

## Signal Processing Techniques Applied In RFI Mitigation Of Radio Astronomy

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**Abstract:** Radio broadcast and telecommunications are present at different power levels everywhere on Earth. Radio Frequency Interference (RFI) substantially limits the sensitivity of existing radio telescopes in several frequency bands and may prove to be an even greater obstacle for next generation of telescopes (or arrays) to overcome. A variety of RFI detection and mitigation techniques have been developed in recent years. This study describes various signal process methods of RFI mitigation in radio astronomy, choose the method of Time-frequency domain cancellation to eliminate certain interference and effectively improve the signal to noise ratio in pulsar observations. Finally, RFI mitigation researches and implements in China radio astronomy will be also presented.

**Keywords:** Mitigation methods, radio astronomy, RFI, signal processing

### INTRODUCTION

Radio astronomers use different techniques to detect weak signals in the radio spectrum from celestial sources. The astronomical signal is very weak and has passivity, high sensitivity, broad band characteristics, so it is easy to be distorted even disable recognized by other radio emissions. Additionally, the radio astronomers spectral domain extends from a few MHz to a few THz. Every use of the radio frequency spectrum, broadcast radio and TV, communication satellites, navigation satellites, as well as monitoring systems has the potential to affect a radio astronomical observation.

Around 1980, with the rapid development of technology, more and more radio spectrum was becoming occupied and radio observers started to mitigate the RFI in electronic equipment (Offringa *et al.*, 2010). A variety of RFI detection and mitigation techniques have been developed until the most recent times. However, as the required sensitivity of observations increased significantly and the radio radiation from people activities expanded quickly, new methods had to be developed to deal with the situation.

RFI comes from many ways and in many forms (Fridman and Baan, 2001). To avoid RFI, several considerations should be taken into account:

- Choose sites as far as possible from RFI.
- Urge wireless management to strict with spectrum power management nearby observed frequency.
- Improve RFI mitigation methods.

Many authors have discussed many techniques to excise or mitigate RFI in recent years (Baan, 2011).

According to the special circumstances of Xinjiang Astronomical Observatory (XAO), we choose the method of Time-frequency domain cancellation to eliminate certain interference and achieve the desired results of RFI cancelation.

### RFI CATEGORIES

RFI comes in a wide variety of frequencies and intensities. Every year, an increasing amount of Radio-Frequency (RF) spectrum in the VHF, UHF, and microwave bands is being utilized to support new commercial, and all have the potential to interfere with radio astronomy observations.

**Satellites:** As far as RFI is concerned, satellites are potentially a serious problem. The signals from the constellations (GPS, GLONASS and IRIDIUM) are probably always present at a low level (via weak sidelobes), so their frequencies may well be a lost cause. However, some satellites are a serious problem. Cloud satellite, for example, at 94 GHz, is powerful enough to damage a sensitive receiver system if an overlap of the satellite and the telescope beams were to occur.

**Aircraft:** Transmissions from passing aircraft are a transient problem and so may not represent a problem when observations are averaged over an extended period of time. However, when mobile and network traffic direct radiation, the interference will get worse. In addition, the reflection of ground-based transmissions can also affect the sensitivity of the receiver.

**Ground-based:** The RFI from ground-based installations tracks the population density, which is why observatories tend to be located in remote sites. As mentioned earlier, some effective preventive measures will be work.

**Observatory-based:** Apart from externally generated RFI, the occurrence of self-interference is a major concern at any modern radio telescope site. For example, antenna servo motor controllers, data acquisition processors, and fast computing capabilities operate very close to extremely sensitive and wideband radio astronomical receivers (Ambrosini *et al.*, 2010).

### RFI MITIGATION STRATEGIES

The goal of this study is to consider various mitigation methods and evaluate their applicability and consider how much they may help to decrease the impact of RFI on the astronomical data. These methods are all based on the characteristics of modern digital signal processing algorithms and the techniques that are commonly used at existing radio telescopes.

Proactive strategies provide the best defense of all, keeping the spectrum clean by removing the sources of RFI. For example (Kexteven, 2007): regulation, radio quiet zones and the observatory environment. More and more evidence shows that the conditions are changing for the worse. There is more RFI; and so experiments become more challenging, with less tolerance to RFI; and telescopes are becoming more sensitive.

There is no universal method of RFI mitigation in radio astronomy observations. In particular, the applicability and the success of certain mitigation procedures depend on a number of factors: the type of radio telescope, observations and RFI. In reactive RFI mitigation we identify the RFI in the data stream and remove it, so that the subsequent processing data is RFI-free data.

Robust receivers must be linear enough to prevent any spread of strong interferences and reach sufficient spectral resolution to extract radio astronomical information from interference lines. All in the following there is a basic assumption, the receiver's response is linear. This puts a requirement on the receiver designers to provide adequate reserve against overloading (Clerc *et al.*, 2002; Weber *et al.*, 2002; Tuccari *et al.*, 2004).

**Excision in the time-frequency domain-thresholding:** A general description of a telescope input signal  $x(t)$  is expressed as function (1):

$$x(t) = x_{sig}(t) + x_{sys}(t) + x_{RFI}(t) \quad (1)$$

where  $x_{sig}(t)$  is the signal-of-interest,  $x_{sys}(t)$  is the total system-noise (the radio sky plus the feed plus the receiver), and  $x_{RFI}(t)$  is the RFI signal. For digital signal sequence, according to various algorithms, set up different thresholds in the time domain and/or frequency domain. When the signal strength is greater than the threshold value, it is considered RFI and eliminated. This method is the simplest one of all, and can be handled online or offline in the time or frequency domain. However, It is difficult to prescribe a time resolution  $\Delta t$  and a frequency resolution  $\Delta f$  for detection of all possible varieties of RFI (Fridman and Baan, 2001). The effectiveness of this process is set by the Interference-to-Noise Ratio (INR). This method can be applied to the telescopes in a radio telescope array. Reference (Baan *et al.*, 2004) has described an impressive RFI mitigation machine installed on the Westerbork Array.

**Blanking postcorrelation data-flagging:** Flagging is a traditional RFI excision strategy, operating on the post-correlation data. But it can be laborious and time-consuming (Lane *et al.*, 2005). It will be effective to the extent that the RFI is impulsive so that useful RFI-free times can be identified. Algorithms have now been devised that can largely automate the procedure and Pieflag displays its results concisely and allows the user to add and remove flags interactively (Middelberg, 2006).

**Null steering:** Any phased array will have sidelobes and nulls in its reception pattern. The adaptive algorithms require high INR and their work will be done better if the array is set up to track some specific target directions (in a beamforming mode). The Allen Telescope is the only astronomical array exploring this technique (Harp, 2005). Classical soft computing is fuzzy logical and neural network which are used to solve nonlinear mapping problem.

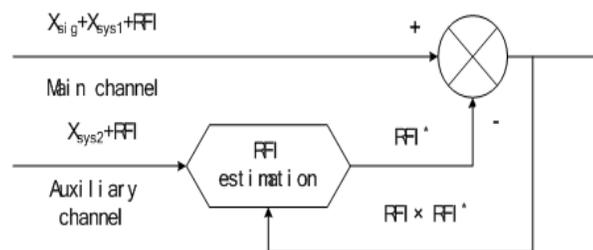


Fig. 1: The fundamental concept of adaptive interference cancellation as applied to a single dish radio telescope

**Adaptive filters:** Figure 1 shows the fundamental concept of adaptive interference cancellation as applied to a single dish radio telescope. There are two data channels: a main channel with the radio telescope pointing on source and containing the RFI signal, and an auxiliary or reference channel at a separate antenna pointing off source and also containing the RFI signal. As long as it gives an independent copy of the RFI, it will be able to remove RFI from a corrupted data channel (Barnbaum and Bradley, 1998). The filter will reduce the RFI in the astronomy Intermediate Frequency (IF) by a factor  $1/(1+INR)$ . At the same time, a section of the reference channel receiver noise will be added to the filter output. This will be equal to  $1/(1+INR)^{0.5}$  in magnitude. In addition, the adaptive filter can be applied to a synthesis array.

**Subspace filtering:** The ideal strategy in this class of mitigation would dispense with the RFI copy from the reference antenna, because it can identify the RFI in the data itself. The goal of this method is to find some statistical characteristics that distinguish RFI from RFI-free data. Cyclostationarity (Feliachi *et al.*, 2009) is one such a signature.

**Generalized spatial filtering:** Reference (Amir and Van der Veen, 2000) has described a more general and elegant scheme. The basic idea is that the RFI must stand out if it is a problem. Receiver noise is generally white, uncorrelated from one sample to the next and quite uncorrelated from one receiver to the next. RFI has a variety of correlations-in time and between antennas. Each object within the field of view of the array will add a special signature to the full set of correlation products between the antennas. An eigen value decomposition of the product matrix will isolate the strongest sources. Spatial filtering attempts to categorise the samples via the correlation properties, and then discard the RFI. This scheme has long history, most recently successfully demonstrated in the Low Frequency Array (LOFAR) trials.

### RFI RESEARCH IN CHINESE RADIO ASTRONOMY

In China, the RFI has been seriously impacting on every Radio Astronomy Observatory. Xinjiang Astronomical Observatory (XAO) has been researching on RFI detection and mitigation methods and Five hundred meter Aperture Spherical radio Telescope (FAST) also need considering RFI influence.

**FAST:** FAST is an ongoing large astronomical project in China and it will be able to observe at a zenith angle of 40 degrees without a notable loss in gain. The simplified feed system will continuously cover the frequency range between 200 and 2000 MHz, with possible capability up

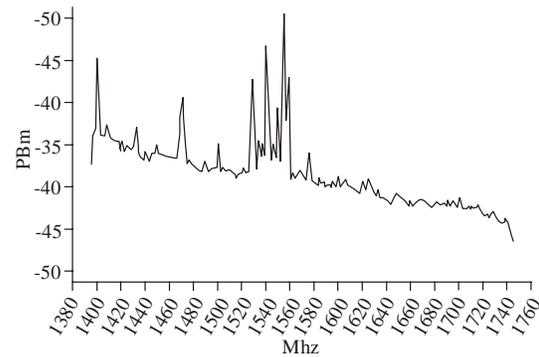


Fig. 2: 18 cm-receiver's interference test

to 5 or even 8 GHz depending upon the cost. The high sensitivity and wide frequency range of the receiver will cause the system very susceptible to RFI.

**XAO:** The main device of XAO is a 25 m radio telescope. The antenna has a primary mirror 25 m in diameter and a 3 m secondary mirror. It operates at waves between 92, 49, 18, 3.6/13, 6 and 1.3 cm, respectively. It is actively involved in radio astronomy, especially in the fields of pulsar, AGN, star-formation and evolution, and radio astronomy techniques. In addition, it is the only radio telescope for Pulsar Observation in china. The widespread use of microwave bands for telecommunication and other active purposes has resulted in the loss of much quiet spectrum previously available for XAO observation. Figure 2 shows the 18 cm-receiver interference test at XAO.

Two levels of RFI mitigation processing exist within the Pulsar Digital Filter Bank (PDFB) (Grant and Andrew, 2008) hardware, firstly large transients in the time series data can be removed and secondly the frequency channels can be filtered. Either one or both of these mechanisms can be employed during folding and spectrometer modes. Removal of large transients from the time series data (clipping) is implemented prior to the polyphase filter bank. Any data that exceeds a preset threshold is removed from the time series and replaced with the running mean of the data. The RFI clipper is shown in (Grant and Andrew, 2008). RFI filtering is achieved through the use of the second set of inputs (RFI reference) on a PDFB system and an adaptive filter. The adaptive filter has two input parameters, a time constant over which the RFI average is calculated and a gain coefficient to prevent filter overshoot. The RFI adaptive filter is shown in (Grant and Andrew, 2008). Now the PDFB cannot give play to its full functionality without reference antenna.

The experiments firstly test on the pulsar signal data of J1136+1551. According to the 18 cm-receiver interference test at XAO, we choose the method of Time-frequency domain cancellation to eliminate certain

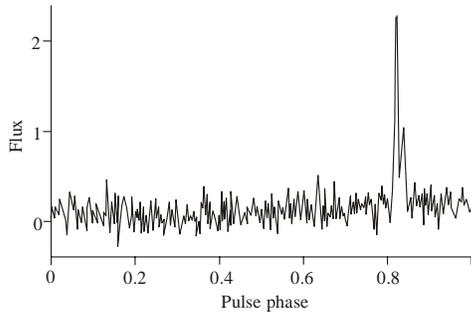


Fig. 3: After eliminate RFI

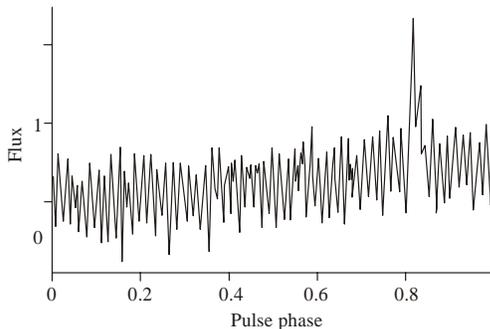


Fig. 4: Before eliminate RFI

interference and achieve the desired results of RFI cancelation in Fig. 3. Through the time-frequency domain processing and compared with Fig. 3 and 4 shows a clearer outline of pulsars after eliminating part of the strong RFI and effectively improves the signal to noise ratio. It shows good effect and we will test on spectrum line signal data and other observation in the next step.

### CONCLUSION

There is no universal method for RFI mitigation and the choice of one method depends on RFI characteristics and the type of the observation. A problem for most of the techniques described in this study is that they depend on identifying the RFI in real time. The scheme will no longer be valid when the RFI is comparable to the system noise. Low level RFI will be much more likely to escape mitigation. We can see that the adaptive filter uses a reference antenna directed towards the RFI, and it has advantages in the detection of RFI. In addition, the LOFAR is considered an important pathfinder for the Square Kilometres Array (SKA) in demonstrating the potential of (sparse) aperture arrays.

In China, with the rapid increasing of RFI in radio astronomy, more research is needed to further research the impact of the various RFI sources and towards special RFI mitigation techniques to reduce the impact of the interferers.

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