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Authors	MONTEBUGNOLI, STELIO, BORTOLOTTI, CLAUDIO, BIANCHI, GERMANO, MONARI, JADER, Maccone, Claudio, PERINI, FEDERICO, ROMA, MAURO, SCHIAFFINO, MARCO
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Project of a multibeam UHF receiver to improve survey capabilities.

**Stelio Montebugnoli¹, Claudio Bortolotti¹, Germano Bianchi¹, Jader Monari¹, Claudio Maccone²,
Federico Perini¹, Mauro Roma¹, Marco Schiaffino¹.**

(1) INAF- Institute of Radioastronomy, Via Fiorentina 3513, Bologna Italy, +39 335 8140271
s.montebugnoli@ira.inaf.it, g.bianchi@ira.inaf.it, j.monari@ira.inaf.it

(2) International Academy of Astronautics and INAF, Via Martorelli 43, 10155 Torino, Italy
clmaccon@libero.it

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Abstract

The Institute of Radioastronomy (IRA-Bologna) of the National Institute for Astrophysics of Italy (INAF -Rome) joined the European group for the Square Kilometer Array Design Study (SKA-DS) in the frame of the FP6 program. One of the goals of the Design Study was the construction and test of a state of the art very small SKA prototype.

A segment (1/8) of the N/S arm of the large Northern Cross array was exploited to obtain a prototype array, made up by 8 cylindrical concentrators (23,5 x 7.5 mt) equipped with 4 receivers each. In this way a 32 receivers array with a total collecting area of about 1400 m² was obtained. Signals are directly carried from the receivers, located on the focal lines, down to the back end, located in the processing room, via a very cost effective analogue optical links. Here a fast back end, presently based on Field Programmable Gate Array (FPGA) Berkeley-Roach boards, takes care of running the required complex algorithms to perform (non-adaptive) multi-beamforming with a 2D FFT.

The main advantage of such an already working array is to produce 21 independent 31' x 104' beams located inside a 38° deg² Field Of View (FoV). Our plan is to search for funds to refit the remaining 56 cylinders of the N/S arm, to dramatically increase both the sensitivity and number of beams (pixels) placed in the same FoV. In this way, it could be possible to perform a deep SETI survey in the UHF band by an about 11.200 m² antenna (equivalent to a 119 mt dish), a 37.6 deg² FOV and 189 beams. The system could be further expanded by installing more receivers on each N/S focal line, increasing the FOV and the number of pixels with the same sensitivity. Assuming that adequate funds could be found for refitting the giant E/W arm as well, an equivalent 180 mt dish could be obtained to perform a very deep SETI sky survey with a 120 deg² FOV at high sensitivity. This would allow a very fast and deep sky survey in the UHF band.

INTRODUCTION

The Italian INAF Radioastronomy Station located in Medicina (Bo), is composed by two radiotelescopes: the 32 mt (VLBI) dish and the $\approx 27.000 \text{ m}^2$ T Shaped Northern Cross array, a cylindrical-parabolic structure as reported in Fig.1 and 2 respectively. It lies in the Padana Valley in the northern part of Italy, close to Bologna where is located one of the oldest university in the world. The VLBI dish (Fig.1) is a 32 m in diameter and it is characterized by a collecting area of about 800 sqm. It can operate in the radio astronomical bands inside the 1.4 – 23 GHz range. Up to now it has been equipped with a very high frequency resolution SERENDIP IV real time spectrometer (0.6 Hz), coming from the Berkeley University SETI signal processing group, operating in piggy back mode since 1998.

The Northern Cross (Fig.2 and 3) is a 564 x 640 m T shaped UHF array characterized by a large collecting area with 3x5 beams at 4x4 arcmin cross section each. This is one of the larger collecting area on the planet and it operates at up to 5 MHz bandwidth centered at 408 MHz ($\lambda=73.5 \text{ cm}$). Two arms (564 mt E/W x 640 mt N/S) are equipped with 88 focal lines, with 64 dipoles each, hosting in total 5632 dipoles as reported in Fig.3

Due to its extremely large collecting area, this array could be suitable to look for very weak ET signals.



Fig. 1: Medicina 32m VLBI dish

In terms of frequency, the 1420 MHz “magic frequency” is still considered the best one, but why not to search for radio signals in other bands given by i.e $1420 \times n\pi$ ($n=1,2,\dots,10$) or $1420/n\pi$ ($n=1,2,\dots,10$)? In this last case we could de-tune the Cross array at $1420/\pi$, that is 452.23 MHz to listen to the ET “radio voice”.

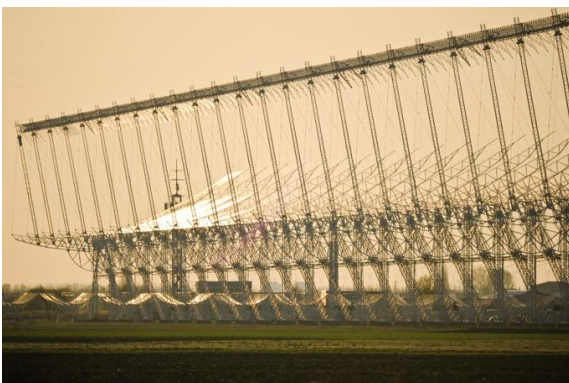


Fig. 2: a partial view of the Northern Cross Array

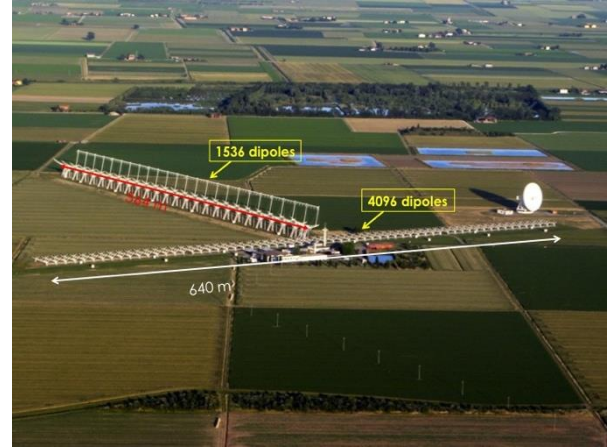


Fig. 3: aerial view of the 564 x 640 m Northern Cross array.

SCOPE OF THE PROJECT

The SETI search is a very challenging program because it deals with the search for an unknown shaped signal coming from an unknown direction in the sky at an unknown frequency [1]. The best strategy is to quickly scan the whole sky on a frequency range as wide as possible. In this way the plan is to exploit the experience gained from the design of a Square Kilometre Array test bed, developed in the frame of the FP6 SKADS (2005-2009) program. Eight cylinders from the N/S arm of the Northern Cross radiotelescope, as visible in Fig. 4, were refitted to obtain a 21 beams wide Field of View (FoV) array as a first SKA test bed (second Basic Element for SKA Training → BEST-2). As a proof of concept this small array could already be used in a first SETI wide FoV sky survey test, starting from the present 408 MHz @16 MHz Bandwidth.



Fig. 4: The BEST-2 test bed is composed by 8 cylindrical concentrators with 4 receiver each.

This paper deals with the plan to extend such small multi feed array architecture to the overall 64 cylindrical concentrators of the N/S arm.

THE BEST-2 SMALL ARRAY

The BEST-2 [2] small array is composed by 32 single conversion superhet receivers as visible in the block diagram reported in Fig. 5. The low noise wide dynamic range front-ends are installed on 8 cylindrical concentrators, 4 per each focal line, connected with the back end in the analog/digital processing room via a wide bandwidth analogue optical fiber. The total collecting area is 1400 m² similar to that one of a 42 m dish, with a 16 MHz wide IF channel centered at 408 MHz or, as already mentioned, at 452.23 MHz.

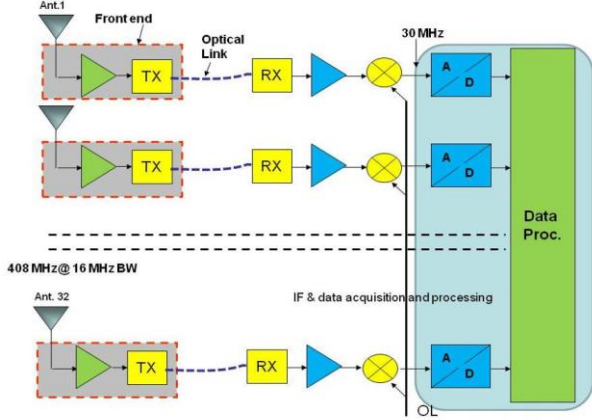


Fig. 5: Block schematic diagram of the BEST-2 SKA test bed.

As already mentioned, by exploiting the performances of the BEST-2 small array, we could scan the northern sky searching for extraterrestrial radio signals starting at the frequency of 408 (452.23) MHz covering, in scanning mode, the whole hemisphere in about 20 days. The main features of the BEST-2 array are reported in Tab.1

Ac $\approx$ 1400 m ² (equivalent to a 42 m dish)
Sensitivity/antenna gain = 0.36 K/Jy
FoV = 37.6 deg ²
Beam $\approx$ 31 arcmin (Dec.)
104 arcmin (R.A.)
N. of independent beams = 21

Tab. 1

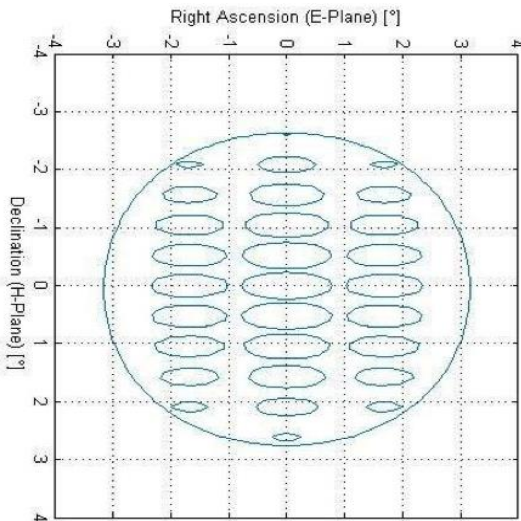


Fig. 6: Multibeam from the BEST-2 array.
(By courtesy of G. Naldi)

The high sky scanning velocity is due to the 37.6 deg² wide

FoV, pixelled by 21 (104 x 31 arcmin) total beam. The BEST-2 prototype is a transit array covering a 360° x 5° strip of sky every 24h.

THE MULTIBEAM PROJECT

Based on the experience gained from the BEST-2 design and operation, the extension of the 4 receivers per cylinder is considered for the overall 64 cylinders of N/S antenna called BEST-Total (Fig.7) hosting 256 receivers in total. The schematic block diagram of this configuration is visible in Fig. 8

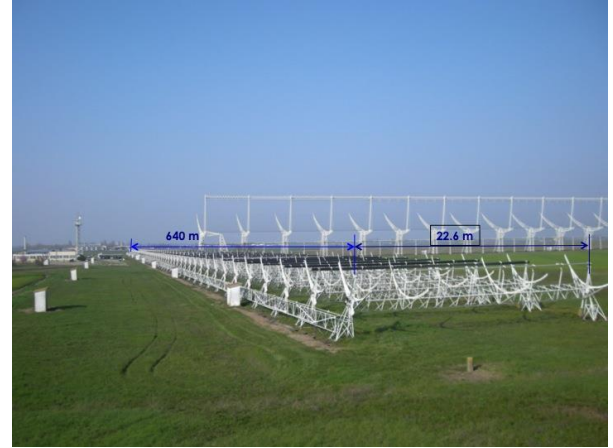


Fig. 7: The global view of the N/S arm: BEST-Total.

In this architecture the overall blocks are represented by 256 LNAs, 256 optical links, 256 IF stages and 256 A/D converters. The main system criticality is primarily due to the data processing system that has to deliver an impressive processing power for each of the 256 receivers chain. The engine of each data processing block is based on very fast Field Programmable Gate Arrays (FPGAs) from XilinxTM that exploits the flexibility of the software along with the velocity of the hardware. The single receiver processing block diagram is reported in Fig. 9. The input is composed by two A/D converters running at about 100 MS/sec with a very high dynamic range (12 bits $\rightarrow$ 72 dB). Data are sent to a Polyphase Filter Bank (PFB). The output of the PFB fills up a Corner Turn Memory (CTM) with M spectra composed by N channels each. In this way, implementing a FFT on each column, we obtain a spectrum composed by MxN channels. For instance if a 64 Million channels spectrometer for SETI observations is requested, the CTM has to be filled up with 8K spectra with 8K channels each. Of course the Fig. 9 processing block diagram has to be repeated for each of the 252 receivers. Considering that such a spectrometer is connected to each receiver with 16 MHz bandwidth, it turns out that the frequency resolution is 16MHz/64.000.000=0.25 Hz while the time resolution is relatively low (about 4 seconds). The output from the A/D converters can be sent to a separate processing engine aimed at the KLT (Karhunen Loeve Transform) [3] computation. Such a transform is considered to be a very promising transform suitable to extract any unknown radio signals from noise, not possible with standard spectrum analysis (FFT). In practice the KLT extracts the basis functions from the signal itself while the FFT try to apply *cos* and *sin* basis functions to any kind of signal.

It is estimated that 32 Roach boards (Berkeley University) are necessary for the data processing block. This means about 12.8 kWh of energy consumption and a cost of more than 100 K€.

The main features of the BEST-Total are reported in Table 2.

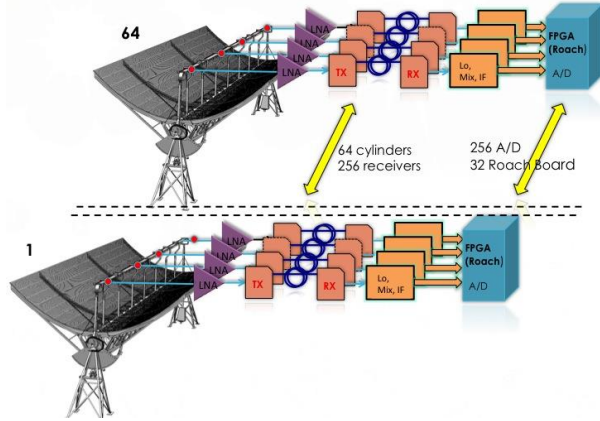


Fig. 8: Schematic block diagram of the overall N/S refitted system

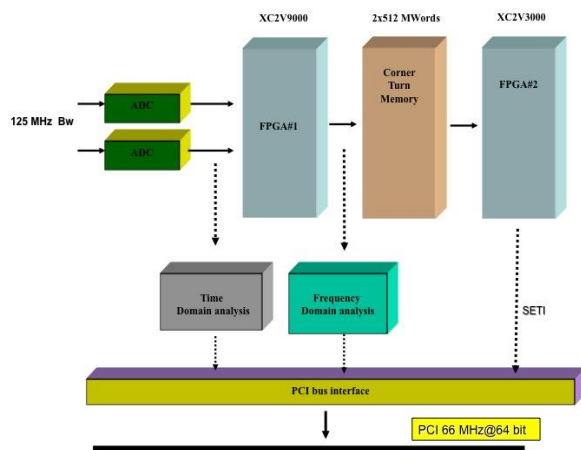


Fig. 9: Schematic block diagram of the single acquisition and processing system

N. Cylinders = 64 (7.5 x 23.5mt)
Size = 640 mt x 23.5 mt
Collecting area $\approx 11.200 \text{ m}^2$ (equivalent to a 120 m dish)
Central Freq. = 408 (452.22 $\rightarrow$ H line / π) MHz
BW = 16 MHz (up to 50 MHz)
Scan angle = (0-90) deg (mechanical steering)
Right ascension = (-3.3, +3.3) deg (electrical steering)
FoV = 37.6 deg ² (Dec. 5.7 deg, R.A. 6.6 deg)
Beam = 4 arcmin (Dec.), 104 arcmin (R.A)
Number of independent Beams = 189

Tab. 2

Like the BEST-2 is, the BEST-Total Array is a transit radiotelescope and it can be pointed in declination on the meridian plane. Due to the earth rotation, the sky flows through a sort of grid composed by the cross section of the multiple beams inside the 37.6 deg² large FoV.

In this way if the signal is coming from the outer space, it scans the FoV from the right to the left (Fig. 10) giving back a validation on the extraterrestrial target since the same signal is confirmed through different beams.

Local RFI are reported in the multibeam as a random mosaic of pixel that can be removed at the post processing level since the RFIs coming from satellite ... of course do not have a sidereal "signature".

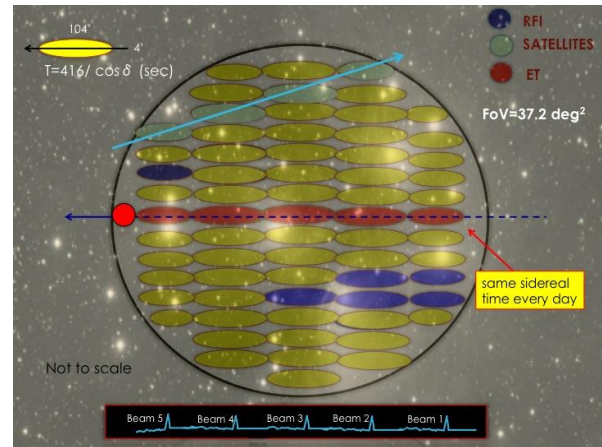


Fig. 10: wide FoV pixelled by a large amount of beams.

CONCLUSION

The experience gained from the design and operation of a SKA prototype based on 8 cylinders of the Cross array N/S arm (BEST-2@32 receivers), allows to extend the concept of wide FoV multibeam array to all of the 64 cylinders composing the whole N/S arm (BEST-Total@256 receivers). Such an array could be extremely suitable to scan at high sensitivity (about 11.200 m² collecting area) the northern hemisphere in about 20 days. Such a very short scanning time allows to face the problem to complete the north hemisphere coverage at different frequencies. Covering two of the many axes of the search space (scanned area and frequency), gives back a higher probability to have a positive result in searching for the ET existence.

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