A LOW COST STEERABLE RADIO-TELESCOPE

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ABSTRACT

We present the technical characteristics of a low-cost radio telescope for solar/non solar observations at decimetric (1200–1700 MHz) and centimetric (2700 and 5000 MHz) wavelengths known as Brazilian Decimetric Array (BDA). The technical specifications of the antenna, tracking system, log-periodic feed, preamplifier and the frequency-synthesised receiver with a Single Side Band (SSB) video output of 2.5 MHz are given.

INTRODUCTION

A team of brazilian engineers and scientists is co-ordinating the efforts of developing the Brazilian Decimetric Array (BDA) (Sawant et al., 1998; Sawant et al., 2000a; Sawant et al., 2000b; Sawant et al., 2002). The BDA is a collaborative programme of the National Institute of Space Research - INPE with participation by several national and international institutions. Details of the BDA project, planned developments, and imaging capabilities has been discussed by Lüdke et al. (2000) and Sawant et al. (2000b). The main objective of the first phase of the BDA project (BDA-I) is to develop subsystems for the interferometric array, by involving local industries and using in-house infra-structure and optimise the performance-to-cost ratio.

ANTENNA

The antenna to be used in the project is a 4-meter diameter parabolic dish with wire mesh surface having focal length (f) to diameter (d) ratio as $f/d = 0.425$ and $h/d = 0.147$, where h is the depth of the parabolic dish. Operational wind velocity is $\sim$ 60 km/hr. However, it can stand maximum wind velocity of 120 km/hr. To get the radiation pattern of 4 meter diameter parabolic reflectors from various companies, each antenna was mounted on a pole and solar observations were carried out, in the frequency range of 1200–1700 MHz, at local noon time, keeping, the antenna in a fixed position. The plots of solar transit obtained at local noon-time on 13 days as sun enters and goes out of the antenna beam are shown in Figure 1. The half power beamwidth at 1400 MHz is $\sim$3.8°. and hence the efficiency is $\sim$0.63. The technical specifications of altitude-azimuth (alt-az) mount antenna and its steerability, speeds, motor capacity, gear ratio and torques are given in Tables 1 and 2, respectively.

Tracking System

In order to get a system with good pointing accuracy, we have selected a set of shaft encoders, controller, drives and motors normally used for controlling the Computer Numeric Control (CNC) machines. Besides

*On sabbatical leave from the NCRA - GMRT, Pune, India good performance, the control and drive system offer facilities such as modular hardware, low cost and quicker adaptability and reduction in development time.

Two servo motors are used to control the movements of the antenna in the azimuth and altitude axes. The suppliers and joint designers of the drive system, Inteltek Automation Co. (Pune, India), have offered a Baldor NextMove-BX motion controller for the task, together with a combination of Baldor drives and brushless AC servo motors. Operating at just 0.6 RPM, the motors drive the loads through a combination of reduction and spur gearing to provide a positioning resolution of just 2.5 arc seconds, at wind speeds of up to 60 km/hr.

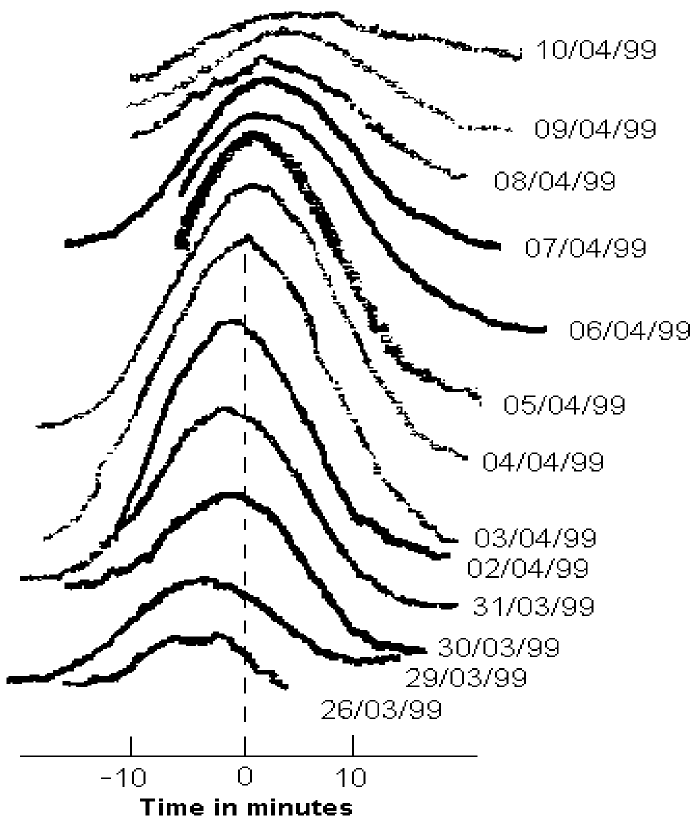


Fig. 1. Solar transit curves obtained for different days for testing 4-meter diameter parabolic reflector with linearly polarised feed at 1500 MHz.

NextMove-BX is well suited to this control task because of its combination of facilities, including dual axis capability, ruggedness for easy mounting below the antenna dish, and easy to use Mint motion language software.

Each of the 38 NextMove-BX units is linked to a host PC using a multi-drop RS-485 network. By running a position control software developed for this project, the PC transmits new position commands to the remote motion controllers at intervals of typically 60 seconds. The motion controllers then autonomously provide interpolated movement commands to drive the azimuth and altitude servo motors, which ultimately move the axes at around one thousandth of a revolution per minute, with the help of the gear reduction 800:1, between the load and the drive system.

Prototype altitude-azimuth mounted dishes (Figure 2) for this project have already been tested in India. The measured accuracy of the positioning and tracking was found to be better than 3 minutes of arc. Subsequently, the style of the gear and gear ratios have been improved to minimise backlash in the mechanical system and improve the pointing to be better than 2.5 arc seconds. The modifications in the gears are being implemented in the BDA-I, involving an interferometric array of five antennas. Further, Inteltek Automation Co. is also implementing error correction software, which it is hoped will further improve the accuracy, in the systems of the subsequent deployment phase of the BDA from late 2002 onwards.

Table 1. Technical specifications of the alt-az mount antennas for BDA

Diameter of reflector	4000 mm
Focal length	1700 mm
f/d ratio	0.425
h/d ratio	0.147
Maximum wind speed	120 km/hr
Operational wind speed	60 km/hr
Reflector weights	148 kg
Weight of supporting structure	60 kg
Porosity of the dish	0.33
Maximum pointing error	10 arc min
Limit switches	Non contacting type
Encoders	12 bit

Table 2. Steerability, speeds, motor capacity, gear ratio and torques

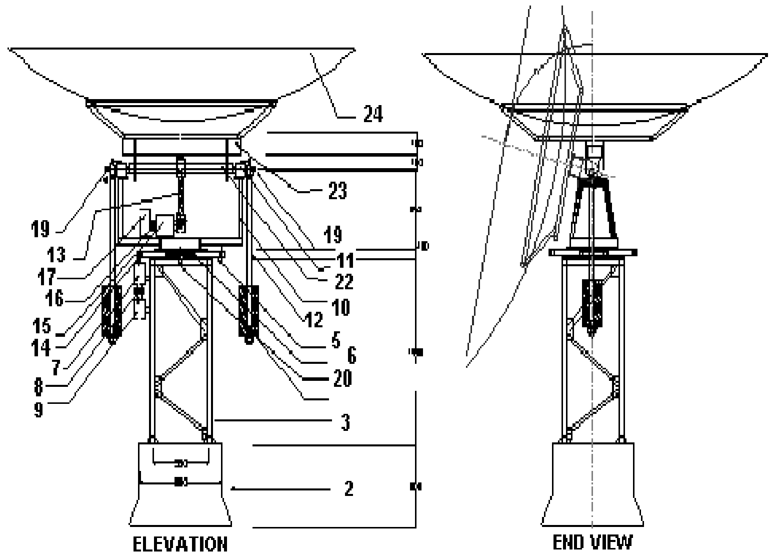
Item	H.A. slew	H.A. track	Declination	Azimuth	Elevation
Antenna speed	20°/min	15°/hr	20°/min	30°/min	20°/min
Design torque	300 kg m	–	200 kg m	200 kg m	200 kg m
Pinion ratio	10:1	10:1	10:1	10:1	10:1
Gear box ratio	100:1	100:1	100:1	100:1	100:1
Gear box output torque	36 kg m	–	24 kg m	24 kg m	24 kg m
Motor speed	60 RPM	0.7 RPM	60 RPM	60 RPM	90 RPM
Motor torque	45 kg cm (630 oz in)		30 kg cm (420 oz in)	30 kg cm (420 oz in)	30 kg cm (420 oz in) -2 Nos.
Conter-weight	300 kg @ 1200 mm		150 kg @ 550 mm	Nil	70 kg-2 Nos.@ 850 mm
Encoder	12 bit		12 bit	12 bit	12 bit
Limit. Switches	2 Nos.	2 Nos.	2 Nos.	2 Nos.	2 Nos.

The tracking system is composed of three parts of software: a software for the calculations of the trajectory which generates the positioning lookup table written in high level language; a software for the communication and synchronization of all antennas with the host PC and monitoring the movements including diagnostics menus also written in high level language; a software for the feedback and control of torque, speed, position and time, written in low level language; this will be the resident software in the individual controllers. These three parts give full control to scientists, easy diagnosis for the engineers and complete independent adjusts for the technical feedback control.

A simple, inexpensive and accurate test done with a laser source revealed that the positioning error does not exceed 3 minutes of arc in some measured quadrants. The test consists of projecting a laser beam on a fixed point on a wall some 25 meters away from the antenna and measure the laser spot displacement for a chosen antenna movement. Full performance tests will be done later by pointing the antenna beam towards sources in the sky.

Antenna feed

A dual polarised octave bandwidth log periodic feed has been developed by the INPE team. The in-house fabricated feed shows good VSWR (1.2) and low cross polarization coupling (less than 20 dB) in the 1200–1700 MHz band.



SR NO	TITLE	QTY	WT. (kg)	ORG. NO.
1	ALT AZ MOUNT	1		001
2	FOUNDATION	1		002
3	TOWER	1	100.0	003
4	BEARING BOTTOM PLATE	1	70.0	004
5	AZ BULL GEAR	1	100.0	005
6	AZ BEARING	1	11.5	006
7	AZ GEAR BOX	1	25.0	007
8	AZ COUPLING	1	4.0	008
9	AZ MOTOR	1	4.0	009
10	YOKE	1	58.0	010
11	EL BEARING HOUSING & BEARING	2	40.0	011
12	CWT ARM	2	22.0	012
13	EL BULL GEAR	1	60.0	013
14	EL PINNION	1	1.5	014
15	EL GEAR BOX	1	25.0	015
16	EL COUPLING	1	4.0	016
17	EL MOTOR	1	4.0	017
18	CWT BLOCK	2	140.0	0.18
19	EL ENCODER	1		0.19
20	EL POTENSOMTER	1		0.20
21	AZ ENCODER	1		0.21
22	EL SHAFT	1	23.5	0.22
23	BACKUP STRUCTURE	1	78.5	0.23
24	DISH	1	208.0	0.24

Fig. 2. Diagrams of the prototype altitude-azimuth mounted dishes designed and tested in India.

LOW NOISE AMPLIFIERS

At the INPE, two models of Low Noise Amplifiers (LNA) have been developed, one using MiniCircuits Lab. (MCL) chip costing around US$ 150.0 having a gain ∼20 dB and noise figure around 1.5 dB. This amplifier has been tested for field operation for about 6 months. And the other with PHEMT (Pseudomorphic High Electron Mobility Transistor) low noise IC, having a gain 15 dB, good dynamic range, 1 dB compression at 10 dBm and 0.9 dB of noise figure across the entire 1200–1700 MHz band. The un-cooled PHEMT preamplifier has been totally assembled and tested in laboratory.

RECEIVER

A monolithic InGap broadband microwave amplifier having high stability, high dynamic range (IP3 ∼32 dBm) and gain ∼20 dB is used in the second stage. A Band Pass Filter has been introduced in between the two stages to avoid adjacent band interference from transmitters like cell phone. It has constructed on microstrip on 1/16" thick (Polyimide) circuit board, double-clad with 1 oz per sq. ft copper and a GaAs MMIC (Monolithic Microwave Integrated Circuit) used as a second stage. The microstrip filter is an inter digital type having high rejection (∼30 dB) at 900 MHz.

Figure 3 shows the receiver diagram. The BDA receiver of this first phase is a conventional receiver consisting of triple mixing, local oscillators (LO), intermediate frequency (IF) and video stages. In order to get a low phase noise performance and reduce the development time, we surveyed the literature and chose the monolithic integrated circuit frequency synthesiser (SI41356 EVB - Silicon Labs Products) for generating the three local oscillators for the receiver chain. The monolithic integrated circuit that has been optimised for generating two LO signals in the band from 2025 MHz to 2500 MHz and one LO, in the range of 62.5 MHz to 1000 MHz. The stable, low phase noise characteristics (-130 dBc/Hz, for 1 MHz offset) are achieved through a self-tuning fully integrated Voltage Controled Oscillator (VCO) and loop filter architecture. This circuit has low power consumption - only 15.7 mA supply current at 3 V, and is a 0.35μ Complementary Metal Oxid Semiconductor (CMOS) based integrated circuit. The synthesiser is locked to a 10 MHz reference derived from a rubidium standard. Surface Acustic Wave (SAW) filter has been used in 70 MHz IF stage having, attenuation greater than 35 dB outside the frequency band and typical 40 dB bandwidth of 9 MHz. Inside the specified bandwidth the insertion loss is around 7 dB. This receiver is low cost and has no adjustments or trimming.

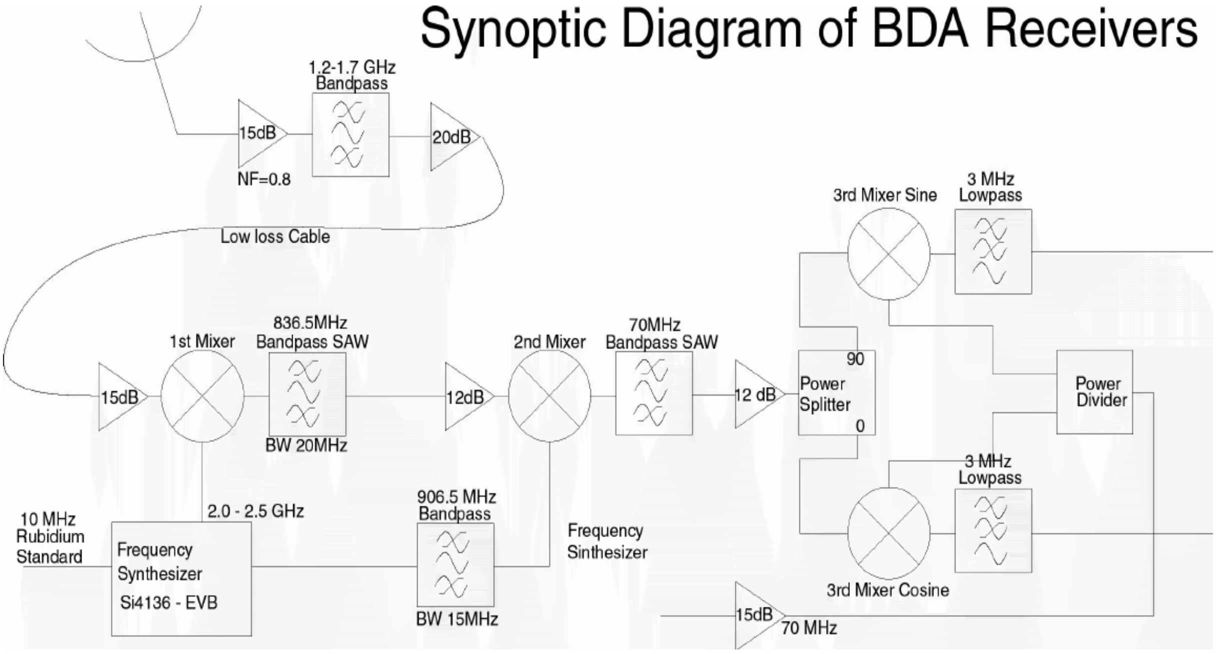


Fig. 3. Block diagram of the BDA-I receiver.

The Video stage consists of mixers for generating sine/cosine outputs and has a bandwidth of 2.5 MHz. The LO for the video stage is derived from the synthesiser chip Si 4136. The MSB (most significat bit) and LSB (least significant bit) out puts are interfaced with digital system. Digital system consists of analog-to-digital conversion, Walsh switching modulation and demodulation, delay tracking and one bit correlator.

CONCLUSION

The development of this first phase of BDA indicates that by involving local industries and combining it with in-house development, one can increase the ratio of performance/cost. The total cost of 4-meter diameter parabolic mesh type antenna operating in the frequency range of 1200–1700 MHz with alt-az mount, tracking system hardware/software and receiver is around US$ 13 k.

After successful engineering testing for about three months, base lines of the five antennas will be increased to the positions of the second phase of the BDA, i.e. E - W and South baselines will be 244 and 144 meters, respectively. Thus spatial resolution will be 3 $\times$ 4 minute of arc. around 1.5 GHz.

Thus BDA-I will provide positional information for long lasting intense solar flares. This will enable decimteric activity to be associated with X-ray more accurately and hence will improve the on going investigations carried out bt using observations obtained by Brazilian Solar Spectroscope (BSS) (Sawant et al., 2001) such as acceleration of particles (Kane et al., 2003).

On the other hand, one can investigate the quasars variability, active galaxies and BL Lacertae like objects at 1.4 GHz, those having flux above 1 Jy, observable by BDA-I with 3 $\times$ 4 minute of arch of spatial resolution. This data obtained at low frequencies cab be investigated jointly with those obtained at high frequencies by Michigan group. One can study radio sources that can be observed from Southern Hemisphere and are listed in catalogues like the Kuhr (1981).

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REFERENCES

Kane, S. R., H. S. Sawant, J. R. Cecatto, et al., Hard X-ray and high-frequency decimetric radio observations of the 4 April 2002 solar flare, *Adv. Space Res.*, this issue, 2003.

Kuhr, H., A. Witzel, I. I. K. Pauliny-Toth, U. Nauber, A catalogue of extragalactic radio sources having flux densities greater than 1 Jy at 5 GHz, *Astron. Astrophys. Supp. Series*, **45**, 367-430, 1981.

Lüdke, E., H. S. Sawant, K. R. Subramanian, et al. , Solar imaging capabilities of the Brazilian Decimetric Array, *Geofisica Internacional*, **39**, 147-150, 2000.

Sawant, H. S., K. R. Subramanian, E. Lüdke, et al., Brazilian Decimetre Array for solar imaging. in *Proc. VIII Simpósio Brasileiro de Microondas e Opto-eletrônica - SBMO (CDROM)*, 1998.

Sawant, H. S., K. R. Subramanian, E. Lüdke, et al., Brazilian Decimetre Array, *Adv. Space Res.*, **25(9)**, 1809-1812, 2000a.

Sawant H. S., E. Lüdke, K. R. Subramanian, et al., A high resolution decimetric solar radioheliograph, in *ASP Conference Series*, edited by R. Ramaty and N. Mandzhavidze, **206**, pp. 341-346, 2000b.

Sawant, H. S., K. R. Subramanian, C. Faria, et al., Brazilian Solar Spectroscope (BSS), *Solar Phys.*, **200**, 167-176, 2001.

Sawant H. S., F. C. R. Fernandes, J. A. C. F. Neri, et al., Southern Hemisphere Solar Radio Heliograph, in *Proc. 10th European Solar Physics Meeting*, edited by A. Wilson, ESA-SP **506**, vol. 2, 971-974, 2002.

Swarup G., Giant meter wave radio telescope (GMRT) - Scientific Objective and Design Aspects, *Indian Journal of Radio & Space Physics*, **19**, 493-511, 1990.

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