Acta Astronautica 67 (2010) 1350–1355

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

SETI-ITALIA 2008: On-going searches and future prospects

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ARTICLE INFO

Article history:
Received 10 August 2009
Received in revised form
3 March 2010
Accepted 4 March 2010
Available online 10 April 2010

Keywords:
Radioastronomy
Data acquisition
Signal extraction
Algorithms
Fast data processing
SETI

ABSTRACT

The Medicina Radioastronomical Station is located nearby Bologna, in Italy. It consists of two receiving antennas currently dedicated to the astronomical research at radio frequencies. The 32 m diameter parabolic dish performs observations from 1.4 to 22 GHz whereas the Northern Cross (a 30.000 m^2 wide T-shaped array transit antenna) works at 408 MHz. So far SETI observations have been performed using a SERENDIP IV high resolution spectrometer connected to the parabolic antenna. Data acquisition were performed meanwhile the antenna was employed in ordinary astronomical observations (piggy-back mode). An innovative method to search for possible extraterrestrial signals could be provided by using the UHF Northern Cross transit telescope. In this paper observational modalities and the required technological set-up are investigated.

1. Introduction

The Medicina Radioastronomy Station (MRS) is located nearby Bologna (Italy). It is one of the three radio observatories of the Istituto di Radioastronomia (IRA) of the Italian Istituto Nazionale di Astrofisica (INAF). MRS is provided with two radiotelescopes: the 32 m dish, mainly dedicated to Very Long Baseline Interferometry (VLBI) observations and the Northern Cross, a large T-shaped parabolic/cylindrical antenna with an area of 30.000 m^2 (Fig. 1).

The parabolic VLBI antenna is charachterized by a collecting area of 800 m^2 and it works in the radio astronomical bands included in the 1.4–23 GHz range. It is equipped with a very high frequency resolution SERENDIP IV real time spectrometer (0.6 Hz) fully dedicated to the SETI program. This backend operates in *piggy-back* mode (i.e. data are collected meanwhile the antenna is employed in the ordinary radio-astronomical activity). In this way SETI observations can be performed for 24 h a day and 365 days a year at an extremely low cost. The Northern Cross is a 564 × 640 m T-shaped UHF array having a collecting area of 30.000 m^2 and a 4 × 4 arcmin beam cross section size. Due to the large collecting area, this array turns out particularly efficient to look for very weak signals. The Northern Cross operates at 408 MHz (λ = 73.5 cm) within a 2.7 MHz bandwidth. Part of this antenna has been recently refitted with new technologies and architectures to prepare a UHF demonstrator for the Square Kilometre Array (SKA) [1]. Another section was technologically upgraded to implement a 800 m^2 superstation operating from 120 to 240 MHz, for the Low Frequency Array (LOFAR) project [2].

Even though the 1420 MHz frequency has been historically considered the most appropriate for SETI observations, new radio frequencies have been recently investigated by several groups for the search for extraterrestrial life. Some examples are given by the SERENDIP

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0094-5765/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.actaastro.2010.03.005

V SETI spectrometer that has increased the bandwidth up to 300 MHz around the hydrogen, and by the Allen Telescope Array that currently covers the entire "water hole" range of 1420–1720 MHz [3]. The use of the radiotelescopes in piggy-back mode puts strong constraints on the observational frequencies of the SETI program performed at MRS. However such a wide frequency range (from 1.4 to 22 GHz for the VLBI antenna and from 120 to 240 MHz and 480 MHz for the Northern Cross) presumably increases the chances of detecting ET signals.

2. Bioastronomy projects at MRS

Within the last decades beside the SETI activities, both MRS antennas have been involved in several projects based on bioastronomical topics. In this section an overview of the most important bioastronomical programs carried out at MRS will be given. For each program the induced technological developments are also underlined.

2.1. The ITASEL project

The Italian Search for Extraterrestrial Life (ITASEL) [4] program is the result of a collaboration between the INAF-IRA and the Italian Space Agency (ASI). The aim of the project is the detection of possible water maser emissions from the higher levels of the atmosphere of extrasolar planets. The emission of water spectral lines, due to maser phenomenon, occurs at radio frequencies (22.35 GHz). This peculiarity allowed the detection of the water maser emission during the impact of the SL9 comet on Jupiter in July 1994 [5]. So far, no evidence of the presence of water in extrasolar planetary atmosphere has been obtained with this method, however further investigations are going to be performed due to the availability of a new high sensitivity observational set-up at MRS (new multifeed low noise receiver, fast data acquisition and processing system).

Fig. 1. A top view of the Medicina radiotelescopes. In the foreground the T-shaped antenna Croce del Nord. In the background the 32 m diameter parabolic dish.

In the framework of the ITASEL project, a new extremely fast and reconfigurable data acquisition and processing system was designed.

The core of the system, namely SPECTRA-1, is based on fast Field Programmable Gate Arrays (FPGAs) from

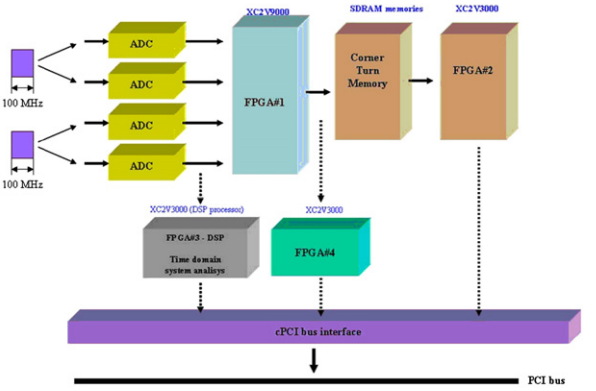

Fig. 2. Schematic block diagram of the acquisition and processing system SPECTRA-1.

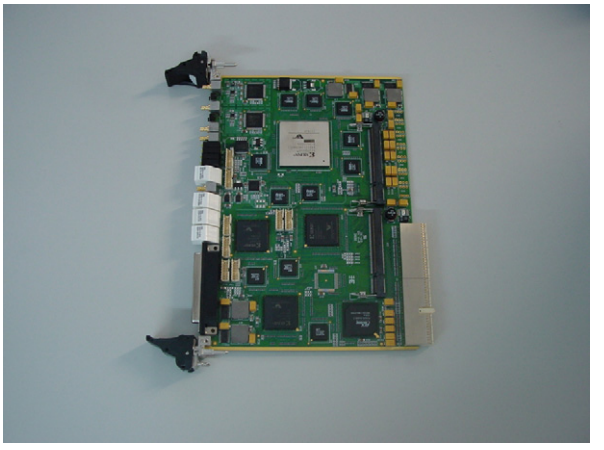

Fig. 3. Photo of the SPECTRA-1 board.

Fig. 4. The PCI crate equipped by the host computer and the SPECTRA-1 board.

Xilinx™ that exploit the flexibility of the software along with the velocity of the hardware. A block diagram of the system is reported in Fig. 2.

The input is composed by two A/D converters running at about 100 MS/s with a high dynamic range (14 bits→ 84 dB). Data can be processed in the time domain, if requested, and sent to a Polyphase Filter Bank (PFB). The filtered data can be squared and integrated in order to provide power spectra through the PCI bus (64 bit, 66 MHz). In this way, a programmable spectrometer with a channel to channel rejection of more than 60 dB is obtained. At the same time the output of the PFB fills up a Corner Turn Memory (CTM) with M spectra of N channels each. Subsequently the implementation of the FFT on each column, produces a spectrum composed by $M \times N$ channels.

In the SPECTRA-1 board (Fig. 3), a 64 million channels spectrometer for SETI observations can be obtained by filling up the CTM with 8 K spectra at 8 K channels each.

Due to the high flexibility, SPECTRA-1 (Fig. 4) can be employed in a wide range of bioastronomical activities.

For the SETI program the spectrometer was conceived to operate in piggy-back mode in connection with the parabolic antenna. With this configuration SPECTRA-1 is planned to operate for more than 300 days/year (the remainder 65 days being dedicated to standard antenna maintenance). Considering that such a spectrometer is connected to the 32 m dish, where a 16 MHz

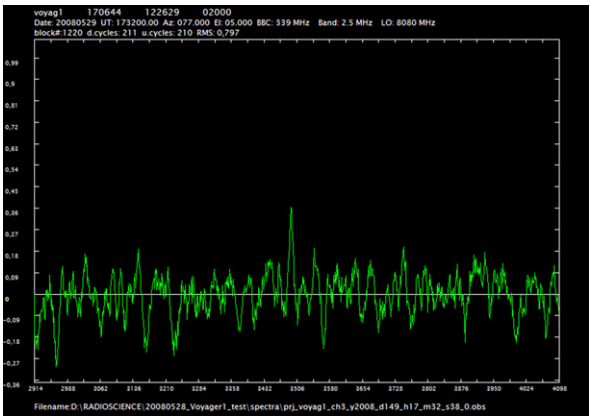

Fig. 5. The weak signal coming from the Voyager 1 spacecraft, traveling at 105 AU from the Earth.

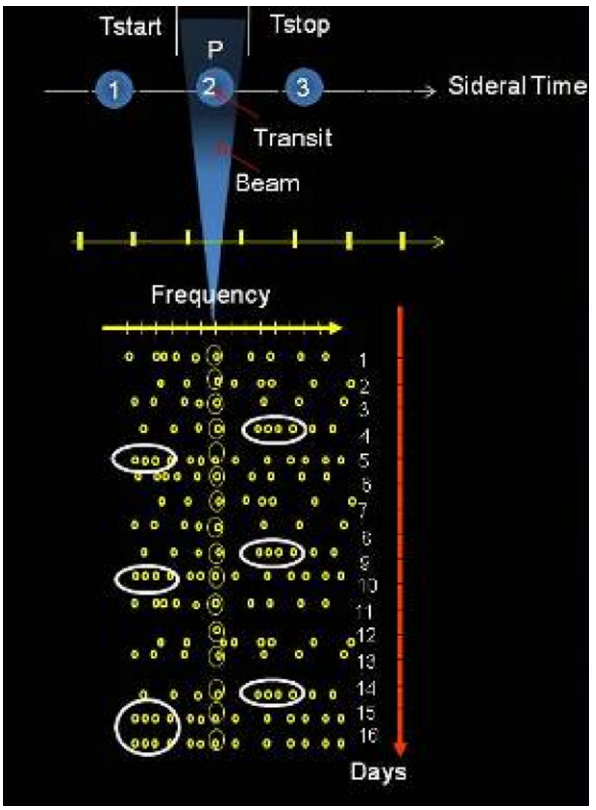

Fig. 6. Subsubmatrix related to the transit of the "ET source" on the local meridian.

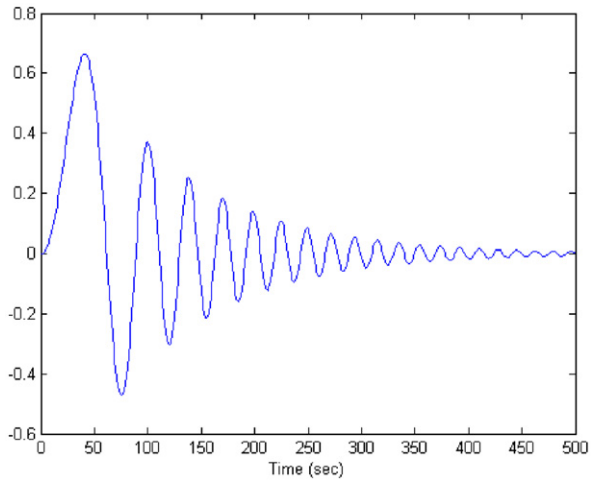

Fig. 7. Chirped signal.

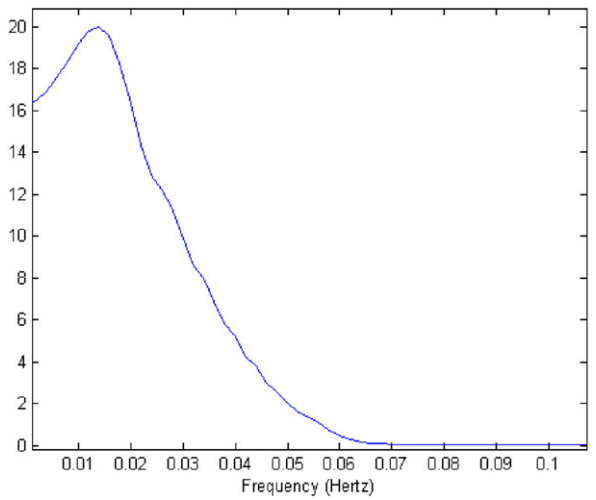

Fig. 8. FFT of the chirped signal.

bandwidth is available (independently from the selected receiver), the frequency resolution is given by 16 MHz/64,000,000=0.25 Hz while the time resolution is relatively low (about 4 s).

In order to check the sensitivity of the new spectrometer, a detection test of an extremely weak signal (the carrier coming from the Voyager 1 spacecraft, launched in 1977 and now at a distance of 105 AU from the Earth) was performed. After several hours of integration, the signal was extracted from the noise (see Fig. 5).

2.2. The search for C252α

The Northern Cross array, due to its very large collecting area, is characterized by an extremely high sensitivity. This results particularly effective to detect some carbon isotopes' emission lines occurring at approximately 408 MHz. Observations of the carbon isotope C252α (in CAS A) were already performed in 2000 in the framework of a collaboration between INAF-IRA and the Russian Academy of Sciences [6]. However, at that time these observations resulted particularly critical because of the weakness of the line and the very high power level of the background. These requirements can now be fulfilled by observational facilities that are characterized by a high dynamic range in both analog (receiver) and digital (high number of bits of the A/D converter) domain. Such device could be provided by the extremely fast and reconfigurable data acquisition and processing system SPECTRA-1 coupled with the large Northern Cross array.

3. New SETI observational strategies

In order to facilitate data interpretation and to introduce alternative methods to search for possible extraterrestrial radio signals, the use of the large UHF Northern Cross transit telescope is considered as well. Sky observations, performed at least within one or two months, could provide for each day a number of submatrices labeled according to the local sidereal time, in which that portion of sky is transiting inside the beam. The whole set of submatrices will be characterized by an averaged spectrum on each row per day per transit time interval. Keeping constant the transit antenna declination, a coherent signal coming from a definite position of the sky, would produce a "flag on" in the same submatrix at the same sidereal time (i.e. same point in the sky) (Fig. 6).

If the ET source is on the position of the sky labeled 1, the flag does not switch on into the spectrum of the relative submatrix. When it is in position 2 (transit on the local meridian), it switches on and then off when in position 3. In the same figure is clearly visible the flag switched on every day while the Radio Frequency Interferences (RFIs), highlighted by the white circles, are present in many subsequent spectra independently from

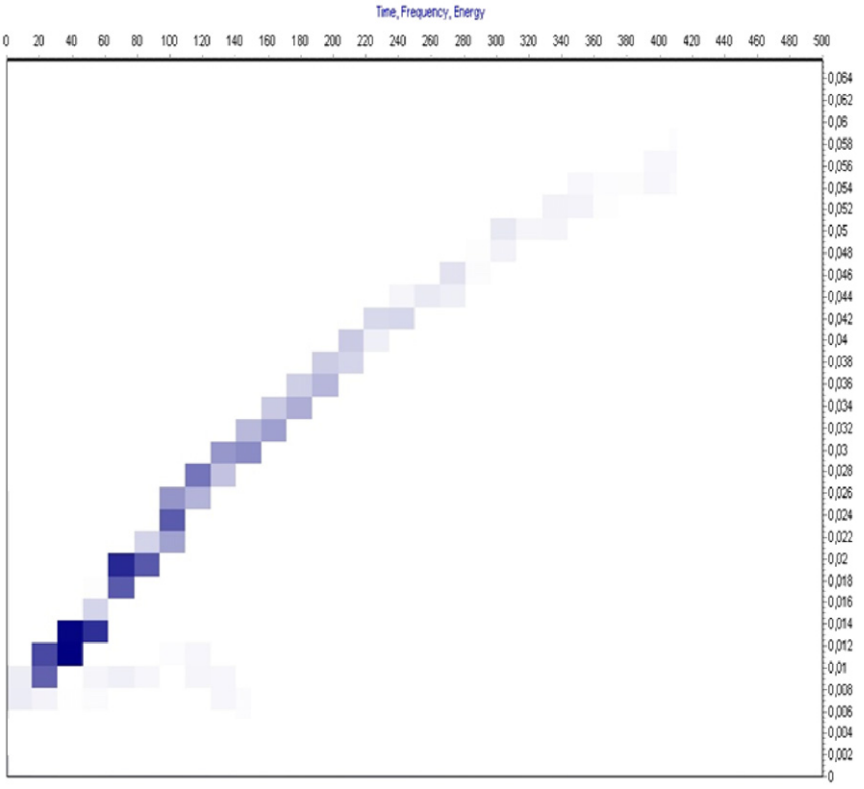

Fig. 9. HHT output (time, frequency, energy).

the sky transiting through the beam. In addition this detection could also be considered already "confirmed" since it comes from the same region of the sky and observed regularly for many days.

4. Data processing

Up to now, the SETI data processing has been based on the classical Fast Fourier Transform (FFT), valid only if it is applied to linear and stationary signals. Investigations carried out at the Medicina labs [7] proved that the Karhunen Loéve Transform (KLT) could work more efficiently than the FFT since it extracts the orthonormal basic functions from the autocorrelation matrix. These basic functions are always optimized since they are extracted from the signal itself. However the same investigations also proved that KLT suffers from some limitations, mainly due to the fact that it operates properly with only high S/N ratios. In order to increase the "signal extraction sensitivity", an eigenspectrum evaluation from functional method is under development. In case of non-linear and non-stationary (i.e. fast Doppler variation or a chirped signal), alternative transforms need to be investigated. Obviously, in this case it is not conceivable to integrate in time in order to increase the S/N ratio. Therefore, a single shot very high efficiency transform needs to be investigated. The INAF-IRA received from NASA (Goddard Space Flight Center, Greenbelt, MD) the permission to evaluate, for a limited period of time, the Hilbert Huang Transform (HHT) computation software within a Software Usage Agreement (SUA GSC14591). Very preliminary results indicate that the HHT has good possibilities to be used in SETI observations under the above mentioned circumstances. As an example, Fig. 7 shows a chirped signal whose FFT (shown in Fig. 8) is meaningless.

Conversely, Fig. 9 shows how the HHT algorithm is suitable to handle nonlinear signals. In the *X* axis we have the time, in the *Y* axis the frequency and in the *Z* axis the energy (false colors tonality). Further investigations are required to understand how much the algorithm is "efficient" when it is forced to work with low S/N ratio conditions. This is a crucial situation since nonlinear signals do not allow integration to obtain better detections.

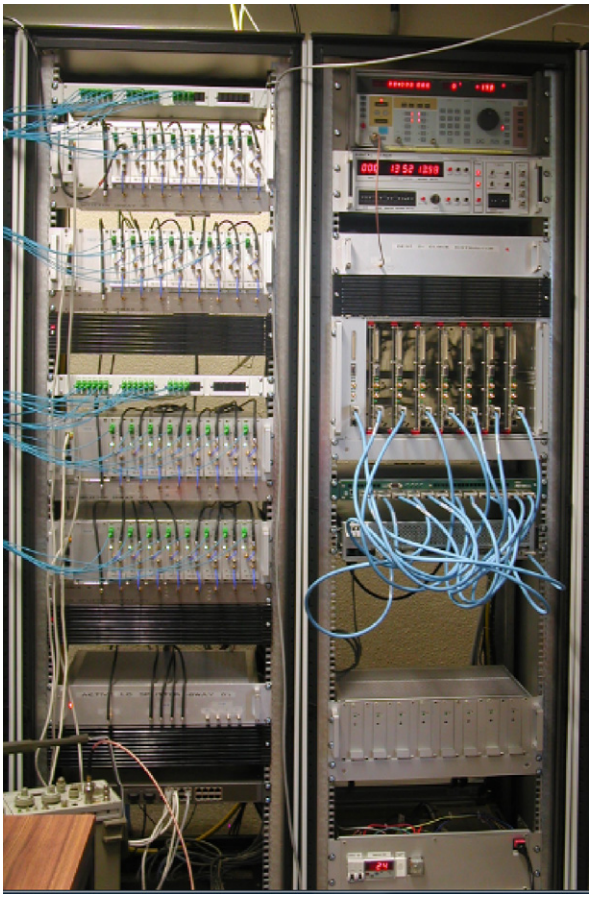

Fig. 10. The system is visible in the rack on the right side.

5. Next generation

5.1. Data processing approach

The future SETI-Italia post processing approach is principally based on the use of an extremely powerful programmable FPGAs cluster called BEE2. This is a state of the art number crunching that allows to test different algorithms aimed to the extraction of weak signals from the noise. A reduced version of such a flexible platform is under programming in the framework of the ITASEL and Space Debris programs of (ASI) and of the Square Kilometre Array Design Study (SKADS) funded by EU. The system was developed by the CASPER group of the Berkeley Wireless Research Center, University of California. It is composed by a certain number of wide band A/D converters (8 bits @ 1GS/s), IBOBs serializer boards and a multi FPGS BEE2 platform rated at about 1 Tops/s [8,9]. In Fig. 10 the picture of a test bench installed at the MRS, equipped with these boards, is shown.

6. Conclusions

A general review of the present and future SETI-Italia activities has been presented in this paper. The future of this program represents an incredible challenge from both scientific and technological point of view. A lot of work and research efforts need to be aimed to new observation methodologies, new algorithms for weak signal extraction from the noise, and new fast flexible electronic.

References

[1] S. Montebugnoli, G. Bianchi, F. Perini, C. Bortolotti, A. Cattani, A. Maccaferri, A. Cremonini, M. Roma, J. Roda, G. Zacchiroli, Italian SKA test bed based on cylindrical antennas, Astron. Nachr./AN327, (5/6) (2006) 624–625, DOI 10.1002/asna.200610606.
[2] S. Zaroubi, J. Silk, LOFAR as a probe of the sources of cosmological reionization, MNRAS 360 (2005) L64.
[3] 〈http://test.seti.org/pdfs/ATA-posters/blair-aas-pasadena.pdf〉.

[4] C.B. Cosmovici, S. Montbugnoli C. Maccone, J. Monari, E. Flamini, The ITASEL project (Italian search for extraterrestrial life), in: International Astronautical Congress (IAF), Valencia, Spain, 2006.
[5] C.B. Cosmovici, S. Montebugnoli, A. Orfei, S. Pogrebenko, P. Colom, First evidence of planetary water maser emission induced by the comet/Jupiter catastrophic impact, Planet. Space Sci. 44 (8) (1996) 735–739.
[6] G.T. Smirnov, S. Poppi, S. Cortiglioni, S. Montebugnoli, Search for radio recombination lines at 408 MHz with the Northern Cross, European Astronomical Society, Euro-Asian Astronomical Society, Joint European and National Astronomy Meeting, JENAM 2000, 2000.
[7] S. Montebugnoli, J. Monari, C. Bortolotti, A. Cattani, A. Maccaferri, M. Poloni, P.P. Pari, A. Orlati, S. Righini, S. Poppi, M. Roma, M. Teodorani, D. Caliendo, C. Maccone, C.B. Cosmovici, N. D'Amico, SETI-Italia 2003 status report and first results of a KL transform algorithm for ETI signal detection, Acta Astronaut. 58 (2006) 222–229.
[8] B. Brodersen, C. Chang, J. Wawrzynek, D. Werthimer, M. Wright, BEE: a multi-purpose computing platform for radio telescope digital signal processing applications, EECS, UC Berkeley, Space Science Laboratory, Radio Astronomy Laboratory, UCB, 2004.
[9] Pierre-Yvez Droz, "Physical design and implementation of BEE2: a high-end reconfigurable computer", M.S. Thesis, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, May 2005. Advisor: Prof. J. Wawrzynek.