POWERLINE INTERFERENCE MITIGATION
FOR PULSAR OBSERVATIONS AT THE GMRT

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ABSTRACT

Pulsar observations at any observatory are vulnerable to powerline interference, which, if strong, could considerably distort the radio pulsar signal. The powerline interference at the GMRT consists of a significant number of strong harmonics, besides the powerline harmonic frequencies themselves varying with time, thus making the task of its mitigation complicated. Three frequency domain filtering methods are formulated, each progressively sophisticated, leading to a tracking filter that tracks the frequency variations of the powerline harmonics before filtering. It is shown that such an algorithm is able to reject most of the powerline interference, consequently improving the signal-to-noise ratio (SNR) substantially. The pattern of the powerline interference behaviour across all channels is studied, leading to certain inferences. It is also shown that such a filtering scheme increases the probability of detection of new and yet unknown pulsars.

INTRODUCTION

Pulsars are rapidly rotating neutron stars [2] which emit intense beams of radio radiation from the poles of a predominantly dipolar magnetosphere. The detailed functioning of these exotic astrophysical objects is not yet understood and hence they continue to be actively studied by radio astronomers. The GMRT is the world's largest radio telescope operating at metre wavelengths. In the phased array mode of operation [4], it is a very sensitive instrument for studies of radio pulsars. However, like most radio observatories, pulsar observations at the GMRT are also significantly affected by the presence of powerline interference signals. This interference at the GMRT has the following peculiar properties that make its suppression more difficult than normal:

(i) It consists of a large number of harmonics of considerable strength.
(ii) The harmonics themselves are lobes of finite width rather than single, narrow lines.
(iii) The fundamental and its harmonics slowly wander around the mean frequency, in the range 49 - 51 Hz for the fundamental, on time scales shorter than a typical pulsar observation duration.

The presence of this powerline interference in the pulsar data can lead to

(i) Significant distortion of shapes of individual pulses, which can affect the scientific interpretation of the data.
(ii) Substantial reduction in the effective signal to noise ratio of the pulsar data sequence, thereby leading to significantly reduced possibility of detection of weak pulsars in the data.

In this paper, we investigate methods of mitigating the effects of powerline interference in the pulsar mode data taken with the GMRT. For a complete treatment, refer to [1].

TECHNIQUES FOR POWERLINE RFI MITIGATION

The problem is best addressed using frequency domain filtering methods where the time series of intensity data is Fourier transformed, the interference frequencies identified in the spectrum, their effect reduced or cancelled, and the data transformed back into the time series. Three frequency domain filtering methods are proposed, each progressively sophisticated:

METHOD 1: THE BRUTE FORCE METHOD

The Fourier transform of the pulsar data record is obtained, which shows sharp, well-defined periodic lines with a smooth envelope – the pulsar harmonics, and very strong lobes at the powerline frequencies. The envelope is the Fourier transform of the single pulse (average), and the periodic pulse train that convolves with the single pulse gives the enveloped spectrum in the Fourier domain. Zero-valued notches are placed at pre-defined frequencies - usually 50 Hz, 100 Hz, etc with a pre-defined width. This spectrum is now inverse-transformed to get back the time series.

METHOD 2: THE NOISE SUBSTITUTION METHOD:

In the previous method, placing zero-valued notches results in unwanted ringing effects - these are marked by the presence of 50 Hz and their harmonics in the time series where originally there was none. It is also because of the ideal-notch, which by Fourier inversion results in an 'infinite time' response, namely - the sinc() function. To overcome this problem, we instead substitute the zeroes with generated random noise, the power of which is commensurate with the noise floor present in the spectrum. The time series now obtained by Fourier inversion looks better by the conspicuous absence of 'ringing'.

METHOD 3: THE TRACKING FILTER

The two earlier methods work well only if the powerline frequencies are well-behaved, i.e. they remain stationary in the spectrum over time. This is not the case with GMRT data. Both the methods suffer due to the non-stationary nature of the powerline frequency, requiring fairly broad notches in the frequency domain, increasing the potential risk of rejecting genuine pulsar signals especially around the higher harmonics of the powerline frequency.

As a first step towards formulating a filtering scheme to take care of the handicaps mentioned above, available sets of pulsar data from the GMRT were analyzed to measure the timescales over which the powerline interference lines wander. The criterion used was the maximum data length over which the powerline fundamental moved not more than 0.1 Hz on either side. Since the number of bins corresponding to 0.1 Hz depends on the FFT length, an independent quantity would be the time over which this criterion holds. This was found to be about 8 - 16 seconds. In order to ensure sufficient frequency resolution of the Fourier transform of pulsar data, 16 seconds was chosen as the length of the data block within which the power line frequency was quasi-stationary. The length of each block of data is the product of the sampling frequency used for that particular observation run and the quasi- stationary period - here 16 seconds.
For the first block of data of this length, the Fourier transform (via the FFT) is obtained. The apriori locations of the powerline harmonics are fixed at 50 Hz, 100 Hz, etc. for the first block. The peaks of the powerline harmonics are searched for on either side of these frequencies for a few bins. This is logical and not prone to error when the powerline interference is strong enough to ensure that the peak value in these bins is always a powerline interference line, and not a pulsar harmonic. The short length of the data and consequently the short duration over which the pulsar signals have been transformed, ensure that the total pulsar signal energy within the block is small enough for any pulsar harmonic around the powerline interference lines not to overshoot the powerline interference line itself. Once the peaks are located, their respective frequency positions make the next set of apriori powerline frequencies for the next data block. Thus, the subsequent blocks of data are subjected to a highly localized search around the apriori frequencies. This ensures minimum lock-in time for locating the powerline peaks. Once the peak of each harmonic is located for a particular block, their widths are estimated by comparing the strength of the neighbouring bins on either side with a threshold by descending from the peak. The threshold is programmable, and it is computed from the statistics of the noise floor in the spectrum of each block of data. The frequency bins on either side of the peak where the lobe strength equals or falls above the threshold are the ones within which random noise has to be substituted. The peak frequency, strength and width of the lobe for each harmonic are also recorded for each block of the data. Each block of data is then inverse-transformed to get the time series.

Using the estimated powerline frequency positions of the previous block for the apriori values of the next block is in effect a sort of tracking algorithm robust enough to track the small changes in powerline frequency from block to block. A sample of the time series as the result of such filtering is shown in Fig. 1. The added feature is the adaptive nature of estimating the lobe width. In a scenario where the lobe width is also rapidly changing, the actual lobe portion above the threshold surface is eliminated, no matter how broad the lobe is. This successfully eliminates all trace of the lobe,

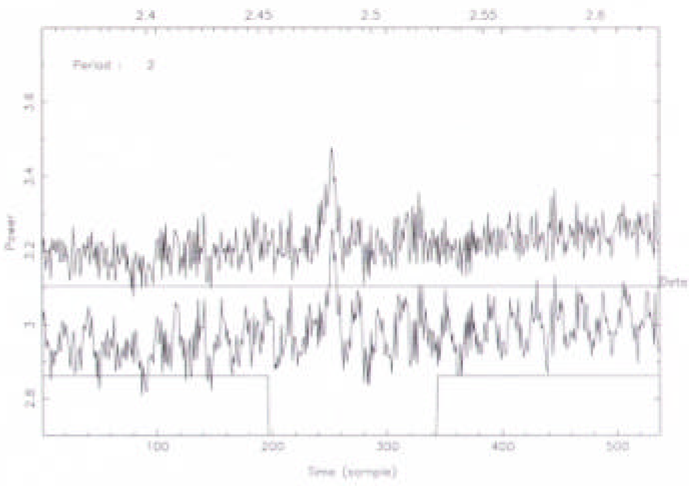

Fig. 1: Single-pulse profile of b0943+10 before and after filtering

bringing alongwith a potential risk of doing away with one or two pulsar harmonics with which the lobe has overlapped above the threshold level. But this risk is not persistent, as we find that the width behaviour of the lobes is on the whole not as erratic as that of its center frequency. An occasional data block may randomly miss in a couple of pulsar harmonics, especially around the fundamental 50 Hz, which is acceptable.

RESULTS AND FINDINGS

1) Filtering shows a marked improvement in the SNR, considering 50 Hz as noise too. Table 1 below gives a comparison of the SNR from different methods
2) The sub-pulse covariance shows substantial improvement after filtering, as clearly seen from Fig. 2.
3) The pulse evolution shows weaker and only imperceptible striations of power line interference after filtering.

The 325 MHz band of the GMRT exhibits strong, consistent powerline interference patterns in two particular channels, besides the broadband nature. The broadband powerline interference is due to arcing at junction points of high tension power transmission lines, whereas the narrowband interference in the two channels has been found to be a low power RFI very strongly modulated by 50 Hz and its harmonics. Other bands however show broadband powerline interference, but the narrowband interference in the two specific channels of the 325 MHz band is conspicuous by its strength and consitency as Fig. 3 clearly shows. However, the RF energy of these two channels is continuous with the neighbouring channels.

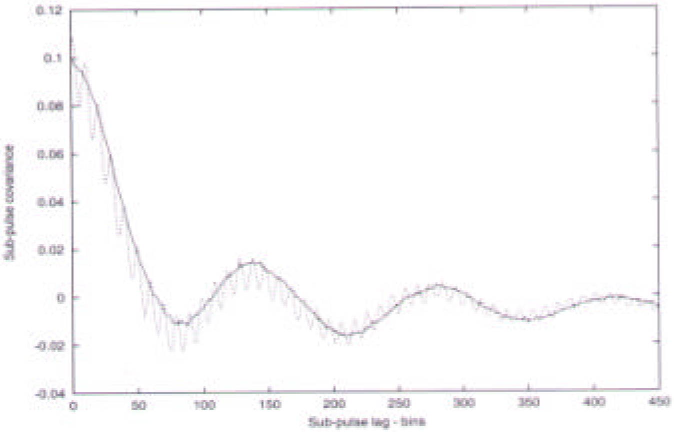

Fig. 2: Sub-pulse covariance for PSR b0943+10 before and after filtering

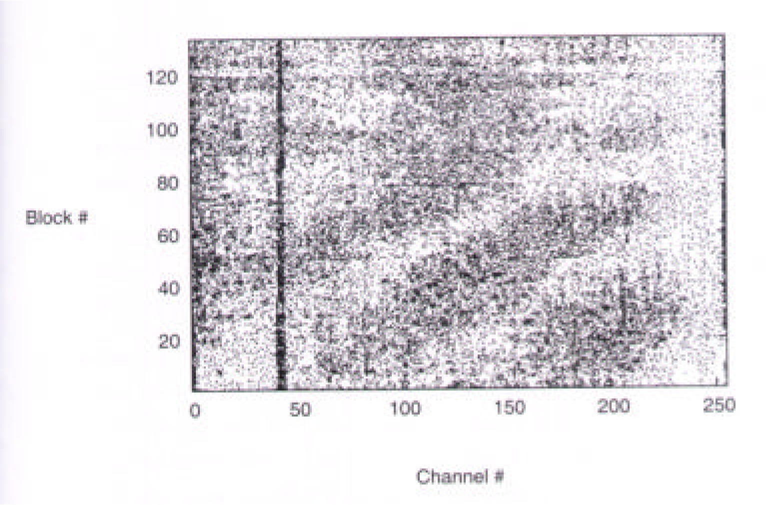

Fig. 3: 200 Hz trajectories across all 256 channels

Table 1: Comparison of SNRs

Mode	Peak SNR	Best SNR
Data dedispersed with true DM	33.88	73.53
Filtering after dedispersion with true DM	44.11	149.07
Dedispersion with true DM after filtering	46.03	162.67
Dedispersion with zero DM before filtering	4.94	9.75
Dedispersion with zero DM after filtering	5.25	25.03

REAL-TIME IMPLEMENTATION

The tracking filter has also been made available as a module in the real-time data processing and recording software for pulsar observations at the GMRT. When data compression techniques are used for pulsar search observations, such filtering reduces the probability of missing valid pulsar signals which might otherwise be masked by the periodic signal-like-interference from the powerline.

D.C. bias contributes to the highest encoded bit in the data. A running mean subtraction annuls the effect of a slowly varying D.C. bias, which is a consequence of a slow gain variation of the receiver electronics. This enables the data to be thresholded and encoded to a 1-bit bitstream. If the pulsar signal rides on a 50 Hz signal and if the running mean of the samples in the buffer is zero, one bit encoding could result in a string of ones and zeroes alternating with the same frequency as that of the powerline. This thwarts any possibility of detecting genuine pulsars in the data. However, if the powerline interference were absent, an alternating string of ones and zeroes should mean the presence of a pulsar. This improved probability of detecting a new pulsar is the motivation for a real- time filtering scheme [1][3], where data can be cleansed of powerline interference as and when it is recorded during a pulsar search observation.

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