Examples of Recent RFI Mitigation Developments at Nançay Observatory

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Abstract

Nançay Observatory is involved in different operational or prospective developments for RFI mitigation. At the time of the conference, two recent examples will be described. The first one is the digital implementation of a real time radar blanker. It is based on a robust reference power estimator and an adapted use of radar temporal characteristics. Thus, HI sources with peak flux densities as low as 5 mJy has been observed with no radar residuals on the baseline. The second example is about the use of cyclostationarity in aperture arrays. By applying a Music-cyclic algorithm, RFI directions of arrival are extracted and then used for null beamforming.

1. Efficient Time Blanking of Radar pulses with reduced hardware implementation

Nançay Decimeter Radio telescope, a single antenna telescope, suffers from local ground based Radar radio frequency interference (RFI) while observing red-shifted H1 recombination lines. Military or civilian radars are allocated every 5 or 10 MHz apart below 1410 MHz and microseconds bursts of radio signals are periodically generated on a millisecond basis. The proper physical rotation of the antenna around its vertical axis at an approximate period of 5 seconds modulates the incoming instantaneous power of the radio burst on the radio telescope between 40 dB over system noise and complete extinction. For some powerful civilian radars located in Paris (200 km away), multi path propagations and echoes generate a never-ending RFI activity. Furthermore, military radars do not steadily operate from the same location and with the same length and pulse rate frequency.

To allow surveys in this frequency band, an analog waveform blanker has been built in Nançay Observatory [1], but only strong pulses could be removed. Some other works have been done to detect and remove such RFI [2,3]. However, the implementation complexity of such algorithms in logic programmable component (FPGA) was a deadlock.

In this paper, we describe an operational digital waveform blanker which has been implemented in the RDH digital receiver [4] available at the Nançay Observatory. This detector is based on a power criterion. To compensate the initial poor performances of such criterion, we included several elaborations that do not strongly bear upon implementation cost but provide significant improvements:

- **Threshold calculation**: the power detector estimates a threshold S based on the data it-self. Assuming that uncorrupted data samples follow a normal distribution law, we show that the estimation of S reduces to the estimation of a mean μ from samples containing outlying values. The clipping of the strongest samples allows for rejection of the strongest pulses that could significantly modify the estimated value of the mean. The threshold value S is then calculated like $S = C^* \mu$ where C is a parameter which compensate the bias induced by the clipping.
- **False alarm reduction**: In detection systems, a given threshold sets a false alarm rate: some sample that should not be classified as RFI trigger the detector because they lie in the right tail of the uncorrupted signal distribution, over the threshold value. Detecting weaker radar pulses can be achieved with a reduced threshold value leading automatically to an unbearable rate of false alarm. Improvements can be made by adding a priori knowledge on the nature of the radar pulses: the blanking will be effective only if successive detections appear. A rule of 3 consecutive detections was decided for the blanking of short strong radar pulses. A rule of at least 25 detections within a 30-samples window was proposed for the blanking of long weak radar pulses.
- **Constrained Blanking**: Blanking data blocs of waveform is not harmless. It was carefully studied in [5] and avoided in our design. Rather than dealing with frequency line broadening (which is uncommon in the frequency bands that are studied), we simply blank data blocks that are synchronized with the data blocks used to perform spectral analysis. Thus, no discontinuities are present in the waveform fed to the FFT. The drawback of such method is that frequency resolution (i.e. FFT size) imposes the granularity of the blanking. For our design, this leads to an unnecessary amount of blanked data (coarse-grained). For other designs, this might lead to fine-grained blanking that can be adjusted to will with simple glue logic.

A performance comparison is given at figure 1. The hardware that computes the mean estimation and the detection of strong and weak pulses will be presented at the conference. The design operates at a maximum sampling rate of 145 Ms/s. However, we only used it at 14 Ms/s which implies no more than 3 radars in the observing frequency band. The overall blanking rate is about 4% but this figure could significantly increase for a wider band carrying many more radars. The logical gates used to implement the algorithm occupy 4% of a 3 Mgates FPGA and 2 of the 96 18x18 multipliers available. Some hardware could be saved since a lower sampling rate could be acceptable for our use. The design has been used to observe radio-galaxies with flux densities as low as 5 mJy. No radar residuals could be seen on the base line as shown on figure 2.

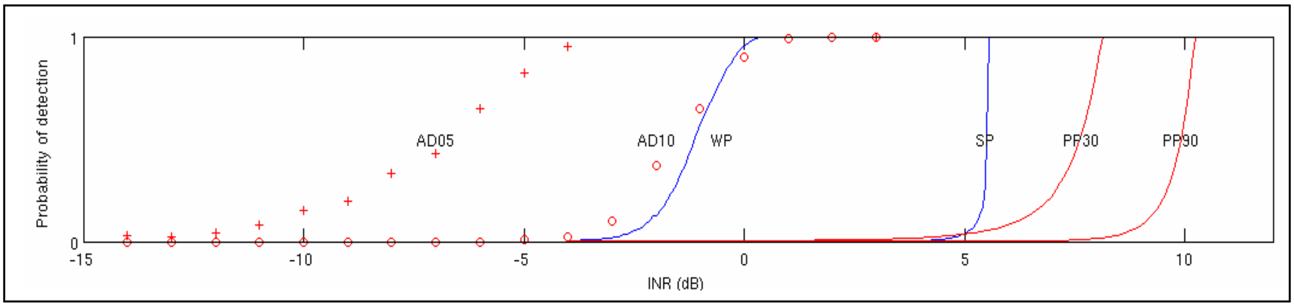

Figure 1: Performance comparison between different detectors for several interference to noise ratios (INR). The blue curves annotated SP (respectively, WP) corresponds to the behavior of the strong pulse detector (respectively, weak pulse detector). We included the results of [5] presenting a simple pulse detector for 2 different setting (PP30 and PP90) and the results of [3] presenting a much more advanced algorithm that gives better performances for its finest setting but includes a lot of information about a specific radar pulse shape (AD05 and AD10). Any radar pulse whose shape gets to far from the model will not be detected as easily.

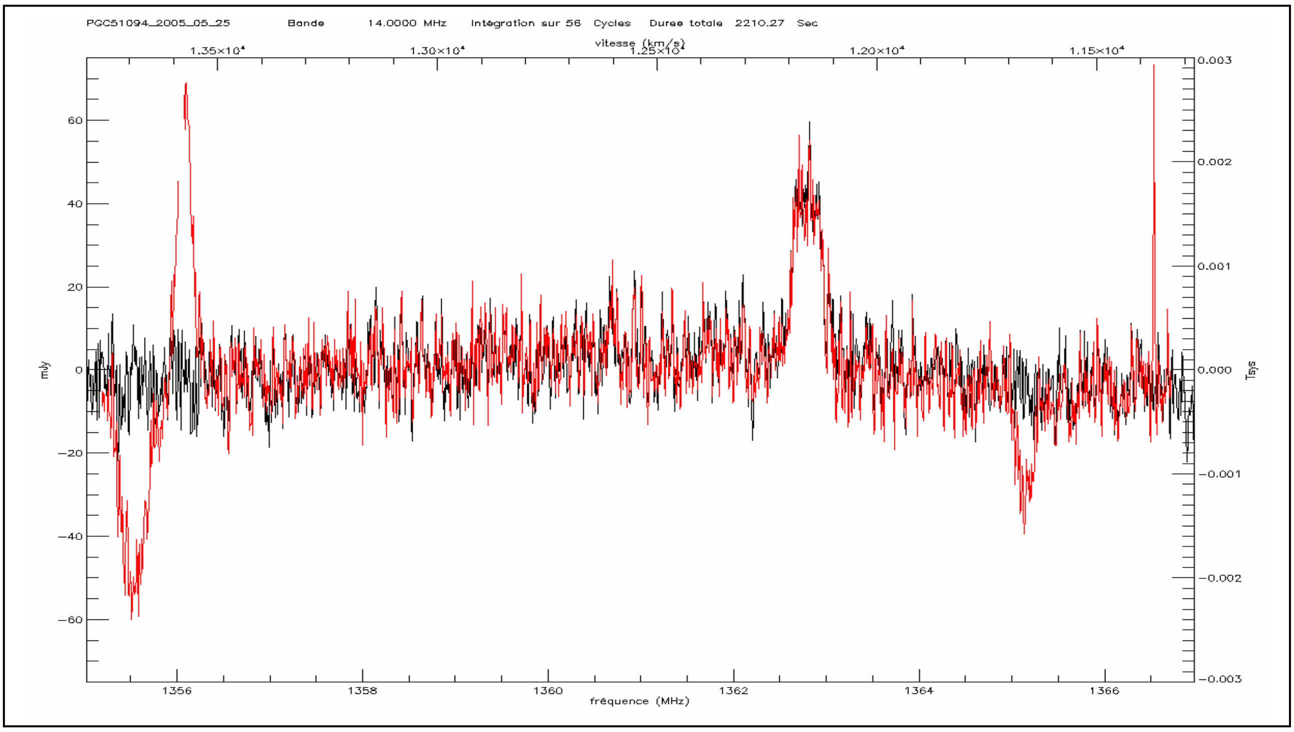

Figure 2: Test of the radar blanker with real data and in real time. The observed source is PGC51094. The red curve is the spectrum obtained without time blanking and the black one is the spectrum obtained with the blanker on.

2. First results of cyclostationary nulling with a phased array.

The new generation of telescopes (LOFAR, SKA,…) will make a strong use of spatial filtering. In [6], a study of such algorithms in the context of radio astronomy has been carried out. We propose to extend some of these techniques by using cyclostationary properties of the RFI. A signal I(t) is said to be cyclostationary if its autocorrelation function is T-periodic: $R_I(t+T,\tau)=R_I(t,\tau)$ [7]. Thus, $R_I(t,\tau)$ can be developed into Fourier series and its Fourier coefficients are the cyclic autocorrelation functions, $R_I^\alpha(t)$, with $\alpha = k/T$ the cyclic frequency :

$$R_I^\alpha(t) = E\left[I(t+\frac{\tau}{2}).I^*(t-\frac{\tau}{2})\exp(-j2\pi\alpha\, t\tau) \right]$$

where E [.] is the expectation operator. In [8], an example of detector using the cyclic correlation function is given.

We can extend this definition to a multidimensional signal. Thus, let us define the cyclic covariance matrix :

$$\mathbf{R}^\alpha = E\left[\mathbf{Z}(t+\frac{\tau}{2}).\mathbf{Z}^H(t-\frac{\tau}{2})\exp(-j2\pi\alpha\ t\tau) \right]$$

where $\mathbf{Z}$(t) is the vector formed by the M outputs of the antenna array. By decomposing $\mathbf{R}^\alpha$ into singular values, we can define 2 orthogonal subspaces. In particular, the noise subspace, $\mathbf{U}_n$, is formed by the singular vectors associated with the least significant singular values. The directions of arrival of the RFI, θ_{rfi} are obtained by minimizing $\left\|\mathbf{U}_n^H\mathbf{a}(\theta)\right\|^2$ where $\mathbf{a}(\theta)$ is the classical steering vector. This method is an extension of the MUSIC algorithm [9]. Let's consider, $\mathbf{A}_{rfi}$, the matrix containing the RFI estimated steering vectors $\mathbf{a}(\theta_{rfi})$, we can realize a spatial projection in order to null these RFI by computing the following matrix $\mathbf{P}_{Nul} = \mathbf{I} - \mathbf{A}_{rfi}(\mathbf{A}_{rfi}{}^H\mathbf{A}_{rfi})^{-1}\mathbf{A}_{rfi}{}^H$. The beamformer weights, $\mathbf{w}$, will be defined by $\mathbf{w} = \mathbf{P}_{Nul}{}^H\mathbf{a}(\theta_0)$ where $\mathbf{a}(\theta_0)$ is the source steering vector. Figure 3 and figure 4 present some preliminary results.

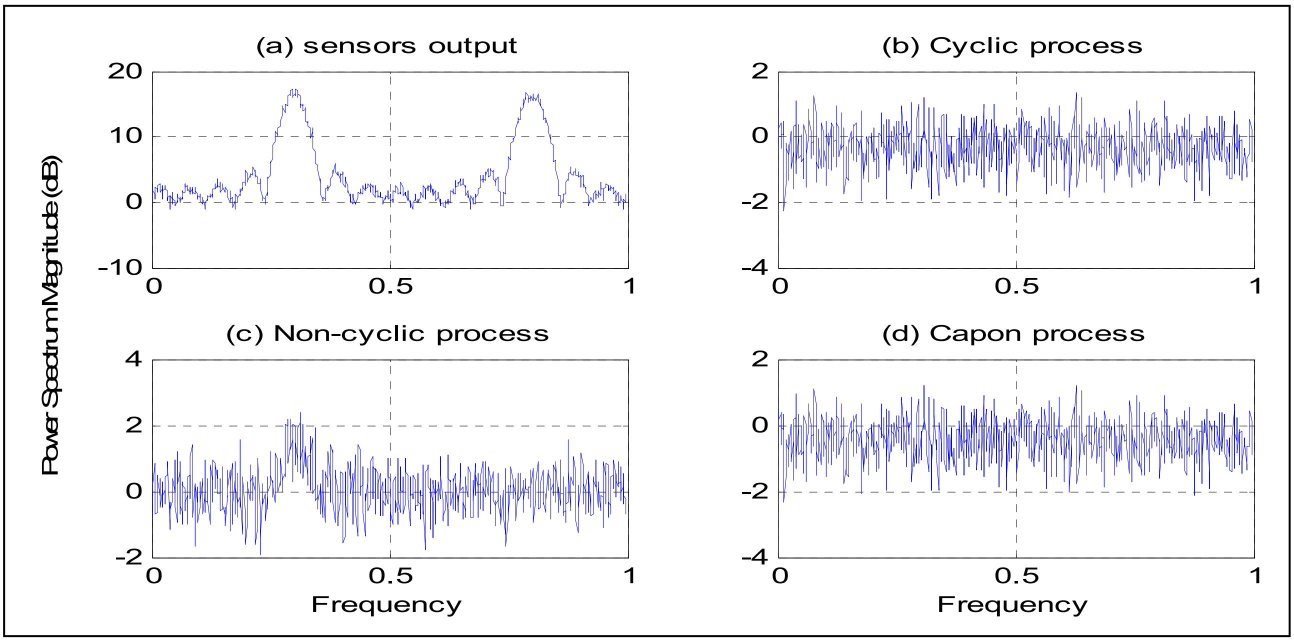

Figure 3: Simulation of different nulling methods. Two interference signals BPSK (Binary Phase Shift Keying modulation) at 50° and 10° enter a 10 antennas linear array, with an interference to noise ratio of -5 dB. (a) spectrum obtained at one of the 10 antennas. (b) Cyclic spatial nulling (c) classical spatial filtering (d) Capon method.

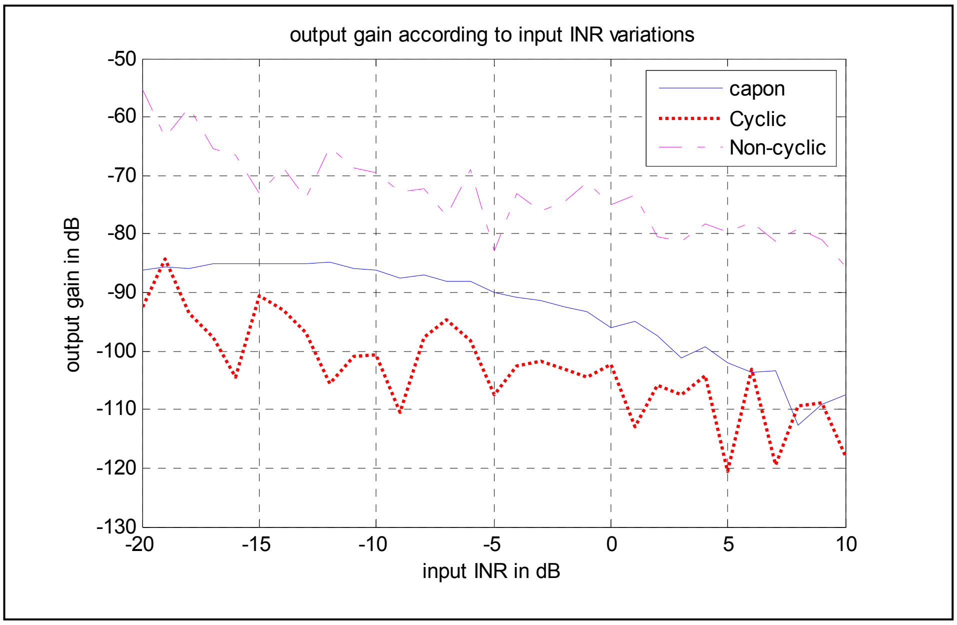

Figure 4: RFI Attenuation after nulling vs. the input INR for the different methods. From up to down, classical spatial filtering, Capon and cyclic-nulling.

4. Conclusion

The radar blanker is now operational at Nançay Observatory. The cyclic nulling gives some preliminary interesting results. More details and other results will be provided at the conference.

5. References

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