

## Mitigation of GPS L<sub>2</sub> signal in the H<sub>1</sub> observation based on NLMS algorithm

Zhong Danmei<sup>1, a</sup>, Wang zhan<sup>1, a</sup>, Cheng zhu<sup>1, a</sup>, Huang Da<sup>1, a</sup>

<sup>1</sup> National University of Defense Technology, Changsha 410073, China

<sup>a</sup>z1181203374@163.com

**Keywords:** evaluating indicator, radio astronomy, NLMS, auxiliary channel, RFI.

**Abstract.** In the radio observation based on the large single antenna, in order to reduce the interference of navigation signal L<sub>2</sub> from observation of the red-shifted H<sub>1</sub> spectral line at L-band, we used the an auxiliary channel and normalized LMS algorithm, and proposed new evaluating indicators deduced by theoretical method. Finally, we verified the suppression performance and the indicators' utility by multiple simulations and statistical method.

### Introduction

With the rapid development of the radio astronomy, the technology of the large radio antennas is improving. However, the radio frequency interference (RFI) significantly limit the research of the radio astronomy in China. Usually, radio astronomy signal is very weak and almost the receipt power spectral flux density by radio signal source is less than 1Jy (1Jansky= $10^{-26}$ W/m<sup>2</sup>/Hz). So that the radio signals is susceptible to RFI. In addition, as radio telescopes are high-sensitivity, high-resolution and wide range of operating frequency, they are sensitive to weak interference, such as navigation signal. Even though the minimum level of navigation signals just approximately -160dB [1], it still has a huge impact on radio astronomy observations.

The observation of H<sub>1</sub> is an important issue in radio astronomy observation. As H<sub>1</sub> is one of main components of the interstellar mediums and distribute throughout the galaxy, the study for H<sub>1</sub> will contribute to galaxy kinematic [2]. The H<sub>1</sub> without red-shift is usually called 21cm spectral line and its center frequency is 1420.406MHz. However, the frequency range of in actual observation is from 400MHz to 1400MHz or even wider due to the red-shift which caused by cosmic expansion [3]. Moreover, navigation signals almost distribute on L-band as well, such as L<sub>2</sub> (1227.06 MHz), L<sub>3</sub> (1381.05MHz) and so on, which observation frequency overlaps red-shift H<sub>1</sub>. Therefore, we need an effective anti-interference algorithm to eliminate the interference and obtain the useful H<sub>1</sub>.

Usually, the methods to eliminate the interference by navigation signals are classified into two pieces. One is only using the statistical data of radio observation, including threshold processing in time or frequency domain and the model reconstruction method. The core idea of threshold processing is that we can drop a part of data which is obvious over the variance or other eigenvalues. It is easy and convenience for auto-processing, but it has an influence on the integrity of the radio signal [4, 5]. The model reconstruction method is using priori information of navigation signals to model the interference signal, then we estimate the interference by navigation signals to eliminate it [6]. This simulation method can often get obvious effect on anti-interference, even reaching to 20dB, but it need a large number prior information to model, which can hardly apply on reality. The second one is adaptive noise cancelling (ANC) [7, 8] method, which is using the correlation of main antenna and auxiliary antenna to eliminate the interference. The method performs very well on kinds of interferences, however, we cannot research the performance of ANC on radio observation as the limitation of evaluation criteria.

To solve those problems proposed before, this paper put forward some evaluation criteria for performance of anti-interference in simulating H<sub>1</sub> and L<sub>2</sub> signal, and this simulation is based on the 25-meter cassegrain antenna in Xinjiang Observatory, and in consideration of the free space propagation loss, atmospheric loss, different observing angles at the same time [9]. These criteria are radio signal attenuation,  $G_s$  and interference suppression,  $G_i$ . This paper apply

single-auxiliary-antenna ANC to eliminate the interference from signals of main antenna. On the one hand, we verify and study anti-interference effectiveness of the method that applying the LMS algorithm in radio observation by those criteria we proposed before. On the other hand, we verify the effectiveness of the criteria itself.

### Basic principle

Table 1. The power of each part of received signals

Antenna \ Signal (dBW)	H <sub>1</sub>	L <sub>2</sub>	Noise
Main antenna $r(n)$	- 91.89	- 53.32	- 44.39
Auxiliary antenna $r_{aux}(n)$	- 159.86	- 78.49	- 88.38

From table 1, there are the power comparison of the main and auxiliary antenna through the processes which amplify, mixing and so on. The navigation signal L<sub>2</sub> will interfere the radio signal H<sub>1</sub> observation in the 25-meter antenna, according to the table, the interference power is more than the H<sub>1</sub>'s, but less than the noise's in the main antenna, as result of the low interference-to-noise ratio (INR), the LMS algorithm show the poor performance. Therefore when navigation satellite pass the main-lobe, we can obtain a strong L<sub>2</sub>. The auxiliary antenna can improve the received power of L<sub>2</sub> by rising the antenna aperture, and the data in the table is the result of 5-meter auxiliary antenna aperture. The power of L<sub>2</sub> is more than the noise's in auxiliary antenna, and the power ratio of L<sub>2</sub> to H<sub>1</sub> reaches 10<sup>8</sup>, therefore the H<sub>1</sub> in auxiliary antenna can be ignored.

### Algorithm

#### Signal model.

From the above analysis, it can be seen that the received signal  $r(n)$  of the main antenna is the sum of H<sub>1</sub> from main lobes, L<sub>2</sub> from the third side lobes (the observing angle is 2°) and the Gaussian noise:

$$r(n) = s(n) + i(n) + N(n) \quad (1)$$

$s(n)$ ,  $i(n)$  are respectively H<sub>1</sub> signal and L<sub>2</sub> signal,  $N(n)$  is Gaussian noise, all of them are obtained from the main antenna receiver IF amplifier.

Similarly, the  $r_{aux}(n)$  from auxiliary antenna is as follows:

$$r_{aux}(n) = i_{aux}(n) + N_{aux}(n) \quad (2)$$

where,  $i_{aux}(n)$  and  $N_{aux}(n)$  express L<sub>2</sub> and the Gaussian noise from the auxiliary antenna.

Defines the H<sub>1</sub> in the computer simulation environment as Gaussian white noise [10].

#### Algorithm.

For the correlation between  $i(n)$  and  $i_{aux}(n)$  in time domain, we can use the adaptive algorithms to eliminate the L<sub>2</sub> in main antenna. There are least squares /recursive least squares (LS/RLS) and least mean square (LMS) algorithm. Compare to the former algorithms, the latter has a lower convergence rate, but a simpler structure, a smaller amount of computation, a more stable performance and easily implemented.

Due to the extremely weak power of signal in main and auxiliary antenna, a very large step factor (about 10 orders of magnitude) in LMS algorithm is required in order to make the weight vector convergence. The normalized LMS (NLMS) is used to figure it out, and increased the convergence speed and stability, the procedure is divided into two steps, and details are as follows:

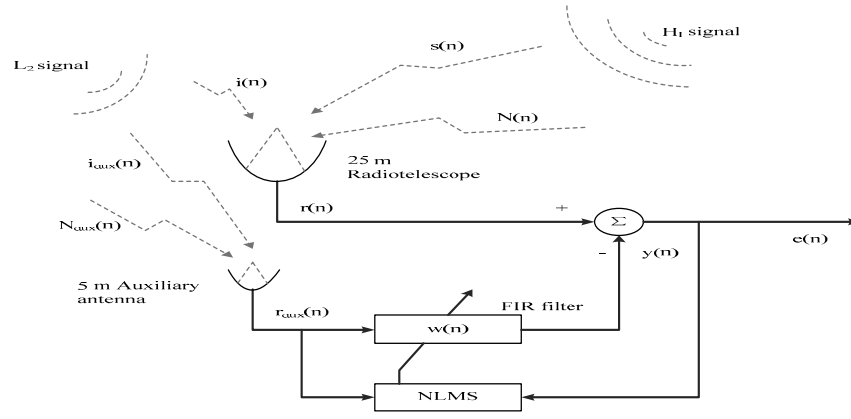


Fig1. The schematic of the NLMS:

- 1)  $y(n)$  is output signal of the FIR filter and evaluated by  $\mathbf{w}(n)$  and  $\mathbf{r}_{aux}(n)$ , the relationship is as follows:

$$e(n) = r(n) - \mathbf{w}^T(n) \mathbf{r}_{aux}(n) \quad (3)$$

$e(n)$  is the difference between  $r(n)$  and  $y(n)$ ,  $\mathbf{w}(n)$  is the weight vector and the length of it represents the filter order  $L$ ,  $\mathbf{r}_{aux}(n)$  is the auxiliary signal in every circulation process, which is the  $L$  number data from  $r_{aux}(n)$ , backward extracting the increasing of  $n$  step by step.

- 2) Weight vector adjustment:  $\mathbf{w}(n)$  is adjusted as follows:

$$\mathbf{w}(n+1) = \mathbf{w}(n) + \frac{\mu}{\|\mathbf{r}_{aux}(n)\|^2} \mathbf{r}_{aux}(n) e(n) \quad (4)$$

$\mu$  is the step factor and normalized by the magnitude of  $\mathbf{r}_{aux}(n)$ .

## Evaluation indicators

Define the received signals in main antenna as follows:

$$r(n) = \sqrt{G_m F(\theta_s)} s(n) + \sqrt{G_m F(\theta_i)} i(n) + N(n) \quad (5)$$

Where  $G_m$  is the main antenna gain,  $F(\theta_s)$ ,  $F(\theta_i)$  express the normalized directivity function of the radio signal and the navigation interference respectively. Denote  $s(n)$ ,  $i(n)$ ,  $N(n)$  as radio signals, navigation interference and noise before they enter the antenna.

Define

$$r_{aux}(n) = \sqrt{G_r F_r(\theta_i)} i(n+n_0) + N_{aux}(n) \quad (6)$$

as the signal in the auxiliary antenna, where  $G_r$  represent the auxiliary antenna gain and  $F_r(\theta_i)$  is the normalized directivity function of navigation interference in auxiliary antenna,  $n_0$  is the time delay and  $N_{aux}(n)$  is the auxiliary antenna noise.

In general, assume that after the anti-interference algorithm there's only changes of normalized directivity function and noise, as below:

$$r'(n) = \sqrt{G_m F'(\theta_s)} s(n) + \sqrt{G_m F'(\theta_i)} i(n) + N'(n) \quad (7)$$

assume  $G_m$ ,  $s(n)$ ,  $i(n)$  are not changed before and after the algorithm, while  $N(n)$ ,  $F(\theta_s)$ ,  $F(\theta_i)$ ,  $r(n)$  are turned into  $N'(n)$ ,  $F'(\theta_s)$ ,  $F'(\theta_i)$ ,  $r'(n)$  separately after the anti-interference algorithm.

In the computer simulation, parameters  $s(n)$ ,  $i(n)$ ,  $N(n)$ ,  $N_{aux}(n)$ ,  $G_m$ ,  $G_r$ ,  $F(\theta_s)$ ,  $F(\theta_i)$  and  $F_r(\theta_i)$  are given.

As a result, with  $s(n)$ ,  $r(n)$  and  $r'(n)$  we can get two cross-correlation functions:

$$R_{rs}(m_1) = E[r(n)s^*(n+m_1)] = \sqrt{G_m F(\theta_s)} E[s(n)s^*(n+m_1)] \quad (8)$$

$$R_{r's}(m_2) = E[r'(n)s^*(n+m_2)] = \sqrt{G_m F'(\theta_s)} E[s(n)s^*(n+m_2)] \quad (9)$$

Make time delays  $m_1=m_2=0$ , we get signal power attenuation  $G_s$ :

$$G_s = \frac{R_{rs}(0)}{R_{r's}(0)} = \frac{\sqrt{F(\theta_s)}}{\sqrt{F'(\theta_s)}} \quad (10)$$

In the same way, use  $i(n)$ 、 $r(n)$  and  $r'(n)$  we get another two cross-correlation functions:

$$R_{ri}(n_1) = E[r(n)i^*(n+n_1)] = \sqrt{G_m F(\theta_i)} E[i(n)i^*(n+n_1)] \quad (11)$$

$$R_{r'i}(n_2) = E[r'(n)i^*(n+n_2)] = \sqrt{G_m F'(\theta_i)} E[i(n)i^*(n+n_2)] \quad (12)$$

Make  $n_1=n_2=0$  and we get interference power suppression  $G_I$ :

$$G_I = \frac{R_{ri}(0)}{R_{r'i}(0)} = \frac{\sqrt{F(\theta_i)}}{\sqrt{F'(\theta_i)}} \quad (13)$$

It can be seen that  $G_s$  and  $G_I$  relate to the changes of normalized directivity functions only, thus, they are able to reflect the changes of radio signal power and interference power respectively correctly before and after the anti-interference algorithm, moreover they can be used to verify the performance of the algorithm at the same time.

## Results of Matlab emulation

$L$  is the filter order, through multiple simulations, when  $L=2$ ,  $\mu=0.01$  the inhibitory effective of  $L_2$  is rather better.

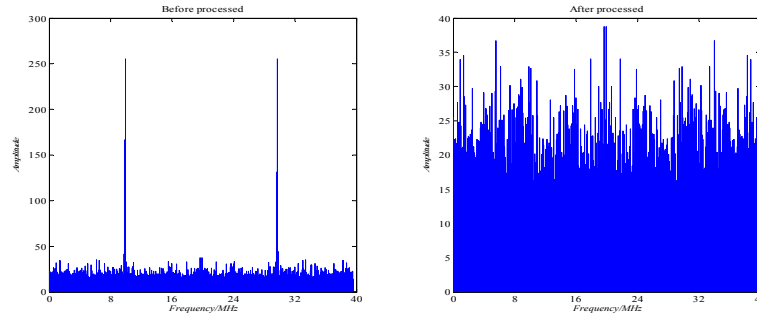


Fig 2. The power spectrum of received signal before and after the NLMS

Fig 2.depicts the power spectrum of received signal in main antenna in the left picture and the 100 average value of power spectrum disposed the interference by the Monte-Carlo method in the right. The simulation result shows that  $G_s=0.11\text{dB}$ ,  $G_I=21.55\text{dB}$ .

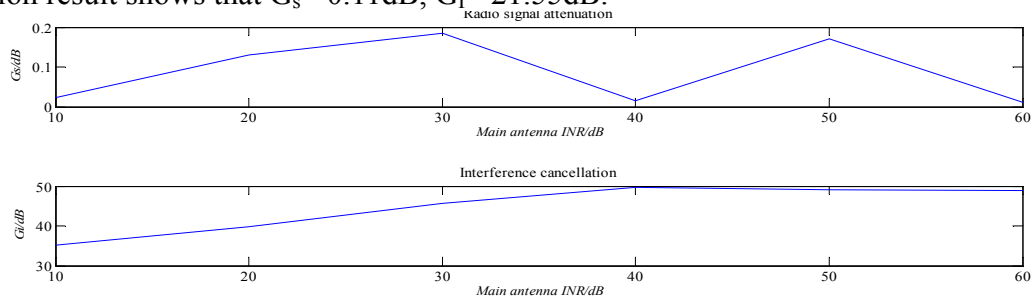


Fig 3. Trends of  $G_s$  and  $G_I$  with the main antenna INR increasing

Fig 3.respectively shows the change of  $G_s$  and  $G_I$  with the step-by-step increasing of main antenna INR, obviously,  $G_s$  is basically constant. Comparing to  $G_s$ ,  $G_I$  is improving with the increasing INR value, and when INR reaches 40dB,  $G_I$  is basically stable.

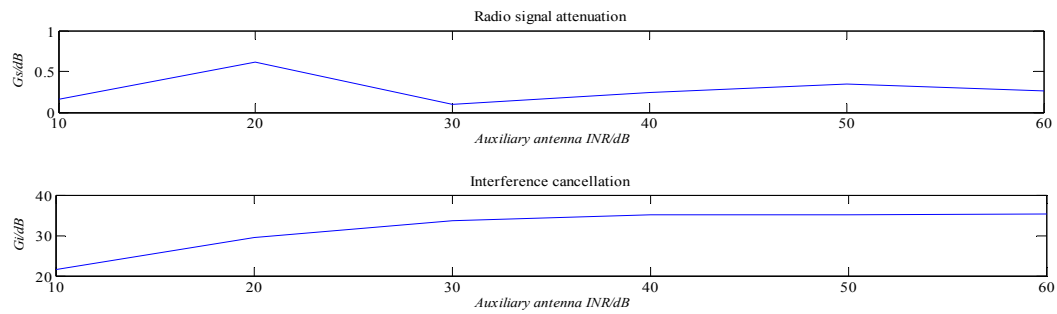


Fig 4. Trends of  $G_s$  and  $G_I$  with the auxiliary antenna INR increasing

Fig 4. respectively shows the change of  $G_s$  and  $G_I$  with the step-by-step increasing of auxiliary antenna INR, relatively,  $G_s$  is basically unchangeable,  $G_I$  is raising with INR, and when INR approaches 40dB,  $G_I$  is generally stable.

## Conclusions

This paper proposed some new evaluation criteria,  $G_s$  and  $G_I$  by modeling the processing of received signal from the 25-meter cassegrain antenna in Xinjiang Observatory with single-auxiliary-antenna ANC. It verified cancellation performance of the method that apply NLMS algorithm on navigation signal, and also showed that the algorithm has a lower damage on radio signal, but the suppression performance for interference is reduced as small INR of signal from main antenna. Therefore, we can improve the performance of the algorithm by slightly increasing the INR of the auxiliary antenna.

## References

- [1] GLONASS GLOBAL NAVIGATION SATELLITE SYSTEM GLONASS INTERFERENCE CONTROL DOCUMENT. Edition 5.1.2008.
- [2] K.Rohlf T.L.Wilson, Biwei Jiang . SHE DIAN TIAN WEN GONG JU [M]. Beijing Normal University Publishing House. Apri, 2010.
- [3] Xuelel Chen, Huli Shi. Tianlai project: Radio detection of dark energy and square kilometer array (SKA) [J]. Physical. 42. Vol. 2013 No. 1, P 2-p 11.
- [4] G.Hellbourg<sup>1,2</sup>, T.Trainini<sup>3</sup>, R.Weber<sup>1,4</sup>, E.Moreau<sup>3</sup>, C.Capdessus<sup>4</sup>, A.J.Boonstra<sup>2</sup>. RFI SUBSPACE ESTIMATION TECHNIQUES FOR NEW GENERATION RADIOTELESCOPES 20th European Signal Processing Conference. 2012. p200-p204.
- [5] Andre Gilloire, Herve Sizun. RFI mitigation of GNSS signals for radio astronomy: problems and current techniques [J].Ann.Telecommun.2009.p625-p638.
- [6] Chowdhury M.R. Shahriar. MITIGATION OF INTERFERENCE FROM IRIDIUMSATELLITES BY PARAMETRIC ESTIMATION AND SUBTRACTION.2006.
- [7] ITU-R P.676-9 Recommendation: radio wave attenuate in atmospheric gases.
- [8] Brian D. Jeffs and Karl F. Warnick Spatial Array Processing Methods for Radio Astronomy RFI Mitigation 2013 IEEE.
- [9] ITU-R RA.2126-1: Techniques for mitigation of radio frequency interference in radio astronomy. 2013. P10-P11.
- [10] Michael Elmer, Brian D. Jeffs; Beam Former Design Methods for Phase Array Feeds. International Workshop on Phased Array Antenna Systems for Radio Astronomy. May 4, 2010. Provo, Utah, USA.