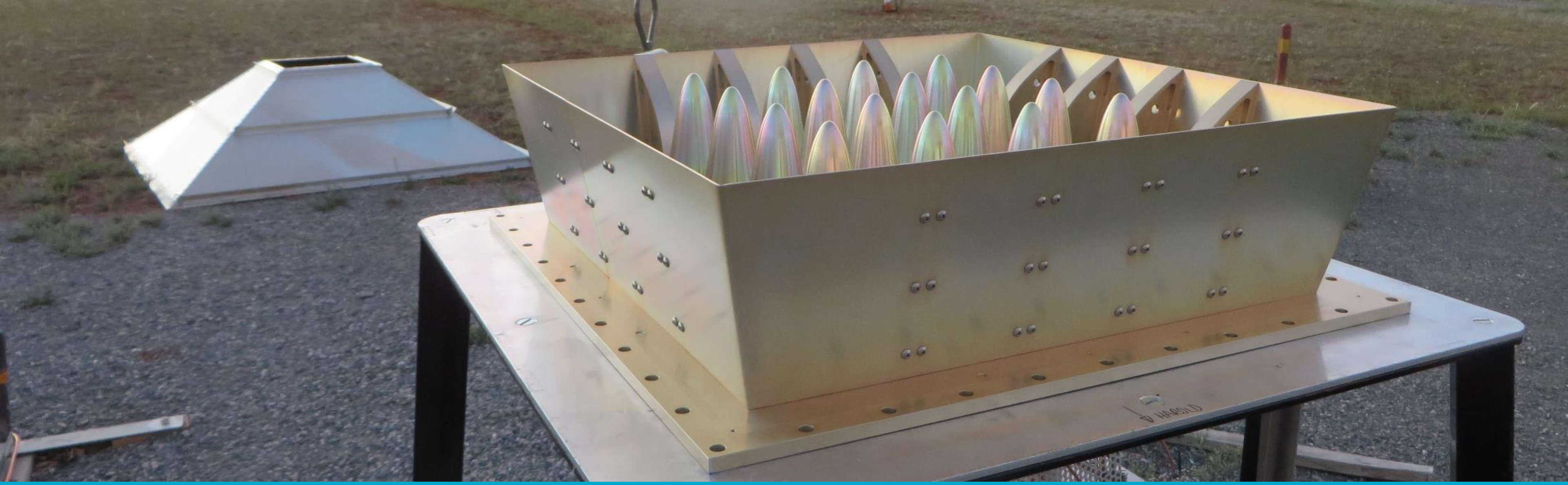

PAF Aperture Array Tests: Analog and Digital Beamforming Compared

Douglas B. Hayman, Robert D. Shaw, Alex Dunning, Aaron P. Chippendale

PAF Workshop 2016, Cagliari

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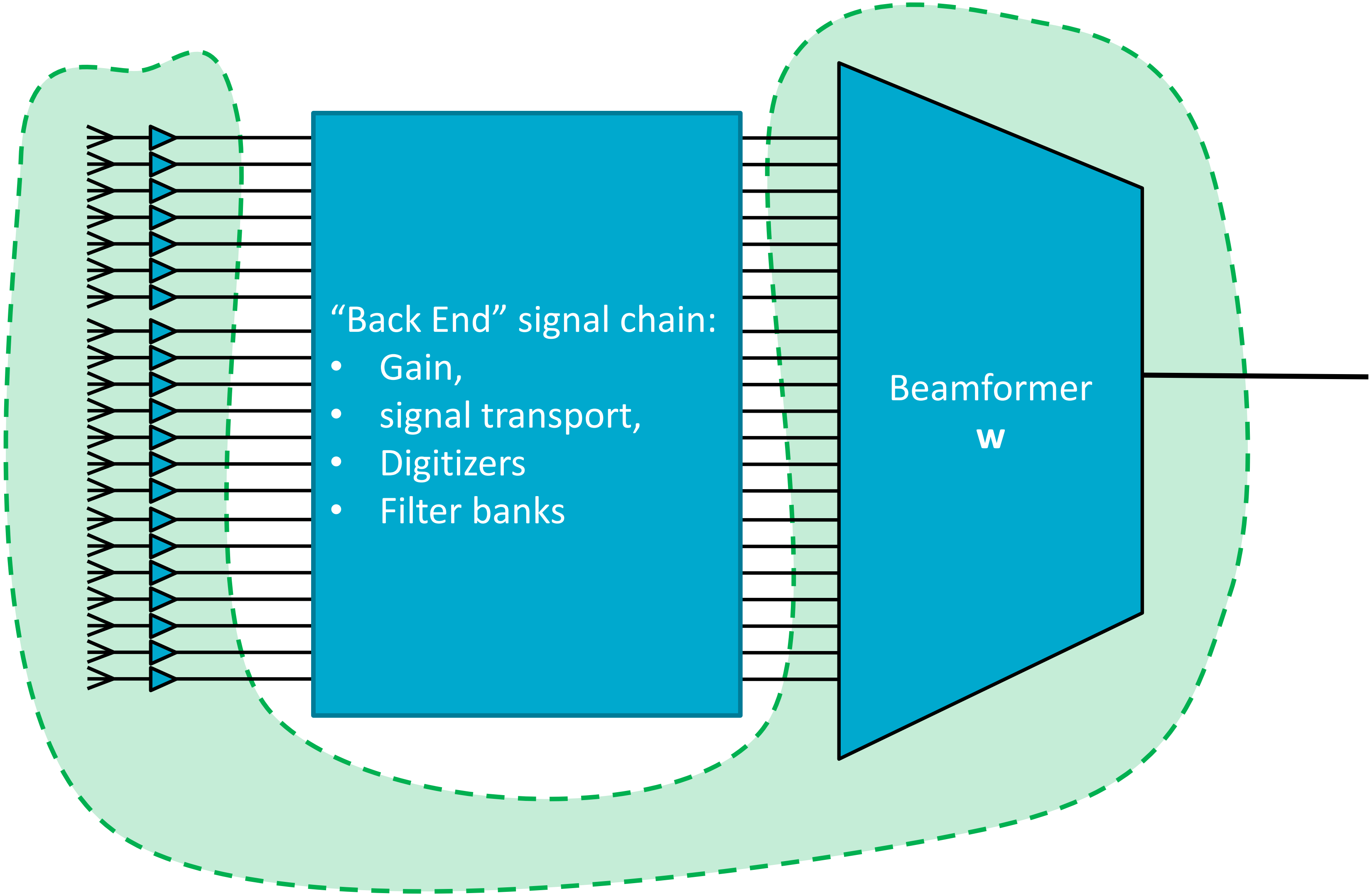
Motivation for simple analogue beamformer use

- We have had the luxury of working with receiver chains and digitizers and beamformers from the ASKAP development
  - BETA – Aperture array facility at Parkes
  - ADE – Marsfield, Murchison Radio Observatory (ASKAP)
- Covariance Matrices → "Post correlation beamforming"
- But with this great power comes great complexity
  - Designed for Lower RFI environment
  - Unresolved anomalies

Motivation – Our Approach

- Investigate simple equal weight combiners
  - Additional tool to digital beamformer
- Independent check of digital beamformer
  - The signal comes out on a single port
    - Known and trusted test equipment can be used
- Portable
- Fast to set up
- Very little data processing – less chance for errors
- Extending the band is much easier

Device Under Test



Device Under Test – Figure of Merit

“Sky referenced beam equivalent noise temperature”

Chippendale et al, PASA 2014

$$T_{\mathrm{lr}} = \frac{T_{\mathrm{rec}} + T_{\mathrm{loss}}}{\eta_{\mathrm{rec}}} = T_{\mathrm{iso}} \frac{\mathbf{w}^H (\mathbf{R}_{\mathrm{rec}} + \mathbf{R}_{\mathrm{loss}}) \mathbf{w}}{\mathbf{w}^H \mathbf{R}_{\mathrm{ext,iso}} \mathbf{w}}$$

Receiver Noise Eigenvalue Spectrum as a Diagnostic Tool for Y -factor Measurements of Phased Array Feeds, Warnick, Chippendale, Hayman, and Dunning, draft white paper 2016

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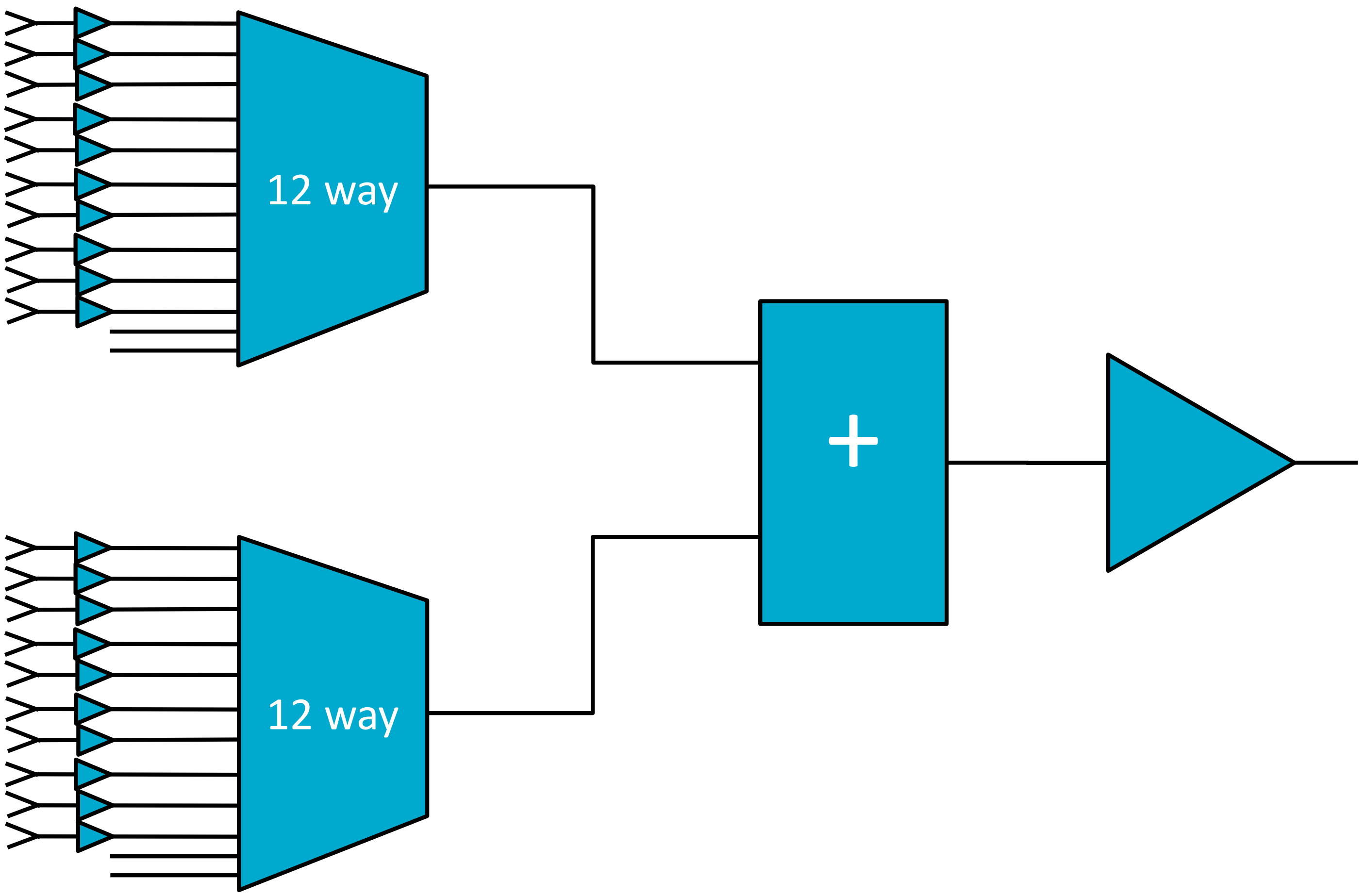
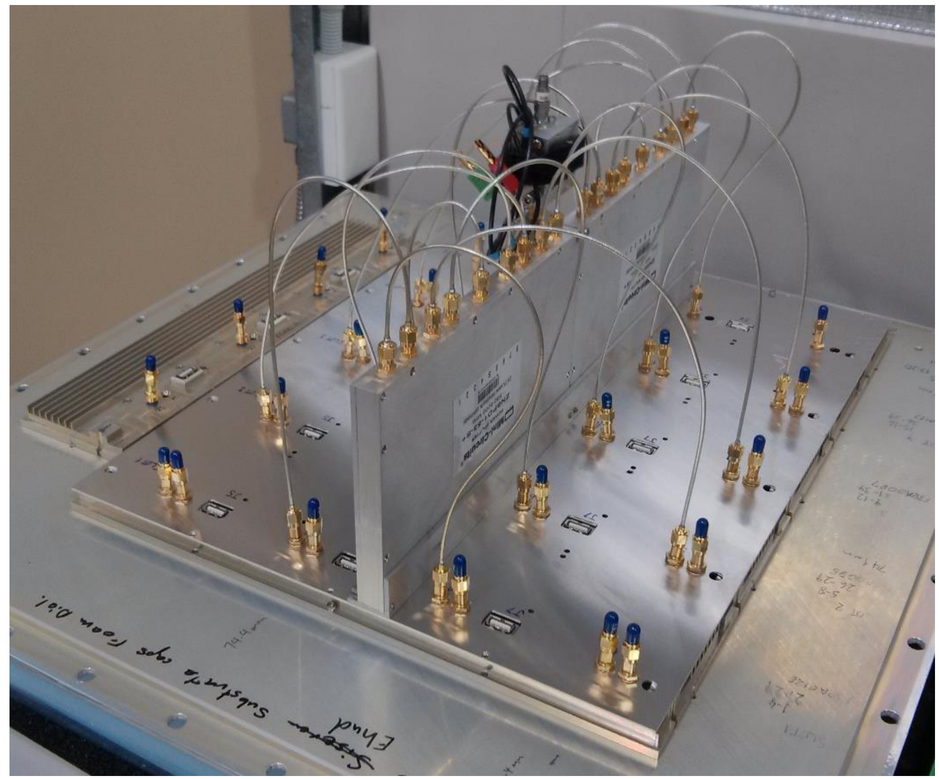
Analogue Beamformer Schematic

20 way equal weight



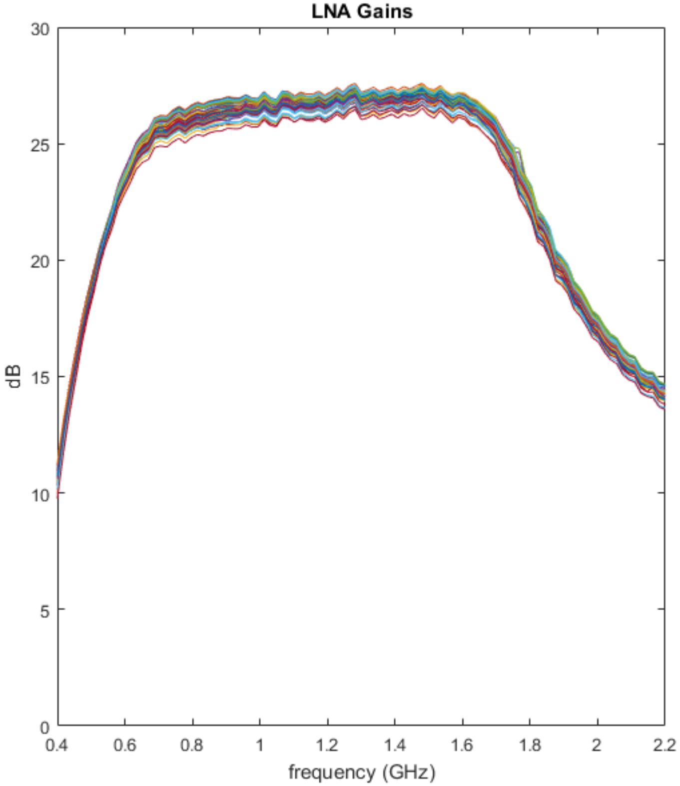
Analogue Beamformer

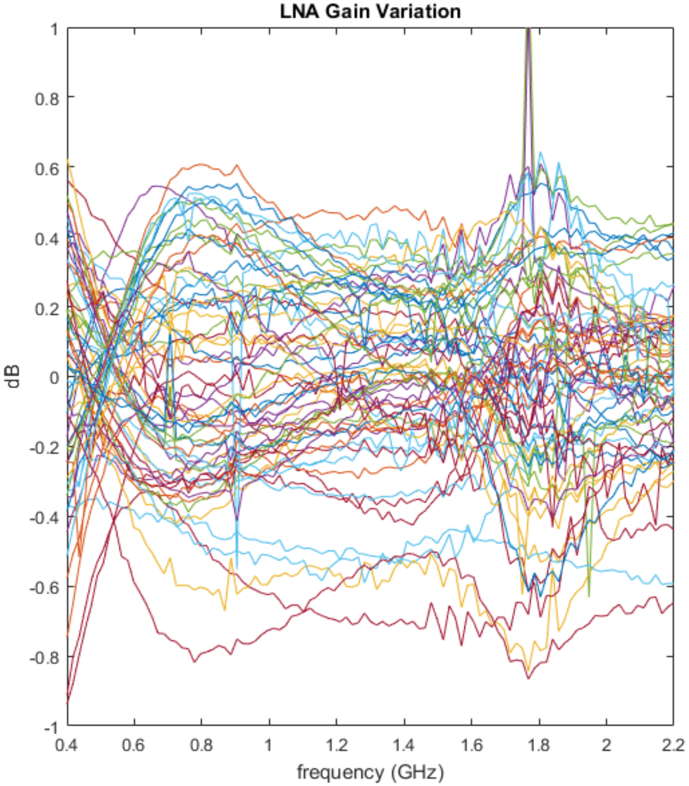
- 20 elements combined
- Rocket array needs a 180 degree hybrid
  - LNA layout arrangement led to half being inverted



Analogue Beamformer accuracy

- Gain dominated by LNA gain variation





LN2 Bin design

Insulated outer

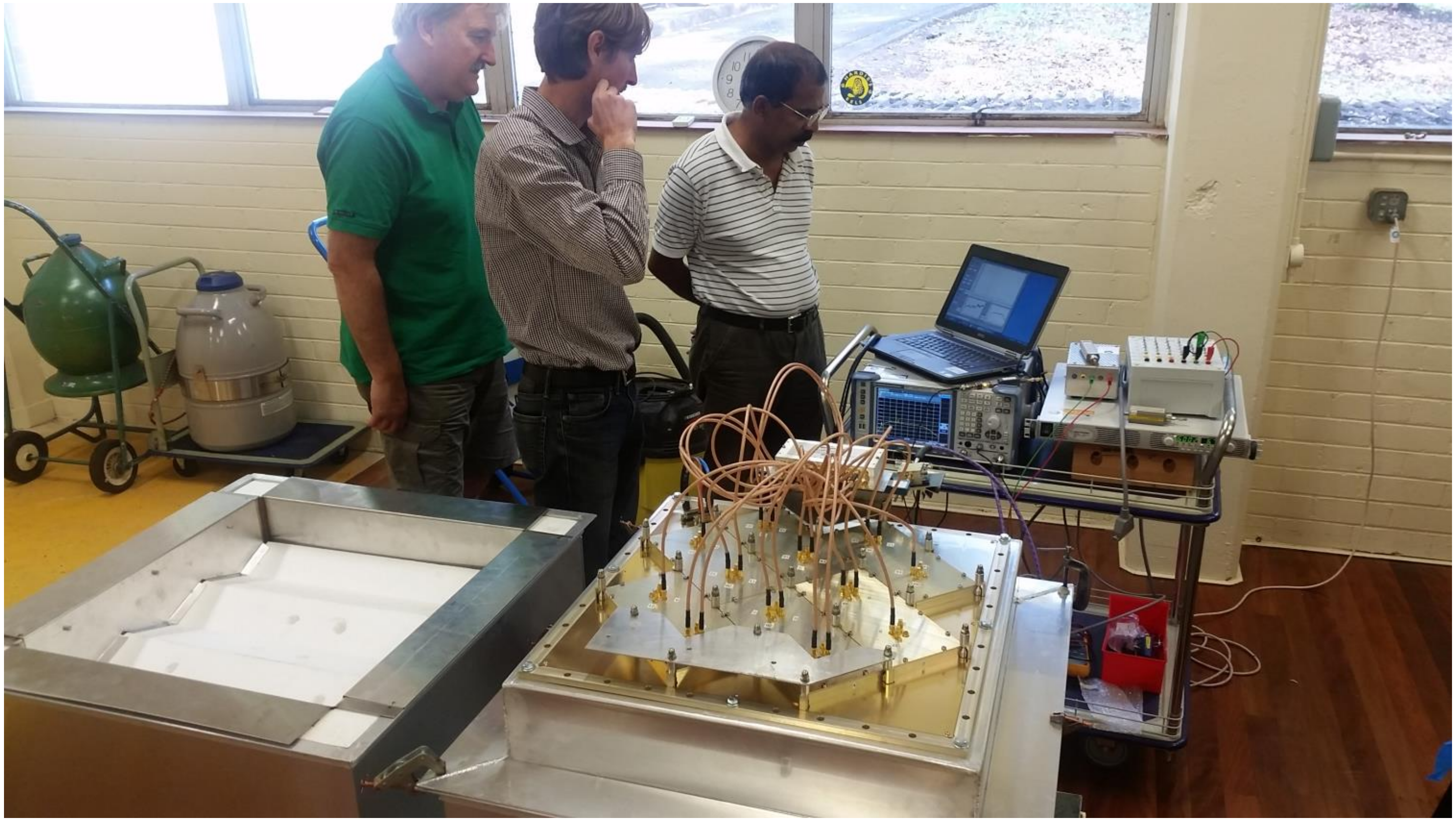
Stainless liner

Absorber

LN2 surface disruptor
and volume reducer

Safety first …

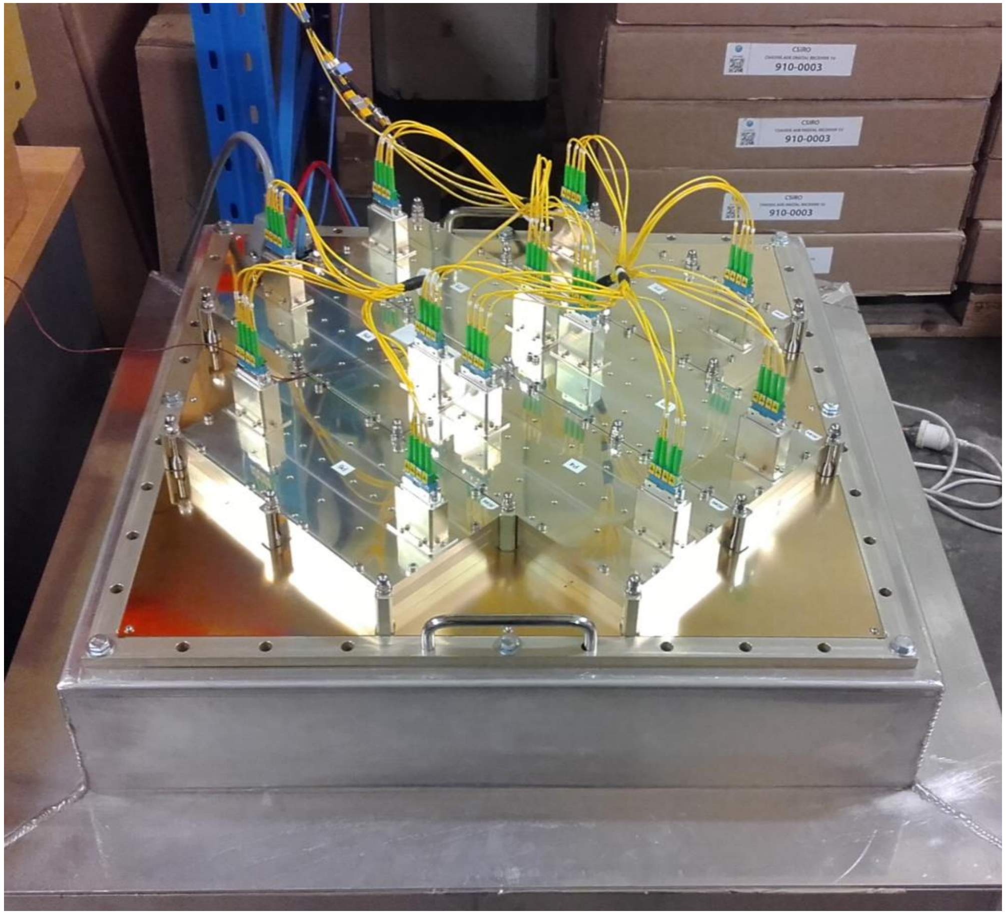
LN2 Analogue beamformer



LN2 measurements using the ADE backend

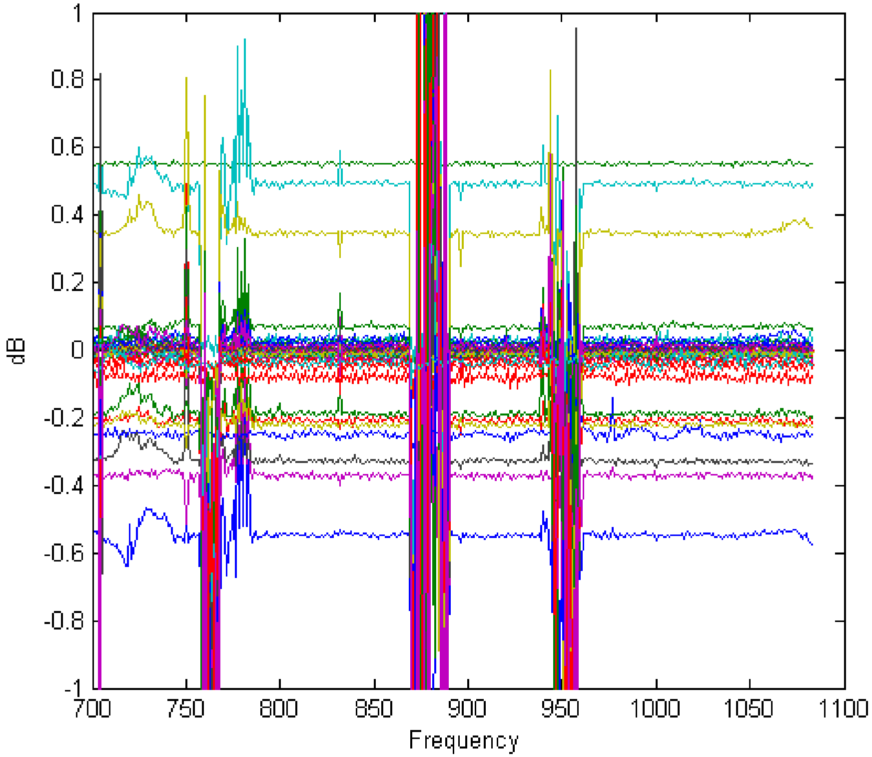
Using RFoF transmitters we are able to connect all 40 ports of the PAF to an ADE backend

We have a reference noise source radiating from the ceiling enabling gain equalisation and Max SNR beamforming

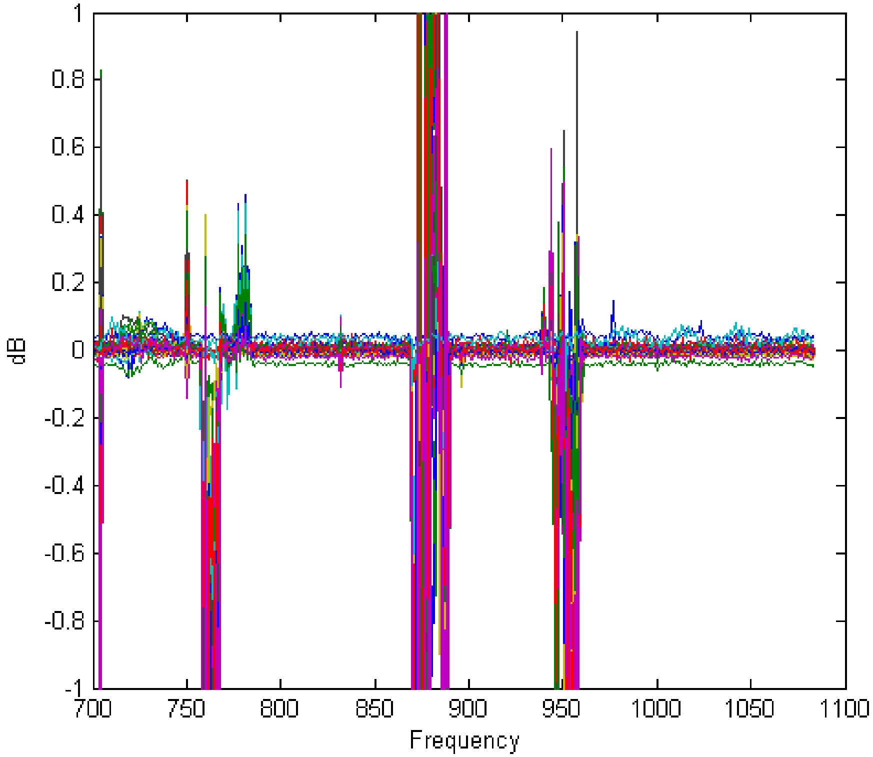


RF over fibre stability

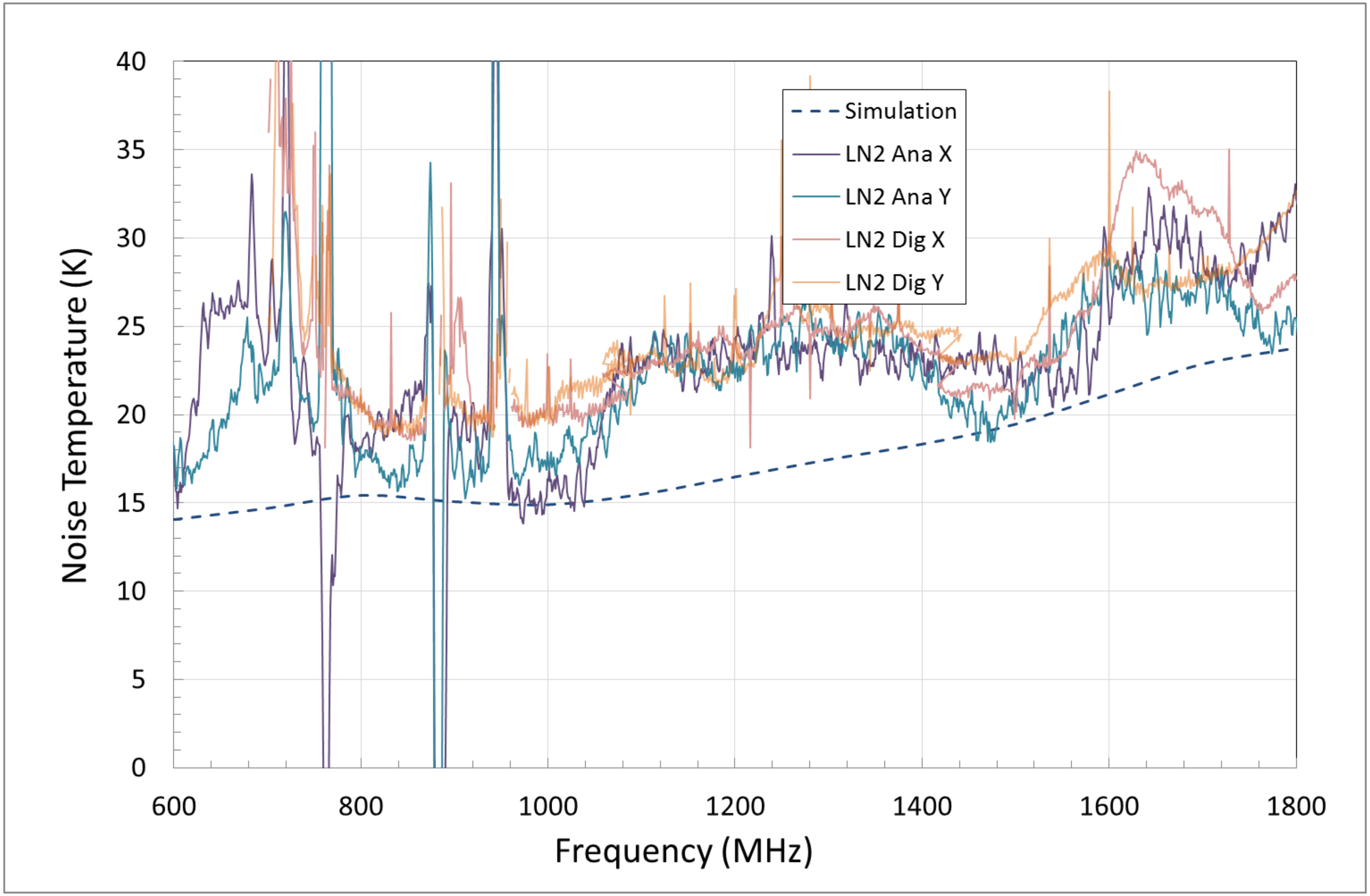
Hot load change with moving PAF



After normalising by optical power



LN2 Analogue vs digital



Sky @ Parkes: Cold

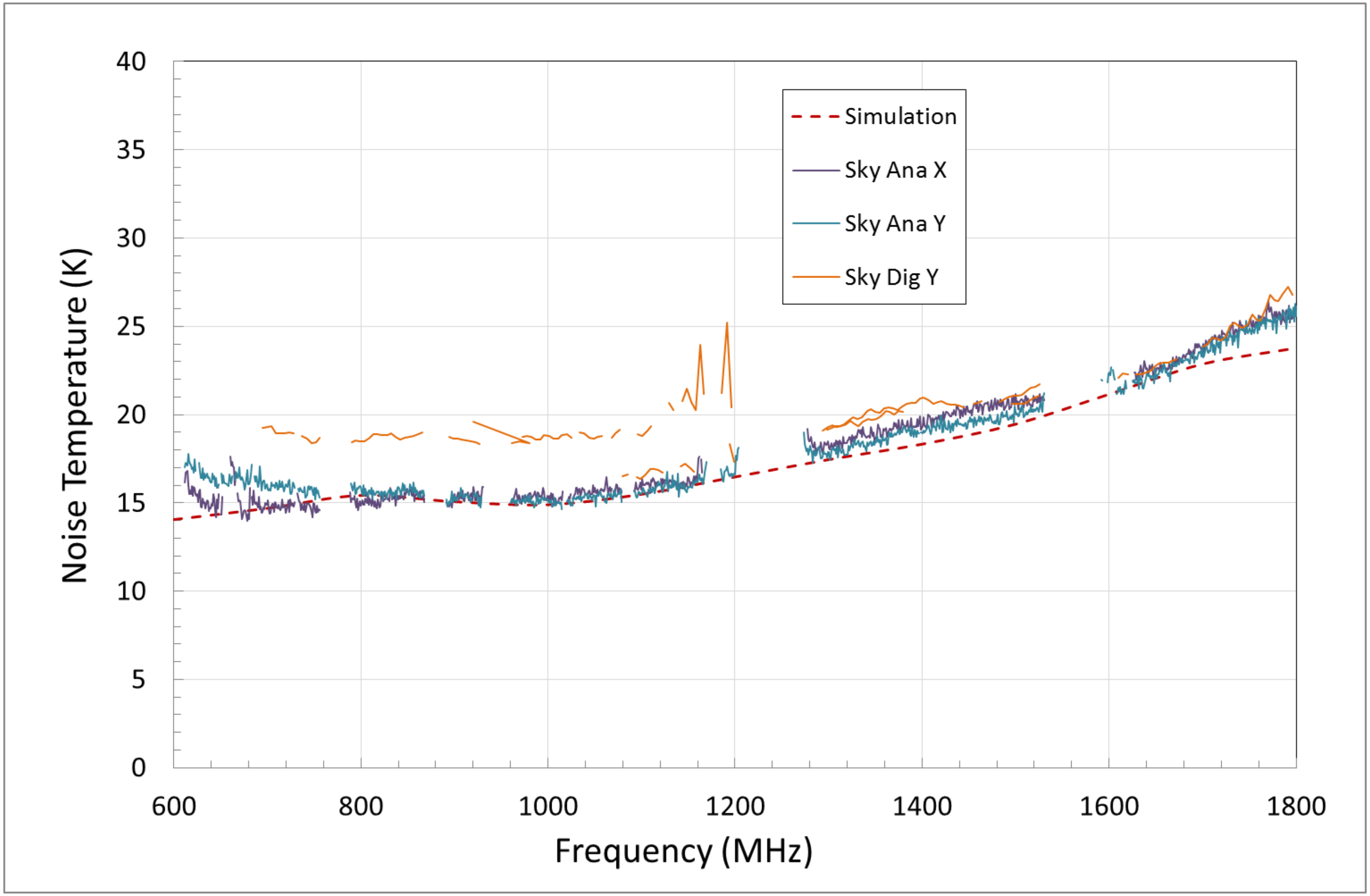
Sky @ Parkes: Hot

Sky @ Parkes: Reference Signal

Corrections – Digital BF

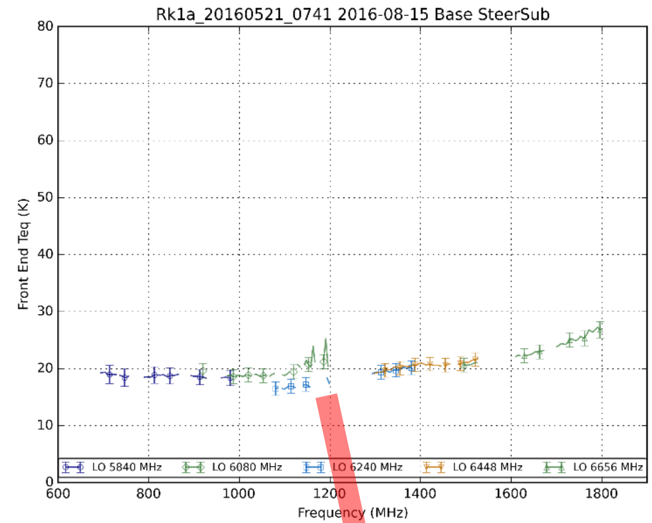
- Backend noise:
  - 8 channels calibrated at a time
  - Backend noise subtracted from diagonal of ACM
- Modelled element pattern used to correct reference antenna signal.

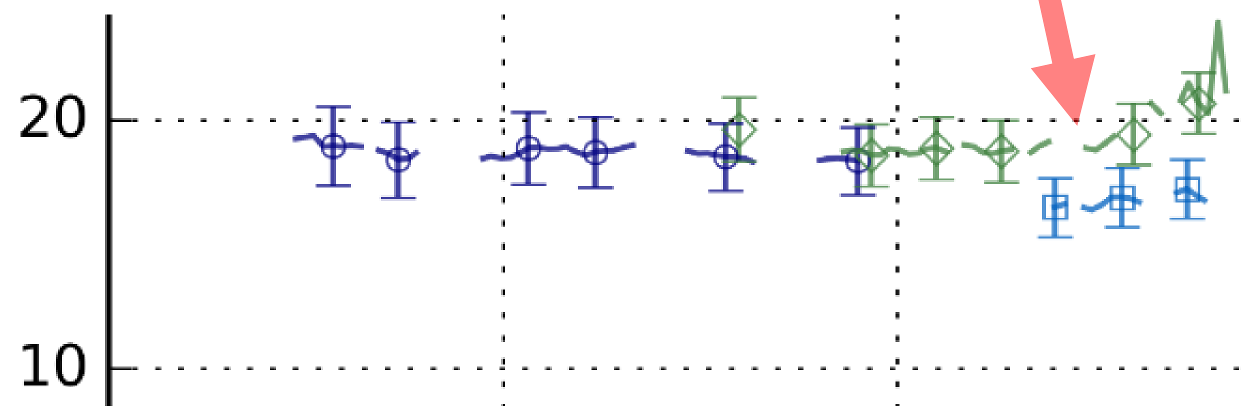
Sky Analogue vs digital



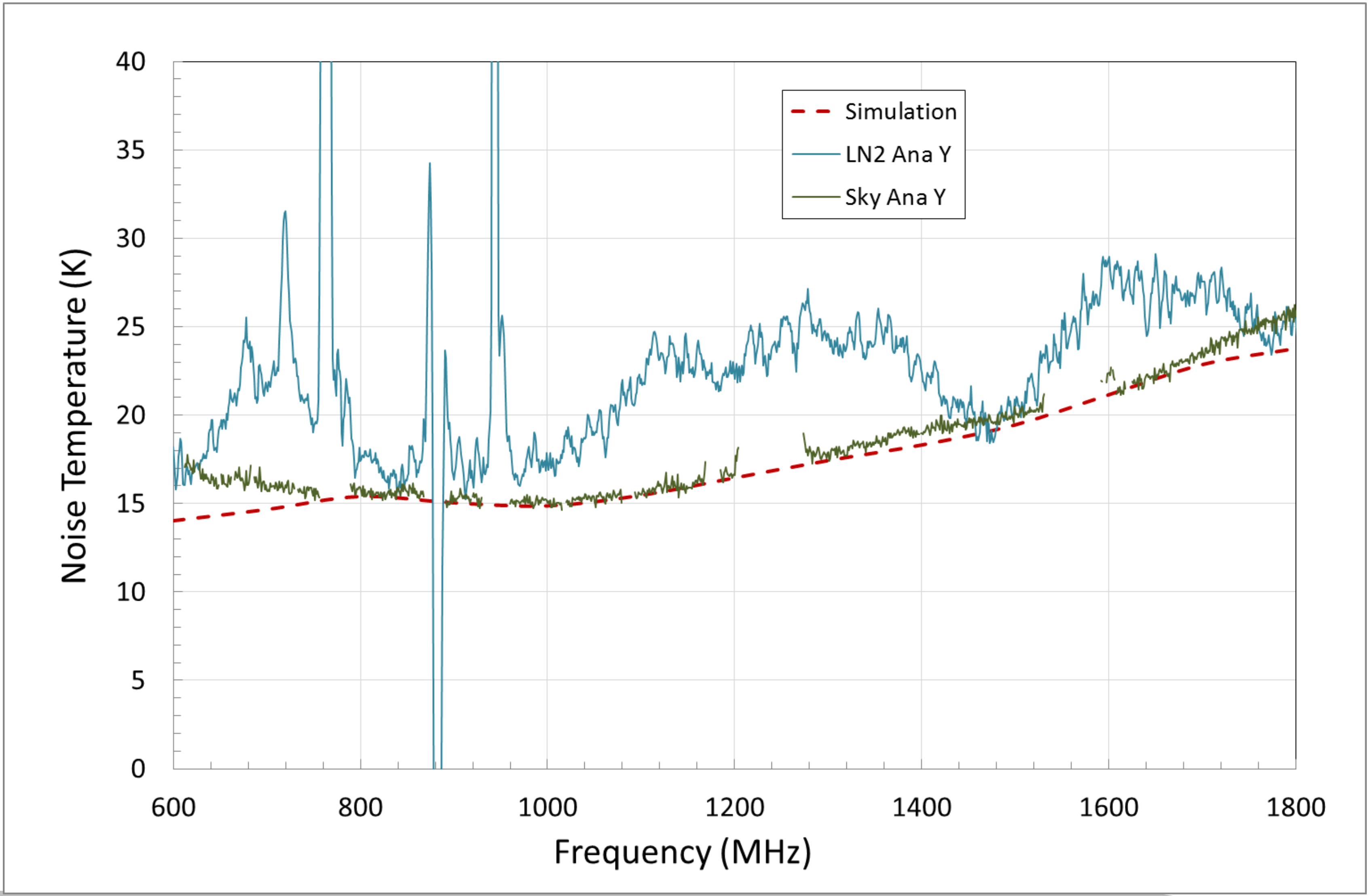
Aperture Array Tsys @ Pks – Discrepancy

- Discrepancy at band change
- Low band has higher attenuation in the back end due to RFI
  - Changing down converter band (LO setting) introduces
- RFI distortion induced noise?
- Compression?





LN2 vs Sky



Simulation
LN2 Ana Y
Sky Ana Y
Noise Temperature (K)
0
5
10
15
20
25
30
35
40
600
800
1000
1200
1400
1600
1800
Frequency (MHz)

Summary

- Sky results
  - Analogue and simulated results confirm agree very well – confirms both
  - Good agreement for analogue and digital > 1250MHz
  - Still have issues < 1200MHz
- LN2 results
  - More research required

Conclusion

"The use of a simple analogue beamformer has proved an excellent adjunct to full ACM measurements"

Future work

- Resolve backend issues
- Try other simple analogue approaches
  - Tapering
  - Subset of array
- LN2 – investigate issues

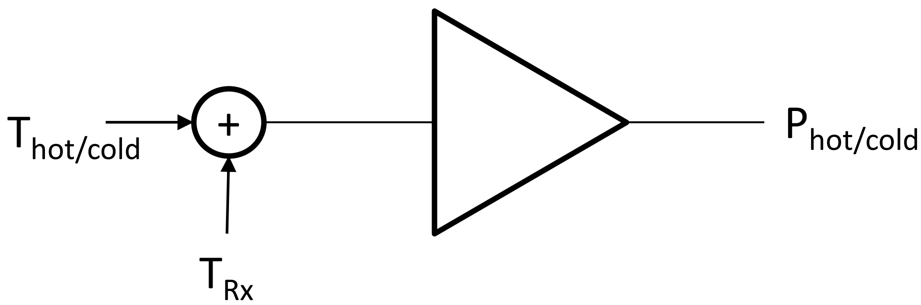
Acknowledgements

Parkes staff
Marsfield workshop

We acknowledge the Wiradjuri people as traditional custodians of the Parkes Radio Observatory site

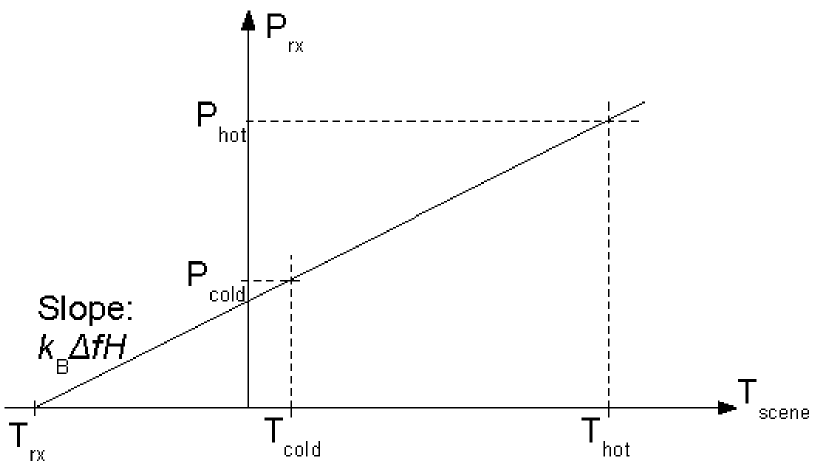
Contact: Douglas Hayman | douglas.hayman @ csiro.au

Basics of Y factor Tsys measurements



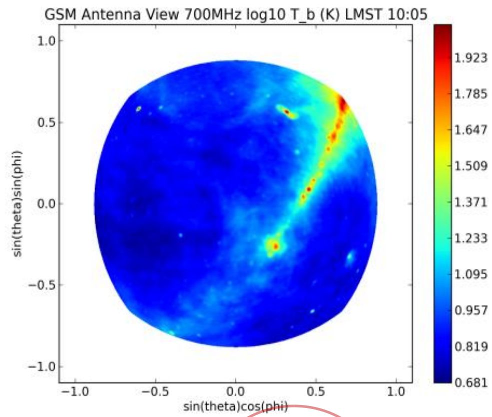
$$Y = \frac{P_{hot}}{P_{cold}} = \frac{k(T_{rx} + T_{hot})\Delta f G}{k(T_{rx} + T_{cold})\Delta f G}$$

$$T_{rx} = \frac{T_{hot} - Y T_{cold}}{Y - 1}$$



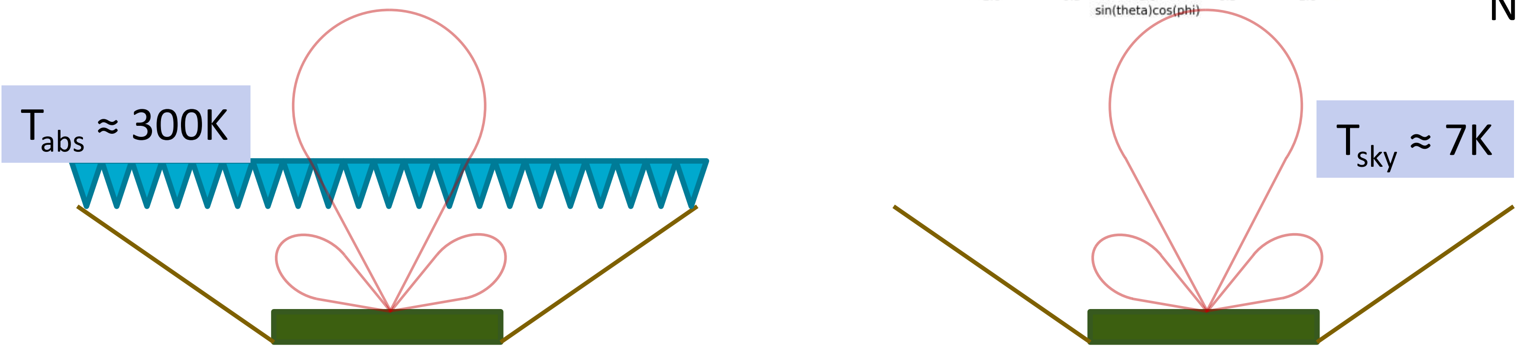
- Result independent of G and Δf
  - Assumes stability and linearity
- “Back end” contribution can be subtracted from result.

Aperture Array Tsys - Concept



Angelica de Oliveira-Costa et al. Global Sky Model

No Sun



$P_{hot} = kGB(T_{abs} + T_{rx})$

$$Y = \frac{P_{hot}}{P_{cold}}$$

$P_{cold} = kGB(T_{sky} + T_{rx})$

$$T_{rx} = \frac{T_{abs} - YT_{sky}}{Y - 1}$$

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