

# **Checking the pointing corrections implementation for the 40m radiotelescope**

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## Revision history

<b>Version</b>	<b>Date</b>	<b>Author</b>	<b>Updates</b>
1.0	18-04-2008	P. de Vicente	First version
1.1	04-08-2009	P. de Vicente	Added notes on collimation in azimuth for manual pointing corrections

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## 1. Introduction

This report describes tests to check pointing corrections implemented by MT-Mechatronics following instructions given in report IT OAN 2003-7 and in report IT OAN 2007-26. A preliminary determination of the most significant pointing model parameters for the 40m antenna using an optical telescope is also included. Pointing corrections are currently implemented by three commands: manual pointing corrections, pointing model corrections and refraction corrections.

All the tests described here were performed after the first light with the 40 m described by de Vicente (2007). An estimation of the azimuth and elevation encoder errors was discovered then by trial and error and this estimation allowed to fulfill tests described here.

## 2. Pointing corrections implementation in the ACU

The 40 m antenna encoders indicate the antenna position in its own reference system. Protections that prevent the antenna reaching its limits in azimuth and elevation are referred to the encoder reference system. However azimuth and elevation must be referred to an ideal antenna (without instrumental errors) located on the Earth without atmosphere or at least without refraction effects. One must be able to recover the right ascension and declination of the observed source from horizontal coordinates, the antenna location and time (UTC). Observed azimuth and elevation are always stored in FITS files and hence must be referred to this ideal antenna system.

Let us suppose that antenna coordinates referred to the encoders system are  $(Az', El')$  and the same position referred to an ideal antenna system is  $(Az, El)$ . Both systems are related according to the following expression:

$$\begin{aligned} Az &= Az' + \Delta Az \\ El &= El' + \Delta El \end{aligned}$$

If the encoder system had not pointing errors  $\Delta Az$  and  $\Delta El$  would be 0 and both systems would coincide.

When the antenna is used to observe sources in the sky, the observed errors  $\delta Az'$  and  $\delta El'$  are defined as the difference between the observed position  $(Az'_{\text{obs}}, El'_{\text{obs}})$  and the commanded or theoretical position  $(Az'_{\text{cmd}}, El'_{\text{cmd}})$ .

$$\begin{aligned} \delta Az' &= Az'_{\text{obs}} - Az'_{\text{cmd}} \\ \delta El' &= El'_{\text{obs}} - El'_{\text{cmd}} \end{aligned}$$

These errors are referred to the servo system since in an ideal antenna system the error is always 0 and the commanded and observed positions are the same:

$$\begin{aligned} Az_{\text{cmd}} &= Az_{\text{obs}} \\ El_{\text{cmd}} &= El_{\text{obs}} \end{aligned}$$

It is obvious that the observed errors are exactly the difference between the ideal antenna reference system and the servo system since the commanded values are the same in both systems:

$$\begin{aligned} Az_{\text{cmd}} &= Az'_{\text{cmd}} \\ El_{\text{cmd}} &= El'_{\text{cmd}} \end{aligned}$$

Hence:

$$\begin{aligned} \Delta Az &= -\delta Az' \\ \Delta El &= -\delta El' \end{aligned}$$

There are two ways to correct the observed errors inside the ACU:

- The astronomer commands the coordinates in the ideal reference system. The commanded values are transformed to the servos reference system inside the ACU adding the observed error:

$$\begin{aligned} Az'_{\text{obs}} &= Az_{\text{cmd}} + \delta Az' \\ El'_{\text{obs}} &= El_{\text{cmd}} + \delta El' \end{aligned}$$

The new values,  $Az'_{\text{obs}}$ ,  $El'_{\text{obs}}$  are commanded to the servos.

- The readout from the encoders is corrected by subtracting the observed error, and the commanded values (in the ideal reference system) are injected in the servos:

$$Az_{\text{ideal}} = Az'_{\text{servo}} - \delta Az \tag{1}$$

$$El_{\text{servo}} = El'_{\text{servo}} - \delta El \tag{2}$$

and the antenna moves until:

$$\begin{aligned} Az_{\text{ideal}} &= Az_{\text{cmd}} \\ El_{\text{ideal}} &= El_{\text{cmd}} \end{aligned}$$

MT-mechatronics implemented the second method in the ACU, and azimuth and elevation values are displayed in the LCP and in the status message referred to an ideal system once a pointing model is loaded. If no pointing model, manual pointing corrections and/or refraction is loaded, the reference system is the encoders' one. When any of the previous corrections are loaded the antenna moves to the new position until the LCP shows the same azimuth and elevation values as before loading them. If a positive correction is applied to azimuth or elevation the antenna instantly shows a lower value than before the correction, as expected from equations 2 and 1, until the previous position is reached.

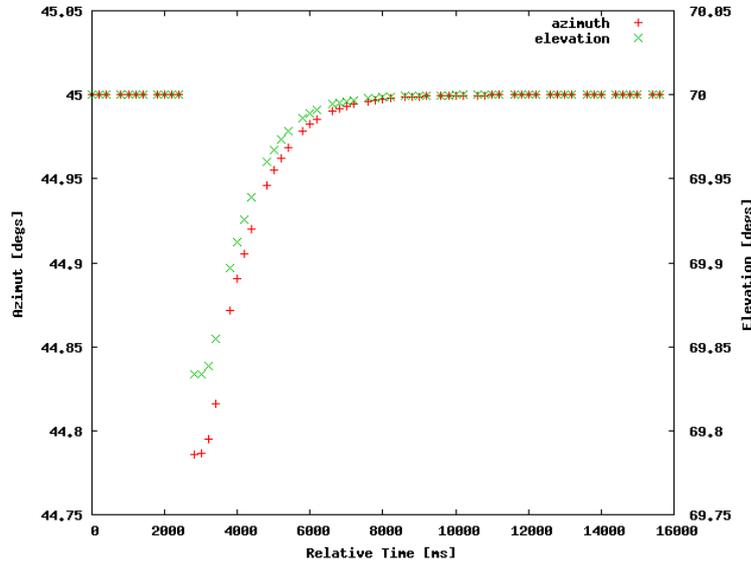


Figura 1: Azimuth and elevation before and after loading a pointing correction in the ACU. The jump is due to a change of the reference system. The antenna moves to the original commanded position (45, 70) in the new reference system after the change. The buggy behaviour described in 4.1 was still present.

See 1 for an example. Antenna position (azimuth and elevation) is displayed versus time. The antenna is at (45,70) before the pointing correction. When the correction is loaded there is a jump and then the antenna moves to (45,70) in the new reference system.

The pointing correction is also easily seen in the LCP when the antenna is stowed. For example, if there is no pointing model the stow position will be (45, 89.57). If a pointing model is loaded in the ACU, the stow position will differ from the previous values. To avoid confusion the current antenna component resets the pointing model, any manual pointing correction and refraction correction everytime the antenna is sent to stow position. In any case refraction has a negligible contribution at 89.57 degrees elevation.

### 3. Pointing corrections commands

The ACU provides three commands to correct the pointing of the 40m antenna and all of them are implemented as described in the previous section. These commands are included in the ACU component and are briefly described below:

- Manual pointing correction. The IDL command is:

```
pointingCorrection(in cmdPointingCorrectionMode azPointCorrMode,
                  in cmdPointingCorrectionMode elPointCorrMode,
                  in double pointingCorrectionAz,
                  in double pointingCorrectionEl)
```

where `azPointCorrMode` and `elPointCorrMode` are the correction modes and they may take the following values:

- `RELATIVEpc`. Corrections are summed to previous ones entered by this same command.
- `ABSOLUTEpc`. Previous corrections by this same command are disregarded and the new ones are taken into account.

In both cases these corrections are added to the other two pointing correction commands. `pointingCorrectionAz` and `pointingCorrectionEl` are the pointing corrections to be applied in degrees. The allowed range is  $[-3^\circ, 3^\circ]$ .

**Note on version 1.1:** This command was modified by MT-Mechatronics as requested by OAN in 2008 so that the azimuth correction is the horizontal angle in the sky. Hence the correction in the servo system should be:

$$\delta Az_0 = \frac{\delta Az}{\cos El} \quad (3)$$

and it constantly depends on the elevation of the antenna.

- Refraction correction. This command is described by de Vicente 2003. The algorithm is as follows:

$$\delta El = R_0 \text{abs} \left[ \tan(90^\circ - El - \frac{B_1}{El + B_2}) \right] \quad (4)$$

where  $El$  is the elevation and  $R_0$ ,  $B_1$  and  $B_2$  are parameters which depend on the current weather conditions. Units for  $R_0$  are arcsecs and degrees for  $B_1$  and  $B_2$ . This correction is applicable for radio observations and should be used with care when observing in the visible part of the spectrum. Up to 40 arcsecs of error at 10 degrees is made if this algorithm is used to correct at optical wavelenghts (see Planesas 2007).

The IDL command is:

```
pointingModelMeteorologicalData(in cmdRefractionCorrectionMode rcm,
                                in double b1,
                                in double b2,
                                in double r0)
```

where `rcm` may take the following values:

- `USENEWVALUESrc` Values passed as parameters are used for the correction.
- `USEDEFAULTSRC` Default values, 0, are used and passed parameters are ignored.

- Pointing model correction.

The signs of some pointing model parameters described by de Vicente 2003, were modified in the ACU in 2007, and the final pointing algorithm to be used is the one described in de Vicente 2007c. We include it here for simplicity:

$$\delta Az = P_1 + P_2 \sec El + P_3 \tan El - P_4 \cos Az \tan El + P_5 \sin Az \tan El \quad (5)$$

$$\delta El = P_7 + P_4 \sin Az + P_5 \cos Az + P_8 \sin El + P_9 \cos El \quad (6)$$

Each parameter is described throughly by de Vicente 2007c.

The IDL command is:

```
pointingModelParameter(in cmdPointingModelMode pmm,
                      in pointingParameters pps)
```

where `pmm` can take the following values:

- `defaultPM`. Use default values (usally 0). Parameters are ignored. Default values are set by MT-Mechatronics.
- `newPM`. Use new parameters, that is, passed parameters.

and `pps` is a sequence of 9 doubles. Units are arcsecs. The maximum allowed correction is 2 degrees.

The total pointing correction in azimuth and elevation from the three previous commands is displayed in the ACU status message. Individual contributions are not included in the ACU status message.

In order to check if the pointing corrections (values and signs) were correctly implemented, observations with the optical telescope were performed. The results are summarized in next section.

## 4. Pointing corrections check using an optical telescope

We tested the current pointing model using the optical telescope and a CCD camera described in report IT-OAN 2007-25, while observing Venus. The procedure to check pointing corrections was done in several steps:

1. Venus was centered in the center of the optical CCD crosshair, using the ACU command which allows to add az and elevation offsets, and taking into account that all pointing parameters were 0. The IDL command for the `oanAcu40m` component that allows to add relative offsets to the main drives is:

```
mainDriveOffset(in cmdOffsetModeMD azOffM,
               in cmdOffsetModeMD elOffM,
               in double azOffset,
               in double elOffset)
```

where `azOffM` and `elOffM` can take the following values:

- relative offsets to the current value (`relOffsetMD`,
- absolute offsets (`absOffsetMD`
- clear the offsets to 0 (`clearOffsetMD`).

and `azOffset` and `elOffset` are the offsets used in degrees.

Let `OffAzi` and `OffEli` be the required offsets to center Venus in the CCD when refraction and the pointing model are not active in the ACU.

2. The pointing correction parameter (could be refraction, manual pointing or pointing model) to be checked was set to 1000 arcsecs. After applying the change, the antenna moved and Venus was off the center of the crosshair.
3. Venus was recentered again using the same command as in the first item. Let `OffAzf` and `OffElf` be the required offsets to center Venus again.
4. Both offsets, the final one and the original one were subtracted and a pair of values were obtained:

$$\begin{aligned}\delta\text{OffAz} &= \text{OffAz}_f - \text{OffAz}_i \\ \delta\text{OffEl} &= \text{OffEl}_f - \text{OffEl}_i\end{aligned}$$

5. These values were compared with the expected ones ( $\delta Az$  y  $\delta El$ ) according to 5 and 6 if we were checking the pointing model or according to 4 if refraction was being checked.

Table 1 summarizes the tests performed in December 10th 2007, using the pointing correction command, the refraction command and the pointing model command from the ACU.

Conclusions:

- The sign of the pointing corrections seems to be correct in all cases.
- The magnitude of the pointing corrections is close to the expected values, except for parameters  $P_8$  and  $P_9$ , which seem to be exchanged in the algorithm implemented in the ACU.

MT-Mechatronics corrected the latter error by the time this report was written, and currently the pointing model algorithm seems to work correctly.

#### 4.1. Manual pointing corrections: azimuth collimation. Version 1.1

After the tests described previously, the author requested a modification in the manual pointing correction command to use azimuth collimation corrections instead of azimuth correction in the servos. Azimuth collimation is the horizontal angle in the sky and it is related to azimuth as expressed in equation 3. The implementation is easier to be done in the ACU since elevation has to be constantly read and used for the correction.

$Az$ (°)	$El$ (°)	Parameter / Value (")	$\delta\text{OffAz}$ (")	$\delta\text{OffEl}$ (")	$\delta Az$ (")	$\delta El$ (")
180.0	38.1	$P_1 = 1000''$	-1010	0	-1000	0
188.6	37.0	$P_2 = 1000''$	-1260	0	-1236	0
192.0	36.6	$P_3 = 1000''$	-740	-5	-742	0
194.0	36.5	$P_4 = 1000''$	-720	235	-720	241
195.6	36.4	$P_5 = 1000''$	200	955	200	963
185.2	37.4	$P_7 = -2780''$	0	2790	0	2780
197.9	35.5	$P_8 = 1000''$	0	-815	0	-581
213.1	31.0	$P_9 = 1000''$	0	-530	0	-857
184.0	37.4	$p\text{corrAz} = 780''$	-1010	0	-981	0
184.0	38.1	$p\text{corrEl} = -2790''$	0	2790	0	2790
213.8	30.9	Refraction = 95,5''	0	75	0	95.5

Cuadro 1: Columns 4 and 5 are the corrections applied to compensate for the antenna movement after applying corrections on column 3. Columns 6 and 7 list the expected values to compensate for the corrections applied on column 3. Observations were performed on Venus. Applied offsets can have errors as big as  $\pm 15$  arcsecs.

After the implementation by MT-Mechatronics the command was tested. Figure 2 shows an interesting behaviour from the test. When a manual pointing correction in azimuth (600 arcsecs) was included and the antenna moved from 30 degrees elevation to 80 degrees elevation, azimuth showed an oscillation that repeated each  $\sim 6$  degrees. This was an implementation bug: elevation was not converted from degrees to radians.

The bug was fixed in the ACU and the command currently works correctly.

## 5. Primitive pointing model search with an optical telescope

The first pointing offsets were determined by pointing the antenna towards the moon, and adding experimental offsets in steps of 900 arcsecs, until the image was centered in the CCD. On October 4<sup>th</sup> 2007 a series was done around  $Az, El = (260 \text{ degs}, 49 \text{ degs})$ . Measured offsets were (0, -2300 arcsecs).

In order to obtain a simple model we assumed that the most important contributions to pointing errors came from parameters  $P_1$ ,  $P_2$  and  $P_7$ , which arise from encoder offsets and collimation errors respectively.  $P_7$  has a strong influence depending on elevation and in order to make tests with the antenna at different elevations this parameter should be determined as soon as possible. We assumed that the pointing model could be written as a first approximation as:

$$\delta Az = P_1 + P_2 \sec El \quad (7)$$

$$\delta El = P_7 \quad (8)$$

taking into account that  $P_4, P_5, P_8$  and  $P_9 \ll P_7$ , which cannot be justified by the time this was assumed, but can be accepted as the first step of an iterative process.

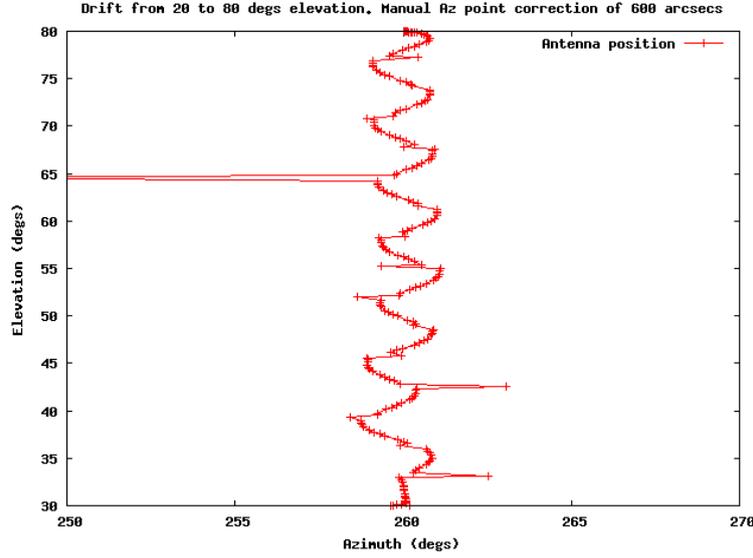


Figura 2: Elevation versus azimuth while moving the antenna from 30 degrees to 80 degrees elevation. A manual pointing correction of 600 arcsecs was applied. This shows an implementation bug in which degrees have not been converted to radians. The bug was fixed.

Vega was observed at two different positions in the sky and offsets were applied to the main drives to place the star in the center of the CCD crosshair. The difference between the applied azimuth offsets allows to estimate  $P_2$  once the elevation is known:

$$\Delta Az = \delta Az_1 - \delta Az_0 = P_2 \sec El_1 - P_2 \sec El_0 \quad (9)$$

$$(10)$$

and

$$P_2 = \frac{\delta Az_1 - \delta Az_0}{\sec El_1 - \sec El_0} \quad (11)$$

$$(12)$$

Results are summarized in table 2.

$Az$ ( $^\circ$ )	$El$ ( $^\circ$ )	$\delta Az$ ( $''$ )	$\delta El$ ( $''$ )
82	64	-480	-2400
87	71	-1680	-2250

Cuadro 2: Columns 1 and 2 are Vega's azimuth and elevation. Columns 3 and 4 are offsets entered at the antenna to center the star in the crosshair.

$P_2$  was estimated to be  $-1518''$  and  $P_1 = 3125''$ .  $P_7 \simeq -2300''$ . This correction allowed to make tests with the optical telescope at a wide range of elevations. The different offsets applied at elevations of  $64^\circ$  and  $71^\circ$  show that discarded pointing parameters cannot be neglected.

After this preliminary determination a pointing session with bright stars covering a wide range of Az and El was performed. The session was done using the pointing model parameter command and the estimated values for  $P_1$ ,  $P_2$  and  $P_3$ . This allowed to complete the observation without adding offsets to keep the star image within the CCD field of view. The result from this pointing session and the parameter determination from a least square analysis is described in a different technical report (see Alonso et al. 2008).

This pointing model is not usable for radio receivers at the 40m radiotelescope since the collimation errors are different in both cases. However some parameters, like azimuth encoder offset, non perpendicularity between azimuth and elevations axis and lack of verticality of the azimuth axis, are common for both the optical and the radio receivers.

## Referencias

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