Mem. S.A.It. Suppl. Vol. 10, 126

Memorie della
Supplementi

The panels for primary and secondary mirror reflectors and the Active Surface System for the new Sardinia Radio Telescope

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Abstract. In this paper we will describe the panels for the primary and secondary mirror reflectors and the active surface system that will be provided on the Sardinia Radio Telescope. The panels for the primary and secondary mirror have been designed to allow an operating frequency up to 100 GHz. The active surface system will be used to overcome the effect of gravity deformation on the antenna gain and to re-shape the primary mirror in a parabolic form, in order to avoid large phase error contribution on the gain for the highest frequencies placed in the primary focus.

1. Introduction

The antenna efficiency depends on many factors (illumination function, blockage effects, spillover, phase error, diffraction and so on). In this paper, we will consider only the efficiency loss factor (η_{surf}) determined by the total surface RMS error (σ). Such error is a measure of how real surfaces, including the antenna optics, deviate from the ideal shape. It depends on:

- Shape errors on the panels due to manufacturing, gravity, temperature and wind, for both the primary and the secondary mirrors.
- Shape errors on the backup structure due to gravity, temperature and wind, for both the primary and the secondary mirrors.
- Residual shape errors due to field alignment of the panels of the primary and secondary mirrors.
- Residual shape errors due to positioning inaccuracy and nonlinearity of the active surface actuators.

Each error source can be described by its own RMS. These are then root sum squared in order to obtain the total surface RMS error σ. The relationship between η_{surf} and σ is a Gaussian function:

$$\eta_{surf} = e^{-(4\pi\frac{\sigma}{\lambda})^2}$$

where λ is the observing wavelength.

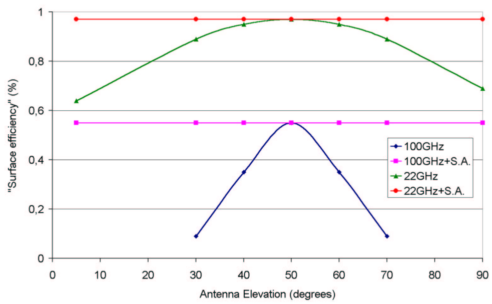

Fig. 1. A prediction of the SRT surface efficiency with and without an Active Surface System at 22 GHz (upper lines) and 100 GHz (lower lines).

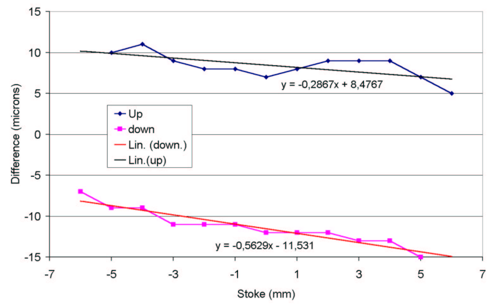

Fig. 2. SRT Actuator backlash and pitch irregularity

2. The Active Surface System

With the aim of reaching the best antenna performance, the antenna gain must be as high as possible. Until some years ago, it was generally accepted to reach the highest gain value at one elevation only: the one where the field alignment is done. The antenna efficiency of a large antenna is strongly affected by the effect of gravity on the backup structure. The shape is ideal at the elevation angle of the panel's alignment but, as the antenna points to different positions on the sky, the mirror deforms, losing its ideal shape and consequently reducing the antenna gain. The gain reduces very much when the antenna points far from the alignment position, much degrading the performance. And this effect worsens as the frequency increases. This is the primary reason for the gain to show a typical parabolic form, when plotted against antenna elevation. Since the primary mirror of a large antenna is formed by thousands of panels, a way to overcome this effect is to move all panels forming the mirror, recovering the ideal shape at every elevation. This can be called an Active Surface System. In Fig. 1 a prediction of the surface efficiency for the SRT antenna at 22 GHz (upper lines) and 100 GHz (lower lines) is shown. As we can see, the surface efficiency at 22 GHz becomes lower than about 50% at the borders of the elevation range, without an Active Surface System. At the frequency of 100 GHz, with a variation in elevation of only ±20° with respect to the position of alignment, the whole surface efficiency is lost.

For the SRT antenna 1116 electromechanical actuators with a stroke of ±15 mm will be mounted on the backup structure. Each actuator is supported by studs and can move the corners of the four nearest panels, in the direction normal to the local surface. They are organized in 96 radial lines with a minimum of 9 and maximum of 16 actuators each. Each radial line acts like a bus where the actuators are connected using a RS485 communication protocol. Each group of twelve radial lines connects to a junction box, where each radial line will converge to an RS485/LAN Ethernet gateway so that the control of the network is made by a LAN Ethernet. A master computer has the main control of the whole system. Each actuator consists of three parts. In the electromechanical part, the rotation of a step motor is converted to a linear motion using a backlash-free ball screw mechanism and a low backlash worm gear. This worm gear has a 35:1 reduction ratio. The core of the electronics part is a commercial device, a controller/driver able to independently manage the movement of the actuator when it recognizes its address. The third part is an anchor plate with four studs used to connect the actuator to the "four corners". The linear position of the actuator isn't directly measured, but calculated through the steps of the motor, so the position accuracy of the actuator is affected both by the backlash inversion of the mechanical system and by the pitch irregularity of the jackscrew thread. In Fig. 2, a measurement made on a prototype for the SRT is shown. We can see that the backlash is around 20 μm, while the pitch irregularity is

Table 1. A performance comparison between Vertex and INAF for the primary mirror panels' row 14 (units are in μm)

Error Source	Vertex RSI	INAF-IRA	Remark
Gravity	109	67	Normal to surface
Wind	32	30	30Km/h Normal
Thermal	108	11	T around 20 C
Manufacturing	100	65	None

Table 2. A performance comparison between Vertex and INAF for the secondary mirror panels' row 2 (units are in μm)

Error Source	Vertex RSI	INAF-IRA	Remark
Gravity	3	3.5	Normal to surface
Wind	3	4	30Km/h Normal
Thermal	N.A.	9	T around 20 C
Manufacturing	75	50	None

of the order of some microns. The values are reported only in the range ±6 mm with respect to the mid-range of the actuator travel, because this is the predicted peak-to-peak stroke for compensating the gravity deformation.

3. The panels for primary and secondary mirrors

The Sardinia Radio Telescope is a 64-m antenna with a shaped primary mirror and a Gregorian shaped sub-reflector. The primary reflector surface consist of 1008 individual aluminium panels which are divided into 14 rows of principal panel types. These panels, having an area between 2.4 m^2 and 5.3 m^2, are built using aluminium sheets glued (with a layer of epoxy resin) in two longitudinal and several transversal slotted aluminium Z-shaped stiffeners. The sub-reflector surface consists of 49 individual aluminium panels, 48 of which are divided into 3 rows of principal panel types and one is the central panel. The panels have an average area of about 1 m^2 and, as for the primary reflector panels, are made of aluminium with a glued technology. The central panel is an aluminium cast design. In order to get panels at the state-of-the-art of the glued technology, the original Vertex RSI design of both panel types was modified by INAF-IRA. Also the specification was changed for the manufacturing surface accuracy. In Tables 1 and 2 a list of the error sources affecting the panel surface accuracy is reported, together with a comparison between the specifications of the original Vertex RSI panel design and the new INAF-IRA panel design.

4. The SRT's total surface accuracy

The optical design of the SRT was done with the aim of allowing the antenna to work up to 100 GHz (λ=3 mm). This performance is achieved only when the total surface accuracy error σ does not exceed $\sim$ 190 μm RMS (λ/16). In the original Vertex RSI design, this task is planned to be achieved only when the antenna will be provided with a holography system which should allow a field alignment of the primary mirror panels of 50 μm RMS (phase 2). In our opinion this is still a very challenging task. Therefore, as mentioned in Sect. 3, the primary and secondary mirror panels were redesigned by INAF-IRA in order to allow operational frequencies up to 100 GHz already at the end of the erection phase of the radiotelescope (phase 1), with primary mirror panels aligned to about 150 μm RMS. This value seems to us more reasonable for such a dish dimension. In Table 3 a list of the er-

Table 3. Total surface accuracy performance comparison between Vertex and INAF-IRA (all units are in μm)

Error Source	Vertex RSI phase 1	INAF-IRA phase 1	Vertex RSI phase 2	INAF-IRA phase 2
Primary mirror panels	124	72	124	72
Field alignment primary mirror	150	150	50	50
BUS primary mirror	40	40	40	40
Active Surface System	35	20	35	20
Secondary mirror panels	75	50	75	50
Field alignment secondary mirror	40	40	40	40
BUS secondary mirror	22	22	22	22
Total Surface Accuracy σ	220	185	169	119
Surface Efficiency Factor (λ=3mm)	0.42	0.55	0.60	0.78

ror sources affecting the total surface accuracy σ is reported, together with a comparison between the original Vertex RSI design and the new INAF-IRA design, for both phase 1 and phase 2. The values reported are valid in excellent environmental conditions only, i.e. during the night (no solar radiation) and for wind velocities $\leq$15 km h^{-1}.

5. Another use of the Active Surface System

Once an Active Surface System is available it can also be used to accomplish other interesting tasks. In the case of the SRT antenna, it could be used to switch the primary mirror from the shaped to the parabolic configuration. The electromagnetic design of SRT takes advantage of the shaped geometry whenever the Cassegrain and BWG receivers are used, but when used in primary focus, in absence of the compensating effect of the sub-reflector mirror, the phase error increases a lot, causing the maximum usable frequency to be 1.4 GHz (λ=21 cm). A way to keep the positive aspects of both geometries, shaped and parabolic, is by re-shaping the primary mirror from one configuration to the other. The panels forming the 64-m dish are manufactured so as to get a global shaped contour, but each individual panel is quasi-parabolic. As shown in Table 4, the calculated rms of the difference with respect to a true parabolic panel ranges from 16 to 255 μm.

Table 4. Calculated rms of the difference between shaped panel with respect to a best-fit parabolic panel

Panel row	RMS (μm)	Panel row	RMS (μm)
1	174	8	26
2	89	9	19
3	73	10	18
4	49	11	18
5	39	12	18
6	32	13	16
7	29	14	255

If we calculate a geometrical rms of a parabolic 64-m dish best-fitting the shaped dish, we find 214 μm, neither weighed for the area nor for the illumination function. This is a source of surface inaccuracy that must be combined with the other ones affecting the total surface accuracy. Considering that the gravitational deformation is overcome as well, the total surface accuracy calculated from Table 3 is σ = 275 μm rms and is low enough to accommodate very high frequency receivers in the prime focus.

In order to evaluate the stroke of the actuator to accomplish this re-shaping, the difference between the shaped reflector and the best-fit parabola, having a focal length of 21023.6 mm, has been calculated. The result is a stroke in a range +14 mm/−11.2 mm with

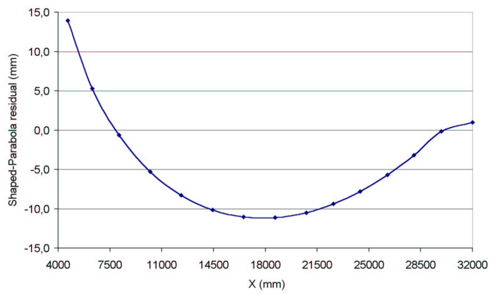

Fig. 3. Calculating Shaped - Best Fit Parabola residuals

respect to the mid-range of the actuator travel (see Fig. 3).

6. Status of the work

In November 2003 the Italian company Cospal Composites S.r.l. signed the contract for the manufacturing of the primary mirror panels. In March 2005 the same company signed the contract for the manufacturing of the secondary mirror panels. Delivery is expected to be completed by June 2006. In August 2004 the Italian company Vitrociset S.p.A. signed the contract for the manufacturing of the actuators, which is expected to be completed by January 2006. The actuator network and the software control network is being developed by IRA staff and it is expected to be completed at the same time as the actuators.

7. Conclusion

The SRT antenna will have a surface accuracy good enough to allow it to operate at frequencies up to 100 GHz, already at the end of the erection phase of the radiotelescope, when the primary mirror panels will be field-aligned at about 150 μm rms. Moreover, it will have the capability to switch the primary mirror between shaped and parabolic configurations. It is also important to underline that the INAF-IRA staff's ability to provide such facilities originates from the experience gained with the design and installation of the Active Surface System on the Noto 32-m antenna in 2001, and from the continuing collaboration with Italian companies, like Cospal Composites and BCV.