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Detection of Solar Bursts and CME using FFT

Debojyoti Halder
Department of Physics, Rishi Bankim Chandra Evening College, Naihati, West Bengal, India

Bipasa Raha
Department of Physics, D. S. College, Katihar, Bihar, India
Corresponding Author: Debojyoti Halder

ABSTRACT: *The Log Periodic Dipole Array (LPDA) is a broadband, multi-element narrow-beam antenna, is used conveniently for the reception of solar bursts. The dynamic pattern of solar corona is formed by condensed tubes of solar plasma and it is extremely structured. There are various kinds of transient phenomena happening on numerous time scales from hours to few milliseconds accompanying with the development of these condensed tubes of solar plasma. Observed from ~20 MHz up to near 10 GHz, these bursts with characteristic time less than 1s contain spikes, spike like very small period regular or irregular pulsations, dips in radio emission, eruptions, zebra pattern structures, etc. Especially, solar flares are one of the major active phenomena where magnetic energy deposited in these structures is converted into kinetic energy of highly accelerated charged particles through magnetic reconnection. Unique characteristic parameters of solar flares are its duration. Solar flares detected at radio frequencies (called bursts) within period less than one second can be a key to comprehend the elementary energy release procedure in flares. The paper reports measurements of solar radio emissions as observed by using log periodic dipole array (LPDA). Detection capability, technique employed and outline of the instruments are also presented.*

I. INTRODUCTION

Our Sun, being the primary source of energy for our solar system has a significant influence on our lives. The solar corona consists of ionized gas at temperatures exceeding one million Kelvin, which is much higher than photo-spheric temperature of 6000 K, the visible surface temperature of the Sun. Solar corona is a structure formed by dense tubes of solar plasma. A solar coronal mass ejection (CME) is a significant ejection of plasma mass from the Sun's corona into the heliosphere. CMEs are often associated with solar flares and other forms of solar activity. CMEs release large quantities of matter from the Sun's atmosphere into the solar wind and interplanetary space. The ejected matter is a plasma consisting primarily of electrons and protons embedded within its magnetic field. This magnetic field is commonly in the form of a flux rope, a helical magnetic field with changing pitch angles. There are many kinds of transient phenomena occurring on various time-scales from milliseconds to few hours associated to the evolution of solar plasma. When observed in decameteric wavelength range (~20 MHz) up to microwave wavelengths (~10 GHz), these bursts with characteristic time less than 1s include spikes, spike-like very short-period pulsations (regular or irregular) dips in radio emission, bursts, etc. Figure 1 shows two examples of a coronal mass ejection (CME). The black disk blocks out the bright light from the Sun, creating an artificial eclipse so that the dim light from the CME can be observed. The disk blocks out light from a region that is 1.6 times the diameter of the Sun. Each row shows the evolution of a CME with time. In particular, solar flares are one of the paradigmatic active phenomena where magnetic energy stored in these structures is transformed into kinetic energy of highly accelerated particles via magnetic reconnection. Jansky first detected radio emissions from extraterrestrial origin [2]. Out of various solar activity events, solar flare and CME are the two most gigantic phenomena with sudden release of electromagnetic energy. Basically, they are transitory energy releasing phenomena in every window of electromagnetic spectrum and develop in the magnetically active region [3]. One of the characteristic parameters of solar flares is its duration. Solar flares observed at radio frequencies (called bursts) with duration less than 1s can be a key to understand the basic energy release process in flares.

The Log-Periodic Dipole Antenna (LPDA), first built in 1958 by Du Hamel and Dwight Isbell, an undergraduate researcher in the ECE Antenna Laboratory and the prepared by Carrel. Since that, this type of antenna has been used widely and become as one of the essential parts in the recent explosion in information technology and wireless communications. In principle, this application lies the study of electromagnetic energy in an unbounded medium or from space which can be detected with a special arrangement of conductors. Simple design and effective detector are the most factor why this type is still relevant. Moreover, this antenna is also easy to construct and suitable to monitor the solar activities. The radiation characteristics vary considerably below the lower frequency limit of the antenna.

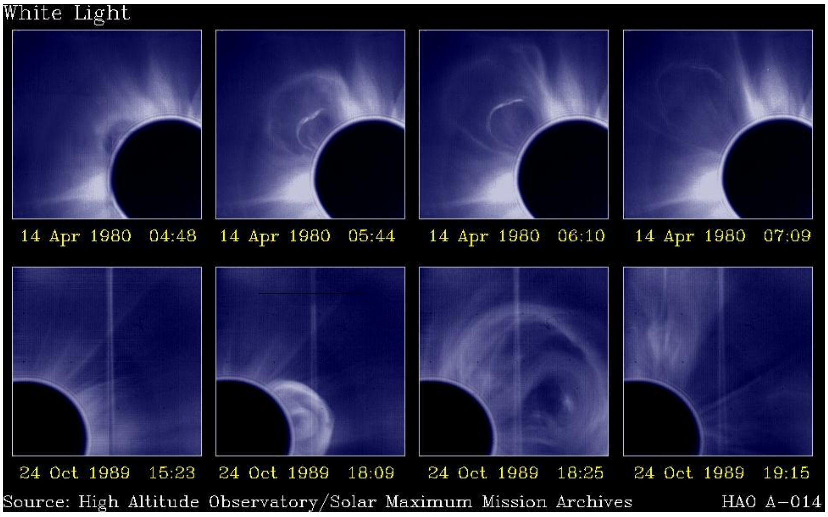

Fig. 1. Visible interpretation of Solar corona and CME from HAO [1]

II. VARIATION OF SOLAR ACTIVITY

The Variation of solar activity is the change in the amount of total solar radiation and its spectral distribution over multi-millennial time-scales. There are periodic and aperiodic components to these variations. The solar radiation reaches the earth surface at about 8.3 minutes traveling at the speed of light. The amount of average solar radiation received at the outer surface of Earth's atmosphere is about 1366 W/m². Figure 2 depicts the solar radiation spectrum i.e. the spectral irradiance in a wide range of wavelengths (nm).

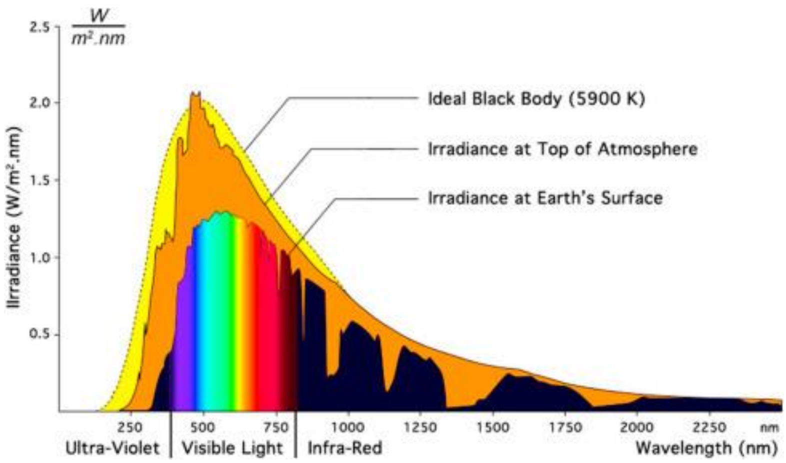

Fig. 2. The plot of the spectral irradiance in a wide range of wavelengths [4]

The sunspot number, also called the Wolf number, measures the number of sunspots or their groups on the surface of the sun. The relative sunspot number ***R*** is given by,

$$R = k\,(10g + s) \quad (1)$$

Where,***s*** is the individual number of spots;
g, the number of sunspot groups and
k, a factor depending on location and the instrument used for observation.

From an analysis it appears that sunspot activity is cyclical and reaches its maximum around every 9.5 to 11 years. It may be noted that when there is a sudden increase in the radiation given out by a flare event, it causes plasma from the corona with their own magnetic field and then that type of solar activity is termed as coronal mass ejections which may disrupt temporarily or permanently the background pattern [5]. Out of the various solar activities, the main one is the 11-year solar cycle or Schwabe cycle. It is a magnetic activity cycle which nearly periodic 11-year change in the Sun's activity measured in terms of variations in the number of observed sunspots on the Sun's surface. The solar cycles from 1750 are shown in Figure 3 with the monthly average sunspot numbers [6].

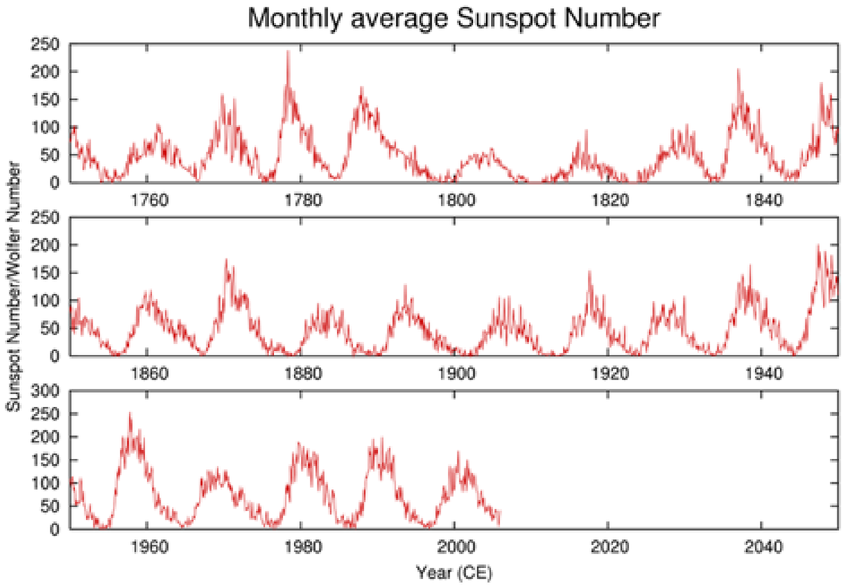

Fig. 3. Monthly average Sunspot number plots with Solar cycles [6]

In figure 4, four different plots have been shown to showcase the solar activity variation. Figure 4a shows the variation of aa index with sunspot number (SSN) from 1900s, figure 4b shows the variation of solar polar faculae or magnetic flux with SSN from 1900s, figure 4c shows the variation of solar polar field strength with SSN and lastly figure 4d shows the variation of meridian flow speed with SSN [7].

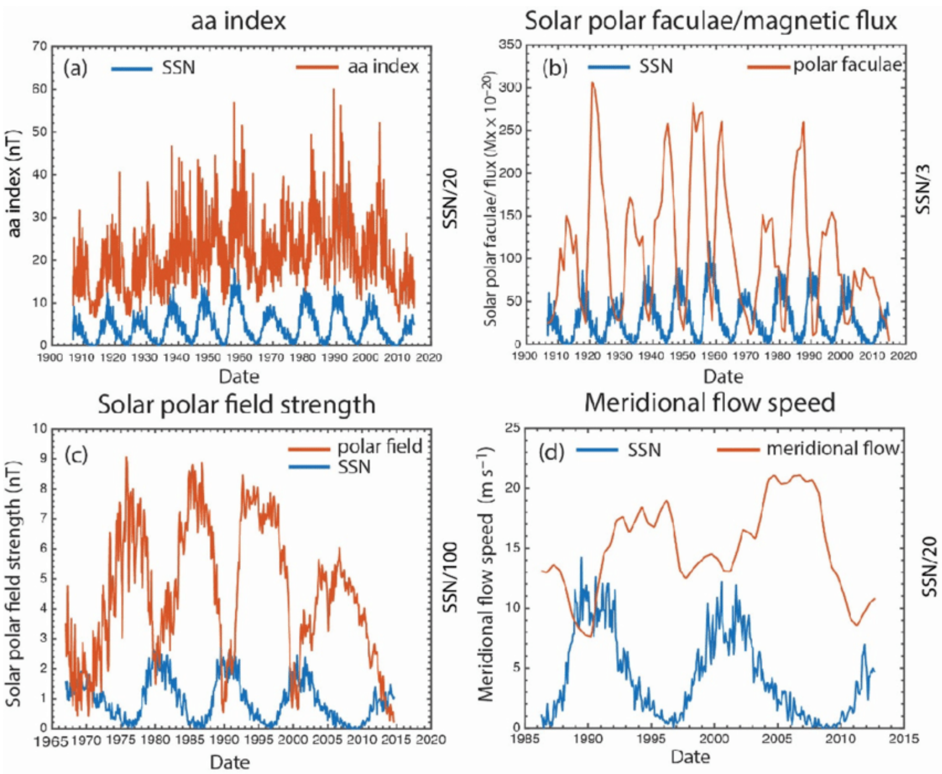

Fig. 4a the variation of aa index with sunspot number (SSN),
Fig. 4b the variation of solar polar faculae or magnetic flux with SSN,
Fig. 4c shows the variation of solar polar field strength with SSN,
Fig. 4d the variation of meridian flow speed with SSN [7]

III. RADIO BURSTS FROM THE SUN IN THE DYNAMIC SPECTRUM

The modern classification system for solar flares uses the letters A, B, C, M, or X, according to the peak flux in W/m^2 of soft X-rays with wavelengths 0.1 to 0.8 nm as measured by GOES satellites in geosynchronous orbit which is given in table 1. This system was originally devised in 1970 and included only the letters C, M, and X [8]. These letters were chosen to avoid confusion with other optical classification systems. The A and B classes were added in the 1990s as instruments became more sensitive to weaker flares. The strength of an event within a class is noted by a numerical suffix ranging from 1 up to, but excluding, 10, which is also the factor for that event within the class. Hence, an X_2 flare is twice the strength of an X_1 flare, an X_3 flare is three times as powerful as an X_1. M-class flares are a tenth the size of X-class flares with the same numeric suffix. An X_2 is four times more powerful than an M_5 flare. X-class flares with a peak flux that exceeds 10^{-3} W/m^2 may be noted with a numerical suffix equal to or greater than 10 [9].An earlier classification system, sometimes referred to as the flare importance, was based on H-α spectral observations is given in table 2 [10]. The scheme uses both the intensity and emitting surface. The classification in intensity is qualitative, referring to the flares as: faint (f), normal (n), or brilliant (b). The emitting surface is measured in terms of millionths of the hemisphere and is described below.

Table 1. Classification of the solar flares according to the intensity [8]

Classification	Peak flux range (W/m^2)
A	$< 10^{-7}$
B	$10^{-7} - 10^{-6}$
C	$10^{-6} - 10^{-5}$
M	$10^{-5} - 10^{-4}$
X	$> 10^{-4}$

Table 2. Earlier classification system of the solar flares based on H-alpha spectral observations [10]

Classification	Corrected area (millionths of hemisphere)
S	< 100
1	100–250
2	250–600
3	600–1200
4	> 1200

The space weather monitor data graph below (Figure 5) shows the changes to the signal strength caused by sunrise, sunset, and solar flares. The solar flares are classified by strength, from low to high as A, B, C, M and X.

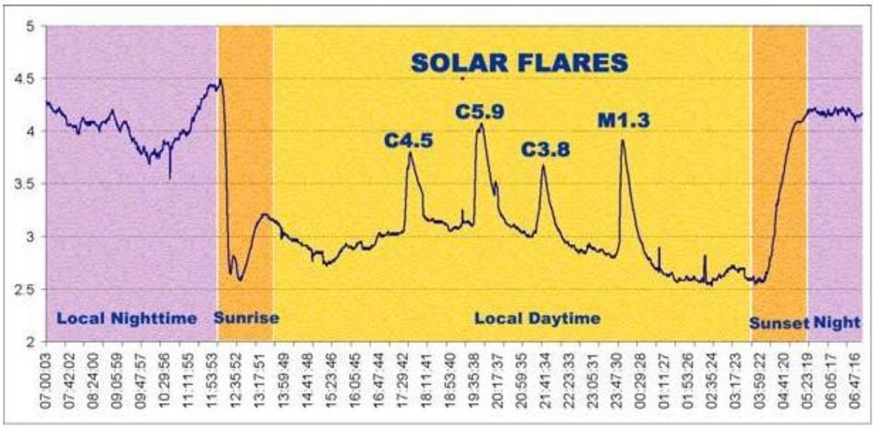

Fig. 5. The space weather monitor data plot shows the variations in signal strength due to sunrise, sunset, and 4 solar flares classified as A, B, C, M, and X.

IV. RECEPTION AND IDENTIFICATION OF SOLAR FLARE BURSTS

The most common form of log-periodic antenna is the log-periodic dipole array or LPDA. Log Periodic Dipole Array is a directional antenna with relatively constant characteristics across its wide frequency range. The LPDA consists of a number of half-wave dipole driven elements of gradually increasing length, each consisting of a pair of metal rods. We had designed and constructed the time-shared log periodic dipole array (LPDA), for capturing radio signals emitted during disturbed sun and to investigate its plasma behavior. The simplified log-periodic antenna we have built is to reduce problems of frequency dispersion and non-linear phase responses over ultra-wide bands at low cost. Solar radio bursts of Types I, II, and III as seen in dynamic spectrum observations from the Learmonth Solar radio-spectrograph is shown in Figure 6. The color corresponds to the intensity. The perfectly horizontal features seen at specific frequencies correspond to radio frequency interference from human-generated sources.

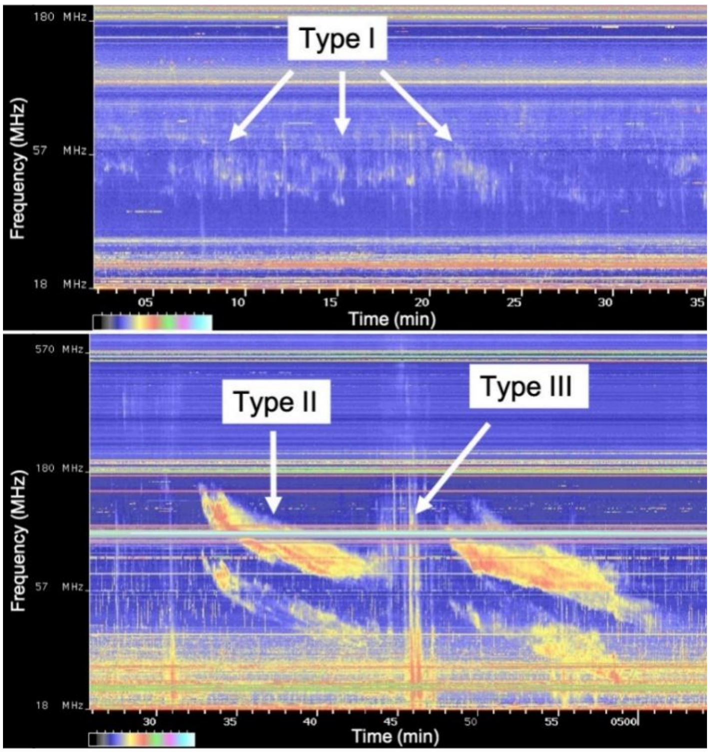

Fig. 6. Record of solar type II and III radio bursts obtained at different freq. [11]

Identifications of solar bursts may be divided into the following three steps:
(i) We first converted all the recorded voltage-time scale data to voltage-frequency data by FFT (using MATLAB).
(ii) Then we calculated the average of summed anti-sunward data. For this data for a period of three months have been taken into consideration.
(iii) Finally, we subtracted this average data from each of the expected solar burst data for identification.
The subtracted data so obtained were analyzed and compared with other reported data for verification.

We have then plotted frequency (in MHz) vs. power (watt) data by using MATLAB programming as shown below. The subtracted data so obtained analyzed elaborately and then compared with other reported data for verification. Some records of the solar bursts captured using the LPDA is documented in Figures 7, 8 and 9.

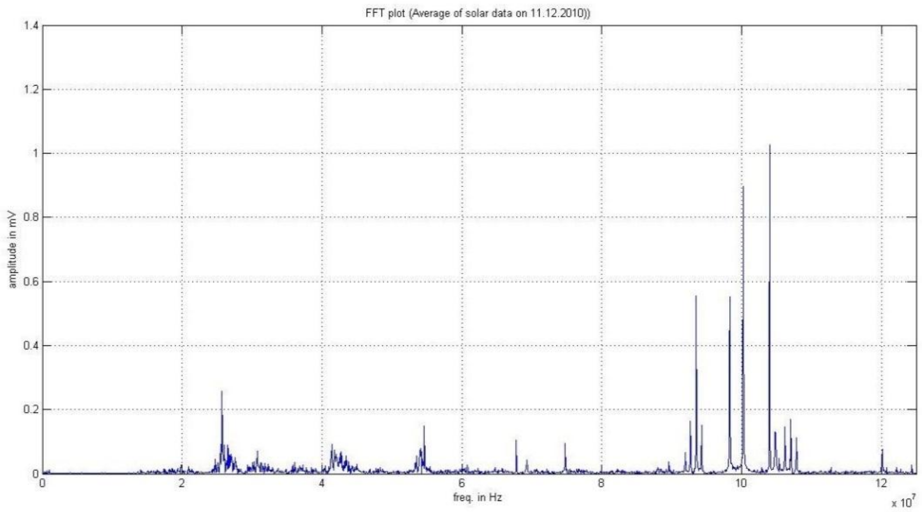

Fig. 7. FFT plot of average of all the recorded solar data which do not contain expected solar burst

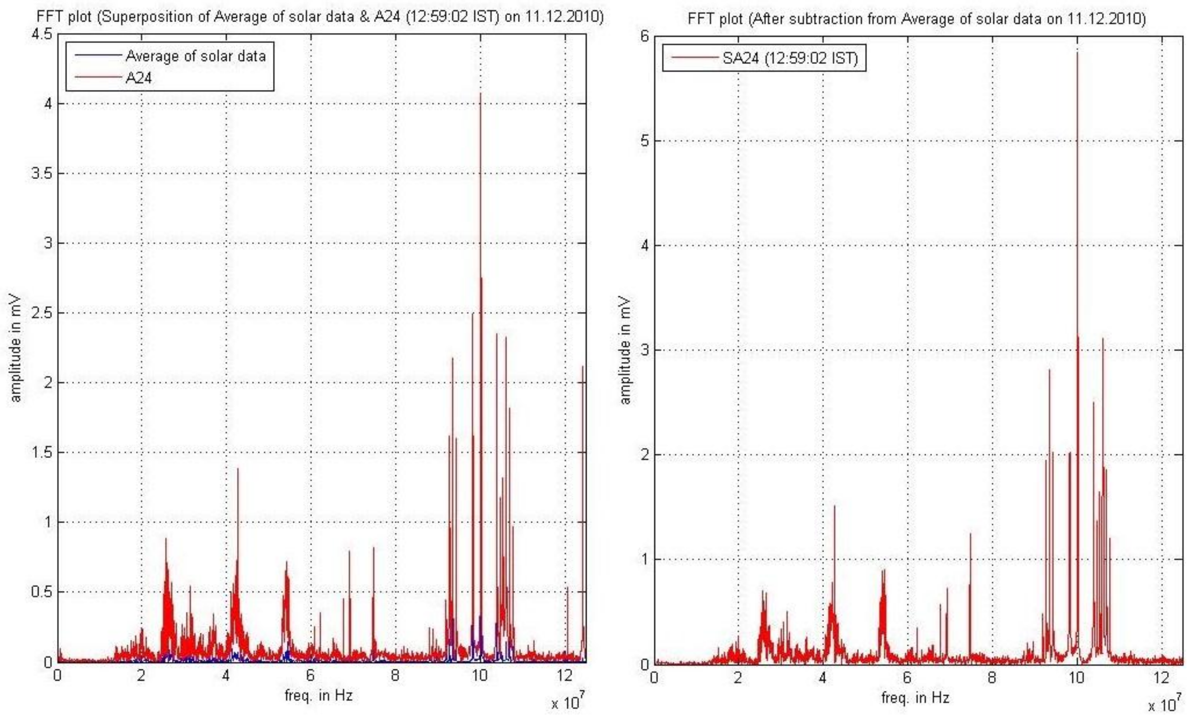

Fig. 8. reveal FFT plots of superposed and subtracted average solar data and solar data of just before and after expected solar bursts

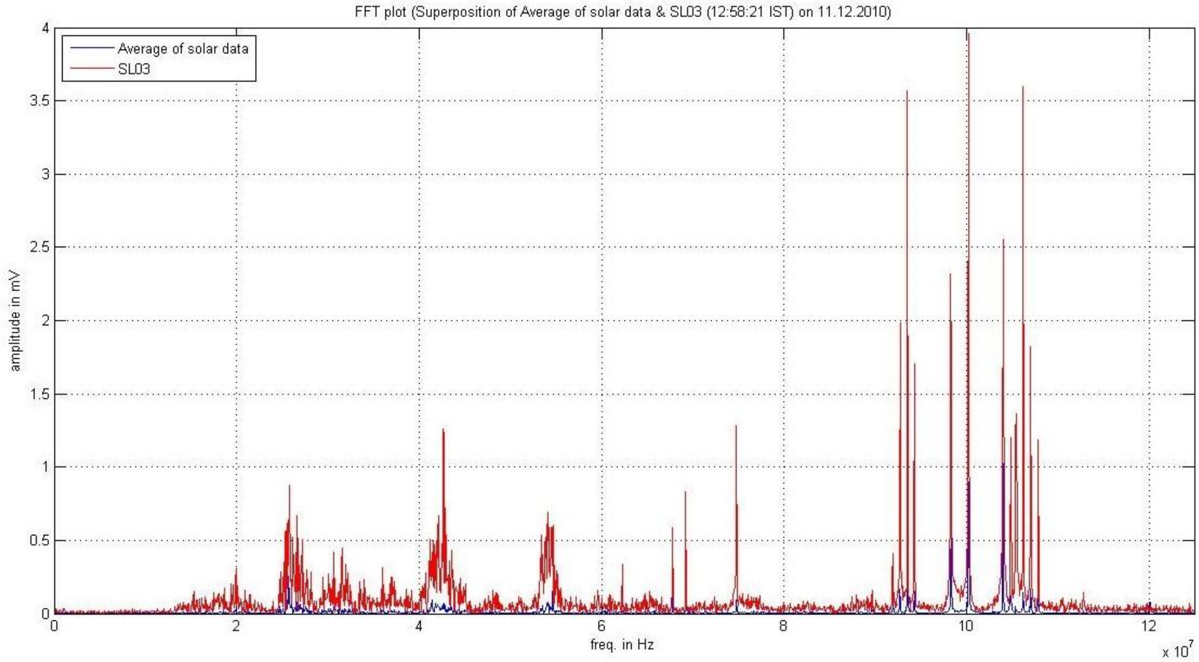

Fig. 9. show FFT plot of superposition average solar data and solar data which contain expected solar bursts

V. DISCUSSION AND CONCLUSION

The study of the fine structure of the solar radio emission is a key to understanding of plasma processes in the solar corona [12, 13]. It remains a reliable means for both diagnosing the solar corona and verifying the results of laboratory plasma experiments on the wave-wave and wave-particle interactions. High time and frequency resolution data have improved our studies of similar fine structures in star areas. So, the continuum radio emission of the type IV was associated for long time with the synchrotron emission of electrons trapped into a magnetic cloud [14, 15], but the analysis of fine structure suggested that the plasma mechanism is predominant in the meter and decimeter waveband.

Stripes in emission and absorption against the continuum background of solar type IV radio bursts in the meter and decimeter wave ranges are traditionally subdivided into two kinds: zebra pattern (ZP) and intermediate drift bursts [16]. Since the end of the seventies, microwave observations of solar emission with high temporal and spectral resolution have also shown fine structures: millisecond spikes (with the duration of single spikes of a few tens of milliseconds), and fast pulsations, usually super imposed on a smooth continuum emission [17]. With a view to simplify the analyzing technique, we need to fine-tune the algorithm. This can help particularly when a large number of data is required to handle more systematically. A more appropriate solar burst identification strategy may be highly profitable at this time when the when the solar activity is picking up. Efforts are currently underway to calculate the response matrix for flare time intervals. In this regard, detailed spectral analysis and cross-calibration with other solar instruments are essential. We are planning to install on our server the response matrix software and generate response files for all flare time intervals. Figure 10 represents the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) page indicating the records of A, B, C, M and X type of solar activity of 11 December 2010. It is the same date; we have illustrated elaborately with our own data as a typical case and so can be used as a conclusive comparison. A solar burst is a huge explosion in the Sun's atmosphere which affects different layers of the sun, e.g. photosphere, chromospheres, and corona.

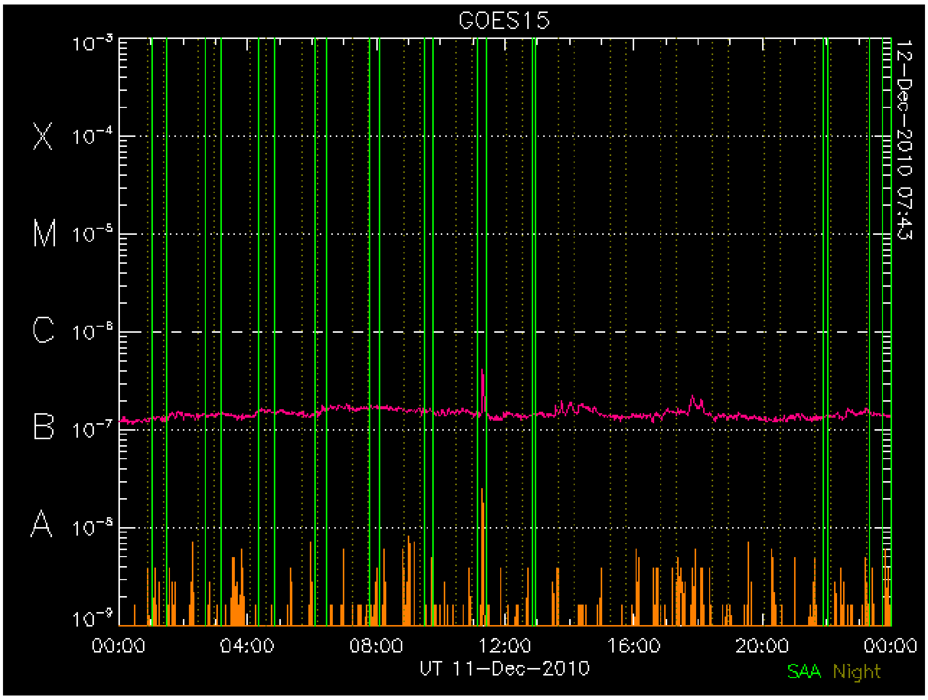

Fig. 10. Solar activity identification from RHESSI archive

It is responsible for heating plasma to very high temperature (~107 K) and accelerating nucleons and heavier ions to near the speed of light [18]. As a matter of fact, they generate radiation across the electromagnetic spectrum from radio waves to gamma rays. Most of the bursts occur in active regions around sunspots, where strong magnetic fields penetrate the photosphere to link the corona to the solar interior. Solar flares are powered by the sudden release of magnetic energy stored in the corona. A strong flare can cause coronal mass ejections (CME). X-rays and UV radiation emitted by solar flares can affect Earth's ionosphere when long-range radio communications may be disrupted [19]. The occurrence of solar flares becomes more when the Sun is active and less when the Sun is quiet. Large flares are less frequent in comparison to smaller ones.

DATA SOURCES

1. *http://www.ucar.edu/news/releases/2006/brightness.html*
2. *http://omniweb.gsfc.nasa.gov*
3. *http://commons.wikimedia.org*
4. *http://igscb.jpl.nasa.gov*
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