The Metrology Systems of Sardinia Radio Telescope

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on behalf of Metrology team*
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Sardinia Radio Telescope

RadioNet Technical Workshop "*Metrologies at radio astronomy antennas*"

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Agenda

- SRT status at the end of technical validation (scientific validation in progress)
- SRT metrology short-term goals
- Work progress status of the first SRT metrology systems:
  - With-phase microwave holography
  - Inclinometers
  - Optical laser and Position sensing devices (PSD)
  - Temperature probes
- Other systems and future plans
- Conclusions

SRT status: introduction

A quick summary of the SRT features:

- fully steerable quasi-gregorian alt-azimuthal mounting reflector antenna
- active surfaces (64m-dia primary mirror and 8m-dia reflectors) made up of more than a thousand adjustable panels
- Frequency range: 0.3-100 GHz
- 3 main focal positions able to host up to 20 receivers

Focal position	Minimum Frequency	Maximum Frequency	F/D ratio
Primary focus (F_1)	300MHz	20GHz	0.33
Gregorian focus (F_2)	7.5GHz	~100GHz	2.35
BWG foci (F_3 and F_4)	1.4GHz	35GHz	1.37 for F_3 and 2.81 for F_4

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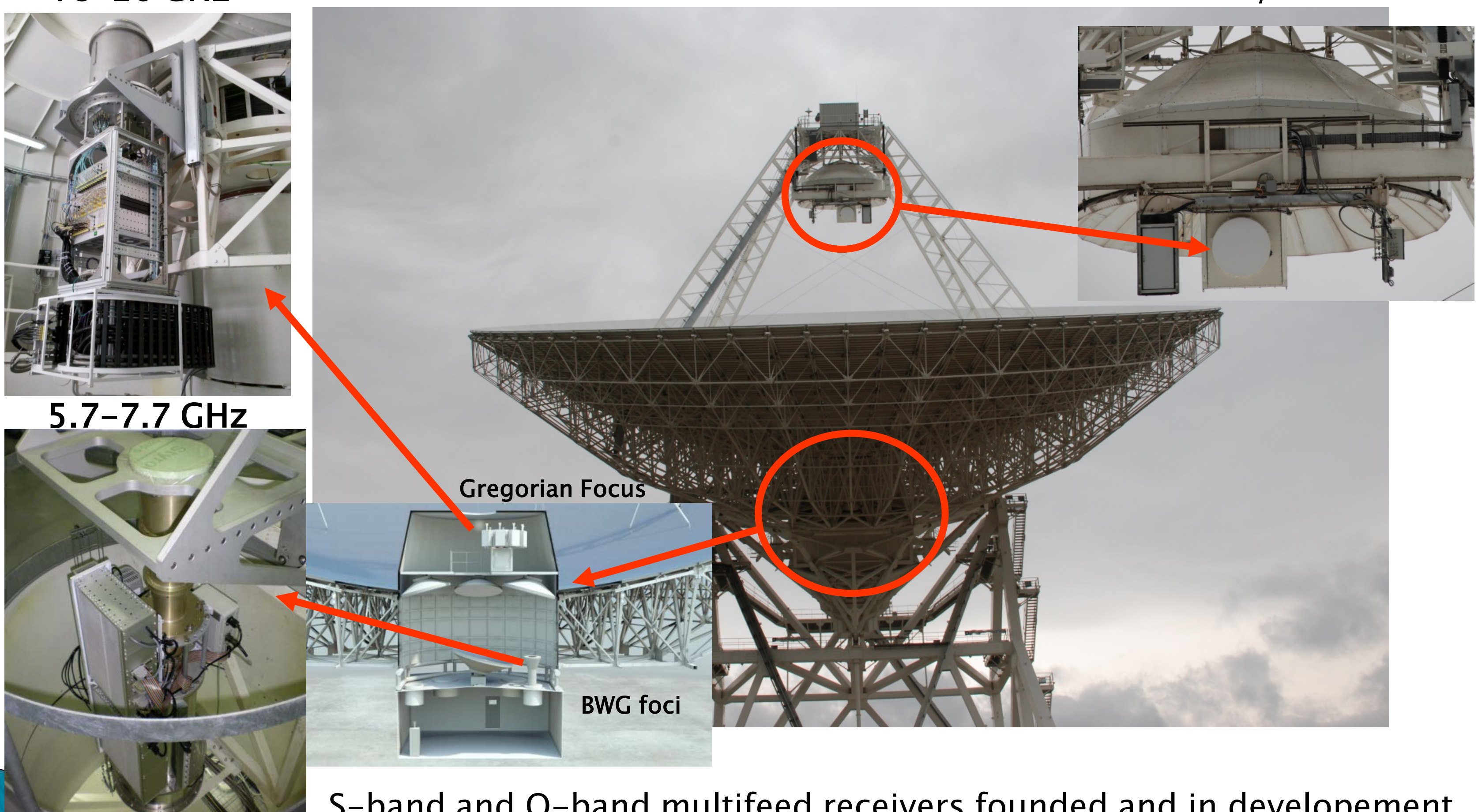
SRT status: receivers

At the present SRT is able to observe the sky in the frequency range: **0.3-26 GHz**



S-band and Q-band multifeed receivers founded and in developement.
A 100 GHz receiver got from IRAM

SRT status: surface accuracy

After the first panels alignment of the secondary (in 2010) and primary mirror (in 2012) with fotogrammetry measurement (by SIGMA 3D)

Subreflector surface

Accuracy: ~ 60 μm RMS @ 45° elevation

Primary reflector surface

Accuracy: ~ 290 μm RMS @ 45° elevation

Overall RMS accuracy of the reflecting surfaces ε~ 310 μm (= λ/20 @ ~ 48 GHz)

Very good surface efficiency up to 48 GHz

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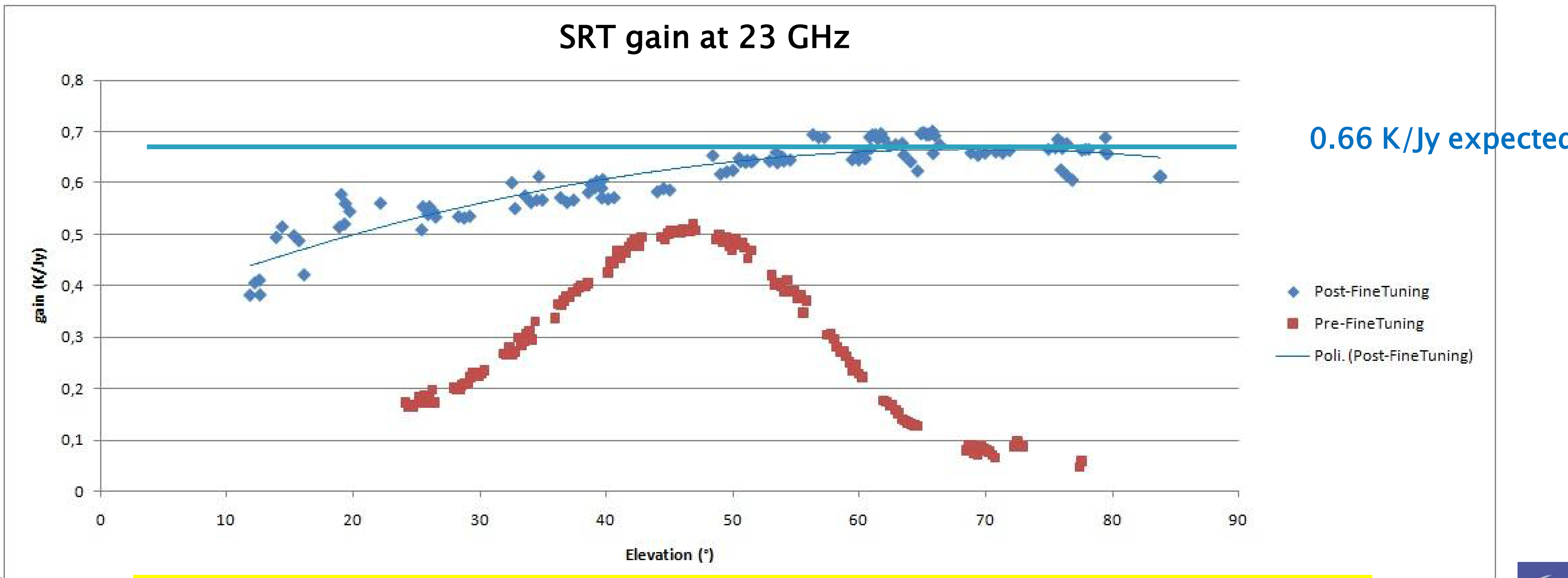
SRT status: antenna performances

After the fine tuning of the telescope with active surfaces working, the pointing model allows SRT to observe at 22 GHz with a:

- focusing accuracy < 1 mm (λ/10 @ 1 cm → ~ 30 GHz)
- an azimuth and elevation pointing errors < 4 arc sec (HPBW/10 @ λ =1 cm → ~ 30 GHz)
- gain at 23 GHz over the SRT elevation angular range



Note. Recent antenna optics calibration has improved the gain at lower elevation angles

SRT metrology short-term goals

Waiting for the higher frequency receivers, the metrology team is working to further improve the current SRT efficiency

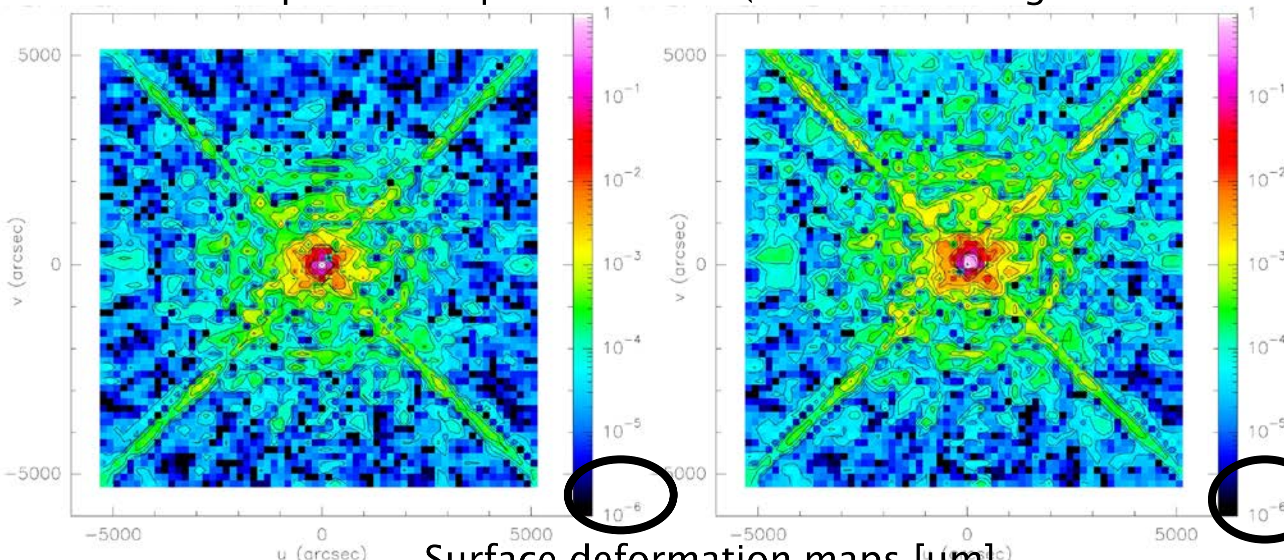
- Short-term goals:
  - primary surface accuracy better than 150 μm (i.e. an overall surface accuracy 190 μm, a very good efficiency up to ~80 GHz) with **Microwave holography system** to measure RT far-field pattern by pointing a Ku-band GEO satellite (elevation angle 44 deg)
  - azimuth and elevation errors < HPBW/10 (~ 1 arcsec with HPBW =12 arcsec @ 100 GHz) with **two inclinometers on the alidade**
  - focusing accuracy < λ/10 (~0.3 mm @ 100 GHz) with **optical laser-PSDs** behind the subreflector central panel

Work progress status of holography system

The holography system for SRT was already tested in 2010 at the Medicina 32-m diameter RT.

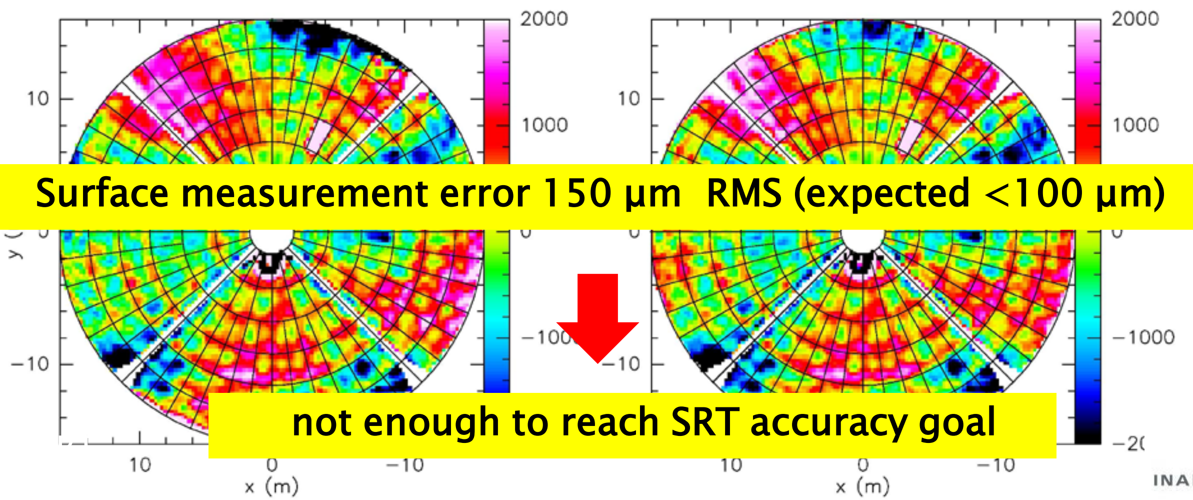
Two beam pattern maps @ 39° elev (GEO satellite signal @ 11.5 GHz)

±1.45° angular range
(HPBW = 0.056°)



SNR =60 dB

Surface deformation maps [µm]



Surface measurement error 150 µm RMS (expected <100 µm)

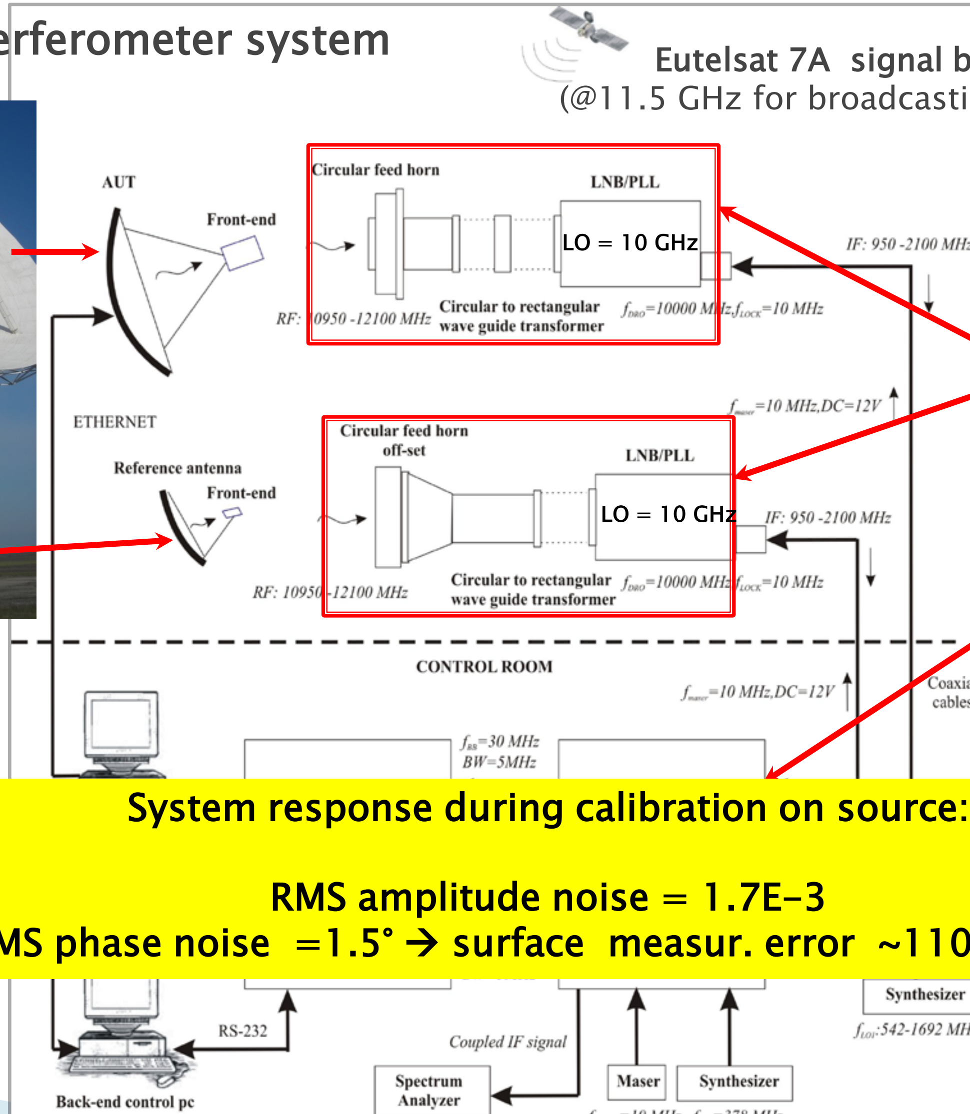
Measured surface accuracy 880 µm WRMS (average)

not enough to reach SRT accuracy goal

Work progress status of holography system

Measurement set-up of holography system installed at Medicina RT

Wide band interferometer system



LNBs
(internal LO, PLL,
10 MHz→10 GHz
with a frequency multiplier)

1.5 GHz
Output signals

Dual-channel IF receiver

30 MHz
Output signals
(5 MHz BW)

ator

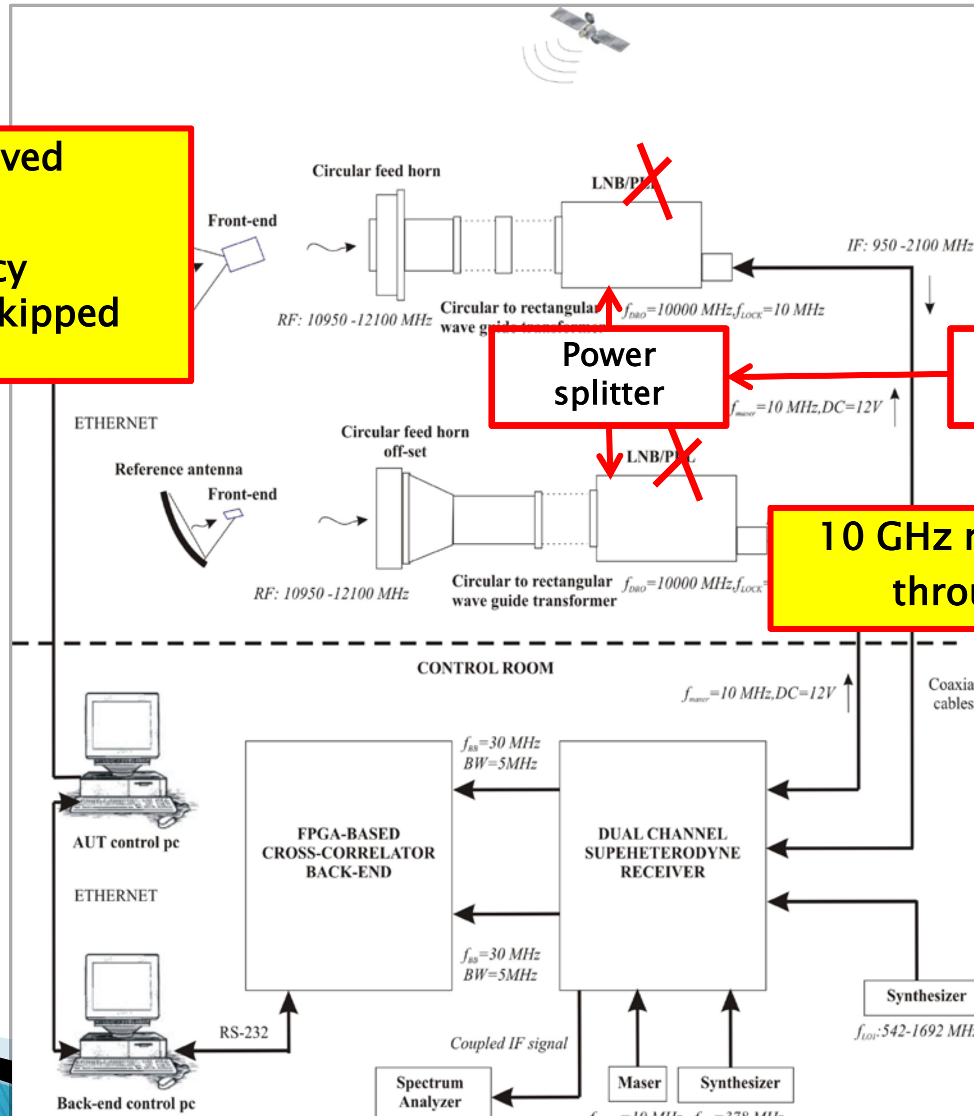
Interferometer output
(x-corr coefficients
amplitude and phase)

System response during calibration on source:

RMS amplitude noise = 1.7E-3
RMS phase noise =1.5° → surface measur. error ~110 μm RMS

Work progress status of holography system

To reduce the RMS phase noise both LNBS were modified :



1) internal LO removed

2) PLL and frequency multiplier circuits skipped

Power splitter

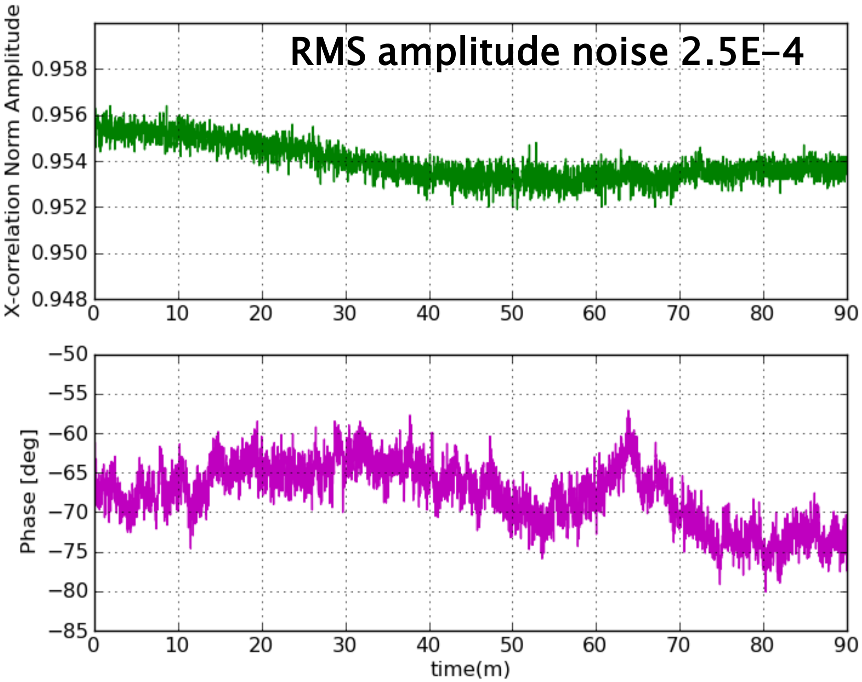
External Oscillator @ 10 GHz

10 GHz reference signal injected through a power splitter

Work progress status of holography system

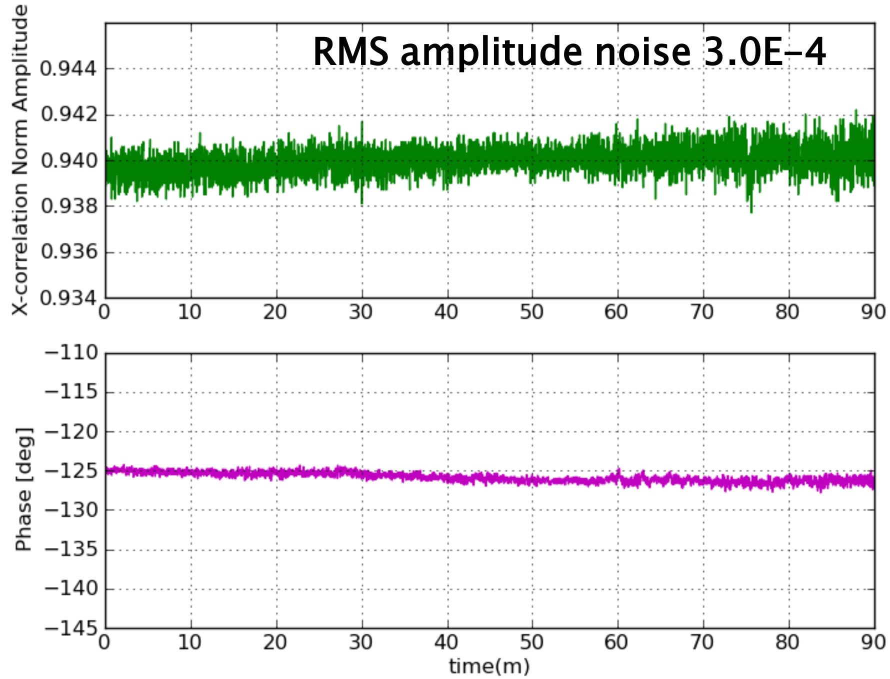
Lab tests have confirmed the RMS phase noise improvement. Here below the interferemeter response before and after.

With LNBs before being modified



RMS phase noise 1.54°
→ RMS surface measur. error ~110 µm RMS

With LNBs after being modified



RMS phase noise 0.26°
→ RMS surface measur. error ~ 20 µm RMS

Surface measurement error decreases by more than 5 times !!

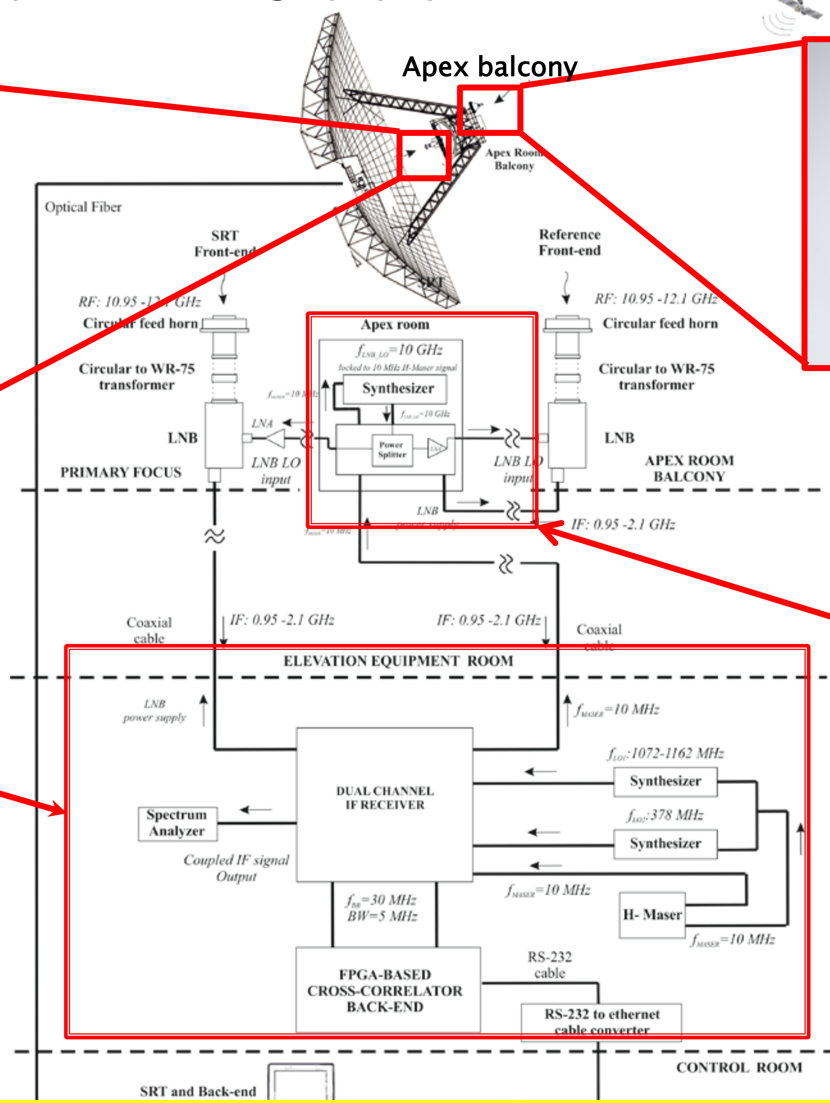
Expected surface measurement error with new system configuration 60 µm RMS

Work progress status of holography system

New measurement set-up for SRT holography system

RT front-end

modified LNB
on the primary focus



Reference front-end

0.6m-diameter antenna and
modified LNB

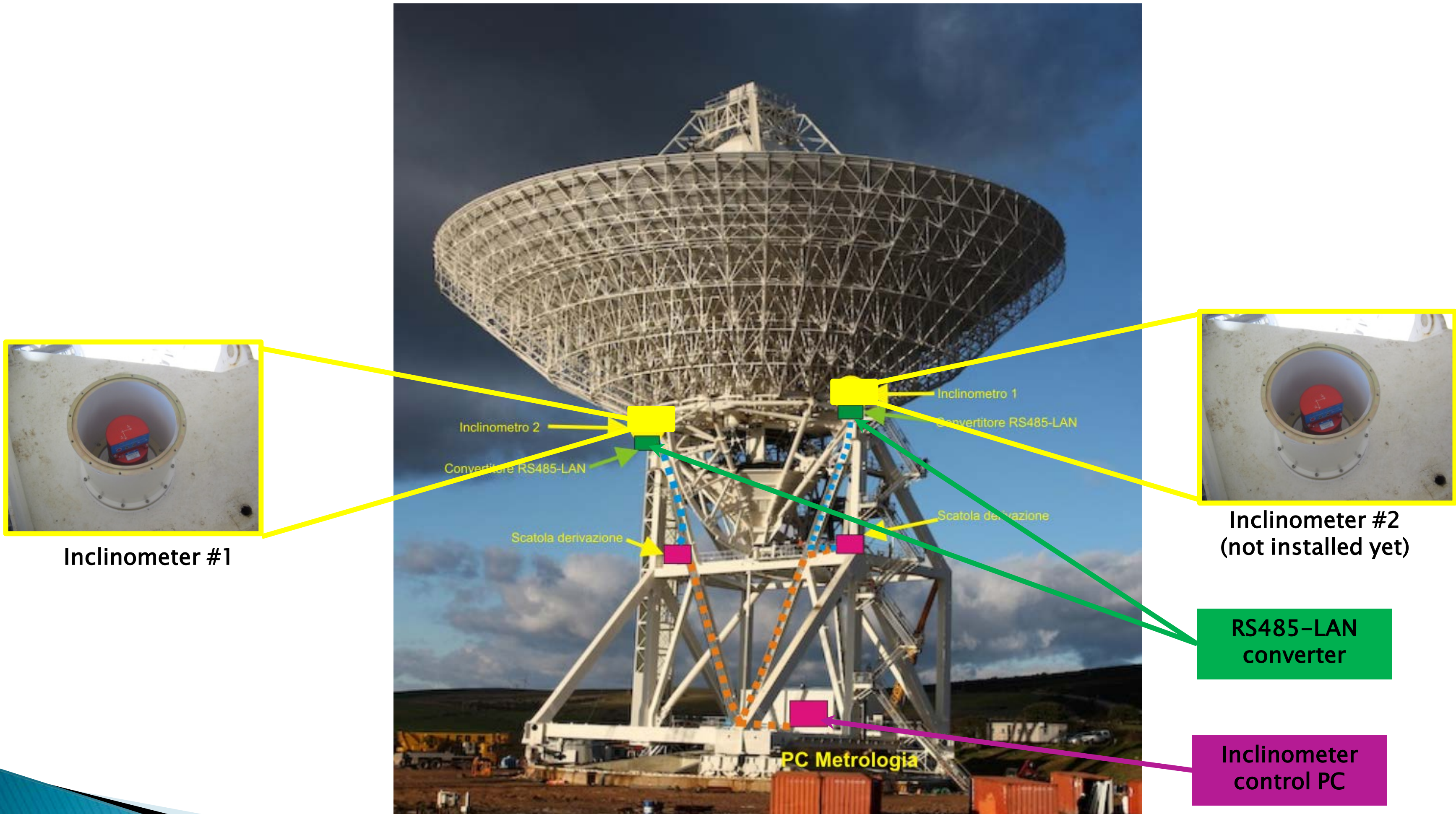
RF electronics rack at EER
(where IF-BOX and digital
backend will be soon installed)

RF equipment for injecting the
10 GHz LO signal to LNBs
at the apex room

Installation completed by 2014 and right after the first holography campaign at SRT

Work progress status of Inclinometer

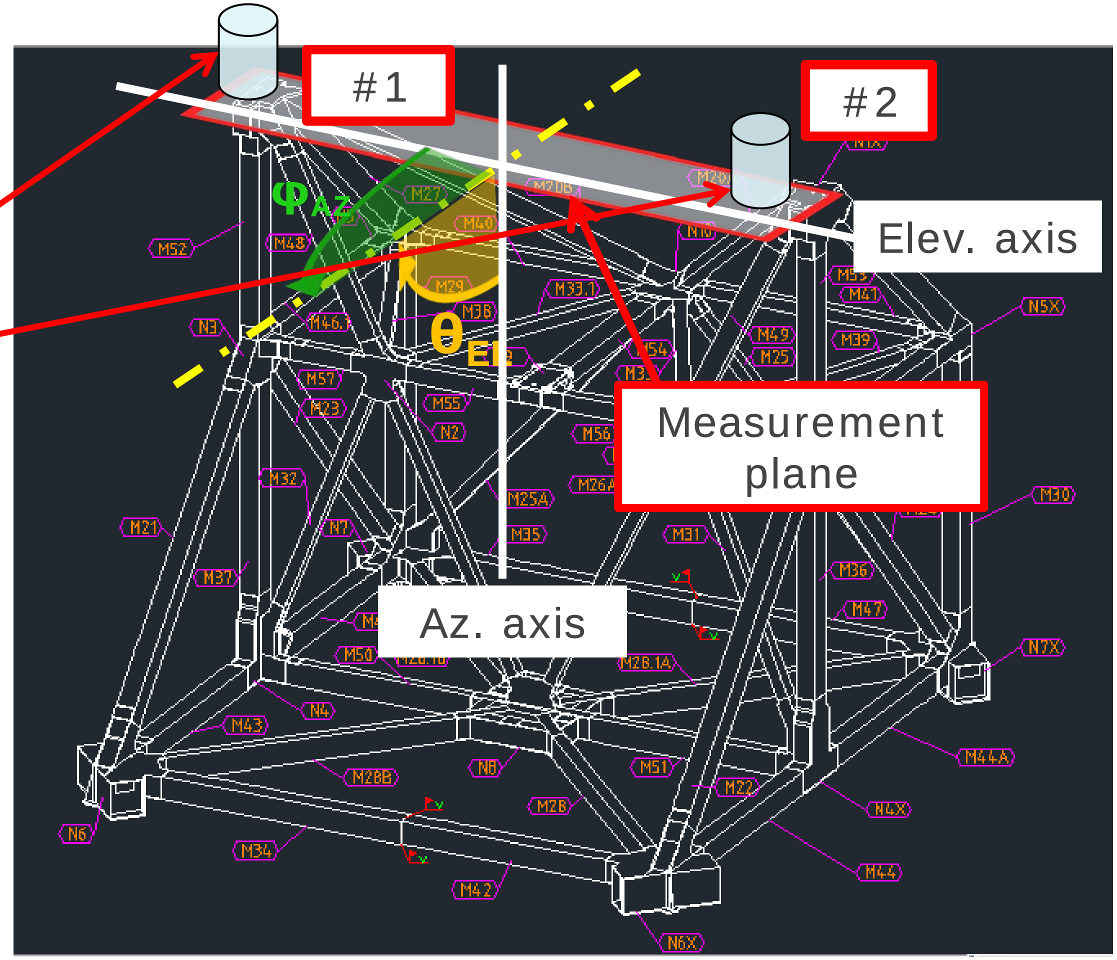
On the base of the recommendations coming from the SRT thermal design study



Work progress status of inclinometer

Two axes measurement inclinometer
by Wyler

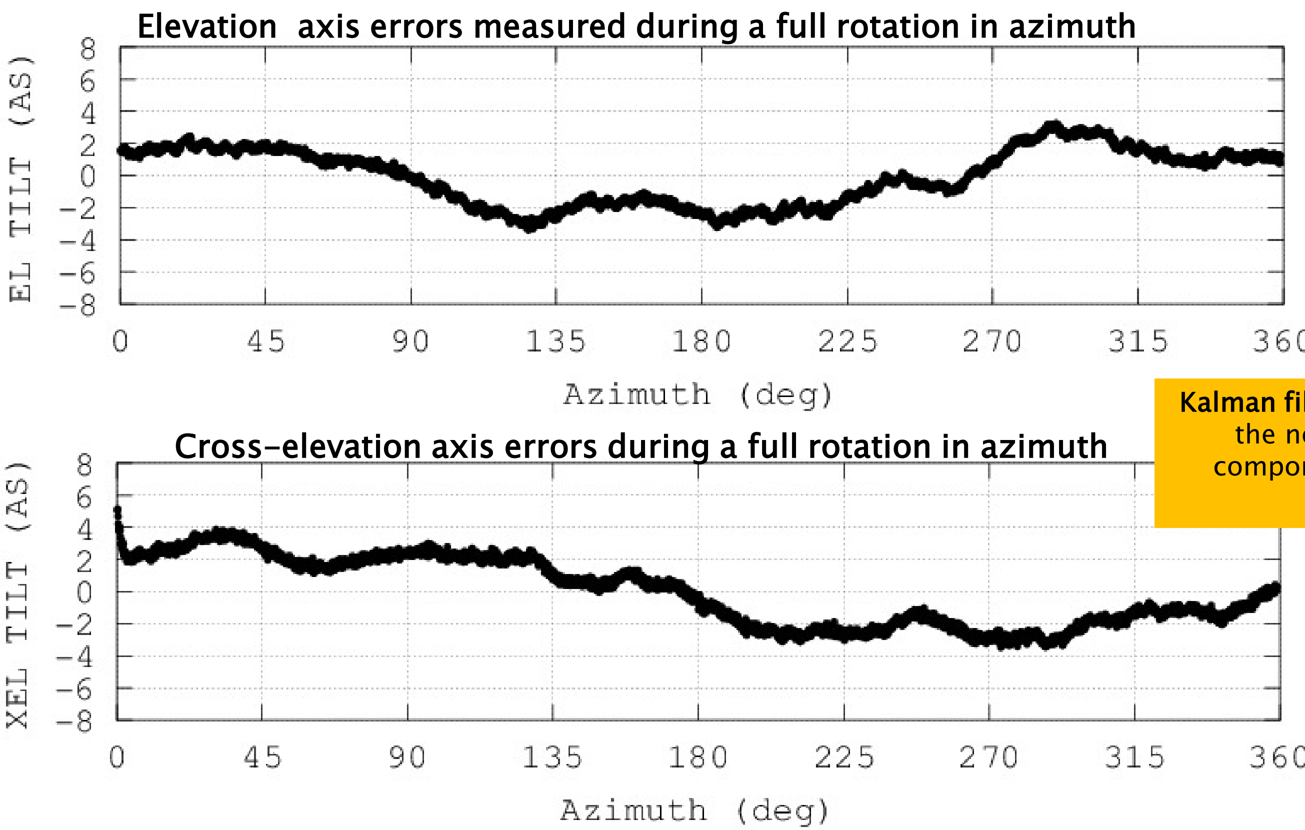
Measurement range: ± 1 deg
accuracy: **± 1arcsec (± 4.8 μm / m)**



Just one inclinometer has been fully tested on SRT up to now

Work progress status of inclinometer

Tests to check the planarity of the azimuth rail



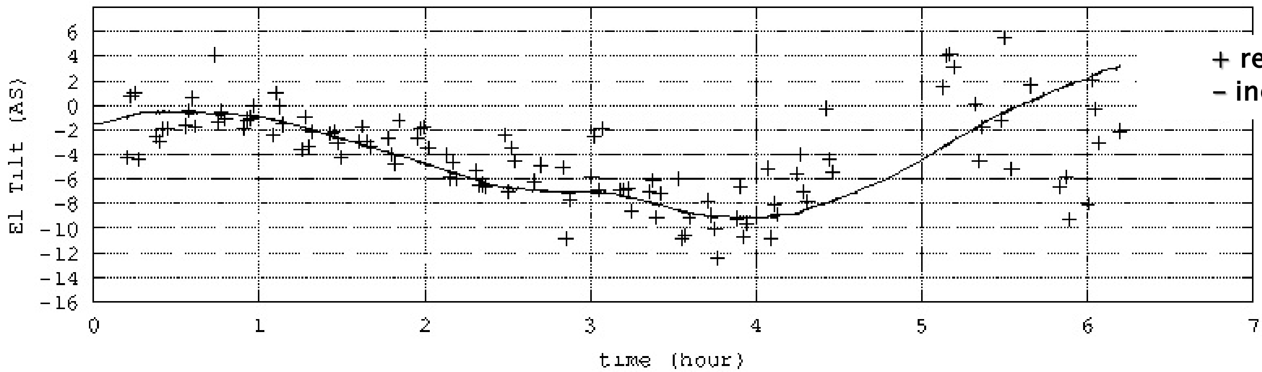
Kalman filter was used to remove the noisy high frequency components due to antenna acceleration.

Systematic errors not far from the expected one (±3 arcsec) deriving from the rail planarity tolerance. However they can be included in the antenna pointing model

Work progress status of inclinometer

Inclinometer measurement during astronomical observation on a circumpolar radio source at 23 GHz (K-band receiver) from sunrise to noon.

Elevation axis errors caused by antenna thermal deformations

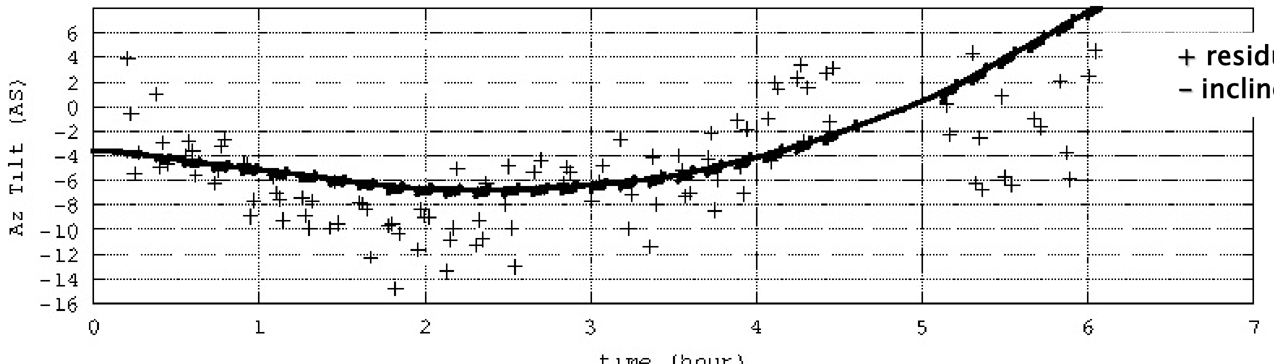


+ residual offset
– inclinometer meas

Residual offsets calculated from a Gaussian fit of the antenna beam after a cross-scan.

Kalman filter was used to remove the noisy high frequency components from inclinometer meas. due to antenna acceleration.

Azimuth axis errors caused by antenna thermal deformations

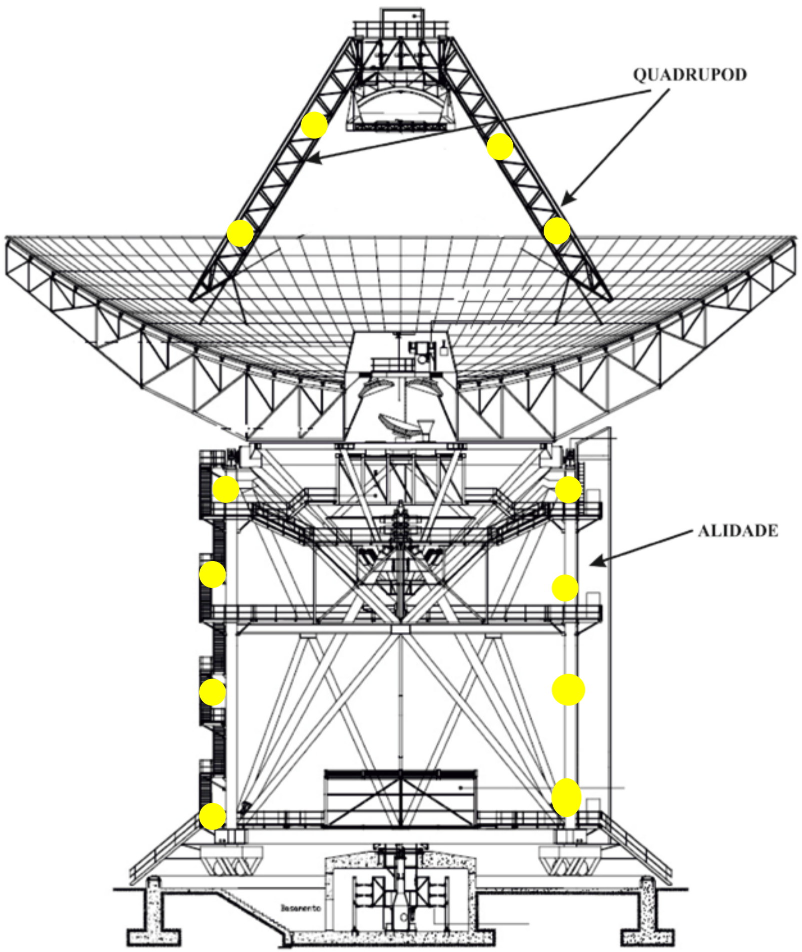


+ residual offset
– inclinometer meas

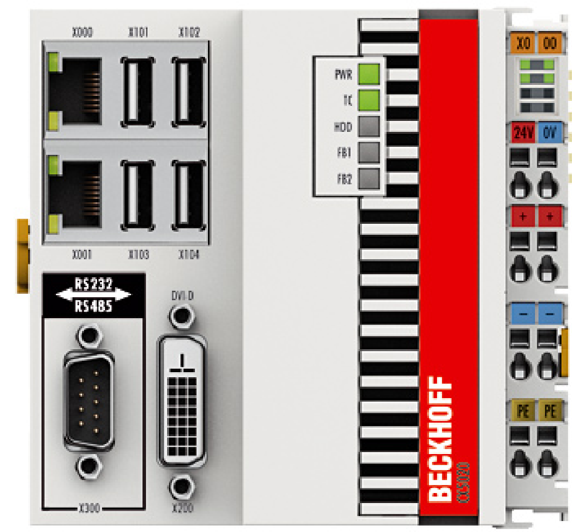
NOTE. With the antenna pointing model working, **residual offsets** take into account both alidade and quadripod temperature variation (not only alidade as in the inclinometer measurement)

Work progress status: temperature probes

The number and position of the temperature probes on SRT structure were inferred by FEM model:



- 16 probes on the alidade
- 8 probes on the quadrupod



Probes installation, cabling and interfacing with Beckhoff embeddes pc will be soon accomplished

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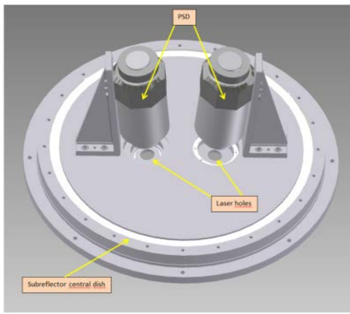
Work progress status: optical laser PSD

Two PSD for a real-time measurement of the secondary mirror misalignments will be soon installed behind the central panel of the sub-reflector

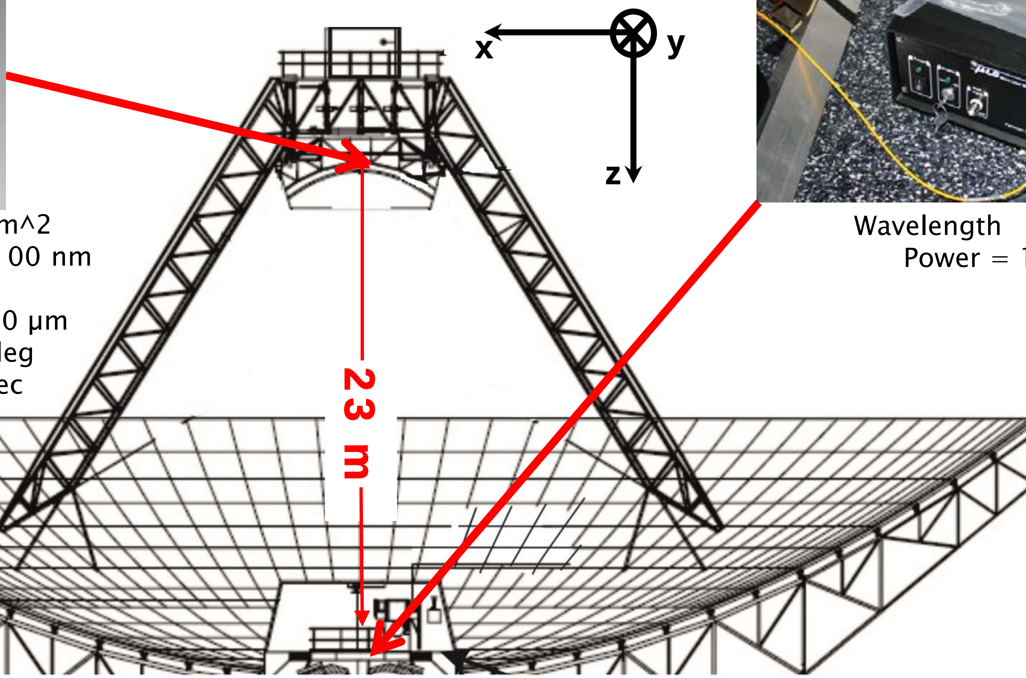
PSDs



sensitive area = 22.5 x 22.5 mm^2
Operational spectral range : 350-1100 nm
power range: 0.1-5 mW
Accuracy over calibrate area= ± 50 µm
Angular measur. range = ± 2 deg
Angular resolution = ± 1 arcsec

Laser diodes

Wavelength = 658 nm
Power = 10 mW



PSDs can measure X, Y, Z translation (derived by two X measur.) and X,Y axes rotation of the subreflector. But not installed yet.

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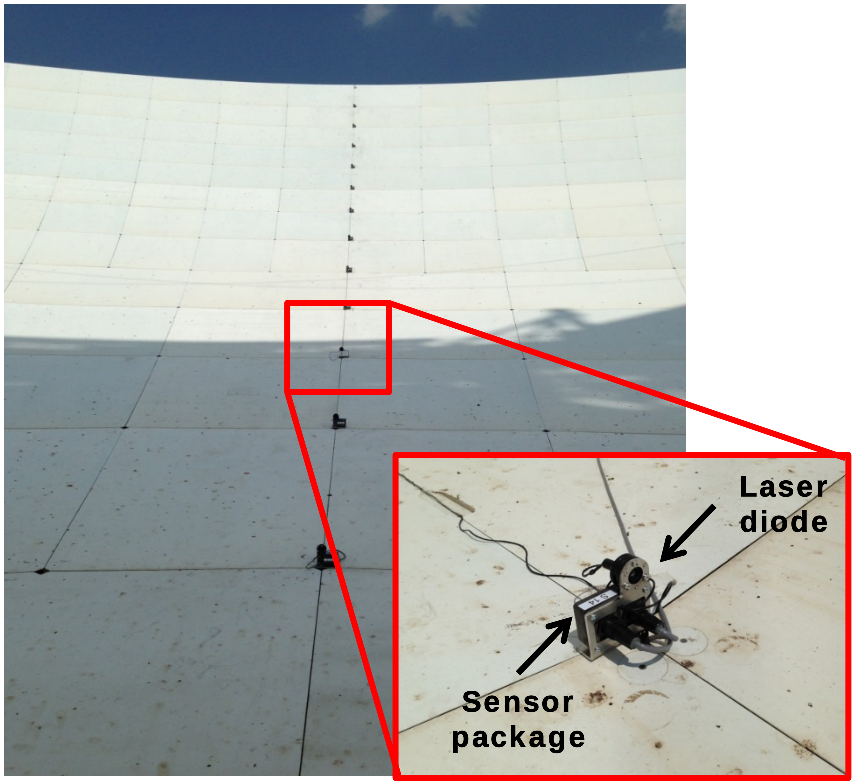
Other systems for primary surface metrology

Radial optical linear sensors



Real-time photogrammetry

Project funded by Sardinian regional government to:

- develop a simulation environment for photogrammetric measurement
- obtain the best configuration of the camera suitable for the SRT during operations

Both systems are under test for a real time measurement of primary surface panel deformations

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SRT metrology future plans

- Include inclinometer, PSD and temperature probe data in the antenna pointing model in order to compensate for alidade and quadrupod thermal deformations and monitor the antenna temperature in real time
- Beside the traditional holography, test the Out-of-Focus method on SRT for a quasi-real time mapping of the primary surface deformations due even to thermal gradients
- Finally, approach a closed-loop control for a quasi-real time correction of pointing errors and primary surface deformations

Conclusions

- At the present, the SRT scientific validation is keep going without intermission to make SRT ready to be shared with the radioastronomy community as soon as possible
- Even if the metrology systems, here presented, are not still ready, they look like very promising to preserve high antenna performances even at the higher frequencies
- Step by step we are getting confidence to reach the closed-loop control of the SRT metrology, i.e. final goal for the SRT metrology.

Thanks for you attention!

Any questions?

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