RADIO FREQUENCY INTERFERENCE REJECTION IN RADIO ASTRONOMY RECEIVERS

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ABSTRACT

Methods of radio frequency interference suppression in radio astronomy are considered. Estimations of signal-to-noise ratio for temporal and frequency methods of RFI rejection are made. Implementation of these methods in real-time digital signal processing could be an effective mean for supporting radio astronomy observations in worsening radio ecology environment. Radio telescope RATAN-600 experience shows the advantages of such a processing.

1 Introduction

The radio-ecology environment at radio observatories is worsening every year. The increasing radio frequency interference (RFI) from radio stations, radars, communication systems, cars, etc. limit the real sensitivity of radiotelescopes. Improvements in antenna quality and receiver parameters do not give the expected results because of RFI. Even at radio telescopes situated at secluded locations it is very difficult to reach the potential sensitivity, especially at low frequencies.

Radio astronomers are interested in the entire radio spectrum because different physical processes produce electromagnetic radiation at different frequencies. Modern radio telescopes are available for observations in any segment of radio spectrum. Radio astronomy signals are extremely weak; the typical signal-to noise-ratio (SNR) is -30dB or lower and in many cases the SNR can be as low as -60dB. Therefore, radio astronomy is very vulnerable to (RFI)[1]. As a consequence of their sensitivity, radio telescopes are susceptible to RFI from transmitters which do not even share the same frequency band. The influence of RFI on a radio astronomy measurement can vary from total disruption by saturation of the receiver to very subtle distortions of the data. Broad-band RFI raises the general noise level of receivers, thus degrading the sensitivity. Narrow-band RFI may imitate spectral lines. If strong RFI occurs in short bursts for a small fraction of the total time, it may not be so dangerous as long correlated RFI which it is difficult to trace. The degradation effects on data may be found only after considerable *off-line* data reduction, if ever, and a false

scientific conclusion may result.

Most radio astronomers try to monitor RFI sources and choose observation time and frequency bands so as to receive the minimum possible industrial noise. Thus only passive methods are used mainly. Investigations of the different types of RFI showed that in many cases it is possible to counteract them actively, and prevent the final contamination of radio astronomy signals. The joint application of analogue and digital filtering and nonlinear processing can save quality of observational data.

Single dish radio telescopes are mostly vulnerable to RFI. Radio interferometric systems suffer from RFI in a less degree but auxiliary noise power measurements made at each antenna for calibration are also distorted by RFI. So in this paper single dish observation RFI problems are considered and positive results obtained in real time anti-RFI data processing at one of the world biggest radiotelescope RATAN-600 [2] are shown.

2 Main results

Signal received by a radio telescope may be expressed as a sum:

$$y = x_{sig} + x_{syst} + x_{RFI}, \quad (1)$$

where x_{sig} is useful noiselike signal from an extraterrestrial radio source, x_{syst} - is a noise of antenna, feeds and receiver(system noise). Both x_{sig} and x_{syst} are normal random processes $N(0, \sigma_{sig})$, $N(0, \sigma_{syst})$. Usually $\sigma_{sig} \ll \sigma_{syst}$. The bandwidth of x_{sig}, x_{syst} is Δf , of $x_{RFI} - \Delta F_{RFI}$. All types of data processing in radio astronomy give output information about second-order moments of x_{sig} -variance(noise temperature), spectral density, correlation function. RFI may be basically represented as a superposition of two types of waveforms: large impulselike bursts and long narrowband, strongly correlated random oscillations[3]. To suppress x_{RFI} two types of processing are possible: detection of x_{RFI} and elimination of corrupted intervals("CUT") and filtering of data with the aim to suppress RFI("CLEAN"). For the first stage of detection a cumulative sum(CUSUM)

random sequence y_{in} . A modified version of CUSUM in our case looks like

$$\begin{aligned} S_0[\mu_k] &= 0, \\ S_n[\mu_k] &= \sum_{i=1}^n (\hat{\mu}_k[i, l] - \overline{\mu_k[l-1]}), \\ m_{n,k} &= \min S_j[\mu_k], 0 < j < n, \end{aligned} \quad (2)$$

where $\hat{\mu}_k[i, l]$ - running estimate of a central moment μ_k at l -th interval. The change points of μ_k $i_{ch,k} = \arg(|S_i[\mu_k] - m_{n,k}| > h_k)$, h_k - threshold for moment μ_k , $i = 1 \dots n$ - number of samples at each l -th interval. This procedure determines the "dirty" intervals, suspected of RFI presence. A future of such an interval depends on the kind of detected RFI. Short and strong, burstlike RFI are cut out from the data stream y_{in} . The limit length of thrown intervals with x_{RFI} which could be tolerable from the point of view of sensitivity loss is determined at a 5 ÷ 10% level of *rms* error growth while estimating σ_{sig} . It ought to be mentioned here that the *rms* error of estimating of σ_{sig} is inversely proportional to $\sqrt{t}$ - time of averaging after square-law detection. So if a part αt , $0 < \alpha < 1$ is lost because of RFI-cutout, the relative *rms* error growth is equal to $\sqrt{1/(1-\alpha)}$. The ratio of *rms* without CUT of RFI to *rms* after CUT may be considered as a gain obtained in consequence of this procedure:

$$G_{cut} = \sqrt{\left(1 + \frac{2\alpha^2 \Delta f \cdot t}{Q_1^2}\right) (1-\alpha)} \quad (3)$$

where $Q_1 = \sigma_{sys}^2 / \sigma_{RFI}^2$, σ_{RFI}^2 - the variance of RFI. Long strongly correlated RFI could be suppressed using noise cancellation techniques consisting of estimating RFI and subsequent subtraction from signal + RFI mixture y , [5]. RFI estimate $x_{RFI}(t)$ may be obtained both in frequency and time domain (adaptive spline smoothing, Wiener smoothing, wavelet denoising etc.). In general final estimate of noiselike signal-of-interest $\widehat{x(t)}$ is:

$$\widehat{x(t)} = y(t) - \widehat{x_{RFI}(t)} \quad (4)$$

Potential error variance of $x_{RFI}(t)$ may be estimated as the variance at the output of Wiener filter:

$$VAR_{x_{RFI}} = \frac{\sigma_{sys}^2}{\frac{\sigma_{sys}^2}{\sigma_{RFI}^2} + \frac{\Delta f}{\Delta F_{RFI}}} \quad (5)$$

and the total output variance after RFI rejection and averaging is:

$$VAR_{tot} = \frac{\sigma_{sys}^2}{\sqrt{2t \cdot \Delta f}} + \frac{\sigma_{sys}^2}{\left(\frac{\sigma_{sys}^2}{\sigma_{RFI}^2} + \frac{\Delta f}{\Delta F_{RFI}}\right) \sqrt{2t \cdot \Delta F_{RFI}}} \quad (6)$$

Filtering gain considered as a ratio of variance after filtering to the variance before filtering is

$$G_{clean} = \frac{[(Q_1 + Q_2)^2 - Q_2] (Q_1 + \sqrt{Q_2}) \sqrt{Q_2}}{Q_1(Q_1 + Q_2) [Q_1 + (Q_1 + Q_2) \sqrt{Q_2 - 1}]}, \quad (7)$$

and a ratio of residual *rms* due to RFI to "ideal" one (without RFI) after square-law detection and averaging is

$$R_T = \frac{\sqrt{Q_2} [(Q_1 + Q_2)^2 - Q_2]}{(Q_1 + Q_2) [Q_1 + (Q_1 + Q_2) \sqrt{Q_2 - 1}]}, \quad (8)$$

where $Q_2 = \Delta f / \Delta F_{RFI}$, Fig.1.

Fig.1. Dependence of R_T on Q_1 while Q_2 is parameter, $Q_2 = 2; 5; 10$.

Frequency rejection is for the time being the most popular method of RFI suppression. Bandpass filters are placed mainly at the input of frontend so as to prevent saturation of high sensitivity receivers by strong RFI and intermodulation distortions appearance. Let us consider a simple case of multichannel radiometer. The whole input bandwidth Δf is divided on M frequency channels while RFI bandwidth is ΔF_{RFI} . Input signal-to-noise (SNR) ratio is $\sigma_{sig}^2 / (\sigma_{sys}^2 + \sigma_{RFI}^2)$. Channel outputs are weighted with the factors $p_k = \sigma_{sys}^2 / (\sigma_{sys}^2 + \sigma_{RFI,k}^2)$, which are inversely proportional to the variance $\sigma_{k,ch}^2 = \sigma_{sys}^2 + \sigma_{RFI,k}^2$ in each particular channel. Thus the filterbank output signal after weighting (FBW subscript) could be represented as the weighted sum of the channel signals y_k after total-power detectors and averaging:

$$y_{FBW,out} = \sum_{k=1}^M p_k y_k. \quad (9)$$

Radiometer output SNR without weighting in the presence of RFI is equal to:

$$SNR_{RFI} = \frac{\sigma_{sig}^2}{\sigma_{sys}^2} \cdot \frac{Q_1}{(Q_1^2 + Q_2)^{1/2}} \sqrt{\Delta f \tau}, \quad (10)$$

where $Q_1 = \sigma_{sys}^2 / \sigma_{RFI}^2$, $Q_2 = \Delta f / \Delta F_{RFI}$, τ = the integration time. Output radiometer SNR_{FBW} with filterbank and subsequent weighting is

$$SNR_{FBW} = \frac{\sigma_{sig}^2 / \sigma_{sys}^2 [(Q_1 + Q_2)^2 - 2Q_1 - Q_2] \sqrt{\Delta f \tau}}{\sqrt{(Q_1 + Q_2)^4 - 4Q_1^3 - 5Q_1^2 Q_2 - 4Q_1 Q_2^2 - Q_2^3}} \quad (11)$$

So the gain obtained after weighting could be estimated as the ratio $G_{FR} = SNR_{FBW} / SNR_o$, that is

$$G_{FR} = \frac{[(Q_1 + Q_2)^2 - 2Q_1 - Q_2] \sqrt{Q_1^2 + Q_2}}{Q_1 \sqrt{(Q_1 + Q_2)^4 - 4Q_1^3 - 5Q_1^2 Q_2 - 4Q_1 Q_2^2 - Q_2^3}} \quad (12)$$

The ratio $R_{FR} = SNR_{FBW} / [(\sigma_{sig}^2 / \sigma_{sys}^2) \sqrt{\Delta f \tau}]$ characterizes residual decrease in output SNR due to non-ideal rejection of RFI. Fig.2 shows how R_{FR} depends on Q_1 while Q_2 is a parameter.

Fig.2. Dependence of R_{FR} on Q_1 while Q_2 is parameter, $Q_2 = 2; 5; 10$.

Several blocks of the proposed procedure were implemented in real-time processing using digital signal processor (DSP) TMS320C50 at RATAN-600 radiotelescope. Observation data records of radio source with and without anti-RFI processing are demonstrated in Fig.3. Significant positive effect can be seen.

3 Conclusion

The variety of interferences and different types of radio telescopes do not allow to propose universal method of RFI suppression. This paper gives lower bounds for residual errors or upper bounds for SNR which might be obtained after signal processing. Real signals at real radio telescopes would yield different and sometimes worse results. The RATAN-600 experience of RFI excision gives rise to a hope that good observational results could be obtained even in the presence of strong RFI. The effectiveness of the application of the proposed methods depends on the DSP hardware performance. Implementation of modern DSP and application specific integrated circuits (ASIC) in radio astronomy *real-time*

data processing will help in obtaining reliable observation data with sensitivity close to potential one even in bad radio ecological environment. Next generation radioastronomy projects ought to include real-time anti-RFI subsystems as a necessary facilities.

Fig.3. Radiosource records, upper) without RFI suppression, low) with real-time RFI suppression.

References

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