Receiver Systems

Christoph Brem

Based on a talk by Alex Dunning

The Basic Structure of a typical Radio Telescope

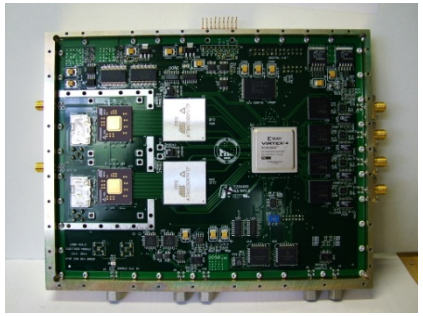
Antenna

Receiver

Conversion

Digitiser

Signal Processing / Correlator



They are much the same

Radiotelescope Receivers

Radio Receivers

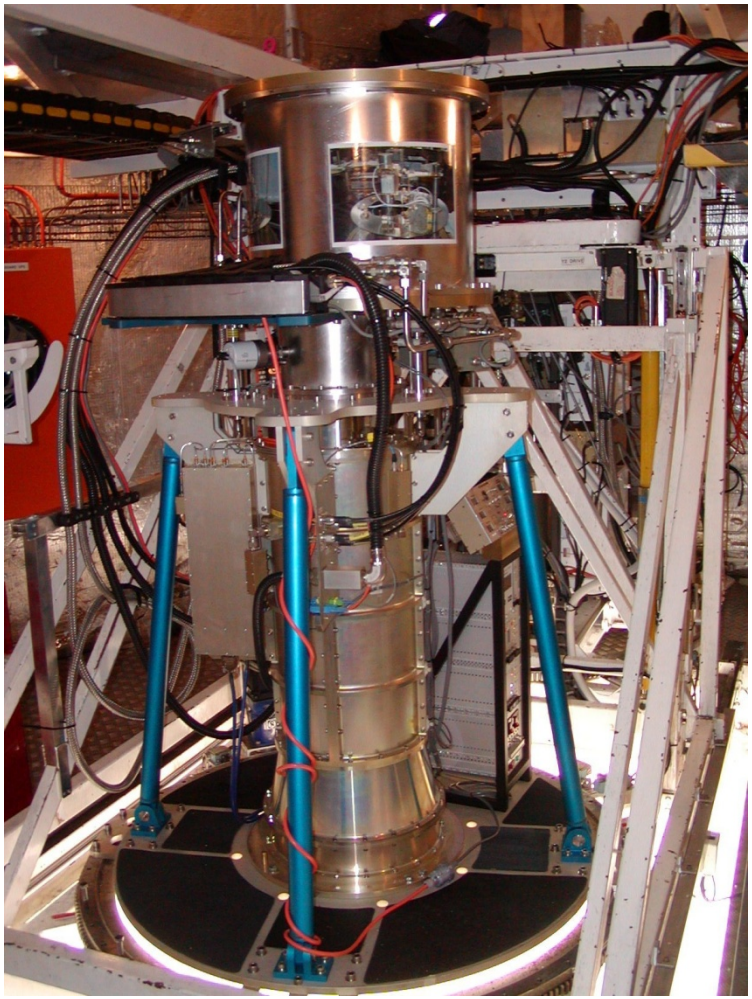
"A radio receiver converts signals from a radio antenna to a usable form" Wikipedia

Ours look more like this...

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

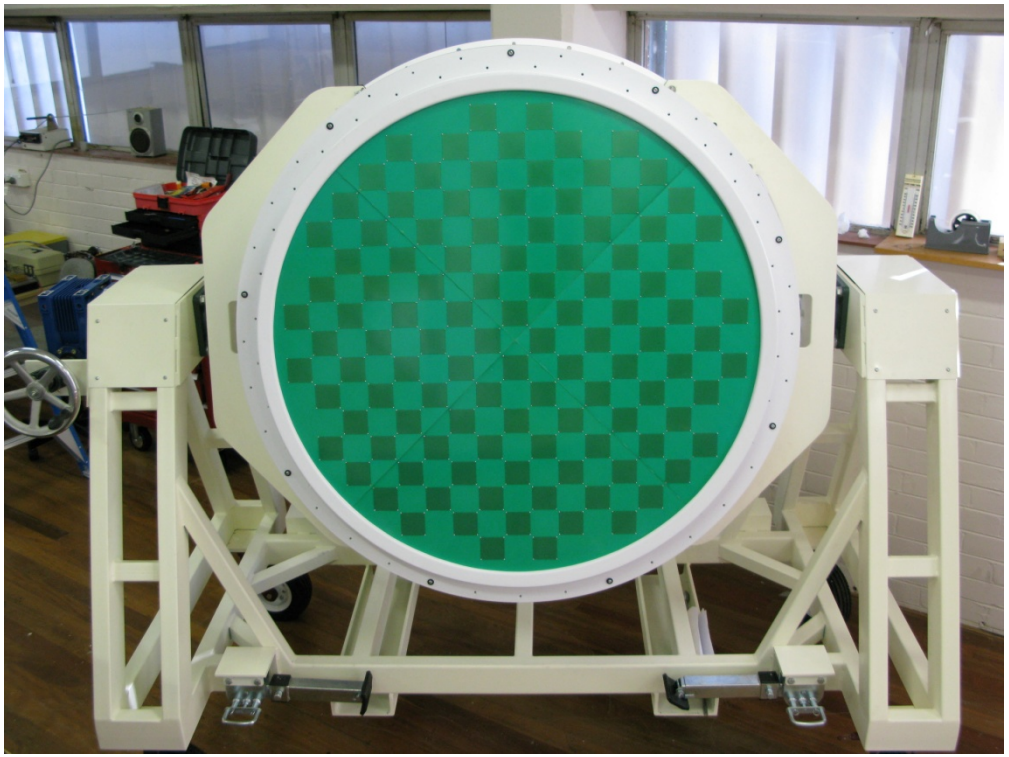
Compact Array
3/7/12mm Receiver

Or this...



Parkes 10/50cm
Receiver

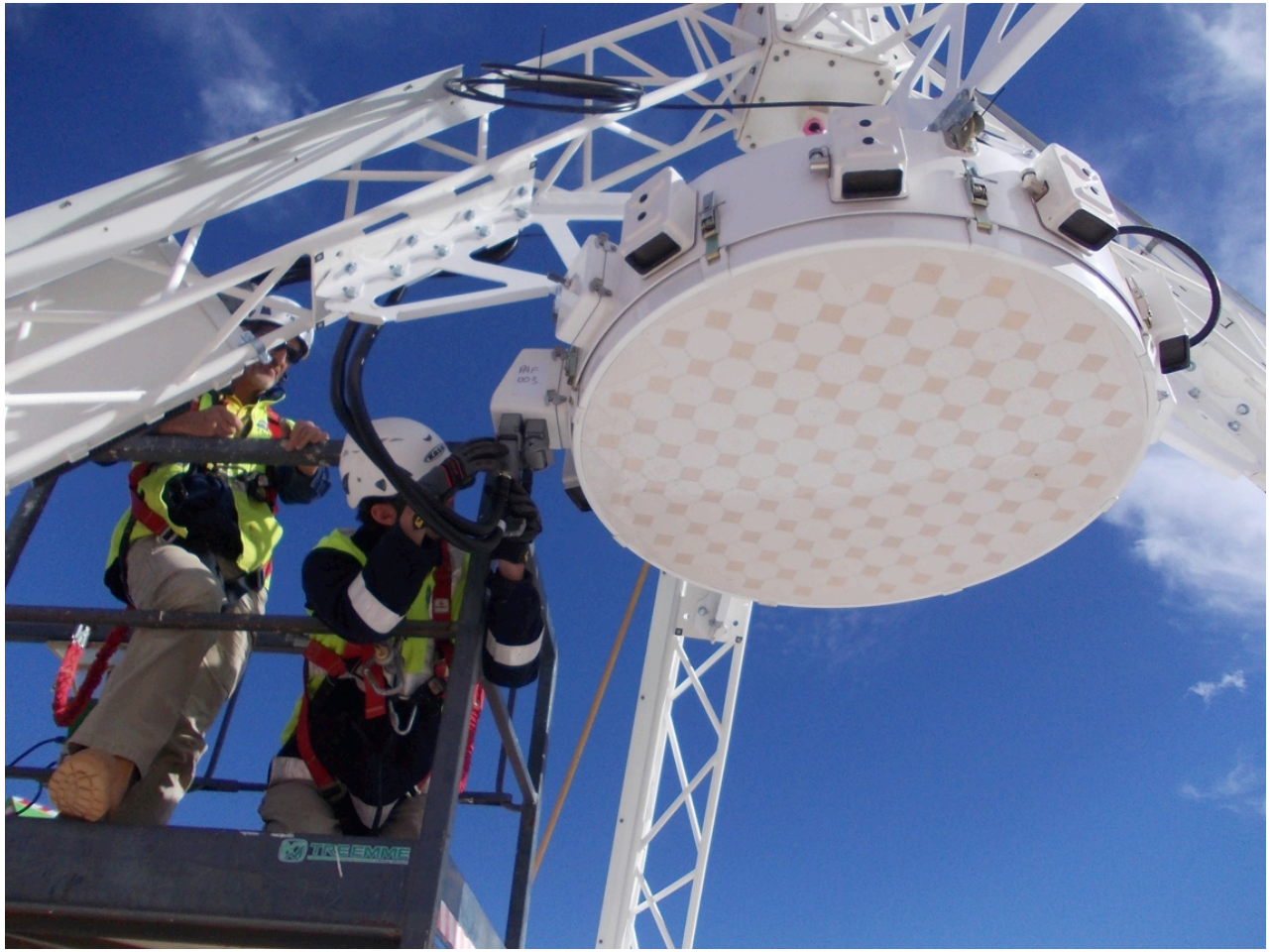
Or this...



ASKAP Phased Array Receiver (BETA)

…and our newest ones look like this

ASKAP Phased Array Receiver (ADE)

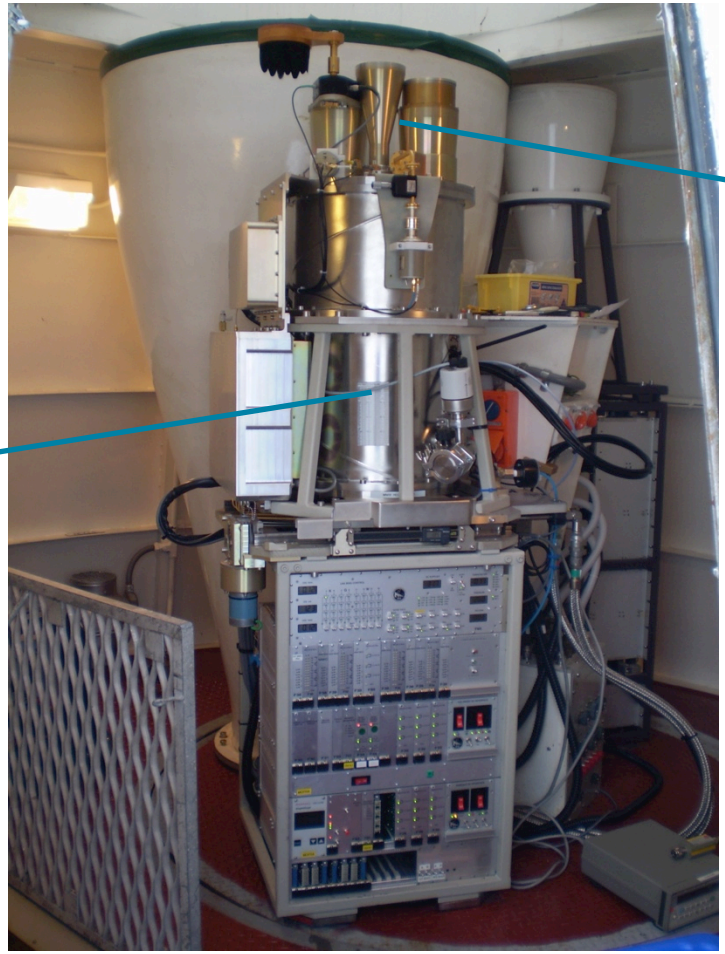


Some even look like this...

Allen Telescope Log Periodic Receiver

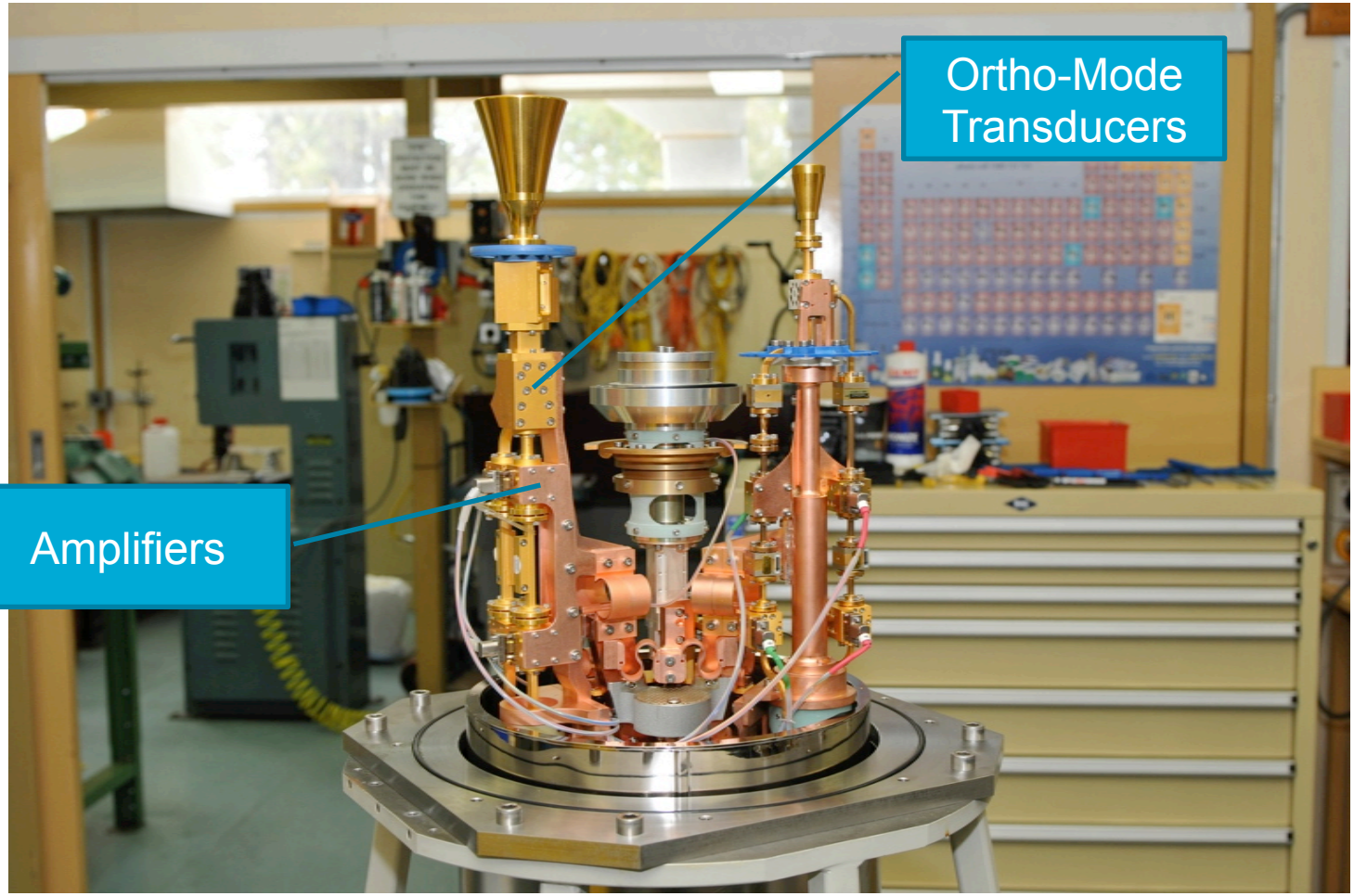
The Receiver

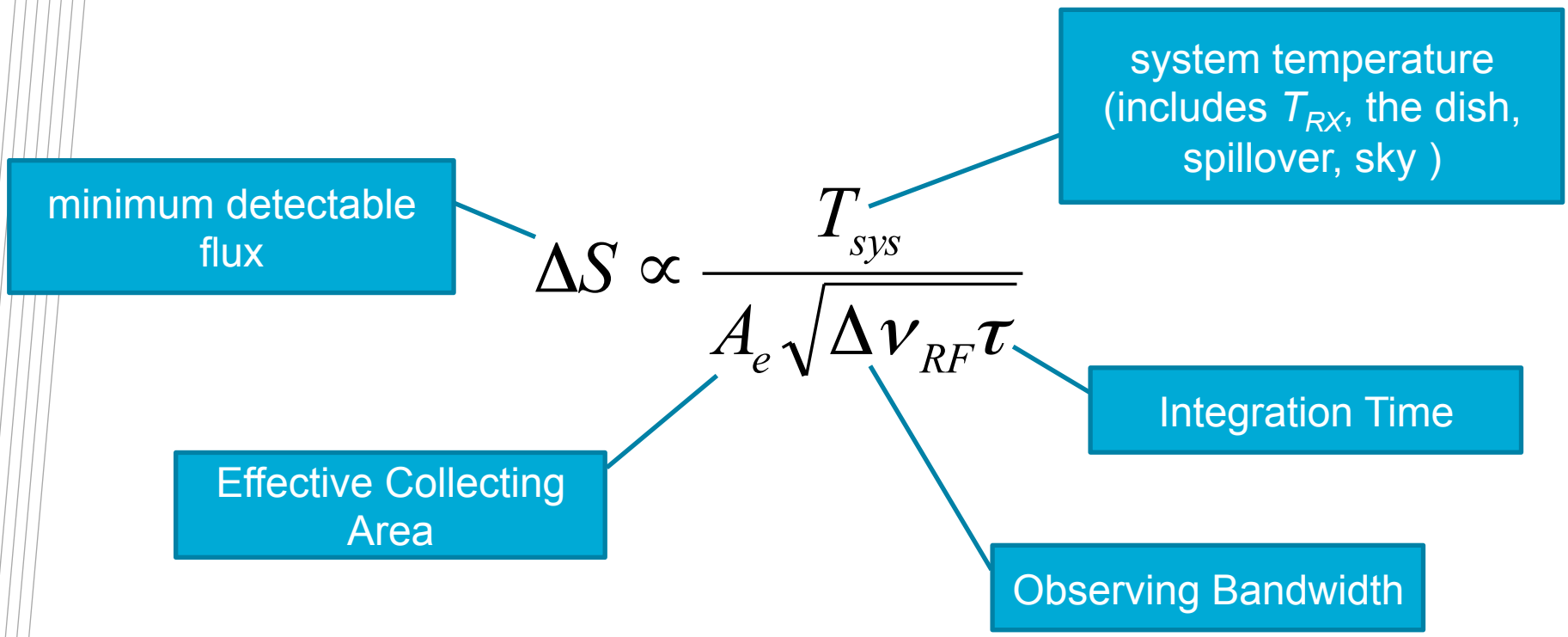
On the outside...

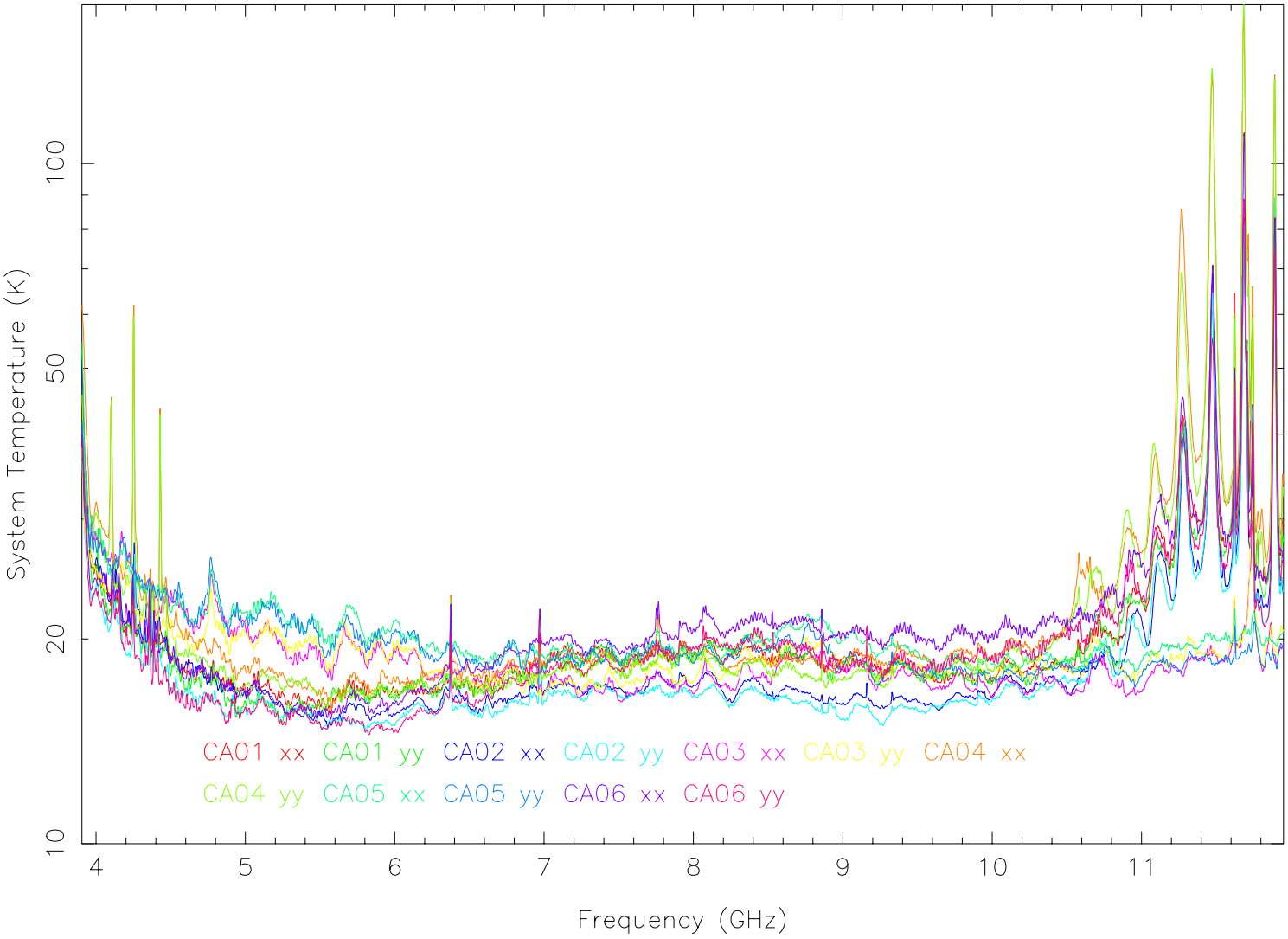


The Receiver

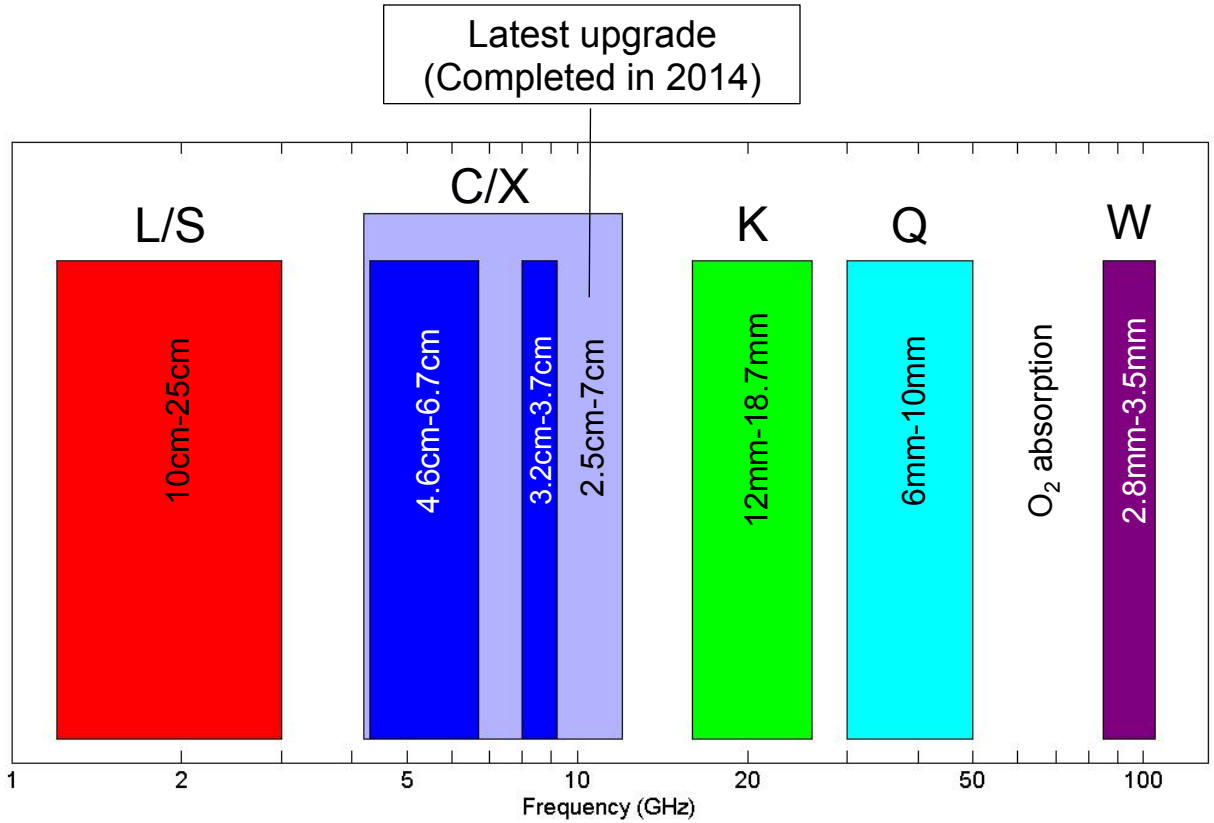
On the inside...



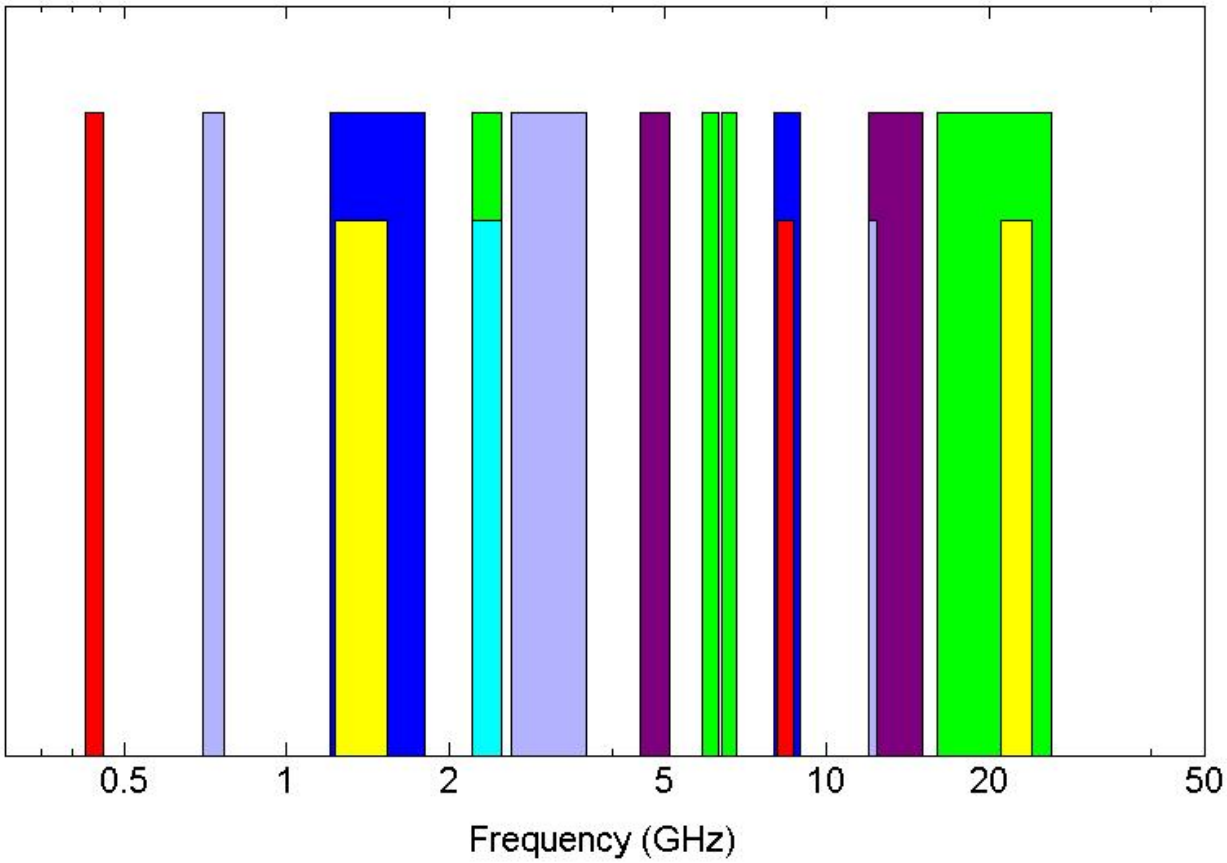

minimum detectable flux
$\Delta S \propto \frac{T_{sys}}{A_e \sqrt{\Delta \nu_{RF} \tau}}$
system temperature (includes T_{RX}, the dish, spillover, sky)
Integration Time
Effective Collecting Area
Observing Bandwidth


System Temperature (K)
10
20
50
100
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

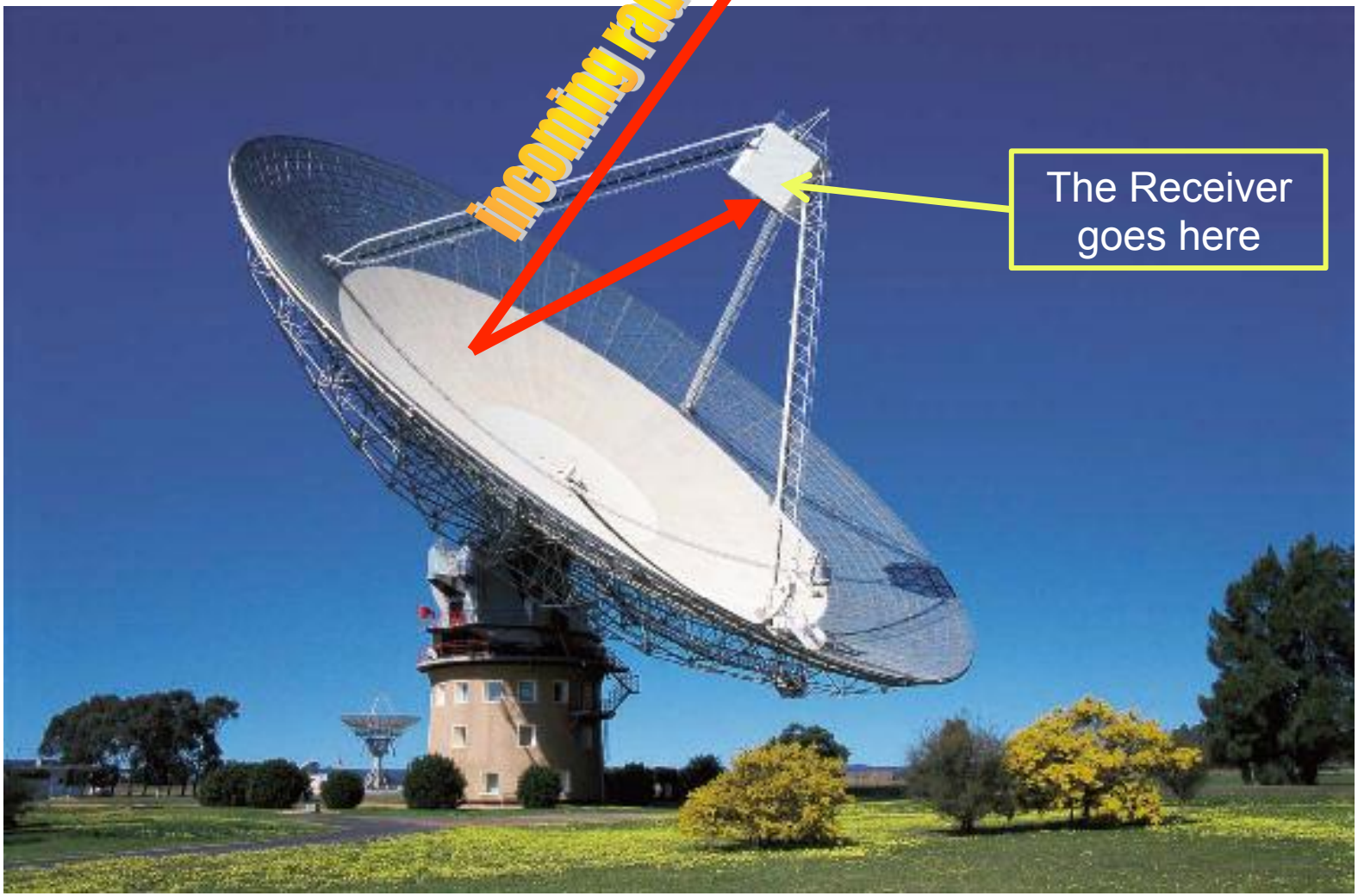


Parkes Receiver Bands

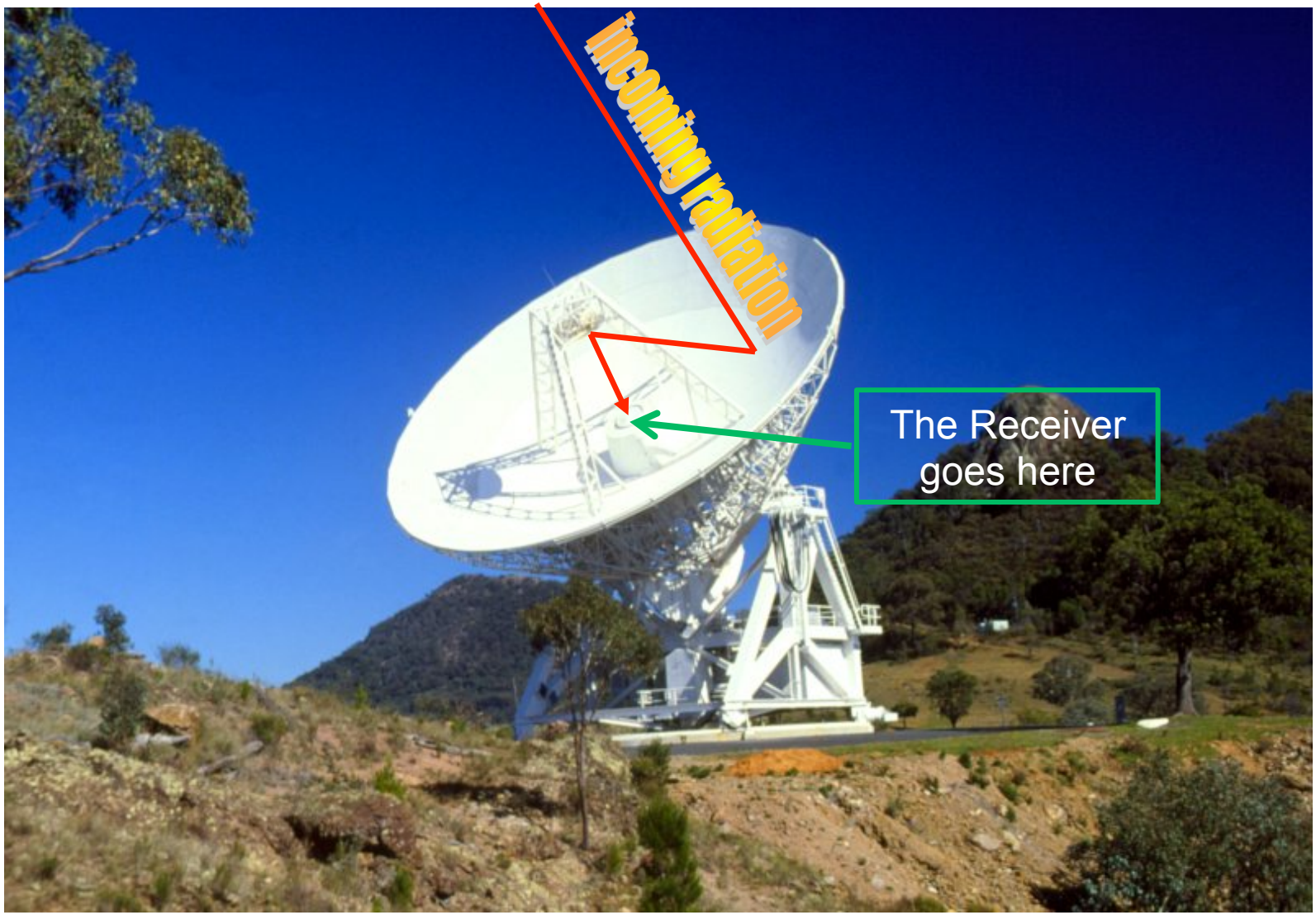


Where do they go?

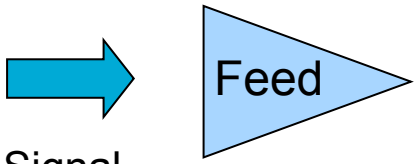
In a prime focus...



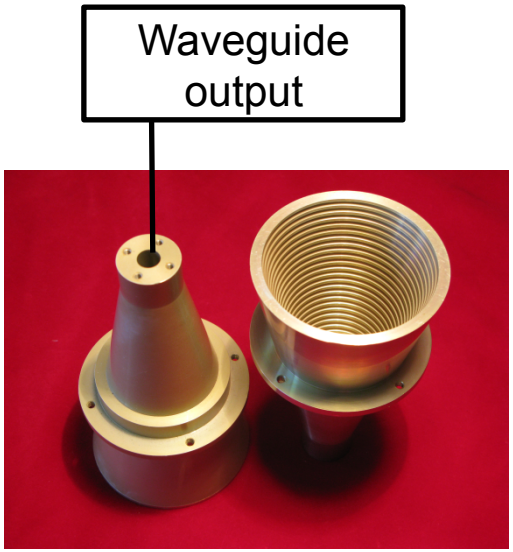
In a Cassegrain system...



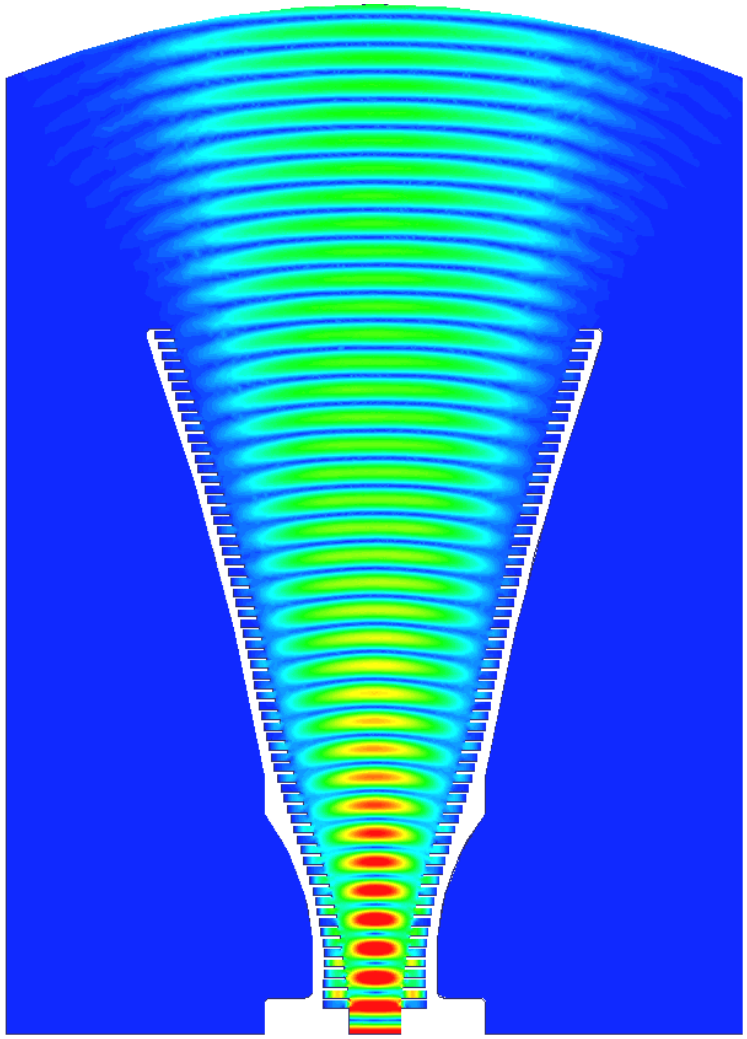
Receiving the signal – Feed horns



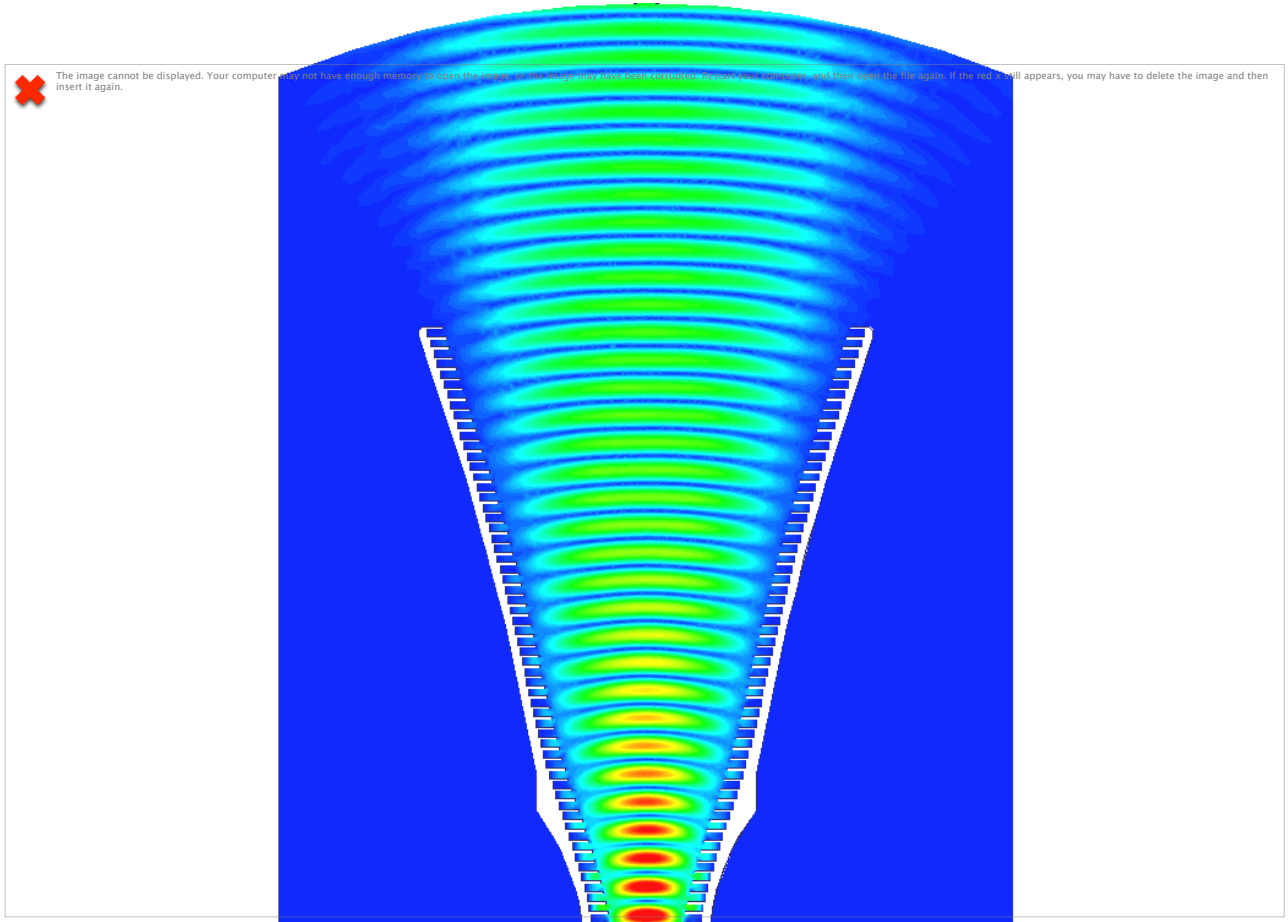
Captures the focused microwaves into a waveguide output



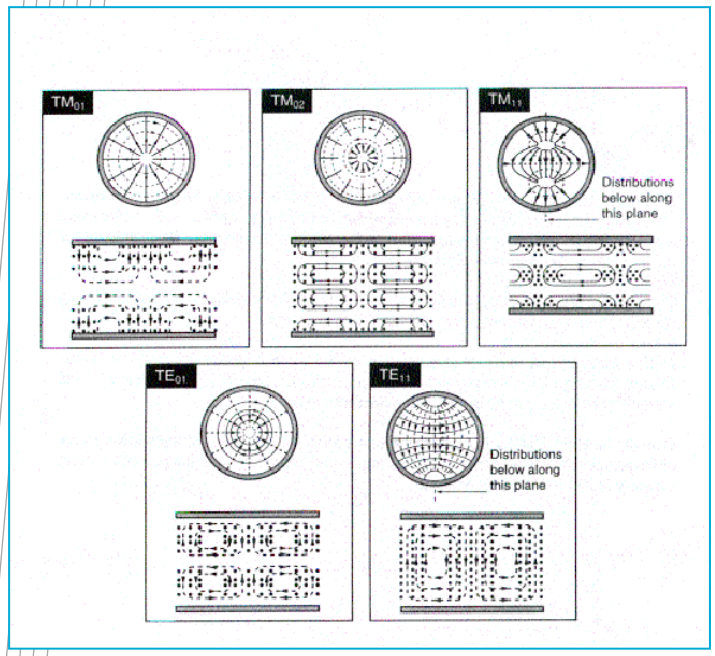
Feed Horns



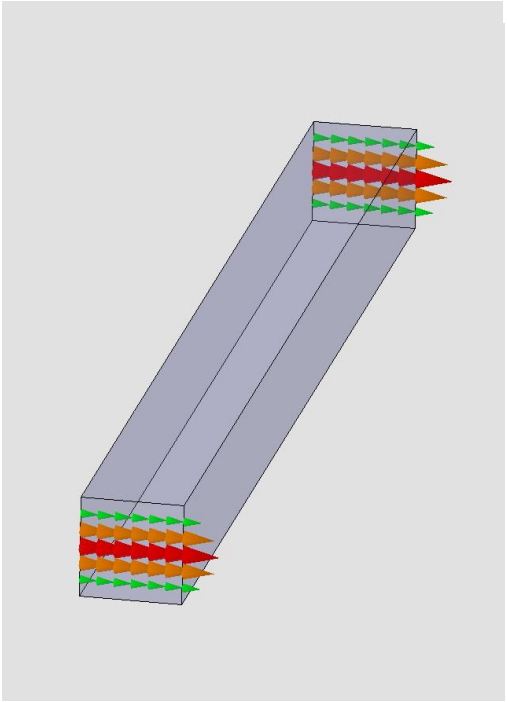
Feed Horns

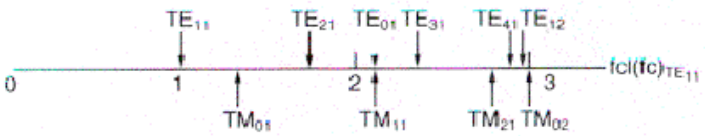

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

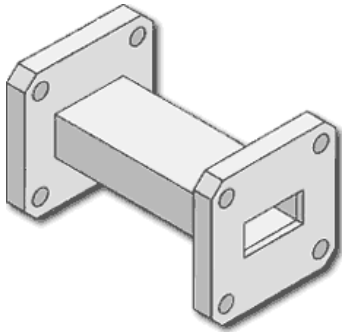
Detour: Waveguides



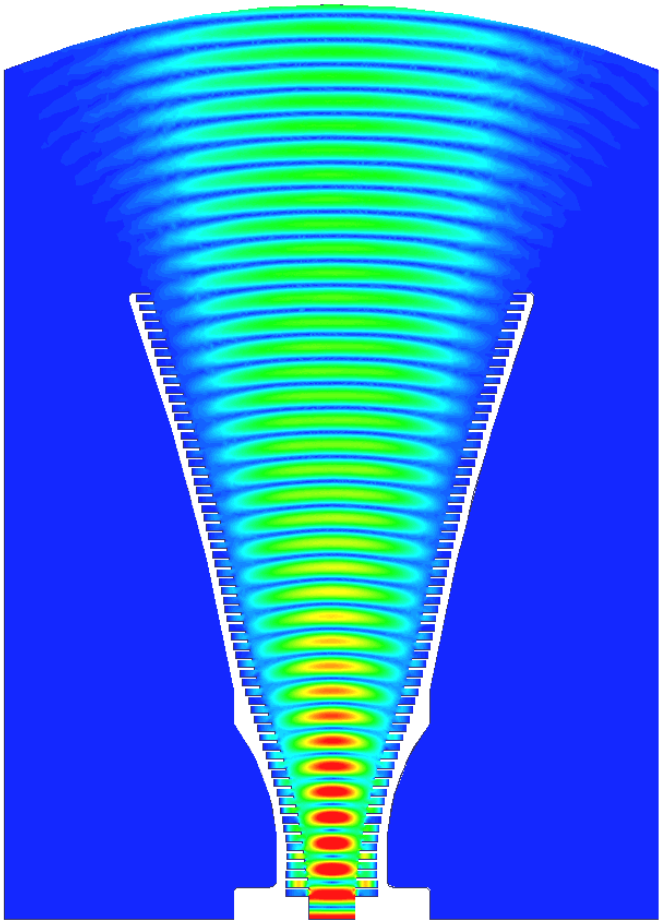
- Replace cables at high frequencies
- Operate like optical fibres for microwaves
- Only work over a limited frequency range
- Can support signals with two polarisations

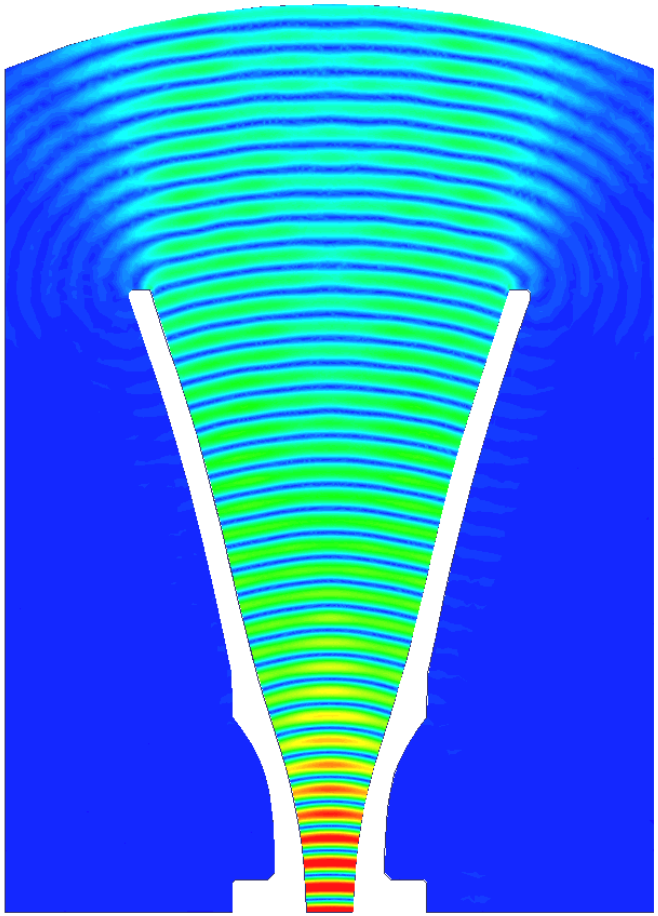






A Tale of Two Feedhorns



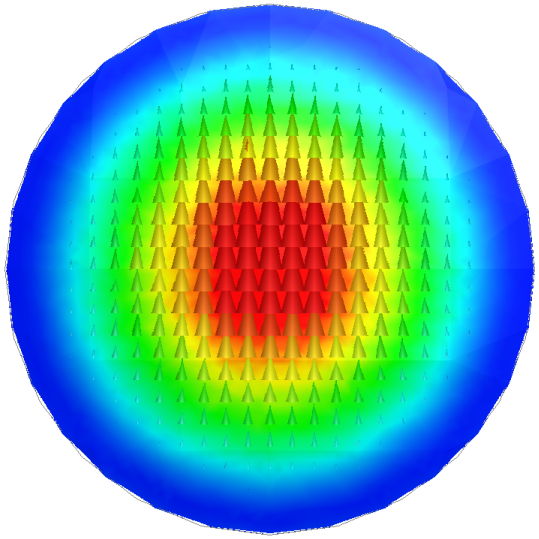


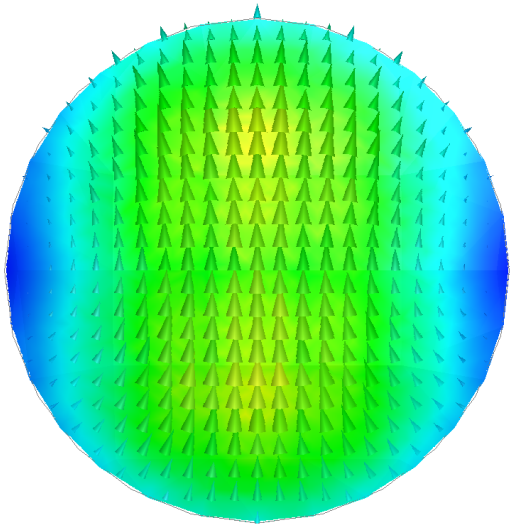
A Tale of Two Feedhorns

Corrugated

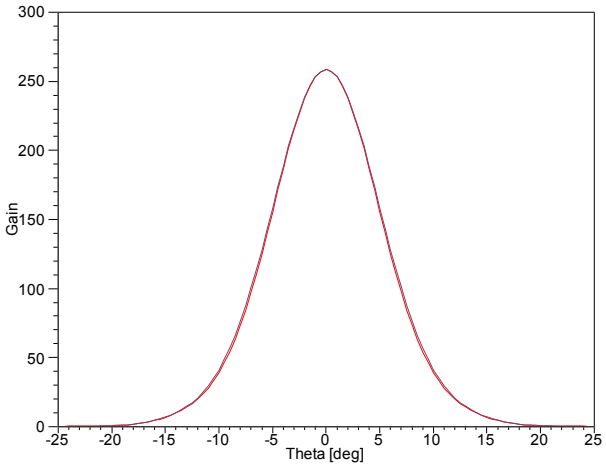
Smooth Walled

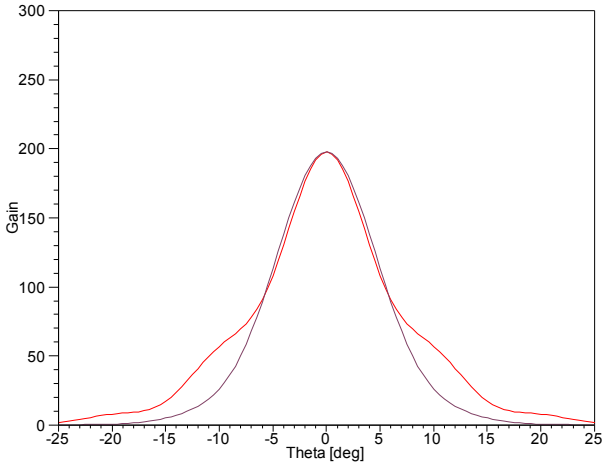
E-Field At Feed mouth



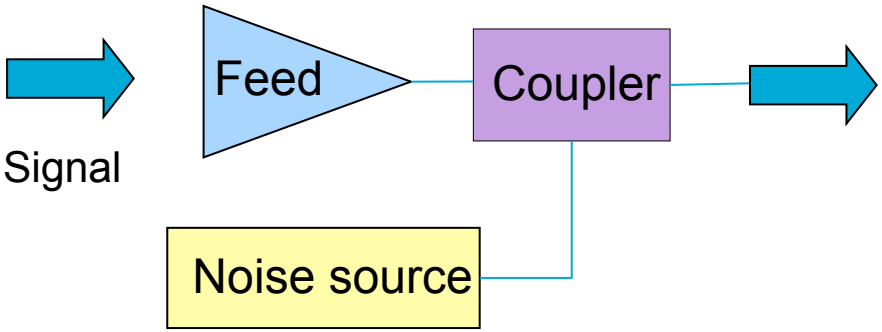


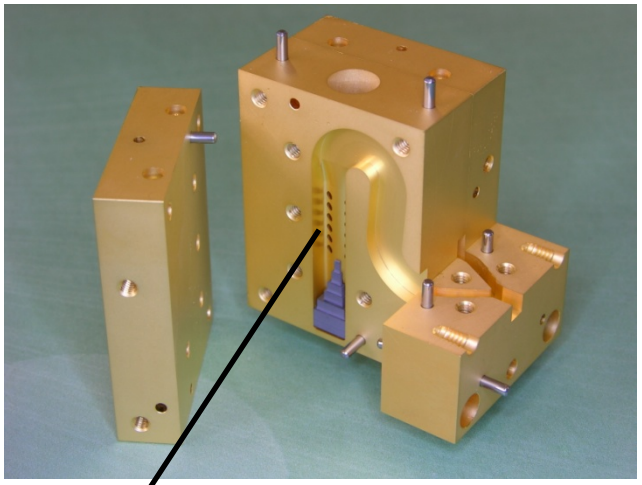
X and Y Feed Patterns





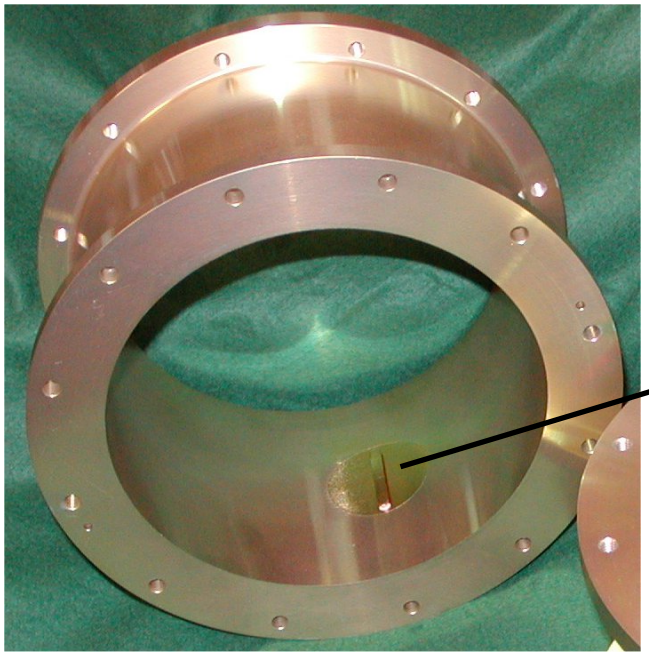
Coupling noise into the System





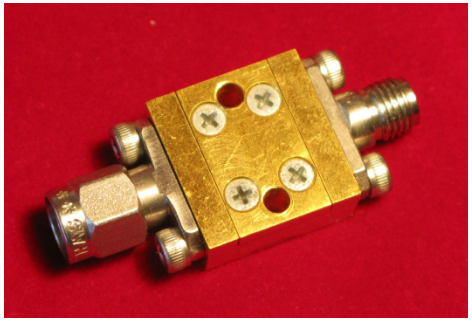
Noise coupled in through small holes

7mm waveguide coupler



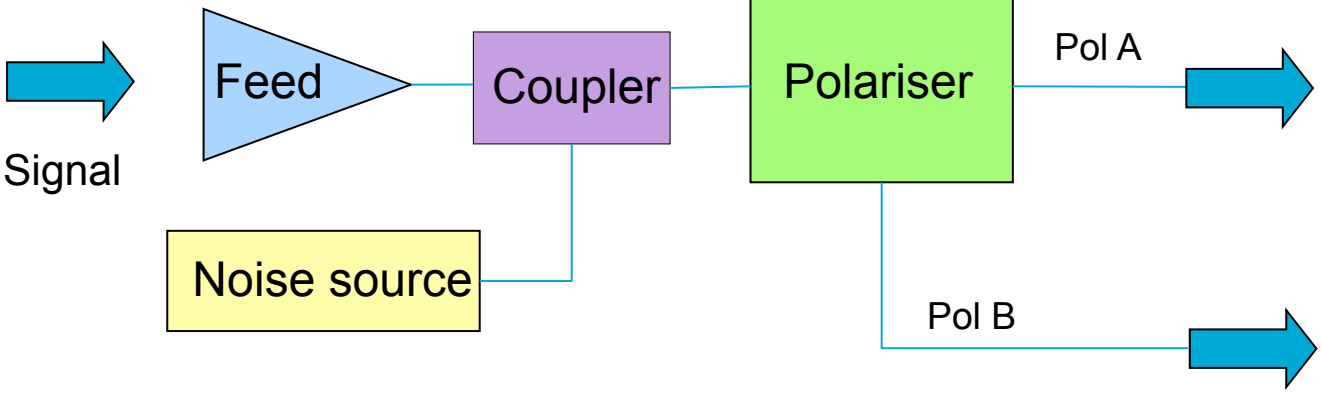
Noise coupled in through vane

21cm waveguide coupler

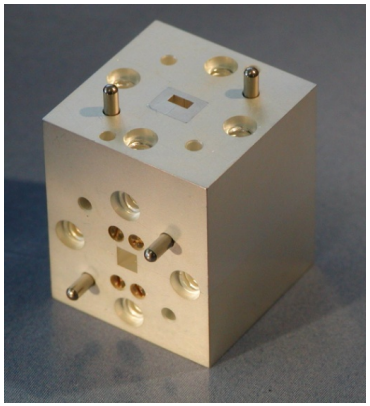


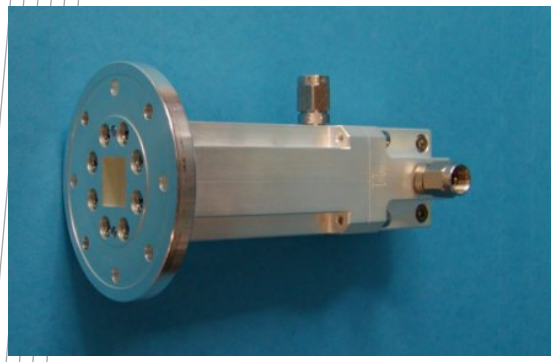
12mm noise source

Separating Polarisations – Ortho-mode Transducers (OMTs)



3mm Ortho-mode transducer





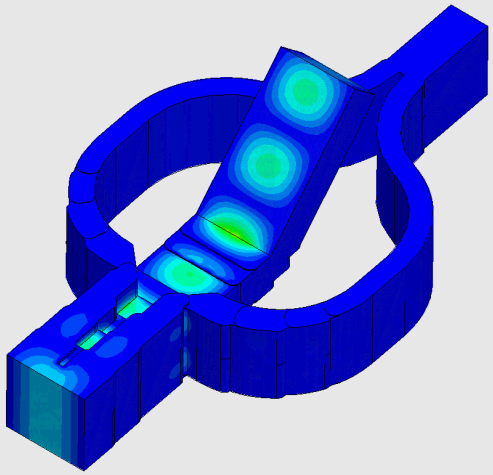
12mm Ortho-mode transducer

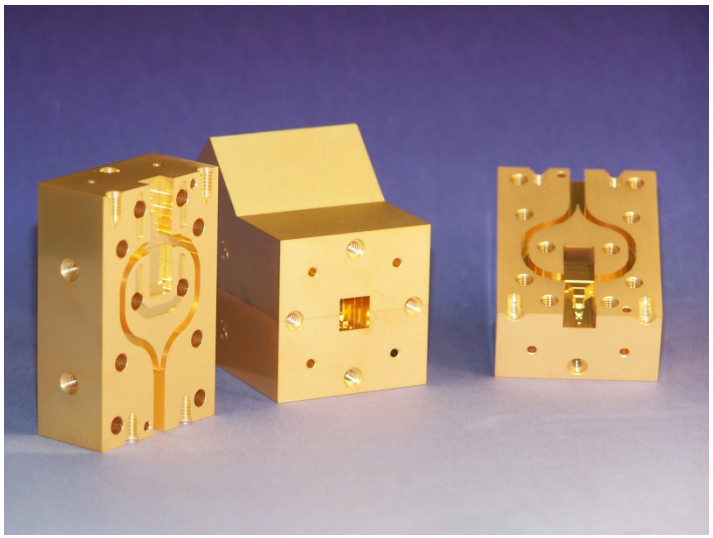
Separates incoming signal into two linear or circular polarisations

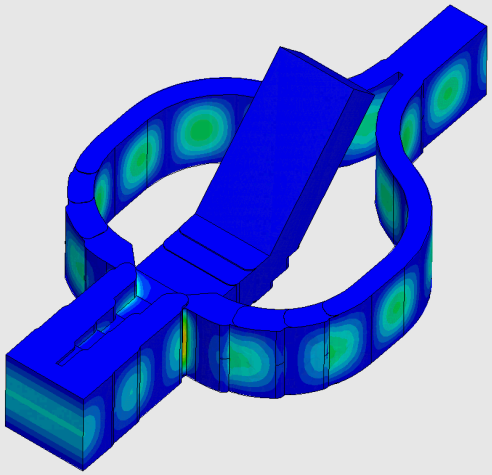
Linear OMTs exhibit higher polarisation purity over broad frequency bands (usually)

4cm Ortho-mode transducer

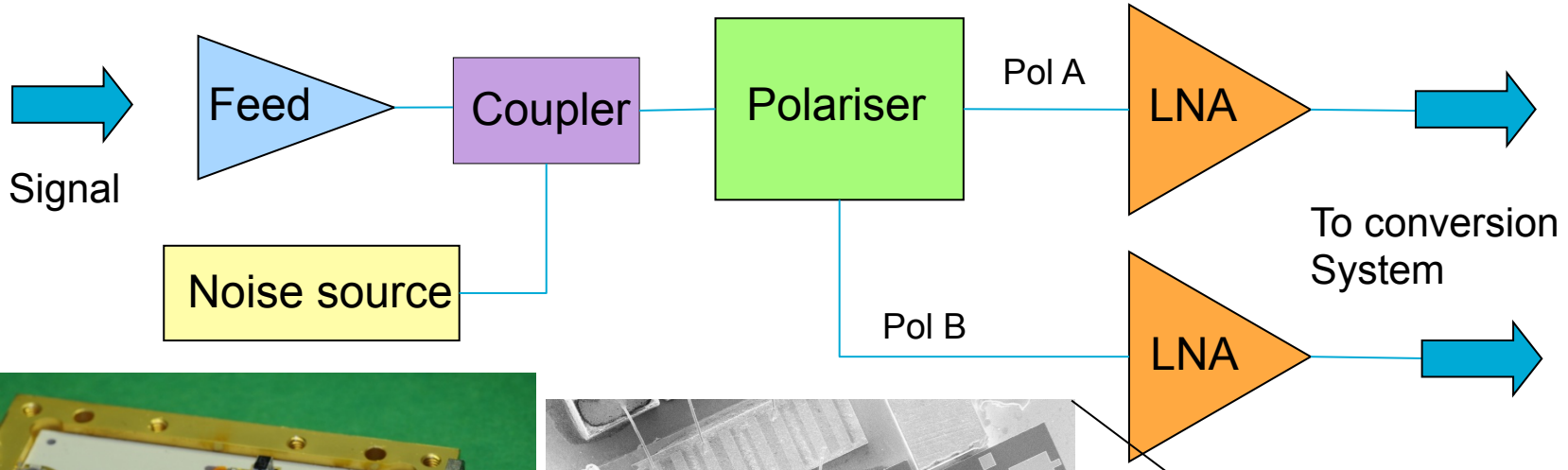
Separating Polarisations – Ortho-mode Transducers (OMTs)

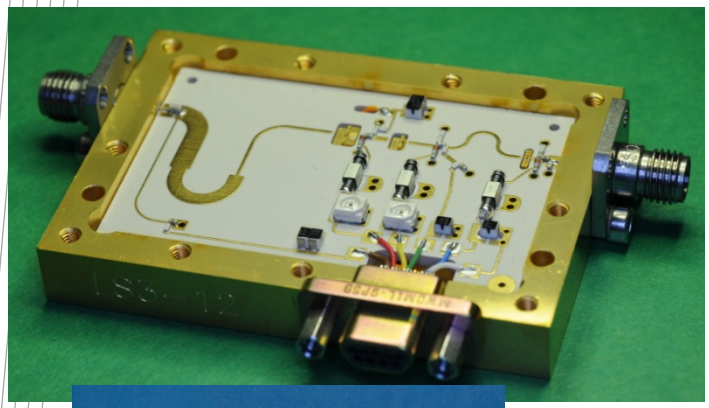


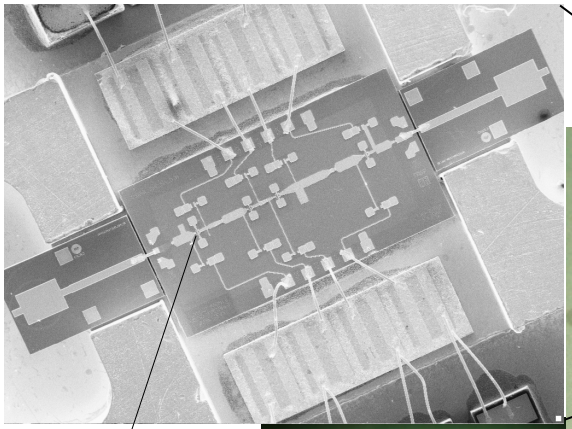


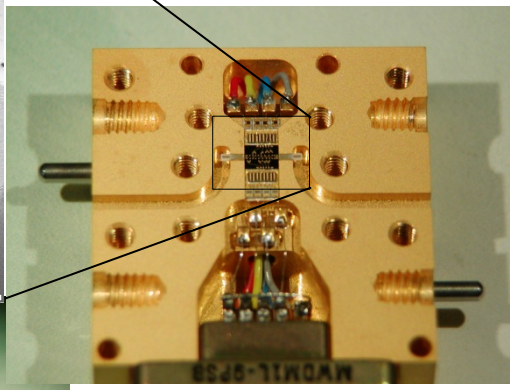


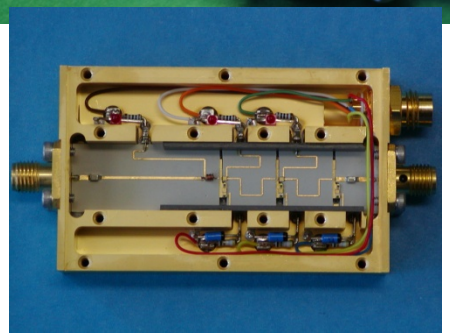
Low Noise Amplifiers (LNA)



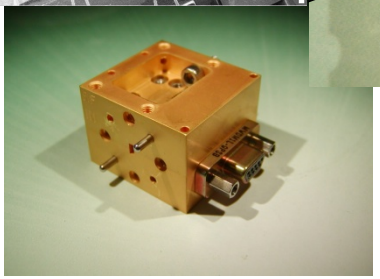






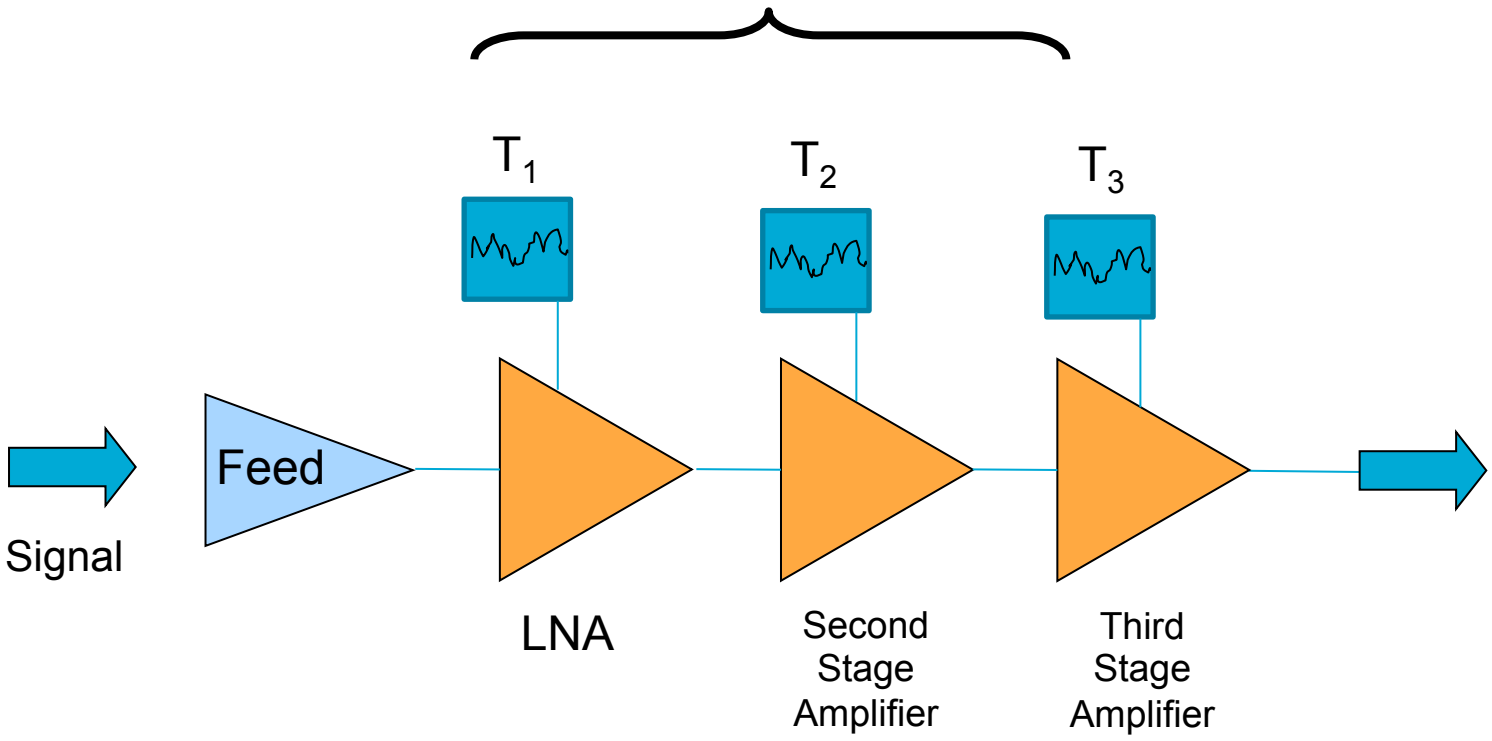


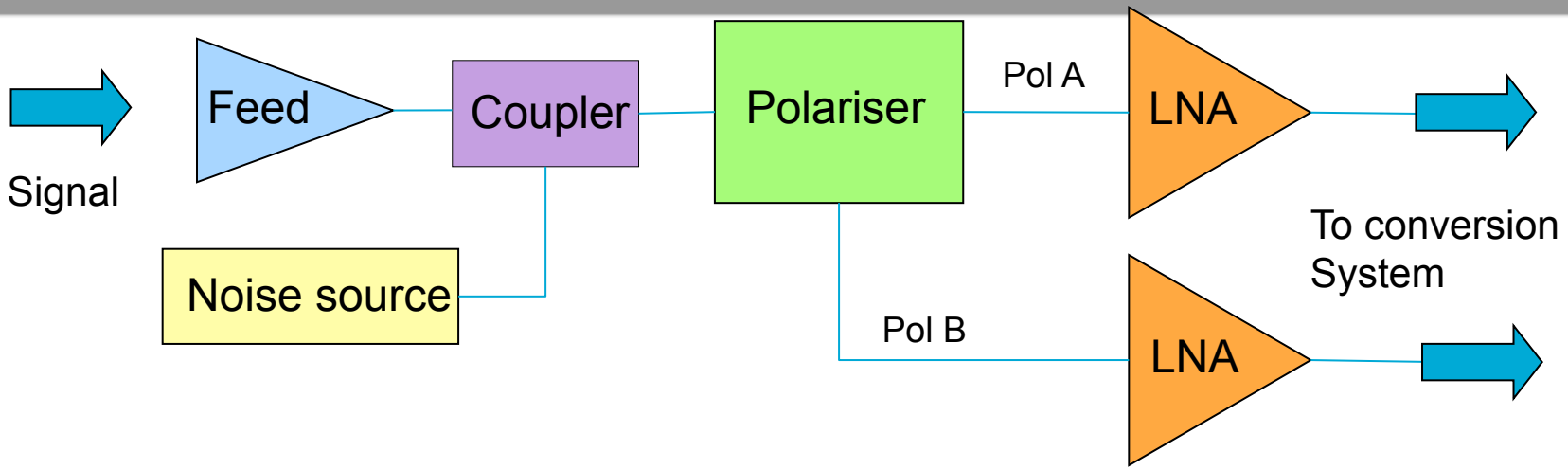
High Electron Mobility Transistor (HEMT)



Why is the first Low Noise Amplifier so important?

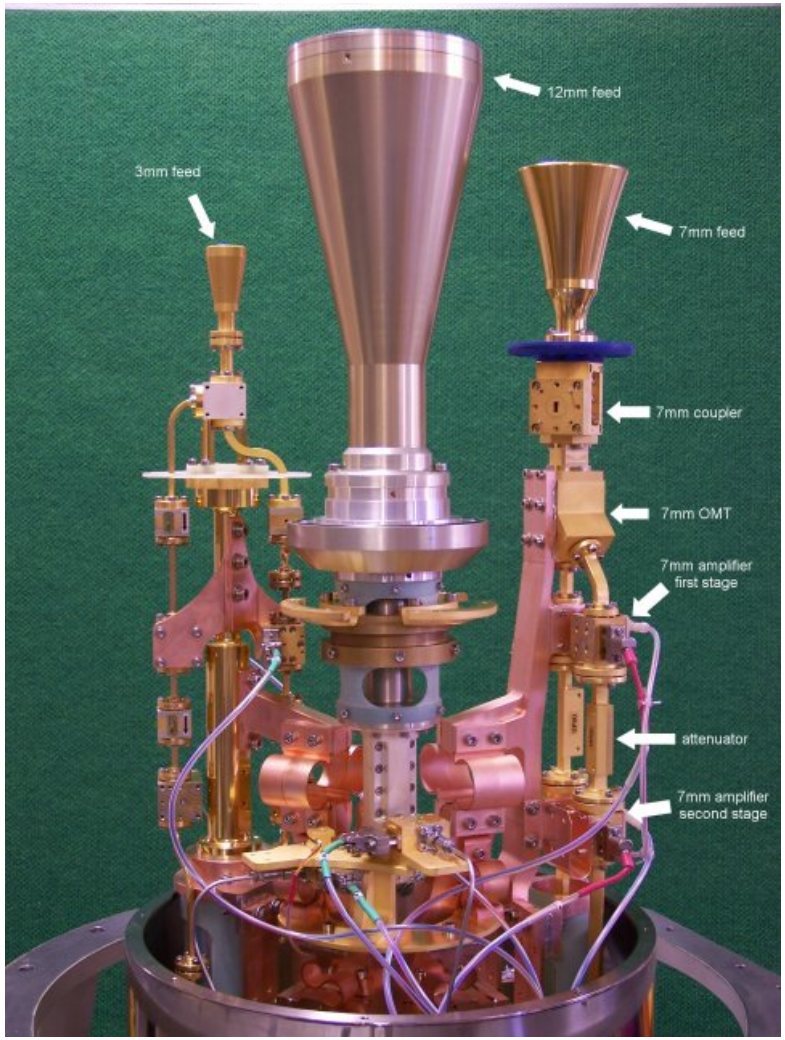
$$T_{system} = T_1 + \frac{T_2}{Gain_{LNA}} + \frac{T_3}{Gain_{LNA} \times G_2} + \frac{T_4}{Gain_{LNA} \times G_2 \times G_3} \quad \ldots\ldots$$





….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

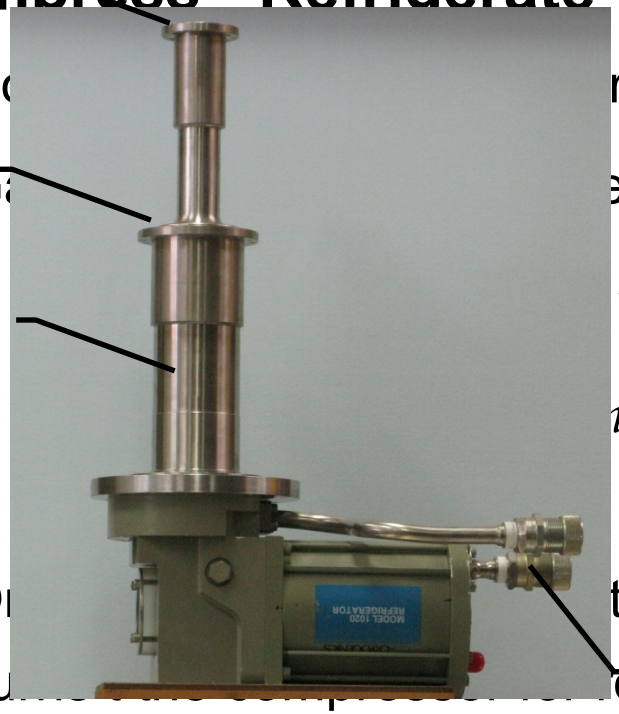
What is the rest of the stuff?

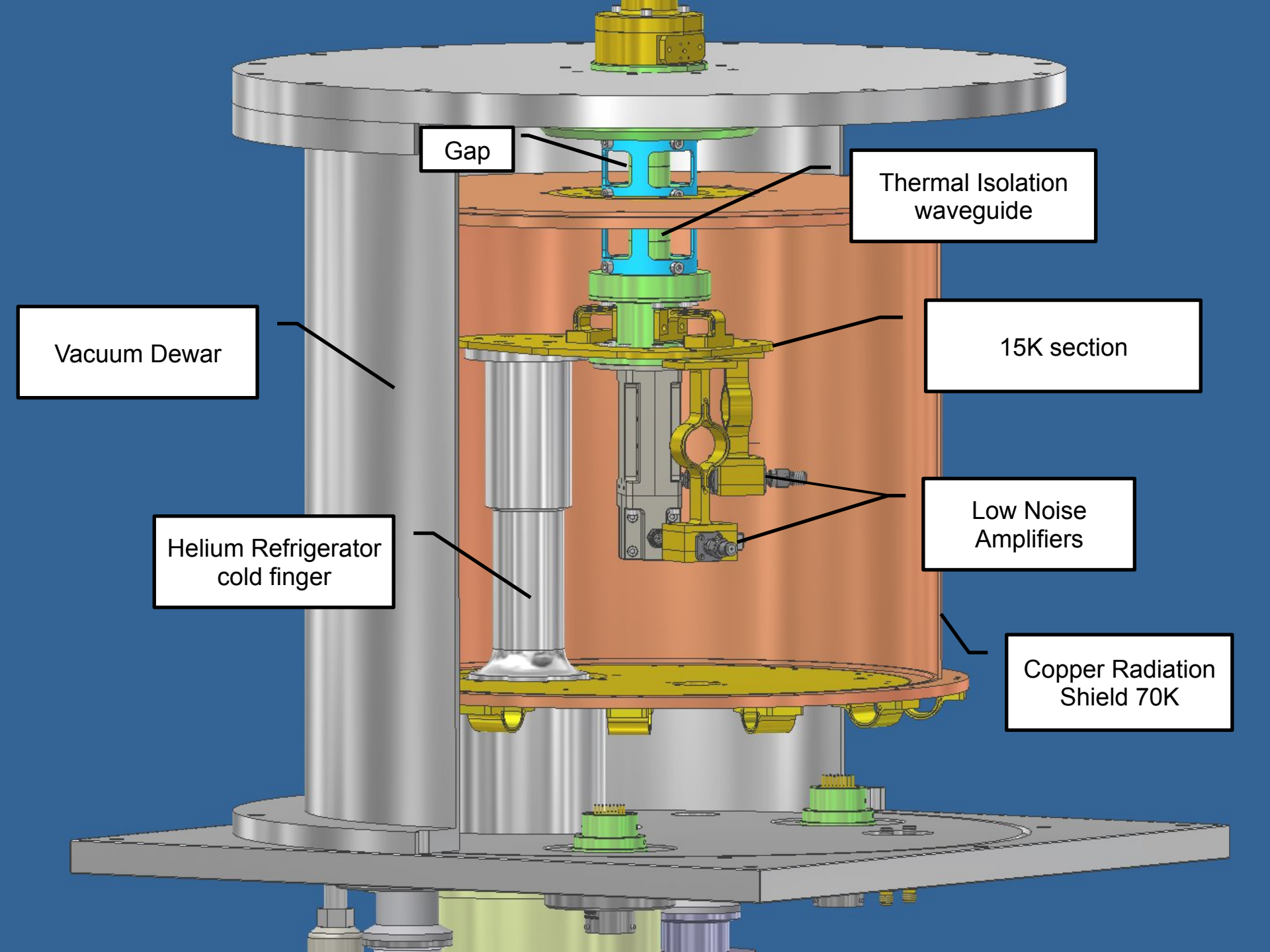
Cryogenics

mpress - Refrigerate - Compre

1. Co ressed gas ~
   Ga e it is expand
   the cooling pr
   n reverse, gett
3. Or t exits the cryodyne at ~80psi and
   retu ec .

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 →

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

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

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→

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

$\approx 10Jy$

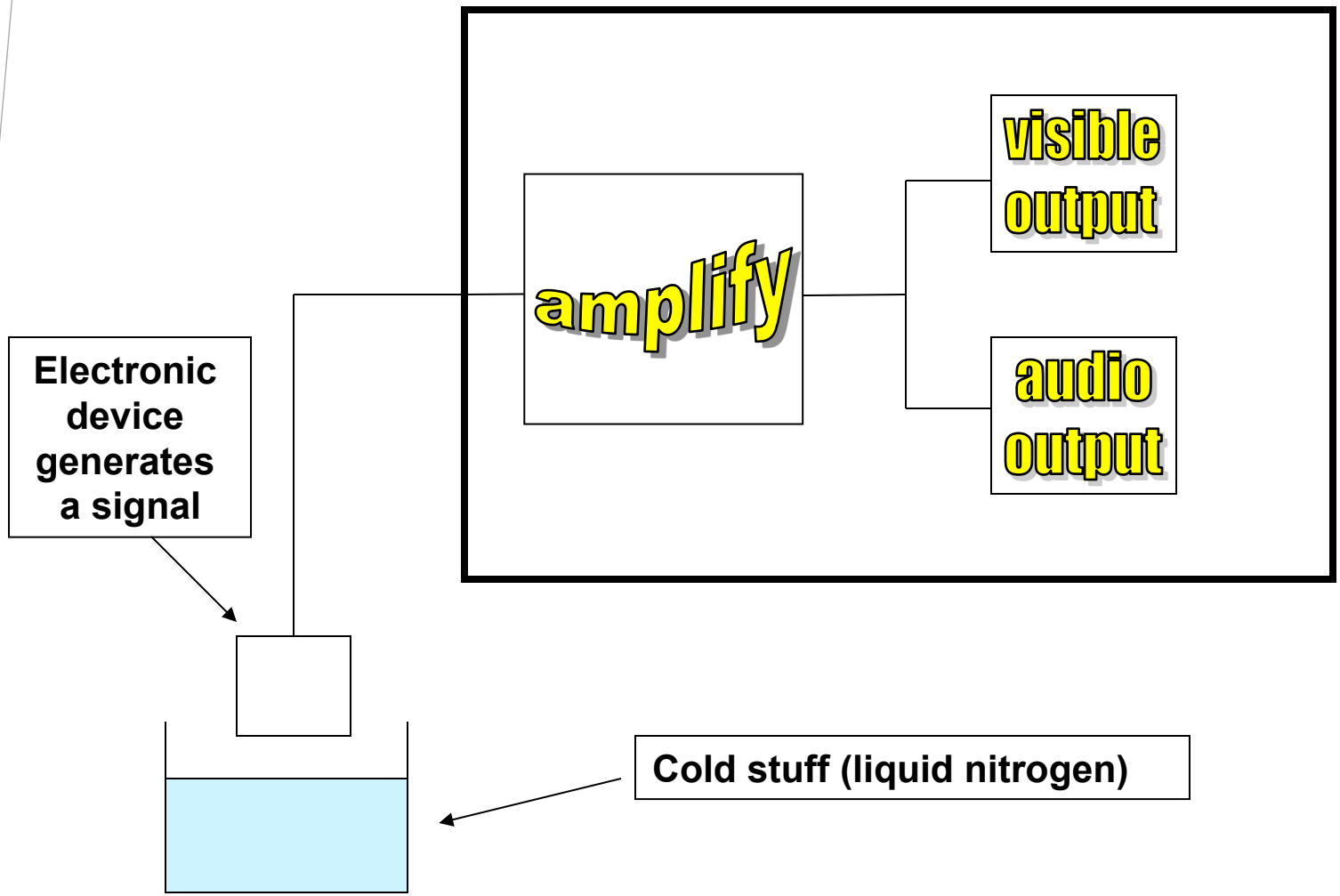
Lunar Distance

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.

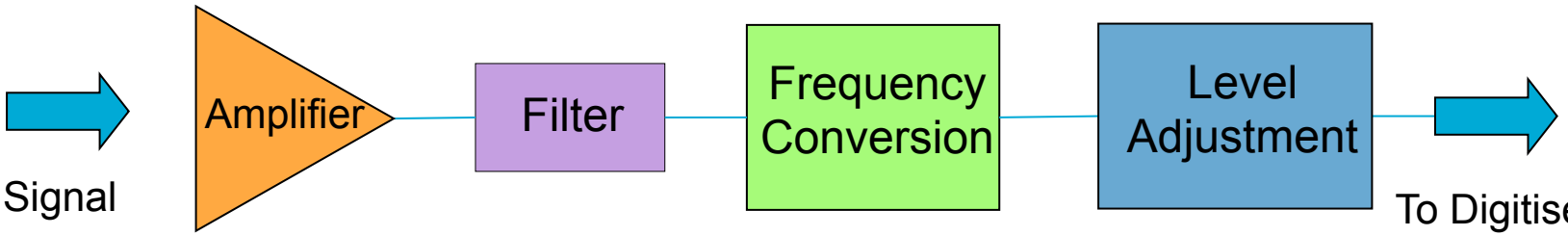
By cooling the receiver we reduce these thermal sources of noise and improve the sensitivity of the receiver by 7-10 times.

Reduce noise by cooling



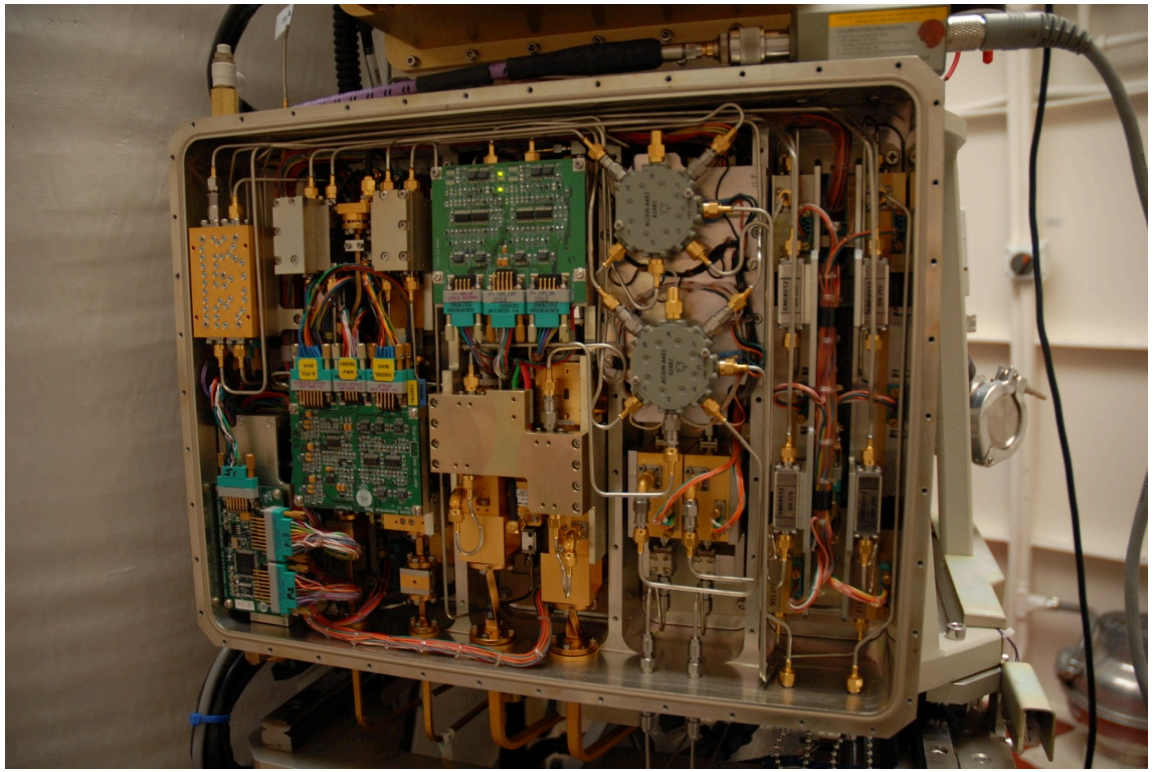
What is the rest of the stuff?

The Conversion System



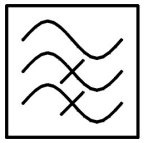
Contains:

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

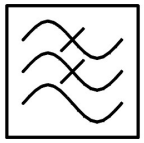


Filters

High Pass Filter

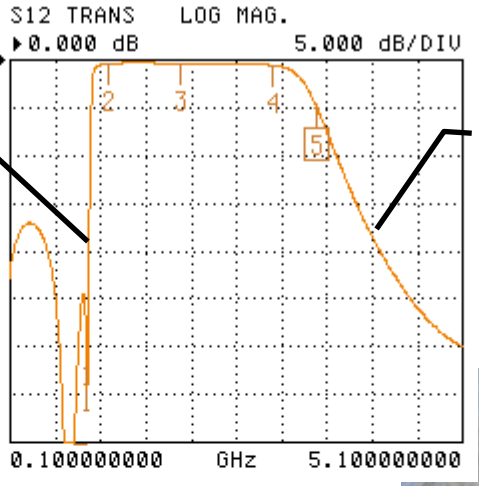


Low Pass Filter



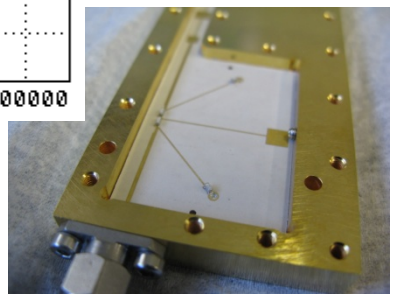
Band Pass Filter

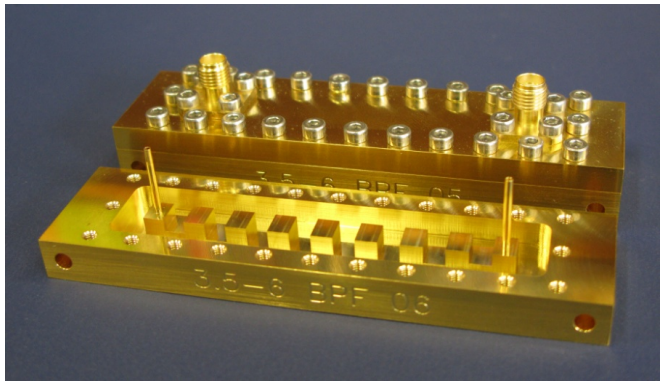
Hard roll off where necessary to stop strong interference



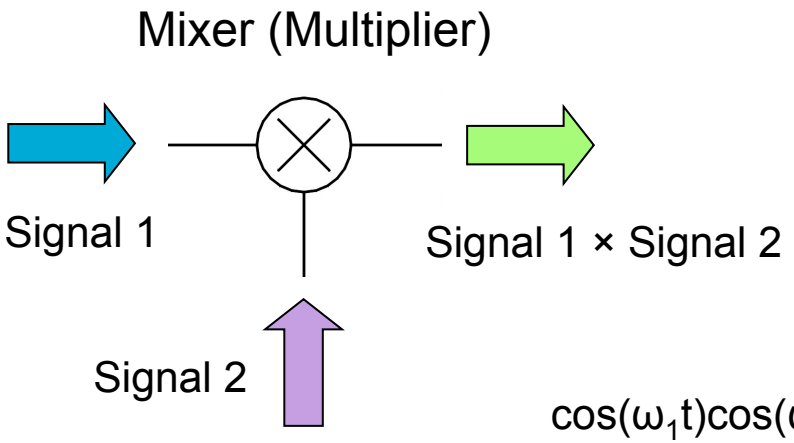
Slow roll off where possible so you can push the band edges

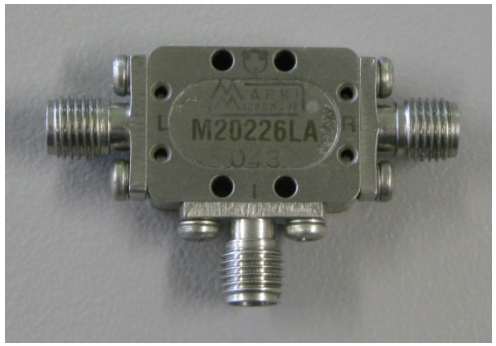
21cm band filter



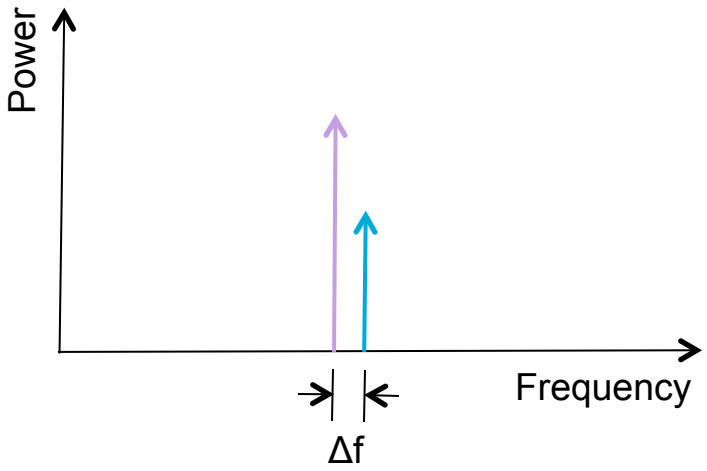


Mixing it down – Frequency Conversion

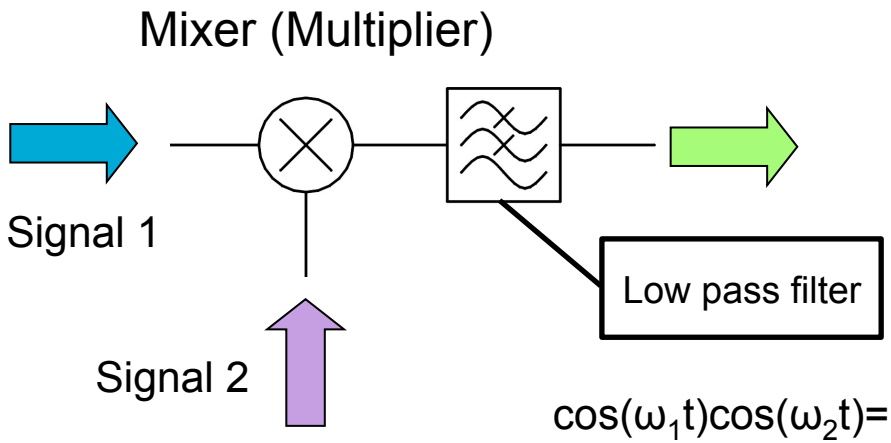


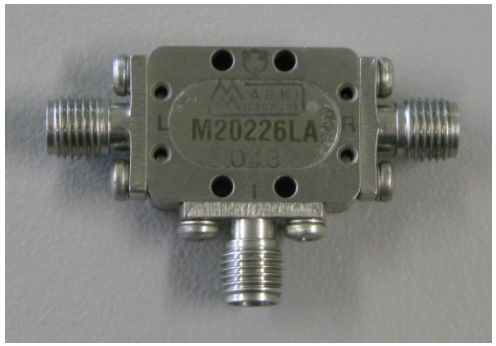


$$\cos(\omega_1 t)\cos(\omega_2 t)=\tfrac{1}{2}[\cos((\omega_1+\omega_2)t)+\cos((\omega_1-\omega_2)t)]$$

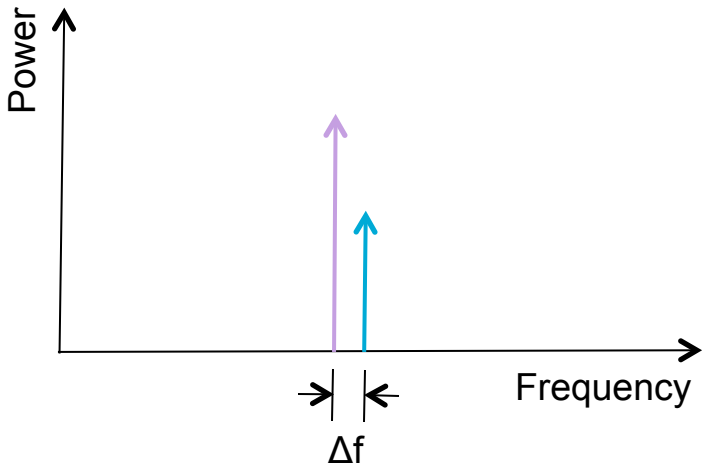


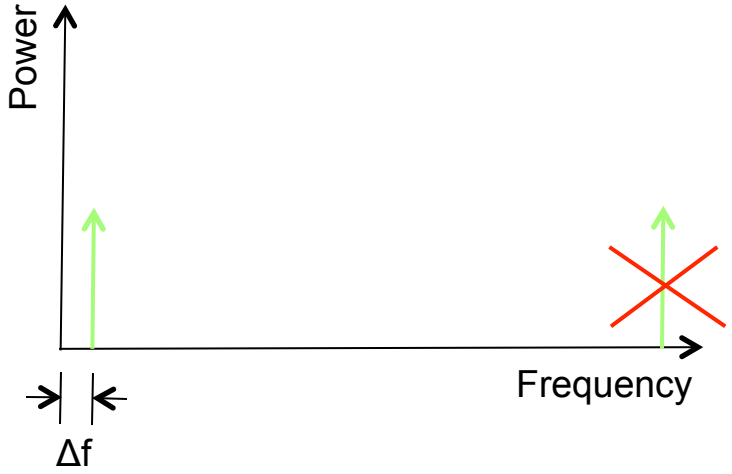
Mixing it down – Frequency Conversion



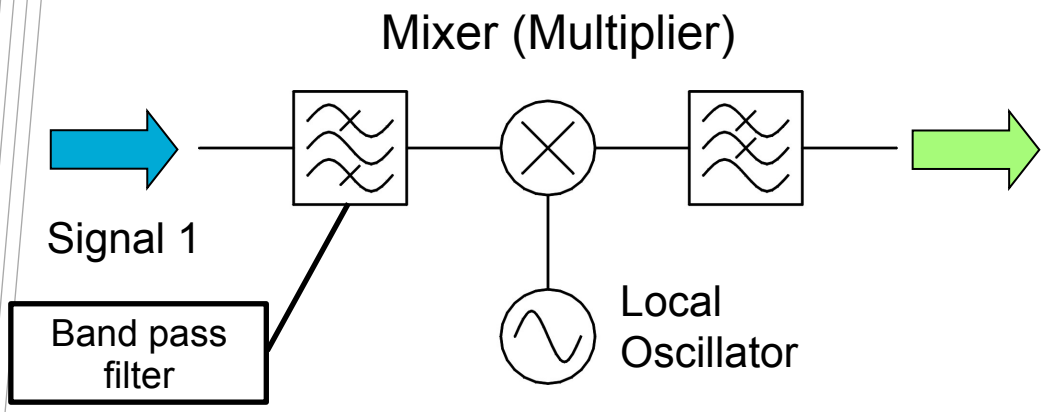


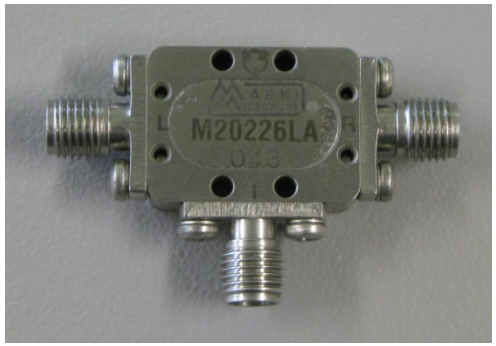
$$\cos(\omega_1 t)\cos(\omega_2 t)=\tfrac{1}{2}[\cos((\omega_1+\omega_2)t)+\cos((\omega_1-\omega_2)t)]$$

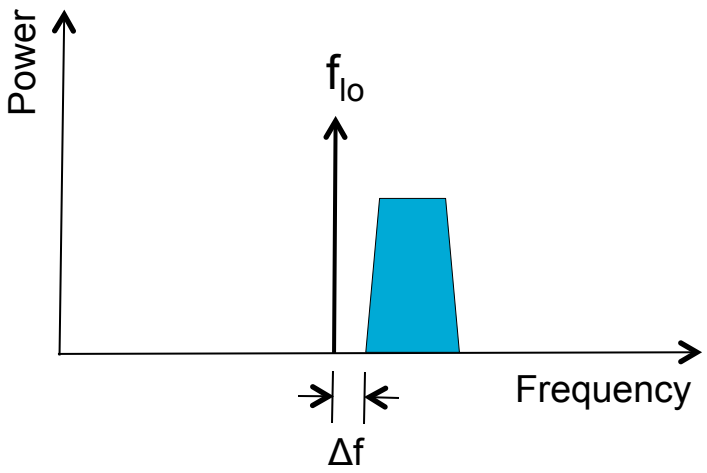


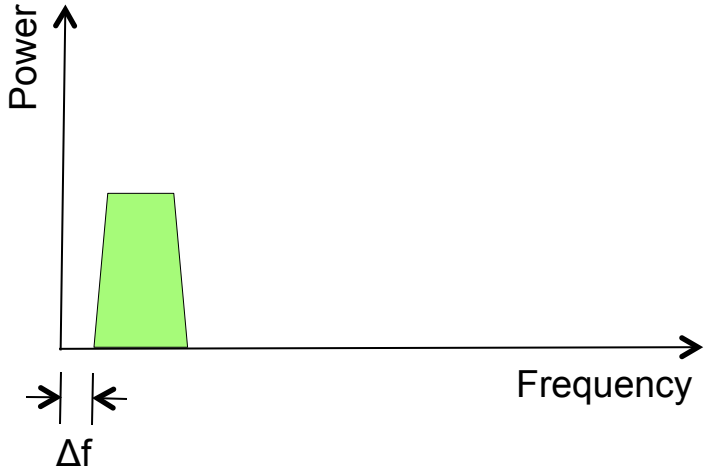


Mixing it down – Frequency Conversion



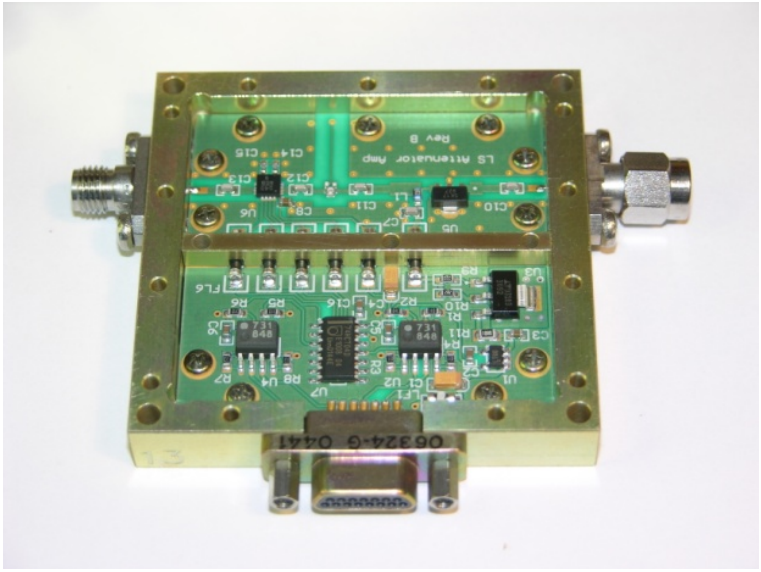






Attenuators – The Volume Knob

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

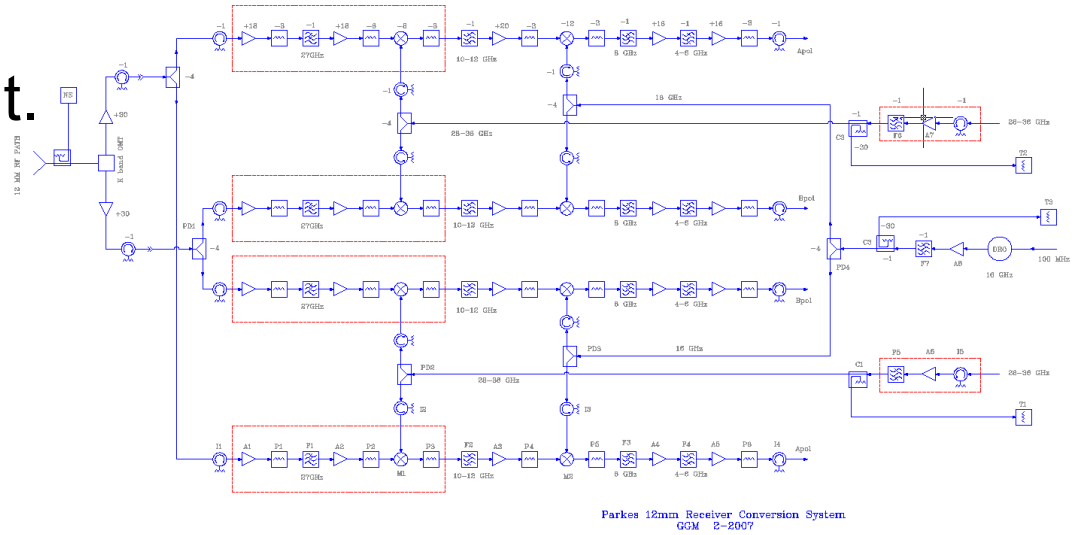


Just like some other systems if you turn the signal down too far all you get is noise and if you turn it up to far you get distortion!

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.



What is the rest of the stuff?

What's this?

temperatures and pressures

K-band LNAs

Window Navigator Setup Export Help

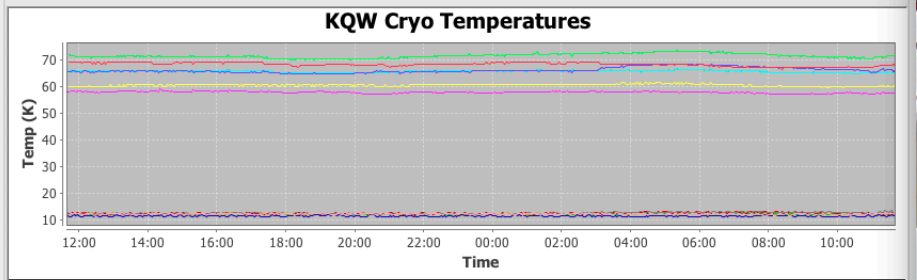
Display | Layout | Point Table

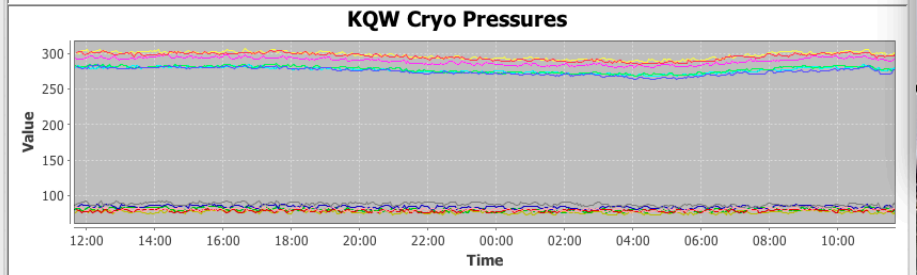
Point	ca01	ca02	ca03	ca04	ca05	ca06	Units
KA FET drain current – stage 1	3.0128	3.0909	6.0256	6.0573	5.989	4.0931	mA
KA FET drain current – stage 2	8.0398	5.0868	8.0264				
KA FET drain current – stage 3	10.0247	10.1492	9.097				
KA FET drain voltage – stage 1	0.99539	1.01236	0.9975				
KA FET drain 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				

KQW Cryogenics Summary

Window Navigator Setup Export Help

Display | Layout | Time Series | Time Series | Point Table





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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