Phased Array Feed Receiver Development for the Australia SKA Pathfinder

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CSIRO

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- Antenna Measurements
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- Analogue and Signal Distribution
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- Computing and software, observing
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- Parkes team
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- Project Management
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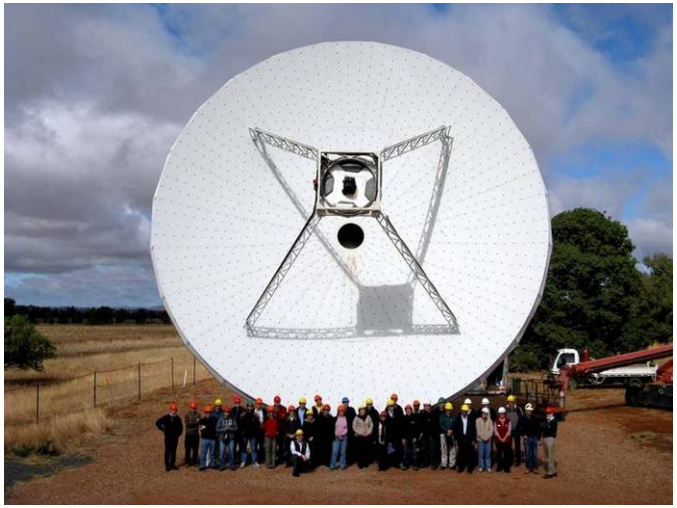

Outline

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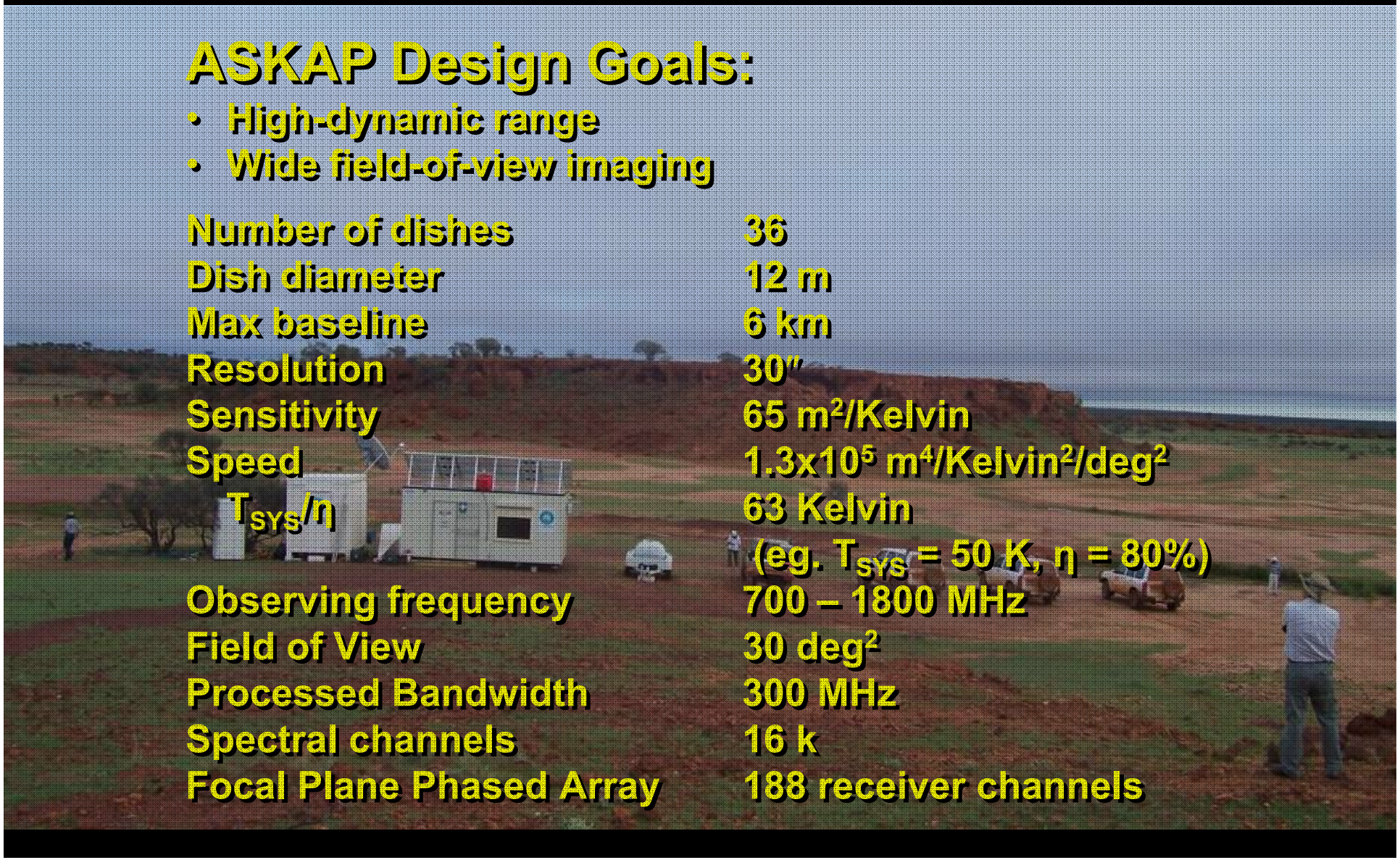
ASKAP specifications

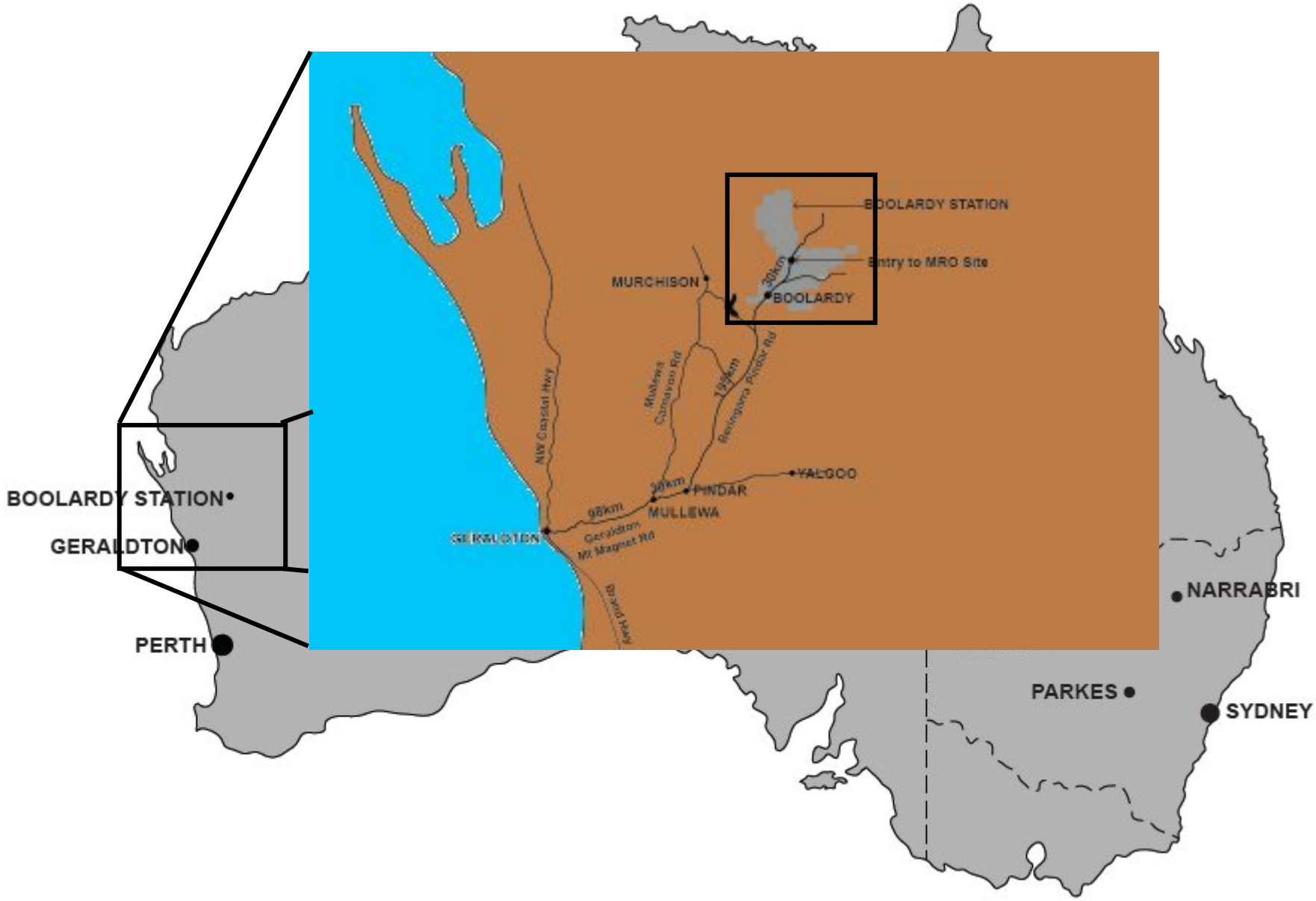


ASKAP Design Goals:

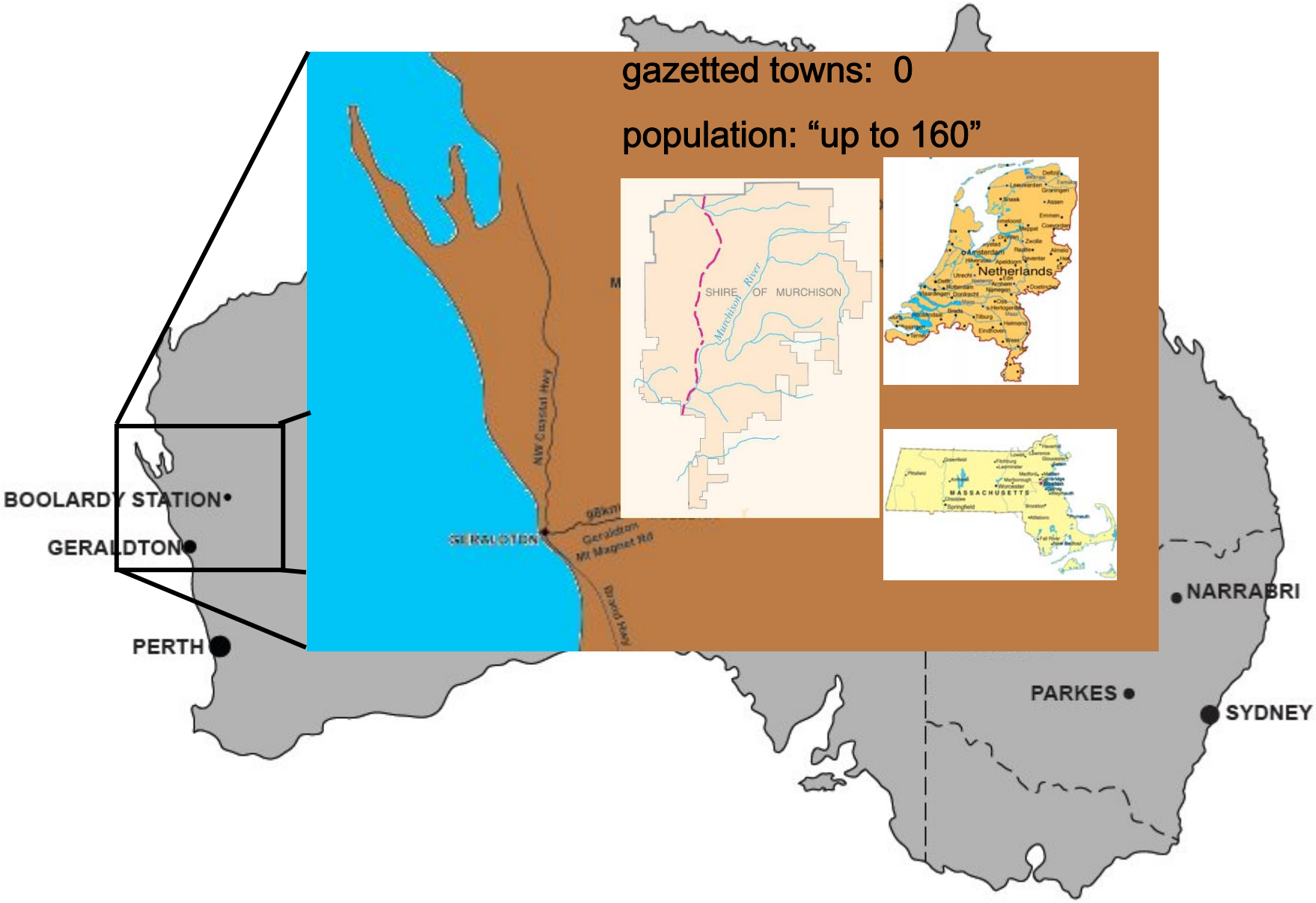
- High-dynamic range
- Wide field-of-view imaging

Number of dishes	36
Dish diameter	12 m
Max baseline	6 km
Resolution	30″
Sensitivity	65 m^2/Kelvin
Speed	1.3×10^5 m^4/Kelvin^2/deg^2
T_{SYS}/η	63 Kelvin
	(eg. T_{SYS} = 50 K, η = 80%)
Observing frequency	700 – 1800 MHz
Field of View	30 deg^2
Processed Bandwidth	300 MHz
Spectral channels	16 k
Focal Plane Phased Array	188 receiver channels

Murchison Radio Observatory

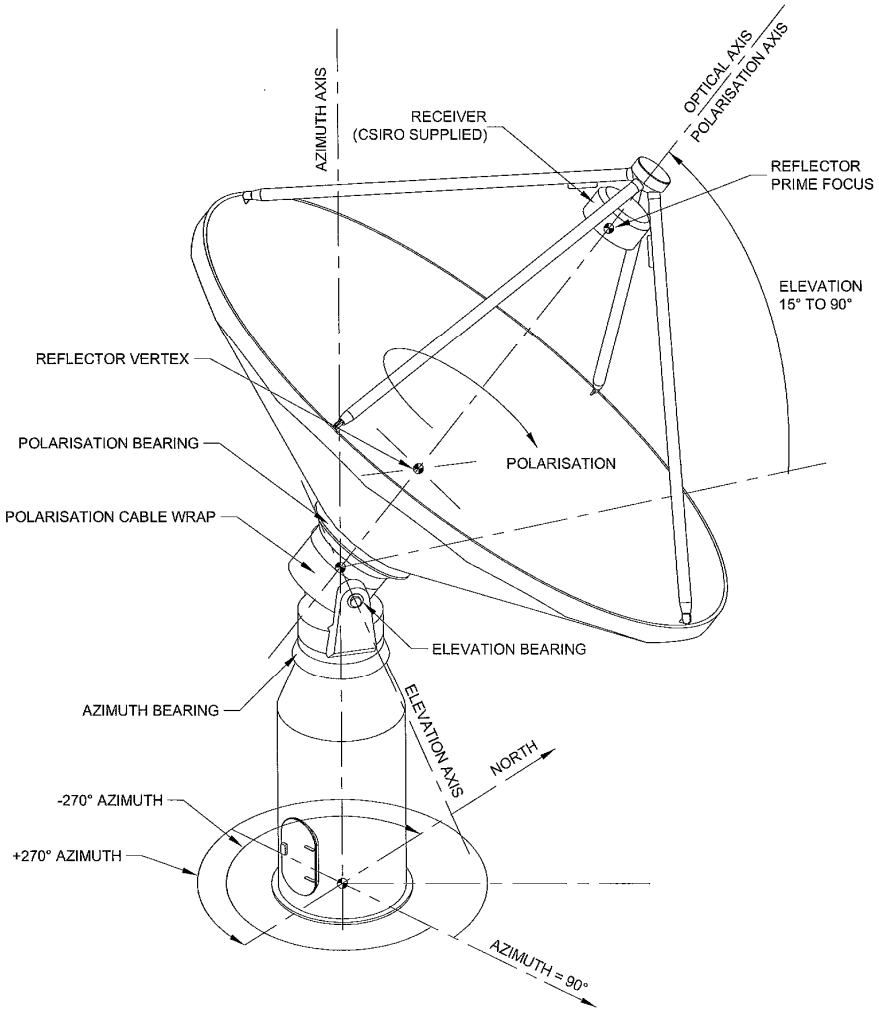


Murchison Radio Observatory

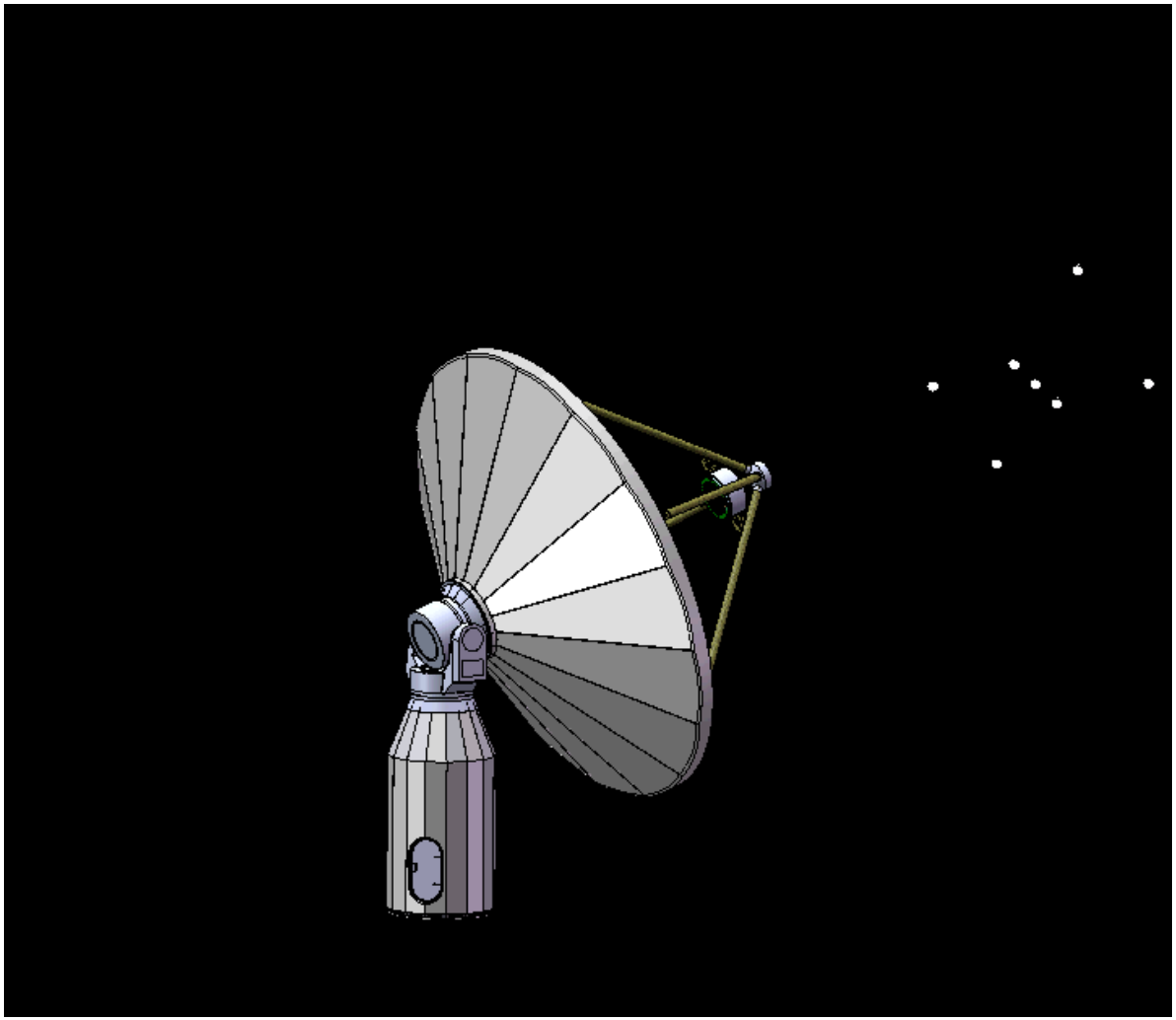


The ASKAP antenna specification

- 12m – prime focus, unshaped
- f/D = 0.5
- Alt-Az mount, with 3rd polarisation axis (Sky mount)
- Surface accuracy 1mm RMS
  (Operation to 10 GHz)
- Pointing accuracy 30 arcsec
- 2 arcsec alignment of optical axis and polarisation axis
- 45 km/h operational wind speed
- 160 km/h survival wind speed
- Feed mount capable of supporting a 200 kg PAF
- Accommodation for CSIRO equipment, eg, beamformer
- Accommodation for ~200 RF channels (coax) to PAF
- Operation in a desert environment



The ASKAP antenna specification



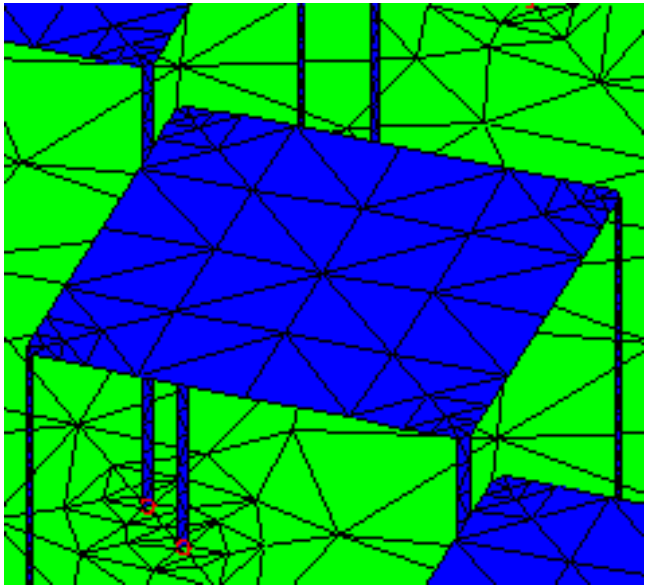
Advantages focal plane arrays over an array of feed horns

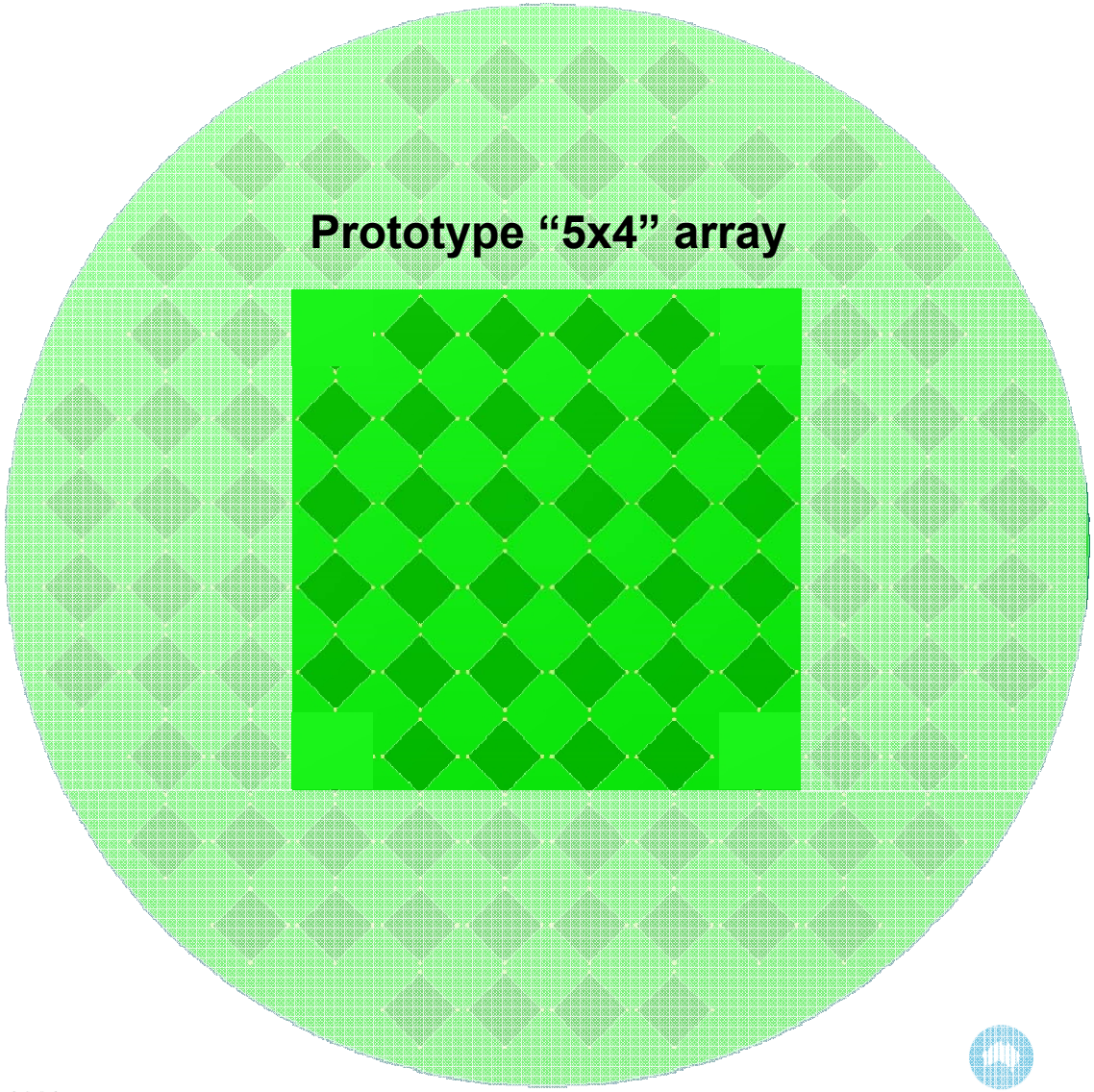
- By choosing the appropriate beamformer element weights we can maximise efficiency, sensitivity or beam quality.
  - **For maximum efficiency**
    we choose weights that are the conjugate of the received signal gain on each port.
  - **For maximum sensitivity**
    we choose weights as for optimum efficiency (above), but also multiply the weights by the inverse of the noise covariance.
  - **For optimum beam quality**
    we choose weights to control the primary beam sidelobes, and cross polarisation.
    That is, we choose weights to fit a desired, circularly symmetric reflector aperture illumination.

- We can also optimise a combination of the above: for example, trading-off sensitivity for beam quality.

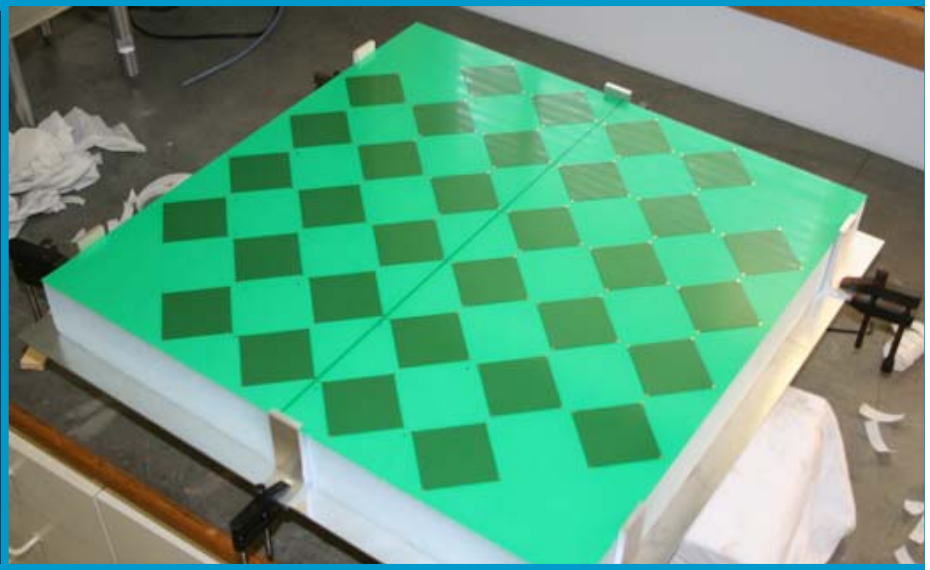
Checkerboard Array

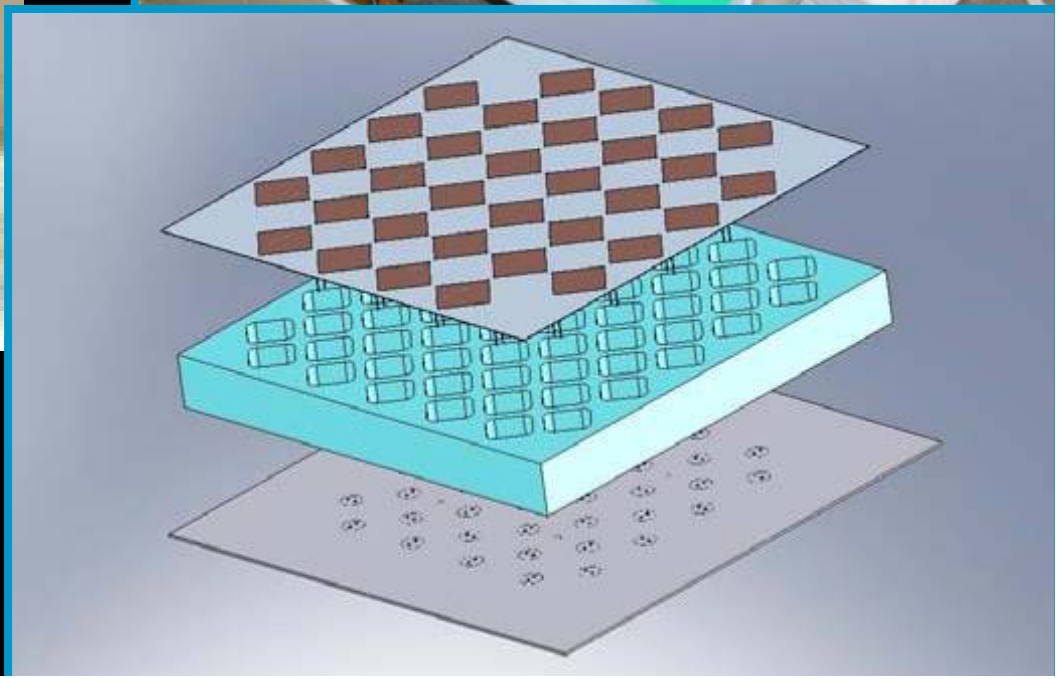
- ASKAP PAF array size
  - 12 x 12 patches with 6 patches omitted from each corner
  - ~1100 mm diameter





Checkerboard Array



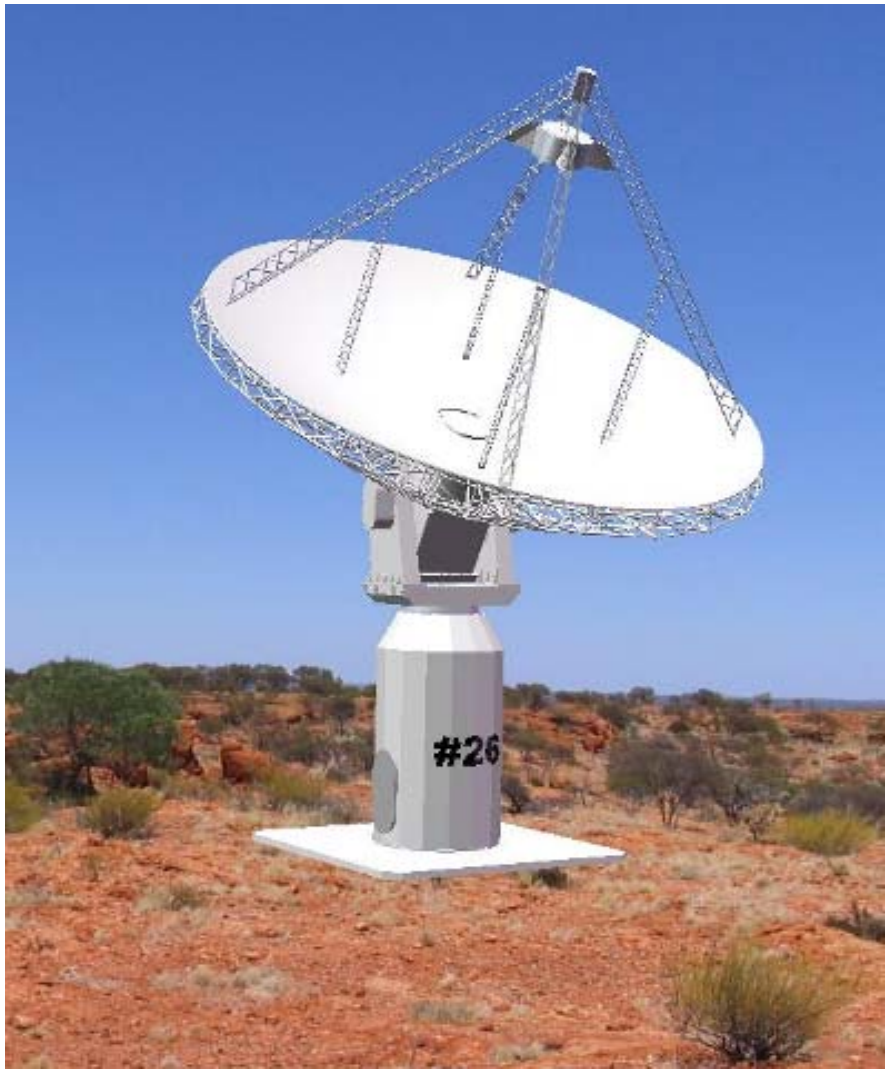


Analog System specifications

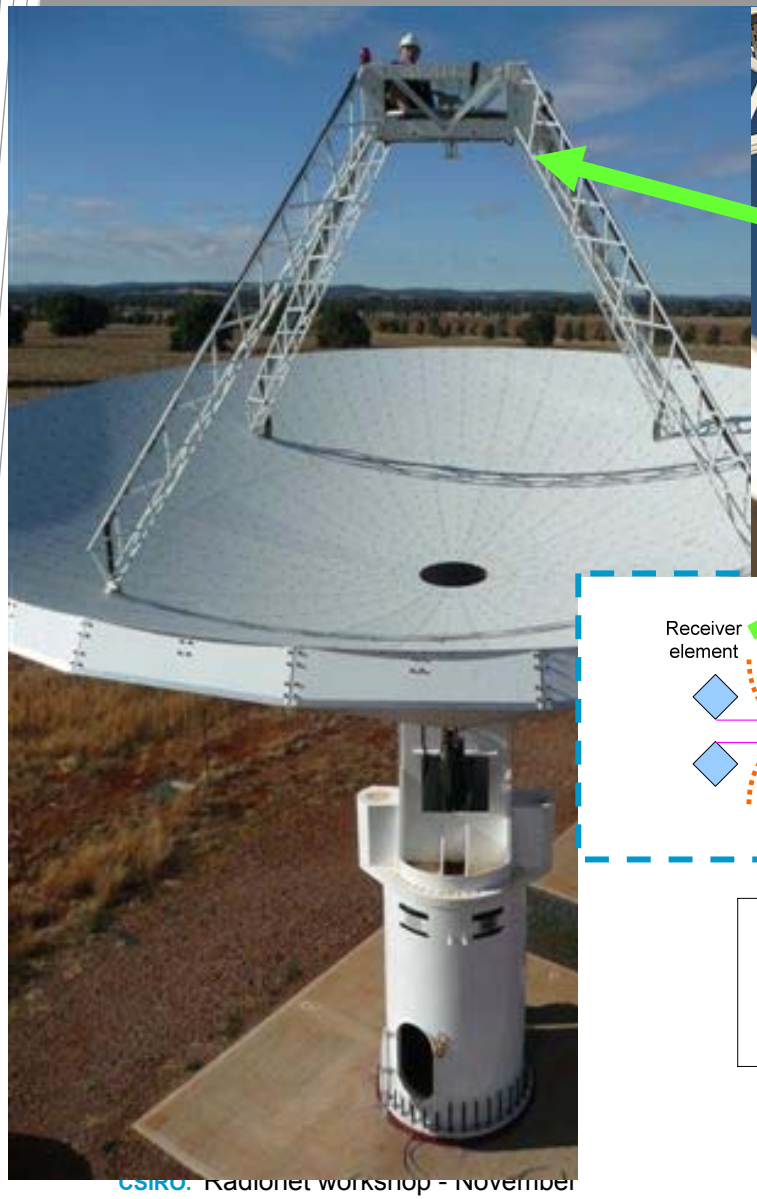
- Phased array receiver size
  - Receiver elements ~200 per antenna
- Frequencies
  - RF band 700 – 1800 MHz
  - Instantaneous bandwidth 300 MHz
  - Sampled band 424 – 724 MHz
  - Sample clock 768 MHz
- Low-noise amplifiers
  - amplifier noise temperature 40 Kelvin
  - amplifier gain 27 dB
- System gain
  - Nominal total nett gain 72 dB
- Output power (to digitiser)
  - Nominal IF output power -19 ±1 dBm into 50 Ohms

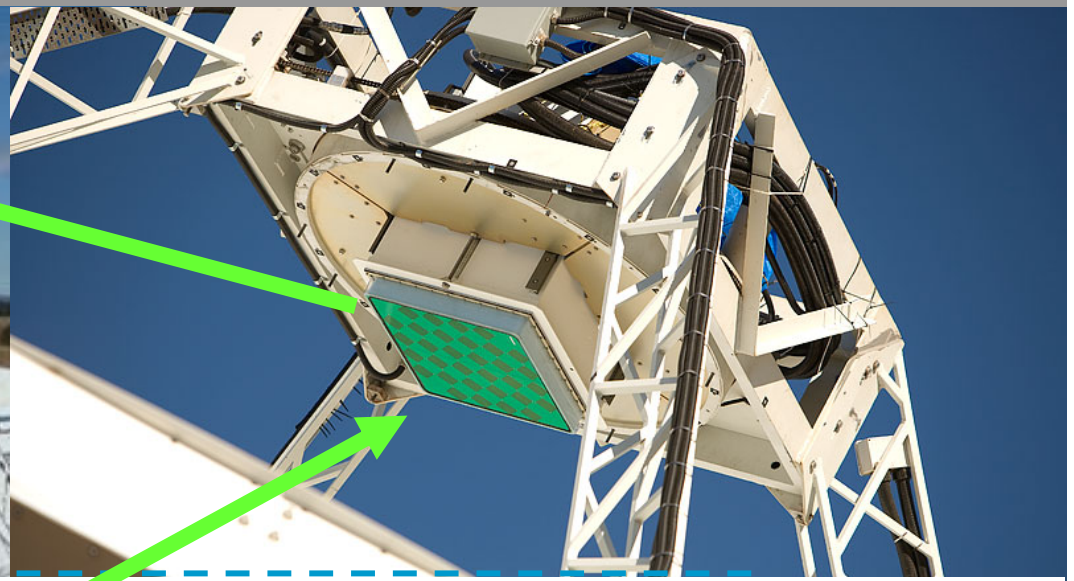
Receiver design constraints

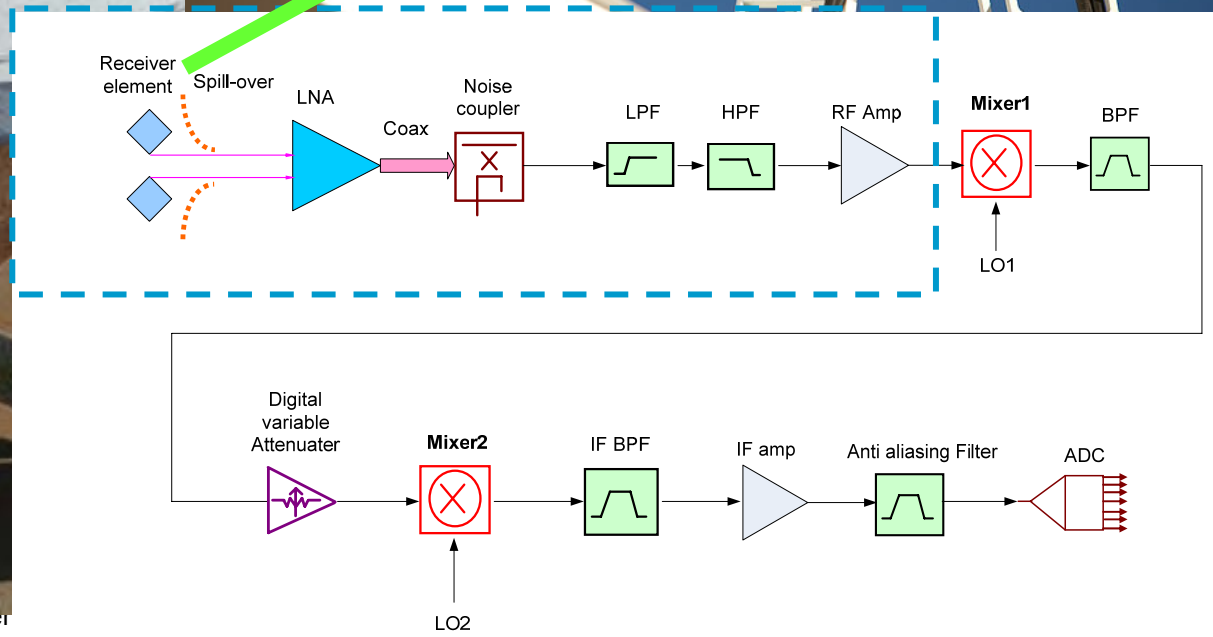
- Relatively long f/D ratio (f/D = 0.5)
- PAF receiver weight must be less than 200kg
- High attenuation in coax cable from prime focus to pedestal
  - 17dB at 0.7GHz
  - 31dB at 1.8GHz
- Minimise RFI generated
- Maximise RFI immunity



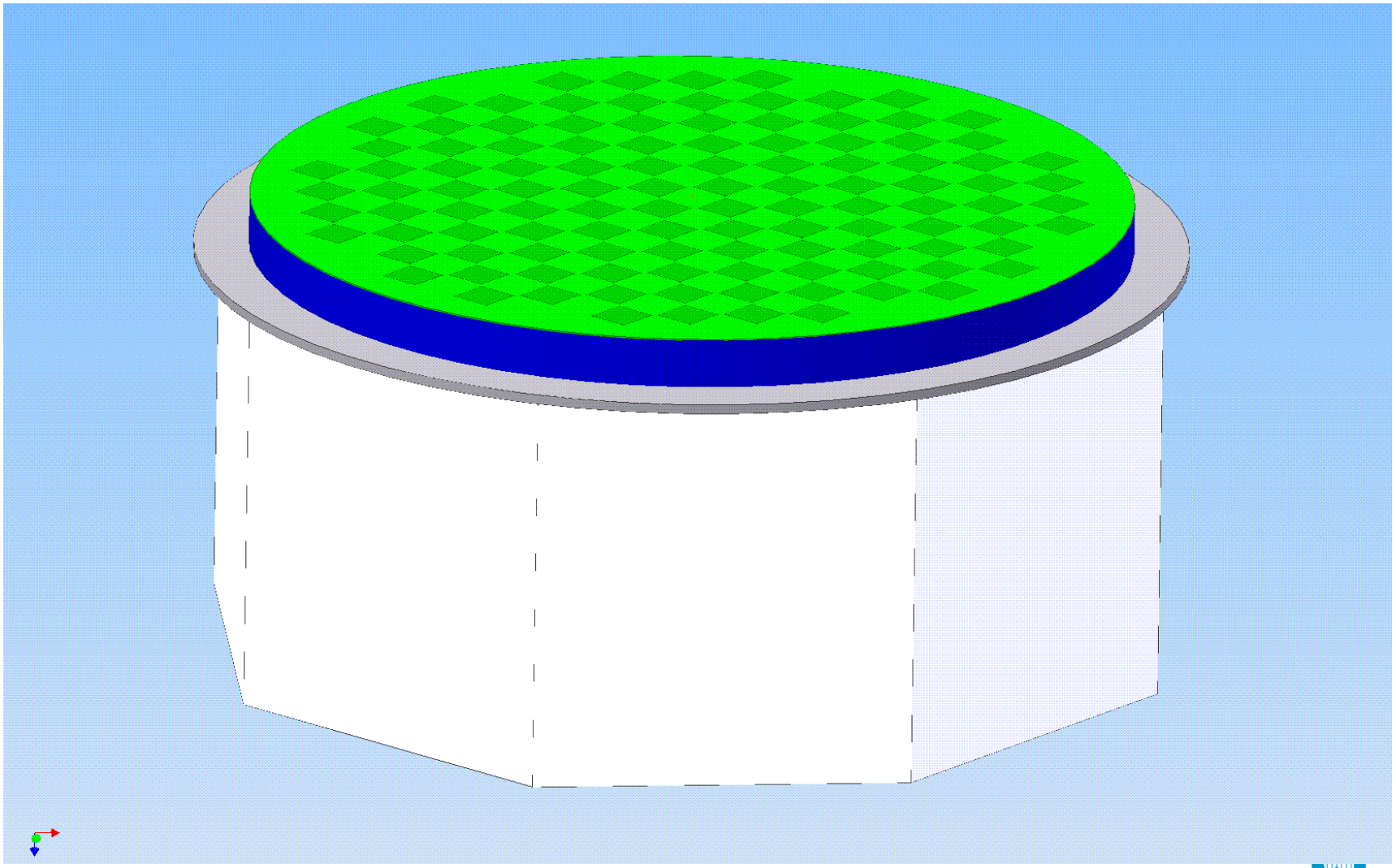
ASKAP Analog System architecture







Prime Focus package



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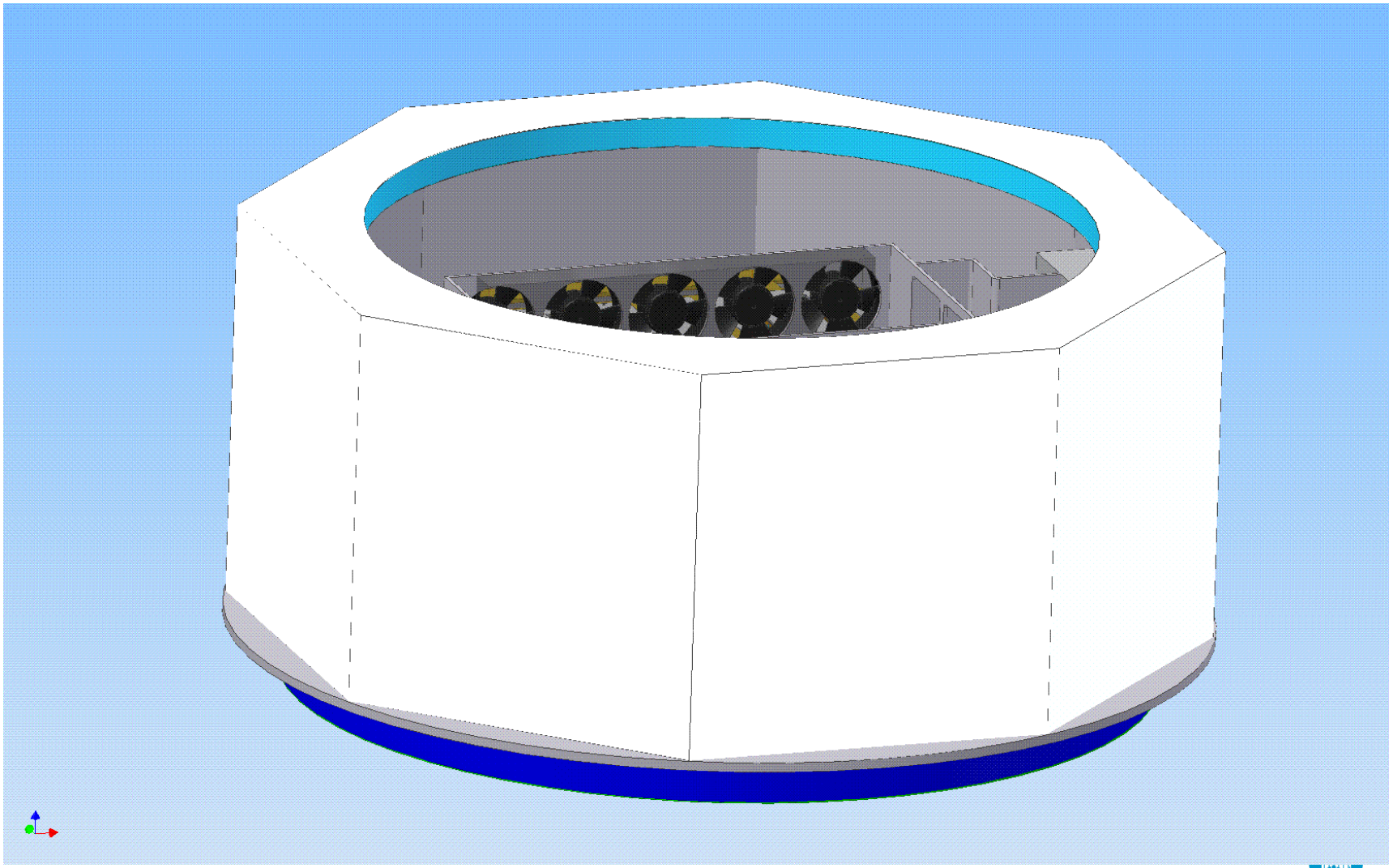

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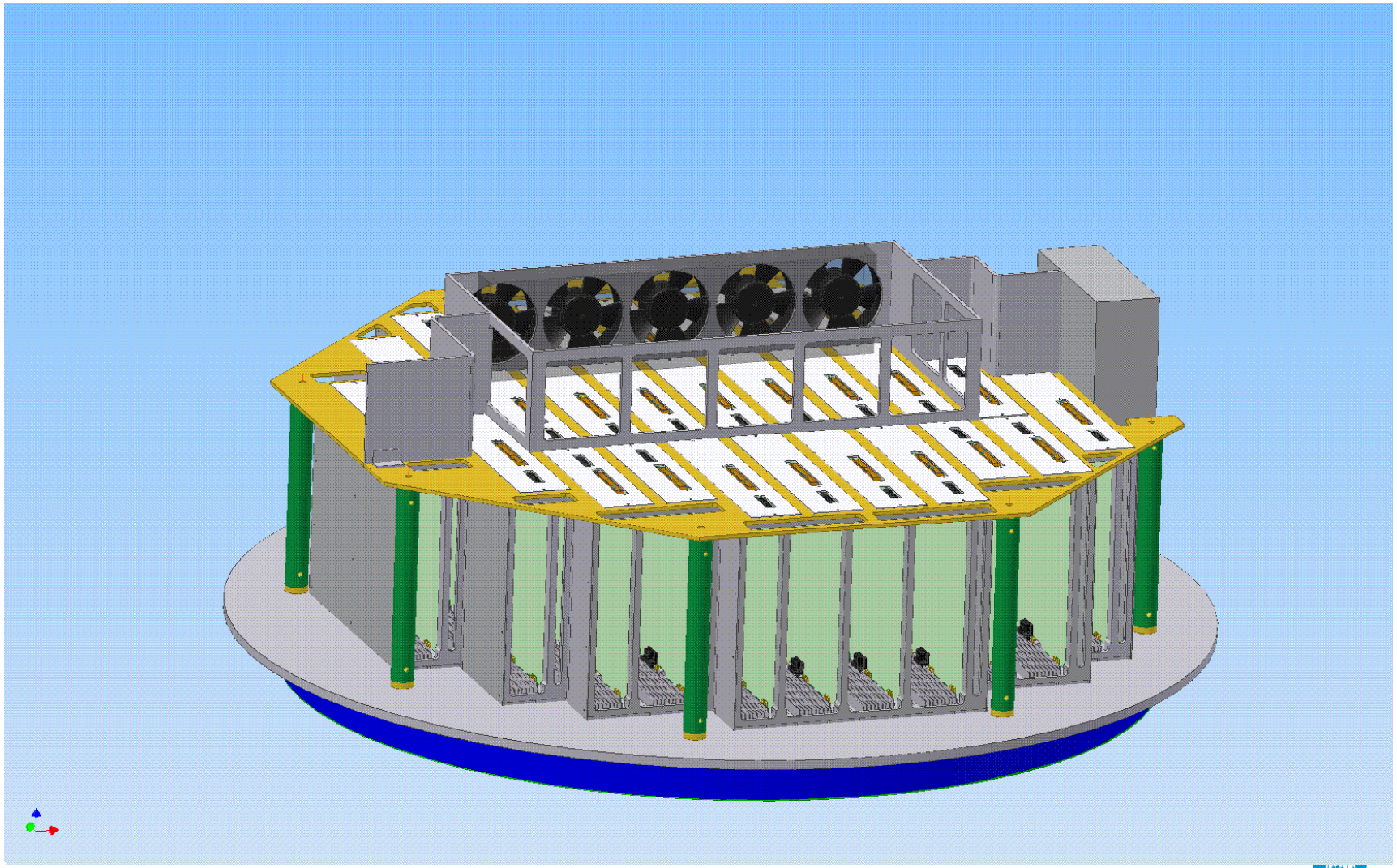

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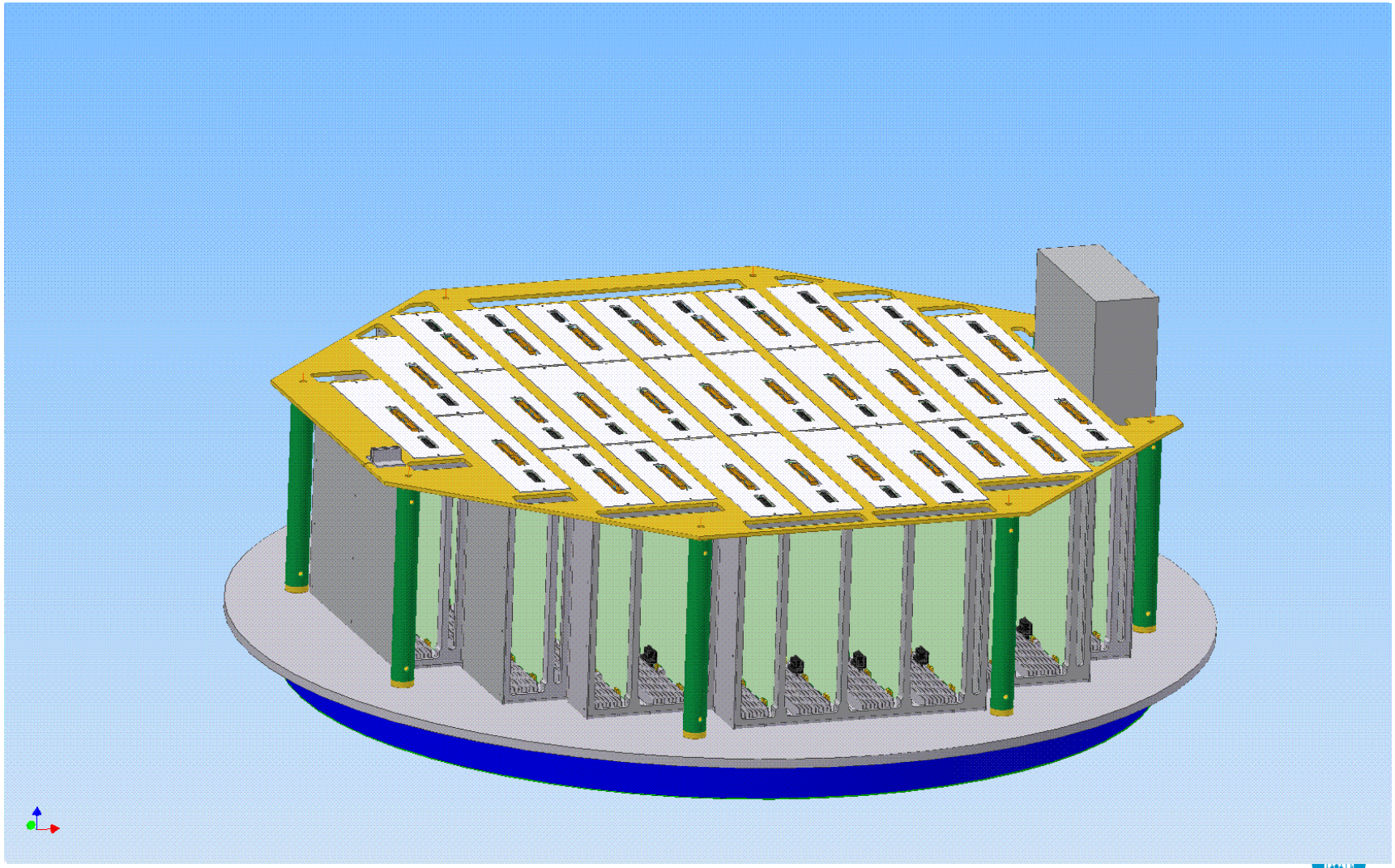

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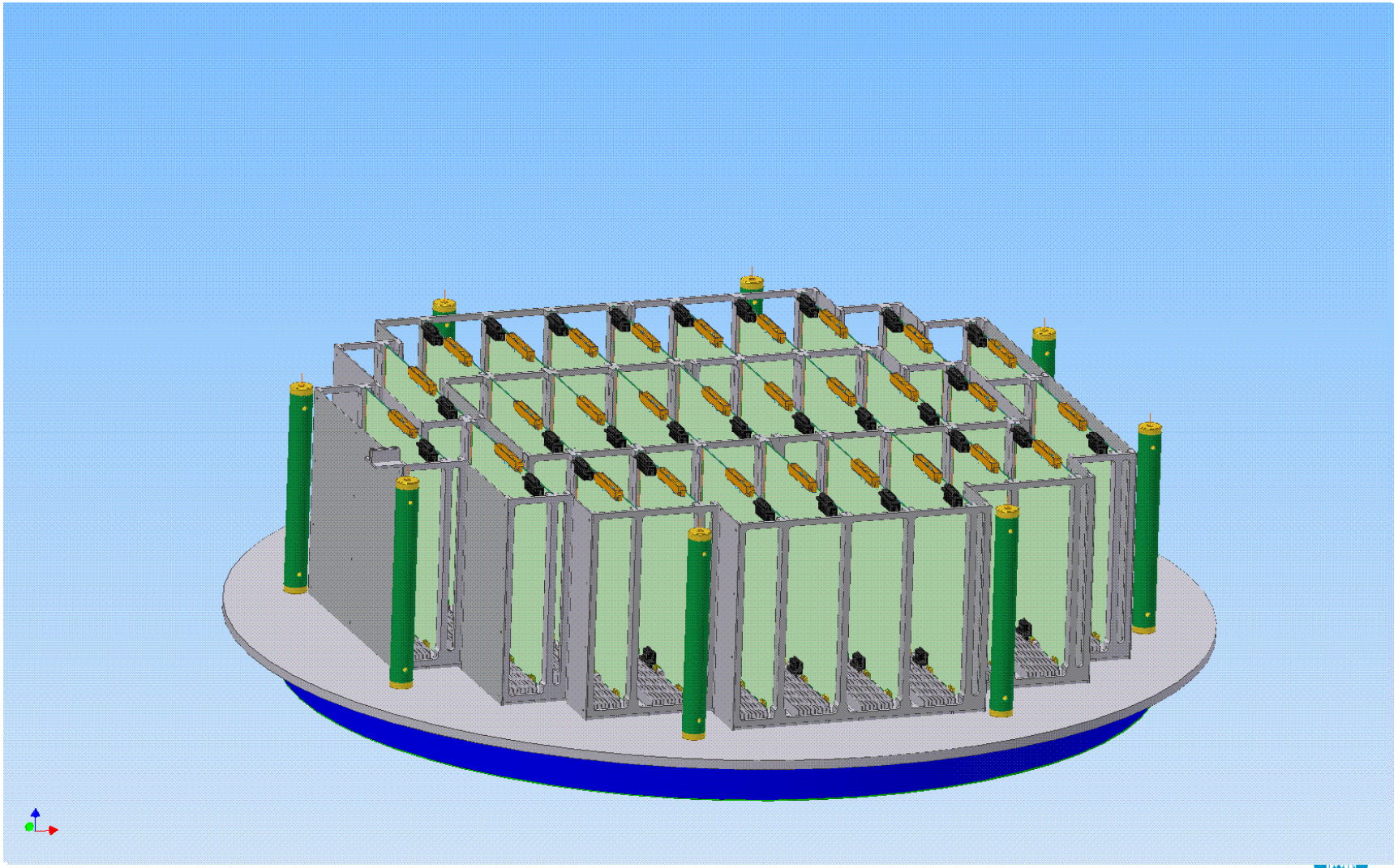

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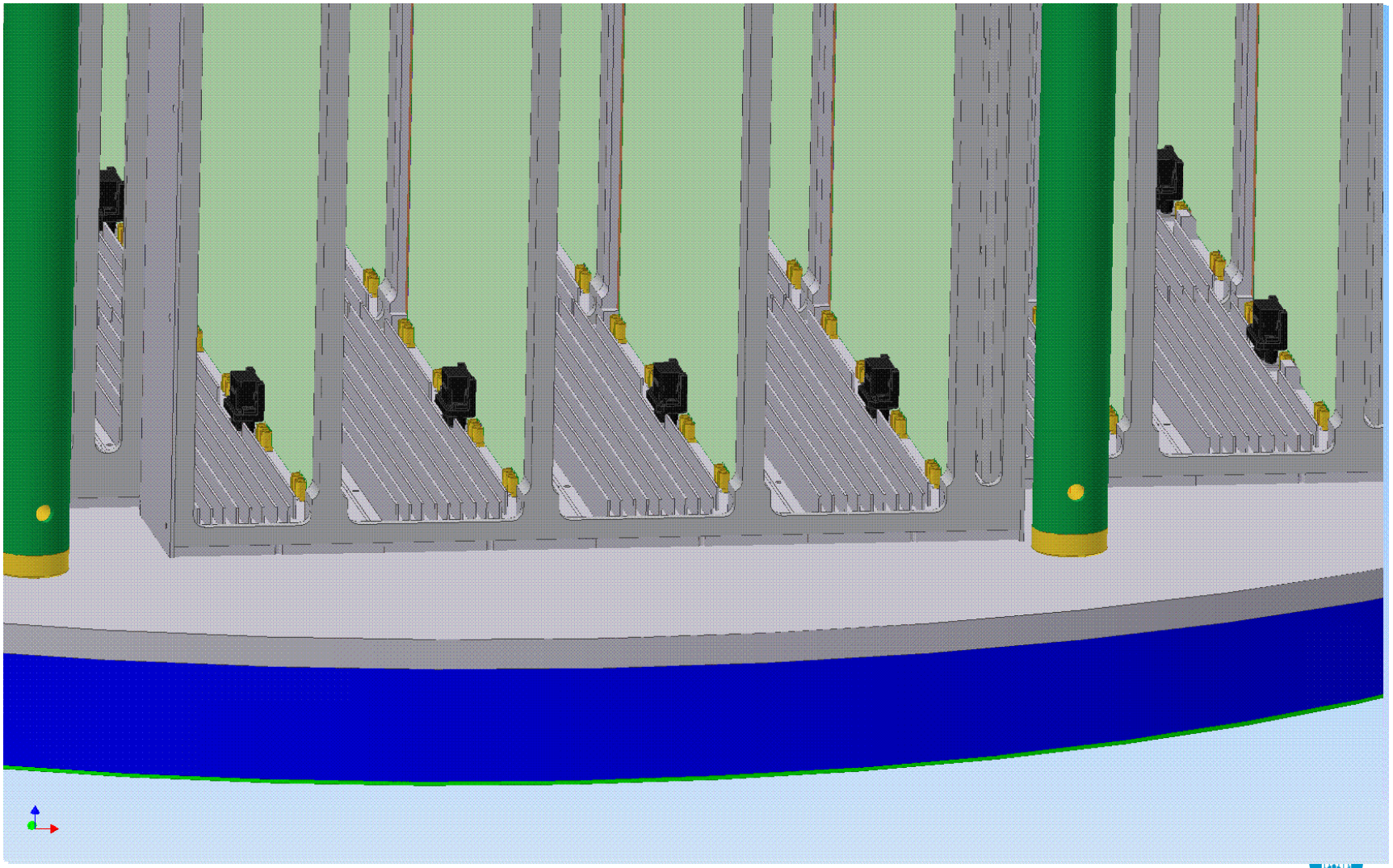


Calibration issues

- Calibration
  - Calibration signal(s) transmitted from dish surface
  - Both polarisations
  - Correlate transmitted signal with received signal in each receiver channel

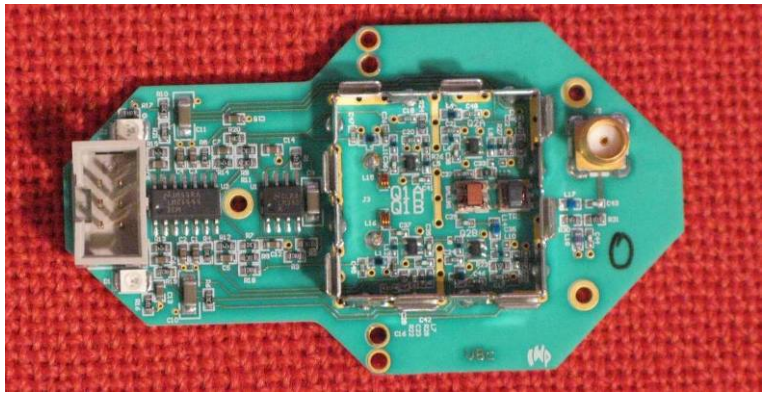
- Gain and Phase stability - post electronic calibration (if any)
  - Maximum RMS gain/phase fluctuation in ~ 1 minute *
    0.026 dB, 0.16°
  - Maximum RMS gain/phase fluctuation in ~ 1 second **
    1.4 dB, 10°

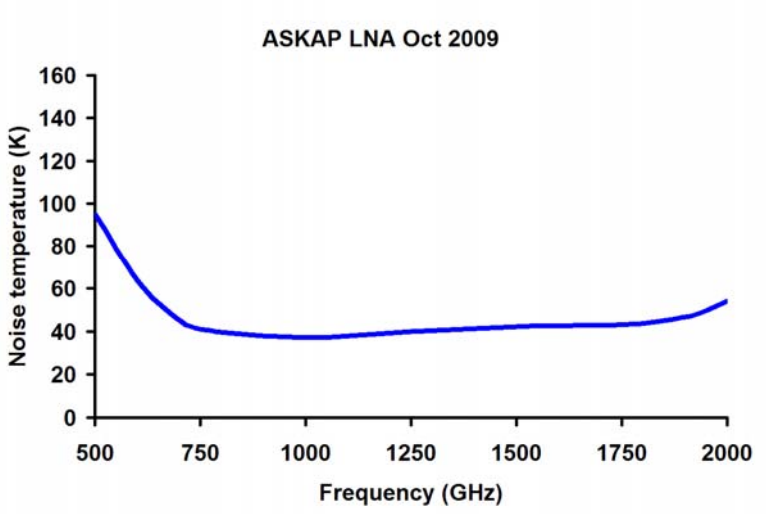
* To minimise the residual error sidelobes from sources in the field-of-view (no self-cal within the field-of-view is possible on these short time scales)

** Larger gain/phase fluctuations will cause signal loss through decorrelation

Low-noise amplifier

- Design frequency range:
  0.7 – 1.8 GHz
- Design system impedance at input :
  300 Ω (differential)
- Low noise transistors:
  Avago ATF 35143
- Two stages of gain
  Configured as two independent amplifiers with a single (difference) output
- Gain:
  28 dB
- Noise temperature:
  35 – 55 Kelvin
  (measured in a 300 Ω differential system impedance)

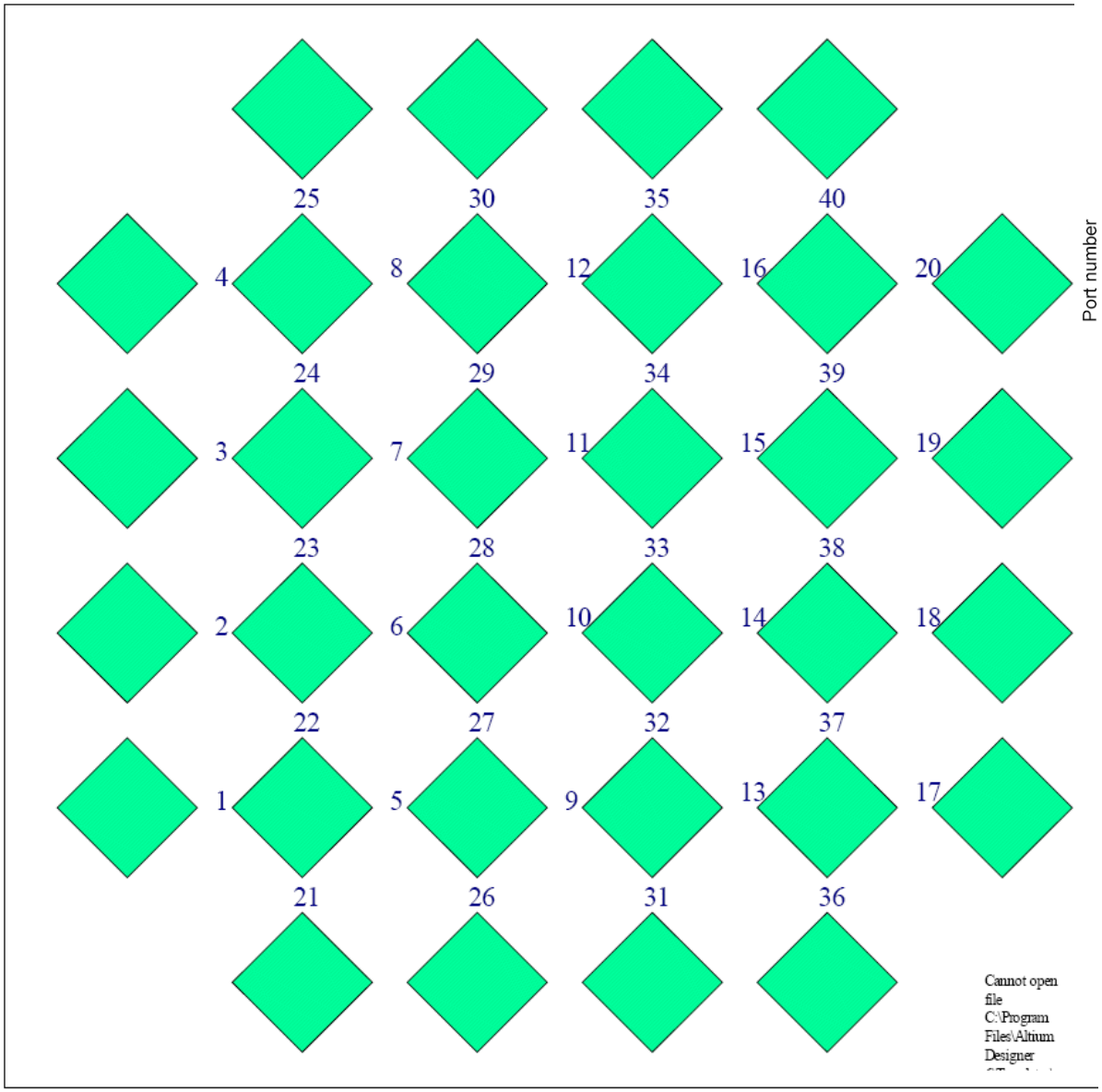


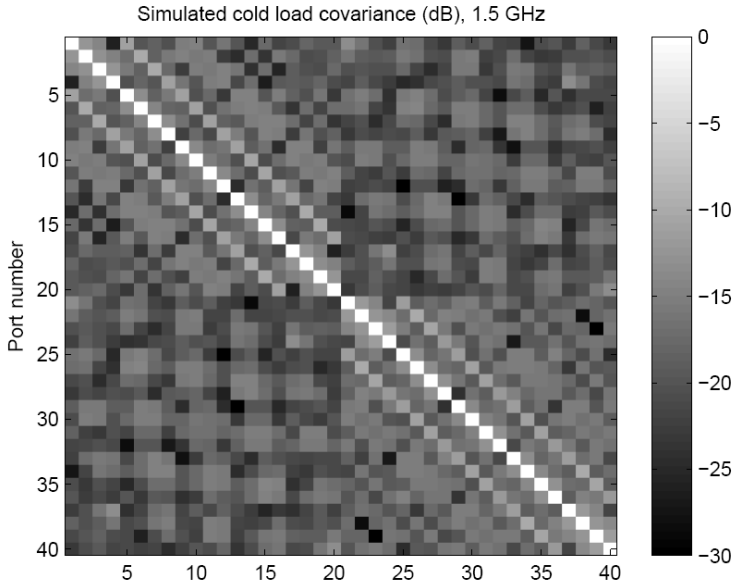


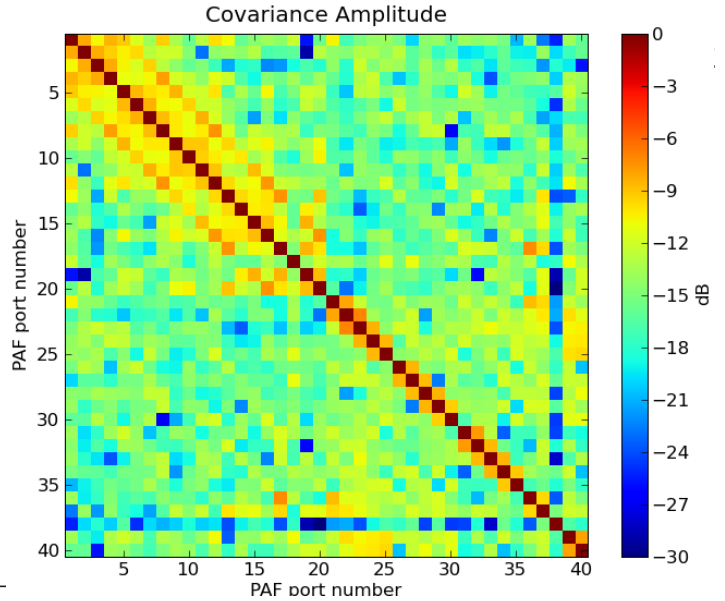
Measurement of prototype “5x4” array

- Early days
  - More work need to be done as results are inconsistent
- Typically, the beamformed T_{SYS} is ~ ¼ of the single element T_{SYS}
- Characterising array performance as an aperture array
  - Element weighting is different from that when the array is used as a focal plane array
  - “Hot-box” and sky
  - 2.4 m x 3.0 m load
- Estimated T_{SYS}
  - Single element ~240 K
  - Beamformed 60-80 K

Measurement of prototype “5x4” array







Astronomical measurements

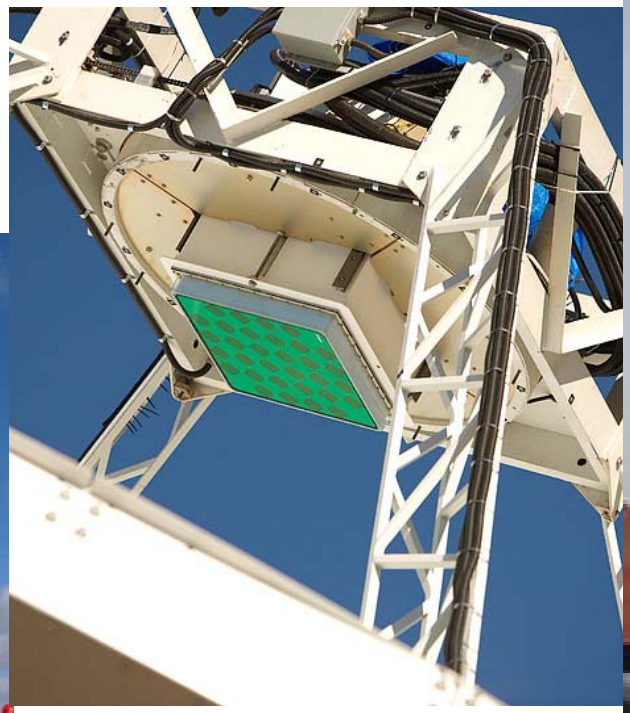
- Characterising array performance as a Phased Array Feed:
  - Single dish measurements
  - Interferometry measurements with the Parkes 64 metre dish
- Measurements of:
  - Virgo A,
  - 1934-638 and
  - An extended HI region (S9).

- Best estimate
  - Single element T_{SYS}/η ~ 600K at 1310 MHz
  - Beamformed T_{SYS}/η ~ 150K at 1310 MHz
  - Phased Array feed results are inconsistent with aperture array results
  - And both results are inconsistent with modelling

Project status

Recent milestones

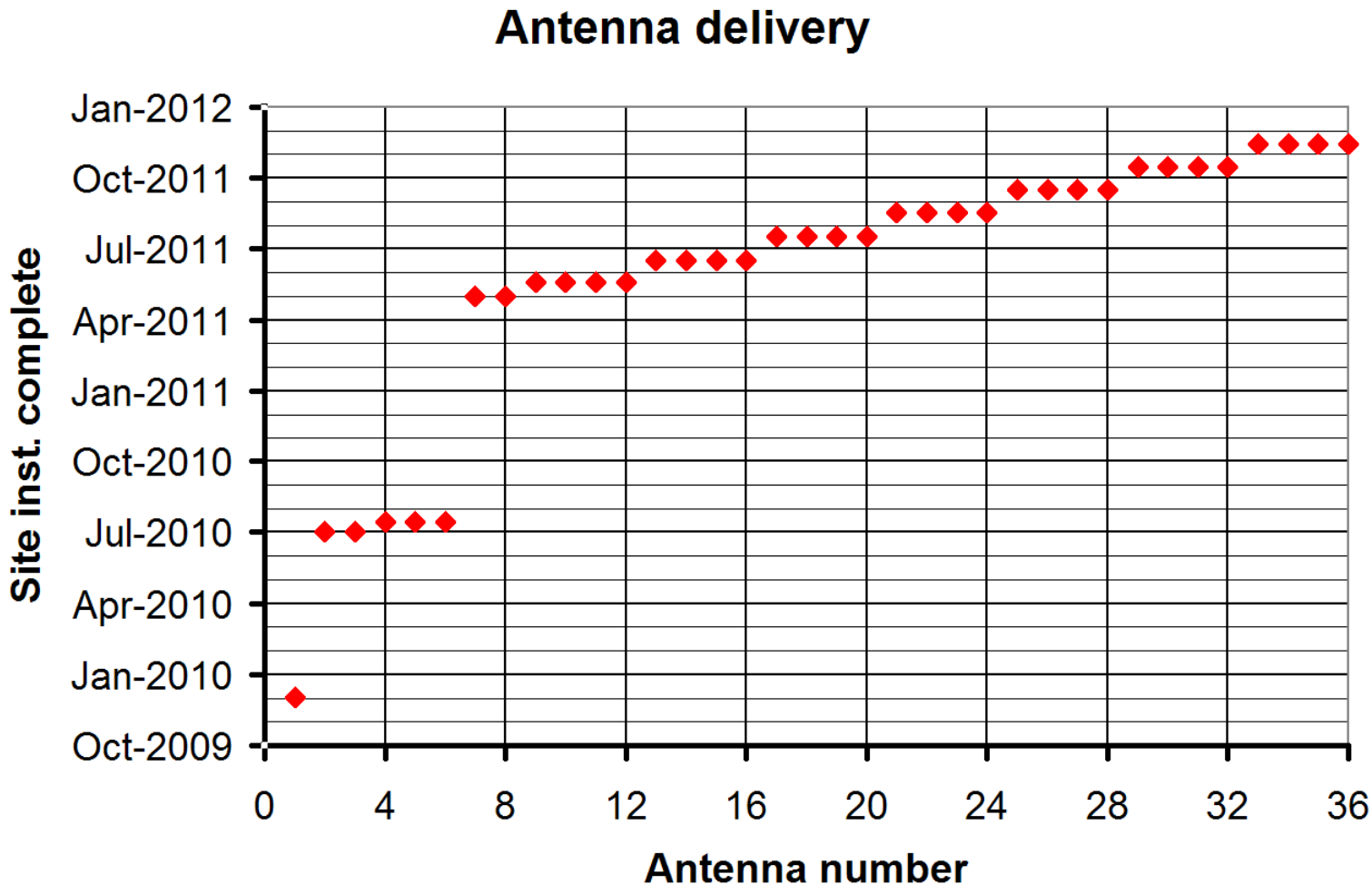
Dedicated 12m testbed antenna at Parkes for PAF development, commissioned early 2008.

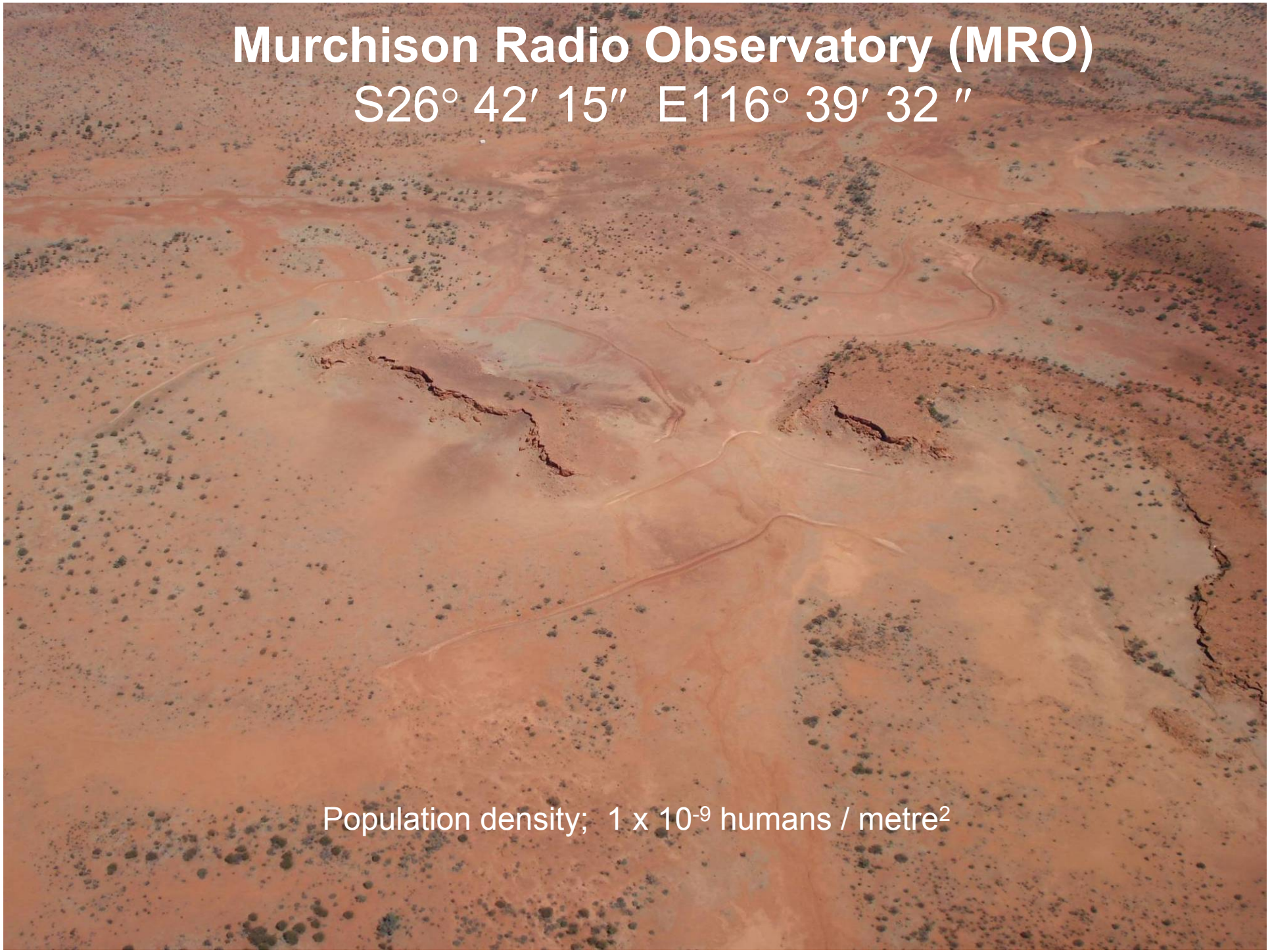


Prototype 5x4 array complete – first light August 2008.

ASKAP Antenna 1
Factory acceptance test
September 2009

Project status




Murchison Radio Observatory (MRO)
S26° 42′ 15″ E116° 39′ 32 ″
Population density; 1 x 10-9 humans / metre2

Australia Telescope National Facility

Russell Gough

November 16, 2009

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Thank you

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