RFI mitigation at Nançay Observatory: Impulsive Signal Processing

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The observation of known pulsars (pulsar timing) or the search for new pulsars can be limited by radio frequency interference (RFI) generated by telecommunication activity. In this paper, we propose several RFI mitigation techniques to cope with impulsive and/or narrow band RFI at Nançay Observatory. For pulsar timing, we have implemented, a pulse blanker and a cyclostationary blanker, both in real time. For pulsar search, we propose a new approach which combines a hardware-efficient search method and some RFI mitigation capabilities. This method is based on a 2D FFT and Radon transform.

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1. Introduction

Pulsars are rapidly rotating highly magnetized neutron stars which produce radio beams that sweep the sky like a lighthouse. The corresponding periodic pulse profiles can be measured with radio telescopes and dedicated backends. If the pulsar is already known, radio astronomers are interested in its precise timing. Coherent de-dispersion processing is then implemented to compensate the frequency-dependent time-shift due to non-linearities in the interstellar medium (see [1] for more details). If not, an iterative search procedure is implemented to identify new pulsars. In both cases, the quality of pulsar observations is limited by radio frequency interference (RFI) generated by various (and growing) telecommunication activities.

In this paper, we propose several RFI blanking techniques to cope with impulsive and/or narrow band RFI. Depending on where the detectors are implemented in the system, different types of RFI can be detected. For pulsar observation, three possible implementations have been identified within the system architecture defined in Figure 1:

    a) a Pulsed-RFI detection based on power criteria at the input of the polyphase filter bank, just after digitization. This configuration is appropriate for impulsive or burst broadband RFI.

    b) Cyclostationary detector dedicated to continuous RFI just after the polyphase filter bank.

    c) a cyclostationairy detector just after the FFT. This configuration is more appropriate for narrow band and continuous RFI.

In sections 2 and 3, the implementations of these two detectors are described. Both detectors can be used for pulsar timing mode or pulsar search mode.

In section 4 a specific approach for pulsar search mode is proposed. It combines a hardware-efficient search method and some RFI mitigation capabilities both for impulsive and narrow band RFI. This method is based on a 2-dimensional FFT (2D FFT) and Radon transform. It covers case c.
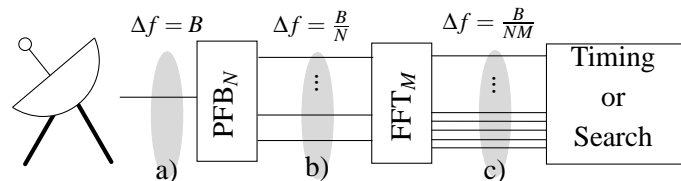

Figure 1: Typical pulsar backend architecture with detector implementation. a) Stage 1: waveform acquisition; b) Stage 2: polyphase filter bank (PFB) to split the input frequency band (usually hundreds of MHz) into smaller bands (few MHz); c) Stage 3: dedispersion step. During their travel through the interstellar medium, the pulsar pulses are spread over time. If this dispersion is known (i.e. in pulsar timing mode), it is cancelled coherently in real time by applying the correct phasing on each channel. If not (i.e. pulsar search mode), a set of successive pulsar parameters will be tested for detection.

2. Pulsed-RFI detection with a power detector

The power detector principle is quite simple: outlier samples that exceed a certain level are considered as interference and trigger the blanking of the corresponding data block. However, the
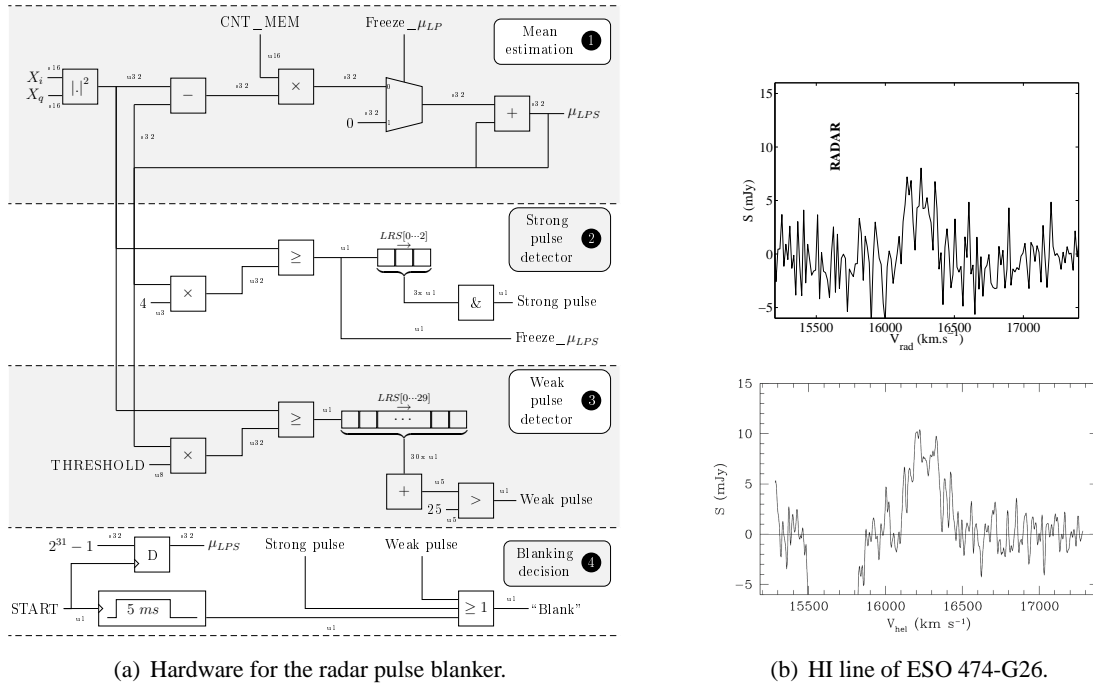
(a) Hardware for the radar pulse blanker.

(b) HI line of ESO 474-G26.

Figure 2: Power detector: (a) LRS is a Logical Right Shift unit. The symbols *s* and *u* specify the databus widths for signed and unsigned operands. (b) Top: Neutral Hydrogen (HI) spectrum of ESO474G26 observed at the Nançay Radio Telescope with pulse blanking. Bottom: without pulse blanking.

efficiency of such detector depends on the robustness of its decision threshold. The issue is that the same block of data is used for threshold estimation and for outlier detection.

Our approach is based on the χ^2 distribution model. So, only one parameter (the mean μ) is needed to fully define the signal statistics. Consequently, the threshold value S is calculated as $S = C\mu$ with C a parameter defined by the user. The mean value is recursively estimated (see Fig. 2(a)-1). To make this estimation robust against outliers due to RFI, the strongest samples are systematically discarded. The effect of this clipping on mean estimation can be theoretically derived [2], and the proper correction is included in the parameter C. From this basic scheme, two improvements are proposed to enhance the performances for strong and weak radar pulses:

- For strong pulses, the blanker is triggered if three consecutive samples exceed the threshold (see Fig. 2(a)-2).

- For weak radar pulses, we have shown that counting the number of detections in a time window provides better performances. In practice, we set the time window to 30 samples and the triggering number of detection to 25(see Fig. 2(a)-3).

The design operates at a maximum sampling rate of 145 Msamples/s. The logic gates used to implement the algorithm occupy 4% of a 3 Mgates FPGA (Virtex II) and 2% of the 96 18×18-multipliers available. The design has been used to observe cosmic sources with flux densities as low as 5 mJy. No radar residuals could be seen on the base line as shown in Figure 2(b).

3. CycloDet: A cyclic detector

It is also possible to apply power detection on narrow band RFI. However, precise thresholding implies careful calibration of the frequency band and it assumes that the signal level is constant over time.

An alternative is to use a criterion that can discriminate between temporal signatures independently of the power level. Cyclostationarity is such a criterion. It is based on some hidden periodicities due to the periodic characteristics involved in the RFI signal modulation (carrier frequency, baud rate, coding scheme...). For an illustration of this principle, see [3] in the same RFI 2010 proceedings. In [1], we have demonstrated the interest of such an approach for pulsar applications. In the following, the detector principle is briefly presented and its real time implementation is described.

We assume that $x(t)$ is a mix of a stationary signal (*i.e.* a cosmic source and/or the system noise) and a cyclostationary signal (*i.e.* RFI signal). Let us consider the following criterion:

$$C_N^\alpha = \frac{1}{N} \sum_{n=0}^{N-1} |x|^2(n) \exp(-j2\pi\alpha n) \tag{3.1}$$

where α is the cyclic frequency. This parameter is linked to the above-mentioned RFI periodic characteristics. This detector expresses the search for periodicities in the instantaneous power fluctuations. To make this detector robust against slow power variations, we define a normalized version of our previous criterion:

$$D_N^\alpha = \frac{\sqrt{N} C_N^\alpha}{C_N^0} \tag{3.2}$$

In [4], we have derived the statistical properties of this detector as a function of the interference to noise ratio (INR).

From the above consideration, an operational cyclic detector has been implemented on a real time digital backend at Nançay Observatory. The algorithm is implemented into a digital programmable Virtex II FPGA component. The successive steps are described in figure3(a).

Figure 3(b) shows some results obtained in the decameter band where calibration signals (wide band stationary noise) were used to simulate four pulsar pulses with different power levels. The red time-frequency slots correspond to RFI detected by our real time detector. Narrow band RFI are clearly detected.

For pulsar observations, these experiments demonstrated that the cyclostationary detector can discriminate between bursts due to pulsars and bursts due to RFI.

4. Real time Pulsar search procedure

The search for new pulsars is a difficult task since neither the dispersion measure (DM) nor the periodicity are known. The procedure consists in recording all the data and in trying off-line a set of DMs and periodicities. This approach needs disk space and is quite time consuming. In this section, we propose a new real time pulsar search method, requiring less disk space, fewer computational resources and providing a simple way to blank RFI. It is based on a two dimensional Fourier transform (2D-FFT) and a Radon transform.
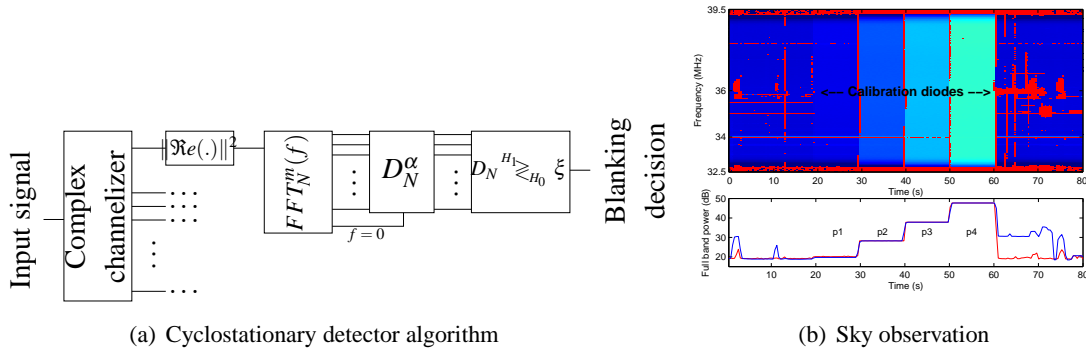
(a) Cyclostationary detector algorithm   (b) Sky observation

Figure 3: Cyclostationary detector application: (a) The structure of the cyclostationary detector algorithm. (b) Results obtained in the decameter band at Nançay observatory. (top) Time-frequency power plane. The red time-frequency slots correspond to RFI detected by our real time cyclic detector. (bottom) Total power versus time. The red curve is the total power after blanking. The total bandwidth is 7 MHz. The number of channels is $M = 2048$. On each channel, $N = 2048$ samples are used to compute the criterion. The cyclicdetector is insensitive to steady power levels generated by the successive calibration noise diode pulses (p1 to p4) added to the signal.

The different steps of the algorithm are presented in Figure 4 and an example with a real pulsar pulse is provided for illustration. In short :

- The final output of the real time part consists of a $N \times N$ image corresponding to the mean of M consecutive square absulot 2D-FTT of the images. An example of such an image is given at Figure 4.b. Each 2D-FFT is computed on independent $N \times N$ time-frequency power planes such as the one provided at Figure 4.a. With this approach, all dispersed pulsar pulses are projected at the same location in the 2D-FFT image. This location depends only on the pulsar DM and is different from the one obtained for RFI. In other words, any impulsive (respectively narrow band) RFI will be concentrated in the horizontal (respectively vertical) line centered in the 2D-FFT image. Thus, to remove RFI and to obtain a clean image, all that is required is to blank these vertical and horizontal lines which cross at the center of the 2D-FFT image.

- Off-line, a Radon transform is applied on the cleaned 2D-FFT image. It consists in summing the image intensity along successive radial lines [5]. When this integration line corresponds to the line where the pulsar pulses have been projected, all the pulsar power is concentrated in one point. At other integration angles, only the noise contribution will be integrated. Figures 4.c and 4.d illustrate this principle with respectively the dirty and clean image.

In [6], we have investigated the sensitivity of this approach compared with the classical one. For a low signal to noise ratio, our pulsar detector is less effective but the advantage of this approach is that only a limited amount of data (the $N \times N$ 2D-FFT image) is stored for off-line processing. Furthermore, it provides simple RFI mitigation capabilities.

5. Conclusion

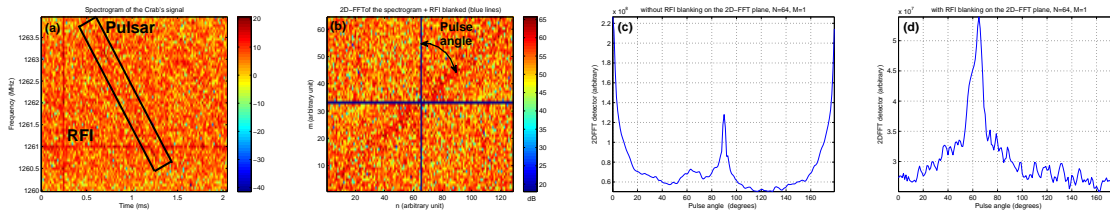Several RFI mitigation techniques applicable to pulsar observation have been presented. In

Figure 4: Application of a 2D-FFT pulsar search approach on the Crab pulsar. (a) A 128×64 time-frequency power plane of the Crab pulse. We added a number of synthetic RFI signals. (b) The 2D-FFT image time-frequency power plane. The blue cross in the center corresponds to the blanked RFI locations. (c) A radon transform of the dirty 2D-FFT image (*i.e.* with RFI locations not blanked). Pulsar detection is not possible. (d) A radon transform of the clean 2D-FFT image. The pulsar can be easily detected.

the case of pulsar timing, a Pulsed-RFI detector and a cyclostationary detector have been implemented for real time experiments. In the framework of the UNIBOARD FP7 European project, these algorithms will be implemented in a multi-purpose scalable computing platform for radio astronomy as part of the pulsar receiver. In the case of pulsar searches, a new approach has been proposed that combines a hardware-efficient search method and some RFI mitigation capabilities. It could serve as an alternative for the next generation of radio telescopes such as the LOFAR radio telescope (www.lofar.org) or the Square Kilometer Array (SKA, www.skatelescope.org) where the large amount of data to be processed by classical search procedures is an issue.

References

[1] D. Ait-Allal, R. Weber, I. Cognard, G. Desvignes and G. Theureau, "Rfi mitigation in the context of pulsar coherent de-dispersion at the Nançay radio astronomical observatory" in *Proc. EUSIPCO 2009*, Glasgow, UK, September 4-8. 2009.

[2] D. Ait-Allal, C. Dumez-Viou, R. Weber, I. Cognard, G. Desvignes and G. Theureau, "RFI mitigation at Nançay Observatory:Impulsive Signal Processing," Widefield Science and Technology for the SKA, S. A. Torchinsky, A. van Ardenne, T. van den Brink-Havinga, A. van Es, A.J. Faulkner (eds.), ISBN 978-90-805434-5-4, 2010.

[3] R. Weber, R. Feliachi, A.J. Boonstra, "Cyclostationarity for phased array radio telescope " in *Proc. RFI 2010*, PoS(RFI2010)33, Groningen, NL, April 29-31, 2010.

[4] R. Weber, P. Zarka, V. Ryabov, R. Feliachi, J. Grießmeier, L. Denis, V. Kozhyn, V. Vinogradov, and P. Ravier, "Data preprocessing for decametre wavelength exoplanet detection: an example of cyclostationary rfi detector," Eusipco, Poznan, Poland, 2007.

[5] S. Deans, "The radon transform and some of its applications " Krieger Pub. Co., 1983.

[6] D. Ait-Allal, R. Weber, C. Dumez-Viou, I. Cognard, and G. Theureau, "RFI Mitigation Implementation for Pulsar Radioastronomy" in *Proc. EUSIPCO 2010*, Aalboorg, DN, August 18-22, 2010.