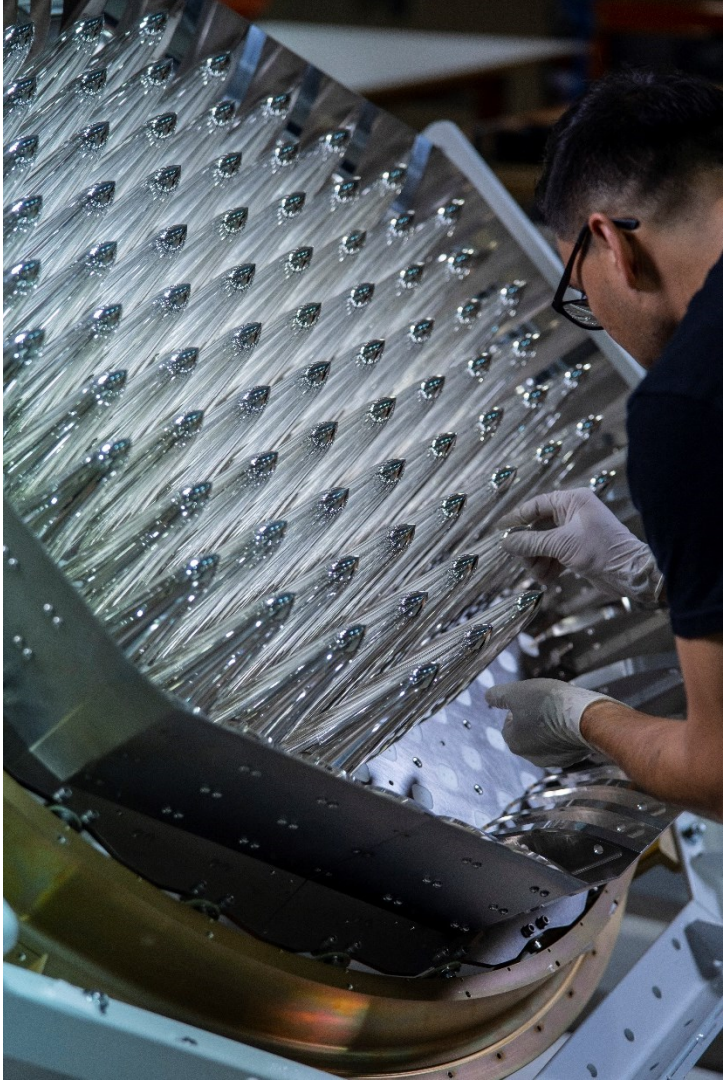
Radio Telescope Receivers

Robert Shaw
Content by Alex Dunning

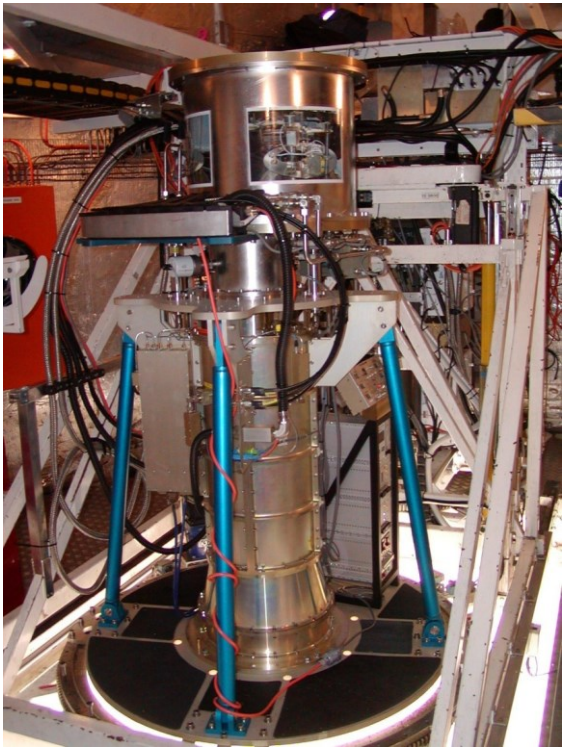


"A radio receiver is an electronic device that receives radio waves and converts the information carried by them to a usable form"

Wikipedia

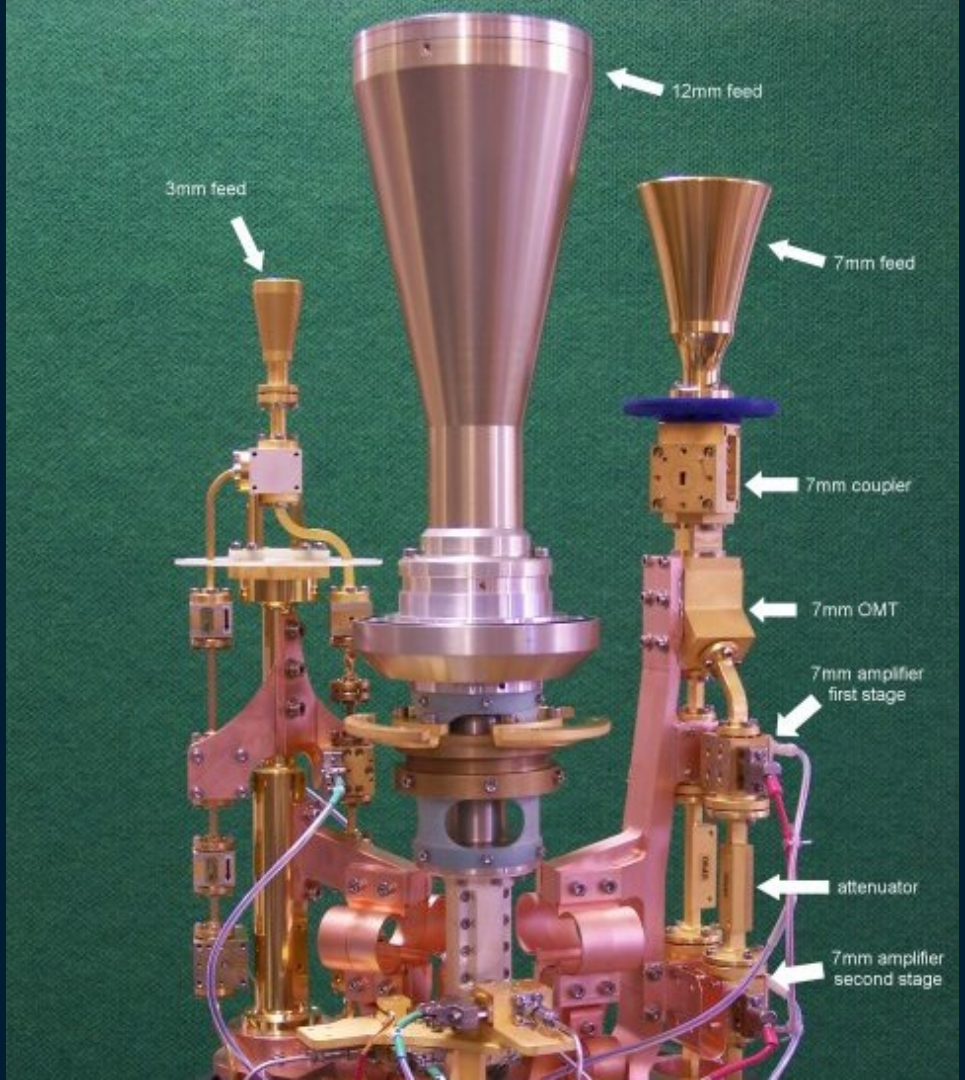
Ours look more like this

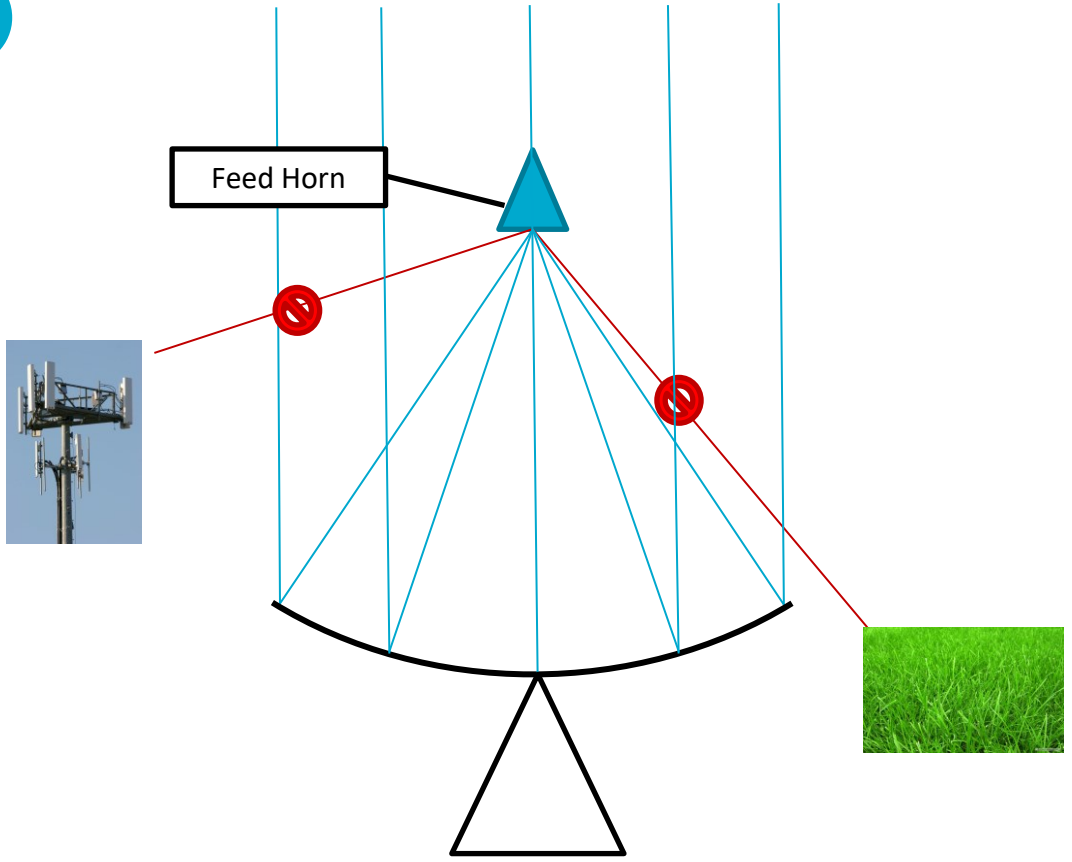
- Captures the signal reflected from the antenna
- Amplifies the signal
- Conditions the signal for digitisation

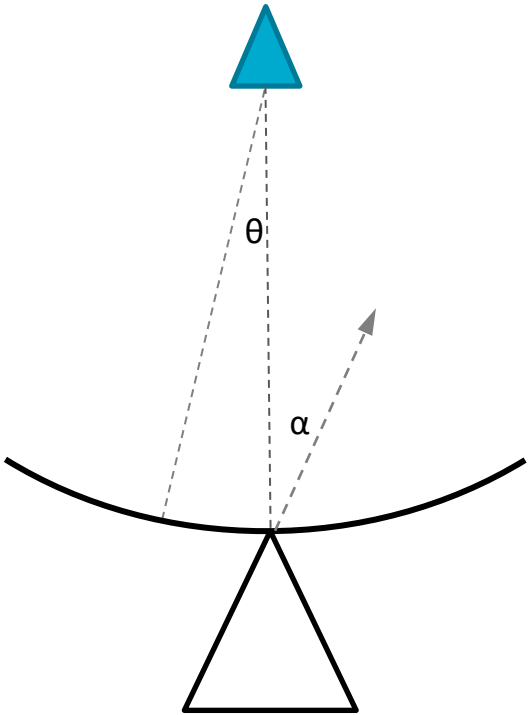


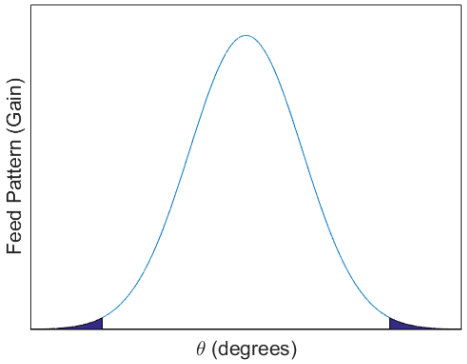
Parkes 10/40cm Receiver

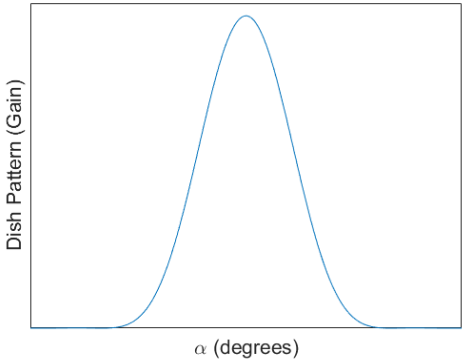

Feed Horns
Vacuum Dewar
Radio Frequency (RF) system
Control and Monitoring electronics

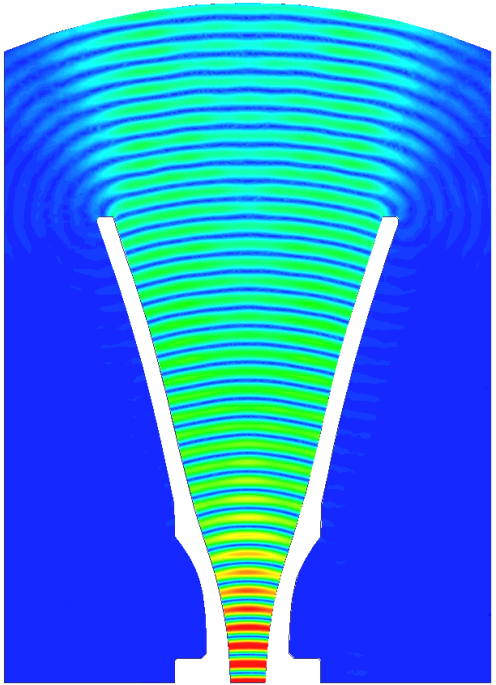

12mm feed
3mm feed
7mm feed
7mm coupler
7mm OMT
7mm amplifier
first stage
attenuator
7mm amplifier
second stage

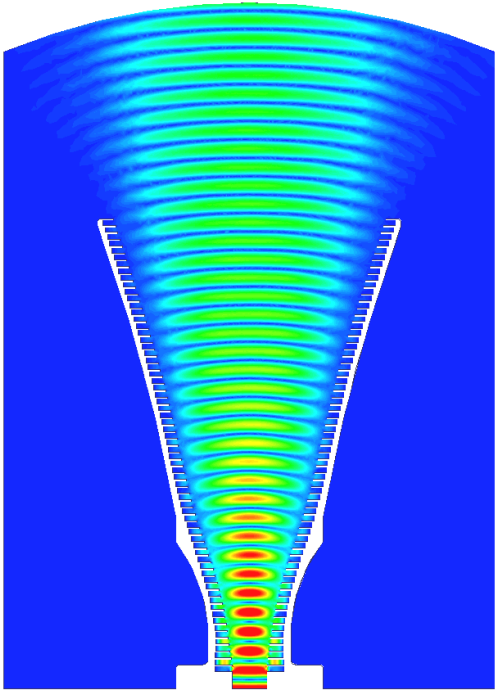

Feed Horn


θ
α


Feed Pattern (Gain)
θ (degrees)


Dish Pattern (Gain)
α (degrees)

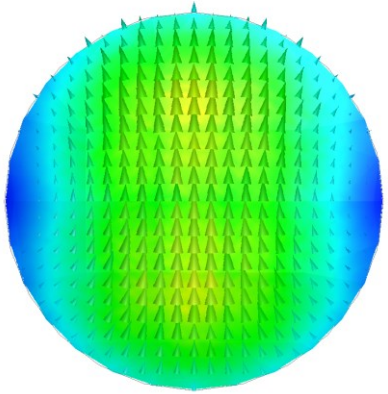


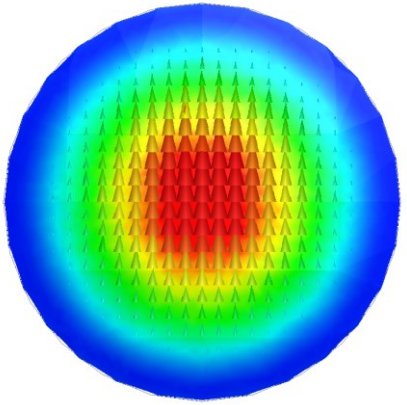


Smooth Walled

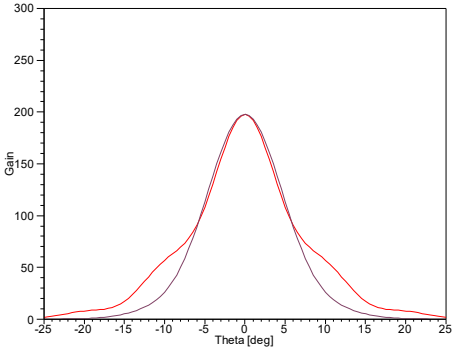
Corrugated

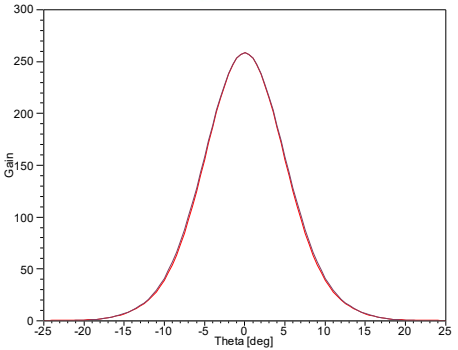
E-Field At Feed mouth

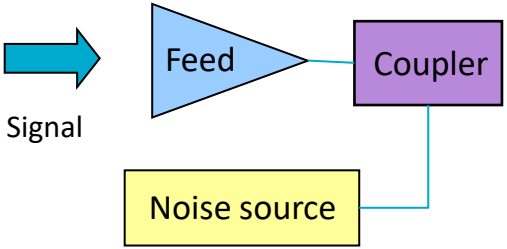


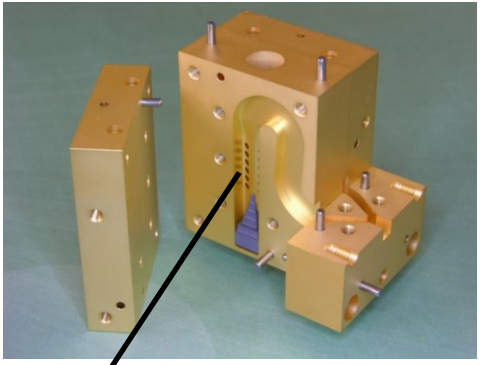


X and Y Feed Patterns



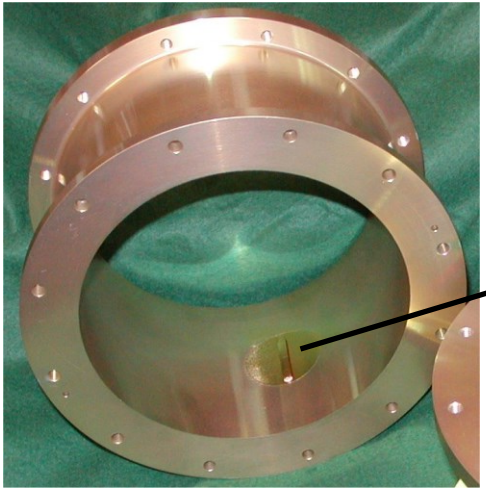






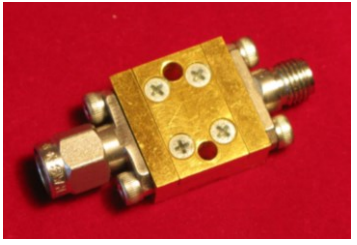
Noise coupled in through small holes

7mm waveguide coupler

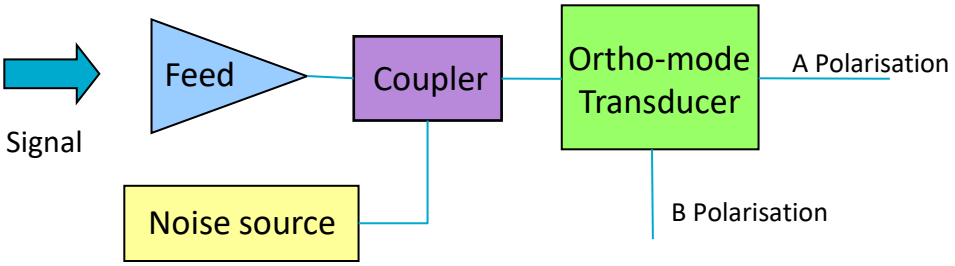


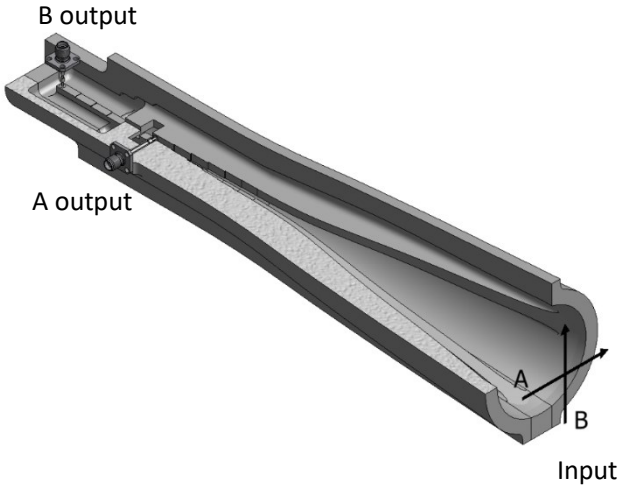
Noise coupled in through vane

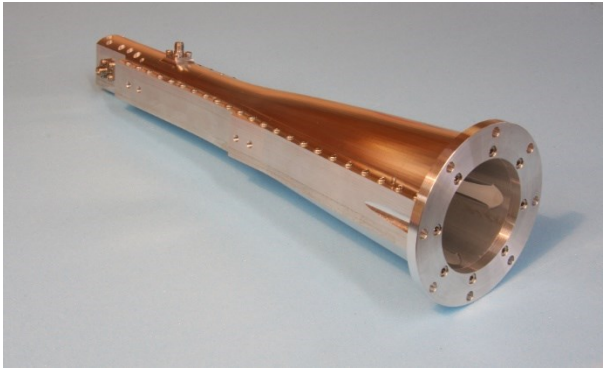
21cm waveguide coupler

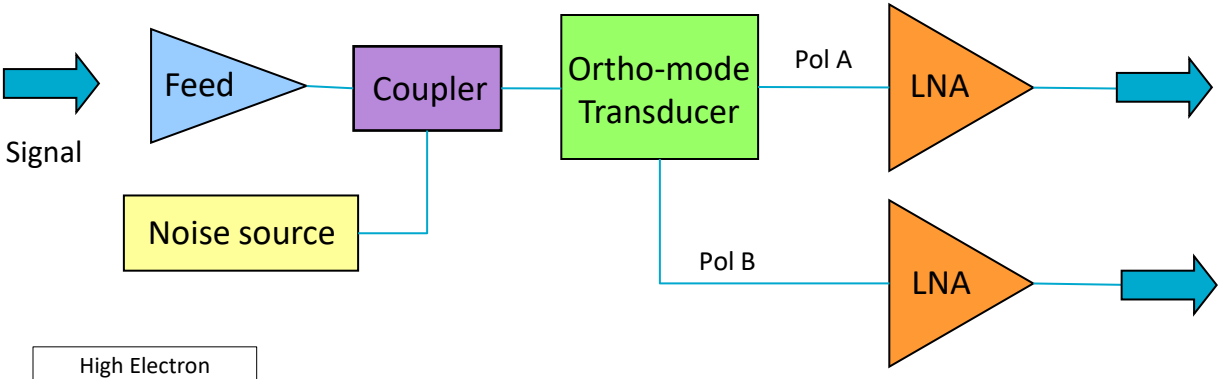


12mm noise source

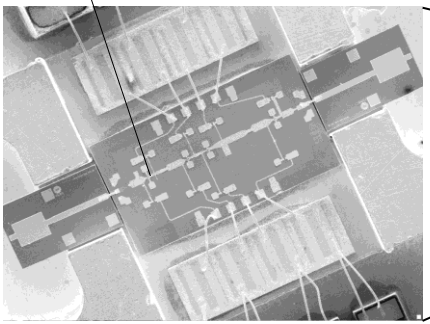

Signal
Feed
Coupler
Ortho-mode Transducer
A Polarisation
B Polarisation
Noise source

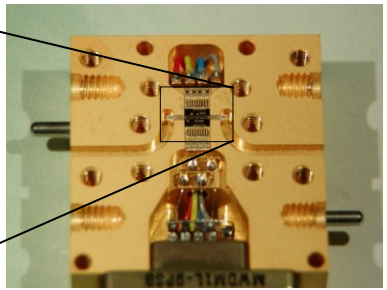

B output
A output
A
B
Input

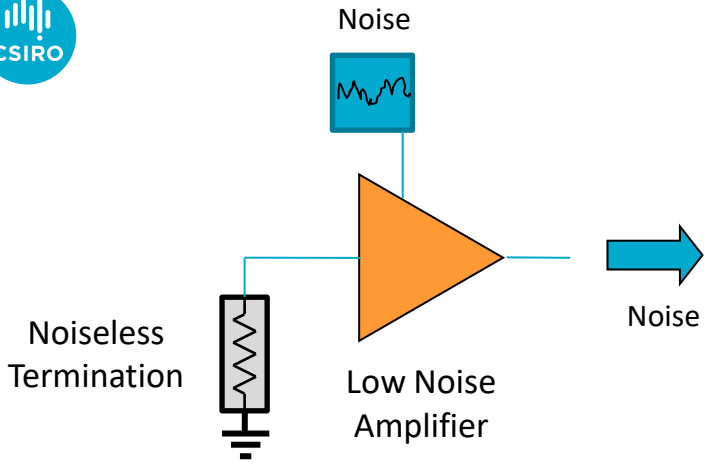




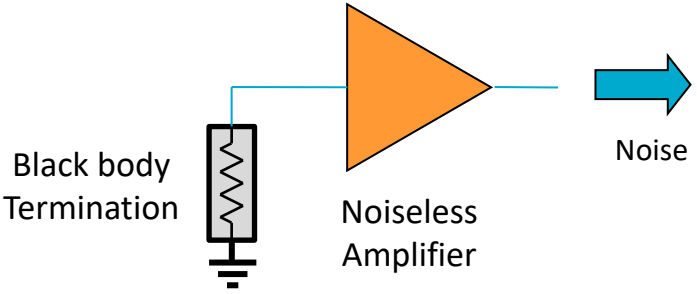
High Electron Mobility Transistor (HEMT)







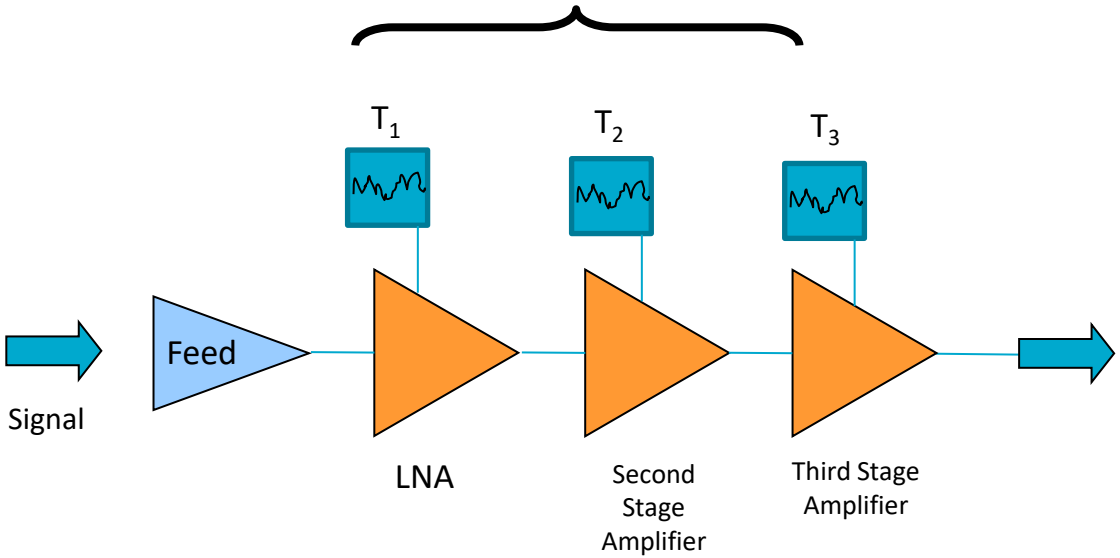
$$P_{output} \propto Gain\, \Delta freq$$

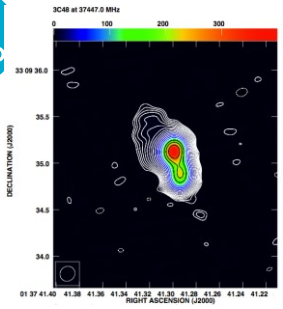


$$P_{output} = Gain\, \Delta freq\, k_B\, T_{resistor}$$

$$T_{equivalent} = \frac{P_{output}}{Gain\, \Delta f\, k_B}$$

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





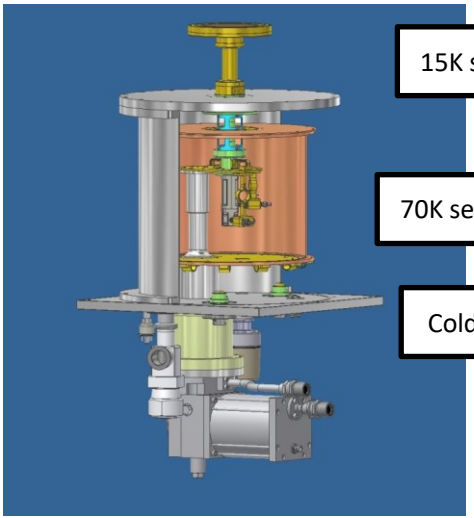
10Jy radio source → ~1K additional noise

Your hand → ~300K additional noise

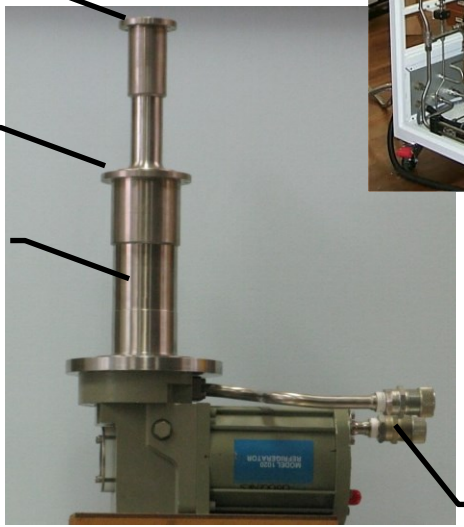
Mobile Phone at 1 km→ ~10^{11} K !!
(in primary beam)

Noise contributions of a typical receiver

Part	Room Temperature	Cryogenic	Ratio
Sky + CMB (T_{sky})	6K	6K	1
Spillover (T_{spill})	3K	3K	1
Feed + OMT	10K	2K	5
LNA (T_{lna})	35K	5K	7
Rest of the System	1K	1K	1
Total (T_{sys})	**55K**	**17K**	**~3**

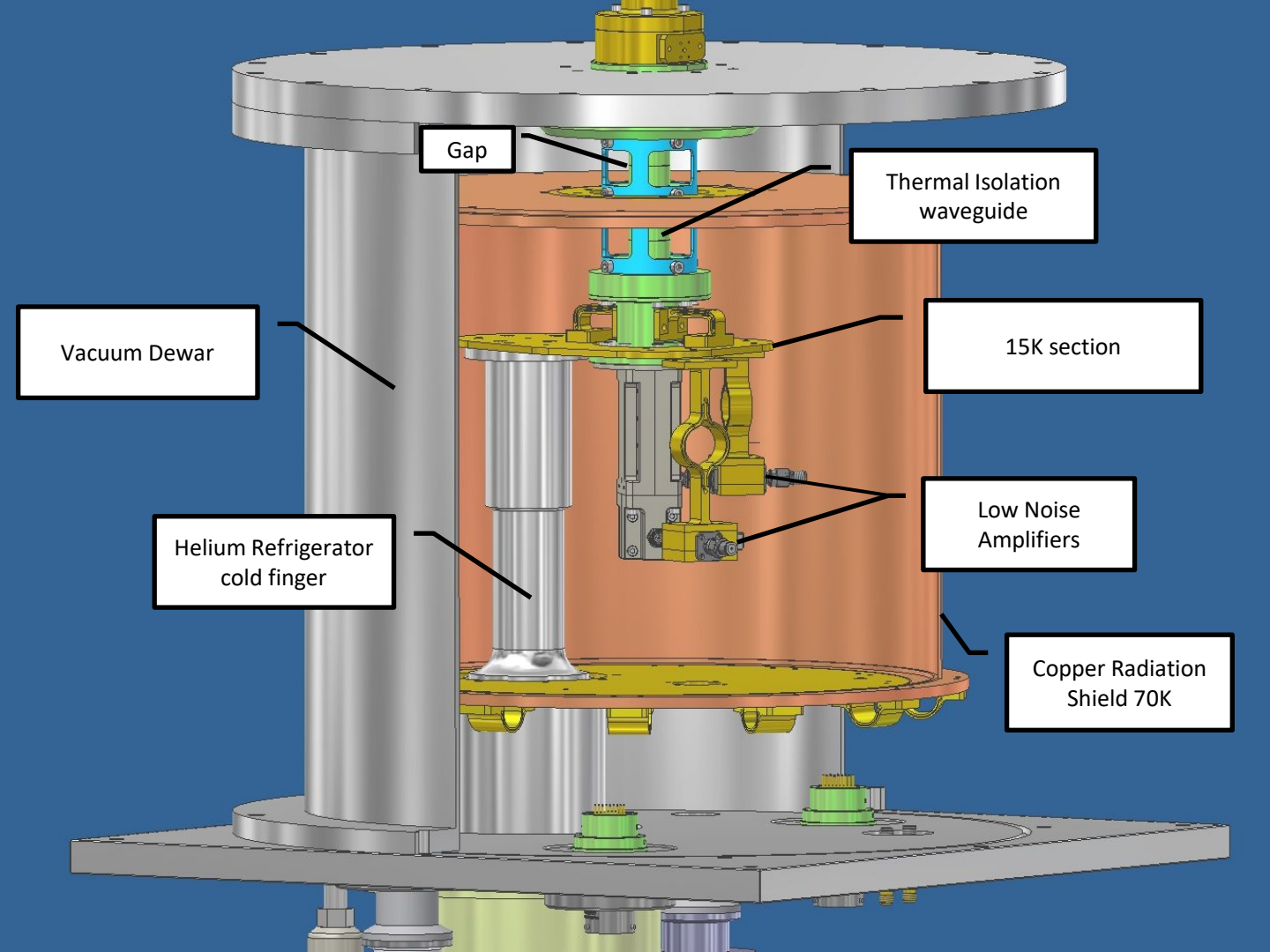


Refrigerator in the Parkes 12mm receiver

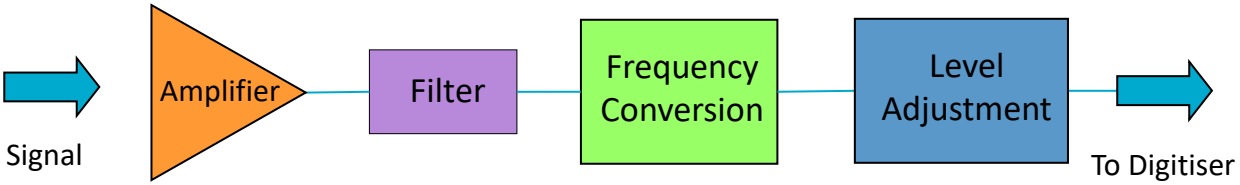


Helium Refrigerator

Helium Compressor

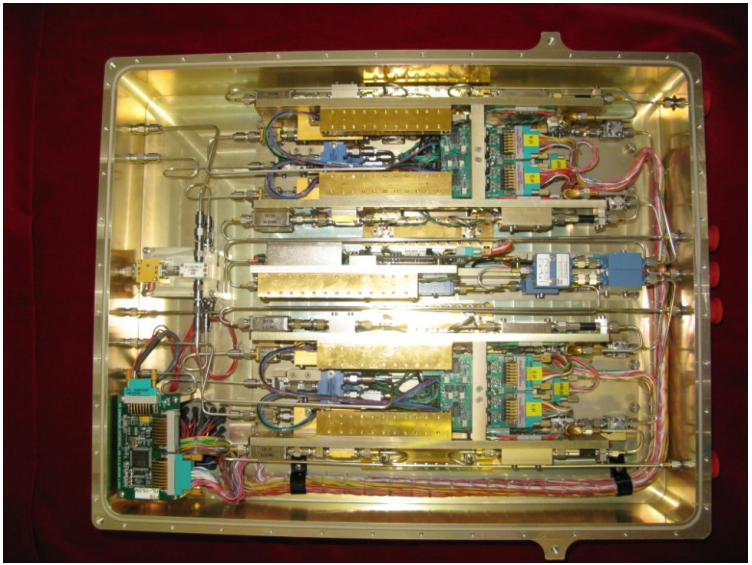

Gap
Thermal Isolation waveguide
Vacuum Dewar
15K section
Low Noise Amplifiers
Helium Refrigerator cold finger
Copper Radiation Shield 70K

The RF System

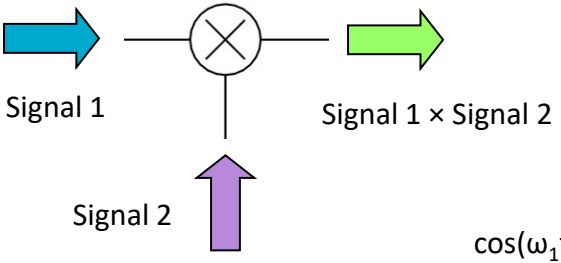


Contains:

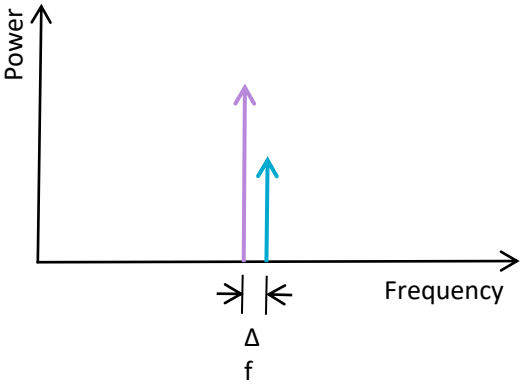
- More amplification
- Band defining filters
- Frequency conversion
- Level adjustment
- Signal detection
- Band shaping

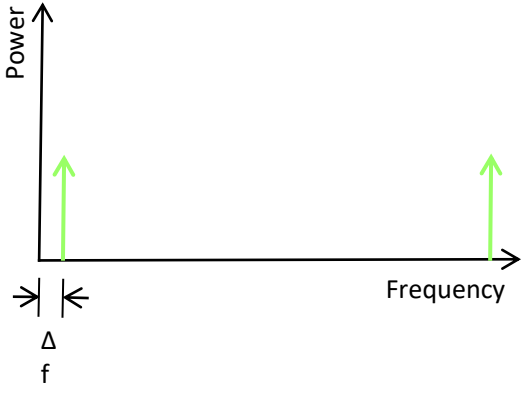


Mixer (Multiplier)

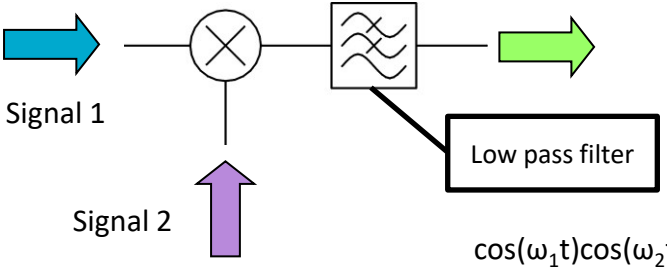


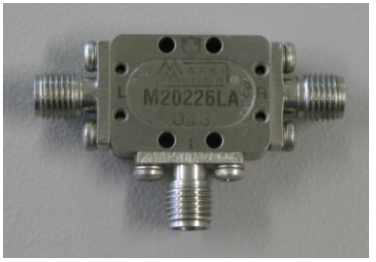
$\cos(\omega_1 t)\cos(\omega_2 t)=\frac{1}{2}[\cos((\omega_1+\omega_2)t)+\cos((\omega_1-\omega_2)t)]$





Mixer (Multiplier)





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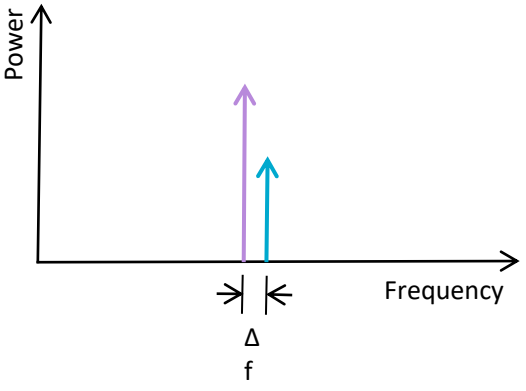
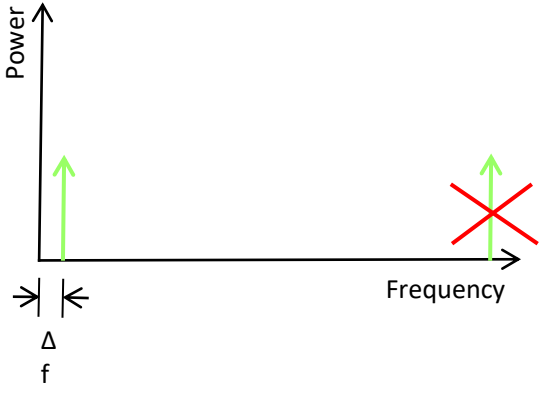
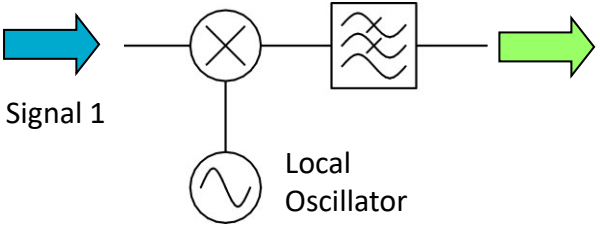
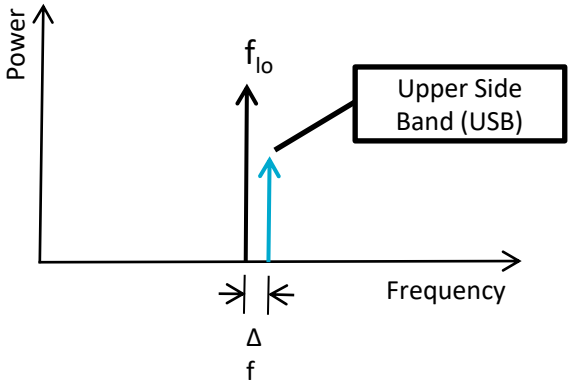


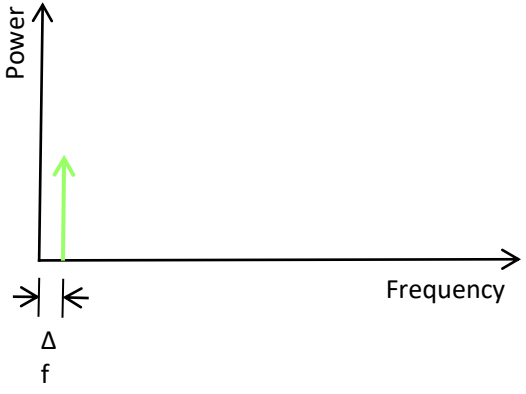


Mixer (Multiplier)

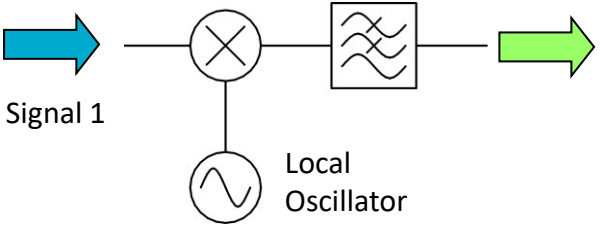


$\cos(\omega_1 t)\cos(\omega_{LO} t) \rightarrow \frac{1}{2}\cos[(\omega_1 - \omega_{LO})t]$





Mixer (Multiplier)



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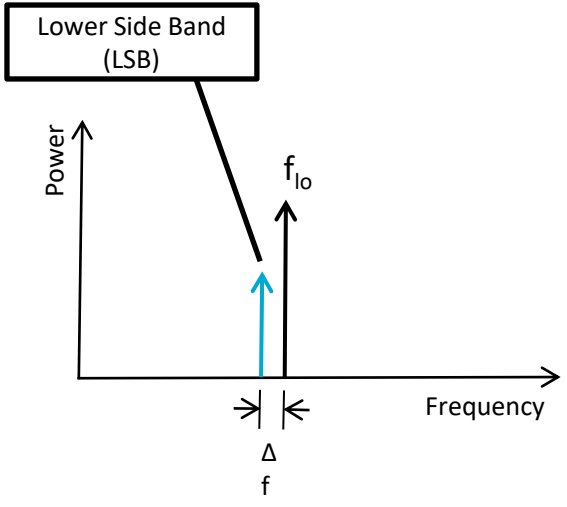
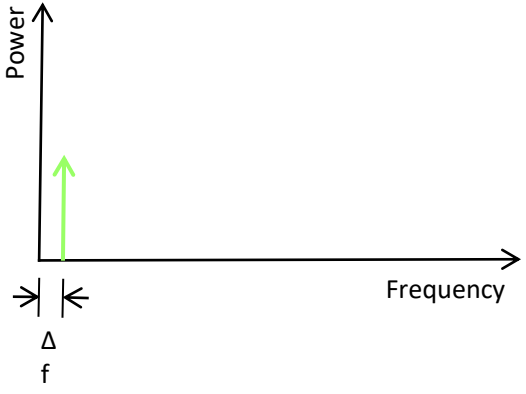
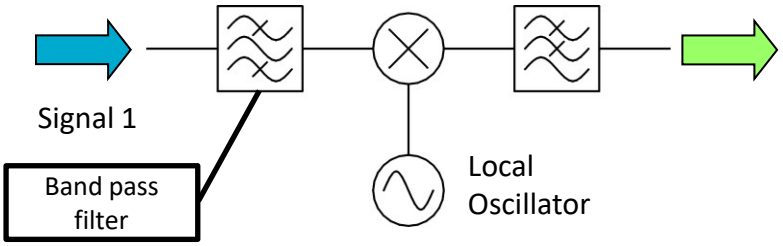
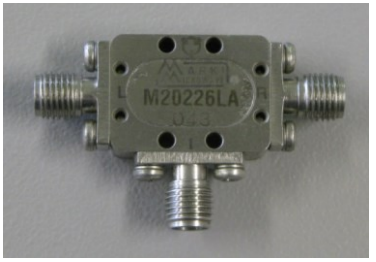
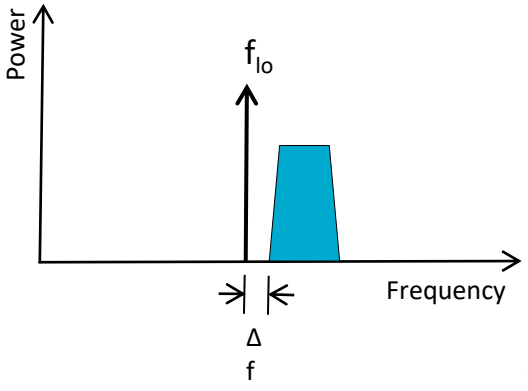


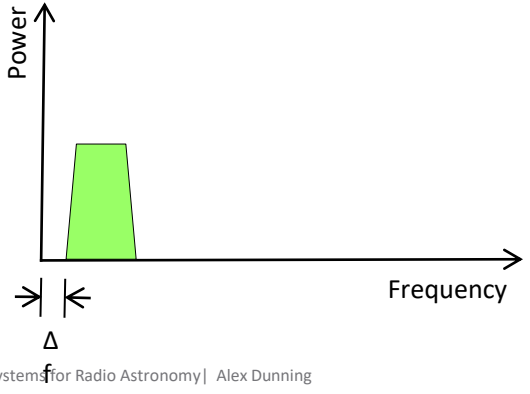


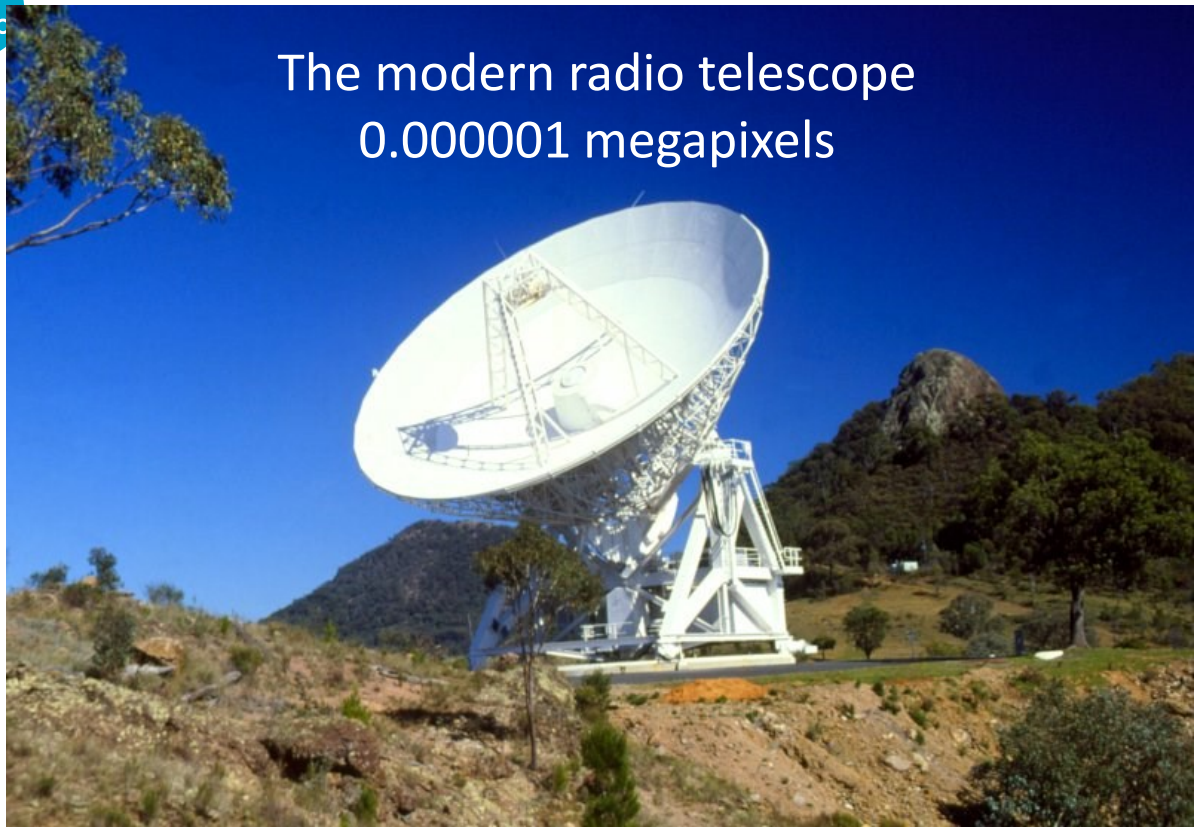
Mixer (Multiplier)










The modern radio telescope
0.000001 megapixels

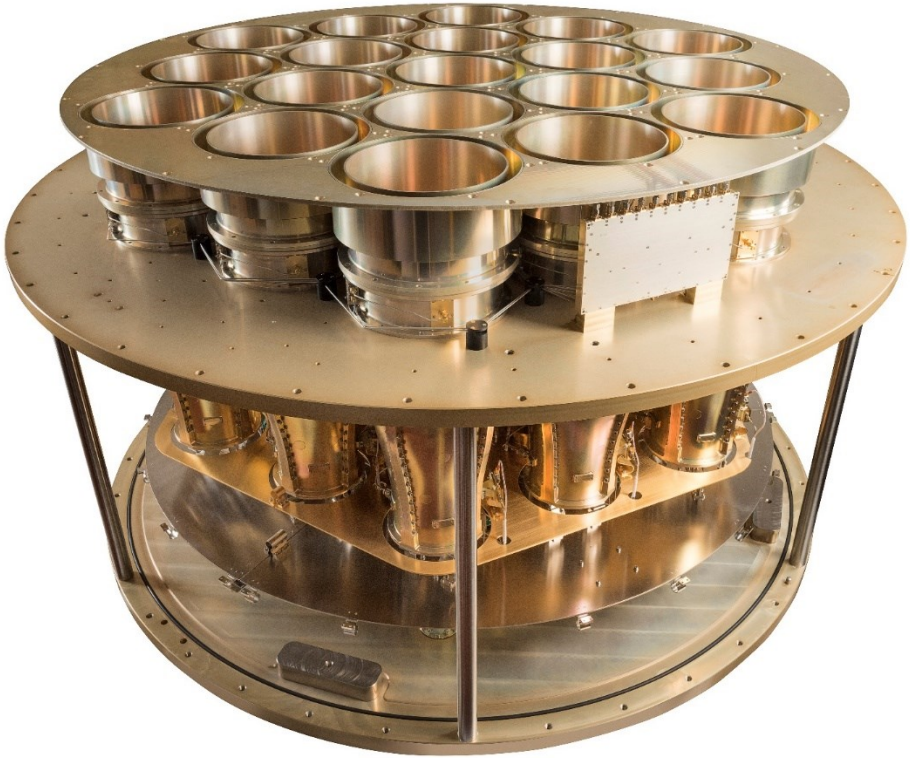
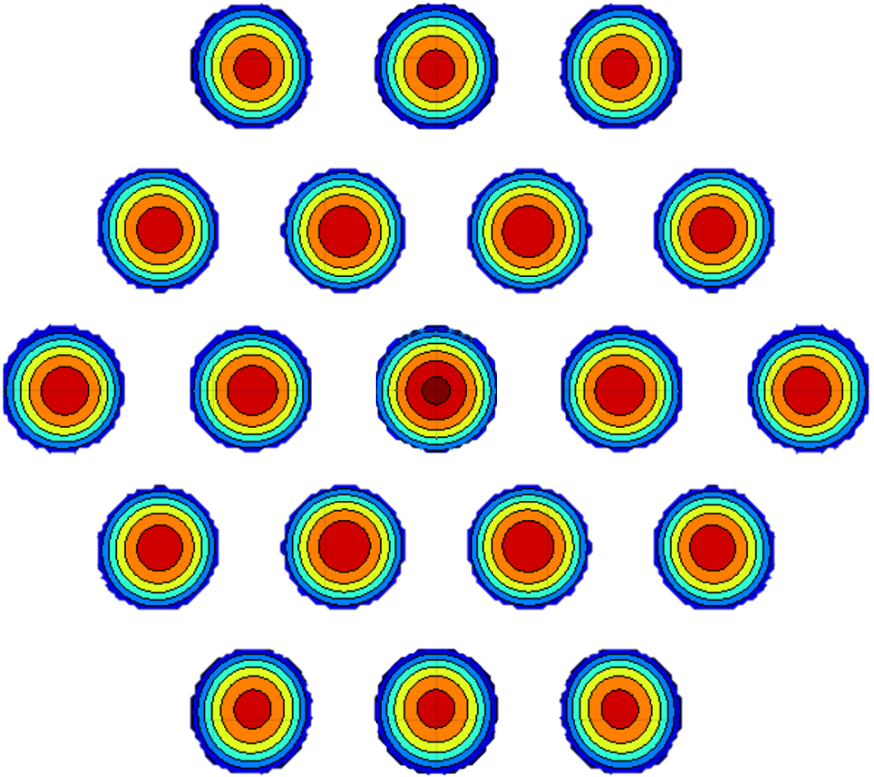
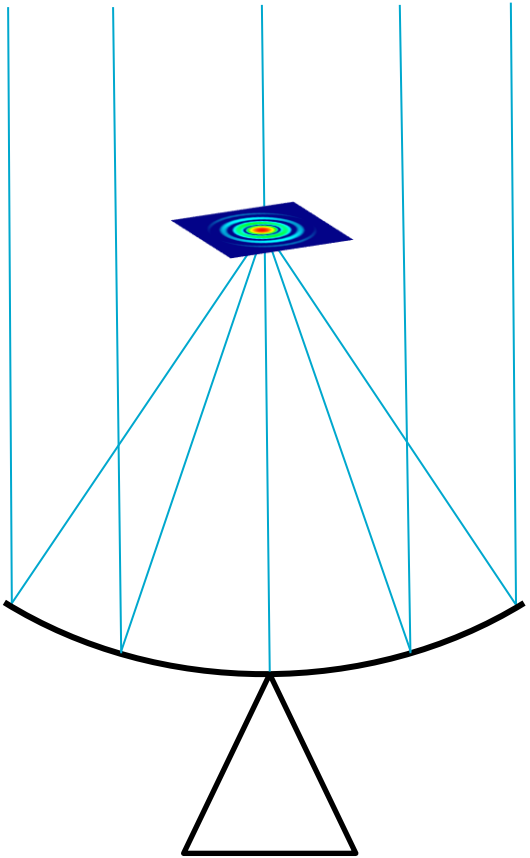
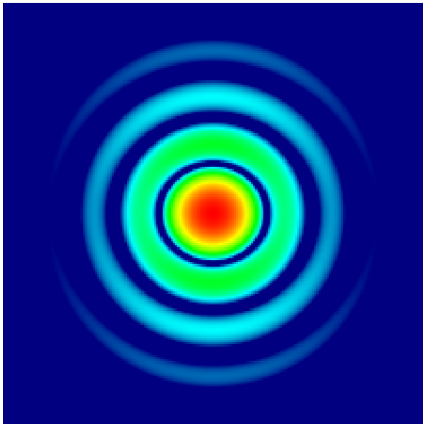
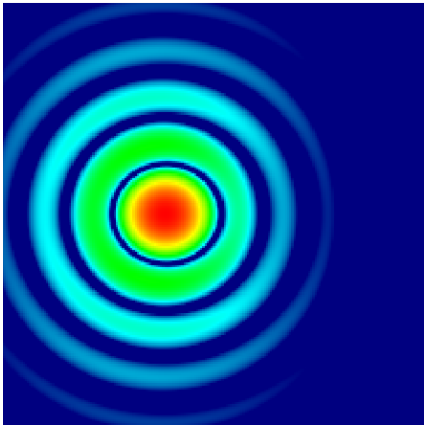


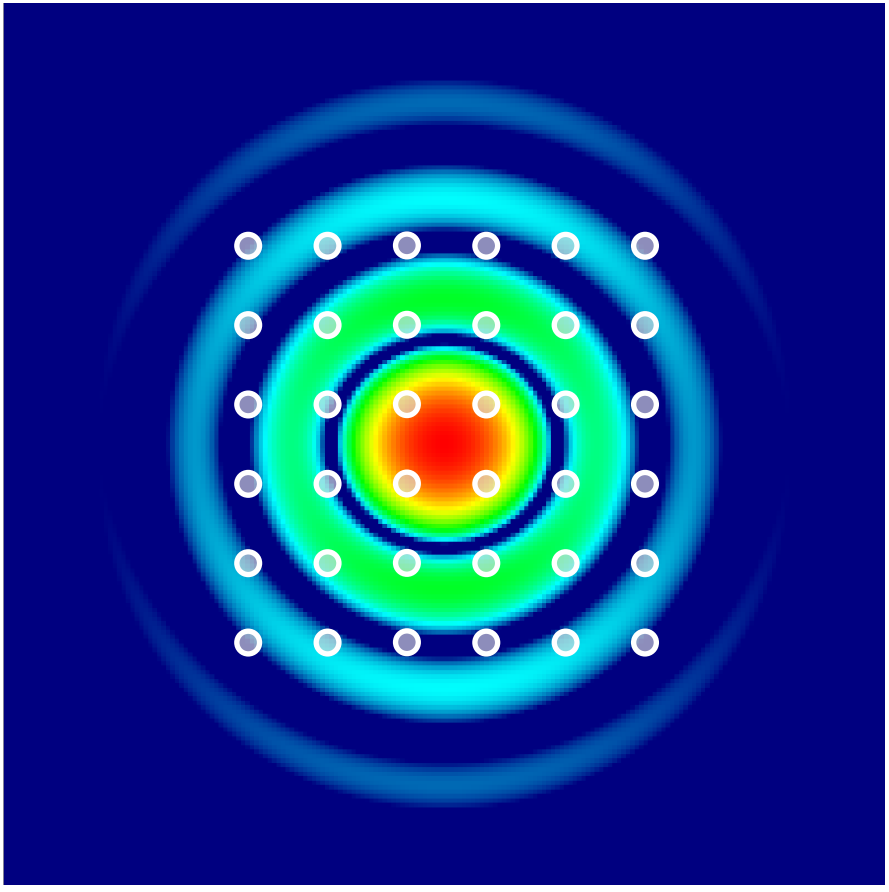
Photo credit: Wheeler Studios

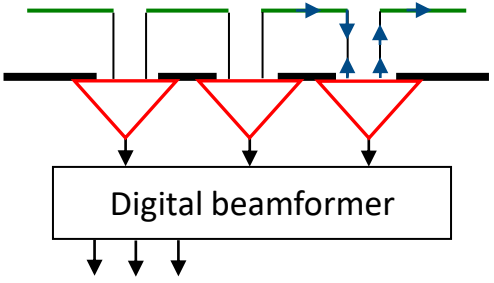




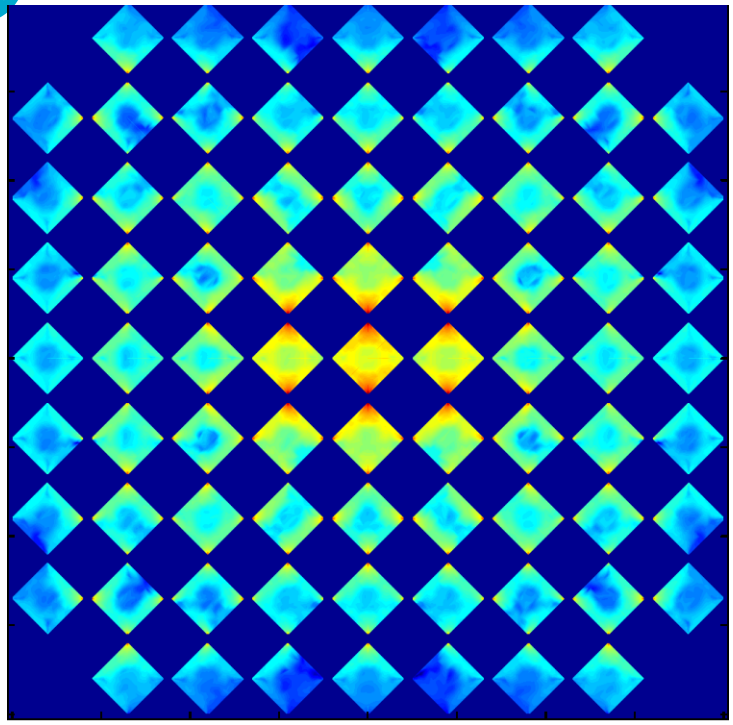


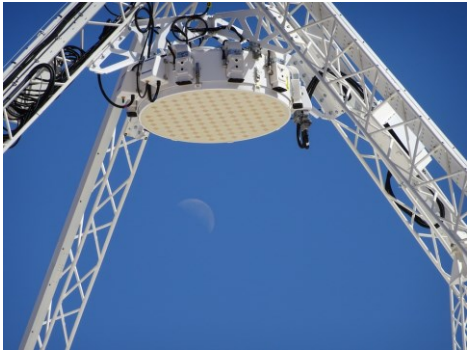




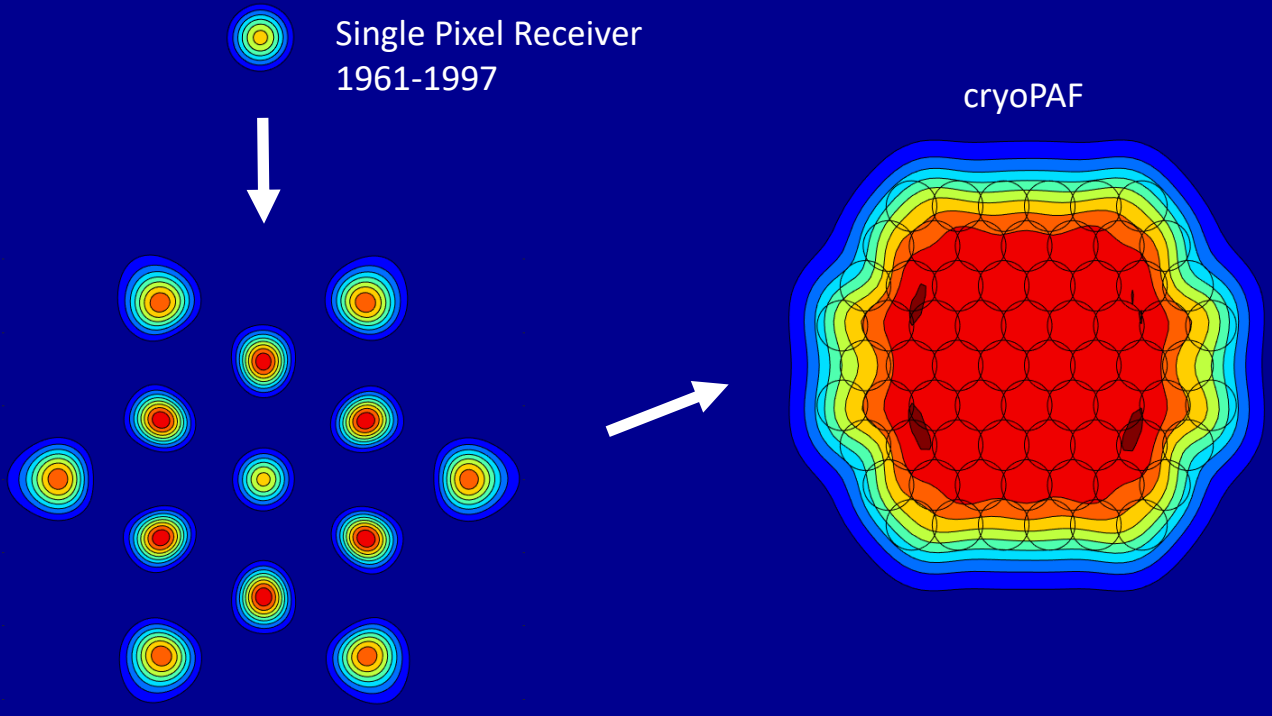


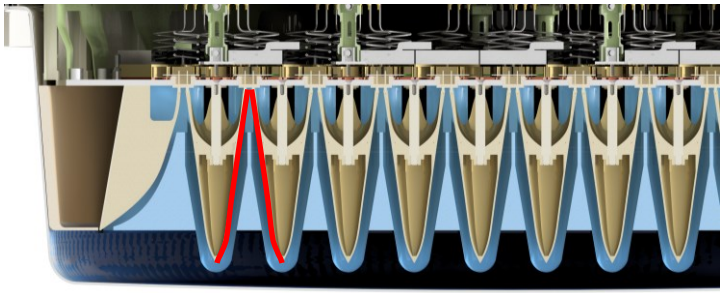
Weighted (complex) sum of inputs





Murriyang Radio Telescope field of view





Phased Array Advantages

- Higher Efficiency
- Lower Noise
- Interference spatial discrimination

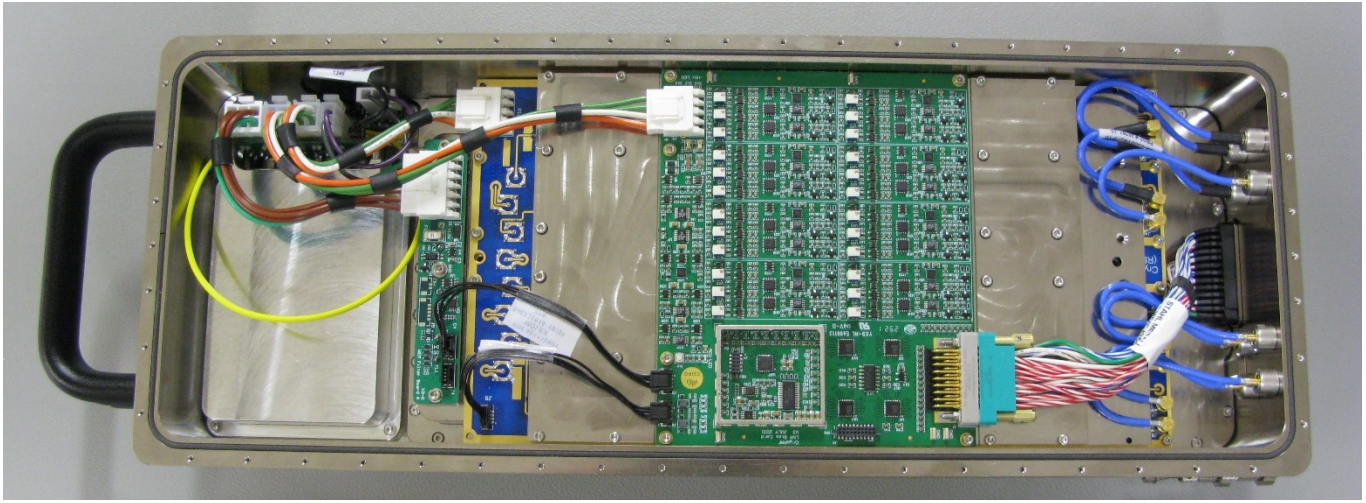
Phased Array Disadvantages

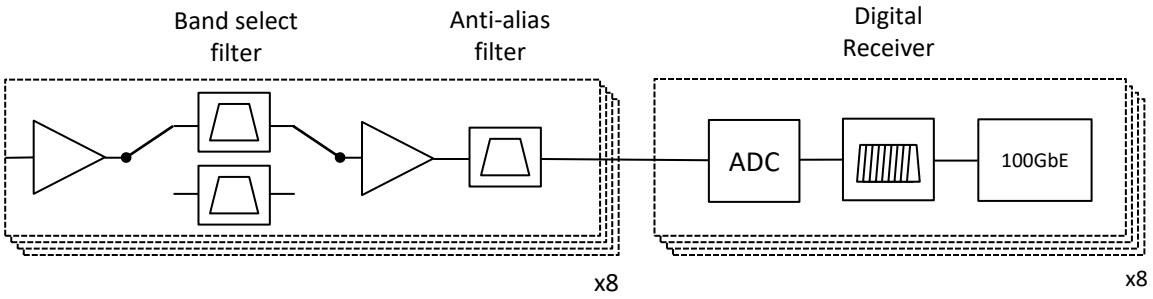
- Huge data rate
- Reduced bandwidth (but still very wide ☺)

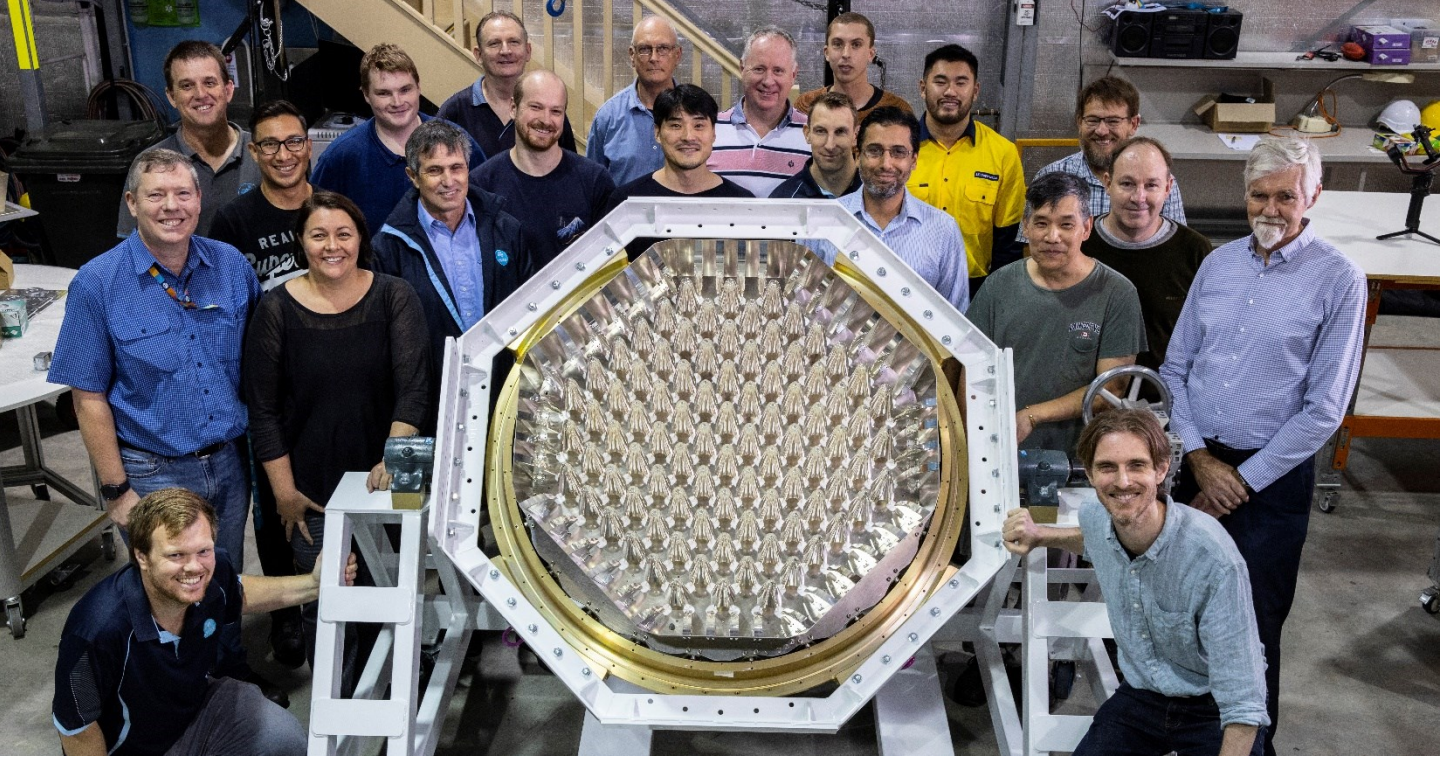
cryoPAF System Specifications:

- Based on ‘Rocket’ elements
- Frequency: 700-1950 MHz (700-1200,1100-1950 MHz)
- Ports: 196 (98 vertical, 98 horizontal)
- Beams: 72 Dual Polarization
- System Temperature < 20K
- Digital data rate out of PAF: 7.8 Tb/s
- FPGA beamformer, GPU backend
- Instantaneous bandwidth initially 150MHz increasing to 900MHz

Warm Electronics Module







Thank you

CSIRO Space and Astronomy
Alex Dunning