IRAM 30m Telescope Control

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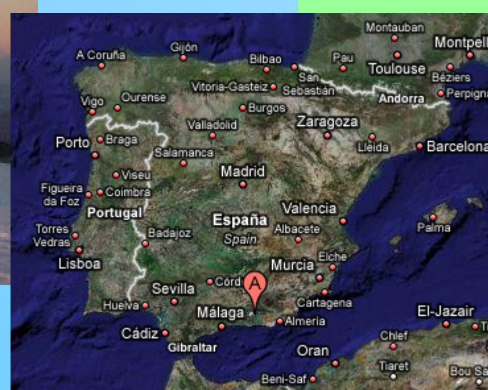
IRAM: Institut de Radioastronomie Millimétrique

Three countries: Germany, France and Spain

Two observatories:

interferometer of Plateau de Bure in France
single dish antenna of Pico Veleta in Spain
(also called 30m antenna)

30m coordinates (WGS84):



Latitude North	**37º 03' 58"**
Longitude West	**03º 23' 34"**
Height	**2904.0 m**

The IRAM-30m Antenna

Characteristics:

Parabolic Antenna with Altazimuth Mount	
Diameter	30 m
Operating Frequency	73 to 375 GHz
(wavelength	4.1 to 0.8 mm)
Focal Length	10.5 m
Hyperboloidal Subreflector	2 m
Eccentricity	1.0746
Cassegrain Magnification	27.8
Number of Panels (honeycomb)	420
Weight	800 tons
Azimuth Range	60^o to 460^o
Elevation Range	0^o to 90^o
Maximum Velocity	1^o/sec
Total r.m.s. of the surface	60 µm
Maximum Wind Speed when observing	65 km/h
Maximum Wind Speed supported	200 km/h
Constructed in steel	
Quasi-Homology Design	
Cassegrain with Nasmyth optics	

The IRAM-30m Antenna

<u>Topics to review</u>:

- **Antenna Thermal Control (gain elevation curve)**
- **Antenna Servo Control**
- **Pointing Model**

Antenna Thermal Control

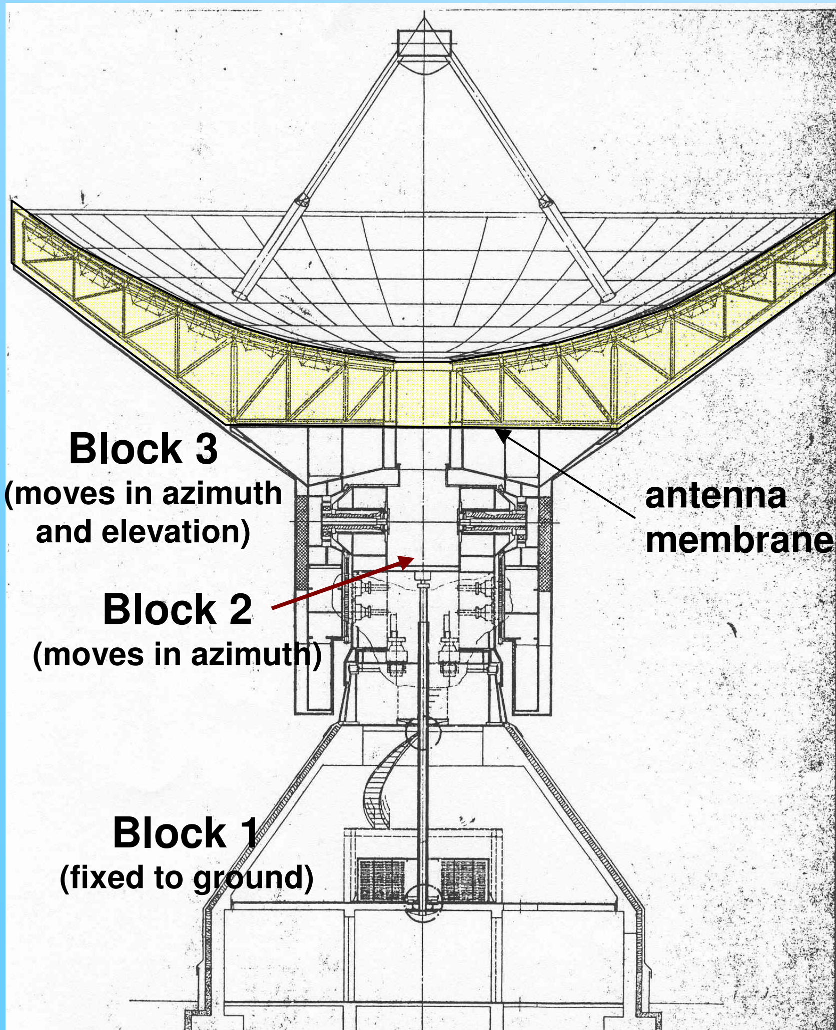
- The Antenna was regulated in temperature with the following resources:

General	Cooling Compressor	22 Kw
	Glycol Pumps	2 x 1.5 Kw
Reflector Structure	Glycol Pump	1.5 Kw
	Ventilators	5 x 3 Kw
	Heaters	5 x 6 Kw
Quadrupod	Glycol Pump	7.5 Kw
Yoke-Membrane		
CounterWeights		

- 160 temperature sensors (type pt100) are distributed around the Antenna to monitor temperatures every 5 minutes

- Regulation of temperature is better than 1 K respect to the master temperature

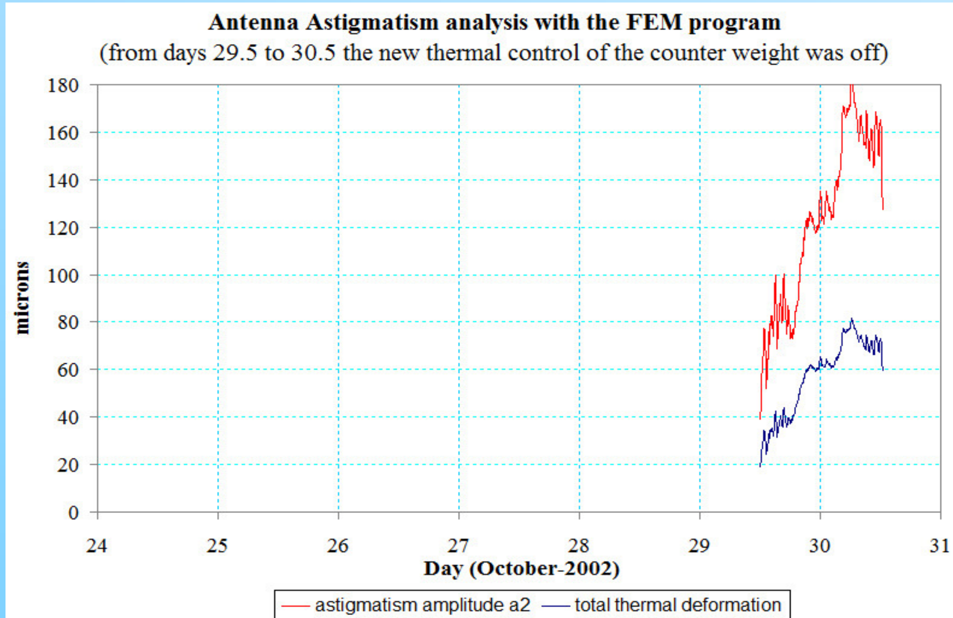
Antenna Thermal Control



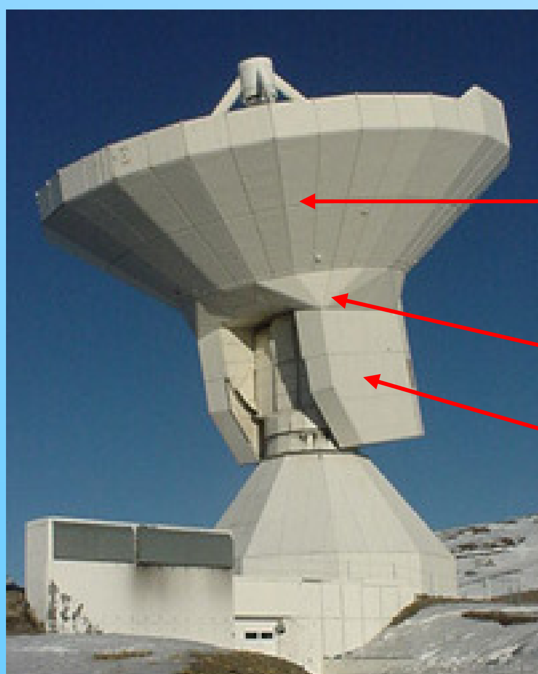
In the antenna intial design only the steel frame above the membrane (BUS) was regulated in temperature

- BUS was typically between 4º and 6º above ambient temperature
- CounterWeights at ambient temperature

consequence:
STRONG ASTIGMATISM!



Antenna Thermal Control



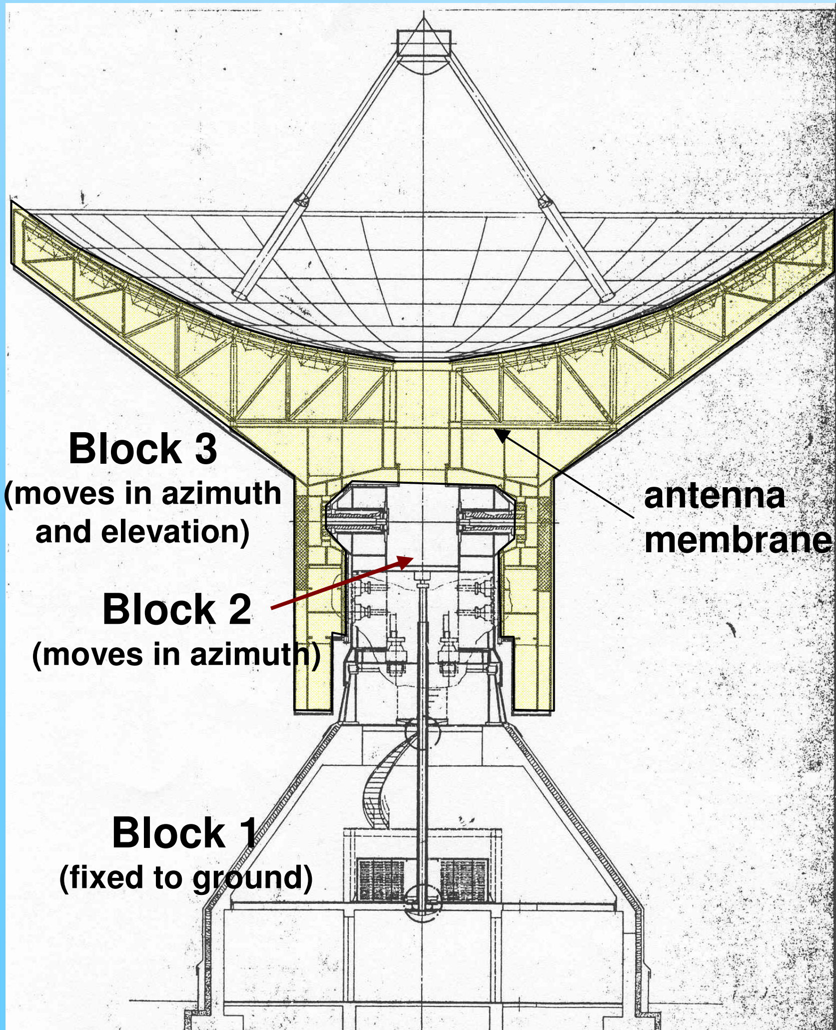
- **The Antenna is regulated in temperature with the following resources:**

General	**Cooling Compressor (off)**	**22 Kw**
	Glycol Pumps	**2 x 1.5 Kw**
Reflector Structure	**Glycol Pump**	**1.5 Kw**
	Ventilators	**5 x 3 Kw**
	Heaters	**5 x 6 Kw**
Quadrupod	**Glycol Pump**	**7.5 Kw**
Yoke-Membrane	**Ventilators (2002)**	**4 x 0.5 Kw**
CounterWeights	**Ventilators (2002)**	**2 x 0.5 Kw**
	Heaters (2002)	**4 x 3 Kw**

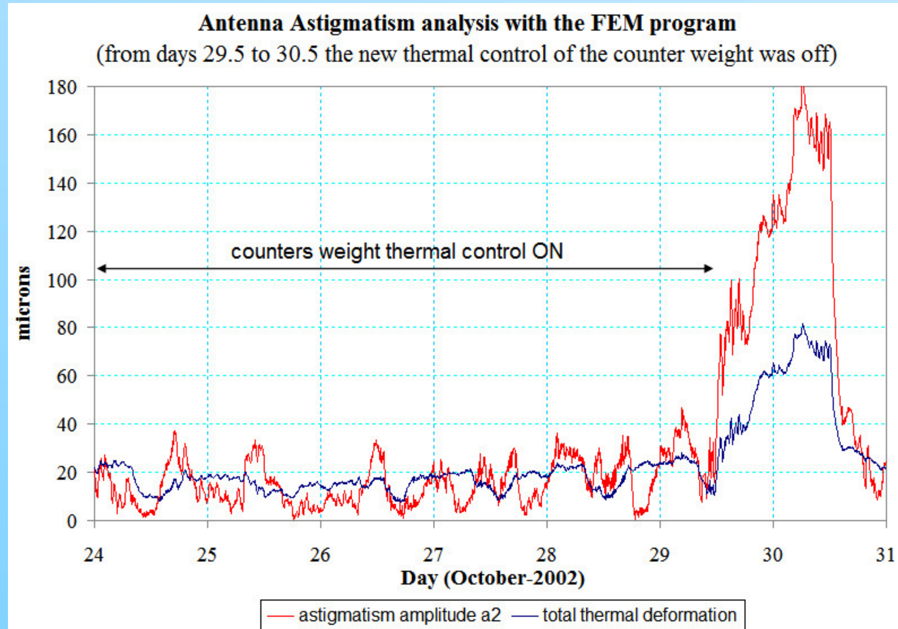
- **160 temperature sensors (type pt100) are distributed around the Antenna to monitor temperatures every 5 minutes**

- **Regulation of temperature is better than 1 K respect to the master temperature**

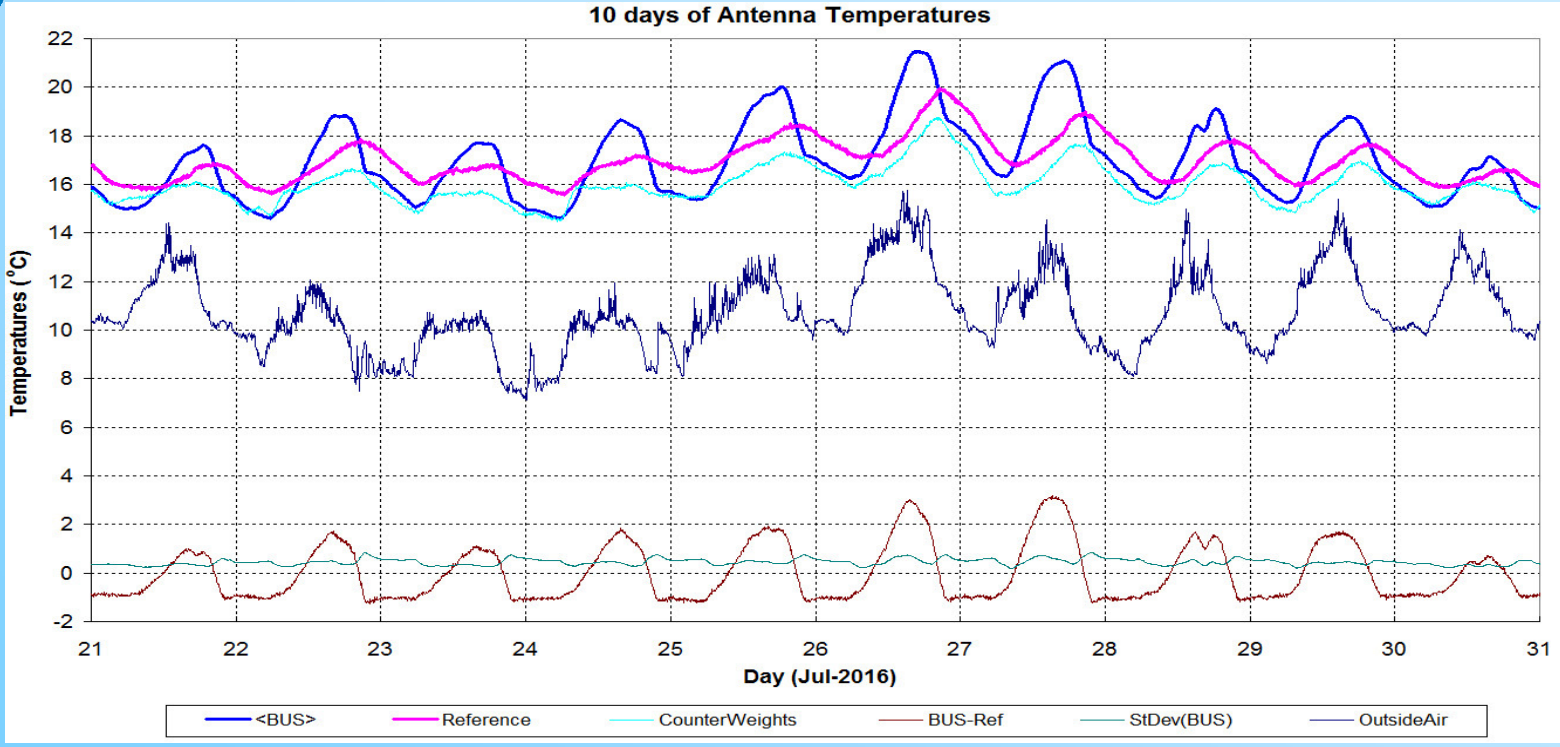
Antenna Thermal Control



In 2002 the antenna thermal control below the membrane and counterweights was also included



Antenna Thermal Control



conclusions:

- **BUS temperature shows day-night effect, typically between -1°C and +2°C**
- **CounterWeights are controlled 1° below the Reference Temperature**
- **Reference temperature ~ 6° above outside air temperature**
- **Standard Deviation of BUS temperatures is below 0.7°C**

Antenna Thermal Control

Power distribution collected by the antenna:

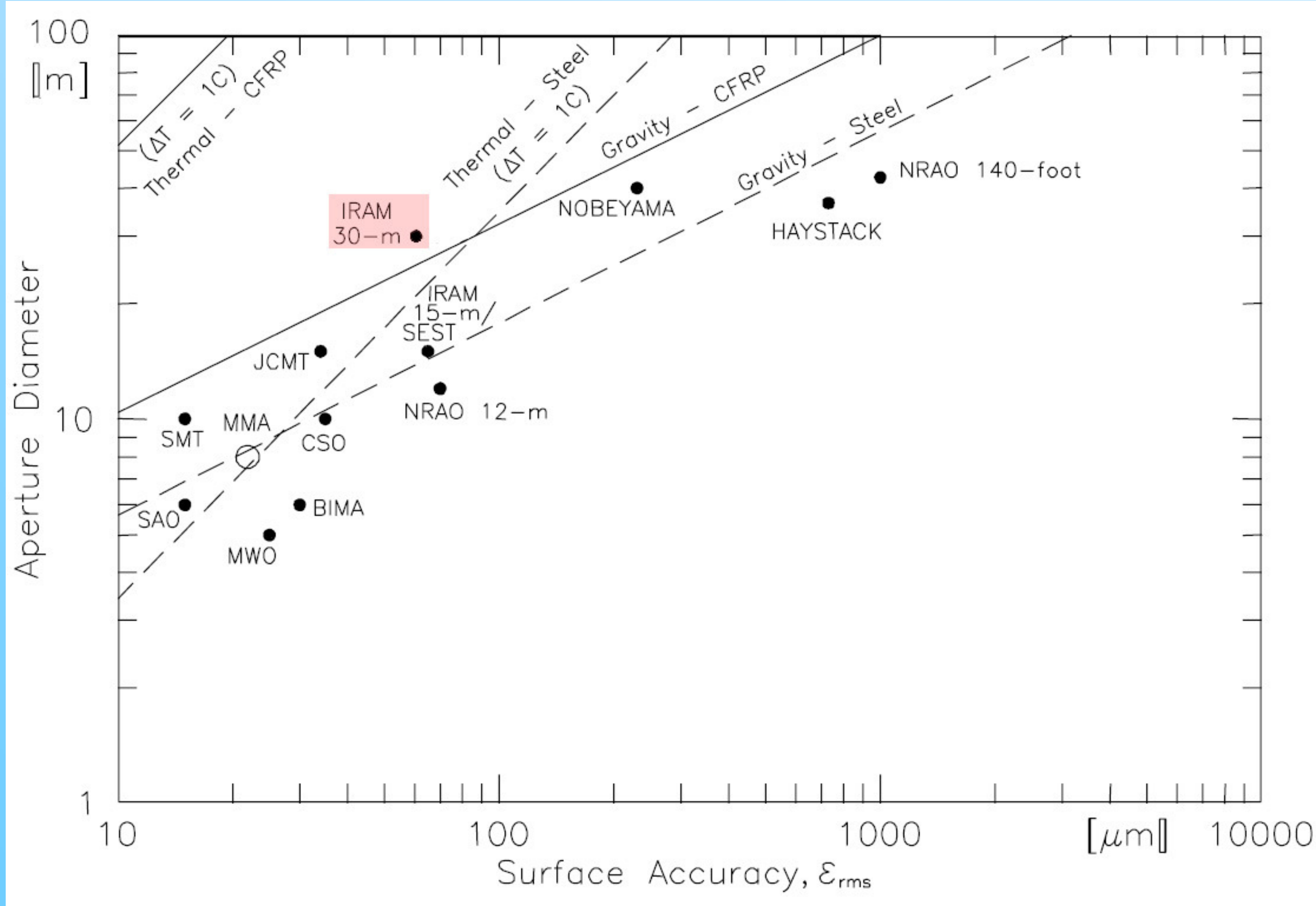
	86 GHz	145 GHz	210 GHz	280 GHz	340 GHz
Aperture Efficiency	0.62	0.56	0.47	0.36	0.27
Main Bean Efficiency	0.806	0.726	0.608	0.468	0.352
1st Error Beam (large scale, 6 m)		0.015	0.035	0.029	0.028
2nd Error Beam (panel misalign. 1.5 m)	0.064	0.075	0.095	0.091	0.118
3rd Error Beam (panel frame grid 0.4 m)	0.058	0.057	0.071	0.125	0.145
Error Beams	0.122	0.147	0.200	0.245	0.291
MBE + Error Beams	0.927	0.873	0.808	0.713	0.643
Forward Efficiency	0.95	0.93	0.94	0.88	0.81
Forward Scattering and Spillover (Feff – MBE – Error Beams)	0.023	0.057	0.132	0.167	0.167
Rear Scattering and Spillover	0.05	0.07	0.06	0.012	0.19

<u>considerations and conclusions:</u>

- **Power lost due lo the limitations of the antenna thermal control goes into the 1st Error Beam and partially into the Forward Scattering**
- **The antenna power lost due to the limitation of the thermal control is at the lower frequencies less than 3 % and at the higher frequencies less than 20 %**

Von Hoerner diagram

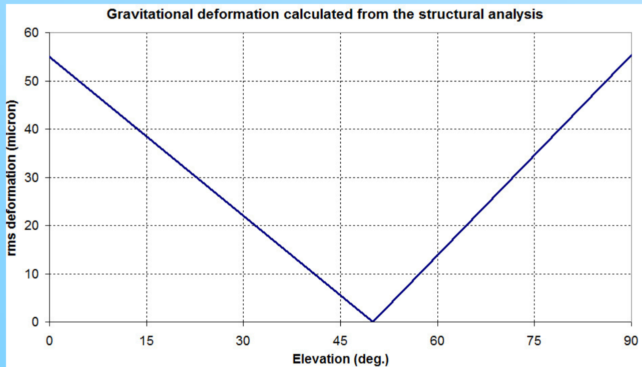
showing achievable surface accuracies as limited by thermal and gravitational effects

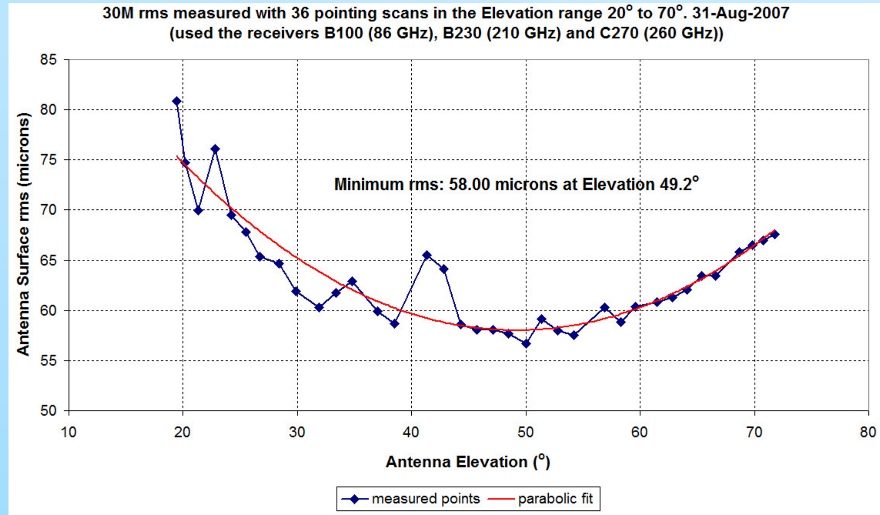


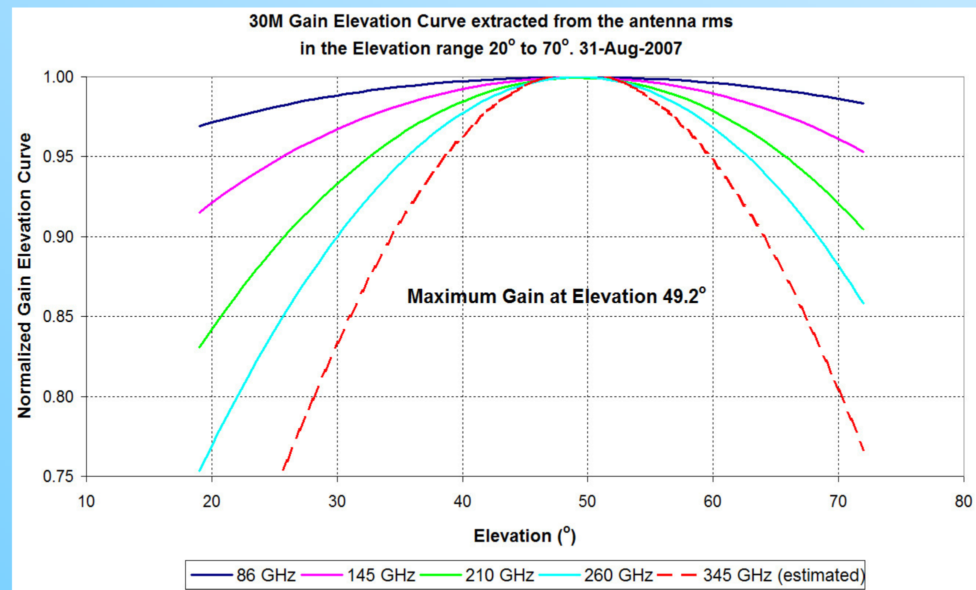
from MMA Memo 83

Gain Elevation Curve

Quasi-Homology Design:







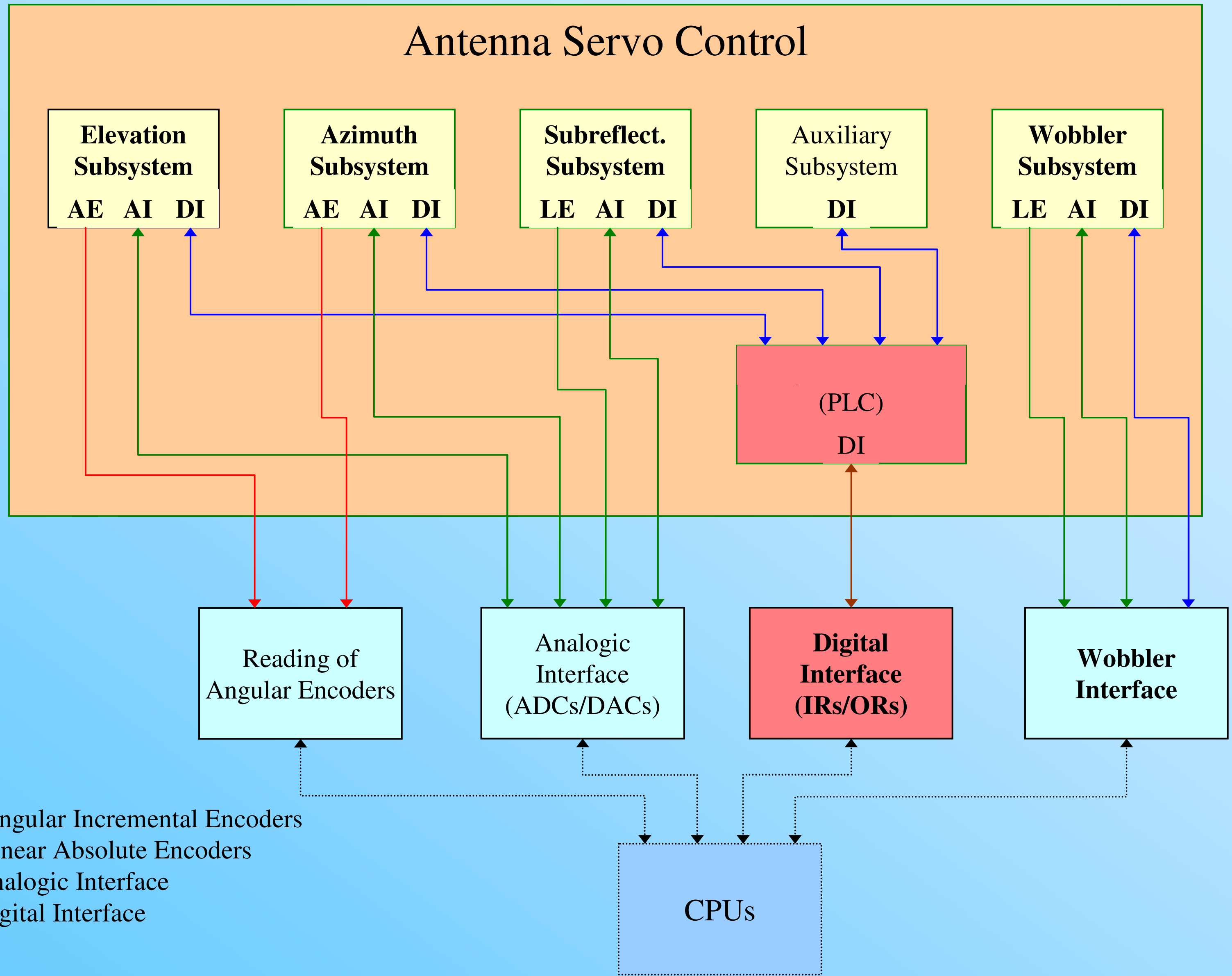
Gain Elevation Curve

- We measure the Aperture Efficiency at several frequencies
- We use the Ruze formula to calculate the surface rms
- We repeat the previous two steps at several elevations
- From the surface rms we recalculate the gain elevation curve

Antenna Servo Control

- Main Antenna Axes, Azimuth and Elevation
- Subreflector
- Wobbling Subreflector

Antenna Servo Control, azimuth and elevation

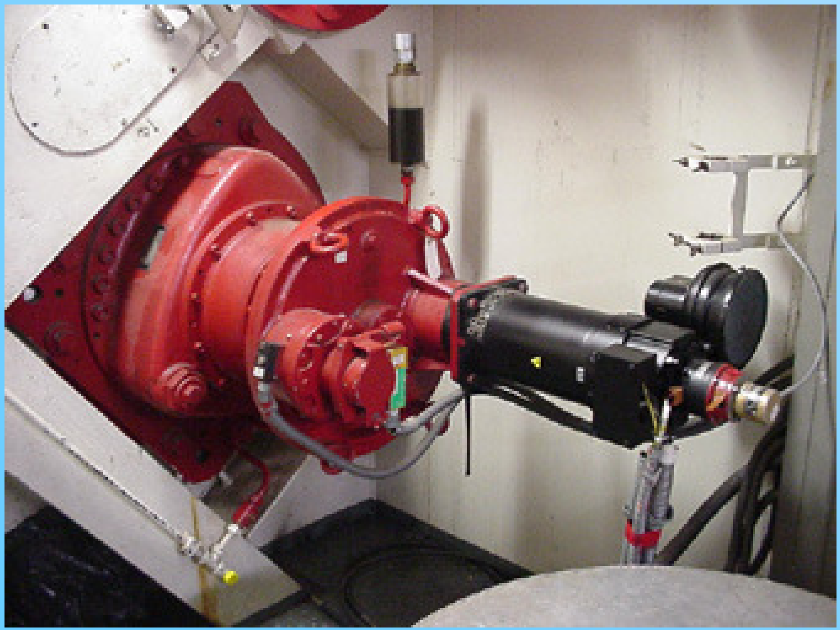


AE = Angular Incremental Encoders
LE = Linear Absolute Encoders
AI = Analogic Interface
DI = Digital Interface

Antenna Servo Control, azimuth and elevation

Antenna Motors and Servoamplifiers:

- The antenna is moved by two groups in Elevation and one group in Azimuth
- Each group has two motors, one pushing and the other pulling for antibackslash
- Elevation motors develop a maximum power of 10 Kw each
- Azimuth motors develop a maximum power of 20 Kw each
- Motors are DC type with brushes and high precision in the positioning
- Servoamplifiers to drive the DC motors are of the type "pulse width modulation"
- Demultiplication factor between motors and antenna is 15000



Gearboxes:

- New Gearboxes installed between 2010 and 2012
- Each Gearbox has three planetary systems
- Azimuth Gearbox:
  - demultiplication: 1164
  - stiffness: 6 x 10E7 Nm/rad
- Elevation Gearbox:
  - demultiplication: 718
  - stiffness: 2 x 10E7 Nm/rad

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Antenna Servo Control, azimuth and elevation

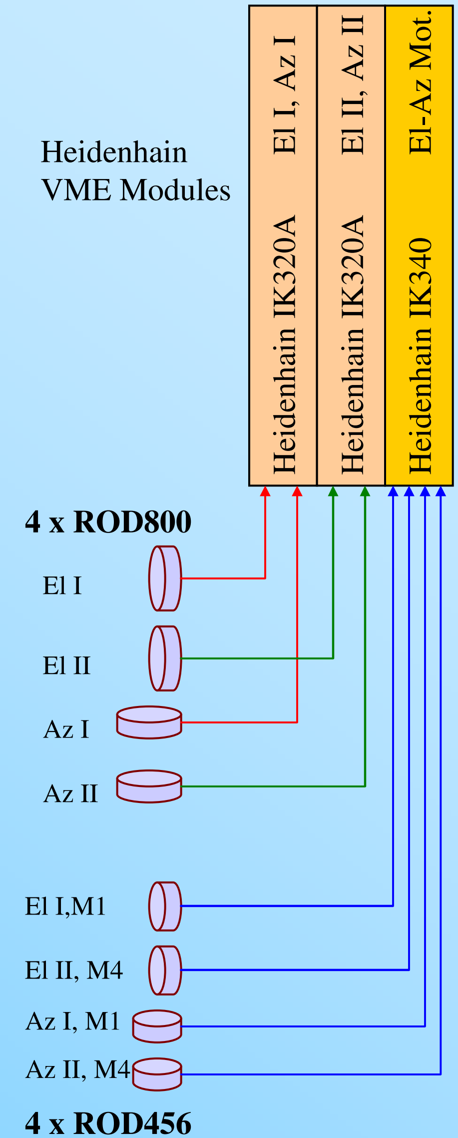
Antenna Encoders
- Four incremental encoders Heidenhain ROD 800
- 36000 lines per revolution
- Absolute accuracy **< 1''**

Motor Encoders
- Four incremental encoders ROD456
- 1800 lines per revolution

IK320A
- VME modules used to read the antenna axis encoders ROD800
- Two axes encoders read with each VME IK320A module
- Reading of both axis in 800 μsec.
- Neither preamplifier nor correctors boards are necessary
- Repetition of encoder reset better than 0.1”
- Axis position reading with a resolution of 36”/4096 = **0.0088”**
- Possibility of compensation to improve the sinusoidal signal shape

IK340
- VME module used to read the antenna motor encoders ROD456
- Four motor encoders read with each VME IK340 module
- Reading of the four axis in 20 μsec.
- No preamplifier board is necessary
- Motor position reading with a resolution of (720”/256)/15000 = **0.0002”** (of antenna movement)

Encoders connection



Antenna Servo Control, azimuth and elevation

Azimuth and Elevation Servo Loop:

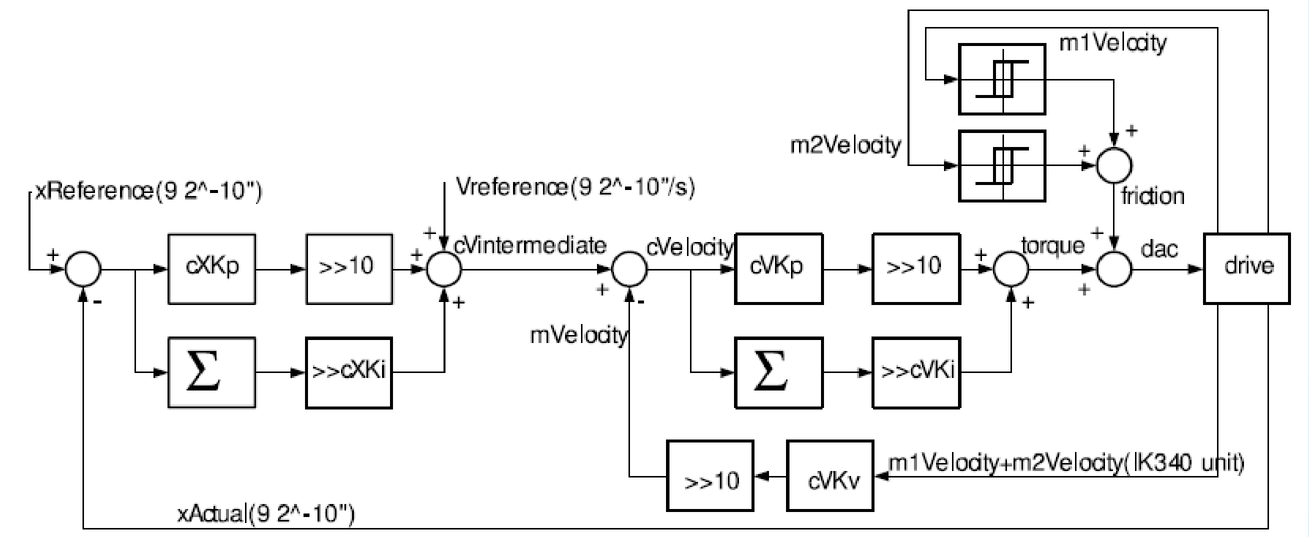


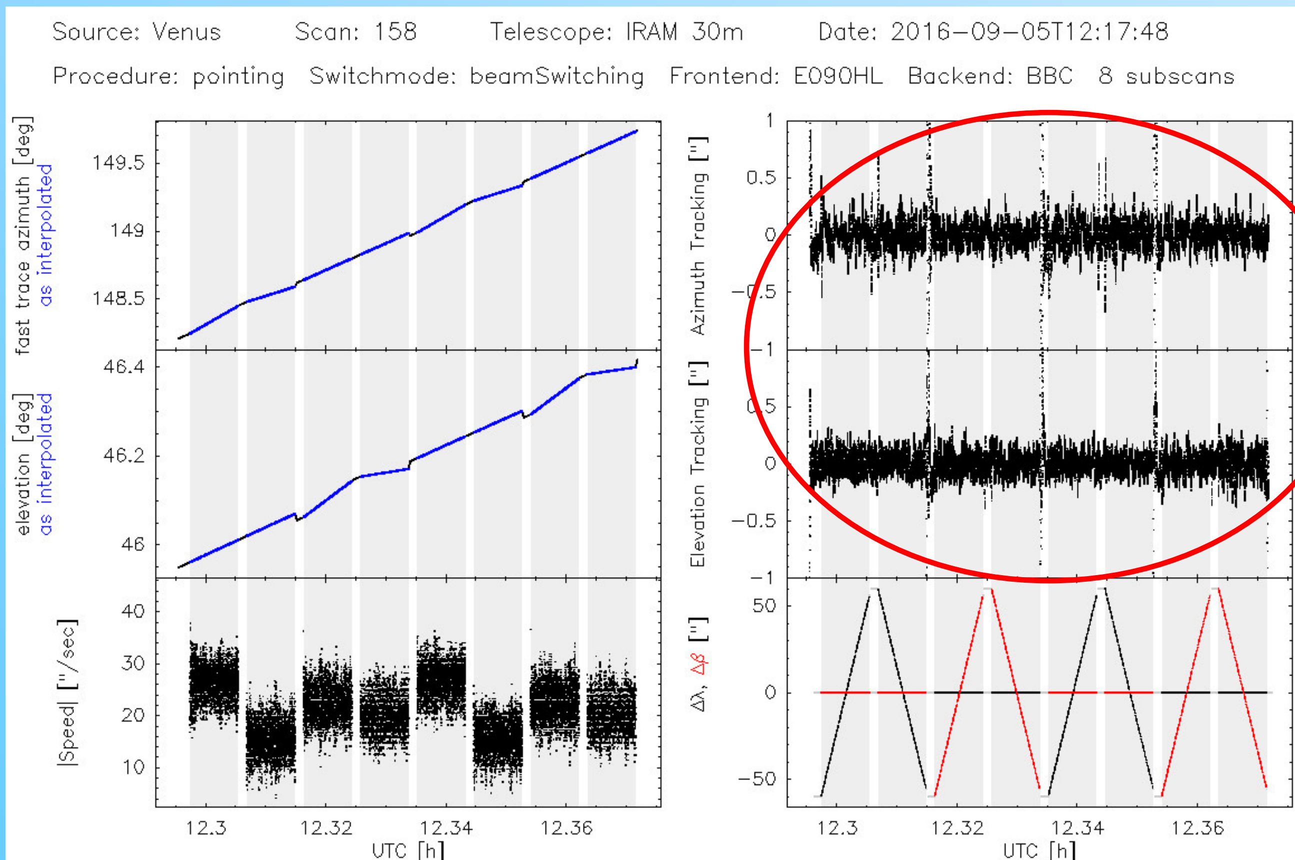
Figure 4 - Cascade controller – VME implementation

Characteristics of the servo loop

- **Interrupt latency 128 / sec**
- **Two servo loops, one for position and other for velocity**
- **Only proportional and integral components**
- **Friction compensation**

Antenna Servo Control, azimuth and elevation

Sample information of a pointing scan:

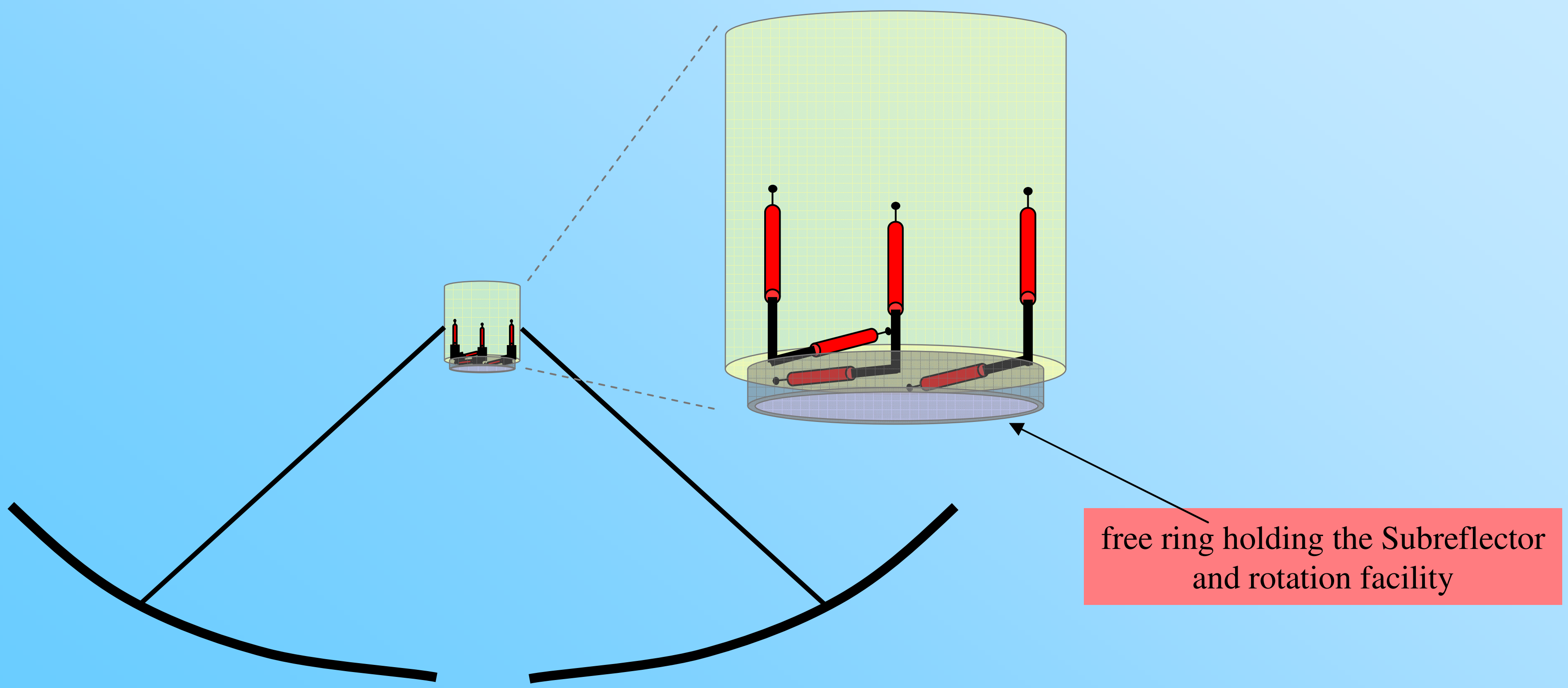


typical
rms tracking error:

0.14'' ± 0.04''

Antenna Servo Control, subreflector

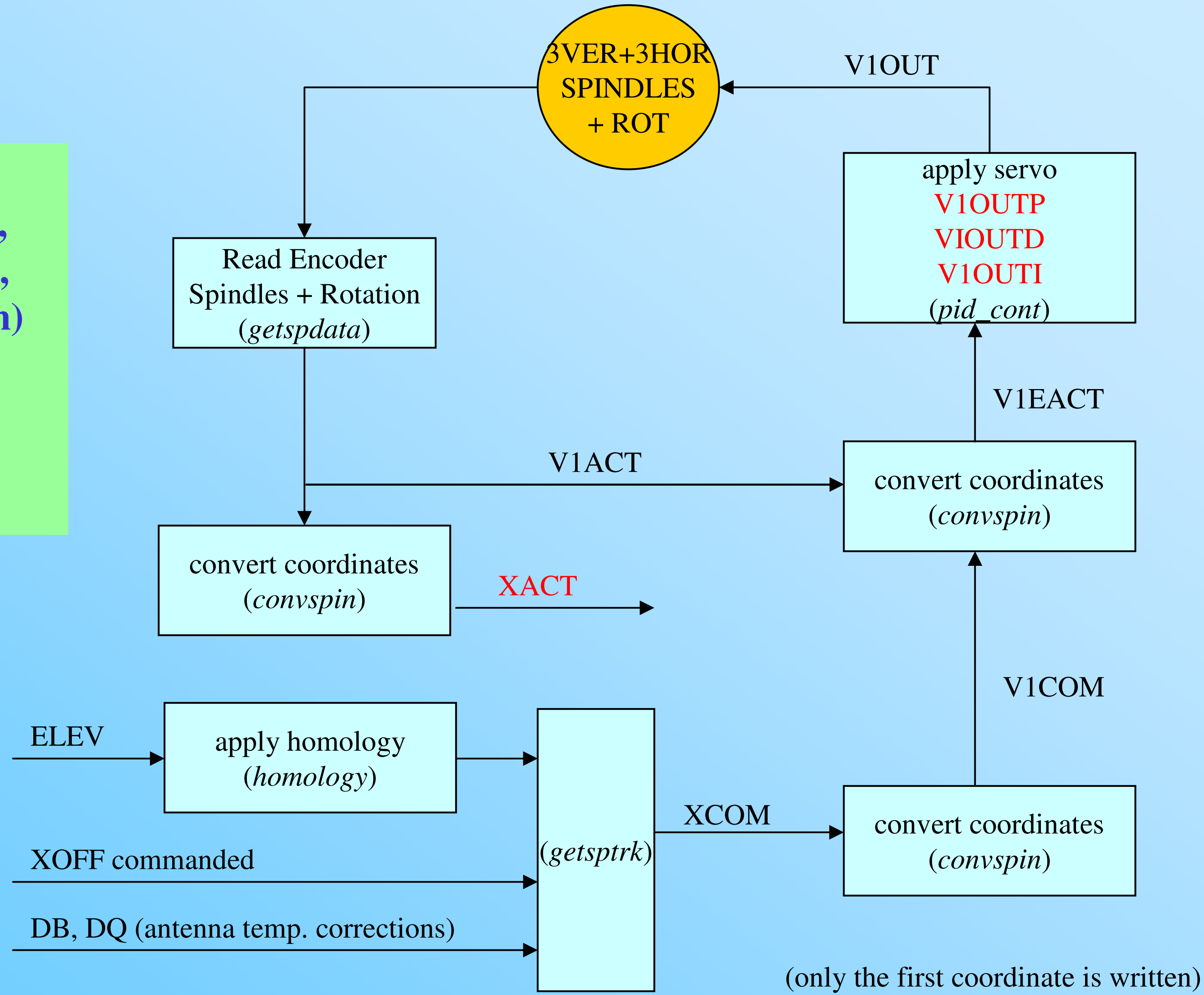
- 3 Vertical + 3 Horizontal Spindles permit the Subreflector shift and tilt
- On top of the previous movements the Subreflector can also be rotated



Antenna Servo Control, subreflector

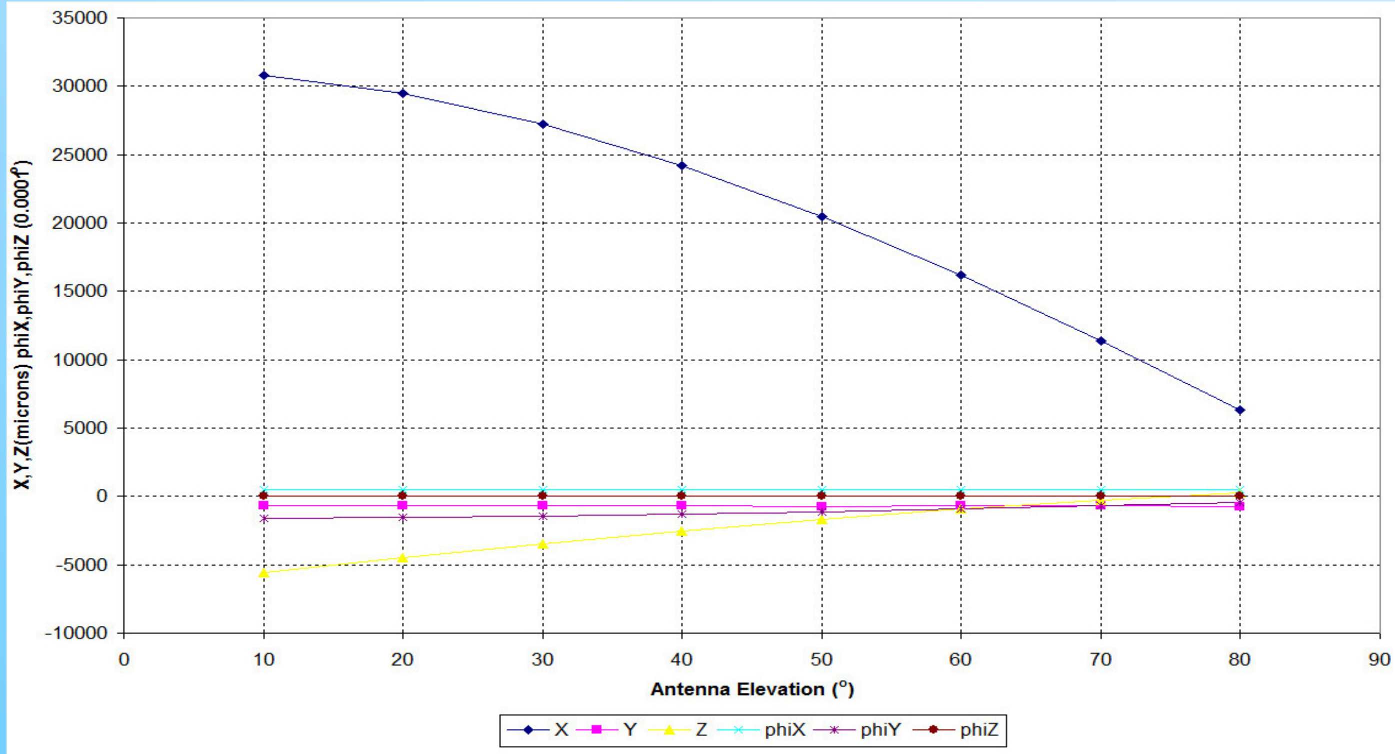
Subreflector movements:
Spindles (X,Y,Z: ±30mm,
tilt X,Y: ±0.72º,
resolut.: 3.8 µm)
Rotation (±90º)

Servo loop:
Latency 4 per second



Antenna Servo Control, subreflector

Homology corrections:



The subreflector movements to apply homology corrections when moving the antenna elevation from 10º to 80º are:

- vertical shift (X) about -25 mm
- axial shift (Z) about +6 mm
- vertical inclination (phiY) about +0.11º

Antenna Servo Control, subreflector

Considerations

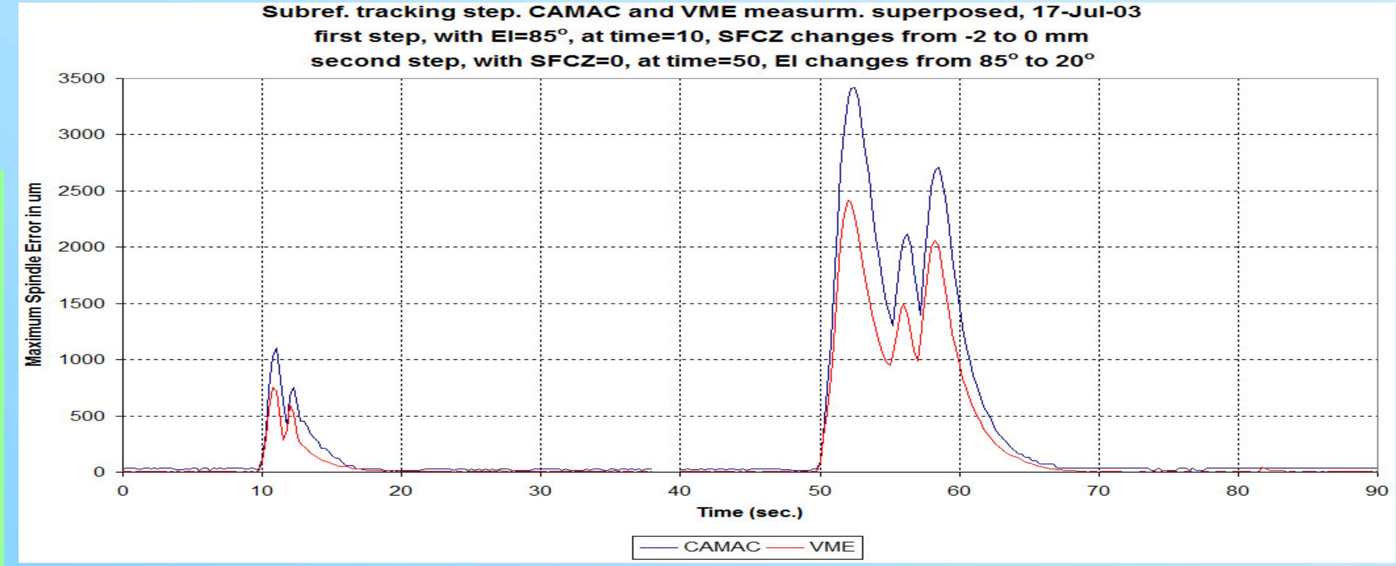
tracking is good with error < 50 µm

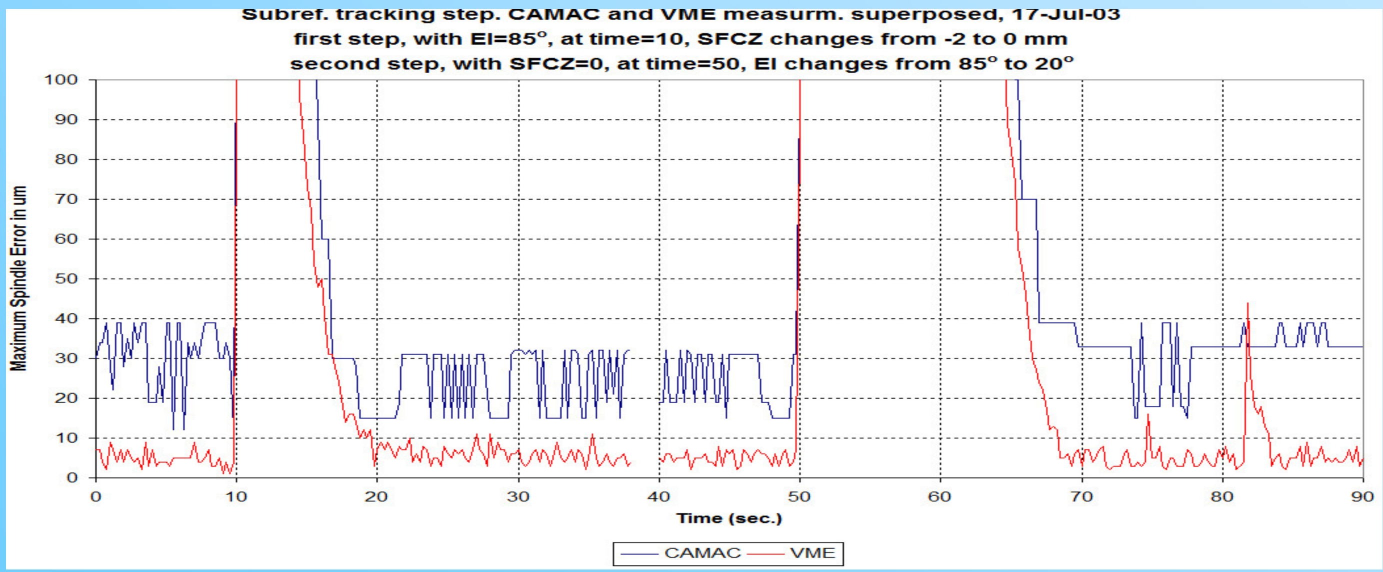
typical tracking error < 10 µm

first step, change of Z-focus: 6 sec.

second step, change of elevation: 16 sec.

Subreflector steps in z-focus and elevation:

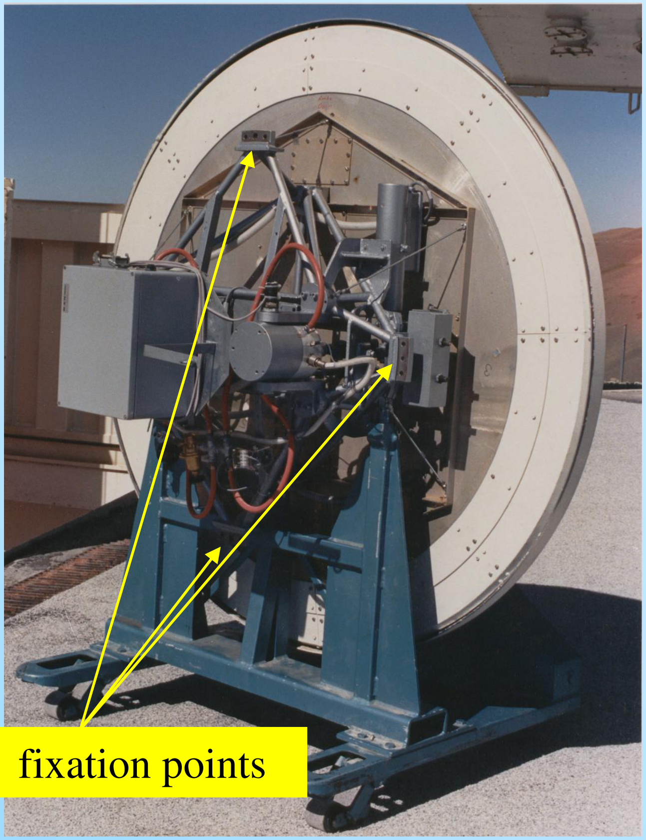




Antenna Servo Control, wobbling subreflector

platform access to the prime focus

lateral view



rear view with wobbling mechanism

Wobbler characteristics:

- Maximum amplitude: optical ±0.4º, sky ±120”
- Maximum operating frequency: 2 Hz (at ±45”)
- Blanking time: from 40 ms (at ±15”) to 90 ms (at ±120”)
- Cyclic interruption: 2000 Hz

Pointing Model

parameter	Type of error	V_i(Az,El)	H_i(Az,El)
P_1	Zero offset of Azimuth encoder	0	cos(El)
P_2	Collimation error	0	1
P_3	Inclination of Elevation axis	0	sin(El)
P_4	Inclination of Azimuth axis (toward north)	- sin(Az)	cos(Az) sin(El)
P_5	Inclination of Azimuth axis (toward west)	cos(Az)	sin(Az) sin(El)
P_6	Declination error of the source	cos(Az) sin(El)	sin(Az)
P_7	Zero offset of the Elevation encoder	1	0
P_8	Gravitational bending	cos(El)	0
P_9	Gravitational bending	sin(El)	0

in addition we apply Nasmyth offsets related to the position of the receivers

In BLUE color, parameters that usually remain constant

In GREEN color, parameters determined with inclinometers. They reflect the tilt of the azimuth axis with respect to the astronomical zenith

In RED color, parameters that still have to be determined by astronomical measurements. They reflect deformations on top of the azimuth bearing (P_3 and P_7) and on the antenna frame (P_1 and P_2)

Modelling of the true angle offset:

$\Delta V = \sum [P_i\ V_i(El,Az)]$

$\Delta H = \sum [P_i\ H_i(El,Az)]$ with i=1,2,…,9

True angle offset:

$\Delta V = \mathbf{\Delta El}$

$\Delta H = \mathbf{\Delta Az}\cos(El)$

Pointing Model

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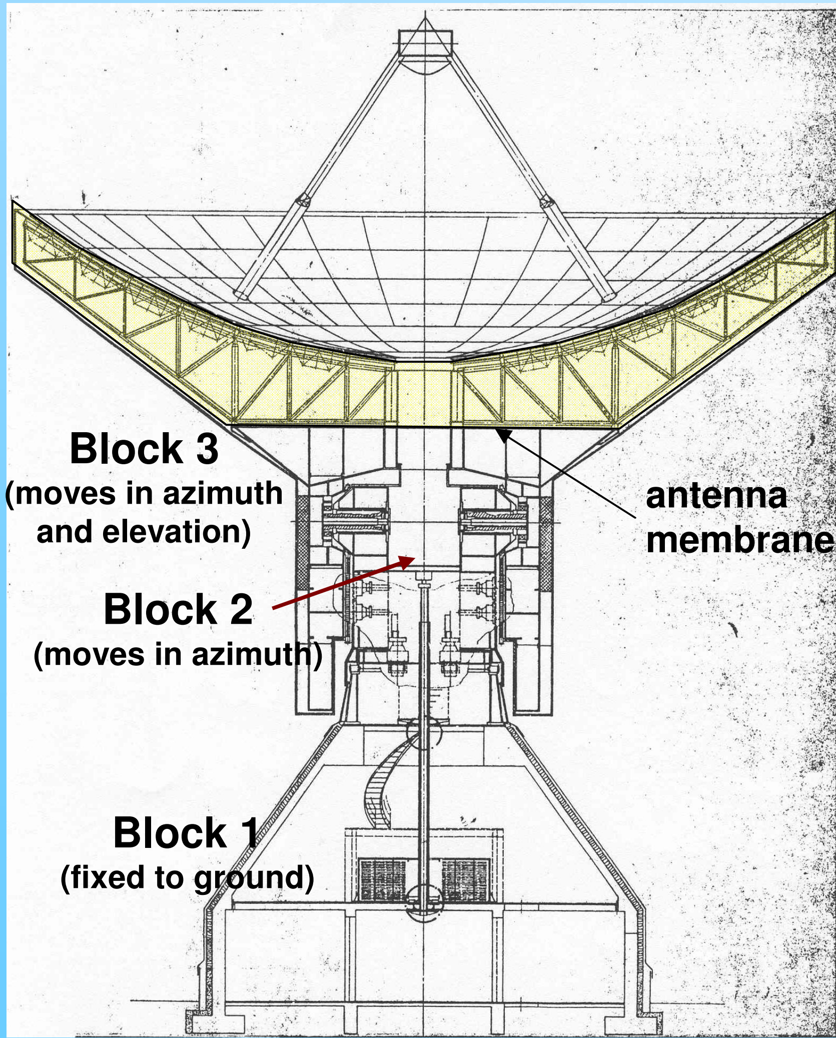
Contributions of the different antenna Blocks:

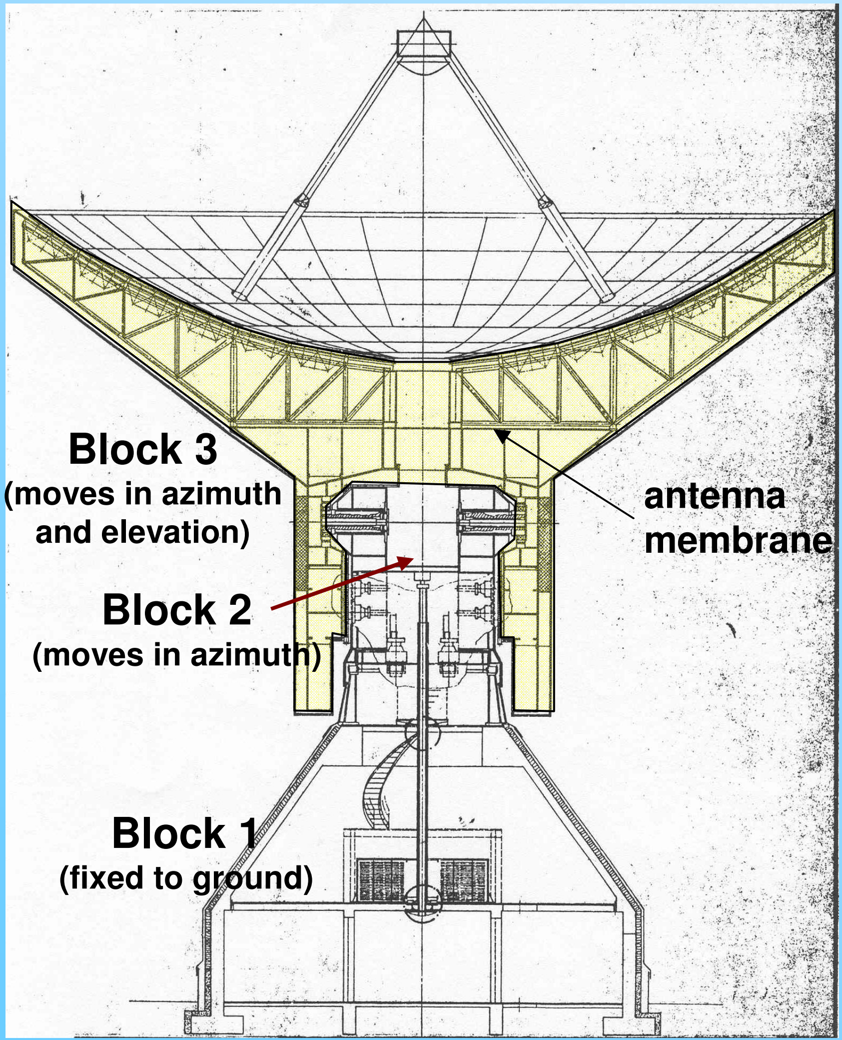


Origing of the Pointing Model Parameters	
Block 3 (moves in azim. and elev.)	P1, P2
Block 2 (moves in azimuth)	P3, P7
Block 1 (fixed to ground)	P4, P5

- **In the antenna intial design only the frame above the membrane was regulated intemperature**

Pointing Model

Contributions of the different antenna Blocks:



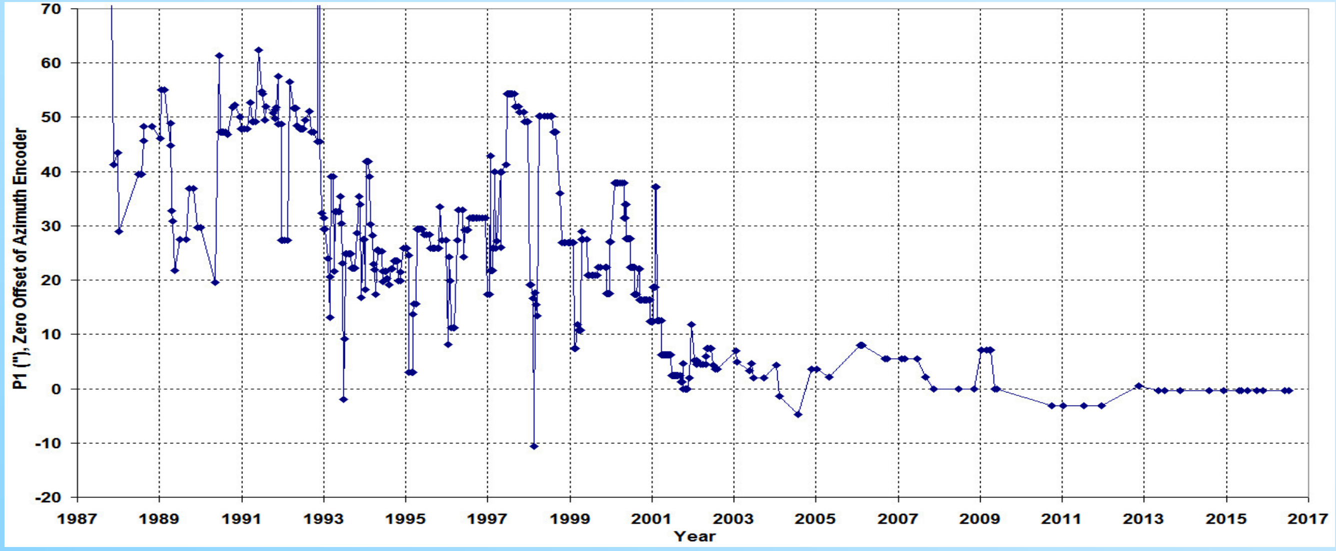
Origing of the Pointing Model Parameters	
Block 3 (moves in azim. and elev.)	P1, P2
Block 2 (moves in azimuth)	P3, P7
Block 1 (fixed to ground)	P4, P5

- In 2002 the antenna temperature control below the membrane and counterweights was also included
- Parameters P1, P2, P3 and P7 are more stables
- There is still a winter-summer fluctuation of P7 up to 10''

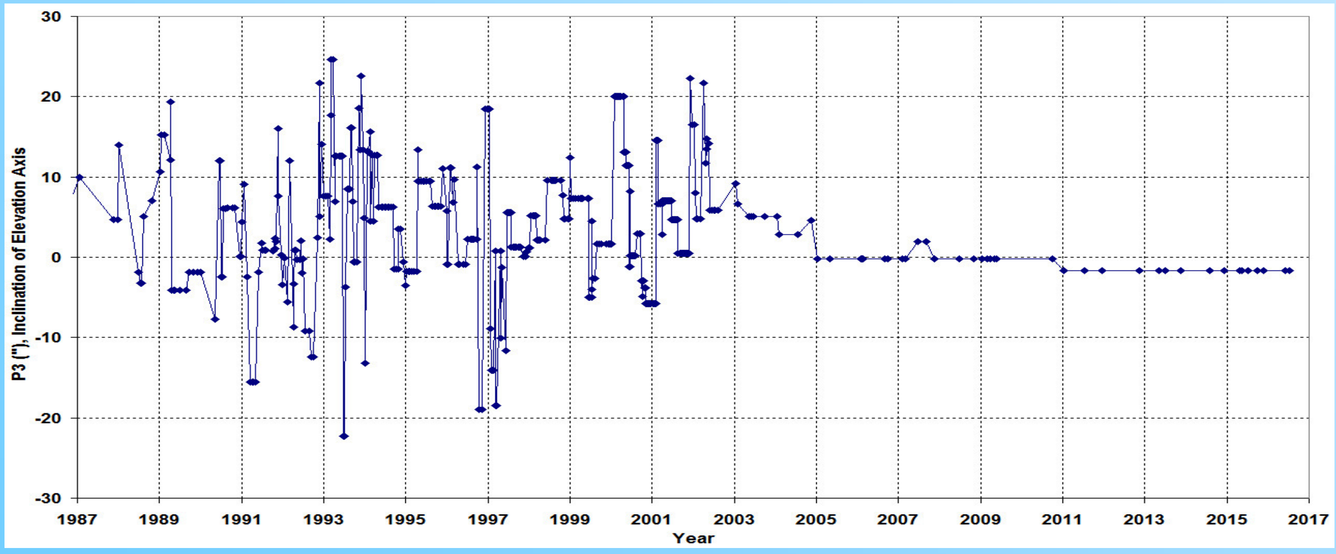
Pointing Model

Evolution of the Pointing Model parameters, case of P1 and P3:

P1:

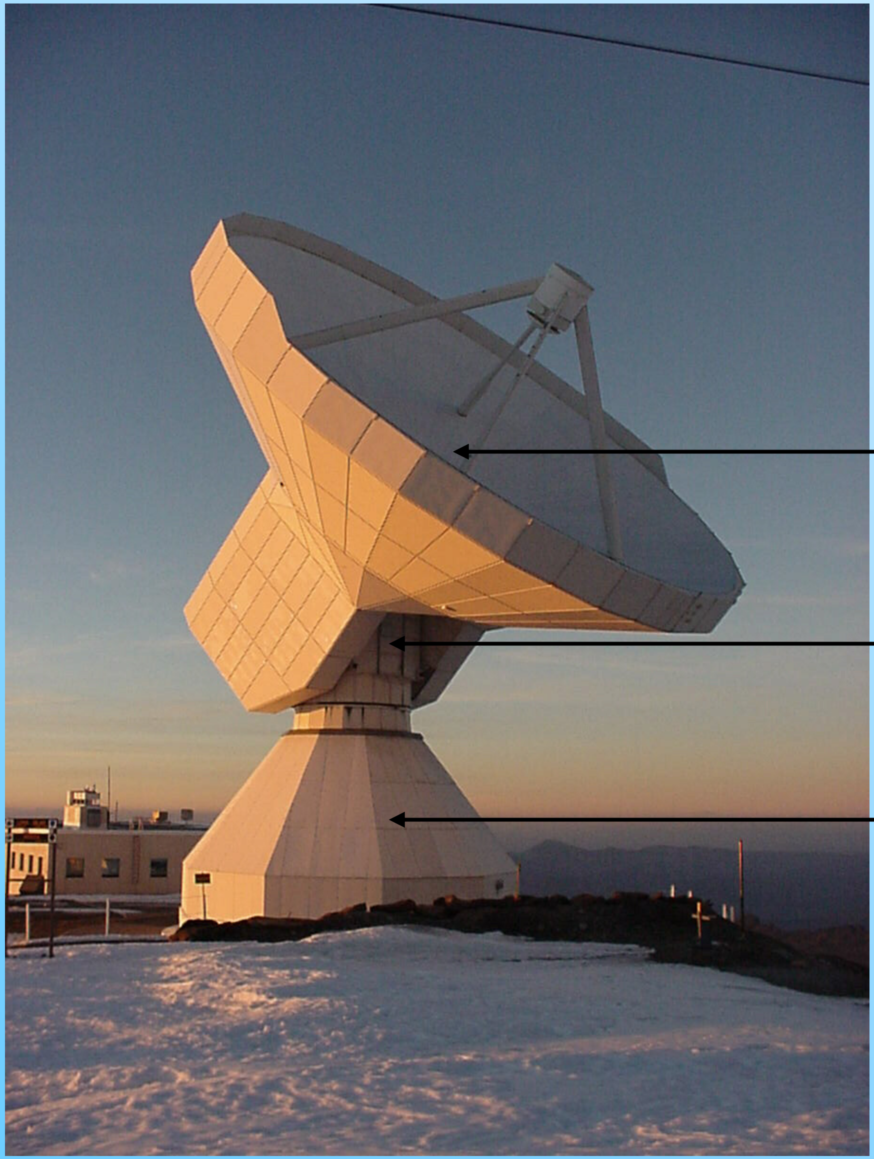


P3:



Since 2002, after installing the full temperature control of the antenna, the pointing model parameters are more stable

Pointing Model



Where is the source of the Pointing Parameters fluctuation?

P1, P2

P3, P7

P4, P5

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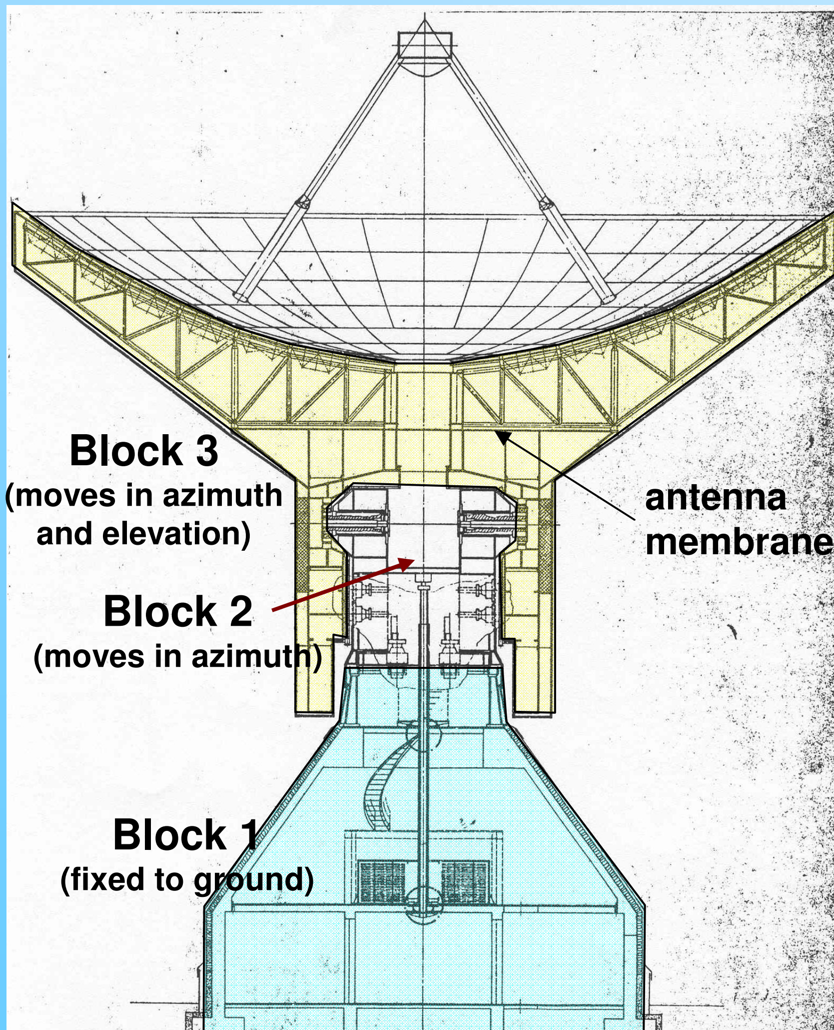
Pointing Model

Contributions of the different antenna Blocks:



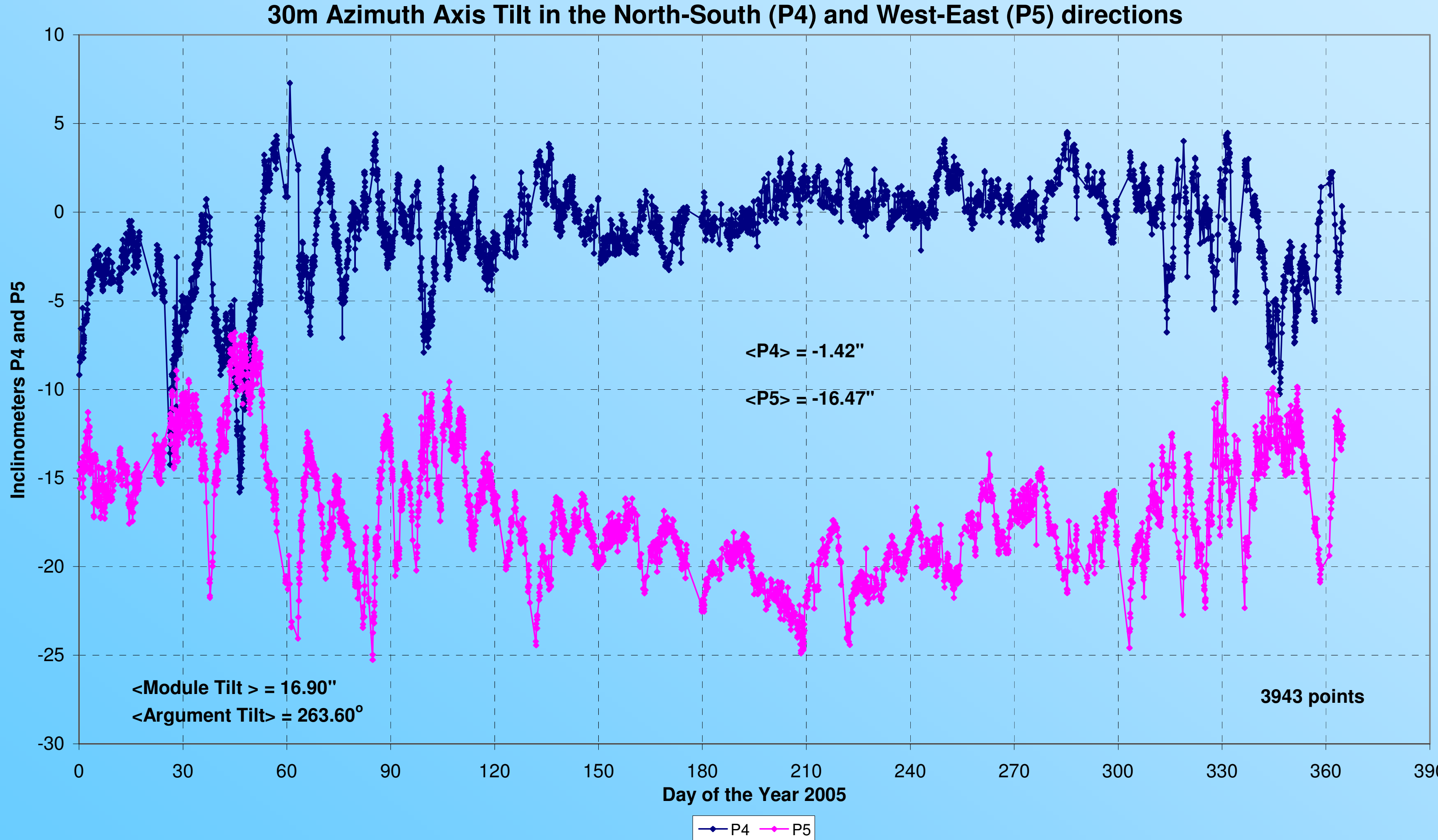
Leica – Nivel 20 Inclinometer

Applied Geomechanics 755-1150 Inclinometer

Since 2003 the installation of inclinometers on top of the azimuth axis permit the determination of P4 and P5 automatically every time we move the antenna more than 60^o in slew rate in azimuth

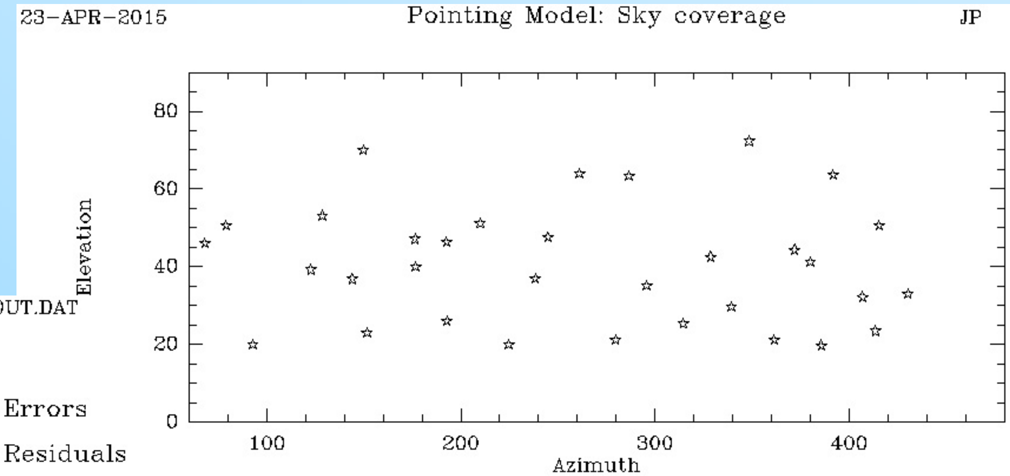
Pointing Model

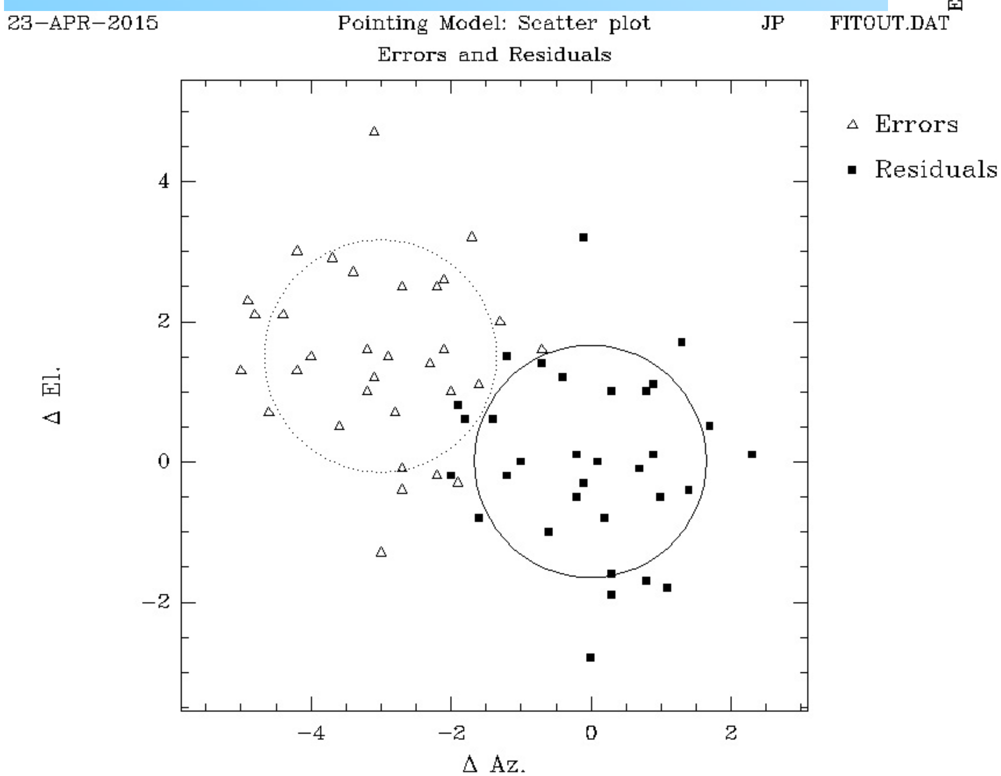
Inclinometer Measurements during one Year, values P4 and P5:



Pointing Model

How good is the Pointing Model?





<u>Resume of a Pointing Session:</u>

Date of session:	**23-Apr-2015**
Previous session:	**8-May-2014**
Sources observed:	**33**
Duration of session:	**2h 30m**
rms observed:	**1.66”**
rms after fit:	**1.66”**

<u>Conclusions</u>:

- **Pointing model is stable in time**
- **Pointing is good if no disturbances like bad weather, wind, sun radiation, or others**

Time Use at the 30m-Antenna

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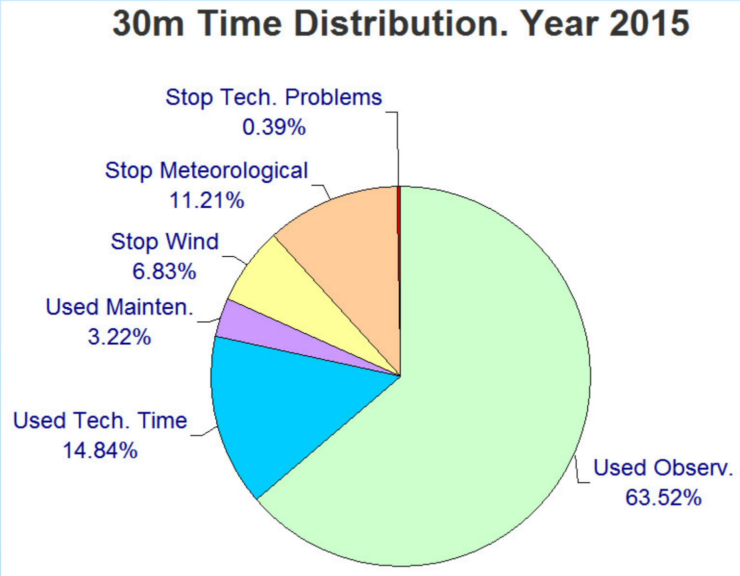
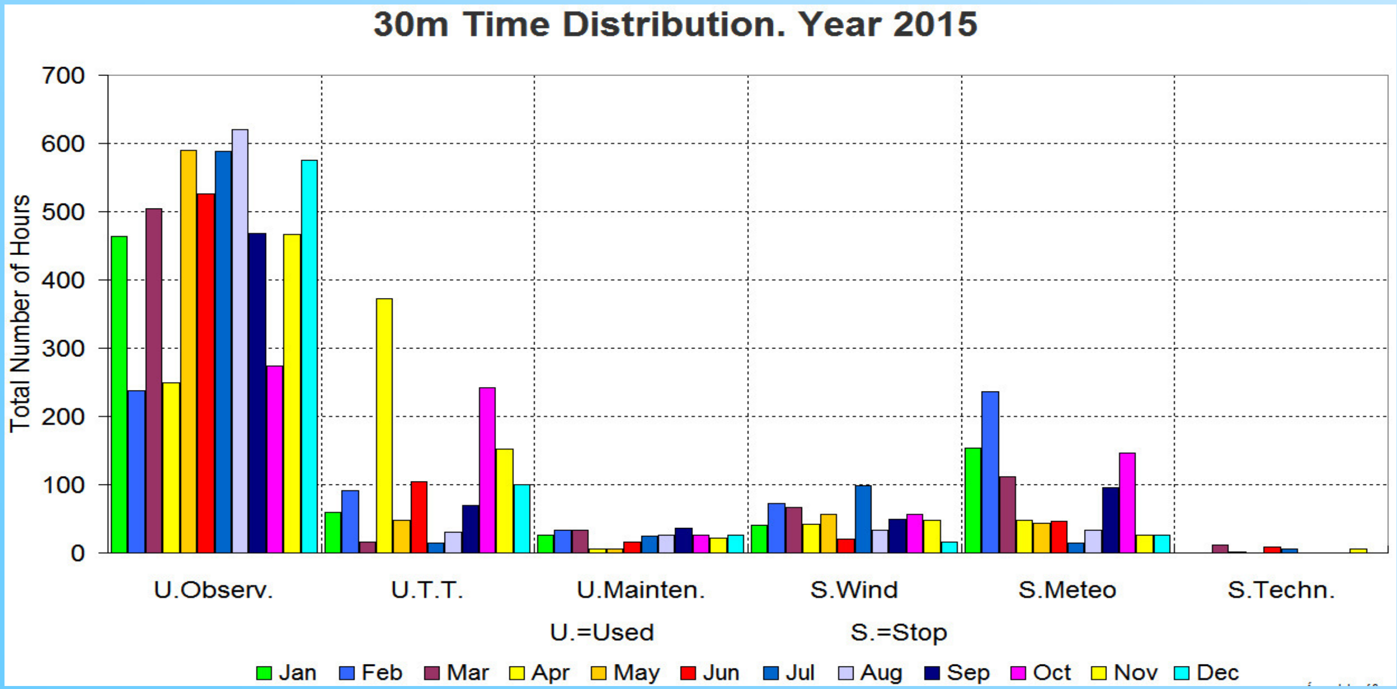
We keep a log of how the time is used at the observatory with an entry by the operator every two hours





IRAM 30m Telescope

Thanks for your attention !