Solar Radio Burst Data Processing of CALLISTO and Frequency Drift Rate Determination of Solar Radio Burst Detected by CALLISTO Network in Indonesia

M Batubara*, T Manik, R Suryana, M Lathif, P Sitompul, M Zamzam, and F Mumtahana

Space Science Centre – Indonesian National Institute of Aeronautics and Space (LAPAN), Bandung, West Java, 40173, Indonesia

*batubaramario@gmail.com

Abstract. Space Science Center of Indonesian Institute of Aeronautics and Space called LAPAN has installed several solar radio receivers named CALLISTO in various parts of Indonesia. The equipment has made some solar radio observational data which is indicate solar radio burst since its operation. All of the observational data stored in the file format of Flexible Image Transport System (FITS) which is the raw data. Therefore, it is required a such kind of related data processing to produce a data that can be used for further research. In this paper will discuss how the observational data of CALLISTO could be generated included the information of data format, CALLISTO data processing techniques used in these activities as well as some of the data processing based on data indicating solar radio bursts. As the results, a map of solar radio spectrum as spectrograph profiles and some determinations of frequency drift base on the data will also be discussed in this paper.

1. Introduction

The field of radio astronomy of the sun has become a wide of science field since in the 19 centuries. This field was initiated by the discovery of the basic components of a major of solar radio emission: the quiet sun, the slowly varying component, and various types of radio bursts including noise storm [1]. Radio burst can be classified into 5 (five) types in dynamic spectrum [2]. Its classification is based on the band width, frequency drift and duration of emission. The five classifications of radio burst are types I, II, III, IV and V. The appearance of radio burst is convinced that a burst generated by a fast excitation of electrons at the local plasma frequency level or at the level of both harmonic. In radio astronomy, bursts considered as significant characteristics of solar activity because it is generally associated with sudden acceleration of particles from the Sun [3,4].

Solar flare is one of the major events on the Sun that affect space weather and climate change [34-36]. Observations of solar radio bursts is done by using a compact astronomical Low Cost, Low Frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO) of BLEIN with 7 meter telescope dish at ETH, Zurich in the frequency range of 45 to 870 MHz. [37,38]. The antenna
is a broadband log-periodic antenna, multi-element, unidirectional, narrow-beam antenna. Its impedance and radiation characteristics are regularly repetitive as a logarithmic function of the excitation frequency [27,28,36,39,40]. Another thing that these antennas can cover a frequency range of 45-870 MHz [41-44]. CALLISTO spectrometer is a cheap radio spectrometer used to monitor metrics and decametric radio bursts, and the installation has spread into several parts of the world to allow for 24-hour monitoring of solar radio activity [45,46].

In this regard, Indonesia in particular LAPAN take the focus of solar radio observation are located in Sumedang with frequency range of 45-870 MHz [47]. This area is the best area with minimal interference in local radio frequency. The data selection has been chosen from 180 MHz to 870 MHz which has a clean area with radio frequency interference is very minimal [48]. In this paper focused on the flow production of observational data following with the content of the file header. The solar radio data processing techniques within background noise elimination method is also described in detail as a methodology. As a part of this paper, some of the results and discussion of data processing based on the method above by using data indicating solar radio bursts will also be described in detail.

2. Solar Radio Burst

Radio burst type IV is an indicator of the formation of a new active region [5-7]. It shows the wave-particle and wave interactions in a magnetic trap in the solar corona [8]. However, type IV events are fully developed and very complex. At a meter wavelength, the type IV burst is usually, preceded by a burst of type II (slow-drift). There are two main categories of solar radio burst type IV, which (i) broadband radio pulsations (BBP) and (ii) the zebra patterns (ZP). The fine structure (FS) of solar radio burst type IV is the principal interest in the flare plasma diagnostics in the low corona [9]. On the other hand, the BBP sources begin close to the active region and decays away from it [10]. Both BBPs and ZPs in type IV of solar radio emissions are rather frequently observed, especially a few days before the solar flares and Coronal Mass Ejection phenomena [11-13]. Meanwhile, solar radio bursts of type III is the most dominant solar flare with the phenomenon of solar flares. Type III was first introduced in 1963 [14] at range of frequency 500-10 MHz [15-17]. On the other hand, in this stage can be considered as pre-flare which could be a signature of accelerated electrons [18] as evidenced by found that 60% of the drift (type III) bursts of solar radio synchronized at the same time with the solar flare [19]. In addition, the dynamic structure of Type III solar radio bursts known as ejection of local plasma oscillations due to interference of atoms excitation in radiation of incoherent plasma frequency such as gyro synchrotron and emission-free that appear in radio wavelengths dominant in the meter and decimeter [20,21]. Type III bursts commonly occur early in the rise of impulsive solar flares may indicate that open field lines are important parts of model for release energy by magnetic fields such as flares [22,23].

Solar flare Type II is found roughly more than 60 years ago [24,25]. It can be divided into two main components: (i) fundamental (F) and (ii) the harmonic structure (H) and the slow drift Burst [26]. Temperatures that implied between the two classes of emissions is from $10^7$ - $10^{13}$ K [27,28]. Time of onset of this type precludes the possibility of a CME that cause bursts of type II [29]. The shock motion through the radial plasma density profile can be observed based on signal decreasing in frequency. Type II solar radio bursts were first identified by [30] and also described by [31] and are classified as broadband which lasted from 20 minutes to several hours. Thus, CME produces a certain kinetic energy which is an indicator of the life time of the bursts of type II [32,33].

3. Instrumentation

CALLISTO system installed at locations Aerospace Observation Center (BPD) Sumedang with geographic coordinates 6.913047°S; 107.83714°E which covers the frequency range of 45 MHz - 870 MHz. An antenna Log Periodic Dipole Antenna (LPDA) is installed outside the control building. This antenna is connected to the CALLISTO through the coaxial cable. However, before connecting to CALLISTO, a Low Noise Amplifier (LNA) is used to amplify signals with low signal power without reducing the signal to noise ratio (SNR). The output feeder is connected to a main computer via RS232.
cable IO for controlling, monitoring, and maintenance as well as signal processing to generate observation data. The whole observation data are automatically saved into a standard FIT file format that represents frequency versus time profile.

4. Observation Data

The data used in this activity is the FIT file which contains two levels data where the first data is the header file and the second level is the observation data in two dimensional of frequency and observation time. The header data explain the global information of the observation as shown in Table 1.

| Header Name  | Values | Notes                                             |
|--------------|--------|---------------------------------------------------|
| SIMPLE       | T      | file does conform to FITS standard                |
| BITPIX       | 8      | number of bits per data pixel                     |
| NAXIS        | 2      | number of data axes                               |
| NAXIS1       | 3600   | Length of data axis 1                             |
| NAXIS2       | 200    | Length of data axis 2                             |
| EXTEND       | T      | FITS dataset may contain extensions               |
| COMMENT      | FITS (Flexible Image Transport System) format defined in Astronomy and Astrophysics Supplement Series v44/p363, v44/p371, v73/p359, v73/p365. Contact the NASA Science Office of Standards and Technology for the FITS Definition document #100 and other FITS information. |
| DATE         | 2016-05-03 | Time of observation                                      |
| CONTENT      | 2016/05/03  | Radio flux density, e-CALLISTO (INDONESIA)            |
| Title of instrument | SUMEDANG                  | Organization name                                        |
| OBJECT       | Sun     | Type of instrument                                  |
| DATE-OBS     | 2016/05/03 | Date observation starts                             |
| TIME-OBS     | 02:39:03.375 | Time observation starts                             |
| DATE-END     | 2016/05/03 | Date observation ends                               |
| TIME-END     | 02:54:03  | Time observation ends                               |
| BZERO        | 0       | Scaling offset                                     |
| BSCALE       | 1       | Scaling factor                                     |
| BUNIT        | Digits  | $z$-axis title                                     |
| DATAMIN      | 115     | Minimum element in image                           |
| DATAMAX      | 166     | Maximum element in image                           |
| CRVAL1       | 9543    | Value on axis 1 at reference pixel                 |
| CRPIX1       | 0       | Reference pixel of axis 1                          |
|CTYPE1        | Time [UT] | Title of axis 1                                    |
| CDELT1       | 0.25    | Step between first and second element in $x$-axis  |
| CRVAL2       | 200     | Value on axis 2 at the reference pixel             |
| CRPIX2       | 0       | Reference pixel of axis 2                          |
| CTYPE2       | Frequency [MHz] | Title of axis 2                                 |
| CDELT2       | -1      | Step between first and second element in axis      |
| OBS_LAT      | 6.913047 | Observatory latitude in degree                     |
| OBS_LAC      | S       | Observatory latitude code {N,S}                    |
While data on the second level contains information on observational data in 2D array format [NAXIS1 X NAXIS2]. Each element of observational data is in the form of bit pixel data with sized 8-bit bytes (Table 2). In addition, the frequency range data used and the observational time series are stored in a data file on second level.

Table 2. The information of header file in the 2nd level.

| Header Name | Values | Notes |
|-------------|--------|-------|
| XTENSION    | BINTABLE | Binary table extension |
| BITPIX      | 8      | 8-bit bytes |
| NAXIS       | 2      | 2-dimensional binary table |
| NAXIS1      | 30400  | Width of table in bytes |
| NAXIS2      | 1      | Number of rows in table |
| PCOUNT      | 0      | Size of special data area |
| GCOUNT      | 1      | One data group (required password) |
| TFIELDS     | 2      | Number of fields in each row |
| TTYPE1      | TIME   | Label for field 1 |
| TFORM1      | 3600D8.3 | Data format of field: 8-byte DOUBLE |
| TTYPE2      | FREQUENCY | Label of field 2 |
| TFORM2      | 200D8.3 | Data format of field: 8-byte DOUBLE |
| TSCAL1      | 1      | |
| TZERO1      | 0      | |
| TSCAL2      | 1      | |
| TZERO2      | 0      | |

5. The Method of CALLISTO Data Processing

Since CALLISTO generate an output file with a standard FIT format within content of frequency and time. FIT data is difficult to characterize the type of solar flare. Therefore, the data processing is required to produce a specific diagram that gives a clear pattern profile of the solar flare or even CME.

The first time the data should be extracted from the header files to obtain numerical data observations. This observation data in numeric X still contains background noise (X) which is mixed in the observational data hence the noise needs to be eliminated by using equation (1) where \( \chi \) is a constant additional threshold of data:

\[
X = (X - \bar{X}) + \chi
\]  

Furthermore, the data collected by the specified interval data specified to get the peak value. Up to here, the data is still in the format of 8-bit bytes and will be converted into the form of the power unit (dB). The conversion process using the following equation:

\[
X = X \left( \frac{2}{2^{-2} - 4} \right)
\]

6. Frequency Drift Determination

Frequency drift rate of solar radio bursts is a change in the frequency of solar radio bursts of maximum intensity every time occurrence. In general, the value can be determined by taking the value at the
beginning to the end of time occurrence and start frequency to the end of solar radio frequency occurrence. Mathematically, the frequency drift can be calculated by the following equation:

$$\frac{\Delta f}{\Delta t} = \frac{f_2 - f_1}{t_2 - t_1}$$  \hspace{1cm} (3)

where, $f_2$ and $f_1$ is the frequency at the start and end of solar flare occurrence, $t_2$ and $t_1$ is the start and end times of solar flare events.

$\Delta t$ value is obtained by gradient constant of intensity average data linearization every time. While the value of $\Delta f$ is obtained from the value of frequency difference at the maximum and minimum intensity. The problem is how to determine both starting and ending time duration of burst occurrence. The frequency range itself also could be determine to get the estimation value of equation (3) results. We use the averaging value of whole signal strength in every time scale to get the time slope during solar burst event and the results shows in fig.2. Next, the curve fitting with 3rd order of polynomial function and finding the absolute difference of each data used in this works to get the estimation of $t_1$ and $t_2$.

7. Result and Discussion

![Fig.1. Spectrograph of solar radio burst detected in Sumedang, Indonesia](image)

Fig.1 is a spectrogram of solar radio bursts were detected by the CALLISTO system in Sumedang, West Java, Indonesia in 2015. In plain view, fourth spectrogram showed solar radio bursts of type III that has the intensity and time duration in different events. Fig.1a – Fig.1d could not be obtained the exact value at the maximum intensity and time duration of bursts occurrence. Meanwhile, the recorded intensity relative above the background noise which is incorporated along with the data. The background noise elimination and the binary conversion of data into a signal strength in dB has been done in this activity using equation (1) and equation (2) respectively.

Fig.1a – Fig.1c are solar radio burst data that received by the system with similar range of frequencies between 45 MHz - 200 MHz. Concerning to the time of data collection, the entire burst occurs after several time of data storage. For example, Fig.1d, solar radio bursts occurred when about 400 samples of data after hours 02:15:03 UT.
The horizontal axis in Fig. 1 shows the time of burst occurrence that explains the number of data samples. So that, it needs to be changed and converted into a standard unit of time. Fig. 2 shows the profile duration of time during the incident of solar radio bursts. Fig. 2b is the same data as the data in Fig. 1b, which is unique where the time duration of radio burst events is about 5.5 seconds compared with long period bursts of other events such as Fig. 2a that shows the incidence of bursts in Fig. 1a for 79 seconds. Other burst events in Fig. 2c and Fig. 2d, its occurrence happened around 60 seconds of period.

Figure 2. Profile of time duration during solar radio burst detected in Sumedang, Indonesia

Figure 3. Profile of solar radio wave frequency during solar burst detected in Sumedang, Indonesia
During the events of solar radio bursts, frequency drift depending on the radio signal frequency range of the sun. Fig.3 shows several patterns for the radio frequency range that ejected by the sun simultaneous with the burst occurred in 15th May 2015 at 05:15 UT, 9th May 2015 at 05:30 UT, 16th Oct 2015 at 06:00 UT and 15th Sept 2015 at 02:15 UT. The four images were obtained by taking the maximum value of the intensity of each frequency level. The maximum value is chosen beside in order to getting the peak value of burst intensity but also to prevent the loss of intensity information. The frequency difference during the solar burst even can be calculated by using the maximum and the minimum of selected frequency which is 0.25 above the median value. Thus, the value of the frequency range of solar radio bursts is based on the Fig.3a – Fig.3d are 255.25 MHz, 195.06 MHz, 231.88 MHz and 35.63 MHz respectively.

Referring to the equation (3), a frequency drift certainly can be calculated by using data on the above calculation. So, the solar radio bursts of data in Fig.1a to Fig.1d, the obtained frequency drift values are 3.23 MHz / s, 35.47 MHz / s, 3.86 MHz / s and 35.63 MHz / s respectively.

8. Conclusion
CALLISTO system installed in Sumedang, West Java, Indonesia have produced some data indicating FIT solar radio bursts of type III in 2015. By using solar radio bursts of data in 2015, has been done a FIT data processing in order to determine the estimation value of the frequency drift while solar radio bursts occurred. Based on drift frequency calculation process that the solar radio bursts occurred in 15th May 2015 at 05:15 UT, 9th May 2015 at 05:30 UT, 16th Oct 2015 at 06:00 UT, 15th Sept 2015 at 02:15 UT, the estimation of drift frequency are 3.23 MHz / s, 35.47 MHz / s, 3.86 MHz / s and 35.63 MHz / s respectively.

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