The Southern SERENDIP Project

F. Stootman
Western Sydney University

A. Y. De Horta
Western Sydney University

Carol Oliver
UNSW Sydney

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Frank H. Stootman, Ain Y. De Horta, Carol A. Oliver

University of Western Sydney Macarthur, P. O. Box 555, Campbelltown NSW 2560, Australia

Kelvin J. Wellington

Commonwealth Scientific Research Organisation, P. O. Box 76, Epping NSW 2121, Australia

Abstract. The University of Western Sydney Macarthur has two 29.4 Million Channel spectrometers respectively attached to two beams of the thirteen beam 21 cm cryogenically cooled Multibeam Receiver on the 64 m Parkes Radio Telescope in Australia. Called "Southern SERENDIP", it is a piggyback SETI experiment with 0.6 Hz resolution, a 1.7 sec integration time, and an instantaneous coverage of 17.6 MHz on both beams. This paper summarizes and introduces the project.

1. The Southern SERENDIP Spectrometer

Southern SERENDIP is a dual 29.4 Million channel high resolution spectrometer (total 58.8 Million channels) which has recently been installed at the ATNF's 64 meter Radio Telescope in Parkes, Australia. It has a frequency resolution of 0.6 Hz and covers an instantaneous 17.6 MHz bandwidth, per spectrometer, of the total telescope baseband IF (50 MHz to 350 MHz) in a sampling time of 1.7 seconds per spectra. It operates in "piggyback" mode on two of the thirteen beam cryogenic Multibeam Receivers (1.2 to 1.5 GHz) (Staveley-Smith *et al.* 1996). This receiver has a system temperature of better than 25 K, a typical beam width of ≈ 14 arc minutes and a system sensitivity of ≈ 20 mJy (600 s integration, $5\,\sigma$ detection limit, and channel width of 62.5 kHz). It is currently being used to do a number of neutral Hydrogen line surveys (Putman *et al.* 1998).

The Southern SERENDIP spectrometer is a smaller version of the 167.8 Million channel SERENDIP IV instrument, which is currently in service at NAIC's 305 meter Radio Telescope in Arecibo, Puerto Rico. This instrument was designed by Dan Werthimer of the Space Astrophysics Group (SAG) at the University of California Berkeley (Werthimer *et al.* 1997).

The spectrometer has just been placed in operation again (October 1999) after a major upgrade. It operated for most of 1998 as a dual 4.2 Million channel spectrometer with an instantaneous bandwidth of 2.5 MHz per beam.

A schematic of the spectrometer is given in Figure 1. Each spectrometer performs a digital complex Fast Fourier Transform (FFT) of the input signal. Such a spectrometer has the advantage of fulfilling the Nyquist sampling theorem at half the digital sampling rate of a real FFT spectrometer by providing complex I & Q inputs.

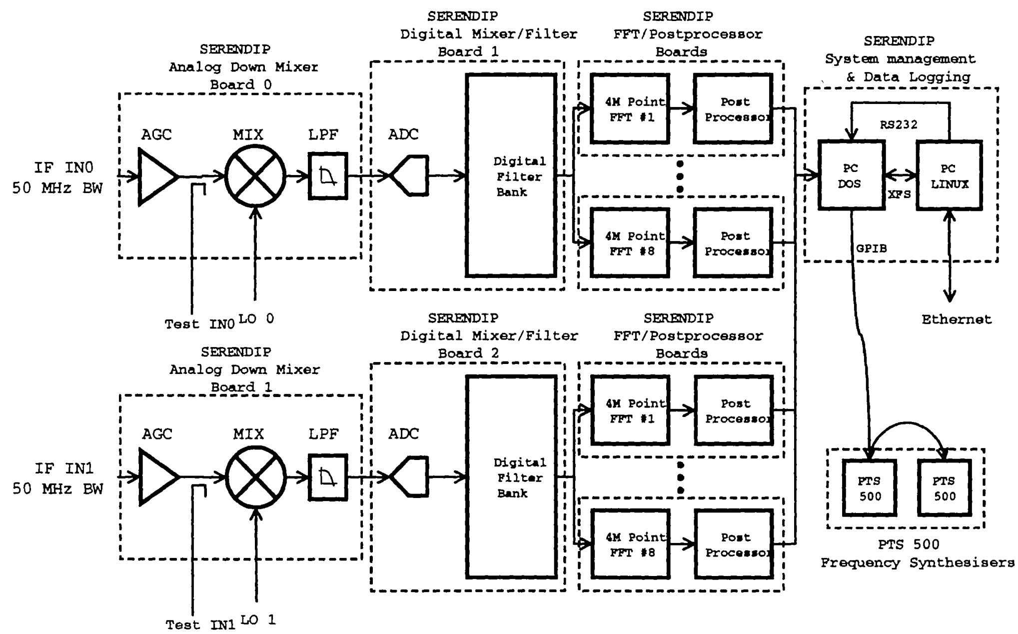

Figure 1. The Southern SERENDIP Block Diagram

Southern SERENDIP consists of five major components:

1. A Down Converter which comprises two Analog Mixer/Filter boards one for each of the two spectrometers. These boards down mix the 300 MHz IF bandwidth to a $\pm$ 7.5 MHz (1 db points) centred bandwidth signal. The latter may be positioned anywhere over the 300 MHz total bandwidth via a GPIB controlled LO. In addition a frequency swept "birdie" is injected at -85 dbm as an artificial intelligent signal source to provide a simple check of system integrity and a bench mark for the RFI rejection software.

2. Two Digital Filter Boards (DFB) which sample the applied IF and use digital filtering to each produce seven 2.5 MHz slices of the $\pm$ 7.5 MHz IF. The first and last slice have some frequency roll-off because the total BW is only 15 MHz at the 1 db points. The total BW is 17.6 MHz.

3. Fourteen FFT/Post processor Boards, each of which compute a complex 2^{22} point FFT every 1.7 secs using pipeline processing. This divides the instantaneous 15 MHz band into 0.6 Hz channels. The resultant power spectra is analysed by an Intel i960 Post processor on the boards and only those channels with RF power exceeding a preset threshold ($12\,\sigma$) are reported as "hits" and recorded.

4. Two PTS 500 frequency synthesizers under GPIB control. The synthesizers are used as a local oscillator (LO) and a narrow band test birdie generator. To maintain high frequency accuracy the synthesizers and the spectrometer are all locked to the telescope maser.

5. System management and data logging computers. A PC provides DOS based program control of the spectrometer, system start up and synchronization, and logs the data. A second PC, running LINUX, provides a 2 GB disk buffer for the logging of the "hits", and an Intenet connection to UWSM. Complete remote control of the spectrometer exists. Raw hit data are stored on CDROM for further post processing in the Space Science Laboratory at UWSM. The rate of data collection is ≈ 20 Mbyte per 3 hours.

The Digital Mixer/Filter boards and the FFT/Postprocessor boards are housed in a 21 slot 9U $\times$ 280 mm VME card cage and the entire system is housed in a single 42U standard 19″ shielded rack.

2. The SETI Experiment

Southern SERENDIP (Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations) is the first non-targetted all sky survey ETI search of the southern celestial hemisphere from declinations between +20 to −90 degrees. It is expected to take four years and will search for potentially interesting radio signatures near the 21 cm neutral HI line. At 12 σ the detection threshold power for the Parkes telescope is $2.5 \times 10^{-24}\,\mathrm{W\,m^{-2}\,Hz^{-1}}$ assuming a 64 m diameter dish, a system temperature of 25 K, a 0.6 Hz channel width and an integration time of 1.7 sec. This corresponds to an effective isotropic radiated power (EIRP) of transmission at 1000 light years of 2.8×10^{15} W. Assuming a forward power gain of 70 db for a transmitting antenna this is reduced to 2.8×10^{8} W. For comparison, the Arecibo S-band planetary radar has an EIRP of 2.4×10^{13} W of microwave energy (Horowitz & Sagan 1993) suggesting that detection of directed radiation from civilizations with Arecibo-like transmitters is well within our capacity. Equally the Figures make it unlikely to detect isotropic radiation from such civilizations, for, even at 10 light years the EIRP is 2.8×10^{11} W which is significantly higher than what is transmitted terrestrially. One obvious solution is to integrate the spectra when the telescope is in a "point and shoot" mode. This requires hardware modification of the spectrometer and is addressed below.

Southern SERENDIP operates in "piggyback" mode on the Parkes telescope and so takes advantage of current experiments looking for photons from HI spectroscopic transitions using the multibeam receiver. Currently these are:

1. *HIPASS*: an all sky survey of HI mass distribution in the southern sky from $-90 < \delta < 20$ in strips of $\Delta\delta = 8°$ at fixed RA. It will cover the visible sky from Parkes five times. The telescope is driven at 1° of declination/minute and so for a beam with an FWHP of 14 minutes of arc this corresponds to a sky point dwell time of ≈ 15 sec. The sky dwell time is well in excess of the 1.7 s sample and integration needed.

2. *ZOA*: a Zone of survey is similar to the HIPASS survey except that it concentrates on the galactic plane scanning $\pm 5°$ in galactic latitude and the visible longitude of the galactic plane seen from Parkes between 220° and 25° twenty five times.

3. *PULSAR*: a pulsar survey along the galactic plane ±5° of galactic latitude and stepping ahead in galactic longitude by 5°. It is however, a much slower survey dwelling on sky points for 35 minutes in "point and shoot" mode.

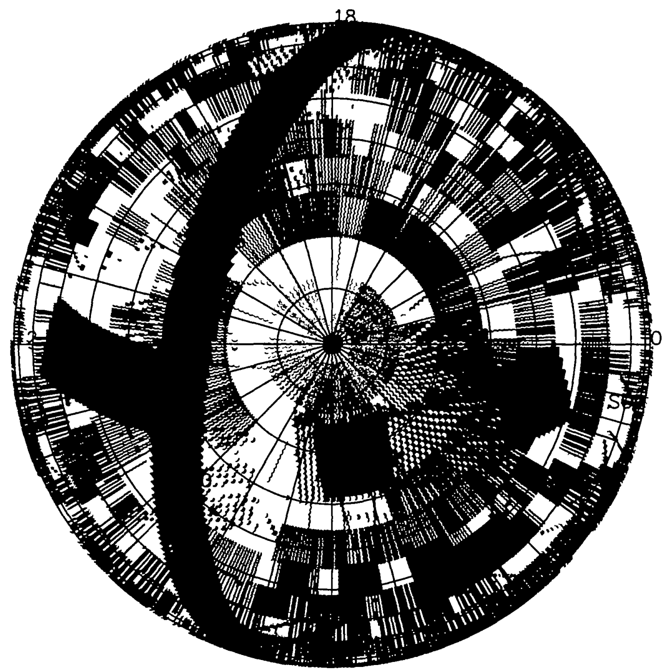

Figure 2. Southern SERENDIP sky coverage for the period March 98 to Feb 99. The plot is of the southern sky in RA and declination. RA = 0 h is on the RHS. The SCP is in the centre of the figure. The dark band is the coverage over our galactic plane

Southern SERENDIP operated from March 1998 to March 1999 with two 4.2 Million channels spectrometers respectively attached to two beams of the multibeam 21 cm HI receiver. The spectrometer was upgraded to 29.4 Million channels and placed in service again in October 1999. Sky coverage by SERENDIP for all three surveys in the first period is given in Figure 2. The instantaneous bandwidth in Figure 2 is 2.5 MHz from 1420.5 MHz to 1418 MHz. This is more than adequate to detect all potential Doppler red-shifted near HI frequencies transmitted out to the edge of our galaxy. Typical Doppler shifts at 21 cm are 4.74 kHz $\mathrm{km}^{-1}\,\mathrm{s}^{-1}$.

Table 1 summarizes the data yield for the sky coverage of Figure 2. The yield are data for which telescope is properly tracking and the multibeam receiver is at the focal point. This data are considered valid.

Figure 3 gives typical spectral plots of "hit" data (also known as waterfall plots) as a function of time received with the updated instrument and indicates low radio interference at Parkes. The plots are for the period covered in Table 1. The new instantaneous bandwidth is 15 MHz (1 db points) and covers the frequency range 1420.8 MHz to 1405.8 MHz.

Data reduction is in progress to produce a candidate data base of interesting signals. The central aim of data reduction is to reject all hits which can be

Table 1. Summary of valid data yield from March 1998 to March 1999. The sky coverage of the valid data is plotted in Figure 2.

Month	No.†	Yield
April 98	495	39.6%
May	504	44.0%
June	572	38.3%
July	572	52.9%
August	217	82.0%
October	267	13.9%
November	258	23.6%
December	354	40.0%
January 99	403	61.2%
February	256	38.5%

† Number of Raw Files (≈ 1 Mbyte each)

shown to be from interference. That is, removal of most of the "hits" in Figure 3, retaining those which are correlated in some way. This is a multi-step process and is modelled on SERENDIP IV data reduction techniques developed by the UC Berkeley team (Cobb *et al.* 1997) however use is also made of simultaneously recorded hit data in two beams. These are rejected as RFI.

3. Future Plans

There are two major improvements planned for Southern SERENDIP (De Horta *et al.* 2000). Firstly a redesign of the Digital Filter Boards to convert the dual spectrometer (now each 29.4 Million channels) to thirteen spectrometers of 4.2 Million channels with an instantaneous BW of 2.5 MHz. Use of all thirteen beams gives better instantaneous sky coverage and provides a ready means of RFI rejection. Moreover, as pointed out above, a smaller bandwidth of 2.5 MHz is not a major limitation for detection of Doppler shifted signals in our galaxy transmitted near HI. Indeed the issue in this region is sensitivity. Thus a second future development will allow for deeper integration than 1.7 secs and so improve the sensitivity of Southern SERENDIP. A novel addition to the hardware would bypass the post processor on the current FFT board and provide consecutive summation of complete 4.2 Million point spectra in real time.

4. Conclusion

Southern SERENDIP is a new dual beam SETI spectrometer attached to the Parkes Radio Telescope, Australia, and operated by UWSM to investigate the southern celestial hemisphere ($-90^\circ < \delta < 20^\circ$) for potential intelligent civilisations. It operates currently in piggyback mode undertaking a non-targeted search. In the near future, using an integrator, it will also be capable of search-

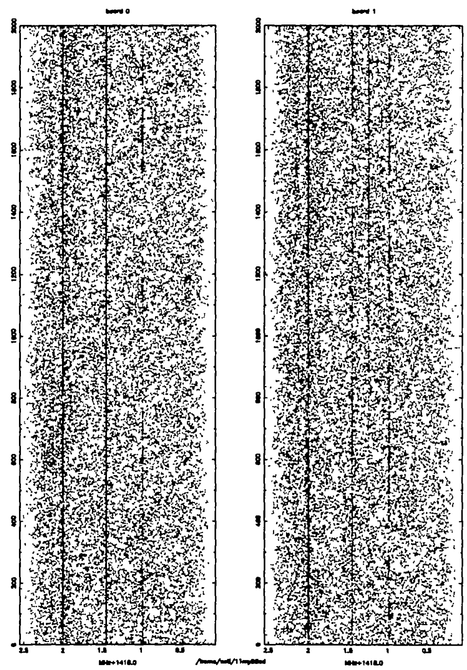

Figure 3. Waterfall plots of hit data. The slightly denser patterns on the LHS of the figures is galactic plane HI. The BW is 2.5 MHz

ing with higher sensitivity for barycentric candidate signals using long sky dwell time surveys. The instrument is also be capable of targeted searches.

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