



Practical Aspects of Focal Plane Array Testing

Lessons from an FPA Test-bed at CSIRO, Marsfield

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Overview

- Historical context
- Description of the testbed at the Radiophysics Lab, Sydney
- Some results
- Lessons/issues confronted

Historical Context – Focal Plane Array (FPA) Work at CSIRO

- ~2002: Collaboration on FARADAY array with ASTRON:
 - Near field antenna measurements
 - Testing with a Luneburg lens
- 2003/4: FPA projects
 - Two PhD students start:
 - Receiver on a chip: Suzy Jackson
 - Beamforming FPAs: Doug Hayman
 - Plans for a testbed at Marsfield underway
 - New Technology Demonstrator (NTD) Interferometer
 - Plans for (what was to become) ASKAP
 - Focus on digital beamforming
 - Western Australia site planning
- 2006: FPA for NTD (THEA tile) arrives from ASTRON
- 2006-2008: NTD operational
- 2008 Parkes 12m testbed “first light”



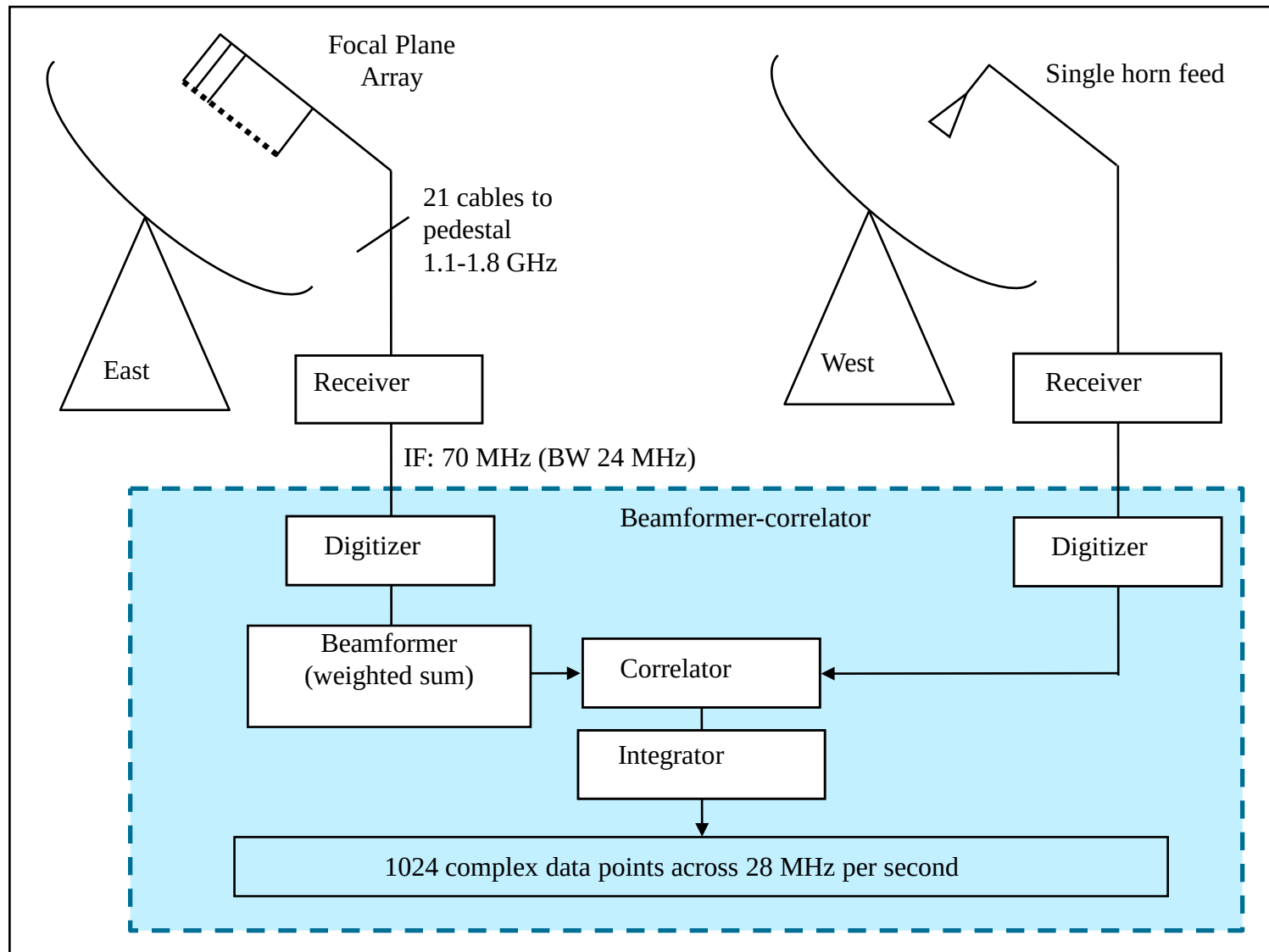
NTD¹ Interferometer Overview

- Get FPA test bench going fast
- On site dedicated system
- Support decisions needed for the ASKAP
- Learn about FPAs
- 2 dishes at Marsfield Radiophysics Laboratory
 - Recycled Fleurs dishes
 - One with an FPA:
ASTRON's 8x8 THEA tile
 - One with a single feed
 - f/D : ~ 0.4
 - Diameter: 14m. Large enough for astronomical signals.
- 24MHz beamformer-correlator



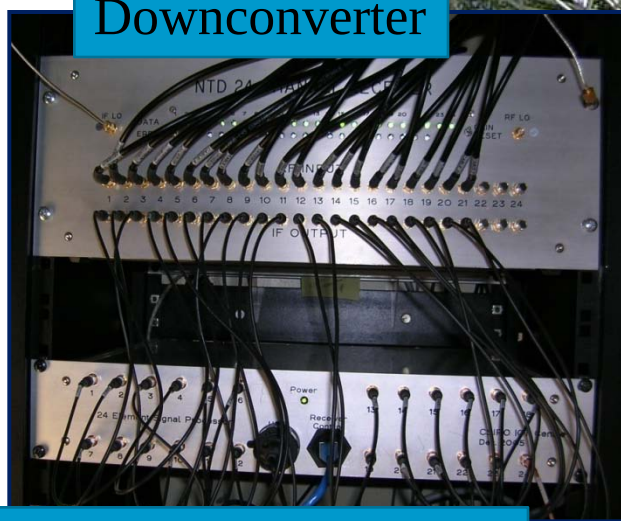
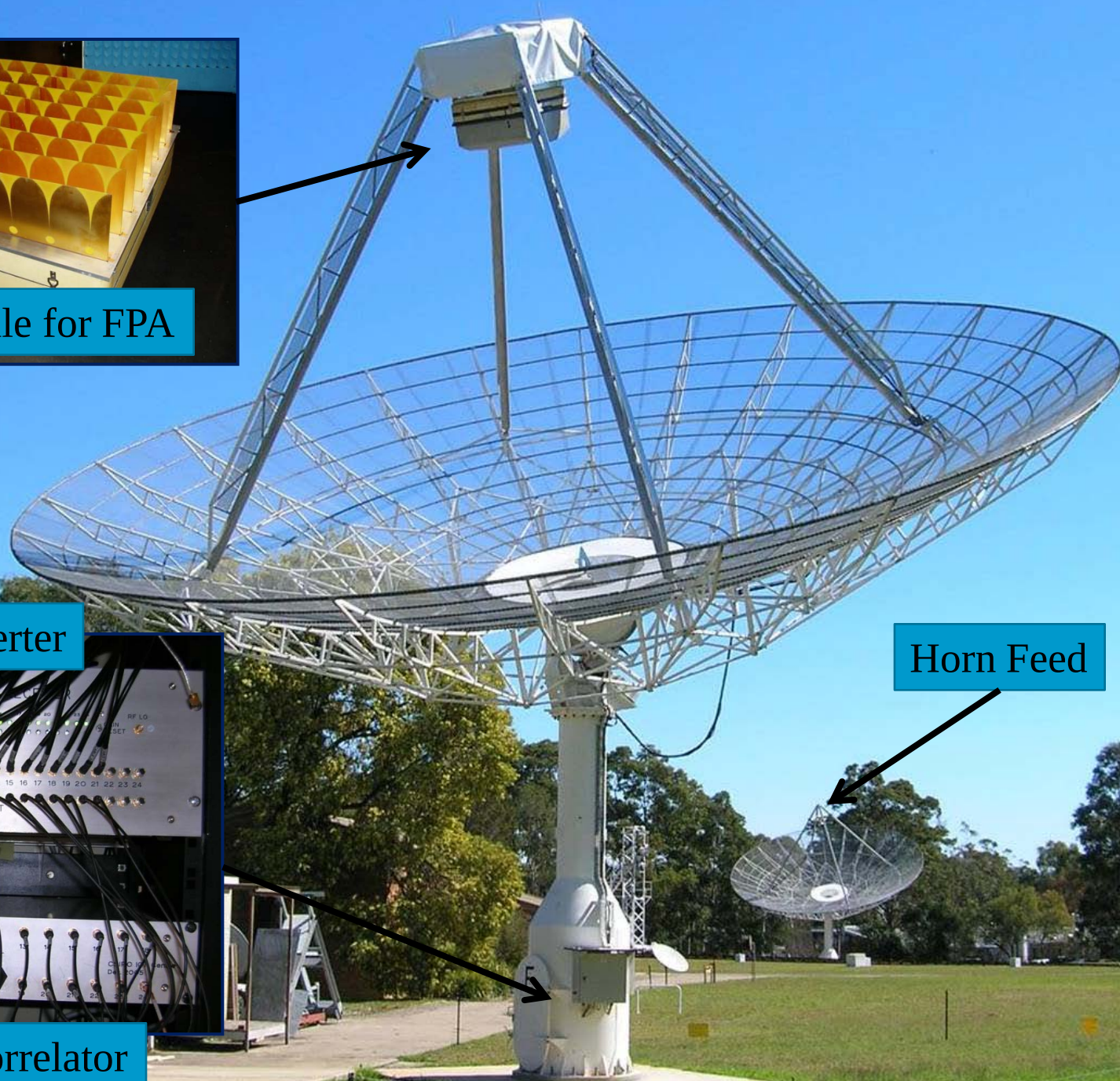
¹New Technology Demonstrator: Project name for CSIRO's early PFA development

NTD Interferometer Block Diagram





THEA Tile for FPA



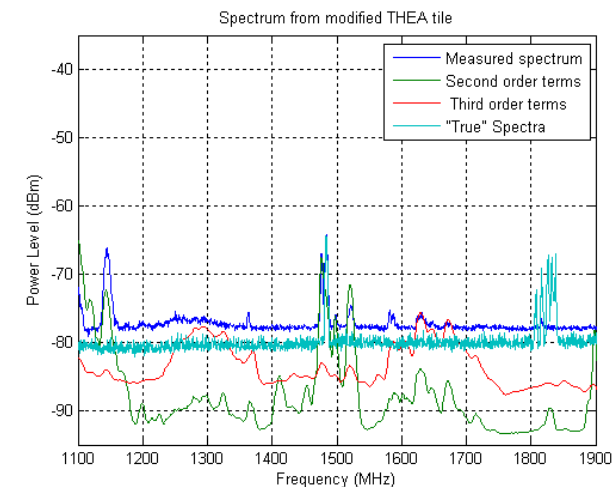
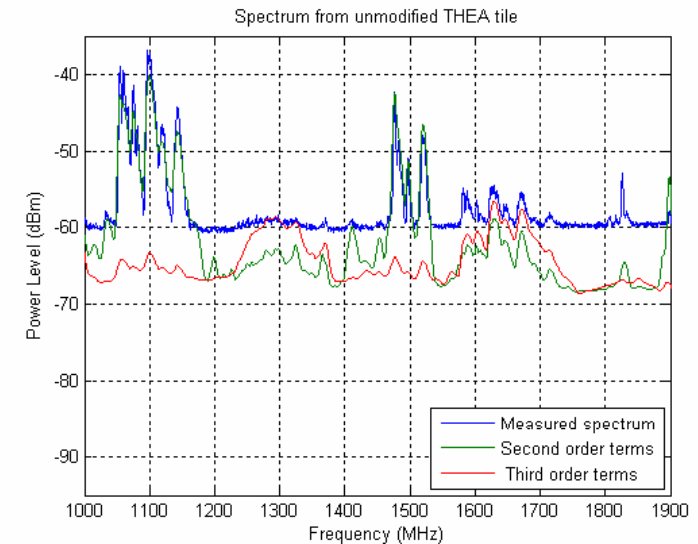
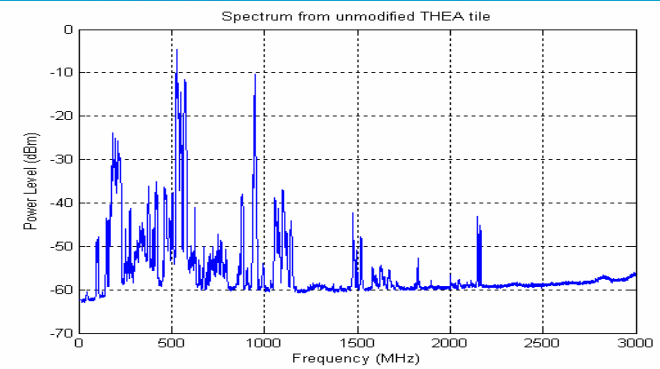
Downconverter

Beamformer/Correlator

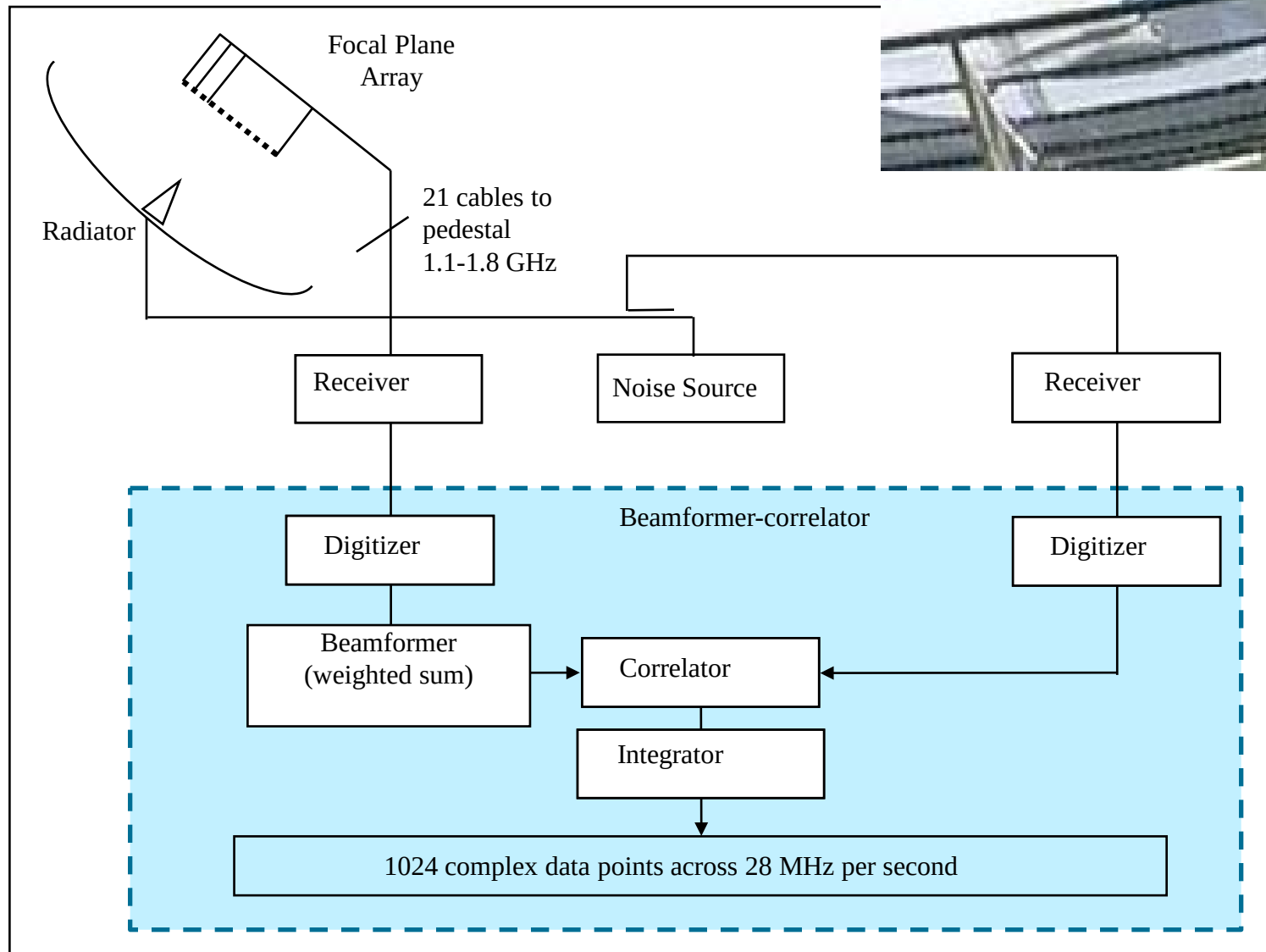
Horn Feed

Front End Filter

- Significant second and third order distortion:
 - mobile phone base station at 947MHz and a TV station at 527MHz.
- A filter (1100 to 1700MHz) was added between the first and second stages of amplification resulting in:
 - 5-10dB improvement in distortion products
 - $\text{Freq} \geq 1200\text{MHz} \Rightarrow 0.51\lambda$ element spacing.



Vertex calibrator



Vertex calibrator

- Amplified noise diode for signal
- Log periodic antenna
- Correlated a coupled signal from source with each element's signal to get a magnitude and phase measure
- Proved a useful diagnostic tool
 - Beamform on the calibration signal
 - Independent of antenna pointing
 - System “self test”
- Current focus – ASKAP
 - Continuous $\sim 1\%$ T_{sys} cal. signal
 - Radiator choice?
 - Signal to radiator: fibre or coax?



Aaronia AG HyperLOG



Measurement Method – Data for Weights

- Point source for element responses (~20min)
 - Virgo A (M87) in interferometer mode
- Blank sky for noise covariance matrix (~ 1hr)
 - Correlation between each element
 - Avoid any strong sources in the sky
- Calculate maximum G/T weights
- Apply weights in the beamformer
 - Interferometer response ...
 - Single dish response ...

$$\mathbf{e}(\theta, \phi)$$

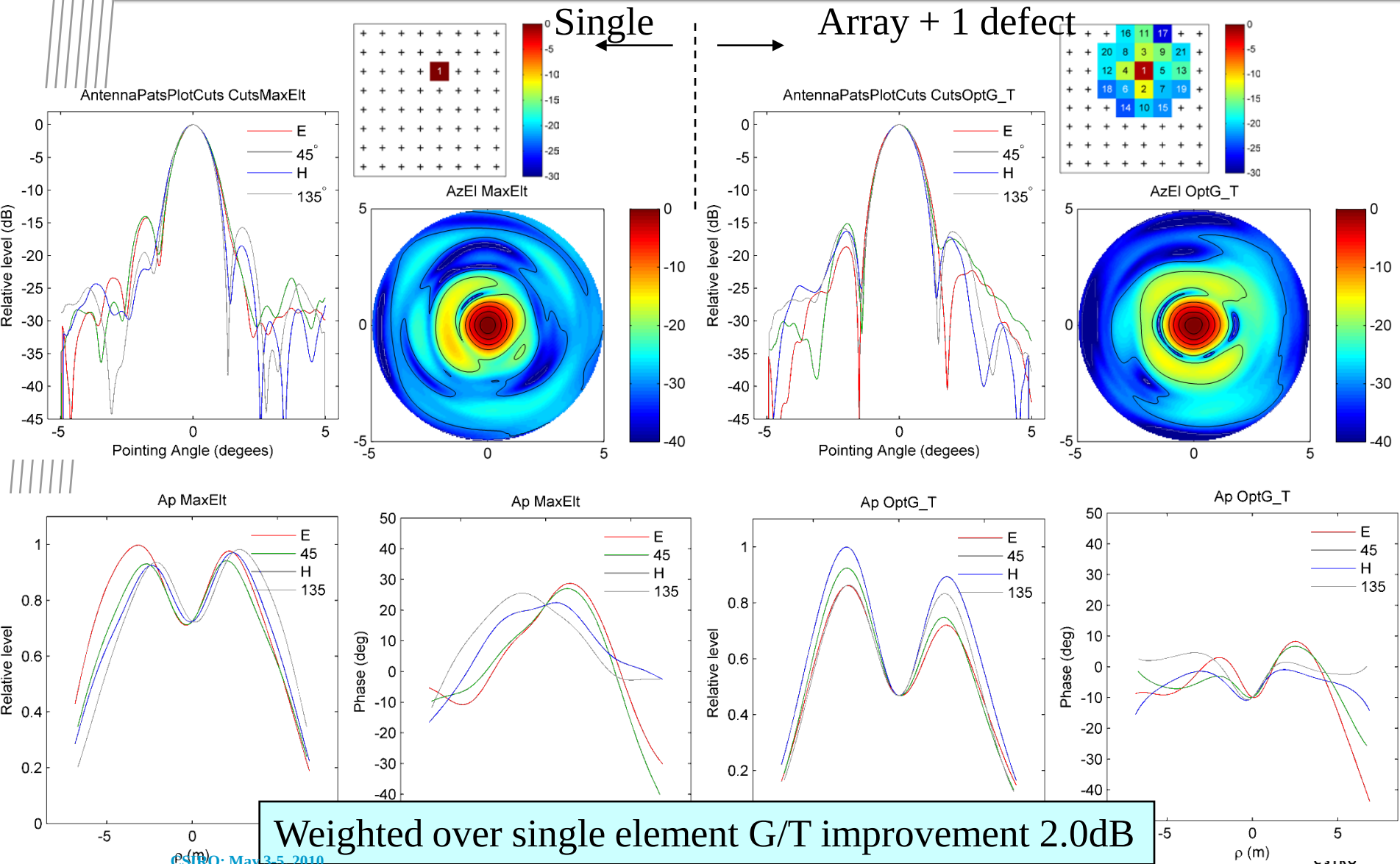
$$\mathbf{C}$$

$$\mathbf{w} = \mathbf{C}^{-1} \mathbf{e}^*$$

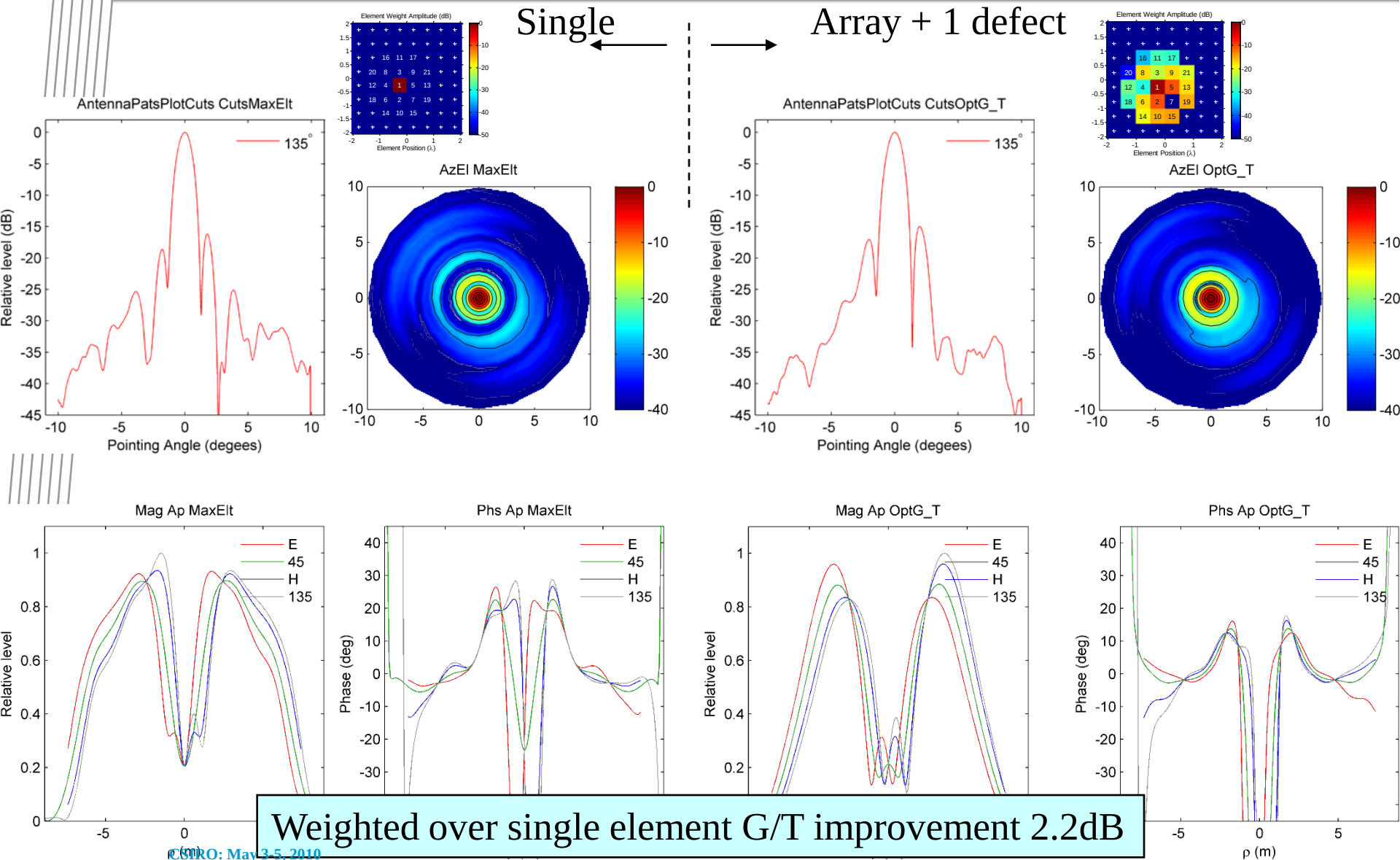
Measurement Method – Interferometer Mode

- Relative G/T against single element
(more precise than single antenna measurements):
 - Signal level: Virgo A (M87) in interferometer mode
 - Noise level: Blank sky: autocorrelation
- Pattern cuts against SGRA* and Virgo A
 - Made with respect to beam centre (coordinate transforms wrt antenna pointing)
 - Try to get as much information from short pattern cuts (~6 beamwidths)
 - Interpolate to get 2D far field
 - Project to aperture (Fourier transform with Hamming filter)
 - Allows qualitative comparisons between different cases single element and weighted cases

Results for Offset Array + 1 Defect



Results for Central Array + 1 Defect



Measurement Method – G/T Performance

- Single dish mode
- Y factor On/Off M87 $G/T = 4\pi \frac{2k_B(Y_{\text{src}} - 1)}{\lambda^2 \mathcal{S}}$
- Y factor On/Off absorber
- T_{rx} estimate 137 (-17 +29) K $\Rightarrow$

$$T_{\text{scene}} = \frac{T_{\text{abs}} - T_{\text{rx}}(Y_{\text{abs}} - 1)}{Y_{\text{abs}}}$$



Weighting	Number of Elements	G/T (dB(1/K))	T_{scene}	T_{sys}	η (%)	T_{sys}/η (K)
Single Element	1	17.2	112	249	41	614
Max G/T	5	18.8	66	203	49	419
~Max Gain	21	19.6	64	201	57	350
Max G/T	21	19.5	55	192	54	357

For details see [1]

Move to Parkes

- Much lower RFI
- 12m prime focus dish
- Test bed for prototype FPAs for ASKAP
- More powerful beamformer & correlator (data collection much faster)
- Used with 64m allowing much better SNR



System considerations

- Real time vs. store and process
- Ideally use both providing verification: e.g. Parkes system

	Real Time	Store and Process
Set up for observation:	Setup easy to fine tune:Fringes clearly visible	Setup difficult to fine tune
Beamforming	Beamformer committed at observation time Requires more stability	Free to apply different beamformers during processing
Prototype for final:	Closer to final system operation	Easier to re-run processing to match different scenarios

- Interferometer advantages over single dish
 - Allows much lower strength sources to be used
 - Much higher SNR and phase in pattern cuts
 - Less sensitive to gain variations

Conclusions

- Demonstrated digital beamforming in prototype radio telescope (with an interferometer)
- System performance was modest but explainable.
- A team was trained in FPA system design and testing
- FPA characterization techniques were evaluated and refined
- Project management issues and lessons for rapid prototyping
 - Early definition of port numbering
 - Nomenclature: Ports, channels, beams, primary pattern ...
 - Keep it simple
 - Subsystem testing vs. entire system debugging
 - Propose early integration tests
 - Identify interface issues
 - Clarify specifications
 - Early results
 - Follow by comprehensive review and rework if required

Acknowledgements

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- More information

[1] D. Hayman, R. Beresford, J. Bunton, C. Cantrall, T. Cornwell, A. Grancea, C. Granet, J. Joseph, M. Kesteven, J. O'Sullivan, J. Pathikulangara, T. Sweetnam, and M. Voronkov,

“The NTD interferometer: A phased array feed test bed,”
Workshop on Applications of Radio Science (WARS08), 2008

[2] Hayman, D. B.; Bird, T. S.; Esselle, K. P.; Hall, P. J.; , "Experimental Demonstration of Focal Plane Array Beamforming in a Prototype Radiotelescope," IEEE Transactions on Antennas and Propagation, June 2010 (already on Xplore)

Questions?

