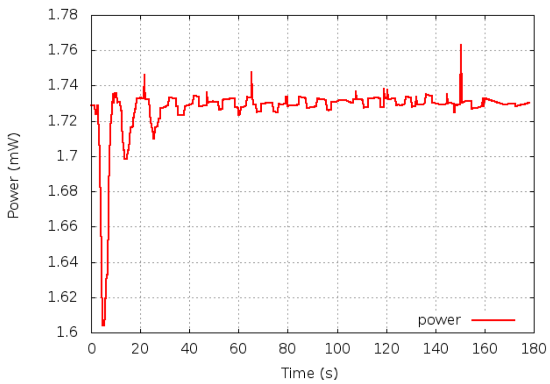
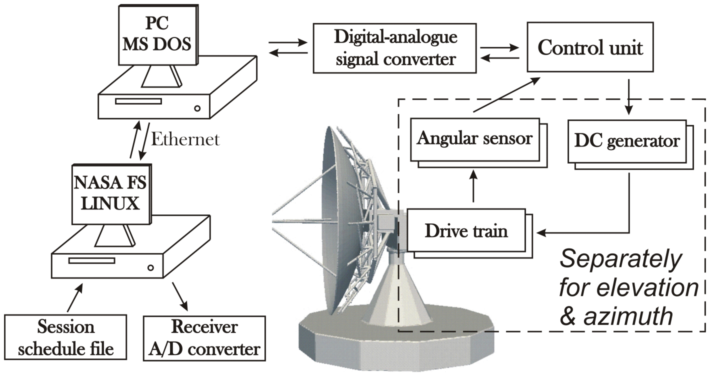
Pointing of large antennas, route planning and control algorithms





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Outline of the presentation

- Introduction
- Control function and its improvements
- Route planning algorithm
- Control system and its non-linearity
- Further work for suppression of remaining oscillations
- Summary

Introduction

- Two large ground based radio telescopes: RT-32 and RT-16 with diameters of 32m and 16m, respectively
- Cassegrain system antennas: dual reflector system with primary and secondary reflectors
- The azimuth and elevation rotation axes

Usage: VLBI networks & radar-VLBI

- The *European Very Long Baseline Interferometry* (VLBI) *Network* (EVN) is an interferometric array of radio telescopes spread throughout Europe (and beyond) that conducts unique, high resolution, radio astronomical observations of distant radio sources (quasars, masers).

***Requirements**:* fast switching between observational objects

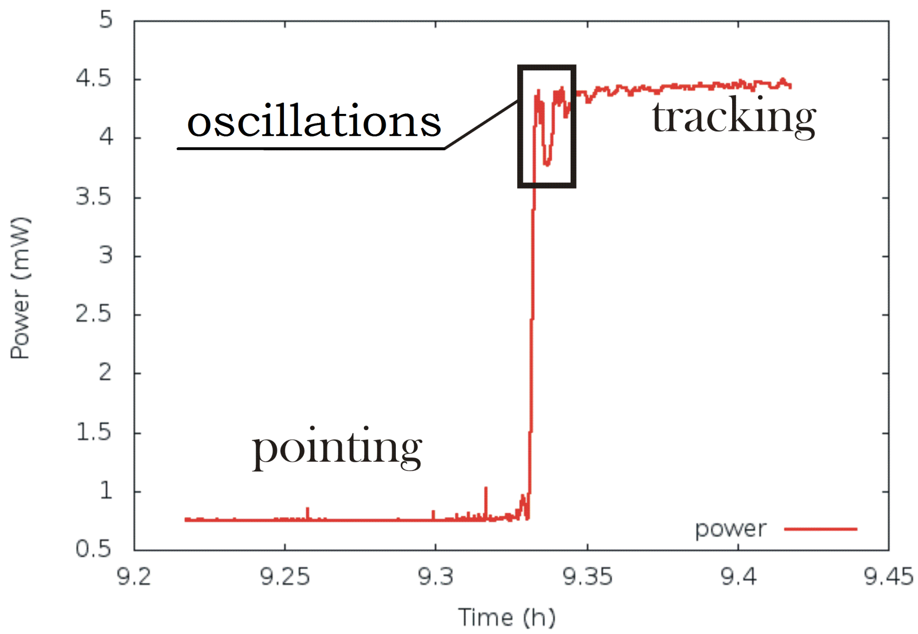
- The *radar-VLBI* method represents potentially a powerful tool for investigating radio-silent near-space objects (cosmic debris, asteroids).

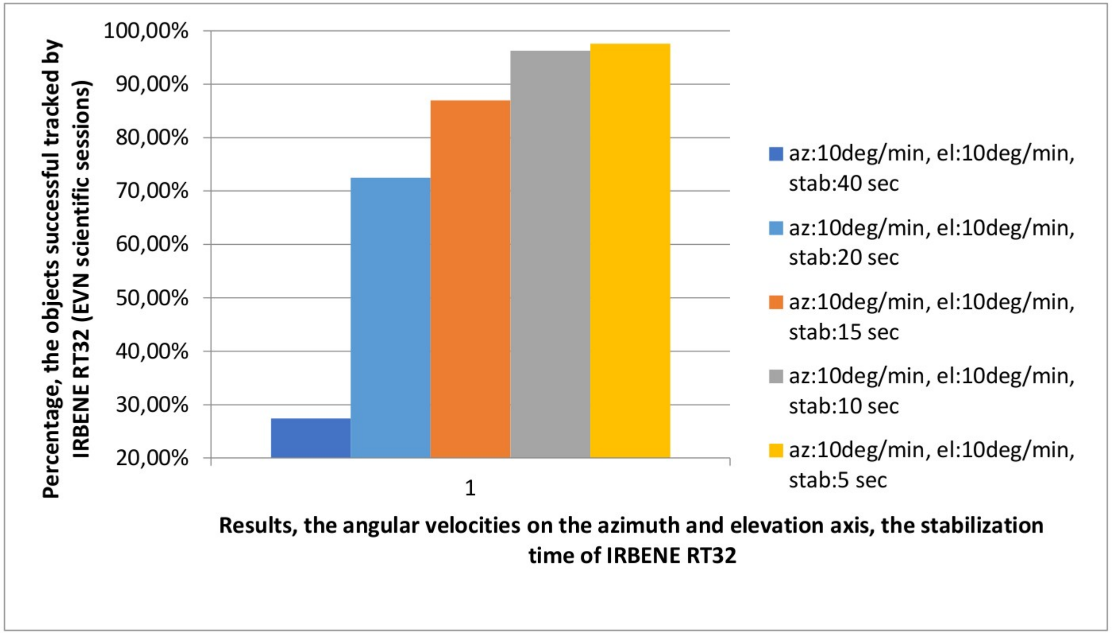
The combination of both techniques - radar for good range and radial velocity resolution and VLBI for angle and angular rate information - results in three dimensional measurements.

***Requirements**:* tracking of relatively fast objects.

The impact of oscillations

- Originally the stabilization time of RT-32 antenna was ~40sec, the azimuth and the elevation angular velocity ~10deg/min.
- More targets can be tracked by suppression of oscillations after target switching.





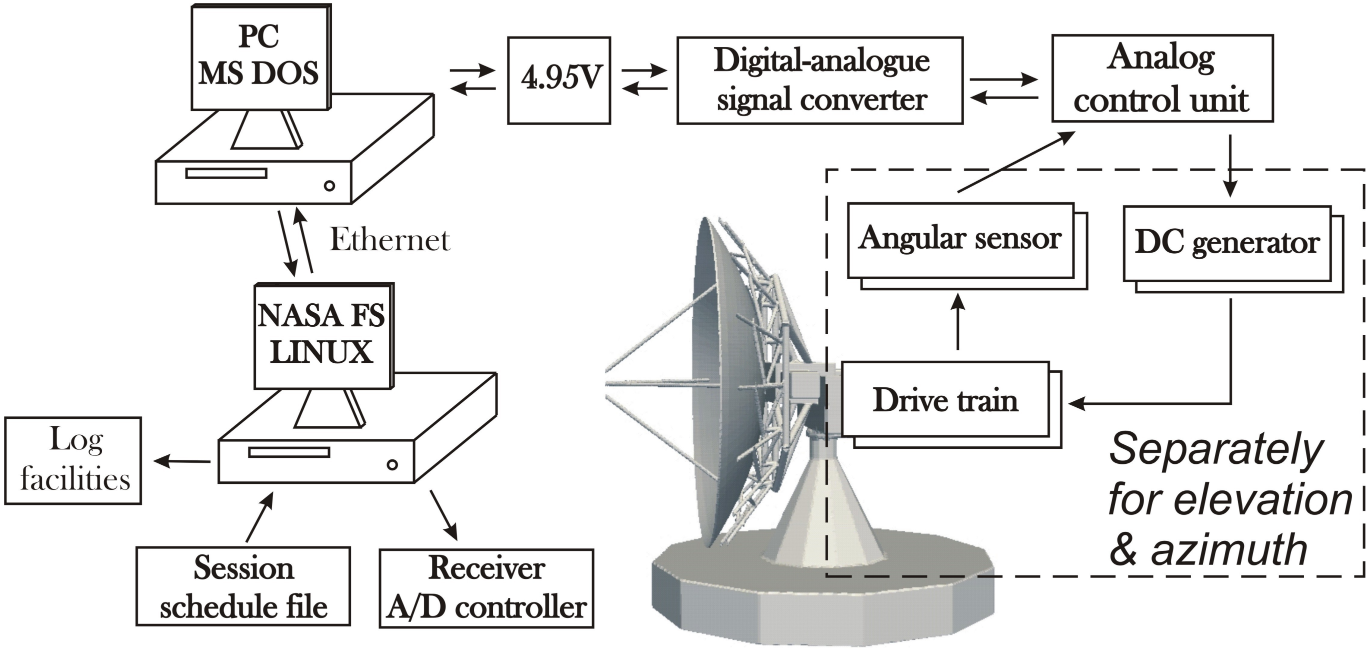
Aim of the studies

Objective of the study is to analyze and optimize control algorithms of the antenna without changing the existing hardware in terms of requirements for high accuracy observations.

Control system of the RT-32

Control system of RT-32 consist of two applications:

- MAIN – provide work of the antenna and astronomical modules for determination of the movement trajectory of the antenna (PC with MS DOS)
- CAP – provide remote connection to the MAIN application (PC with Linux)



Initial control function
(built in control software)

Proportional-Integral-Derivative (PID) control function

$$u = c_1 \Delta\varphi + c_2 \Delta\dot{\varphi} + c_3 I_\varphi \qquad (1)$$

$$I_\varphi = \int_0^t \Delta\varphi(\tau)\, d\tau \qquad (2)$$

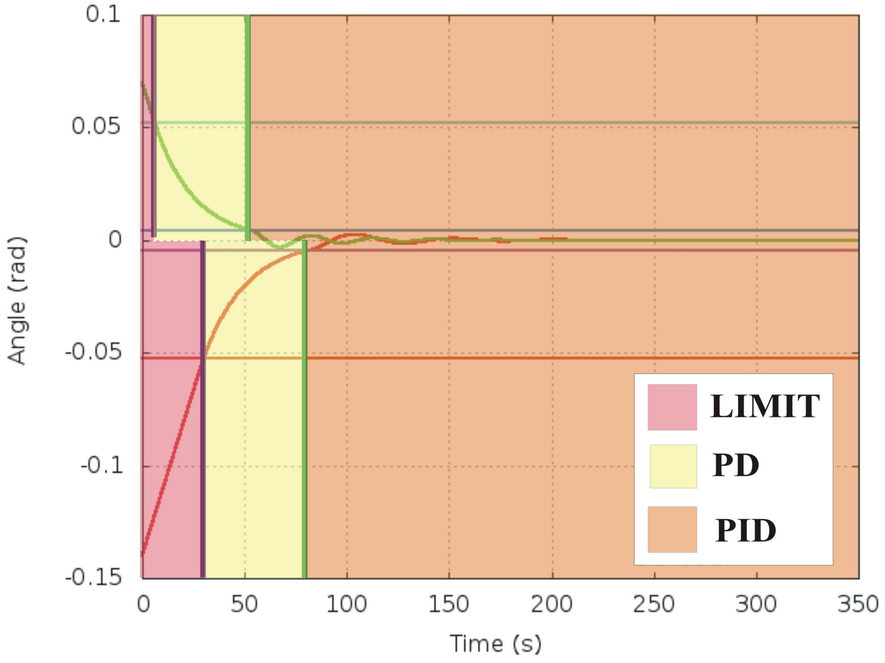
where $\Delta\phi = \phi - \phi_t$, ϕ – telescope azimuth (a) or elevation (e) angle, ϕ_t – target angle and the dot indicates time derivative.

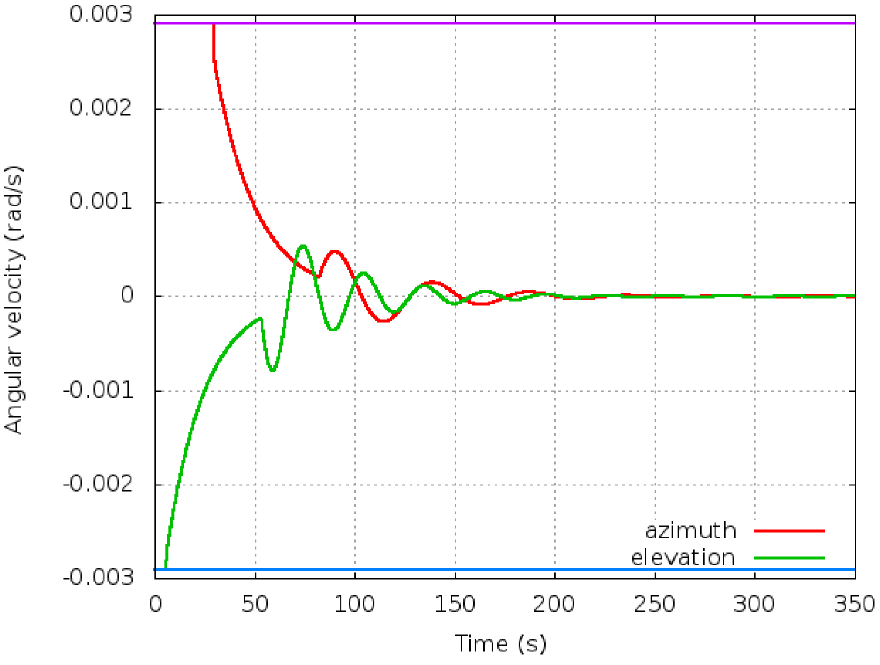
The AD converter imposes limit of output voltage

$$|u| < u_{0,}\ \mathit{where}\ u_0 = 4.95\text{V}\ \mathit{is\ a\ control\ voltage}$$

which breaks linearity of (1).

Modes of operation
(regions separate for each axis)

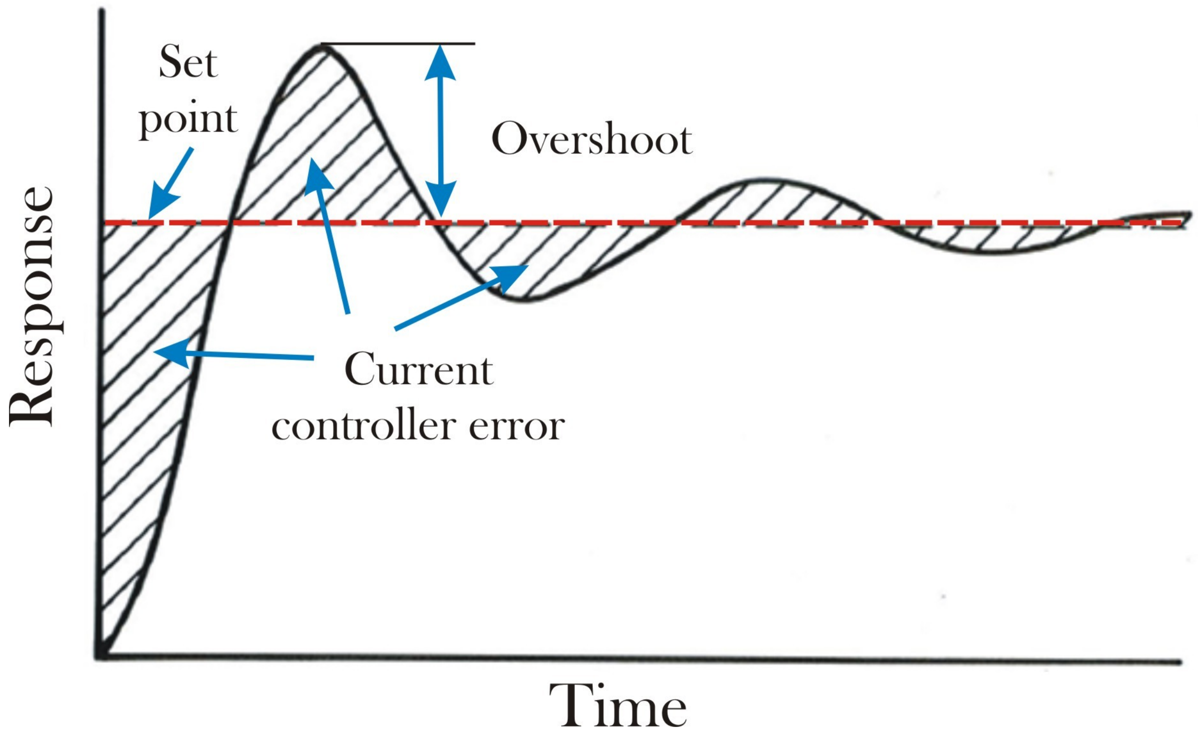




- More as ± 3deg – move with maximum speed (**LIMIT**)
- ± 3deg control function (Proportional-Derivative (**PD**))
- ± 0.25deg integral term (**PID**)

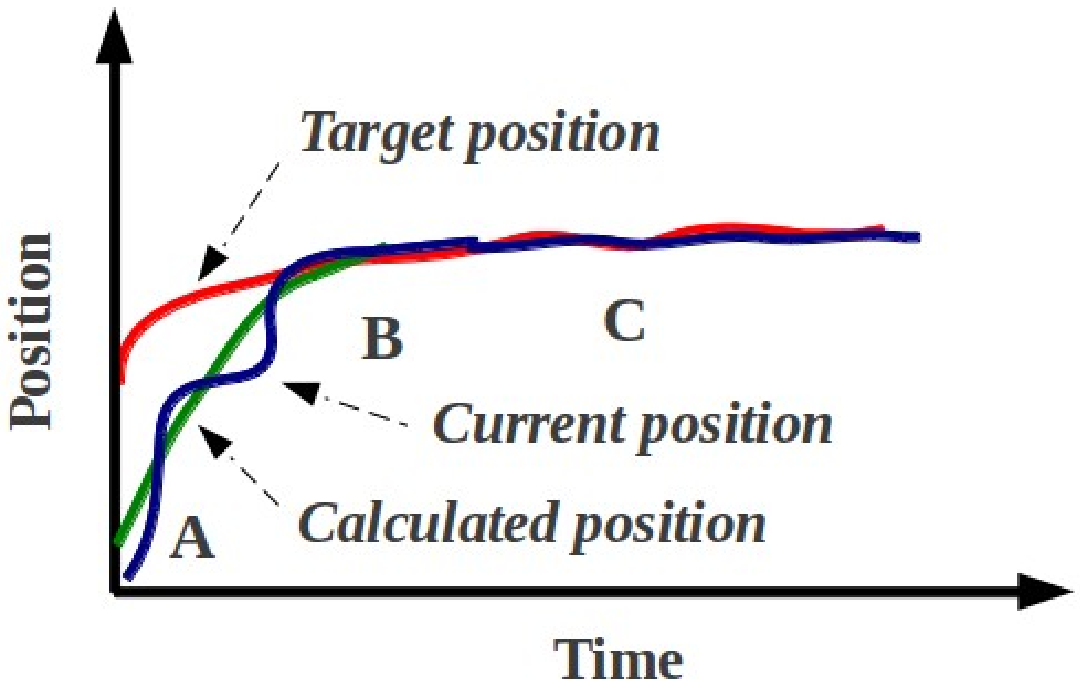
The integral wind-up

- The integral sum starts accumulating when the controller is first put in and continues to change as long as controller error exists.
- If there is a difference between desired and measured values, the resulting error will cause a continuing increase in the integral term, referred to as ***integral wind-up***.
- When the error term changes its sign, the integral term starts to 'unwind'.



Suppression of the integral wind-up

- Difference between existing position of antenna and object when pointing algorithm starts can be large, which contributes to the integral wind-up accumulation.
- The main idea is to introduce a modeled trajectory which starts at the initial position of the antenna (A) and finishes at some point on the trajectory (B) of the target.
- Since antenna is on-track from the beginning accumulation of integral windup is suppressed.



Route planning

When the angle between an antenna and an object is 3 degrees there is used second order polynomial (4) and is found trajectory of a movement that allow an antenna hit off an object trajectory.

$$x(t) = x_0 + \alpha\tau + \beta\tau^2 \quad (4)$$

$$\alpha = x'_1 + 2\frac{x_1 - x_0 - x'_1 \Delta\tau}{\Delta\tau^2}$$

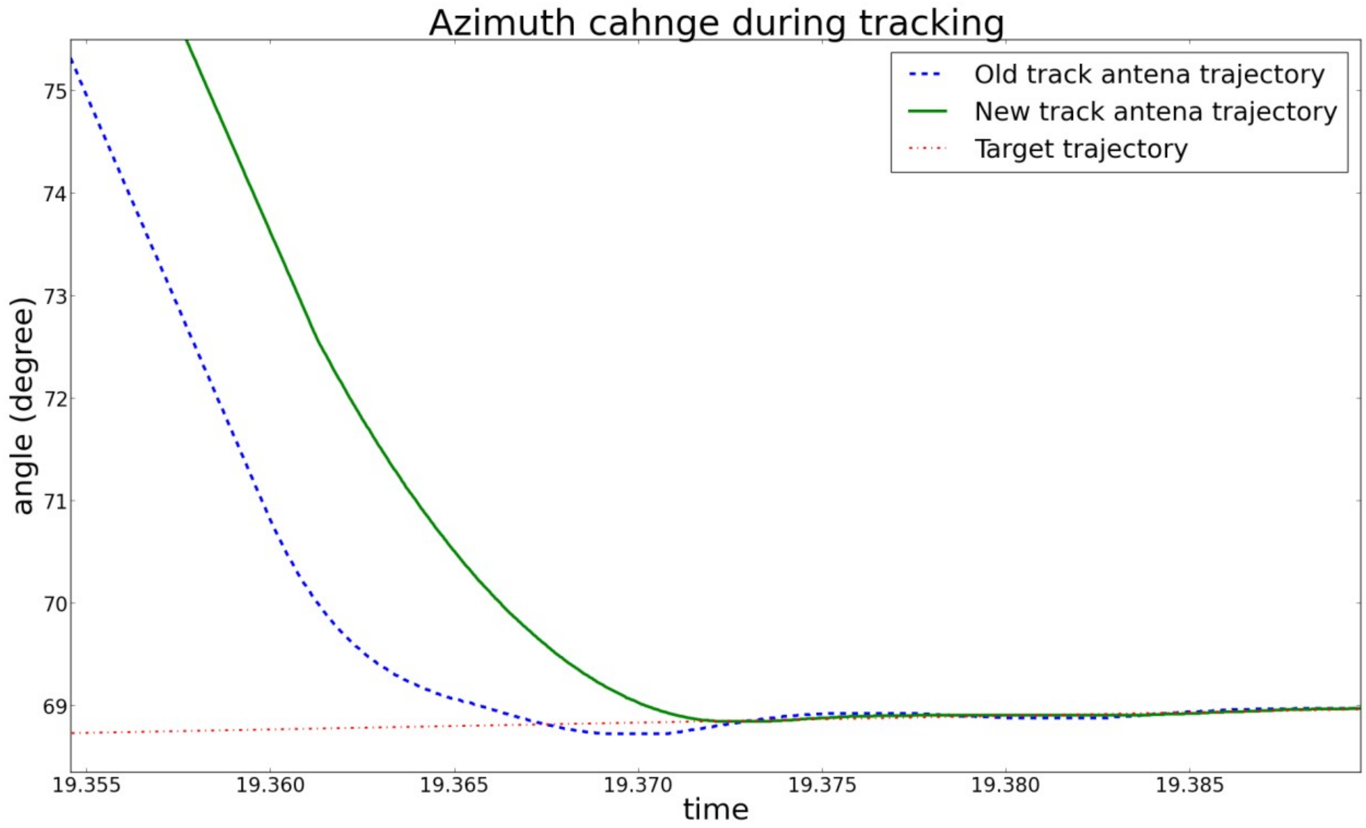
$$\beta = -\frac{x_1 - x_0 - x'_1 \Delta\tau}{\Delta\tau^2} \quad (5)$$

where x_1 – coordinates of the object

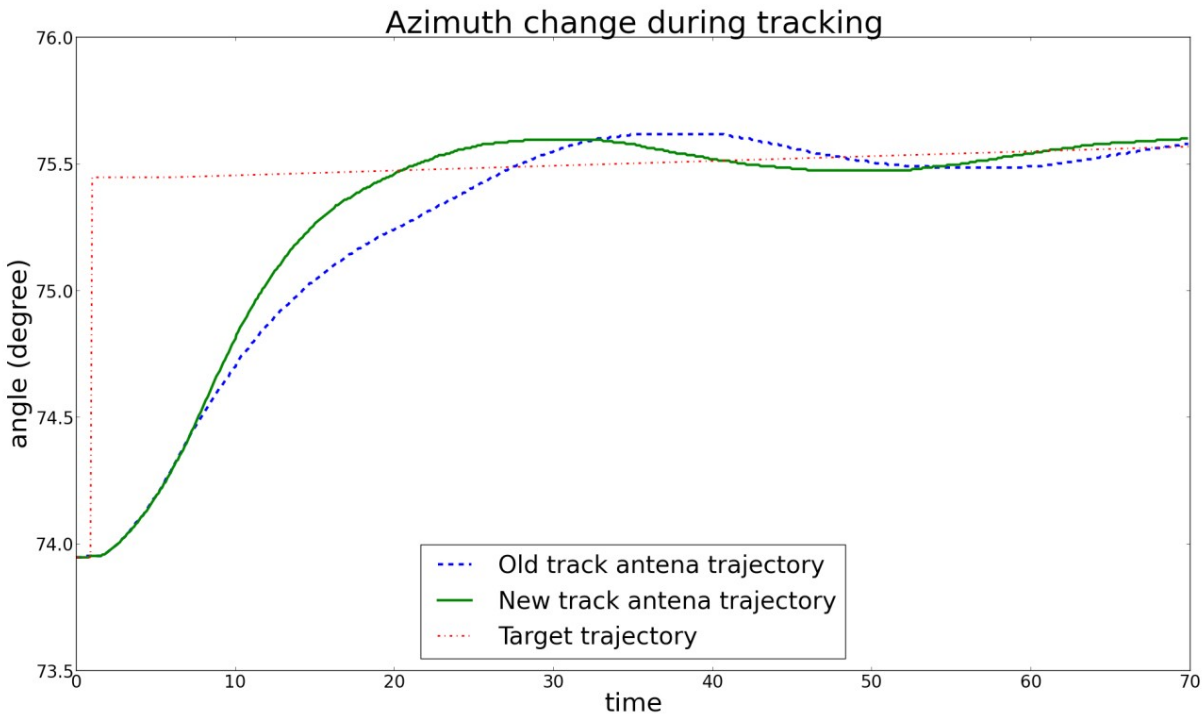
x'_1 – velocity of the object at point x_1

$\Delta\tau$ – time difference between current time t_0 and time when antenna must be on object trajectory t_1 (find iteratively).

Comparison of algorithms



Problem: near objects
(distance less than 3 degrees on both axes)



Possible cause: in this case (small distance and slow speed) the antenna must accelerate faster than that can be possible to move on calculated trajectory. The antenna can't catch target trajectory.

Solution: trajectory description with 3rd order polynomial

- Take into account both the antenna initial speed and the antenna end speed
- Check that the acceleration is not larger than maximum possible antenna's acceleration

$$x(t) = x_0 + \alpha\tau + \beta\tau^2 + \gamma\tau^3 \qquad (6)$$

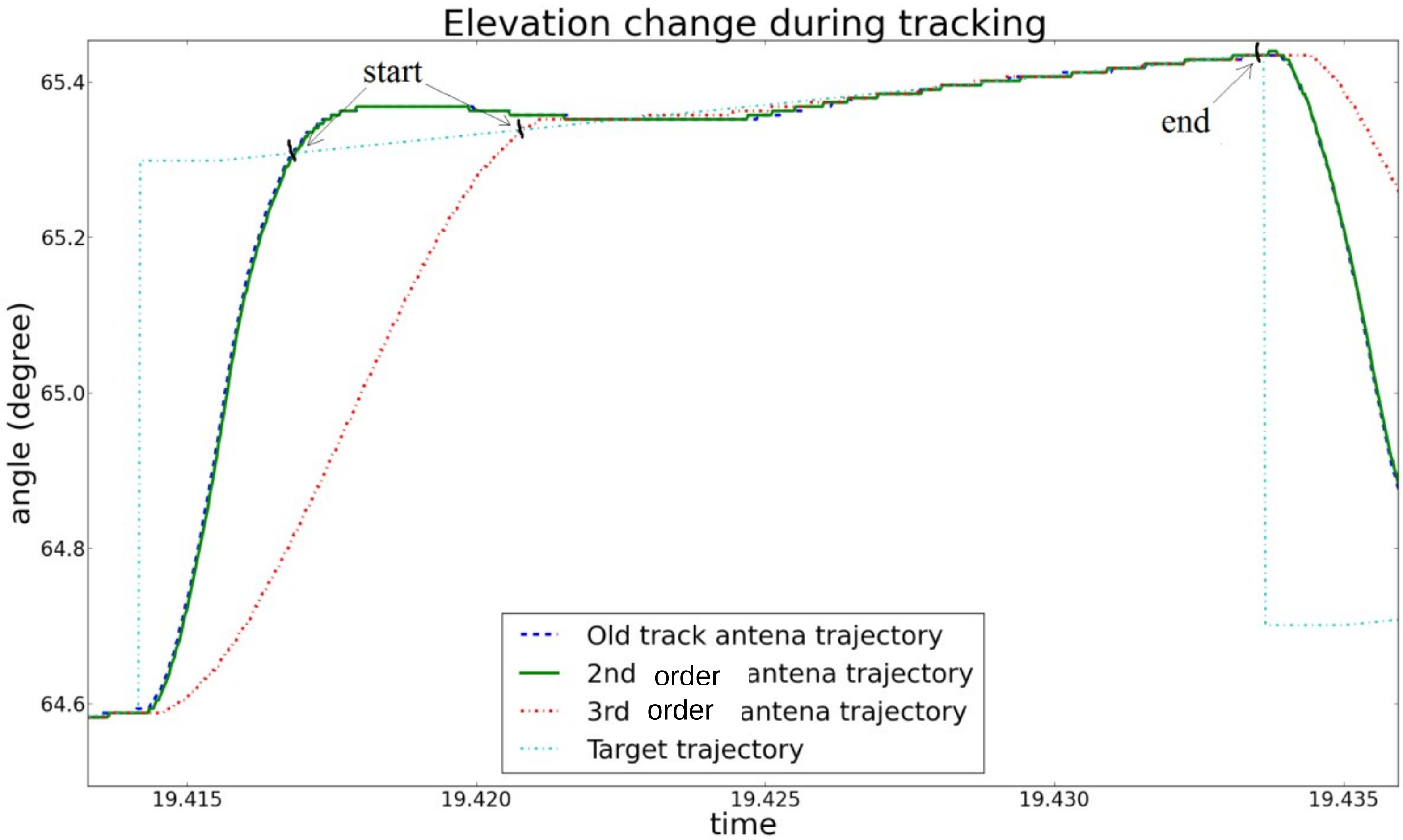
$$\alpha = x'_0$$

where x'_0 – velocity of the object at the point x_0

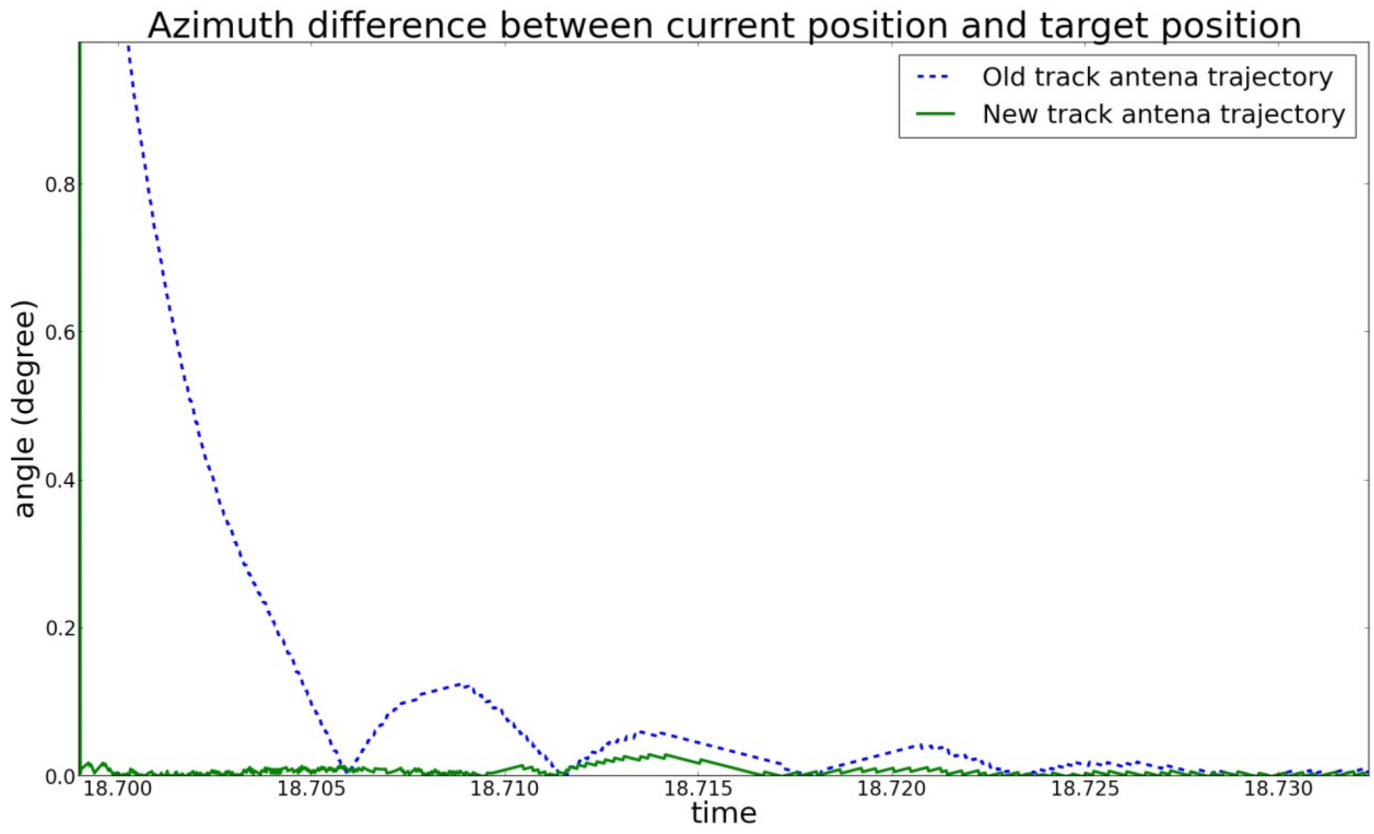
$$\beta = \frac{x_1 - \alpha - 3\gamma(\Delta\tau)^2}{2\Delta\tau} \qquad (7)$$

$$\gamma = \frac{-2x_1 + 2x_0 + \alpha\Delta\tau + x'_1\Delta\tau}{\Delta\tau^3}$$

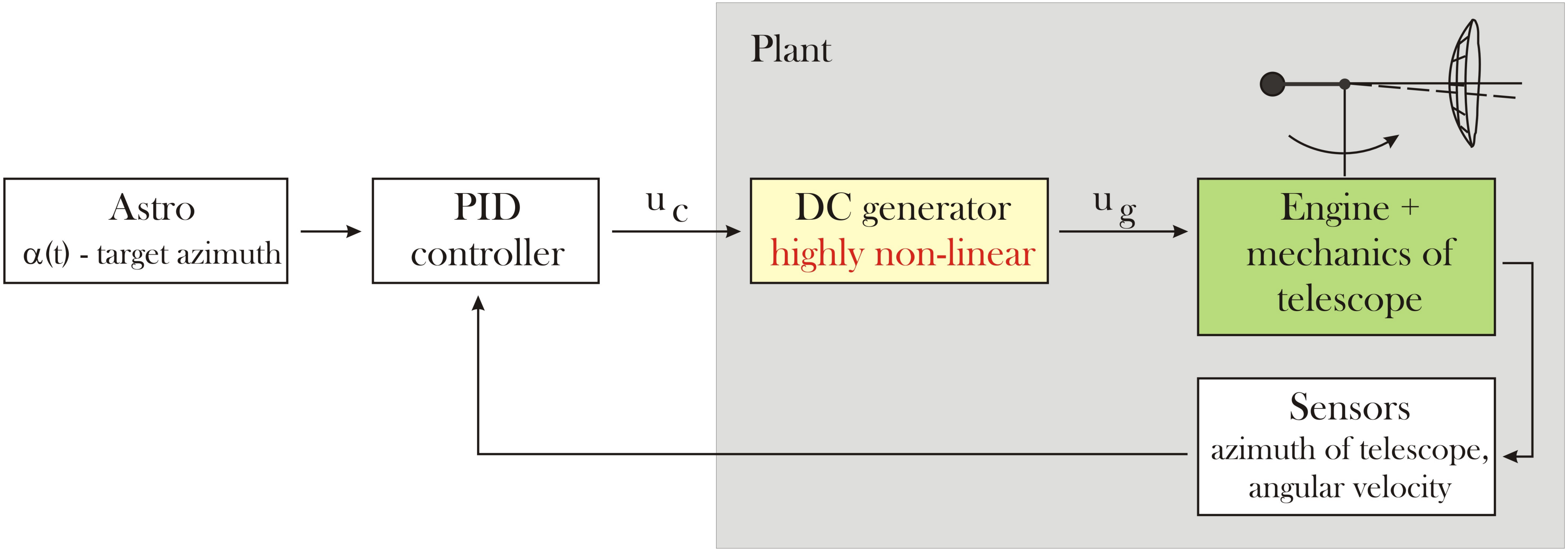
Real time test of the algorithm



Another cause of oscillations?



Control system for single channel (azimuth, the same for elevation)



Simplified model of plant

Description of antenna dynamics:

$$\ddot{\alpha} = M_0 u_g \left[1 - \frac{\omega}{\omega_0(u_g)}\right] - \frac{\omega}{\omega_s}\left(\mu + \kappa \left|\frac{\omega}{\omega_s}\right|\right) \quad (8)$$

where M_0 – torque constant, ω_s – maximum angular velocity
u_g – DC generator voltage

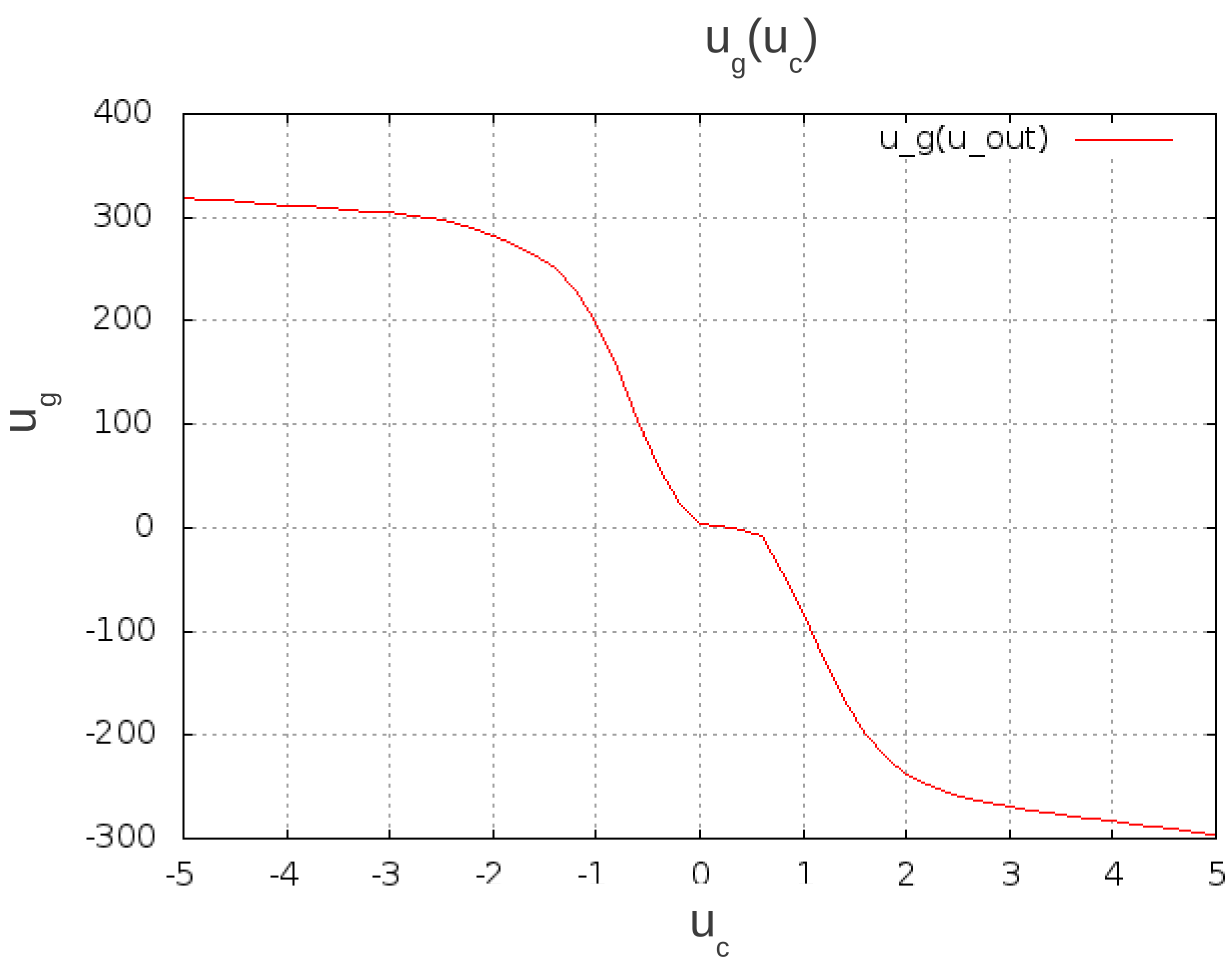
Description of antenna kinematic:

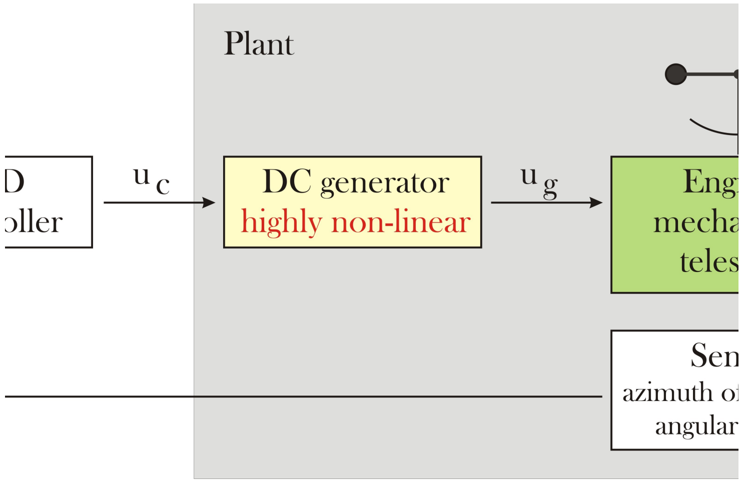
$$\dot{\alpha} = \omega$$

$$\dot{\alpha} = \int_{t_0}^{t_n} \ddot{\alpha}\, dt + \dot{\alpha}_{t_0} \quad (9)$$

$$\alpha = \int_{t_0}^{t_n} \dot{\alpha}\, dt + \alpha_{t_0} \quad (10)$$

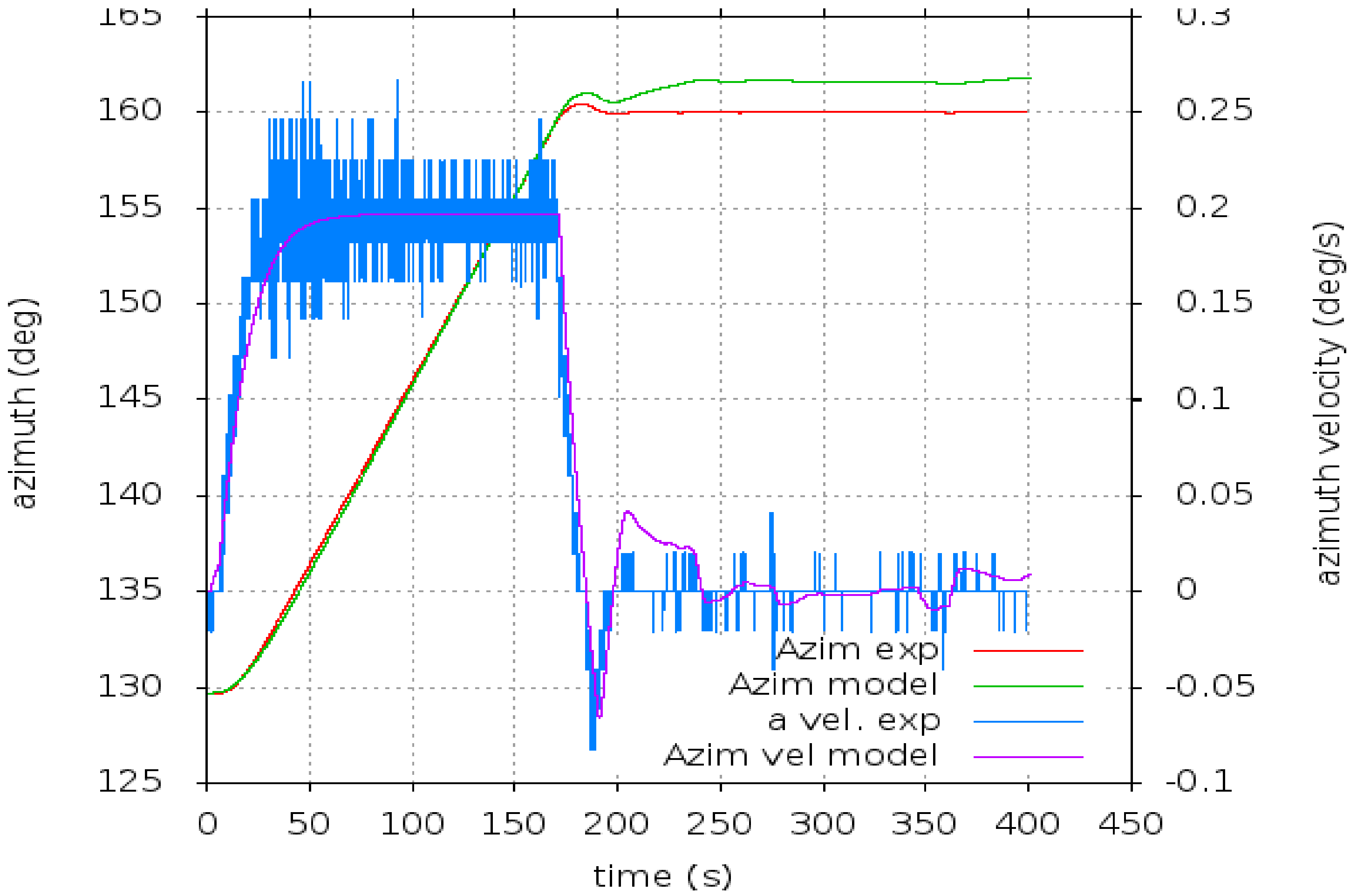
Non-linearity: measured DC motor-generator amplifier transfer curve



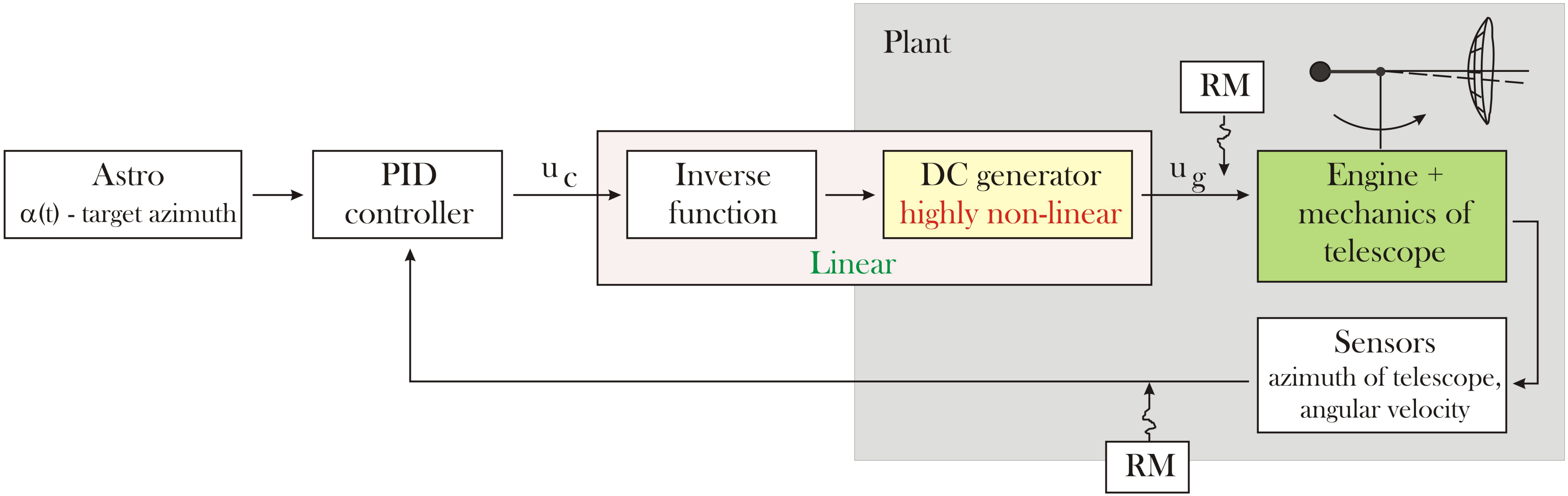


Identification of parameters

$$\dot{\omega} = M_0 u_g \left[1 - \frac{\omega}{\omega_0 (u_g)} \right] - \frac{\omega}{\omega_t} \left(\mu + \kappa \left| \frac{\omega}{\omega_t} \right| \right)$$

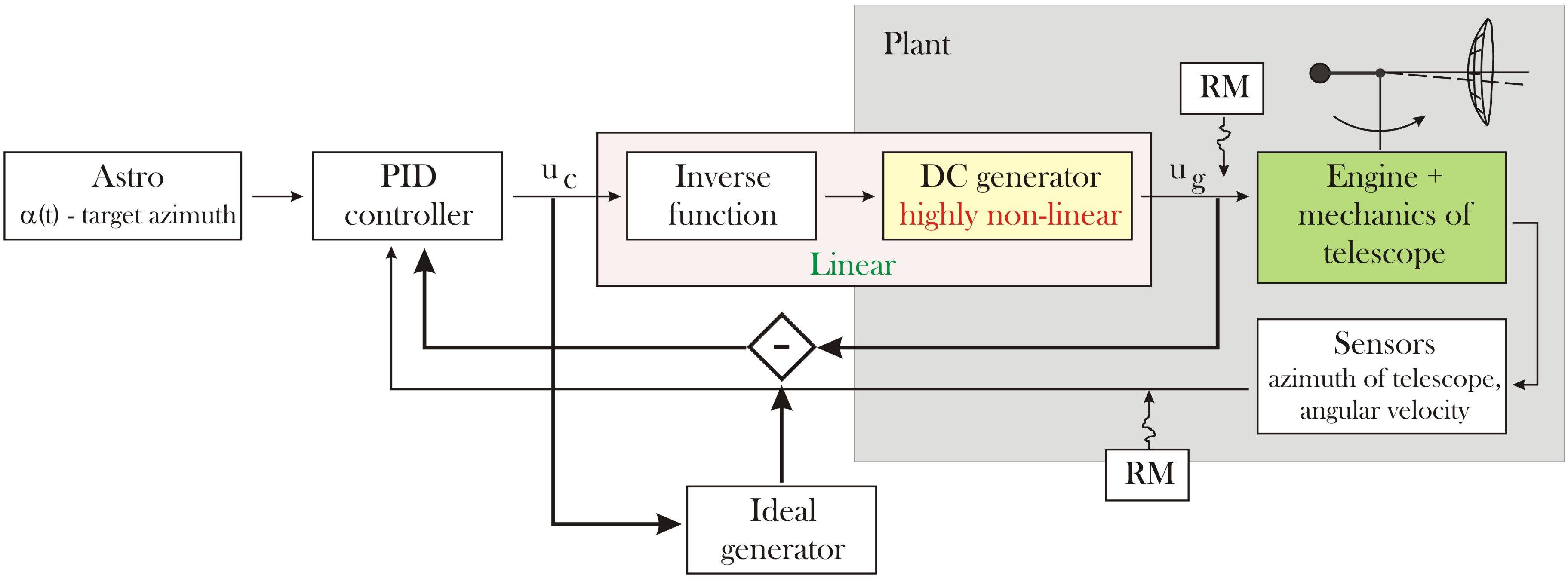


Feasible solutions

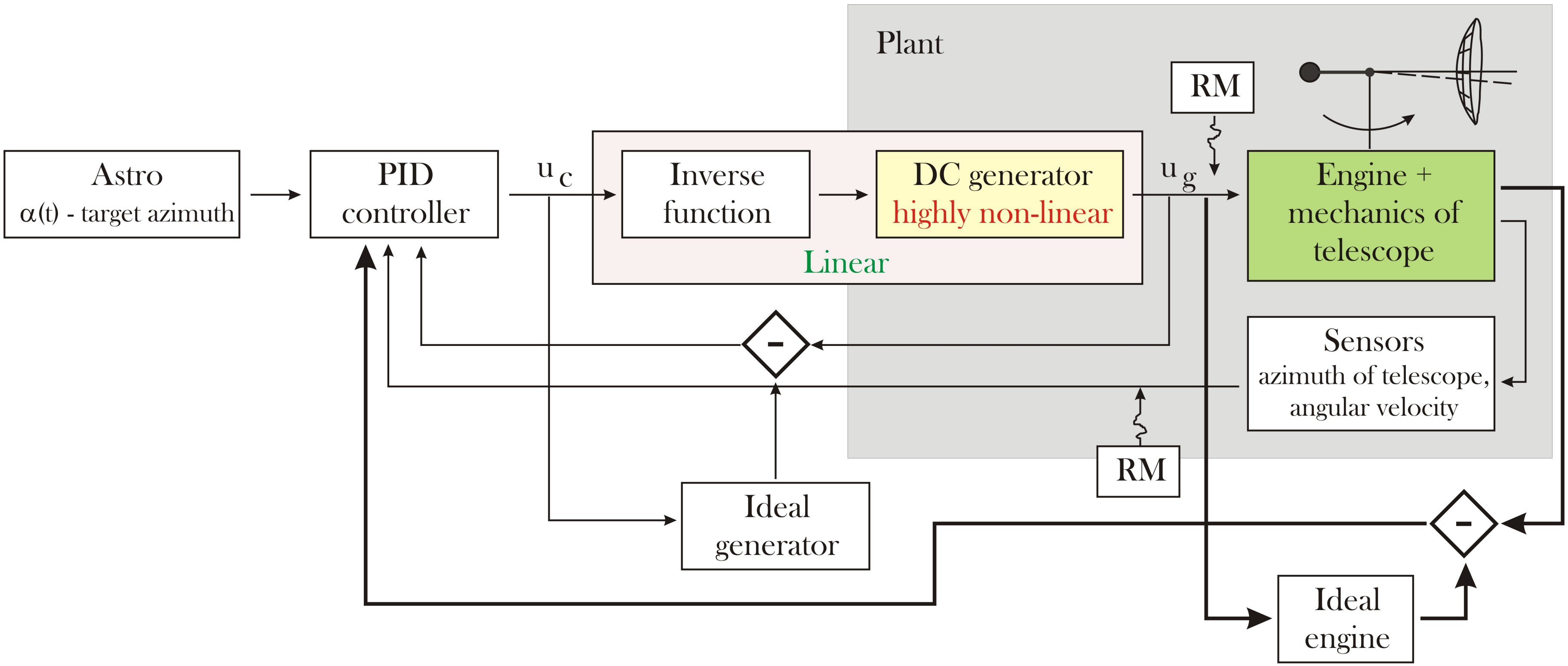


The configuration is modeled numerically for several typical pointing scenarios with the model of antenna described above and artificial source of white noise.

In all cases control system behaviour improves scientifically.



The improvement of militarization depends on exact compensation of DC motor-generator amplifier non-linear behaviour. However, the latest may change during the experiment. Possible solution can be an other control feedback loop.



Configuration above introduces additional compensation of slight non-linearity of motors and transmission.

No experimental verification on a real telescope yet.

More elaborate control models with LQG (Linear-quadratic-Gaussian control) controller elements with an additional parameters for optimization are under development.

Summary (1/2)

- Resultant accuracy and agility of the pointing and tracking system limits the performance of the antenna.
- 3rd order polynomial are utilized for optimal antenna movement planning between observational object and current antenna position.
- In order to check the algorithms the radio telescope RT-32 is used.
- Experimental results show that route planning approach ensure less oscillations of radio telescope when moving from one object to another than relying only basic control algorithms.

Summary (2/2)

- Mathematical models of the plant system mechanics are created and implemented in computer code, for investigation of the control system dynamics.
- During parameter identification significant non-linearity of excitation voltage controlled DC motor-generator amplifier (MGA) is measured. Linearization gives significant improvement of the control behaviour.
- MGA parameters do slight changes due to heat up of windings, etc. This has to be compensate as well.
  Further development and experimental verification is required.

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