



# 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



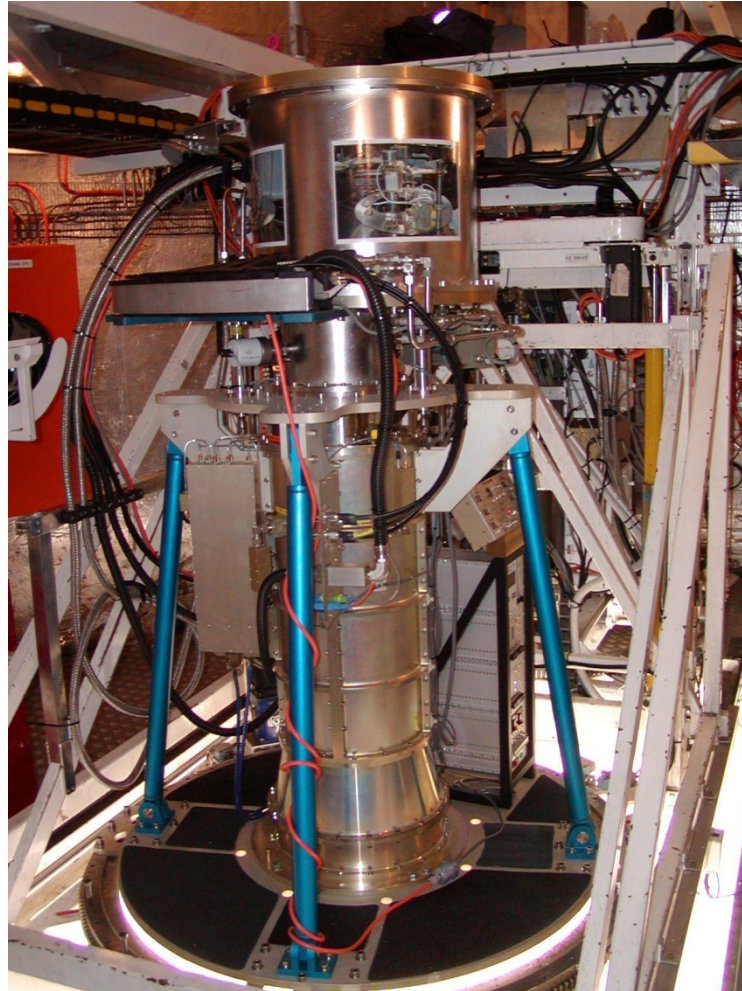
# Ours look more like this...

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



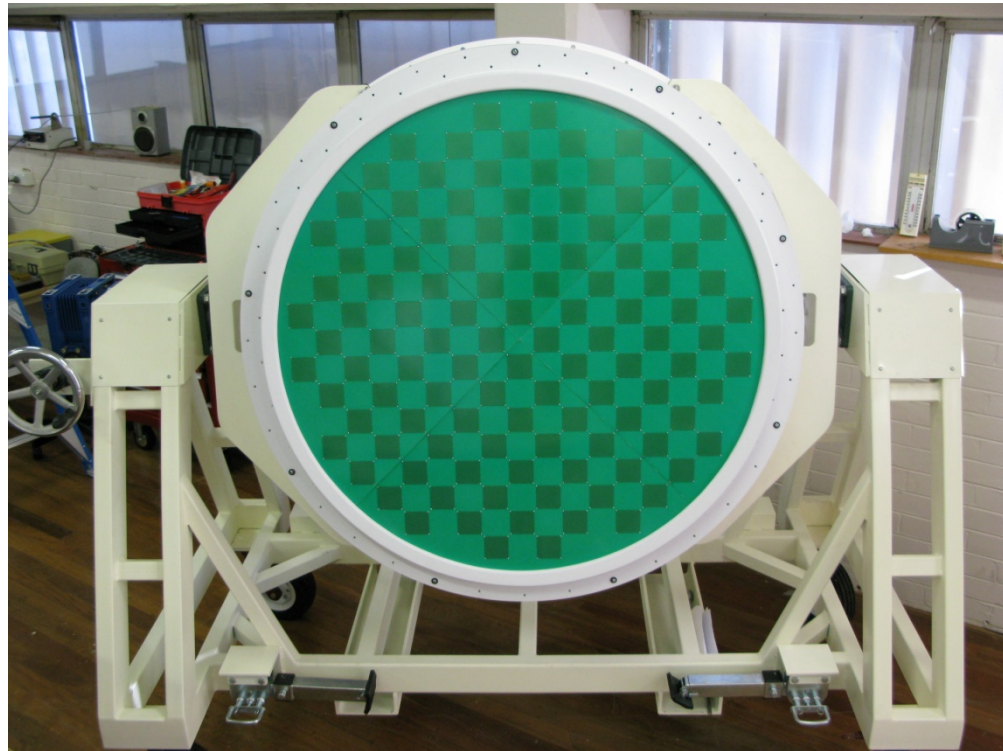
Compact Array  
3/7/12mm Receiver

Or this...



Parkes 10/50cm  
Receiver

Or this...



ASKAP Phased  
Array Receiver  
(BETA)

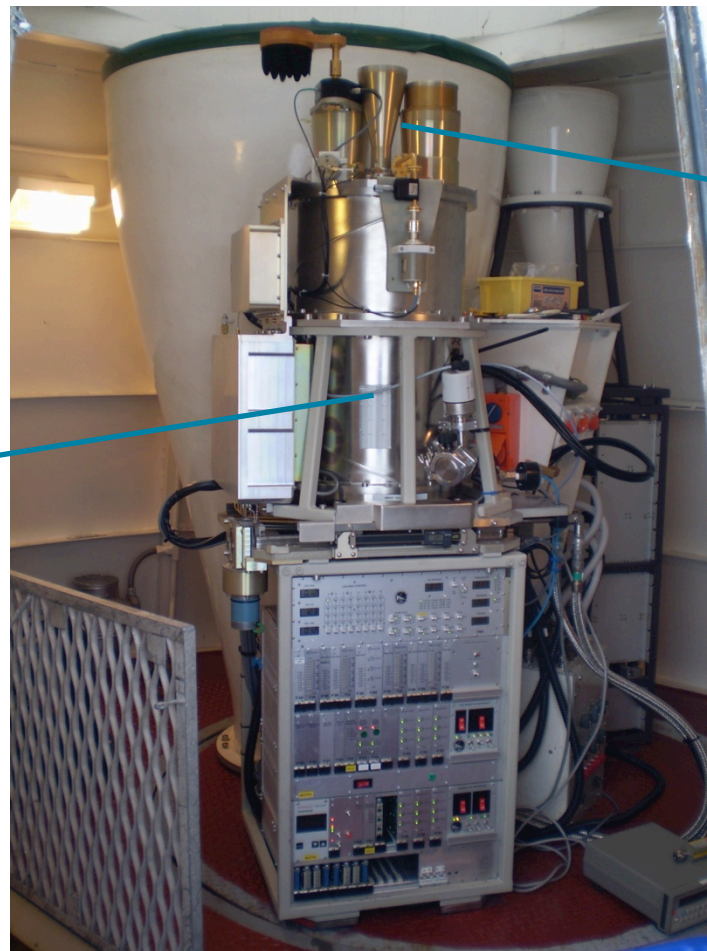
Some even look like this...



Allen Telescope Log  
Periodic Receiver

# The Receiver

On the outside...

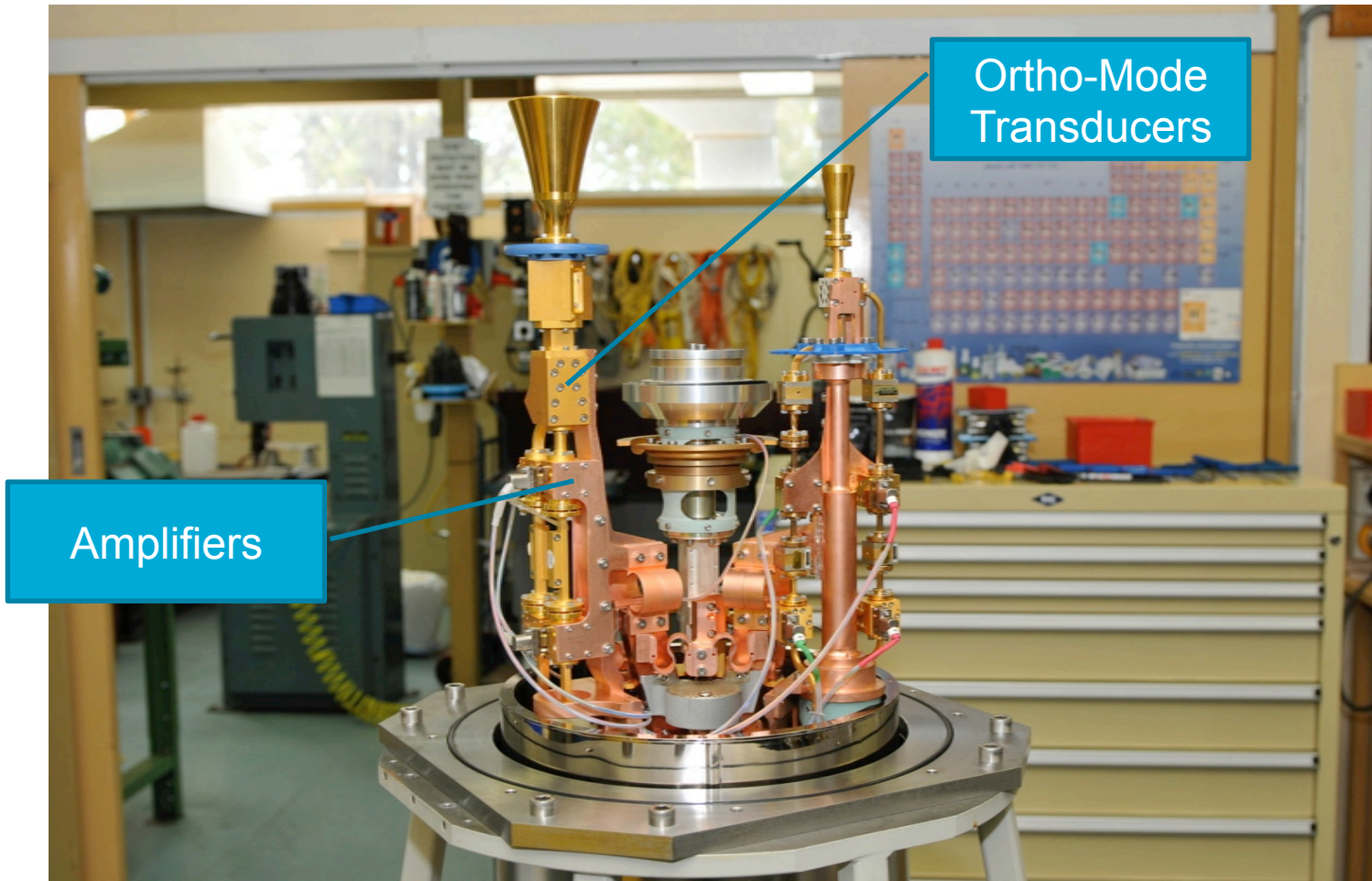


Vacuum Dewar

Feed Horns

# The Receiver

On the inside...



minimum detectable flux

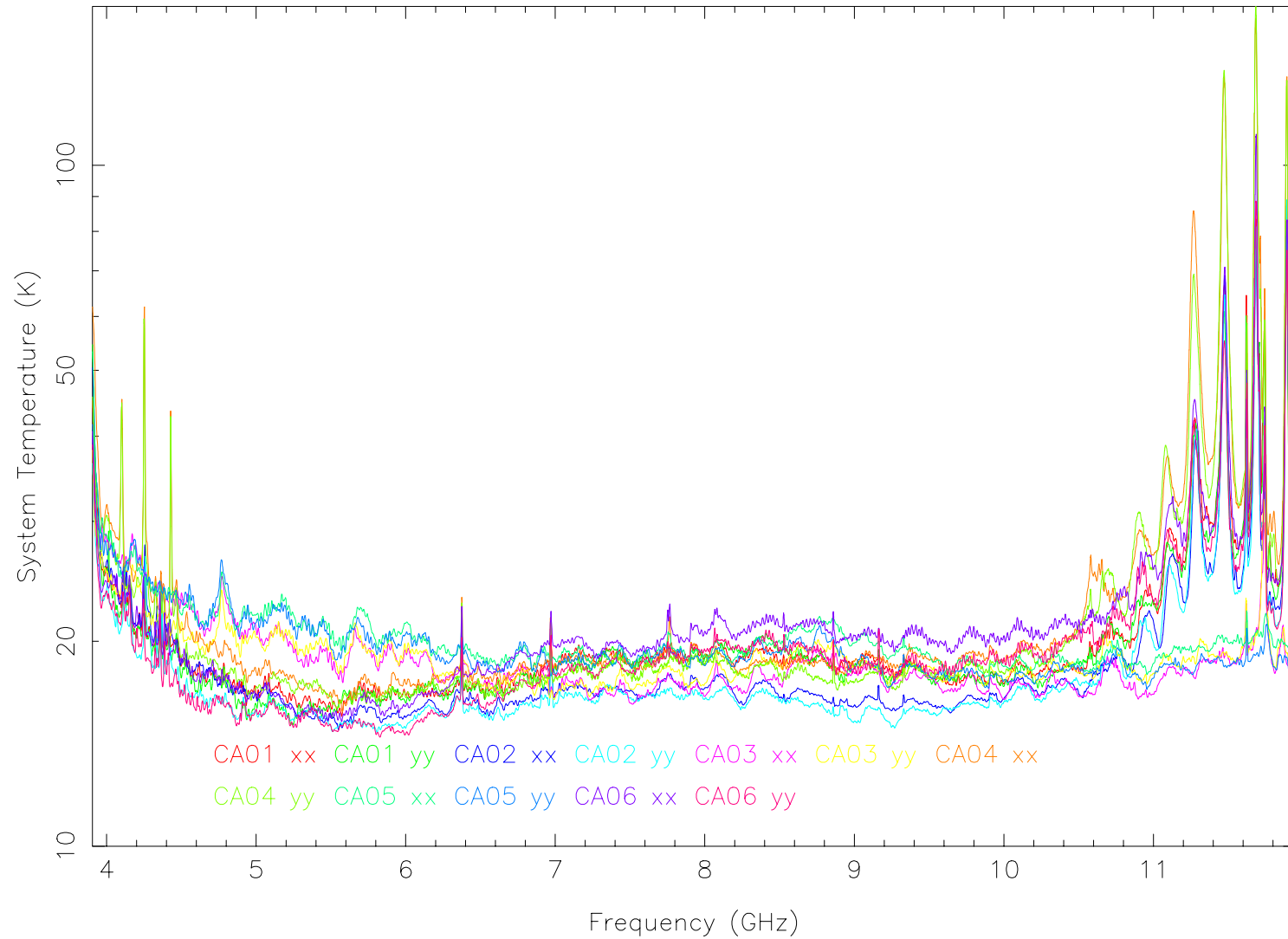
$$\Delta S \propto \frac{T_{sys}}{A_e \sqrt{\Delta \nu_{RF} \tau}}$$

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

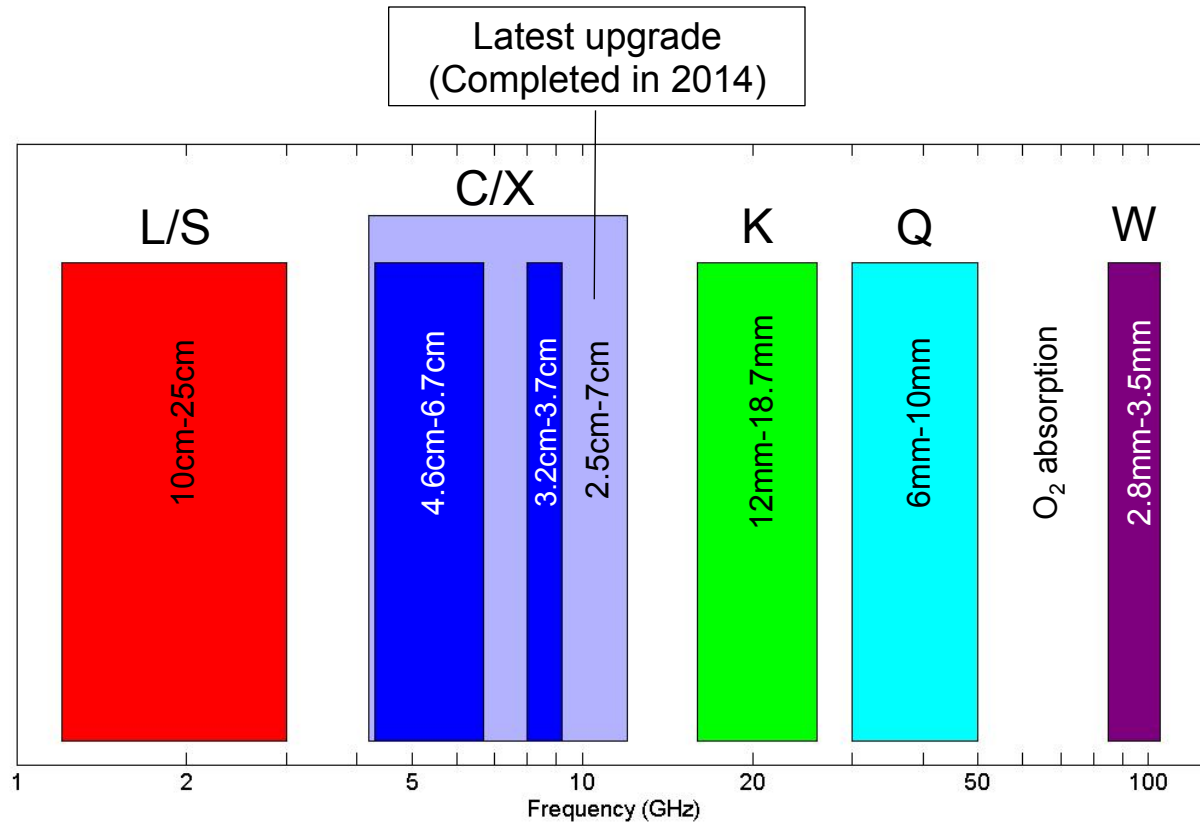
Effective Collecting Area

Integration Time

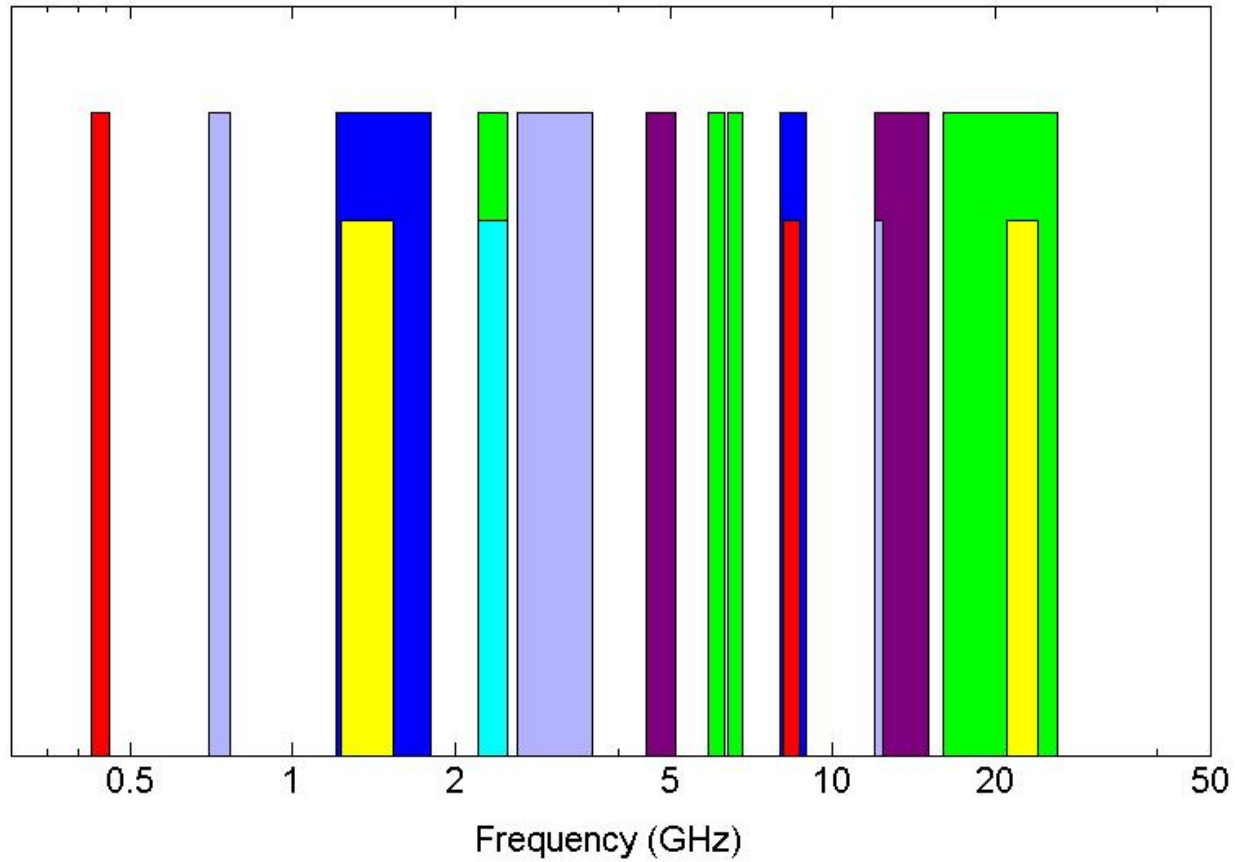
Observing Bandwidth



# The Australia Telescope Receivers

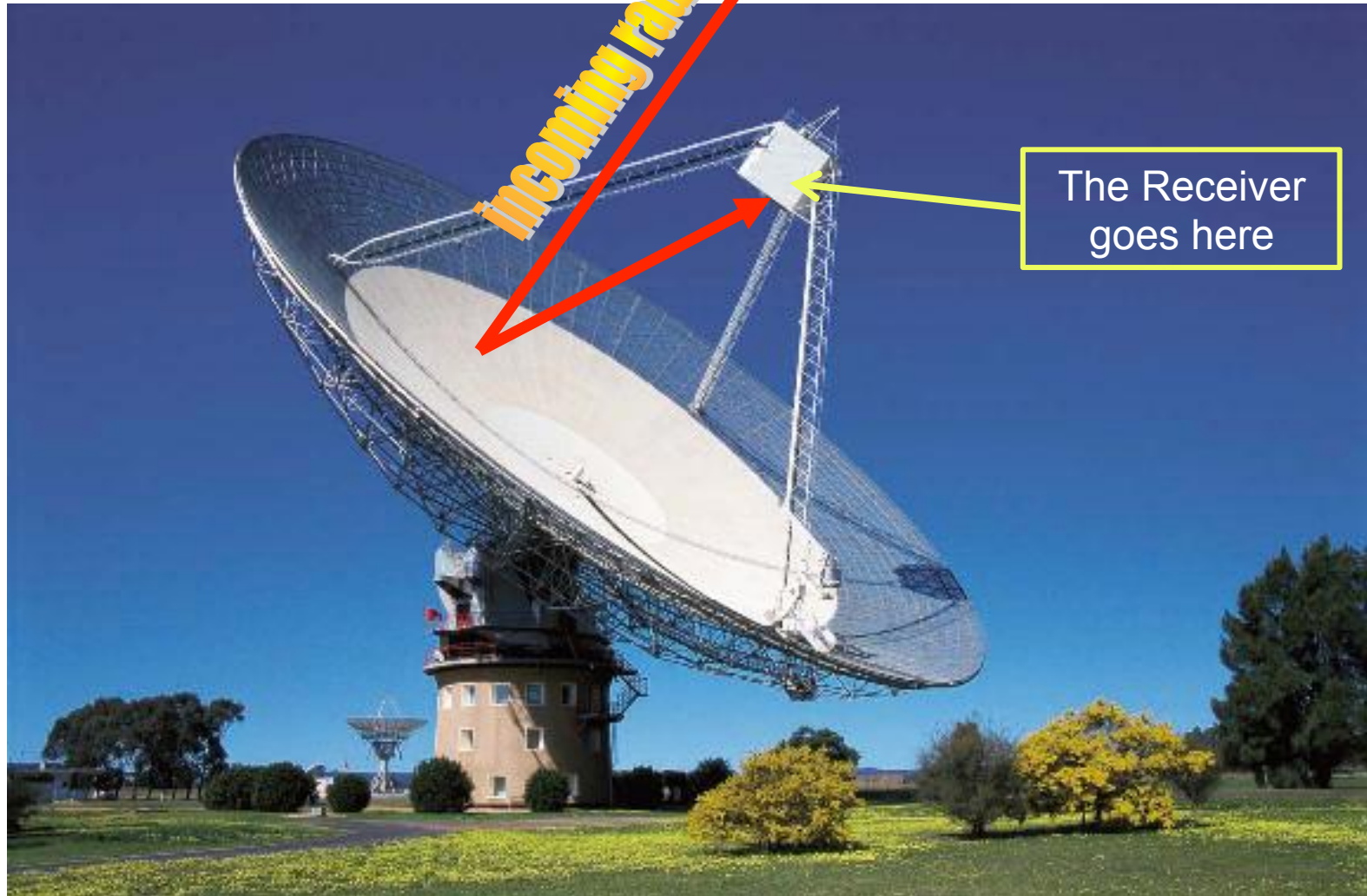


# Parkes Receiver Bands

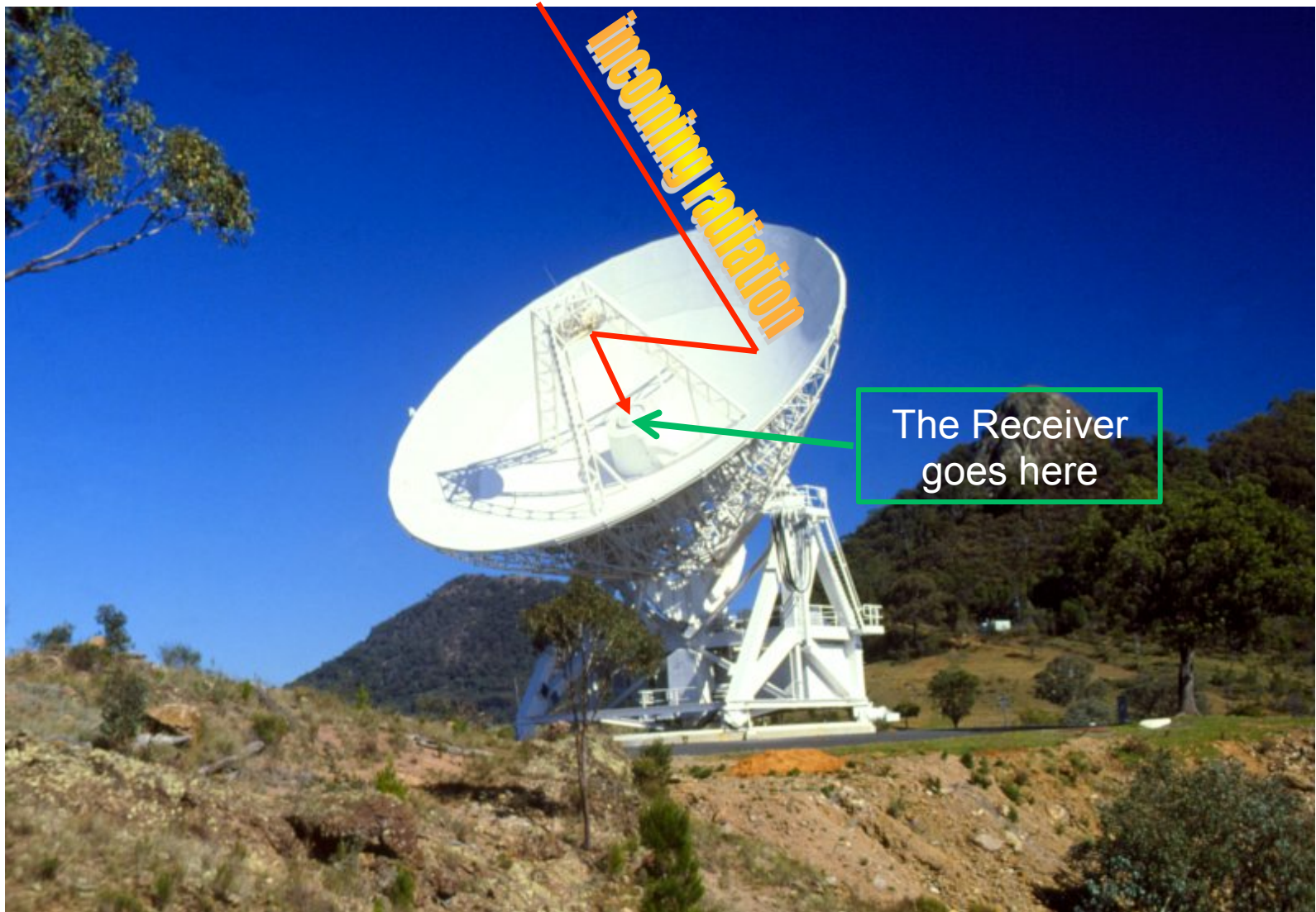


# Where do they go?

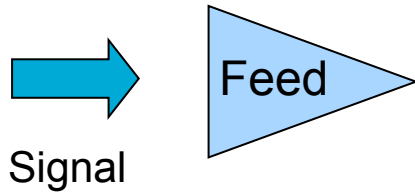
In a prime focus...



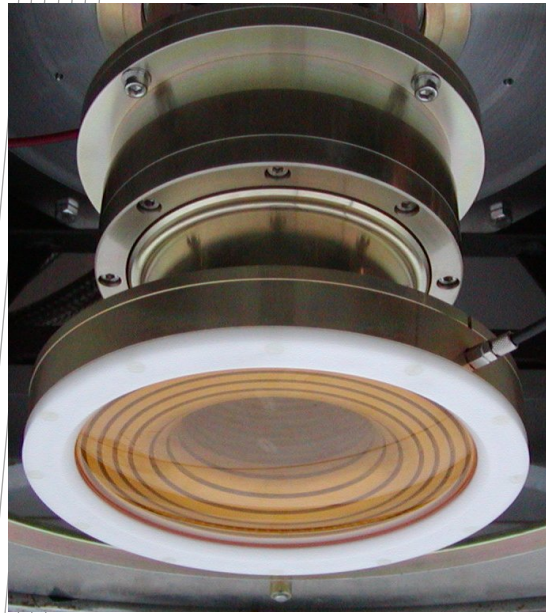
# In a Cassegrain system...



# Receiving the signal – Feed horns



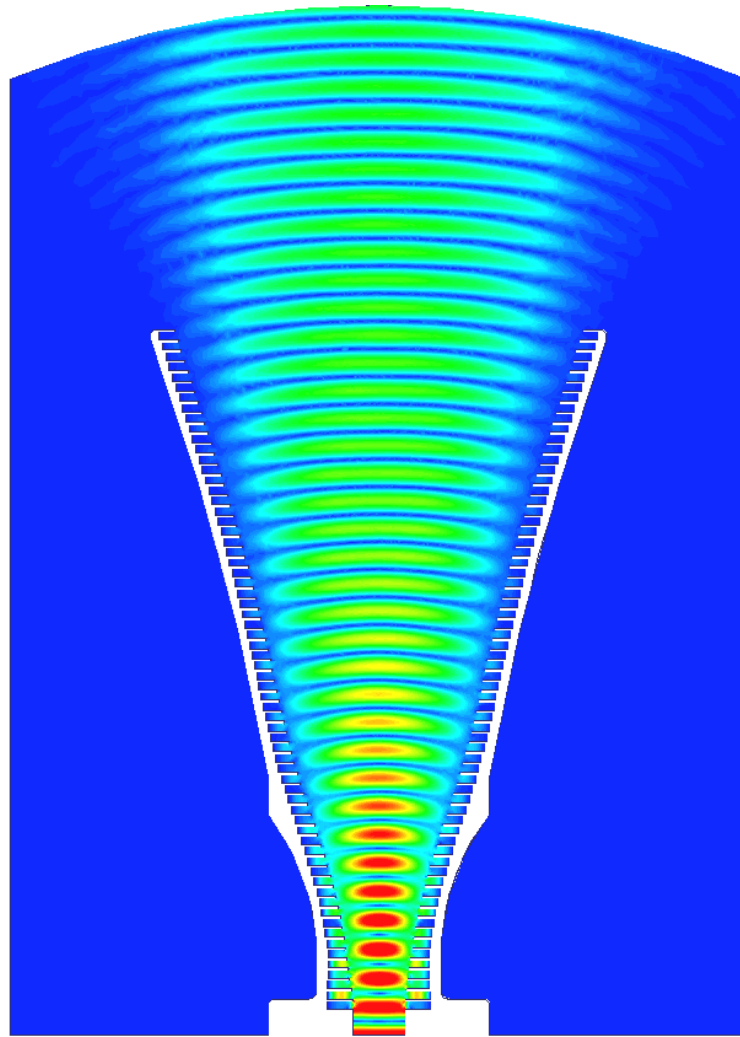
Captures the focused microwaves into a waveguide output



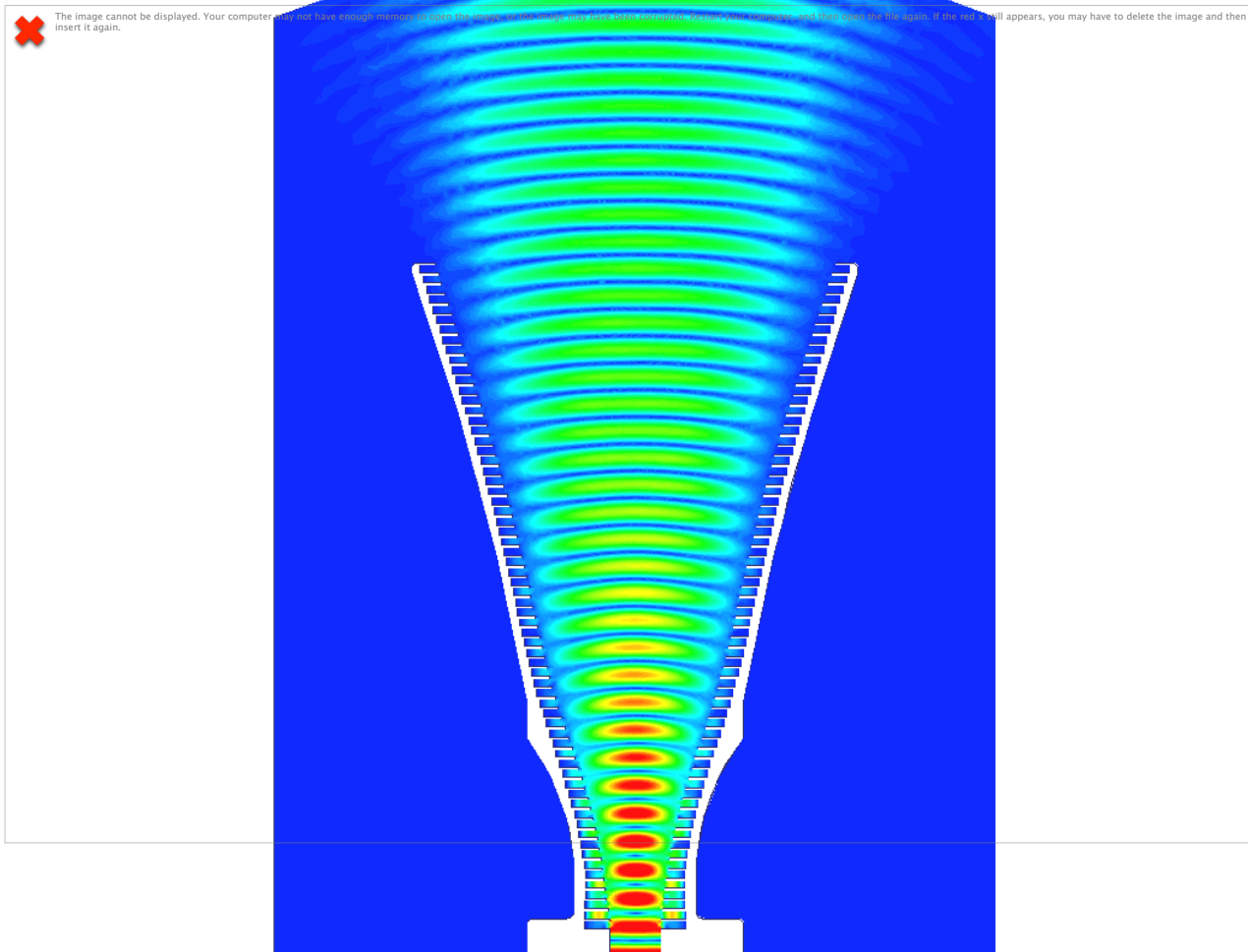
Waveguide output



# Feed Horns

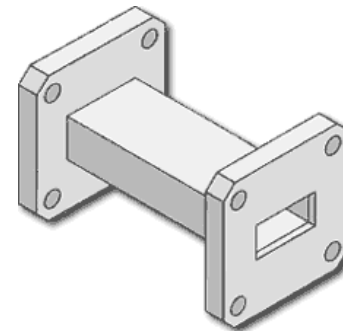
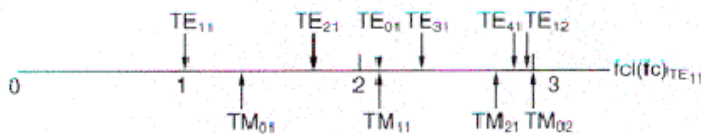
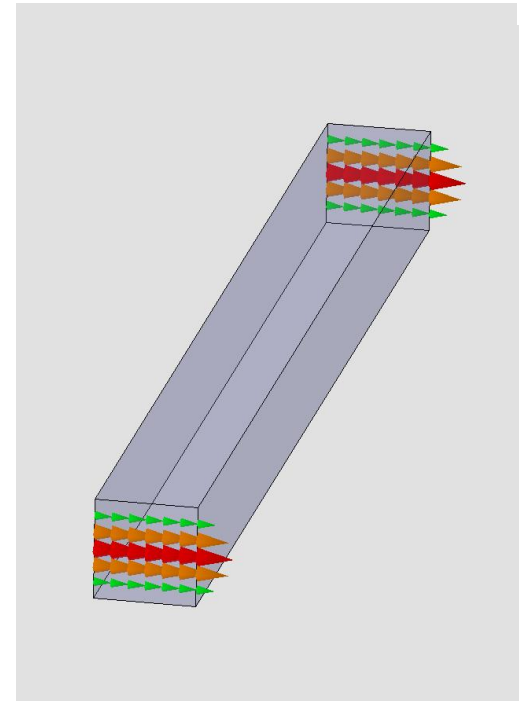
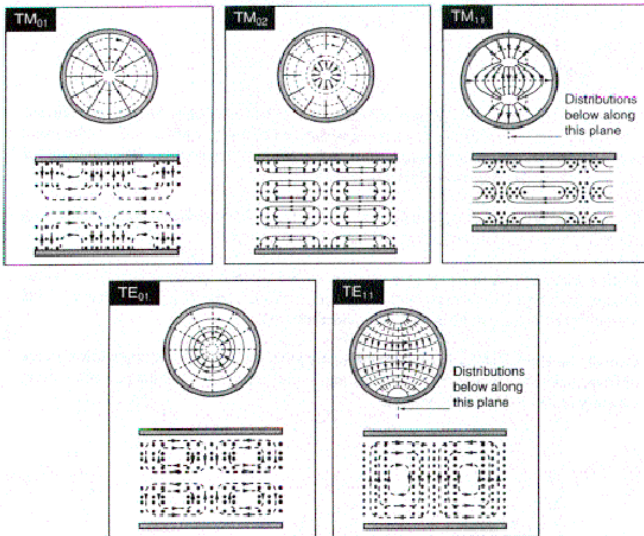


# Feed Horns

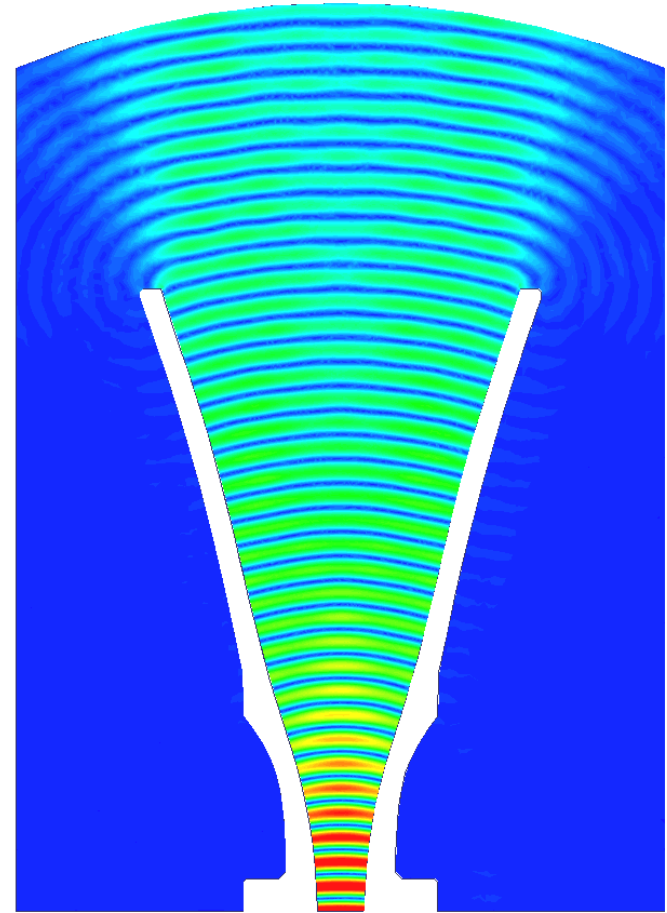
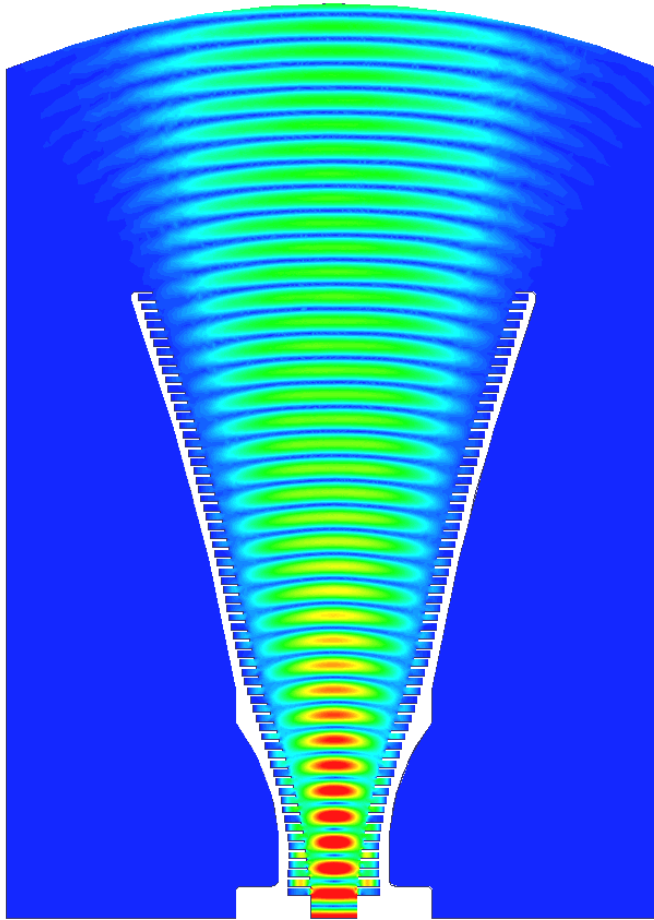


# Detour: Waveguides

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

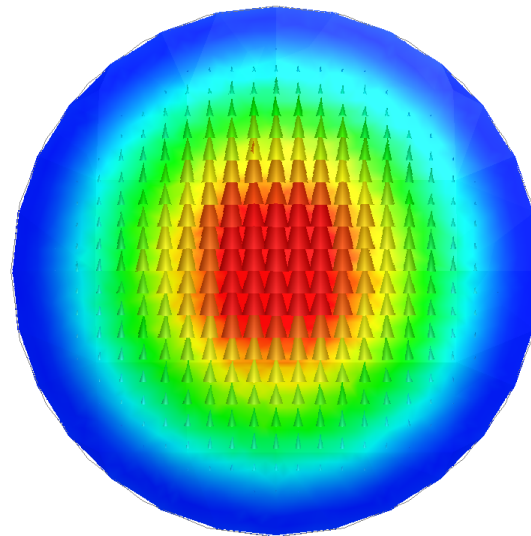


# A Tale of Two Feedhorns



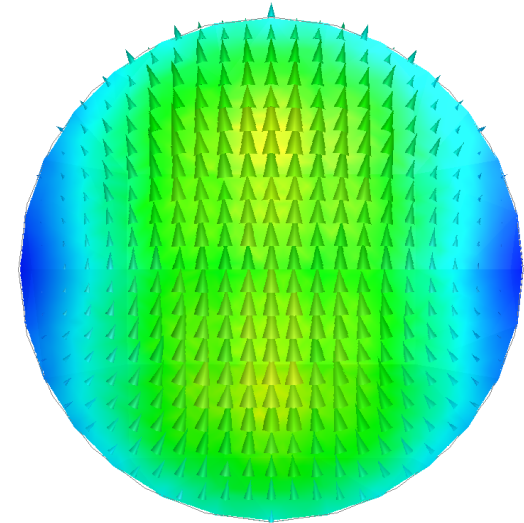
# A Tale of Two Feedhorns

## Corrugated

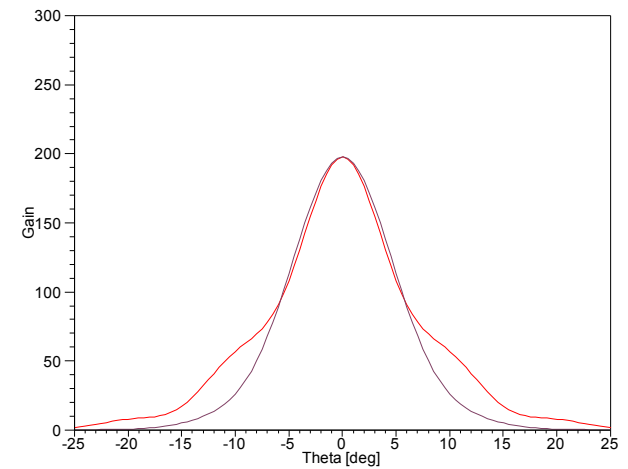
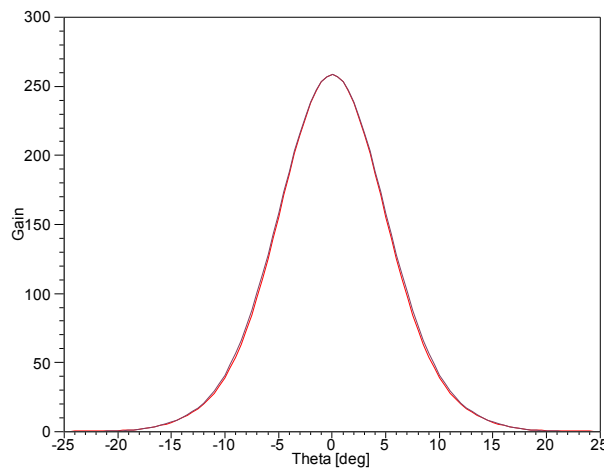


E-Field At  
Feed mouth

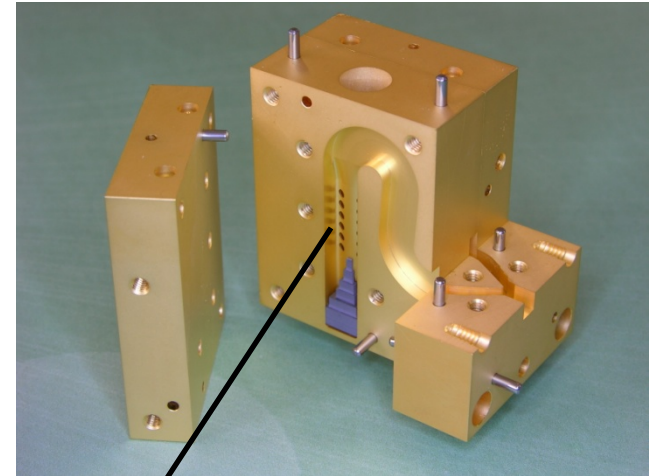
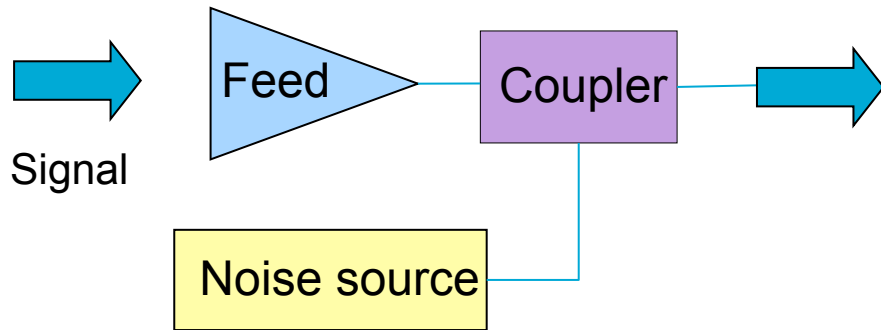
## Smooth Walled



X and Y Feed  
Patterns

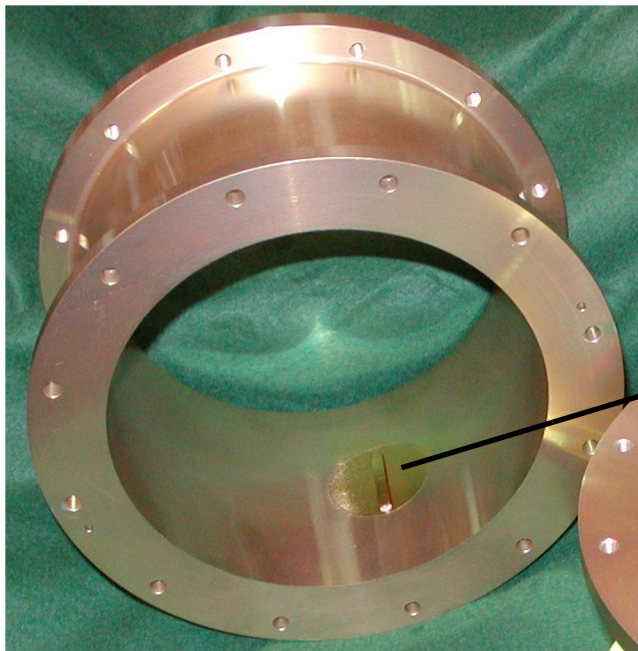


# Coupling noise into the System



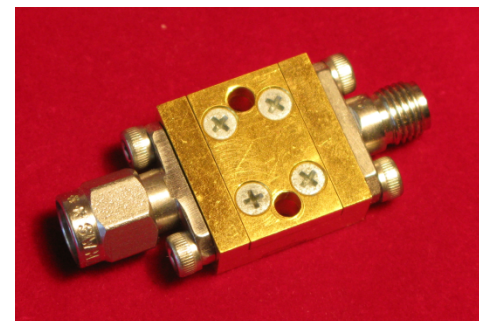
Noise coupled in through small holes

7mm waveguide coupler



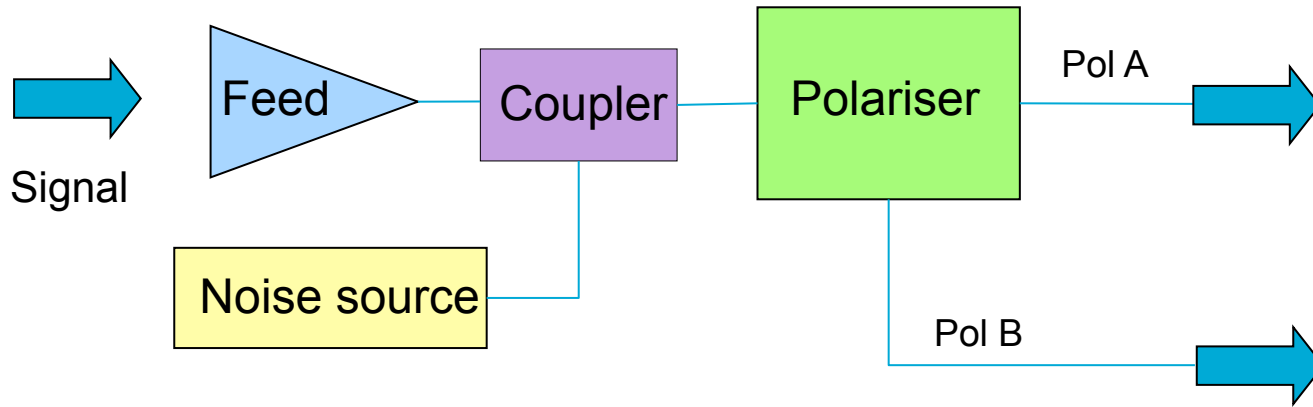
Noise coupled in through vane

21cm waveguide coupler

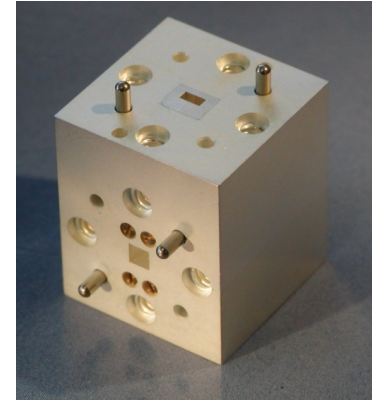


12mm noise source

# Separating Polarisations – Ortho-mode Transducers (OMTs)

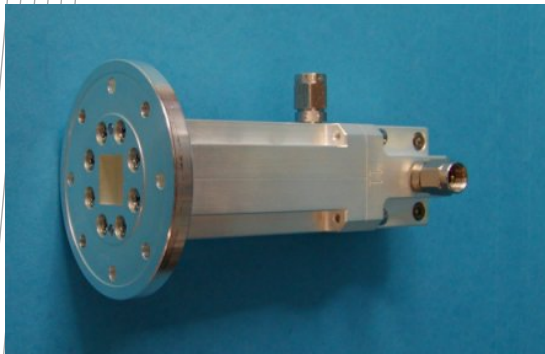


3mm Ortho-mode transducer



Separates incoming signal into two linear or circular polarisations

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

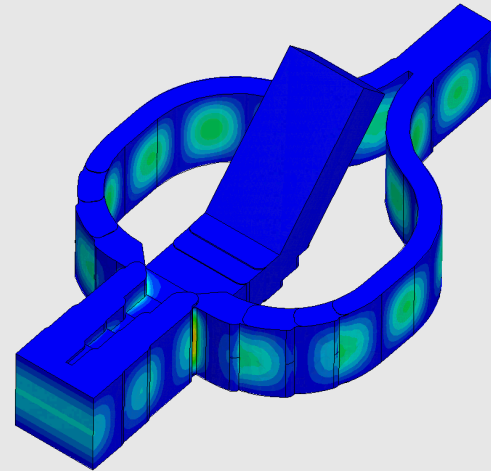
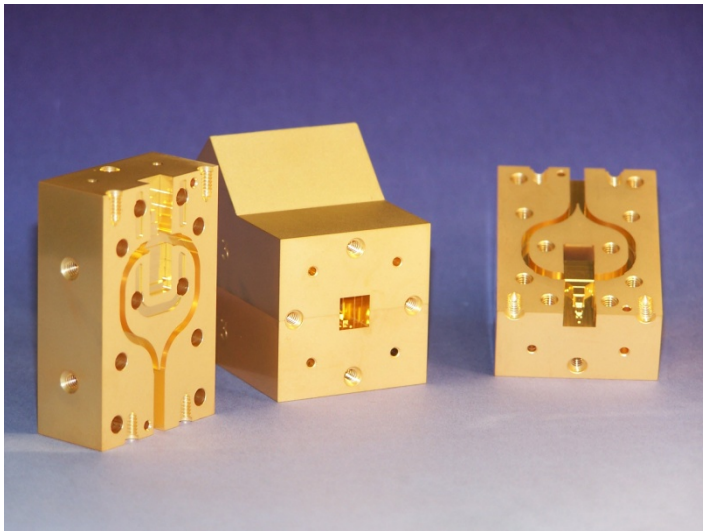
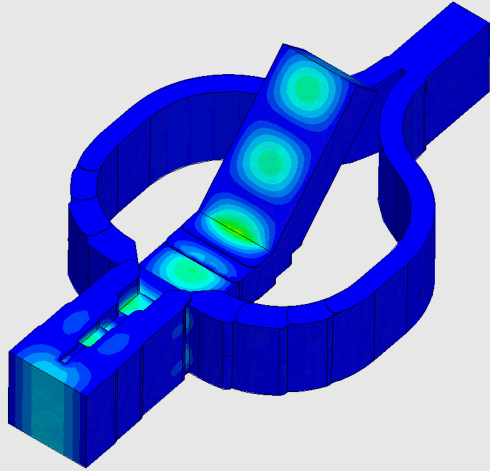


12mm Ortho-mode transducer

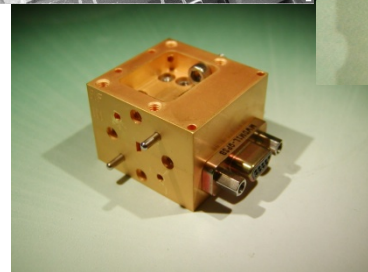
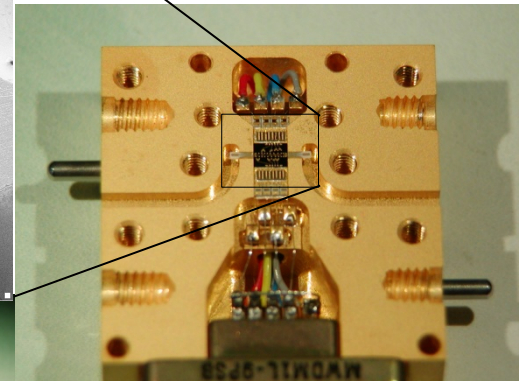
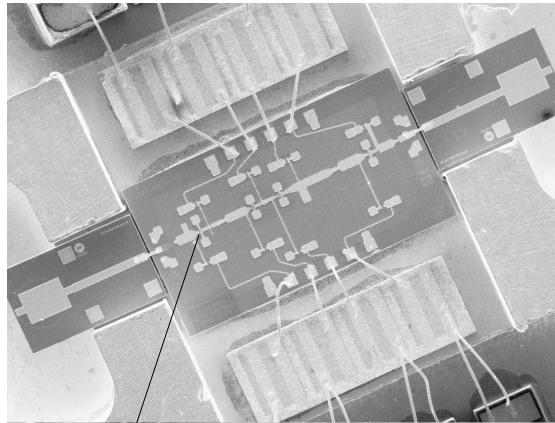
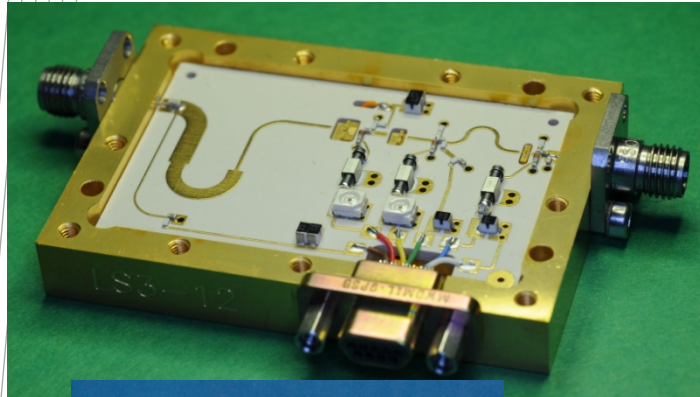
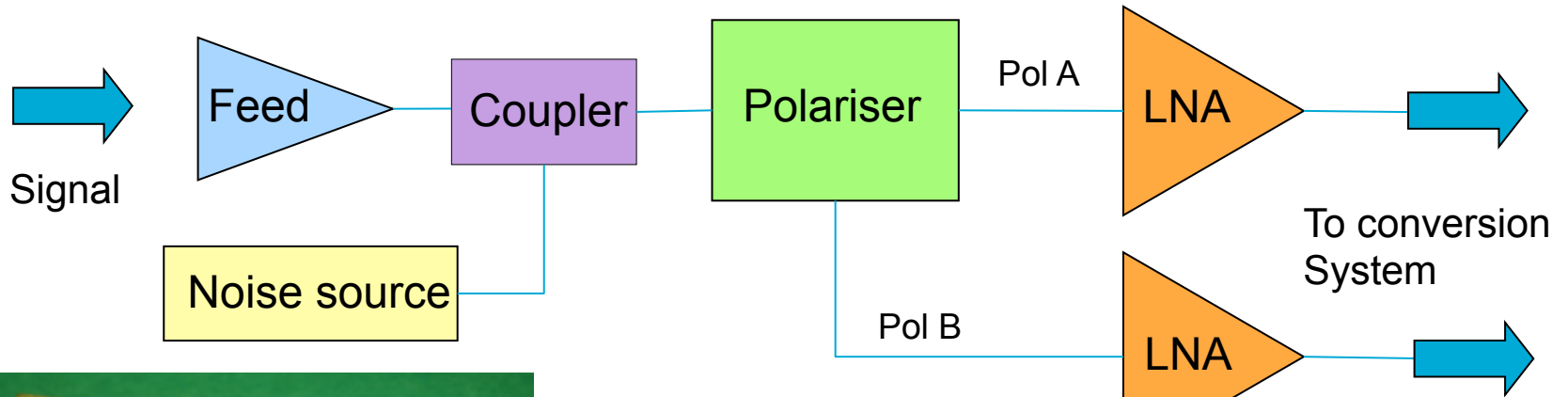


4cm Ortho-mode transducer

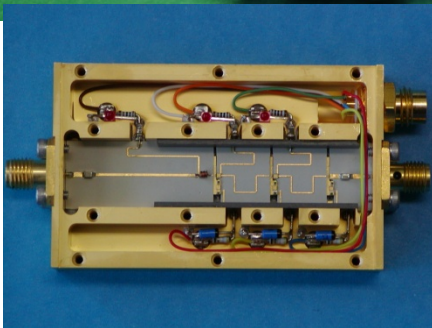
# Separating Polarisations – Ortho-mode Transducers (OMTs)



# Low Noise Amplifiers (LNA)

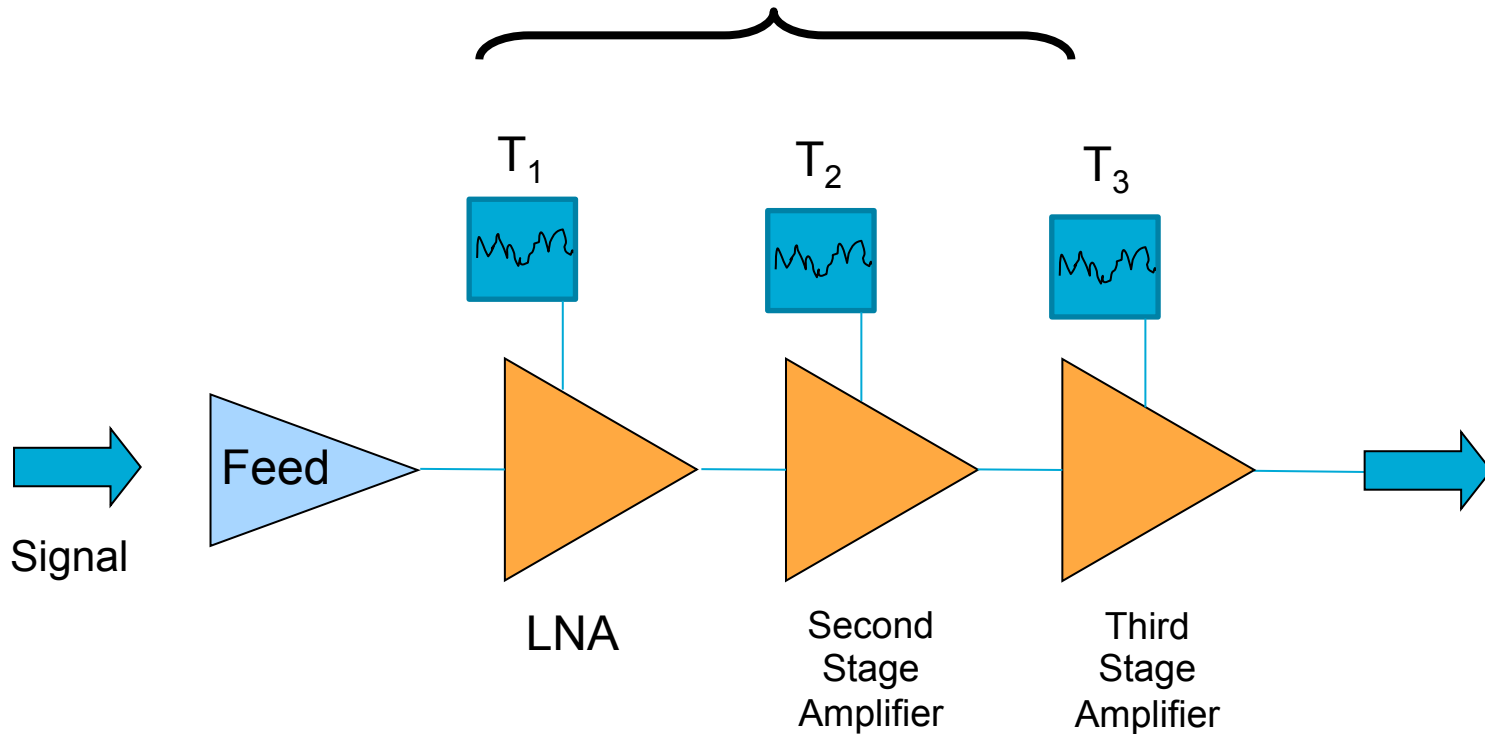


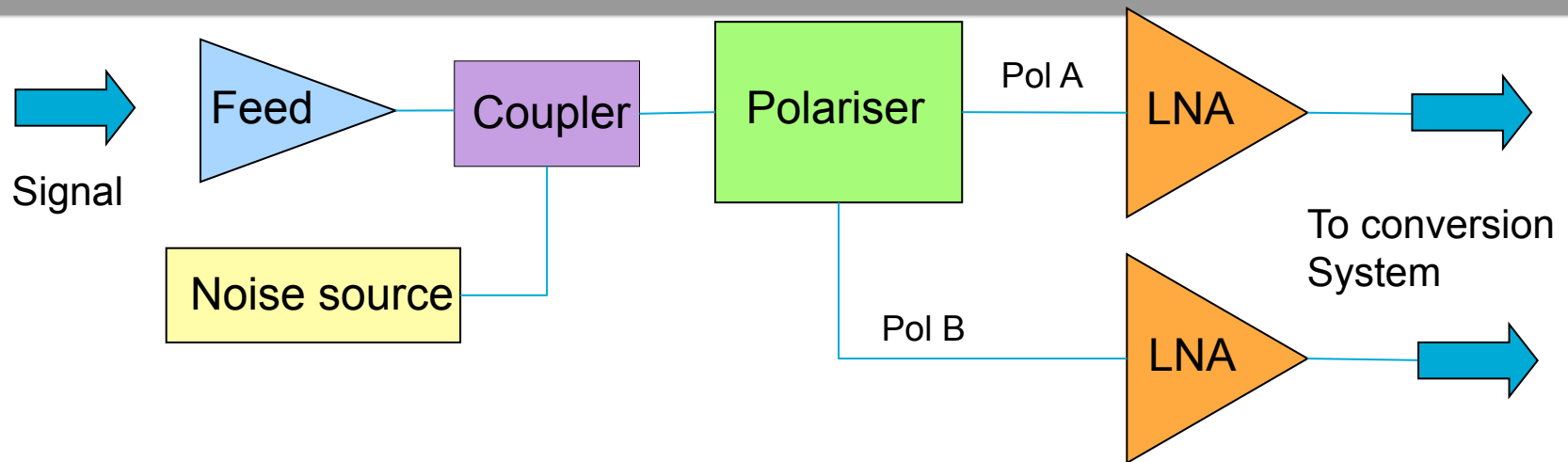
High Electron Mobility Transistor (HEMT)



# Why is the first Low Noise Amplifier so important?

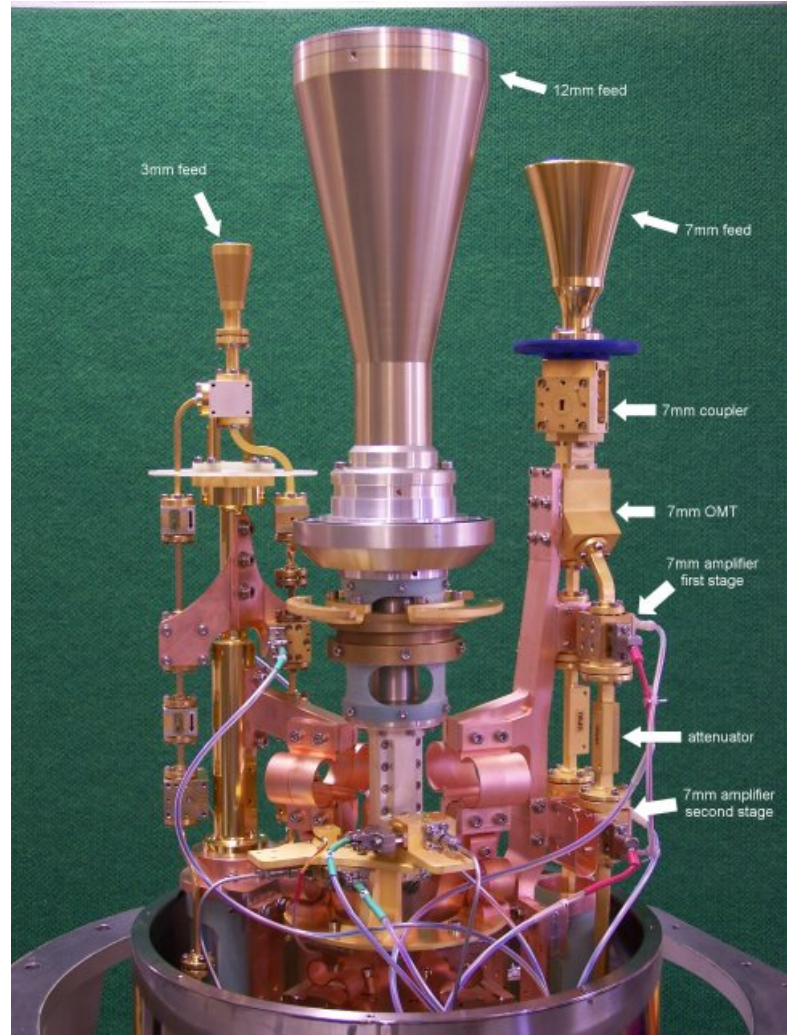
$$T_{system} = T_1 + \frac{T_2}{Gain_{LNA}} + \frac{T_3}{Gain_{LNA} \times G_2} + \frac{T_4}{Gain_{LNA} \times G_2 \times G_3} \dots\dots$$





....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.



# What is the rest of the stuff?



What's this?

What's this?

What's this?

# Cryogenics

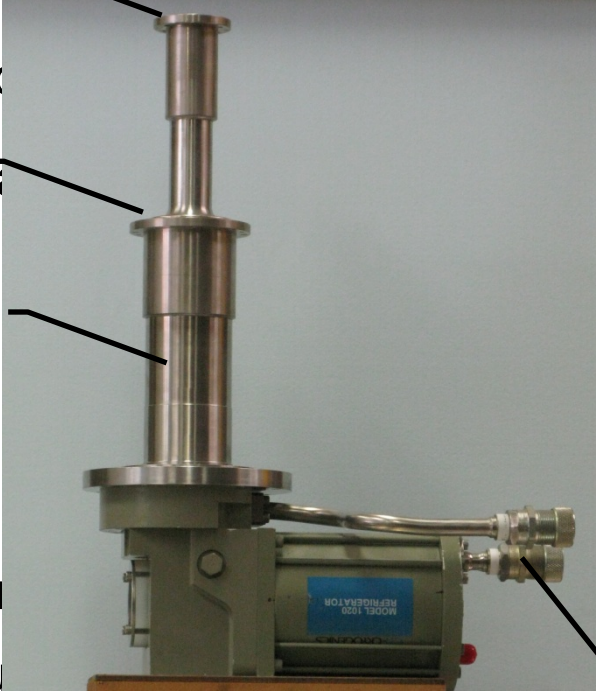
## Compress - Refrigerate - Compress

15K section

1. Compressed gas

70K section

Cold finger



3. On return

Compressed gas

As it is expanded

the cooling power

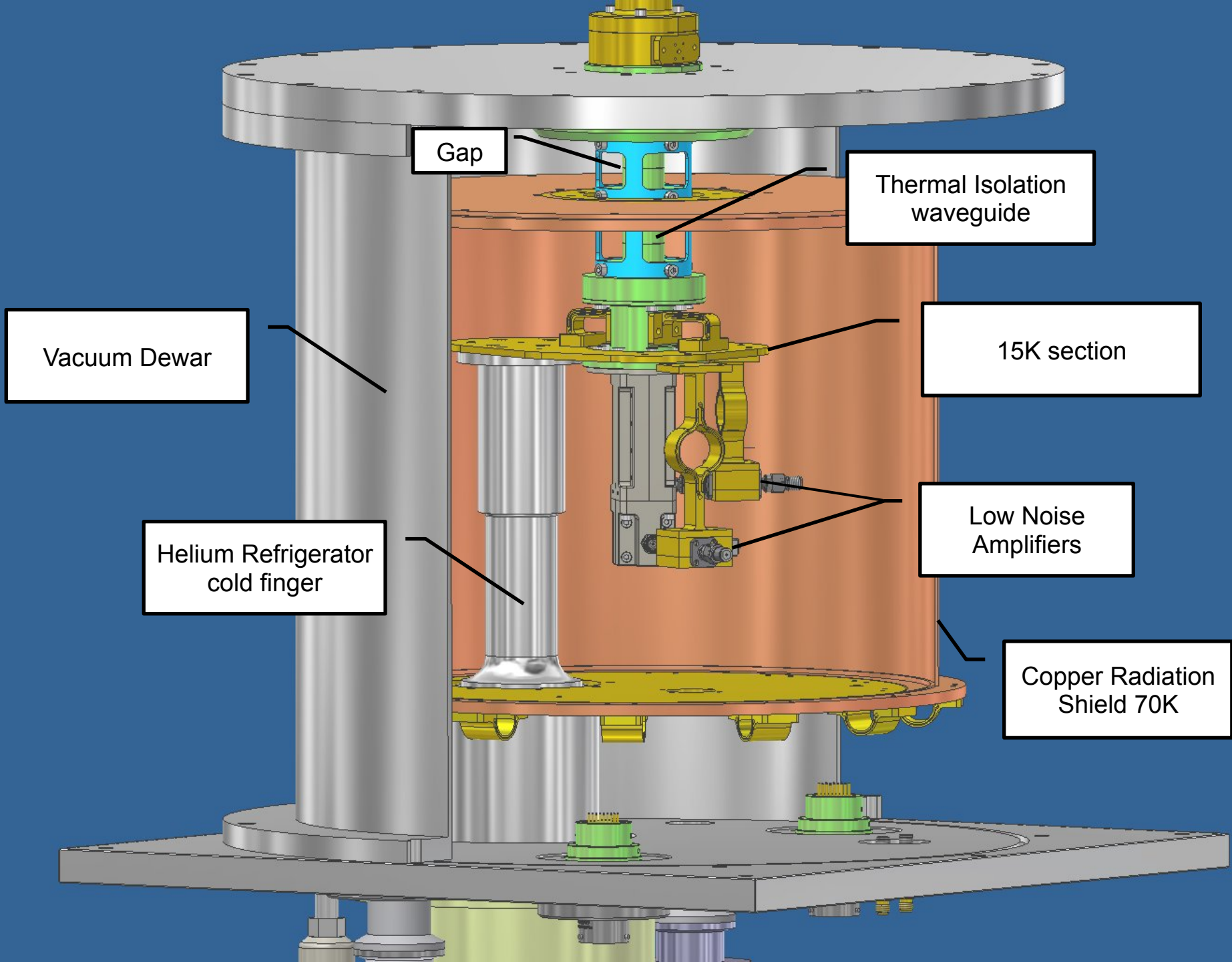
is reversed, getting

It exits the cryodyne at ~80psi and

Helium Lines

Helium Refrigerator  
Hence closed cycle system.





Gap

Thermal Isolation waveguide

Vacuum Dewar

15K section

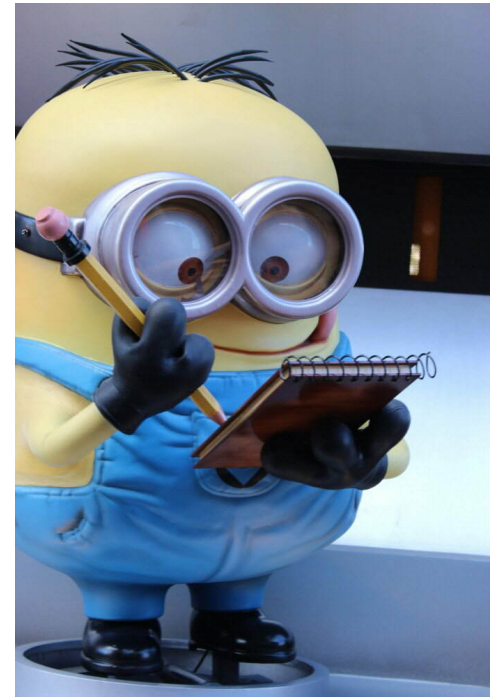
Helium Refrigerator cold finger

Low Noise Amplifiers

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 →

$$10 \times 10^{-26} \text{ W m}^{-2}\text{Hz}^{-1} \times 1900\text{m}^2 \times 1 \times 10^9 \text{ Hz} \\ = 2 \times 10^{-13} \text{ W}$$

Effective area of Parkes telescope dish

Bandwidth of Digital Filter Bank 3

Your Hand →

$$1.38 \times 10^{-23} \text{ W Hz}^{-1}\text{K}^{-1} \times 300\text{K} \times 1 \times 10^9 \text{ Hz} \\ = 4 \times 10^{-12} \text{ W}$$

Boltzmann's constant

Mobile Phone →

$$\approx 1\text{W}$$

Mobile Phone on the moon →

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

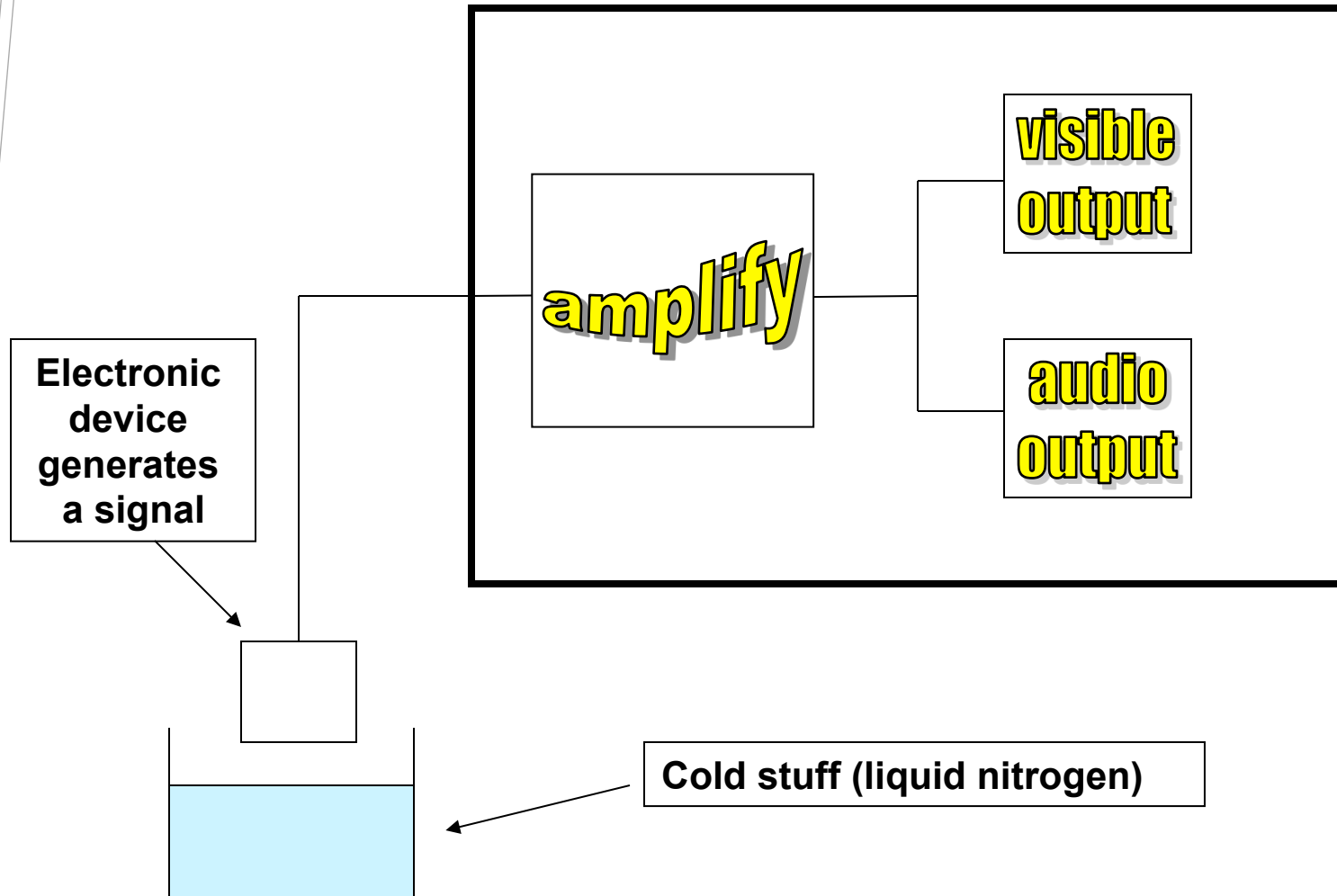
Lunar Distance

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

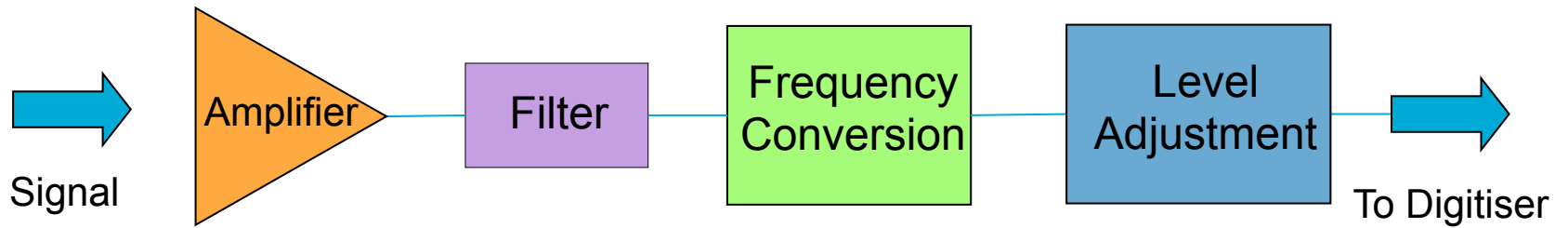


# What is the rest of the stuff?



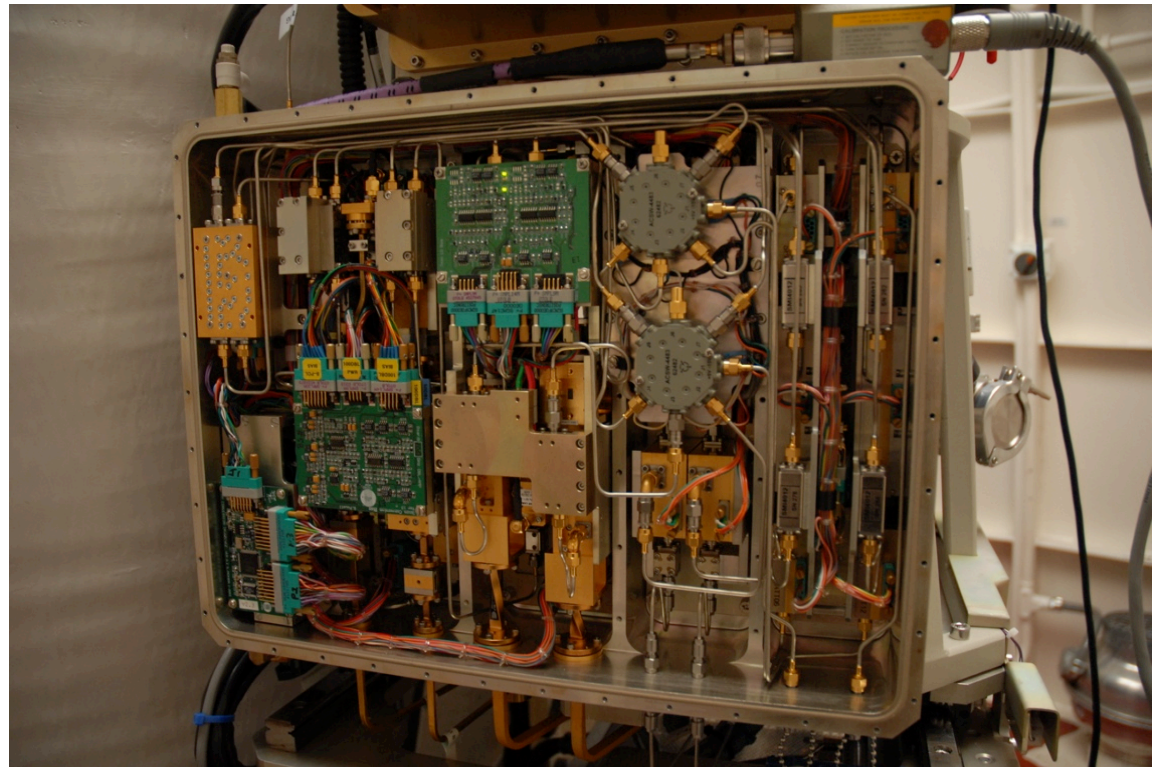
What's this?

# The Conversion System



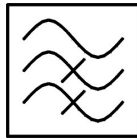
Contains:

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

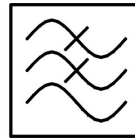


# Filters

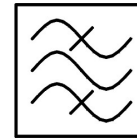
## High Pass Filter



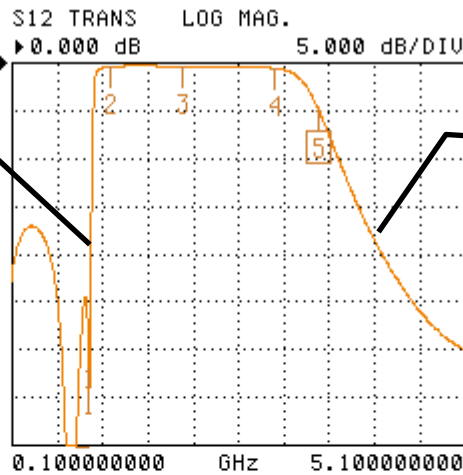
## Low Pass Filter



## Band Pass Filter

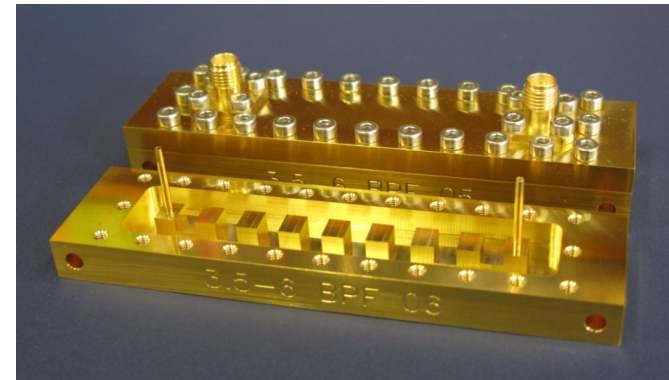
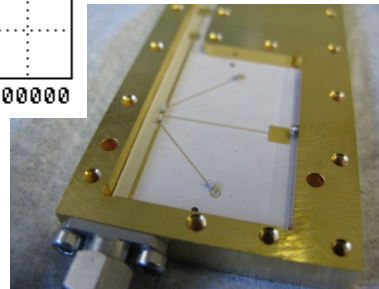


Hard roll off where necessary to stop strong interference

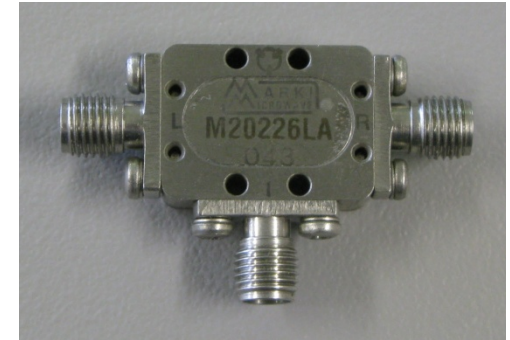
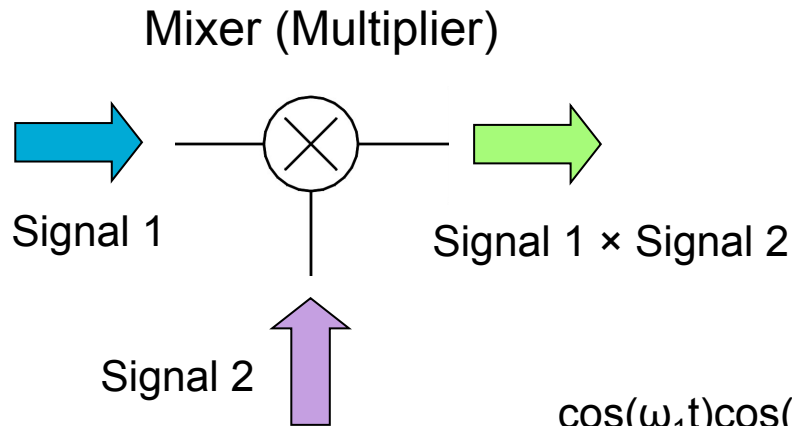


Slow roll off where possible so you can push the band edges

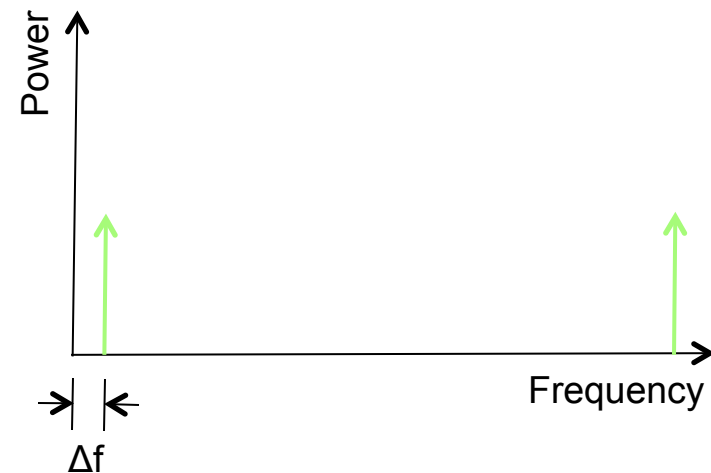
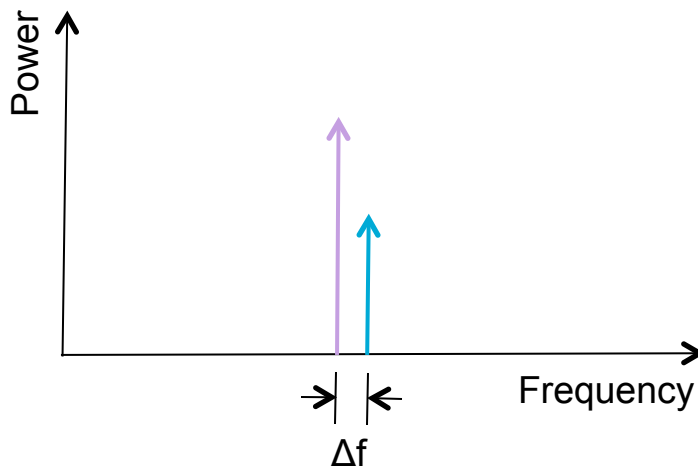
21cm band filter



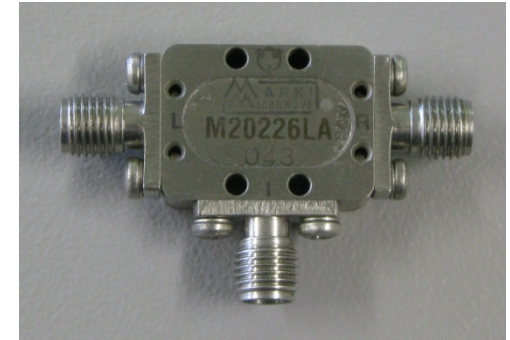
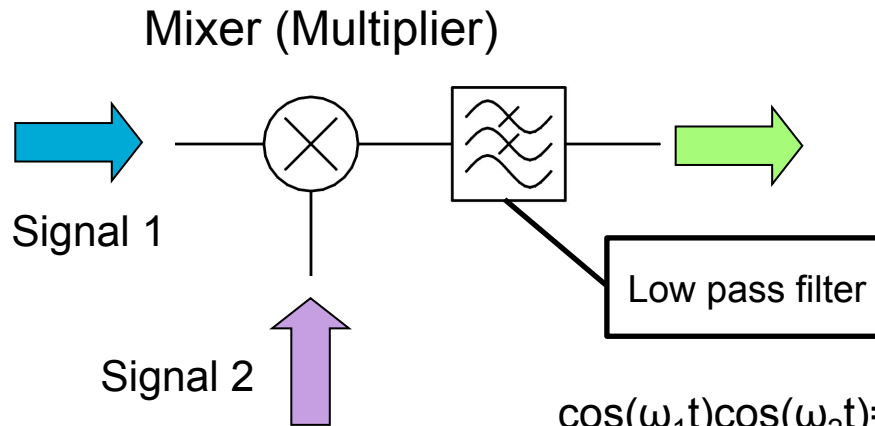
# Mixing it down – Frequency Conversion



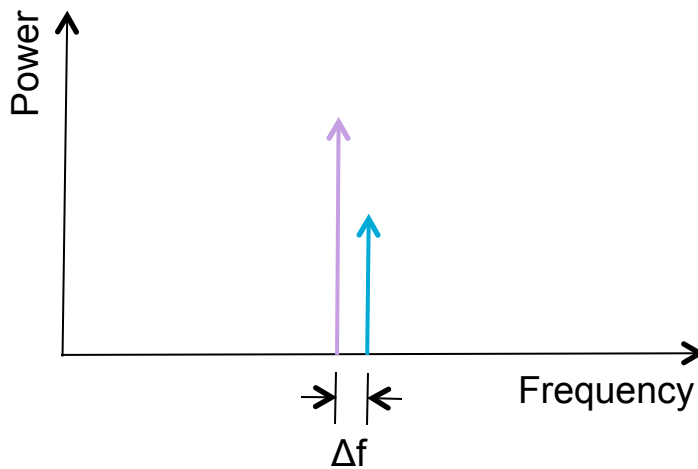
$$\cos(\omega_1 t)\cos(\omega_2 t) = \frac{1}{2}[\cos((\omega_1 + \omega_2)t) + \cos((\omega_1 - \omega_2)t)]$$



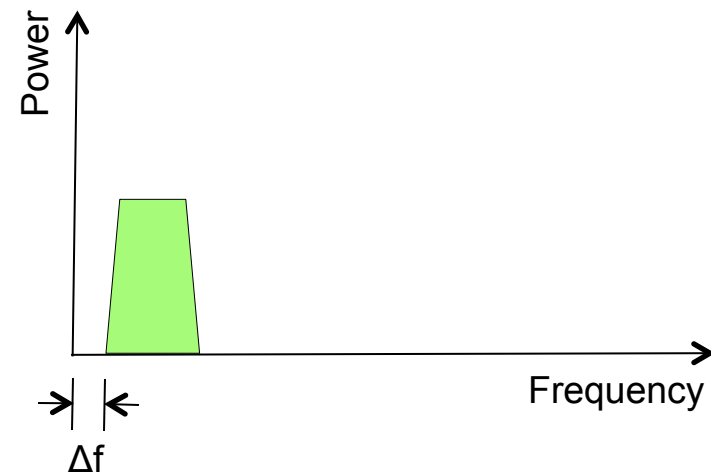
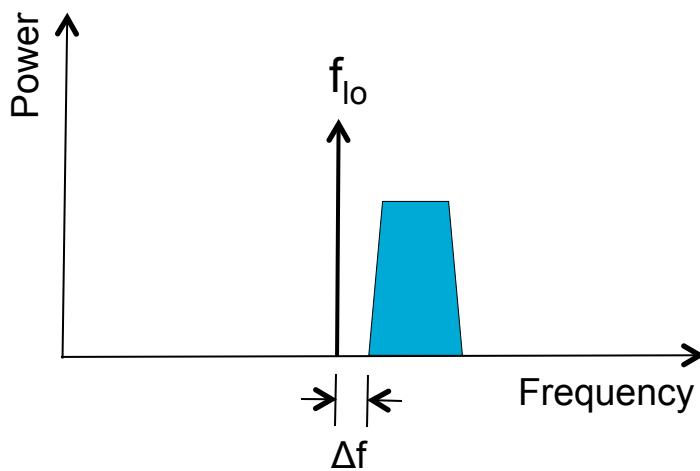
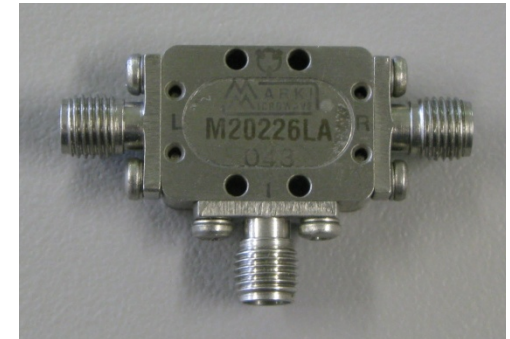
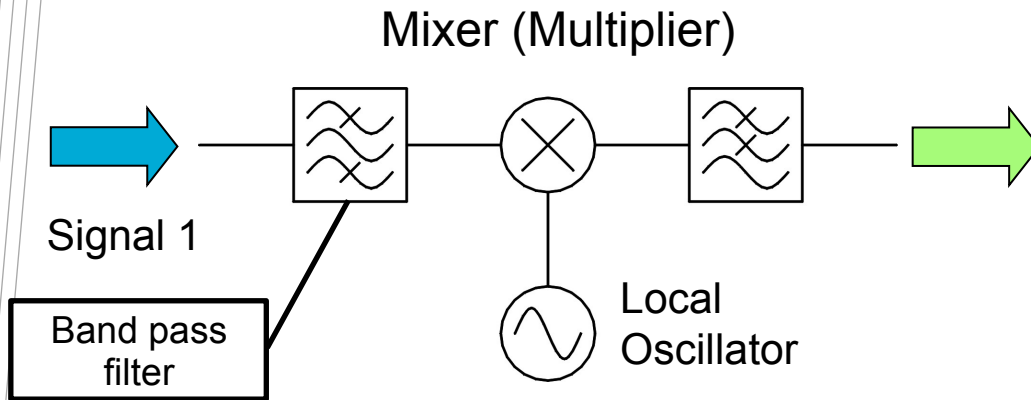
# Mixing it down – Frequency Conversion



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

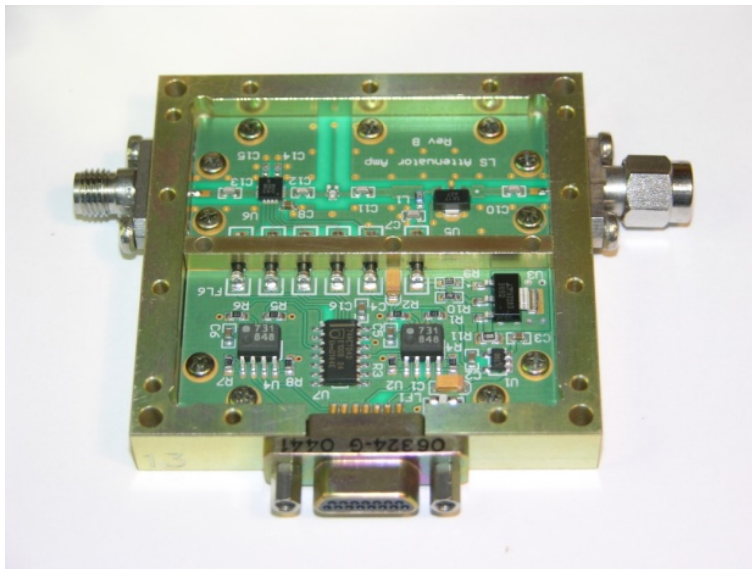


# Mixing it down – Frequency Conversion



# Attenuators – The Volume Knob

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

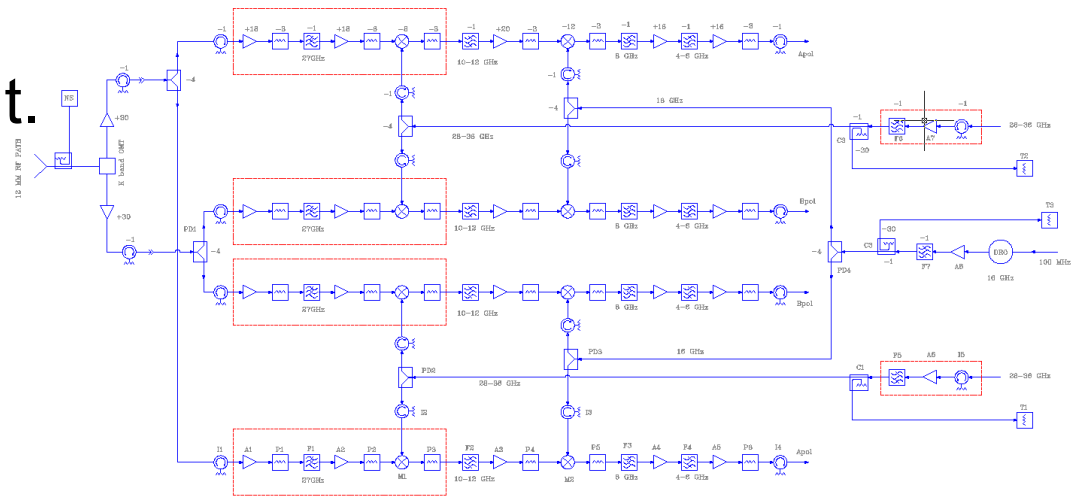


Just like some other systems if you turn the signal down too far all you get is noise and if you turn it up to far you get distortion!

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.



Parkes 12mm Receiver Conversion System  
GGM 2-2007

# What is the rest of the stuff?

What's this?



Display Layout Point Table

| Point                          | ca01    | ca02    | ca03   | ca04   | ca05  | ca06   | Units |
|--------------------------------|---------|---------|--------|--------|-------|--------|-------|
| KA FET drain current - stage 1 | 3.0128  | 3.0909  | 6.0256 | 6.0573 | 5.989 | 4.0931 | mA    |
| KA FET drain current - stage 2 | 8.0398  | 5.0868  | 8.0264 |        |       |        |       |
| KA FET drain current - stage 3 | 10.0247 | 10.1492 | 9.097  |        |       |        |       |
| KA FET drain voltage - stage 1 | 0.99539 | 1.01236 | 0.9975 |        |       |        |       |
| KA FET drain voltage - stage 2 | 1.10355 | 1.12113 | 1.1026 |        |       |        |       |
| KA FET drain voltage - stage 3 | 1.30412 | 1.32475 | 1.2993 |        |       |        |       |
| KA FET gate voltage - stage 1  | 0.07654 | 0.06201 | 0.0584 |        |       |        |       |
| KA FET gate voltage - stage 2  | 0.14576 | 0.09888 | 0.0610 |        |       |        |       |
| KA FET gate voltage - stage 3  | 0.15235 | 0.15332 | 0.0598 |        |       |        |       |
| KB FET drain current - stage 1 | 2.9713  | 4.0431  | 6.0012 |        |       |        |       |
| KB FET drain current - stage 2 | 9.6072  | 10.1358 | 7.6028 |        |       |        |       |
| KB FET drain current - stage 3 | 9.0139  | 12.1989 | 9.9857 |        |       |        |       |
| KB FET drain voltage - stage 1 | 1.00589 | 1.11515 | 0.9982 |        |       |        |       |
| KB FET drain voltage - stage 2 | 1.10184 | 1.62688 | 1.0985 |        |       |        |       |
| KB FET drain voltage - stage 3 | 1.30448 | 1.83355 | 1.2988 |        |       |        |       |
| KB FET gate voltage - stage 1  | 0.06214 | 0.04028 | 0.0405 |        |       |        |       |
| KB FET gate voltage - stage 2  | 0.16041 | 0.08594 | 0.0207 |        |       |        |       |
| KB FET gate voltage - stage 3  | 0.10779 | 0.09363 | 0.0455 |        |       |        |       |

temperatures and pressures

KQW Cryogenics Summary

Window Navigator Setup Export Help

Display Layout Time Series Time Series Point Table

### KQW Cryo Temperatures

### KQW Cryo Pressures

| Point                       | ca01  | ca02  | ca03  | ca04  | ca05   | ca06  | Units |
|-----------------------------|-------|-------|-------|-------|--------|-------|-------|
| mm cryogenics summary       | OK    | OK    | OK    | OK    | OK     | OK    |       |
| mm 20 K temp 1              | 12.2  | 12.5  | 12.3  | 11.4  | 11.3   | 12.3  | K     |
| mm 20 K temp 2              | 12.7  | 13.2  | 13.3  | 12.6  | 12.2   | 12.8  | K     |
| mm 70 K temp 1              | 68.2  | 65.5  | 71.5  | 60.1  | 57.5   | 65.3  | K     |
| mm 70 K temp 2              | 94.7  | 82.6  | 92.7  | 75.8  | 73.2   | 84.5  | K     |
| mm Helium supply pressure 1 | 297.6 | 277.9 | 276.9 | 300.7 | 292.3  | 279.5 | psi   |
| mm Helium return pressure 1 | 81.6  | 89.4  | 80.4  | 81.9  | 79.8   | 76.6  | psi   |
| mm pressure differential 1  | 216.0 | 188.5 | 196.5 | 218.8 | 212.4  | 202.9 | psi   |
| mm Vacuum 1                 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0025 | 0.001 | mBa   |

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# Thank you

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