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Gauribidanur radio array solar spectrograph (GRASS)

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Abstract. We describe the Gauribidanur radio array solar spectrograph (GRASS) and its various systems. The system consists of an array of 8 log periodic dipoles, a spectrum analyzer and a data acquisition system. The spectrograph normally operates in the frequency range of 30 - 150 MHz with a frequency resolution of 250 KHz and a time resolution of 43 msec. The Gauribidanur radio array solar spectrograph operates approximately from 04:00 UT to 10:00 UT each day. We illustrate the working of the spectrograph with a few observations.

Keywords : Sun: radio-radiation, antenna – instrumentation: spectrograph, solar radio bursts

1. Introduction

Since the classification of solar radio bursts into five types (Type I to Type V) by Wild & McCready (1950), solar radio spectrographs have become an important tool for the study of various physical processes like particle acceleration and shock wave generation in the solar corona. Various fine structures in the solar radio emission discovered by the solar radio spectrographs have opened a rich field in the theory of radio bursts. Below 150 MHz, most of the solar radio emission is due to plasma emission at the fundamental or harmonic. Various signatures of plasma processes like particle acceleration, excitation and decay of various wave modes are shown in the dynamic spectra as different patterns of solar radio bursts. The electron plasma frequency f_p is related to the electron density N_e by $f_p = 9000\sqrt{N_e}$ where N_e is in cm^{-3}. The electron density and therefore the plasma

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frequency decreases outwards in the solar corona. Solar radio bursts in the frequency range of 30 - 150 MHz originate at the outer corona in the solar heights of approximately 1.8 to 1.2 solar radii. Frequency resolution of 15 KHz at 75 MHz corresponds to about 450 km on the Sun. Hence spectrographs with high frequency resolution can detect radio emission from small scale structures on the Sun. At the solar heights of 1.8 to 1.2 solar radii, the magnetic field shows an open configuration and the solar wind is accelerated there. Also, it is the height range where Coronal Mass Ejections (CMEs) are launched. Energy release in the corona at frequencies below 150 MHz usually produce coronal shock waves that generate type II radio bursts. The association of coronal type II radio bursts with flares and/or CMEs is not still well understood (Cliver et al. 1999; Gopalswamy et al. 2001). The study of the association of coronal type II radio bursts with CMEs has attained considerable importance in recent years due the importance of space weather predictions. The study of shock associated (SA) events in the corona is of great interest because of their association with proton events (Cane & Erickson 2005). A number of ground based broadband solar radio spectrographs have been developed in recent years and are being used for the observations of solar radio bursts (Ebenezer et al. 2001; Cho et al. 2002; Bradley et al. 2004; Benz et al. 2005). A solar radio spectrograph operating in the frequency band of 30 to 150 MHz is in operation at the Gauribidanur radio observatory since July 2002. In this paper, we describe this radio spectrograph called as Gauribidanur Radio Array Solar Spectrograph (GRASS). We illustrate the working of the instrument with a few examples of dynamic spectra of solar radio bursts.

2. Instrument description

2.1 Antenna system

The Gauribidanur radio array solar spectrograph (GRASS) is located at Gauribidanur radio observatory (Long: 77° 26′, Latt: 13° 36′), about 100 km north of Bangalore, India. This observatory is a joint collaboration between Raman Research Institute and Indian Institute of Astrophysics. The antenna system used for the GRASS consists of 8 antenna elements. The basic antenna element used is a log periodic dipole, which is designed for a gain of ≈ 8 dB with a geometric ratio τ of 0.89 and half apex angle α of ≈ 29 degrees (Balanis 1997). The effective collecting area of each dipole is $\approx 0.5\lambda^2$. The log periodic dipole can operate in the frequency range of 30 - 150 MHz with a VSWR of ≤ 2. The antenna elements are made up of aluminium tubes and are mounted on insulated cement poles. The impedance of a log periodic dipole is ≈ 50 ohms and the antenna elements accept linear polarization. The half power beam width of a log periodic dipole along the E - plane is about 60° and the same along the H - plane is about 100°. The length of the longest arm is 2.755 m and the shortest arm is 35 cms. The longest and shortest spacings between the arm elements respectively are 54.8 and 6.7 cm. The arm lengths and the spacing between the elements decrease geometrically by the scale factor τ. There are 19 arm elements in a log periodic dipole which is 5.505 m long. The antenna is fed by a RG58 U cable. Eight log periodic antennas are arranged with an inter-element spacing of 7 m with its E plane along the east - west direction and stacked in the north south direction with its H - plane along this direction. Such an arrangement of the antennas gives an array pattern with beam widths of $\approx 60^\circ$ in the east - west direction at all the frequencies in the range of 30 - 150 MHz. This will enable more than ± 2 hours of observations around the local noon without the use of any tracking system. Along the north - south direction the beam width varies from about 2° at 150 MHz to about 11° at 30 MHz. Hence the Sun remains unresolved in the entire operating frequency of the spectrograph. Fig. 1 shows the picture of the antenna system.

Figure 1. Antenna system for the GRASS. Eight log periodic dipoles stacked along the north - south direction with their E -plane along the east-west direction are shown. The inter-element spacing is 7 m along the north - south direction.

The RF signal from each log periodic dipole is passed through a high pass filter (MAN PHP-25 of Mini circuits Ltd) which provides an attenuation > 20 dB at frequencies below 19 MHz and thus most of the low frequency interferences are eliminated. The filtered RF signal is then passed through a 28 dB gain amplifier (MAN 1LN of Mini circuits Ltd) which has a noise figure of 2.8 dB and a third order inter-modulation intercept of $+18$ dBm. This will further prevent loading of the pre-amplifiers due to any strong low frequency interference. The filtered and amplified RF signals from the eight antenna elements are then combined in a Christmas tree arrangement using cables, power combiners and delay shifters. A delay shifter unit consists of different lengths of RG 174 U cables, which can be switched in /or out using diodes. These delay shifters can change the N-S beam of the array in the north-south direction from -32° declination to +58° declination. These delay shifters are remotely controlled from the receiver building using digital circuits. The combined RF signals from the 8 antennas are further amplified in the field and brought to the receiver building which is about 500 m from the array using low loss cables.

2.2 Spectrograph

The heart of the spectrograph is the commercially available off-the-shelf agilent spectrum analyzer model E4411B. The block diagram of the spectrograph is shown in the Fig. 2. Fig. 3 shows a picture of the spectrograph. RF signal reaching the receiver room is passed through an attenuator, a low pass filter, and an amplifier and then connected to the input of the spectrum analyzer. The spectrum analyzer is interfaced to a Pentium computer using a GPIB interface, which is supported through a VESA-GPIB interface. This network is set as a listener, talker and controller and transfers 32 bit control data and instruction information between the spectrum analyzer and the PC that works under the Windows operating system. The set of instructions like the duration of observation and the start and end frequencies of the observation are given as inputs from the observer through an interactive programme written in visual C++ language. The programme codes provide all the management and data communication instructions for the system. The spectrum analyzer is operated in continuous sweep mode. The control PC initiates a sweep and one sweep consists of 401 frequency samples in the band 30 - 150 MHz and takes 43 msec. The spectrum analyzer displays online the RF signal swept in the 120 MHz band. The linear amplitude of the trace which corresponds to the RF signal level is written as a 32 bit number in the computer along with timing information. Observations are usually carried out for about 6 hours. The collected binary data of ≈ 1.2 GB is compressed and then archived in a compact disc. The data is analyzed using standard software packages like IDL/Matlab and a raw JPEG image of 6 hours of the data is made everyday. Selective data is then processed for further analysis. The specifications of the GRASS are shown in the Table 1.

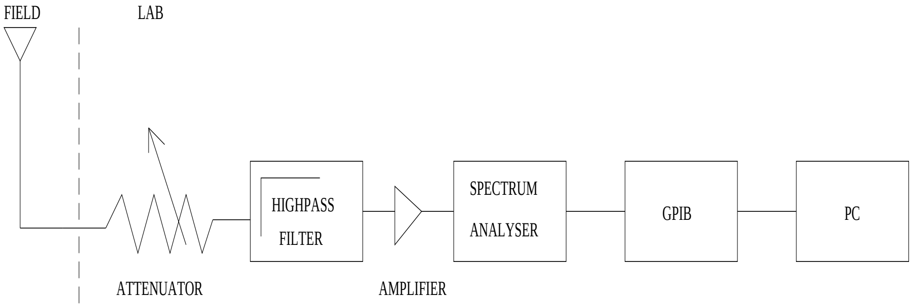

Figure 2. Block diagram of the GRASS.

Figure 3. Gauribidanur Radio Array Solar Spectrograph (GRASS). The agilent spectrum analyzer along with control and data acquisition PC are shown.

Table 1. Specifications of the GRASS.

Spectrum analyzer	Agilent Model EB 4411 B
GPIB interface	HP-IB PCI 82350
Data transfer rate	32 bit/s
System control	Programmable user interface (PUI)
Dynamic range	30 dB
Frequency samples	401 in the band of observation
Frequency coverage	30 to 150 MHz (variable)
Time resolution	43 ms
Spectral resolution	250 KHz
Time of observation	04:00 UT to 10:00 UT approximately
Sensitivity	5000 Jy at 150 MHz

3. Examples of observations

GRASS is in operation since July 2002 and is being used to observe the Sun everyday. Here we present some examples of observations of solar radio bursts. Fig. 4 shows a typical example of the dynamic spectrum of radio bursts observed on 23rd August 2002. One can see type III radio bursts followed by a type II radio burst. The type III radio burst started at 05:46:00 UT above 130 MHz and drifted towards the low frequencies. These bursts were associated with a flare which started at 05:37 UT in the solar active region AR 10085 located at S10 W80. This optical flare of importance 2N lasted for about 51 minutes (*http://sgd.ngdc.noaa.gov/sgd*). Type III radio bursts are due to a beam of fast electrons from the flare site. As these electrons propagate outwards, they excite plasma oscillations at increasing heights from the Sun. These plasma waves are converted into EM waves at the fundamental by scattering on the background ions and the harmonic by coalescence of two plasma waves (Melrose 1985). The type II radio burst started around 05:55 UT. Fundamental/harmonic structures and also band splitting can be seen in this type II radio burst. The drift rate of this type II radio burst is 0.07 MHz/s and assuming 4 times Newkirk's density ($4.2\times10^4 \times10^{4.32}/\rho$ where ρ is measured in solar radii) we have estimated the shock speed as 420 km/s. Type II radio bursts are due to MHD shock waves traveling at a speed greater than the local Alfven speed (Robinson 1985). From the high-time plot of the CME, we have determined the onset of the CME at 1.5 solar radii. From this timing information and start of the type II radio burst it was found that a CME with a speed of 496 km s^{-1} (*http://cdaw.gsfc.nasa.gov/CME-list*) was associated with this type II radio burst. The dynamic spectrum of a group of type III radio bursts observed on September 30, 2002 with the GRASS is shown in the Fig. 5. The group of type III radio bursts started after a solar flare which was of importance SF. The optical flare occurred in the active region AR 10134 and started at 04:15 UT and lasted up to 04:28 UT. The time profiles of the groups of Type III radio bursts at

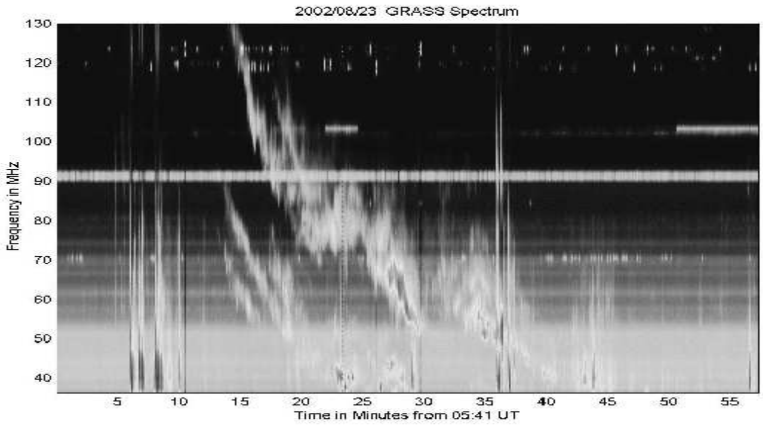

Figure 4. Example of type III radio bursts followed by a type II radio burst. The horizontal intense continuous line in the dynamic spectrum is due a FM station (91 MHz) in Bangalore, about 100 km away.

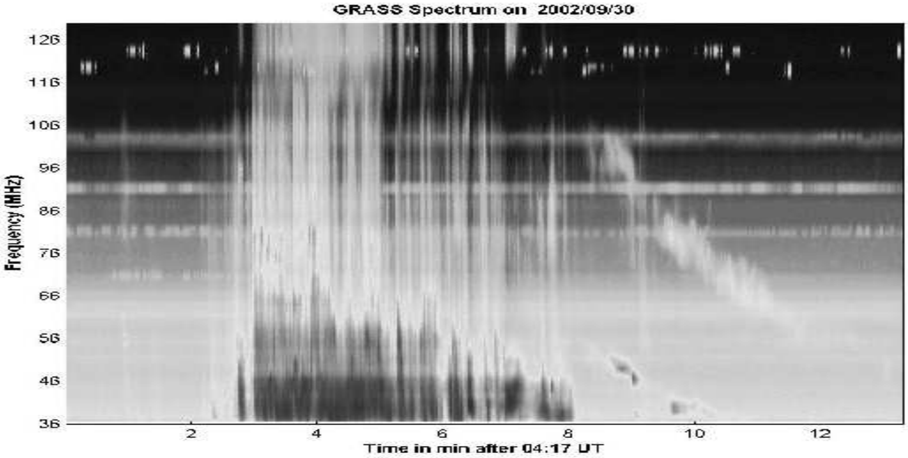

Figure 5. Example of a group of type III radio bursts followed by a type II radio burst. The intensity of the type III bursts decreased as a function of time especially below 66 MHz.

selected frequencies are shown in the Fig. 6. The study of time profiles of solar radio bursts with a time resolution of 43 msec will be useful in studying the excitation and decay mechanism of radio bursts. These groups of type III radio bursts lasted for about 4 minutes in our records. The electron stream of type III groups is suggested due to the discrete process: either quasi-periodic sequence of ejection of electrons or clustering of several successive ejection of material (Ashwanden & Benz, 1994; Bastian & Vlahos, 1997). A weak type II radio burst followed this group of type III radio bursts. The drift rate of this type II burst is about 0.12 MHz/s, and the estimated shock speed is $\sim$ 912 km s^{-1}. But no CME was reported during this type II burst even though the speed of the type II burst is $>$ 500 km s^{-1}. One of the strongest X-ray flares of this solar cycle accompanied by a Halo CME with a speed of 882 km s^{-1} and the strongest SEP event in the last 15 years occurred on January 20, 2005. The optical flare of importance 2B associated with this event started in the active region 10720 located at N12 W58. The flare started at 06:41 UT and lasted for about 133 minutes. The radio signature of this X7.9 flare event is shown in Fig. 7. The observed frequency range was increased on this day. The type IV continuum lasted for about 19 minutes in our records.

4. Conclusions

A solar radio spectrograph operating in the frequency range of 30 to 150 MHz at the Gauribidanur radio observatory to observe the transient radio emission from the Sun was described. With a time resolution of 43 msec and flexible selection of the observed band of frequencies, observations of the Sun both in wide and narrow bands of frequencies can be carried out. Multi-wavelength observations of the Sun from this spectrograph and those

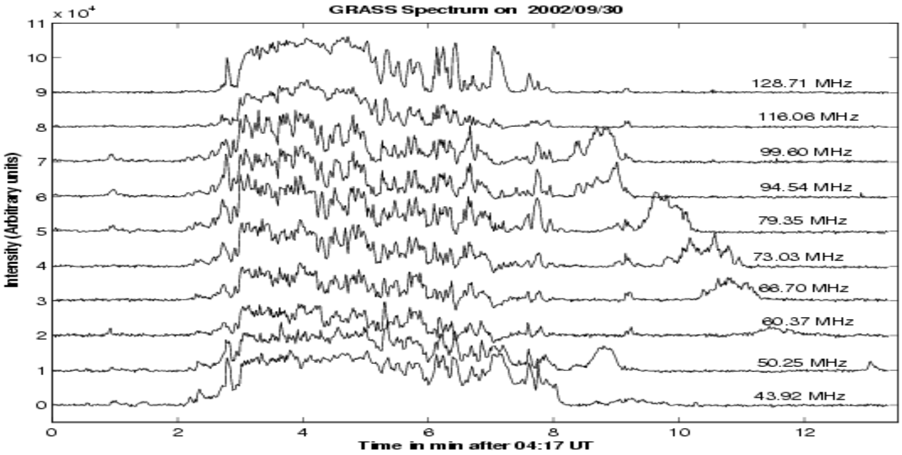

Figure 6. Time profiles of a group of type III radio bursts and the following type II radio burst observed on September 30, 2002.

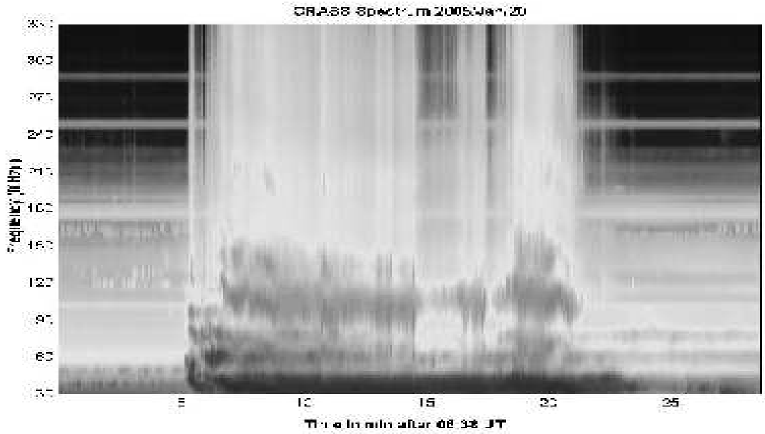

Figure 7. Continuum emission seen after the X7.2 flare of January 20, 2005.

on board space missions like SOHO, TRACE, RHESSI, and recently sent space missions like STEREO and HINODE are expected to be useful in understanding the dynamics of the outer corona in the height range of 1.2 to 1.8 solar radii.

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