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To: Deuterium Array Group

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Subject: Single station spectra beamformer

1] Introduction

A single station consisting of 50 crossed dipoles will be capable of forming 25 independent beams in each polarization for each frequency bin. In practice we may choose to process a smaller set of beams and a limited number of frequency bins.

2] Analog processing

The analog portions of the receiver will provide a tunable bandpass with a nominal bandwidth of 5 MHz.

3] A/D Conversion

The analog signals from each port will be digitized by up to 8 bits per real sample. 8 bits should be adequate because the analog filtering limits the signals to within the radio astronomy band which is relatively clear of strong signals. Thus the variation of signal level will be almost always between about 100 K (when the plane of the galaxy is below the horizon) and about 200 K (when the plane of the galaxy is up).

4] Digital down conversion

The GrayChips provide a complex output for each antenna port of 32 bits per complex sample. For a nominal complex sample rate of 1 MHz there are 2048 complex samples in 2 milliseconds.

5] FFT in DSP chips

The beamforming could be accomplished before or after spectral analysis. The advantage of doing the FFT first is that a spectrum can be obtained for each individual port which in turn allows a greater flexibility in data editing for interference reduction and diagnostics. However each time a sample can be checked prior to the FFT and 2 millisecond blocks with samples greater than some threshold over the norm can be flagged. Following the nominal 2048 complex FFT the spectrum can be obtained and accumulated for a nominal integration period of 1 second. [In practice 488 2048 blocks take 0.999425 seconds and since some “dead” time may be required during each integration period an integration period might be 448 blocks or 0.917 seconds of data and 0.08 seconds of dead time.]

6] Beamforming in the motherboard

The complex spectral samples from each antenna port are normalized and compressed to 2 bytes per complex sample and moved to the motherboard. The average data transfer rate per port being 16 Mb/s. For each spectral channel

$$B(Az, el) = \sum_{p} x(w,p)\, b(w,p)$$

where x = is the complex sample
w = frequency rad/s
p = port
b = beam function

if port coupling is neglected

$$b(w,p) \approx e^{ikp_x \sin Az} e^{-ikp_y \sin El}$$

where p_x, p_y are port coordinates
k = $2\pi / \lambda$

The beamforming operation requires

$N_{spec} \times N_{port} \times N_{beam} \times B_{rate}$ CMACs per polarization

Where N_{port} = number of ports = 25
N_{beam} = number of beams = 25
B_{rate} = FFT block rate = 448 per sec
N_{spec} = number of spectral bins = 2048

Which totals 573 million complex multiply accumulates per second if all beams and all spectral are processed. A modern motherboard (Pentium 4) is capable of about only half this rate so that greater computational efficiency will be required. The following efficiencies are expected:

1] If the azimuth and elevation terms are separable into a product the summation can be separated into parts so that the sum requires only

$$Nspec \times \left(N_{port}^{1/2} \times N_{beam}^{1/2} + N_{port} \times N_{beam}^{1/2} \right) \times B_{rate}$$

which totals 138×10^6 CMACs/sec.

2] Limit the number of spectral channels in each beam. [Only about 18% of the bandpass is useful]

3] Reduce the sample rate and bandwidth to 500 KHz.