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Measuring solar radio bursts in 20–650 MHz

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Abstract

The solar radiospectrograph of the University of Athens is installed at the Thermopylae Satellite Telecommunication Station. The observations cover the frequency range from 20 to 650 MHz. The spectrograph has a 7-m moving parabola feeding by a log-period antenna for 100–650 MHz and a stationary inverted *V* fat dipole antenna for 20–100 MHz. Two receivers are operating in parallel: a sweep frequency for the whole range (10 spectra/s, 630 channels/spectrum) and an acousto-optical receiver for the range 270–450 MHz (10 spectra/s, 128 channels/spectrum). The data acquisition system consists of two PCs (equipped with 12 bit, 225 ksamples/s DAC, one for every receiver). The daily operation is fully automated: receiving universal time from a GPS, pointing the antenna to the Sun, initiating system calibration, starting and stopping the observations at preset times, data acquisition, and archiving on DVD. We can also control the whole system through modem or Internet. The instrument can be used either by itself to study the onset and evolution of solar radio bursts and associated interplanetary phenomena or in conjunction with other instruments.
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Keywords: Instrumentation; Solar radio astronomy; Solar radio bursts; Radiospectrograph

1. Introduction

Radio Spectrography of the solar corona, at decimeter, meter and decameter wavelengths, provides basic information on the origin and early evolution of many phenomena that later extend and some of them reach the Earth. The ARTEMIS-IV (Appareil de Routine pour le Traitement et l' Enregistrement Magnetique de l' Information Spectral) solar radio spectrograph at Thermopylae is a complete system

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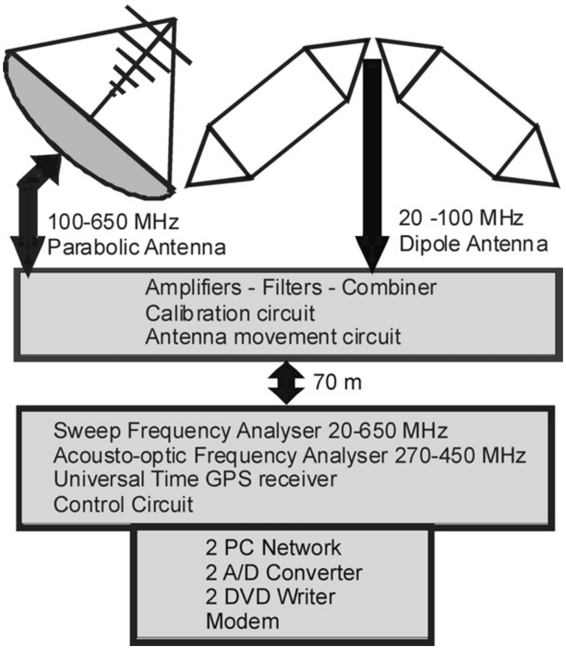

Fig. 1. The ARTEMIS IV solar radio spectrograph block diagram.

that receives and records the dynamic spectrum of solar radio bursts in the 20–650 MHz range on a daily basis [1,2]. It consists of two antennas, two receivers and two PCs with A/D converters (Fig. 1).

2. The two antennas

The solar radio spectrograph has a parabolic and a dipole antenna (Fig. 2).

The parabolic antenna has a diameter of 7 m and is fed by a log-periodic antenna for the 100–650 MHz range (High Band, HB). This antenna has a length of 2.25 m and consists of 13 dipoles. The mean gain is about 21 dbi and the mean half power beam width about 6°. The antenna has a typical equatorial mounting and tracks the Sun. The received signal is directed to band pass filters (100–650 MHz) and 40 db multistage transistor amplifiers (Fig. 3). Every morning, the system starts automatically the antenna movement and performs self-calibration by a white noise generator that varies gradually its temperature from 10^2 to 10^8 K in 64 steps of 1 db (Fig. 7).

The dipole antenna, for the range 20–100 MHz (Low Band, LB), is a stationary very fat inverted *V* dipole, on the east–west vertical plane. Each leg has a length of 3.5 m and a width of 1 m. It is constructed by copper tube [3,4]. The two legs form a 90° angle and its apex is 3.6 m above the ground. The antenna receives solar radio signals during all the day and a lot of interfering signals because it is almost omni directional. After reception, the signal goes through a balance band pass filter (11th order Chebychev, $f_L = 20$ MHz and $f_H = 90$ MHz, pass band ripple 0.1 db) to reject strong interference from local FM broadcastings. In Greece there are not TV broadcastings in the range 40–68 MHz, so LB range is free from strong interference. An active balun–broadband amplifier follows, composed of two CA 2830 [5] hybrids operated in parallel. This design, enables signal amplification and impedance matching between the balanced high impedance of

Fig. 2. The two antennas at Thermopylae.

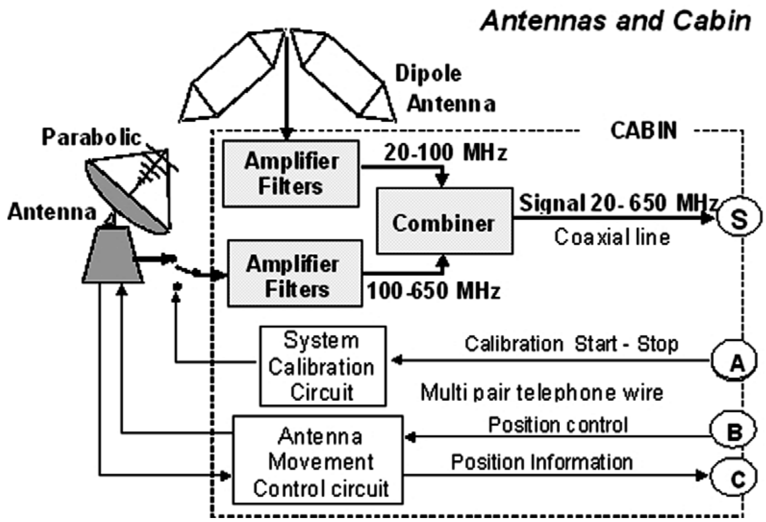

Fig. 3. Block diagram of the two antennas and the cabin.

the dipole antenna and the unbalanced 50 Ohm transmission line.

A combiner combines the signals from the two antennas, and drives them to the control room through a 50 Ohm, 70 m long, low loss transmission line (Fig. 3).

3. The two receivers and data acquisition

The combined signal enters into the control room, through the transmission line, and it is equally divided by a splitter in two paths (Fig. 3) and (Fig. 4).

First path (Fig. 4): It includes a classical sweep frequency analyzer (Analyseur de Spectre Global, ASG) and a PC (ASG PC) equipped with 12-bit (4096 level) ADC card (Keithley KPCI 3100, [6]). The frequency analyser covers the whole range from 20 to 650 MHz at 10 sweeps/s (or one spectrum in 100 ms) with instantaneous bandwidth 1 MHz and dynamic range of 70 db.

A pulse from a timer on the ADC card triggers every sweep (Fig. 5). The analogue output from

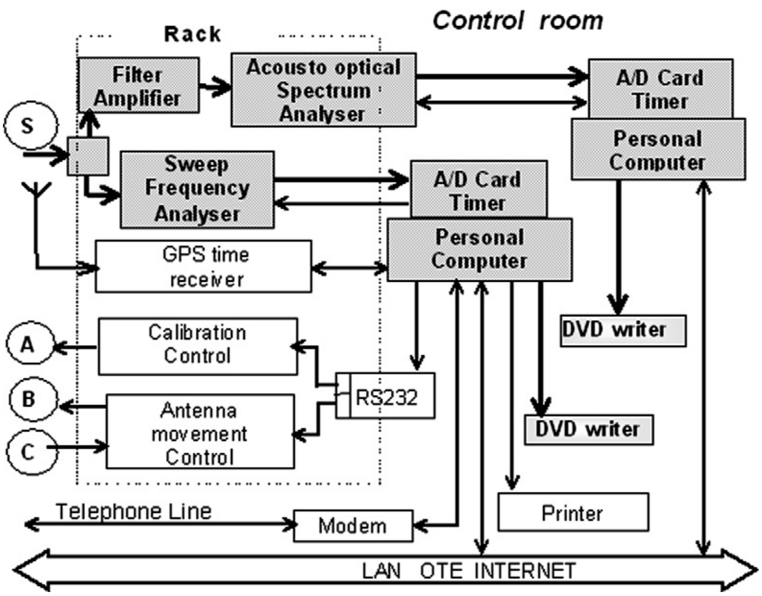

Fig. 4. Block diagram of the control room.

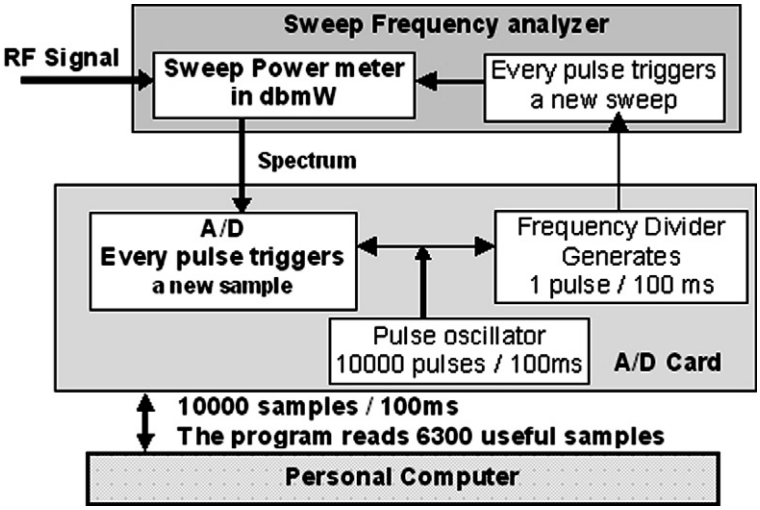

Fig. 5. Timing of the A/D converter and sweep frequency analyser.

the ASG drives the ADC card that takes 6300 samples/sweep. Every sample is an 12 bit integer number between 0 and 4095. The samples are grouped in tens and the mean value is extracted for every group, so the whole spectrum (20–630 MHz) is divided into 630 channels, with a resolution bandwidth of 1 MHz. Strong interference from FM radio and TV broadcasting is rejected by ignoring high values data at these a priori constant noted frequencies, in real time. These arrangements lead to a high "signal from solar radio bursts to noise ratio". The data from five successive sweeps (spectra) form a block that is transferred to the hard disk with a universal time stamp. Simultaneously we have the dynamic spectrum on the PC screen. At the end of the day, or later, we can retrieve the daily activity and store it on a DVD. The daily data are about 0.5 Gbyte. Every day, before starting measurements, the ASG PC controls the calibration and the antenna movement; also this PC receives the Universal Time from a GPS and corrects its clock.

This PC is equipped with a telephone line modem for telemetry purposes. Also, there is an Ethernet connection with the other PC.

Second path (Fig. 4): It includes a band pass filter (270–450 MHz), 30 db RF amplifier, and finally an acousto-optic spectral analyzer (Spectrograph Acousto-Optic, SAO) [7], for the range 270–450 MHz with

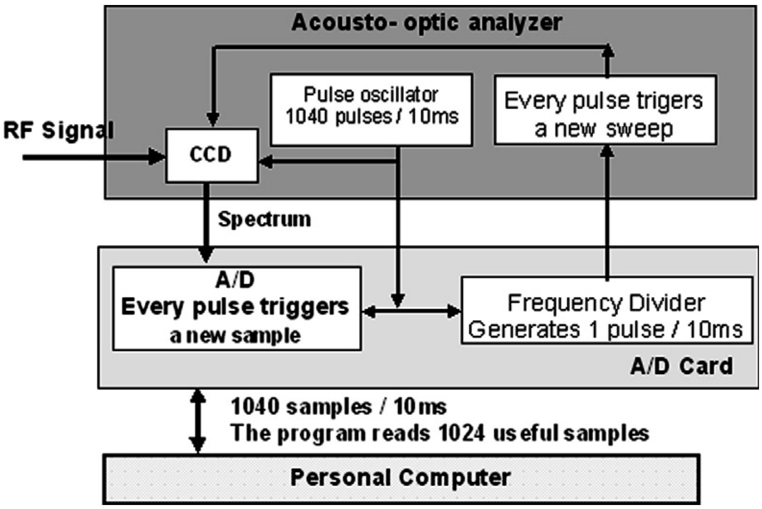

Fig. 6. Timing of the A/D converter and acousto-optic frequency analyser.

25 db dynamic linear range, very good frequency resolution of 200 kHz and very fast frame rate of 100 Hz (one frame or spectrum in 10 ms). There is also a PC equipped with 12-bit ADC card (Keithley KPCI 3100, [6]). Every 10 ms the ADC takes 1024 samples from the SAO analogue output (Fig. 6). Eight samples together form a group and the mean value is extracted for every group, so the range 270–450 MHz is divided into 128 channels with a resolution bandwidth 1.4 MHz. This arrangement leads to a high "signal from solar radio bursts to noise ratio". The data from 50 successive sweeps (spectra) form a block that is transferred to the hard disk with a universal time stamp. Simultaneously we have the dynamic spectrum on the PC screen. At the end of the day or later we can retrieve the daily activity and storage it on a DVD. The daily data are about 1 Gbyte. The Universal Time is received every morning from the other PC through the Ethernet connection.

Fig. 7 shows an example of ASG dynamic spectrum in grey scale (black for strong signals and white for weak). On the left we see the calibration signal from the noise generator, in the middle (inside the circle) a type III solar radio burst [10] and on the right the greyscale. Horizontal black or grey lines indicate strong FM radio and TV interference at constant frequencies.

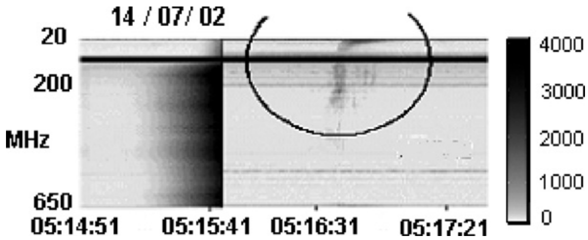

Fig. 7. Dynamic spectrum from the ASG. The calibration signal is shown at the left. The circle marks a type III solar radio burst. Black or grey horizontal lines are strong interference from FM radio and TV broadcastings at constant frequencies. Grey scale on the right is in arbitrary units.

4. Calibration

Calibration is performed to derive the relationship between the flux density (W m^{-2} Hz^{-1}, or Solar Flux Unit, 1SFU = 10^{-22} W m^{-2} Hz^{-1}) that arrives from the solar radio burst at the antenna site, and all possible data values (0-4095) for 630 channels, from 20 to 650 MHz with 1 MHz bandwidth. It consists of two steps, step one for the LB and step two for the HB.

Step one: We find the relationship between the flux density and all possible data values with the aid of technical specifications of the LB antenna,

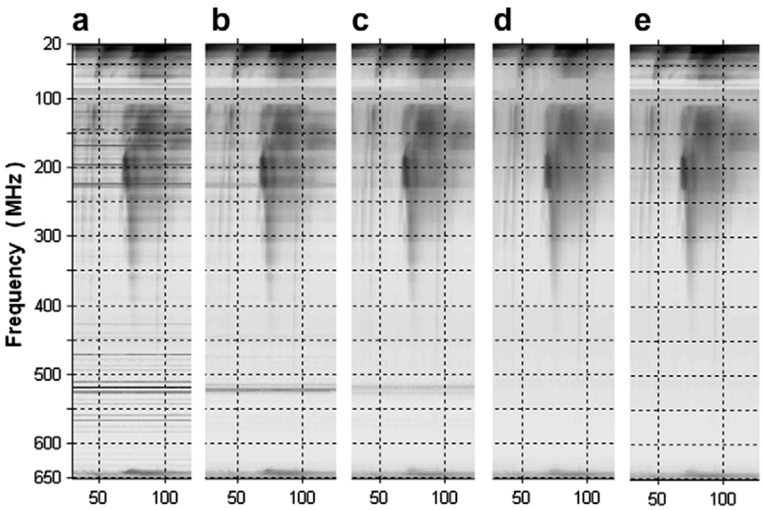

Fig. 8. The influence of the moving median filtering on dynamic spectrum. (a) Initial dynamic spectrum. (b) Moving median filtering with constant bandwidth 5. (c) Moving median filtering with constant bandwidth 15. (d) Moving median filtering with constant bandwidth 25. (e) Moving median filtering with variable bandwidth. Large bandwidth rejects all the interference and a lot of details in the radio solar burst. Small bandwidth allows details in the solar radio burst but can not reject interference. Using variable bandwidth the spectrum is divided in regions and we apply moving median filtering with variable bandwidth as follows: region 20–80 MHz, 80–400 MHz and 400–650 MHz with bandwidth 2, 17 and 25 respectively.

filters, amplifier, transmission line, ASG and ADC card.

Step two: First, the antenna temperature is derived from the recorded values of the calibration signal and the known noise temperature of the noise generator. Second, the relation between the antenna temperature and the flux density is derived from the antenna temperature and the antenna far field pattern.

The results show that the sensitivity is about 3SFU in LB and about 30SFU in HB with dynamic

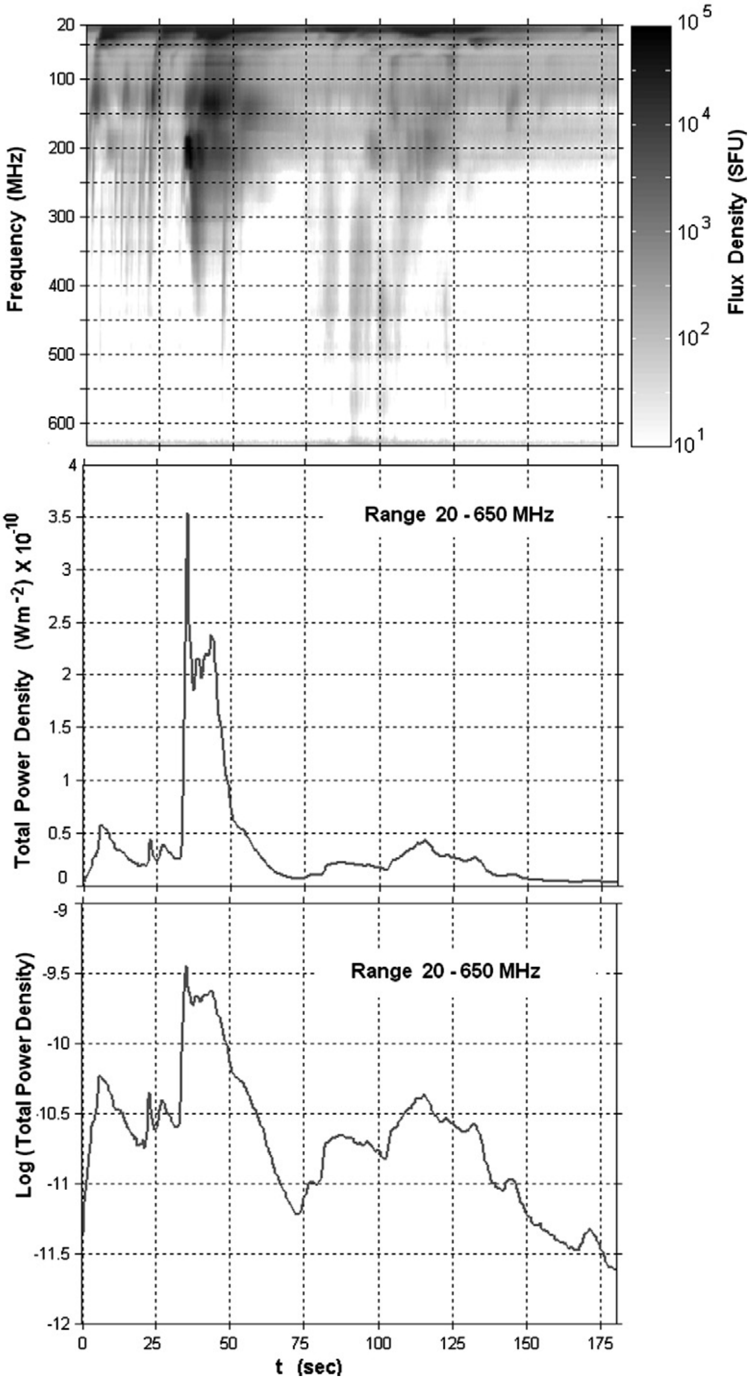

Fig. 9. Dynamic spectrum of type III and V solar radio burst from 08:05:00 UT on 26 April 2003. The graphs show the Total Power Density and its logarithm for the range 20–650 MHz.

range of 45 db. We can thus detect only solar radio bursts and no radio signal from the quite Sun that produces lower flux density.

Detecting the noise from the Galactic Center in LB, and finding values that are referred in bibliography [8] checks the method of calibration.

5. Data processing

Data processing involves filtering the signal to remove interference and finding the flux density of the dynamic spectrum and the power density ($W\,m^{-2}$) for the whole range from 20 to 650 MHz. Filtering is achieved by using, for every spectrum, moving median filters with variable bandwidth, Fig. 8 shows an example. Using calibration values we derive the dynamic spectrum flux density in SFU and the total power density in $W\,m^{-2}$ for the whole range 20–650 MHz. An example is shown in Fig. 9.

The time and frequency resolution of the instrument in conjunction with a low noise level permit

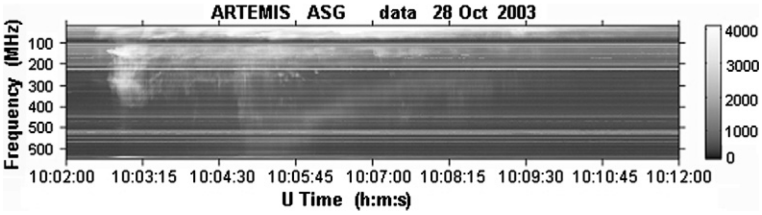

Fig. 10a. Dynamic spectrum of a large solar event recorded by ASG from 10:02:00 to 10:12:00 on 28 October 2003. Grey scale on the right is in arbitrary units.

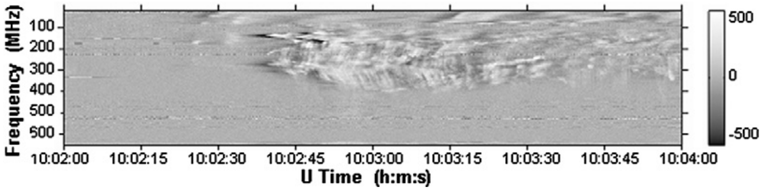

Fig. 10b. Detail of the Fig. 10a, shows the time differential dynamic spectrum from 10:02:00 to 10:04:00, derived after special 2D filtering. Ascending and descending lines are produced by ascending and descending electron beams in the solar corona.

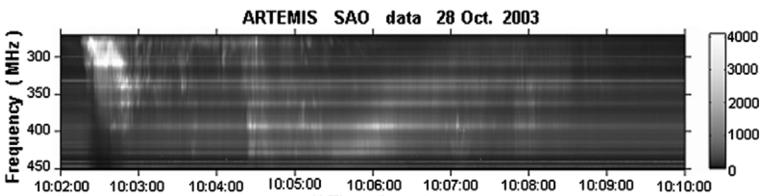

Fig. 11a. Dynamic spectrum of the same large solar event recorded by SAO from 10:02:00 to 10:10:00 on 28 October 2003. Grey scale on the right is in arbitrary units.

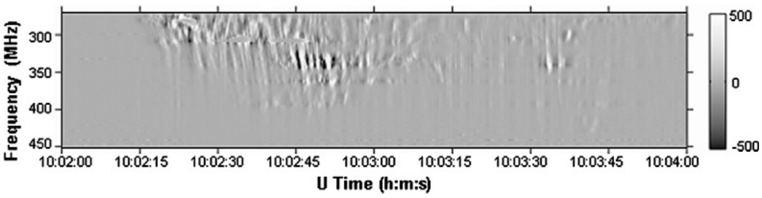

Fig. 11b. Detail of the Fig. 11a, shows the time differential dynamic spectrum from 10:02:00 to 10:04:00, derived after special 2D filtering. Grey scale on the right is in arbitrary units.

the detection of fine structures [9]. Fig. 10a shows the dynamic spectra of a 10 min large solar radio event on 28/10/2004 recorded by ARTEMIS IV ASG solar radio spectrograph. *Grey scale* on the right shows the signal intensity in arbitrary units. Fig. 10b is a 2 min small part of the above event, it shows the differential dynamic spectrum derived after special 2D filtering where we can distinguish fine structure which indicates ascending and descending electron beams in the solar corona. Figs. 11a and 11b shows the same event as recorded by SAO in the 270–450 MHz band where more details are distinguished in the frequency and time domain.

6. Conclusions and perspectives

We have designed and constructed a system, with two antennas and a frequency sweep radio spectrograph, that observes solar radio bursts in the range 20–650 MHz with time resolution 100 ms, frequency resolution 1 MHz, sensitivity 3 SFU and 30 SFU in the 20–100 MHz and 100–650 MHz range respectively. Using an acousto-optic radio spectrograph in the range 270–450 MHz, time resolution is 10 ms and frequency resolution is 1.4 MHz.

Future perspectives are the use of the instrument for routine observations of solar radio bursts, the construction of new dipole antennas perpendicular to the present so that we can make polarimetric measurements, as well as the extension of the SAO frequency range.

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