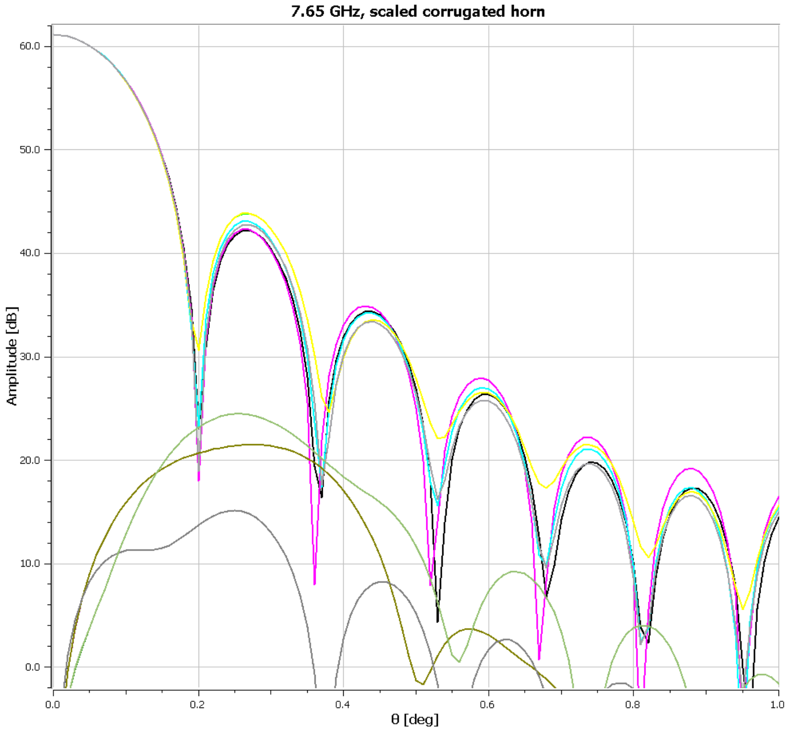
- Sidelobes are fringes caused by constructive and destructive interference – in a similar way to Fraunhofer diffraction from a single slit in optics.

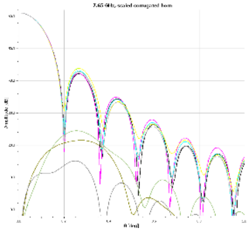
- Far-field beam width angle ~ λ/D.

- This acts to **limit the angular size** of the detail that we can see on the sky with the telescope.

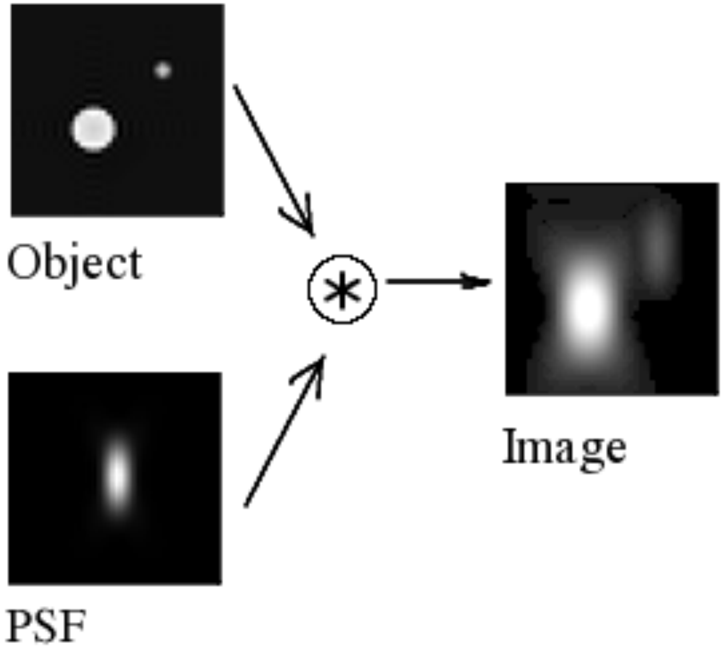
- Bigger D = more resolution (detail).

- Smaller λ relative to D = more resolution.


7.65 GHz, scaled corrugated horn
Amplitude [dB]
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0
0.2
0.4
0.6
0.8
1.0
θ [deg]



Convolution telescope "sees" sky convolved with (blurred by) the beam pattern (called Point Spread function or PSF in optical astronomy. See Lectures on Fourier Transform theory next week.



Flux, Brightness Temperature

Given the definition of the brightness temperature through (9), and the definition of the brightness or specific intensity $B_\nu(\Omega)$ for a given source of angular extent Ω_s, it follows that

$$S = \frac{2k}{\lambda^2} \int\int_{\Omega_s} T_b(\Omega)\, d\Omega \tag{11}$$

where S is the flux density in units of W m^{-2} Hz^{-1}

Antenna Gain

Antenna Gain

2.5 Antenna Gain $G(\theta, \phi)$ and Directivity D

The gain is a function of direction (i.e. θ and ϕ) and is defined as the ratio of the power from the antennas beam pattern at (θ and ϕ) and the power one would get if the power was radiated the same in every direction i.e. isotropically.

$$G(\theta, \phi) = \frac{4\pi P(\theta, \phi)}{\int\int_{4\pi} P(\theta\, \phi)\, d\Omega} \tag{5}$$

The directivity is the *maximum value* of the gain usually occurring at $\theta = 0, \phi = 0$. Note, if $P_n(\theta = 0\, \phi = 0)$ is normalised such that $P_n(\theta, \phi) = 1$, as is commonly done then

$$D = \frac{4\pi}{\int\int_{4\pi} P_n(\theta\, \phi)\, d\Omega} \equiv \frac{4\pi}{\Omega_{4\pi}} \tag{6}$$

Aperture Efficiency

2.6 Aperture Efficiency $\eta_{\rm ap}$

The *Aperture Efficiency* $\eta_{\rm ap}$ is defined as

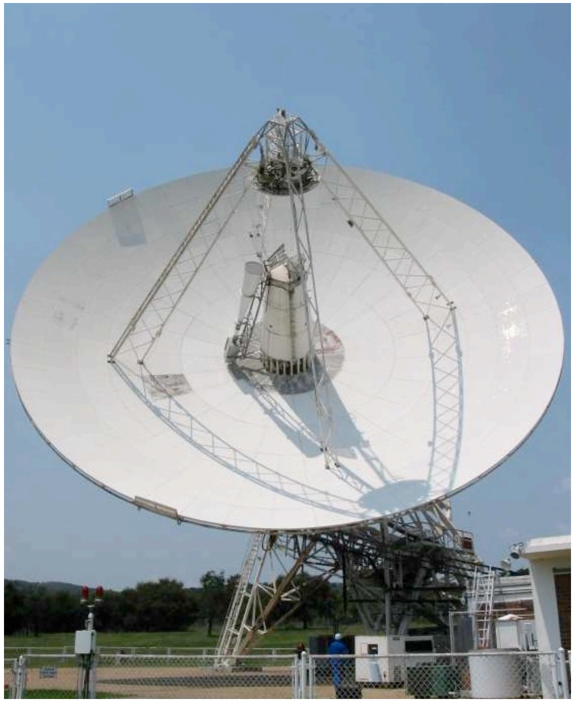
$$\eta_{\rm ap} = \frac{A_e}{A} = \frac{\lambda^2}{A \int\int_{4\pi} P_n(\Omega)\, d\Omega} \equiv \frac{\lambda^2}{A\Omega_{4\pi}}, \tag{7}$$

where A is the physical area of the antenna and A_e is the effective collecting area of the antenna. This effective collecting area is essentially defined by the above relation (8).

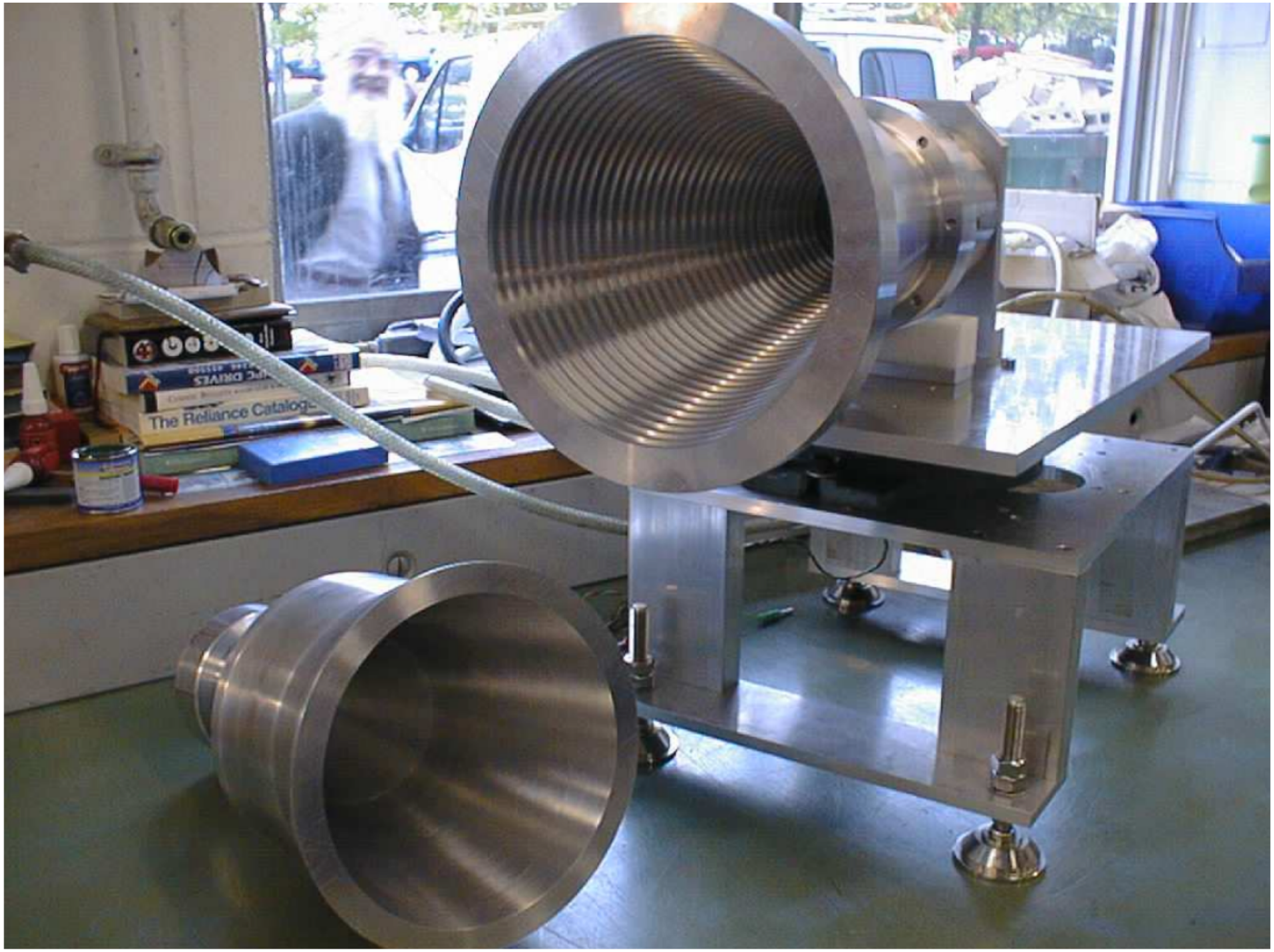
The aperture efficiency can be written in terms of the gain. If if $P_n(\Omega)$ is normalised such that $P_n(\Omega) = 1$, then

$$\eta_{\rm ap} = \frac{\lambda^2}{A\Omega_{4\pi}} \equiv \frac{D\lambda^2}{4\pi A} \tag{8}$$

- Receiving the signal
- Or by reciprocity "Illuminating" the antenna:
- Feed Horns



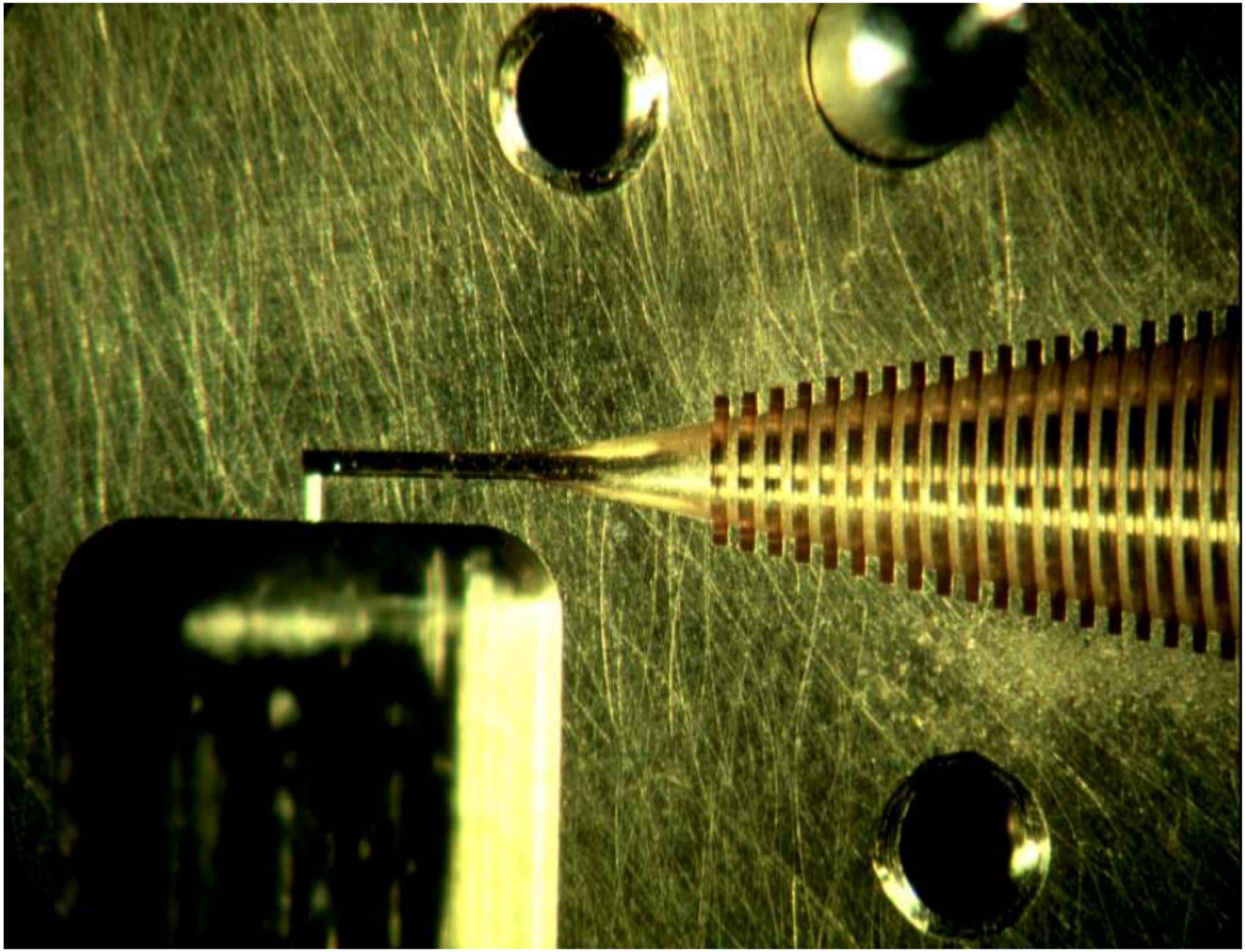
Corrugated horns: 15 GHz horn (2 cm)



Corrugated horns: Theory

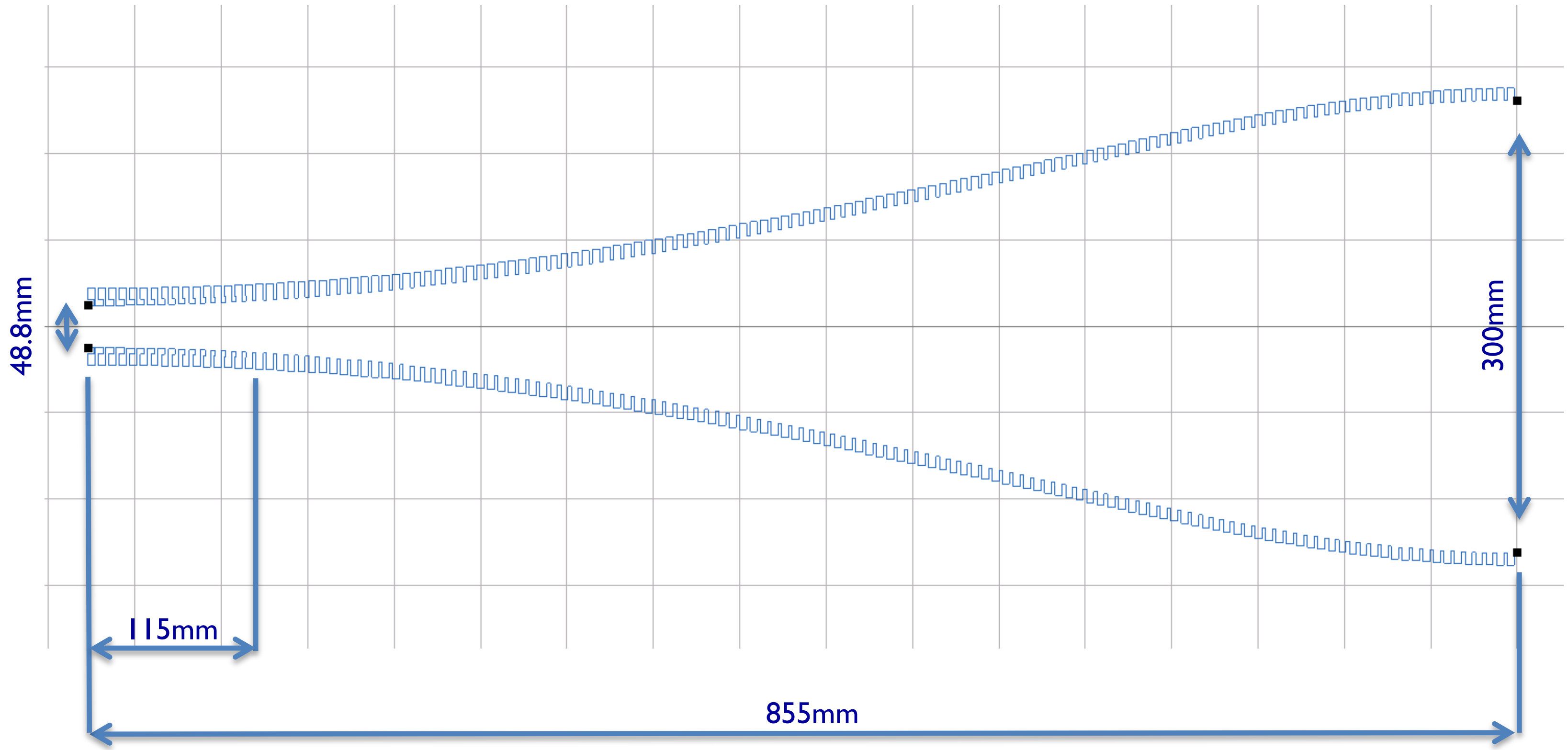
- Corrugations block azimuthal currents, changing the waveguide boundary condition leading to the propogation of a HE11 mode rather than a TE11 mode.
- This “cleans up” the aperture distribution. The far-field pattern is the Fourier transform of this.
- The resulting fair field patterns has lower sidelobes and lower cross-polarization that a smooth walled conical horn.
- See Olver (1994) for a complete review of the theory.

Corrugated horns: 350 GHz horn (850 um!)



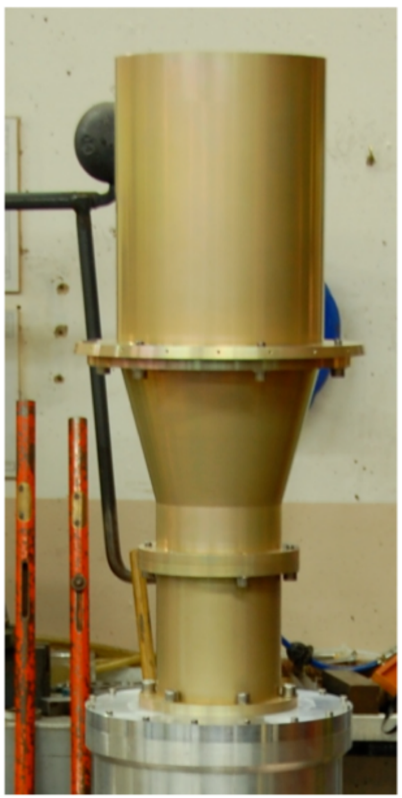
Corrugated horns: Goonhilly 8-12 GHz

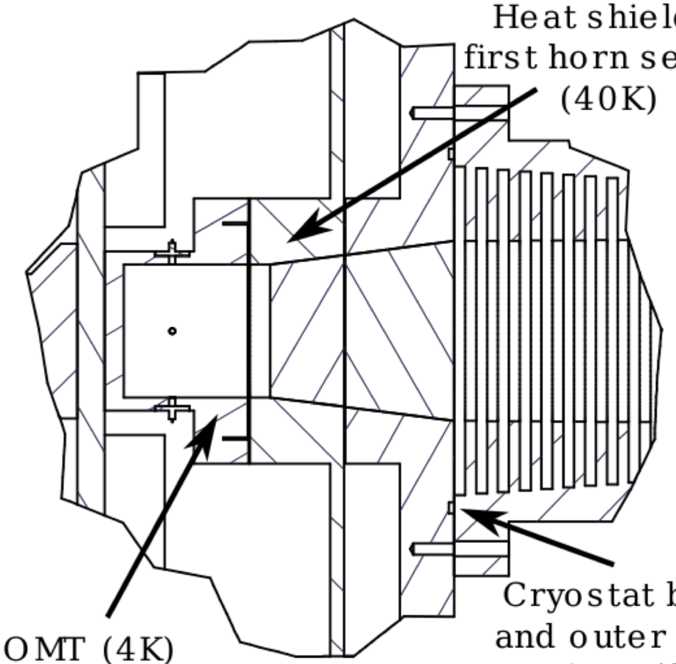
- Ringloaded Corrugated Feedhorn

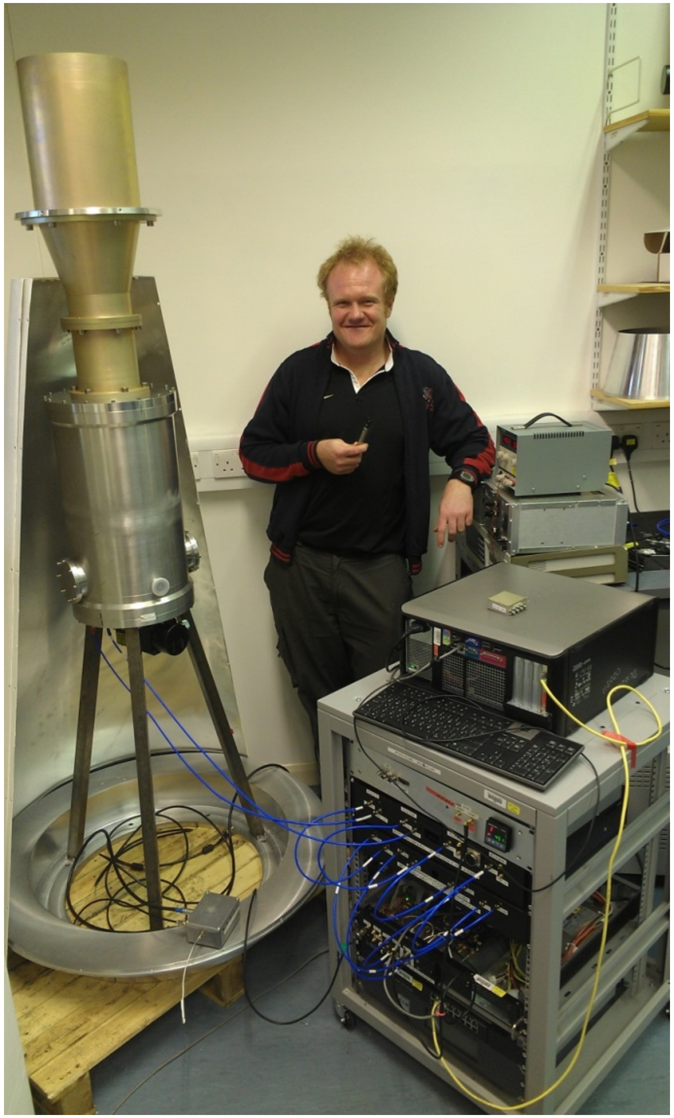


Corrugated Horns – CBASS (5 GHz)

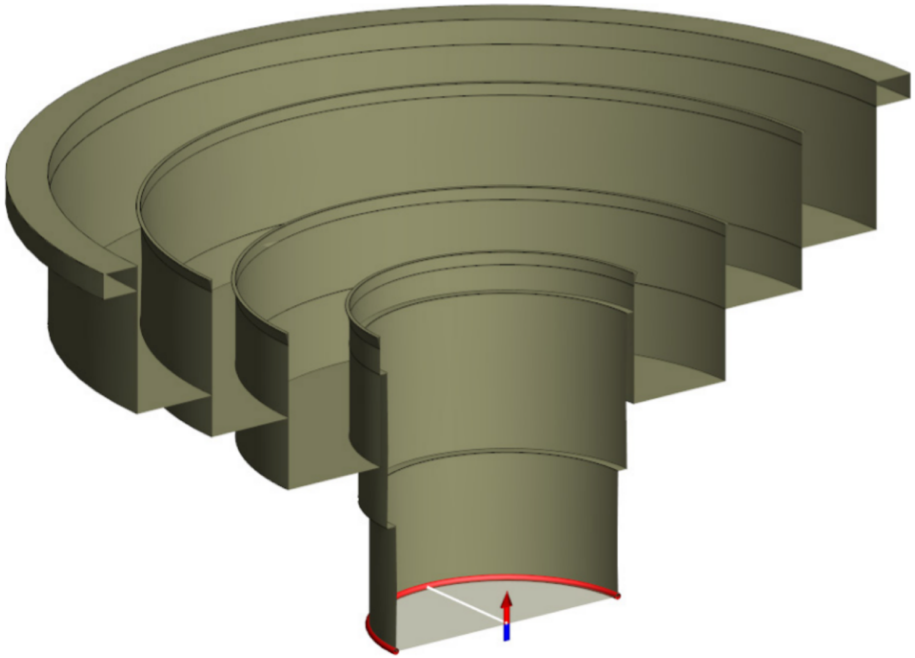
- Profiled corrugated horn and details of thermal break





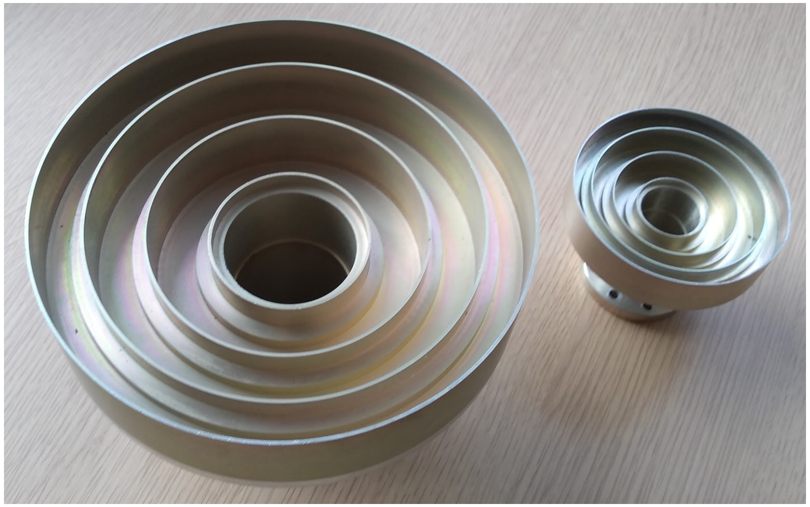


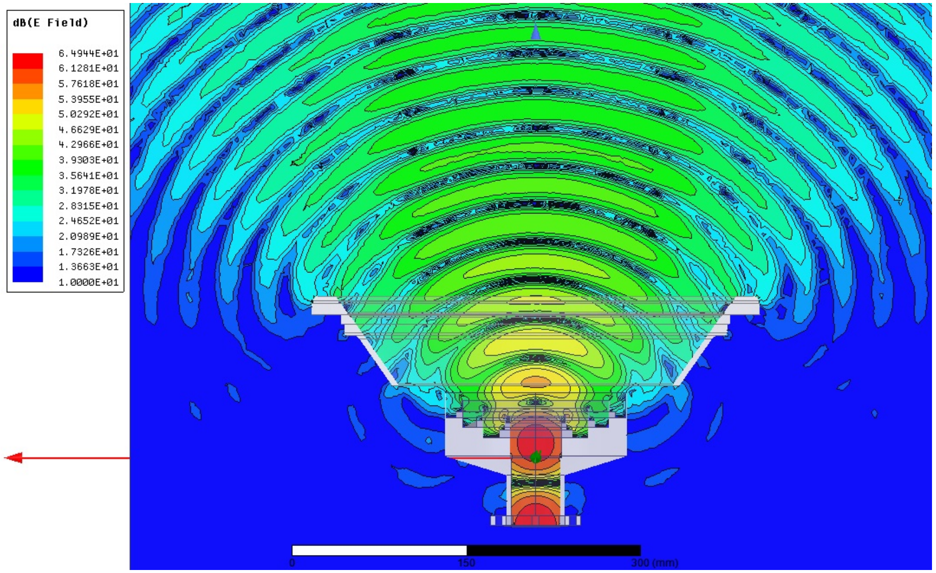
Corrugated horns: SKA Band 2



Example corrugated design for SKA band 2 (design courtesy of EMSS, Stellenbosch)

Corrugated horns: SKA Band 5a,5b

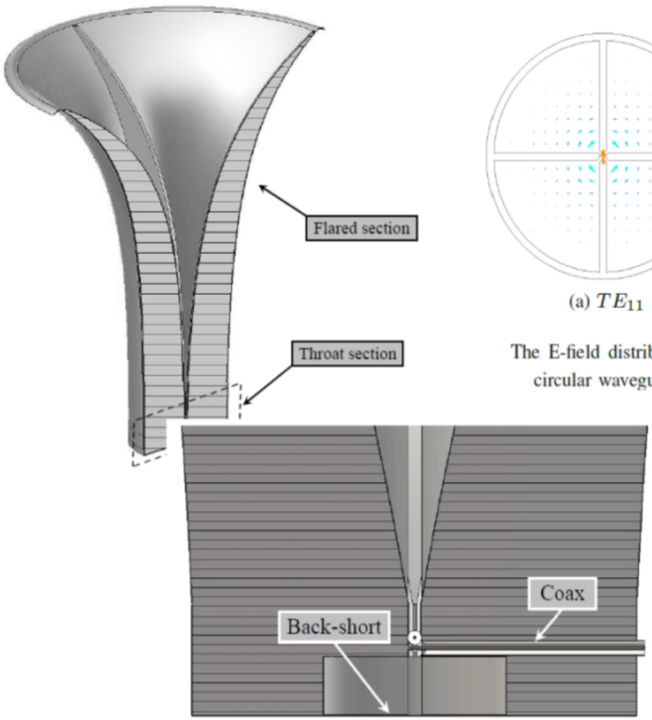


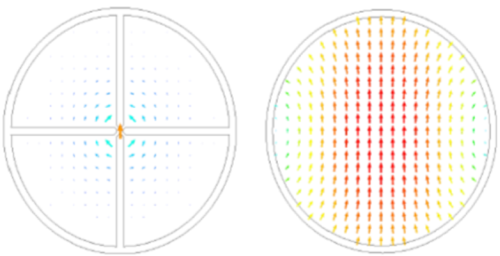


Left: SKA band 5a and 5b feed horns (design courtesy of JLRAT, China)
Right: CST Electromagnetic simulation of field from horn through window.

Quadridge Feed horns

- Development of good broadband quadridge feedhorn designs is still a major research area…





(a) TE_{11} (b) TE_{11}

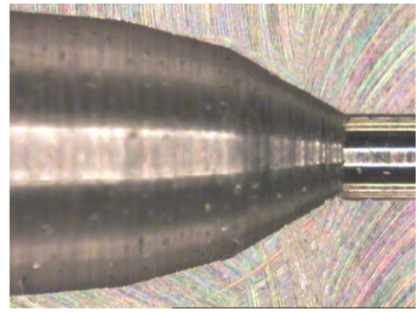
The E-field distributions of the TE_{11} modes in circular waveguides with and without ridges

A JLRAT QRFH prototype

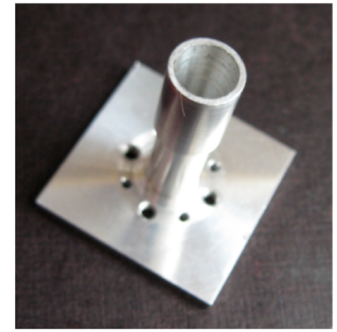
Smooth walled feed horns – sub-mm

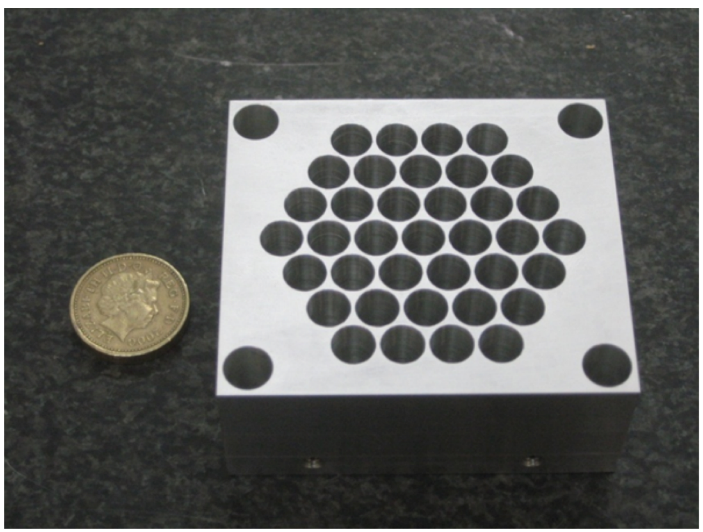
Shaped machine tool

Split horn (near throat)

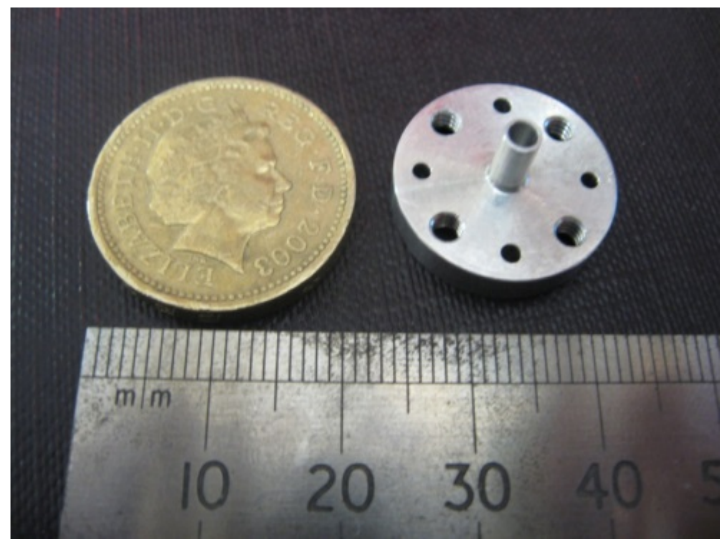


Finished horn



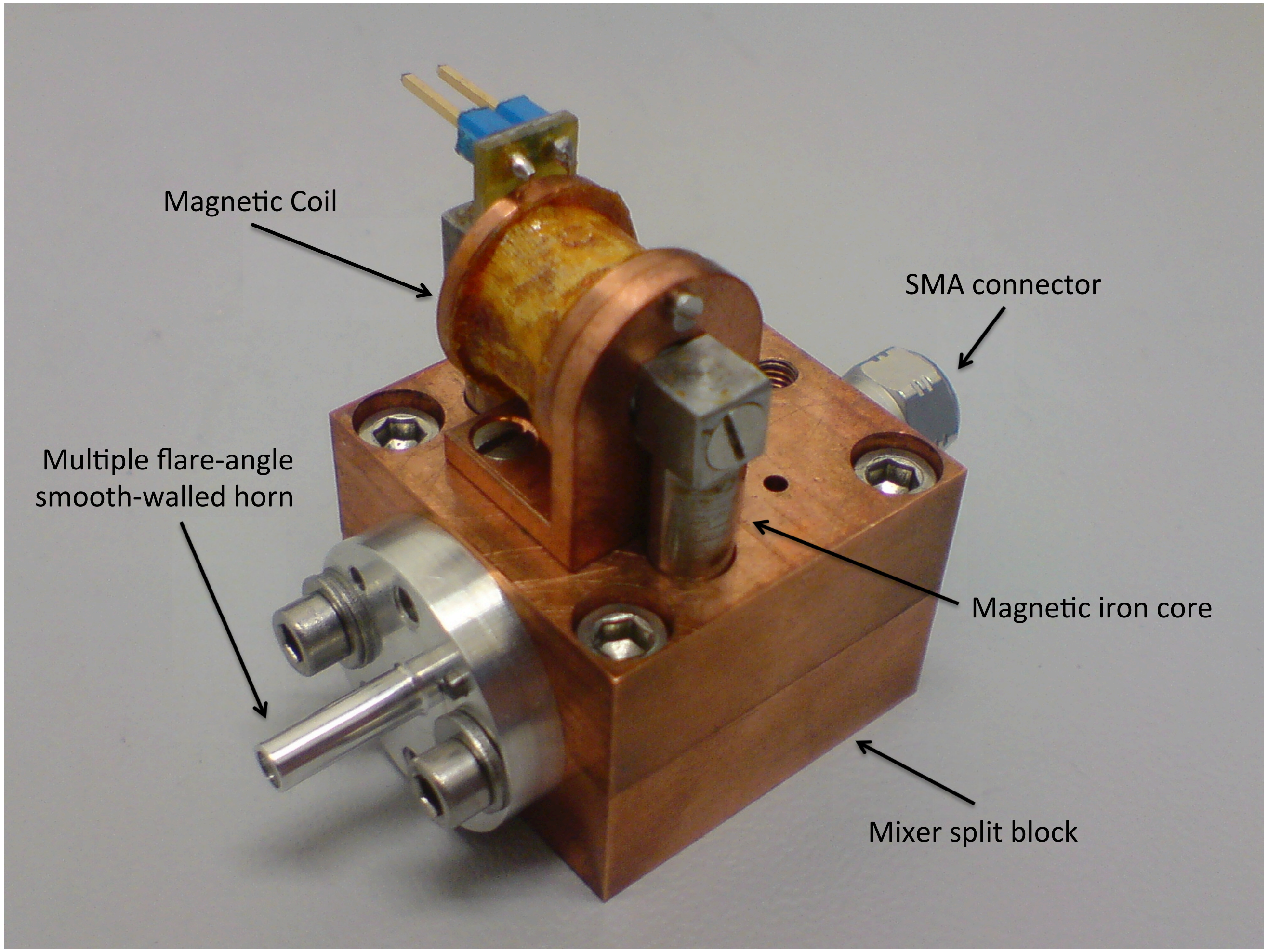


37 element, 230 GHz array
(Leech et. al IEEE TS&T, 2012.)



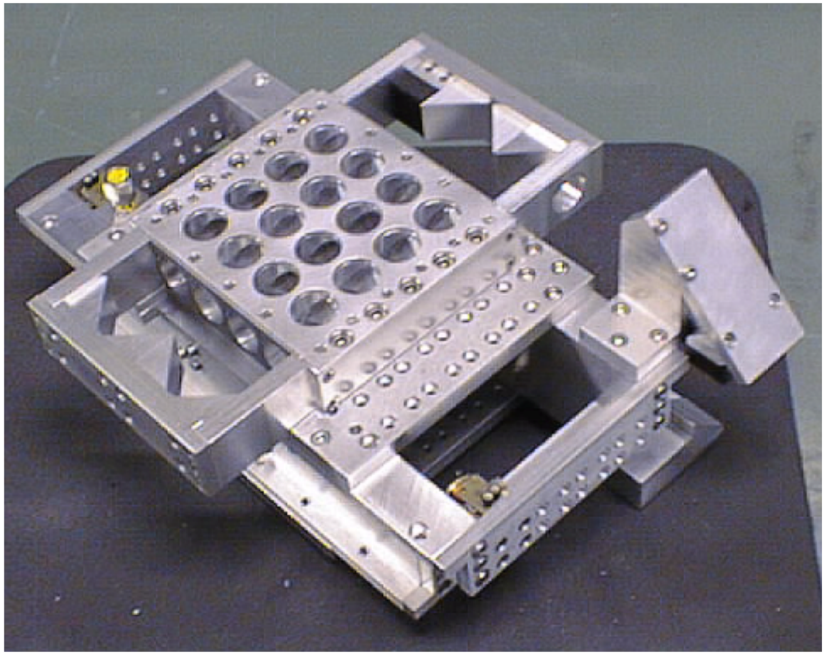
A 3-section, 700 GHz horn
(Tan et al, Journal of Infrared and Terahertz waves, 2012.)

Smooth walled feed horns attached to SIS mixer



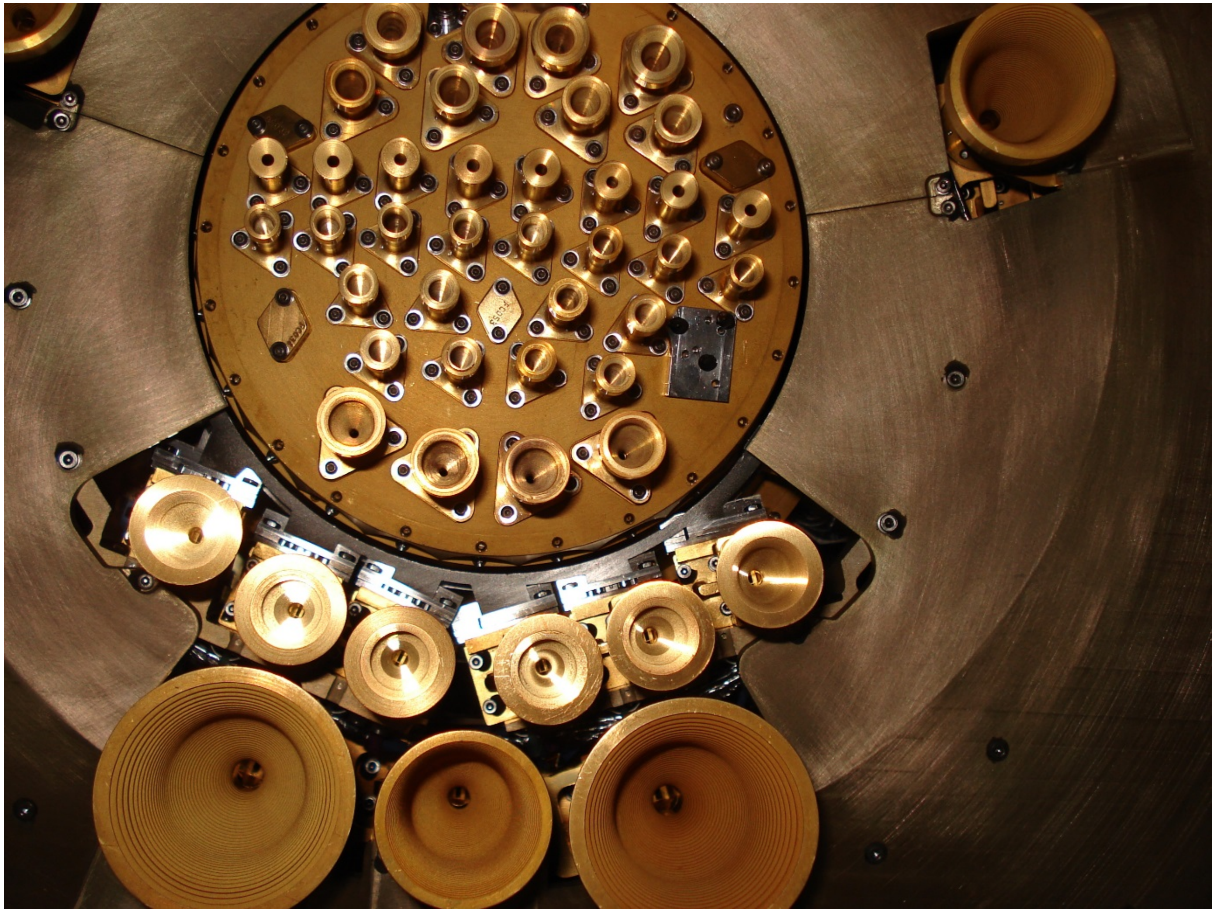
Focal plane arrays

- **Put more feed horns in the aperture plane, observe different parts of the sky at the same time!**
- **Increases mapping speed in proportion to the number of feed horns.**
- **Important if the area of science interes is larger than the beam – can make a map to a given sensitivity in 1/N of the time (where N no. of feeds).**



HARP focal plane array unit. 16 element, SIS-based array at 350 GHz, quasi-optical meander-line LO injection. Commissioned on the JCMT, 2005.

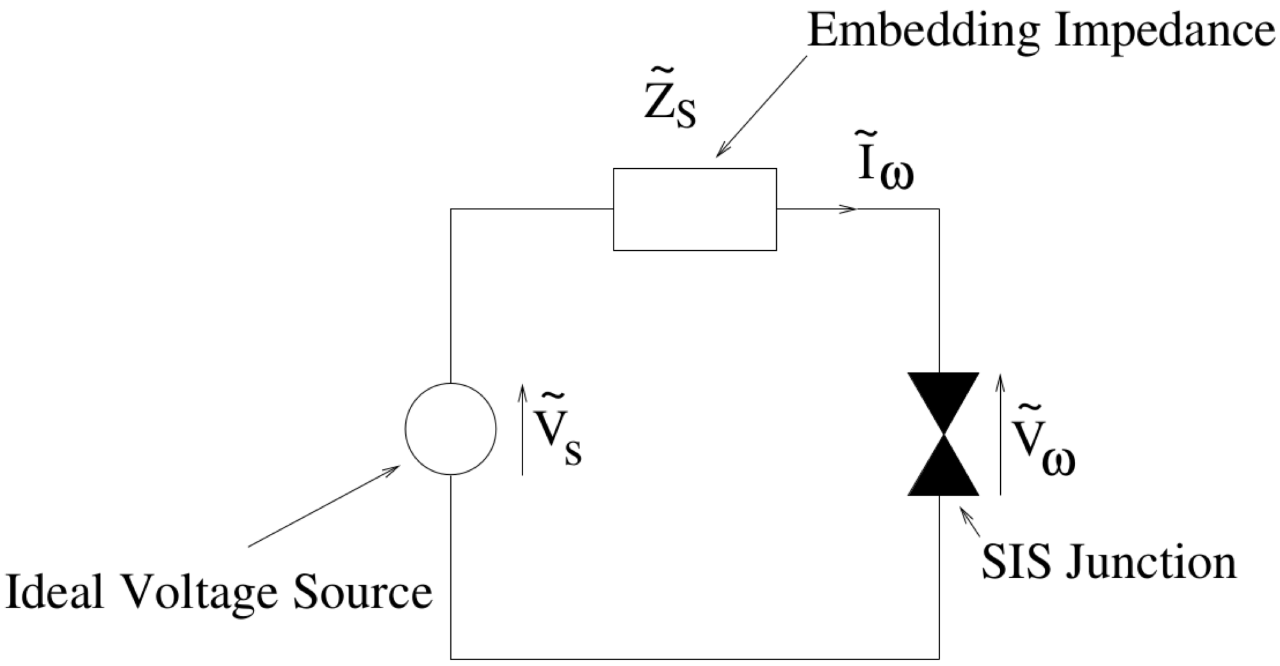
Focal plane arrays



Planck Satellite Focal plane array. Variety of corrugated feeds for 30 - 875 GHx © ESA/Thales

Impedance matching

- Maximum power transmitted with the two impedances are matched i.e. equal to each other.
- Every component of the receiver must be impedance matched to each other horn to OMT to cable to Low noise amplifier etc. etc.

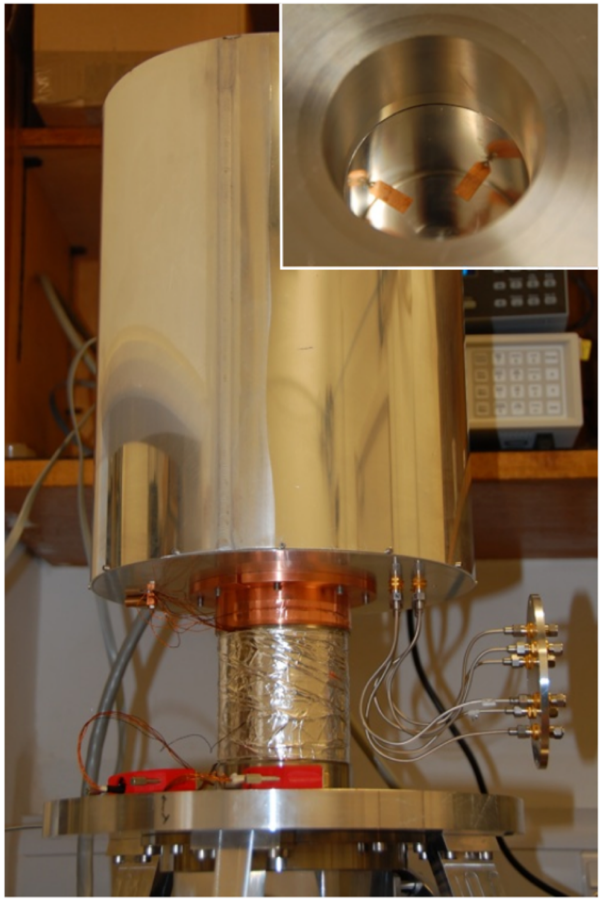


Waveguides

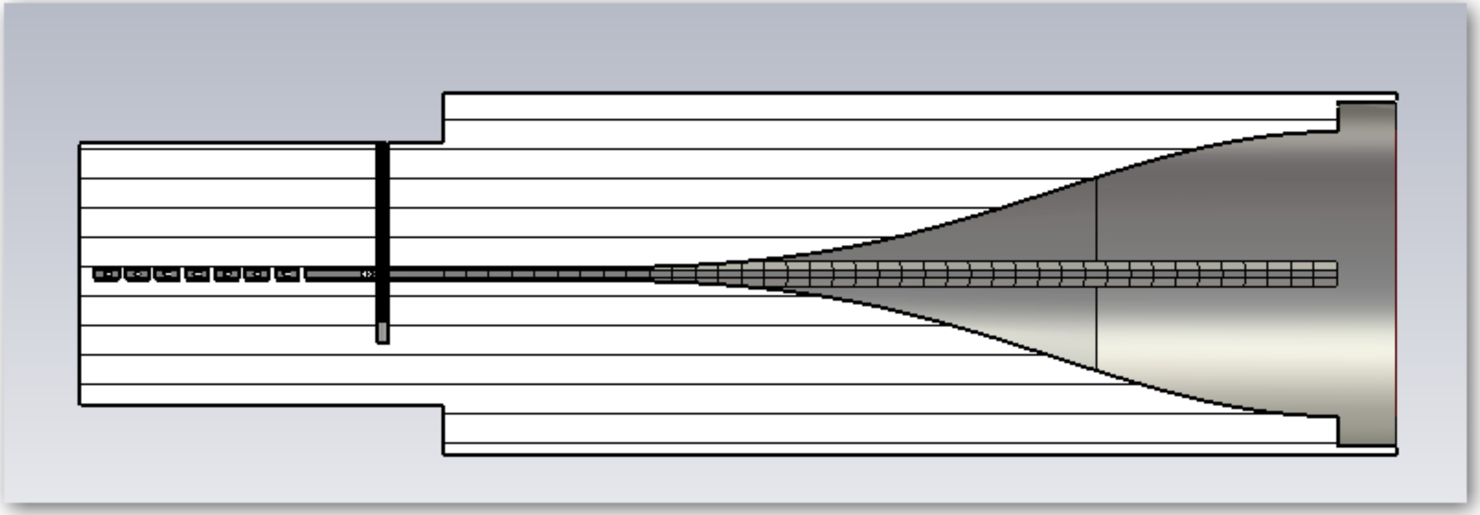
- Waveguides

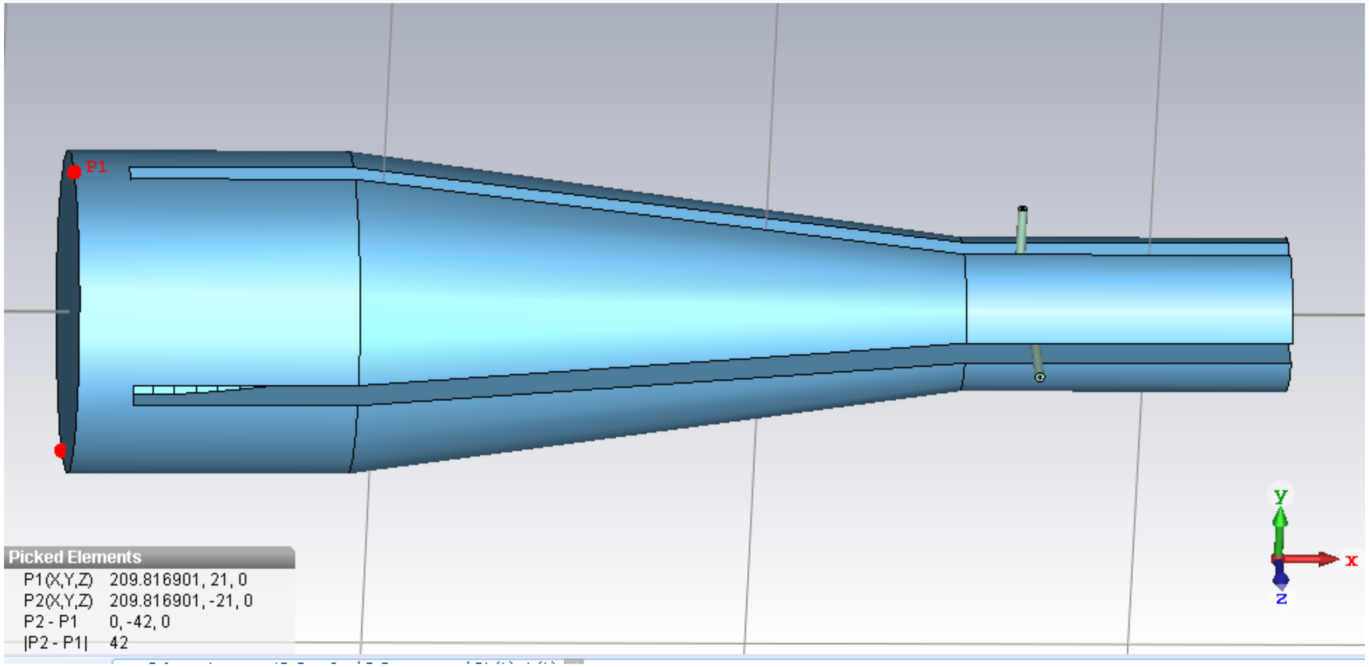
- **OMTs – OrthoMode Transducers.**
- **Capturing both polarizations from the waveguide connected to the horn.**
- **Output – typically two coaxial cables.**

- 4 Probe OMT within the cryostat

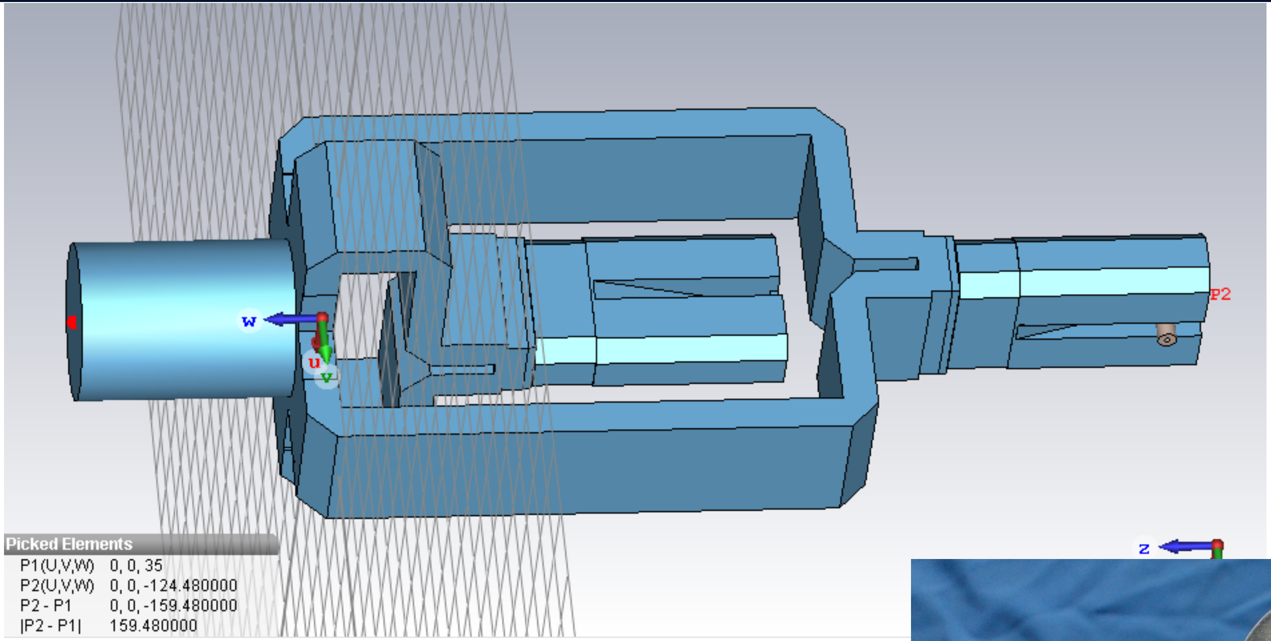


JLRAT- 5a OMTs, finline



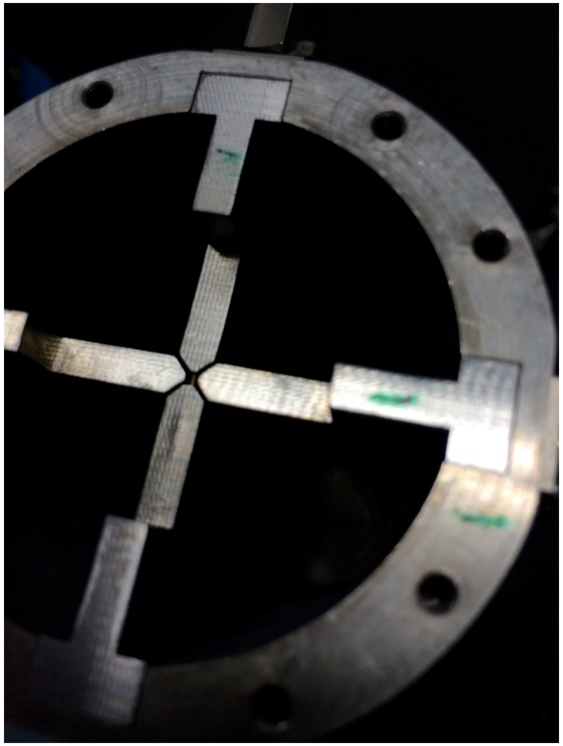


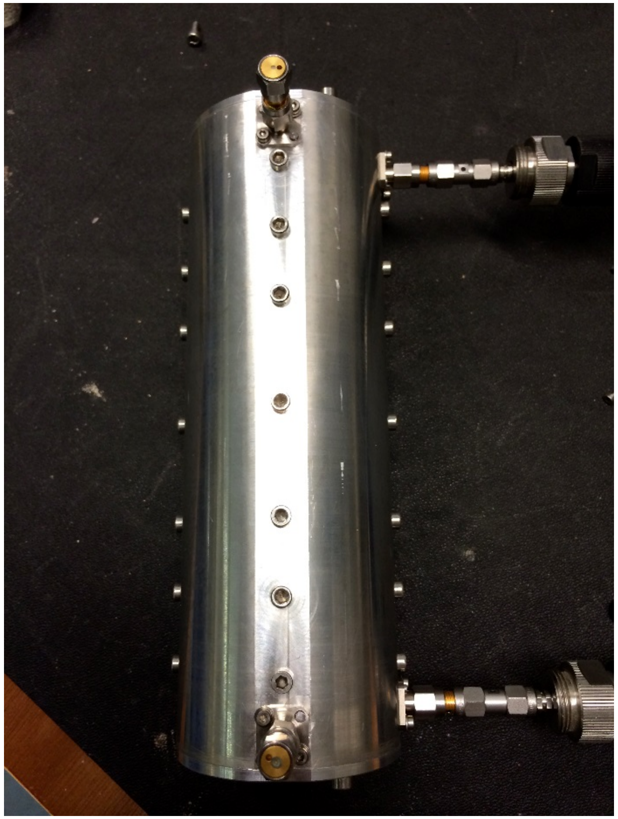
JLRAT 5b OMTs – turnstyle type

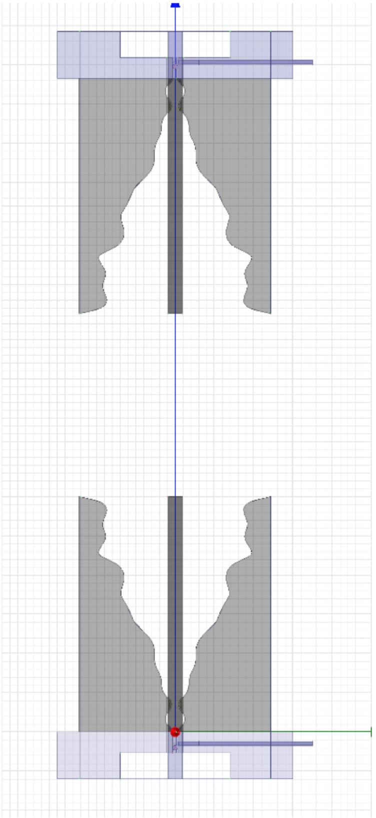


Example: OMT design for Goonhilly

- Compact Quad-Ridged Orthomode Transducer

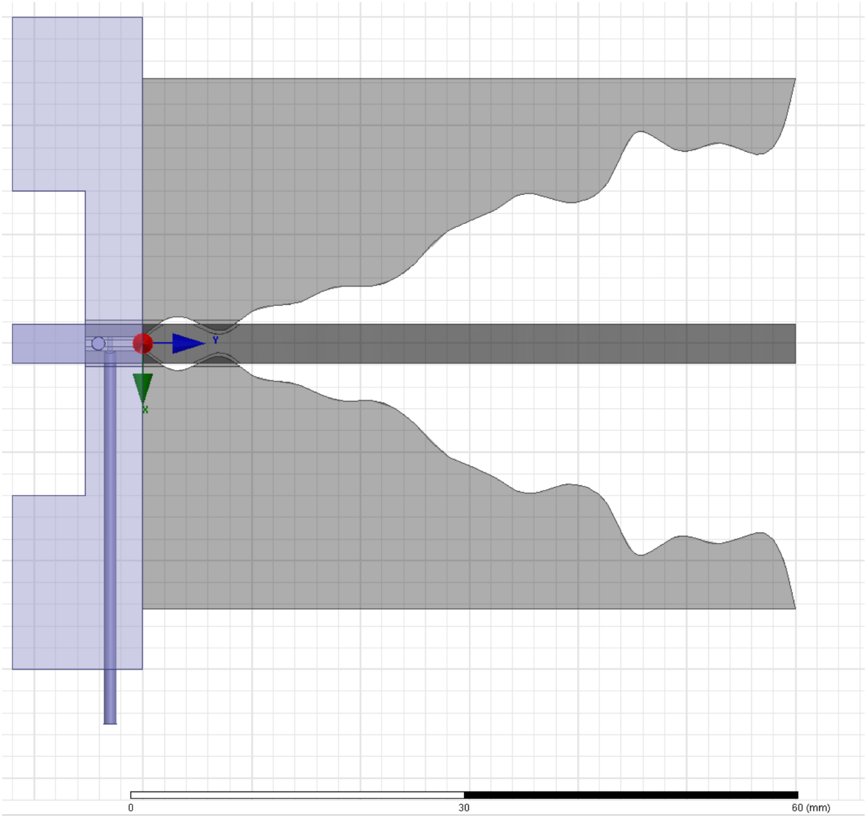


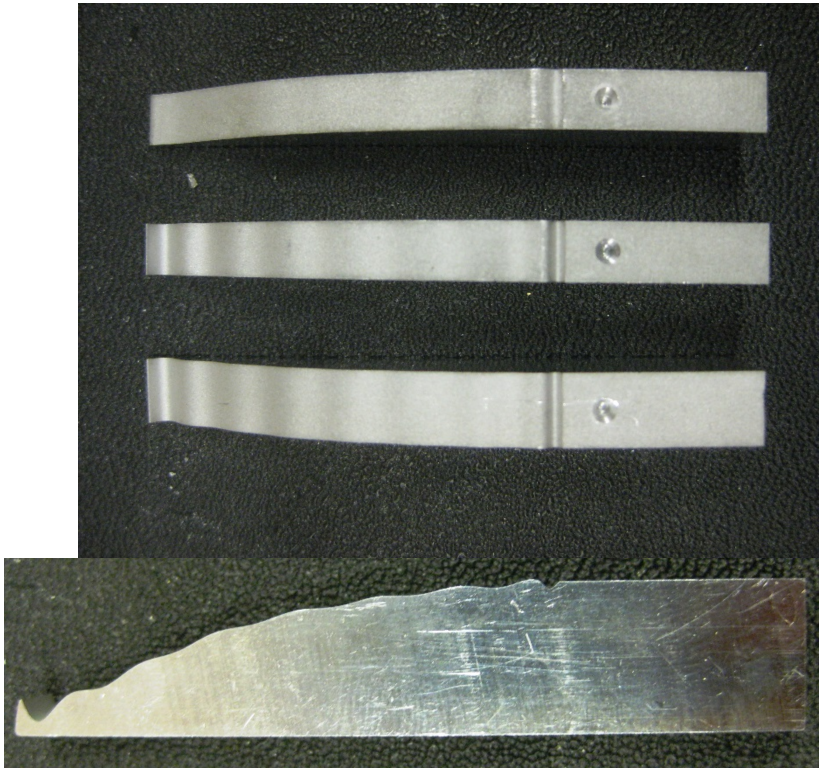




Example: OMT design for Goonhilly

- Compact Quad-Ridged Orthomode Transducer



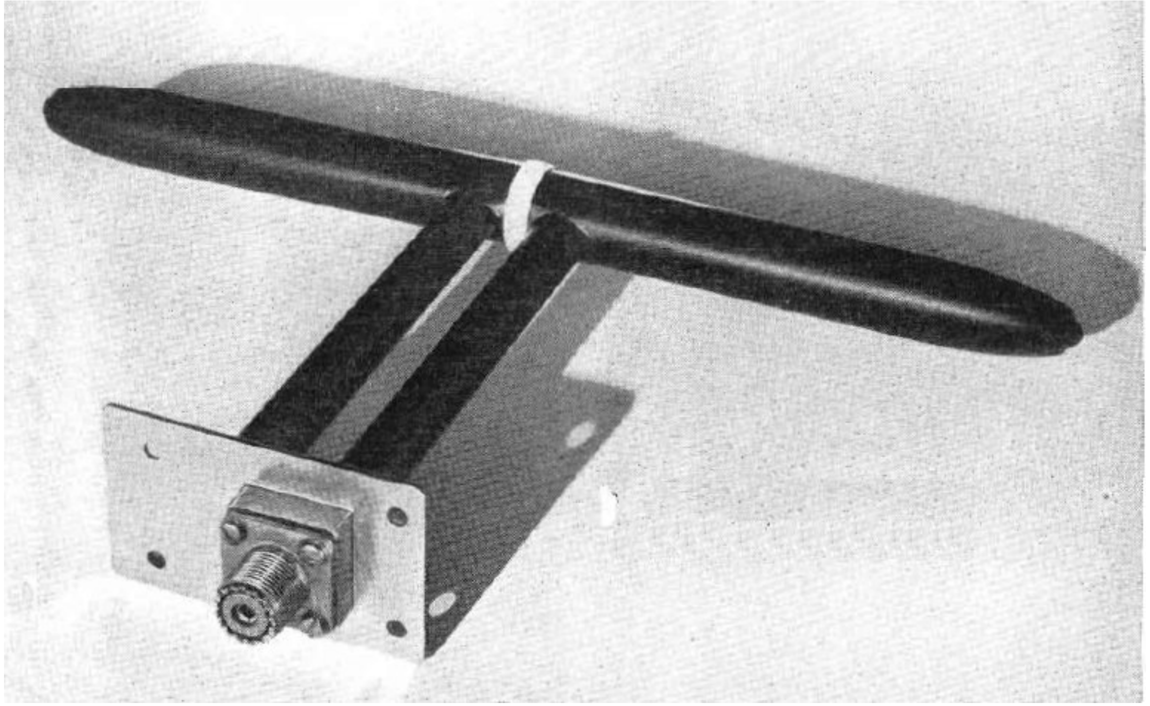


Non-dish antennas

- Useful in astronomy at “low” frequencies – usually below 300 MHz or so.

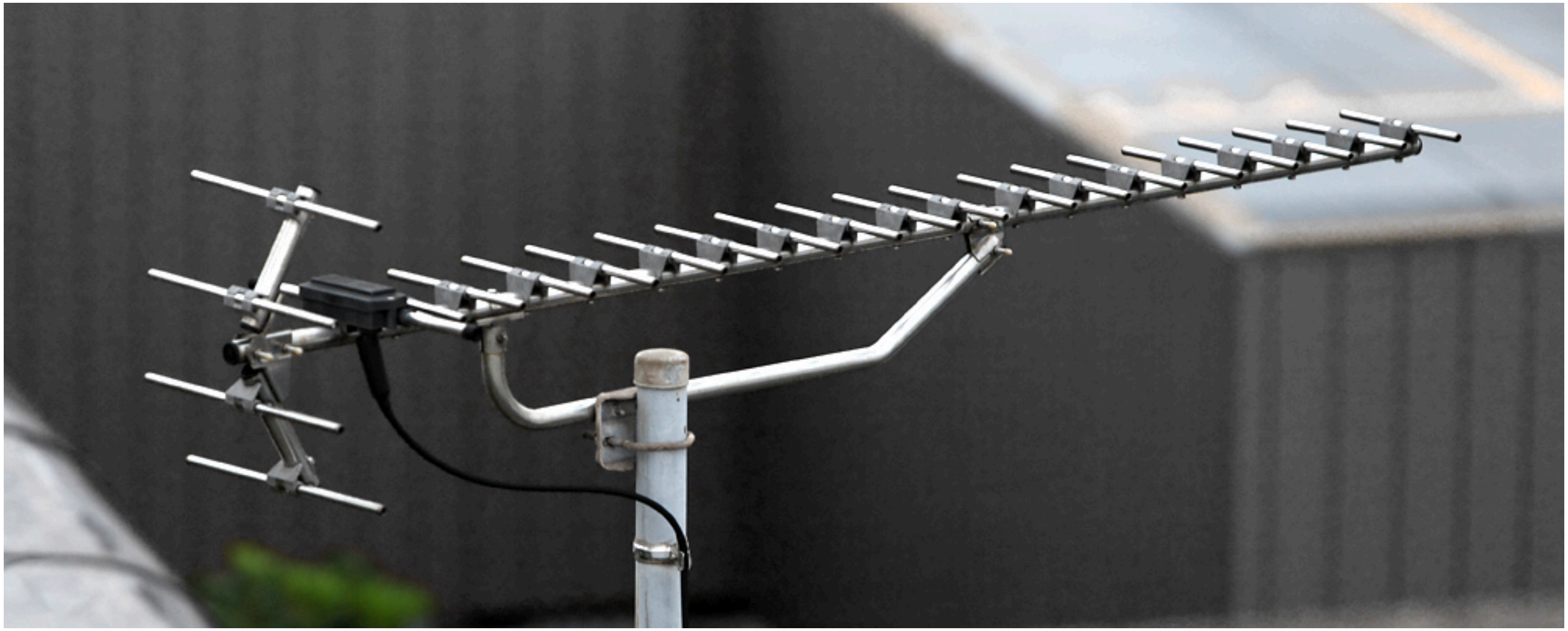
Non-dish antennas

- Hertzian Dipole - simplest possible antenna.



Non-dish antennas

- Yagi



Non-dish antennas

- Log-periodic e.g. SKA-LOW antennas in Western Australia.

- Images © ICRAR.

Thank You

Non-dish antennas

- Yagi
- Log-periodic
- Useful in astronomy at “low” frequencies below 300 MHz.

Overview

- Basic concepts:
  - Spherical trig /solid angle revision.
  - The angular response of a telescope: concept of a beam pattern.
  - Aside: dB scale for relative powers.
  - Aside: Reciprocity theorem.
  - The beam pattern as a diffraction pattern. Fourier transform of illumination. Main beam width.
  - Calculating or measuring a beam pattern.
  - Examples of beam patterns.
- Common types of dish antenna in radio astronomy. Radio "optics".
- Beam pattern solid angles, efficiencies, gains. Convolution.
- Feed horns: Capturing the waves or "Illuminating" the antenna.
- After the feed horn: waveguides, Orthomode transducers, coaxial cables, impedance matching.
- Amplifiers and mixers and the "RF chain".
- "Non-dish" radio astronomy antennas – the world below ~300 MHz.

- Things to remember.