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Solar Radio Spectro-polarimetry (50 - 500 MHz)

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Abstract

A Cross-polarized Log-Periodic Dipole Antenna (CLPDA) for spectro-polarimetric observations in the frequency range *50-500 MHz* was developed at the Gauribidanur radio observatory of the Indian Institute of Astrophysics to study the characteristics of the polarized radio waves that are emitted by the impetuous solar corona. This summary paper describes the design and developmental aspects of the CLPDA, its characteristics and briefs about the configuration of the analog receiver. Throughout the above frequency band, the CLPDA has gain ≈ 6.6 *dBi*, return loss < -10 *dB*, and polarization cross-talk < -27 *dB*. The CLPDA with a spectro-polarimeter backend receiver system can measure a flux density of $5.3 \times 10^3 Jy$ (at *50 MHz*) for *290 K* receiver temperature, *1.1 MHz* bandwidth, *10 μs* integration time, and *10* records average. At *50 MHz*, the observed spectra show a signal-to-noise ratio (SNR) and Dynamic range (DR) of *30 dB* and *40 dB*, respectively.

1. Introduction

The performance of space borne technological systems depends on the weather conditions (called space weather) that prevail in the Earth's geospace [1]. Space weather (SW) could be disastrous [2] at times due to transient activities such as flares, coronal mass ejections (CMEs), etc. that take place in the outer solar atmosphere. Identifying the precursors of such events would therefore become essential to forecast SW reliably to safeguard the space borne systems. In the latter context, different types of radio outbursts (type-II, III, V, etc.) were recognized to be some of the precursors of above transients, especially in the low frequency radio regime [3]. Observational studies show that the onset of aforementioned radio outbursts is predoinantly decided by the strength, configuration, and spatio-temporal evolution of the associated solar active-region cum ambient magnetic field system [4]. Thus, we present the design of broad-band Cross-Polarized Log-Periodic Dipole Antenna (CLPDA) and its back end to observe the polarization state and strength of the associated radio outbursts and estimate the CME bulk plasma properties such as density, temperature, magnetic field strength, etc.

2. Design of a CLPDA

Log-Periodic Dipole Antennas (LPDA) is a coplanar array of dipoles; it has unequal length and unequally spaced parallel and linear dipoles that are fed alternatively (*180°* phase difference between adjacent dipoles) by a parallel transmission line with a desired characteristic impedance [5]. The CLPDA, to outline simply, is a combination of two identical LPDAs. We extensively used empirical relations suggested by Carrel [6] for the antenna design with certain additional modifications to enhance the performance of the antenna. This includes: i) varying the dipole arm outer diameter with frequency of operation to maintain the ratio of electrical length (L_e) to physical length (L_p); ii) modifying the transmission line pairs from a rectangular boom to a rectangular bar and reducing the interboom spacing. Fig. 1 shows the schematic of the CLPDA.

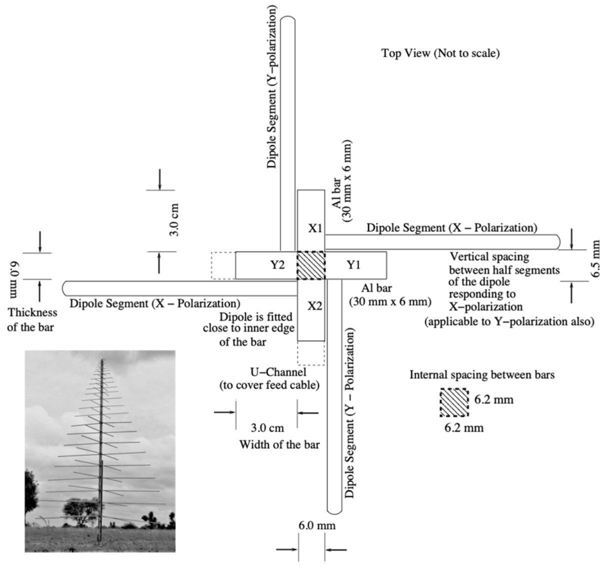

Figure 1: Schematic showing top view of the CLPDA. The fully assembled CLPDA using the schematic is shown at the bottom left.

The final design of LPDA had *22* dipole arms, it worked for *50-500 MHz* and its height was *3 m*. The LPDA/ CLPDA frequency independent was measured by characterising it as discussed in the next section.

3. Characterization of the CLPDA

The Voltage Standing Wave Ratio (VSWR), an indirect measure of impedance was measured for it and the values were found to be below *2.0* throughout the observing bandwidth. We also measured far field radiation pattern was measured by keeping the transmitting and receiving antennas *40 m* apart because the theoretical far field distance ($R > 2D^2 / \lambda$) limit is about *30 m*. The designed antenna was used as a receiver and a LPDA with known transmission characteristic was used as the transmitter. Fig. 2 shows the radiation patterns of the antenna in the two principal planes at a few frequencies.

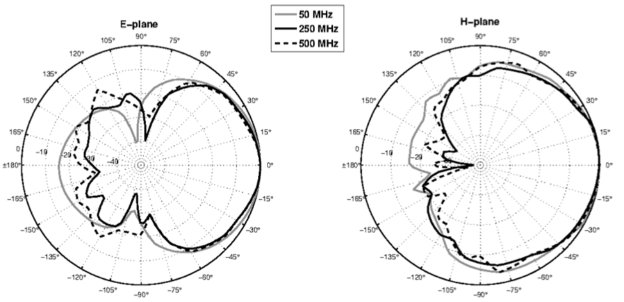

Figure 2: Measured E-plane (left panel) and H-plane (right panel) radiation patterns at *50, 250* and *500 MHz*.

Since the primary objective of this study is to measure the circularly polarized radio emission from the Sun using a CLPDA frontend system, restricting the E- & H-fields, within a narrow region about their respective mean positions of vibration is important. Otherwise, one of the fields will spill over into the other (cross-talk). The magnitude of spill-over determines the uncertainty involved in any parameter deduced from the polarization measurements. In order to determine the cross-talk, the transmitter was kept in both horizontal and vertical orientations successively, and the signal strengths were measured with both horizontal and vertical arms of the CLPDA. Fig. 3 shows the cross-talk or isolation pattern of the CLPDA at different frequencies.

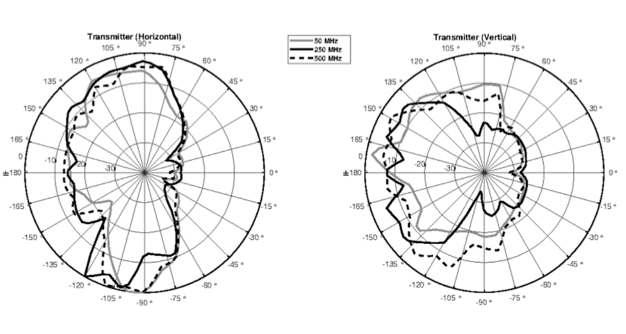

Figure 3: Polarization cross-talk or isolation pattern of the CLPDA at *50* (solid-gray), *250* (solid-black), and *500 MHz* (dotted-black). Left: Transmitter kept in horizontal orientation; Right: Transmitter kept in vertical orientation.

4. Analog frontend & digital backend receiver

The signals received by the two orthogonal arms of the CLPDA were fed into two analog front-end receivers. The signal chain consisted of low-noise amplifier, high-pass filter and a FM reject filter in the field. The signal was brought to the laboratory using optical fiber cables. the original RF signals were retrieved from optical signals and fed to the inputs of a Quadrature Hybrid (QH). QH is a four port RF device having two input and two output ports, which splits the signal into two components whose amplitudes are nearly equal but with a *90*° phase difference. The outputs of the QH were fed into two conventional spectrum analyzers (SAs).

Both SAs were initialized using the GPIBs which set the observational parameters such as start frequency (*50 MHz*), end frequency (*500 MHz*), sweep time (*4 ms*), no. of data points (*401*), bandwidth resolution *1 MHz*), number of spectra to be averaged onboard (*10* records), etc. The data transfer from the SA to the observational computer takes about *240 ms*. An initial software trigger was given to start the frequency-sweep to synchronize the SAs. The flux density detectable by the receiver (S_{rcvr}) alone was calculated:

$$S_{rcvr} = \frac{2k}{A_e} \frac{K_s T_{rcvr}}{\sqrt{\Delta\nu \Delta t n}} \qquad (1)$$

In Eqn. 1., k and A_e are Boltzmann Constant and effective aperture ($0.4\ \lambda^2$), respectively; while K_s, T_{rcvr}, , $\Delta\nu$, Δt and n are sensitivity constant, receiver noise temperature, integration bandwidth, integration time, and number of records averaged onboard, respectively. The S_{rcvr} for the system was found to be *0.53 sfu* and *53 sfu* at *50 MHz* and *500 MHz*, respectively. This indicates that the new spectro-polarimeter would be able to detect almost all kinds of solar radio bursts.

5. Error in degree of circular polarization estimation

We calculated the Stokes parameters (total intensity, *I* and circular polarized intensity, *V*) and characterized the error induced in the estimate of degree of circular polarization (DCP = *V/I*). To estimate accurately the Stokes parameters and the DCP, the contributions of the antenna and the backend electronics to the circular polarization (CP) must be determined precisely. For the latter, broadband helical antennas that were available in the observatory were used to generate left- and right-hand CP signals. It should also be noted here that any linearly polarized component (Stokes-Q and U) would vanish in the intended frequencies (i.e. meter wavelengths) because of the Faraday rotation [7]; and therefore the emission in total intensity (Stokes-I) and circular polarized intensity (Stokes-V) can only be observed. The test was carried out by varying the azimuthal angle for different frequencies within the band. Fig. 4

shows the measured DCP values along with the mean fit. We found that the error in DCP to ± *3%*.

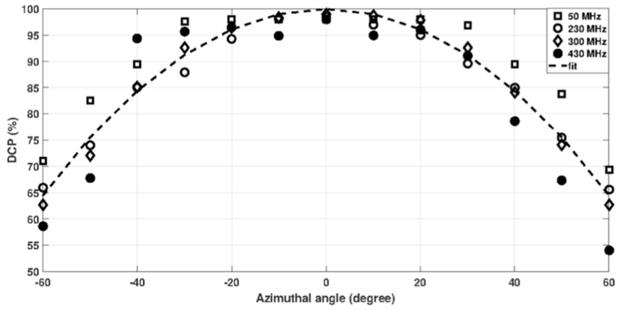

Figure 4: Measured DCP as a function of azimuthal angle.

5. Solar Observations

In order to examine the observing capability the SP set-up was kept for observations at the Gauribidanur radio observatory. Theoretical studies suggest that B can be estimated from the observed DCP of a radio burst (ex: type-III, type-V) using Eqn.2, if (i) the burst is due to second harmonic plasma emission [1] and (ii) its associated source region lies close to the solar limb:

$$B = \frac{f_p \times DCP}{2.8 \times a(\theta)} \qquad (Gauss) \qquad (2)$$

here, f_p is the plasma frequency and θ is the viewing angle of the observer with respect to the radial direction of the magnetic field. The function $a(\theta) \approx 1$ for sources located near the solar limb.

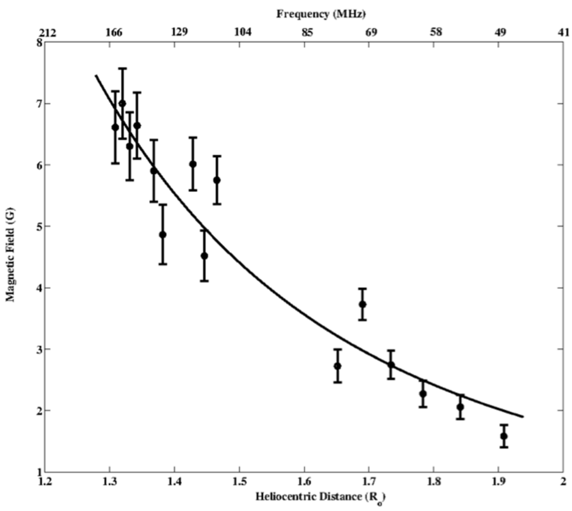

Figure 5: Magnetic field strength (y-axis) associated with a type-V radio burst, as a function of heliocentric distance (bottom x-axis) / observing frequency (top x-axis).

There was a type V burst observed with the SP on March 30, 2018, for which we estimated coronal magnetic field using eqn. 2. This was associated with C4.6 class flare erupted from the active region 12703 located at S10E70. The power-law fit to the data points gives $B(r)=16.8 \pm 0.5\ r^{-3.3}$ *Gauss*. This distribution is similar to those published earlier: for example, Patzold et al. [8] found that $B(r)$ varies as $r^{-2.7}$ in the middle corona. Fig. 5 shows the coronal magnetic field distribution with respect to heliocentric distances and observed plasma frequencies.

6. Summary

We designed and fabricated a CLPDA that works in the *50 - 500 MHz* frequency range. A spectro-polarimeter was set up using the CLPDA, an analog receiver and a digital receiver (Spectrum Analyzer), and the system as a whole was characterized; the analog receiver has a noise figure of *3 dB* and a T_{rcvr} of about *290 K*. The receiver was found to have a sensitivity of *0.53 sfu* at *50 MHz*, and *53 sfu* at *500 MHz* for an effective integration time of $100\ \mu s$. The polarization cross-talk was measured to be ± *3%*. It was inferred that lower cross-talk values can give rise to better accuracy in the estimated DCP. To demonstrate the instrument capability, the Stokes-I and Stokes-V spectrum of the type-V burst obtained on March 30, 2018, with the SP was used to calculate the DCP. Using the DCP, magnetic field (as a function of heliocentric height) associated with the type-V emission was determined; the distribution $B(r)=16.8 \pm 0.5\ r^{-3.3}$ *Gauss*.) is in good agreement with those reported earlier. Methods to lower the cross-talk further and to have a uniform value over the entire field of view may be evolved to reduce the error in DCP estimates. Also, it would be a very good advancement in technology, if an optimal design is conceived in which the CLPDA can be used as a feed in dish antennas.

6. Acknowledgements

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7. References

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