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Gauribidanur Pulsar System

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Abstract

A dedicated system for observations of Pulsars and other astrophysical transients in the frequency range of 50-80 MHz has been recently commissioned at the Gauribidanur Radio Observatory near Bangalore, India. One of the salient features of the system is digital delay beamforming to simultaneously phase the antenna response pattern ("beam") to different directions in the sky as compared to the generic cable phase/delay shifters which help to observe only a particular direction of the sky at a given epoch. Mechanical steering is difficult for the large antenna arrays used at low frequencies. The work reported is expected to provide useful inputs for similar work with SKA-Low.

1. Introduction

The detections of transients like Fast Radio Burst (FRB) [1] have taken the astronomy community by storm and exploration of such transient phenomena has become a rapidly growing field in Radio astronomy. However, observations of Pulsars and other transients below 100 MHz is still a largely uncharted territory. Observations of Pulsars below 100 MHz are necessary to understand their emission mechanism and characteristics like spectral turn-over which are still poorly understood. Till date no FRB has been observed below 100 MHz. A dedicated low-frequency instrument can help investigate this by continuously monitoring the FRBs some of which are known to repeat. Considering this, a new antenna array [2] has been set-up at the Gauribidanur Radio observatory (Longitude: 77.4^0E, Latitude: 13.6^0N)

2. The Gauribidanur Pulsar System

The newly developed system consists of an array of 16 Log Periodic Dipole Antennas (LPDA) as its primary receiving element. LPDA is a broadband directional antenna with nearly constant characteristics over its entire operating frequency [3]. LPDAs have larger effective collecting area and Half-power beam width (HPBW) compared to other frequency-independent elements like inverted-V and Bowtie antennas which are usually used in other such systems. The LPDAs used in this array have Half-power Beam width of 80^0 along E-plane and 110^0 along H-plane. The antennas are arranged on a North-South baseline (with their E-planes in that direction) with 5m spacing between them and combined in phased array mode. The result is a fan beam that is broad in E-W (Hour angle, up to ~7hrs) and narrow in N-S (Declination, ~3^0) and can be tilted to the desired direction along the declination.

Initially, a delay-cable based system was designed to add the signals from all antennas coherently. An FPGA-based digital spectrometer converts the combined voltage signal to power spectrum using the Polyphase Filterbank (PFB) technique with a frequency resolution of ~44 kHz and time resolution of up to 1ms (Details of the backend receiver can be found in Ref. 2). Pulsars B1919+21, B0834+06, B0950+08, and B1133+16 were detected using this setup.

3. Digital beamformer

In order to reduce the hardware and corresponding losses due to the analog beamforming, the system is presently equipped with Digital beamforming. Eight separate channels from the array (combination of two antennas in each channel) are digitized using 8-bit ADCs at a rate of 90 MSPS and appropriate delays are added in terms of digital units (1 unit = 11.11 ns) to coherently add the signals. The advantage of this approach is that the final beam can be pointed to any desired direction without having to change the delay cables which have different attenuations based on their lengths and thereby reducing the systematic gain variations.

Another advantage with digital beamformer is that multiple beams looking in different directions can be formed simultaneously. Such a setup can be useful for surveying the sky for transients like FRBs as a large area of the sky can be covered. The wide-field coverage using multiple beams is of great interest now for the radio astronomy community, especially in the context of The Square Kilometre Array [see for example Ref. 4, 5, 6].

4. Initial testing

To test the Digital beam forming capabilities and characterize the system, an observation of the Galactic plane was carried out with two simultaneous beams: one at +26^0 declination (12^0 to north of local zenith 14^0) and another at +2^0 declination (12^0 to south of zenith). The observation was carried in meridian transit mode, with 1s integration time for about 20 hours. As the two beams will be cutting across two different patches of the sky which are sufficiently separated from each other, the amount of noise received due to the Galactic background should be different for the two beams.

Figure 1 shows the result of this test. As the galactic plane passes across the two beams, difference in the strengths of the received signal could be noticed. And as expected the beam pointing at +2^0 declination has higher counts as it is closer to the Galactic center (-29^0). Note that the two beams formed are symmetric about the zenith of the telescope, so their gain differences due to the primary antenna beam are expected to be very minimal. The small distortions we see in the plots are due to transient local RFI.

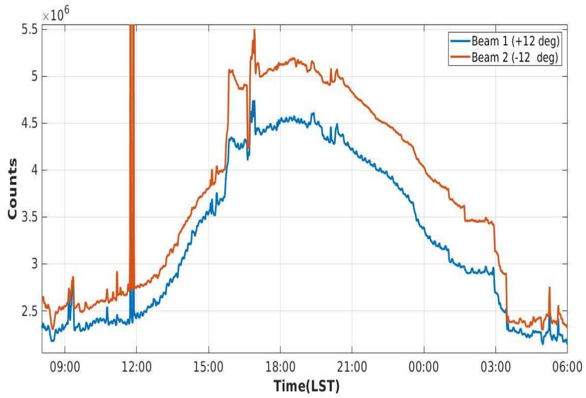

Figure 1. Galactic plane observation with two simultaneous beams +12^0 and -12^0 away from zenith along declination at 60 MHz.

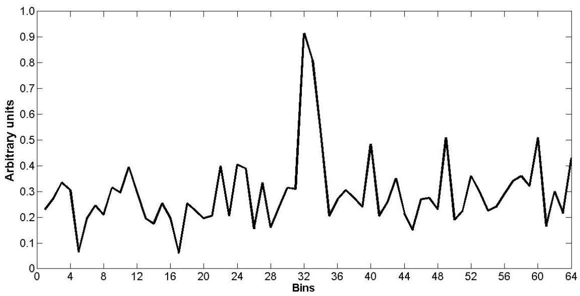

Figure 2. Pulsar B0834+06 pulse profile detected with upgraded system. (1 bin ≈ 20 ms).

Pulsar B0834+06 was also observed and detected with the upgraded system. This observation was carried out with integration time of 4ms over the frequency 50-80 MHz for 2hrs. The data was processed using PRESTO package [7]. The pulsar was detected with period of 1.2738 s and Dispersion measure of 12.938 pc/cm^3. Figure 2 shows the profile of the detected Pulsar.

5. Conclusion

The Gauribidanur Pulsar System has been upgraded to have digital beamforming facility that allows multiple beams to be formed simultaneously covering a wider area in the sky. Initial testing of the upgraded system has been carried out and expected performance is seen. Further developments are being done to optimize the system. Targeted observations of some of the strong Pulsars and Pulsars which are known to emit Giant pulses (e.g., Crab Pulsar) are being carried out. Some of the repeating FRBs are also being observed.

FRBs are still eluding astronomers about their origin. FRBs have been detected at 120 MHz [8] and 111 MHz [9]. This suggests that there might be a possibility to detect them at even lower frequencies. For which, continuous monitoring of the sky at low frequencies is essential. The geographical location (Lat.: ~14^0 N) allows observation of the Southern hemisphere sky, and as it's a dedicated instrument, it can be used to monitor pulsars and other transients continuously. Instrument collecting area (sensitivity) is not a major issue here as some of these transients are known to be very bright [for example, Ref. 10] Its wide-field coverage (110^0 x 80^0), capability to form multiple simultaneous beams, large bandwidth, high spectral and temporal resolutions, geographical location, and the fact that it is a dedicated telescope for time domain astronomy are expected to be very useful for observing pulsars, radio bursts from the Sun, and other high time resolution astrophysical phenomena.

6. Acknowledgements

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