CALLISTO Spectrometer at IISER-Pune

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ABSTRACT

A CALLISTO spectrometer to monitor solar radio transient emissions from $\approx 0.8 - 1.6 \, R_\odot$ (above photosphere) is installed at IISER, Pune, India (longitude 73°55′ E and latitude 18°31′ N). In this paper, we illustrate the instrumental details (log-periodic dipole antenna and the receiver system) along with the recorded solar radio bursts and radio frequency interferences produced by the thunderstorms in the frequency range 45-870 MHz. We also developed the image processing pipelines using ‘sunpy’ and in-house developed python library called ‘pycallisto’.

Subject headings: solar radio bursts; radio spectrometer; radio instrumentation; thunderstorms
1. Introduction

A Compound Astronomical Low-Cost Low-Frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO) is a radio spectrometer which is primarily designed to observe the transient radio emissions / radio bursts from the solar corona (Benz et al. 2005, 2009). The dominant magnetic field controls the structure evolution, kinematics and dynamics in the solar corona. The Sun is said to be ‘undisturbed’ or quiet if there are no contribution from the transient events (sunspots, plages, active regions, filaments, prominences and other transient eruptions like solar flares). The slowly varying component is observed above and near the vicinity of the active regions and chromospheric plages (Kundu 1965). These two emissions are thermal in nature. Presence of the previously mentioned solar events along with the large scale structures like Coronal Mass Ejections (CME) trigger the non-thermal radio emissions or radio bursts. In general, these bursts are classified into different types viz. Type I to Type V, based on drifting speed and morphology in the dynamic spectrum. Type J and Type U bursts are few other complex bursts which are often observed (Kundu 1965; McLean & Labrum 1985; Wild 1967). For the sake of completeness, we summarize properties of different radio bursts in a Table 1. In this paper, we describe solar radio Type II burst observed at IISER Pune on 04 November 2015.

In order to monitor these bursts continuously (24 hours a day), CALLISTO spectrometers are distributed around the globe and established an e-CALLISTO network\textsuperscript{1}. The real time data observed at different observatories are uploaded to the server located at ETH Zurich, Switzerland automatically. Although, the instrument is designed to monitor the solar radio bursts, it is efficient to record the radio frequency interferences (RFI). Primarily, radio interferences or noise can be classified into two categories: (1) Man made

\footnote{http://www.e-callisto.org}
or terrestrial interferences: modern life style demand the use of FM, AM, television, walkie-talkies, GSM and CDMA mobiles and are the sources of terrestrial interference. The industrial noise from automobiles, aircraft ignition, electrical motors, switching equipment, voltage leakage from the electrical lines, fluorescent lights etc are few more examples.

(2) Natural interferences: solar noise due to the activity in the Sun, cosmic noise from the celestial radio sources and transients, thunderstorms and lightening from Earth’s atmosphere (also observed from other planets) and other natural electrical discharges (Bianchi 2007; Kennedy et al. 2013). In this paper, we also report the RFI produced during the thunderstorms.

Since 2015, CALLISTO spectrometer is in operational at Indian Institute of Science Education and Research, Pune, India. The longitude and latitude of the place is 73°55′ E and 18°31′ N respectively and situated at an altitude of 558 meters above the sea level. Although, the instrument is located in the middle of the city, the radio spectrum is clean above 115 MHz with only standard terrestrial interferences.

2. Instrumentation

In this section, we describe different sections of our CALLISTO spectrometer.

2.1. Log-periodic dipole antenna

In solar corona, most of the radiation at radio wavelengths originates due to the coherent plasma emission mechanism. In such case, plasma frequency ($f_p$) is proportional to the electron density ($N_e$) of that height (McLean & Labrum 1985; Rybicki & Lightman 1986; Gary & Keller 2004). Since the electron density in the corona decreases with the increasing radial height, different frequency of observations correspond to specific layers in
| S. No. | Type of burst | Event characteristics | Associated phenomenon | EM | Frequency bandwidth | Duration | dcp (%) |
|-------|--------------|-----------------------|------------------------|----|--------------------|---------|--------|
| 1     | Type I       | Narrow band, short duration spikes superposed over a continuum emission | Active regions, flares, eruptive prominences | PE | 50-500 MHz | Single burst: $\approx 1$ s Noise storm: hours-days | $\approx 0.5 - 1$ |
| 2     | Type II      | Slow drifting $\approx 1$ MHz s$^{-1}$; second harmonics occurs | Flares, MHD shocks, proton emissions | PE | 20-150 MHz | 3-30 mins | $\approx 0.5$ |
| 3     | Type III     | Fast drifting $\approx 100$ MHz s$^{-1}$; occurs isolated, in groups or storms second harmonics are seen | Active regions, flares | PE | 10 kHz-1 GHz | isolated: $\approx 1 - 3$ s groups: $\approx 1 - 10$ mins storms: $\approx$ mins-hours | $F \approx 0.5$ $H \lesssim 0.3$ |
| 4     | Type IVs     | Smoothly varying broad band continuum | Flares, proton emissions | GS | 20 MHz-2 GHz | Hours-days | $\approx 0.5$ |
| 5     | Type IVm     | Smoothly varying broad band continuum; slow drifting | Eruptive prominences, MHD shocks | GS | 20-400 MHz | 30-120 mins | Increases from low to $\approx 1$ |
| 6     | Type V       | Smooth, short lived continuum emission; always follow by Type III groups/storms | Active regions, flares | PE | 10-200 MHz | 1-3 mins | very low ($< 0.1$) |

Table 1: Low frequency radio bursts and their physical properties. EM: Emission mechanism, PE: Plasma emission, GS: Gyrosynchrotron emission, dcp: degree of circular polarization. For more details refer Kundu (1965); McLean & Labrum (1985); Sasikumar Raja (2015) and [http://www.sws.bom.gov.au/World_Data_Centre/1/9/5](http://www.sws.bom.gov.au/World_Data_Centre/1/9/5).
solar corona. Hence, low frequency observations probe outer layers in corona. Therefore, we
need a broadband antenna to understand radio bursts and their propagation.

In general, an antenna whose bandwidth extends 40:1 or more, are referred to frequency
independent antenna. Log-periodic dipole (LPD) is one of such frequency independent
antenna and its designing aspects were discussed by Duhamel & Isbell in 1957 (Balanis
2005; Carrel 1961; Duhamel & Isbell 1957; Sasikumar Raja et al. 2013). The input
impedance of the LPD is a periodic function of logarithm of the frequency and hence
the name ‘log-periodic dipole’. Other antenna characteristics like: radiation patterns,
directivity, beamwidth and side lobe levels etc also undergoes similar variations (Balanis
2005). Mathematically it can be expressed as,

$$\log(f_{n+1}) = \log(f_n) + \log(1/k)$$

(1)

where, ‘f’ is the frequency, ‘k’ is the scaling factor, and ‘n’ indicates dipole number.

The primary receiving element in the CALLISTO system is a LPD which operates
over 100-900 MHz. Over the operating bandwidth the voltage standing wave ratio (VSWR)
$\lesssim 2$. The LPD was designed and built in the Electronic Science Department of SP
Pune University. It consists of a stack of dipoles (of different sizes) mounted along two
transmission lines (booms) in criss-cross fashion at different heights (Ashish Rojatkar &
AnanthaKrishnan 2012). The criss-cross fashion of the adjacent antenna arms introduce
the phase shift of 180° among them and cause the radiation to beam towards the shorter
arms. Therefore, we should always mount the LPD such that shorter dipoles point toward
the source direction (i.e. zenith in our case) as shown in Figure 1. The signal from the LPD
is tapped from top side using a co-axial cable (RG214) and run through the hallow square
boom of the antenna in which the ground is connected. LPD is a linearly polarized antenna
and have the half power beamwidth (HPBW) in E-plane (along the direction of arms) $\approx 75°$
and H-plane (perpendicular to the E-plane) $\approx 110°$ (Kishore et al. 2014; Sasikumar Raja
In the present case, we mounted LPD such that the dipoles are aligned parallel to the North-South direction. The broader HPBW of H-plane in East-West direction and E-plane in North-South direction allow us to observe the Sun within 2-8 UT and for all declinations of a year.

2.2. CALLISTO Spectrometer

Fig. 1.— Log-periodic dipole antenna mounted at rooftop of the main building at IISER, Pune. The shorter arms of the LPD is pointing the zenith. The antenna arms are aligned along the North-South direction. With this setup, the Sun will be in the field of view (FOV) during 2-8 UT. As the LPD tilts by some angle, antenna beam also rotates accordingly and therefore change in observing time. The broader E-plane of LPD enable us to monitor the Sun for all declinations of the year.

As shown in Figure 2, the signal from the LPD is pre-amplified using a low noise
Fig. 2.— Schematic diagram of the CALLISTO setup. The broadband LPD output is pre-amplified with LNA of gain 34 dB at the rooftop. Using the RG214 coaxial cable the amplified signal is fed to the CALLISTO receiver. The spectrum is read to computer using RS-232 serial communication standard. The recorded data is fetched to the ftp-server at ETH Zurich.

amplifier (LNA) whose gain is 34 dB. The DC power supply of 12 V is supplied to the LNA from the receiver room. The LNA output is fed to the CALLISTO receiver using a RG214 coaxial cable of length 50 meters. A linear DC power supply of 12 V (with current 225 mA) is supplied to the CALLISTO receiver. The operating bandwidth of the receiver is 45-870 MHz. This frequency range probes $\approx 0.8 - 1.6 R_\odot$ above photosphere ($1 R_\odot = 6.957 \times 10^8$ meters), in the solar corona. The time and frequency resolutions are 250 ms (when channel number is 200) and 62.5 KHz respectively. The spectral data from the receiver is read to computer using RS-232 (serial communication standard) with a baud-rate of 115200 bits per second (bps). The data acquisition and other softwares are readily available on a CALLISTO web-page. Most of them are compatible with windows operating system. Every 15 minutes one file of size 760.3 kB will be saved into hard disk. A PERL script automatically uploads a newly created file to the ftp-server located at ETH Zurich, Switzerland and maintains a backup in the local machine. The data collected from different locations around the world forms a network called e-CALLISTO. The data is made
accessible to the international community\textsuperscript{2}.

\section*{2.3. Image Processing}

We processed the data stored in flexible image transport system (fits or fts) format recorded by the spectrometer using sunpy\textsuperscript{3}. Also, we developed a python library called ‘pycallisto’, which is available for the public at git-hub\textsuperscript{4}. The ‘pycallisto’ library is developed using the standard python libraries: ‘matplotlib’ and ‘pyfits’. The developed library can be used to process the data obtained at different observatories in addition to the non-CALLISTO spectrometers.

\section*{3. Observations}

The preliminary observations carried out at IISER Pune were briefly discussed in this section.

\subsection*{3.1. Solar radio Type II bursts}

Type II bursts are slow drifting bursts $\approx 1 \text{ MHz s}^{-1}$. Type II bursts are the radio signatures of the shocks produced by a CME or flare. Since these bursts are electromagnetic in nature, they reach Earth in 8.3 minutes and provide the warning of interplanetary shocks (McLean & Labrum 1985; Gopalswamy et al. 2005). Figure 3 shows the first observation

\begin{itemize}
\item \textsuperscript{2}http://soleil.i4ds.ch/solarradio/callistoQuicklooks/
\item \textsuperscript{3}http://docs.sunpy.org/en/stable/guide/tour.html?highlight=callisto
\item \textsuperscript{4}https://github.com/ravipawase/pyCallisto
of Type II radio burst observed using our CALLISTO spectrometer at IISER Pune (on left-side) and the same event observed at Gauribidanur observatory (on right-side) (Ramesh 2011) on 04 November 2015. The Type II radio burst was triggered by a shock caused by a reported M-class flare at 03:20 UT. The peak GOES X-ray flux of the flare was \( \approx 1.9 \times 10^{-5} \text{ W m}^{-2} \) at 03:25 UT\(^5\). The flare was associated with an active region NOAA 12445 located at heliographic coordinates N14W64. The Type II burst was first seen at 03:23 UT which lasted in 15 minutes in the frequency range 40-470 MHz. In the present case, the measured drifting speed of Type II burst was \( \approx 1.18 \text{ MHz s}^{-1} \).

Fig. 3.— The Figure shows the dynamic spectrum with solar Type radio II burst observed using CALLISTO at IISER Pune (on left-side) and at Gauribidanur observatory (right-side). This event was observed on 04 November 2015 at 03:23 UT. The burst was triggered by a M-class flare erupted at 03:20 UT. At IISER Pune and Gauribidanur Observatory the burst was observed in the frequencies range 115-465 MHz and 50-410 MHz respectively.

\(^5\)https://www.solarmonitor.org
3.2. Lightning Signatures

As previously mentioned, there exists many natural and artificial sources which produce RFI. Thunderstorms (lightning) produce RFI ranging from few kHz to MHz (Smith et al. 1999; Siingh et al. 2009). The Figure 4 shows the observed RFI due to the thunderstorms in the range 120-500 MHz on 02 October 2015. During the monsoon, we have got many of such observations in the year 2015. Although, we verified the reasonable performance of the instrument in the frequency range 45-870 MHz by conducting few experiments, we noticed a sharp cutoff of RFI above $\approx 500$ MHz. We have to investigate on it further. Figure 5 is the spectral overview recorded using CALLISTO at IISER Pune. Because of the closest FM stations many harmonics are seen in the spectrum. Otherwise, the radio spectrum is clean at higher frequencies with a few selective interferences.

![Dynamic Spectrum](image)

Fig. 4.— The dynamic spectrum shows the radio frequency interferences observed at IISER Pune during a thunderstorm in total power mode on 02 October 2015. Such observations are very common during monsoon with a sharp cutoff at $\approx 500$ MHz.
Fig. 5.— The figure shows the radio spectrum at IISER Pune. Note that the spectrum is recorded using CALLISTO (using spectral overview option) and hence harmonics of the FM are seen. However, the spectrum at higher frequencies is clean with a few selective interferences. The computed flux density of the quiet Sun and Cygnus-A is plotted for the reference.

4. Summary and future plan

Although, CALLISTO spectrometer is designed to monitor the corona continuously 24 hours a day by having a worldwide network called e-CALLISTO, it can be further used to monitor the terrestrial and natural interferences like thunderstorms. Note that observing thunderstorms may damage the whole setup including computer by a lightning strike. It is advisable to use the lighting arresters for monitoring such interferences. However, e-CALLISTO is a powerful network with more than 75 stations/observatories around the globe to monitor the solar radio bursts. The e-CALLISTO network enable us to cross check the radio emissions across different observatories and to carry out scientific investigations. In future, at IISER Pune, we are planning to setup a spectropolarimeter. To achieve
this, we are in a process of fabricating two more LPDs. By mounting these antennas in orthogonal fashion and using 4 port quadrature hybrid we can observe the left and right circularly polarized emissions (Kishore et al. 2015). The quadrature hybrid outputs have to be connected to two separate CALLISTO receivers. Note that spectropolarimeter with increased sensitivity will play a crucial role in understanding the polarization properties of different radio bursts and magneto-ionic modes etc (Ratcliffe 1959; Aschwanden 2005).

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