Radio Frequency Observations of Jupiter-Io Interactions and Molecular Clouds with PNU's Telescope

Joud AlGhumaiz, Wujud AlZamil, Sahar Al-dowsari, Lubna Al-dowsari, Latifa Al-Otaibi, Rahaf Al-buraih, Yara Albaiz, Ghala Alshehri, Razan Aladdal, Supervisor Prof.Yazan Allawi

Department of Electrical Engineering, College of Engineering, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia

Abstract

This project aims to enhance PNU's 5-meter radio telescope by implementing a dual-frequency feed system capable of receiving both the 1420 MHz hydrogen line and 20–30 MHz radio bursts from Jupiter and Io. The system is designed to integrate a horn antenna for high frequencies and a dipole antenna for low frequencies at the same focal point. Signal processing is handled through the RTL-SDR Blog V4 and simulated using MATLAB.

The system is currently in the theoretical evaluation and simulation phase and is expected to expand the telescope's research and educational capabilities without requiring structural modifications.

Introduction / Background

Radio astronomy enables the study of both nearby and distant celestial sources. At Princess Nourah University (PNU), the current 5-meter radio telescope was originally designed to detect the 21 cm hydrogen line (1420 MHz) — a key emission from neutral hydrogen gas in the spiral arms of our galaxy.

However, this system is not suitable for detecting planetary radio phenomena within the solar system. To overcome this limitation, we propose a dual-frequency system capable of capturing both the radio emissions from Jupiter and its moon Io (20–30 MHz), resulting from magnetic interactions, and the traditional hydrogen line (1420 MHz) emitted by galactic molecular clouds.

To achieve this, a horn antenna is used for high-frequency signals (like HI), and a dipole antenna is added to receive low-frequency signals (like those from Jupiter). Both antennas are combined in a shared dual-feed system within the telescope's focal point. The received signals are then processed using the RTL-SDR Blog V4, after being passed through bandpass filters for precise frequency separation.

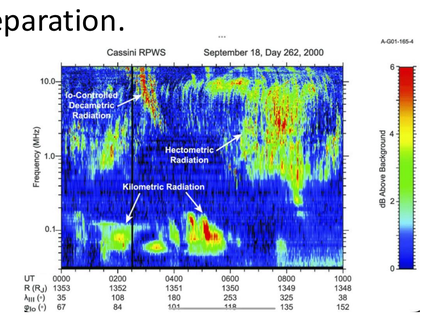


Figure 1. Jupiter-Io Signal

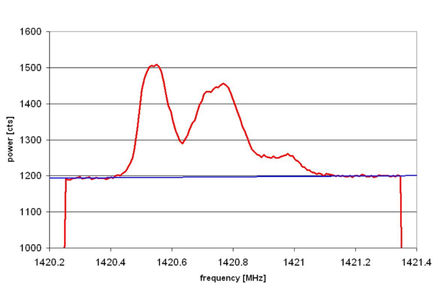


Figure 2. Hydrogen Line Signal

System Model / Methodology

The current system at Princess Nourah University's radio telescope relies on a 5-meter parabolic dish designed to receive hydrogen line (H1) signals at 1420 MHz. In this project, the system was enhanced to also detect radio emissions from Jupiter (in the 20–30 MHz range) and the spectral features of the Orion Arm, by integrating a dipole antenna and a dual-feed setup connected to the same dish. We used the RTL-SDR Blog V4 receiver for its flexibility in covering a wide frequency range, in addition to MATLAB for signal simulation and time-frequency spectrum analysis of both sources.

From a physics perspective, our analysis was based on two key equations:

- **Lossy medium EM waves assuming**

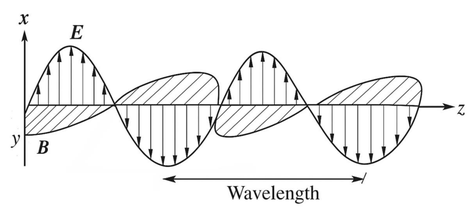
$$E(z,t) = E_o e^{-\alpha z} \cos(\omega t - \beta z) a_x$$

This equation is used to simulate the propagation of radio signals from Jupiter and the hydrogen line. It describes the wave behavior over time and distance and is used to generate signal models in MATLAB.

- **Electromagnetic wave equation**

$$\nabla^2 E = \mu \epsilon \frac{\partial^2 E}{\partial t^2}$$

Used to understand how electromagnetic signals propagate through free space.



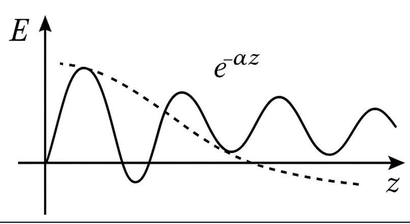


Table 1. Comparison Between Current System and Developed System.

Element	Current System	Developed System
Supported Frequencies	1420 MHz only	20 MHz (Jupiter) + 1420 MHz (HI Spectrum)
Observed Objects	HI Spectrum (Orion Arm)	Orion Arm HI Spectrum + Jupiter Pulses
Antenna Type	Horn Antenna Only	Horn Antenna (HI) + Dipole Antenna (Jupiter) on the same focal point
Signal Receiver	Conventional or limited devices	RTL-SDR Blog V4 (multi-band receiver

Proposed Solution / Main Idea

We propose a dual-feed upgrade to the existing 5-meter radio telescope at Princess Nourah University to enable simultaneous observation of two distinct astrophysical signals. The system is configured to receive the 1.42 GHz hydrogen line from molecular clouds in the Orion Arm, along with the 20–30 MHz decametric radio emissions resulting from Jupiter's magnetic interaction with its moon Io.

The design incorporates both a horn antenna and a dipole antenna positioned at the telescope's focal point. Signals from each antenna are directed to an RTL-SDR Blog V4 receiver and separated using bandpass filters to isolate the respective frequency bands. System performance was evaluated through MATLAB simulations.This configuration enhances the telescope's observational capabilities while maintaining its structural integrity and cost-efficiency.

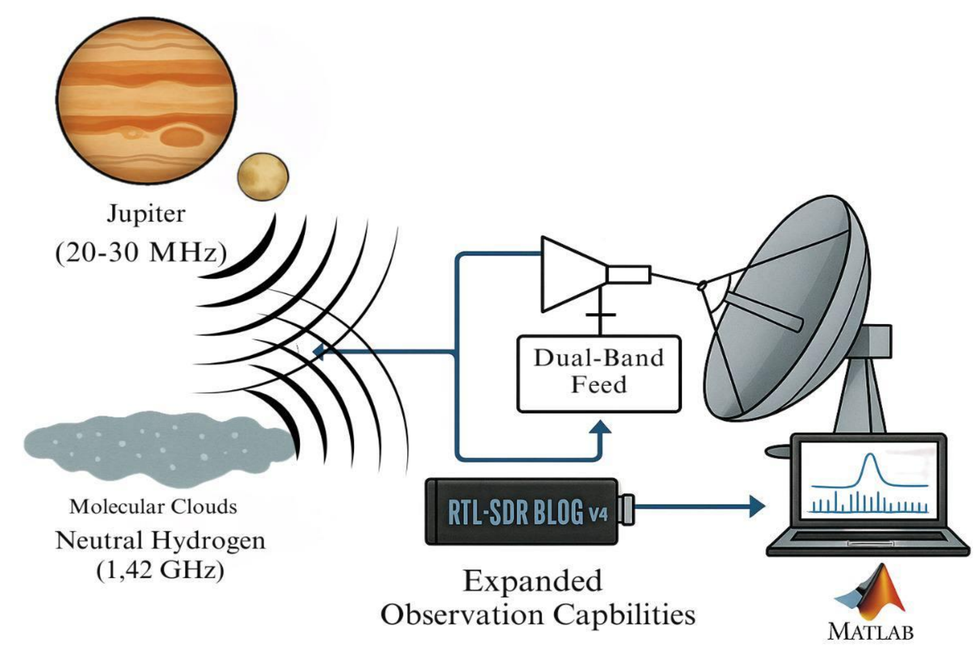


Figure 3. Dual-band system concept for receiving Jupiter and hydrogen signals

Results / Simulation / Discussion

The proposed system was evaluated by simulating two target signals: Jupiter-Io decametric emissions (20–30 MHz) and the hydrogen line at 1420.4 MHz. The results confirmed that both signals could be received and distinguished using a dual-feed setup and RTL-SDR receiver. This supports the system's ability to handle wideband, multi-source observations.

Time-domain simulations show clear differences between the two signals: Jupiter's burst-like waveform at 22 MHz contrasts with the stable hydrogen line at 10 MHz. This highlights the need for dual-band handling and selective filtering in the system design.

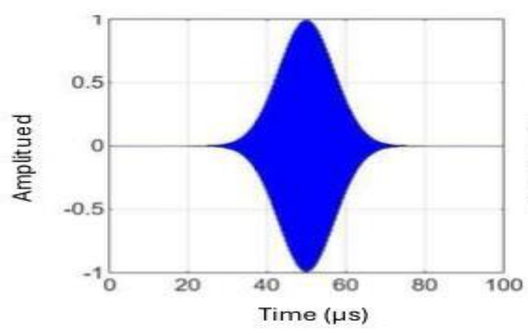


Figure 4. Simulated Jupiter-Io Signal at 22 MHz.

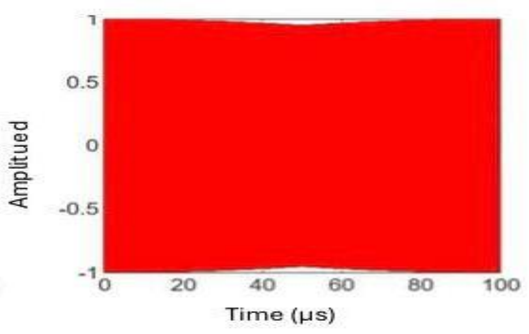


Figure 5. Simulated Hydrogen Line Signal at 10 MHz

This variation highlights the importance of separating both paths using band-specific filtering. The results confirm that a shared reflector with a dual-feed design can effectively receive both signal types, supporting the feasibility of expanding PNU's radio telescope from a single-purpose HI detector to a versatile astrophysical instrument.

Conclusions

We proposed and simulated a dual-band configuration for the radio telescope capable of capturing both planetary and galactic signals using a shared feed system. The design, which integrates a horn antenna and a dipole antenna, was validated through MATLAB simulations, showing its ability to distinguish between Jupiter–Io bursts and the hydrogen line signal. The RTL-SDR device provides a flexible and cost-effective solution. Upcoming steps will involve implementing the system in hardware and testing it on real sky signals.

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Joud S.AlGhumaiz	444009357	61T
Wujud Z.AlZamil	444000200	61T
Latifa Al-Otaibi	444000331	62O
Sahar Al-dowsari	444000085	62O
Lubna Al-dowsari	444000307	62O
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