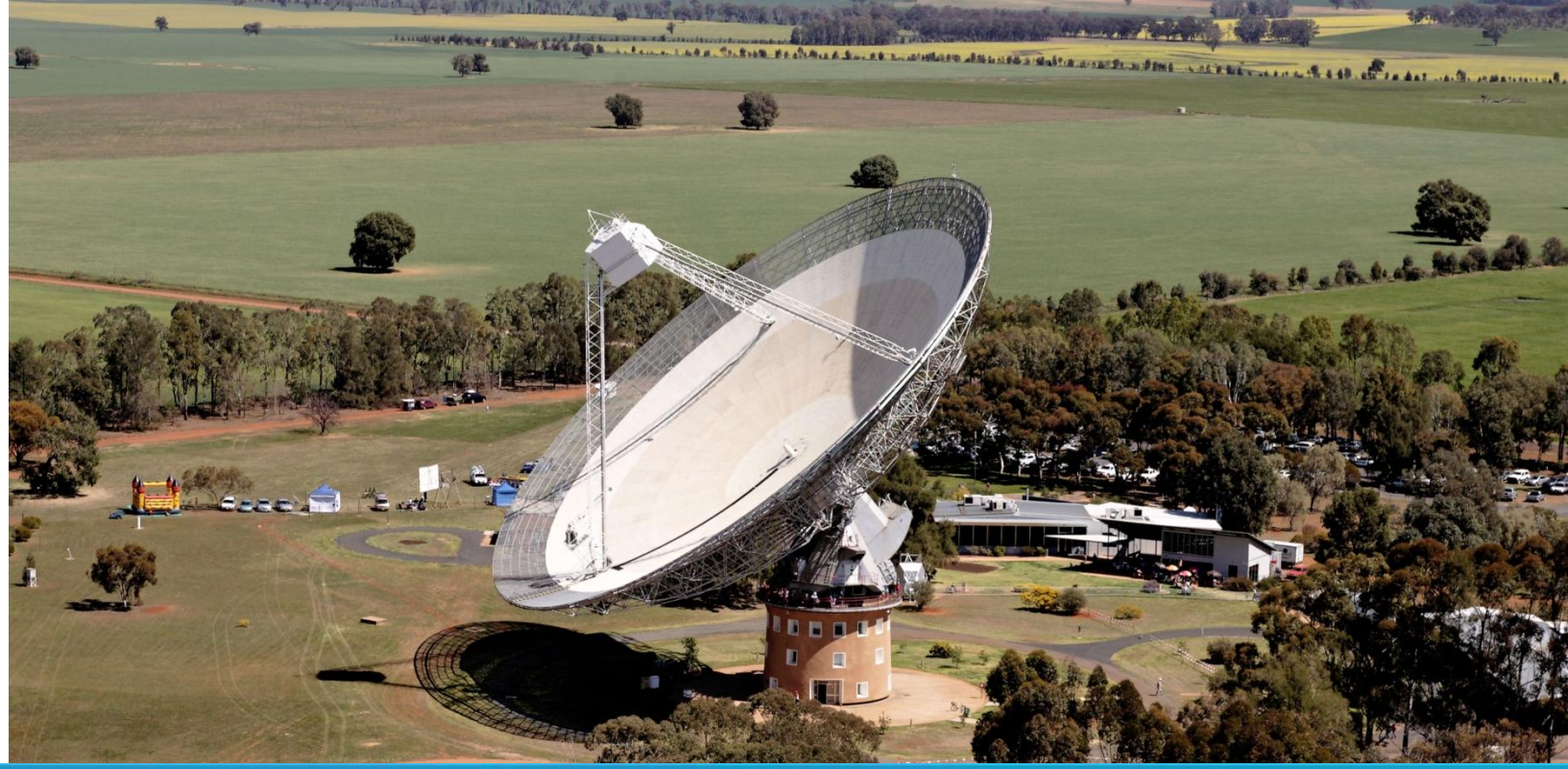


Receiver Systems

Alex Dunning

CSIRO

The Basic Structure of a typical Radio Telescope

Antenna

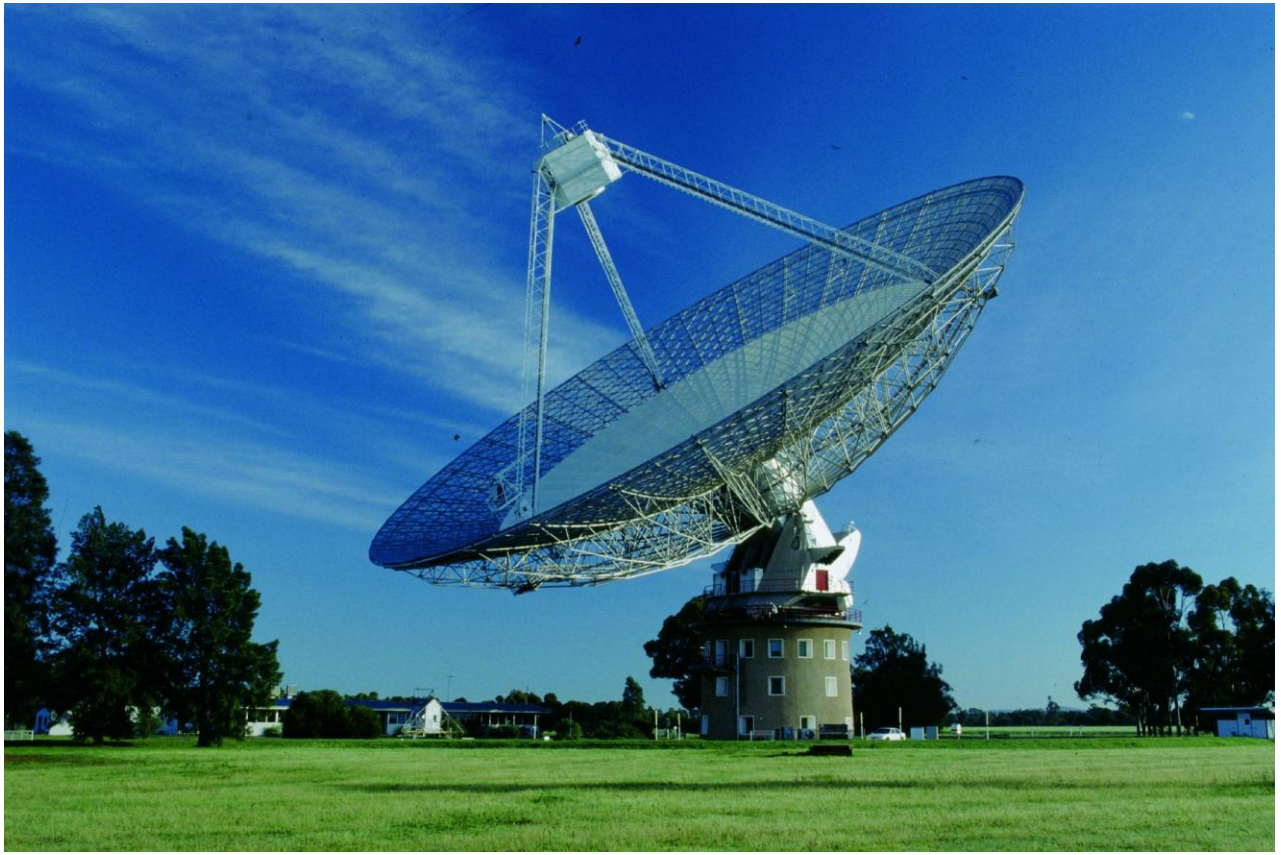
Receiver

Conversion

Digitiser

Signal Processing / Correlator

They are much the same



Radiotelescope Receivers

Radio Receivers

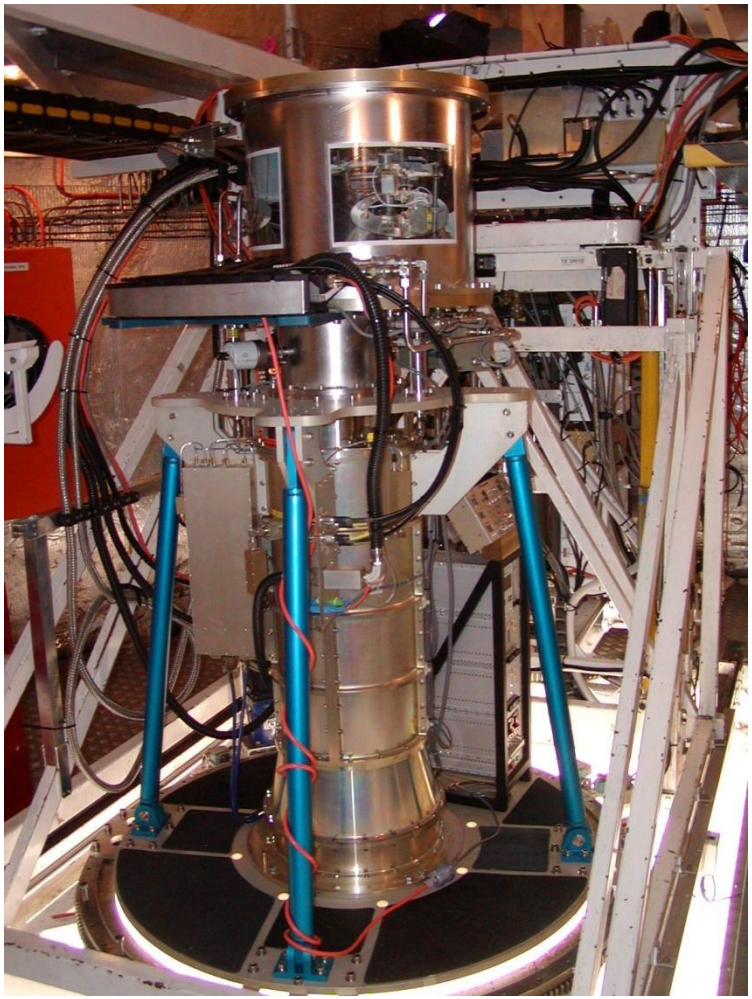
"A radio receiver converts signals from a radio antenna to a usable form" Wikipedia

Ours look more like this...

- Captures the signal reflected from the antenna
- Amplifies the signal

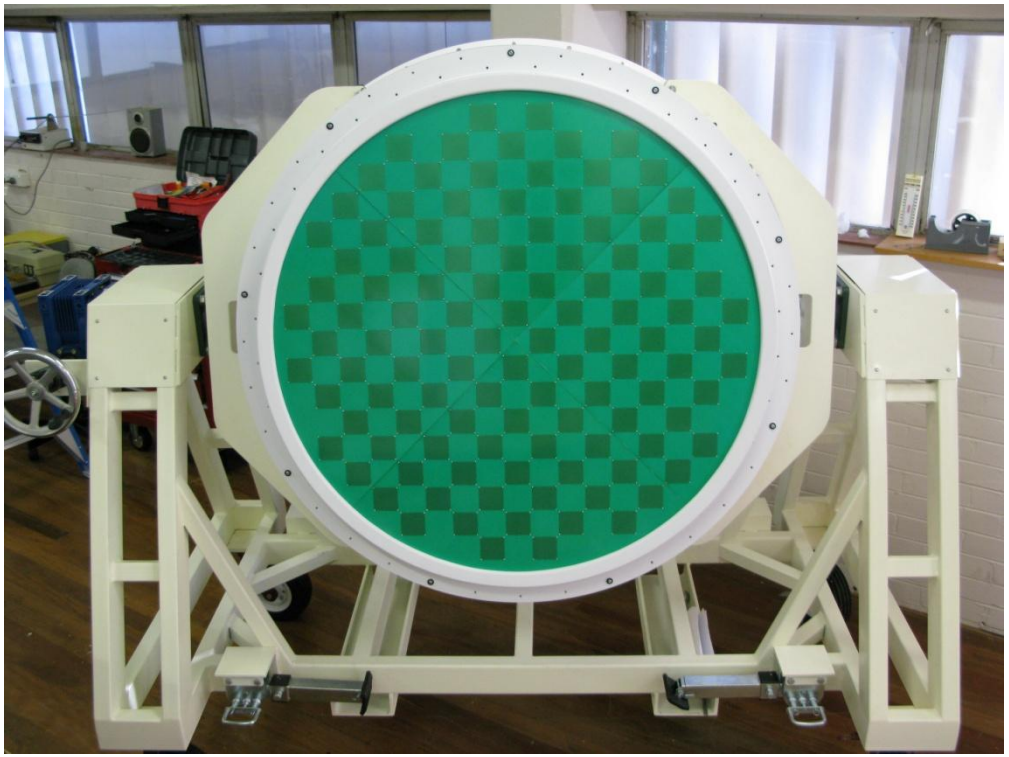
Compact Array
3/7/12mm Receiver

Or this...



Parkes 10/50cm
Receiver

Or this...



ASKAP Phased Array Receiver

Some even look like this...

Allen Telescope Log Periodic Receiver

The Receiver

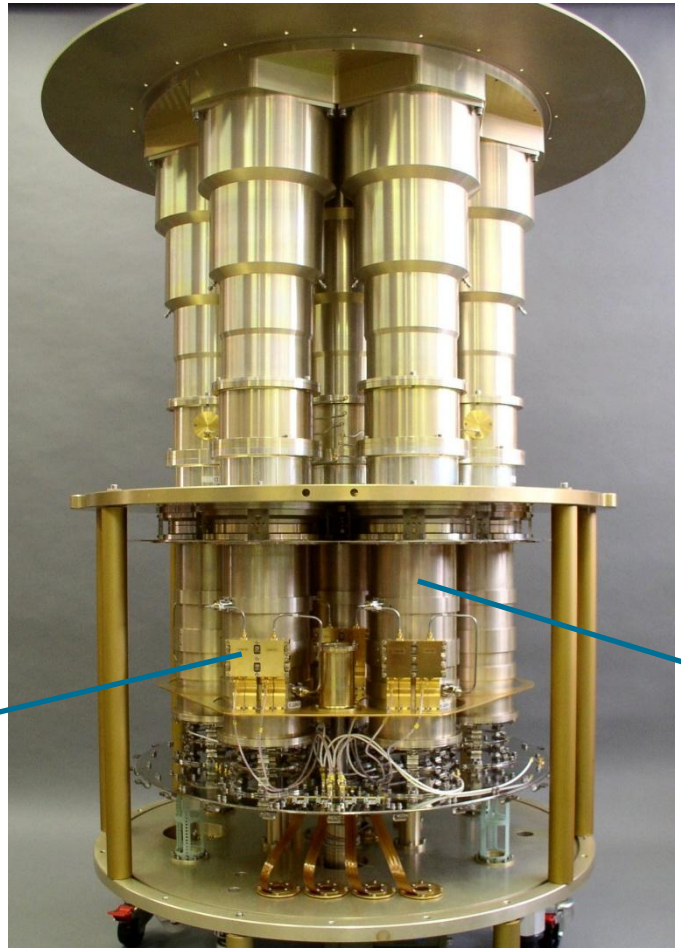
On the outside...

Vacuum Dewar

Feed Horns

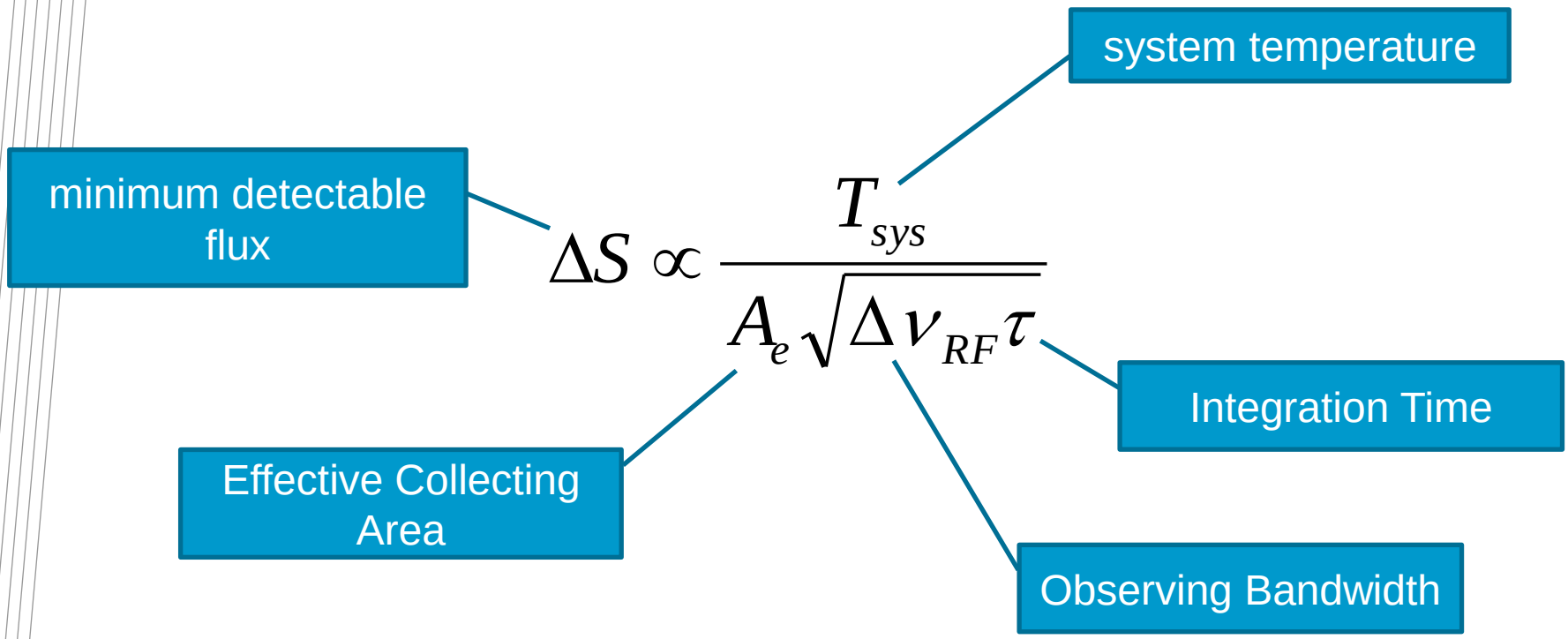
The Receiver

On the inside...

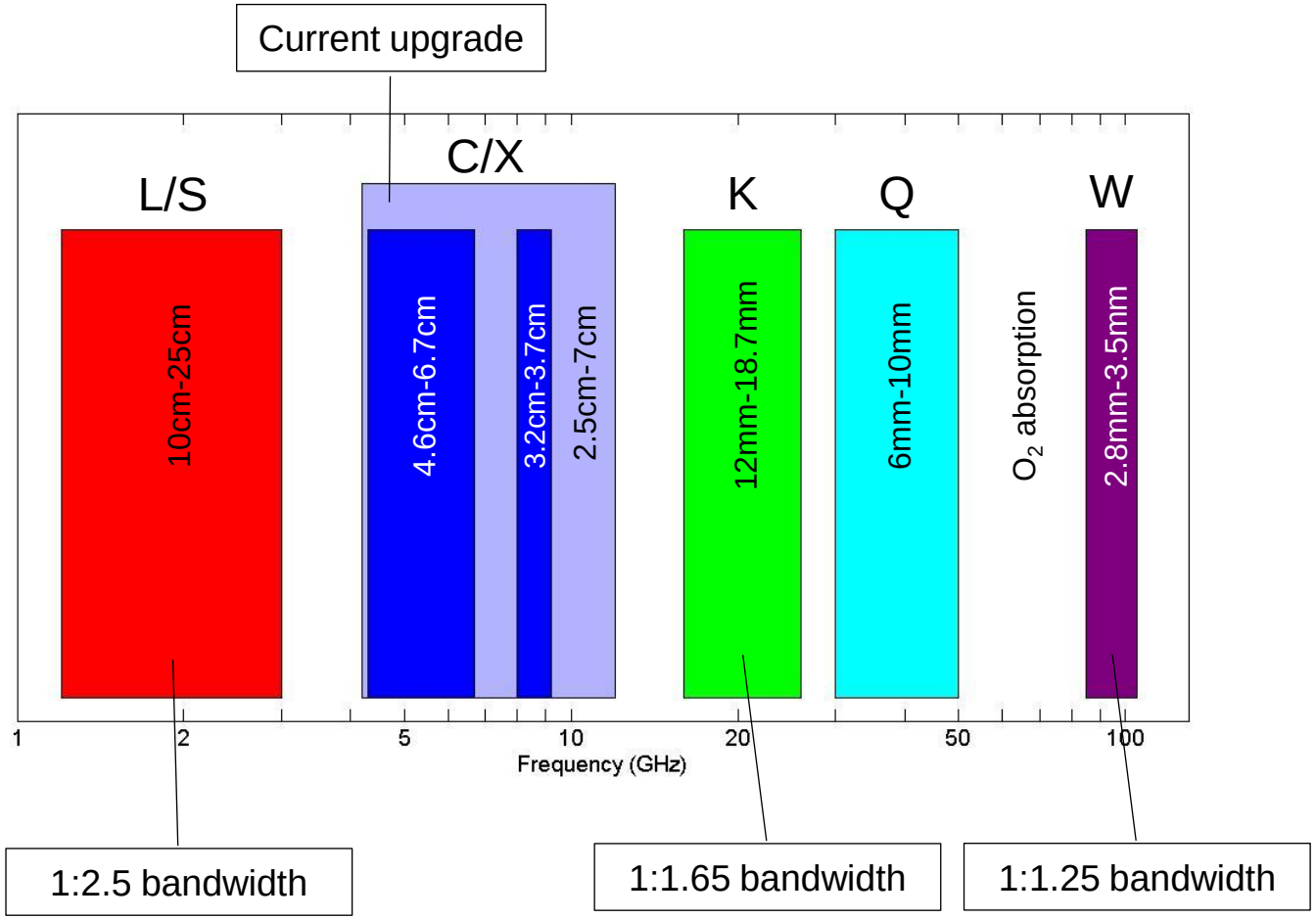


Amplifiers

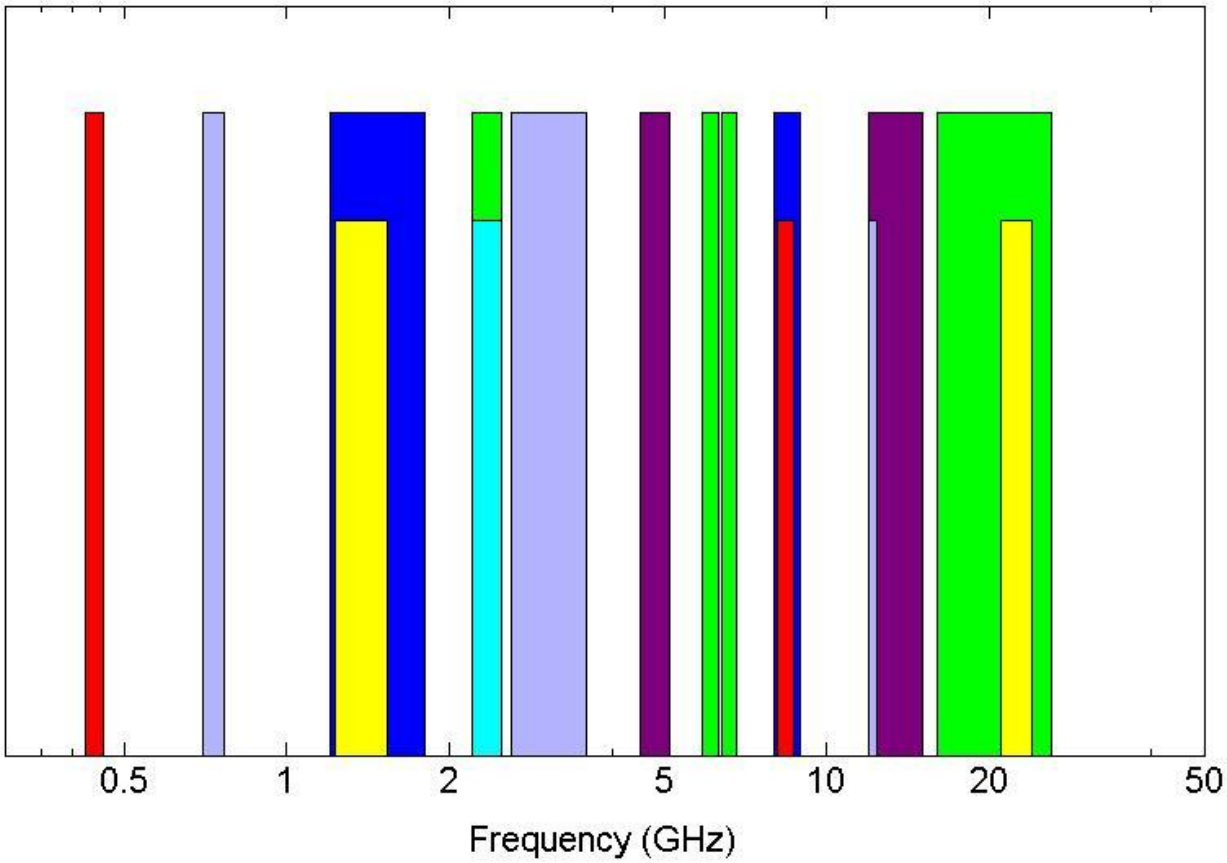
Ortho-Mode Transducers


system temperature
minimum detectable flux
$\Delta S \propto \frac{T_{sys}}{A_e \sqrt{\Delta \nu_{RF} \tau}}$
Integration Time
Effective Collecting Area
Observing Bandwidth

The Australia Telescope Receivers

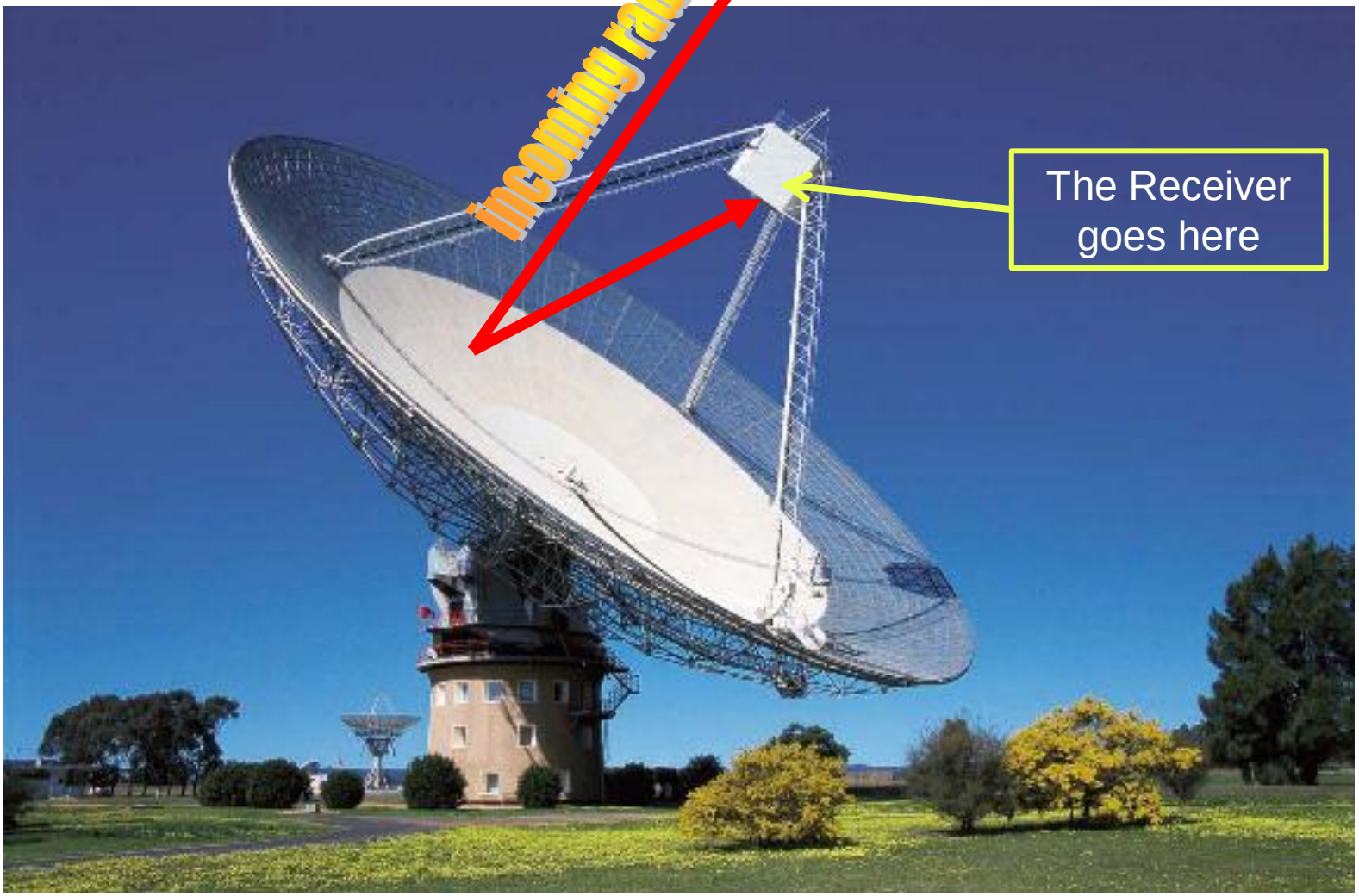


Parkes Receiver Bands

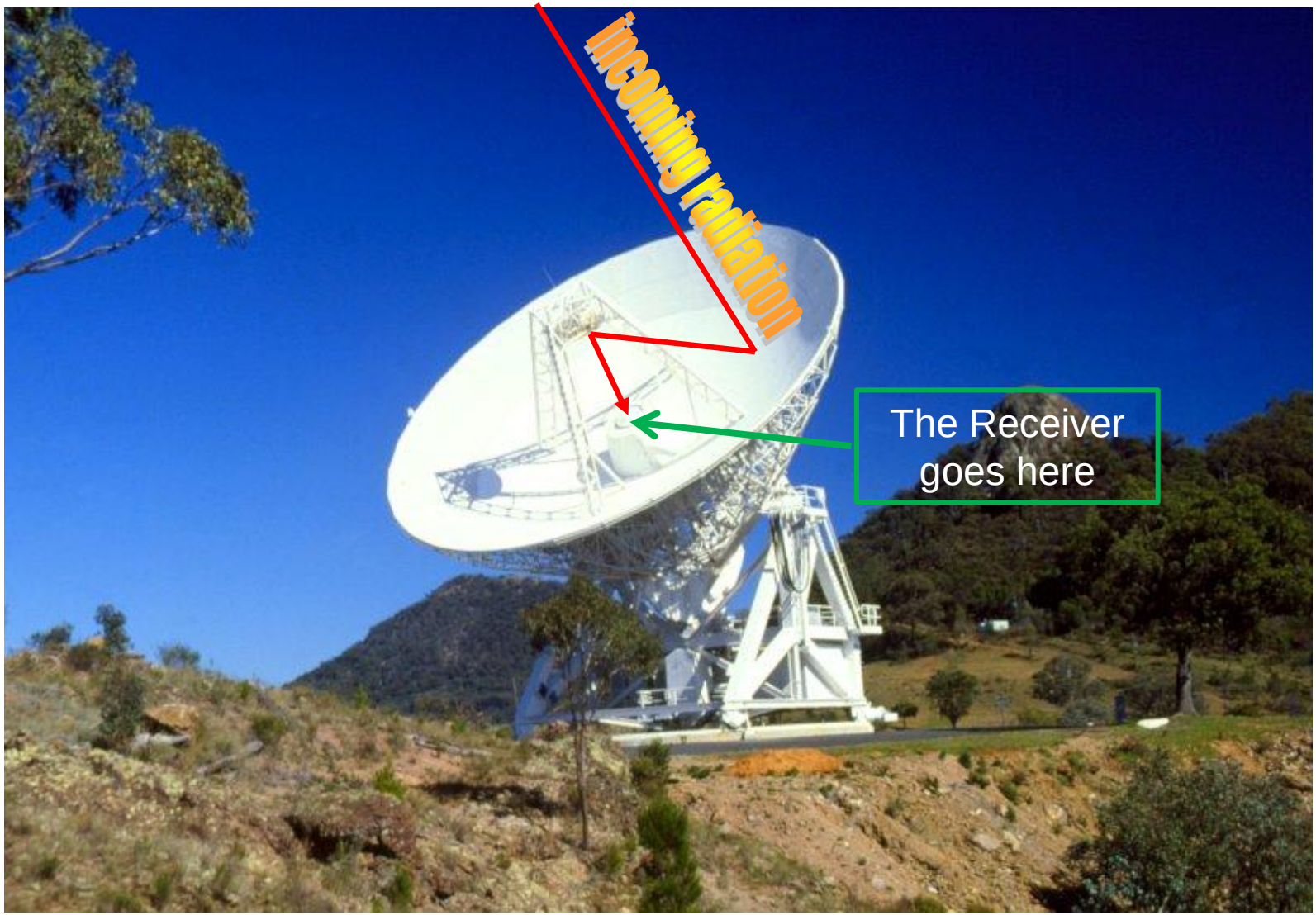


Where do they go?

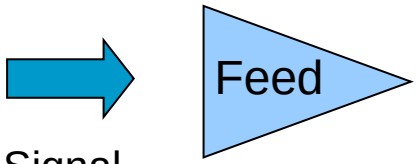
In a prime focus...



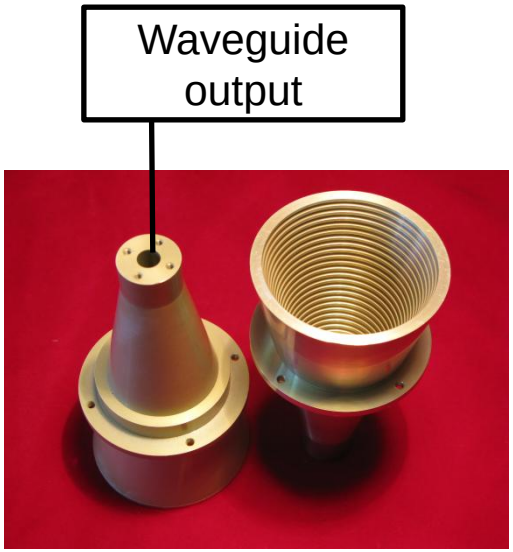
In a Cassegrain system...

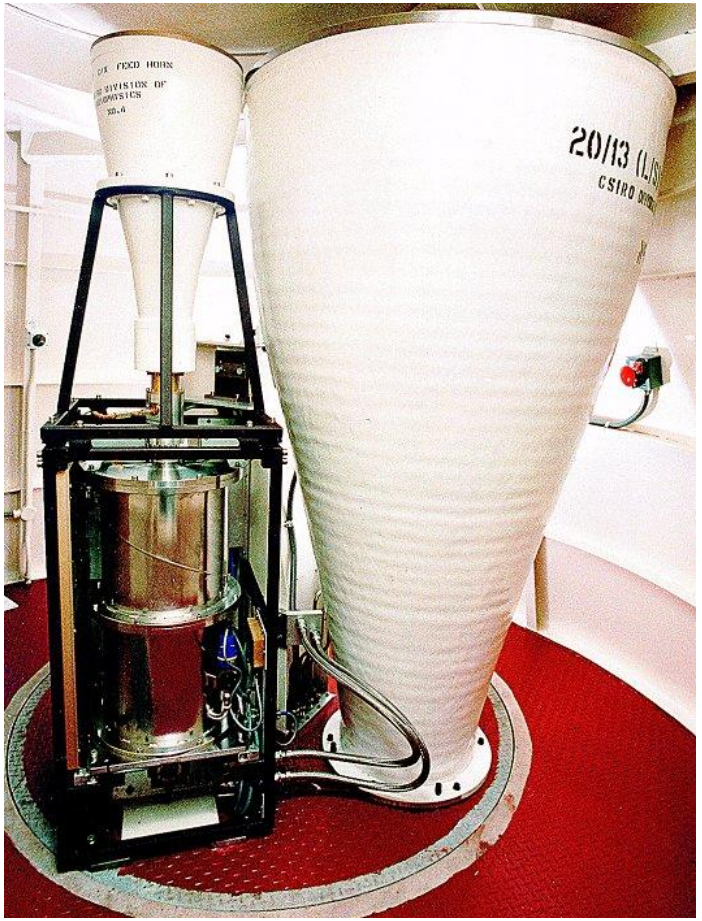


Receiving the signal – Feed horns

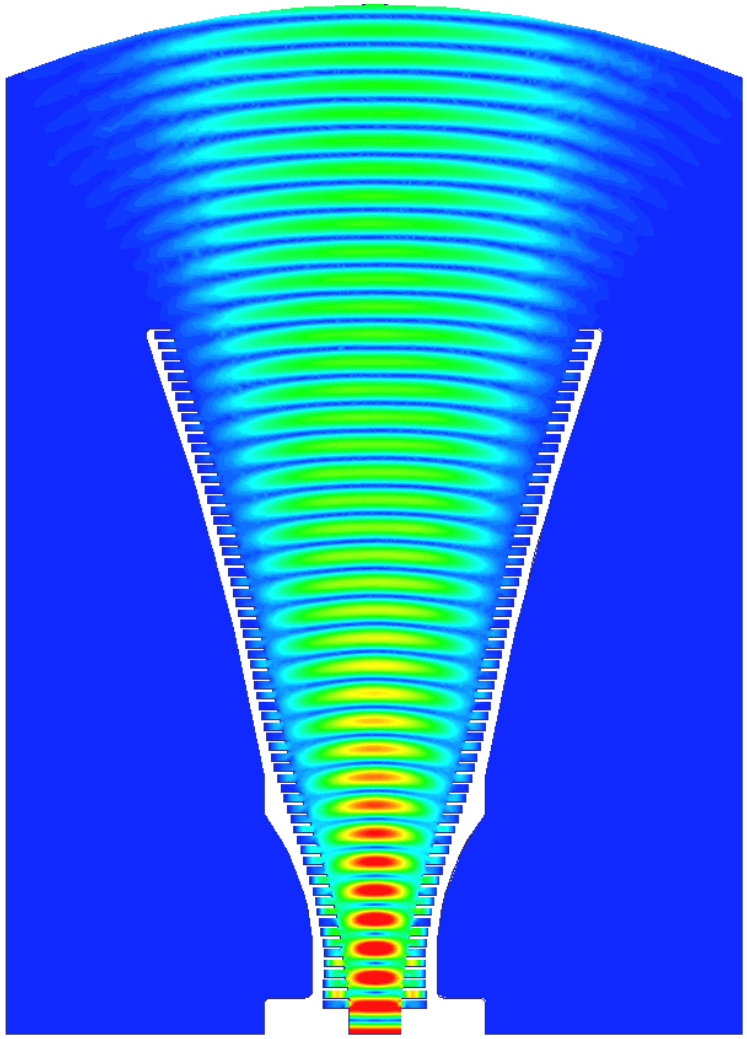


Captures the focused microwaves into a waveguide output

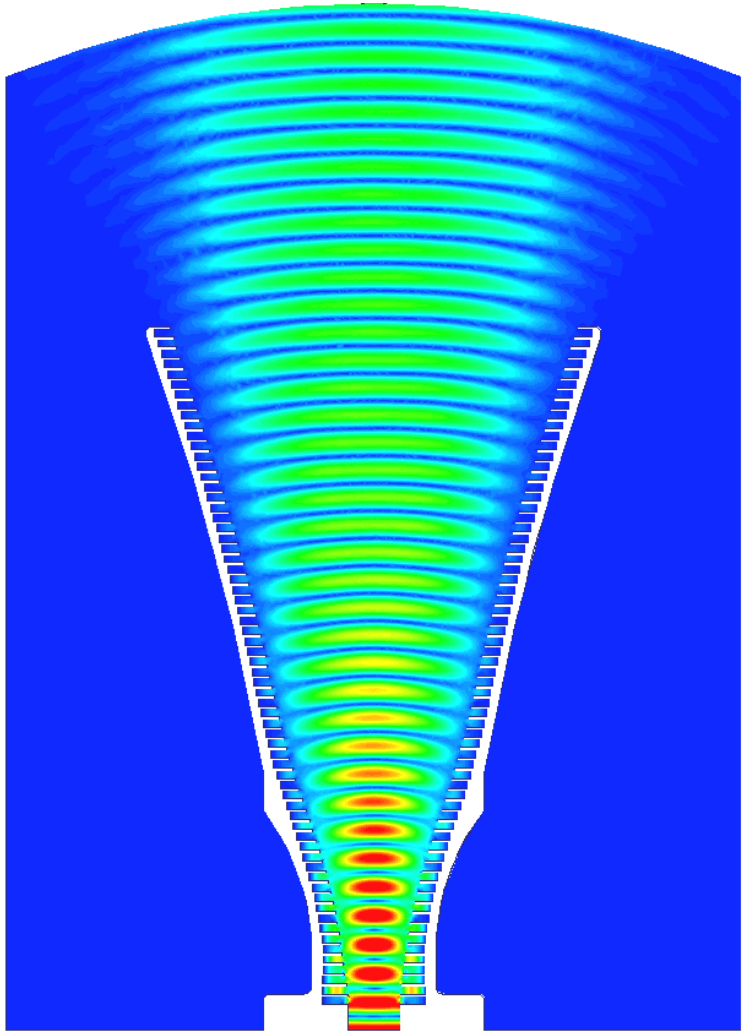




Feed Horns



Feed Horns



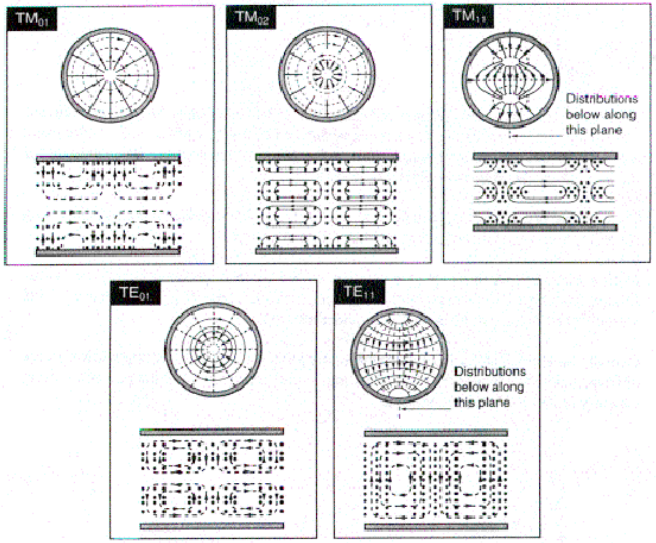
$$\nabla \cdot E = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot B = 0$$

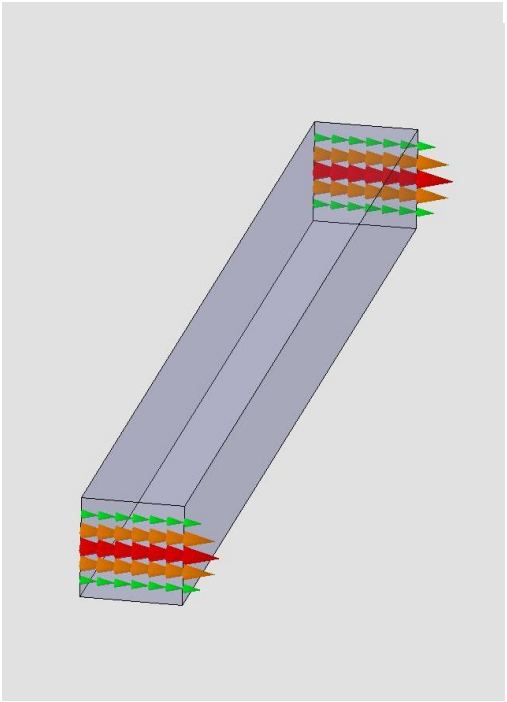
$$\nabla \times E = -\frac{\partial B}{\partial t}$$

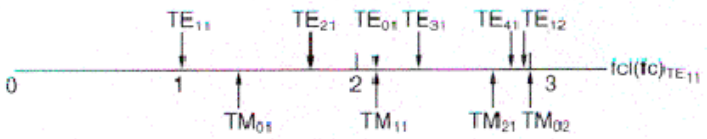
$$\nabla \times B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial E}{\partial t}$$

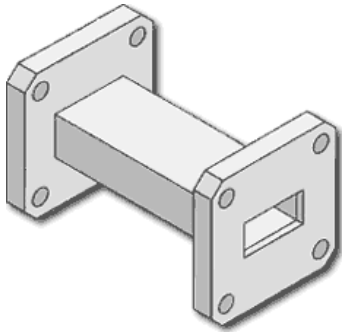
Detour: Waveguides



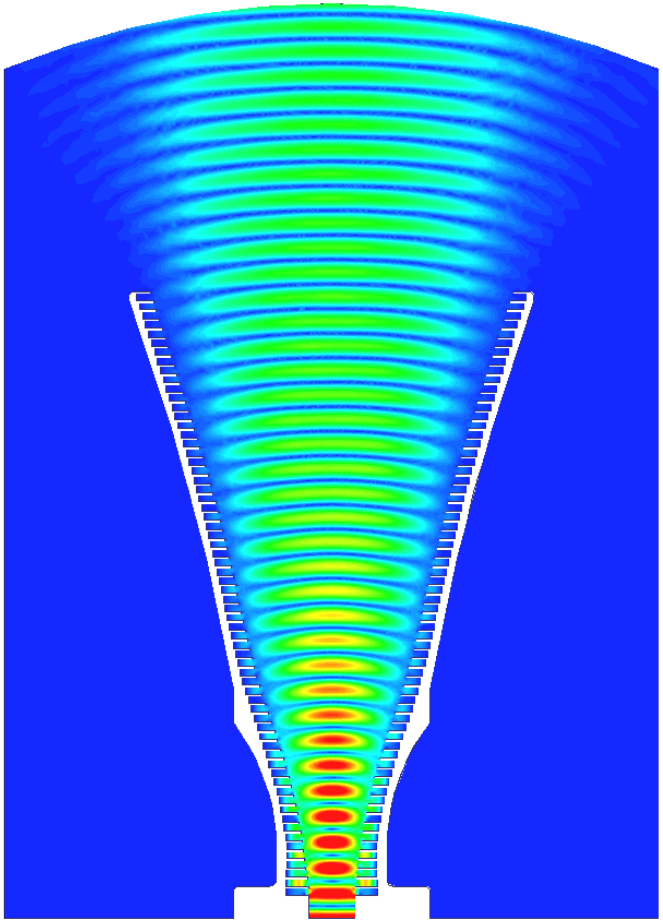
- Replace cables at high frequencies
- Operate like optical fibres for microwaves
- Only work over a limited frequency range
- Can support signals with two polarisations

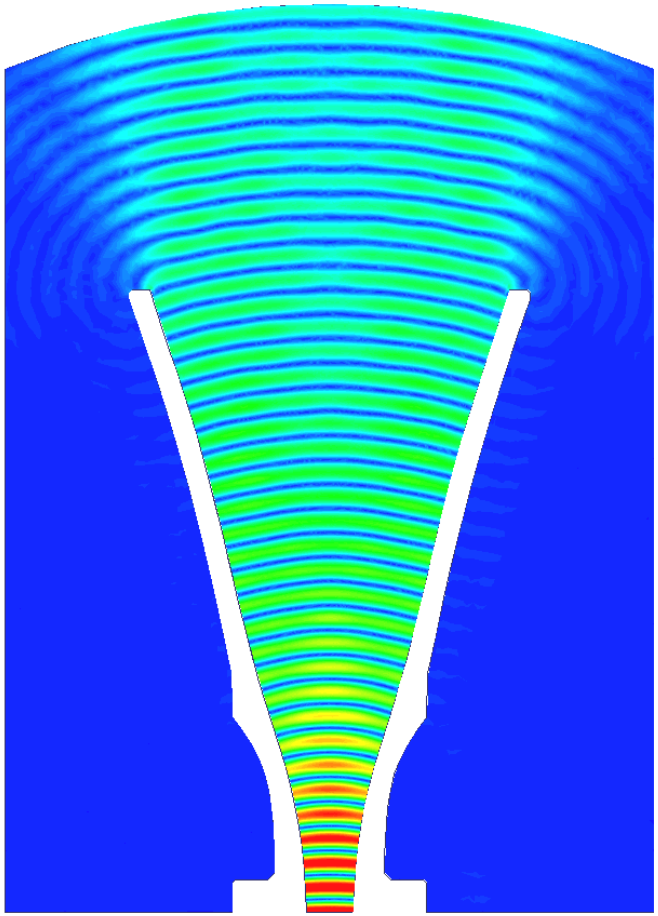






A Tale of Two Feedhorns



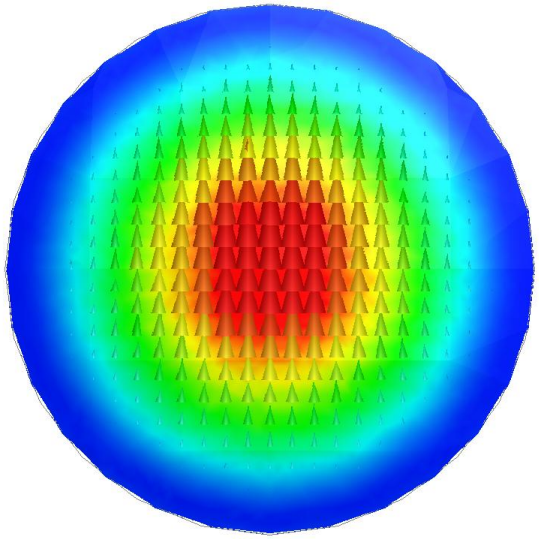


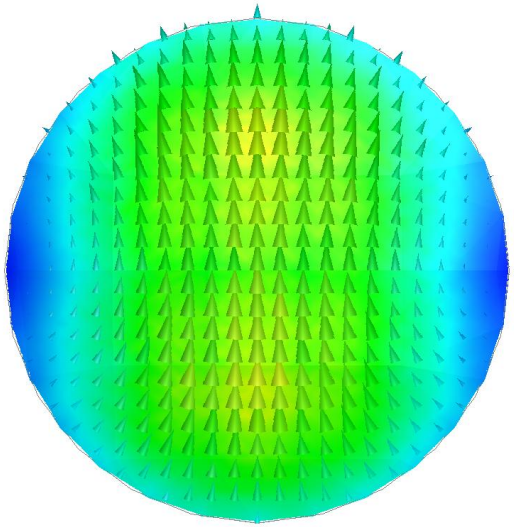
A Tale of Two Feedhorns

Corrugated

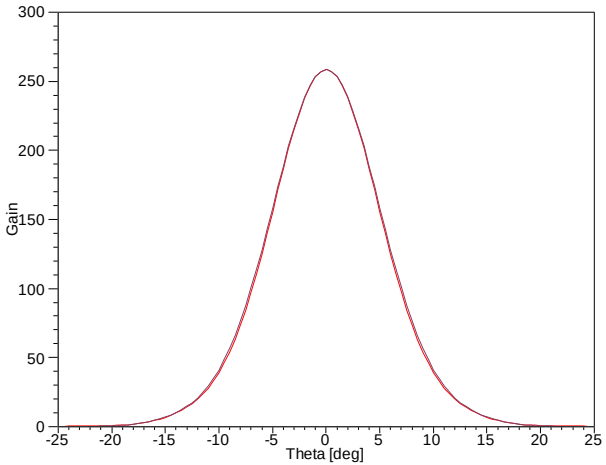
Smooth Walled

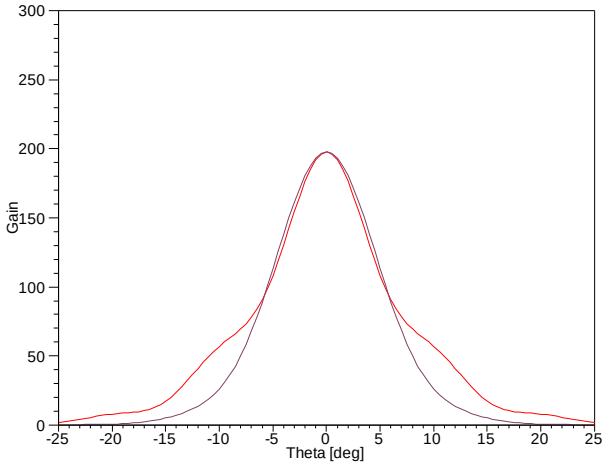
E-Field At Feed mouth

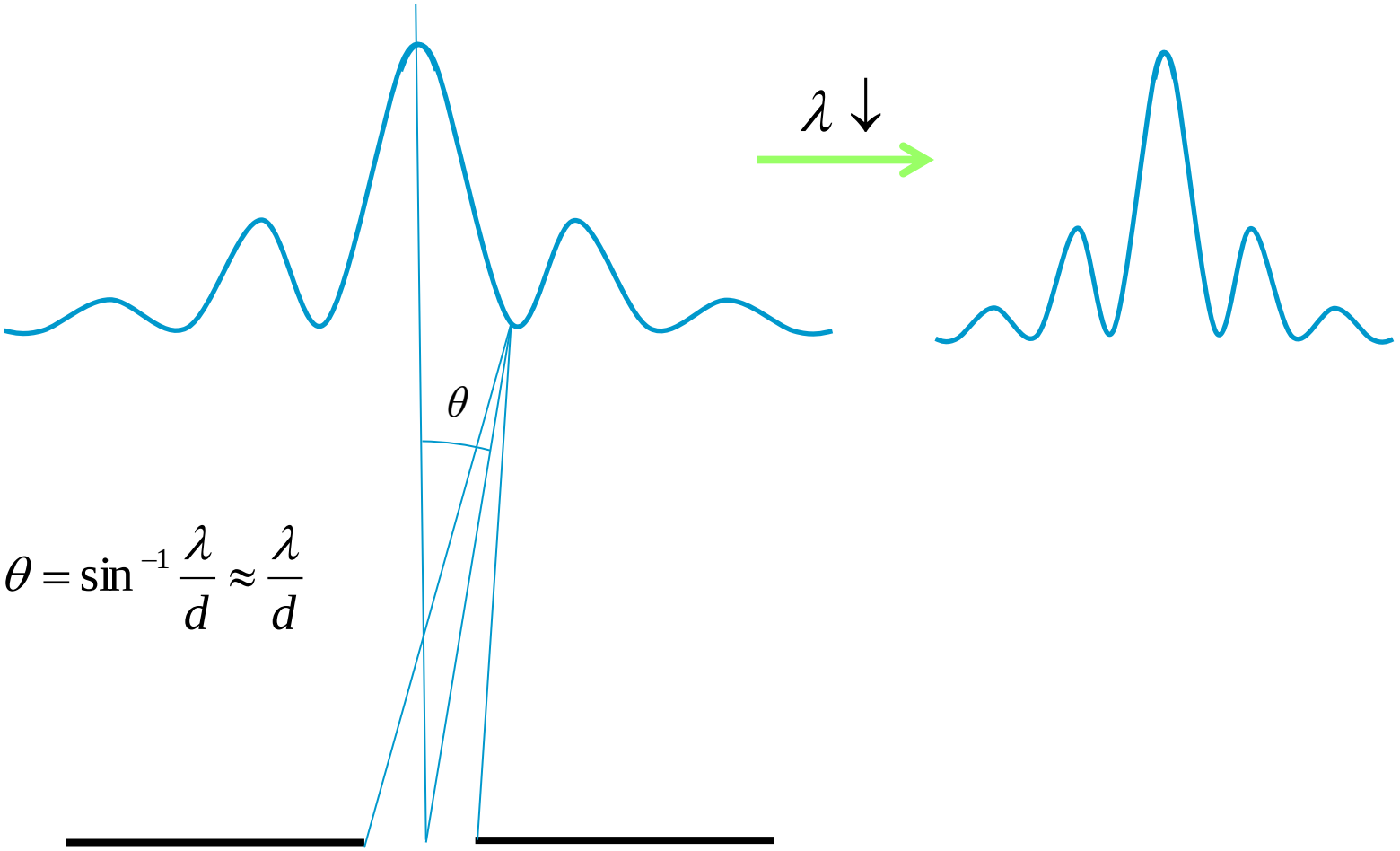




X and Y Feed Patterns

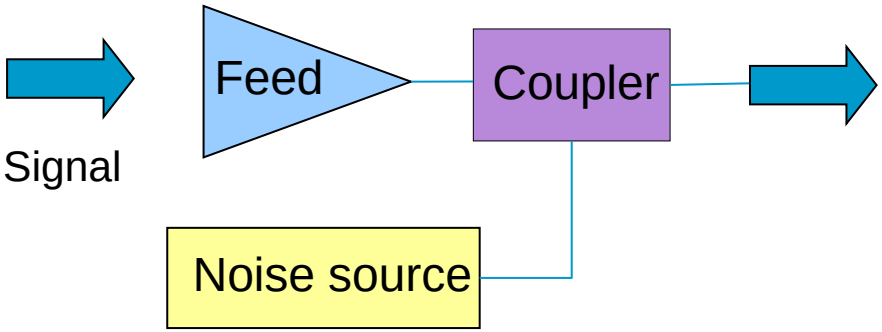


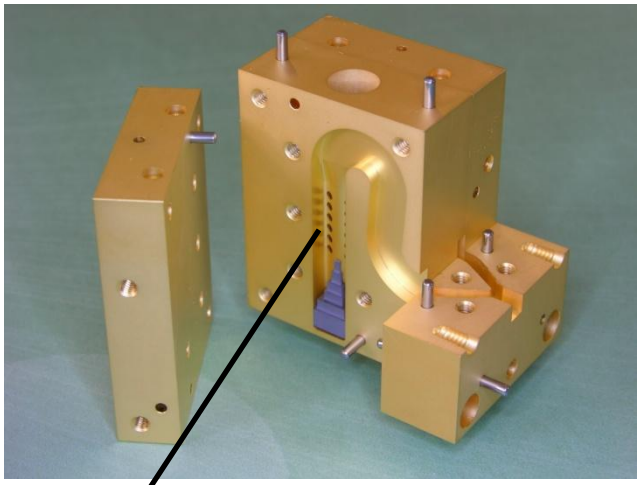




$$\theta = \sin^{-1}\frac{\lambda}{d} \approx \frac{\lambda}{d}$$

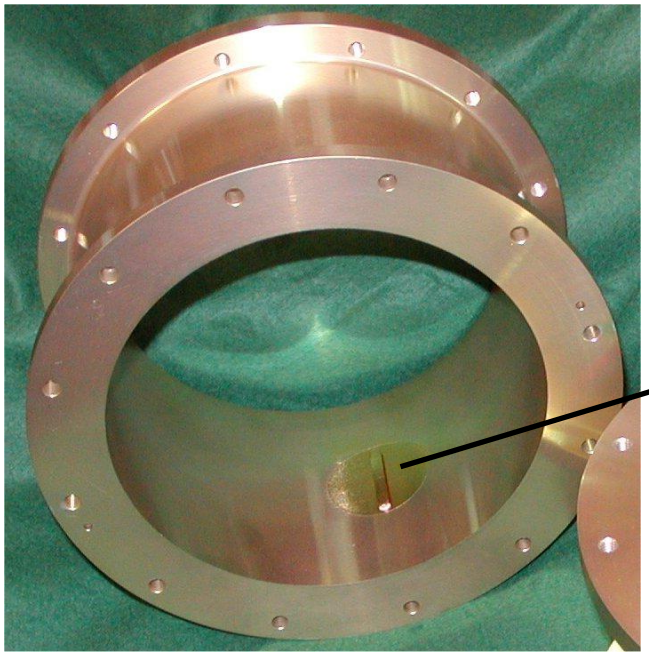
Coupling noise into the System





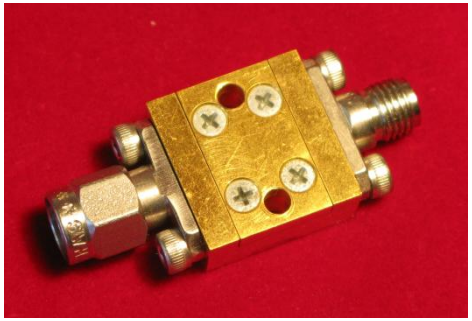
Noise coupled in through small holes

7mm waveguide coupler



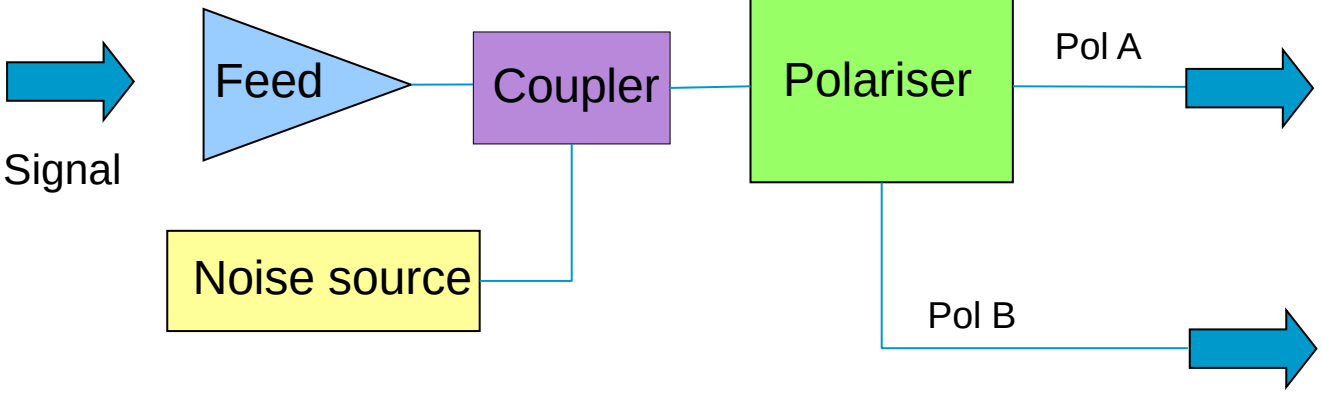
Noise coupled in through vane

21cm waveguide coupler

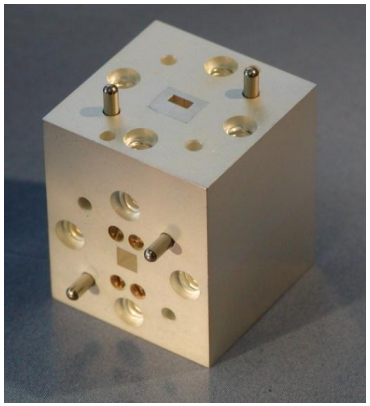


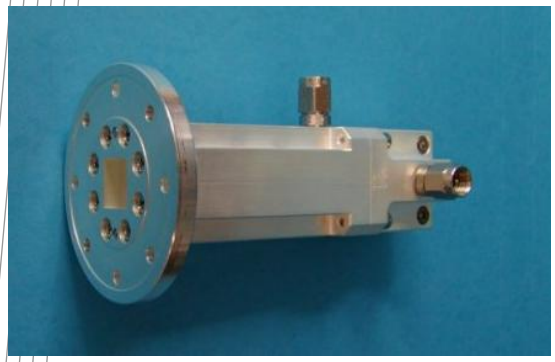
12mm noise source

Separating Polarisations – Ortho-mode Transducers (OMTs)



3mm Ortho-mode transducer





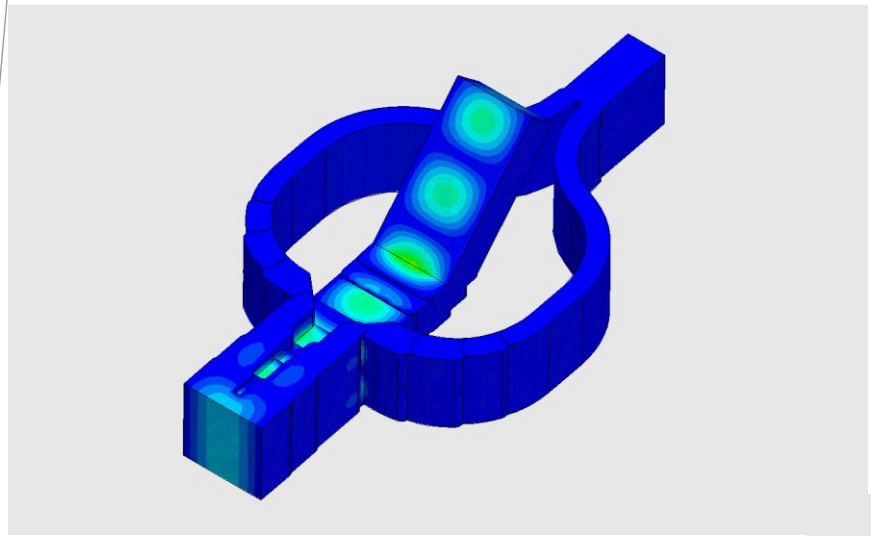
12mm Ortho-mode transducer

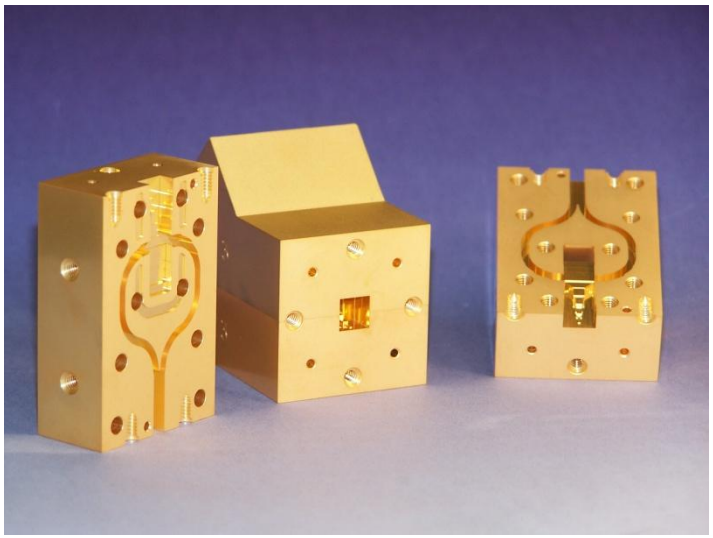
Separates incoming signal into two linear or circular polarisations

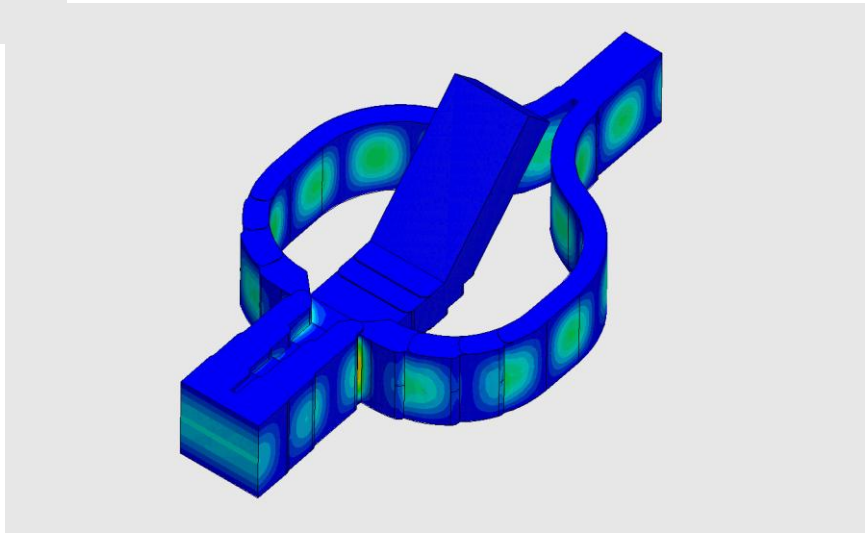
Linear OMTs exhibit higher polarisation purity over broad frequency bands (usually)

4cm Ortho-mode transducer

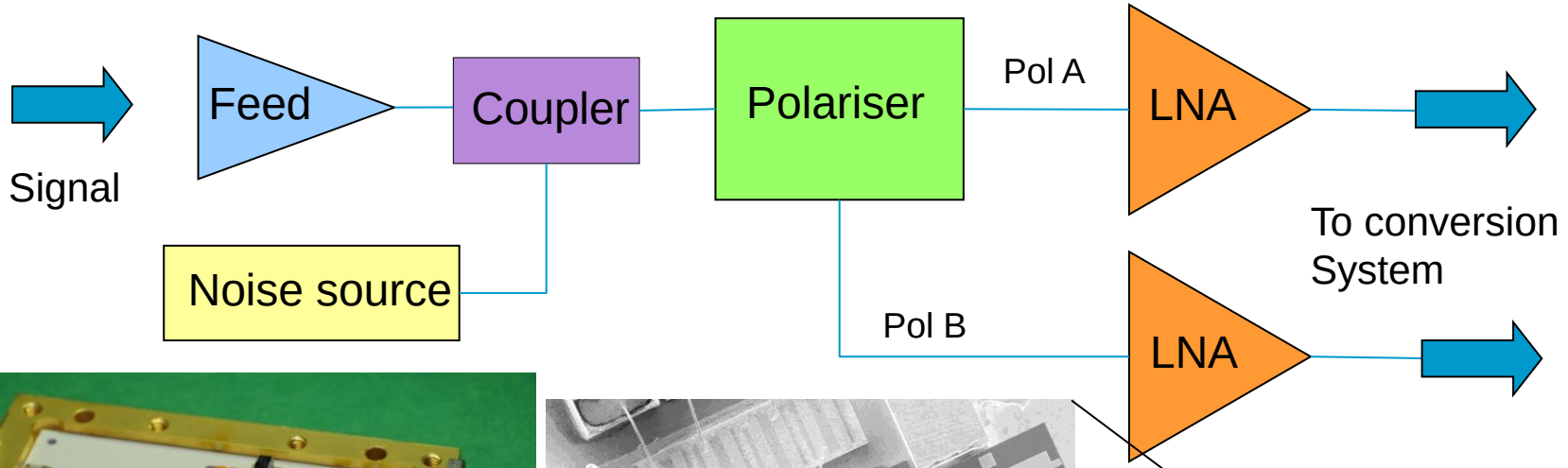
Separating Polarisations – Ortho-mode Transducers (OMTs)

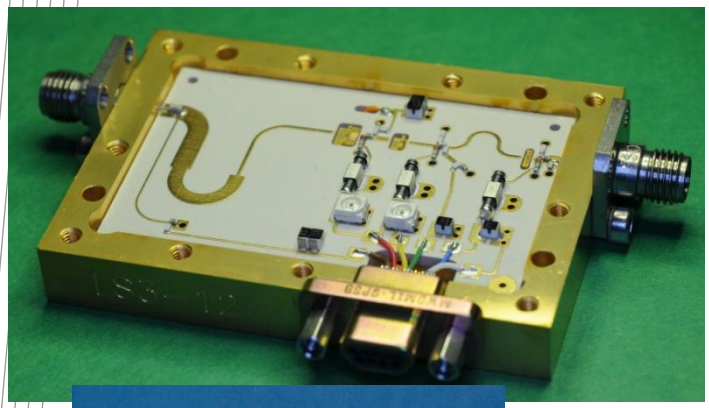


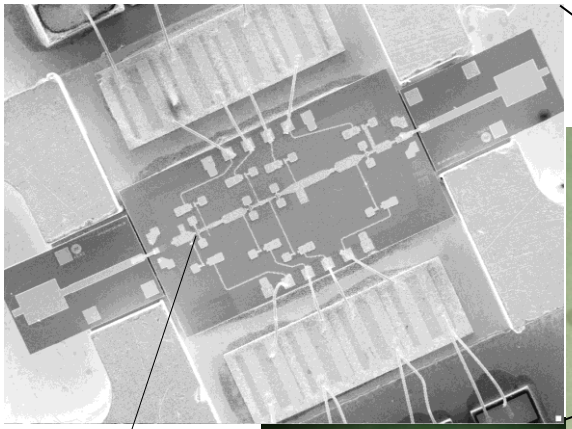


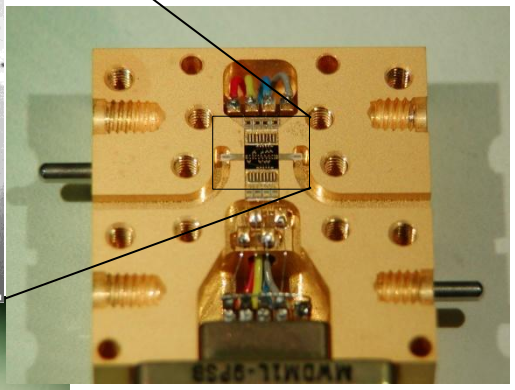


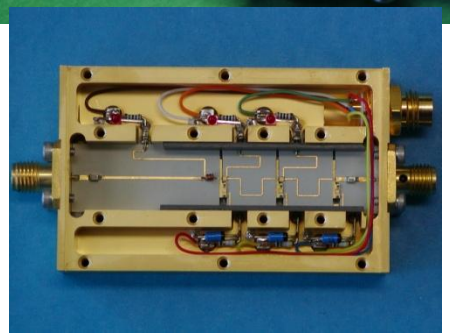
Low Noise Amplifiers (LNA)



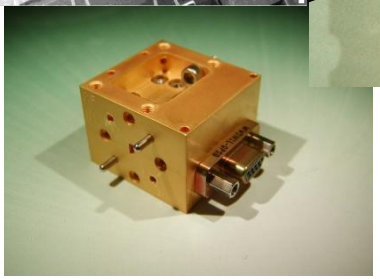






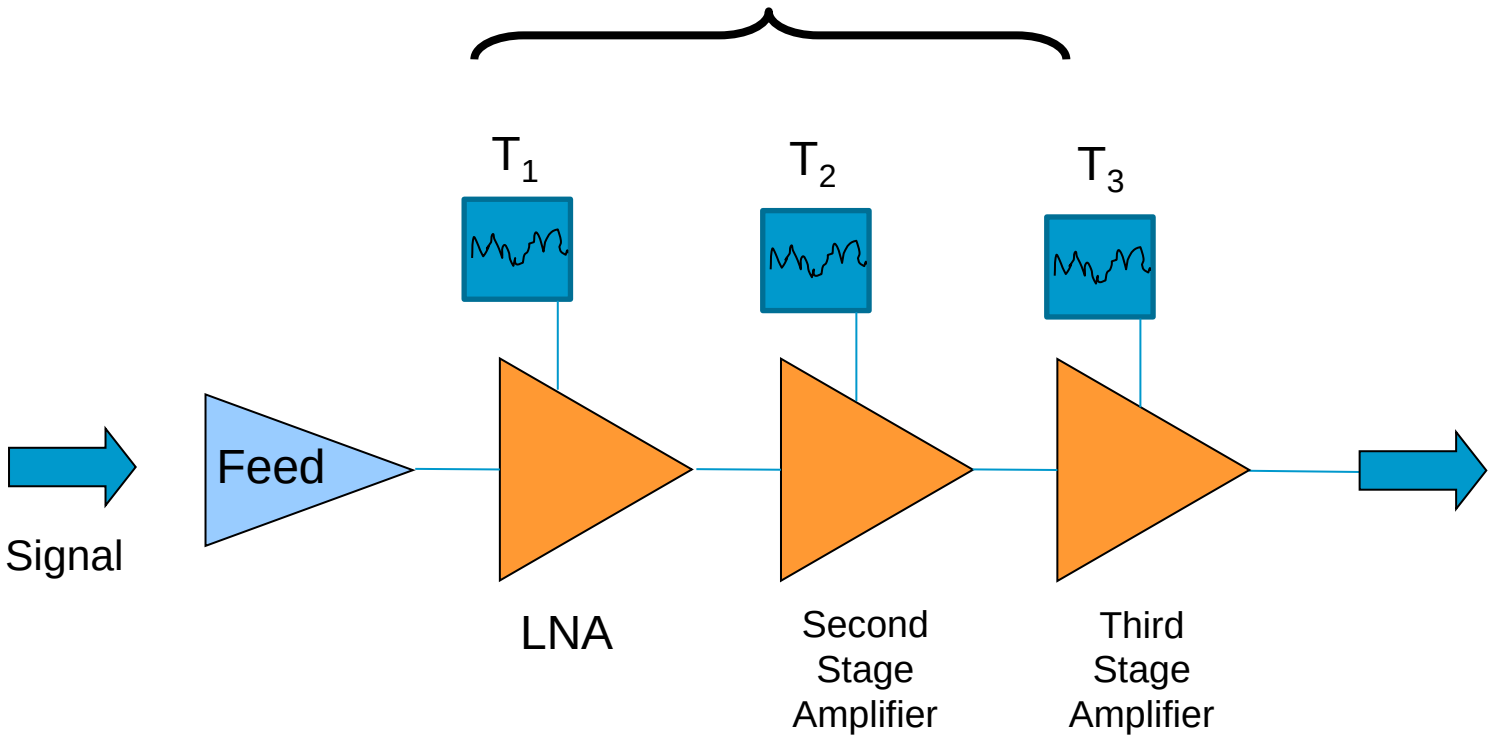


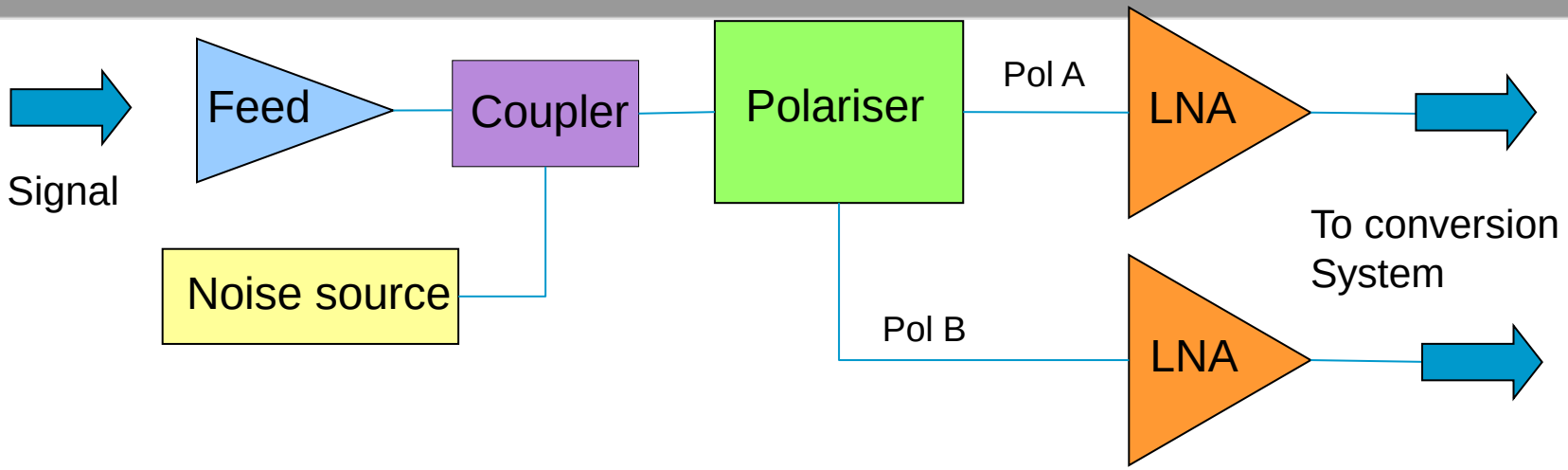
High Electron Mobility Transistor (HEMT)



Why is the first Low Noise Amplifier so important?

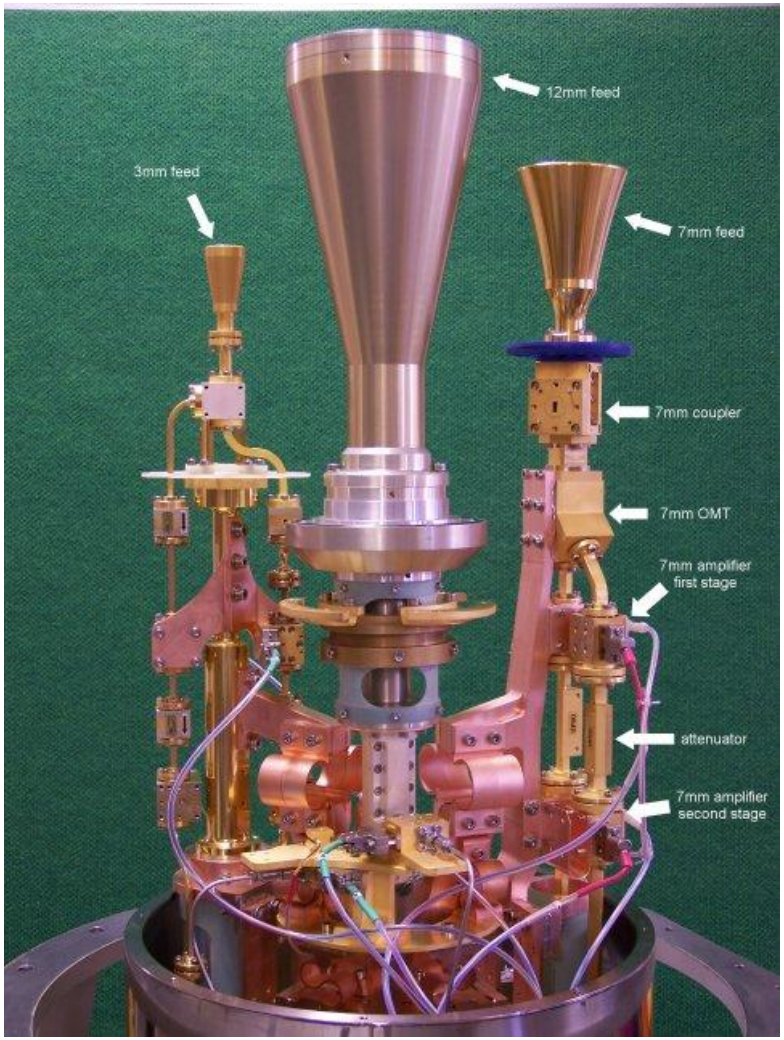
$$T_{system} = T_1 + \frac{T_2}{Gain_{LNA}} + \frac{T_3}{Gain_{LNA} \times G_2} + \frac{T_4}{Gain_{LNA} \times G_2 \times G_3} \quad \ldots\ldots$$





….so although receiver topologies can be quite varied I'm saying that this is a pretty typical structure of our receivers

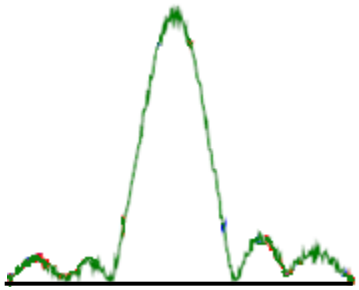
……and the Compact Array 3/7/12 mm systems reflect this.

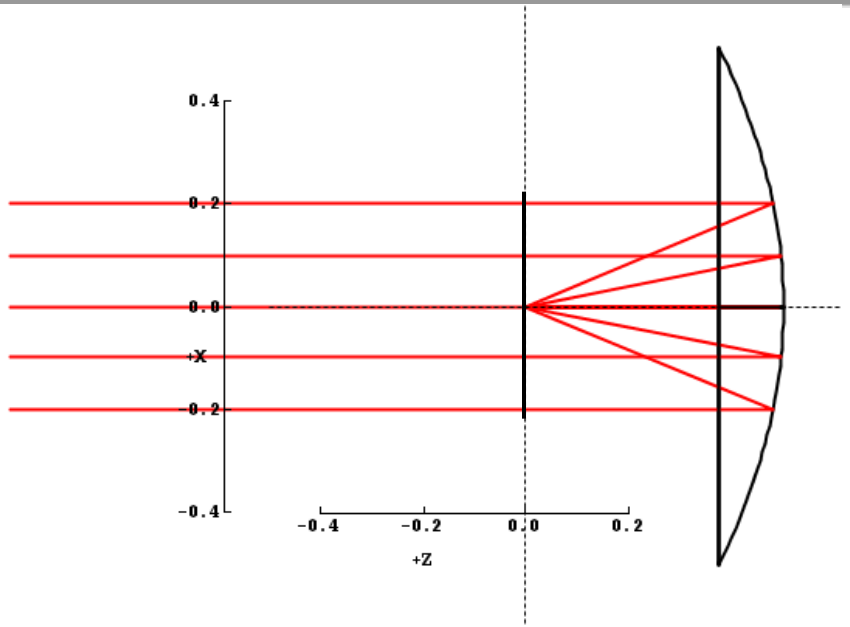

12mm feed
3mm feed
7mm feed
7mm coupler
7mm OMT
7mm amplifier
first stage
attenuator
7mm amplifier
second stage

The Phased Array Approach

Getting more from each antenna

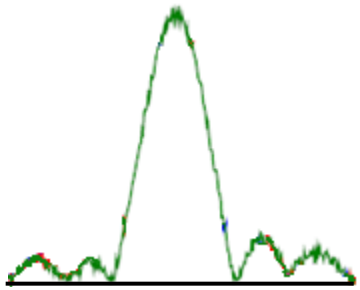
- Simple Receiver Collects

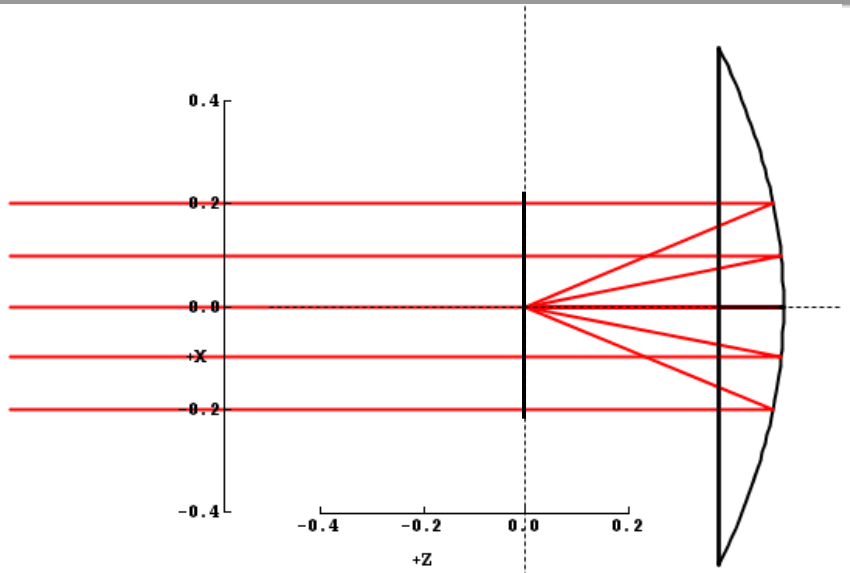




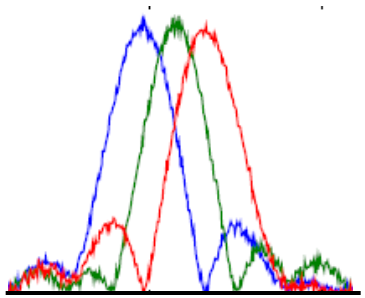
Getting more from each antenna

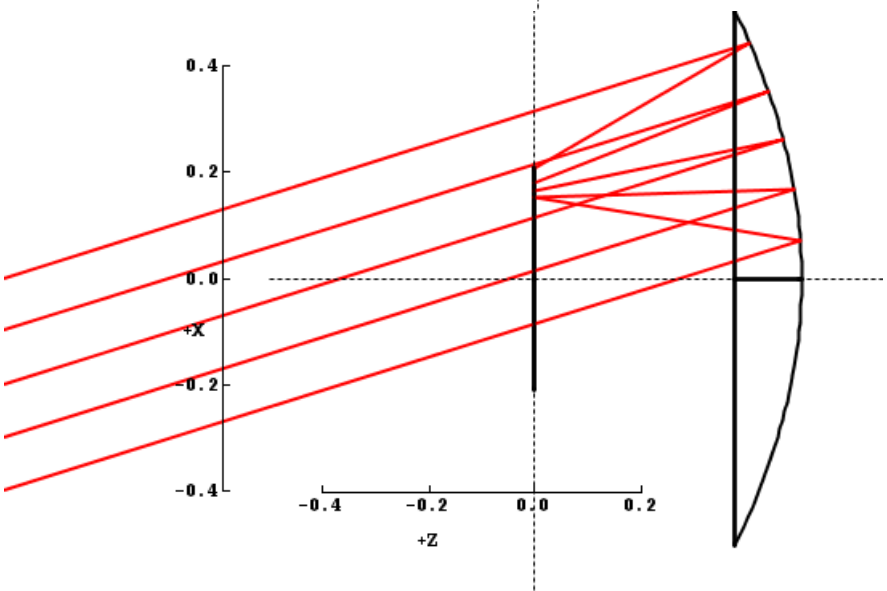
- Simple Receiver Collects





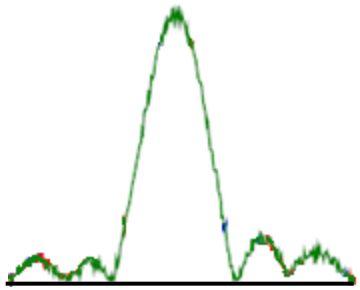
- Phased Array Feed
  - collects more (~every $\lambda/2$)

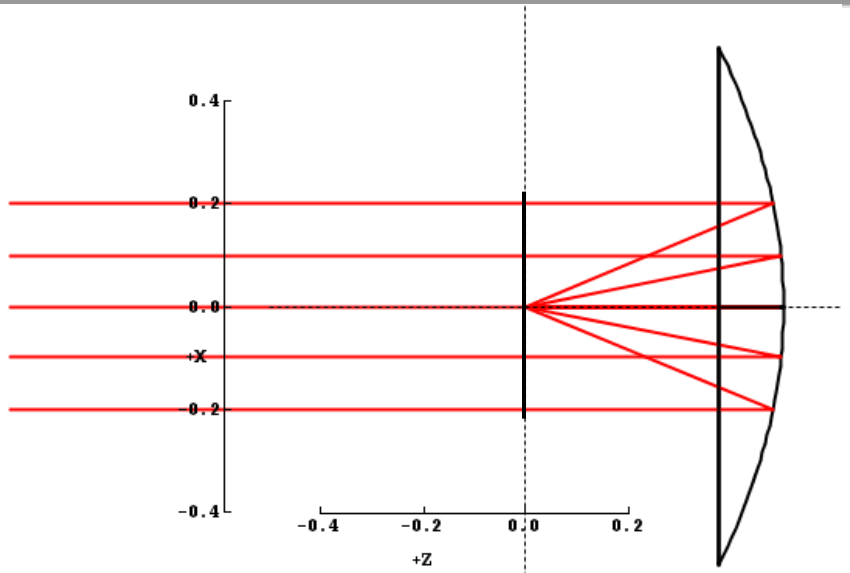




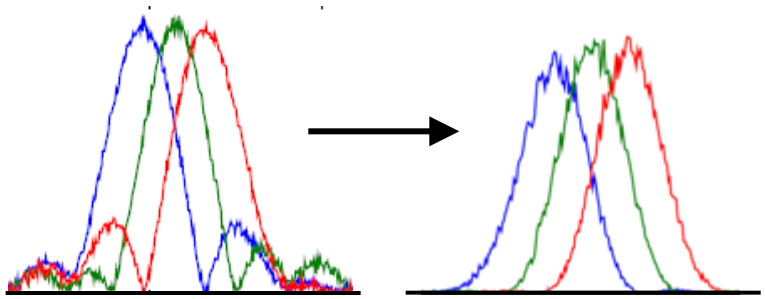
Getting more from each antenna

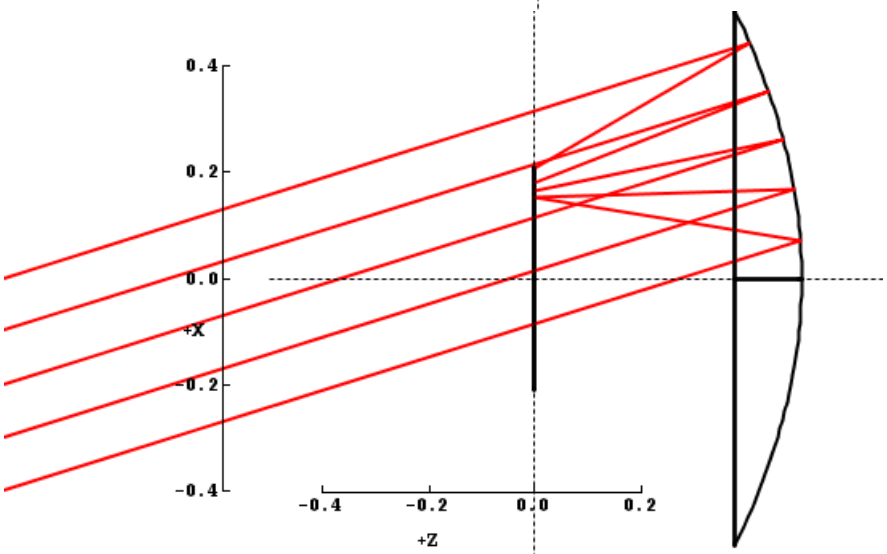
- Simple Receiver Collects





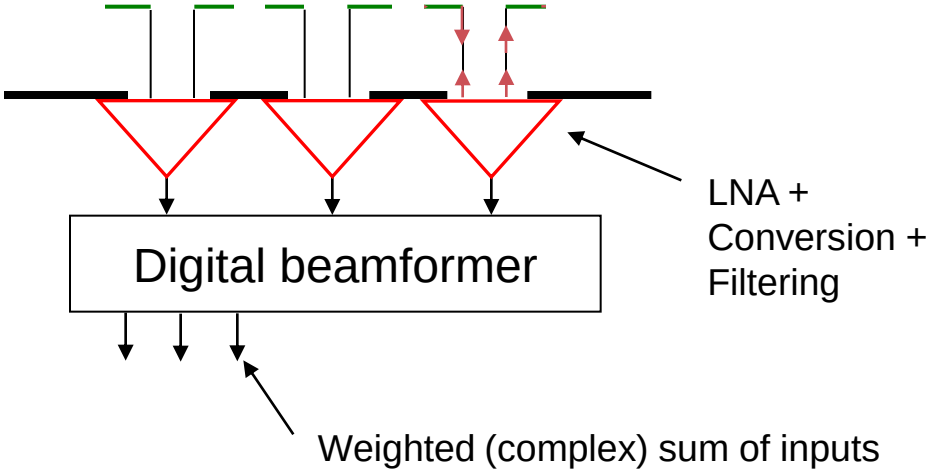
- Phased Array Feed
  - collects more (~every $\lambda/2$)
  - allows corrections





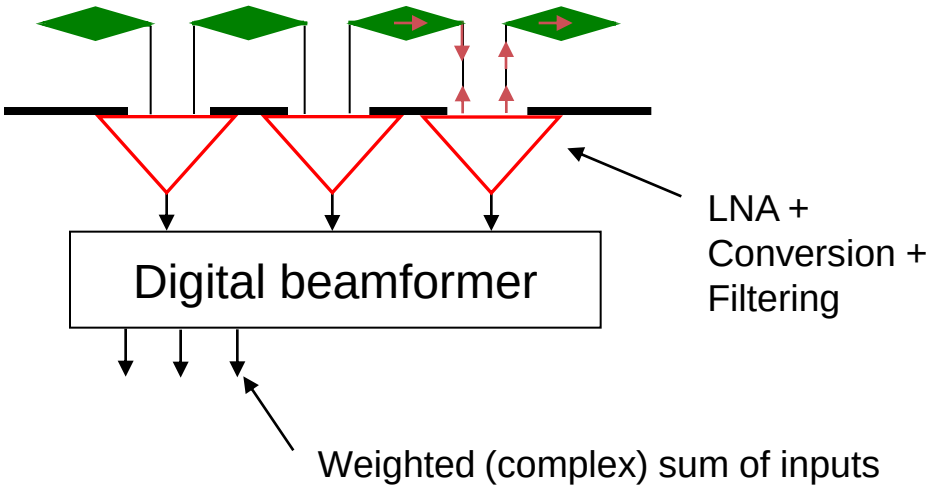
Connected Array

- Start with a simple array of dipoles
- Join them together

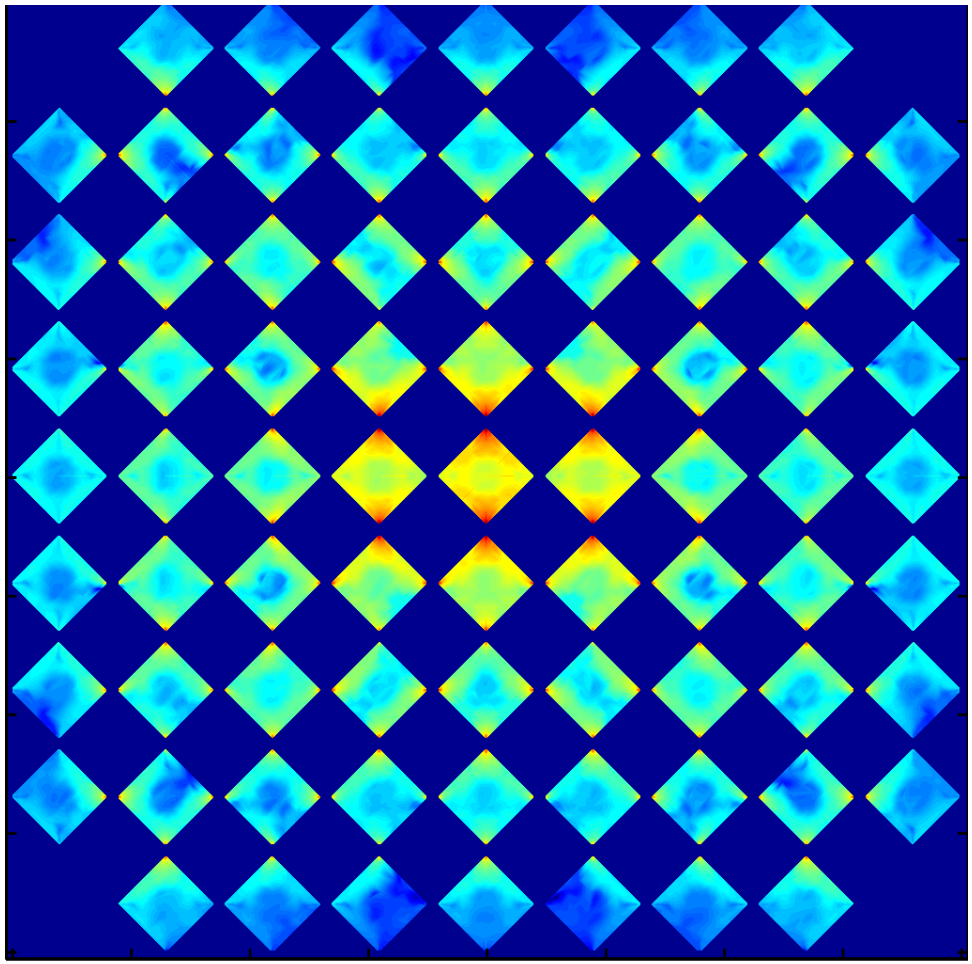


Connected Chequerboard Array

- Complete sampling of focal region fields
- Digital beamforming



Single Beam Excitation of a Phased Array

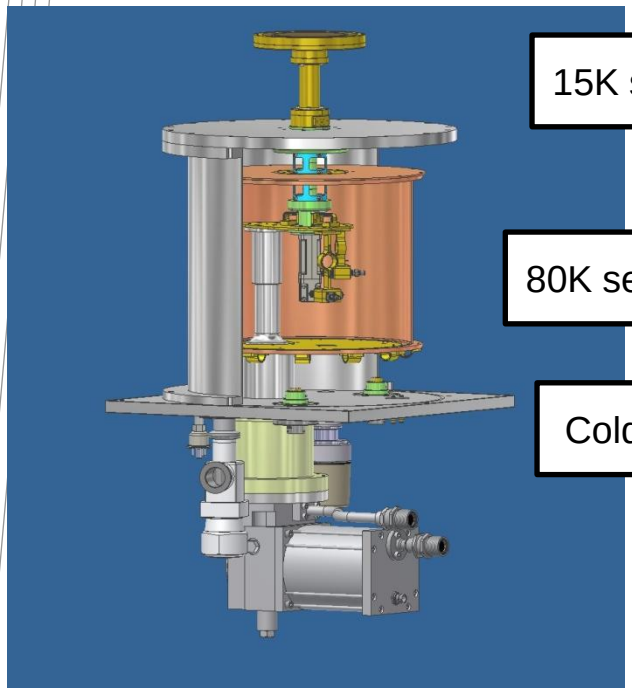


What is the rest of the stuff?

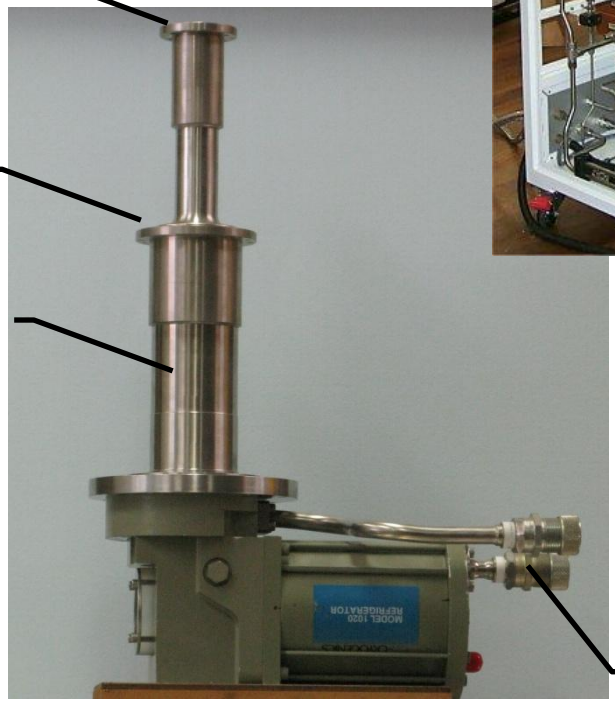
Electronics

- Supplies and monitors all amplifier voltages and currents
- Monitors system temperatures and pressures

Cryogenics

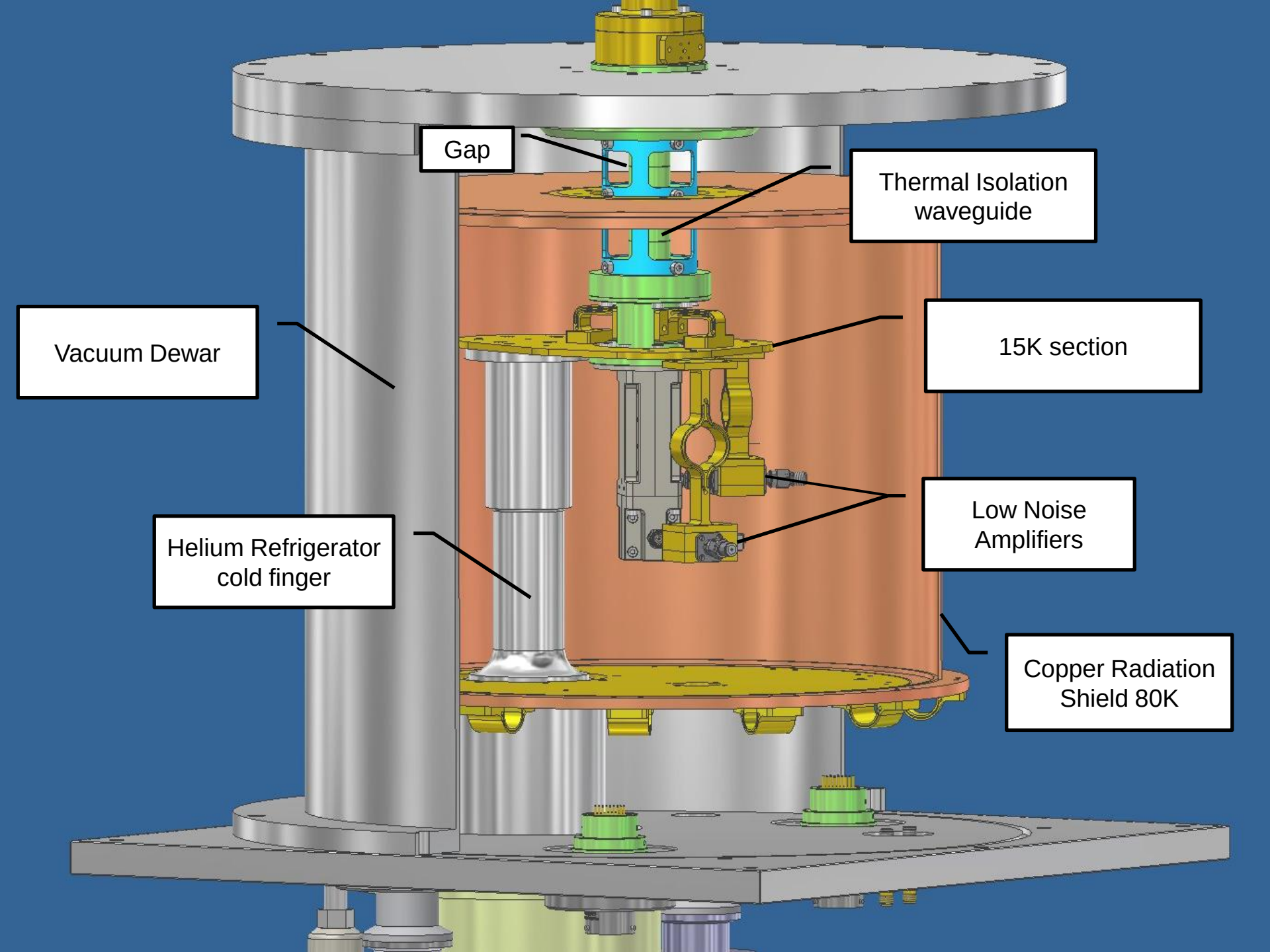


Refrigerator in the Parkes 12mm receiver



Helium Refrigerator

Helium Compressor


Gap
Thermal Isolation waveguide
Vacuum Dewar
15K section
Low Noise Amplifiers
Helium Refrigerator cold finger
Copper Radiation Shield 80K

….but why do we need to cool our receivers at all?

……well first

How weak is the signal?

10Jy radio source →

$10 \times 10^{-26}\,W\,m^{-2}Hz^{-1} \times 1900m^2 \times 1 \times 10^{9}\,Hz$

$= 2\times 10^{-13}\,W$

Effective area of Parkes telescope dish

Bandwidth of Digital Filter Bank 3

Your Hand →

$1.38\times 10^{-23}\,W\,Hz^{-1}K^{-1} \times 300K \times 1 \times 10^{9}\,Hz$

$= 4 \times 10^{-12}\,W$

Boltzmann's constant

Mobile Phone →

$\approx 1W$

Mobile Phone on the moon→

$\approx 1W \div 4\pi\,(3.8\times10^{8}m)^2 \div 5\times10^{6}Hz$

$\approx 10Jy$

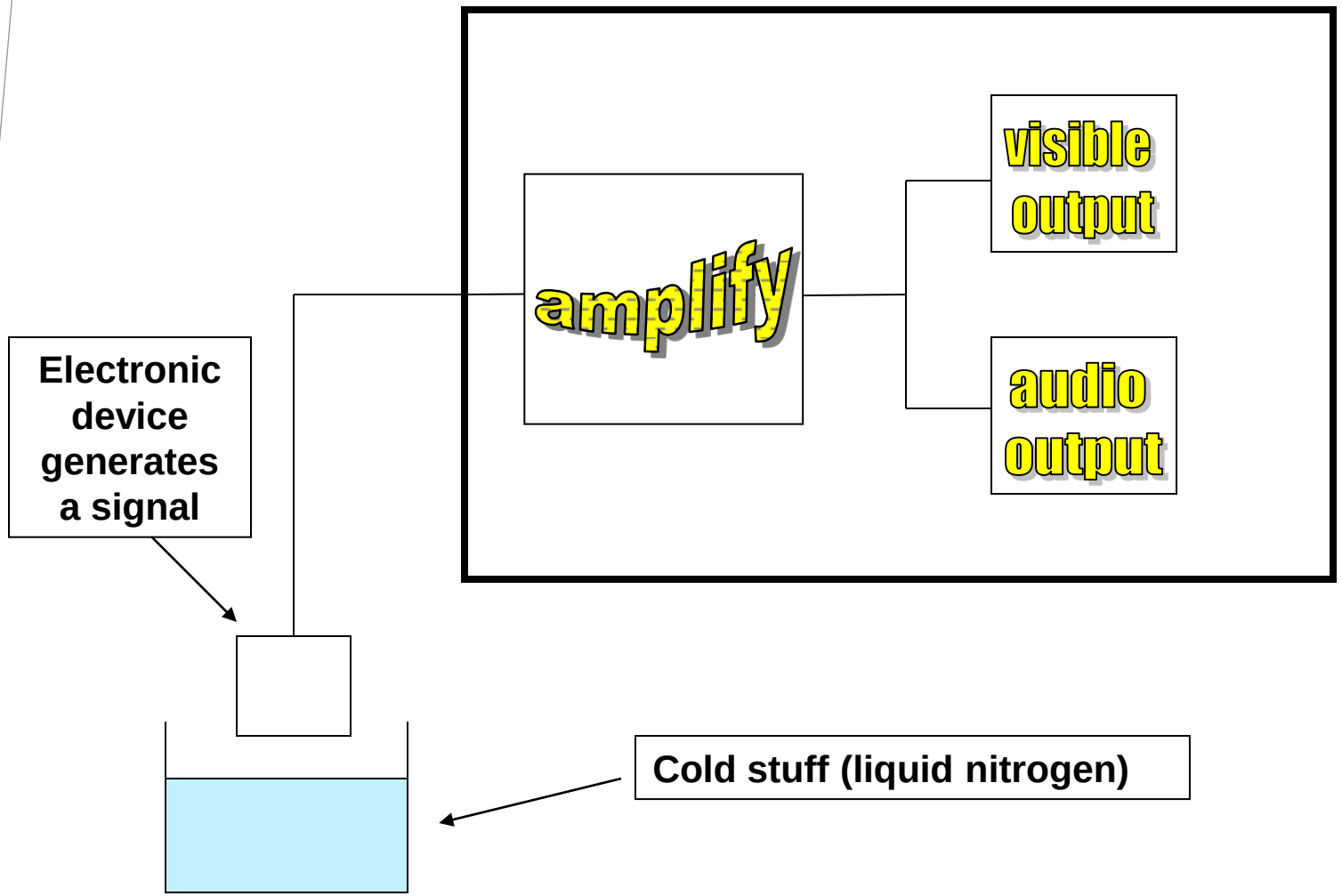
Lunar Distance

3G transmit bandwidth

Like your hand all the components in the receiver system contribute a thermal noise signal which masks the astronomical signal we are trying to observe.

By cooling the receiver we reduce these thermal sources of noise and improve the sensitivity of the receiver by 7-10 times.

Reduce noise by cooling



CSIRO Astronomy and Space Science
Alex Dunning
RF Engineer

Phone: 02 9372 4346
Email: alex.dunning@csiro.au
Web: www.csiro.au/org/CASS

www.csiro.au

Thank you

Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: enquiries@csiro.au Web: www.csiro.au

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