CSIRO

The Australian SKA Pathfinder Project

ASKAP Digital Signal Processing Systems
System Description & Overview of Industry Opportunities

This paper describes the delivery of the digital signal processing systems for ASKAP. The scope of the expected involvement of industry, outlined in the Australian SKA Pathfinder Industry Opportunities Register (IOR)[1], is expanded in this document.

Note that this document is not an invitation to tender a solution, nor will the submission or existence of an apparently-compliant design imply any established relationship with CSIRO. As part of an ongoing R&D project, any aspect of the digital systems design may be refined prior to the release of any formal approach to market.

The ASKAP digital system specification – remit & relationship to the SKA Project

The Australian SKA Pathfinder radio telescope (ASKAP) will comprise an array of 36 12-m diameter parabolic (dish) antennas, situated at Australia's candidate site for the international Square Kilometre Array telescope in Western Australia. ASKAP is intended to be a fully-functional radio telescope, with a science case based on its wide-field-of-view capabilities at cm-wavelengths.

ASKAP does not intend to demonstrate the full frequency coverage specified for the Square Kilometre Array (SKA), nor does it intend to develop a fully-optimised design for any part of the SKA due to the differences in quantity and technology maturity: i.e. SKA antennas, receivers and any other components may differ to those adopted by ASKAP. ASKAP antennas will be capable of operation to 10 GHz ('high frequency') although ASKAP's initial complement of receivers is unlikely to extend to this range.

Primarily, ASKAP is to demonstrate:

1) The viability of phased array feed receivers (PAFs) as sensitive radio astronomy receivers and their broader impacts in enabling wide field of view, high dynamic range, fast survey instruments,

2) The outstanding characteristics of the Murchison Radio Observatory (MRO) site in Western Australia, and

3) Australia's ability to host the SKA.

[1] www.atnf.csiro.au/projects/askap/industry.html

Note that this document relates to the ASKAP digital systems alone: The antenna, RF chain (focal plane array and receiving elements) and imaging systems (hardware & software) are not included in this brief.

ASKAP Digital Systems Design - Overview

The ASKAP digital signal processing system (DSP) comprises a suite of special-purpose filterbanks, beamformers and a correlator which manipulate the data from the receiver (analogue) systems at each antenna and combine the signals into a format which can be processed into radio images and spectral cubes - this being the astronomer's "result" from ASKAP.

As described in the IOR, there will be contracts to build and integrate specific elements of the DSP systems. It must be stressed that these tasks will *not* include design of the DSP systems: CSIRO has significant expertise in design, integration and commissioning of sophisticated digital systems. The ASKAP DSP team also intends to undertake the majority of the final testing and integration of the DSP systems in-house. ASKAP is adopting much of the proven DSP systems designed for the Compact Array Broadband Backend" installed at the Australia Telescope Compact Array (ATCA, Narrabri NSW), and the "SKAMP Correlator" built for the Molonglo Radio Telescope (Captain's Flat NSW).

In what follows we describe the overall systems design for the ASKAP DSP. At the end of this document we describe the work packages which we anticipate will be let to industry.

ASKAP Digital Systems Design

The challenge for the DSP system is the requirement to handle a projected compute load of more than 1 Peta (10^{15}) operations per second, coupled with a data flow rate which, at one point, requires the simultaneous processing of 70 Tera (10^{12}) bits per second. However, given the data manipulation is simple, repetitive, non-recursive and implemented in fixed-point arithmetic, the DSP systems can be implemented on Field Programmable Gate Arrays (FPGAs)[2] to meet the required data processing rates.

The DSP system has two major operations (1) digitising, filtering and beamforming of the data from the individual phased array feeds and (2) correlation (cross-multiplication) of all of the beams from each antenna. The raw input to the first step comprises 96 dual-polarisation signals each of 300 MHz bandwidth from the phased array feed at each antenna. These signals are digitised, weighted and summed in 1 MHz frequency slices to avoid bandwidth smearing.

An overview of ASKAP's data processing is shown in Figure 1: The total system consists of an analogue processing system (yellow), digital signal processing system (blue) and computing (green).

The DSP system requires the *build* of 3 major subsystems:

[2] But also note that the increasing performance and I/O capacity of supercomputers may replace these FPGA-based systems with a single system; We term this the 'Single Digital Backend' (SDB). The development of a prototype SDB is underway within ATNF but the baseline design for ASKAP utilises FPGA-based DSP systems.

1. A digitiser and coarse filterbank which will be physically located at each of the 36 ASKAP antennas. The digitizer and coarse filterbank are implemented via a series of polyphase finite impulse response filters (FIRs) and Fast-Fourier transforms (FFTs). The signals from the filterbank are sent from the antenna pedestal to the MRO control building which houses the 36 beamformers and single correlator system.

2. A beamformer; this includes fine filterbanks which operate on the 1MHz beamformed data: again the filterbanks are implemented as polyphase FIRs and FFTs. The beamformer sums the appropriate elements from the phased array feed to produce the antenna beams. The data from each of the 36 beamformers is sent to the single array correlator.

3. The correlator combines (cross-multiplies) the 16-bit data streams from the 36 beamformers and passes the output to the astronomical imaging computer. Associated with the correlator is a small adjunct system that does post-processing on tied array data for the times that ASKAP is used in this mode.

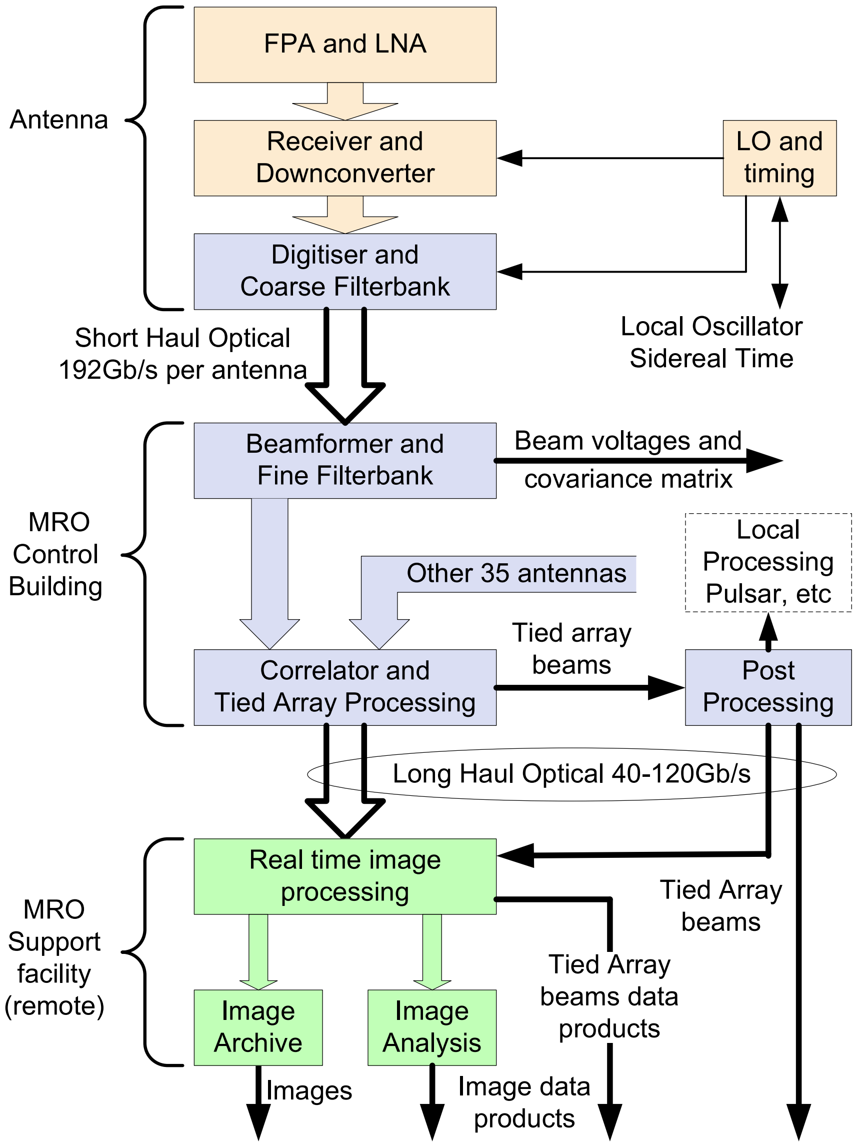

Figure 1 Overview of ASKAP DSP systems (blue) as part of the overall ASKAP system

The DSP systems (hardware and firmware/software) have been designed for flexibility for future astronomical experiments and to ensure that ASKAP optimises the performance of the focal plane array receivers.

The hardware components for these three systems are described in what follows: this detail may alter as the performance and cost of particular devices (e.g. FPGAs and optical transceivers) improves.

ASKAP DSP Elements

Digitiser and Coarse Filterbank

CSIRO has designed the digitiser and coarse filterbank systems to be physically located at each ASKAP antenna. The digitising system accepts 192 analogue inputs of 304 MHz bandwidth from the phased array receiver, digitises the data, implements a 768-point oversampling filterbank and then aggregates data from 4 inputs onto 10Gbit/s optical links. Each link transport 76 MHz of bandwidth. This processing is implemented on a 3U digitiser board. The other subsystems are the card cage and backplane, a power supply board and a command and control card.

For each of the 36 antennas, the digitiser and coarse filterbank systems will be housed in four card cages each with 12 digitiser boards, a control board, and power board, i.e.

- 4 x 12 digitiser boards
- 4 x 1 control board
- 4 x 1 power board
- 4 x 1 card cages and backplanes

Beamformer and Correlator

The ASKAP beamformers and correlator will be located in a central site at the MRO. The design of the beamformers and correlator are such that they share a common processing board. Both are based on the Advanced TCA (ATCA) standard and use commercially-available ATCA shelves. A 21-inch 16-slot shelf with a full mesh back plane is required. I/O into the processing boards is via a Rear Transition Module (RTM) that mounts at the rear of the shelf and communicates with the processing board through zone 3 connectors. The RTMs differ for the beamformers and correlator in that the correlator adopts multimode optical receivers. The tied array post processing system has identical hardware to the correlator.

The full beamformer and correlator system, housed in the central MRO building, comprises

- 36 beamformer ATCA shelves each with
  - 16 processor cards
  - 16 beamformer RTMs
- 16 correlator ATCA shelves each with
  - 16 processor cards

    - 16 correlator RTMs
- 1 tied array post processor ATCA shelf with
    - 16 processor cards
    - 16 correlator RTMs

i.e. in total ASKAP requires 53 ATCA shelves, 848 processing boards, 576 beamformer RTMs and 272 correlator RTMs: Added to which is the development of some prototype systems and approximately 10% extra for spares.

ASKAP Digital Systems Delivery Timescale

The construction of the ASKAP array will be a two-stage process:

1. An initial sub-array, the Boolardy Engineering Test Array (or BETA). The operation of BETA will allow for some review of the full ASKAP DSP system design. However, given the ambitious timescale of the ASKAP project - a mandate arising from the SKA timeline - there will be only limited scope for substantive feedback from BETA into the full build of ASKAP.

The six antennas which make up BETA will be deployed in Q2 2010. DSP systems to handle the data from these six antennas will be delivered to meet this timeline.

2. Subsequent to the build of BETA we will commence construction of the remainder of the ASKAP array. The limited experience of operations with BETA may lead to some minor design changes to the DSP systems, but these are not foreseen as being major deviations from the base design. As the antennas are delivered, the DSP systems will be installed to support the growing array.

Due to its complexity, the development of ASKAP will involve designing, testing and building a number of prototype DSP system boards en-route to delivering the full ASKAP DSP system. This will be managed by the ASKAP DSP team.

Industry Involvement

As described in the IOR, there will be contracts to build and integrate aspects of the DSP systems in due course. In general, the ASKAP team will handle the original design, final testing and integration of these systems.

The relevant opportunities, as updated in the IOR are:

- Chassis design and/or Manufacture (for all elements of the DSP systems, i.e. the digitiser and coarse filterbank, beamformers, correlator):
  The initial design uses 'off the shelf' designs such as the industry-standard ATCA style. For the final implementation we may choose to move to custom-designed, depending on the final DSP element designs and efficient integration.

- PCB fabrication, assembly & testing to the designs developed in full detail by the ASKAP DSP team for all elements
  Given the current DSP design ASKAP will require, over a 2 year period (2010-2011)
  i. 1700 off 3U 12-layer digitiser boards
  ii. 848 20-layer ATCA boards
  The size and type of components involved requires the use of vapour phase ovens and the boards must be produced to the standards for scientific instruments for example lead free components ball grid arrays are not used. For those components where testing is also part of the contract then CSIRO will supply the test jig and test programs.

- Supply of major electronic components (including FPGAs)
  CSIRO will source most major components from suppliers or manufacturers. Other components may be supplied by CSIRO or the board manufacturer as appropriate.

- Firmware programming & Maintenance
  Due the nature of the firmware and the strong interaction between the astronomy (science) requirements and firmware functionality it has been decided to develop all firmware in-house. Some functions may be outsourced but this will be at the discretion of the ASKAP DSP management.

- Systems integration (the installation & testing of the beamformer and correlator systems at the MRO)
  Integration tasks for the first few DSP units will be handled in-house. Once we move into delivery of many DSP systems we will review this approach.

Further information

Further information on the ASKAP project can be found from www.ska.gov.au and for the digital systems at www.atnf.csiro.au/projects/askap/digital_systems.html

Project Contacts

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