ASKAP Update

September 2014

The ASKAP Update is a regular series dedicated to conveying the latest news about CSIRO's Australian SKA Pathfinder (ASKAP) project to international science and engineering communities. It is available online at www.atnf.csiro.au/projects/askap

Preliminary tests confirm promising system temperature for Mk II PAF

Initial system tests on the full-size, second generation (Mk II) ASKAP phased array feed receiver have indicated impressive system temperature during on-ground measurements at the Murchison Radio-astronomy Observatory (MRO) in Western Australia.

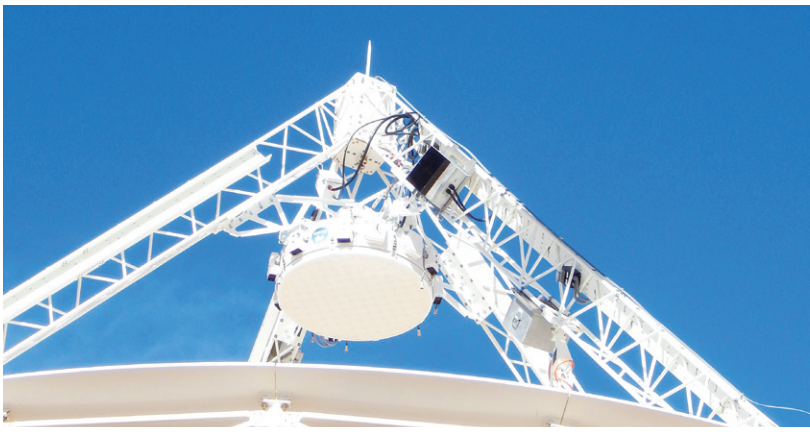
The Mk II PAF was designed, developed, and constructed as part of the ASKAP Design Enhancements (ADE) program. Focused on enhancing the design of CSIRO's phased array feeds for radio astronomy through the use of innovative technologies and assembly techniques, the new PAF design offers significant benefits in system performance across the ASKAP band.

Preliminary 'on-ground' aperture array tests were performed with the new Mk II prototype PAF receiver and associated digital receivers and beamformers in early August. Initial results from these tests have measured system temperature across the ASKAP band, providing the team with vital information about the how the Mk II PAF and associated electronics functions in the radio-quiet environment of the MRO.

In order to assess system performance, 'hot' observations were made using an absorber box positioned above the PAF, followed by 'cold' observations of the sky.

These measurements were made of the beamformed system temperature (Tsys) using similar methods to those used to characterise the proof-of-concept, 40-element Mk II PAF at the CSIRO Parkes Observatory in late 2013 (see *ASKAP Update — December 2013*).

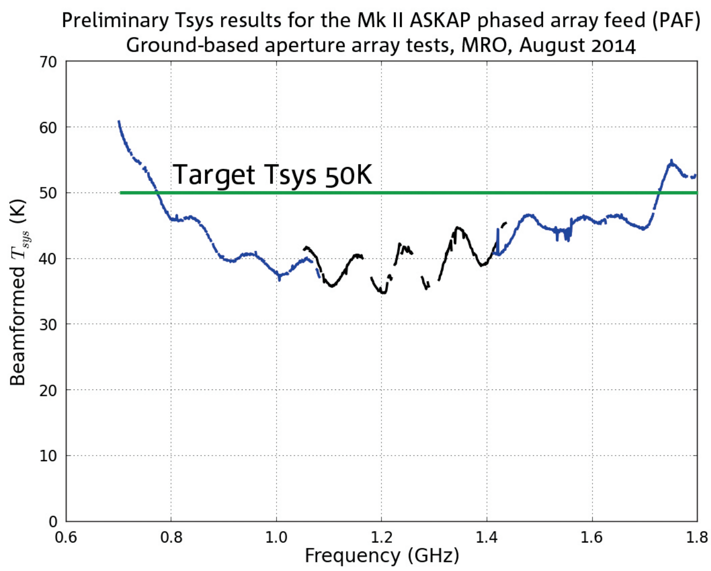
> Preliminary **ground-based** aperture array tests included 'cold' sky observations using the full-size Mk II PAF in early August 2014.



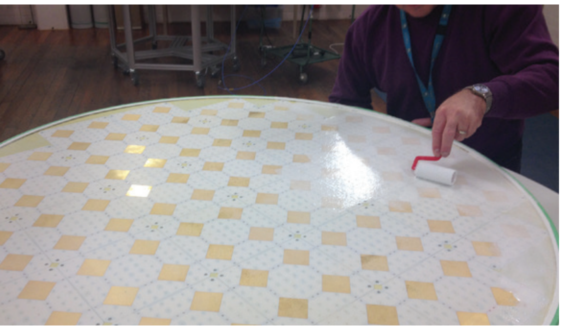
> The full-size second generation (Mk II) phased array feed installed on an ASKAP antenna at the Murchison Radio-astronomy Observatory. Credit: CSIRO.

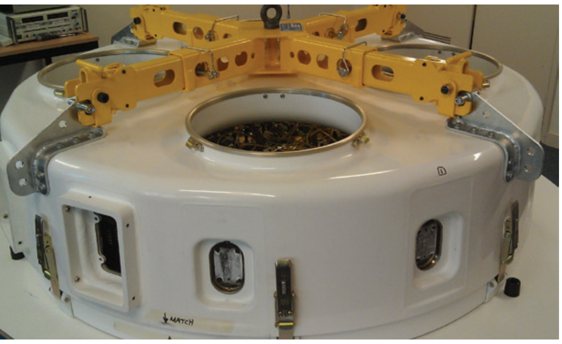
The test system successfully captured 188 radio signals, each with 600 MHz bandwidth, and transported them over 1.4 km of optical fibre to the digital backend housed in the MRO Control Building.

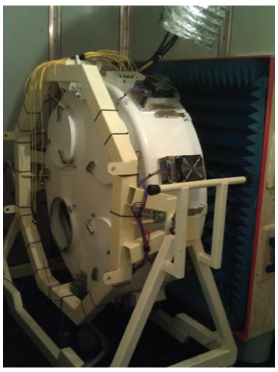
Further data analysis is required to fully characterise the system, but the preliminary measurements are an encouraging indication that the Mk II PAF outperforms the first generation (Mk I) PAF receivers already deployed on ASKAP antennas at the MRO.



> The initial system temperature results are split into three segments corresponding to analog 'sub-bands' that are used to cover the full ASKAP frequency range (700 – 1800 MHz). The 'ripple' is the result of a common artifact of the measuring process while the gaps in the plot are the result of the removal of unphysical data in this initial measurement.







"The (on-ground) tests so far reflect a key success of the Mk II design in the field. It's a great step towards understanding the new first-of-kind system."

- Dr Aaron Chippendale, ASKAP research engineer

Mk II PAF pre-production begins

Concurrent to initial system tests on the prototype Mk II PAF at the MRO, pre-production of eight Mk II PAF systems is now underway in the labs of CSIRO Astronomy and Space Science in Sydney.

The development of the Mk II PAF system has built on many of the lessons from the Mk I, through a design optimisation program focused on improving manufacturability, significantly reducing weight, and making operational enhancements through the use of new technologies and assembly techniques.

Such enhancements include improved bandwidth with low noise performance, signal transmission using RF-over-Fibre (RFoF), direct sampling of the RF signals at the MRO Control Building, and DSP hardware that uses the latest in field-programmable gate array technology and high-speed communication devices.

The Mk II design process has taken advantage of external skills through industry partnerships and engagements, to adapt a diverse range of mature technologies to the problems of developing new instruments for radio astronomy.

This has permitted the design team to use a wide range of components, materials and assembly techniques to increase efficiency, improve performance, and reduce costs.

Marine composites technologies have been used to develop a new design for the PAF casing that integrates management of structural integrity and stability, thermal insulation, environmental protection as well as RFI shielding using carbon fibre.

Heat-pipe technologies used in thermal management in spacecraft have been applied to the specially designed receiver groundplanes. Along with solid-state thermo-electric cooling, this will ensure a stable operating temperature for increased system reliability and an increased on-sky observing time between receiver calibrations.

This cooling method also reduces the need for system support infrastructure in the telescope antennas, with follow-on improvements in reliability and reduced maintenance needs

The enhancements achieved with the Mk II PAF in reduced cost and weight of the systems, improved performance, and long-term reliability also offer secondary benefits such as a reduction in operational power requirements and an increase in digital processing flexibility.

The important industry relationships with that have been built during the Mk II PAF development are a key step in bringing a much wider range of skills to bear on the challenges of rolling out these new receiver technologies on the scales needed to make ASKAP, and SKA, into realities.

Commissioning activities test 'novel' features of ASKAP

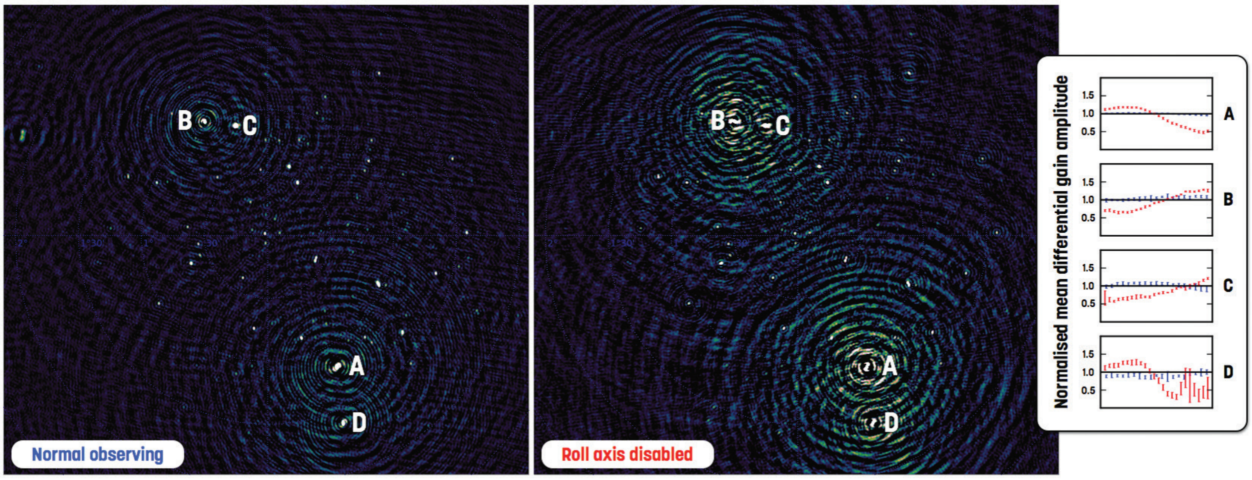
Meanwhile, at the MRO, the Boolardy Engineering Test Array (BETA) — the first six ASKAP antennas installed with Mk I PAFs at the MRO — is already a functioning radio telescope being used to prepare the team for the fit-out of the full ASKAP telescope.

As part of commissioning and early science activities with the BETA, tests on the ASKAP system have demonstrated two key novel features of the telescope:

- ASKAP's three axes of rotation
- Flexible 'footprints' and the beamforming process.

These features have played a significant role in the quality of BETA commissioning and early science results already achieved with the ASKAP system.

> Various steps in the production process of the Mk II PAF - from groundplane through to full end-to-end system tests in the lab, before being deployed to the Murchison Radio-astronomy Observatory for operational tests..



> An observation performed with the roll axis engaged (left) shows a clear improvement in image quality compared to an otherwise identical observation with the roll axis disabled (right). Both data sets were subjected to an identical calibration and imaging pipeline. The inset panel shows the differential gain amplitudes associated with the four dominant sources in the field. The red points correspond to the observation with the roll axis disabled, and demonstrate the level to which the roll axis (blue points) suppresses time and position dependent gain drifts.*

Three-axis antenna movement enables high quality results

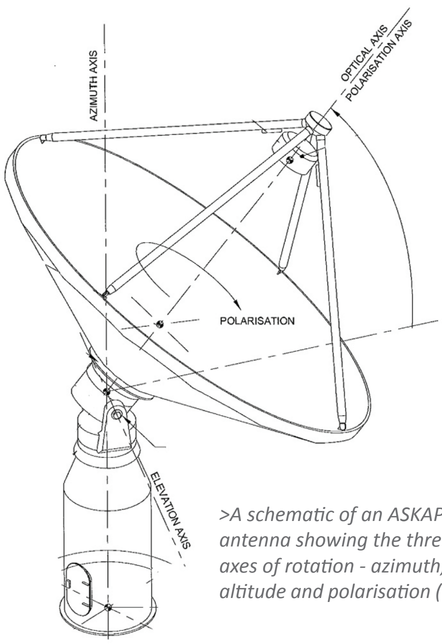
The design of the ASKAP antennas includes not only the azimuth and elevation axes conventional to radio telescopes, but also a third 'roll axis' that allows the primary reflector and receiver to be rotated about its optical axis.

The ASKAP telescope is the first time, anywhere in the world, that dishes moving around three axes have been used for radio astronomy.

The inclusion of the roll axis ensures that the multiple beams formed by ASKAP's Phased Array Feed (PAF) receivers remain fixed with respect to the sky as an observation progresses.

This removes the need to devote significant computing resources to electronically steer the 'off-axis' beams.

In addition to this saving in computational costs, the beam stability offered by the roll axis significantly improves image quality and accuracy of polarisation measurements, and reduce the amount of data processing required to calibrate the data, making further savings on computing resources.



>A schematic of an ASKAP antenna showing the three axes of rotation - azimuth, altitude and polarisation ('roll').

To demonstrate this, observations of a standard test field containing numerous bright sources were made with, and then without, the roll axis engaged.

These two identical length observations were then processed with the same data processing pipeline and the results were compared.

The deconvolved images show (on the same brightness scale) the results a single pass of phase-only self calibration on a subset of the full 850—890 MHz band.

Furthermore, the observation with the roll axis disabled demonstrates significant errors remain, associated with the strong sources that traditional radio astronomy cleaning techniques were unable to resolve.

These are indicative of strong direction-dependent effects, almost certainly due to the rotation of the formed beam on the sky. Importantly, using the roll axis mechanically removes this effect leading to a significant improvement in the achievable dynamic range of the images.

In the images above, solving additional differential gain terms (*Smirnov, 2011*) associated with the four dominant sources in the field (marked A, B, C and D in descending order of brightness) reveals the level to which time and direction dependent primary beam effects are suppressed by the use of the roll axis. The inset panel shows the normalised differential gain amplitudes (averaged across all antennas) as a function of time for the four sources, with the error bars showing the variation in frequency.

The values remain close to unity (i.e. no direction dependent effects) when the roll axis is engaged, and exhibit significant and significantly different drifts when the roll axis is disabled.

Traditional self calibration can only correct for the former scenario. The similarities in the red traces between close pairs A-D and B-C is notable. The small offsets and low level drifts in the blue traces are consistent with known minor offsets in the BETA pointing model present at the time of the observations.

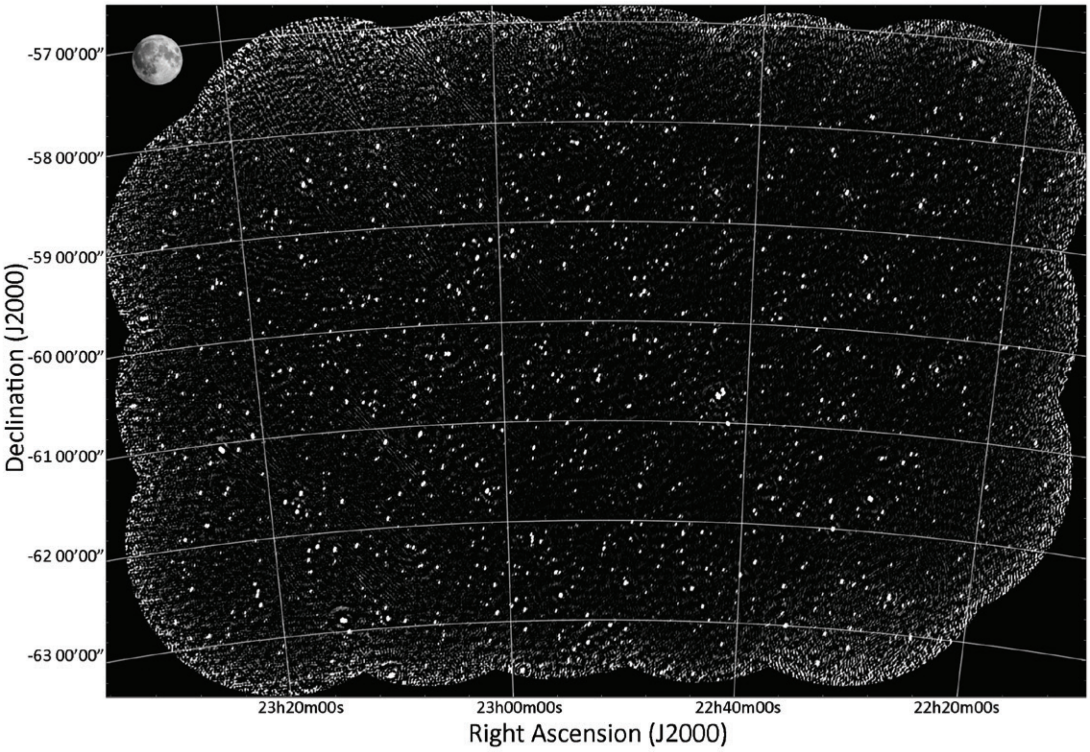
The rotation of the primary beam of a radio telescope with respect to the sky is a long standing problem, particularly for the deepest observations, for a high signal to noise observation, or any other observation where rotating side lobes degrade the image quality. This is generally – and expensively – addressed in the software domain.

Incorporating the roll axis into ASKAP antenna hardware removes this software issue entirely, resulting in significant reductions in the demands placed on the real time data processing system.

Steerable beams allow for flexible footprints

Using phased array feed receivers on radio telescopes offer flexibility, adaptability and simultaneous wide field of view capabilities.

The primary benefit of the ASKAP PAF is a rapid survey speed facilitated by an extremely wide field-of-view provided by the ability to form multiple synthetic beams with each receiver.



> Radio image of the Tucana region made over the 711 - 1015 MHz band.

The image was made from three separate observations: 7 hours and 10 hours on a pair of interleaved pointings centred at 22;50,-60 (left half) and 12 hours on the adjacent region at higher right ascension (right half).

The image covers about 50 square degrees of sky (aproximately 250 times the size of the full moon, shown to scale in the top left corner).

There are approximatley 2000 sources above 5 Sigma (that is five times the image noise). Across most of the image, Sigma is approximately 600 micro Jansky.

Credit: CSIRO.

The BETA system supports the formation of nine synthetic beams on each antenna, and provides an excellent testbed for beamforming methods ahead of ASKAP and its 36 beams.

In order to gain understanding of beam stability and ensure good sensitivity and high dynamic range during commissioning, BETA observations are being made to test primary beam shape, side-lobes, frequency dependence, de-rotation capability and stability in time.

Key to the flexibility of the PAF is the ability to choose a 'footprint' — a specific arrangement of the beams — based on the object or region of the sky being observed.

BETA observations have already produced a number of early results using different beam footprints, including a continuum image based on nine overlapping beams captured simultaneously (see *ASKAP Update — June 2014*); more recent results can be found on the ASKAP website (see link below).

An example of the rapid survey capability of BETA has been demonstrated using a square footprint on the sky, a beam pointing technique known as 'interleaving' and based on three separate observations (of 7, 10 and 12 hours) of two areas in the constellation Tucana.

As shown above, the image covers 50 square degrees of sky — the equivalent of 250 full moons — and reveals approximately 2000 sources above a sensitivity of 5 sigma. Across most of the image, sigma is approximately 600 micro Jansky.

BETA continues to be an incredibly valuable tool for learning about how to do astronomy using PAFs, and also provides some incredibly impressive images.

Results from the six antenna test array continues to provide proof that ASKAP really will function as intended.

While the imaging capabilities of BETA are still limited compared to those of the final ASKAP, the system provides an important testbed for optimising beamforming methods and maximising the scientific output of the instrument.

Dave McConnell, leader of the ASKAP Commissioning and Early Science team, notes that the introduction of phased array feeds and digital beamformers to a radio telescope provide a huge step in the technical armoury of the radio astronomer.

"It gives the astronomers choice in their selection of the most appropriate primary beam and field of view in their observation," says Dave.

"In the future, ASKAP will allow beams to be optimised for shape, sensitivities, polarisation purity and even immunity to RFI. No such choice is currently available with conventional telescopes equipped with wave-guide feed horns."

For the latest BETA commissioning results, see: www.atnf.csiro.au/projects/askap/BETA_results.html

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION

Flornes Yuen
SKA Information Officer

t +61 2 9372 4339
e flornes.yuen@csiro.au
w www.atnf.csiro.au/projects/askap
www.atnf.csiro.au/ska