# SKAMP

## Re-engineering the Molonglo Radio Telescope

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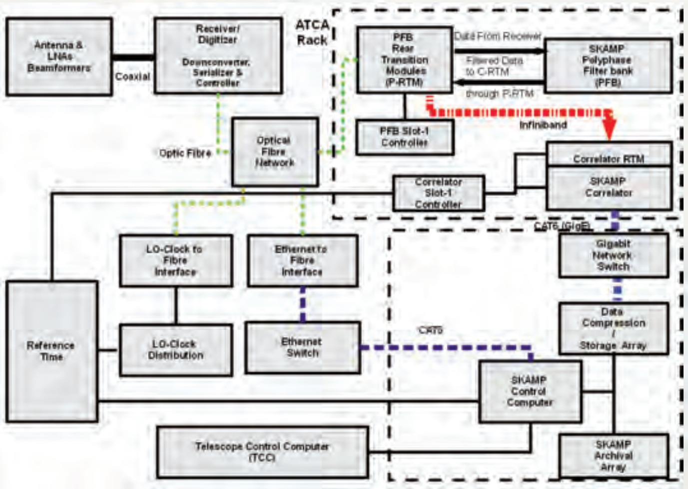
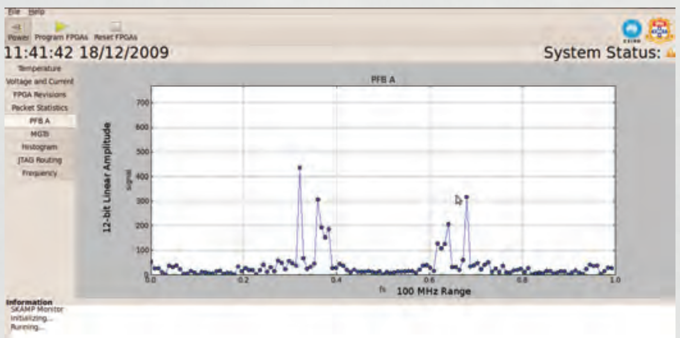
**System Overview:** The Square Kilometer Array Molonglo Prototype (SKAMP) is a project to transform the scientific capabilities of the University of Sydney's Molonglo radio telescope, located outside Canberra. It began life as a Mills Cross-type transit telescope with arms 1.6 km long operating at 408 MHz. In the early 1980s, the east-west arm was converted to operate as an Earth rotation synthesis telescope at 843 MHz with a bandwidth of 3 MHz. The SKAMP project will re-equip the existing telescope with new and innovative technologies for tackling the engineering challenges of operation with a wideband correlator back-end. In a 12-hour observation it will produce a spectral data cube containing 6,480 images, each representing a bandwidth of 14 KHz. The system, when fully implemented, will explore the radio spectrum for redshifted neutral hydrogen and other spectral lines in the frequency range 700-1100 MHz in two linear polarisations.




**SKAMP SYSTEM BLOCK DIAGRAM**

**Communications**: All communications to and from the SKAMP antenna array is based on an 850nm optic fibre network physical layer. The communications system is designed to pass clocks, local oscillator, digitised data and Ethernet-based control signals between the control node and the 88 antenna bays in the array. The control structure allows TCP, ftp and telnet connections. This design enables FPGA firmware upgrading without physically removing the receiver from the antenna.

**Polyphase filter banks**: Conceptually, this is a Fast Fourier Transform with pre-scaling and summation applied to the input signals. The transformation is achieved in two stages: the first stage splits up the band into a number of coarse channels, followed by a second stage to achieve the final spectral resolution. A digital delay system is incorporated prior to the transformation to compensate for individual antenna delays and the constantly changing projected separations between array elements when tracking a celestial source. The SKAMP team have run signals through the receiver and polyphase filterbanks, achieving the following spectrum at the output of the coarse PFB.



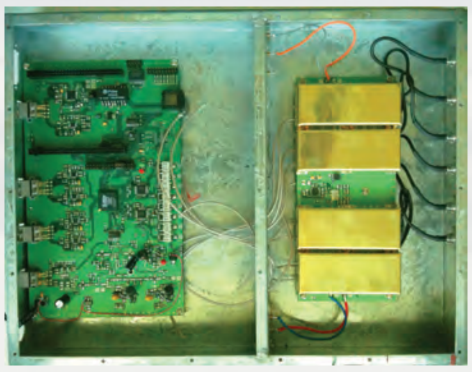

**SKAMP COARSE PFB COMPLEX SPECTRUM**

Above is a complex spectrum at the output of the Coarse PFB and shows a SKY signal injected through the receiver.

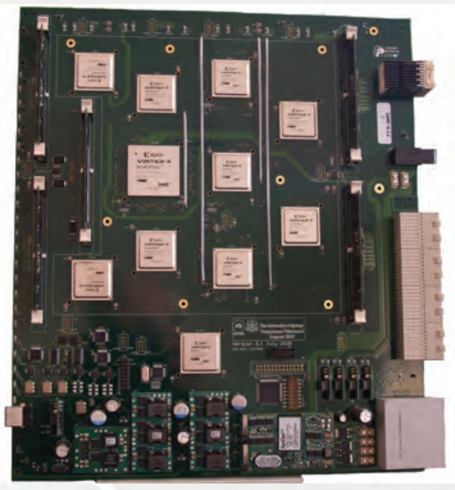
**Correlator**: The fundamental concept of complex correlation involves a simple multiply-and-accumulate operation. However, for SKAMP, there are 384 antenna pairs, each with an input bandwidth of 100 MHz, requiring a real-time processing capacity of nearly 7x $10^{12}$ (tera) multiply-accumulates per second. This is achieved by instantiating about 27,000 DSP48 slice based correlation cells across 192 Xilinx Virtex4 FPGAs, each operating at 256 MHz. The greatest challenge is to route the data to and from the cells while maintaining the required performance.

**Technological Challenges**

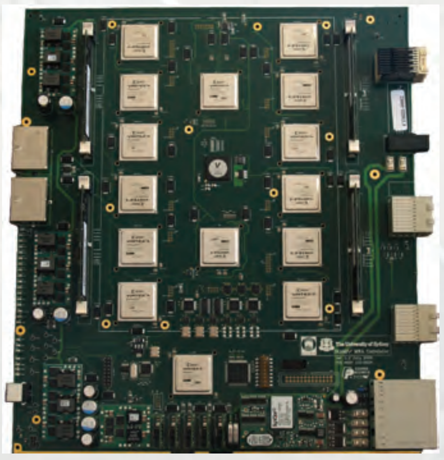
1. Consistent and matched receiver performance.
2. Stable and reliable recovery from power outages.
3. Real time data processing using FPGA technology.
4. Data compression and calibration.
5. Shielding the antenna from the RF noise generated by digital systems.



SKAMP Receiver Box

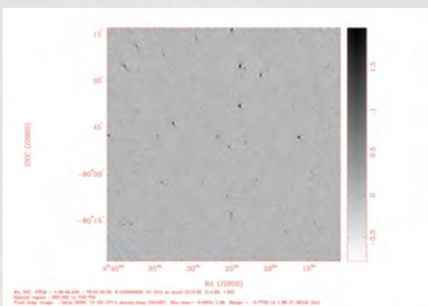


SKAMP PFB Board



SKAMP Correlator Board

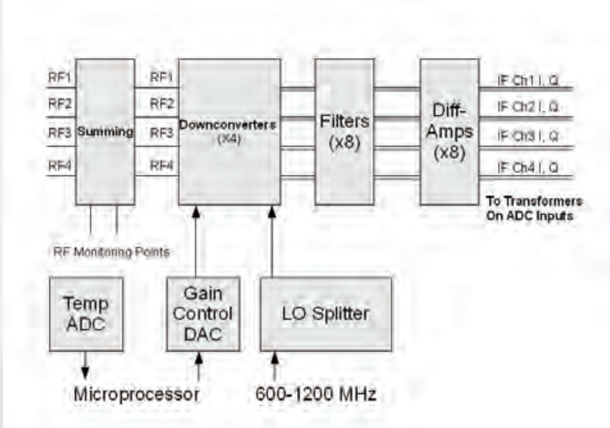
SKAMP Digital Back-end (Screened Room)



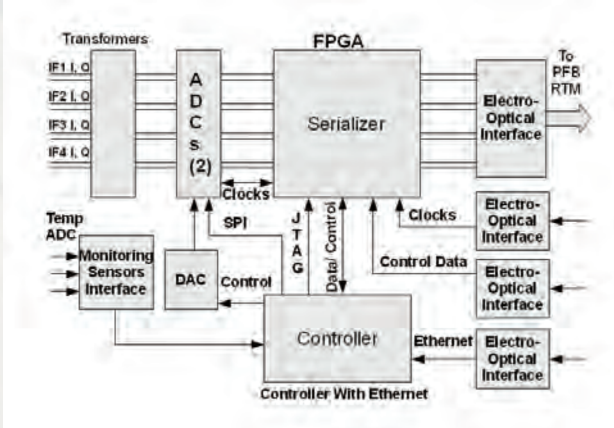
SKAMP-I Image

The image above observed by the SKAMP-I system is an example of the data product expected from one of the 6480 frequency channels available when the SKAMP system is complete. The black dots are radio galaxies well beyond our galaxy.

**Receiver** : There are 88 four-channel down-converting receivers capable of accepting signals in the 700-1100 MHz frequency range. The selection of operating frequency is under computer control. The instantaneous receiver IF bandwidth is constrained to 100 MHz in an I/Q format. Each IF signal is sampled and digitised to 8 bits. The data is passed onto a Lattice FPGA, where the digitised signals are serialised and packeted. The digital data stream is 8/10 encoded for transmission to the control building via multiple 850 nm optic fibres. There are 352 data streams (@ 2 Gbps) in operation when recording an astronomical image. The receiver is standalone and will automatically boot on power up, then program the FPGA and wait for a network connection to be established.

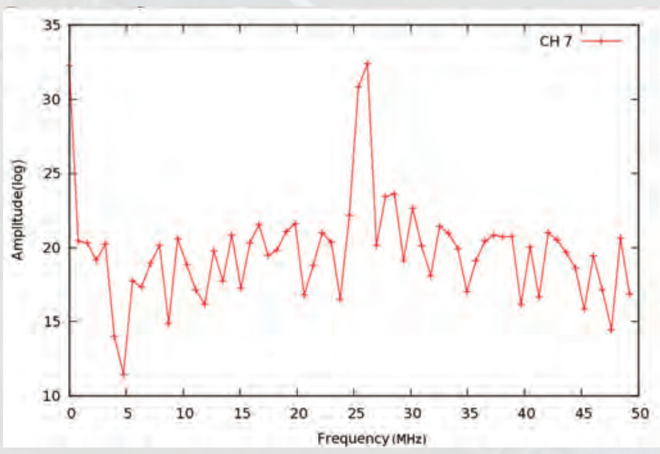



**SKAMP RECEIVER DOWNCONVERTER**




**SKAMP RECEIVER DIGITISER**

**Receiver Control and Status**: The large number of receivers in the SKAMP project means it is crucial to monitor system performance remotely. A 2 km drive is required to service or control the outermost receivers in the array. Due to the distribution of receivers along the 1.6 km array, remote monitoring and control is essential. An on-board Zilog eZ80 8-bit microcontroller with Ethernet connectivity interfaced to sensors and other test facilities allows remote functions such as temperature compensation, monitoring of power rails and receiver gain control. An individual receiver frequency spectrum (as shown below) can be extracted independent of downstream data processing.




**SKAMP RECEIVER FREQUENCY SPECTRUM**

Above is a receiver level spectrum taken in diagnostic mode and shows an injected 25 MHz test signal.

**Lessons being Learnt**

1. The time required for integration and system verification is generally underestimated in the project planning.
2. Parallel development of firmware, hardware and software by geographically separated groups has emphasised the need for effective communication and adherence to the interface specifications.
3. Optimisation strategy within project elements have to be realistically reviewed by the on-site and design engineers.
4. Diagnostics are a critical part of the telescope operation and should be given due consideration in the design phase.

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