SKA Low Correlator & Beamformer - Towards Construction

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Presentation Outline

• Context + Specifications
• Development team
• CDR Status + timeline
• Solution - FPGA + code + SW
• Model verification
• Low.CBF ITF + emulators
• Transition to construction
SKA Low Challenges

- 512 stations each with 256 dual-pol log periodic antennas
- 50-350MHz sky frequency
- 300MHz processed BW
- Real time commensal processing
  - Correlator and 2 Pulsar Beamformers
Processing Terminology

• LFAA forms multiple beams local to each station (total bandwidth 300MHz)
  • Stations may also need an Array Covariance Matrix (or Station Correlator)

• Imaging Correlator
  • Calculates auto and cross correlations between common station beams for all stations in the subarray
    – Cross beam correlations may reveal RFI

• Pulsar/VLBI Beamformers
  • Combines common station beams for all stations into a tied array beam
  • There can be many tied array beams within a station beam
Low.CBF Science Specs

- Up to 16 subarrays
- 512 stations or 2048 substations
- Up to 8 station beams
- 300MHz per station (75 or 18.75MHz per substation)
- Standard Correlator resolution (5.4kHz 55k channels)
- Correlator Zooms (0.2-14kHz 4x16k channels)
- 500 Pulsar Search Beams with 118MHz (14.5kHz)
- 16 Timing Beams with 300MHz (3.6kHz) (up to 4 can be allocated to VLBI Beams)
- RFI excision (fixed and dynamic) at output frequency resolution
International Collaboration

• SKA cannot be built without collaboration
• Low.CBF formed 2 years ago as part of Central Signal Processing (CSP)
• Common expertise, 1+1>2
Low.CBF Timeline

2015 - “Perentie” collaboration
2016 - Preliminary Design Review
2018 - Critical Design Reviews
2019 - Early Production Array (EPA)
2020 - SKA Construction starts
2026 - SKA Phase 1 completes

Winding path, but end worth it!
Critical Design Review (CDR)

Submitted subelement CDR documentation 26th January 2018

- 700-pages of primary documents - waiting on reviewer/SKA comments

Face-to-face subelement review is 5-9 March 2018 at SKAO

CSP element level review delayed

- Submit 30 June, review 17-21 Sep
Low.CBF Structure

Models, subsystems and ICD’s define the overall system structure
Data Model

Software interface critical
- supports all the modes
  ● Describes instrument capabilities
  ● Subarray independence

Interfaces:
  ● Tango based LMC
  ● User interfaces
Signal Processing Model

- Proves the validity of the chosen signal processing algorithms
- Generation of simulated “sky” signals received by stations
- Allows for Quantisation and quick sizing/performance tradeoffs
- Verification in development
  - FPGA Code development
  - Emulator verification system
Gemini FPGA LRU

- Liquid cooled, full optical interconnect, 12 LRU’s per Subrack
- 4 Tera-multiply-accumulates, 1.3 Tera-bits-per-second comms, 16GB DDR4 memory
Future FPGAs

• FPGAs will increase in size, speed, features and decrease in power
• Also, will see RF entering FPGA – receiver on an FPGA
Transformational FPGA Technologies

• Highly interconnected processing nodes
• Low latency/predictable interconnects
• Huge amount of input/output bandwidth
• High density parallel compute
• Liquid cooling to the chip level
• Lower cost per peta-operations-per-second
• High level design flows to reduce effort
• Increasing memory options (sizes and bandwidth)
• High memory bandwidth – not compute limited
FPGA Code

- Monitoring and Control – custom protocol and interface
- RadioHDL – FPGA vendor independent coding style
- Signal Processing, Memory and Data Communications

Station Based Processing

- LFAA
  - Station Statistics
  - Doppler Shift
  - Coarse Delay
- Correlator Filterbank
  - Fine Delay
  - RFI Flagging
- Pulsar Search Filterbank
  - Fine Delay
  - RFI Flagging
- Pulsar Timing Filterbank
  - Fine Delay
  - RFI Flagging

Array Based Processing

- SDP
  - Correlator and Time Integration
  - Output Frequency Accumulator
- Low.PST
  - PSS Beamformer
  - Beam Polarisation Correction
- Low.PSS
  - Station/Beam Polarisation Correction
- Low.VLBI
  - PST Beamformer
  - VLBI Formatter
Low.CBF ITF

Integration Test Facility (ITF) developed for the purposes of:

- development of the Low.CBF system
- selling off at L3 requirements local to the CSIRO team - requires emulators

It’s a single rack (1 of 6 - all very similar).

Already proven useful in the progressing the cooling, power and networking supporting equipment
Low.CBF Key Specifications

Data rates
- 6 Tbps of input data from LFAA
- 55 Tbps of internal data communication
- 5 to 8 Tbps of output data depending on correlator configuration

Processing rate
- Station-based – 58TMACs
- Beamformers – 378TMACs
- Correlator – 631TMACs

Need combination of IO, Compute & Memory

Totals: 69Tbps
1067TMACs

60kW total power estimated
Towards Construction

What happens next?

● More CDRs, IGO, tenders, bids, contracts, construction?
● Can you see people stopping work?
● Engineers never stop thinking
  ○ If they do they are working on a new telescope!

Introduction of an “early” system

● Small number (4) of stations
● End-to-end signal chain
● Representative infrastructure
Early Production Array (EPA)

Aims:

- **Continuity** and momentum of pre-construction teams
- Mitigate interface **risks** by practical integration activities
- Provide a future **pathway** for prototype development
- Develop a **testbed** for subsystem verification after local ITFs
- **Demonstrate** on sky measurements for end-to-end signal chain
- Enable onsite development to kick start **construction** activities
- Progress technically the telescope as a **whole**
  - Not a science instrument but nothing verifies a system better than real signals
CSIRO EPA CSP Thoughts

- Focus on critical interfaces and fundamental DSP architecture
  - Save bells and whistles for construction
- Cut down Low.CBF - correlator
  - Miniature FPGA system
  - Majority of code/equipment developed carries to construction
- Limited functionality (subset of full requirements)
  - No zooms, RFI excision, VLBI
  - One subarray of 4-stations (no sub-stations)
- Low.CBF ITF in Sydney
  - For the development of Perentie (Low.CBF)
  - Also contains emulators (LFAA/LMC/SDP interfaces)
EPA CSP Collaboration

● Continue to work as an international Perentie team
  ○ Requires a broad supporting skill set
● New Zealand - AUT
  ○ Emulators, FPGA code
  ○ Model verification
● The Netherlands - ASTRON
  ○ FPGA code, Hardware, mechanical
● Australia - CSIRO
  ○ FPGA code, Software, Hardware
  ○ Integration Test Facility (CBF and CSP)
Summary

• Need to complete CDR
• The EPA is an exciting new step in the evolution of the SKA telescope
• Need to design and plan EPA, and obtain funding to continue
• Strengthen collaborative relationships with new opportunities - LFAA? PAFs?
• Develop cutting edge, lower power, higher performance compute systems

“You never fail until you stop trying”
- Albert Einstein

“The best way to predict the future is to create it”
- Abraham Lincoln
Thank you

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