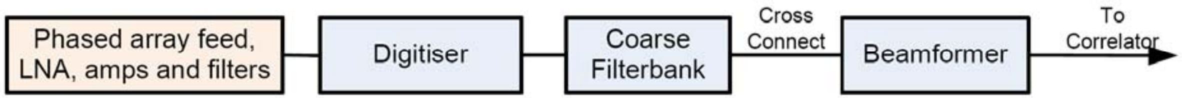
WP2.2 CoDR
PAF Concepts

Stuart Hay and Bruce Veidt
PAFSKA
WP2.2.3

PAF sub-system review

PAF presentations at CoDR



Phased array feed, LNA, amps and filters

Digitiser

Coarse Filterbank

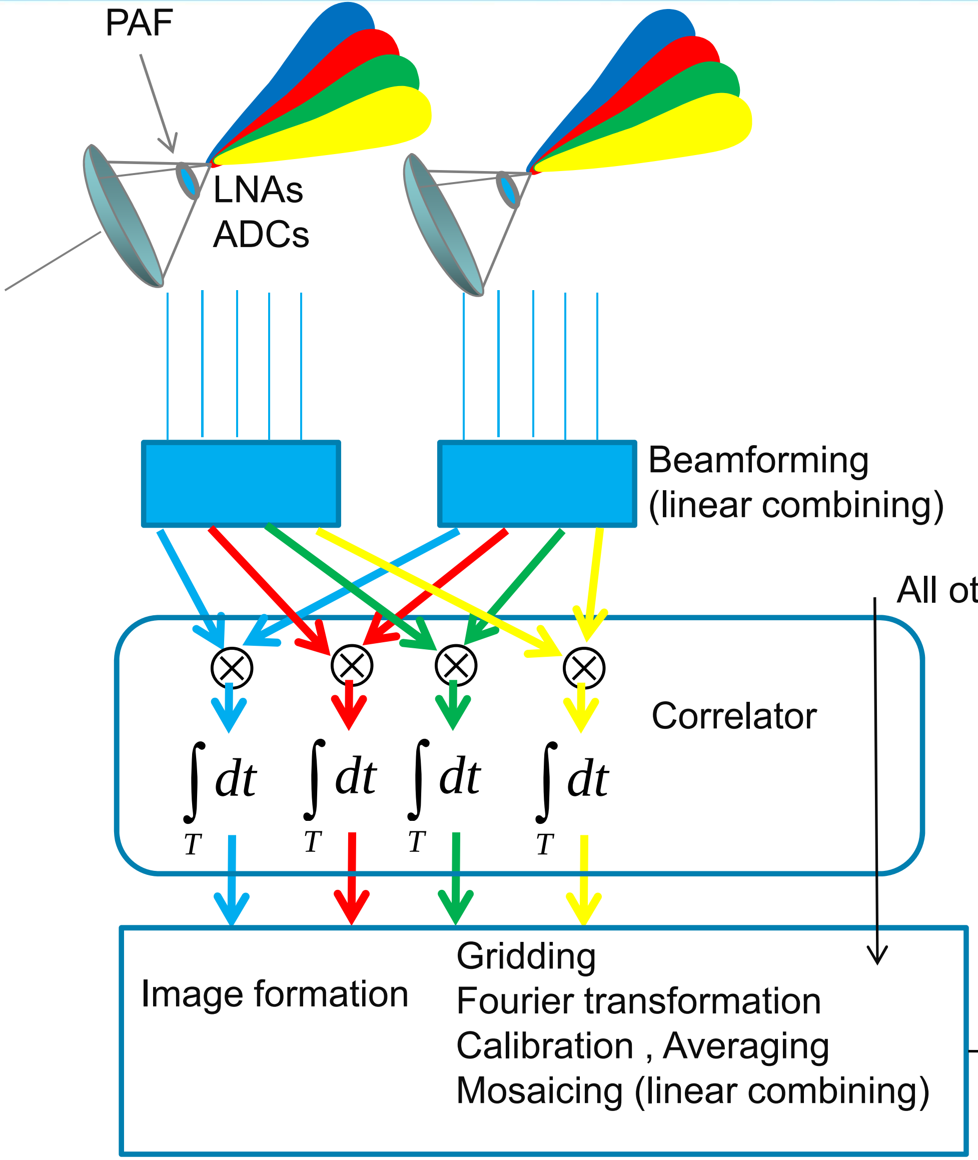
Cross Connect

Beamformer

To Correlator

PAF SKA Context, addressing SKA requirements	Carole
PAF concept – PAF feed, LNA & optics	This presentation
PAF Concept PAF Receiver systems	Russell, Bruce, Grant
PAF Requirements, logistics & risks	Mark
PAF Costs & plans for next phase	Carole

PAF capability



PAF

LNAs
ADCs

Beamforming
(linear combining)

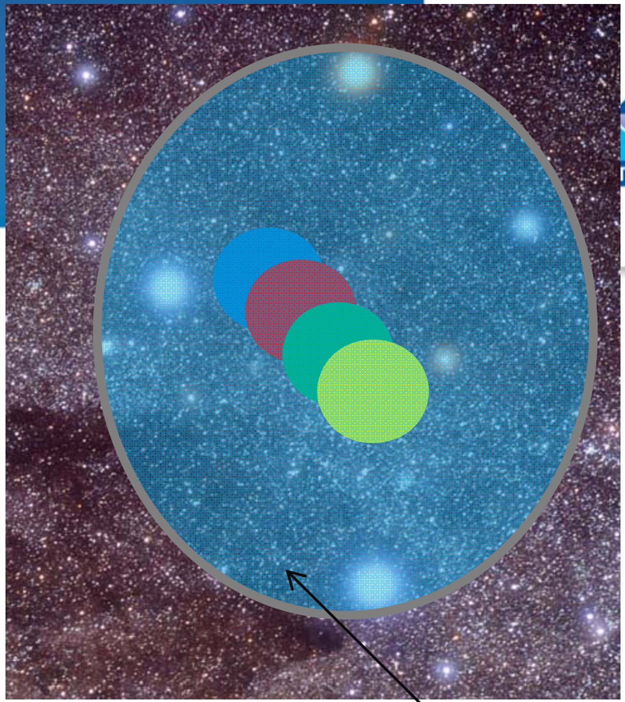
Correlator

All other antenna pairs

Image formation

Gridding
Fourier transformation
Calibration , Averaging
Mosaicing (linear combining)

→ Image (intensity and polarization)



Instantaneous field of view

- Survey speed $\propto \underbrace{(\eta_{ap} A_{phy} / T_{sys})}_{\text{Sensitivity}}{}^2 \ \Omega_{FOV}$

- Dynamic range
- Polarization purity
- Finding transient phenomena

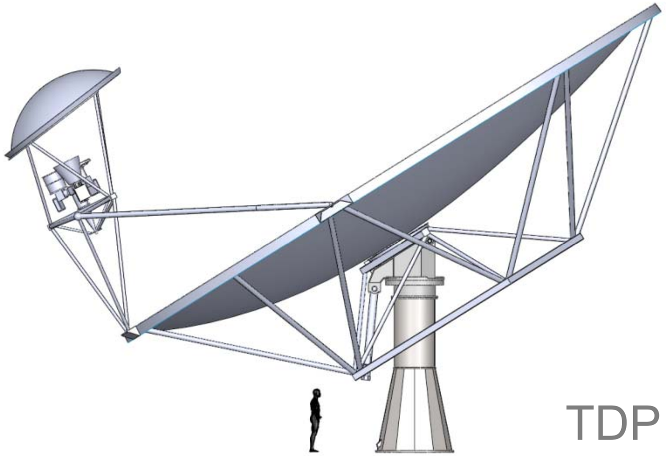
Optics/antenna considerations

1. f/D
2. FoV de-rotation
3. Reflector shaping

f/D

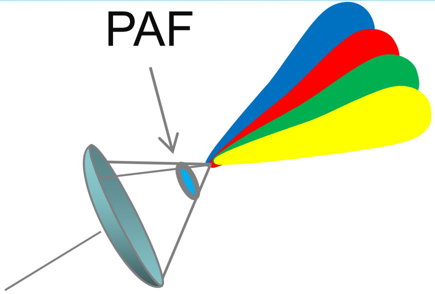
- Moderate f/D ~ 0.4-0.5 is important to minimizing PAF cost
  - Number of PAF elements α $(f/D)^2$ for given FoV
  - Good aperture efficiency
- Consistent with Pathfinder and PrepSKA dish activities
  - Front-fed single reflector
  - Offset-fed dual reflector
- Can be difficult to achieve with small blockage in other configurations

ASKAP

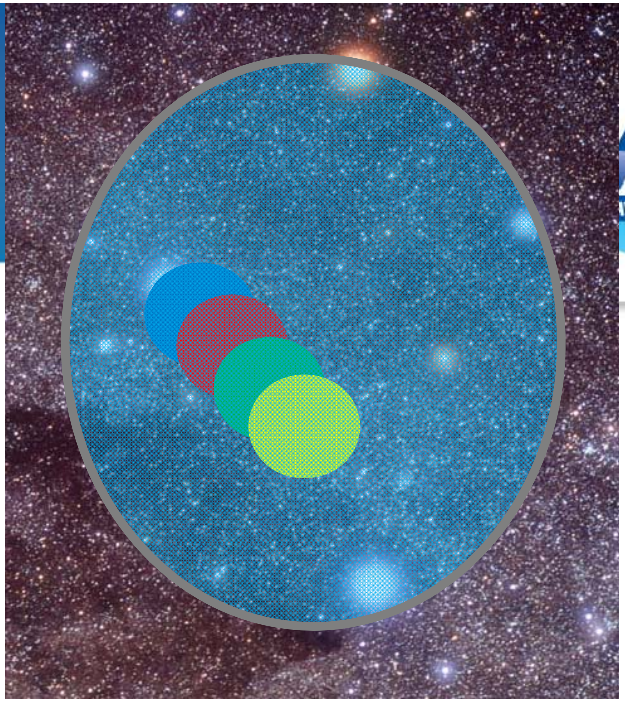


TDP DVA 1

FoV de-rotation



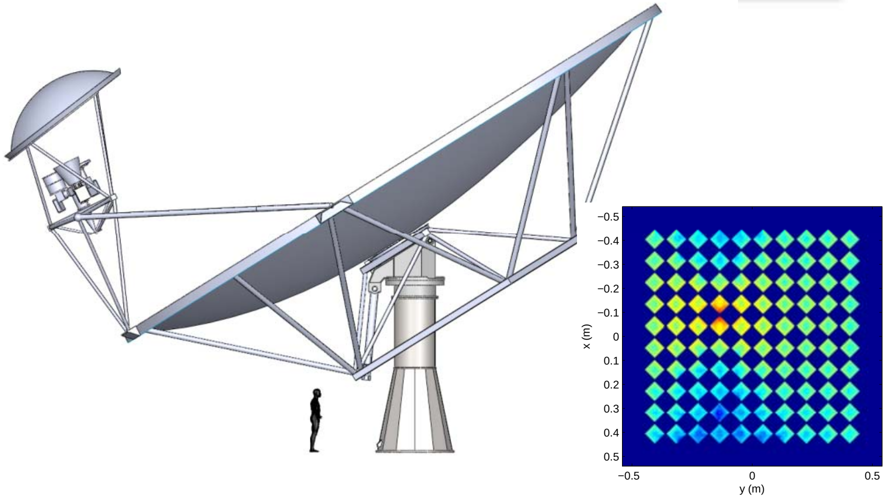
Instantaneous
field of view



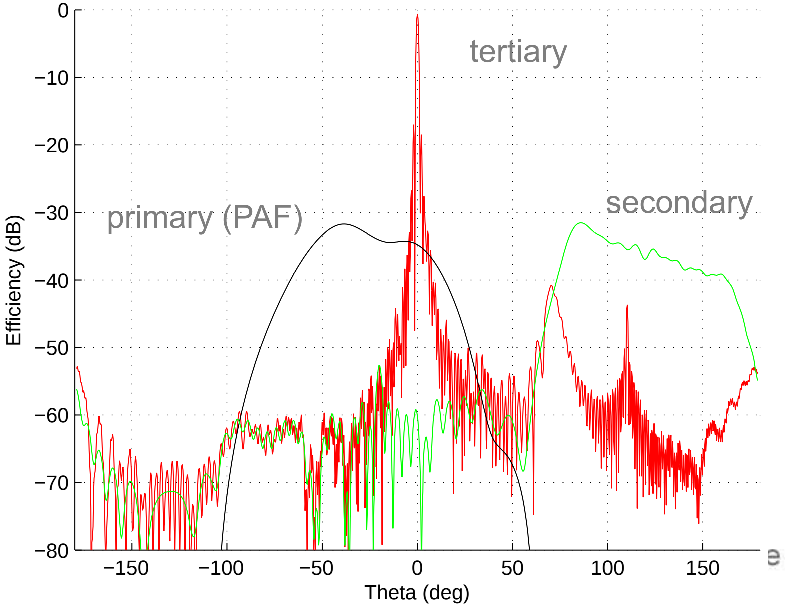
- For high dynamic range, beams must be stable wrt sources whilst integrating in the visibility domain

- Difficult to resolve in image formation
  - Calibration, storage and processing
- Altaz mount + 3rd axis to rotate reflector and feed (eg ASKAP)
- Equatorial mounts (eg WRST)
  - Latitude dependent SKA
- Altaz with electronic beam scan whilst maintaining beam shape

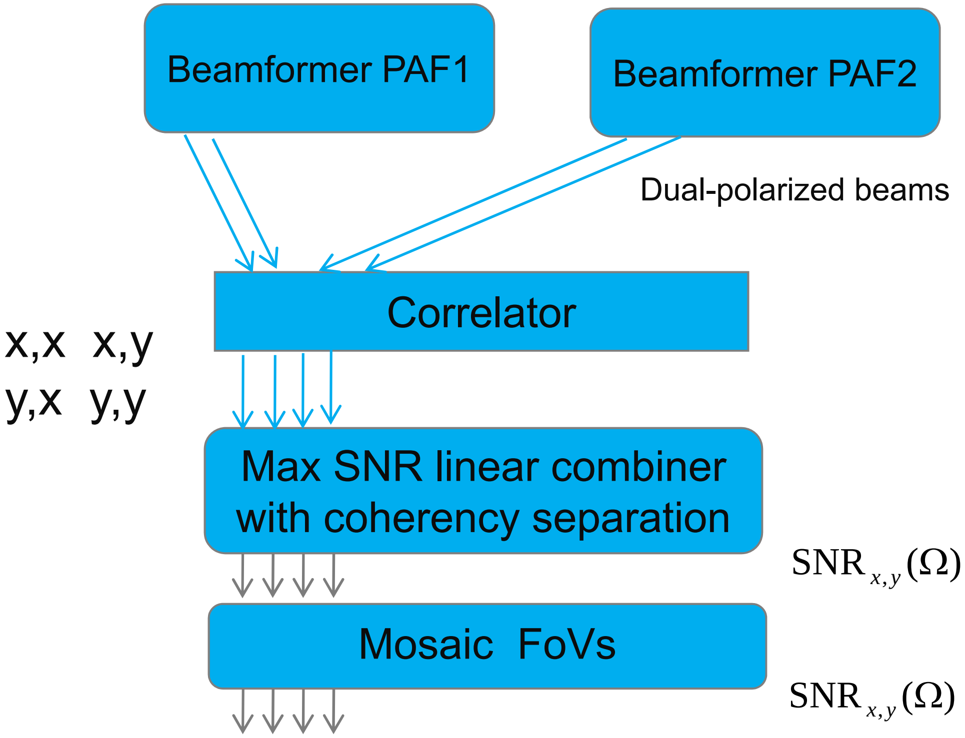
FoV de-rotation



- Front-fed single reflector
  - 3rd axis has been done (ASKAP)
- Offset-fed dual reflector
  - 3rd axis is more difficult
  - Electronic beam scan
    - tertiary pattern must retain shape
    - primary and secondary spillover will rotate wrt sources, so must be small



Reflector shaping and survey speed



Beamformer PAF1

Beamformer PAF2

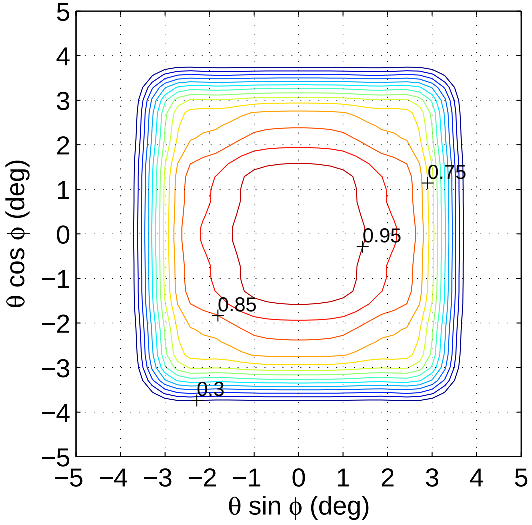
Dual-polarized beams

Correlator

x,x x,y
y,x y,y

Max SNR linear combiner with coherency separation

Mosaic FoVs



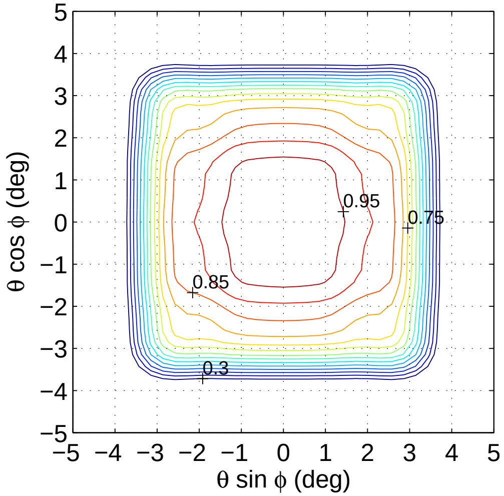
$$\mathrm{SNR}_{x,y}(\Omega) = 2BT \left|\frac{S_{x,y}(\Omega)}{k_B}\right|^2 \mathrm{Sen}^2_{x,y}(\Omega)$$

$$\mathrm{SNR}_{x,y}(\Omega) = 2BT \left|\frac{S_{x,y}(\Omega)}{k_B}\right|^2 \sum_{\text{pointings}} \mathrm{Sen}^2_{x,y}(\Omega - \Omega_{\text{pointing}})$$

$$\underset{\Omega}{\mathrm{average}}\Big(\sum_{\text{pointings}} \mathrm{Sen}^2_{x,y}(\Omega - \Omega_{\text{pointing}})\Big) = \frac{1}{\delta\Omega} \int_{all\,\Omega} d\Omega\, \mathrm{Sen}^2_{x,y}(\Omega)$$

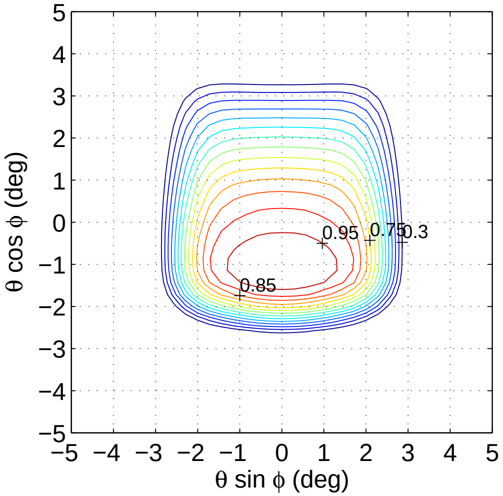
$\Rightarrow$ **Survey speed** $\propto \int_{all\,\Omega} d\Omega\, \mathrm{Sen}^2(\Omega)$

Reflector shaping



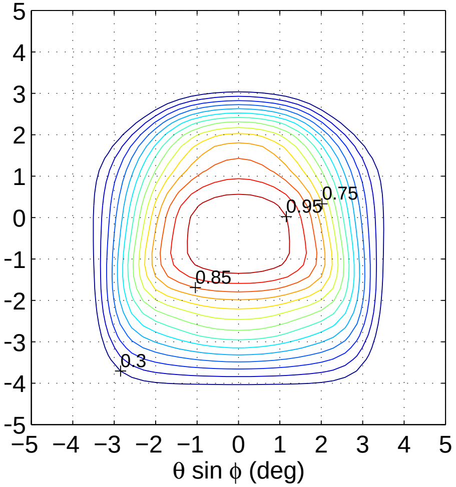
DSEx SSFOV=32.8 deg^2 S_{max}=2.68 m^2/K S^2_{eff}=237

1



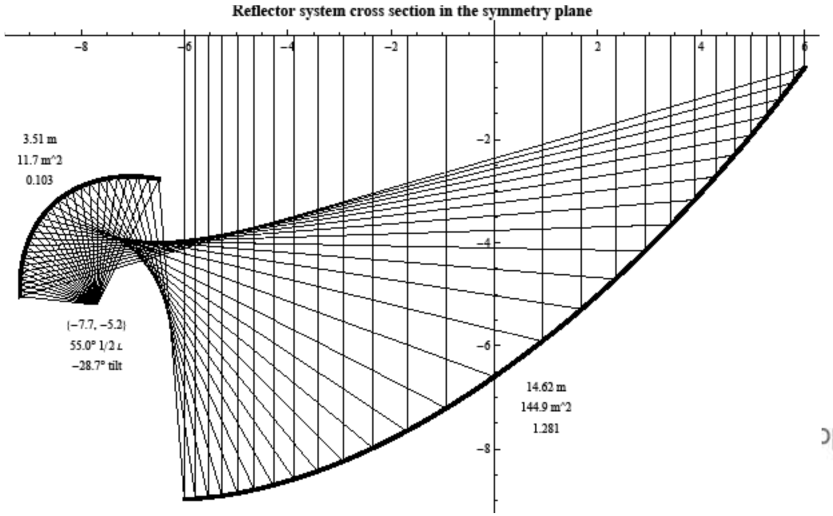
DSEx SSFOV=15.6 deg^2 S_{max}=3.11 m^2/K S^2_{eff}=150 deg^2 m^4/K^2

0.65



SFOV=21 deg^2 S_{max}=2.66 m^2/K S^2_{eff}=148 deg^2 m^4/K^2

0.65

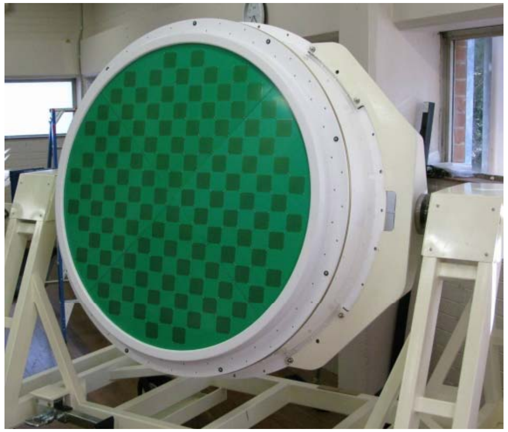


ɔpe

Optics/antenna summary

- Optics/antennas is important
  - Survey speed / cost
  - Achieving high dynamic range
  - Upgradability of SKA
- Particular concerns
  - FoV rotation impact on dynamic range
  - Unshaped reflectors preferred for performance/cost and future FoV expansion

PAF Feed Array Concepts

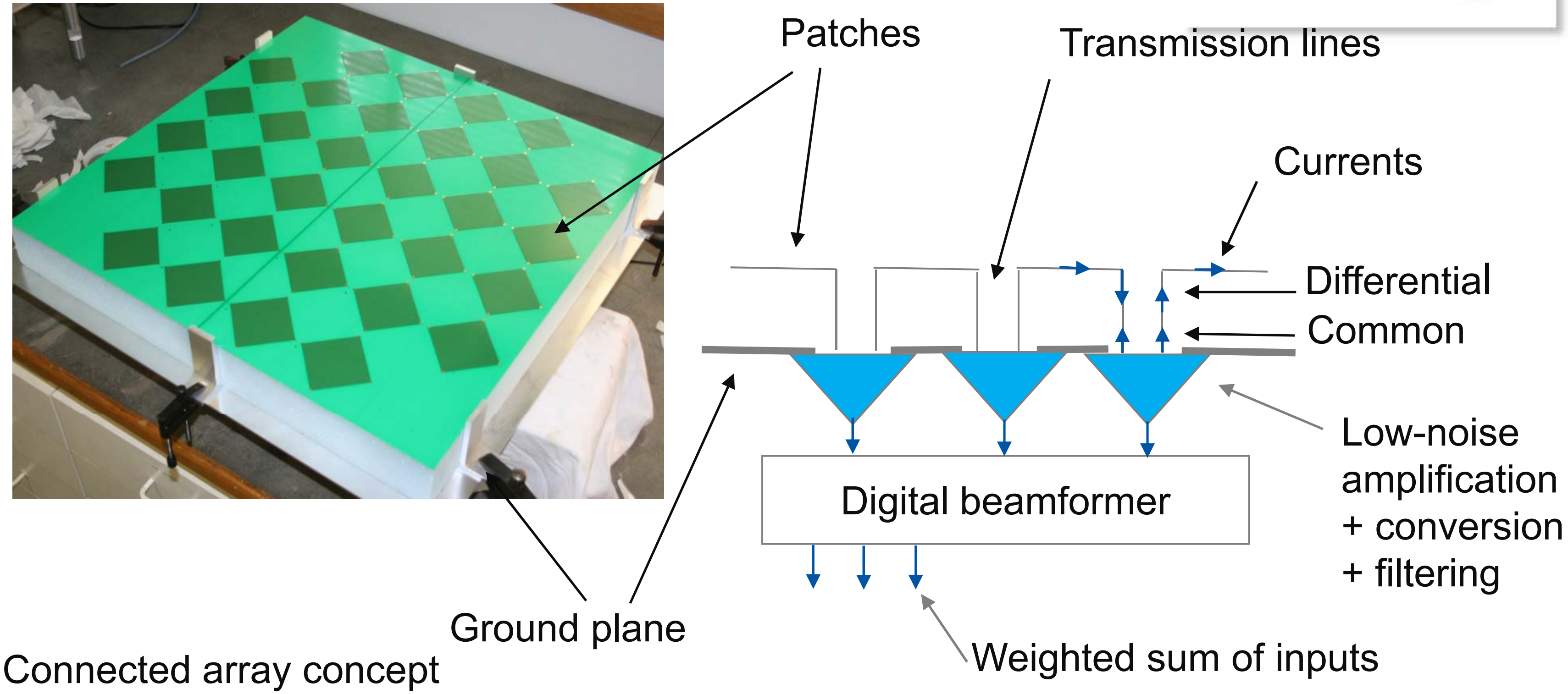


Chequerboard

Vivaldi

Dipole

Chequerboard PAF overview



Patches

Transmission lines

Currents

Differential

Common

Low-noise amplification + conversion + filtering

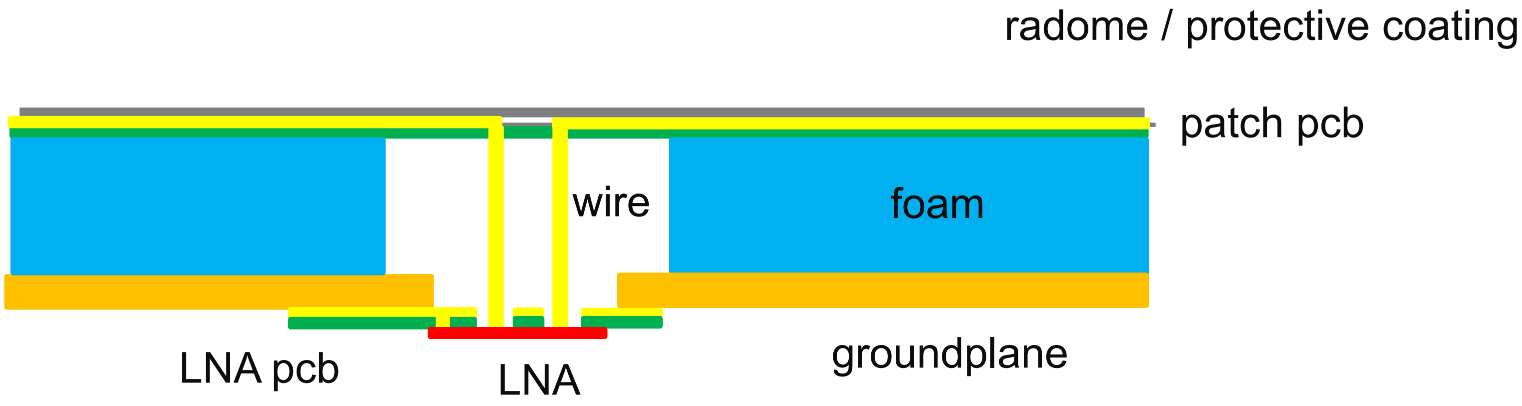
Digital beamformer

Ground plane

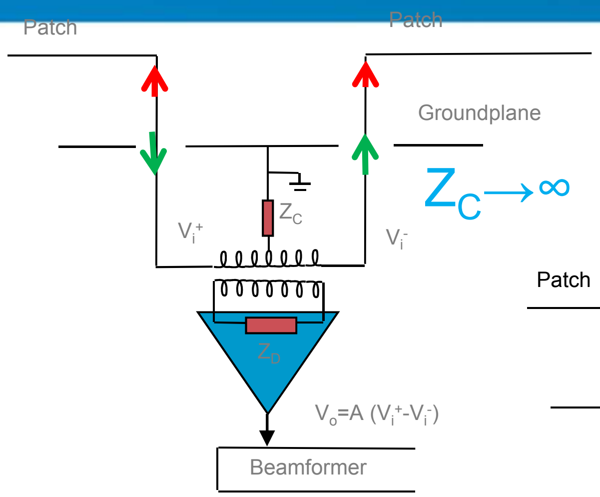
Weighted sum of inputs

- Connected array concept
  - Bandwidth enhanced by flow of conduction current between elements
- Dual-polarized self-complementary patches over groundplane
  - Moderately wideband 2.5:1
  - ~377ohm active impedance
- Potential advantages of planar structure
  - Integration with low noise amplifiers
  - Cost
  - Other performance aspects eg polarization

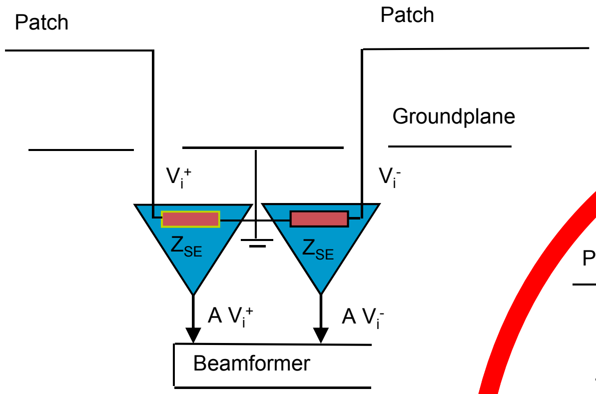
Chequerboard PAF construction



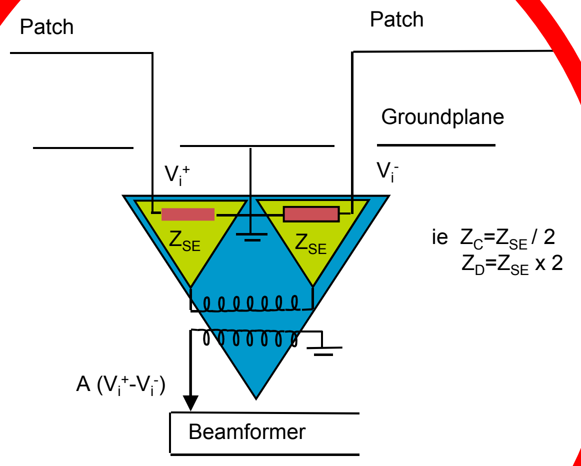
Chequerboard PAF active balun



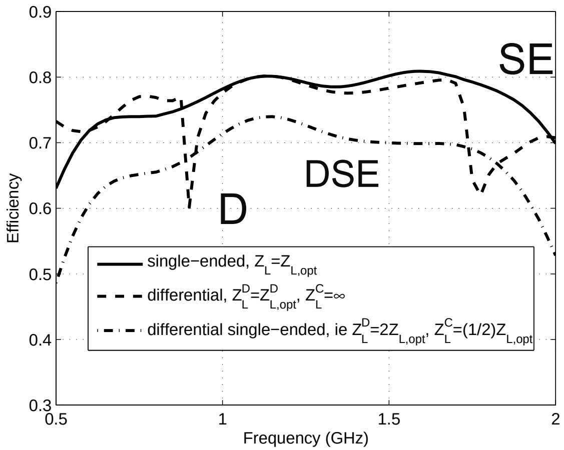
Differential (D)



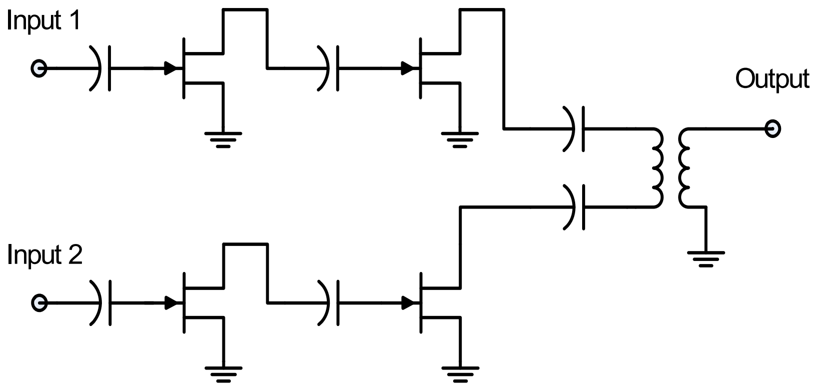
Single-ended (SE)

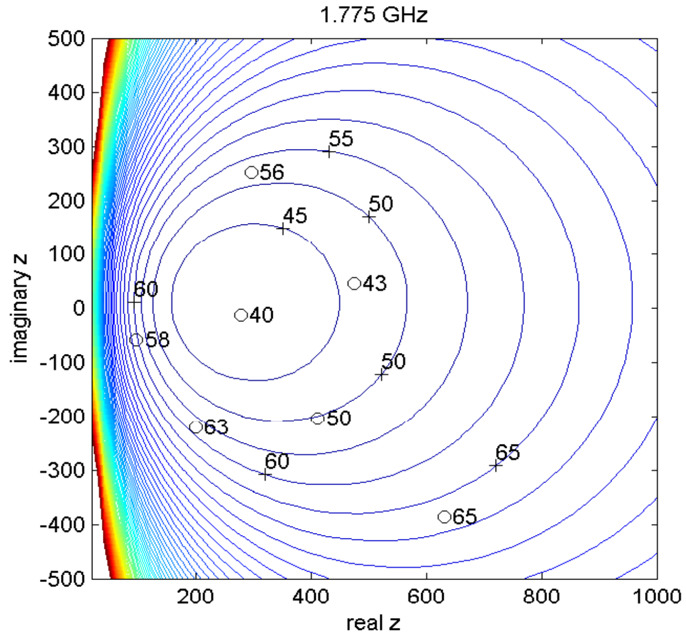


Differential single-ended (DSE)



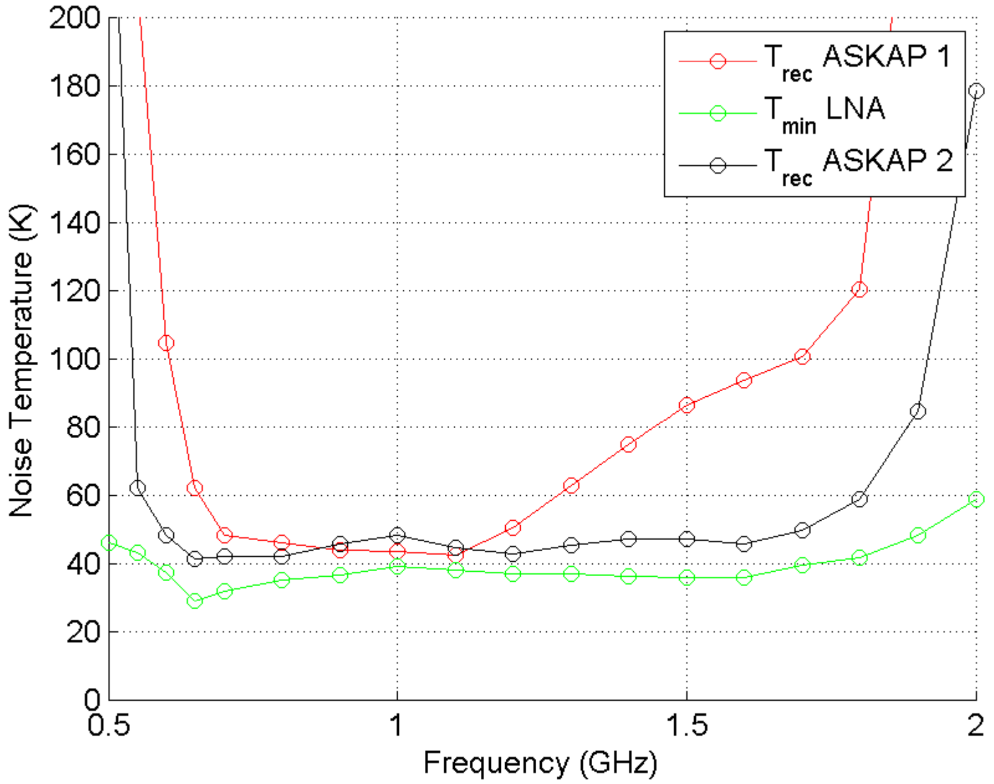
Chequerboard PAF LNA design

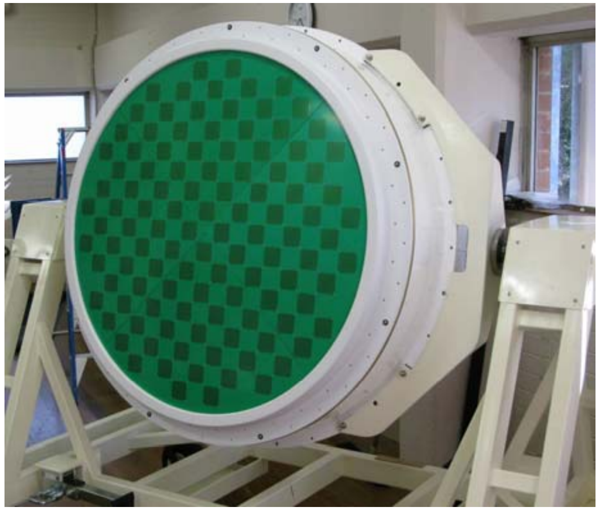




- Discrete components
- Avago ATF 35143 PHEMT FETs
- ~300 ohm differential input Zin and noise source Zopt
- Stable on the array
- Noise parameter estimation from measurements (1/2 and full LNA)

Chequerboard PAF Trec





- Array modelling
  - Consistent with recent measurements on first 188-element ASKAP PAF
  - LNA noise parameters estimated from measurements
  - Enhanced chequerboard (ASKAP 2 above) with same LNA

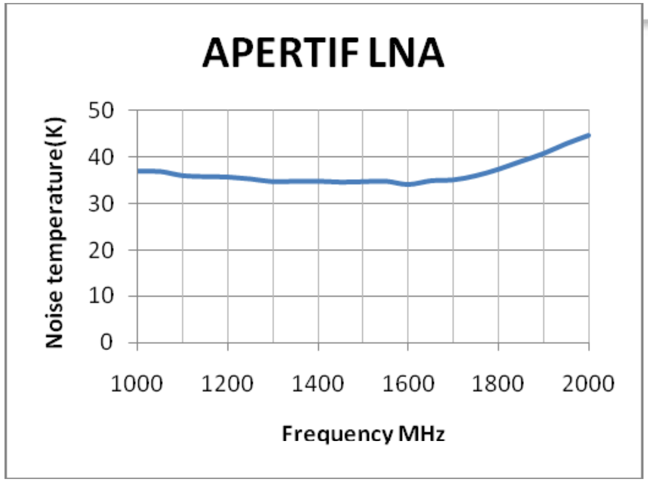
Vivaldi PAF

- Vivaldi array
  - Well characterized element
  - Easy design for 2.5:1 bandwidth
  - Easy design for 50ohm single-ended LNAs
  - High technology readiness level

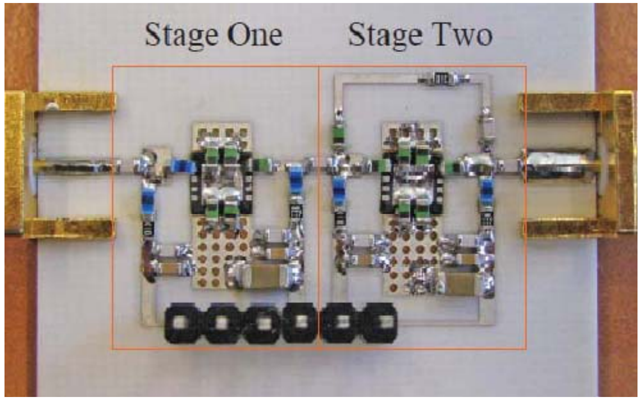
- Eg APERTIF
  - 121 element dual polarized Vivaldi array, 1 – 1.8 GHz
  - Laser-cut aluminum plates
  - Microstrip balun on RO4003
  - Overall radiation efficiency ~98.5%
  - Temperature stabilized at 7 °C

adio telescope

APERTIF LNA



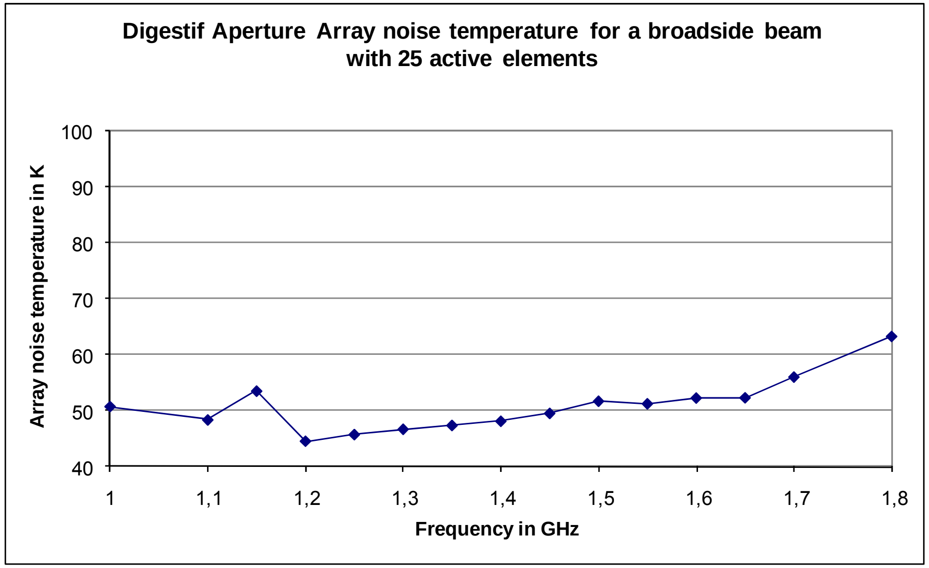
Room temperature LNA
Tmin ~35 K
Discrete components



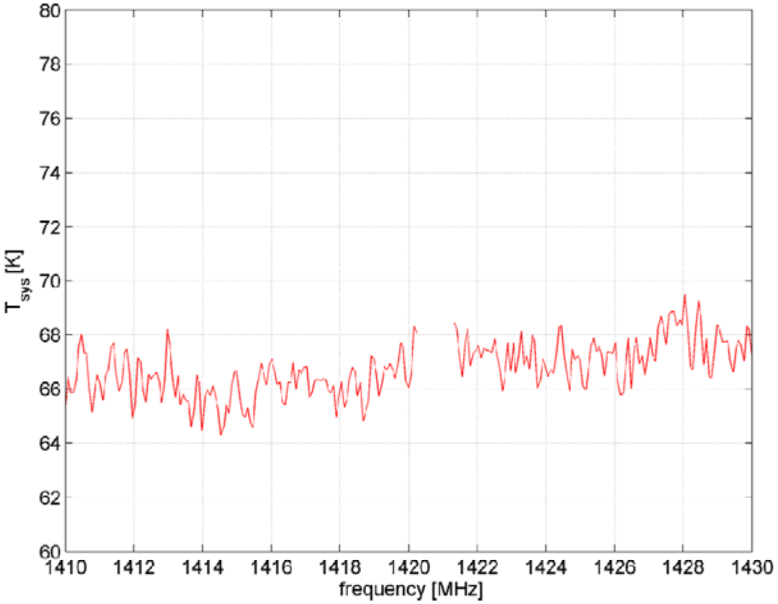
Improved design with
Tmin~25K has been
prototyped

APERTIF PAF

Aperture array



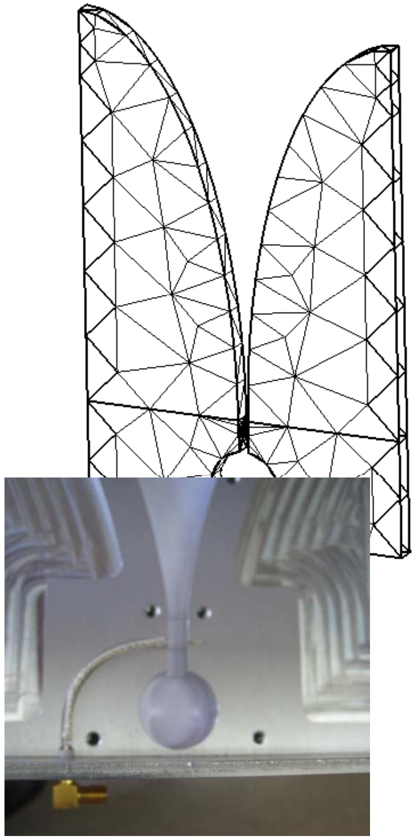
Phased array feed



- Tsys ~50K as aperture array and 68K as PAF (ηap=75K)
- Good agreement between modeling and measurement
- Tsys ~ 55K expected for final APERTIF PAF

Active Vivaldi PAF

- DRAO/UCL effort aimed at reducing Vivaldi loss
- Thicker Vivaldi elements (5mm)
- LNA integrated in element (milled cavity)
- Reduce dielectric
- Use of Tmin 20K single-ended LNAs



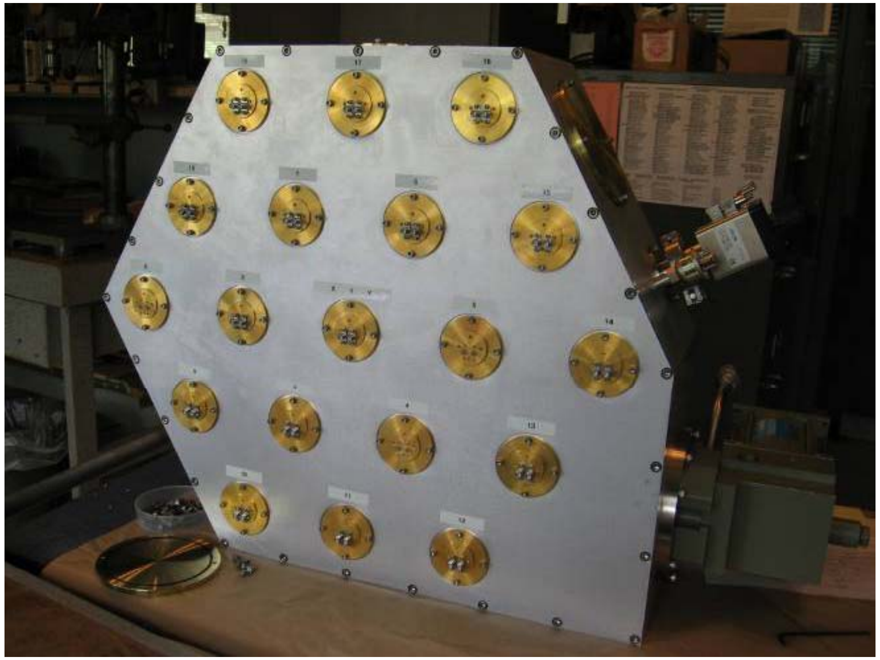
	Current Prototype	**Final APERTIF**
Antenna losses	6	6
LNA + second stage	40	28
Noise coupling / active impedance	9	8
Spillover	10	10
Sky noise	3	3
Total	68	55

APERTIF Tsys budget at 1.4GHz

Dipole PAF

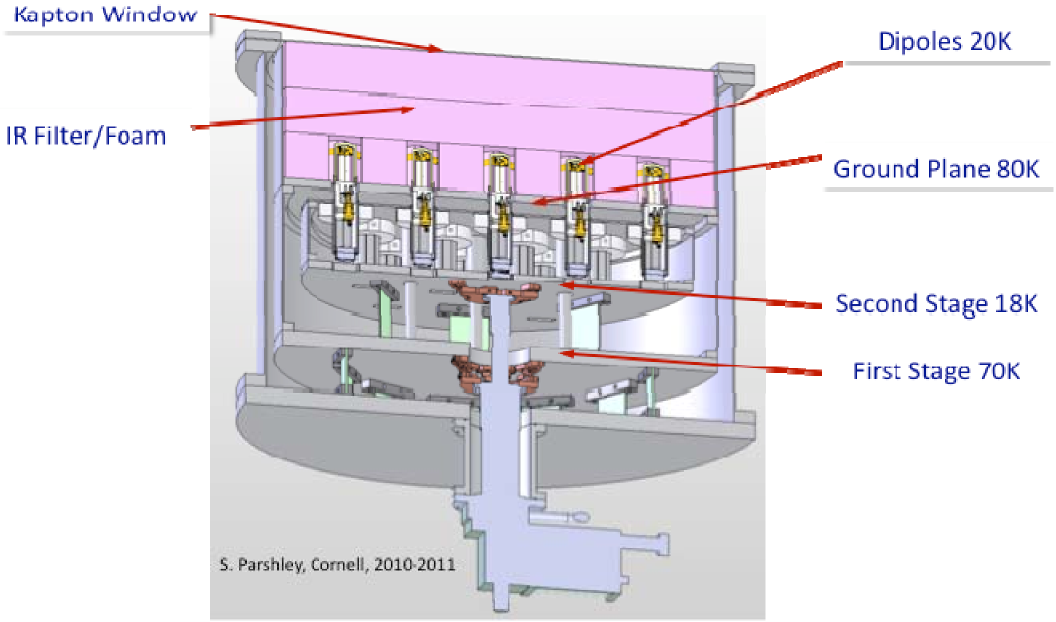
- BYU/NRAO collaboration
- Dual-polarized `Kite’ dipole
- Well characterized element
- Tsys 22K target (35K has been measured)
- ηap 70%
- 1.4:1 bandwidth (1dB)

Dipole PAF LNAs

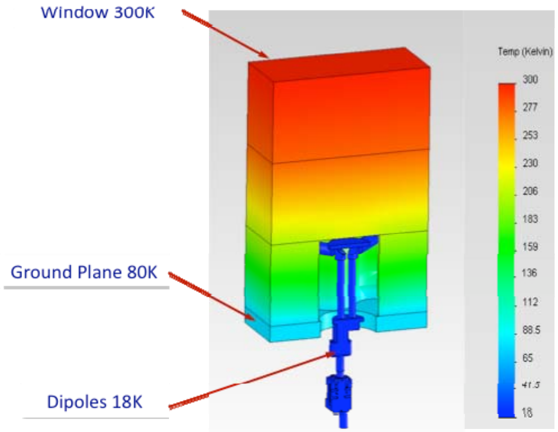


- LNAs in cryostat (stainless steel transition to ambient dipole)
- Single-ended LNAs (balun in dipole) with 50ohm impedance
- Optimized active noise match

Fully cooled PAFs



S. Parshley, Cornell, 2010-2011



By. Stephen Parshley, 2010 2011

- Cornell study
- Dipoles and LNA cryogenically cooled by two-stage system
- Thermal load modeling
- 91 element 1.4m dia PAF for Arecibo would require 4 CTI1020 coolers

Conclusions

- PAF principles and capability demonstrated
  - Modelling
  - Low noise ambient temperature LNAs
  - Dense arrays
  - Cryogenic cooling
  - SKA1 0.45-3GHz could be covered with two PAFs
  - Emerging flexible new technology for radioastronomy
- PAF optimization
  - Optimizations required in FOV, optics, frequency range, processing
- PAF key issues
  - Dynamic range budget
  - Astronomy/cost optimization

CSIRO ICT Centre
Stuart Hay
Research Team Leader - Electromagnetics

Phone: +61 2 9372 4288
Email: Stuart.Hay@csiro.au
Web: www.csiro.au/group

www.csiro.au

Thank you

Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: enquiries@csiro.au Web: www.csiro.au

Exploring the Universe with the world's largest radi e

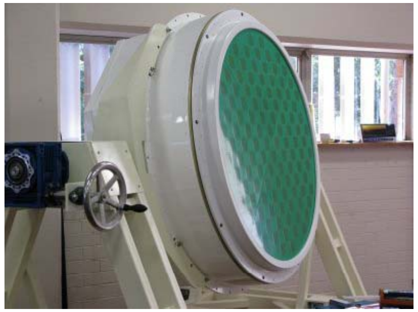
PAF developments

SKA
SQUARE KILOMETRE ARRAY

ASTRON

PAFSKA

NRC·CNRC



CSIRO

Station de Radioastronomie de Nançay

BYU
BRIGHAM YOUNG UNIVERSITY

NRAO
National Radio Astronomy Observatory

Cornell University
National Astronomy and Ionosphere Center