SOLAR RADIO OBSERVATION USING CALLISTO AT THE USO/PRL, UDAIPUR

Kushagra Upadhyay  
Udaipur Solar Observatory  
Physical Research Laboratory  
Udaipur 313 001, Rajasthan, India  
kushagra@prl.res.in

Bhuwan Joshi  
Udaipur Solar Observatory  
Physical Research Laboratory  
Udaipur 313 001, Rajasthan, India

Prabir K. Mitra  
Udaipur Solar Observatory  
Physical Research Laboratory  
Udaipur 313 001, Rajasthan, India

Ramit Bhattacharyya  
Udaipur Solar Observatory  
Physical Research Laboratory  
Udaipur 313 001, Rajasthan, India

Divya Oberoi  
National Centre for Radio Astrophysics  
Tata Institute of Fundamental Research  
Pune 411 007, Maharashtra, India

Christian Monstein  
Istituto Ricerche Solari Locarno (IRSOL)  
Via Patocchi 57, 6605 Locarno Monti, Switzerland

July 6, 2020

ABSTRACT

This paper presents a detailed description of various subsystems of CALLISTO solar radio spectrograph installed at the USO/PRL. In the front-end system, a log periodic dipole antenna (LPDA) is designed for the frequency range of 40-900 MHz. In this paper LPDA design, its modifications, and simulation results are presented. We also present some initial observations taken by CALLISTO at Udaipur.

Keywords e-CALLISTO · LPDA · VSWR · Radiation Patterns

1 Introduction

e-CALLISTO is a worldwide network of radio spectrometers. It is used for the observation of solar radio bursts and radio frequency interference monitoring for astronomical sciences. e-CALLISTO system is a valuable tool for monitoring solar activity and space weather research. Abbreviation e-CALLISTO stands for extended Compound Astronomical Low cost Low frequency Instrument for Spectroscopy and Transportable Observatory.

The entire system of CALLISTO solar radio spectrograph has successfully installed at Udaipur Solar Observatory, Physical Research Laboratory, Udaipur, India (24°34′16.5720″ N and 73°41′29.5584″ E) and has been observing the Sun continuously since installation on October 3, 2018. A proper data pipeline has been developed to process data and transfer it to the server automatically.

The essential component of the front-end part consists of a Log Periodic Dipole Antenna (LPDA). It was designed and simulated in CST software, and fabricated in NCRA, Pune workshop. Other front-end components, such as the low noise amplifier (LNA), FM rejection filter, bias tee, coaxial cables, and connectors with very low attenuation losses were integrated with proper impedance matching. The back-end consists of e-CALLISTO spectrometer, which is a programmable heterodyne receiver designed at ETH Zurich, Switzerland.
Figure 1: Block diagram showing various subsystems of CALLISTO and their configuration

Figure 2: Various subsystems of CALLISTO at the USO/PRL are shown. Panel (a) shows the LPDA. LNA (panel c) is connected between LPDA and CALLISTO spectrograph (panel d). Panel (b) shows zoomed view for thin elements of LPDA, which are resonating at higher frequencies.
Log Periodic Dipole Antenna (LPDA)

2.1 Design and Mechanical structure

Log periodic dipole antenna is a directional antenna that is used for wide band application at VHF/UHF. It is a multi element array in which the elements are arranged in a criss cross fashion to achieve phase reversal between consecutive elements. The mechanical phase reversal between these elements produces a phase progression so that the energy is beamed endfire in the direction of shorter elements. The most active elements in the feed are those that are near resonant with a combined radiation pattern toward the vertex of the array [1].

LPDA is designed using design equations given in [2]. Some basic equations are given below:
\[ L_{i+1} = \tau L_i \ldots (1) \]
\[ R_{i+1} = \tau R_i \ldots (2) \]
\[ \sigma = \frac{R_i - R_{i-1}}{2L_i - 1} \ldots (3) \]
where \( L_i \) is the length of \( i \)th dipole, \( R_i \) is the spacing between with \( i \)th and \((i+1)\)th element, \( L_s \) is the stub length, \( \tau \) is taper, and \( \sigma \) is relative spacing (see Fig. 3).

The value of taper \( (\tau) \) and relative spacing \( (\sigma) \) are finalized such that it provides a gain of 8 dBi and Voltage Standing Wave Ratio (VSWR) less than 2 in optimum length of antenna. Several simulations are done in CST with different values of \( \tau \) and \( \sigma \) and finally we arrived at optimal values of 0.88 and 0.06 respectively. Stub is used to improve VSWR performance and the short circuit stub length is taken as \( \lambda/8 \), where \( \lambda \) is wavelength corresponding to the lowest frequency.

Mechanical parameters for the fabrication of LPDA are given in Table 1.

In the simulation, we found the diameter of the elements changes VSWR because impedance of dipole depend on length to diameter ratio \((L/D)\); so, we tried to make \( L/D \) ratio relatively the same for the entire length of antenna. However, practically there is a limitation regarding availability of different diameter of aluminium pipe in the market. Therefore, we have chosen 5 different diameter variants according to the availability (see Table 2) and mechanical design simulated in CST.

2.2 Simulation Results

The gain \( (G) \) of an antenna is given by the product of total efficiency \((\eta)\) and directivity \((D)\). From Fig. 4, we find that gain is approximately 8 dBi and H-plane Half Power Beam Width (HPBW) is approximately 90° in the entire band. Fig. 5 shows that the VSWR in the entire band (40-900 MHz) is below 2, which implies that the return loss of the antenna is lower than -10 dB in the entire band.

LPDA has a wider beam width so it does not necessarily require tracking system, and hence, offers less mechanical complexity although its performance increases with tracking system. We have fixed the LPDA with vertical mounting where the dipoles are in North - South direction. Our antenna has HPBW of 90°, which provides about \( \pm 3 \) hours of good observations in the East-West direction from local noon (for details, see Fig. 5).

3 Low Noise Amplifier (LNA)

We used broadband low noise amplifier having noise figure of 1.1 dB with input and output VSWR below 2. It provides a gain of 18 - 20 dBi.

4 FM Rejection Filter

The RFI level at CALLISTO/Udaipur site is low but strong FM signals cause severe cross modulation of the real data in nearby frequencies. To prevent this, we have used a notch filter.

5 CALLISTO Spectrograph

It is a compact frequency agile spectrograph operating at the bandwidth of 45-870 MHz. It measures 200 frequency channels with a temporal resolution of 0.25 sec. It has a sensitivity of 25 mV/dB and dynamic range of -120 dBm to -20 dBm [3].

6 Observations taken by CALLISTO at the USO

From Fig. 6, we identify few pre-existing standard frequencies dedicated for commercial and communication purposes. We have used those frequencies as a reference to calibrate the system performance. We used an FM Rejection filter which causes a trench like structure in 88-108 MHz band of the spectral overview. The scientific data is made available every 15 minutes as standard FITS file. Each FITS file contains observation taken by the CALLISTO spectrograph during an interval of 15 minutes. A proper data pipeline has been developed that transfers the data to the server in real time. The JPEG images, constructed from FITS files, are also available in the webpage for the purpose of quick viewing. Further, a light curve is generated in 5 different frequencies which gets updated every 15 minutes on the webpage. For more details, refer to the following link: https://www.prl.res.in/ ecallisto/.
Figure 4: H-plane polar plot (left column) and 3D radiation pattern (right column) at different frequencies (in MHz).
Figure 5: Plot of Voltage Standing Wave Ratio (VSWR) for the LPDA of CALLISTO system at the USO/PRL.

Figure 6: Radio frequency interference (RFI) level measured at the CALLISTO site of USO. We notice the tiny ripple-like patterns on the top of the baseline which represent standing waves in the spectrum.

7 Summary

In this article, we present a brief overview of the CALLISTO radio spectrograph which is being operated at the USO/PRL. We provide details of the LPDA which has been developed indigenously. We report some preliminary observations of solar radio bursts taken by our CALLISTO at the USO/PRL and the RFI level at the CALLISTO site is also reported.

8 Acknowledgement

We are grateful to Dr. Anil Bhardwaj, Director, PRL, Ahmedabad, India for his encouragement and support toward CALLISTO project at the USO/PRL. We also sincerely thank Dr. Yashwant Gupta, Centre Director, NCRA-TIFR, Pune, India for providing technical expertise and facilities to fabricate the LPDA.
Figure 7: 1st light observations of CALLISTO at USO/PRL. The dynamic spectrum shows solar plasma radiation observed on March 8, 2019 during a C-class flare. We note discontinuity in the structure of the radio burst at frequencies 85-120 MHz which is due to the FM notch.

Figure 8: Dynamic radio spectrum showing solar plasma radiation observed on May 6, 2019.

9 References

[1] A. Balanis, Antenna Theory, analysis and design, Constantine Wiley, New York, 1989.

[2] Serge Stroobandt, Michael McCue, Log Periodic Antenna Design Calculator, Available at: https://hamwaves.com/lpda/en/lpda.a4.pdf.

[3] C. Monstein, e-CALLISTO frequency agile radio spectrometer specifications, http://www.e-callisto.org/Hardware/eCallistoSpecification.pdf.