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Design of (2+1+2)D FFT for Interferometric Pulsar Survey

T. Daishido, N. Tanaka, S. Sudo, M. Suzuki, Y. Saito, R. Agehama, M. Adachi and N. Watanabe

Astrophysics Group, School of Education, Waseda University, Shinjuku-ku, Tokyo 169-50, Japan

Abstract. The Following design of a Pulsar Survey System with a Huge Interferometric Array is discussed. (1) A Huge Array of 320m $\times$ 320m with 256(= 16 $\times$ 16) spherical dishes of 20m in diameter, (2) RF is 1.4 GHz, (3) Receivers are frequency modified GPS(1.57542, 1.2276GHz) ones, (4) Phase and Delay Tracking, (5) Phase Calibration using Differential GPS(GPS signal $\times$ 2 $\rightarrow$ CW), (6) (2+1+2)D FFT /256 pixel Imaging + 256 ch Filtering + Dispersion Removal and Period finding(17M point floating 2DFFT by DSP), (8) Observing time required for the same sensitivity to Arecibo τ/τ_A : 0.88(Timing), 0.003(Survey).

1. Present 2D Direct Imaging Interferometer

Direct imaging at Nyquist rate has been achieved in radio wave(RF = 10.6 GHz) by the 64 element interferometer of Waseda University(Daishido et al, 1991, Asuma et al, 1991, Nakajima et al, 1993, Otobe et al,1994). The telescope has overall size of 20m $\times$ 20m, and is watching the sky to search for transient radio sources like Cyg X-3 or GRO J1655-40.

Imaging process in the Digital Lens (Spatial 2D FFT processor) of the interferometer is the same as in an optical lens, i.e., a set of digital phase rotations in the Fourier transform adjusts the phase gradient due to the wave vecter. Spatially sampled 64 electric vectors $\boldsymbol{E}(x,y)$ by the antennas are transformed to 64 vectors $\boldsymbol{E}(k_x,k_y)$ at Nyquist rate(20 MHz). Thus, one could observe 64 directions simultaneously, which makes it possible to survey 64 times faster than a single dish. It is also equivalent to a 64 element multi-feed telescope.

2. Ergodicity and Non-ergodicity in Interferometric Imaging

There are three kinds of interferometers for which we examine the capabilities of a pulsar search and multi-directional survey. (1) Culgoora or Mills cross type single beam forming: pulsar search (yes), multi directions (no), (2) Fourier synthesis(indirect imaging): pulsar search (no), multi directions (yes), (3) Direct imaging: pulsar search (yes), multi directions (yes).

Ergodicity (time average = ensemble average) is asuumed in the observation with Fourier synthesis, because fringes obtained at different times are used for synthesising the fine images. Thus, Fourier synthesis could observe only er-

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godic(stationary) sources. While the direct imaging interferometer could observe both ergodic and non-ergodic(pulsars or comunication signal) sources.

3. Huge Array for Pulsar Survey: our present dream

Huge Array will have the same collecting area as Arecibo, and it will have the same sensitivity with Arecibo in timing observation. In the survey, Huge Array will search for pulsars in 256 directions simultaneously with the above collecting area. Thus, it will be able to survey 256 times faster than Arecibo.

Since a brief design is given in the abstract, we summarize here the relations between three kinds of FFTs. The first spatial 2D FFT(16 $\times$ 16 point) is for the digital beam forming to 256 directions at Nyquist rate. Number of butterfly operations/clock is $N \log_2 N = 256 \times 8$. The second temporal 1D FFT(256 point) works as 256ch digital filters of each 256 pixel. Since a temporal 256 point data of one pixel should be Fourier transformed during 256 clocks, the whole number of temporal butterfly operations to 256 pixel/clock is $(N \log_2 N) \times N/N = 256 \times 8 \times 256/256 = 256 \times 8$.

Thus, required speed of the two processors of 2D spatial FFT and 1D temporal FFT is the same, which means two FFT processors to transform $16 \times 16 \times 256$ point spatial-temporal cubic data to 16×16 pixel $\times$ 256ch data("imaging spectrograph"). Frequency resolution is $\Delta f = 20MHz/256$, and integrated time resolutions are $\Delta t = 50ns \times 256 \times 8 = 102.4\mu s$, or $\Delta t = 50ns \times 256 \times 32 = 409.6\mu s$.

Next 17M(2^{24}) point floating 2D FFT processors are the real time dispersion removal and period search processors, in which DSPs are used. Typical data are 256ch $\times$ 65,536 point or 64ch $\times$ 262,144 point.

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