Antenna Mount Requirements and Use Cases

R. Heald, A. Perrigouard

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Introduction

The Antenna Mount System (AMS) is software developed to drive the ALMA antenna movement for astronomical observations and testing. The requirements, use cases, and risk factors for AMS are given below. All ALMA antennas will use identical hardware and software, however, for this discussion a single antenna is assumed.

In the ALMA system, the AMS sits between the ALMA array Control System (CS) and the Antenna Control Unit (ACU). The CS sends tracking commands to the AMS specifying a *target* with an optional *pattern*. The AMS combines the positions, converts them to horizon coordinates useable by the antenna, applies the appropriate corrections, and sends the results to the ACU. This causes the antenna to move in the desired manner.

The AMS will have exclusive control of the antenna mount hardware through the ACU, and will control all movement of the antenna.

The ACU has the following operational modes

- Shutdown (no power to motors, brakes set)
- Standby (motor power on, brakes set)
- Velocity (rate loop driving of axes from local handset)
- Encoder (drive so encoders equal commanded position)
- Autonomous (drive so boresight equals commanded position)
- Preset (same as Autonomous with limited velocity and acceleration)
- Stow (drive to stow position).

Simultaneously, the ACU may be in either of two access modes, Local or Remote [1].

The topics of obtaining, archiving, and displaying the antenna monitor data are outside this discussion; rather they are discussed in [2]. Notice access to the ACU monitor points is shared between the monitor and AMS software.

The control and monitor of the antenna's subreflector and nutator are also outside this discussion, and there is presently not a document discussing them.

Acronyms

AMS "Antenna Mount System" - the software system that is the topic of this document.

ABM "Antenna Bus Master" - a real-time computer located at the antenna that is responsible for the control and monitor of all devices at the antenna. There is an identical copy of this computer at every antenna, each running identical software. The ABM has a network connection to the ACC, and can access all devices at the antenna (mostly through a CAN serial bus).

ARTM "Array Real Time Machine" - a real-time computer located at the array central control area. It is responsible for the control and monitoring of certain hardware (LO reference generation, fiber optic control, etc.) located only at the array center. It also maintains the "array time".

CCC "Correlator Control Computer" - a real-time computer located at the array central control area. It is responsible for the control and monitor of the correlator.

ACC "Array Control Computer" - the computer responsible for over all control of the instrument. It is TBD whether this is a real-time computer or an ordinary Unix workstation.

ACU "Antenna Control Unit" - the system provided by the antenna manufacturer by which antenna motion is monitored and controlled. The ABM primary access to the ACU is via the CAN bus. There is also an Ethernet connection between the ABM and ACU used for debugging and testing [1]. The AMS directly interacts with the ACU to carry out commands. The protocol used between the ABM and ACU is discussed in [3].

CS "Control System" - the software running in ACC that controls (at a high level) the motion of all antennas, and it sends commands through an interface to which the AMS then responds.

OTF "On-The-Fly" - an observing mode where the antenna motions follow a *pattern* without stopping. At the same time, the antenna actual and commanded positions are recorded at a high rate. The position data are later used in the calibration of the science data.

Definitions

Target the object being tracked in the receiver's main beam. Normally this is a celestial object, but it can be anything that can be specified in an acceptable coordinate system.

Pattern An antenna movement that is superimposed on (added to) the tracking of the *target*. A *pattern* can be as simple as an offset from the *target*, or more complex as moving in a spiral or circle around the *target*. Other example *patterns* are a "5-point" (an antenna movement used to quickly find the current position offset), a raster scan, and a spiral. A *pattern* is composed of one or more *strokes* (see below).

Stroke *Patterns* are composed of a series of separate *strokes*. For example, when a raster *pattern* is being performed a *stroke* is generally a single line in the raster. *Strokes* allow a pattern to be interrupted so other operations (e.g. a calibration) can be performed.

Timing Event the AMS and ACU will receive a precise timing reference signal consisting of a periodic pulse with a period of 48 milliseconds. The leading edge of each pulse marks a *timing event*. The ACU measures the actual position of the antenna at each *timing event* and at the midpoint between *timing events.*

Tracking Requirements an AMS internal storage area where tracking information is placed. The position control loop uses this information to position the antenna.

Risk Factors

1. Specify the interface between CS and AMS.
2. Are galactic, ecliptic coordinates needed? What about catalog objects with proper motion?
3. How are *patterns* specified?
4. Can *strokes* be removed by having the ability to start and stop a *pattern* at any point?
5. What are the antenna capabilities while it is on the transporter? Should it have a telnet or console connection so the antenna can be operated?
6. How is metrology data handled?
7. Should software from JCMT ("Portable Telescope Control System"), IRAM ("astro"), ATNF ("ATOMS"), SLALIB (Pat Wallace), and/or CALC (JPL interferometer model) be used?
8. Can the control of all antennas in a subarray be done from a single source? R. Lucas says all antennas belonging to a same sub-array do not necessarily have the same trajectories. For instance, during a 5-point *pattern* it is better to send the antennas to the points in different order, so the main direction is common but the relative superimposed movement might be different. From this, there is no (or very little) part of AMS common to all antennas in a subarray.
9. Include an encoder calibration routine.
10. Leave in STANDBY for anti-condensation power.

Requirements

R1. Position commands to the ACU shall have 4 parameters consisting of elevation, azimuth, elevation rate, and azimuth rate. The elevation and azimuth shall be integer 32 bit numbers interpreted as signed, twos-complement, fixed-point binary numbers representing angles from -1 turn through $+[1-2^{-31}]$ turn, i.e. the binary point comes just after the sign bit. The elevation and azimuth rates shall be in the same fixed-point format in units of turns per second. A zero elevation shall be the horizon, and a zero azimuth shall be due north [1].

R2. The AMS shall deliver position commands to the ACU within 24 milliseconds following a *timing event* [4]. Commands shall apply at the second *timing event* after the command is sent [1].

R3. The total AMS absolute pointing error shall not exceed TBD (~ 0.01)[1] arc-seconds[2]. This requirement applies only to the coordinate transformation calculations. The system shall apply the pointing corrections needed to achieve this accuracy. See the Pointing Error Budget below.

R4. For each antenna axis, the AMS shall have two positions that define the extremes of antenna movement for that axis. These limits shall never be exceeded. An attempt to exceed a limit shall cause antenna axis movement to stop at the limit and an alarm to be produced. The limit values shall be settable. Notice the antenna movement can be as fast as 6 degrees per second. At this velocity, deceleration is required before the limit to avoid exceeding the limit.

R5. The antenna normal range of azimuth motion is 270 degrees on either side of north [1]. This implies there are two possible azimuths to reach all southern sky regions. Tracking commands to the AMS shall specify the region to be used, either the "+" or "–" azimuth region, or the closest (the default).

R6. The antenna normal range of elevation motion is 2 to 125 degrees [1]. This means there are two possible elevations to reach the sky region above 55 degrees. Tracking commands to the AMS shall specify the region to be used, either 2 to 90 degrees (the default), or 90 to 125 degrees (called "over-the-top"). Notice over-the-top elevation positions are normally only used when determining the non-intersecting axis "K" term of the baseline solution.

R7. When the AMS is given a *target* that is below the elevation limit the AMS shall move the antenna to the elevation limit at the correct azimuth and wait there. The AMS shall begin tracking the *target* when it rises above the elevation limit. The AMS shall work in this manner for both normal "front side" elevations, and "over-the-top" elevations where the lowest elevation limit is 55 degrees above the horizon.

R8. Tracking at the sidereal rate is not possible within a 0.2 degrees radius of the zenith [1]. When tracking within this region the AMS shall move the azimuth as fast as possible to resume tracking the source when it leaves this region. There is no obligation of good tracking while the antenna is within this region.

R9. The AMS shall accept arguments in the following coordinate systems for the *target*.

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[1] Pat Wallace email 2000-04-06: The AMS should have "a noise level at least a couple of orders of magnitude below the rest of the system". Refraction will dominate the pointing errors.

[2] For reference the antenna mechanical system has an absolute positioning error tolerance of 2.0 arc-second RSS (Root Sum Squared), and an offset positioning error tolerance of 0.6 arc-second RSS [1].

- Equatorial in Right Ascension, Declination for J2000 epoch (either mean or apparent, i.e. already precessed)
- Ecliptic in Longitude, Latitude for J2000 epoch
- Galactic in Longitude and Latitude
- Horizon in Elevation, Azimuth

R10. For *target*s of moving objects, the AMS shall accept an ephemeris. Each ephemeris entry shall have a format similar to below (headings are not given, sample data is shown). This format allows direct input from the JPL Horizons system.

Date/time	Right Ascension	Declination	Distance	Velocity
2451675.45833333	04 11 54.0991	+21 36 17.384	2.4885969488	5.99239

- Date/time is given in either a string (various formats) or Julian Date with fractional day (shown).
- Position is given in geocentric J2000 astrometric right ascension (in hours, minutes, and seconds) and declination (in degrees, arc-minutes, and arc-seconds).
- Distance is given in Astronomical Units (AU).
- Velocity is given in kilometers per second.

The AMS shall fit (at least) a third order polynomial to interpolate between the given positions.

R11. The AMS shall cause the antenna to follow a *pattern* superimposed on the *target* being tracked. The motion speed along the *pattern* shall be constant and settable. A pattern can be described in the equatorial or horizon coordinate systems.[3] Available *patterns* shall include (but are not be limited to)[4]:

- simple offset
- raster scan
- circle (promoted by JCMT)
- spiral in either direction, and in or out
- rotating “bowtie”[5] (promoted by Ron Maddalena)

R12. *Patterns* shall be composed of a series of separate, short *strokes* to allow calibration procedures to be performed between them. Antenna motion shall be specified to begin and end with any given *stroke(s)* within the *pattern*.

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[3] From Steve Scott email, 2000-5-22

[4] Brian Glendenning email 2000-7-25: “At a holography meeting today I got agreement that, barring someone doing a [observing efficiency] calculation that proves their necessity, that there is no requirement for other than raster scans during SD holography (with the proviso that it be possible to add them later). Spirals and cloverleaves will probably be labeled "desirable enhancements" for the nonce.”

[5] The "bowtie" pattern is so called because it resembles the necktie in the form of a bow, tied at the center that is worn by some men. Others would say it looks like an ellipse folded at the center. The target is kept at the center of the bowtie while it slowly rotates around the target.

R13. *Pattern* movement shall be precisely synchronized across all participating antennas. This implies the operation is time critical.

R14. The AMS shall be able to perform a drift scan. In a drift scan the antenna is moved to a position preceding the track of the desired object and is then held stationary to allow the object to track through the antenna's boresight.

R15. The AMS shall read the actual positions captured by the ACU and determine whether the error on the sky is within the specified tolerance, that is, whether the position is "on source" or "off source". The AMS shall take the most pessimistic view in this determination. That is, the AMS shall find two consecutive positions within tolerance before "on source" is declared, and when a position is found outside the tolerance both that position and the previous position shall be declared "off source". The AMS shall report the determinations to the CS whenever there is a change. The tolerance value shall be settable.

R16. The AMS shall support the ACU "autonomous" mode. In this mode, the AMS pointing model corrections are disabled except for the receiver axis offset. They are replaced by those provided by the antenna vendor and internal to the ACU. The AMS shall provide a method for setting the coefficients of the vendor supplied pointing model.

R17. The AMS shall provide an OTF mode. When in OTF mode, the AMS shall query the ACU for the antenna's commanded and actual positions during each *timing event*. It obtains two sets of positions for each query. The first set is the positions at the *timing event*; the second set is the positions at the time halfway between the *timing event* and the next one. The AMS shall append a time stamp to the obtained positions and send them to the ACC. In OTF mode, the antenna will move at a rate of up to 0.5 degrees per second on the sky [1].

R18. The AMS shall deliver the monitor requests for the positions to the ACU within a 20-millisecond window preceding the *timing event* by 4-milliseconds [4].

R19. The alignment of each receiver axis will be slightly different. The AMS shall compensate for this.

R20. An antenna in the antenna barn shall be provided with a network connection identical to that provided at a normal antenna foundation. In this way, the antenna shall have full operational capability while in the barn.

Design Choices

DC1. The AMS parts closest to the ACU, if not all of the AMS, shall be implemented as a Device [2]. As a Device the AMS device shall be composed of properties. Some identified properties of the antenna are the pointing model parameters and motion limits.

DC2. Movement along a *stroke* is continuous and atomic. If a *stroke* is interrupted, the entire *stroke* must be repeated.

DC3. The AMS shall use only the ACU modes Shutdown, Encoder, and Autonomous. These shall correspond to the AMS modes Shutdown, Tracking, and Autonomous, respectively. The ACU must pass through the Standby mode when going from Shutdown to Encoder or Autonomous.

Antenna Mount Use Cases

Activate

This use case places the system in Tracking mode ready for the Track or Stow use case.

Actors
- CS (primary)
- ACU (secondary)

Preconditions The ACU is in Remote access mode.
The pointing model has been set.
The limits have been set.

Basic Course
1. The use case starts when the CS requests the system to go to Tracking mode.
2. If the Position Control Loop is not running
   a) The system starts the Position Control Loop
3. If stow pins are engaged
   a) The system commands the ACU to disengage stow pins
4. If the mount brakes are set
   a) The system commands the ACU to release the brakes.
5. If the ACU is in Shutdown mode
   a) The system commands the ACU to Standby mode, then Encoder mode.
6. The system sets the *tracking requirements* to hold at the present antenna position.
7. The system places itself in Tracking mode.
8. The system returns Ok.

Exception Course
1. If the system encounters an error during the *Basic Course*
   a) The system immediately quits the course and returns the error.

Postconditions The antenna brakes are released.
The antenna stow pins are disengaged.
The antenna is in Encoder mode.
The system is in Tracking mode.

<u>Shutdown</u>

This use case places the system in Shutdown mode. Afterwards the system cannot be used until the Activate use case is used.

Computer commanded stow pins for both elevation and azimuth are provided for
- survival (15 degrees elevation, 90 degrees azimuth) and
- maintenance (90 degrees elevation, 90 degrees azimuth) stow positions [1].

Actors
- CS (primary)
- ACU (secondary)

Preconditions The ACU is in Remote access mode.

Basic Course
1. The use case starts when the CS requests the system to go to Shutdown mode.
2. The system commands the ACU to set the brakes.
3. If this position is either survival or maintenance
   a) The system commands the ACU to engage stow pins
4. The system commands the ACU to Shutdown mode.
5. The system places itself in Shutdown mode.
6. The system returns Ok.

Exception Course
1. If the system encounters an error during the *Basic Course*
   a) The system immediately quits the course and returns the error.

Postconditions The antenna brakes are set.
The antenna stow pins are engaged if in survival or maintenance position.
The antenna is in Shutdown mode.
The system is in Shutdown mode.

<u>Track</u>

This uses case causes the antenna to follow a *target* while applying an optional *pattern*. All appropriate corrections and the pointing model are applied.

Actors
- CS (primary)
- ACU (secondary)

Preconditions The system is in Tracking mode.

Basic Course
1. The use case starts when the CS requests the mount to track.
2. The CS supplies the *target*, optional *pattern*, azimuth wrap, and elevation wrap.
3. The system sets the *tracking requirements* for the *target* and *pattern*.
4. The system returns Ok.

Exception Course
1. If the system encounters an error during the *Basic Course*
   a) The system immediately quits the course and returns the error.

Postconditions The system is in Tracking mode.

Stow

This use case moves the antenna to a given stationary position and then places the system in Shutdown mode. These are positions such as stow, park, and wind survival. The position is given in raw elevation and azimuth encoder units; no corrections are applied. (A database of position names with the corresponding encoder position for each antenna will be kept by the control system.) The position may be the current antenna position so no antenna movement is performed.

Actors
- CS (primary)
- ACU (secondary)

Preconditions The system is in Tracking mode.

Basic Course
1. The use case starts when the CS requests the mount to stow.
2. The CS supplies the position, or “current position”.
3. If the position is NOT “current position”
   a) The system sets the *tracking requirements* to move the antenna to the position.
   b) The system waits until the antenna arrives at the position.
4. The system uses the Shutdown use case.
5. The system returns Ok.

Exception Course
1. If the system encounters an error during the *Basic Course*
   a) The system immediately quits the course and returns the error.

Postconditions The system is in Shutdown mode.

Set Pointing Model

The form (terms) of the pointing model are set (compiled) in the AMS. This command sets the coefficients and other parameters of the model. The new parameters become effective immediately after setting. Notice any model term can be effectively removed by setting its coefficient to zero, and setting all coefficients to zero will turn off the whole model.

The pointing model must be set before the antenna can be placed in Tracking mode.

Actors

- CS (primary)

Preconditions none

Basic Course

1. The use case starts when the CS requests to set a pointing model parameter.
2. The CS supplies the new parameter value.
3. The system checks for a reasonable value.
4. The system sets the parameter to the given value.
5. The system returns Ok.

Exception Course

1. If the system encounters an error during the *Basic Course*
    a) The system immediately quits the course and returns the error.

Set Limits

The limits must be set before the antenna can be placed in Tracking mode.

Actors

- CS (primary)

Preconditions none

Basic Course

1. The use case starts when the CS requests to set a limit.
2. The CS supplies the new limit value.
3. The system checks for a reasonable value.
4. The system sets the limit to the given value.
5. The system returns Ok.

Exception Course

1. If the system encounters an error during the *Basic Course*
    a) The system immediately quits the course and returns the error.

Position Control Loop

This use case is responsible for sending position commands to the ACU, and for producing the on/off source and OTF position data.

Actors
- ACU (secondary)

Preconditions none

Basic Course
1. The use case is synchronized to the *timing event*, and starts itself when it occurs.
2. The system derives the ACU position command parameters to satisfy the current *tracking requirements*.
3. The system sends the parameters to the ACU.
4. The system checks limit conditions and an alarm is produced if any are exceeded.
5. The system reads the last two antenna actual positions (encoder reading) from the ACU.
6. The system calculates the commanded positions matching the actual positions.
7. The system compares the commanded and actual positions to produce the ON/OFF Source State that is passed to the CS. "ON" means the antenna tracking is within tolerance. Notice in OTF mode this state is ignored.
8. If OTF mode is active
   a) The commanded and actual positions for the previous two cycles are time tagged and passed to the CS.

Alternative Course
1. If the system is in Shutdown mode
   a) The system does nothing

Exception Course
2. If the system encounters an error during the *Basic Course*
   a) The system produces an alarm.

References

[1] *Atacama Large Millimeter Array U.S. Prototype Antenna Purchase Order*, 2000-February-18

[2] R. Heald, *Device Requirements and Use Cases*, 2000-June-15

[3] J. Kingsley / M. Brooks, *ALMA-US ICD No. 9, Antenna / Monitor and Control Interface*, 2000-January-25

[4] Larry D'Addario, *ALMA Computing Memo #7 Addendum*, 2000-June-27

[5] R. Lucas, et al, *ALMA Software Requirements: Preliminary Report*, 2000-March-7