Receiver Systems

Christoph Brem
Based on a talk by Alex Dunning

The Basic Structure of a typical Radio Telescope

Antenna

↓

Receiver

↓

Conversion

↓

Digitiser

↓

Signal Processing / Correlator

They are much the same

Radiotelescope Receivers

Radio Receivers

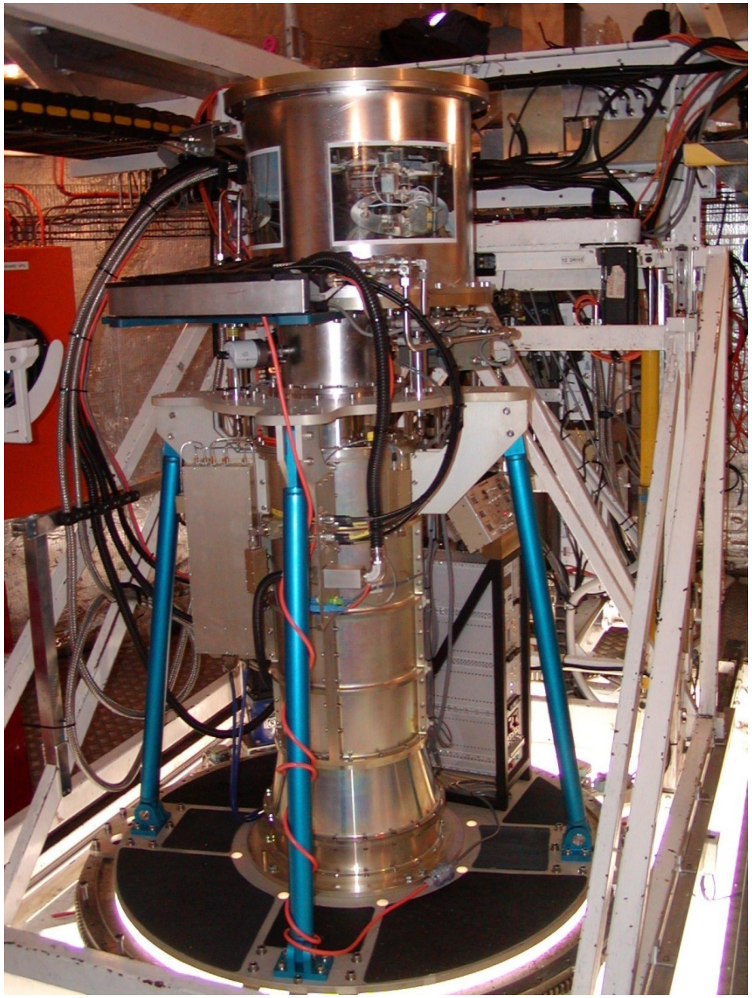
"A radio receiver converts signals from a radio antenna to a usable form" Wikipedia

Ours look more like this...

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

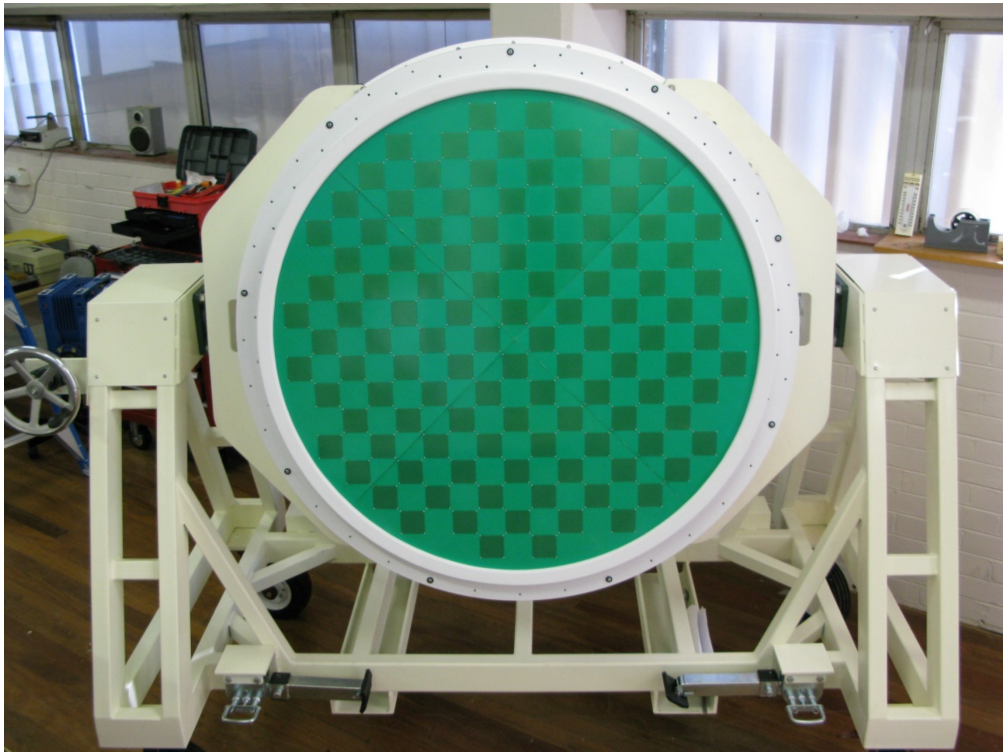
Compact Array
3/7/12mm Receiver

Or this...



Parkes 10/50cm Receiver

Or this...



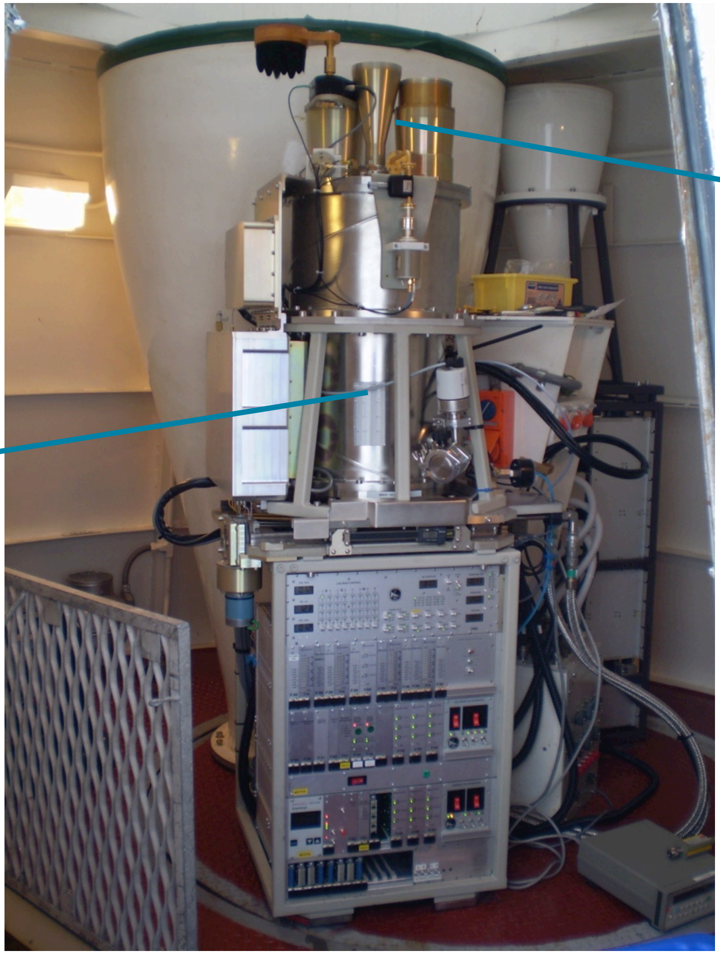
ASKAP Phased Array Receiver (BETA)

Some even look like this...

Allen Telescope Log Periodic Receiver

The Receiver

On the outside...

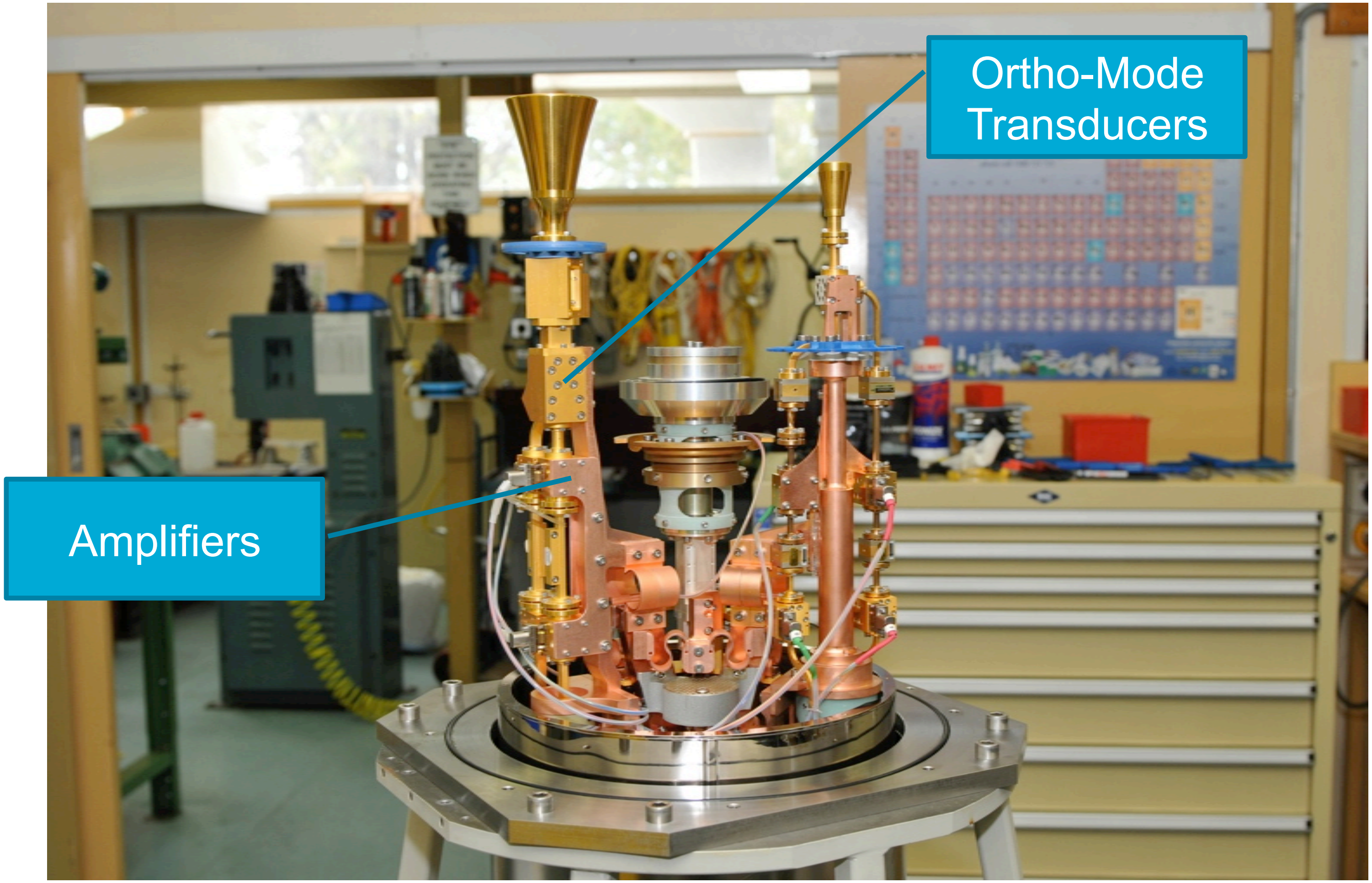


Feed Horns

Vacuum Dewar

The Receiver

On the inside...



$$\Delta S \propto \frac{T_{sys}}{A_e \sqrt{\Delta \nu_{RF} \tau}}$$

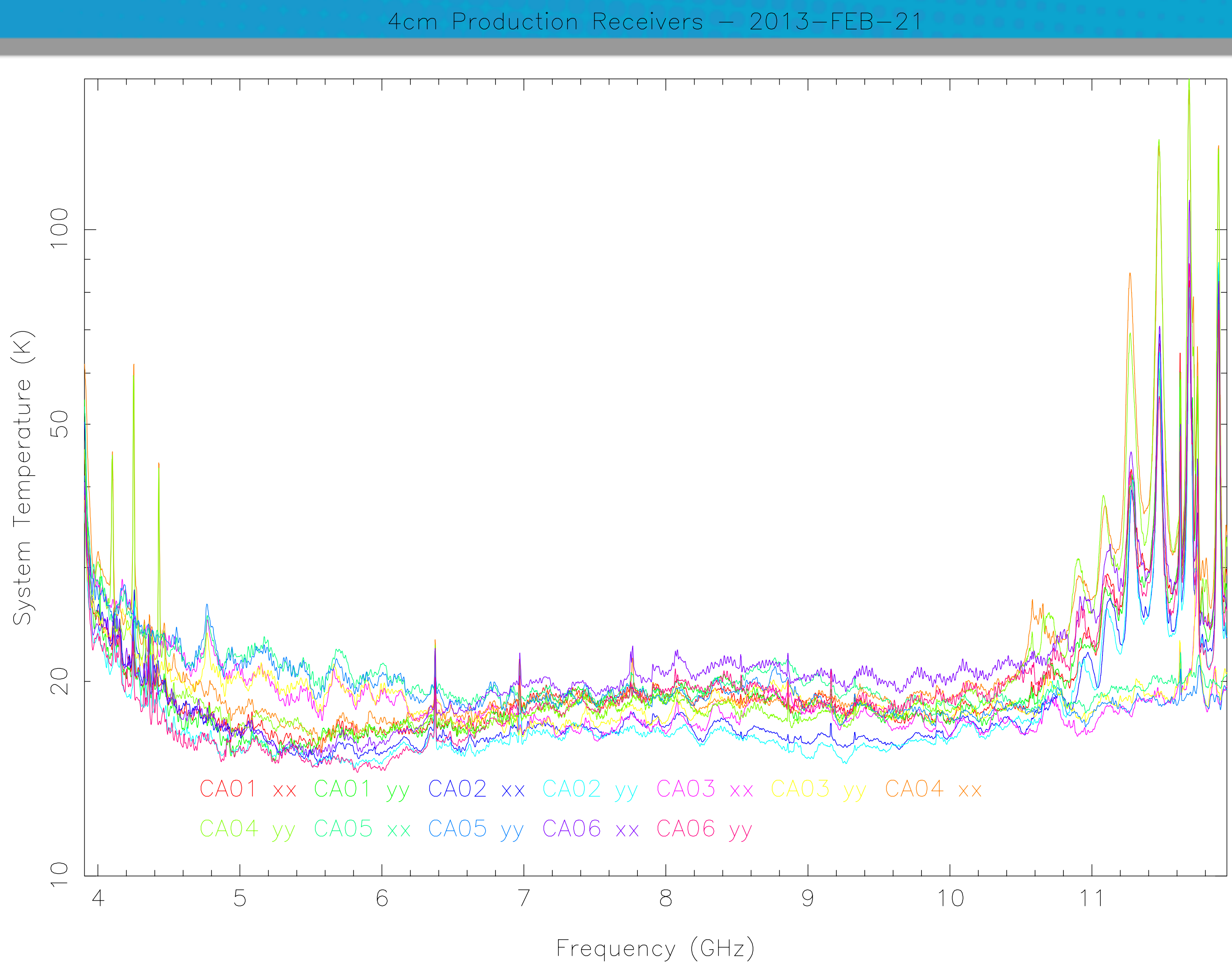
minimum detectable flux

system temperature (includes T_{RX}, the dish, spillover, sky)

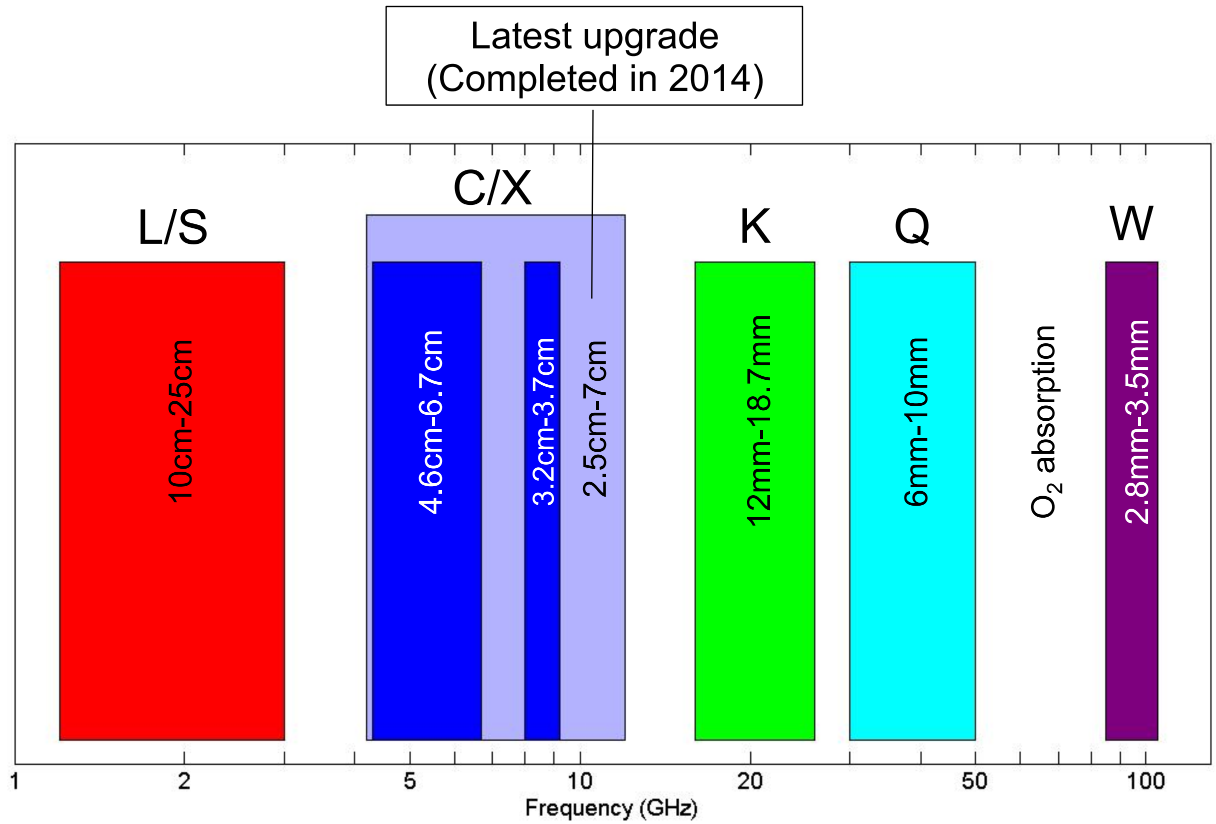
Effective Collecting Area

Observing Bandwidth

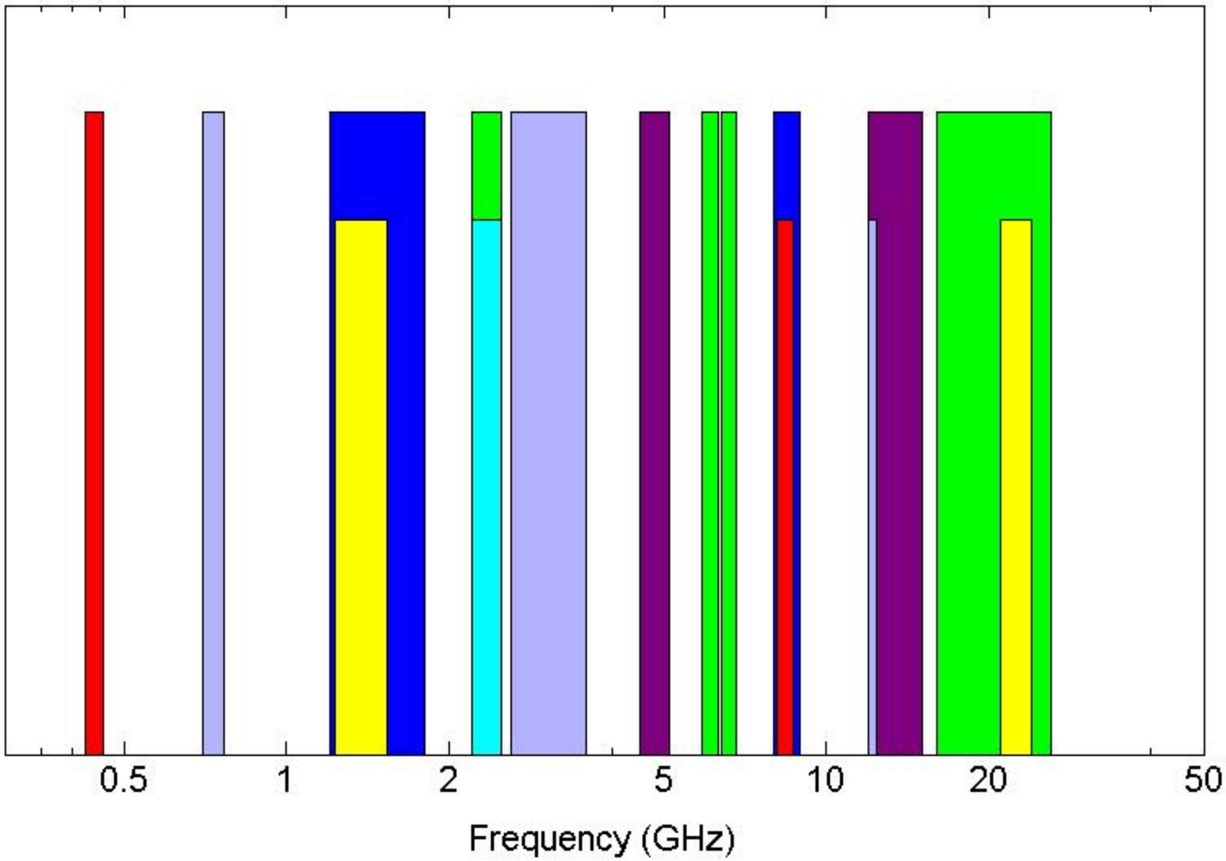
Integration Time


4cm Production Receivers – 2013–FEB–21
System Temperature (K)
100
50
20
10
4
5
6
7
8
9
10
11
Frequency (GHz)
CA01 xx CA01 yy CA02 xx CA02 yy CA03 xx CA03 yy CA04 xx
CA04 yy CA05 xx CA05 yy CA06 xx CA06 yy

The Australia Telescope Receivers

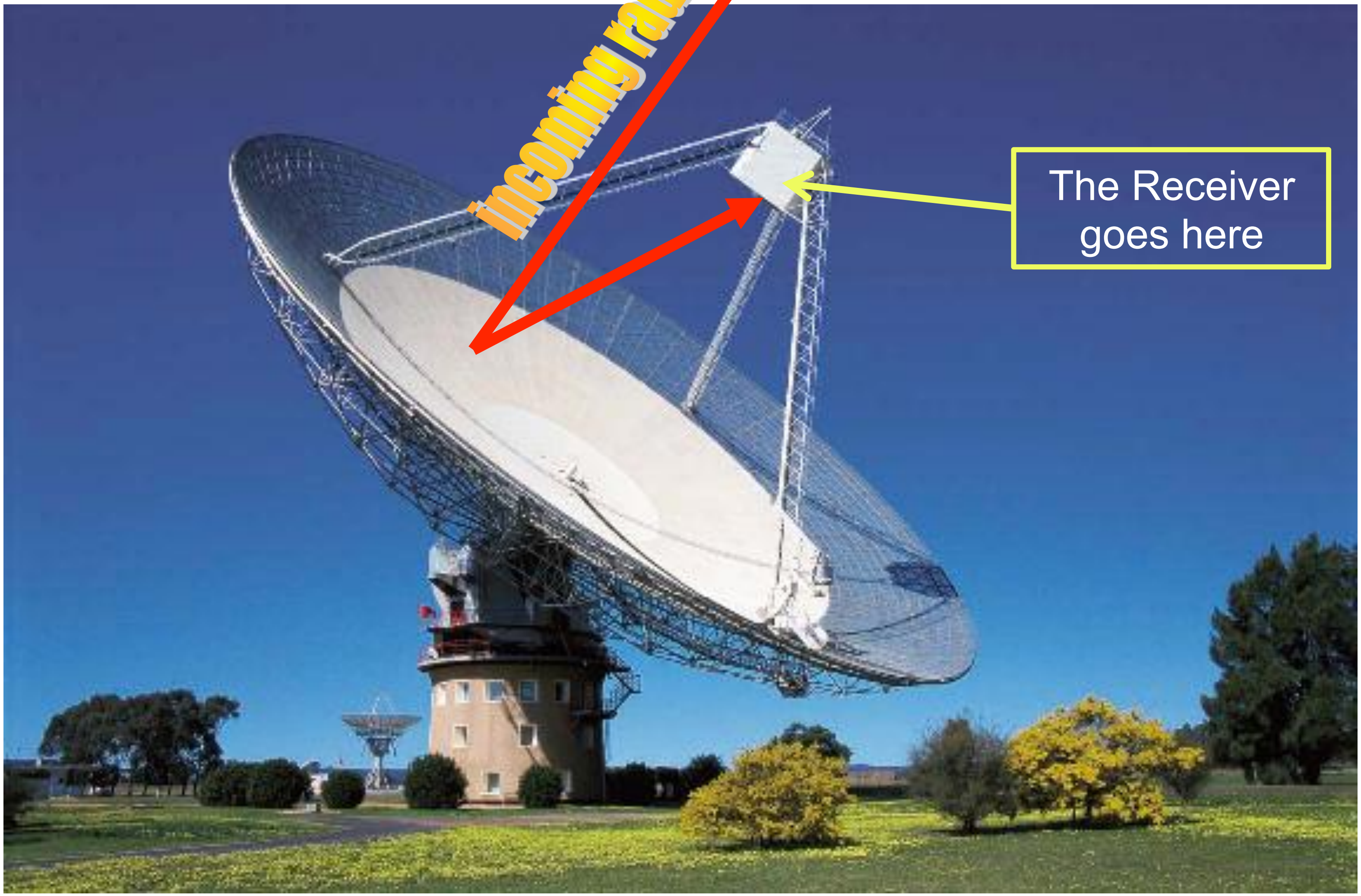


Parkes Receiver Bands

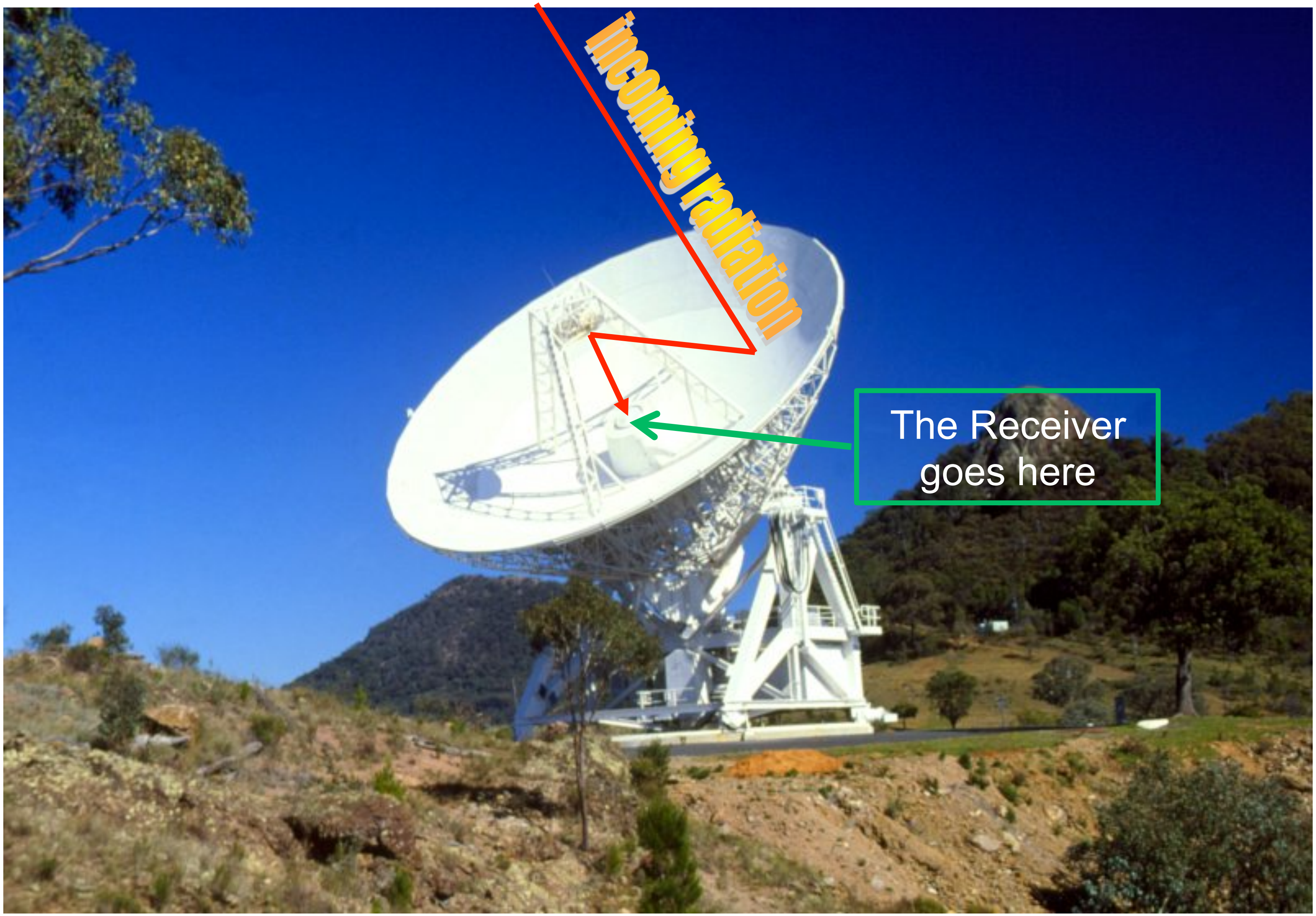


Where do they go?

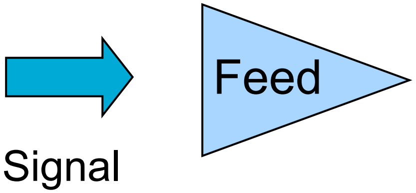
In a prime focus...



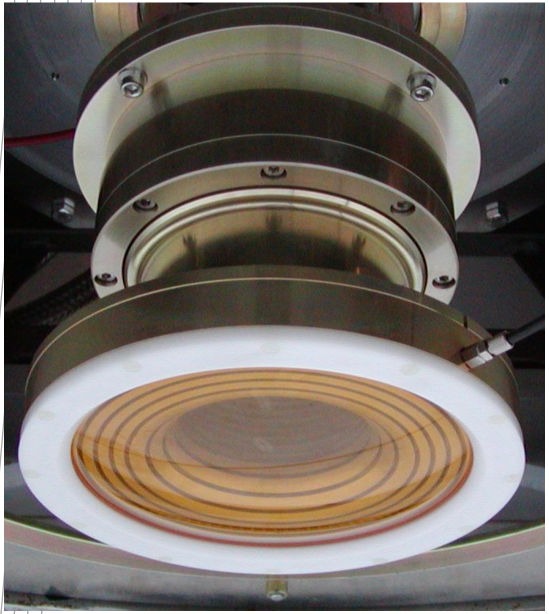
In a Cassegrain system...

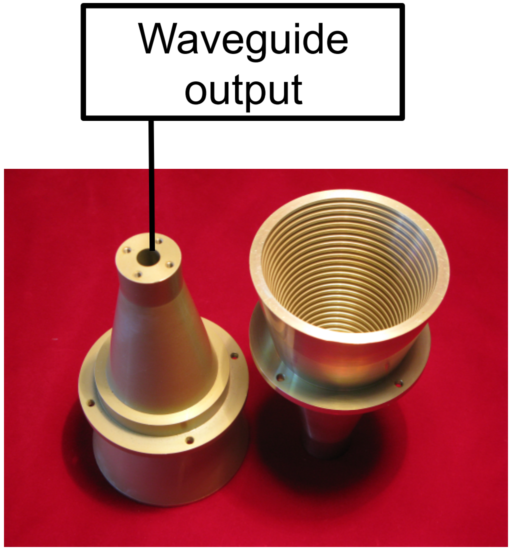


Receiving the signal – Feed horns

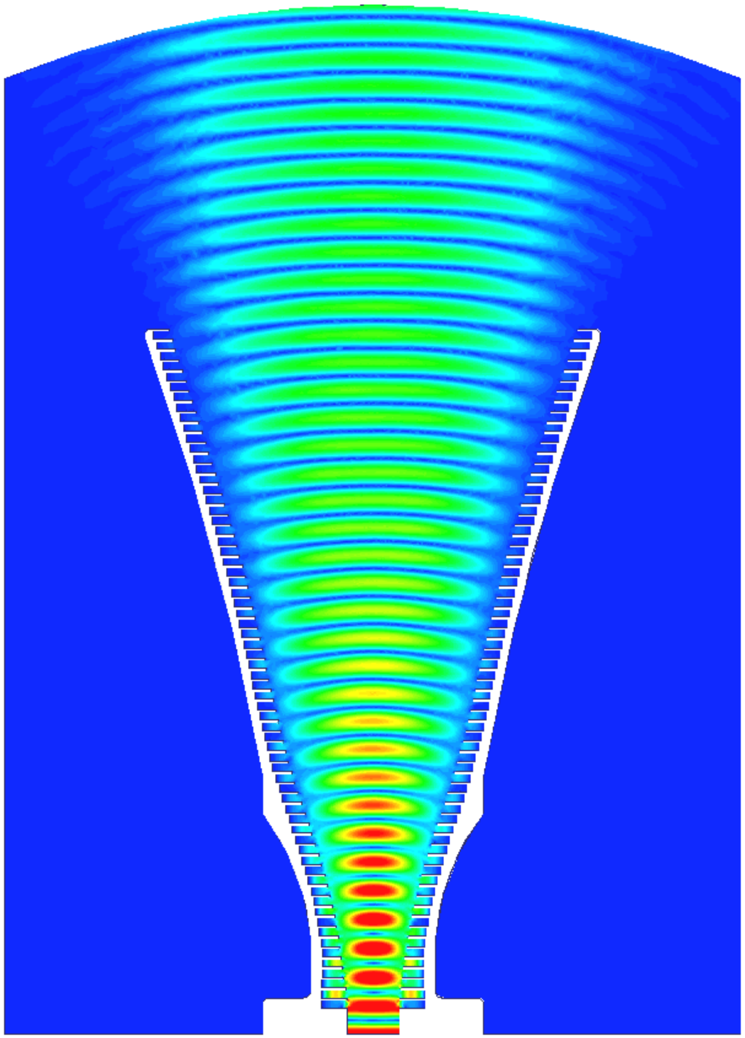


Captures the focused microwaves into a waveguide output

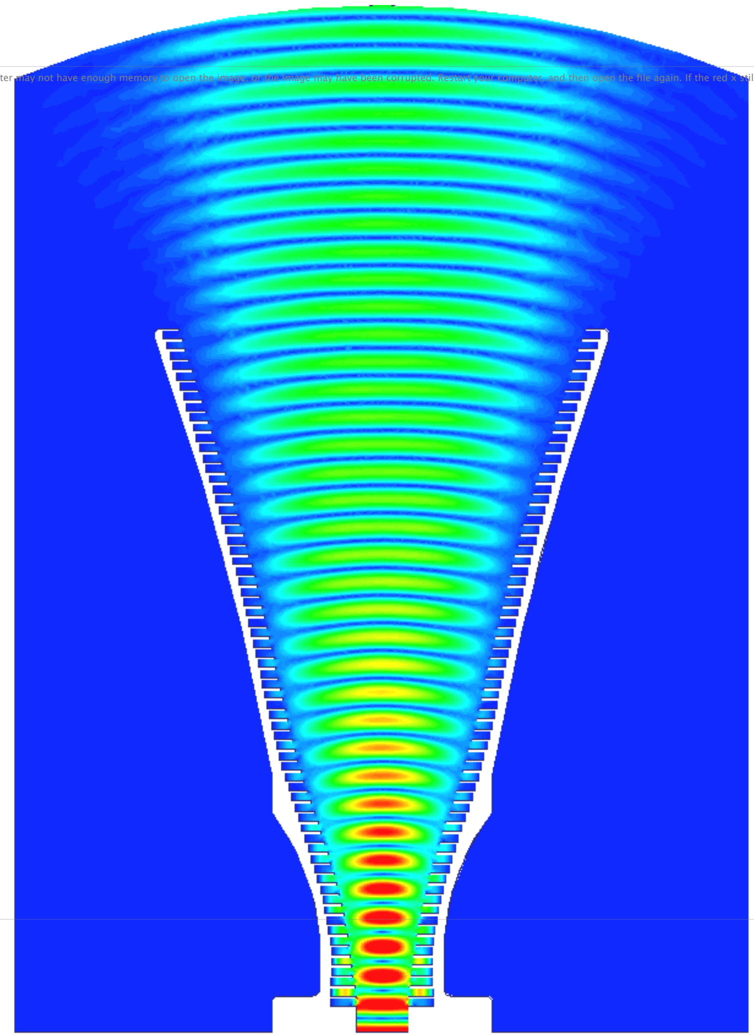




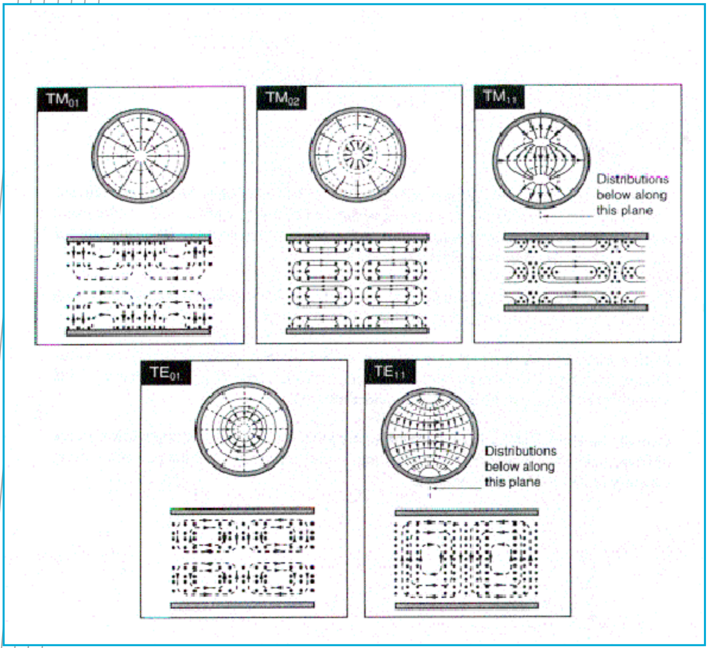
Feed Horns



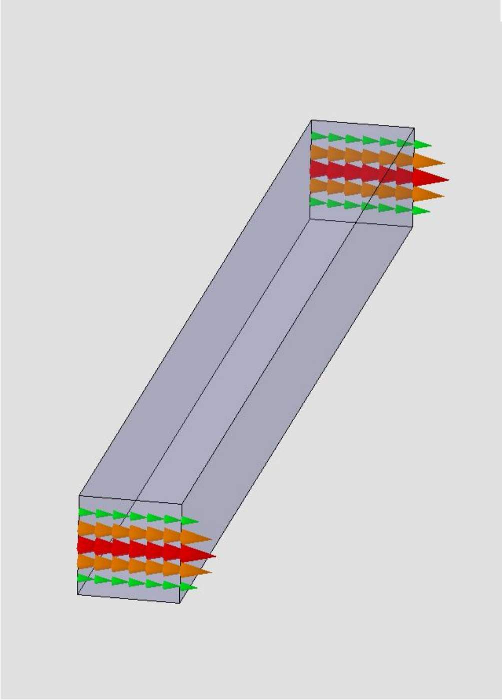
Feed Horns

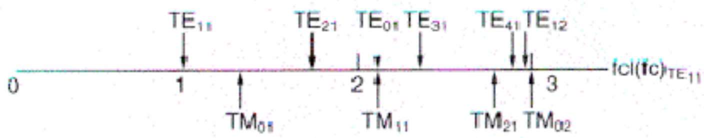


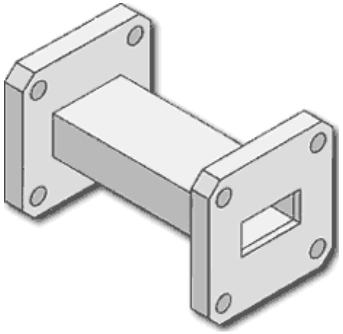
Detour: Waveguides



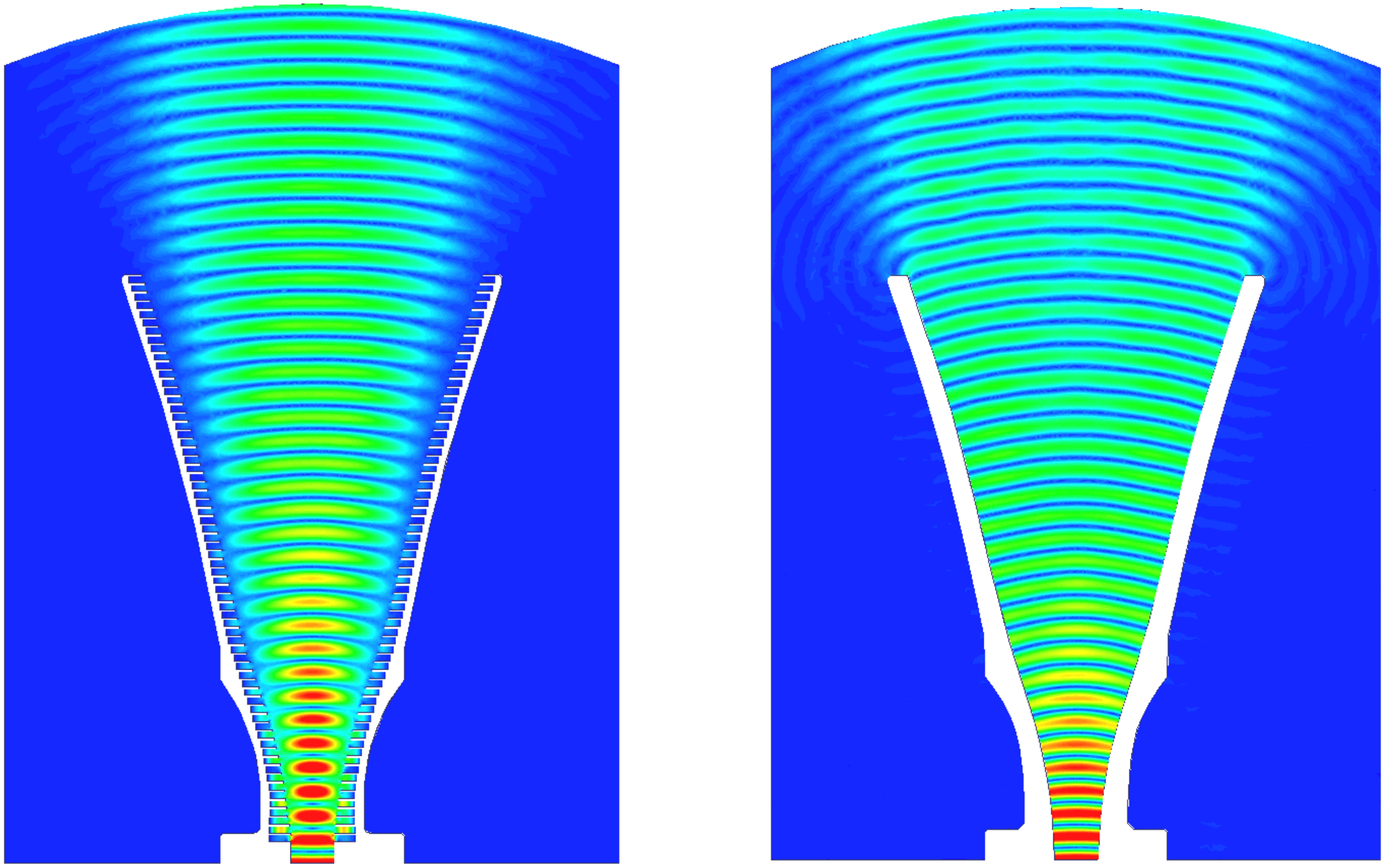
- Replace cables at high frequencies
- Operate like optical fibres for microwaves
- Only work over a limited frequency range
- Can support signals with two polarisations







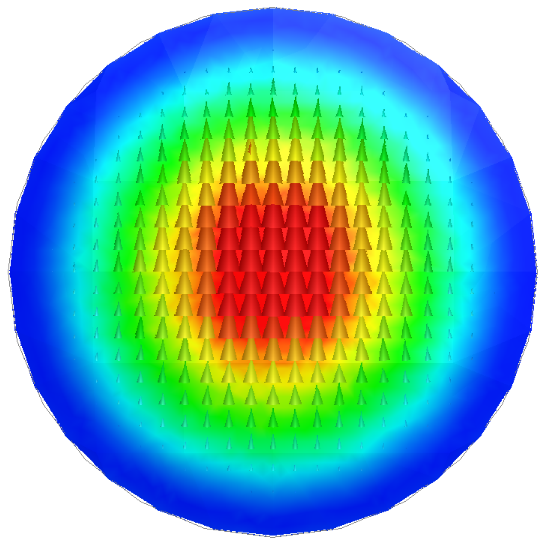
A Tale of Two Feedhorns

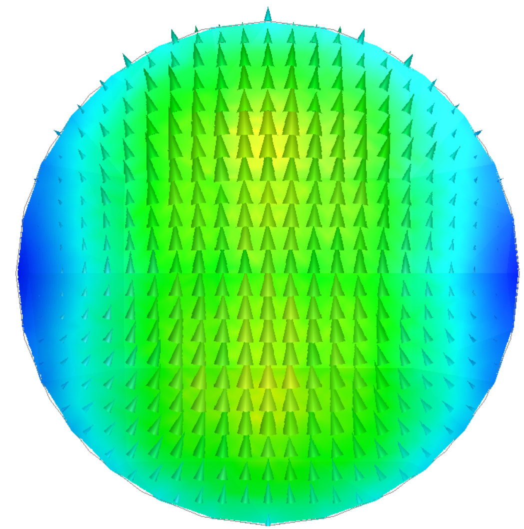


A Tale of Two Feedhorns

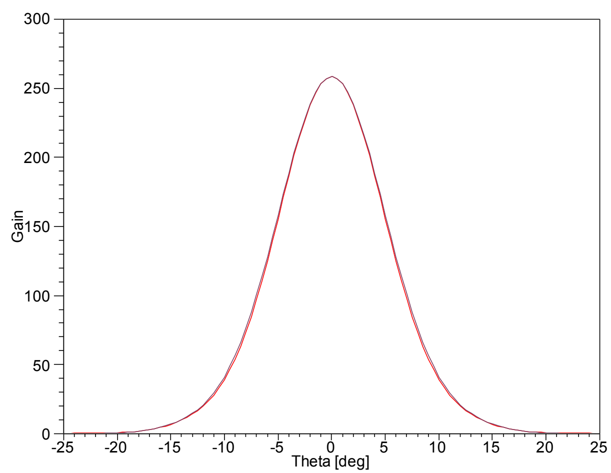
Corrugated | **Smooth Walled**

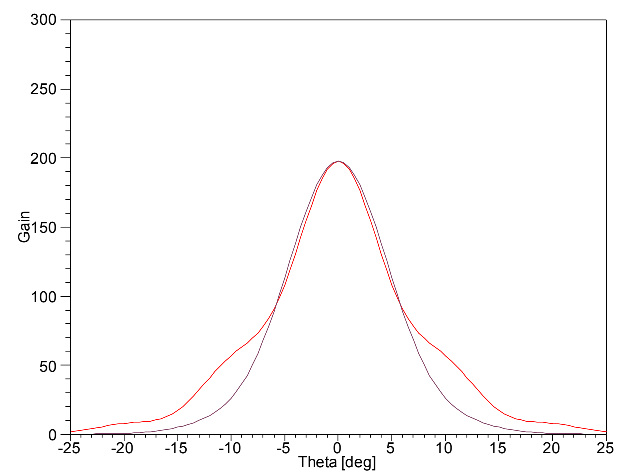
E-Field At Feed mouth



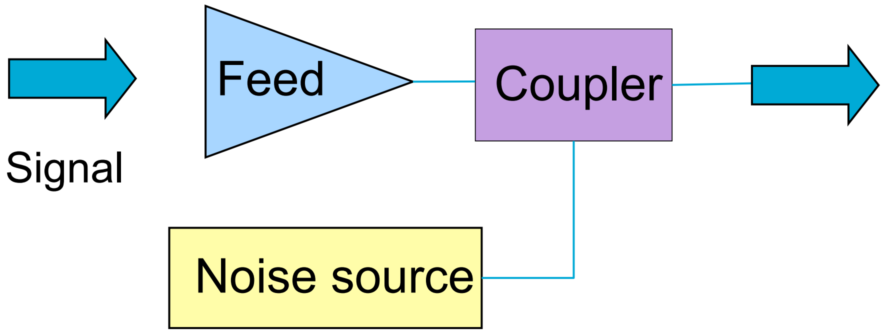


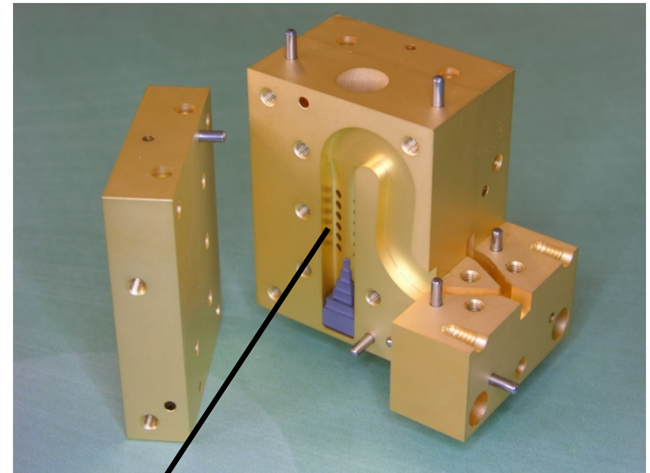
X and Y Feed Patterns





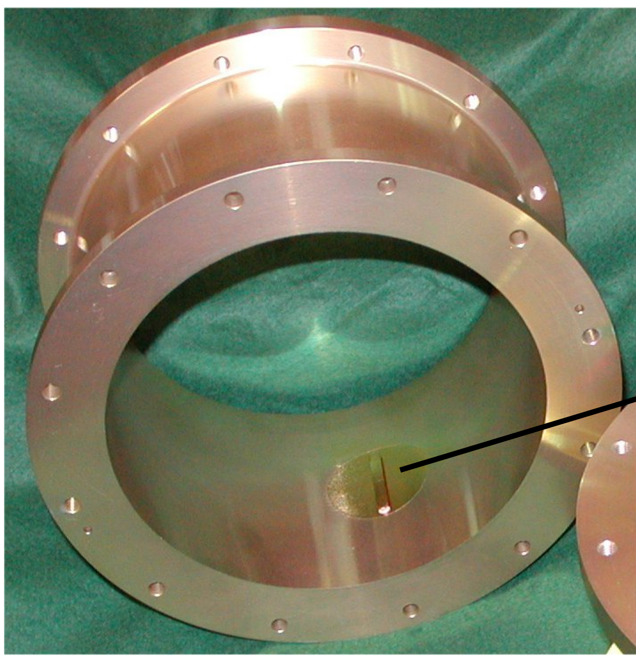
Coupling noise into the System





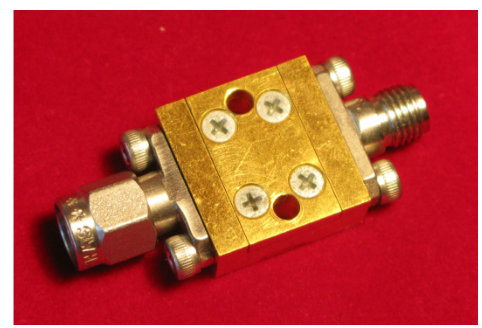
Noise coupled in through small holes

7mm waveguide coupler



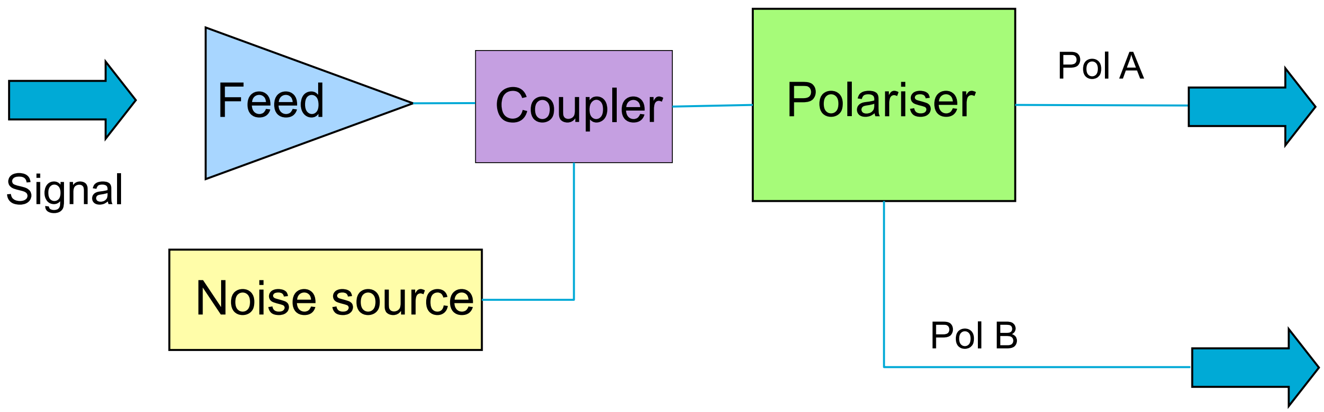
Noise coupled in through vane

21cm waveguide coupler

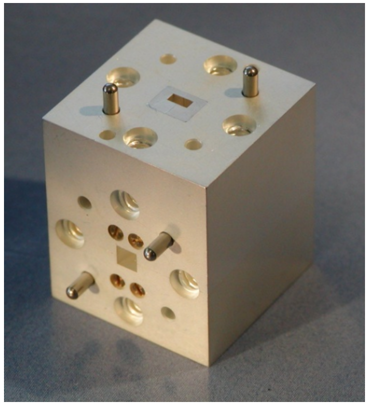


12mm noise source

Separating Polarisations – Ortho-mode Transducers (OMTs)

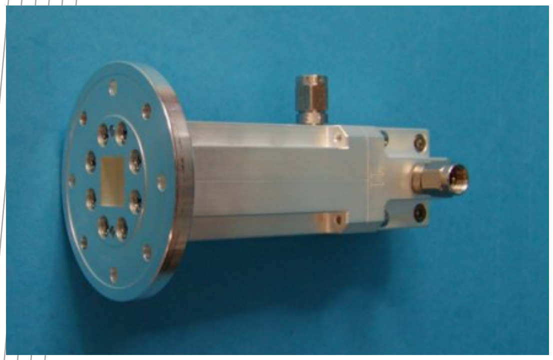


3mm Ortho-mode transducer



Separates incoming signal into two linear or circular polarisations

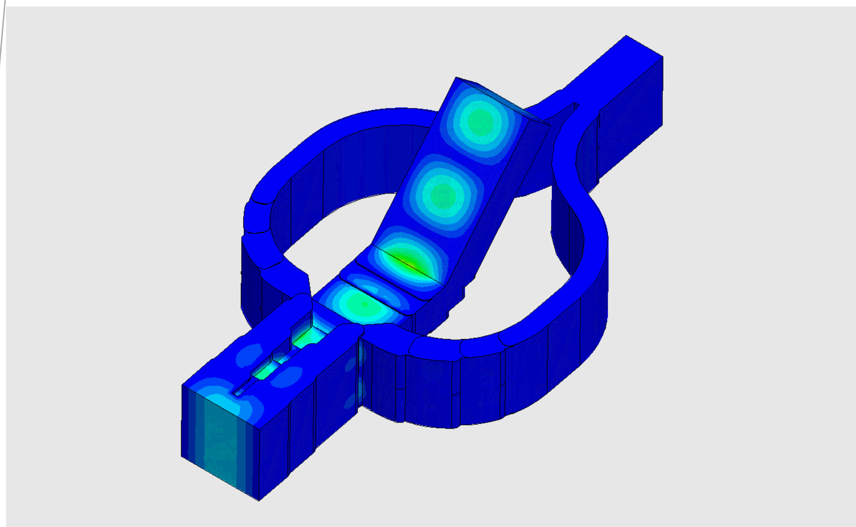
Linear OMTs exhibit higher polarisation purity over broad frequency bands (usually)

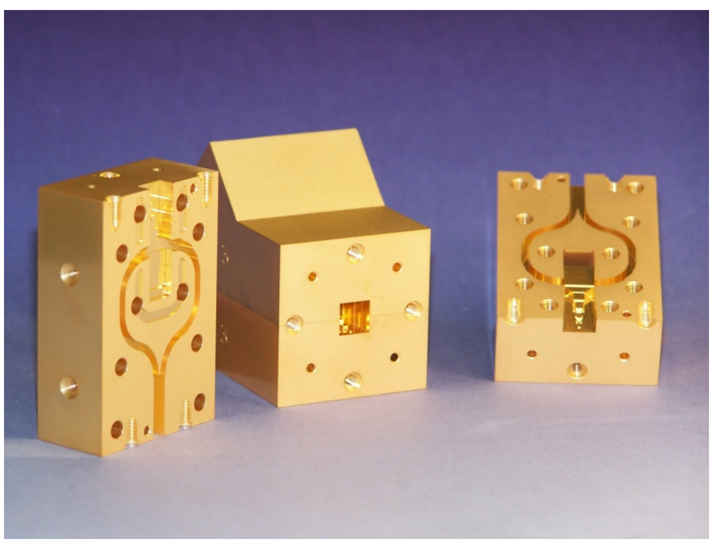


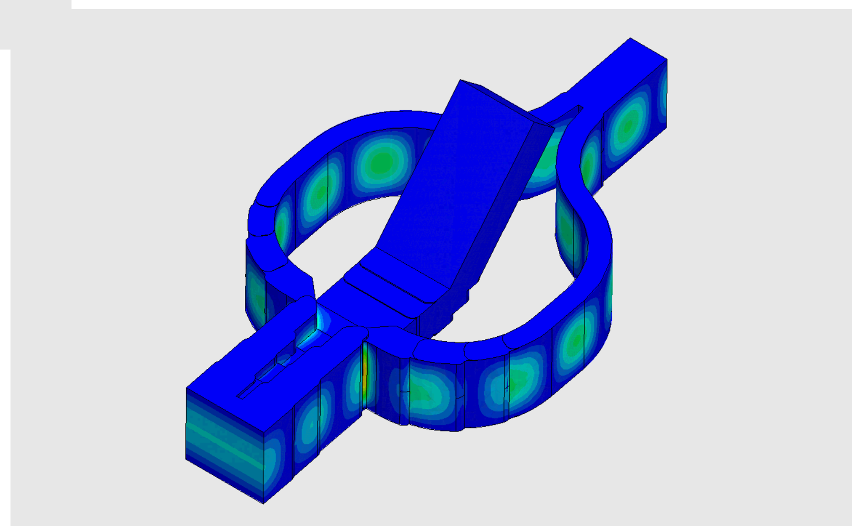
12mm Ortho-mode transducer

4cm Ortho-mode transducer

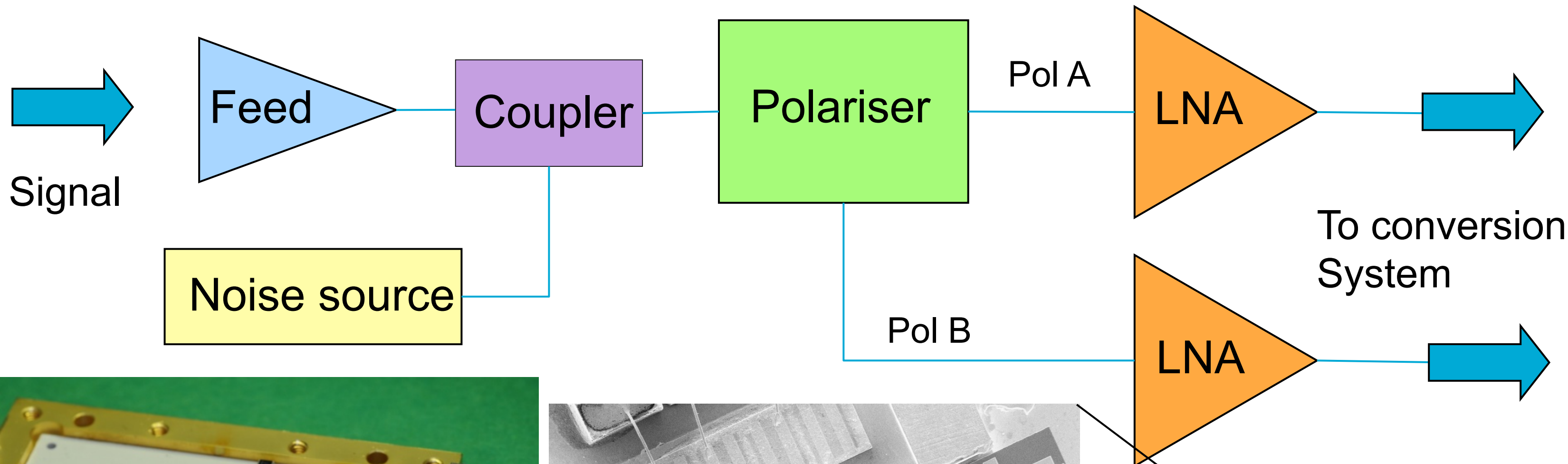
Separating Polarisations – Ortho-mode Transducers (OMTs)

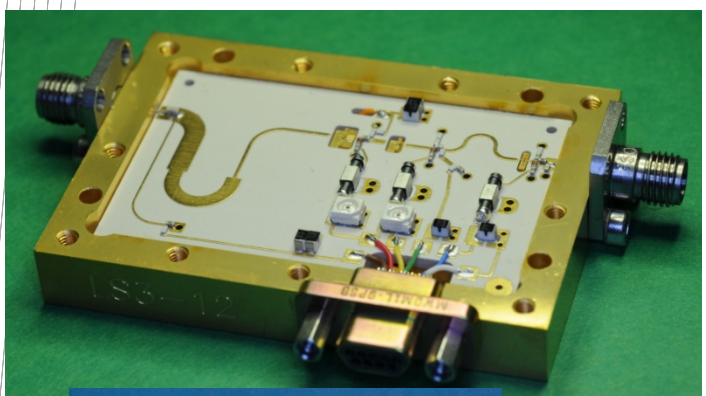


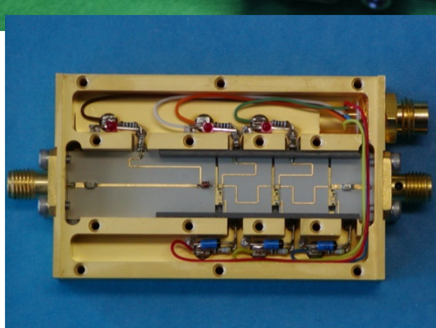


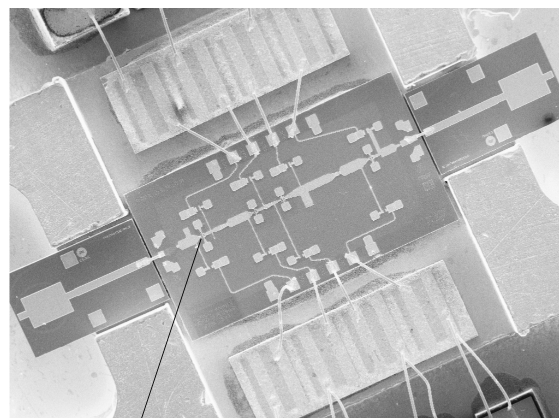


Low Noise Amplifiers (LNA)

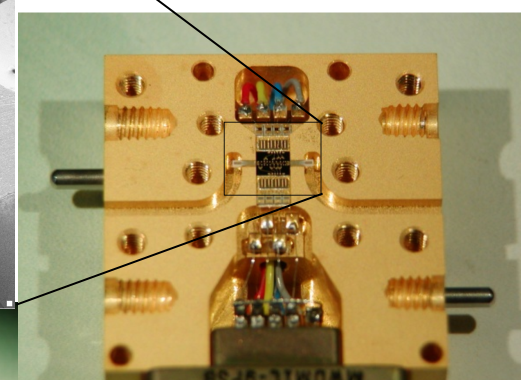


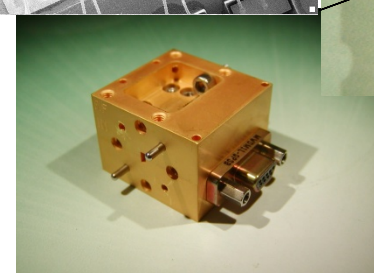






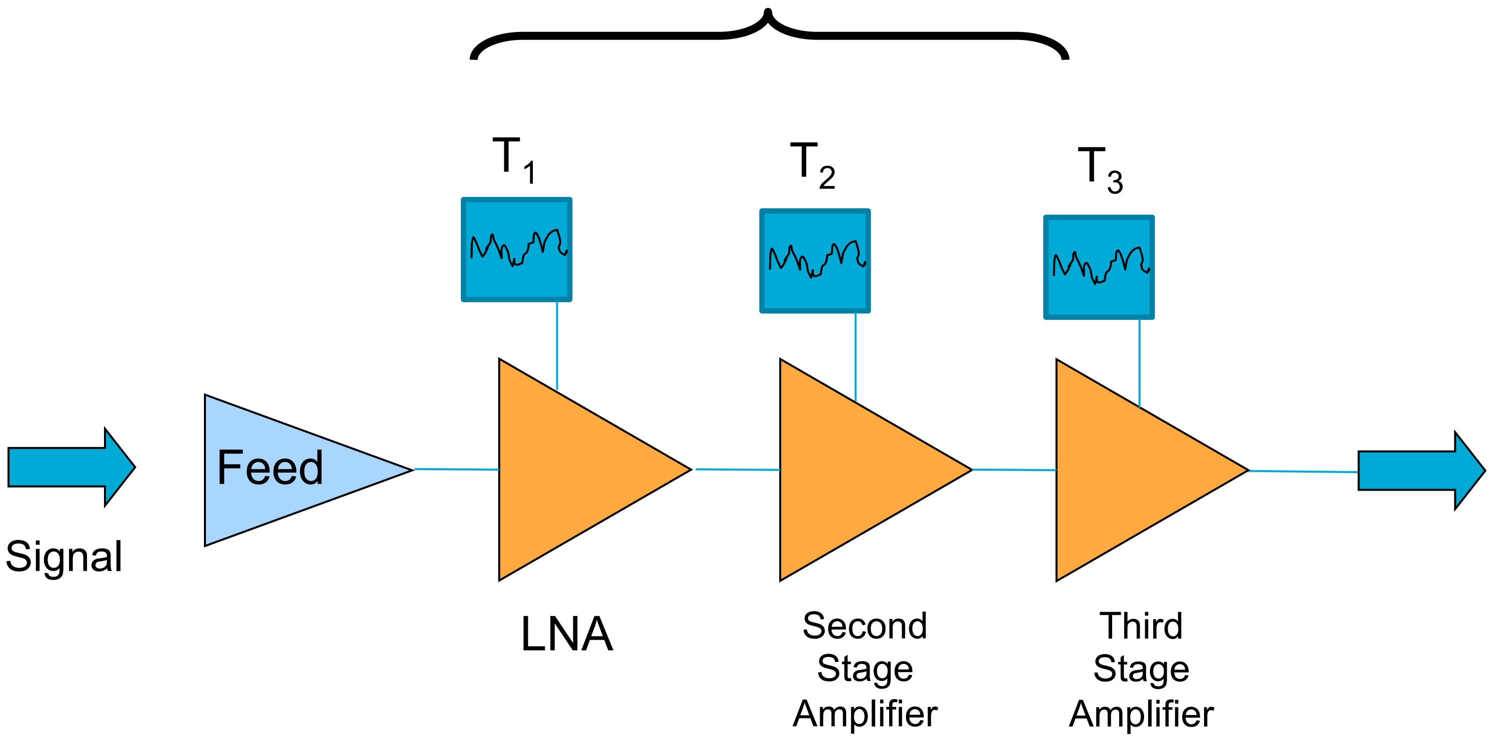
High Electron Mobility Transistor (HEMT)

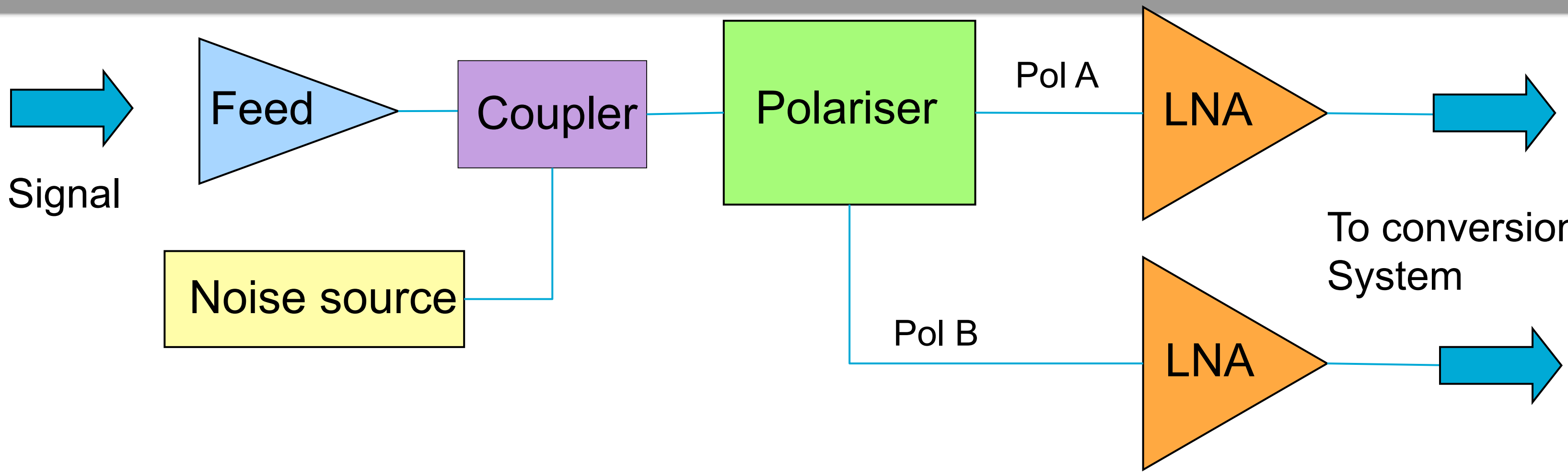




Why is the first Low Noise Amplifier so important?

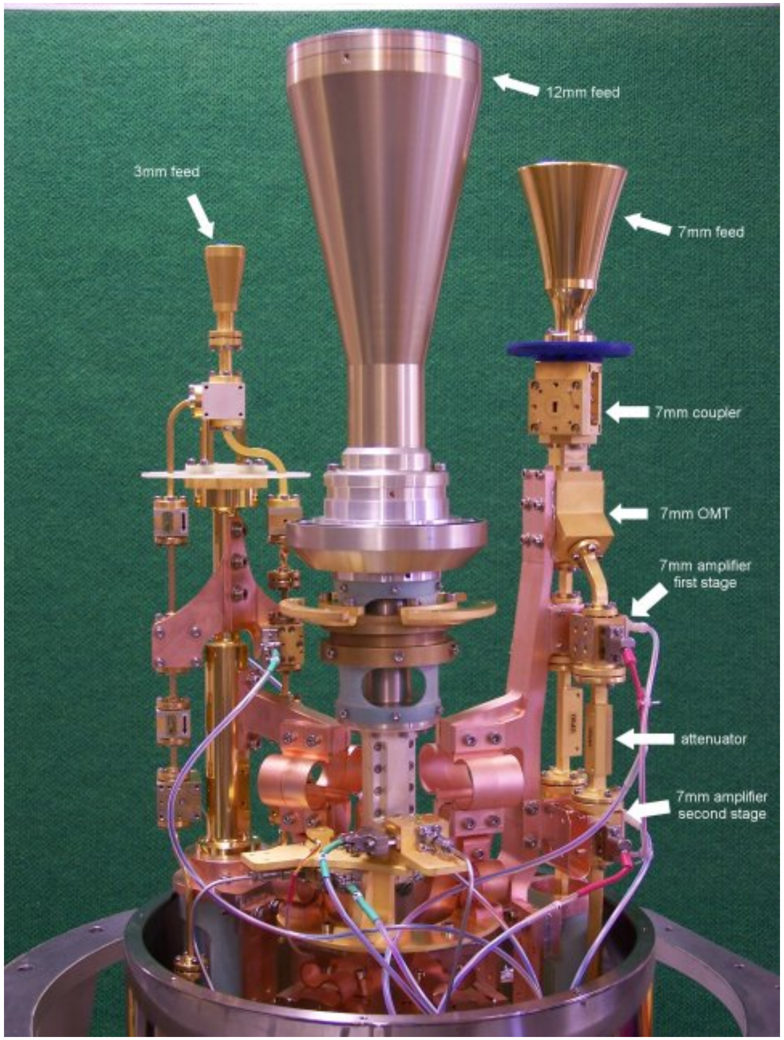
$$T_{system} = T_1 + \frac{T_2}{Gain_{LNA}} + \frac{T_3}{Gain_{LNA} \times G_2} + \frac{T_4}{Gain_{LNA} \times G_2 \times G_3} \quad \ldots\ldots$$





….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

What is the rest of the stuff?

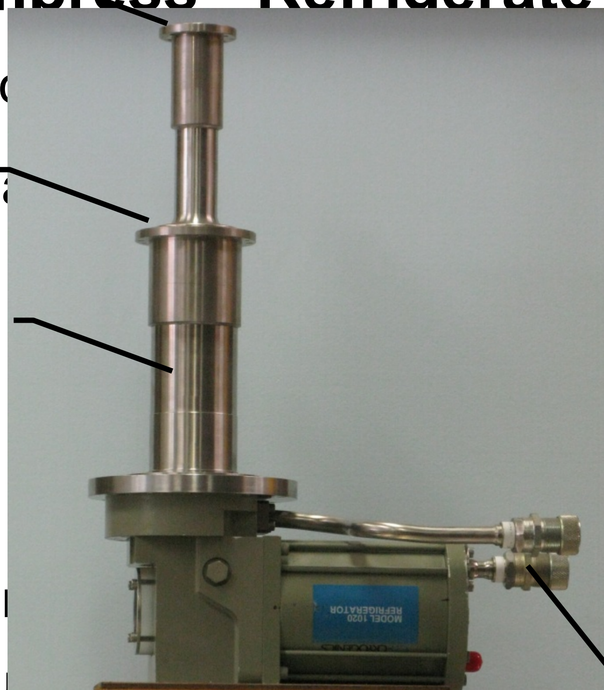
Cryogenics

mpress - Refrigerate - Compres

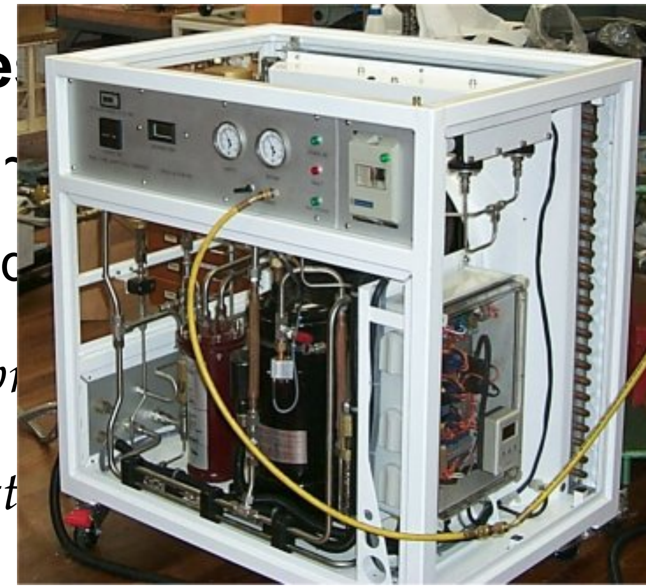
1. C… ressed gas ~
2. Ga… e it is expand

the cooling pr

n reverse, gett

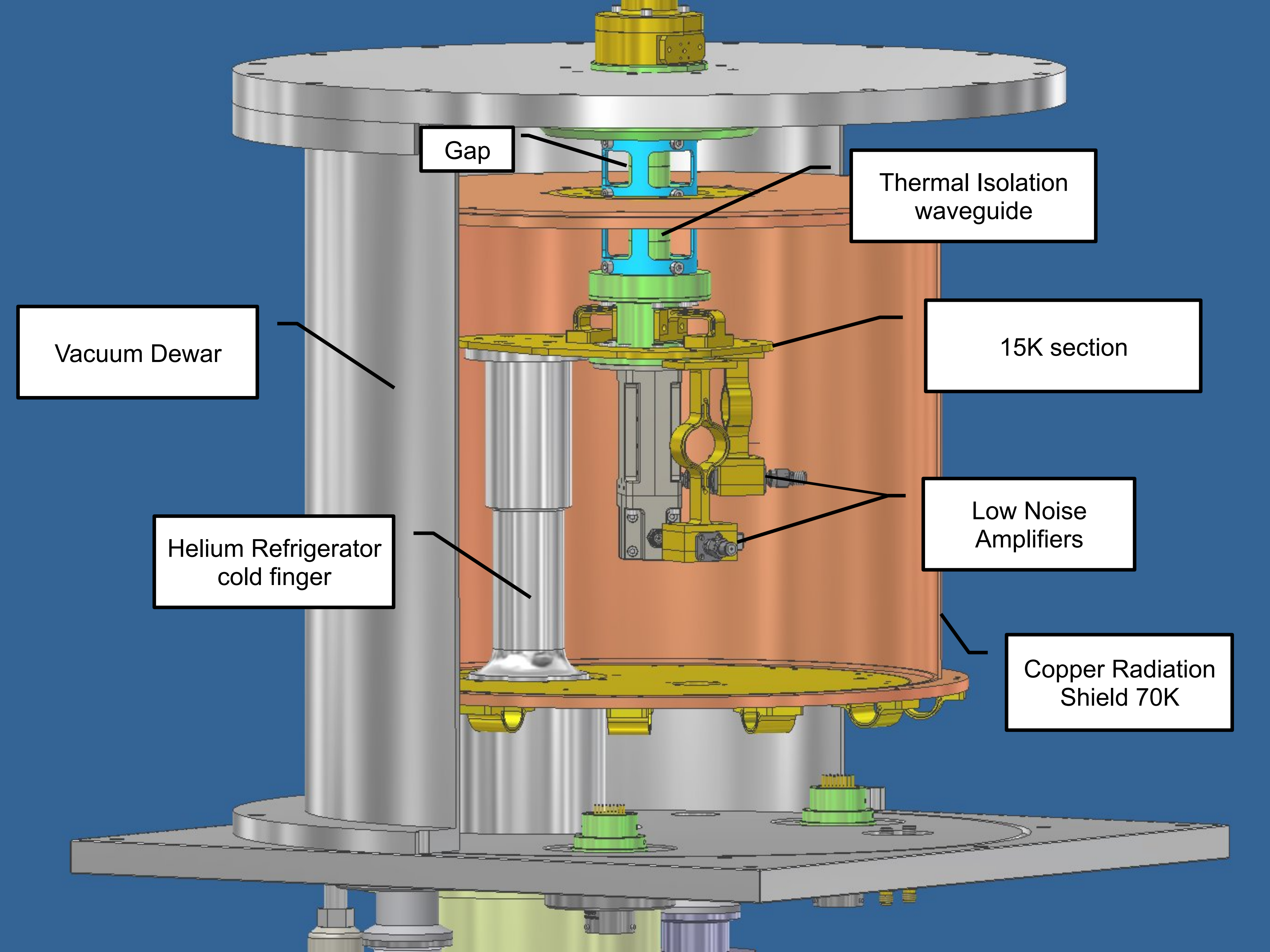


Helium Refrigerator

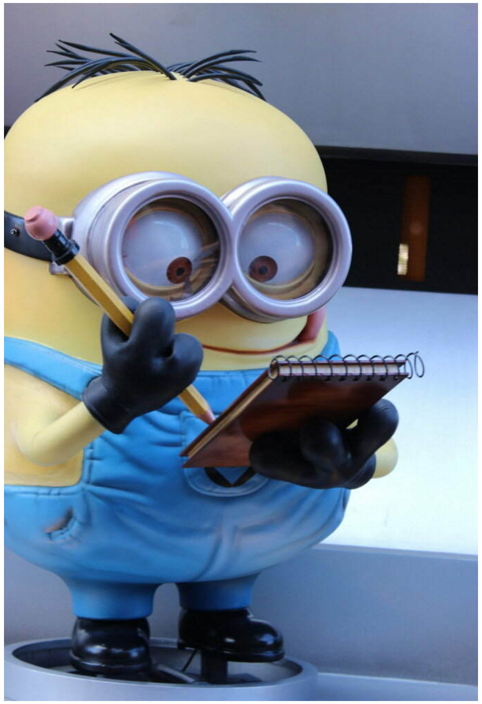


3. O… t exits the cryodyne at ~80psi and retu… the compressor for rec… .

Hence closed cycle system.


Gap
Thermal Isolation waveguide
Vacuum Dewar
15K section
Low Noise Amplifiers
Helium Refrigerator cold finger
Copper Radiation Shield 70K

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



…………..well first

How weak is the signal?

10Jy radio source →

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

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

Effective area of Parkes telescope dish

Bandwidth of Digital Filter Bank 3

Boltzmann's constant

Your Hand →

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

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

Mobile Phone →

$$\approx 1\mathrm{W}$$

Lunar Distance

3G transmit bandwidth

Mobile Phone on the moon→

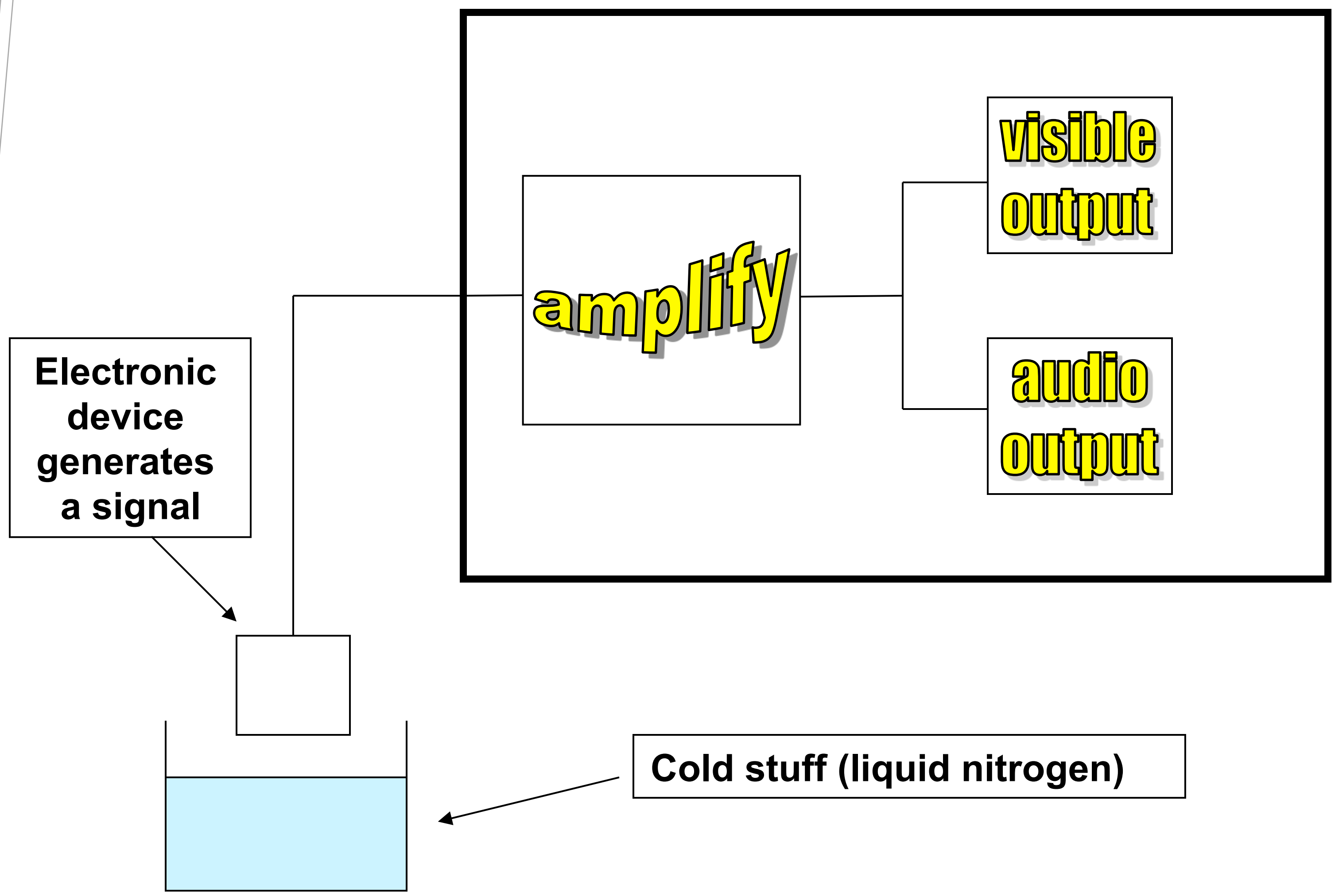
$$\approx 1\mathrm{W} \div 4\pi\ (3.8\times 10^8\mathrm{m})^2 \div 5\times 10^6\mathrm{Hz}$$

$$\approx 10\mathrm{Jy}$$

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.

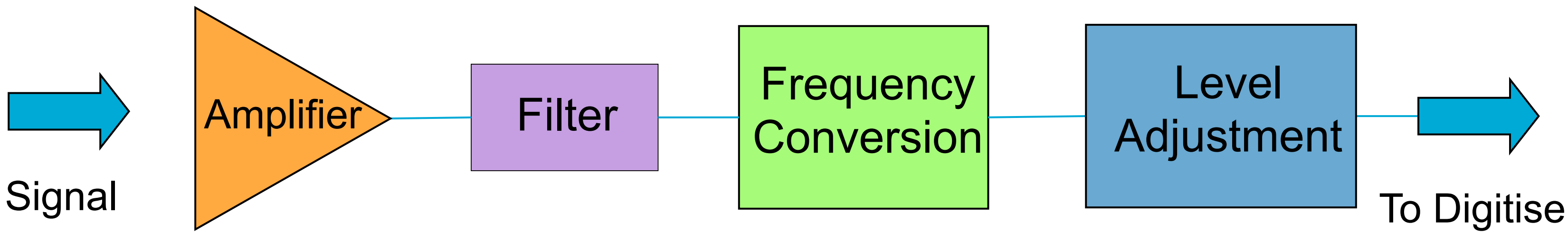
By cooling the receiver we reduce these thermal sources of noise and improve the sensitivity of the receiver by 7-10 times.

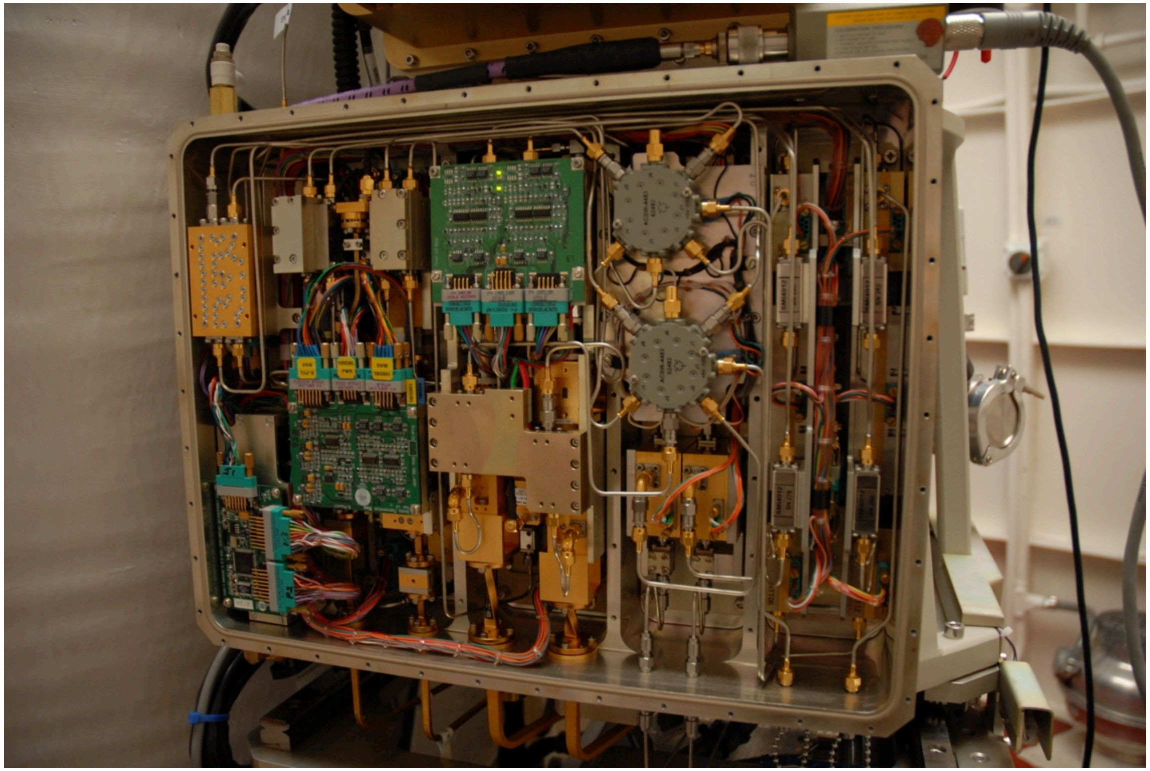
Reduce noise by cooling



What is the rest of the stuff?

The Conversion System

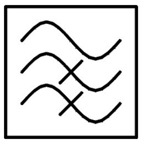




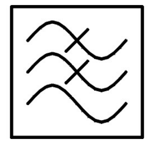
Contains:
- more amplification
- band defining filters
- frequency conversion
- level adjustment
- signal detection
- band shaping

Filters

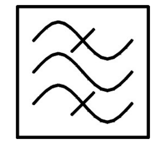
High Pass Filter



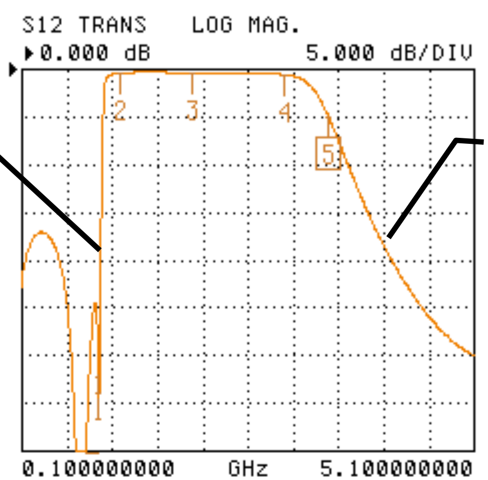
Low Pass Filter



Band Pass Filter

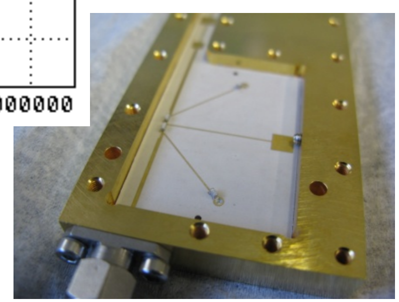


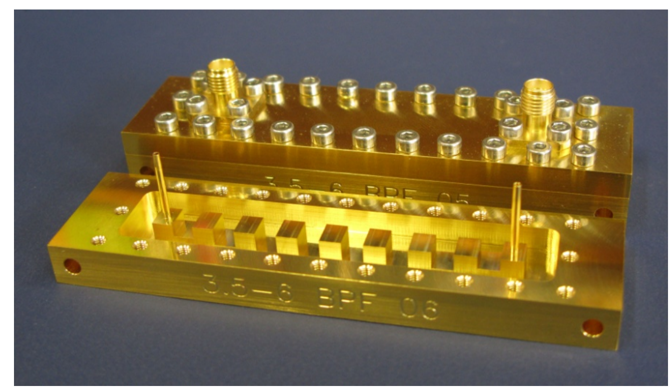
Hard roll off where necessary to stop strong interference



Slow roll off where possible so you can push the band edges

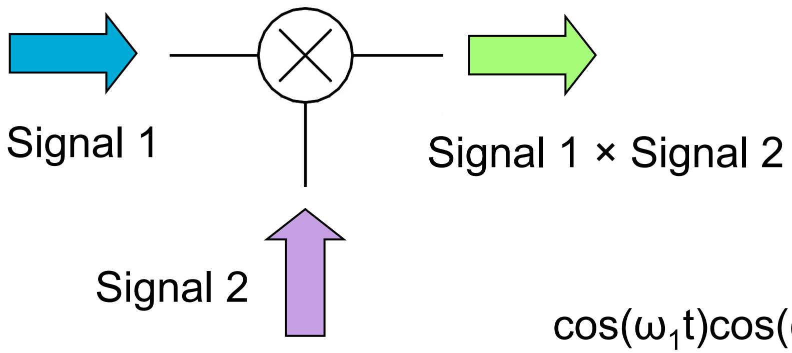
21cm band filter

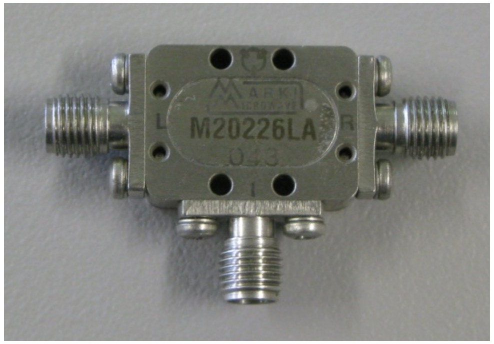




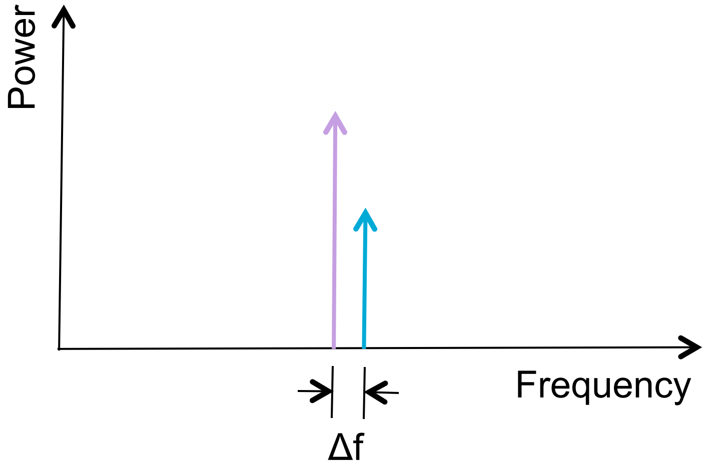
Mixing it down – Frequency Conversion

Mixer (Multiplier)

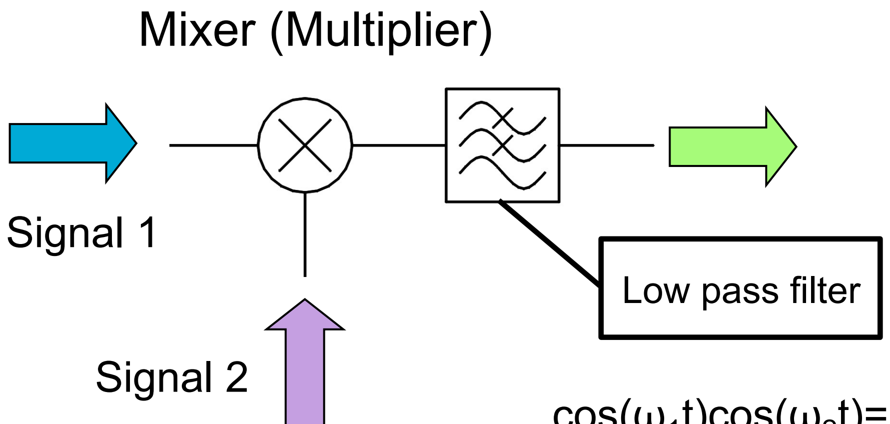


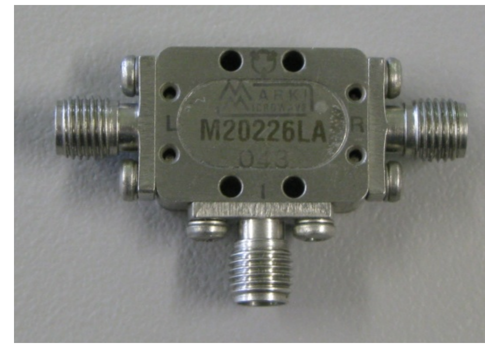


$$\cos(\omega_1 t)\cos(\omega_2 t)=\tfrac{1}{2}[\cos((\omega_1+\omega_2)t)+\cos((\omega_1-\omega_2)t)]$$

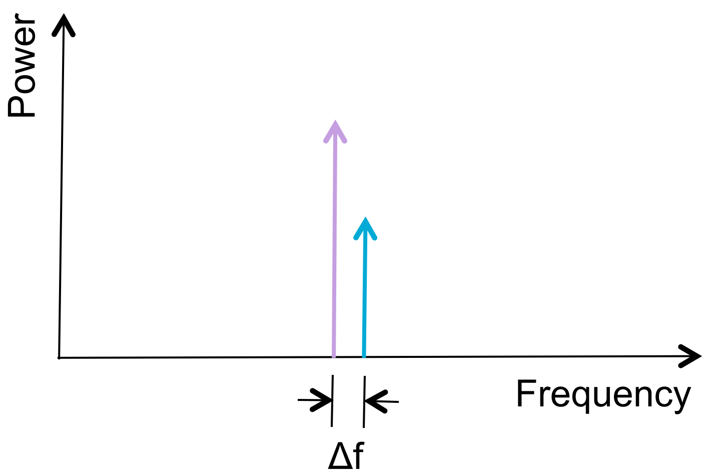


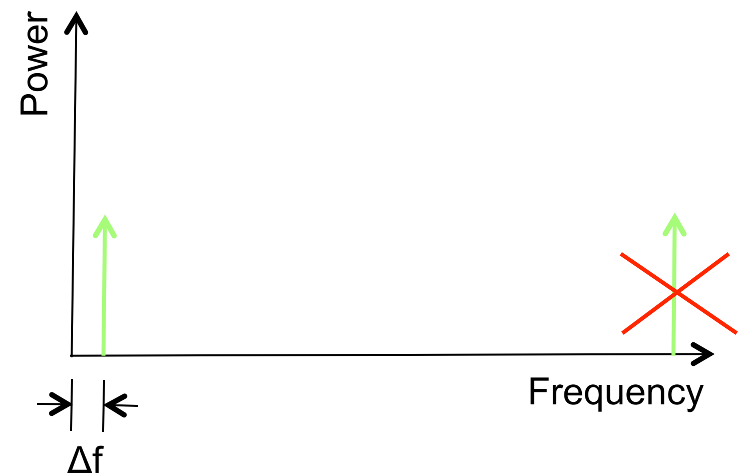
Mixing it down – Frequency Conversion



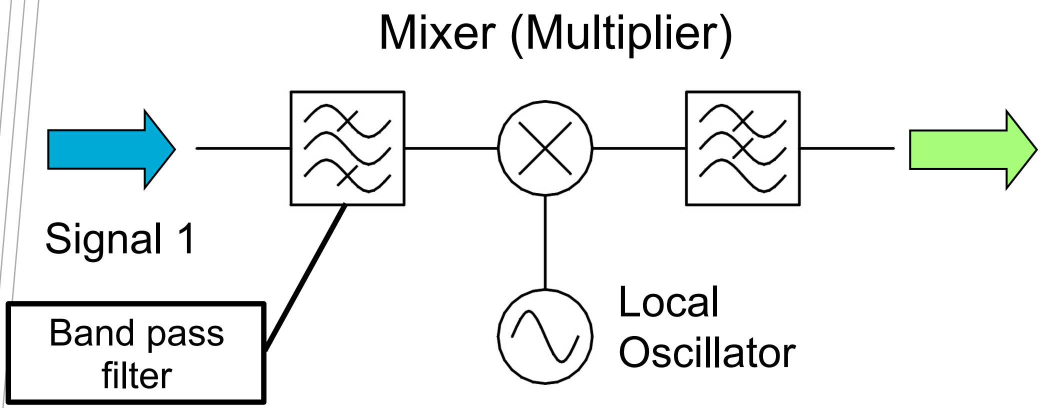


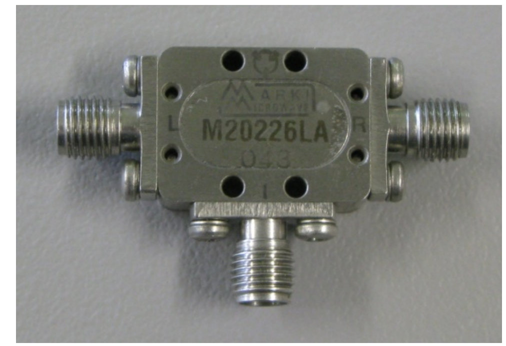
$$\cos(\omega_1 t)\cos(\omega_2 t)=½[\cos((\omega_1+\omega_2)t)+\cos((\omega_1-\omega_2)t)]$$

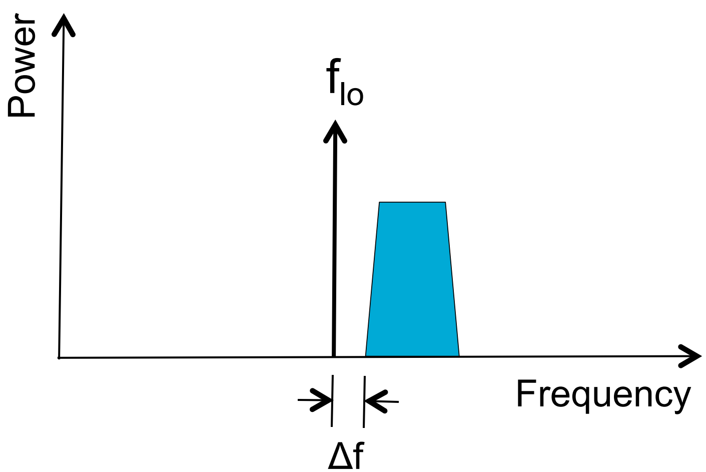


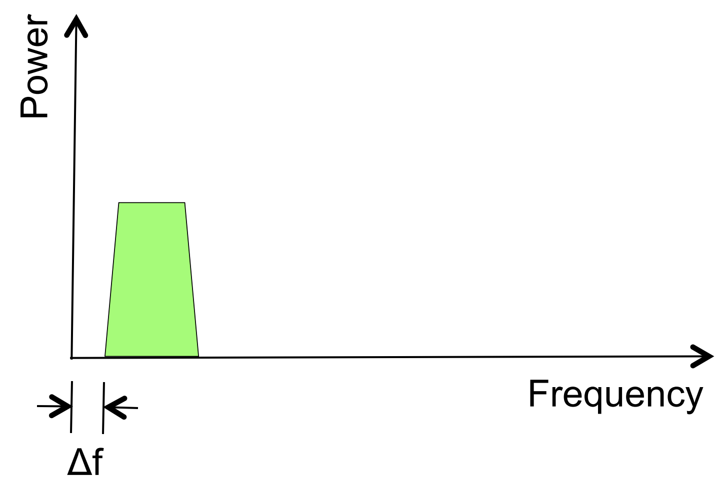


Mixing it down – Frequency Conversion



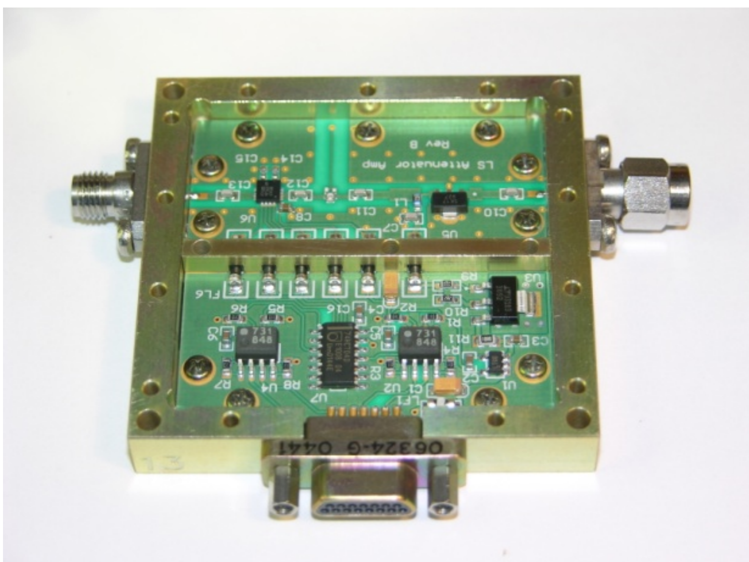






Attenuators – The Volume Knob

- Allow the signal level to be varied
- May be several in the system
- Usually set automatically

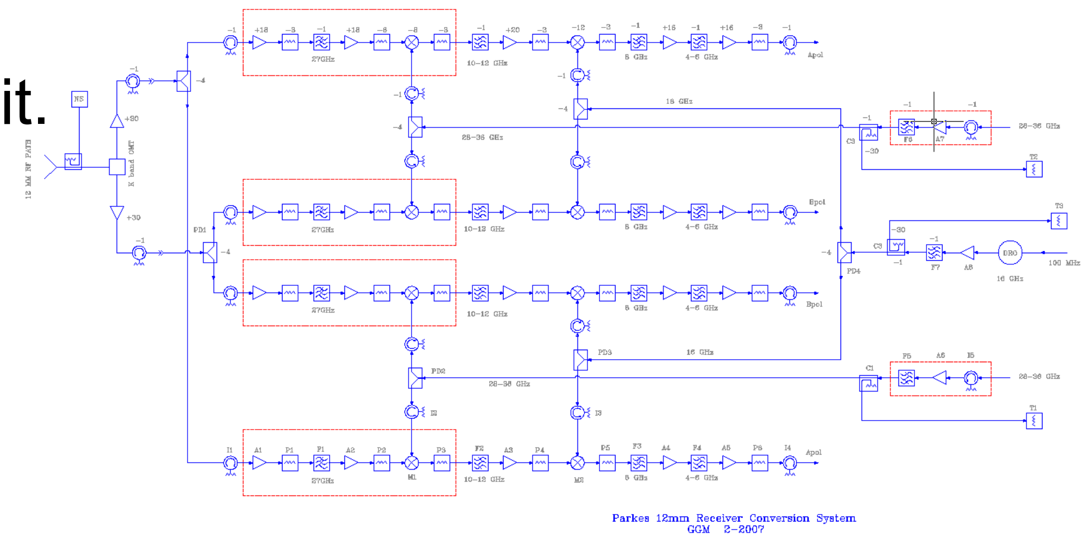


Just like some other systems if you turn the signal down too far all you get is noise and if you turn it up to far you get distortion!

Of course real systems are a little more complicated.....

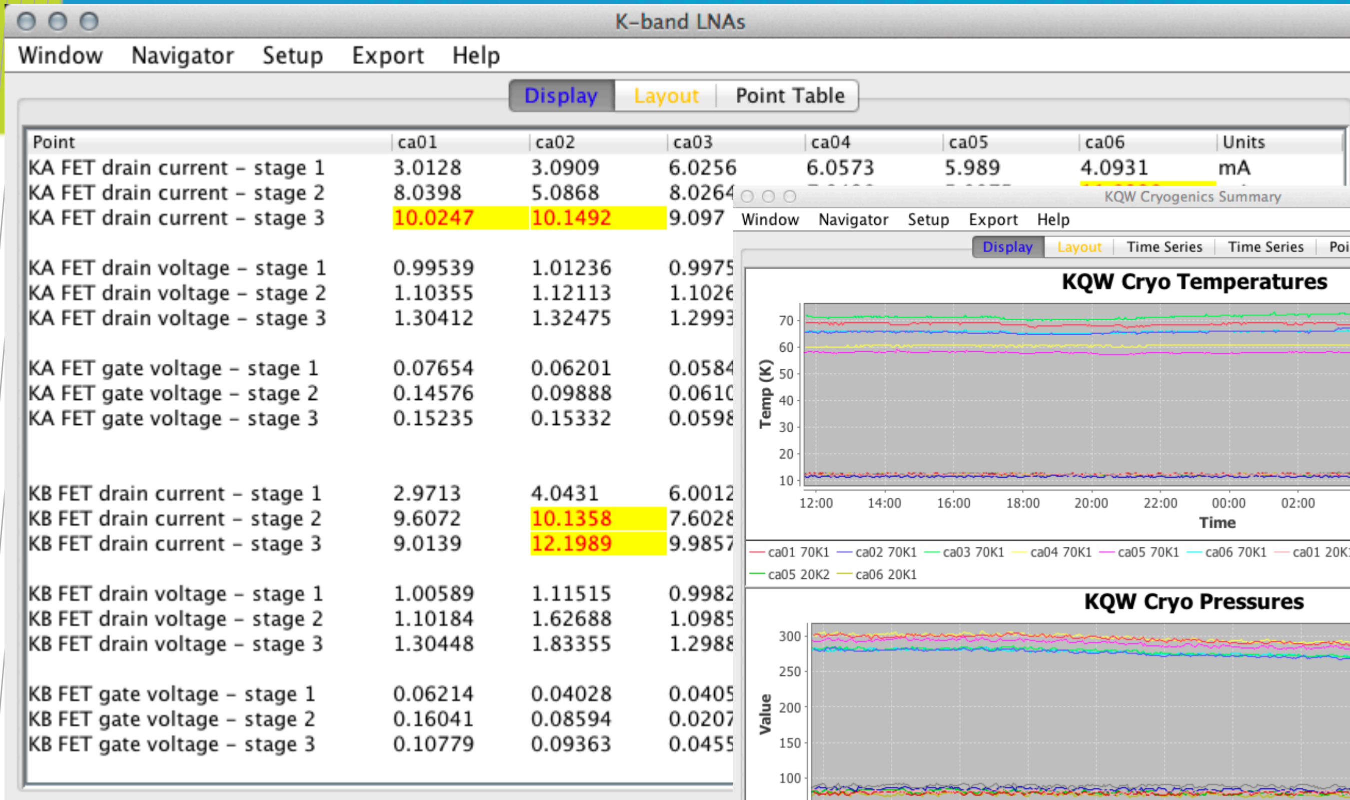
They usually contain multiple conversions and many amplification and filter stages....

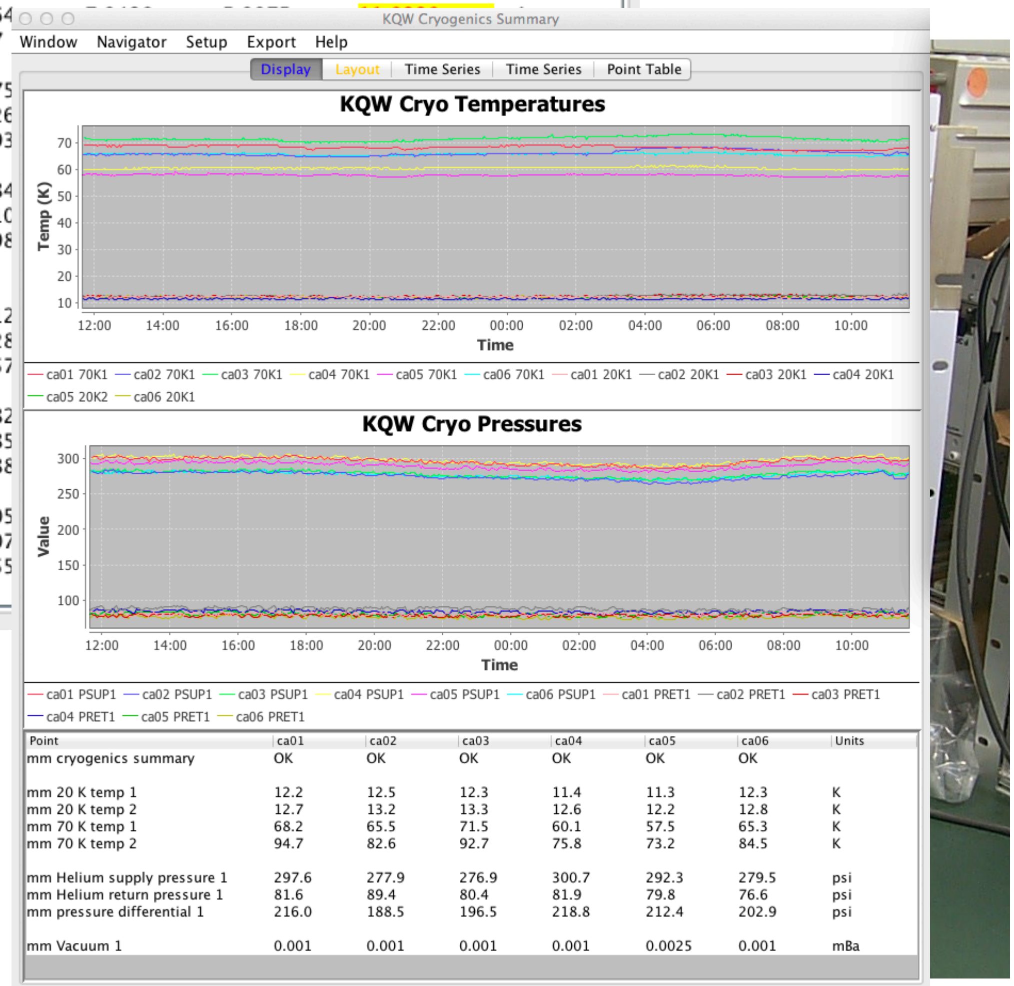
But that’s the gist of it.



What is the rest of the stuff?

What's this?





temperatures and pressures

CSIRO Astronomy and Space Science
Christoph Brem
RF Engineer

Phone: 02 6790 4034
Email: Christoph.Brem@csiro.au
Web: www.csiro.au/org/CASS

www.csiro.au

Thank you

ct Us
Phone: 1300 363 4 +61 3 9 2176
Email: enquiries@csiro Veb: www.c .au

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