EIE GROUP

New metrology system for antennas: the ALMA solutions

Francesco Rampini
Gothenburg
1-2 September 2014

The power of creativity

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THE PROFILE

EIE GROUP has been on the international scene for more than 20 years, delivering ground-breaking engineering solutions for some of the most stunning Astronomical projects worldwide.

EIE GROUP is supported by three main Entities: Management & Contracting, Engineering & Design, Production & Services, specialised in the design and manufacturing of Astronomical Observatories, Telescopes, Radio – Antennas and scientific equipment.

EIE GROUP counts on focused engineering assets and solid know-how in fabrication, assembly processes, mechanisms and plant management.

EIE MANAGEMENT & CONTRACTING

EIE ENGINEERING & DESIGN

EIE PRODUCTION & SERVICES

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EIE in Radio Astronomy

The ALMA Project: Atacama Large Millimeter/Submillimeter Array*
EIE Designer and Technologist of the World's Largest Radio-Telescope

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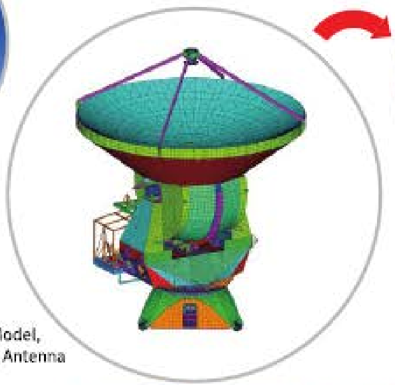
After making the ALMA Prototype



EIE Finite Element Model, for the best performing Antenna

The First European ALMA Antenna on the Transporter

SKA- Square Kilometer Array: a new challenge!

The SKA Array

1999 2005 2006 2006 2011 2012

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EIE in Astronomy

The E-ELT Project: ESO's awarded EIE for both the Detail Designs of the World's Biggest Eye on the Sky

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1986 1992 1993 1993 2005 2006 2008 2009

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Save the date

www.eie.it/anniversary

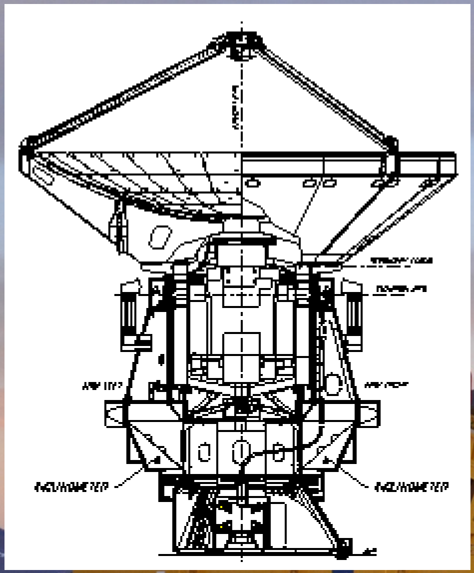
XXV

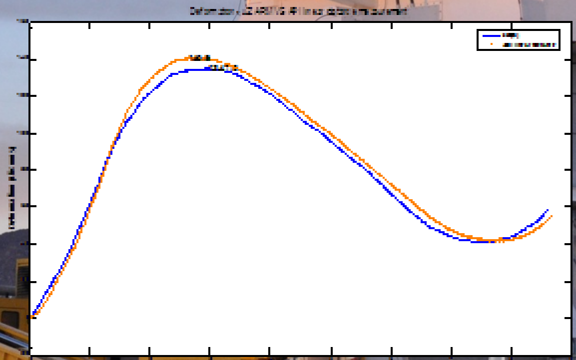
IL XXV ANNIVERSARIO DI EUROPEAN INDUSTRIAL ENGINEERING

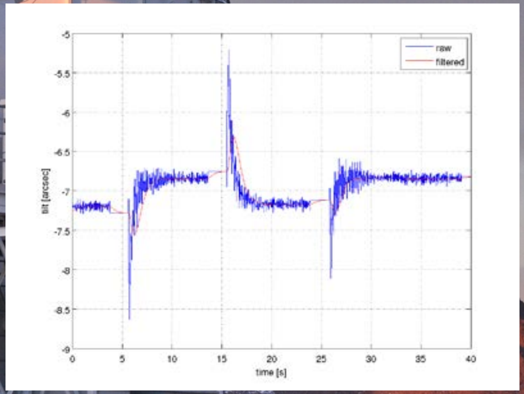
EUROPEAN INDUSTRIAL ENGINEERING 25th ANNIVERSARY

EIE GROUP

- Metrology layout
- Thermal metrology results
- Dynamic metrology results



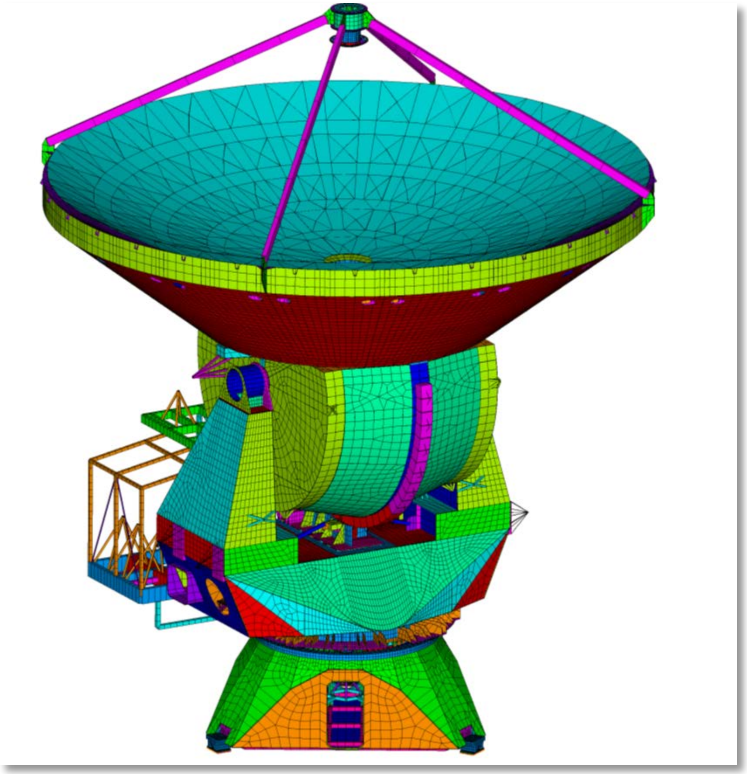




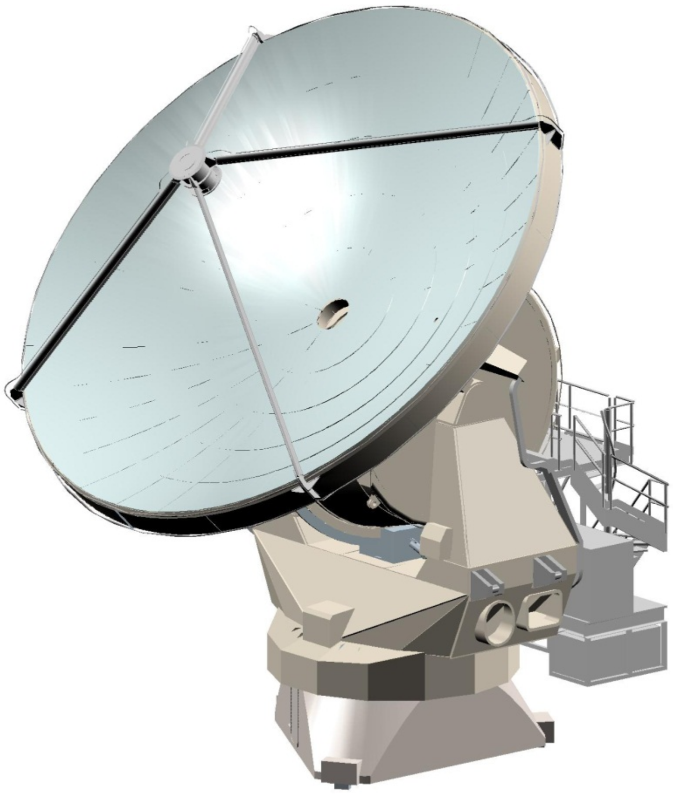
At the moment, ALMA is the most powerful array of the world, and the European Antennas represent the excellence in terms of Design, Technology, but above all in terms of Systemic approach.

Alma Key Specifications:

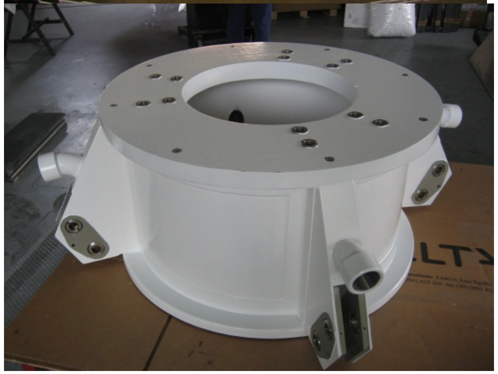
- Surface accuracy 25 µm rms (goal 20 µm);
- Absolute ponting 2 arcsec rms;
- Tracking accuracy better than 0.6 arcsec
- Path lenght stability 15 microns over 3’
- Fast motion: move to a targhet source in 1.5 sec with a step of 1.5 deg. Settle under 3 arcsec in 1.5 sec and track the source under 0.6 arcsec after 2 sec



Metrology concepts



Metrology concepts

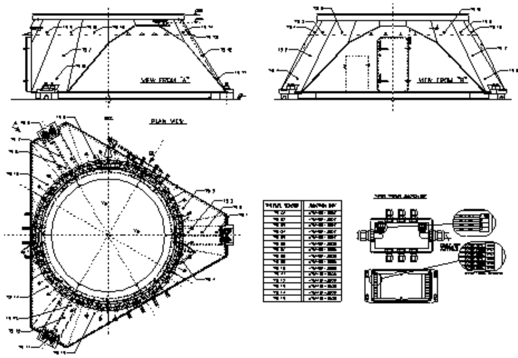


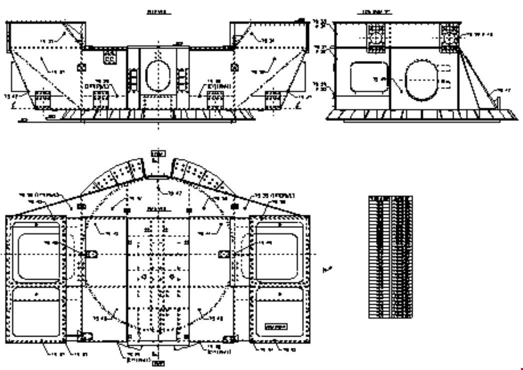
Metrology concepts

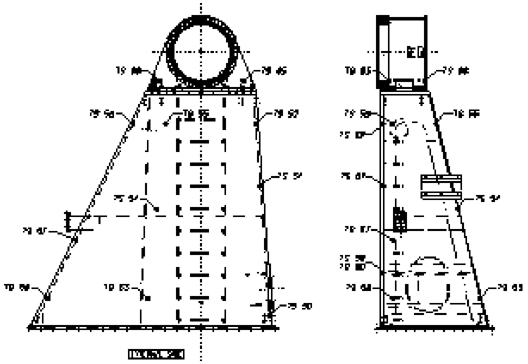
Thermal metrology system layout

The System is constituted by 83 thermal sensors positioned inside the Steel Structure. Their positions have been studied in order to have a temperature distribution capable to predict the real deformation of the structure.

The System will be switch on during absolute and offset pointing conditions.

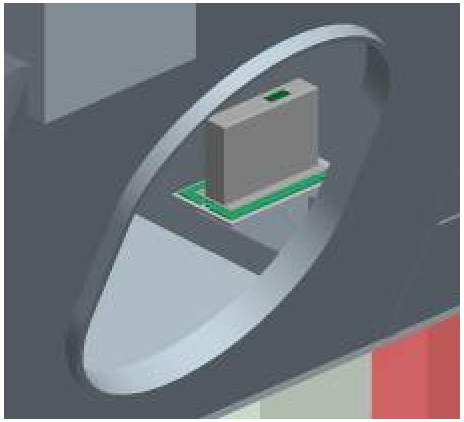


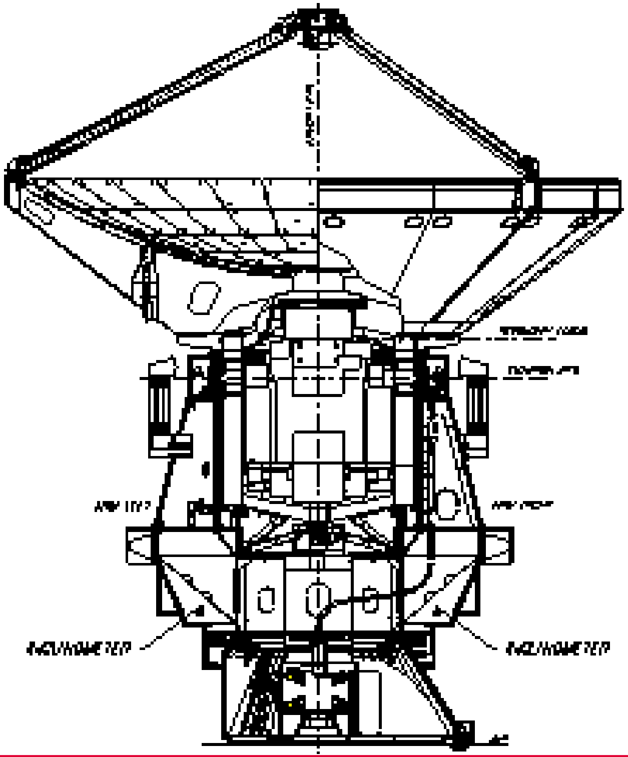




Dynamic metrology system layout

The dynamic metrology is based on two high-accuracy inclinometers placed on the Yoke Base on steel plates thermally coupled with the yoke structure. Through a correlation formula, these inclinometers measure the rotation of the elevation axis due to the wind loads.





High accuracy, resolution, settling time, rotation amplitude and in plane acceleration forced us to study, design, prototype, build and test a specific instrument, as the current marketplace offered no solutions that would meet the requirements simultaneously

Thermal Metrology Performance Tests

First test: Check the correctness direction of the metrology thermal correction.

During this test we verified the direction of the correction done by the thermal metrology imposing different thermal distribution on the thermal matrix. The test was done tracking one reference star with the OPT.

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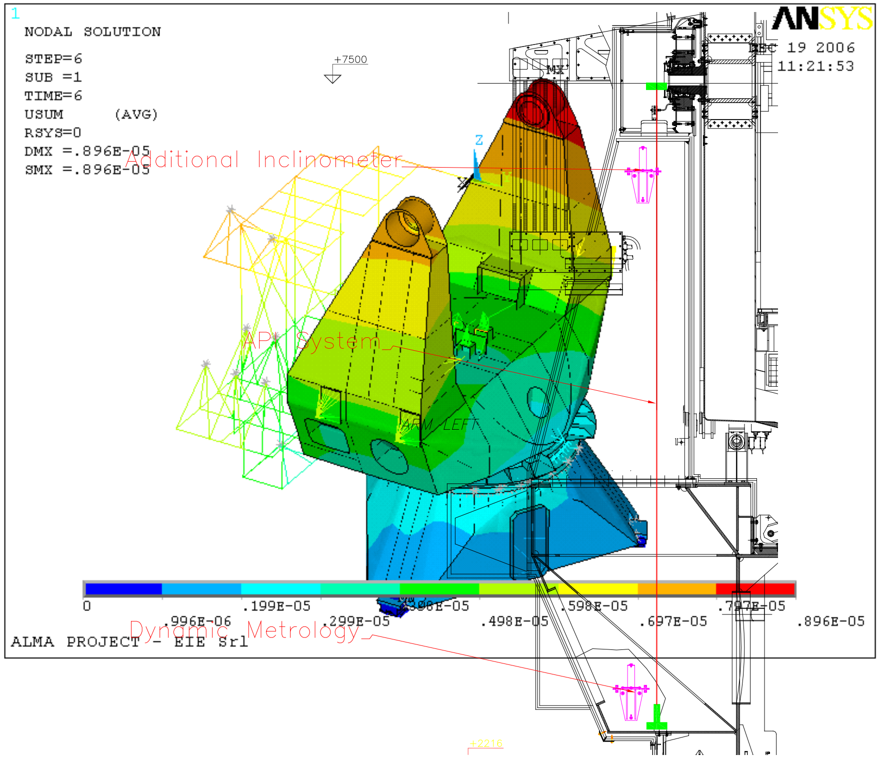
Thermal Metrology Performance Tests

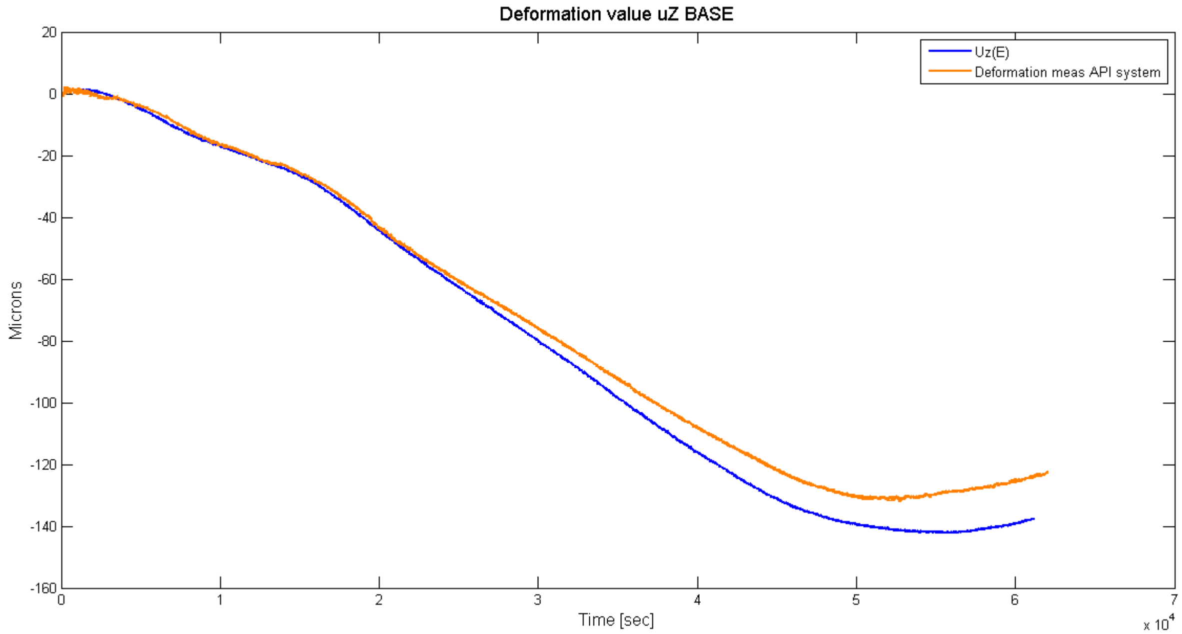
Second test : Evaluate the elongation of the antenna steel structure due to temperature change.

This test has been done in order to evaluate the elongation of the steel structure (base and yoke) comparing the measurement of and API laser system installed inside the antenna and the thermal matrix prediction.



Thermal Metrology Performance Tests

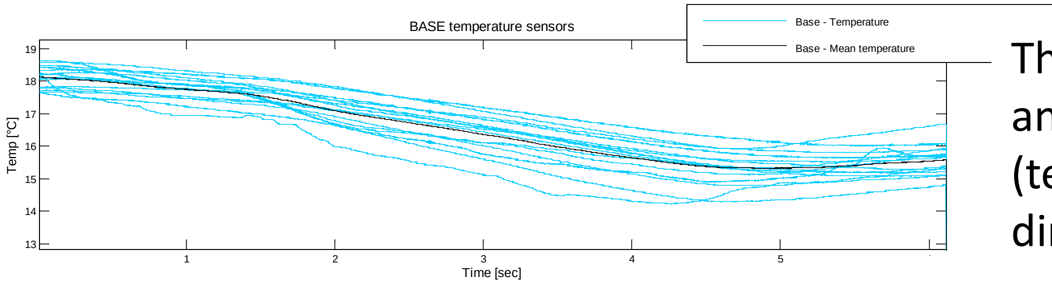
Comparison between the API laser system and the results coming from the Base metrology matrix.

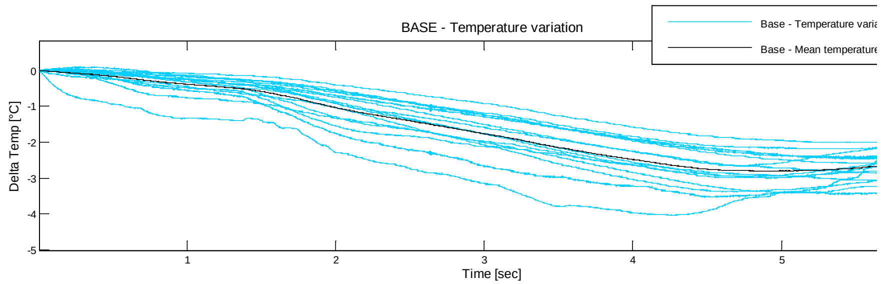


API measurement (red line) and the metrology measurement (blue line)

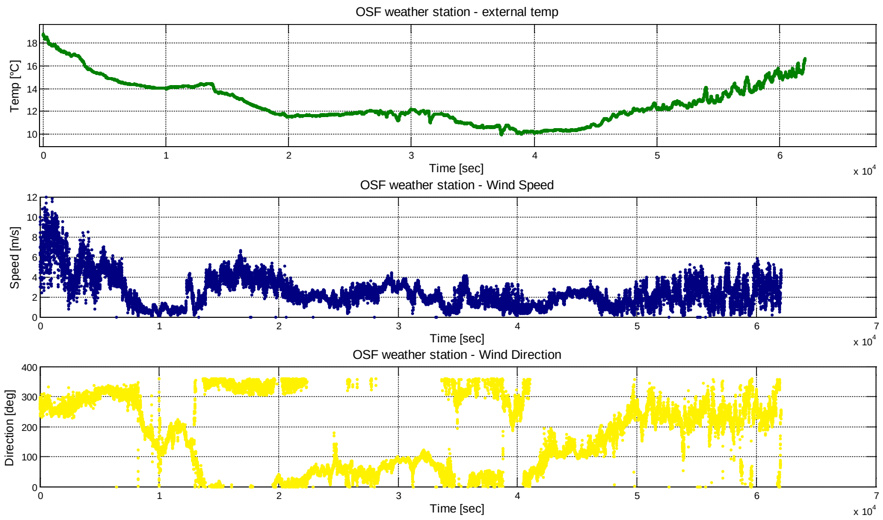
The comparison between the Base Matrix and API measurement is good in terms of trend and amplitude.

Thermal Metrology Performance Tests





Thermal sensor variation on the Base and weather condition during the test (temperature, wind speed and wind direction)



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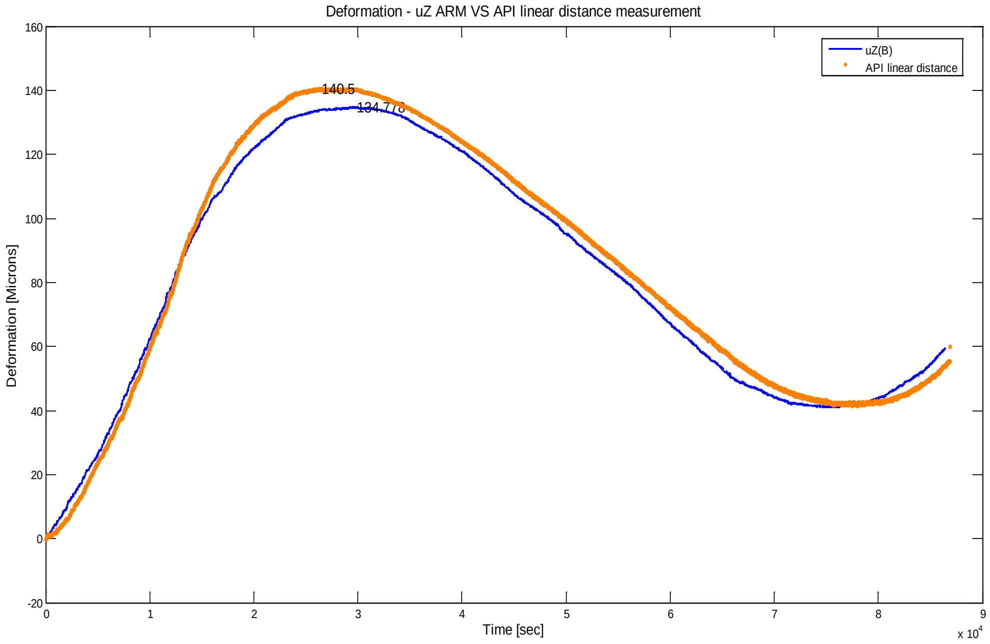
Thermal Metrology Performance Tests

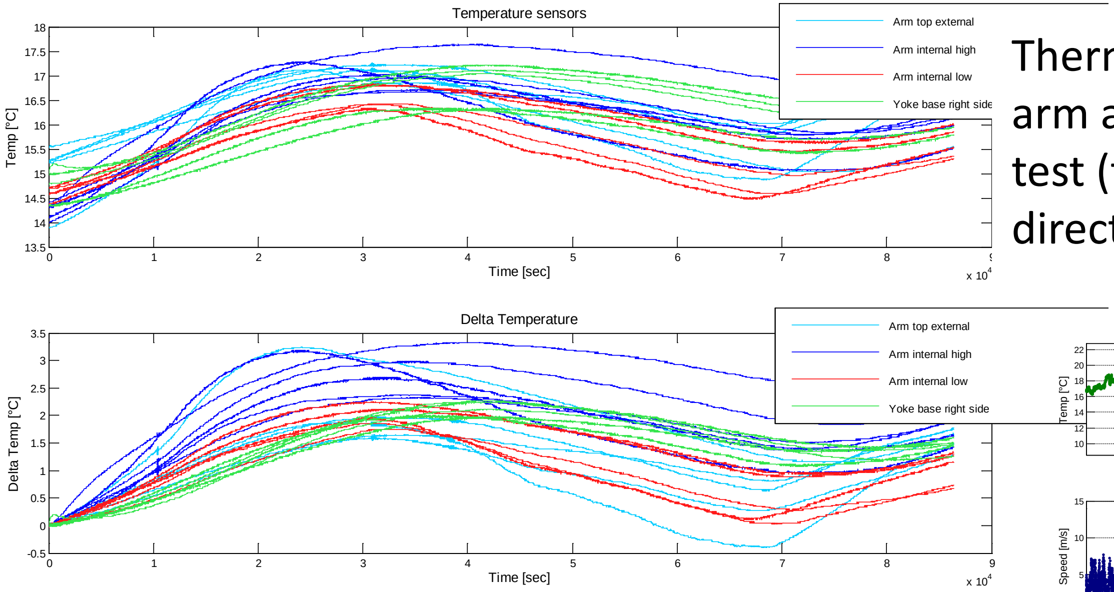
Comparison between the API laser system and the results coming from the yoke arm metrology matrix.



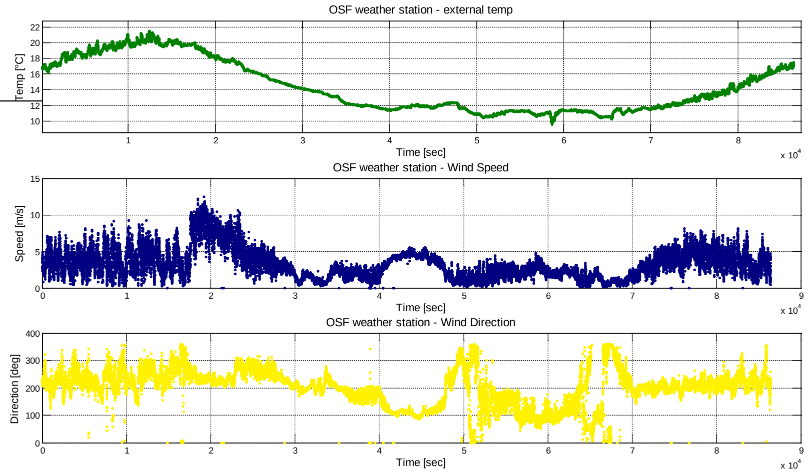
API measurement (red line) and the metrology measurement (blue line)

The comparison between the Yoke Arm Matrix and API measurement is good in terms of trend and amplitude.

Thermal Metrology Performance Tests

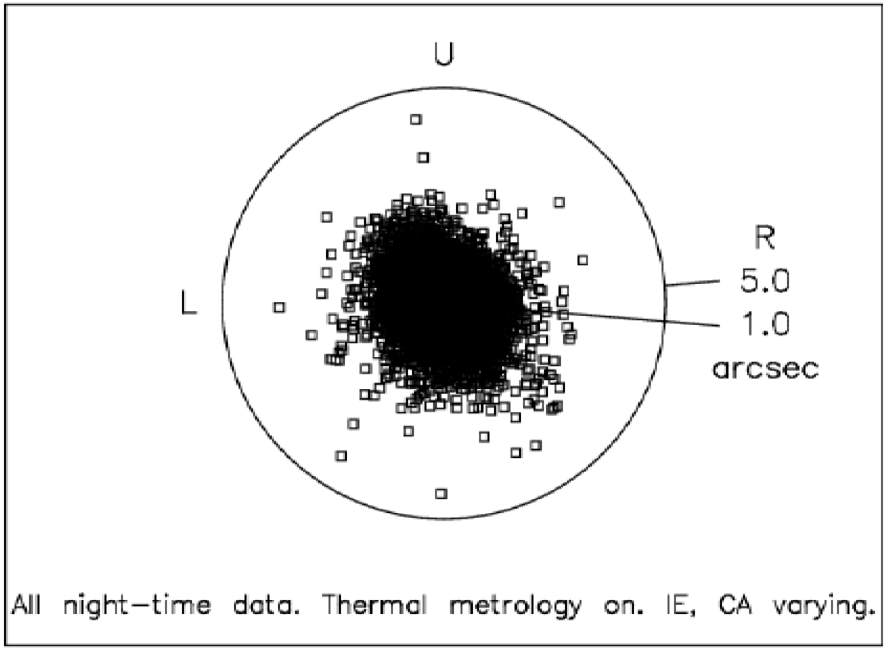


Thermal sensor variation on the yoke arm and weather condition during the test (temperature, wind speed and wind direction)



Thermal Metrology Performance Tests

After 49 individual tests (6274 measurements) we obtain a population SD of 1.00 arcsec. Then the pointing model stability has been checked with excellent result for a period of two weeks. The thermal metrology correction significantly improves the stability of the model.

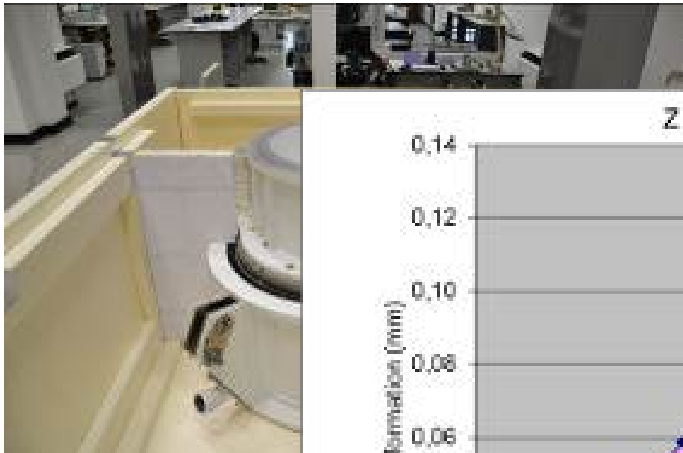


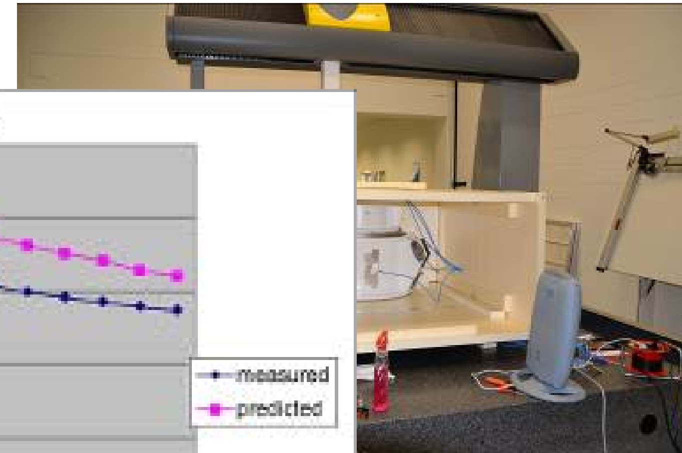
Coefficient	Metrology on		Metrology off	
	Value	rms	Value	rms
IE	−65.41	1.14	−64.99	1.63
CA	+362.17	0.69	+361.55	1.35

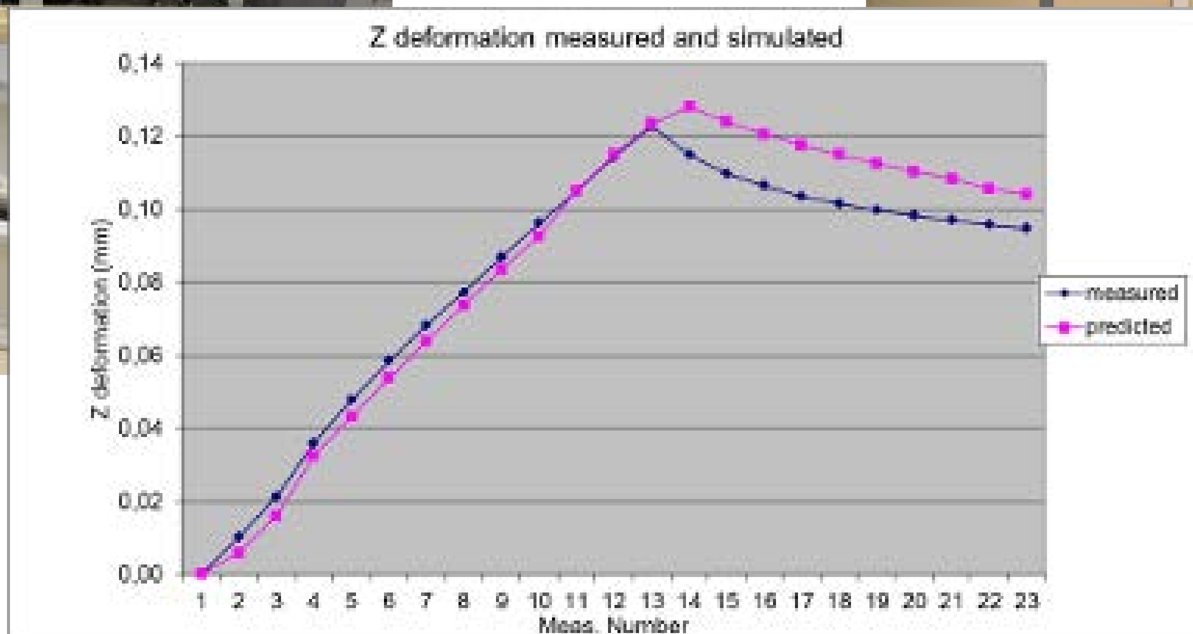
Thermal stability of the pointing model over a period of 2 weeks.

x thermal sensors tests:

ation of the thermal correction matrix of the Apex Cylinder



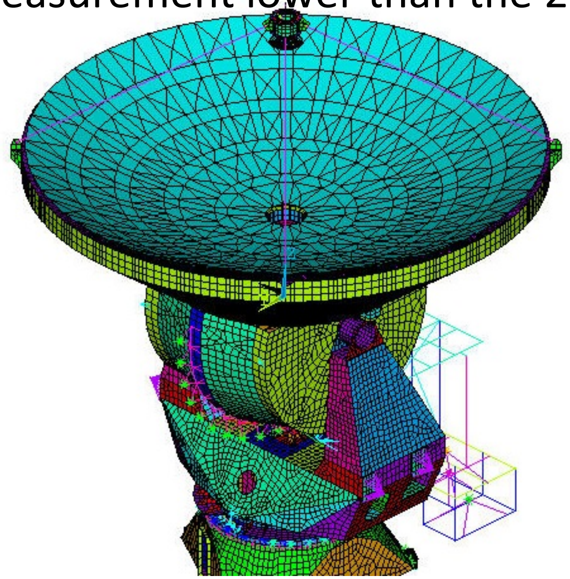


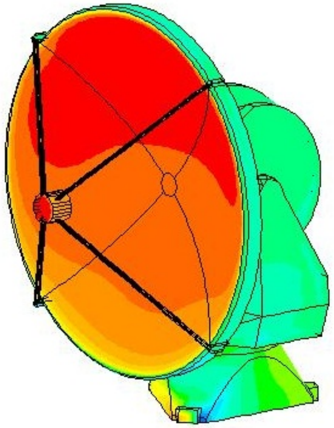


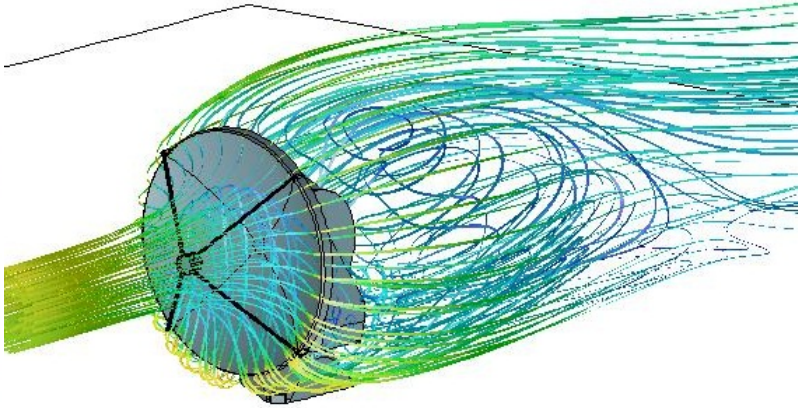
FEM MODEL VALIDATION

Same antenna performances can be evaluated only with the FEM model.

The goal for each test was to have a deviation between the FEM prediction and real measurement lower than the 20%.

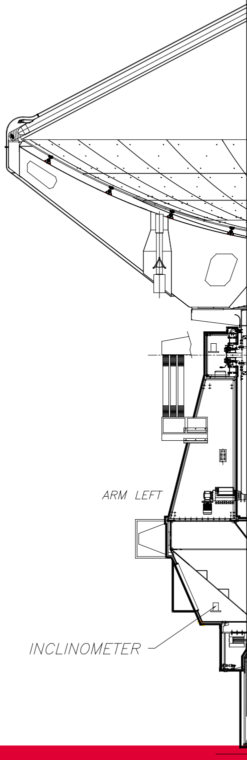


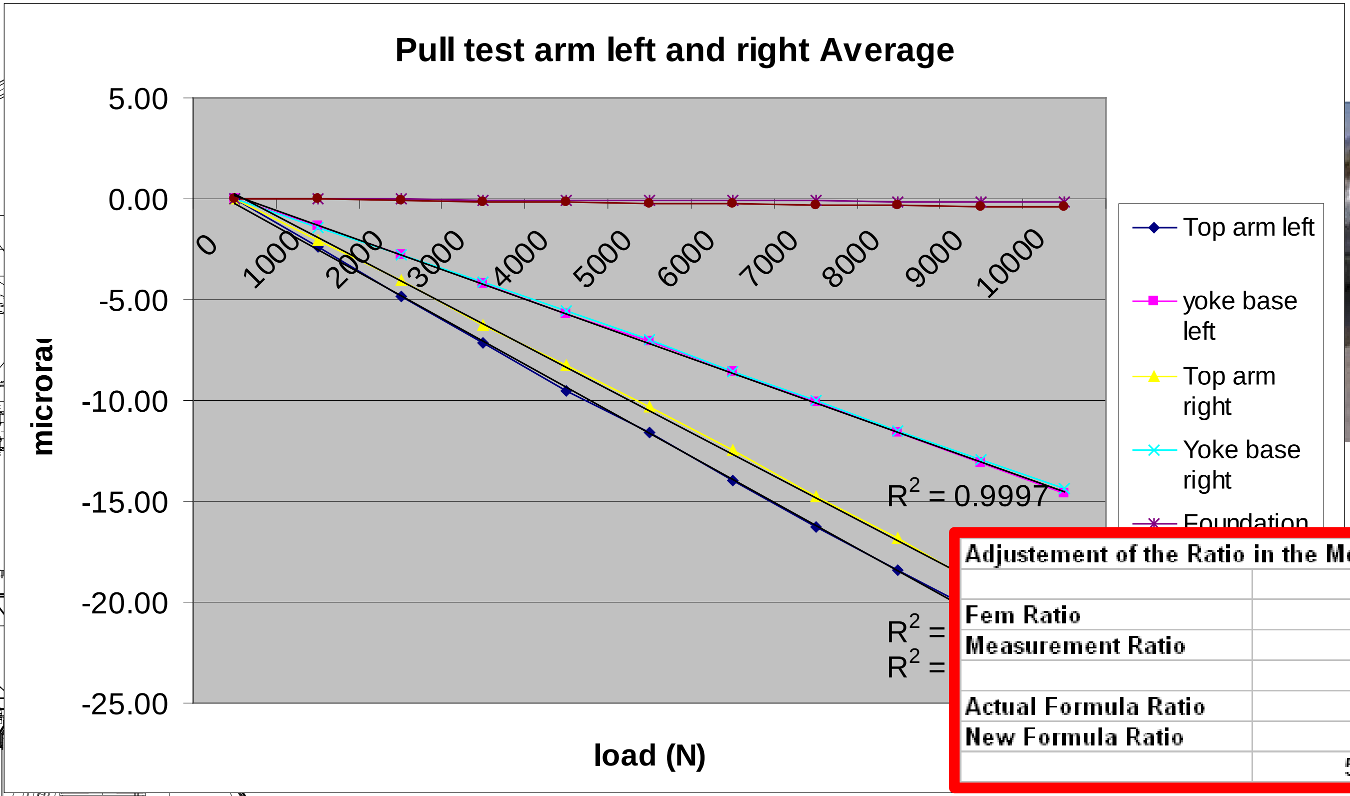


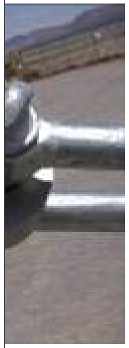


Dynamic metrology Performance Test

Pulling test and correlation formula validation







Adjustement of the Ratio in the Metrology formula		
Fem Ratio	1.46	
Measurement Ratio	1.55	
Actual Formula Ratio	1.50	
New Formula Ratio	1.59	
	5.97%	

The comparison of the real behaviour with the Fem model showed a difference of about 6% in the correlation parameters

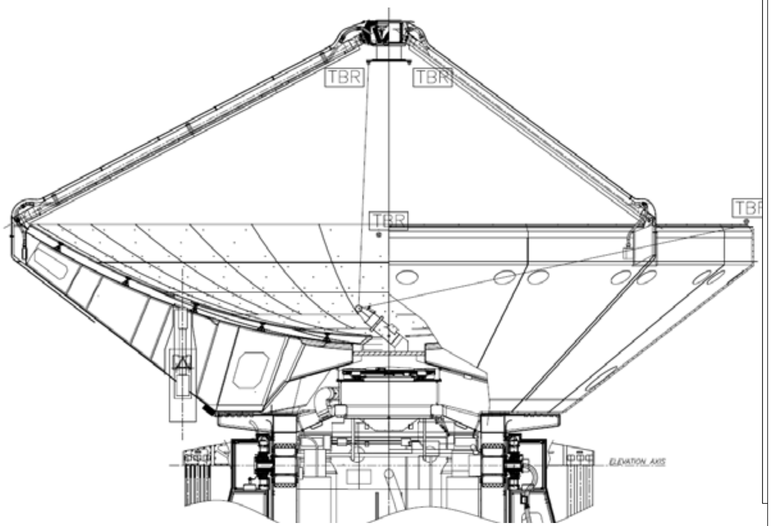
FEM MODEL VALIDATION

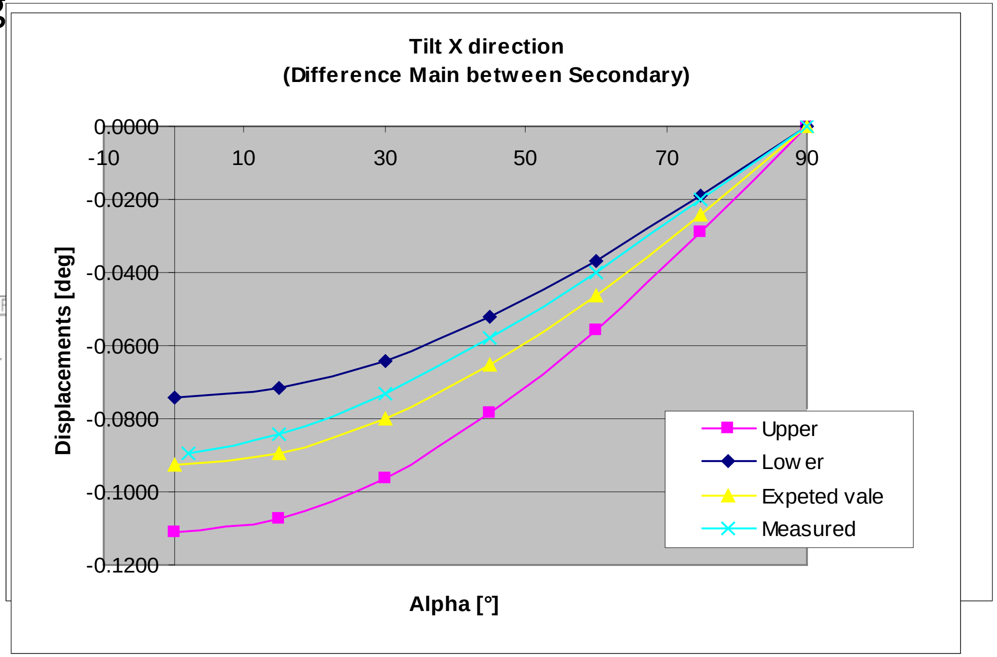
Secondary mirror behaviour

This test has been done in order to identify the Subreflector deviation during EL axis movement.

Subreflector displacement in Y direction

Subreflector rotation around in X axis





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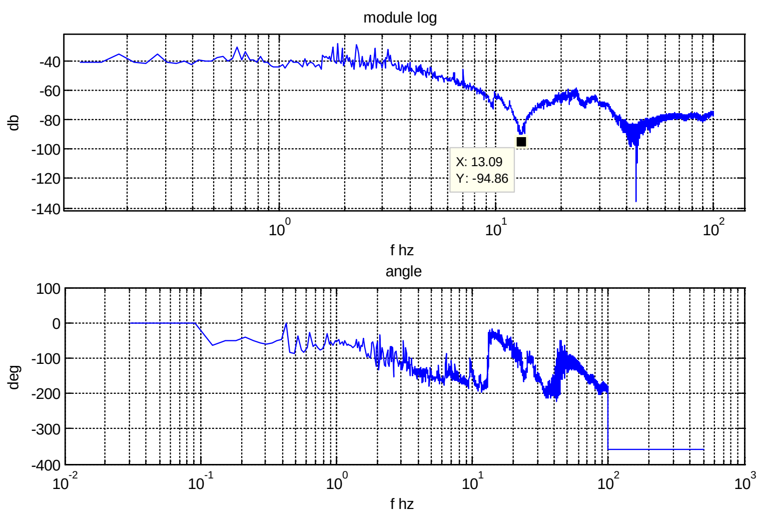
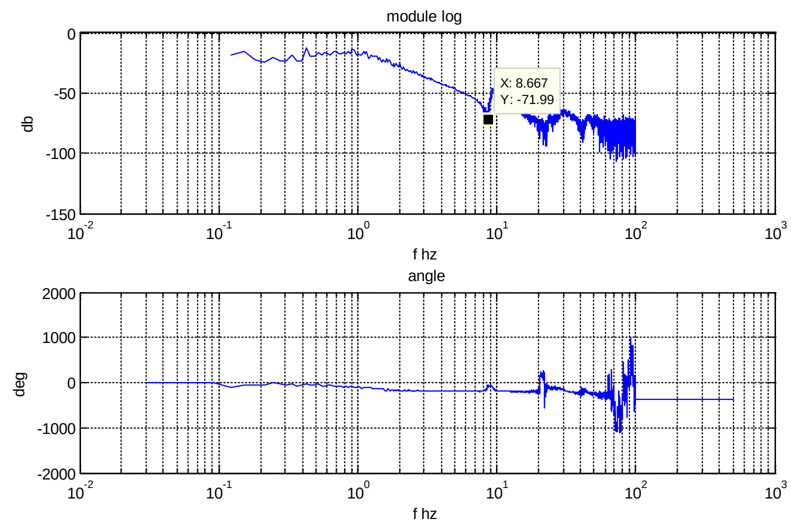
FEM MODEL VALIDATION

Main Structure Eigen frequencies

During the acceptance phase of the antenna control unit the Azimuth and Elevation close loop and open loop transfer function have been done.



Azimuth close loop transfer function



Elevation close loop transfer function

FE results: Elevation axis 9,29 Hz with the ant. at 0° el. and 9.21Hz with the ant. at 90° el. The tests for elevation 8.6 Hz. With a difference of -7%.

Azimuth axis is 9,45 Hz with the ant. at 0° and 9,35 Hz with the ant. at 90°.

The test for azimuth 9.67, with a difference of +3%.

Dynamic metrology Performance Test

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Measurement of the noise inclinometers response at different tracking speed

Verification during tracking motion in quiet conditions and wind condition and derive the noise of the system. The goal was to have a noise below 0.1 arcsec RMS.

El pos	Az vel (deg/sec)	Right inc. (arcsec)	Left inc. (arcsec)	wind (m/s)
3	0.004172	0.08	0.06	2.3
15	0.004314	0.08	0.08	2.7
30	0.004811	0.07	0.05	2.4
45	0.005893	0.05	0.04	2.3
60	0.008333	0.08	0.06	2.2
75	0.016099	0.07	0.05	2.4
85	0.047807	0.07	0.06	2.7
88	0.11939	0.06	0.05	5.1

quiet wind condition

El pos	Az vel (deg/sec)	Right inc. (arcsec)	Left inc. (arcsec)	wind (m/s)
3	0.004172	0.09	0.05	2.4
15	0.004314	0.07	0.06	3.5
30	0.004811	0.04	0.04	1.3
45	0.005893	0.07	0.05	2
60	0.008333	0.06	0.04	0.8
75	0.016099	0.07	0.04	2.5
85	0.047807	0.07	0.04	2.8
88	0.11939	0.05	0.05	5.2

wind torque disturbance corresponding to 7 ms-1 wind + 4S(u)

All the tests passed with good margin. Not particular degradation at high elevation or in windy conditions

Dynamic metrology Performance Test

Inclinometer capabilities during pointing

There are three different operational fast motion phases on which the antenna has to follow different pointing requirements. For each of this requirements we verify the inclinometer capabilities, in particular the settling time and the noise.

1) **fast switching phase calibration**

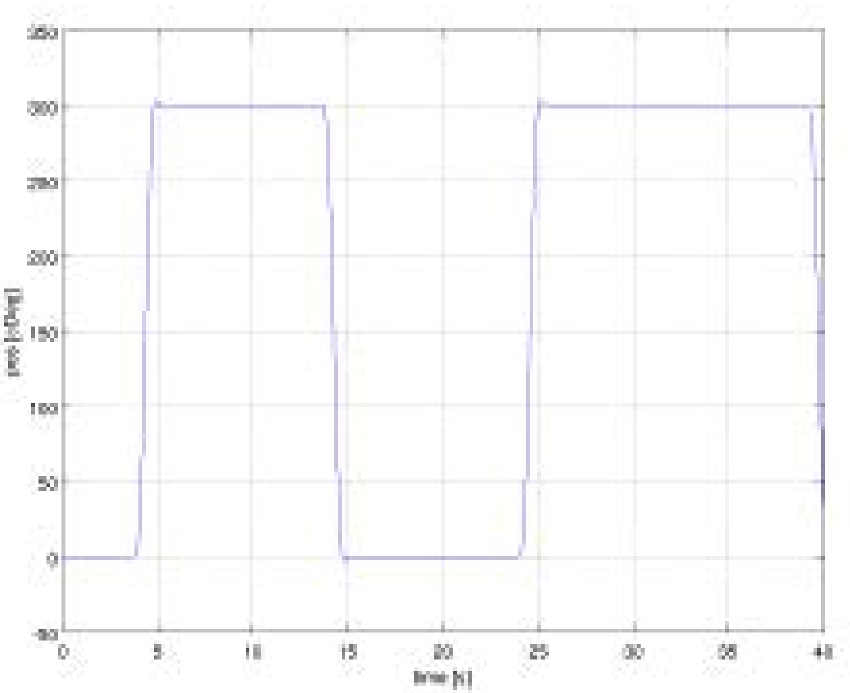
In the fast switching cycle, the antenna shall perform steps of 1.5 degrees and settle to within 3 arcsec error in 1.5 sec. Track on the source.

During each cycle we acquired the external environmental conditions and record the tiltmeters settling. During strong slewing the tiltmeter is "blocked" and is activated after settling.

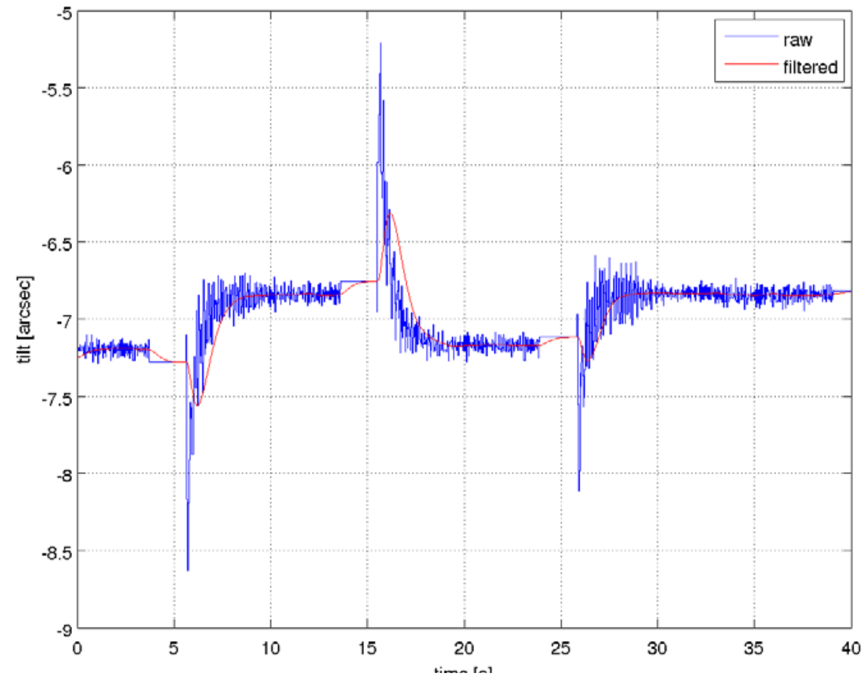
The goal is to obtain a noise of the system after 2 second below of 0.2 arcsec.

Dynamic metrology Performance Test

Inclinometer capabilities during pointing: Fast switching.



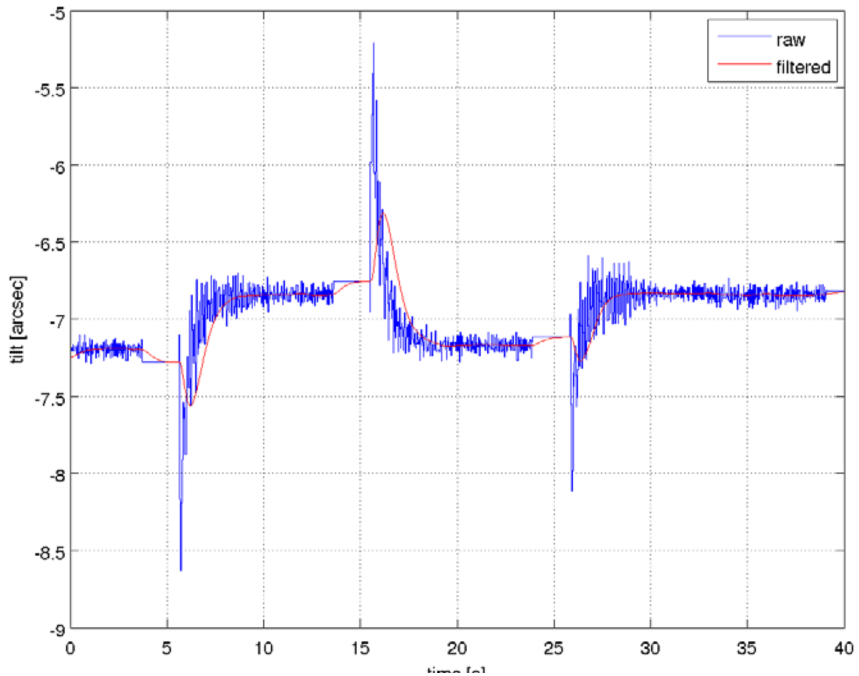
Encoder Azimuth Position



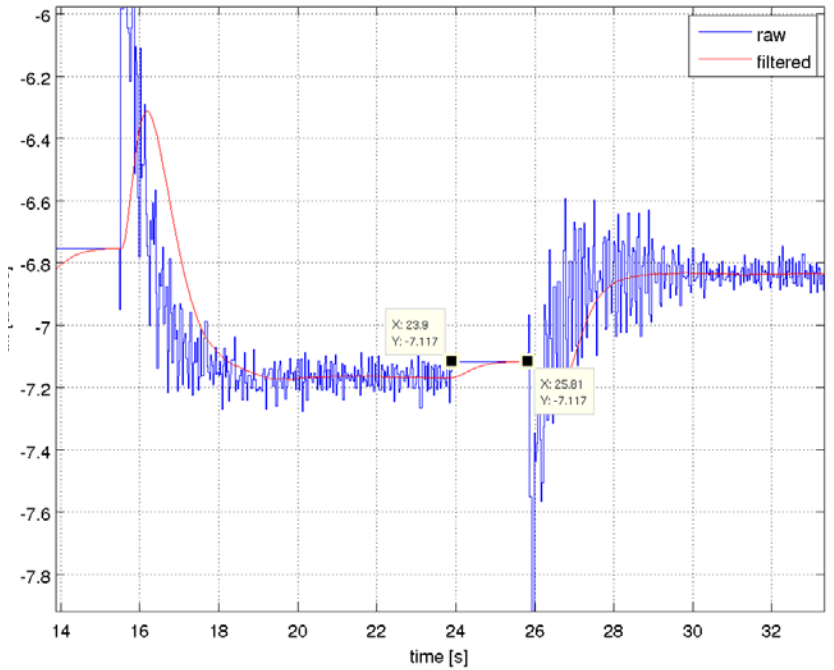
Inclinometer response behaviour

Dynamic metrology Performance Test

Inclinometer capabilities during pointing: Fast switching.



Inclinometer response behaviour



During this test the dynamic metrology introduced a noise of 0.04 arcsec

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Dynamic metrology Performance Test

Inclinometer capabilities during pointing

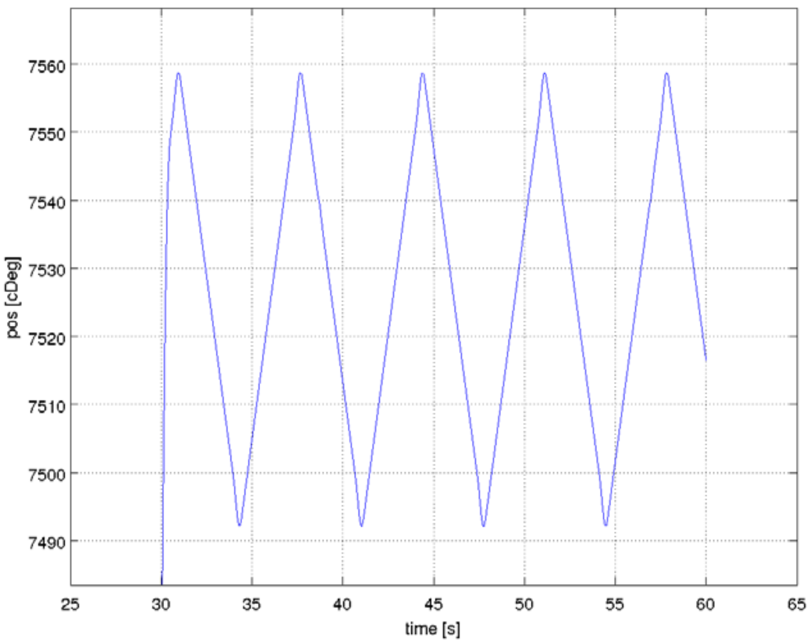
2) **on-the-fly total power mapping**
The antenna shall scan at a 0.5 deg/s on the sky across a target source of one degree in size, then turn around at a distance of 1 arcmin, settle within 0.8 sec time scan back across the source in the opposite direction with a 2 arcsec RMS.

During each cycle we acquired the external environmental conditions and record the tiltmeters settling time at each cycle.

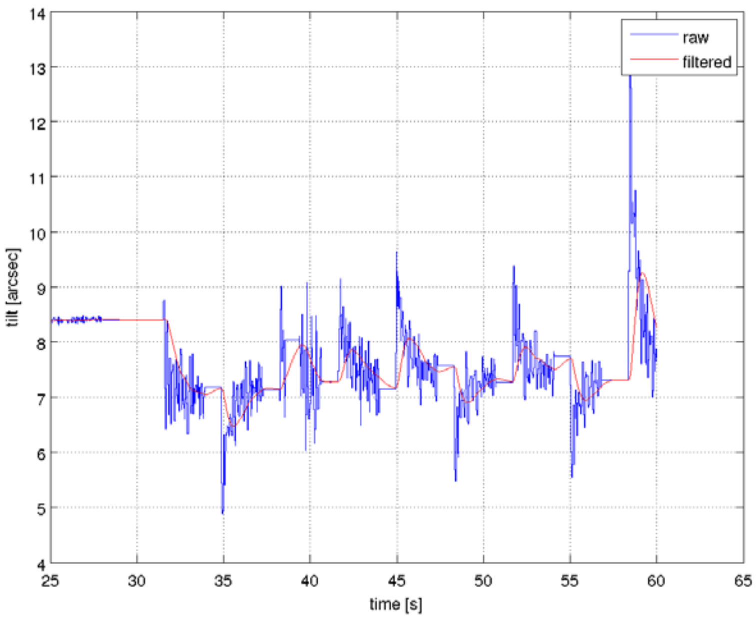
During the On the fly Total Mapping the dynamic metrology is not needed, but the test will be done in order to verify the noise and the influence of the system in case the Dynamic metrology will be switched on.

Dynamic metrology Performance Test

Inclinometer capabilities during pointing: on-the-fly total power mapping



Encoder Azimuth Position



Inclinometer output behaviour

Dynamic metrology Performance Test

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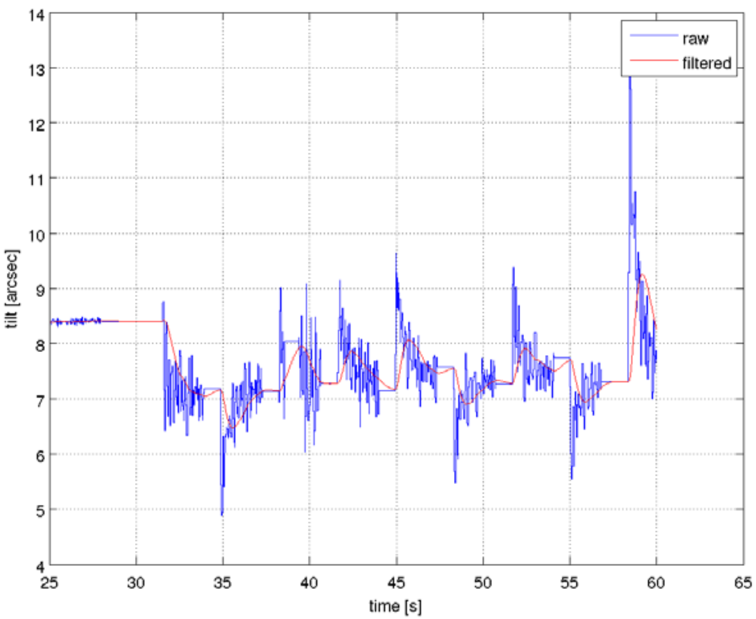
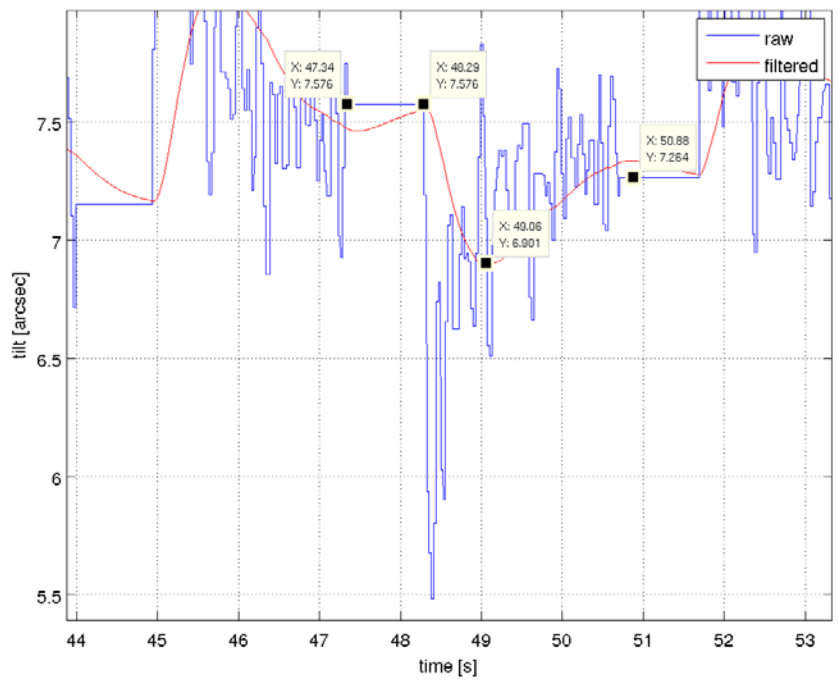
Inclinometer capabilities during pointing: on-the-fly total power mapping





Inclinometer output behaviour

During this test the dynamic metrology introduced a noise of 0.28 arcsec

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Dynamic metrology Performance Test

Inclinometer capabilities during pointing

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3) **on-the-fly interferometric mosaicking**

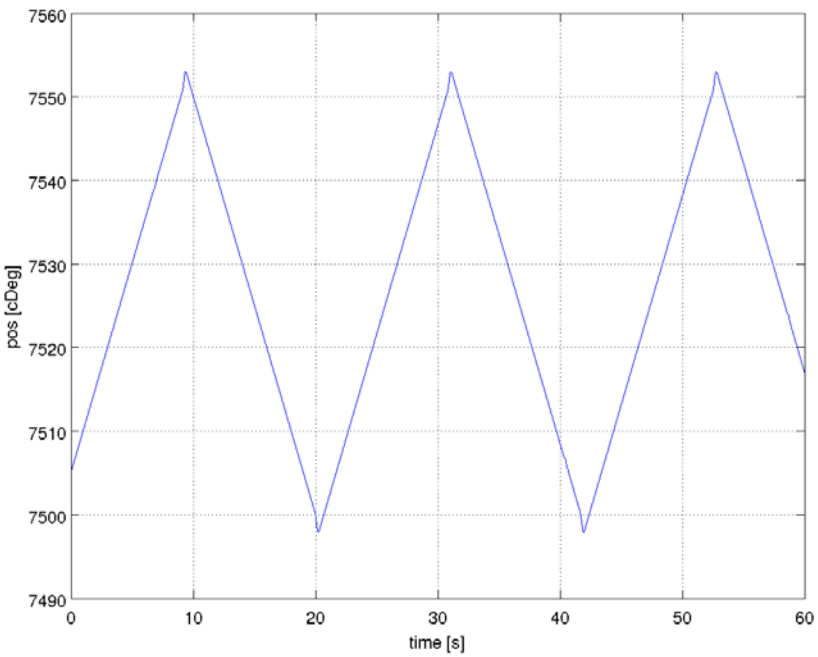
The antenna will scan at a rate of up to 0.05 deg/s on the sky across a target source, ranging from one arcmin to one degree in size then turn around and scan back across the source in the opposite direction. During the scans across the source the antenna shall follow the commanded path to within 1 arcsec RMS.

During each cycle we acquired the external environmental conditions and record the tiltmeters settling time at each cycle.

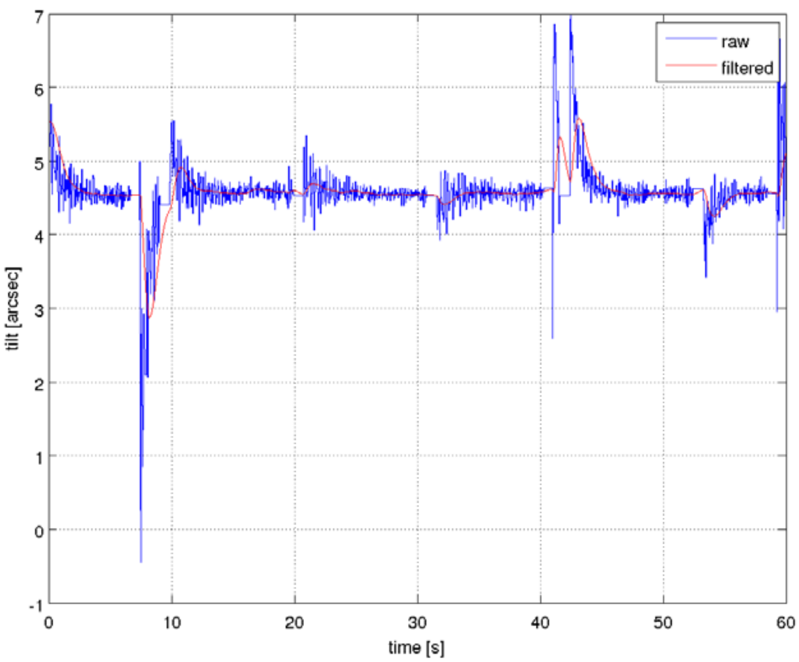
The goal is to obtain Noise of dynamic metrology system below 0.1 arcsec.

Dynamic metrology Performance Test

Inclinometer capabilities during pointing: on-the-fly interferometric mosaiking



Encoder Azimuth Position



Inclinotmeter output behaviour

Dynamic metrology Performance Test

Inclinometer capabilities during pointing: on-the-fly interferometric mosaiking

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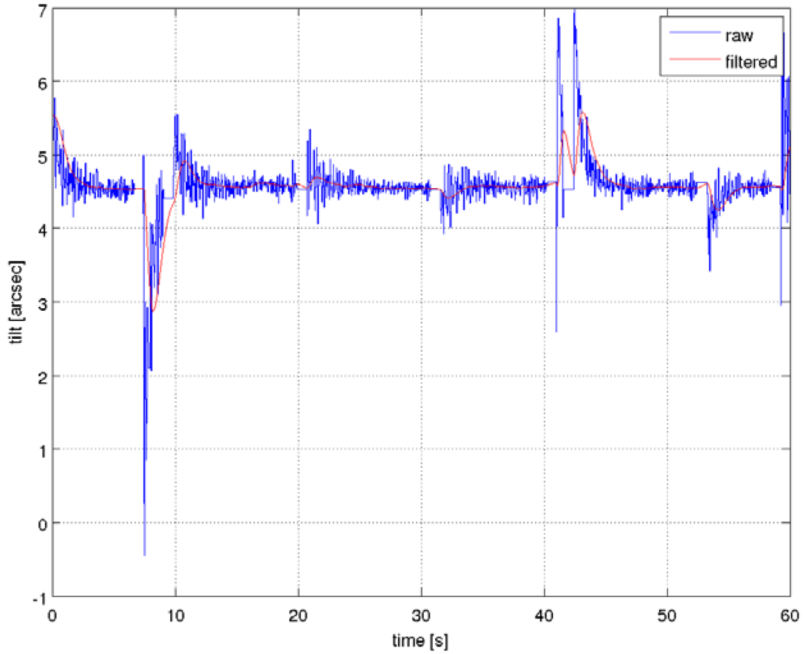
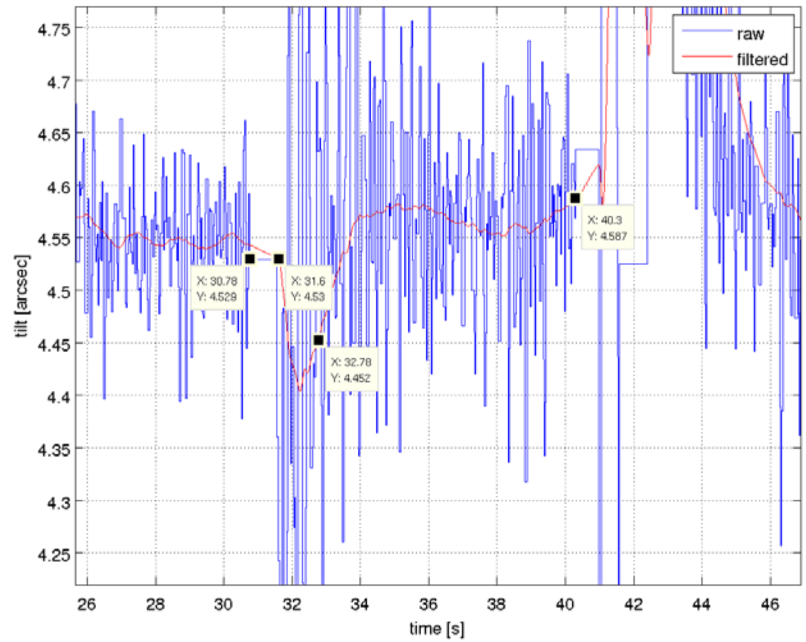
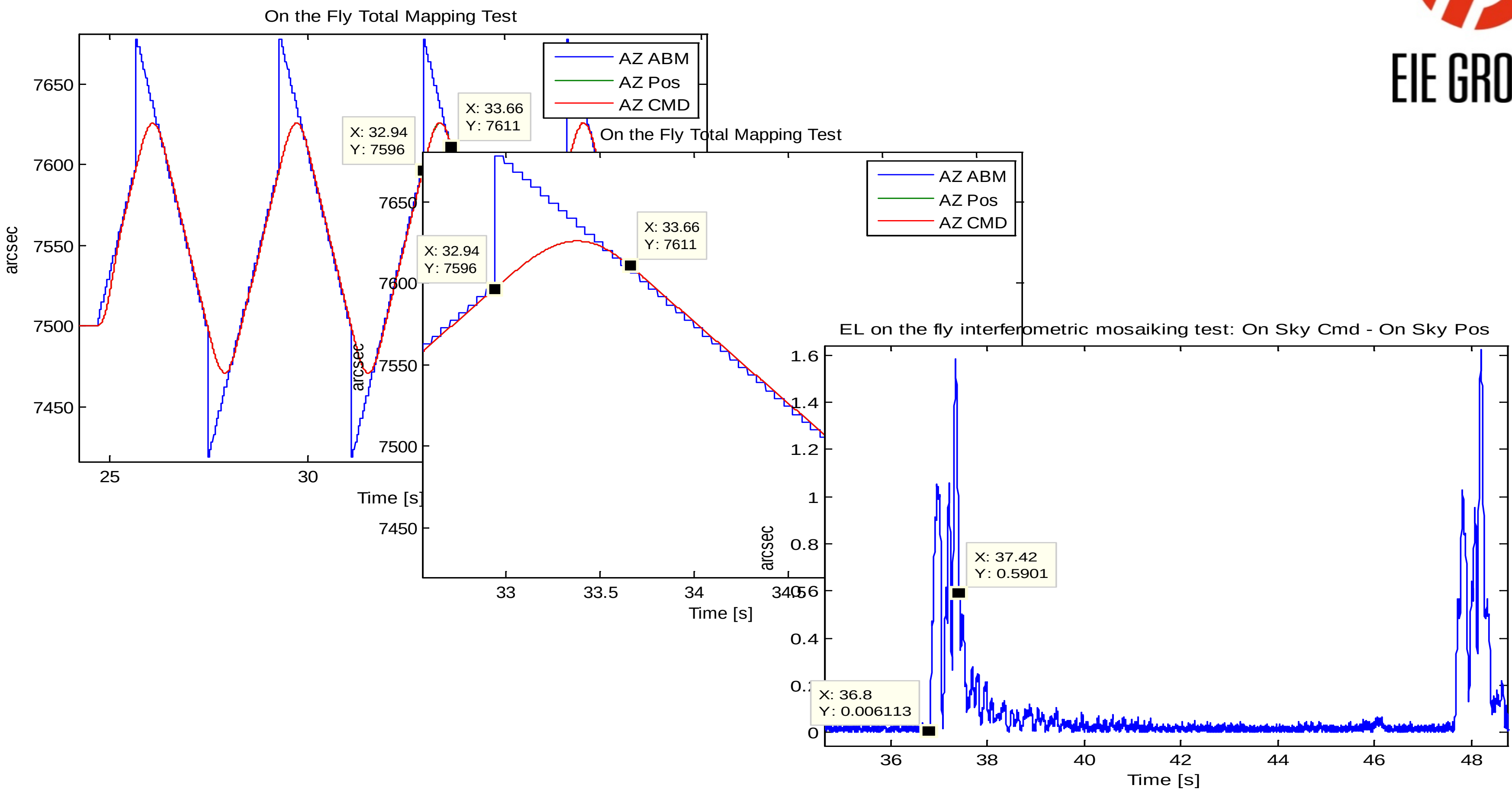




Inclinotmeter output behaviour

We obtained the following results: 0.09 arcsec if switch on after 0.8 sec and 0.045 arcsec if switch on after 2 sec

POINTING ERROR: ON THE FLY



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We obtained the following results: 0.09 arcsec if switch on after 0.8 sec and 0.045 arcsec if switch on after 2 sec

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Dynamic metrology Performance Test

On sky pointing test with inclinometers

After the metrology acceptance phase different pointing tracking and fast motion tests have been done. During all these tests both metrology systems were activated. No degradation of the performance was observed, but conversely improvements of the performances.

The pointing performance of the AEM with metrology system on are:

- All sky pointing error 1.30 arcsec during the night and 1.50 arcsec rms during the day. (specification of 2 arcsec)
- Offset pointing performance AOS are 0.4 arcsec rms. (specification of 0.6 arcsec)
- The average of fast motion test is 0,344 arcsec after 1.5sec, with an rms tracking error in the period 2 – 4 s of 0.037 arcsec. (specification of 0.6 arcsec)

Conclusions

- All the antennas delivered to ALMA have proven excellent performances and the thermal metrology system showed an improvement on the already excellent pointing and tracking results.
- The dynamic metrology is capable to work without any performance degradation of the complicated fast motion requirements.
- During the ten years of work and design done on the AEM antenna, we studied different layouts and selected different types of metrological instruments (laser, capacitive sensors, gyroscopes, fiber optic, tiltmeter offered on the market, etc ...). The only capable ones to fulfill the requirements are the present ones.
- This dynamic system thanks to its easiness of installation (an inclinometer placed on a simple brackets) is definitely a tool that can easily be used in other similar antennas or telescopes in order to improve performances or reduce the manufacturing costs without jeopardizing important scientific requirements.

ACKNOWLEDGEMENTS

We are grateful to ESO (in particular with Mr R. Laing, Mr S. Stanghellini, Mr. P. Martinez, Mr. S.Rossi, Mr. M. Marchesi, Mr F. Gago, Ms E. Ciattaglia and Mr. C.Pontoni that performed a lot of work during the tests campaigns)

The AEM Consortium (TAS-F, MTM, TAS-I, EIE) who provided the support for the manufacturing, erection and tests of the antennas.

Thank you

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