THE PARKES 21CM MULTIBEAM RECEIVER

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ABSTRACT

An extensive Southern Hemisphere extragalactic radio astronomy survey of the λ21 cm emission line of neutral hydrogen (HI) has begun on the 64-m Parkes radio telescope in NSW, Australia. To do this a 13-beam receiver, using a cryogenically cooled front end for maximum sensitivity, has been developed by the ATNF. This paper highlights various design and construction details of the receiver, and reports the results of telescope testing of the receiver system.

I. INTRODUCTION

The primary scientific rationale for a 21-cm multibeam receiver on the Parkes 64-m telescope is to conduct sensitive large-area surveys of the Southern Hemisphere sky for neutral hydrogen emission from external galaxies. A detailed description of the key scientific objectives of this project has been given by Staveley-Smith et al. [1] [2]. These include: a survey for optically obscured galaxies behind the Southern Galactic Plane, a Southern Hemisphere HI survey for faint optical galaxies, a deep HI survey aimed at high-latitude fields, and a Galactic Plane pulsar search which uses the sensitivity of the system, whilst taking advantage of the survey observation mode.

To achieve this, a collaborative venture between ATNF, the University of Melbourne, the Australian National University's Mount Stromlo and Siding Spring observatories, the University of Western Sydney, the Nuffield Radio Astronomy Laboratories, Jodrell Bank, Manchester, and the University of Wales, Cardiff, was set up to mobilise the scientific and engineering expertise required for a project of this size. Accordingly, the ATNF undertook the design and construction of a major receiver system which includes a large 26-channel cryogenic front end system, with a system temperature target of 25 K, a 26-channel down-conversion system, and the development of a high-resolution (1024 channels) 2-bit digitised, 64-MHz bandwidth spectral-line correlator for all 26-channels of the multibeam receiver output.

II. THE 13 BEAM RECEIVER SYSTEM

A block diagram of the overall receiver system is shown in Figure 1.

Figure 1: Block diagram showing LNA and post-LNA stages for each channel, including intermediate-frequency (IF) amplification and filtering, digitisation and correlation. There are 26 channels, two for each feed-horn to give orthogonal-polarised (linear) outputs.

The Feed Horn Array

This consists of 13 stepped circular horns arranged in a hexagonal pattern, the apertures of which are located on the telescope prime focus plane. The horns couple directly into the cryogenic dewar interface through circular waveguide vacuum windows. A plan view of the feed horn aperture plane is shown in Figure 2.

Stepped circular horns were chosen because of their good pattern symmetry, low spillover and good cross polarization properties [3]. They are low cost and also convenient to manufacture , as are the following circular waveguide components in the cryogenic dewar.

Figure 2: Plan view of the 13-beam feed-horn array aperture plane. Note the overall diameter of 1290 mm and horn aperture diameter of 240 mm (λ = 21cm)

The horn aperture diameter is close to one wavelength which, for the Parkes reflector, maximises the forward antenna gain and gives a FWHP beamwidth of 14.4 arcmin, whilst the horn spacing of 1.2 λ gives a beam spacing of two FWHP beamwidths (~29 arcmin) on the sky.

Predicted performance for the array feeds and reflector indicates an efficiency of 69.3% for the central beam relative to an ideal uniformly illuminated aperture, and 59.8% for the most extreme beam on the hexagon. The coma sidelobe level for the extreme beams is 14 dB below the peak value.

An interesting feature of this hexagonal array is, if it is rotated by 15°, it can be tracked across the sky with the beams overlapping at the half-power points, giving a Nyquist-sampled strip approximately 1.7° wide.

The Cryogenic Front End

The cryogenic front end (Figure 3), is situated right at the focal plane area of the telescope optics. It has been constructed as a removable entity (for repairs and maintenance) and can be translated and rotated across the focal plane by the telescope's receiver positioning system.

The complete front end consists of the feed-horn array, the cryogenics dewar containing cooled orthomode transducers and high electron mobility transistor (HEMT) preamplifiers [4], the ambient temperature amplifier-filter module, and a multipurpose electronics module which contains support electronics, HEMT amplifier bias supplies and a comprehensive monitoring system. The monitoring system indicates the bias states of all transistors in these 26 cooled HEMT amplifiers, as well as temperature and vacuum information on the cryogenic system performance.

Figure 3: Cross-section view of the assembled front end. Note the input waveguide path through vacuum window, gapped waveguide and orthomode transition.

Backend and Correlator

Following amplification at the input radio-frequency (1230-1530 MHz) by the frontend, each of the 26 channels is down-converted in a single mixing stage to an intermediate-frequency (IF) of 60 to 360 MHz. The IF signals are sent from the telescope focus cabin to the control room on 26 low-loss coaxial cables where they pass through special filters which compensate for the differential loss in the cables across the 300 MHz band. The IF signals are then split between the correlator, and the pulsar backend. The pulsar backend makes use of the full 300 MHz band whereas the correlator IFs pass through bandpass filters covering the frequency range 128 MHz to 192 MHz. This 64 MHz band is sampled at 128 Msamples/sec in high speed two bit digitisers and the resulting digital signals are sent to the correlator.

The correlator is built around special purpose VLSI chips developed by the NASA Space Engineering Research Center for VLSI System Design [Canaris, 1993] [5]. These chips accept two 2-bit sampled data streams at rates up to 140 Msamples/sec and form either the cross correlation function of the two streams or the autocorrelation function of one stream at 1024 contiguous sample delays. The chip has 1024 32-bit accumulators and a 32-bit output bus and can integrate for up to 16 seconds. In the multibeam correlator, one of these chips, operating in autocorrelation mode, is used on each of the 26 sampled data streams, thereby providing, after Fourier transformation, a measurement of the input spectrum at 1024 contiguous frequencies spaced at 62.5 KHz. This allows astronomers to view the velocity of the neutral hydrogen in the area of the sky covered by each beam to a resolution of 13 km/sec.

III. SYSTEM PERFORMANCE SUMMARY

The completed multibeam receiver was recently installed on the Parkes 64-metre telescope. The performance of the receiver is summarised in Table 1.

Table 1

Operating frequency:	1230 - 1530 MHz
Overall front end RF gain:	60dB {40 db cryogenic }
	{20 db ambient }
Receiver noise temperature:	6 K (measured at dewar window)
Overall system noise temperature:	24 K {average of 26 receivers}
	{measured on telescope }
HEMT amplifier operating temperature:	16 K
Spectral line backend:	64 MHz bandwidth
	2-bit sampling
	62 KHz resolution
	26,000 frequency channels total
	= 1024 channels on each IF

The system has been in use on the Parkes Telescope since March 1997 and has already produced exciting new astronomical results. An example of the final output is shown in Figure 4, the result of a 5 second integration on a position in the Large Magellanic Cloud galaxy.

Figure 4: Neutral hydrogen profiles from all 13 beams of the system, with the telescope pointed at the large magellanic cloud (LMC). The LMC is the nearest galaxy to our own. The horizontal axis is frequency, and the vertical axis is relative intensity. The position of the profiles shows the relative position on the sky.

The installation of the 21 cm multibeam receiver on the Parkes Telescope is the most significant technological development on this instrument in recent times and has led to a new lease of life for this 35 year old radiotelescope.

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REFERENCES

[1] Staveley-Smith, L., Wilson, W.E., Bird, T.S., Sinclair, M.W., & Ekers, R.D. 1995, in Multi-Feed Systems for Radio Telescopes, ASP Conf. Ser. 75, ed. D.T. Emerson & J.M. Payne (San Francisco, Astronomical Society of the Pacific), 136

[2] Staveley-Smith, L., Wilson, W.E., Bird, T.S., Disney, M.T., Ekers, R.D., Freeman, K.C., Haynes, R.F., Sinclair, M.W., Vaile, R.A., Webster, R.L, & A.E. Wright, *Publ. Astron. Soc. Aust.,* 13, 243 (1996)

[3] Bird, T.S., in Proc IEEE Antennas and Propagation Symp., Seattle, 966 (1994)

[4] Gallego, J.D., and Pospieszalski, M. 1990, NRAO Central Development Labs. Electronics Division, Internal Report #286 (1990)

[5] Canaris, J., Proc. Workshop on New Generation Digital Correlators (Tucson: NRAO), 117 (1993)