Design of a 55-65 MHz Band Radio Astronomy Antenna Array Receiver: A Postprint

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Abstract

Low-frequency ground-based antenna arrays in the 30-300 MHz band are important radio astronomy observation facilities. Radio observations in this band face challenges such as complex radio frequency environment and high sky background temperature. This paper introduces a novel low-frequency analog receiver based on microwave chip design. The receiver comprises a primary band-pass filter (30-70 MHz), a primary amplifier, a secondary band-pass filter (55-65 MHz), a 180° phase shifter, and two secondary amplifiers. Based on tests of the short-wave radio environment at Yunnan Astronomical Observatory, the receiver achieves selection and amplification of the observable frequency band of 55-65 MHz, with an overall noise temperature of approximately 320 K and a gain of about 63 dB. Furthermore, as part of the preliminary research for the Chinese radio astronomy low-frequency array, the receiver features small size, low cost, and ease of mass production due to the adoption of Monolithic Microwave Integrated Circuit (MMIC) chips.

Full Text

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Abstract

Ground-based antenna arrays operating in the very high frequency (VHF) band (30-300 MHz) are important instruments for radio astronomy observations. However, observations in this band must contend with complex radio frequency environments and high sky background temperatures. This paper presents a novel low-band analog receiver design based on monolithic microwave integrated circuit (MMIC) technology. The receiver comprises a primary bandpass filter, a primary amplifier, a secondary bandpass filter, a 180-degree phase shifter, and two secondary amplifiers. Based on radio environment measurements conducted at the Yunnan Observatory site, the receiver achieves bandpass filtering and amplification for the 55-65 MHz observation band. The system noise temperature is approximately 320 K, with a total gain of about 63 dB. As part of China' s low-frequency radio astronomy network development, the MMIC-based design offers advantages of compact size, low cost, and ease of mass production.

Keywords: low frequency band; MMIC chips; analog receiver

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1. Introduction

Celestial electromagnetic radiation provides crucial information about the physical characteristics and states of astronomical objects. Radio observations represent an essential tool for studying solar, planetary, and extra-solar system phenomena. Low-frequency radio emissions below 80 MHz offer abundant information about planetary radio bursts and magnetospheric processes within the solar system, while also enabling unique observations of extra-solar objects. The low-frequency band is not merely a simple extension of currently observable electromagnetic spectrum but represents a region of major scientific significance that remains largely unexplored with adequate spatial resolution, leaving our understanding of the universe in this frequency range essentially blank. Numerous astronomical phenomena can only be detected at low frequencies, with anticipated scientific targets including low-frequency Jovian ionospheric and magnetospheric radiation, low-frequency pulsar emissions, solar coronal mass ejections (CMEs) and radio bursts, large-scale high-resolution mapping of Galactic low-frequency emission, surveys of ionized hydrogen distribution, and studies of transient source variability.

Low-frequency observations are particularly valuable for solar physics. CMEs represent magnetically confined plasma ejections that generate shocks when their velocity exceeds the local Alfvén speed, producing special shock acceleration and cyclotron resonance radiation. Radio imaging observations of the associated thermal and non-thermal emissions provide powerful tools for realtime monitoring of CME initiation and early evolution. Low-frequency imaging can reveal the precise relationship between Type II and Type III bursts and CMEs or shock waves, potentially resolving whether electron beams are accelerated by flares or shocks. When combined with optical observations, these measurements can produce a magnetohydrodynamic picture of shock-jet structures and determine the relative positions of CMEs or blast waves. Since radio observations are sensitive to plasma radiation and non-thermal gyrosynchrotron emission from energetic electrons, they represent the best method for identifying when and where coronal energy release occurs. Spectral imaging of Type II and Type III bursts can also trace electron beam trajectories, providing crucial diagnostics for solar energetic particle events. Furthermore, solar low-frequency arrays can monitor high-energy electrons, coronal shocks, and magnetic field structures within 0.5–2.5 solar radii, offering quantitative estimates of coronal parameters and providing the most direct basis for space weather forecasting several days before geomagnetic storms.

However, low-frequency radio astronomy faces significant technical challenges. The sky background temperature is extremely high in this band, often reaching thousands to tens of thousands of Kelvin, making it difficult to achieve required sensitivities with single antennas. Additionally, the radio frequency interference (RFI) environment is severe, particularly from shortwave communications. Increasing the effective collecting area through array configurations becomes essential. International efforts in low-frequency radio astronomy have been limited, with only a few observatories conducting routine observations, such as Ukraine' s UTR-2, the Nançay Observatory in France, Tohoku University' s low-frequency interferometer, and stations in Florida and Hawaii. Current facilities, including the Low-Frequency Array (LOFAR) and the Square Kilometre Array (SKA), provide broadband low-frequency capabilities but have not yet achieved the sensitivity needed to develop comprehensive models for solar CME radio emission or Jovian radiation mechanisms. Systematic interferometric observations remain under development. Consequently, establishing an independent ground-based low-frequency radio observation network in China holds major strategic importance.

2. Radio Environment Measurements at Yunnan Observatory

The Yunnan Observatory site is located in the eastern suburbs of Kunming, Yunnan Province. Radio frequency interference represents an unavoidable challenge for observations in this band. To characterize the environment, we conducted tests using existing low-band dipole antennas. The results for 0–140 MHz are shown in [Figure 1: see original paper]. The primary interference sources within the band are summarized in for 75–110 MHz and for 10–30 MHz. Several strong signals near our observation band include carriers at 77.0 MHz, 81.2 MHz, 88.5 MHz, and 91.8 MHz, with power levels ranging from -67.47 dBm to -32.99 dBm (measured with RBW = 30 kHz, Atten = 0 dB, avg = 0). In the 10–30 MHz range, strong interference appears at 23.1 MHz, 21.4 MHz, 17.5 MHz, 15.4 MHz, 13.6 MHz, and 11.5 MHz.

3. Receiver Design

To avoid FM broadcast and long-wave station interference while accommodating the high sky noise background and uncertain radio environment, we developed a receiver architecture as shown in [Figure 2: see original paper]. The design employs a two-stage filtering approach with wideband initial selection followed by narrowband filtering. Key specifications include:

1. Primary bandpass filter (BPF-C45+, 30–70 MHz) with 0.44 dB insertion loss at 60 MHz
2. Primary amplifier (Gali-74+ MMIC) providing 25.1 dB gain at 100 MHz with high linear dynamic range
    - Output 1 dB compression point: +18.0 to +19.2 dBm
    - Third-order intercept point: +38 dBm
    - Noise figure: 2.7 dB at 100 MHz (2.16 dB at 60 MHz)
3. Secondary bandpass filter (BPF-A60+, 55–65 MHz) with excellent out-of-band rejection
4. 180-degree phase shifter (T1-1-KK81+) for balanced-to-unbalanced conversion
5. Secondary amplifiers (Gali-74+) providing additional gain

The overall system gain is 63 dB with a total noise figure of approximately 3.2 dB, corresponding to a noise temperature of about 316 K. summarizes the component specifications.

To ensure subsequent amplifiers would not saturate, we analyzed the strongest interfering signals after the first filter stage. As shown in , all out-of-band signals are suppressed below the noise floor of -83 dBm, with the 77 MHz interference attenuated sufficiently to prevent saturation.

4. Implementation and Testing

The circuit schematic designed using Protel 99 SE is shown in [Figure 3: see original paper], with the assembled board in [Figure 4: see original paper]. The measured passband response appears in [Figure 5: see original paper], demonstrating a flat gain of 63.56–63.93 dB across 55–65 MHz ($±$0.3 dB variation). Out-of-band interference is suppressed by more than 30 dB, with the 77 MHz carrier attenuated by 25 dB. No saturation was observed when connecting the receiver to antennas.

Preliminary observations using the receiver connected to antennas show effective suppression of radio interference and clear detection of astronomical signals in the 55–65 MHz band [Figure 6: see original paper].

5. Conclusion

The Yunnan Observatory low-frequency antenna array project has completed initial construction, including two sub-arrays at the observatory headquarters and one sub-array at Yunnan University' s Chenggong campus. The next phase will involve tracking observations and dual-station interferometry experiments. The MMIC-based 55-65 MHz receiver design successfully meets the requirements for low-frequency radio astronomy, providing a foundation for China' s ground-based low-frequency observation network.

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Note: Figure translations are in progress. See original paper for figures.