Simulations and Tests of Prototype Antenna System for Low Frequency Radio Experiment (LORE) Space Payload for Space Weather Observations

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Abstract. Low frequency Radio Experiment (LORE) is a proposed space payload for space weather observations from space, operating between few kHz to 30 MHz. This paper presents preliminary design and practical implementation of LORE antenna systems, which consist of three mutually orthogonal mono-poles. Detailed computational electromagnetic simulations, carried out to study the performance of the antenna systems, are presented followed up by laboratory tests of the antennas as well as radiation tests with a long range test range, designed for this purpose. These tests form the first phase of the design and implementation of the full LORE prototype later in the year.

1. Introduction
Low frequency Radio Experiment (LORE) is a proposed space payload for high-time resolution and high-frequency resolution space weather observations from space, operating between few kHz to 30 MHz. Its main scientific objective is to study the propagation of coronal mass ejections (CMEs) from the Sun using Type II and Type III bursts as probes in conjunction with ground based facilities, such as Ooty Radio Telescope (ORT), which are already part of the space weather monitoring program. The proposed design consists of three mutually orthogonal mono-pole antennas of 5-m length mounted on one side of spacecraft. Digitized signals from these antennas, sampled at 1 ms time resolution and 30 kHz or more frequency resolution, are proposed to be correlated on-board to perform gonio-polarimetry, which will allow simultaneous direction finding and polarization measurements for Type II and Type III bursts during solar energetic events.

2. Antenna System Design and Simulations
In this project, simulations and tests were carried out for a scaled design at 70.9 MHz to validate the simulation results, primarily because we have license for radiation tests at this frequency at Ooty. The design is later proposed to be scaled to 0–30 MHz for the actual payload. In the 70-MHz design, computational electromagnetic simulations, using Computer Aided Design
package (CADFEKO)\(^1\) were carried out to get as uniform a sensitivity as possible from the antenna system, a reasonable directional beam and as high gain as possible. The proposed antenna configuration for LORE to carry out direction finding and polarization measurements simultaneously is pictorially shown in Figure 1 and it is similar to that used in a previous solar mission \([1]\).

Figure 2 shows the 3-dimensional simulated beam pattern for the system with excitation to one mono-pole and the ground plane. The simulations were verified against test results (refer to Section 3) conducted in a test range designed by us. Due to large size on the antenna configuration, measurement of the beam pattern was possible in the azimuthal coordinate only. A comparison between the simulated beam pattern and test results in the azimuthal coordinate for the system with excitation to one monopole and the ground plane is shown in Figure 3. The test result is consistent with the simulated beam pattern (with a reduced chi-square value of \(\sim 3\)). However, the simulated and practical radiation patterns are slightly different, which is probably due to the finite ground plane, lossy antenna electrical connections, pickups from human body, small antenna height (1.2 m) from ground and so on.

Figure 4 shows the simulated beam for all the three monopoles excited as a phased array. As an alternative to ground plane, simulation for one excited mono-pole with three parasitic \textit{star-shaped} mono-poles, was also carried out and tested in practice. We have simulated the model for excitations with varying phase difference demonstrating that gonio-polarimetry can be performed by combining different directional information from three monopole antennas with proper phase shift.

The antennas, optimized after simulations, were then fabricated at NCRA-TIFR and these

\(^1\) \url{https://www.feko.info}
practical implementations were tested with a vector network analyser (VNA). The results obtained in VNA tests are also plotted in Figure 5 along-with the simulated results and they show a close match validating the simulations.

3. Field Tests

Field trials with a temporary test range, designed by us, were carried out at the Radio Astronomy Centre, Udhagamandalam, to validate the other results from the simulations. A test range consists of instruments like antennas, transmitting and receiving systems, positioning system and recording system. There are different types of ranges such as the elevated range, the slant range, the compact range, and test ranges in an anechoic chambers. We used a modified version of slant and elevated range for our field tests [2].

The location chosen was Udhagamandalam (Ooty) as the hills in Ooty naturally provide elevation to avoid ground reflections and field tests can be carried out over several kilometres due to large distance between the hills. The radiating antenna in the test range was put on top of a hill at Kollaribeta, whereas the receiving antenna was located near the Radio Astronomy Centre of NCRA-TIFR at Ooty. The distance between these two stations is approximately 10 km. The schematic of the test range is shown in Figure 6.

A signal generator with 20 dBm power output was used for excitation, whereas a hand-held spectrum analyzer with a noise floor of -80 dBm was used for measurement of received signal. We simulated, fabricated and tested several types of antennas for our test range, namely a simple dipole, dipole with a reflector and a Yagi-Uda antenna [3]. The comparison of antenna parameters from the simulation of these different types of antennas using CAD-FEKO is shown.

| Antenna       | Antenna Impedance (ohm) | Reflection Coefficient (dB) | Gain | 3-dB Beam Width (Azimuth Plane) | -10 dB Bandwidth (MHz) |
|---------------|--------------------------|----------------------------|------|---------------------------------|------------------------|
| Half-wave Dipole | 69.64                    | -15.51                     | 1.63 | 78.75                           | 5.58                   |
| Reflective Dipole      | 42.90                    | -20.75                     | 4.41 | 69.22                           | 4.171                  |
| 4 Element Yagi-Uda Antenna | 51.05                  | -39.03                     | 7.39 | 60.67                           | 7.55                   |

Table 1: Parametric Chart of the tested antennas
Figure 6: Antenna test range schematic.

Figure 7: Radiation pattern of the Yagi-Uda antenna.

in Table 1. Yagi-Uda antenna was eventually chosen for field test due to its high directivity and bandwidth. All antennas were adjusted for an input impedance of 50 ohms. First Yagi-Uda antennas were placed on both transmitting and receiving end and their beam pattern were obtained by rotating the receiving element with 10 degree steps. These are shown in Figure 7, along with the results from CAD-FEKO simulations. The obtained pattern was used in the deconvolution to obtain the pattern for the payload antenna systems. Then, the three-monopole antenna system was tested by keeping the source antenna was as Yagi-Uda antenna and the monopole antenna system as receiver.

In order to calculate the power received or the gain of the antennas, we use Friis Transmission Equation, which is,

\[ P_r = P_t + G_t + G_r + 20 \log_{10}(\frac{\lambda}{4\pi R}) - \text{loss} \]  

where \( G_t \) and \( G_r \) are the antenna gains (with respect to an isotropic radiator) of the transmitting and receiving antennas respectively, \( \lambda \) is the wavelength, and \( R \) is the distance between the antennas. From the experimentally measured values (\( P_r = -56.5 \text{ dBm}, \ P_t = 20 \text{ dBm}, \ G_t = 7.39 \text{ dB}, \ R \approx 10 \text{ km}, \ \text{and} \ \lambda = 4.28 \text{ m} \)), we obtain \( G_r = 5.5 \text{ dB} \), for the monopole configuration, proposed to be used for LORE.

4. Conclusions and Future Work

Satisfactory match between the simulations and field tests were obtained for the proposed three monopole system for LORE, with antenna scaled to 70.9 MHz for ease of testing. This provides confidence in design for 0–30 MHz antenna systems with the computational electromagnetic platform. This is important as good field tests at this frequency range will be difficult and challenging and reliance on computational electromagnetic simulation is critical. The design for 0–30 MHz antenna configuration is currently in progress. The monopole design is well suited for space applications as monopole with high stiffness can be made from rolled shape memory alloy providing a very low stow volume and low weight. Nevertheless, alternative 0–30 MHz antenna designs are also being explored.

Acknowledgments

This work utilized support from XII plan grant TIFR-12P0716.

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