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Metrology Improves Pointing at 12m ALMA Telescopes

Green Bank, Sept 2016
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12m ALMA (US / NRAO) Radio Telescope

Location:
Chajnantor plateau, Chile
Altitude 5000m
Qty: 25 US 12m antennas built by VA
25 European 12m antennas
several Japanese 12m and 7m antennas

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ALMA Pointing Requirements

Specification

- All sky, all time
  - 2.0 arcsec rms
- Offset pointing
  - 0.6 arcsec rms
  - within 2 deg window from last calibration
  - During sidereal tracking within 15 min from calibration
- Pointing errors calculated for 11 positions on the sky, weighted according to ALMA weighting factors

Design

- All sky
  - Nighttime 1.17 arcsec
  - Daytime
    - 2.13 arcsec worst case
    - 1.76 arcsec average
- Offset pointing
  - Nighttime
    - 0.63 arcsec worst case
    - 0.47 arcsec average
  - Daytime 0.48 arcsec
- Design pointing errors already include usage of metrology

Achieved

- All sky
  - 0.81…1.45 arcsec
- Offset pointing
  - 0.43…0.63 arcsec
- Errors as per NRAO Report
  ALMA-35.00.666.666-A-SPE

Difficulties

- All sky pointing
  - Design / Components
    - Rigid structure required
    - Lowest natural frequency must be high enough to support high gain servo loops
    - Impact of precision/quality of components (bearings, gearboxes, encoders, etc.) must be <<2 arcsec each
  - Environmental impact
    - Errors caused by wind and deformation due to temperature were larger than the specification allowed
    - ⇨ Usage of metrology was found to be necessary
- Offset pointing
  - Design / Components
    - Structure and servo must be designed that wind error is <~0.3 arcsec rms
    - Impact of precision/quality of components (bearings, gearboxes, encoders, etc.) on random error must be <<0.6 arcsec each
    - Servo noise / tracking accuracy must be in the order of 0.2 arcsec w/o wind

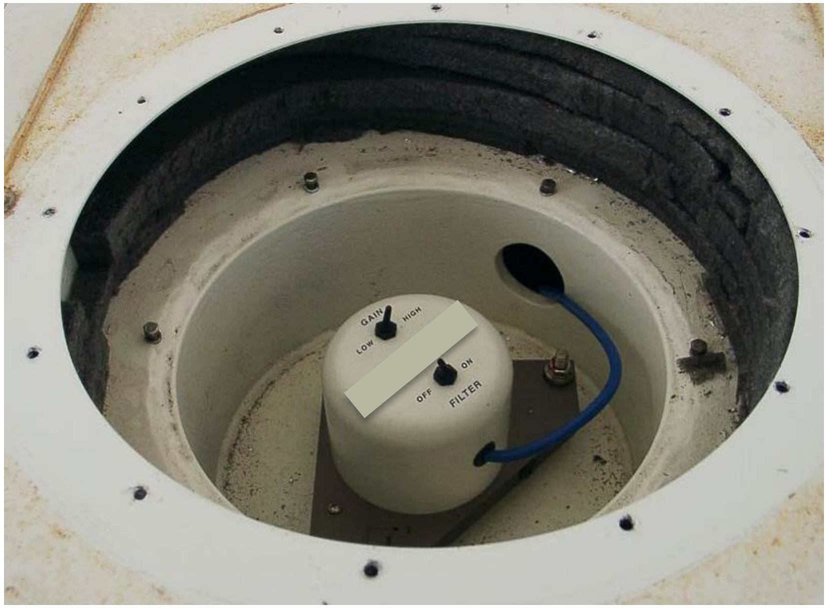
Approach for Metrology

- A bad (i.e. structurally weak) telescope can't be turned into a good one just by adding metrology!
- Use metrology for those pointing error contributions which – without compensation – would blow the error budget
- Sensors must …
  - be of industry standard and appropriate for use on [outdoor] telescopes. Lab-type sensors cannot be used.
  - work with required accuracy over full temperature range of telescope
- Use as little metrology as possible because
  - Sensors have measurement errors which in the first place <u>increase</u> the pointing error
  - Sensors which provide accuracy in the sub-arcsec range are not common.
  - Calibration of sensor readout over temperature may be required.
  - Implementation, testing and calibration doesn‘t come for free and takes time…

Metrology I

Tiltmeter

- High accuracy dual axis tiltmeter installed in center of Az axis at level of Az bearing
- Tiltmeter measures change of Az axis tilt due to
  - Temperature deformation of support cone
  - Constant wind (gusts are too fast to react on)
  - Changing tilt of foundation
- Tiltmeter behavior over full temperature range
  - Output signals change slightly with temperature
  - Determination of calibration curves output signal = f(temp) is required (per tiltmeter)



Note: the constant tilt of the Az axis is measured by the tiltmeter but subtracted from the compensation. It is covered by the systematic error model. Metrology should not be required to remove such systematic errors.

Metrology II

Linear Sensors

- Concept: measure tilt or expansion of one or both yoke arms, mainly caused by temperature gradients
- Sensors
  - installed in the yoke arms
  - One end of each sensor is mounted on a CFRP structure which is attached to the Az bearing
  - Thus any displacements of the yoke arm relative to the bearing is measured
- Compensations
  - Elevation errors (yoke arms extend at front or rear)
  - Azimuth errors (left or right yoke arm extends)

Metrology III

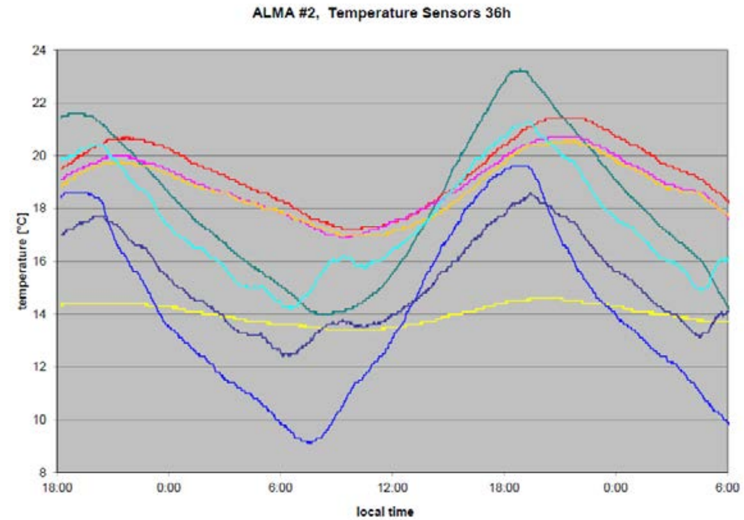
Temperature Sensors

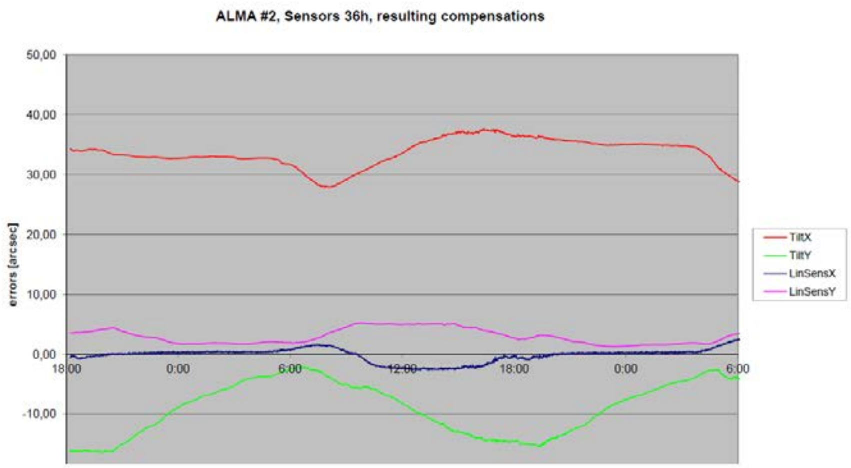
- Temperature sensors at head part
  - Sensors at the apex detect gradients in the support structure for the subreflector positioner
  - Temperature gradients cause mis-pointing of subreflector
  - The resulting deflection is taken into account when calculating the commanded position of the subreflector positioner (which anyway is required to compensate for misplacement of the S/R due to gravity)
- More temperature sensors
  - More sensors are installed at different locations on the telescope
  - They are monitored by ALMA but not used for pointing corrections
  - Some telescopes have been equipped with up to 100 temperature sensors for detailed monitoring

S/R Positioner support structure

Magnitude of Compensated Errors

- Specification
  - 2.0 arcsec all-sky
  - 0.6 arcsec offset pointing (2 deg radius, for 20 min)
- Error Budget
  - Telescope would be in spec at nighttime (no temperature gradients)
  - Wind error ~ 1 arcsec
    - This is a problem only for offset pointing
    - At least partial compensation is required to achieve 0.6 arcsec accuracy
  - Temperature errors
    - ~15 arcsec during daytime
- Measurements
  - Sensor recording over 24h with the sun shining on the telescope
  - Temperature variation ~12K
  - Results confirm the calculations
  - Individual compensations ~±5 arcsec
  - Total compensation ~±8 arcsec





Conclusion

- Pointing of ALMA Telescopes is within specification
- Mechanical and servo system work and perform as expected
- Metrology…
  - is turned on
  - is able to keep impact of environmental effects (wind, temperature, sunshine, etc.) within intended limits
  - is reliable.
    None of the sensors has been returned neither to VA nor (to our knowledge) to the sensor manufacturers.

⇨ The result? ALMA is working and doing great science…

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