ARTEMIS MARK-IV, THE NEW GREEK–FRENCH DIGITAL RADIO SPECTROGRAPH AT THERMOPYLES, GREECE

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Abstract. We present the new digital solar radio spectrograph located at the Thermopyles station, Greece, operated by the University of Athens. Observations cover the range from 110 to 600 MHz, using a 7-m parabolic antenna. The reception system uses two techniques in parallel: sweep frequency and multi-channel, the latter being based on the Acousto-Optical technique. The data acquisition system is based on two subsystems, a Sun Sparc-5 workstation and a front end based on a VME Motorola system. The two subsystems are connected through the Ethernet and are operated using the VxWorks real-time package. The daily operation is completely automated: pointing of the antenna to the sun, starting and stopping the observations at pre-set times, acquiring data, compressing data by silence suppression in real time, and archiving the data on a routine manner on DAT tapes. Apart from its usual function, this instrument will be used in conjunction with other instruments, including the Nançay decameter array and the low frequency radio receivers on the *Wind* spacecraft.

1. Introduction

Radio spectrography of the solar corona (Benz, 1991; Maroulis *et al.*, 1993) at decimeter, meter, and decameter waves provides basic information on the origin and early evolution of many phenomena which later extend through the interplanetary medium and can be observed by spacecraft at lower frequencies, below the ionosphere cutoff – about 15 MHz by day –, and sometimes can be measured *in situ*. Type II bursts, type III bursts and type III storms (Caroubalos, 1973) are such phenomena that can be tracked over very large distances, sometimes even beyond the Earth's orbit. Outstanding problems include the formation of inter-

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planetary shocks, the acceleration of energetic particles from solar and interplanetary shock waves, and the relation of continuous streams of energetic electrons emitted by active regions to the heliospheric current sheet. All three problems require a close combination of high-frequency observations covering the lower corona and obtained from the ground with low-frequency observations spanning the interplanetary medium and obtained from spacecraft.

The new digital solar radio spectrograph operated at the Thermopyles station, Greece by the University of Athens, has been optimized to be operated in conjunction with the WAVES RAD1 and RAD2 low frequency radio receivers on the *Wind* spacecraft (Bougeret *et al.*, 1995). It covers the range from 110 MHz to 600 MHz, using a 7-m parabolic antenna. The reception system uses two techniques in parallel: sweep frequency and multi-channel, the latter being based on the Acousto-Optical technique. The sweep frequency analyser covers the full band, while the high sensitivity multi-channel acousto-optical analyser covers with high frequency and time resolution a critical range where several events seem to originate.

This new facility, ARTEMIS Mark-IV, was jointly designed and built by the Space Research Department (DESPA) of the Paris Observatory and by the Departments of Informatics and Physics of the University of Athens. It inherits from a long experience in digital multi-channel radio spectrographs (Dumas, Caroubalos, and Bougeret, 1982; Maroulis *et al.*, 1993; Bougeret *et al.*, 1995). This new system is installed at the OTE (Hellenic Telecommunications Organization) Ground Satellite Station, at Thermopyles, Greece, and it is operated by the University of Athens.

2. Architecture

The overall structure of the instrument is summarized in Figure 1. It can be divided into two basic functional subsystems: the *analogue part* and the *digital part*.

2.1. The Analogue Part

The primary role of the analogue part is to receive solar radio emission and condition the signal so that it becomes ready to be fed to the digital part. The analogue part also contains the electro-mechanical device that has been assigned the task of moving the antenna to achieve exact tracking of the Sun's orbit.

Radio activity is collected using a 7-m parabolic antenna. The antenna has a typical equatorial mounting: It can be rotated around two axes, using two motors. The antenna mount and dish were derived from the NS-array antennas at the Nançay Radio Astronomy Station.

After collection, the signal goes through a filtering stage. A system of rejection filters tuned in the most intense parasite areas, permits one to avoid intermodulation effects in order to be able to apply large amplification and obtain high sensitivity.

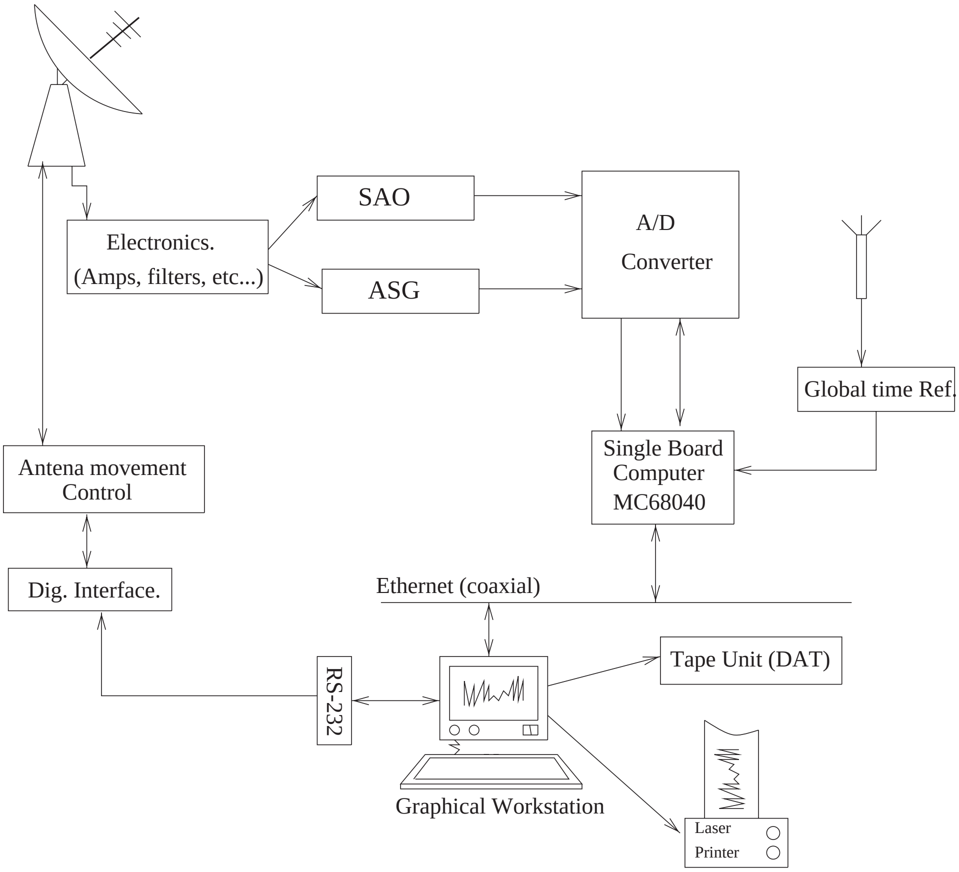

Figure 1. General block diagram.

There follows a carefully designed pre-amplification stage, and a compensation amplification stage. This arrangement leads to a high signal-to-noise ratio. There is yet another amplification stage, responsible for matching the signal characteristics, to the input specifications of the spectrum analyzers.

Two spectrum analyzers are used, called ASG (for 'Analyseur de Spectre Global' or General purpose Spectrum Analyzer) and SAO ('Spectrographe Acousto-Optique' or Acousto-Optical Spectrograph). The first one has a wide frequency reception range (110–600 MHz) and a large dynamic range (approx. 70 dB), but relatively low time and frequency resolutions. It is based on common sweep-frequency technology. The second has a smaller frequency and dynamic range but better time and frequency resolutions. It is based on modern Acousto-Optical technology. Radio spectrographs using Bragg cells have been designed at Paris Observatory, following the initial studies by Cole (1973). A patent with ANVAR (Agence Nationale pour la Valorisation Appliquée à la Recherche, an agency of the Centre National de la Recherche Scientifique) was obtained and the analyzer was

Table I
Receiver specifications

	ASG	SAO
Frequency range	110–600 MHz	270–450 MHz
Frequency resolution	800 channels	1024 channels
Time resolution	0.1 s	10 ms
Dynamic range	approx. 70 dB	approx. 30 dB

constructed by the French company “Automates et Automatismes” following our specifications. The characteristics of both the ASG and the SAO are summarized in Table I.

2.2. The digital part

The digital part is designed and implemented using a *highly modularized approach*, with well-defined interfaces among modules, which allows easy maintenance and offers excellent flexibility for future expansion. The digital part can be subdivided into two *modules* or *subsystems*: One of them is called the *front-end module*, and the other the *main module*. These subsystems communicate by the means of a 10 Mbps Ethernet network.

2.2.1. *The Front-End Module*

The front-end module digitizes the signal using a multiplexed 12-bit A/D converter, controlled by a MC68040 microprocessor clocked at 25 MHz. Signal from the ASG is sampled at 128 channels (frequencies) and a 10 pps time resolution, while the signal from the SAO is sampled at 128 channels (frequencies) also, but at a 100 pps time resolution. The microprocessor buffers the data in a local dynamic RAM. The buffers are then precisely time-stamped (dated). For this purpose an external radio-clock is used, which receives a time-signal from Allouis (France-Inter). Also some elementary processing of the data takes place (e.g., averaging). Finally, digitized data is transmitted over to the 10 Mbps Ethernet network.

The communication among all the subcomponents of the front-end system is done over an industry standard VME bus. All the front-end parts are housed in a VME industrial crate.

The software for the real-time module is written in C and assembly programming languages and runs under the VxWorks real-time operating system.

2.2.2. *The Main Module*

The main system performs the following basic functions:

(a) reception of digitized data from the Ethernet network,
(b) removal of periods of solar tranquillity from the SAO data, in real time,
(c) storage of data on magnetic media,

(d) initiation of the antenna movement, and

(e) timing, synchronization, and automation of the whole instrument's operation.

It is based on a Sun Sparc-5 workstation, running the Solaris operating system.

The observation data is recorded using a two-stage procedure: during the daily observation, data are recorded in a 2-Gbyte SCSI hard disk. After the end of the (daily) observation, data are copied from the hard disk to a 4-mm magnetic tape (DAT). Tape capacities vary from 1 to 4 Gbytes. Using this two-stage method will make possible future addition of off-line elaborate signal processing algorithms and the support of any storage medium. The removal of tranquillity periods is performed using the algorithm (silence suppression) described in Dumas (1982), Dumas, Caroubalos, and Bougeret (1982), and Maroulis *et al.* (1993).

During the daily observation, a graphical representation of the signal being received is plotted in real time on the display of the workstation in the form of a color dynamic spectrum (SAO data). After the end of the observation, a summary plot of the data recorded during the day is plotted on a laser printer in the form of a gray-scale dynamic spectrum (ASG data).

An important aspect is the fact that the instrument is capable of operating automatically, having no need for user intervention, except for those functions that require some physical human presence (e.g. the replacement of a full tape). There are a few such functions and their complexity has been kept to a minimum level so that they can be performed by untrained personnel.

As has already been mentioned, the main system is also responsible for the initiation of the antenna Sun tracking movement.

The software for the main system is written in the C programming language and uses state-of-the-art multi-threaded technology. Interesting is the fact that only about 30% of the CPU power is used, leaving computer power for a lot of additions and improvements.

3. Conclusions – Perspectives

This new digital solar radio spectrograph is characterized by its very high time and frequency resolution, by its capability of operating automatically, by the use of a real-time silence compression algorithm, and the capability of performing real-time data visualization. These are achieved due to the use of state-of-the-art technology and industry standard hardware and software platforms wherever possible.

The spectrograph currently uses two spectrum analyzers (SAO and ASG) and receives two overlapping solar spectra, at different time and frequency resolutions. The first spectrum ranges from 110 to 600 MHz, while the other ranges from 270 to 450 MHz. During a routine operation it records simultaneously 128 channels from each receiver at a rate of 10 and 100 pps, respectively. Data are recorded on high-capacity magnetic media (1–4 Gbyte). An example observation-data extract, from the ASG spectrum, is displayed in Figure 2.

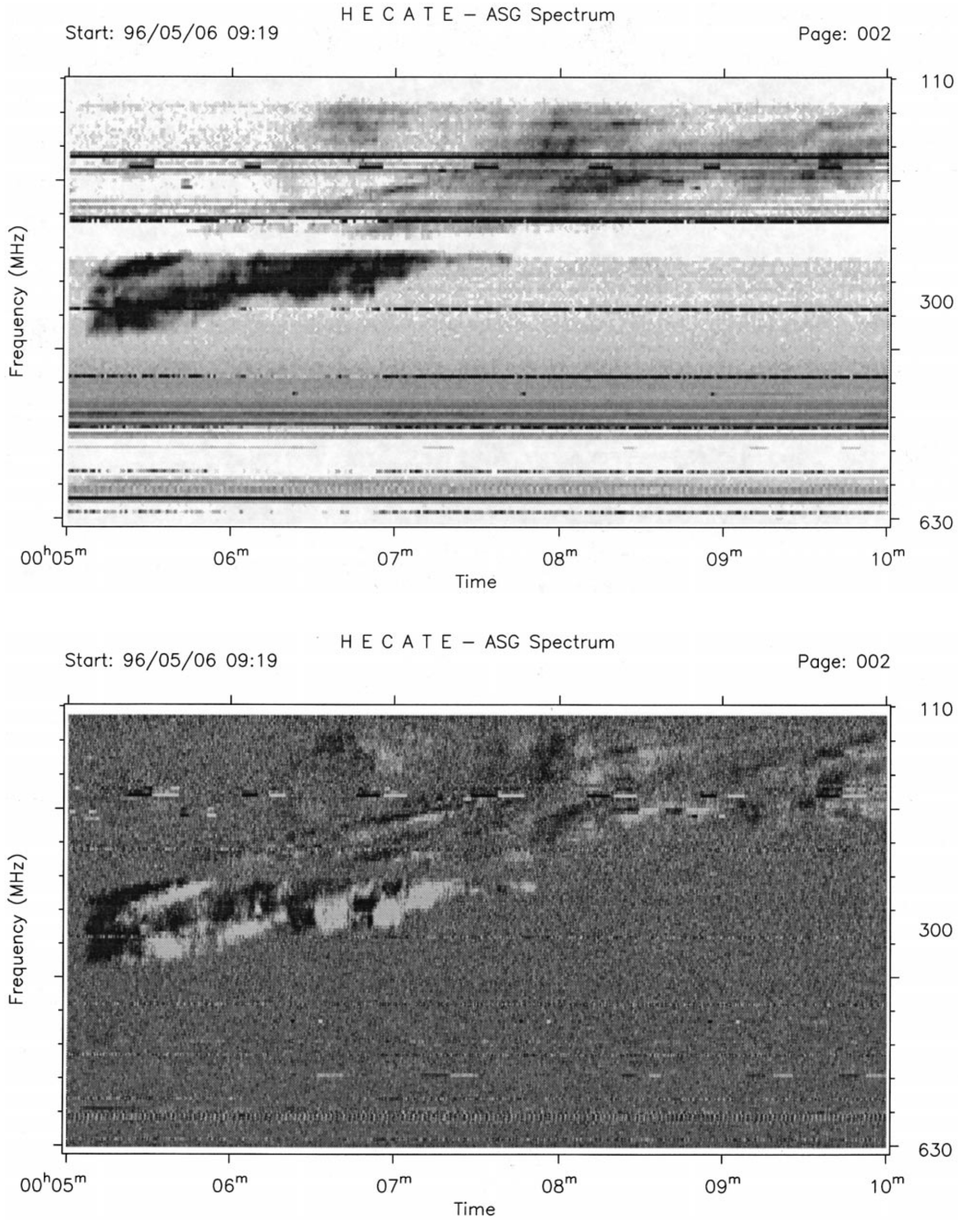

Figure 2. First received data (ASG spectrum). *Top panel:* intensity plot. *Bottom panel:* time derivative plot.

The use of industry standard hardware, and the modular architecture of the system, guarantee great extendibility. Our future plans include the use of more Acousto-Optical spectrometers for an even better time and frequency resolution at

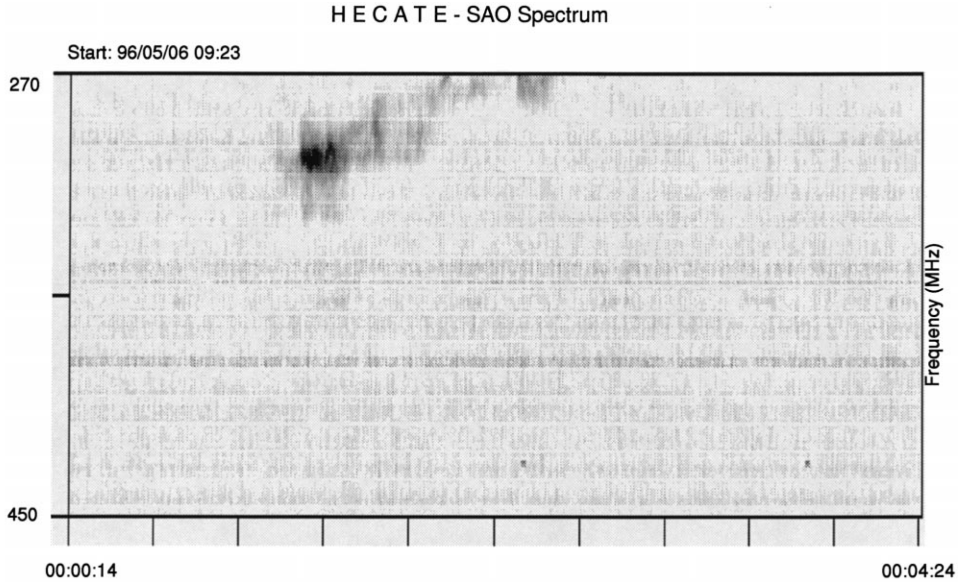

Figure 3. First received data (SAO spectrum).

wider spectrum ranges. We are also interested in integrating elaborate signal processing algorithms, such as compression of active periods, and pattern recognition.

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