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# Fast Switching Modes at the 12m ALMA Telescope

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***Abstract*—This paper presents the simulation and testing of the 12m ALMA Telescope's fast switching mode. This operation mode requires extremely high accelerations (up to 24°/s$^2$), which are unusual for telescopes of this size.**

## I. Introduction

THE prototypes of 12m ALMA Radio Telescope have been installed at the VLA site in New Mexico. The US prototype is in operation since 2003.

The ALMA telescope is very fast compared to other radio telescopes – up to 6 deg/s in azimuth and 3 deg/s in elevation. Nevertheless, the required sidereal tracking performance is even more challenging than usual; it allows for a total of as little as 0.6 arcsec rms during 20 m/s wind over short periods of time, so this budget also includes mechanical deformations due to wind as well as encoder inaccuracies.

Moreover, the scientists' specification includes "Fast Switching Modes", which allow them to scan the sky following a rectangular grid, or to move on and off the source very rapidly. For instance, a 1.5 degree movement of the main dish must be completed within 1.5s with an accuracy of 3 arcsec.

It is obvious that such a variety of dynamic requirements calls both for an extremely stiff structure and a sophisticated control system.

For the ALMA prototype various simulations were performed in order to check the telescope's dynamic performance for all relevant operation modes. This paper describes the simulation and testing of the fast switching mode, which appears to be the most critical operation mode for this telescope.

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**Figure 1.** ALMA US Prototype at the VLA near Socorro, NM

## II. Derivation of the Simulation Model

### A. Simulation Model

The realistic simulation of a telescope with 12m dish diameter requires a precise simulation model, which takes into account all dominant resonance modes as well as all system nonlinearities.

In order to analyse the telescope dynamics a simulation model was derived, which considers the telescope as a flexible structure. Hereby cross coupled effects between the azimuth and elevation axis as well as subreflector oscillations are taken into account. A simulation model which includes the dynamics of the drives as well as of the telescope structure can be derived with the aid of a finite element model and the modal analysis technique. The free rotor analysis of the finite element model provides eigenfrequencies and corresponding mode shapes up to a given frequency limit. These results can be transformed by modal techniques and serve as inputs for the simulation model.

### B. Control Concept

The controller model takes into account the digital (time discrete) control algorithms of the position and velocity controllers and all servo non-linearities. The main control concept is based on a fully digital cascade controller with some "add-on features" as shown in Fig. 2.

The innermost control loop is the current loop, which is fully integrated in the servo amplifiers. The output of these amplifiers are the motor currents, which finally generate the motor torques. The next loop is the velocity loop. The difference of commanded velocity and actual motor velocity is fed to a digital PI controller. The output of that controller is the commanded motor current. The outermost control loop is the position loop. The difference of the command position and the actual antenna position is fed to the digital position controller.

### C. Motion Profiler

All command inputs with steps higher than a given threshold are filtered by a motion profiler. This profiler generates stepless smooth curves for command position, velocity and acceleration. Fig. 3 shows the position step (black curve), the commanded position (blue curve), the commanded velocity (green curve) and the commanded acceleration (red curve). Besides a better servo performance the profiler also helps to reduce stress and wear of mechanical components such as gearboxes and pinions.

## III. Simulation Results

The fast switching mode was simulated for position steps of 1.5° and 4.0°. The requirement of the 1.5° step is to reach the final position with ± 3 arcsec position error within a time interval of 1.5 seconds. In case of a 4.0° step the allowance for settling time is 2.8 seconds.

The azimuth step responses for steps of 1.5° and 4.0° and the corresponding position errors are shown in Fig. 4 and 5 for the 0° elevation model. In case of the 1.5° step the position error limit of ± 3 arcsec is reached after 1.2 seconds. In case of the 4.0° step the settling time amounts to 1.8 seconds.

The elevation step responses of 1.5° and 4.0° and the corresponding position errors are shown in Fig 6 and 7, again for the 0° elevation model. Due to the lower telescope accelerations and velocities of the elevation axis the settling time for this axis is higher than for azimuth. For the 1.5° step the position error limit of ± 3 arcsec is reached after 1.47 seconds. In case of the 4.0° step the settling time amounts to 2.3 seconds.

## IV. Measurement Results

The on-site measurements recorded at the ALMA prototype basically confirm the simulation results. Fig. 8 shows the encoder pointing error as a function of time since the start of a fast switching slew of 1.77 deg. The antenna takes about 1.8 s to get on source, and it does so with a 2 arcsec RMS pointing error, which decays to less than 0.5 arcsec at about 3 s.

Measurements using an optical pointing telescope (Fig. 9) show that the entire telescope follows the movement of the drives very well. Since atmospheric fluctuations and optical seeing are included in these errors, it can be assumed that the accumulated mechanical and servo errors are less than the errors shown in Fig. 9.

## V. Conclusion And Outlook

The achieved performance of the ALMA prototype telescope shows that the very challenging specifications could indeed be fulfilled in reality, after having required a very detailed and lengthy analysis phase. It was consoling for all parties involved that the simulated and measured performance turned out to be very close.

For the ALMA production phase which is about to begin later this year – 50 identical radio telescopes to be installed in the Atacama desert in Chile at an altitude of 5000m – the requirements for Fast Switching have been tightened once again. In addition to be on source ±3 arcsec within 1.5s after a 1.5 degree step, the position must now be within ±0.6 arcsec after 2s. Fig. 8 shows that this has not yet been achieved.

Or, the entire telescope must be able to reverse a 0.5 deg/s movement within 0.8s and track again at an accuracy of ±2 arcsec.

The next challenges for the control system engineers are lying ahead.


## Acknowledgment

A portion of the measurements on site was carried out by the staff of the National Radio Astronomy Observatory (NRAO), which owns and operates the ALMA prototypes. The ALMA US prototype was built under a contract between NRAO / AUI and VertexRSI.


## References


[1] For more information on the ALMA project check http://www.alma.nrao.edu/info.

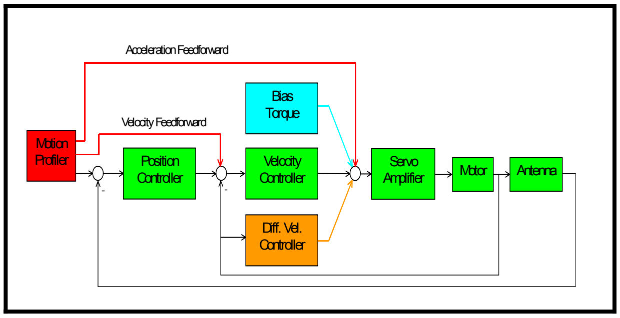


Fig. 2: Controller Concept (Overview)

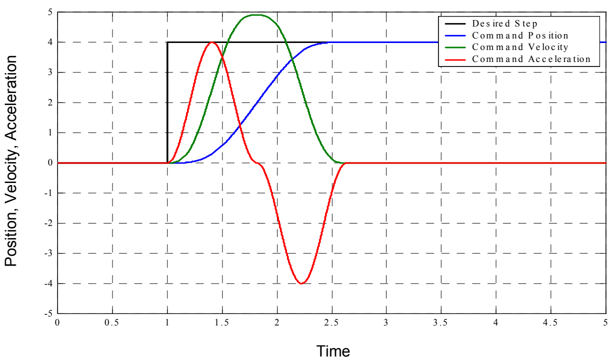


Fig. 3 Command position (blue curve), command velocity (green curve) and command acceleration (red curve), generated by the Motion Profiler

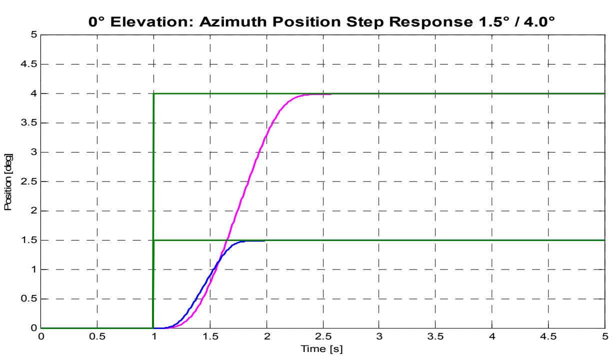


Fig. 4 Simulation of Fast Switching Azimuth: Position

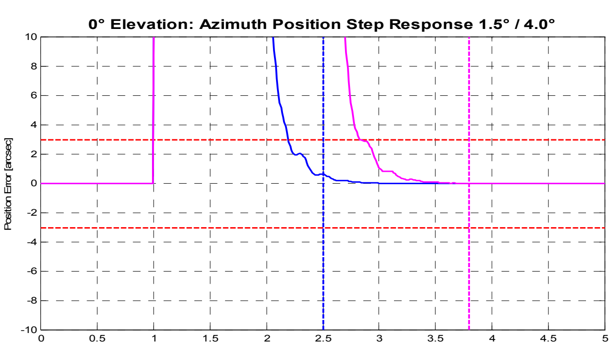


Fig. 5 Simulation of Fast Switching Azimuth: Position Error

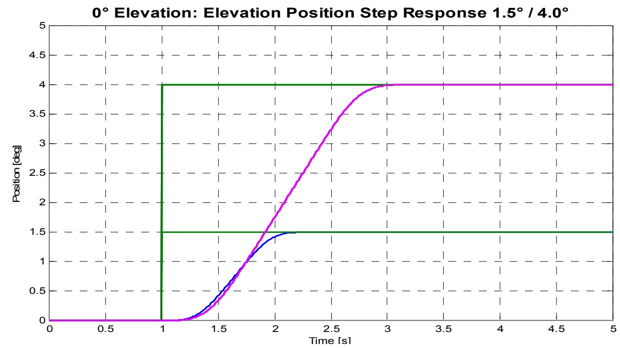


Fig. 6: Simulation of Fast Switching Elevation: Position

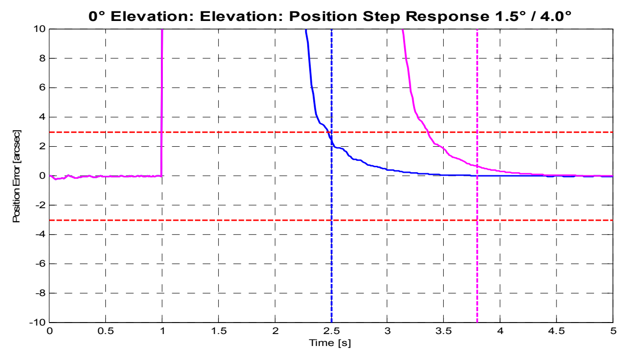


Fig. 7: Simulation of Fast Switching Elevation: Position Error

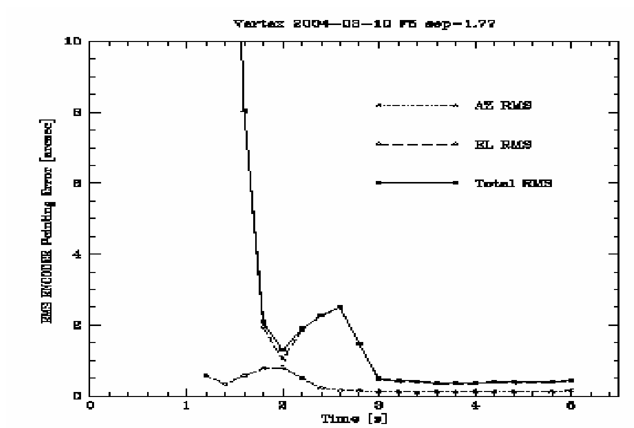


Fig. 8: Measured Fast Switching Performance: encoder position error after step of 1.77 deg

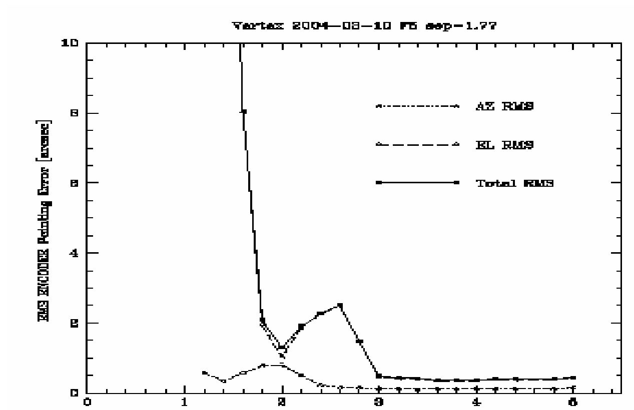


Fig. 9: Measured Fast Switching Performance: RMS optical pointing error after step of 1.77 deg