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DIRECT IMAGING DIGITAL LENS FOR TRANSIENT RADIO SOURCE SURVEY

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ABSTRACT
FFT based 2D Dygital Lens is discussed comparing with Fourier synthesis. The sensitivity of constructing Large Array will be 50mJy. Precise manipuration of the radiation field is possible in it.

INTRODUCTION

Two radio interferometers have been constructed at Waseda University. Both are 8x8=64 element Maximum Redundant 2D array at 10.6 GHz. The Large Array Telescope(overall size is 20m x 20m) is designed for surveying the transient radio sources like Cyg X-3, SS433 or radio supernovae. The Small Array Telescope(overall size is 1.2m x 1.2m) is for the observation of the cosmic microwave background fluctiations.
FFT based Digital Lens is used for direct imaging. It is a 100-220 GOPS real time imaging facility operating at Nyquist rate. $2\cdot10^7$ images of 8x8=64 pixels are obtained every second. Digital Lens manipurates amplitude and phase of the digitised radiation fields as the optical lens in adaptive optics. Main differece between Fourier synthesis and Digital Lens is the imaging capability in the survey of non-ergodic sources like pulsars. Digital Lens will be used in efficient pulsar surveys. The present Large Array is 64 times efficient in surveying than the 20mϕ single dish. Fringe pattern has been obtained in the Large Array(Nakajima et al 1991).

DIGTAL OPTICS

Bigtness distribution of the sky I(k), which we would like to measure, is the number density in momentum space for photons. It is propotional to $E^2(\mathbf{k})$. While, the observable value by the interferometer is $E(\mathbf{r})$. We could obtaine $E(\mathbf{k})$ form $E(\mathbf{r})$ by the real time spatial FFT processor, because momentum represented $E(\mathbf{k})$ and cordinate represented $E(\mathbf{r})$ are re-

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lated with Fourier transform. The instanteneous spatial sampling is required for the processor, and it is illustrated in Fig. 1. for the 1 dimentinal array. Phase gradient of the arrival wave against real space is coserved during the frequency conversion, as $k = \mathrm{grad}\,\phi_{RF} = \mathrm{grad}\,\phi_{IF}$, where $\phi_{RF} = kr-\omega t$ and $\phi_{IF} = kr-(\omega-\omega_L)t$.

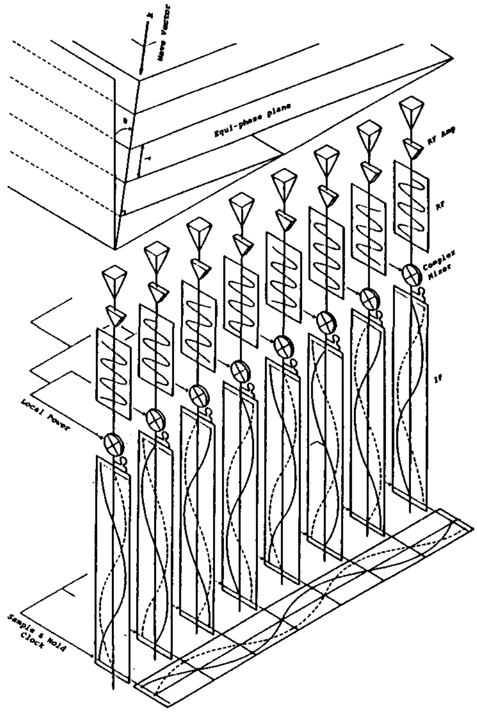

Fig.1. Phase gradient and instanteneous spatial sampling

64 Antennae
↓
64 Converters
↓
64 Comlex Mixers
↓
64 Comlex A/D s
↓
64 Equalizers
↓
XFFT
↓
YFFT
↓
Power Integration

Fig.2. Block Diagram of Digital Lens.
8 bit A/D, 20 MHz clock

Even after samling by A/D converters, radiation fields have phase and ampl' .de. Digitised photons propagate throuh Digital Lens and very pricise manipuration of radiation fields could be done as follows.

```
photon fields -->⊗--> base band signal --> A/D -----------
    RF          |          IF                            ↓
                Lo                          ┌---------------------------┐
                     r exp(i φ) ---> x ¦ digitised photon fields ¦
                                         ¦ (digital manipuration   ¦
                                         ¦  of phase & amplitude)  ¦
                Lo                          └---------------------------┘
    RF          |          IF                            |
photon fields <--⊗<-- base band signal <-- D/A <----------
```

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CORRELATOR AND FFT

Fourier synthesis telescopes currently used are designed to obtaine fine images of radio sources by a small number of antenae. Minimum Redundancy Array is the optimum configuration for this purpose. It requires ergodicity in the observed signal, bcause they are indirect imaging system which uses correlators and integrators.

No correlator is used in the present Digital Lens(spatial FFT processor + complex amplitude equalisers). It could image both ergodic and non-ergodic signal sources at Nyquist rate. Thus, it is possible to survey not only the transient radio sources but the non-ergodic sources like pulsars or comunication signal sources. Survey sensitivityies of Fourier synthesis and Digital Lens are same if the collective area is equal (Daishido et al 1984). Fourier synthesis is compared with Digital Lens in Table 1.

Table 1. Fourier Synthesis and Digital Lens

Fourier Synthesis / Correlator	Digital Lens / FFT
Imaging / Algorithm	
Indirect Imaging Wiener-Khinchin theorem	Direct Imaging Gauss-Cooley-Tukey FFT
$E(r_0),\ldots, E(r_j),\ldots, E(r_k),\ldots$ $\otimes$ ↓ $\int dt$ ↓ $V(u,v)$ indirect FFT ↓ Image $I(k)$	$E(r_0),\ldots, E(r_j),\ldots, E(r_k),\ldots$ ↓ | direct 2D FFT | ↓ $E(k_0),\ldots, E(k_j),\ldots, E(k_k),\ldots$ ↓ $E^2(k_0),\ldots, E^2(k_j),\ldots, E^2(k_k),\ldots$ ↓ $\int dt$ ↓ Image $I(k)$
Imaging / Capability	
Ergodic Signal (stationary noise)	Ergodic and Non-ergodic Signal (stationary noise, pulsars, comunication signal)
Fine Imaging	Sensitive Surveying
	Manipurating Radiation Field Flexible Phase Switching Adaptive Optics

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Array Configuration	
Minimum Redundancy ↓ Maximum Pixels	Maximum Redundancy ↓ Sensitivity Maximum
Any Configuration ○○ ○ ○ ○ ○ ○ ○ ○	Fixed Configuration ○○○○○○○○ ○○○○○○○○ ○○○○○○○○ ○○○○○○○○ 8 x 8, or 64 x 64, ..., 32 x 128, ...
Spectral Observation	
Chikada FX or XF	XFFT --> YFFT --> TFFT 3D real time FFT
Hardware Implementation	
Number of Correlators (N^2)	Number of Butterfly Processors ($N \log_2 N$) Number of Signal Line is conserved along the Signal Flow. In the present Digital Lens, 8bit x 64 cmplex = 1024 lines exist from A/Ds to YFFT.

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