Encoder hysteresis at the 40 m radiotelescope

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Revision history

Version	Date	Author	Updates
1.0	01-04-2009	P. de Vicente	First version
1.1	01-02-2010	P. de Vicente	Second version including tests at the beginning of february
1.2	01-03-2010	P. de Vicente	Third version including last tests

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1. Introduction

In 2008 it was discovered that the 40m antenna elevation encoders did not work correctly. This report describes tests performed to observe and diagnose the problem.

2. First sympthoms

The problem was first seen when making pointing scans at 22 GHz, while tracking a source (3C84) from zenith to the horizon and immediately after tracking another source (DR21) from the horizon to the zenith. Elevation drifts showed a pointing error jump of approximately 40 arcsecs between both sources (see de Vicente 2008). These measurements were done using only one encoder at the antenna since the other one was broken by that time. Figure 1 shows the behaviour.

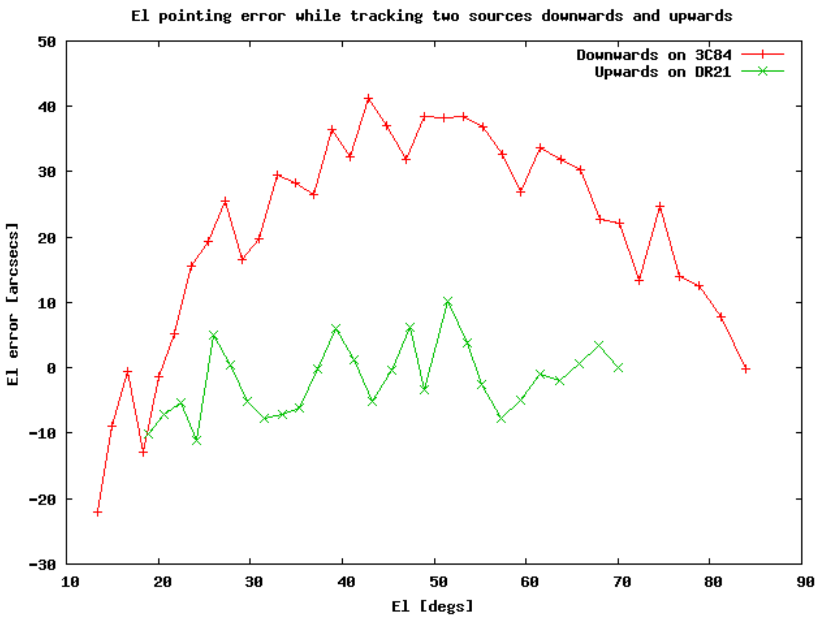

Figura 1: *Elevation errors obtained from elevation drifts on 3C84 (downwards) and DR21 (upwards).*

3. Tests on August 2009

Three kind of tests were performed on August 12th, 2009 with both encoders working in the position control loop.

- The first test consisted in checking the pointing errors on two elevation scans on 3C84, after coming upwards from the horizon or downwards from the zenith. The scans on 3C84 were done at $\sim$ 11 UTC at 33 degrees elevation. Each scan was composed of 4 subscans, two azimuth drifts in opposite directions and two elevation drifts in opposite directions. The results are summarized in table 1.

Area [V km/s]	Pos [arcsecs]	Width [arcsecs]	Ampl. [V]	Drift	Direction
303 ± 6	$21{,}0 \pm 0{,}8$	$80{,}2 \pm 2{,}0$	3.5	Az	Upwards
312 ± 3	$2{,}2 \pm 0{,}4$	$81{,}0 \pm 1{,}0$	3.6	Az	Upwards
285 ± 2	$-1{,}0 \pm 0{,}3$	$87{,}3 \pm 0{,}8$	3.1	El	Upwards
271 ± 2	$-14{,}0 \pm 0{,}3$	$82{,}7 \pm 0{,}8$	3.1	El	Upwards
113 ± 2	$15{,}4 \pm 0{,}4$	$70{,}0 \pm 0{,}9$	1.5	Az	Downwards
128 ± 1	$-0{,}2 \pm 0{,}4$	$76{,}9 \pm 1{,}0$	1.6	Az	Downwards
267 ± 2	$51{,}2 \pm 0{,}4$	$81{,}4 \pm 0{,}9$	3.1	El	Downwards
268 ± 1	$23{,}1 \pm 0{,}2$	$85{,}8 \pm 0{,}5$	2.9	El	Downwards

Cuadro 1: *Two pointing scans on 3C84 (12/09/2009) at 11 UTC, coming previously from the horizon (upwards) and from the zenith (downwards). Elevation was* $\sim 33°$. *Each scan was composed of 4 subscans, two azimuth drifts in opposite directions and two elevation drifts in opposite directions.*

- The second test consisted in reading the encoders positions while moving the antenna from zenith to the horizon and viceversa. The antenna was moved from 3.5 to 89 degrees elevation at an azimuth of 45 degrees and viceversa while reading both elevation encoders. Data were taken on August 12th 2009 at 9:00 UTC, with a time resolution of 50 ms. Figure 2 shows the difference between encoder 1 and encoder 2 readouts as a function of elevation in two different directions.

  Encoder 1 is the left one, as one sees the receiver cabin towards the vertex. Encoder 2 is at the right.

- The third test was performed to check the behaviour of the antenna at mid elevations. The sequence of movements is summarized in table 2 and the result is in figure 3

3.1. Discussion

Figures 2 and 3 show a typical hysteresis curve. Encoder 1 always displays a higher readout than encoder 2 which is maximum ($\simeq 100''$) at low elevations and minimum ($\simeq 10''$) close to the zenith. The difference depends in the direction of movement of the antenna, and generates a typical hysteresis curve. The difference between both encoder positions as a function of elevation is unpredictable, although it is always constrained by the two curves displayed in Fig. 2, obtained by moving the antenna from zenith to horizon and back.

If there were no hysteresis and it existed a difference that increased as elevation descreases, the pointing error generated could be absorbed by the pointing model. The hysteresis causes a pointing error in elevation which can be as high as 60 arcsecs. This value is the difference between the limiting curves at elevations between 20 and 50 degrees. Out of this interval the errors decrease as we move towards the limits (89 and 4 degrees elevation). These errors are

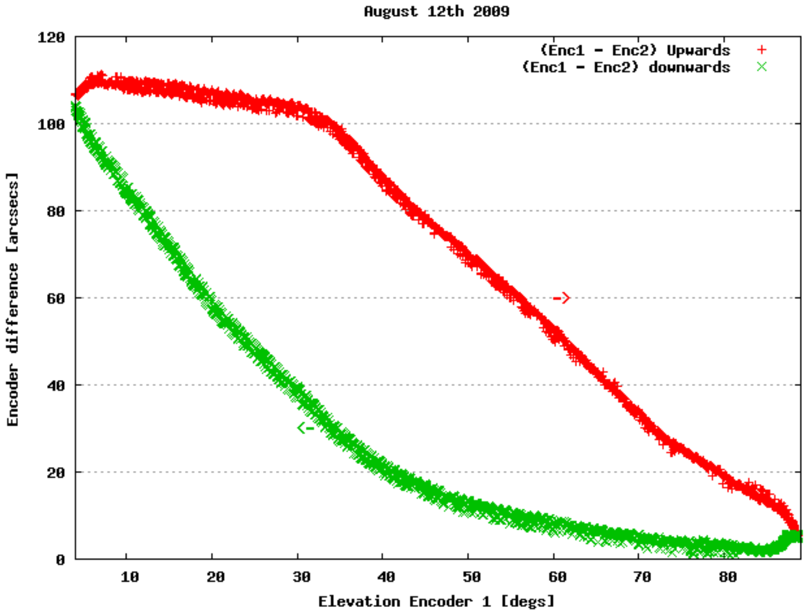

Figura 2: *Encoder difference in arcsecs versus elevation (according to encoder 1) while moving the antenna from the horizon to the zenith (upwards) and viceversa (downwards).*

Starting position	End position
(297, 88)	(297, 33)
(297, 33)	(297, 70)
(297, 70)	(297, 30)
(297, 30)	(297, 70)
(297, 70)	(297, 30)
(297, 30)	(297, 4)
(297, 4)	(297, 30)
(297, 30)	(297, 70)
(297, 70)	(297, 30)
(297, 30)	(297, 4)
(297, 4)	(297, 30)
(297, 30)	(297, 4)

Cuadro 2: *Antenna movements to check the encoders behaviour.*

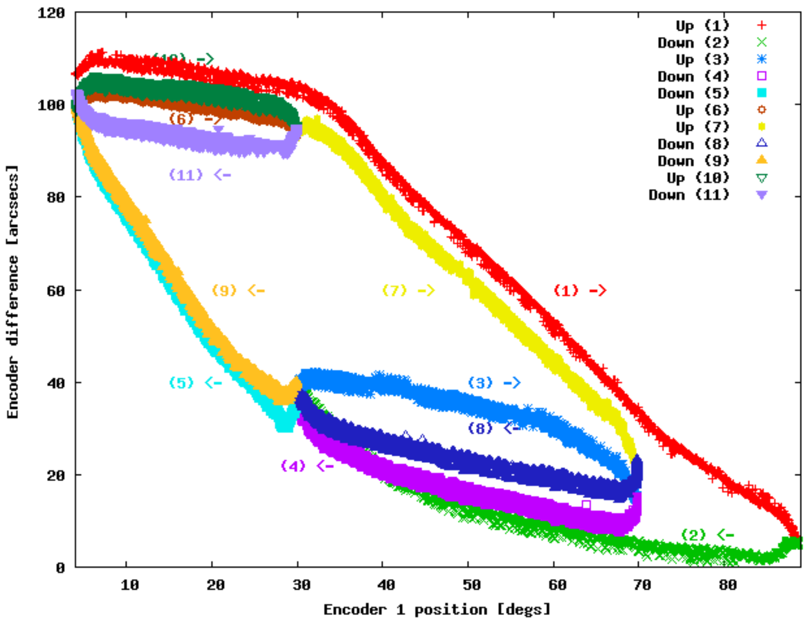

Figura 3: *Encoder difference in arcsecs versus elevation (according to encoder 1) while moving the antenna at different positions.*

so high and depend on the direction of movement that render the telescope pointing at 90 GHz useless and have a very high impact at 22 GHz.

The difference on readout between encoder 1 and 2 as a function of direction may be real or due to a non working encoder. To distinguish between these two possibilities the antenna should be stowed and encoders exchanged. If there is a third encoder then the procedure can be done in two steps so that always one encoder is in the antenna and can be used as a reference for the new encoder to be mounted. After exchanging the encoders the measurements should be repeated.

If after exchanging encoders, the hysteresis curve were the same, then the readous are correct and there is mechanical problem in the antenna. On the contrary, if the curve changes its orientation in such a way that encoder on the left reads less than the encoder on the right, then the error may be due to an encoder which is not working correctly. A simulation is shown in figure 4.

If the readouts are correct there is probably a mechanical problem either due to the connection between the encoders and the axis where they are mounted or, to a lack of balance between both sides of the antenna associated to a friction force.

A non balanced antenna, that is a an antenna in which the counterweights have a different weight, would cause a torque between both sides proportional to the gravity force and hence to the cosine of elevation. It should be maximum towards the horizon:

$$\tau = k\, r \Delta M g \cos(el) \tag{1}$$

where r is the distance to the gravity center of the counterweight and ΔM the difference in mass between both counterweights. k is a constant related to the elasticity of the structure. See

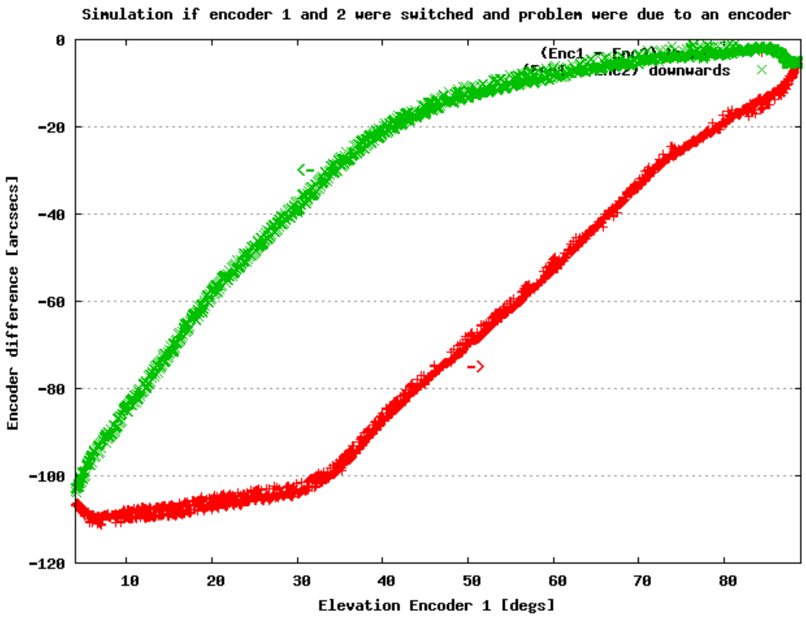

Figura 4: *Encoder difference in arcsecs versus elevation, according to encoder at the left, once the encoders have been exchanged with respect to the situation depicted in 2. This is not real data but a simulatino based on data from figure 2*

figure 5 where we compare that function (for a distance of 2 m and a difference of weight of 6 kg and $k = 1$) with the curve obtained from the encoders. Both curves can be compared if we assume that the encoder difference is proportional to the torque and the proportionality constant is 1. The latter value is totally unrealistic and has been chosen to show the similiarity of the curves.

As it is easily seen the unbalance does not explain the hysteresis curve unless there is a friction force that ”delays” the torque. The friction force works such that the displacement does not begin until a limit value is exceeded. This is clearly seen in hysteresis curves (fig. 2), which are almost flat at the zenith when going downwards and at the horizon when going upwards. When being at the zenith the difference between both encoders stays almost constant for 30 degrees, and the same happens towards the horizon.

4. February 2010 tests

4.1. First series

Three types of tests were performed on February 3rd 2010:

- Encoder 1 was not used in the control loop of the antenna. Movements from zenith to horizon and back were performed. Pointing on Jupiter at 22 GHz was done coming from the zenith and from the horizon.

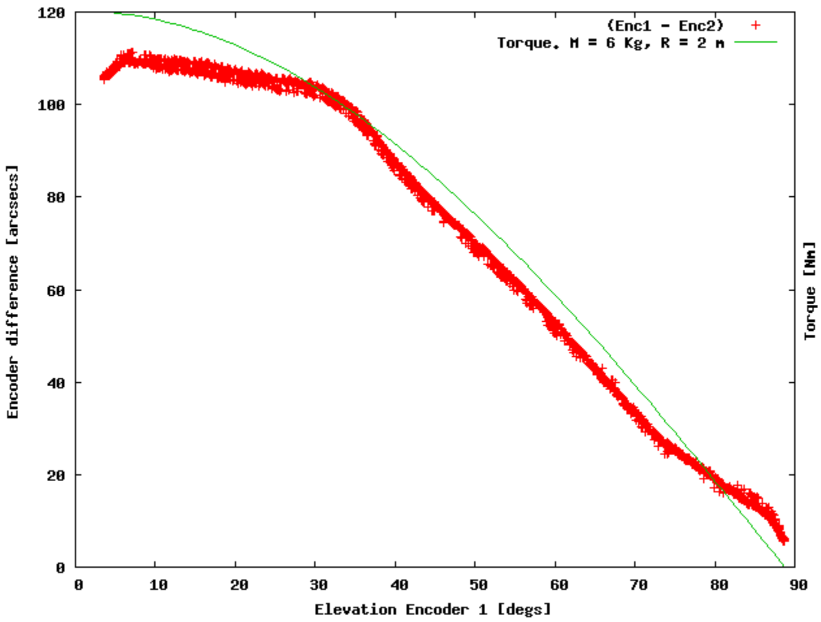

Figura 5: *Torque as a function of elevation due an unbalanced antenna, on top of the encoders' difference. The displacement between both encoders should be proportional to such difference (unknown proportionality constant). An arbitrary mass difference of 6 Kg, a radius of 2 m, and a constant equal to 1 have been assumed.*

- Encoder 2 was not used in the control loop of the antenna. Movements from zenith to horizon and back were performed. Pointing on Jupiter at 22 GHz was also done coming from the zenith and from the horizon.
- Both encoders were used in the control loop and the same conditions as the previous ones were repeated.

The curves Encoder 1 - Encoder 2 versus Encoder 1 are shown in figure 6 for cases 1 and 2 described above. There are no important differences between the three cases. There is a very important fact, encoder 1 readouts are always lower than encoder 2 readouts, contrary to what was seen in August 2009 figures. However, although this is consistent with encoders being exchanged in between both epochs and the hysteresis curve arising from an encoder fault, this is not the case, since encoders were not exchanged. This difference is consequence of reversing the substraction (Encoder 2 - Encoder 1) instead of (Encoder 1 - Encoder 2) as in the previous epoch measurements.

Pointing fits towards Jupiter are summarized in table 3.

As we can see, the pointing error difference between upwards and downwards movements when using only encoder 1 in the control loop, are close to zero, while this is not the case when encoder 2 or when both encoders were used. However these data should be considered carefully since after changing the “active” encoders in the control loop, the pointing correction model algorithm seemed to fail and this may have influenced the results.

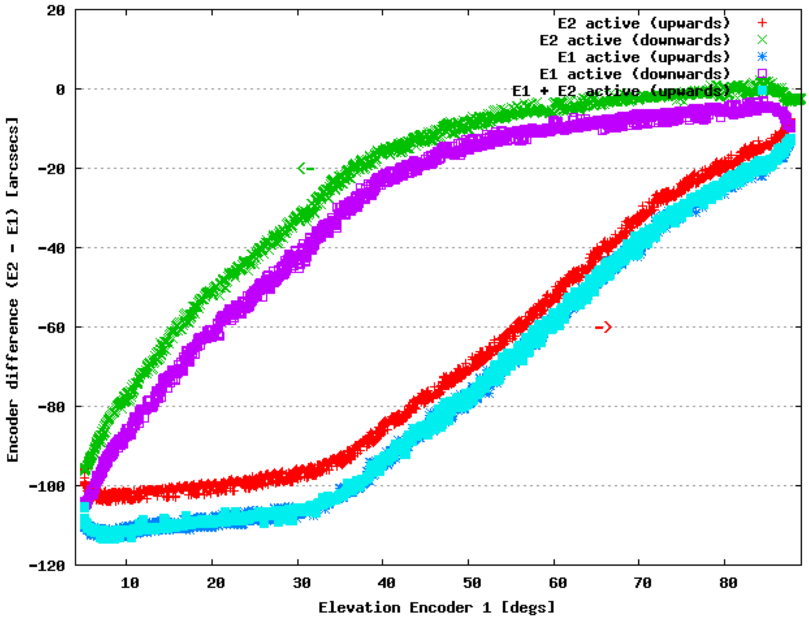

Figura 6: *Encoder difference in arcsecs versus elevation (according to encoder 1) while moving the antenna at different positions. Two series are depicted: encoder 1 being used in the control loop, encoder 2 being used in the control loop*

Area [V km/s]	Pos [arcsecs]	Width [arcsecs]	Ampl. [V]	Drift	Direction	Active encoder
440 ± 5	$18{,}9 \pm 0{,}5$	79 ± 1	5.2	Az	Upwards	E2
565 ± 3	$18{,}2 \pm 0{,}2$	79 ± 1	6.7	Az	Downwards	E2
734 ± 10	$-27{,}6 \pm 0{,}6$	90 ± 1	7.6	El	Upwards	E2
763 ± 4	$31{,}7 \pm 0{,}2$	84 ± 1	8.5	El	Downwars	E2
222 ± 2	$27{,}7 \pm 0{,}3$	$74{,}6 \pm 0{,}9$	2.8	Az	Upwards	E1
92 ± 6	33 ± 3	$100 \pm 8{,}4$	0.9	Az	Upwards	E1
664 ± 6	$64{,}0 \pm 0{,}4$	$82{,}6 \pm 0{,}9$	7.6	El	Downwards	E1
746 ± 3	$73{,}6 \pm 0{,}2$	$85{,}6 \pm 0{,}4$	8.2	El	Downwards	E1

Cuadro 3: *Pointing drifts on Jupiter (03/02/2010) at 11 UTC, coming from the horizon (upwards) and from the zenith (downwards). In the first 4 lines encoder 2 was the only one used in the antenna control loop, and in the last 4 lines encoder 1 was the last used in the antenna control loop.*

4.2. Second series

A second series of pointing checks were done on february 16th and 17th with 3 different encoders. Pointing scans on DR21 using left encoder, right encoder and both encoders were repeated. Since the weather was rainy and cloudy, the X band receiver was used. Pointing scans were composed of 4 subscans: 2 drifts in azimuth (go and return) and 2 in elevation (go and return), with a total length of 1800 arcsecs, a total subscan time interval of 90 seconds per subscan and an integration time of 1 second. The spatial resolution was 20 arcsecs.

Results are summarized in table 4. The first round of tests was done with encoders SN 22729861B (right) and SN 22729960B (left) on 3C84 at 63 degrees elevation and on DR21 at 35 degrees elevation. The second round was done after replacing encoder 2, at the right side (SN: 22729861B) by the spare one (SN: 22729962B). Pointing scans were done on 3C84 at 72 degrees elevation and on DR21 at 45 degrees elevation.

ΔEl_1 [”]	ΔEl_2 [”]	<ΔEl> [”]	$\Delta El_u - \Delta El_d$ [”]	El [degs]	Direction	Encoder(s) used (serial numbers)	Source Source
0	18	9		60	Downwards	E1 (960-B) + E2 (861-B)	3C84
-25	-7	-16	25	61	Upwards	E1 (960-B) + E2 (861-B)	3C84
17	7	12		63	Upwards	E1 (960-B)	3C84
17	1	14	2	65	Downwards	E1 (960-B)	3C84
22	40	30		39	Downwards	E1 (960-B)	DR21
6	7	7	23	34	Upwards	E1 (960-B)	DR21
-87	-86	-86		34	Upwards	E2 (861-B)	DR21
-14	-4	-9	77	33	Downwards	E2 (861-B)	DR21
5	8	6.5		30	Downwards	E1 (960-B) + E2 (861-B)	DR21
-33	-39	-36	42	30	Upwards	E1 (960-B) + E2 (861-B)	DR21
-53	-68	-60		48	Upwards	E2 (962-B)	DR21
7	18	72	72	47	Downwards	E2 (962-B)	DR21
28	34	31		42	Downwards	E1 (960-B)	DR21
11	27	19	12	42	Upwards	E1 (960-B)	DR21
-21	-9	-15		40	Upwards	E1 (960-B) + E2 (962-B)	DR21
-21	-9	-15	24	40	Downwards	E1 (960-B) + E2 (962-B)	DR21
-9	-12	-11		74	Upwards	E2 (962-B)	3C84
-6	-2	-8	4	75	Downwards	E2 (962-B)	3C84
2	-8	-3		69	Downwards	E1 (960-B)	3C84
32	4	17	20	72	Upwards	E1 (960-B)	3C84
-14	0	-7		76	Downwards	E1 (960-B) + E2 (962-B)	3C84
32	-18	16	16	79	Upwards	E1 (960-B) + E2 (962-B)	3C84

Cuadro 4: *Pointing drifts on DR21 and 3C84 at X band on february 16th and february 17th 2010 with different encoders. Column 4 indicates the elevation error difference between upwards and downwards*

Table 4 summarizes the tests performed on february 16th and 17th. First two columns indicate the elevation error obtained in elevation drifts when making an up and a down drift around the source. In principle the error could differ 20 arcsecs at most, due to the available spatial resolution. The third column contains the average of values in column 1 and 2 and it is the accepted elevation error. The fourth column is the difference in arcsecs between elevation errors when coming from the horizon (5 degrees) and from the zenith (87 degrees). The fith column indicates if the scan was preceeded by an upwards movement from the zenith or a downwards from the zenith. The sixth column indicates the encoders used in the control loop. Since encoder 2 was replaced, the serial numbers are also included. The last column contains the radio source used for the pointing.

Two hysteresis curves were done with both encoders activated (see Figure 7). The first one used encoders 861-B (right) and 960-B (left), and the second one 962-B (right) and 960-B (left). Both curves are similar. The difference between encoder 1 and 2 at 87 degrees elevation is almost zero with encoder 2 (962-B), while it is 5 arcsecs with encoder 2 (861-B). This difference depends on how it was referenced when mounted.

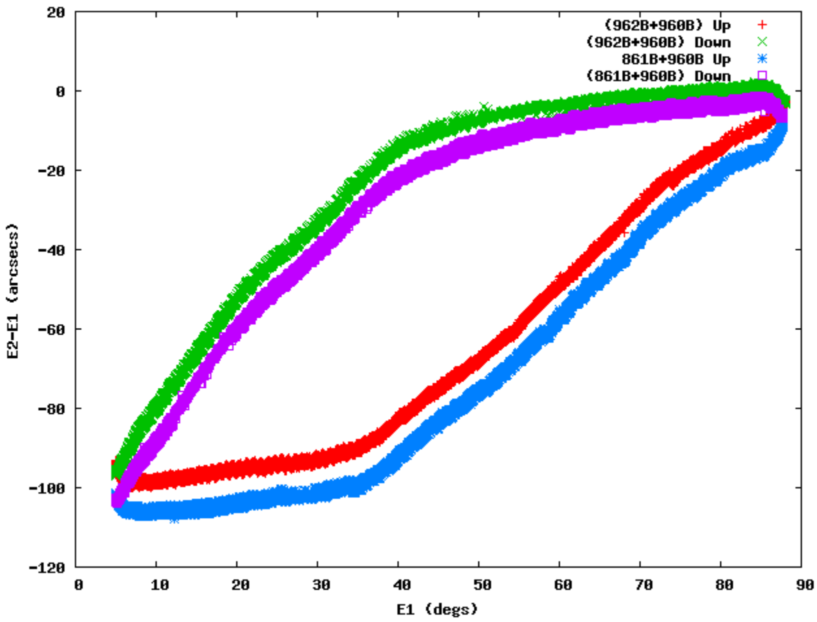

Figura 7: *Encoder difference in arcsecs versus elevation (according to encoder 1) while moving the antenna at different positions. Both encoders were used in the control loop. First series used unit 861-B as encoder 2. The second series used unit 962-B as encoder 1.*

4.3. Third series

A third series of measurements were performed after two supporting pieces of the elevation encoders were dismounted, examined and remounted. Since encoder 2 seems to be most affected only that side went under the examination of E. Sust and C. Albo. Encoder 2 shaft was dismounted from outside and remounted after turning it 180 degrees. A fast test was peformed after this operation. The test consisted in two pointing scans on DR21 with both encoders in the control loop. Results are summarized in table 5

ΔEl_1 [”]	ΔEl_2 [”]	$<\Delta El>$ [”]	$\Delta El_u - \Delta El_d$ [”]	El [degs]	Direction	Encoder(s) used (serial numbers)	Source Source
26	46	37		41	Downwards	E1 (960-B) + E2 (962-B)	DR21
-23	6	-9	46	39	Upwards	E1 (960-B) + E2 (962-B)	DR21

Cuadro 5: *Pointing drifts on DR21 at X band on february 17th 2010 with both encoders after remounting encoder 2 shaft*

4.4. Fourth series

A fourth series was done after the internal bearings of both encoders were inter exchanged on February 19th. Double pointing scans on 3C454.3 were done, with encoder 1 activated, with encoder 2 activated, and with both encoders activated. Results are similar to the previous ones or perhaps slightly worse, but no significative difference was found. The pointing scans wer done with the same charateristics as the second series.

ΔEl_1 [”]	ΔEl_2 [”]	$<\Delta El>$ [”]	$\Delta El_u - \Delta El_d$ [”]	El [degs]	Direction	Encoder(s) used (serial numbers)	Source Source
59	62	60		40	Downwards	E1 (960-B) + E2 (962-B)	3C454.3
3	14	8	52	42	Upwards	E1 (960-B) + E2 (962-B)	3C454.3
54	54	54		46	Downwards	E2 (962-B)	3C454.3
-22	-22	-22	76	46	Upwards	E2 (962-B)	3C454.3
45	43	44		40	Upwards	E1 (960-B)	3C454.3
11	52	31	31	13	Downwards	E1 (960-B)	3C454.3

Cuadro 6: *Pointing drifts on 3C454.3 at X band on february 18th 2010 after exchanging the internal encoder bearings*

A hysteresis curve was done with both encoders activated (see Figure 8). No significative difference was found with previous graphs.

5. Preliminary conclusions

- The hysteresis curve apparently is not caused by non-working encoders.
- Encoder 2 shaft seems to be properly attached. No difference was observed after turning it 180 degrees.
- Internal encoder bearings are apparently not the cause of the hysteresis, since the curve is exactly the same after exchanging them.
- While no cause for the hysteresis behaviour is discovered, a temporal solution would be to deactivate encoder 2 and not use it in the position control loop.

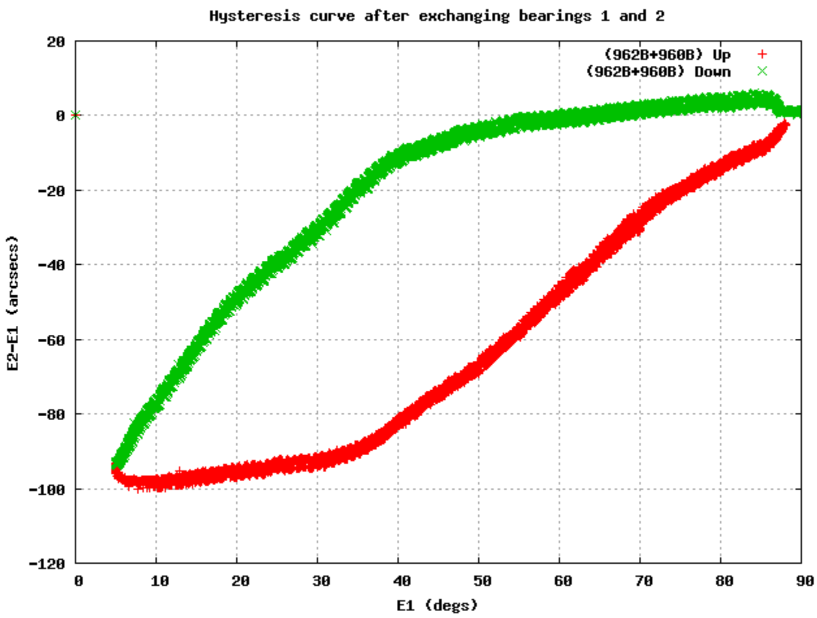

Figura 8: *Encoder difference in arcsecs versus elevation (according to encoder 1) while moving the antenna at different positions. Both encoders were used in the control loop. First series used for encoder 2 unit 861-B. the second series used for encoder 2, unit 962-B.*