Beamforming for IPS and Pulsar Observations

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Sunrise at Mileura – P. Walsh
Function, Inputs and Outputs

- Function - combine the voltage signal from each of the 512 tiles to form up to 16 independent tied array beams for each polarisation

- Inputs
  - Time series of Nyquist sampled voltage spectra for each polarisation from each of the 512 tiles
  - Instrumental gain solutions
  - Ionospheric phase solutions

- Outputs
  - 16 time series of power detected data for each polarisation for IPS observations (IPS beams) OR
  - 16 time series of voltage data for each polarisation for Pulsar observations (Pulsar beams) OR
  - maybe a mix of IPS and pulsar beams
Single station IPS – measurable and model parameters

- The power spectrum of intensity fluctuations
- Model parameters
  - Velocity \( V_{\perp} \)
  - Strength of scattering \( C_{n}^2 \) \( (\propto \delta n_e^2) \)
  - Spectral index of \( n_e \) fluctuations - \( \alpha \)
  - Inner scale - \( q_i \)
  - Axial ratio – \( AR \)
  - Source size - \( \theta_0 \)
  - Freq. of observation - \( \nu \)
Science specifications

• IPS
  – Required
    • 16 dual polarisation beams
    • Time resolution – 10 ms
    • Frequency resolution – 500 kHz
  – Desired
    • Non contiguous spectral coverage
    • Frequency resolution – 100 kHz

• Pulsars
  – Desired
    • At least 1 tied array voltage beam for each polarisation
    • Few chunks, each few MHz wide distributed over 80-300 MHz

0.2 M samples/sec (16 dual pol beams)
128 M samples/sec/beam
\[ B_k(\nu,t) = \sum_i \{ w_i \, V_i(\nu,t) \} \times G_{\text{inst}}(\nu,t-\tau_1,i,\text{pol},\theta_k,\phi_k) \times \phi_{\text{iono}}(\nu,t-\tau_2,\theta_k,\phi_k) \}\]

2G samples/s

\[ B_{\text{IPS},k}(\nu',t') = \sum_{\Delta t} \sum_{\Delta \nu} B_k(\nu,t) \, B_k^*(\nu,t) \]
IPS system

Data volumes (samples)
Hour   Observing Day (8 hrs)   Year
0.7 G   5.9 G   2.15 T

From the beamformer
Power detect and integrate to 10ms and 0.5 MHz
FFT and obtain power spectra of intensity fluctuations
Average power spectra for each pointing (10 min)
To the science package

>0.2 K   1.3 K   0.5 G
Design status

• Beamformer
  – Intimately tied to correlator architecture
  – Level of maturity – low

• IPS system
  – Level of maturity – conceptual
  – Complexity – low

• Pulsar system
  – Level of maturity – low
  – Complexity - low
Key features

- Multi-beaming capability
  - 16 dual polarisation beams which can be pointed independently anywhere above the horizon
- Originally motivated by IPS - useful for (non imaging) high time/frequency resolution observations
- Pulsars
  - ‘Bring-your-own-pulsar-machine’
  - Observation specific analysis (e.g. known pulsars, targeted/blind survey, etc.)
  - Tangible collaborator contribution
Challenges / Risks / Issues

• Technical (Beamformer)
  – Problem of distributing the beamformer within the correlator such that it has access to all the signals it needs without adversely effecting the correlator architecture
  – Getting the instrumental and ionospheric calibration information at the right place at the right time
  – Ionospheric calibration – stale by 16 sec / predicted via a model

• Cost
  – Data transport into the real time computer (2G sample/s)
Skills needed

• Beamforming (Correlator work-package)
  – Hardware - FPGA based digital engineering
  – Bitcode – FPGA programming
• IPS work-package
  – Realtime software experience
  – Knowledge of radio astronomy techniques (IPS)
• Pulsar work-package
  – Realtime software experience
Dependencies on other sub-systems

- Forms a part of the *correlator* sub-system
- Depends on *visibility binner* and *mapper* for instrumental and ionospheric calibration solutions
- Interacts with M&C
- Feeds the IPS science package & the Pulsar Machine
Interface definitions

• Being a part of the correlator system, does not require any independent input interface

• IPS – TBD - output might be a time series of spectra which will be archived in a database along with suitable metadata
  – A software interface to allow the science software to query and access this database

• Pulsars – TBD - a somewhat flexible interface to pipe the data to a custom Pulsar machine
IPS Source density

- **Cambridge IPS survey (81.5 MHz)**
  - 1789 sources (Dec range -10° to 83°, 58% of sky)
  - Sensitivity – 5 Jy total flux, ~0.3 Jy scintillating flux at 90° elongation
  - Source size 0.2” – 2”

- **Puschino IPS survey (102 MHz)**
  - Artyukh and Tyul’bashev, 1996, Astronomy Reports, 42, 601
  - 414 sources in 0.144 sr (1 source/1.14 deg²)
  - Sensitivity – 0.1 Jy
  - 50% of sources < 3”

- **Ooty Radio Telescope (327 MHz)**
  - Manoharan, 2006, Solar Physics, 235, 345-368
  - Observe ~700 sources per day
  - Sensitivity – 0.04 Jy (1 sec, 4 MHz)
IPS Survey parameters

• Cambridge Survey (81.5 MHz)
  – 4096 full-wave dipoles
  – Beam – 26.8’ x 165’ Sec(z)
  – Bandwidth – 10.7 MHz

• Puschino Survey (102 MHz)
  – Physical collecting area – 70,000 m²
  – Beam – 49’ x 26’ Sec(z)
  – Bandwidth – 160 kHz

• Ooty Radio Telescope (327 MHz)
  – Effective collecting area – ~8,000 m²
  – Beam – 105’ x 3.5’ Sec(δ)
  – Bandwidth – 4 MHz