



Reduction of Radio Frequency Interference in 1.42 GHz Hydrogen Line Observations Using LMS Adaptive Filtering and MATLAB Implementation

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Abstract

Radio telescopes are crucial for astronomical observations, enabling the study of celestial phenomena via radio waves. However, urban environments pose challenges due to radio frequency interference (RFI) from artificial sources, degrading the signal-to-noise ratio (SNR) and affecting the detection of the 1.42GHz hydrogen line. This study introduces a method to enhance the performance of a 5-m radio telescope developed at Princess Nourah University (PNU), focusing on the 1.42 GHz spectral line of neutral hydrogen (HI) by mitigating RFI. Using an omnidirectional reference antenna to capture interference and a directional main antenna to record both astronomical signals and interference, adaptive filtering with LMS algorithm in MATLAB was employed to clean the data. Results demonstrated significant noise and interference reduction, improved SNR, and clearer spectral features of the hydrogen line in both time and frequency domains. This efficient, low- complexity approach confirms its efficacy for real-time RFI cancellation in urban radio telescope applications, enabling more accurate analysis of space signals.

Introduction

Radio telescopes are fundamental tools in astronomy, enabling the detection and examination of celestial gadgets emitting radio waves. Unlike optical telescopes, which rely upon seen light, radio telescopes can have a look at the universe irrespective of climate situations and offer insights into phenomena that are invisible in different wavelengths, This particular functionality makes radio astronomy a useful device in exploring the cosmos.However,radio telescopes suffer from radio interference (RFI), which affects the quality of received astronomical signals, especially in urban environments containing many artificial sources such as Wi-Fi networks, communication towers, and electronic devices. This interference weakens the signal-to-noise ratio (SNR) and makes the hydrogen line (1.42 GHz) analysis inaccurate. In this study, we target to Improve a 5-m radio telescope developed at Princess Nourah University (PNU), focusing on the 1.42 GHz spectral line of neutral hydrogen (HI) by improving the quality of the astronomical signal by removing environmental radio interference using an omnidirectional antenna that captures only the interference.

System Model

1.System Architecture and Hardware Setup :

The main channel captures astronomical signals and environmental noise using a 5-meter parabolic dish, amplified by an LNA and digitized via a HackRF One. In the reference channel captures only noise using an omnidirectional antenna (0.5–1 m from the dish), with similar amplification and RTL-SDR digitization. And the channels operate at 1.42 GHz with synchronized sampling.

2. Data Acquisition and Synchronization:

IQ data from both channels are recorded simultaneously. And synchronization in time and frequency is important to enable accurate adaptive filtering.

3. Signal Processing and Adaptive Filtering:

In MATLAB, an LMS filter uses the reference noise to estimate and cancel interference from the main signal. In the filter updates coefficients in real time, enhancing the clean signal.

4. Performance Evaluation:

SNR is measured before filtering and after filtering. Time-frequency plots, along with PSD comparisons, confirm and demonstrate reduced frequency interference and improved signal clarity.

Proposed Solution / Main Idea

To improve how clearly the 1.42 GHz hydrogen line is detected, a smart and practical method is used. A small reference antenna, which can receive signals from all directions, is placed to capture only the unwanted radio signals (called interference) caused by the surrounding environment such as Wi-Fi networks, communication towers, and electronic devices. At the same time, a main directional antenna is aimed at the sky to receive both the weak space signal and the same interference. These two signals are then sent to MATLAB, where a special type of filter is applied called LMS, which stands for Least Mean Squares. This filter is adaptive, meaning it learns and keeps updating itself while comparing the two signals. The goal of the filter is to understand the pattern of the interference and subtract it from the main signal, leaving the useful space signal cleaner. As the LMS filter works, it improves the signal quality by increasing the signal-to-noise ratio (SNR). A higher SNR means the important hydrogen signal becomes easier to detect and analyze. This is especially important in places like cities, where there's a lot of interference in the air. Using this method helps us study space signals more clearly, even in noisy environments.

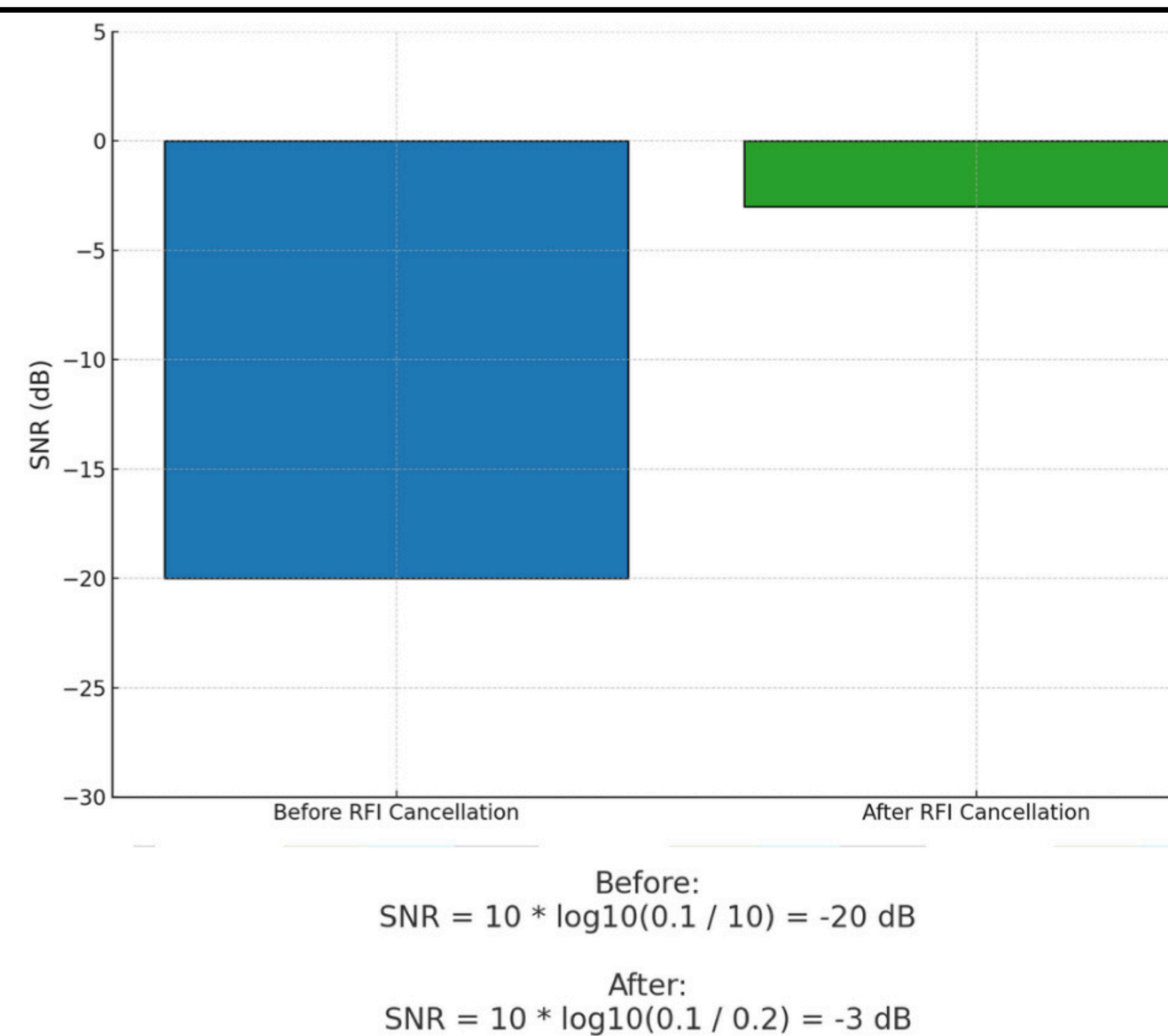


Chart 1. Theoretical SNR Improvement After Adaptive RFI Reduction

Results

The LMS algorithm was applied to a contaminated radio signal, effectively reducing Gaussian noise and revealing the revealing the underlying hydrogen spectral features. Using a correlated reference input, the filter minimized the error and improved the signal-to-noise ratio (SNR), enhancing detection of the 1.42 GHz hydrogen line. The filtered output showed clearer signal features in both time and frequency domains, as illustrated in Figure 1. MATLAB simulations confirmed LMS as a real-time, low-complexity solution for mitigating radio frequency interference in dynamic environments.

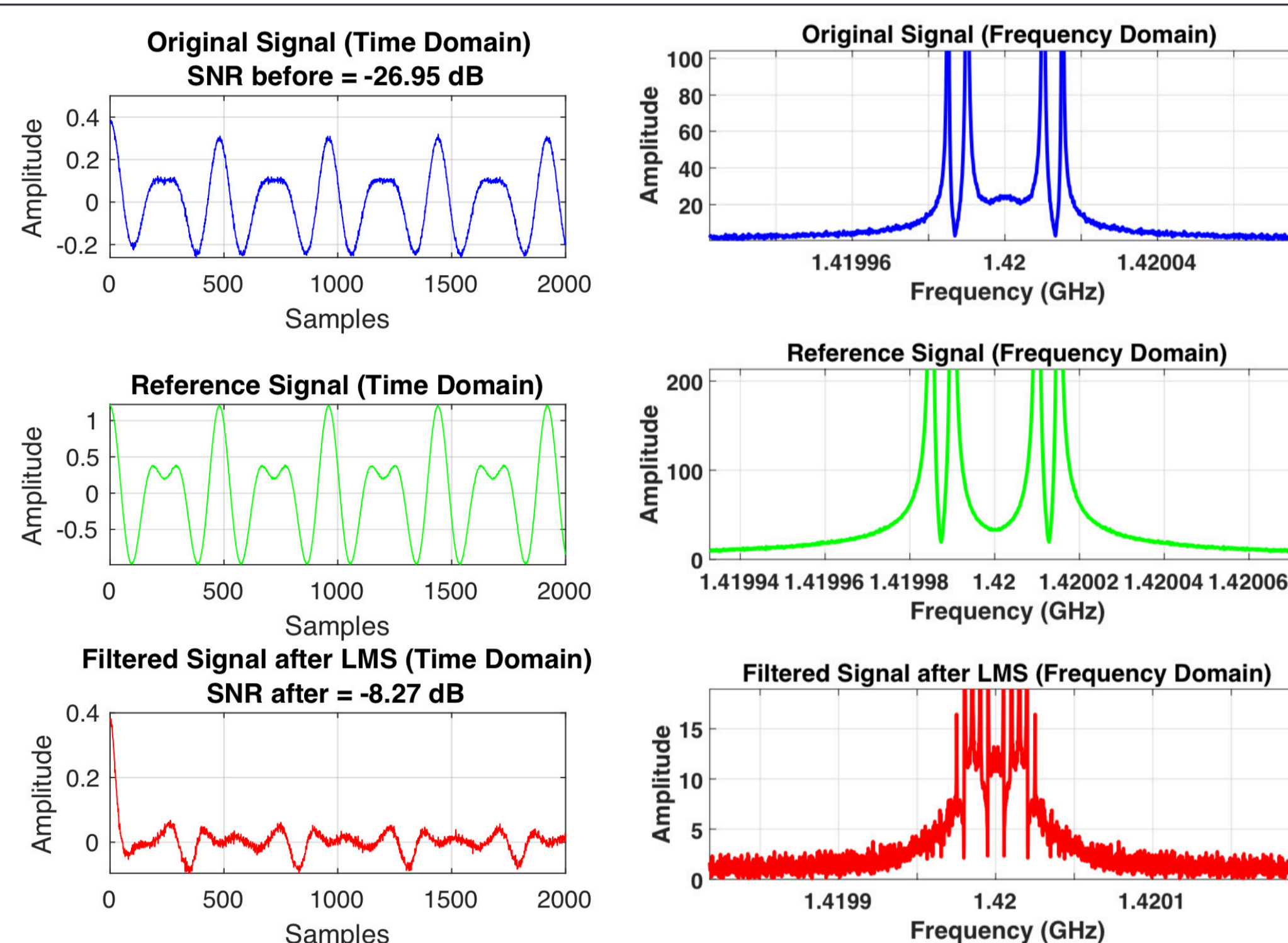


Figure 2. Interference Suppression Using LMS in Hydrogen Line Observations

Conclusions

A significant improvement in the clarity of the 1.42 GHz hydrogen line was achieved by reducing radio interference using an external reference antenna and adaptive LMS filtering. MATLAB simulations showed a clearer spectral response and substantial noise reduction. The results confirm the effectiveness of LMS in real-time RFI Reduction for radio astronomy in noisy environments. This enables more accurate and reliable analysis of astronomical signals using radio telescopes. Power density S and electric field E were calculated to assess RFI strength relative to the astronomical signal, as SNR alone does not provide this insight. These metrics validated the performance of the omnidirectional antenna and the accuracy of LMS-based interference reduction.

Power Density (Poynting Vector Magnitude): $S = \frac{P_{\text{signal}}}{A} = 1.146 \times 10^{-4} \text{ W/m}^2$

Electric Field Strength: $E = \sqrt{S \cdot \eta} = 0.2077 \text{ V/m}$ $\eta=377 \Omega$ is the intrinsic impedance of free space.

For Reference



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