The Australian NTD and xNTD Projects

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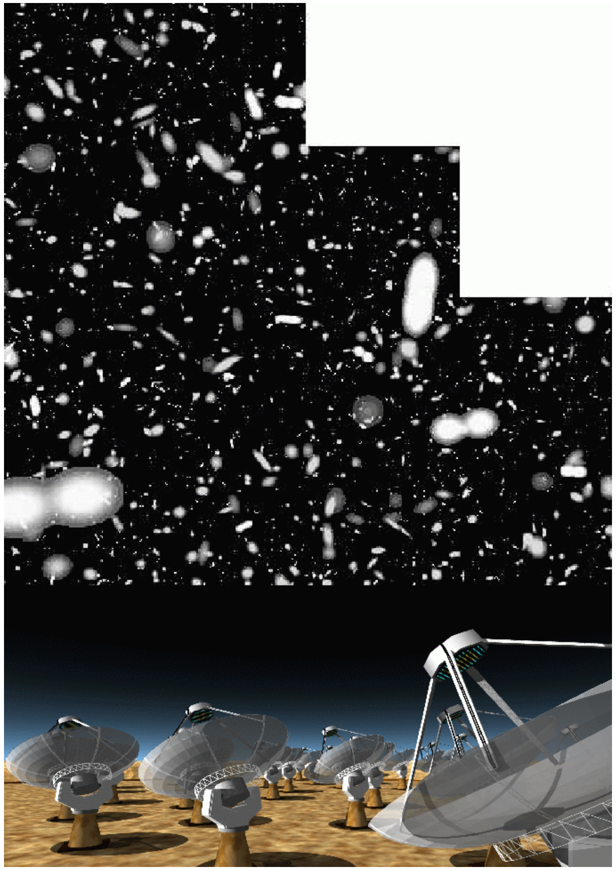
NTD – New Technology Demonstrator

- Funded by Australian government and CSIRO as one of the MNRF - (Major New Research Facility) funded projects over the period 2002 – 2007
- Until June 2004, most of effort was on Luneburg Lenses
- From July 2004, the effort is associated with using Focal Plane Arrays (FPAs)
- Due for completion in July 2007
- 2 dishes fitted with Focal Plane Arrays – initially at Sydney labs
- Ultimately at the Australian candidate SKA site at Mileura in Western Australia (~ 26° 37' S, 117 ° 29.5' E)
- Test bench for key new technologies for SKA

xNTD – Extended New Technology Demonstrator

- Builds upon the designs & deliverables from the NTD
- Extra funding obtained from CSIRO, 2005 – 2008
- We now have the funding, but will not decide if xNTD is technically feasible until March 2006, dependent on NTD progress in mitigating the technical risks
- $25m AUD, 2005 – 2008, 20 dishes with FPAs, at Mileura site
- A useful telescope in itself
- But a vision for xNTD to evolve into technology for SKA



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Goals for NTD and xNTD are different

- NTD:
  - Development of FPAs with all-digital beamforming
  - Demonstration of the integration challenge (antenna, FPA, RXs, DBF)
  - Resource Planning for xNTD
- xNTD:
  - The antenna challenge
  - The integrated RX challenge
  - The correlator challenge
  - The post-correlator processing challenge
  - The data transmission challenge
  - Integration into a useful scientific instrument

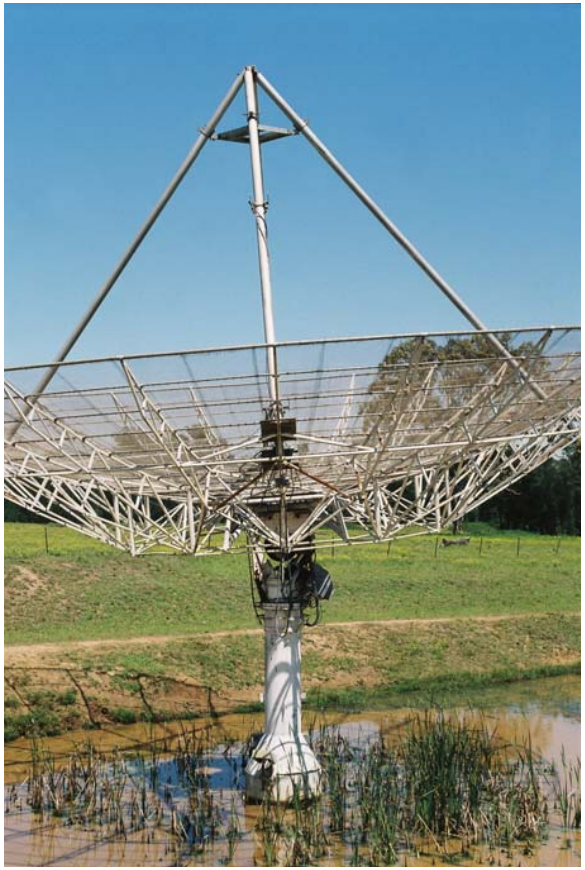
NTD project outline

- Two 13.7 m dishes – test + reference
- 1 Dutch THEA tile 8 by 8 element focal plane array initially
  - Single pol, 700-1500 MHz, Tsys = 150 K
- Follow up with new FPA design(s)
- Ref antenna: single feed, Tsys = 50 K
- Prototype downconverters – 24 initially
- Prototype beamformer + correlator
  - 20 MHz bandwidth, single output beam
  - Single FPGA board solution possible

Refurbished dishes from the former Fleurs radiotelescope

- Two 13.7m dishes have now been removed from Fleurs and are being refurbished at SES
- SES is confident that the condition and design are sound
- New antenna drive system has been designed
- 2-element interferometer @ Marsfield
- Sites chosen for antennas at Marsfield, and infrastructure design has commenced
- Expect antennas to be on site at end of July, and we are preparing infrastructure to meet that date for installation
- Project milestone for the installation to be ready for experiments by end of October

Fleurs dishes



Just needs some paint!

And some grease too

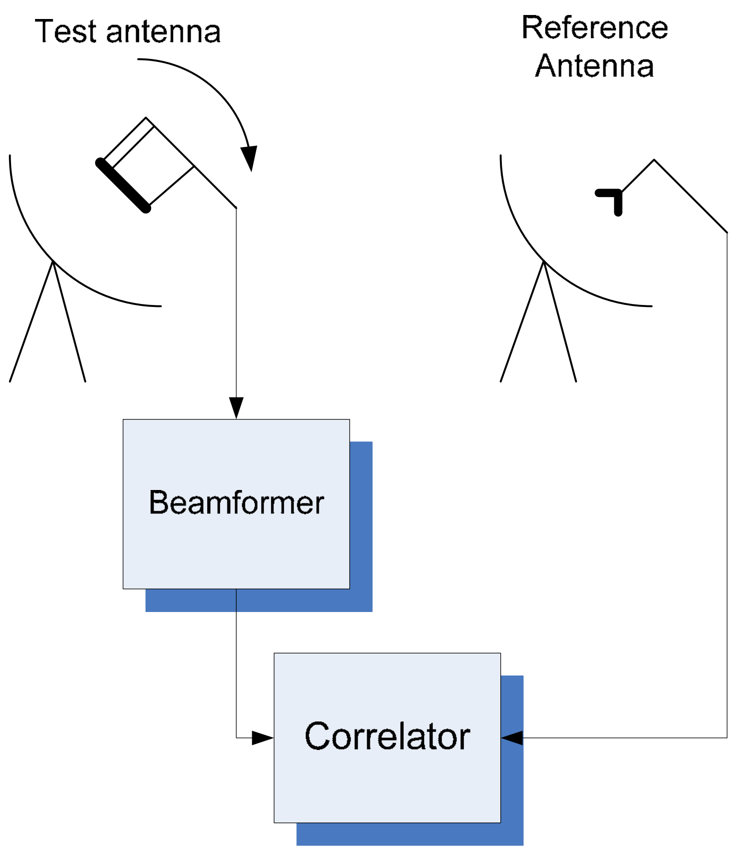
FPA options

- Collaborative development of “Vivaldi” array with ASTRON / U.Mass.
  - Quickest option for short-term demonstrator/experiment
  - ASTRON supply of THEA tile
  - Agreement with U.Mass & Astron for use of s/w for both NTD & xNTD development
- Alternate wideband arrays
  - Looking at promising “rabbit ears” design
  - Inherently wideband structures
  - Foveated array with “natural” scaling of FoV
- Looking at wider system integration aspects of optimisation of FPA elements, LNAs, beamformer, post processing

FPA element to element coupling

- Classic problem for arrays
- Laws of physics!
  - Elements must be ~ $\lambda/2$ at high frequency end to avoid grating lobes and spillover
  - Elements << $\lambda/2$ at low frequency so coupling can get large
- Effectively a single element output has contributions from all elements
- Single element far field or primary beam pattern has extra structure
  - Element has extended 2D point spread function in FP
- Element patterns vary from element to element
- Some form of correction and calibration appears necessary

Calibrator measurements with NTD



- Holography to measure FPA effective element+dish far field response (ie element primary beam)
- Includes element to element coupling, element aperture response
- Can be “deconvolved” to estimate element-element coupling etc
- Other measurements include element-element correlations, beamformer+holography, …

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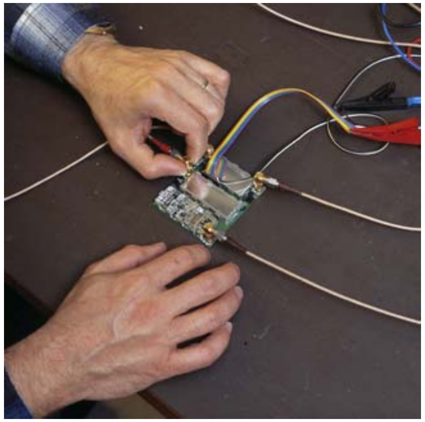
NTD Correlator System

- Based on FPGA test bed originally developed for multiple input multiple output (MIMO) high rate wireless communications
- 6 ADC boards with 4 ADCs
- Virtex-4 FPGA
- Processes 24 MHz bandwidth data
- 2nd Stage PFB as per xNTD down to 16 kHz resolution
- Trivial correlator
- No delay, fringe correction post-correlation

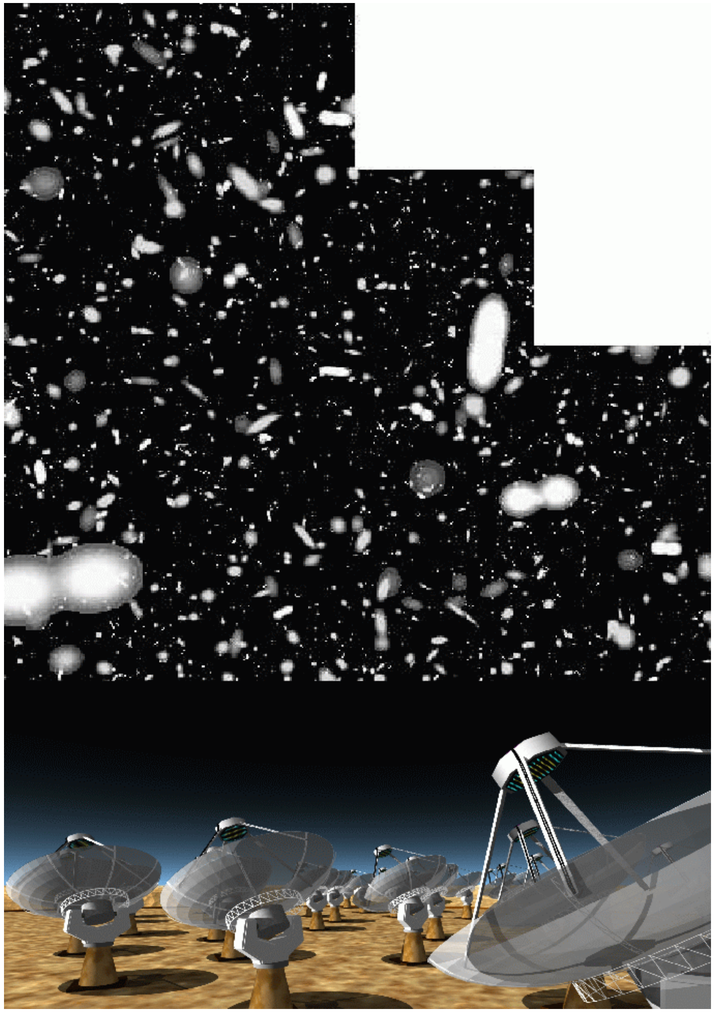


Some NTD measurement goals

- Understand detailed performance of FPA
- Discover issues not yet anticipated!
- Reconcile antenna range measurements with astronomical measurements
  - Coupling, element response
- Reconcile reflector/FPA/coupling/beamformer model with astronomical measurements – validate basic measurement model
- Trial some methods to achieve desired calibration and correction accuracy

SKA Roadmap: The route forward

www.atnf.csiro.au



extended New Technology Demonstrator

- Outline
  - 20 x 15m dishes at WA site
  - Complete by 2008
  - MNRF/WA/CSIRO support
- Goals
  - Maintain Australian radioastronomy at forefront of world science
  - Maximise influence in SKA project
    - Science
    - Technology
    - Siting
  - Deliver outcomes for industry
    - FPA/Digital beamforming
    - Data-mining

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xNTD Specifications

- The xNTD is a **fast survey telescope**

Survey speed α Area x FoV / Tsys²

Note also that

Cost α Area x FoV

And so to maximise the survey speed, the cost of the collecting area and FoV should be roughly similar. Reducing Tsys is also critical!

- xNTD final specifications depend on
  - Science drivers
  - Relative cost/risk of dishes and focal plane arrays
  - Technology constraints
  - Infrastructure
  - Strategic considerations

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xNTD Parameters

- Area = 3500 m^2 (20 dishes, 190 baselines)
- Tsys = 50 K
- Frequency range = 0.8 – 1.8 GHz
- Bandwidth = 256 MHz, 5 kHz resolution
- Number of independent beams = >30
  - each beam 1 sq deg → >30 sq deg FoV at 1.4 GHz
- Maximum Baseline < 1000 m
- Full cross correlation all antennas
- Located in the RQZ at Mileura, Western Australia

- ATA - A=10000m^2, FoV=5.5 sq deg, BW=1GHz, Tsys=50K
- Parkes MB – A=3200m^2, FoV=0.8 sq deg, Tsys=22K
- ATCA – A=1900m^2, FoV=0.6 sq deg, Tsys=30K
- Arecibo – A=70000m^2, FoV=0.02 sq deg, Tsys=35K

Mileura Site

RFI Measurements are under way

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Challenges for xNTD

- Can we make small steerable dishes cheap enough?
- Cheap, high performance (wide band and polarization pure) FPAs?
- Cheap, high performance integrated RXs?
- No self-generated RFI from RXs (or rejection schemes)?
- How to transport signals from FPA?
- DBF and PFB (efficient, cost-effective using FPGAs, size minimisation)?
- Calibration with synthesized varying beam patterns?
- Correlator cost?
- Data storage & transportation?
- Remote operation as a NF from East Coast of Oz?
- Post processing and what to do with 10 Terabyte of data per day
- High dynamic range with wide field of view?
- …

Dish: Low cost prefabricated

- Manufacturing dominates dish cost
- Custom-built mesh reflector using NC machine tools
  - "High-tech" solution with high accuracy, good repeatability, and no tooling-up costs
  - Local manufacture of prefabricated "flat-pack" reflector; assemble on site
- Progress:
  - Engineering consultants have been contacted to provide structural engineering analysis and comments on proposal
  - Manufacturers asked to comment on manufacturability issues of our design
  - Bristow Laser Systems have demonstrated new CNC machinery which appear to be ideal for manufacture

Ongoing efforts towards an xNTD FPA

- Investigation of alternative array elements & tilings
  - Non-ideal aspects of uniform Vivaldi arrays: polarization and large excursions in element impedance
  - Other elements may be better, e.g. arrays derived from self-complementary screens have very large impedance bandwidth
  - Non-uniform arrays may compensate for “small array” effect, or offer much larger bandwidths (foveated arrays)
- Close cooperation between antenna, RF, and DSP engineers to understand system aspects of FPA
  - Investigation of options such as balanced vs. conventional LNA
  - Understanding of how array & reflector choices affect beamformer complexity

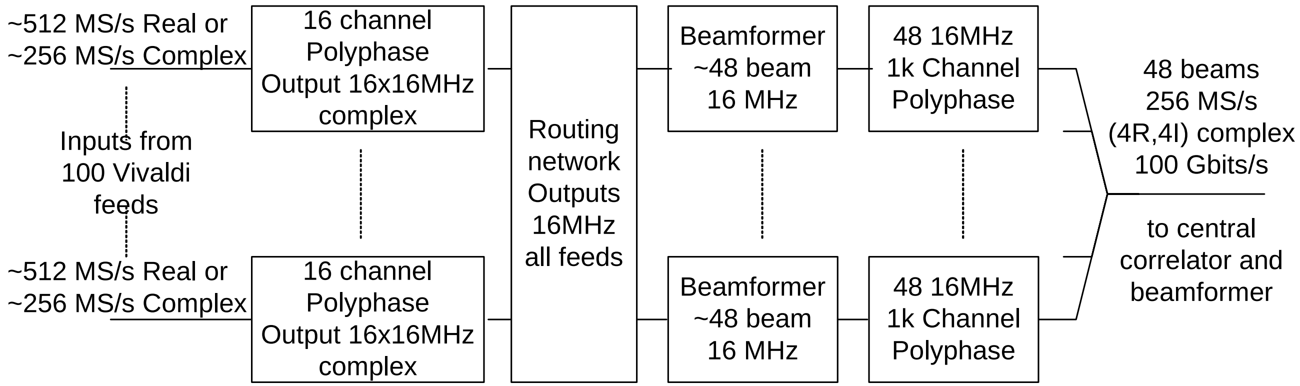
Low noise operation with a wideband, uncooled FPA

- FPA element impedance is strongly determined by array effects (tendency for large variations with frequency)
- For a small FPA of identical elements, the element impedances are all different (modulo symmetry)
- LNA noise contributions: self noise + coupled radiated noise from all other LNAs
- We need to do a lot of work to understand how to achieve optimum low noise operation – it is far from straight forward

Digital Signal Processing

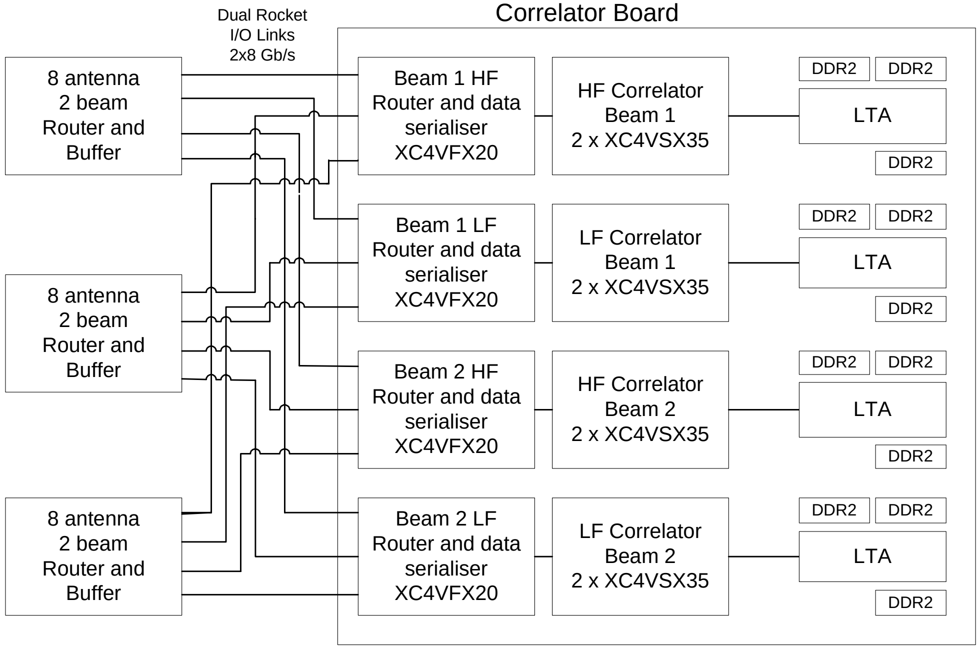
- FPGA-based designs have been refined/partitioned such that they can efficiently handle:
  1. A 20-antenna xNTD using 10x10 element dual polarisation FPAs
  2. A 500-antenna LFD (MIT Haystack) @ Mileura
  3. A SKAMP-3 with 96 antennas
  4. An LFD with only 48 antennas (LFD fallback @ Mileura)
- All require a correlator with much commonality
- NTD, xNTD and SKAMP require a digital beamformer for each antenna
- While LFD requires a digital receiver
- Whitepaper developed together with MIT Haystack shows commonality in the NTD beamformer and the LFD RX

xNTD beamformer



- Input data rate for one polarisation from 10x10 FPA from one xNTD antenna is 100x256Mx2x8 = 409.6 Gbps
- Output data rate is reduced by 4 = 100 Gbps
- (but 20 antennas and 2 polarisations means an output data rate of 4 Tbps to the correlator)
- Will need to limit number of inputs per beam formed!

Possible xNTD correlator



- Need “smart” design to avoid the routing of the data strangling the design
- Design approach is to use a correlator cell that minimises i/o requirements
- 1 Virtex 4 XILINX FPA chip processes 48 frequency channels for all 20 xNTD antennas simultaneously.
- Full xNTD correlator (48 beams) requires:
  - 24 correlator boards, each with 16 mid-sized XILINX chips
  - 72 Buffer boards, each with 5 Xilinx chips and 16 memory chips

Calibration, post processing and dynamic range

- FPA element-element coupling, limited beamformer input size and other effects look likely to have a major impact on the dynamic range achievable if not accounted for
- Answers may include some or all of:
  - Astronomical calibration
  - Injected signals
  - Adaptive beamforming (eg minimise spillover)
  - In-line data correction for element coupling etc
  - Post correlation beam corrections, self-cal etc
  - Mosaicing or dithering (yes! Perhaps in addition to multiple beams)
- There are major post processing challenges

Collaboration

- There is a lot to do here!
- We are completely open to using better mouse traps developed elsewhere.
- In the meantime we are addressing as many problems from an end-end system performance vs cost perspective as we can.