Low Frequency Radio Experiment (LORE)

P. K. Manoharan¹,², Arun Naidu², B. C. Joshi², Jayashree Roy², G. Kate², Kaiwalya Pethe³, Shridhar Galande³, Sachin Jamadar³, S. P. Mahajan³, R. A. Patil³

¹ Radio Astronomy Centre, National Centre for Radio Astrophysics (TIFR), Ooty, India
² National Centre for Radio Astrophysics (TIFR), Pune, India
³ Department Of Electronics and Tele-Communication, College of Engineering, Pune, India

E-mail: mano@ncra.tifr.res.in

Abstract. In this paper, we present a case study of Low Frequency Radio Experiment (LORE) payload to probe the corona and the solar disturbances at solar offsets greater than 2 solar radii, i.e., at frequencies below 30 MHz. The LORE can be complimentary to the planned Indian solar mission, “Aditya-L1” and its other payloads as well as synergistic to ground-based interplanetary scintillation (IPS) observations, which are routinely carried out by the Ooty Radio Telescope. We discuss the baseline design and technical details of the proposed LORE and its particular suitability for providing measurements on the detailed time and frequency structure of fast drifting type-III and slow drifting type-II radio bursts with unprecedented time and frequency resolutions. We also brief the gonio-polarimetry, which is possible with better-designed antennas and state-of-the-art electronics, employing FPGAs and an intelligent data management system. These would enable us to make a wide range of studies, such as nonlinear plasma processes in the Sun-Earth distance, in-situ radio emission from coronal mass ejections (CMEs), interplanetary CME driven shocks, nature of ICMEs driving decelerating IP shocks and space weather effects of solar wind interaction regions.

1. Introduction

Number of outstanding problems in solar physics demand a much deeper understanding and require the quantitative knowledge of the structure and evolution of active regions, flares, filaments, coronal mass ejections (CMEs), and formation and flow of solar wind at heights above the photosphere and their consequences in the heliosphere. Such studies are important for an improved understanding of solar eruptions and the ‘Sun-Earth’ connection events, i.e., space weather effects at the Earth or elsewhere. The proposed Aditya-L1, the first Indian space solar coronagraph, aims to provide unique observables of direct relevance to the understanding of physical processes at the near-Sun region below 2 solar radii. The low frequency radio measurements (~20 kHz to below 30 MHz) at farther heights are to study the complex relationship between CMEs, prominences, interplanetary shocks, radio emissions (fast drifting type III and slow drifting type II radio bursts), and associated nonlinear processes in the inner heliosphere. Such measurements as a function of time or distance from the Sun and their corresponding CME track observed with the Ooty IPS will be useful to understand the shock acceleration of particles in front of the CME.
2. Scientific Objectives

A high-sensitivity low-frequency radio instrument (covering ∼20 kHz to 30 MHz) is essentially required for the understanding of complex relationship between various solar and interplanetary phenomena, as well as their related micro-processes. The lower part of this waveband (below 20 MHz) is reflected by the ionosphere and hence cannot be observed from Earth. Most of the low-frequency radio emission is due to coherent plasma processes and it is closely related to the plasma frequency/density of the solar wind through which the electron beam propagates. Since the plasma density decreases away from the Sun, the plasma frequency also decreases (as $\sqrt{N_e}$), hence radio emission at longer wavelength originates at greater distances from the Sun. At the above frequency range, a rich variety of radio bursts of solar origin can be observed that trace particles produced by energetic phenomena through the solar corona and in the interplanetary medium. Additionally, observations of kilometric waves are valuable to infer processes, such as (i) generation of radio waves, (ii) cascade of plasma turbulence, (iii) reconnection at flux-tube boundaries, (iv) acceleration of particles, etc.

The LORE aims at a high sensitivity radio instrument to address the issue of using radio signals as the potential probe to study the onset and lift-off of CMEs and associated solar processes, such as prominences, shocks, electron acceleration (variety of radio bursts). Some of the key science objectives of the LORE payload are:

(i) **Nonlinear plasma processes**: LORE can address the nonlinear plasma processes in beamed plasma and collisionless shock propagation in the solar wind, and their link to the excitation mechanism of radio emissions. It will allow the high time/frequency resolution observations of in-situ data in the vicinity of CME driven shocks and in the source regions of type III radio bursts along with the Ooty IPS measurements.

(ii) **CME in-situ radio emission**: The detection of weak radio spectral emission near the local plasma frequency (i.e., plasma line) by LORE can be extremely useful to obtain information on electron density and temperature, particularly when a CME passes through the LORE antennas. It will also enhance our understanding on the relationship between waves generated within the CME and in its front.

(iii) **Remote probe of Interplanetary CME-driven phenomena**: Shocks produced by CMEs are efficient accelerators of energetic particles especially close to the Sun. However, their impact at 1 AU is still not negligible and can compress the Earth’s magnetosphere moving the radiation belts to lower altitudes. Despite decades of observations on these critical heliospheric structures, much is still unknown. For example, the study by Manoharan et al. [1] combined the radio and interplanetary measurements and provided the first time report of tracking of the Bastille Day event all the way from the atmosphere of the Sun to 1 AU [1,2]. However, it lacked in giving details of structures within the ICME. The LORE observations would contribute to the significant advances in this field. The sensitive low-frequency radio spectrum will be useful to track the shock produced by the CME and to link the flux of solar energetic particle acceleration site along the “Parkar (Archimedean) spiral” of the interplanetary magnetic field.

As a complementary payload on Aditya-L1 mission, the low-frequency solar radio spectral instrument, LORE, is not only limited to the above scientific objectives, but can also serve in various studies to understand the physical processes of the solar transients and their associated interplanetary phenomena.

3. Baseline Design

As mentioned in the previous section, the primary aim is to obtain high temporal and frequency resolutions of the radio emission generated in association with the type II and III solar radio bursts below 30 MHz. Observations will be accomplished using three non-planar mutually orthogonal monopole antennas mounted at an angle of 45° to the spacecraft.
Figure 1. Block diagram of the required signal processing and electronics systems

either in the Sun-ward or in the anti-Sun-ward direction. A combination of measurements from the three-antenna system in a three-axis stabilized spacecraft has been shown to provide measurements of four Stokes parameters and two direction coordinates of the burst [3]. The three-antenna configuration has been chosen for implementation of direction finding along with the polarimetry of the burst emission.

For the given frequency range of LORE, the monopoles proposed to be employed for this purpose are short dipoles of 7-m length. A scaled version of the antenna operating at 70-MHz has been developed by us recently (refer to Pethe et. al., this issue) and computation of electromagnetic simulations are currently in progress for the final prototype. An attempt to optimize this antenna configuration with detailed electromagnetic simulation is being carried out to obtain the uniform sensitivity and gain over the entire 30 MHz bandpass. It may be noted that previous missions lacked such a uniformity across the bandpass. Each antenna will be fabricated from heat treated tightly rolled Be-Cu sheets.

One of the important challenging aspects of the radio astronomy is the sampling of large bandwidth and processing on short time scales. The current technology allows direct digitization of entire band with 60 Msamples/sec sampling and synthesis of channels with required time and frequency resolutions with digital signal processing. This will allow the experiment to have much superior time and spectral resolutions than the previous missions allowing high quality observations motivated by our science goals. We also propose an electronics design using new technologies to provide greater flexibility and larger number of observing modes than the previous experiments. Such routine sampling is already employed in the Ooty Radio Telescope and the GMRT for pulsar studies [4]. The required signal processing has already been implemented for the above ground-based telescopes and is being suitably modified for the signal processing required for our payload and be ported on space qualified hardware. The conceptual design for the electronics, described below, is based on this experience. A block diagram of the required
signal processing and electronics is shown in Figure 1.

Each antenna will be backed by a high gain pre-amplifier, which will be placed close to the antenna unit. The signal from each pre-amplifier will be directly digitized at a rate of 60 Msamples/s and processed in the electronics unit. This was not attempted in previous missions due to unavailability of high speed digitizers in the last decade and will be one of the significant differences in our design. It is proposed to use a design employing FPGAs for our signal processing. The FFT of the sampled data, followed by an appropriate accumulation, will be carried out to obtain desired frequency resolution for the different modes of operation as discussed below.

The signals from the three-antenna system will be combined and an algorithm encoded in a space qualified single board computer (SBC) will be applied to obtain the required goniopolarimetry. Such SBCs along with included FPGA are being evaluated by us right now from the point of view of required signal processing capabilities. The aim of this design is to do considerable signal processing on board, thereby reducing the volume of data to be downlinked. It is to be noted that powerful SBCs for embedded computing were not available, when previous similar missions, such as WIND/Waves and STEREO/Waves, were designed (in late 1980s and 1990s respectively) with a limited technology available then. A larger on-board processing will allow us a higher cadence (time/frequency resolution) than these instruments, enabling a much higher science output. The use of FPGA also allows for an improvement in calibration and processing by limited one-time reload of programs for very specific science goals. The SBC will also act as a supervisor for the electronic stack by responding to ground based commands. Greater intelligence on-board will also allow autonomous event triggered mode change, eliminating the need for ground based commands, for important solar events. The algorithms for this are being developed after analysis of the data on similar event from previous missions.

There are two broad modes of observations proposed for the LORE. During energetic solar events, such as solar flares, CMEs, etc., type II and III bursts will be monitored with higher time and frequency resolutions, generating higher data rates and volumes for short durations. This mode of observation is called high rate science (HRS). The 30-MHz bandpass will be subdivided digitally into 2048 channels, providing a frequency resolution of \( \sim 15 \text{ kHz} \). Accumulation of about 1500 such spectra will allow 100 ms temporal resolution for each channel. On-board processing will provide four stokes parameters and two direction angles with an 8-bit resolution giving a peak data rate of 1 Mbps and a total volume of 150 Mbytes. On all occasions other than during energetic solar events, the data will be acquired with 512 channels (about 60 kHz frequency resolution) and once every 500 ms at a data rate of 6 kbps, giving a total volume of 4 Gbytes per day. The data rate is much lower for this low rate science (LRS) mode, but overall data volume is large. We are examining strategies to decide a more useful subset of these data so that the data volume would be further reduced. The interface to the electronics for telemetry will be using a MIL-STD-1553 bus interface.

The antenna configuration and pre-amplifiers have been developed as of now and the prototyping the digital electronics is currently in progress.

Acknowledgments
This work is supported by XII plan grant TIFR-12P0716

References
[1] Manoharan P K, Tokumaru M, Pick M, Subramanian P, Ipavich F M, Schenk K, Kaiser M L, Lepping R P, and Vourlidas A 2001 Astrophysical Journal, 559 1180
[2] Manoharan P K 2010 Solar Physics 265 137
[3] Cecconi B and Zarka P 2005 Radio Science b 40 RS3003
[4] Naidu A, Joshi B C, Manoharan P K, and Krishnakumar M A 2015 Experimental Astronomy 39 319