SOLAR RADIO SPECTRO-POLARIMETRY (50 - 500 MHZ) : DESIGN AND DEVELOPMENT OF CROSS-POLARIZED LOG-PERIODIC DIPOLE ANTENNA AND CONFIGURATION OF RECEIVER SYSTEM

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A radio spectro-polarimeter was developed at the Gauribidanur radio observatory (Longitude : 77∘27′07″; Latitude : 13∘36′12″) to study the characteristics of the polarized radio waves that are emitted by the impetuous solar corona in the 50 - 500 MHz frequency range. The instrument has three major components : a Cross-polarized Log-Periodic Dipole Antenna (CLPDA), an analog receiver, and a digital receiver (spectrum analyzer). Here. we elaborates the design and developmental aspects of the CLPDA, its characteristics and briefs about the configurations of the analog and digital receivers, setting up of the spectro-polarimeter, stage-wise tests performed to characterize it, etc. To demonstrate the instrumental capability, the estimation of the solar coronal magnetic field strength (B vs heliocentric height), using the spectral data obtained with it, is exemplified.

Throughout the above band, the CLPDA has a gain, return loss and polarization cross-talk of ≈ 6.6 dBi, .-10 dB, and .-27 dB, respectively. The design constraints, the procedure to tune its impedance and to minimize its dimension, etc. are elaborated. The analog receiver has a noise figure of ≈3 dB and a receiver-noise-temperature (Trcvr) of about 290 K. The digital receiver can sweep and cover the above bandwidth in 4 ms (instantaneous bandwidth of ≈1.1 MHz). The spectral data acquired for ten successive sweeps are integrated (for 100 μs) and averaged onboard. The above parameters give a receiver-flux-density (Srcvr) of ≈ 5.3 ×103, and ≈ 5.3 ×105 Jy at 50 and 500 MHz, respectively. The observed spectral data shows a Signal-to-Noise Ratio and Dynamic range of about 30 dB and 40 dB, respectively, at 50 MHz. The average polarization isolation / cross-talk of the CLPD varies from -30 dB to -24 dB over an azimuthal angle of ±45∘ with respect to the reference position angle (0∘). The average degree of circular polarization (DCP) is ≈100% at the reference position and found to decrease gradually and reaches ≈ 80% at an azimuthal angle of ±45∘. The variation of the cross-talk and DCP as a function of azimuthal angle were used to have a one to one mapping in order to establish an association between cross-talk and DCP; the latter gives an uncertainty of ≈ 0.2,2, and 20% in DCP for -30, -20 and -10 dB cross-talk, respectively. The Stokes-I and Stokes-V spectrum of the type-V burst observed on March 30, 2018 with the SP was used to determine the associated magnetic field strength (B) as a function of heliocentric height. It was found that B(r) ≈16.8 ±0.5 r−3.3 G.

Background

Frequency range 50-500 MHz corresponds to 2$R_\odot$ -1.05$R_\odot$

$$f_p \propto \sqrt{N_e(r)}\ ;\ N_e(r) \propto 10^{\frac{4.32}{r}}$$

f_p = plasma frequency

N_e = electron no. density

r = radial distance (>1$R_\odot$)

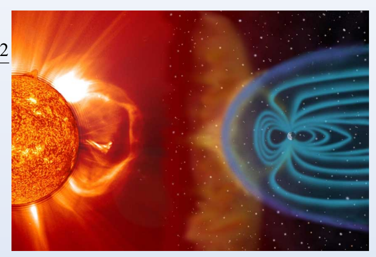


Fig: Sun-Earth Connection (Courtesy: NASA)

Solar transients: Transient disturbances in interplanetary medium and near - Earth space.

Solar radio bursts related to transients like coronal mass ejections (CMEs) and flares originate in above radial distance range.

Solar transients: Magnetically driven.

Magnetic Field Strength: using Polarization properties.

Two radio antennas, oriented orthogonally to each other (coaxially): Cross-Polarized Log-Periodic Dipole Antenna (CLPDA).

Design and development of CLPDA

$$\tau = \frac{R_{n+1}}{R_n} = \frac{d_{n+1}}{d_n} = \frac{L_{n+1}}{L_n} = \frac{f_n}{f_{n+1}} = \frac{1}{k}$$

$$\tan\alpha = \frac{1-\tau}{4\sigma}\quad ; \quad L_1 = \frac{150}{f_1(MHz)}$$

$$N = \frac{\ln(BW)}{\ln(1/\tau)} \text{ and } BW = \frac{f_n}{f_1}$$

$$f_n = \frac{f_1}{\tau^{n-1}} \text{ and } \sigma = \frac{d_{n+1}}{\lambda_n}$$

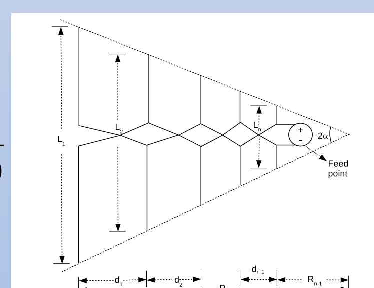


Fig: LPDA Schematic

L_n = Length of nth arm

R_n = Distance of nth arm from apex

d_n = Separation between two arms

α = Apex angle

τ = Design Constant

σ = Spacing Factor

BW: Bandwidth

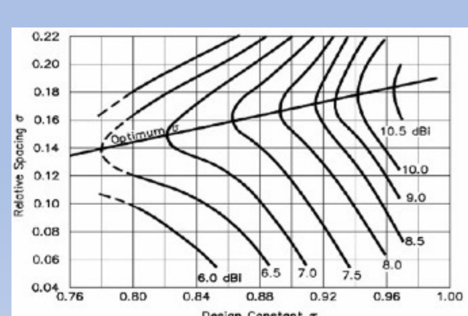


Fig: Gain of LPDA as a function of τ and σ (Courtesy: R. Carrel)

Design and development of CLPDA

Frequency: $f_L - f_H$: 50 - 500 MHz (BW: 10:1)

Gain: 6.5 dBi

Half Apex Angle: 27°

Design Constant: 0.857

Spacing Factor: 0.07

Characteristic Impedance Feeder: 50 Ω

Total number of elements: 19

Antenna length: 3 m

Parameter	Value
HPBW (E)	≈ 65°
HPBW (H)	≈ 100°
Gain	≈ 6.6 dBi
Effective Collecting Area	≈ 0.4 λ^2
Front to back ratio	≈ 30 dB
Side lobe ratio	≈ -24 dB
Polarization Cross-Talk	≈ 30 dB

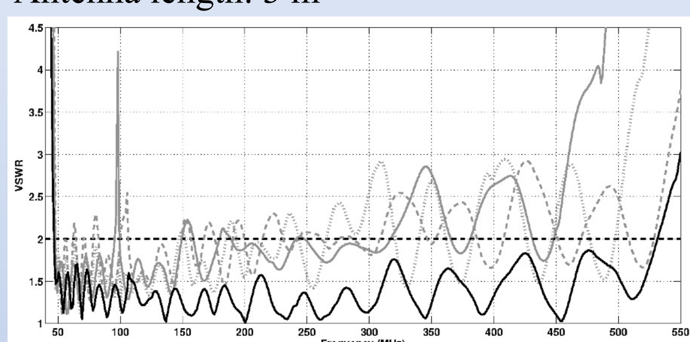


Fig: The VSWR profiles of the 50 - 500 MHz prototype LPDA. (with and without tuning)

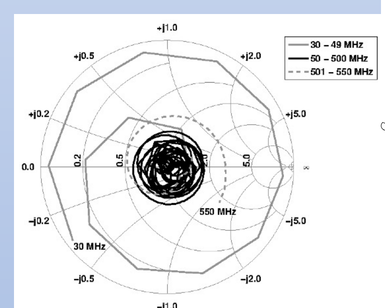


Fig: Smith chart of the prototype LPDA

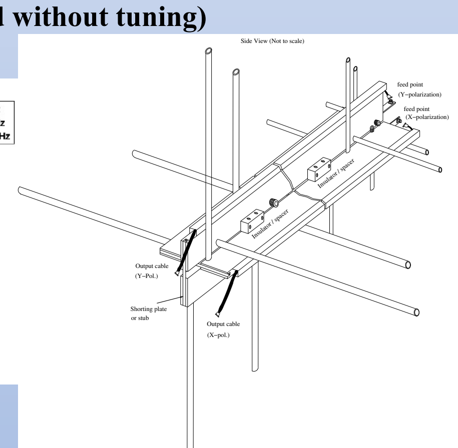
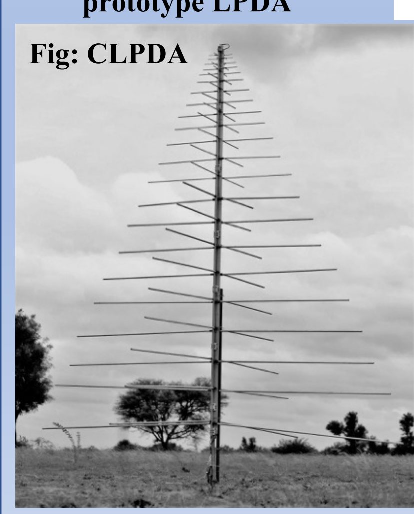


Fig: Schematic of the CLPDA

Fig: CLPDA



Characterization of the CLPDA

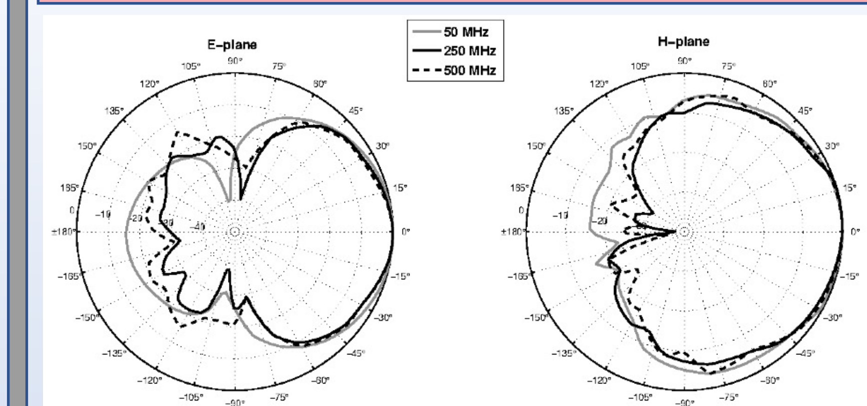


Fig: Measured E-plane (left panel) and H-plane (right panel) radiation patterns at 50, 250 and 500 MHz

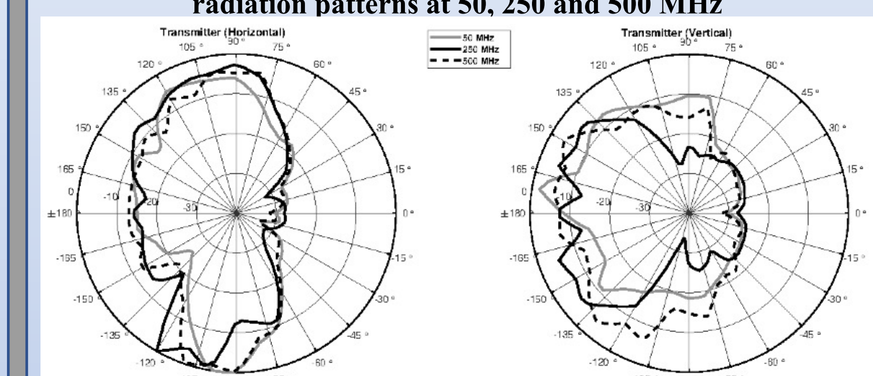


Fig: Polarization cross-talk or isolation pattern of the CLPDA at 50, 250 and 500 MHz

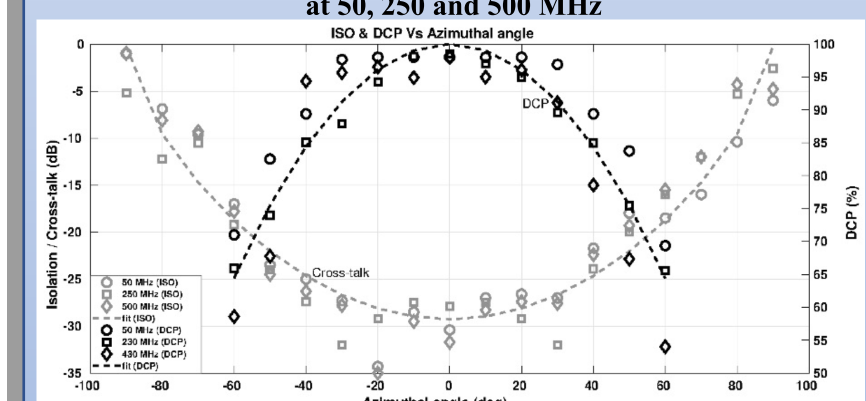


Fig: Measured polarization cross-talk and DCP of the CLPDA as a function of azimuthal angle

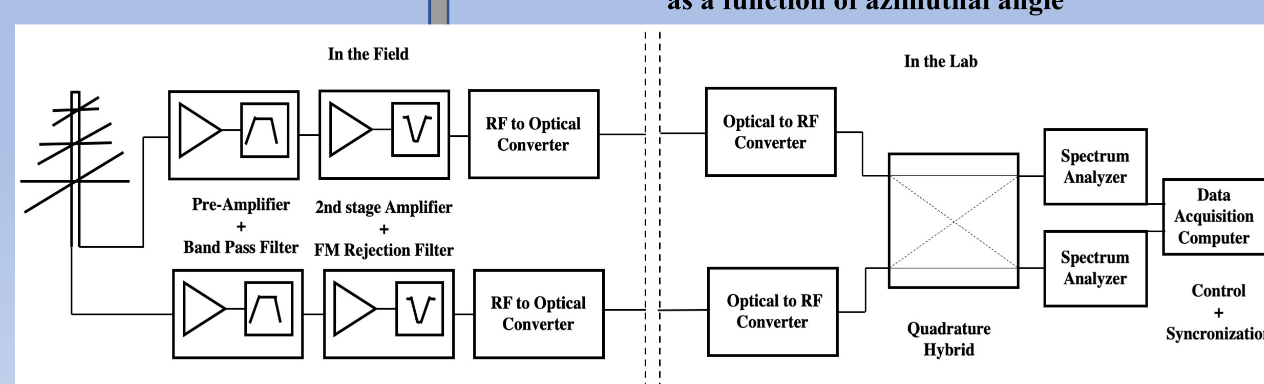


Fig: Block diagram of the spectro-polarimeter setup

Observations

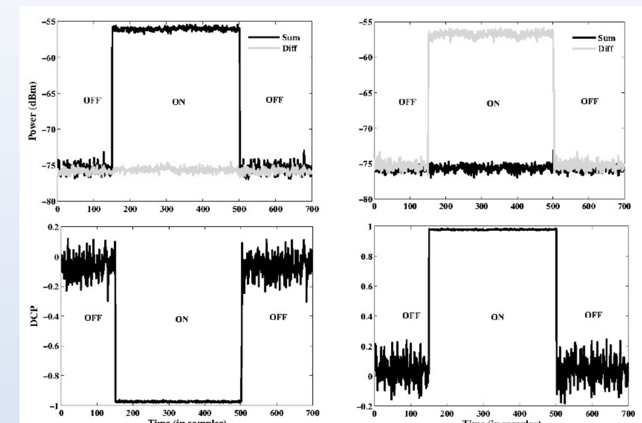


Fig: Power received from the two output ports when CP signal was received by the CLPDA. The left and right panels correspond to left and right CP signals, respectively

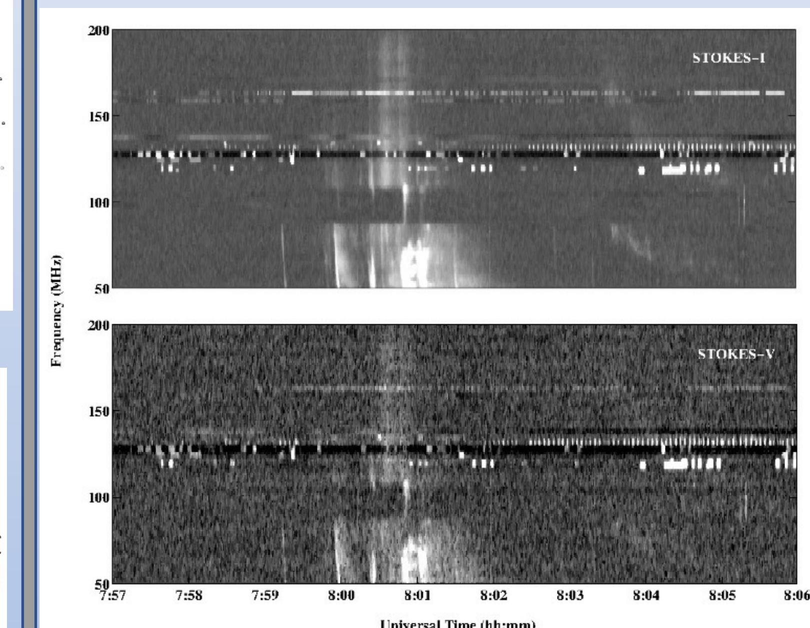


Fig: Stokes-I and Stokes-V spectra of a type-V and a type-II burst observed on March 30, 2018.

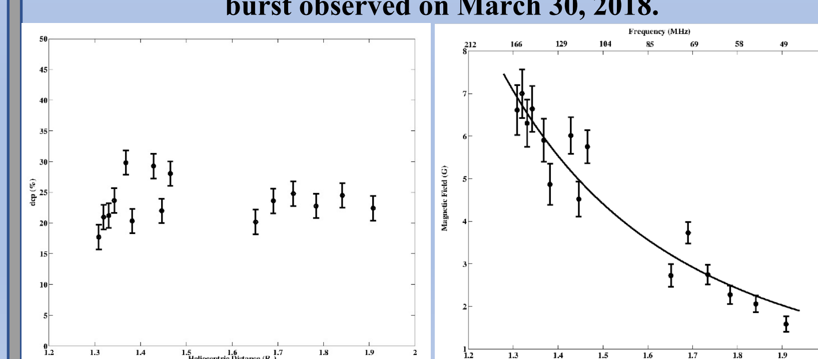


Fig: DCP (with an uncertainty of 3%) and Magnetic field strength associated with a type-V radio burst, as a function of heliocentric distance

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