Chequerboard Phased Array Feed Testing for ASKAP

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BYU Phased Array Workshop

3 May 2010

Photo by David McClenaghan

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Analog Systems Team

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John O'Sullivan (IPT scientist)

Steve Barker   (IPT PM)

- Electromagnetic design of FPA, calibration system, and testing
  - Stuart Hay
  - Rong-Yu Qiao
  - Francis Cooray
  - Doug Hayman
  - Aaron Chippendale
- Mechanical design
  - Deszo Kiraly
  - Russ Bolton
  - Paul Doherty
  - Eliane Hakvoort
  - Workshop staff (3 EFT)
- Low-noise amplifier design
  - Rob Shaw
- Receiver electronics
  - K. Jeganathan
  - Simon Mackay
  - Suzy Jackson
  - Yoon Chung
  - Peter Axtens (PSUs)
- Plus consultation services of:
  - Pat Sykes
  - Michael Brothers
  - Matt Shields
  - Mark Bowen
  - Santy Castillo
  - Henry Kanoniuk
  - Les Reilly

Key Topics

- **Overview** of chequerboard development
- **Results** from the 5×4 prototype
- **Progress** towards ASKAP and SKA

Overview – Why Phased Array Feeds?

- **Key SKA requirement**
  - sensitive observations of the sky over large areas (surveys)
  - collect more information from the sky per antenna
- Achieve target SKA survey speed with
  - order of magnitude fewer antennas
  - 20% to 50% lower cost
    Chippendale et al. 2007, SKA Memo 92
- Optimise performance for science
  - control beam/FOV shape
  - control instrumental polarisation
  - control spillover
  - control baseline ripple
  - mitigate interference

Overview – ASKAP Receiver Specifications

Focus package

- frequency range.................................... 700 MHz to 1800 MHz
- field of view..30 deg^2
- T_{sys}..< 50 K (aspire to 35 K)
- efficiency η..unspecified (but ~65%)
- PAF Ports..188 (94×2 pol.)
- weight..< 200 kg
- continuum dynamic range.....................10^6
- spectral dynamic range........................10^6
- post calibration polarisation purity........ -30 dB

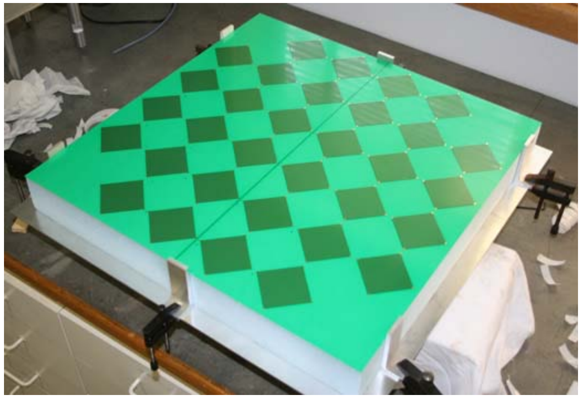
Analog system cost estimate per antenna

- focus (gain + band select)....................$150 k
- pedestal (downconversion)...................$120 k
- cooling... $15 k

Overview – Connected Element Array Evolution

5 port

Hay et al. 2007, EuCAP

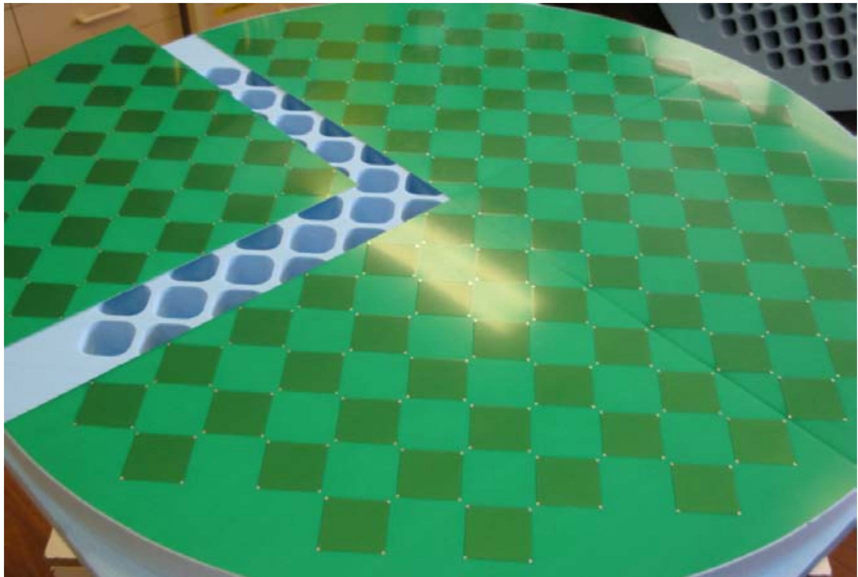


approximately
self complementary

$Z \approx 377\ \Omega$

40 port

188 port

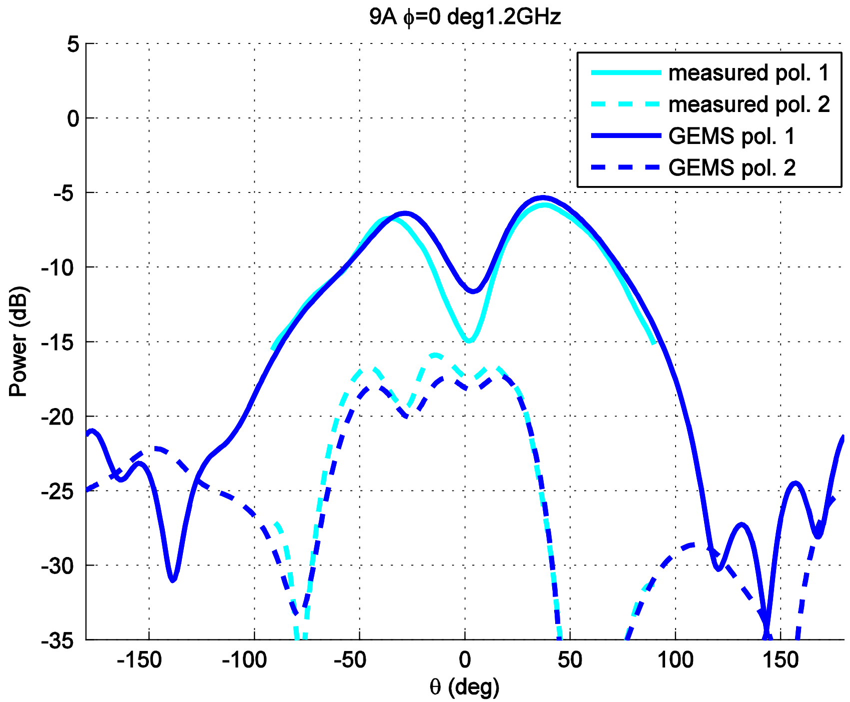


Advantages

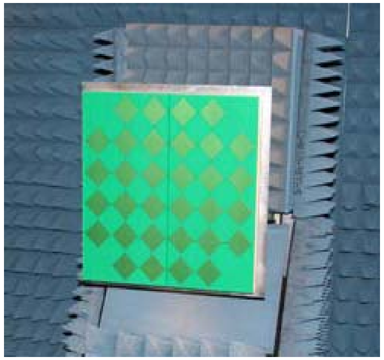
- lower ohmic loss
- lower polarisation variation
- easy manufacture
- cryo-cooling integration potential

Testing – Power Patterns

Simulated and measured port power patterns agree



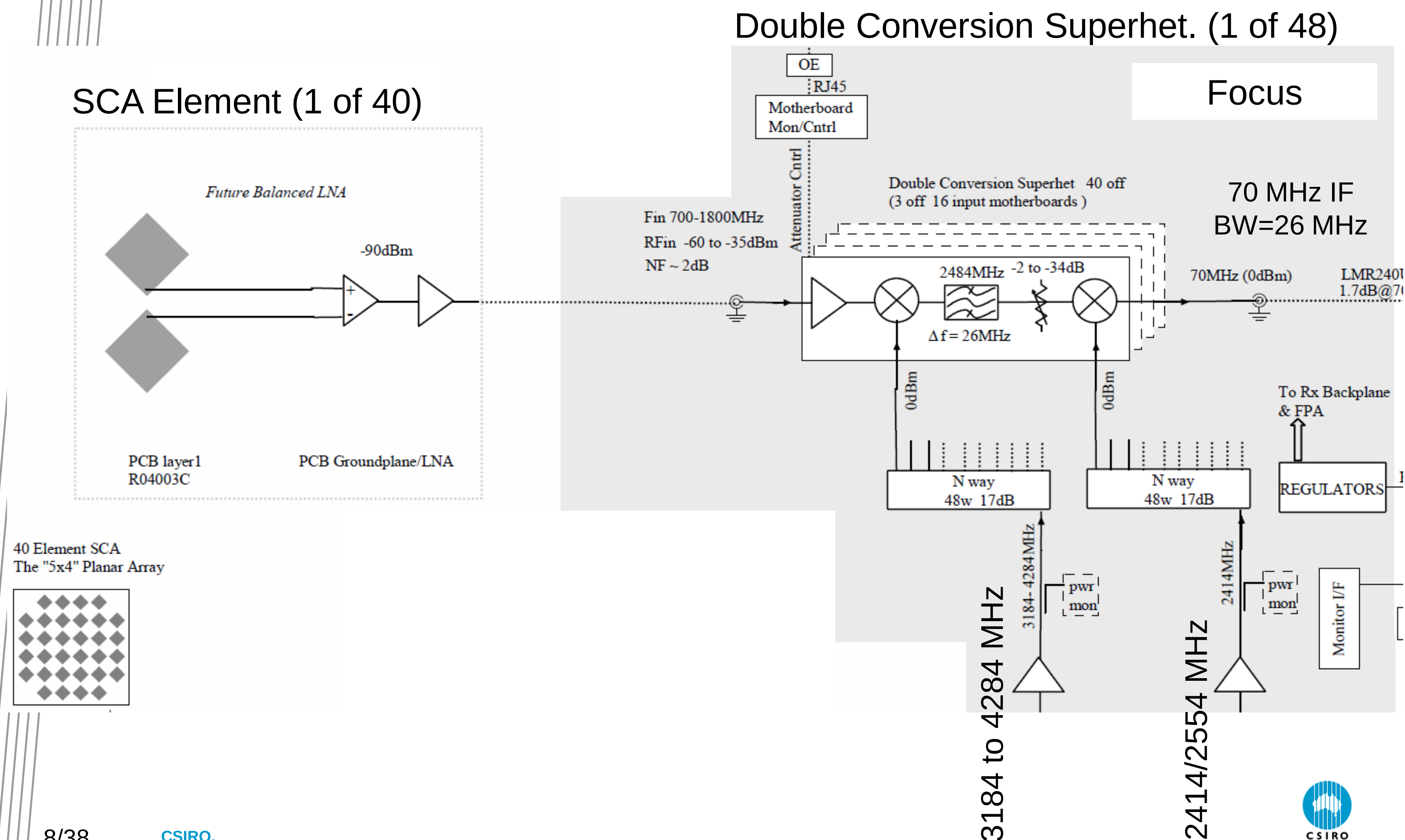
40 port



Measurement Setup

Hay et al. 2007, EuCAP

Testing – 5×4 Rx block diagram



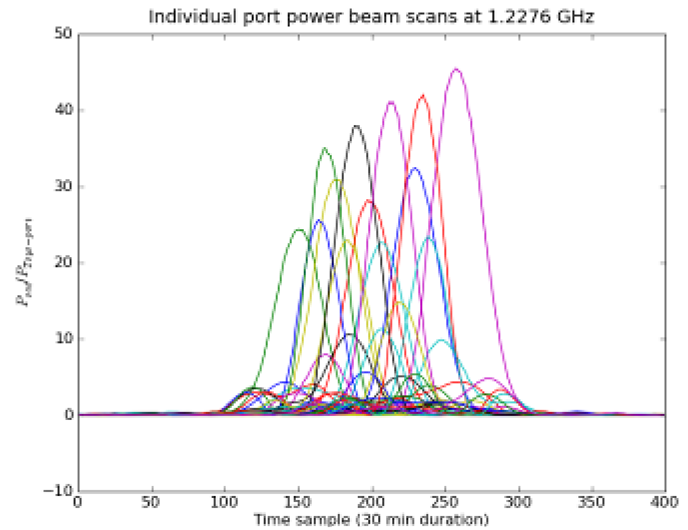
Testing – Parkes Single Dish

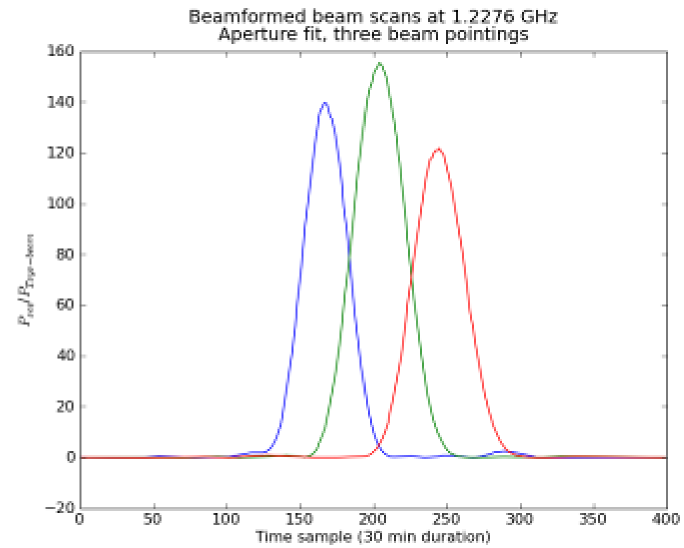
Single dish

- 0.875 MHz BW
- samples → disk
- software correlation
- T_{sys}/η ~ 175 K +/- ?

- driftscans:
  - beamform on GPS (L2 1227.6 MHz)
  - measure T_{sys}/η on Virgo A

- beamformed:
  - $\eta \sim 4 \times$ element η
  - $T_{sys} \sim 0.8 \times$ element T_{sys}



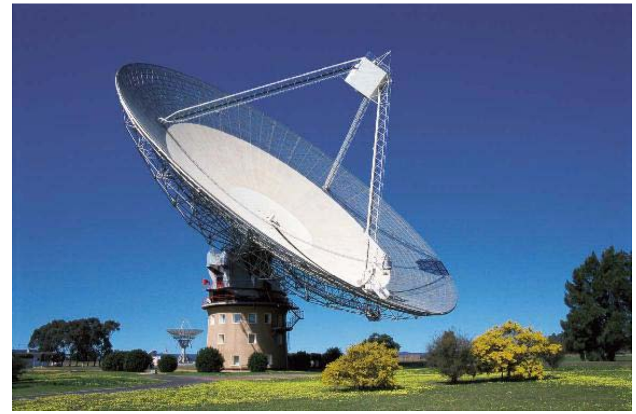


DeBoer et al. 2009, Proc IEEE

Testing – Parkes Interferometer

Photo by Maik Wolleben

Testing – Measuring T_{sys}/η



beamformed PAF voltage $v_{beam} = \sum_i w_i v_i$

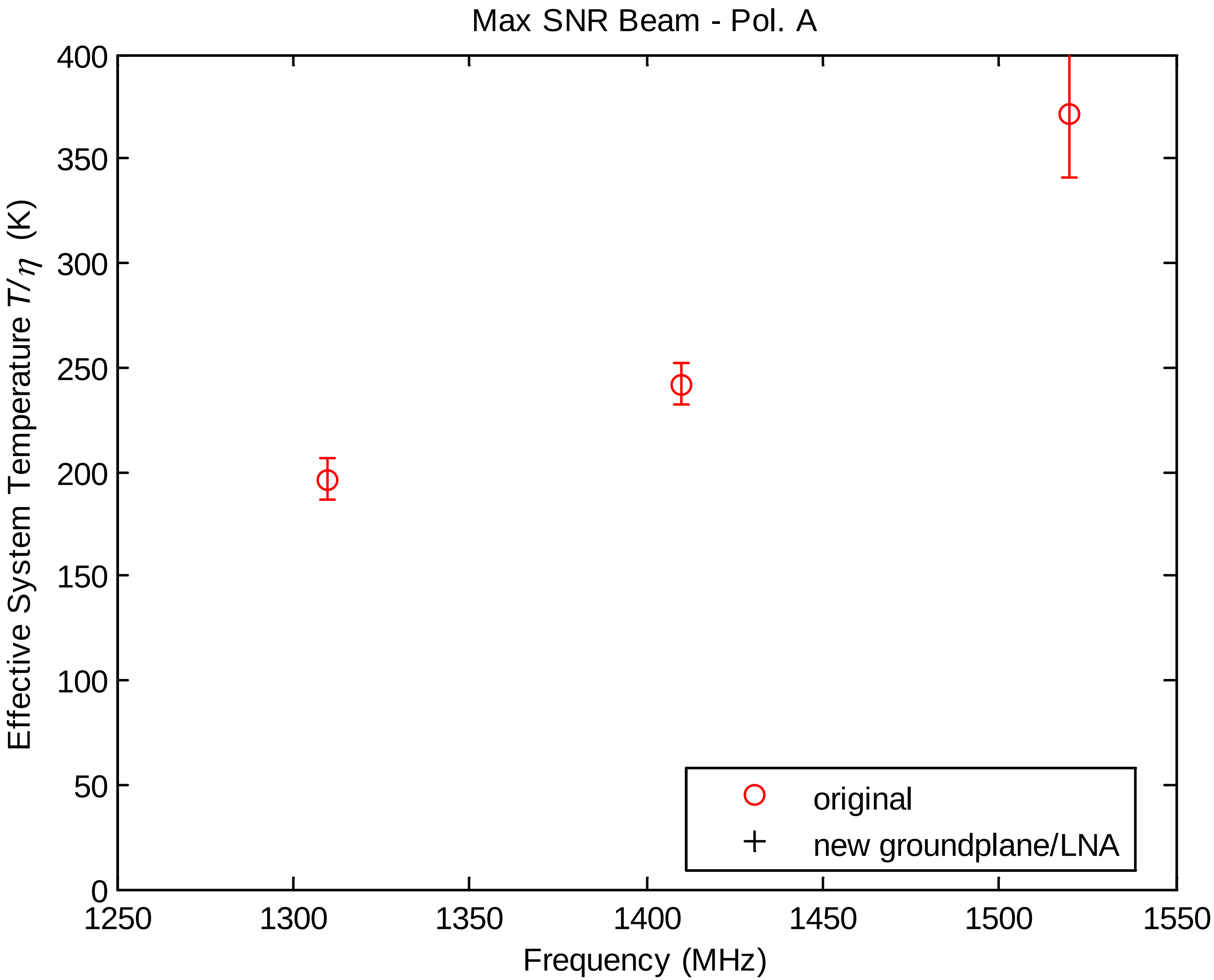
64 m reference voltage r

auto + cross-correlations on/off point source
→ high SNR measure of T_{sys}/η requiring few assumptions

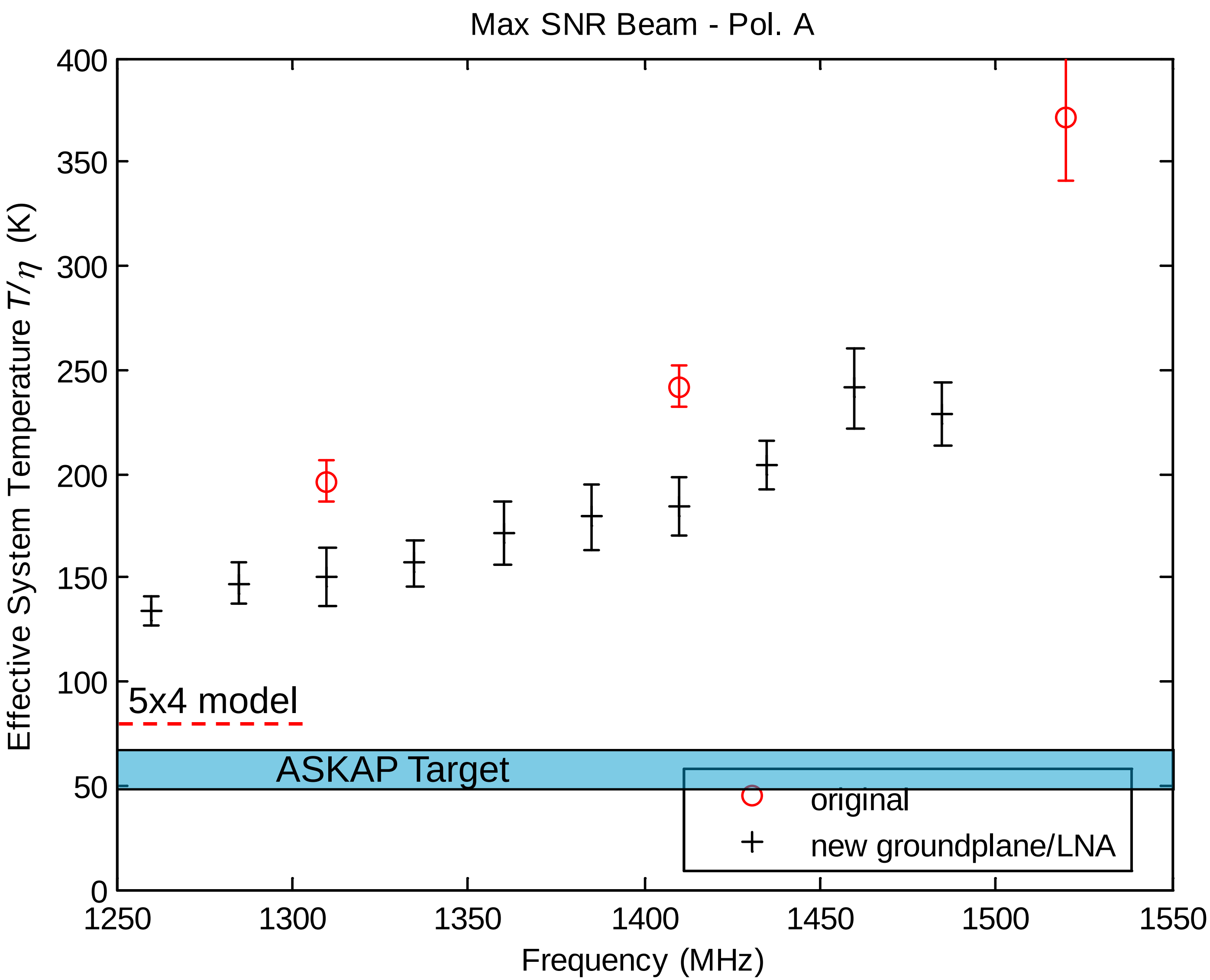
maximise gain $[w_i] = [v_i^*]$

maximise SNR $\mathbf{w} = \mathbf{R}^{-1}\mathbf{v}^*$ covariance matrix $[R_{ij}] = [< v_i v_j^* >]$

Testing – Measuring T_{sys}/η



Testing – Modified Groundplane and New LNA



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Testing – Measuring Aperture Plane Array T_{sys}

Beamformed on hot microwave absorber

Measured *Y*-factor from cold sky to hot load

T_{sys} better than PAF operation if all ports used in beamforming

Poor T_{sys} if central 4 ports used

Finite absorber size was accounted for

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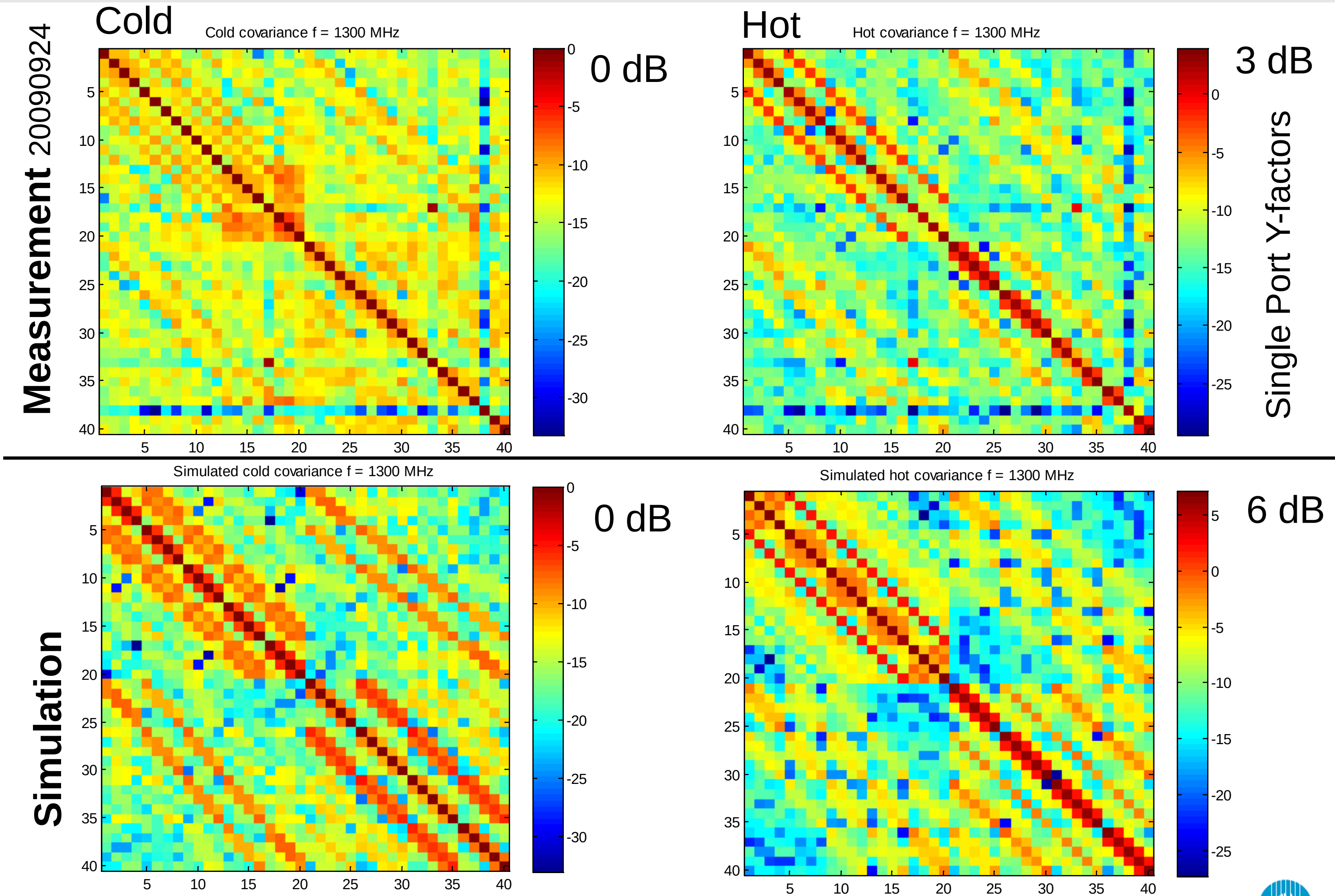
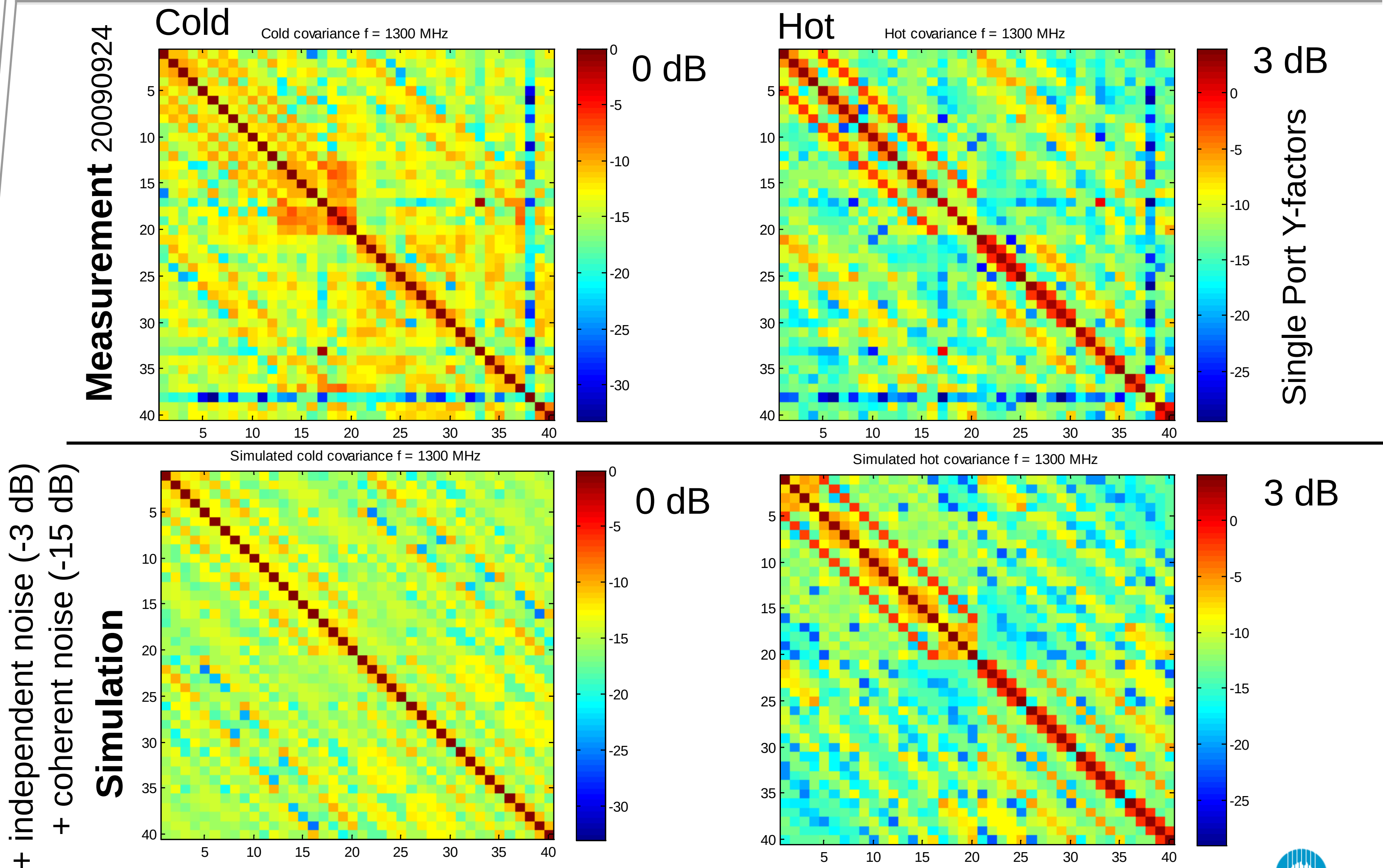
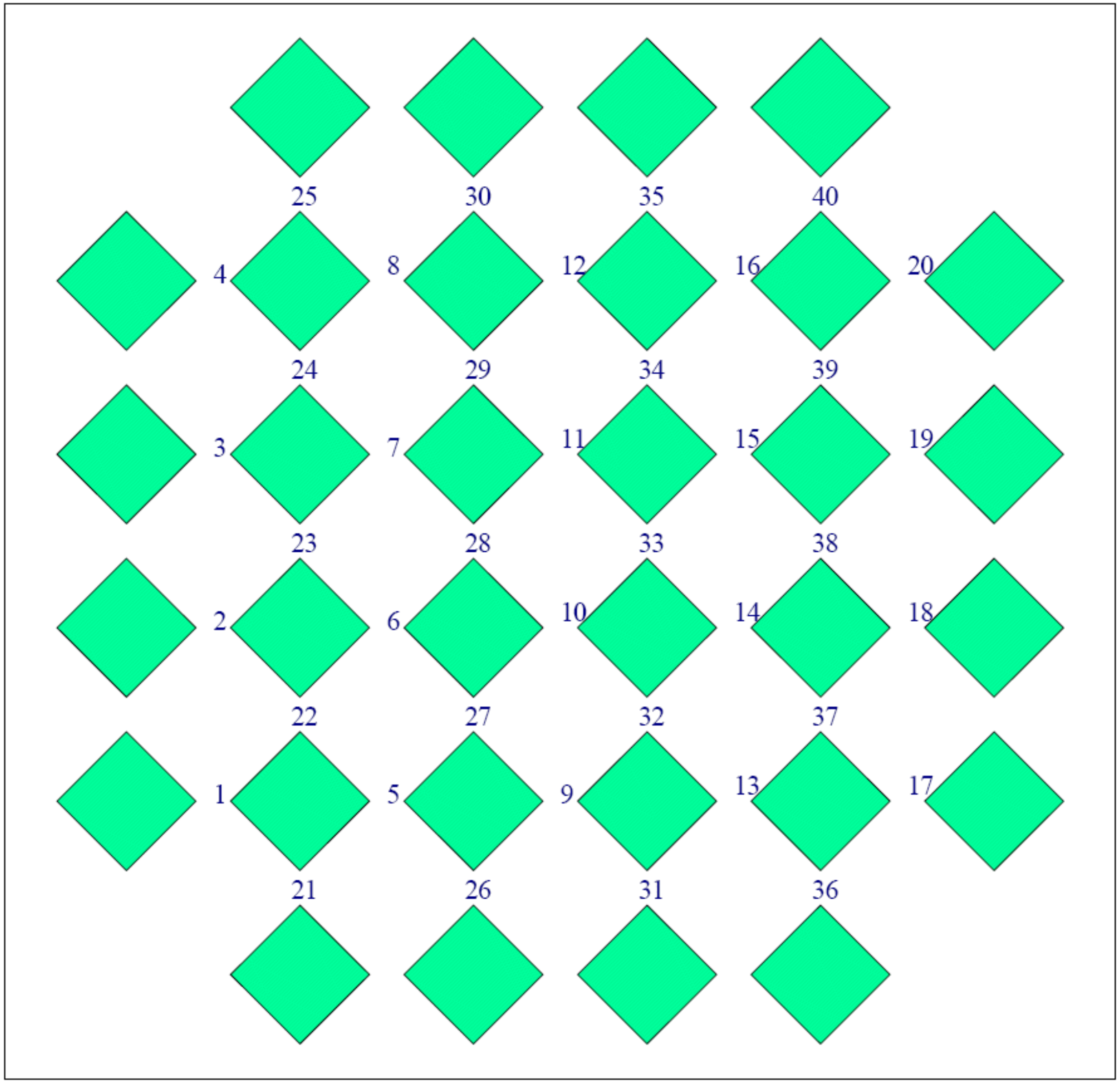
Testing – Measured vs. Simulated Covariance
Normalised to Cold Covariance



Testing – Measured vs. Simulated Covariance Normalised to Cold Covariance



Testing – 5×4 Port Numbering



5X4 Array

Front View in Simulation
Rear View in Measurement

Elements 1- 20 polarity "H"

Elements 21 - 40 polarity "V"

Testing – Hunting Unmodelled Noise

First order candidates

1. Mismatch of active array impedance
   - LNA models inaccurate?
   - ASTRON measurements to improve models
2. Self interference
   - Noise observed at IF from switch-mode power supplies
   - Now using linear supplies for 5×4 prototype
   - Digital noise from back-end?

Second order sources discovered

1. LO distribution noise
   - Not significant if RF input level to mixer set appropriately
2. Blockage and scattering
   - Not expected to be significant if LNA models correct
   - Ongoing modelling by Stuart Hay

Testing – Practical Issues

Practical sources of angst

- press-fit connectors + planar couplers in LO distribution
- insufficient headroom in LO distribution
- unreliable stepped attenuator control
- broken tracks in regulator PCB
- aggressive timeline
- poor heat dissipation from focus package

Lessons learned

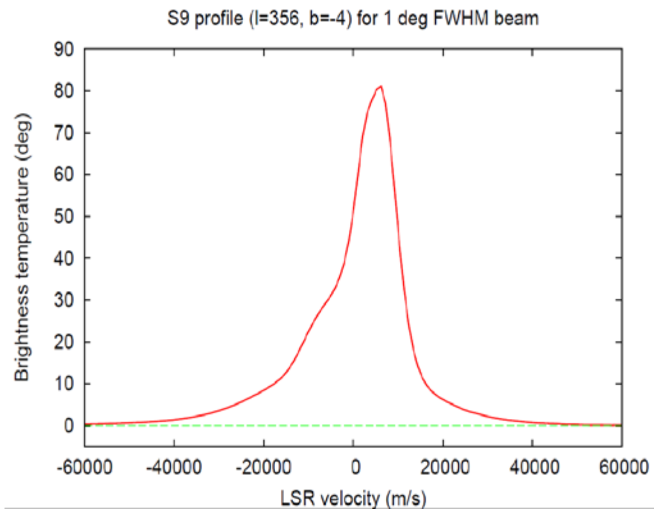
- keep prototype as simple as possible
- make minimum sufficient demonstration of key technology only
- allow more time to cogitate results between tests
- plan testing during design
- test subsystems before integration
- integrate early and often
- don’t unlearn lessons learned (see Doug Hayman’s presentation)

Future directions (parallel)

- refurbish and retest existing 5x4 array + receiver
- implement simplified 4-port receiver
  - 5$\times$4 array + BPF + gain + 4 port oscilloscope

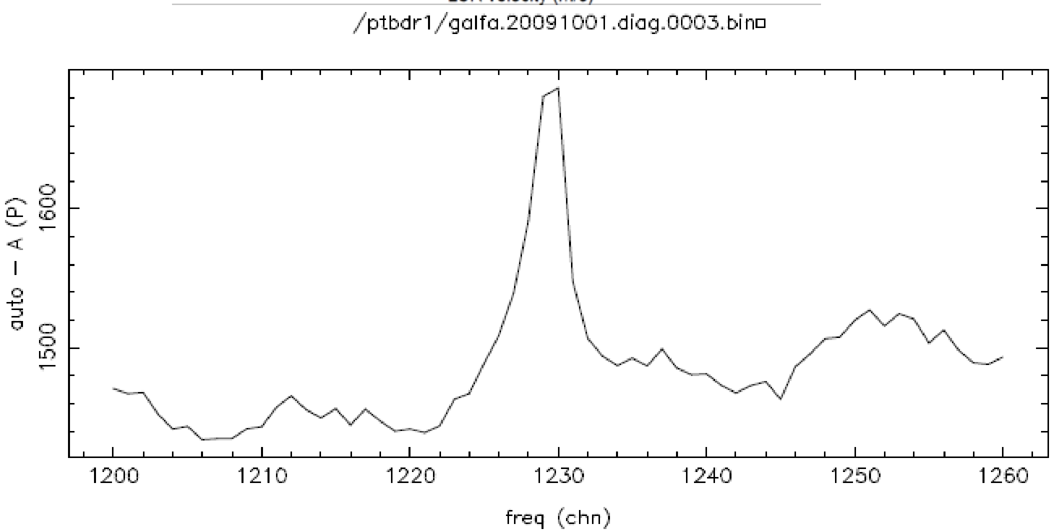
Testing – HI Spectrum from Single Port

S9



LAB Galactic HI Survey
Smoothed to 1 deg

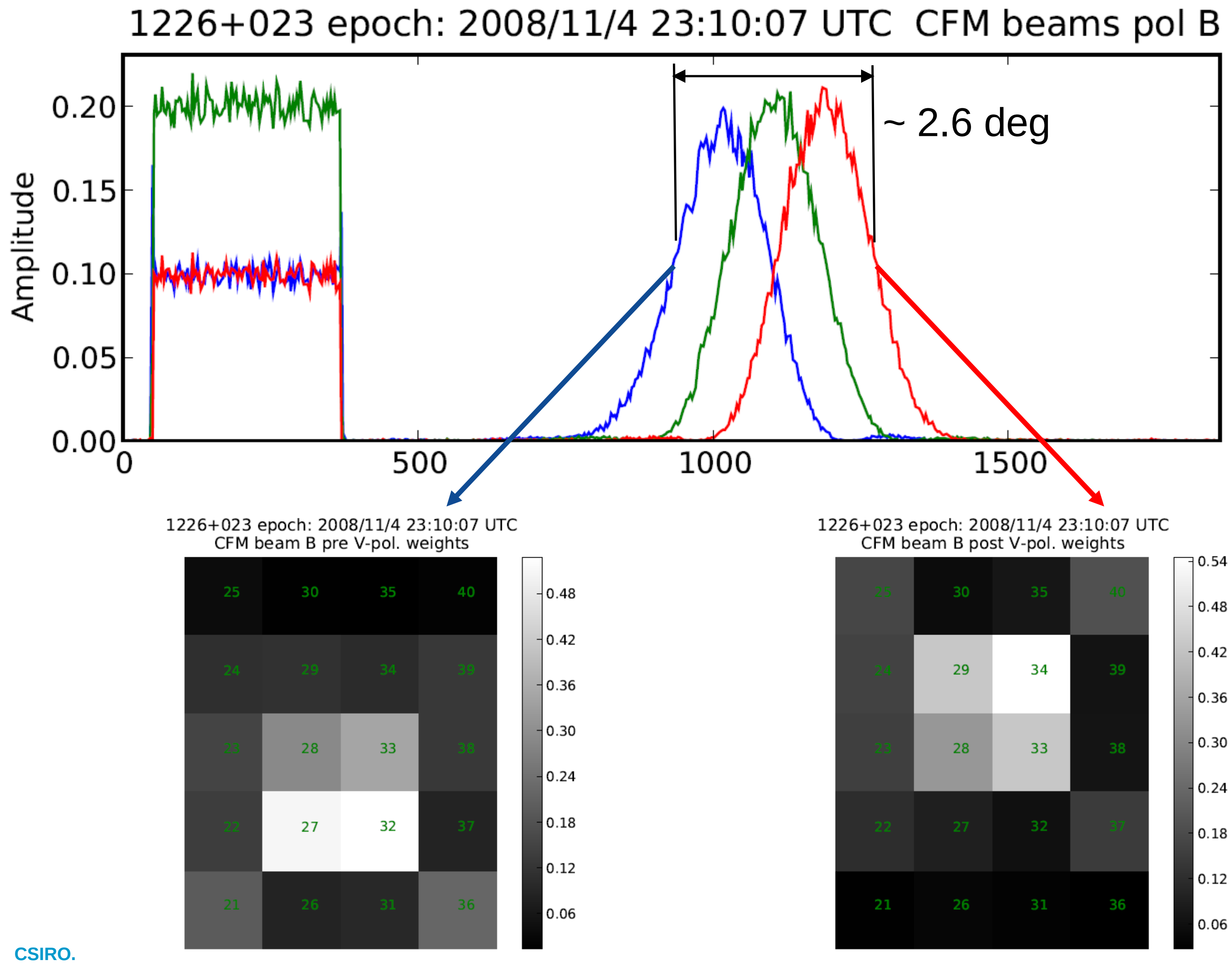
P. Kalberla et al., 2005



5×4 PAF

Single Port Spectrum

Testing – Beamformed Power Pattern



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Testing – Next Steps

June 2010

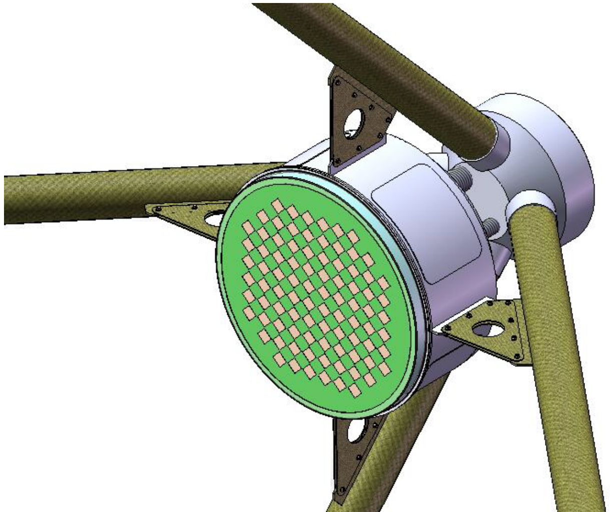
- Hot/Cold measurements at Parkes with linear power supplies

August 2010

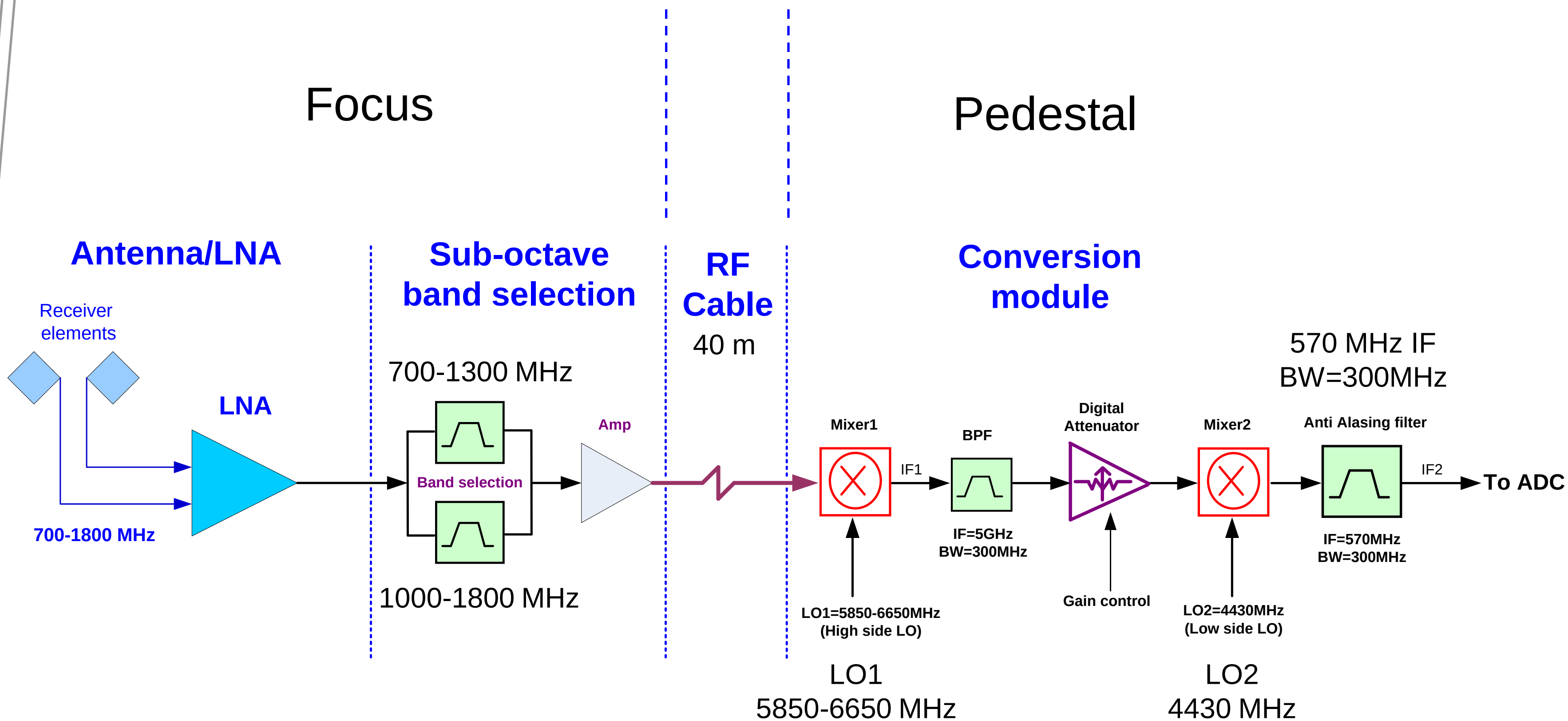
- Repeat hot/cold measurements with simplified back-end

Late 2010

- Start testing 188 port ASKAP PAF

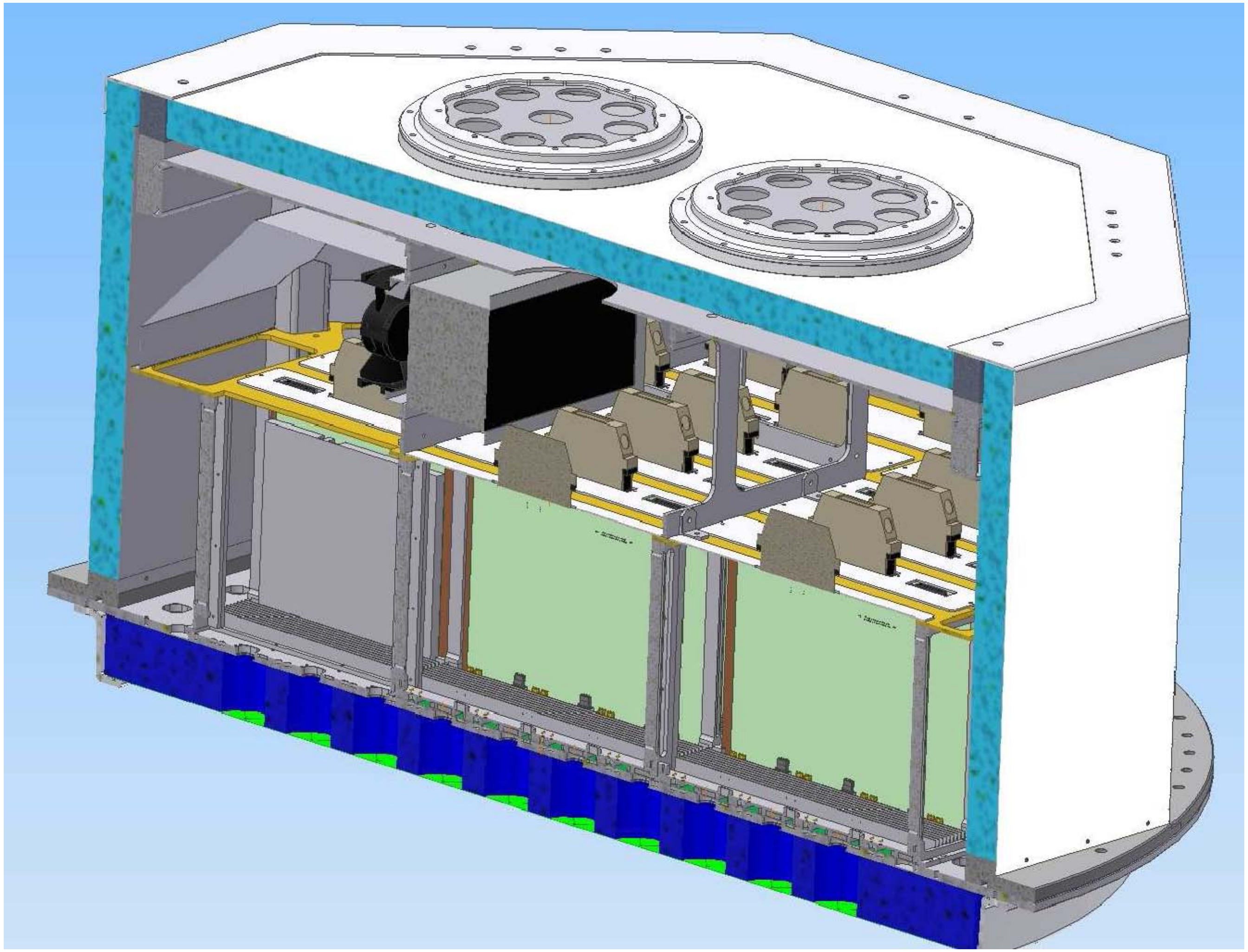


Progress – ASKAP Receiver Block Diagram



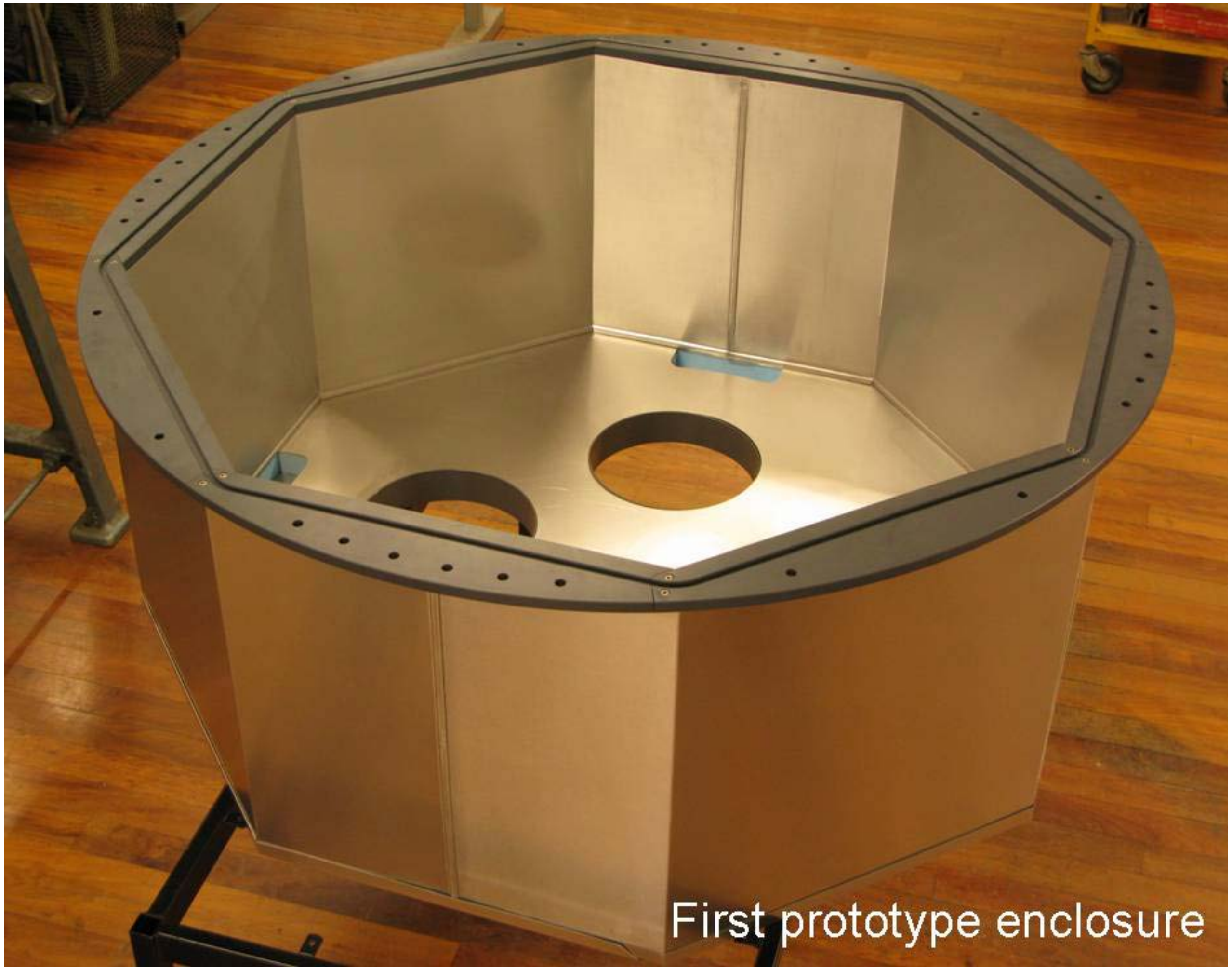
Progress – ASKAP Focus Package Assembly

- Designed for rigidity, EMC/weather-tightness, thermal control



Progress – Focus Package Enclosure

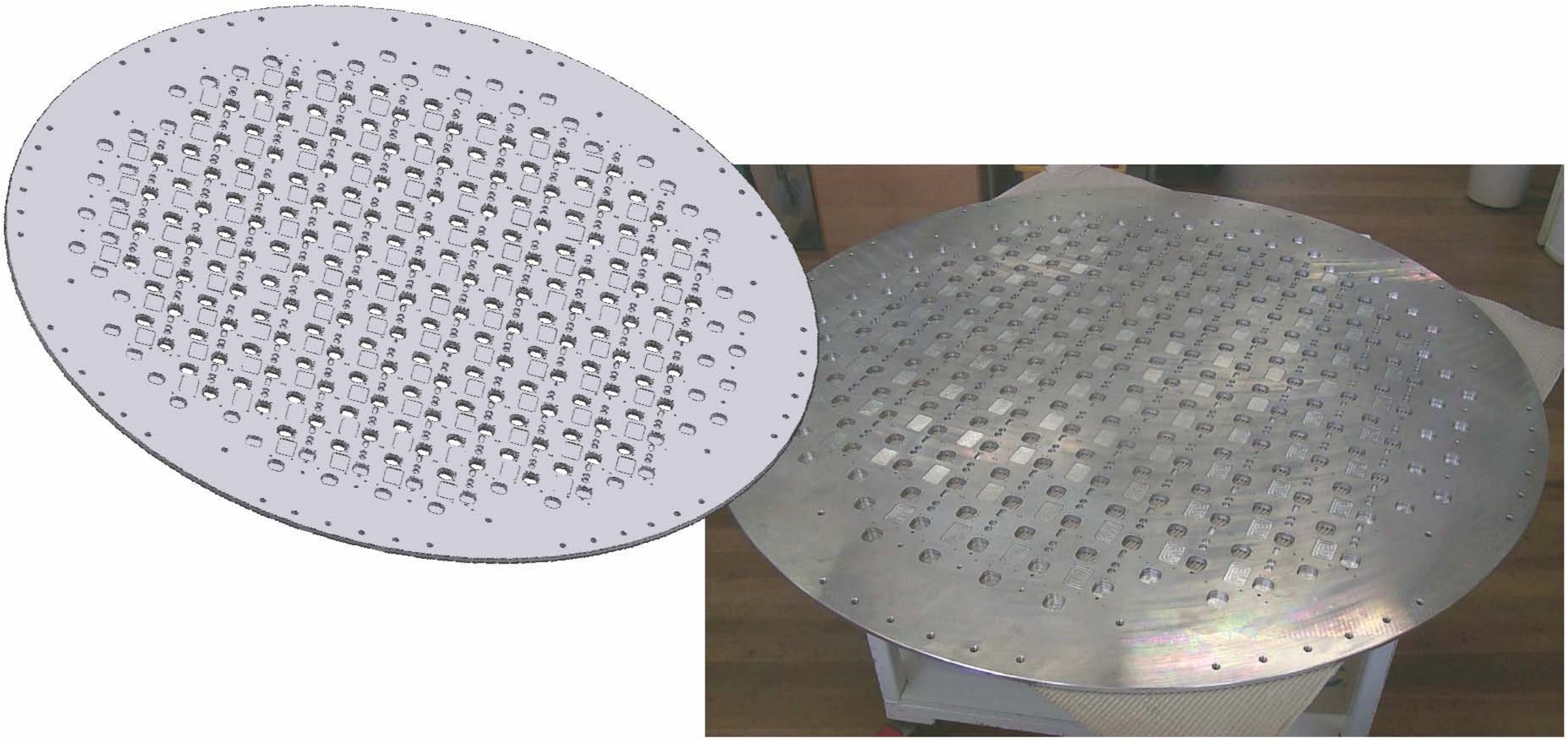
- Double Aluminium skin 40mm EPS foam and PVC flange



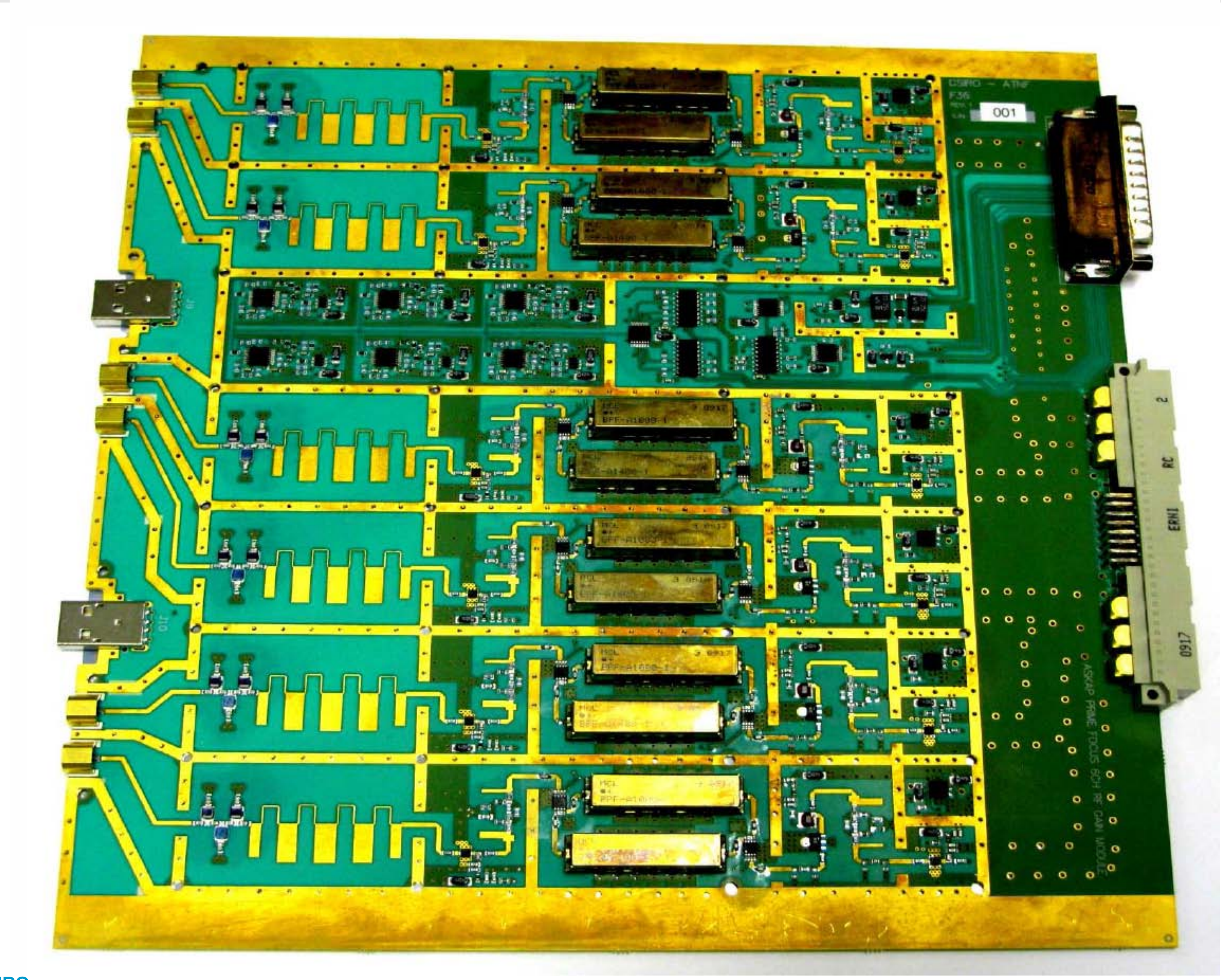
assembly images
c/- Russ Bolton

Progress – ASKAP Baseplate

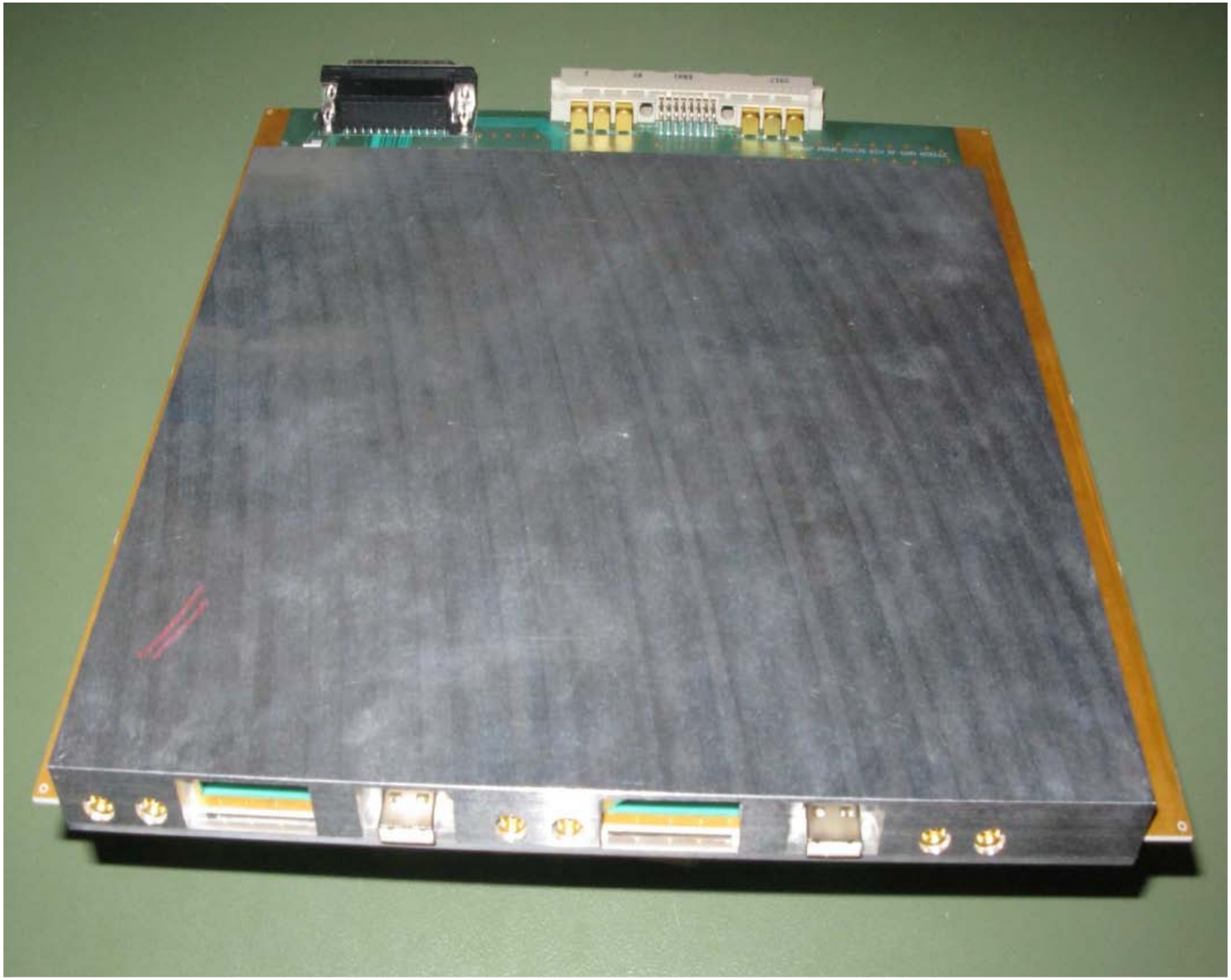
- **Single largest component:** 33 kg weight, 1350 mm diameter
- **Outsourced:** CNC machined 9.5 mm aluminium tooling plate



Progress – Gain Card

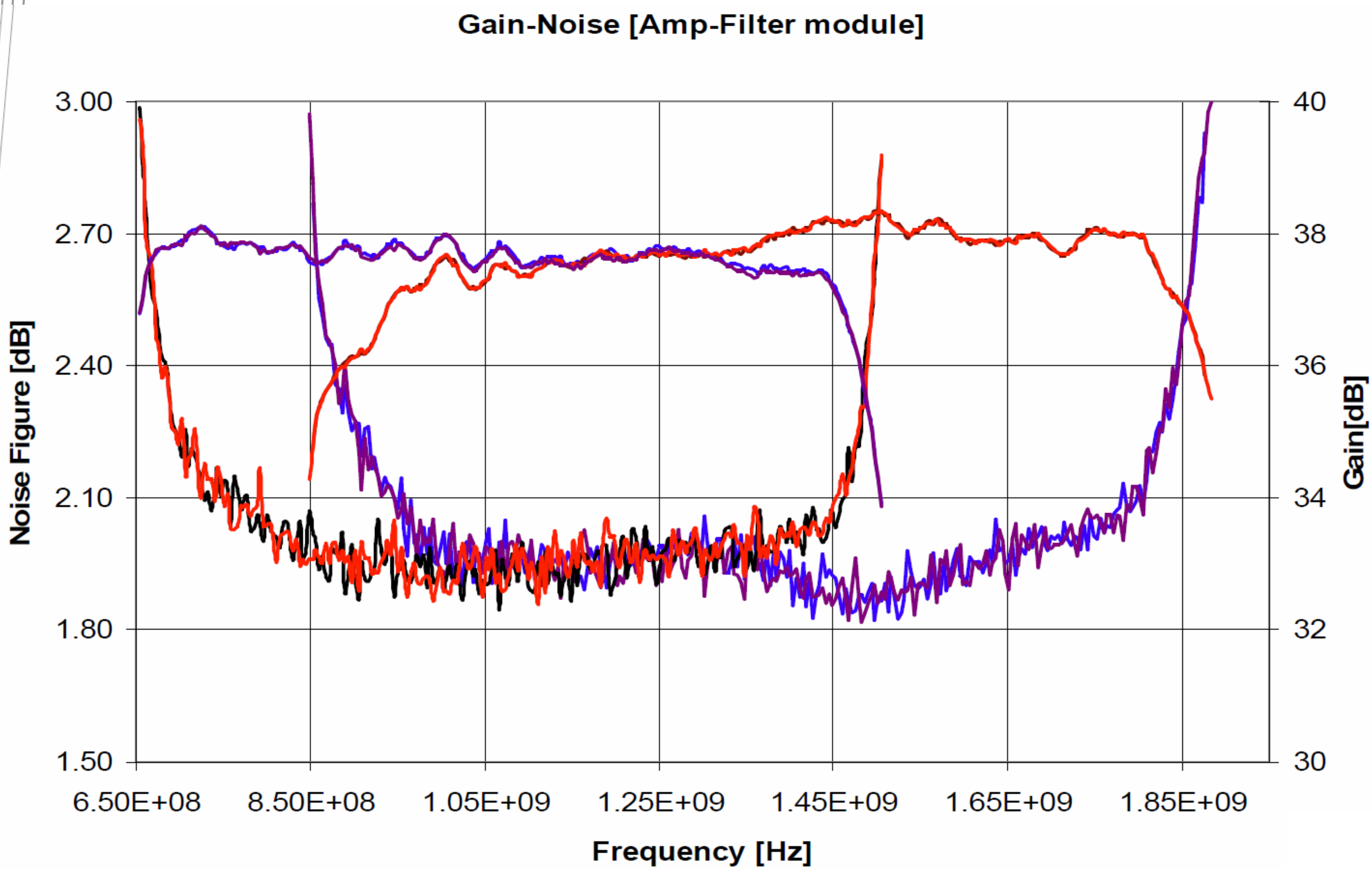


Progress – Gain Card + Shield



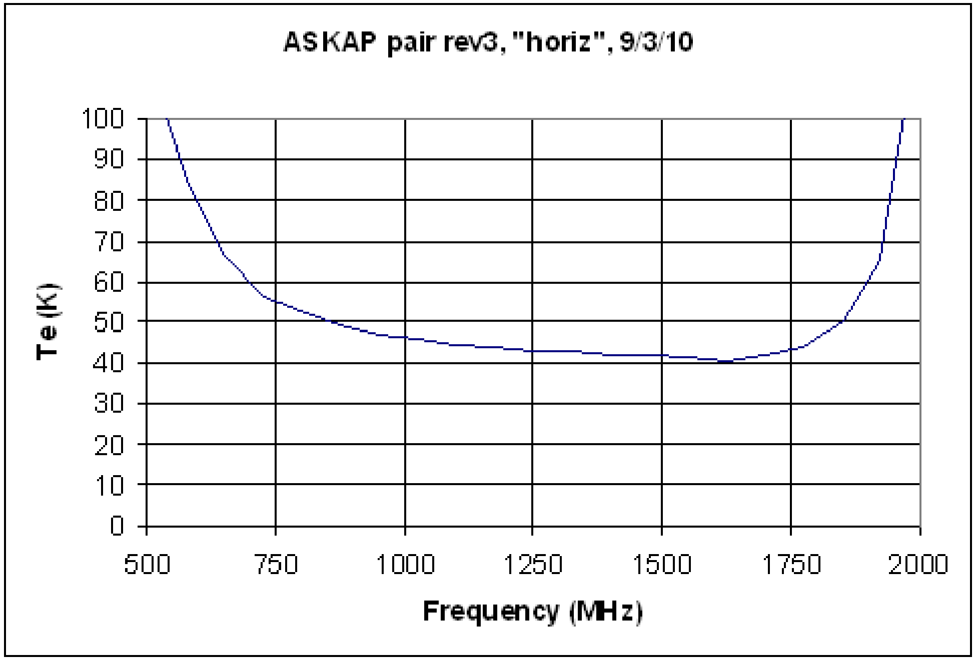
Progress – Gain Card EMC Test
Linear vs. Switched Power Supply

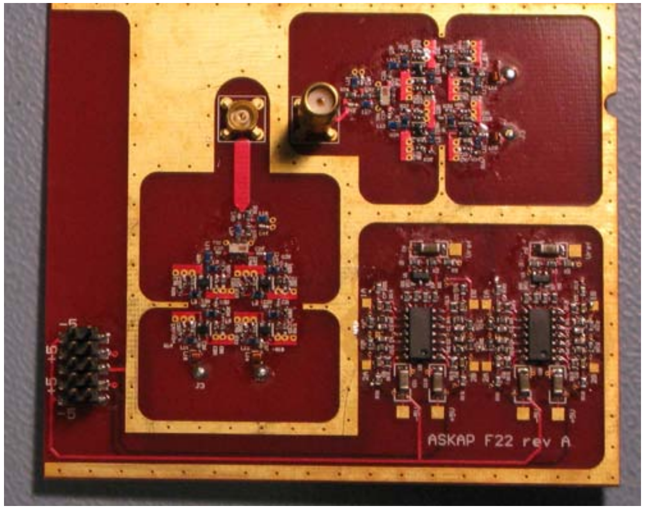
c/- Peter Axtens



Progress – Prototype ASKAP LNA pair

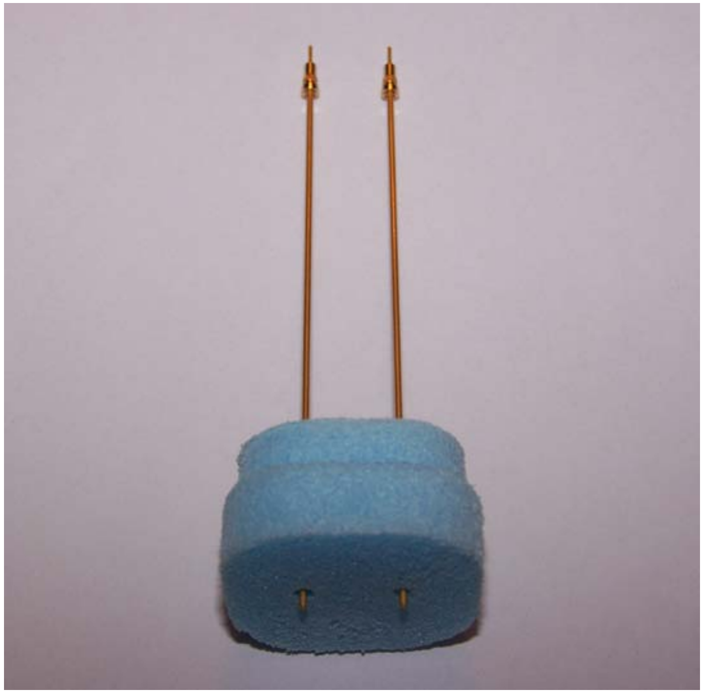
- Noise
  - 40 K
- Gain
  - 28 dB
- Input Impedance
  - balanced 300 Ω
  - SE Γ_{opt} close to 150 Ω
  - thankyou ASTRON for measuring noise parameters
- Frequency Range
  - 0.7 GHz to 1.8 GHz
- Transistors
  - Avago ATF-35143
- Design
  - 2 SE amplifiers + balun and equaliser



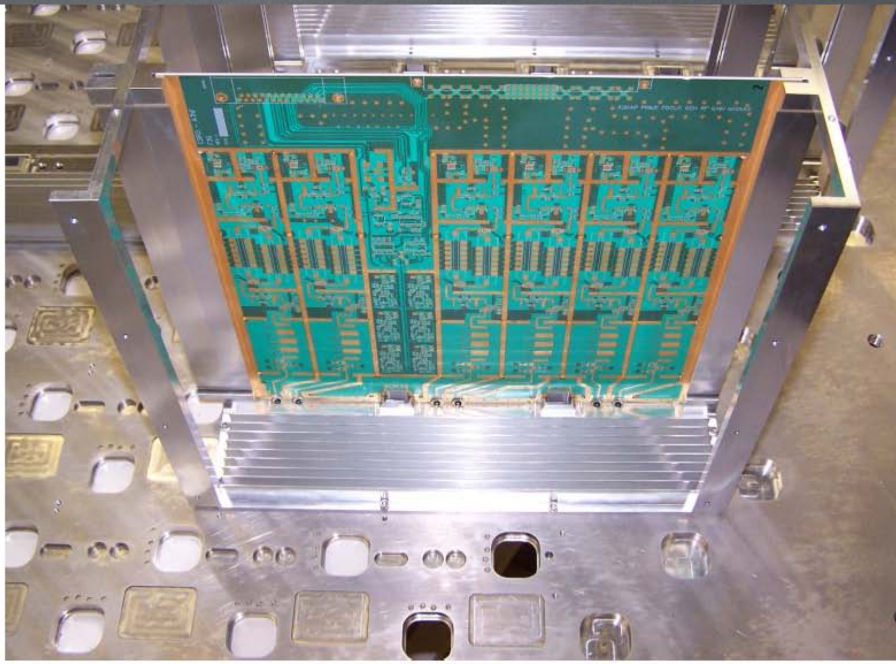


c/- Rob Shaw

Progress – Assembly



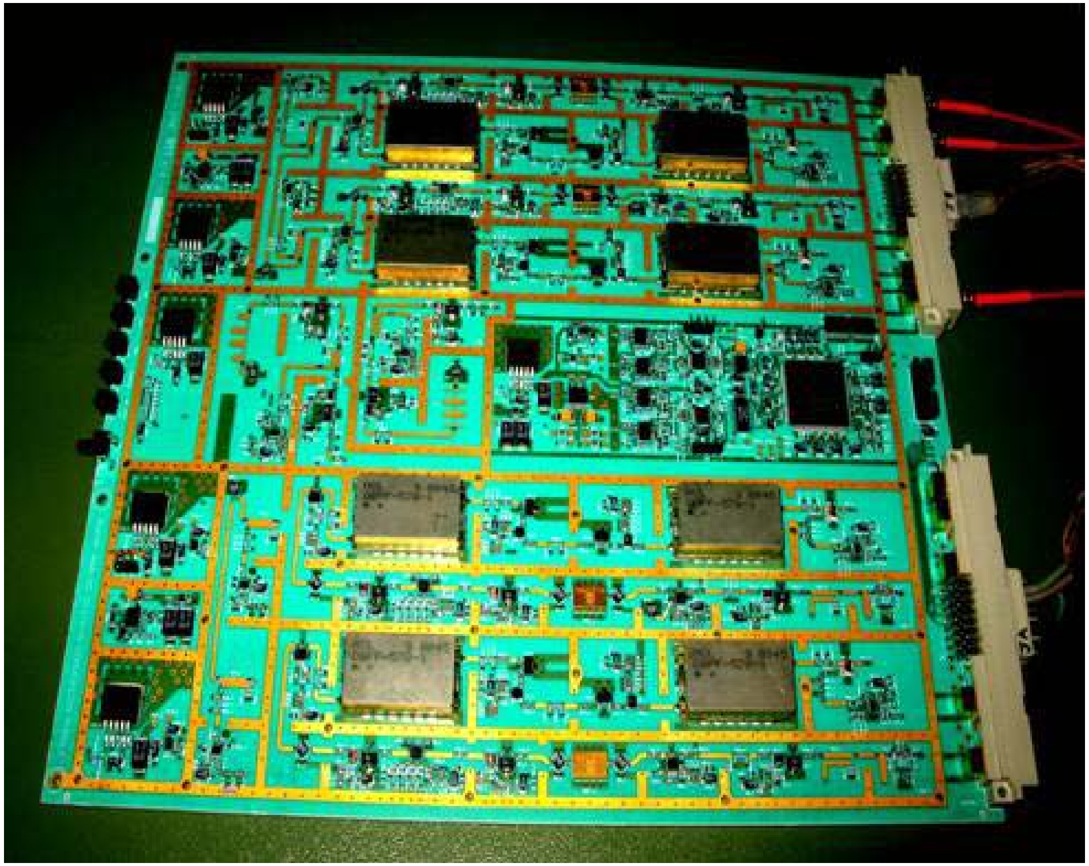
•array feed line



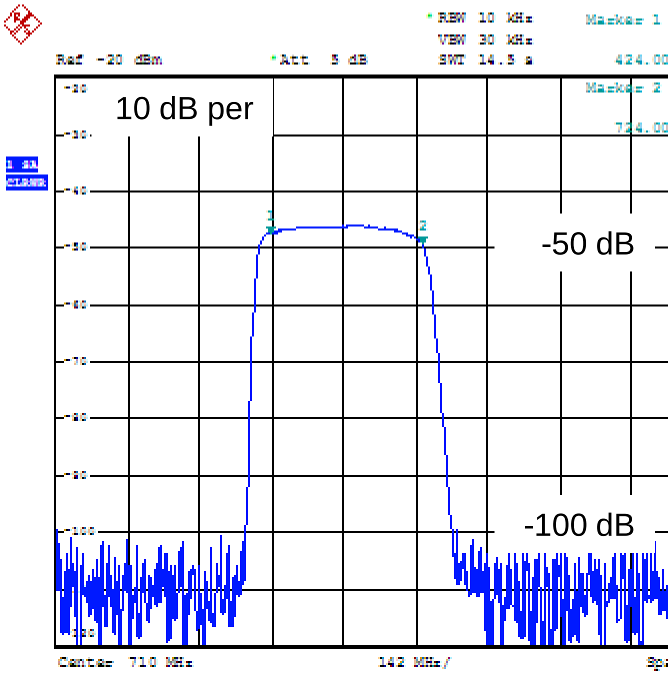
•6 unit Filter card inserts into LNA

Progress – Conversion Module Prototype

- Located in shielded rack in pedestal



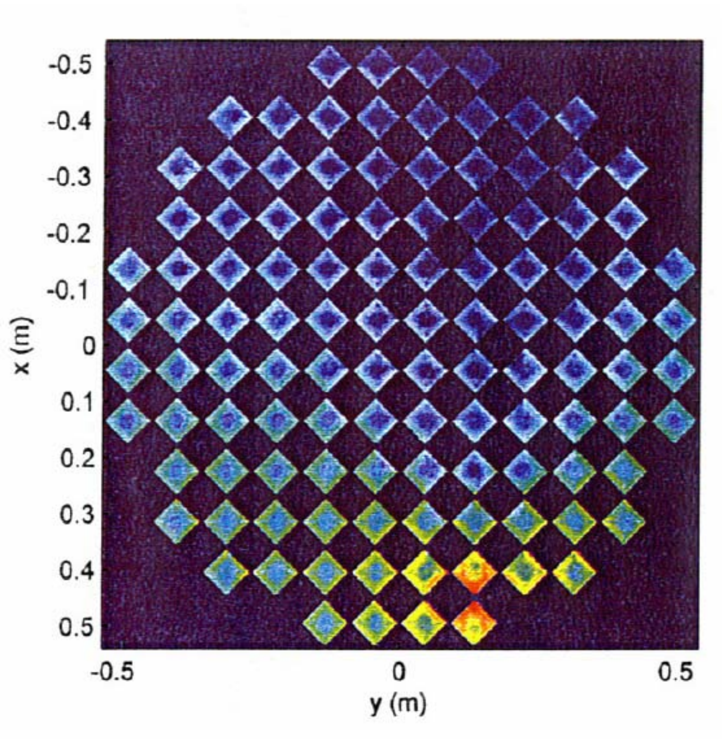
- passband with 40 m RF cable
- alias rejection >65 dB

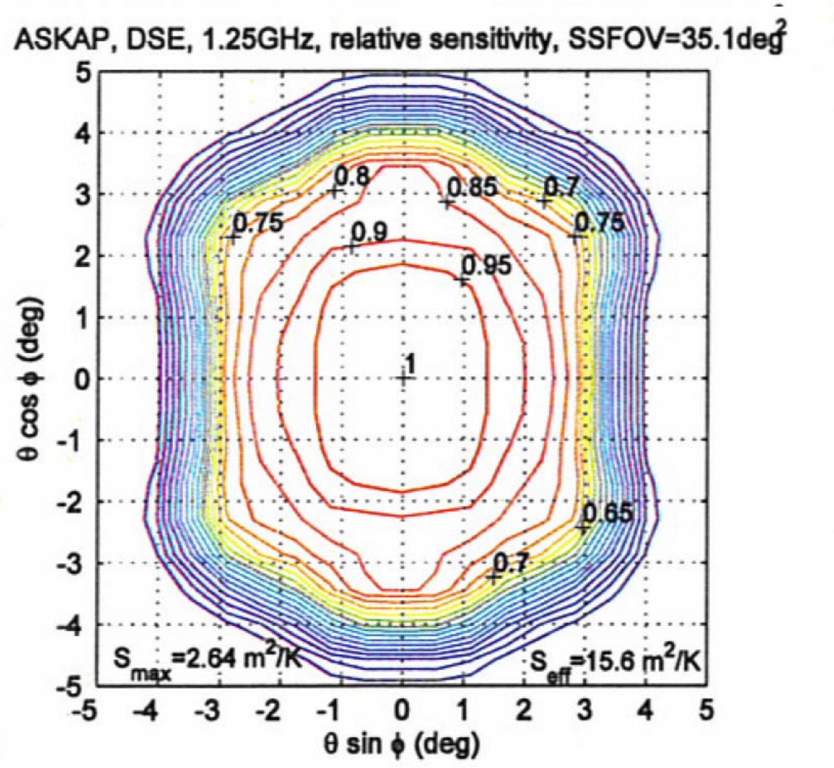


c/- K. Jeganathan

Progress – 30 deg^2 FOV Achieved

188 port ASKAP PAF → 35 deg^2 SSFFOV

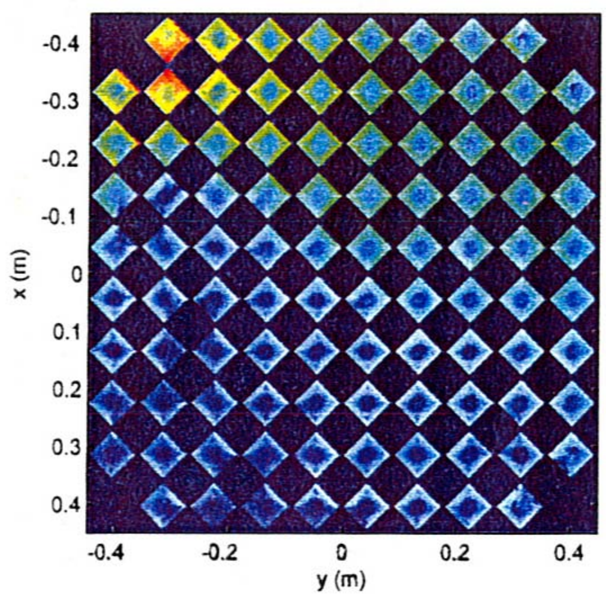


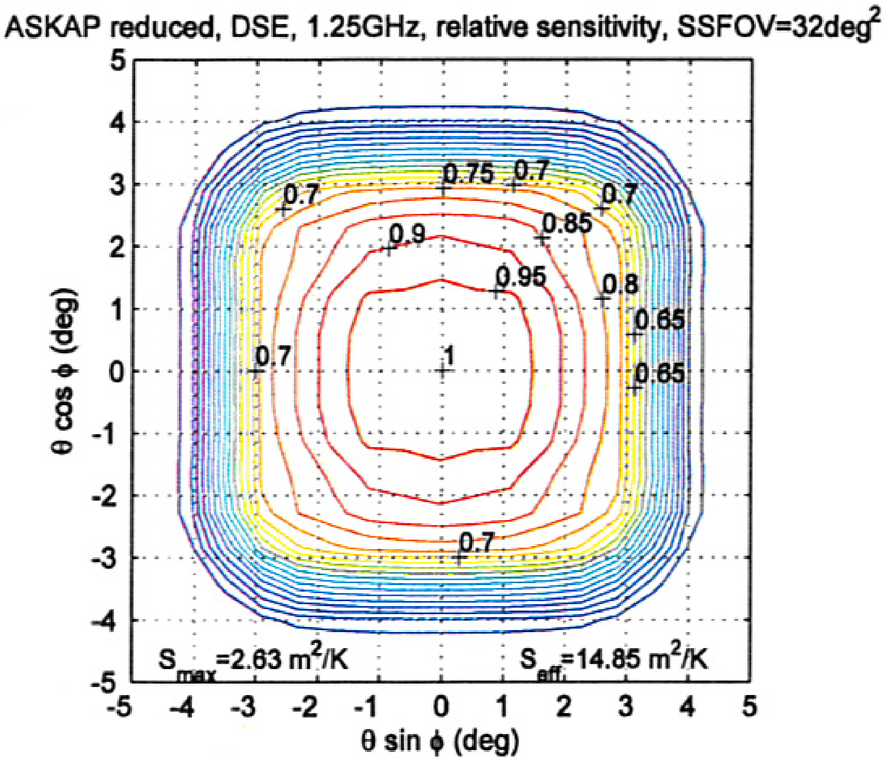


c/- Stuart Hay

Progress – 30 deg^2 FOV Achieved

172 port ASKAP PAF → 32 deg^2 SSFFOV

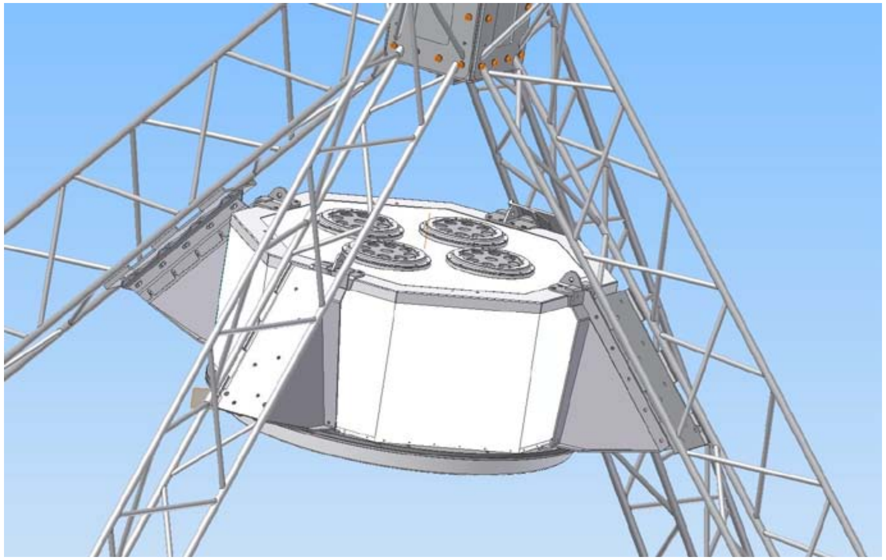




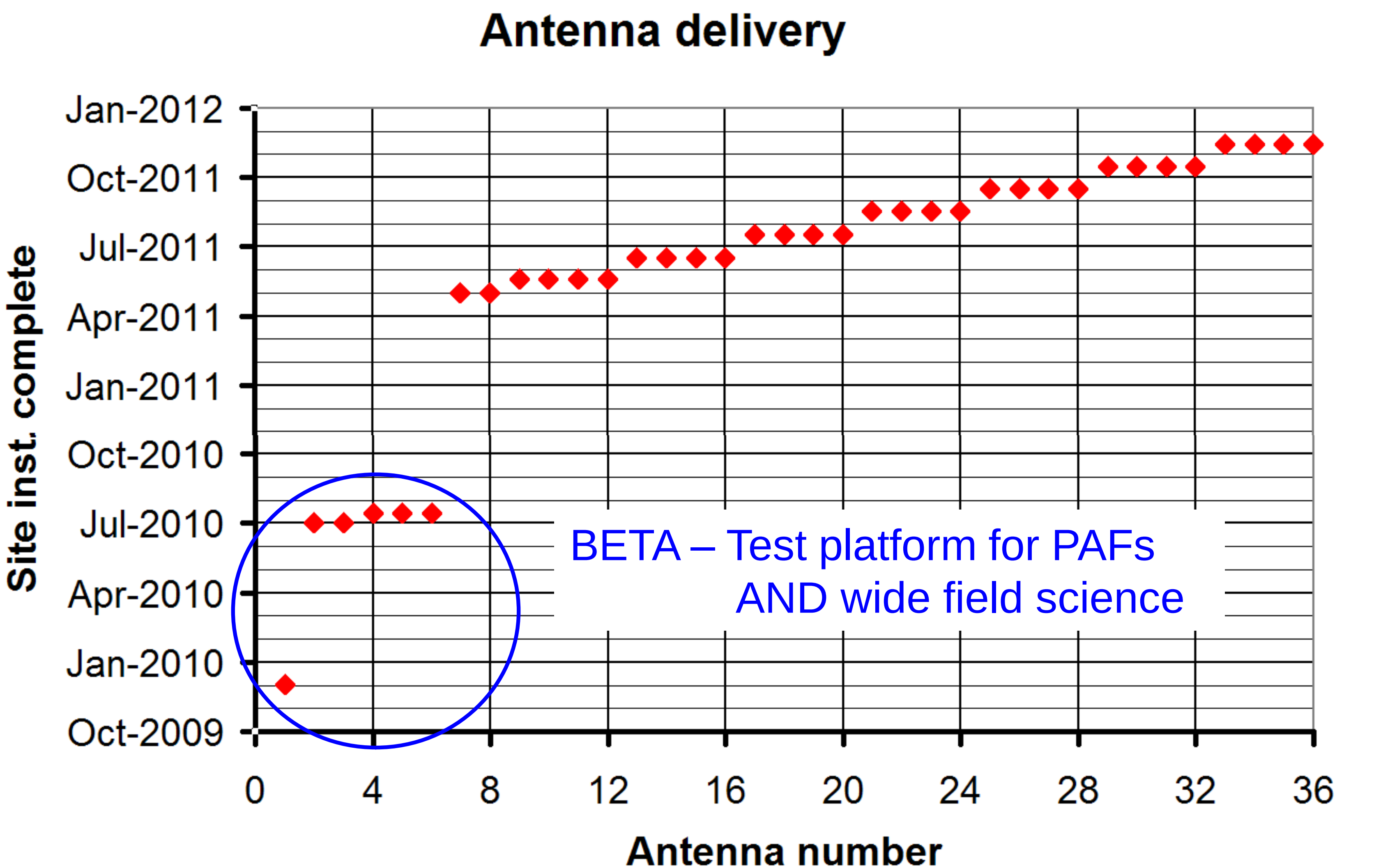
c/- Stuart Hay

Progress – ASKAP & SKA

- Test 188 port PAF this year
  - real-time 192 port digital back-end
  - hot/cold Y-factor measurements
  - interferometry with 64 m
- PAF Port Gain Calibration
  - multi-point noise injection
  - astronomical sources
- Towards SKA
  - modelling with offset dish
  - cost reduction



Progress – Antenna Delivery Schedule



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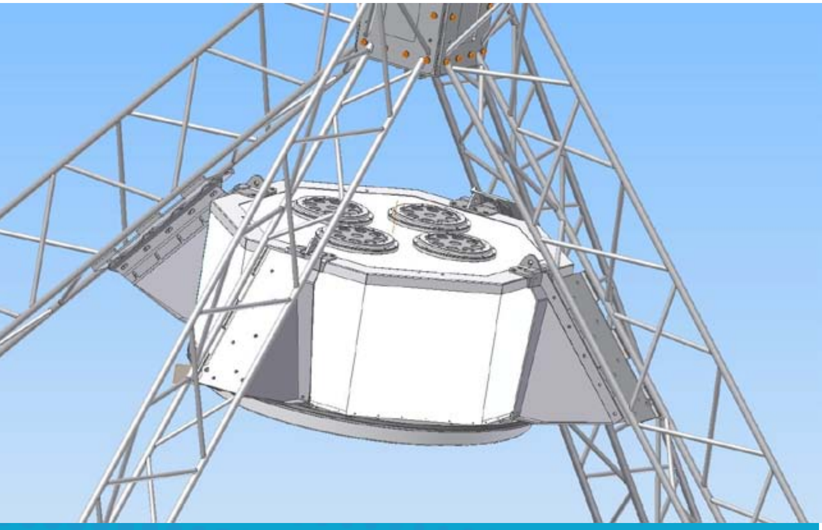
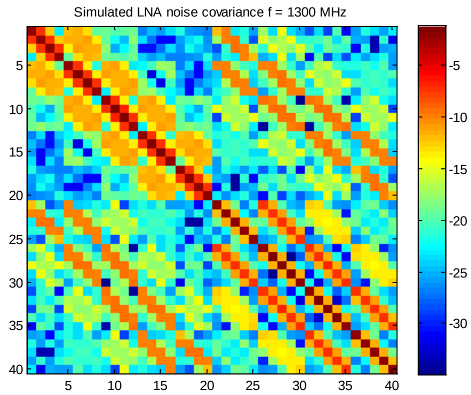
www.csiro.au/org/CASS.html



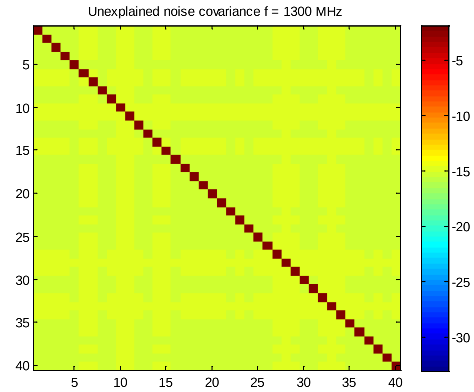
Thank you

Discussion – Noise Model Components

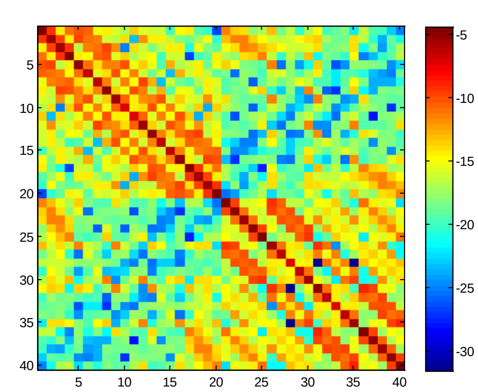
LNA noise -3dB



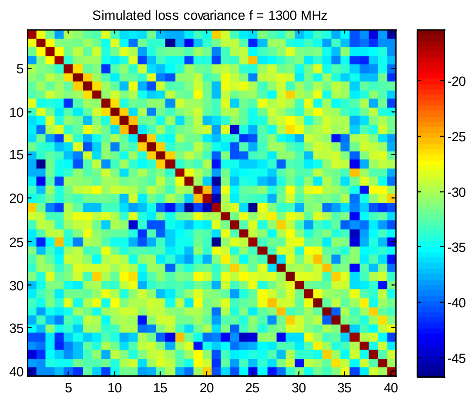
Unexplained Noise -3dB



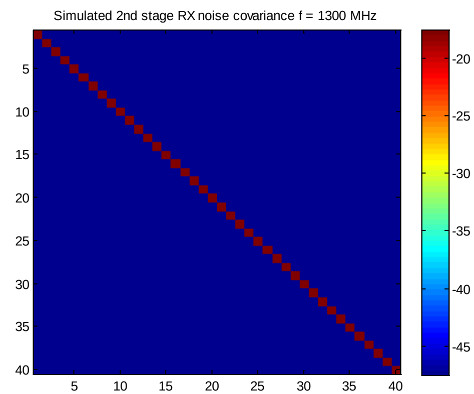
Spillover -5dB



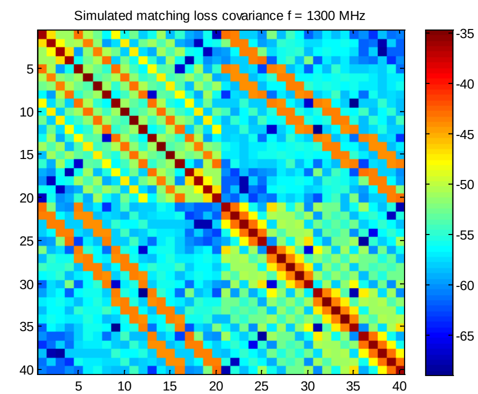
Array Losses -16dB



2nd Stage RX noise -18dB



Matching Net Loss -35dB



Discussion – Analog Connectors

Discussion – Pedestal Configuration