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How to improve the high-frequency capabilities of the SRT

T. Pisanu[1], F. Buffa[2], M. Morsiani[3], M. Natalini[1], C. Pernechele[2], and G. Vargiu[1]

[1] INAF - Istituto di Radioastronomia, Sez. di Cagliari, Loc. Poggio dei Pini, Strada 54, I-09012 Capoterra (CA)
[2] INAF - Osservatorio Astronomico Cagliari, Loc. Poggio dei Pini, Strada 54, I-09012 Capoterra (CA)
[3] INAF - Istituto di Radioastronomia, Via P. Gobetti 101, I-40129 Bologna

Abstract. The SRT is a general purpose, 64-m antenna, designed to be able to operate with a good efficiency in a frequency range from 300 MHz up to 100 GHz. This frequency range, is divided in two parts, one up to 22 GHz with a minimal amount of accessory instrumentation, and the other up to 100 GHz with a full complement of instrumentation. In this paper, we describe the activities of the SRT Metrology group, whose aim is to develop the necessary instrumentation for measuring and reducing the various components of pointing and efficiency errors, necessary for observing with the SRT up to 100 GHz.

1. Introduction

We can divide the errors that degrade the antenna performances, in systematic (e.g. gravity and initial alignment errors) and non-systematic (thermal and wind effects on the structure), depending on time repeatability.

The required antenna performances are illustrated in Table 1, which show the required performances at 22 and 100 GHz and in two atmospheric condition regimes.

We are mainly involved in measuring and correcting the detrimental effects of thermal gradients and wind, even if many of the systems that we are developing can also improve the knowledge and correction of systematic errors.

The main difference between precision and normal atmospheric conditions, is that in the latter case we consider a daylight operation of the telescope.

As we can see from Table 1, the main goals of our work are to obtain an RMS pointing error $< 2''$ and an RMS of the total antenna surface $< 200\mu$m. This is due to the fact that the power pattern of a paraboloidal antenna has an almost Gaussian shape, with an antenna temperature T_i at a distance O_i from the central peak position O_0 of (Rohlfs & Wilson 1996):

$$T_i = T_p \; e^{-4\ln 2 (\frac{O_i - O_0}{FWHM})^2} \tag{1}$$

Therefore we need to be able to point a source with a precision better than $HPBW/10$, which for the SRT at 100 GHz is HPBW $\simeq 10''$.

On the other hand, the Ruze formula (Ruze 1996),

$$\eta_{surf} = exp - (\frac{4 * \pi * \sigma_{RMS}}{\lambda})^2 \tag{2}$$

predicts an antenna efficiency of $\sim 67\%$ with a σ_{RMS} of $\lambda/20$, which at 100 GHz is $\lambda = 3$ mm.

Table 1. SRT performances

Performances (RMS)	Operation up to 22 GHz	Operation up to 100 GHz
Precision condition		
Repeatable Pointing	5 arcmin	5 arcmin
Non-repeatable Pointing	7 arcsec	2 arcsec
Servo Tracking Accuracy	1 arcsec	1 arcsec
Panel Manufacturing	100 μm	100 μm
Panel Total Error	150 μm	150 μm
Subreflector	150 μm	150 μm
Overall Surface	630 μm	190 μm
Normal condition		
Repeatable Pointing	5 arcmin	5 arcmin
Non-repeatable Pointing	13 arcsec	3 arcsec
Servo Tracking Accuracy	2 arcsec	2 arcsec
Panel Manufacturing	100 μm	100 μm
Panel Total Error	150 μm	150 μm
Subreflector	150 μm	150 μm
Overall Surface	630 μm	200 μm

The systems that are under study by our group are:

1. FEM (Finite Element Method) simulation;
2. Sub-reflector alignment;
3. Temperature sensors;
4. Star Tracker;
5. Inclinometers;
6. Pressure sensors;

2. FEM (Finite Element Method) analysis

The FEM model of the SRT could be helpful for the work of our group, allowing us to correct not only systematic but also non-systematic errors. With the FEM model we can: obtain the look-up table of the sub reflector displacement with gravity, understand the thermal behavior of the back-up structure, obtain a look-up table of the primary mirror's deformations, calculate number and dislocations of temperature sensors and simulate the wind effects on the antenna structure.

For the moment we are testing many of our systems on the radio telescope of Medicina, for which we have a FEM model developed in ANSYS, the same simulation program as for the SRT. The first step was to predict the number and dislocations of temperature sensors on the antenna structure. To do this we divided the structure in three parts: the alidade, the back-up structure and the quadripod.

We performed two simulations in order to understand the influence of different trusses under thermal gradients. In the first we apply a constant gradient of temperature of $\Delta 1^{o}C$ on trusses and calculate the displacement of the nodes, which correspond to the position of the elevation bearings or to the displacement of the sub-reflector; in the second we apply a gradient from $-0\overset{\circ}{.}5$ C to $+0\overset{\circ}{.}5$ C on the two sides of the same trusses and measure the same displacements. An example of the simulations regarding the alidade is shown in Fig. 1.

From the simulations we have learned that trusses do not have the same effect under a thermal gradient, but some trusses are more important than others and, to monitor temperature effects, we need to mount at least 20 sensors over the alidade structure and 4 (one in each truss) over the quadripod structure. For the moment we have not yet considered the sensors that should be mounted on the back-up structure.

3. Sub-reflector alignment

From Table 1, we can see that the subreflector position should be known with a precision

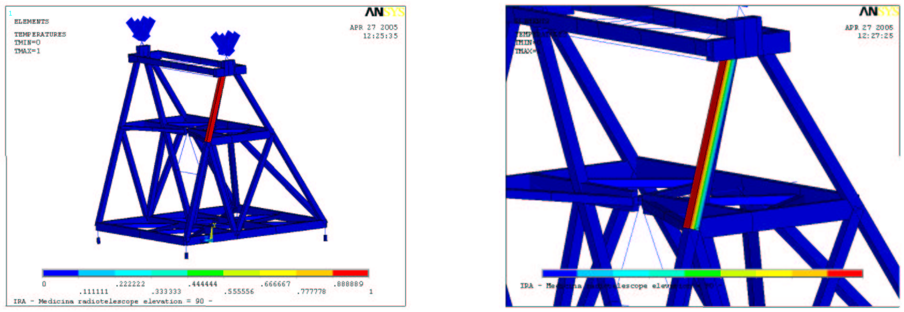

Fig. 1. Homogeneous and gradient of 1^o C on alidade structure.

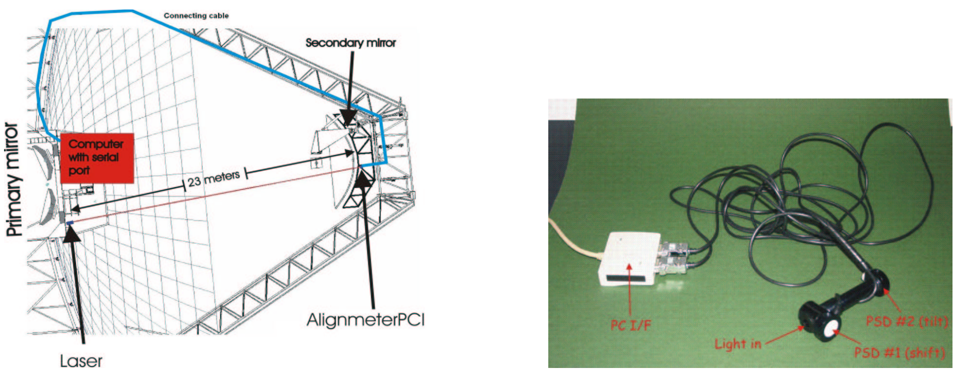

Fig. 2. Left panel: Scheme of the subreflector alignment optical system. Right panel: the AlignMeter by Duma Optronics©.

of 150μm in both precision and normal conditions and at both 100 and 22 GHz. To reach this goal, we need to measure in real-time the position of the secondary mirror, which is $\sim$ 20 m from the primary mirror vertex. One way to do this, is by using an optical system with a laser beam mounted near the primary vertex and an optical sensor capable of measuring 6-degrees of freedom, aligned with the beam and mounted near the quadripod vertex. A schematic view of this system is shown in Fig. 2 (left panel). For the moment we are testing a 4 degrees of freedom optical system: the AlignMeter from Duma Optronics© shown in Fig 2 (right panel), which has two PSDs (position sensing devices), one for measuring the x-y position shift of the sensor with respect to the laser beam model and the other for the tilt. We are planning to mount this system on the Medicina antenna before the end of the year.

4. Temperature sensors

Temperature probes are needed for measuring the thermal gradients along the antenna structure. As we have already described in the FEM

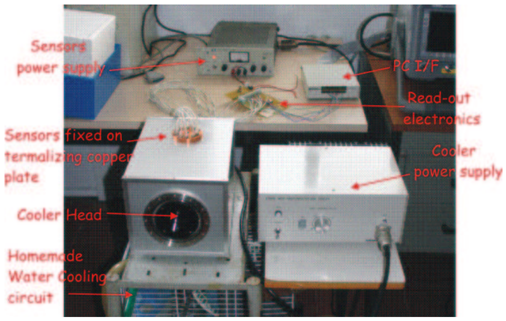

Fig. 3. Laboratory setup of thermistors calibration.

section, the optimized number and dislocation of the probes, should be determined by the FEM model. The model receives as an input the measured temperatures and, from those, it evaluates the structural deformations which produce pointing and surface errors. The sensors that we have already tested in our laboratory are by the YSI© company; they are Glass-encapsulated NTC thermistors, with a $\pm$ $0.^{\circ}1$ C interchangeability tolerance, from 0^{o} C to 70^{o} C. In Fig. 3 we show the laboratory setup used to characterize the sensors.

5. Star tracker

Another way which we are studying to improve the SRT pointing performances, is by coupling a small optical telescope with the radio pointing system. The optical pointing in fact, has some advantages respect to the radio. First of all it has the possibility to control in real-time the pointing and the tracking position, secondly it has a better pointing resolution. The problems with the optical telescopes are related to the difficulty to use it in daylight conditions (unless you observe in the far infrared band) and the stability of the alignment between the optical and the radio beams. The system which we are studying is composed of a reflector telescope with an F/10, a diameter of 180 mm, a CCD camera cooled with a Peltier, a FOV of $20' \times 20'$, a camera size of 512×512 pixel^2 each with a size of 20 μm, for a plate scale of $2.''3$/pixel. In Fig. 4 we show the telescope during the stability test phase, mounted on the 182-cm optical telescope at Asiago.

Fig. 4. Star Tracker (small white telescope), mounted on the Asiago 182-cm telescope.

6. Inclinometers

A metrology system which is mounted on almost every radio telescope, is represented by the inclinometers (see Fig. 5, left panel). They have different utilities. First of all they are used to check the integrity of the antenna structure and the rail track degradation; secondly they are used for obtaining a direct measurement of the azimuth plane inclination and also for measuring the thermal effects on the alidade structure (Morsiani & Orfei 1990). For the SRT we selected the inclinometer of Wyler© model ZEROMATIC 2/2 with a ZETRONIC sensor of $\pm 1^{o}$, as shown in in Fig. 5 (right panel).

7. Pressure sensors

Another non-systematic effect which we should consider is the wind. The main problem of wind effects is the duration time, which is of the order of a few seconds. The system proposed to correct the wind effects, uses 152 pressure sensors (Setra© model 239), dis-

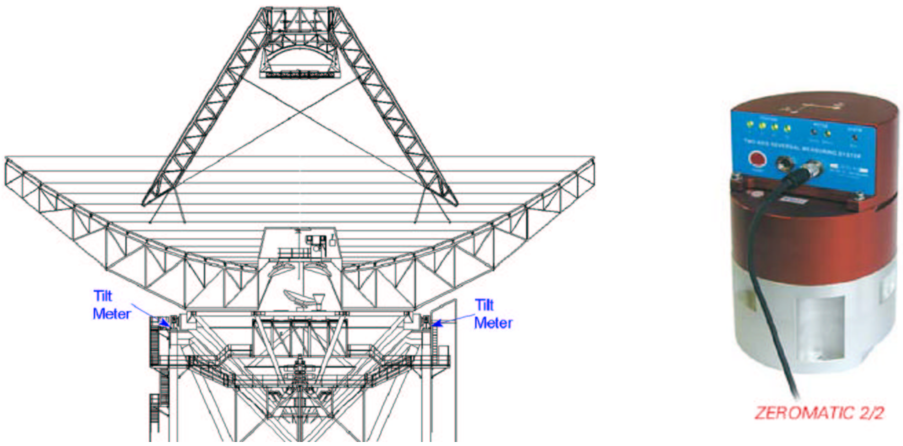

Fig. 5. Left panel: dislocation of inclinometers. Right panel: the Wyler© ZEROMATIC 2/2 inclinometer.

tributed in front of and at the rear of the primary mirror. Starting from single-point measurements we can calculate the wind loads over the radio telescope mirror and, by selecting the appropriate telescope model/stiffness matrix (generated in advance by FEA), corresponding to the elevation angle of the telescope, we can compute the displacements and rotations of the sub reflector, feed, best-fit parabola of the primary, and encoder rotations relative to their mounts.

From the displacements and rotations it should be possible to compute the wind-induced pointing error (uncontrolled portion), focus change and surface RMS due to wind, and send the compensating offsets to the AZ/EL, subreflector, and PACS servo systems. In Fig. 6 we show the laboratory tests of pressure sensors with an anemometer.

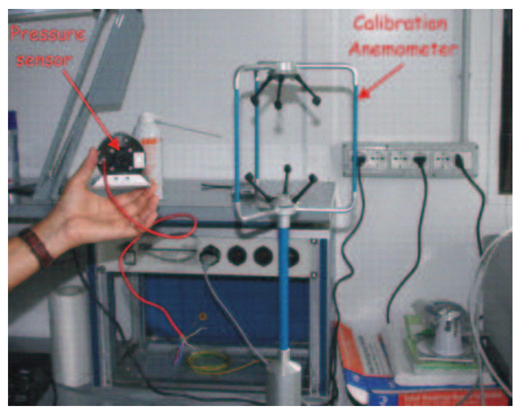

Fig. 6. Setra pressure sensor calibration.

8. Conclusions

Many of the systems that we are testing are prototypes and redundant, but only by testing and by mounting them on a real antenna we can verify their performances. Before having the possibility to test them on the SRT, we will mount them on the 32-m Medicina antenna, where we should start the testing of the Star Tracker systems and of the FEM model with temperature sensors next autumn.

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