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The antenna control system design aspects of MARK-4B of the radio telescope RT-32

Design aspects of the MARK-4B RT-32 radio telescope antenna control system

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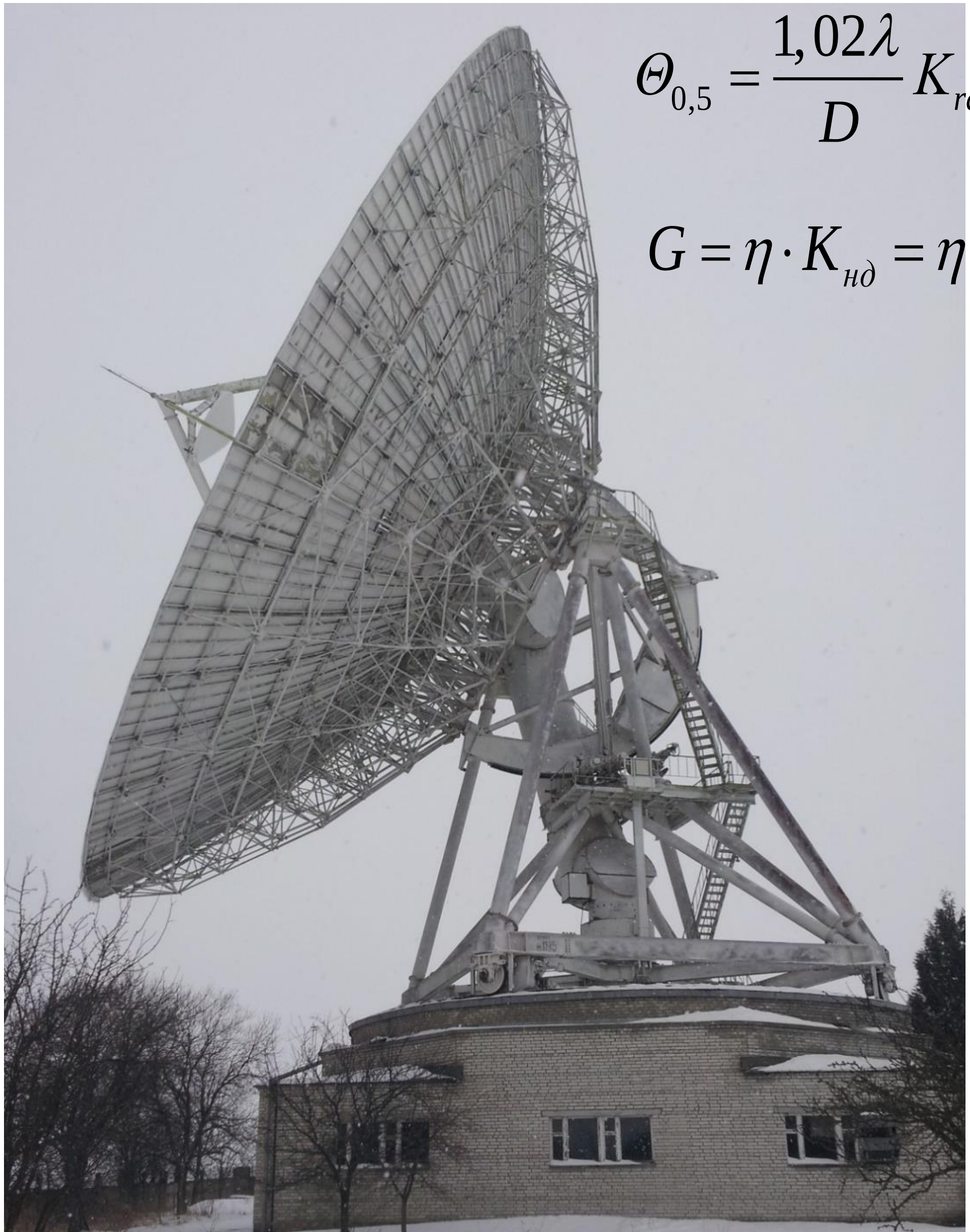
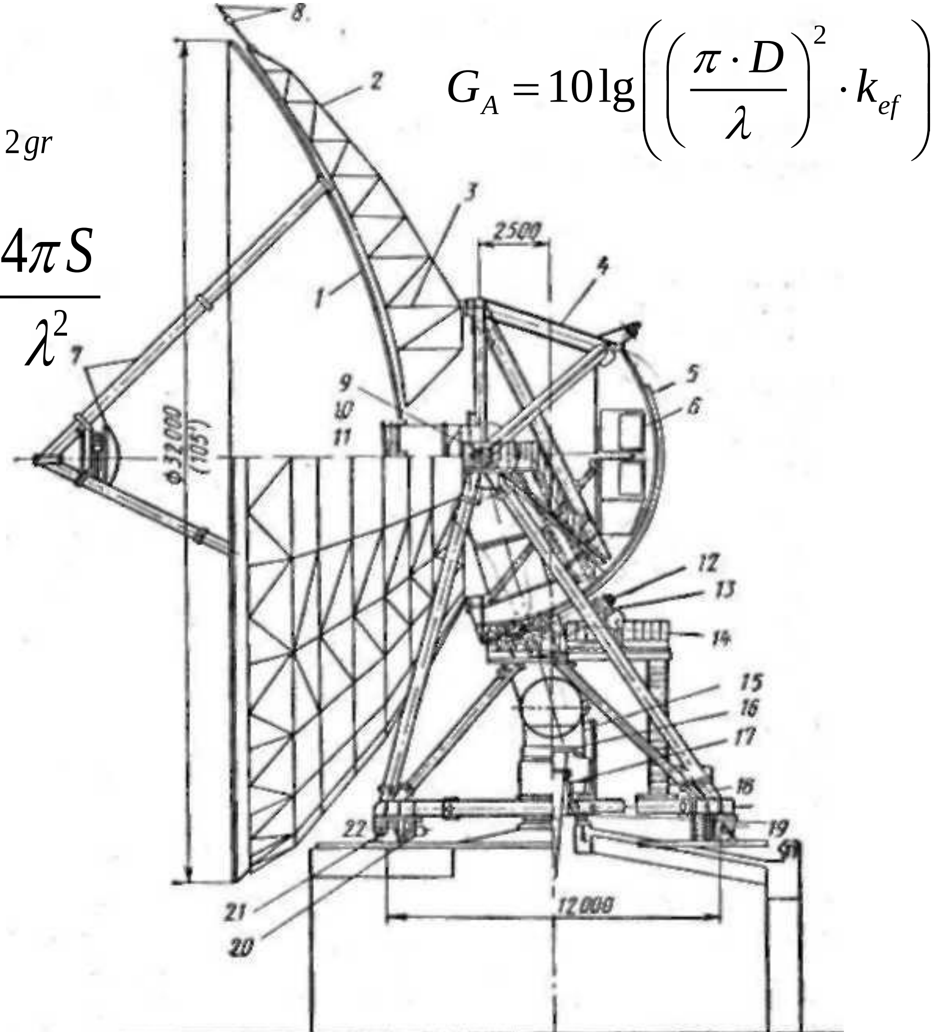
Antenna System MARK-4B



$$\Theta_{0,5} = \frac{1{,}02\lambda}{D} K_{rad\,2\,gr}$$

$$G = \eta \cdot K_{нд} = \eta \cdot \frac{4\pi S}{\lambda^2}$$

$$G_A = 10\lg\left(\left(\frac{\pi \cdot D}{\lambda}\right)^2 \cdot k_{ef}\right)$$



1 — панелі поверхні; 2— фермовий каркас; 3 — центральна ступиця; 4,5 — кутомісна секторна шестерня і вузол її кріплення; 6 — противаги; 7 — контррефлектор і елементи його кріплення; 8 —ліхтар і штир ліхтаря; 9 — кутомісна вісь; 10— кутомісні підшипники і вузли їх кріплення; 11 — кутомісний датчик: 12 — пристрій заштирювання; 13 — буфери (кутомісні); 14— кутомісний редуктор; 15 — кожух для чотирьох дзеркал хвилевода; 16 — ребристий рупор; 17 — кабіна для кабельної петлі і пристрій намотування кабеля; 18 — силовий каркас; 19 — азимутальний підшипник; 20 — азимутальний редуктор; 21 — азимутальне колесо; 22 - центральна вісь.

AS MARK-4B CONSTRUCTION PARAMETERS

- **The diameter of the main mirror is 32 m**, of the counter-reflector is 2.8 m.
- The F / D ratio is approximately 0.35.
- Shading overlapping of the main mirror of the counter-reflector by its supports 2%.
- The standard deviation of the surface shape E / D * (3σ): $4 \cdot 10^{-5}$
- -under normal operating conditions (wind speeds up to 48 km / h -(13.6 m / s) with gusts up to 72 km / h (20 m / s) – less
- under extreme conditions (wind speeds up to 72 km / h (20 m / s) with gusts up to 96 km / h (27 m / s) less $6 \cdot 10^{-5}$

- The maximum permissible wind speed is 193 km / h (53 m / s); expansion should be carried out at a wind speed of 129 km / h (36 m / s);
- **Weight on an angle axis 121 t,** total weight on the rails 243 t;
- Rails diameter 16.97 m; wheels diameter of the cart - 900 mm;
- Permissible solar radiation of 1.2 kW / m^2;
- Ambient temperature -30 ... + 50 C Relative humidity 0-100%;
- Acceptable: rain 100 mm / h; snow 10 cm / h, 30 cm / day;
- Earthquake Resistance: 8-th Mercalli Modified Intensity Scale; ground tangential acceleration 0,3g;
- Frequency eigenvalue at the rotor slowing 2 Hz.

REQUIREMENTS FOR THE AS CONTROL SYSTEM

- The improving of the antenna accuracy of guidance and tracking by the improving the control system;
- Improving of the accuracy and reliability of the antenna angular position determining ;
- The extending of azimuth angles range (up to /- 270 degrees)
- Mechanics disadvantages compensation (OPP, deformation, etc.) by electronic and algorithmic methods, adaptability to changes in mechanics, robustness;
- Adaptation to OPP and electric drives (*modular hardware and algorithmic*);
- Functionality extension, AS intellectualization: automatic execution of most operators functions : forecast of trajectories of CO in the observation area, guidance tables calculation, synchronization of time with GPS / UTC / UT1, search of the max. signal mode , self-diagnosis;
- CS cost reduction due to the modern element base.
- **It is necessary to develop both schematic and software-algorithmic methods in CS AS**.

STAFF EQUIPMENT of ACS

AC drive with thyristor control of electric motors;

<u>Research objectives</u> :

1. Errors source analysis, occurred in tracking Antenna Systems
2. Analysis of design methods of antenna control system;
3. Model synthesis of antenna control system;
4. Experimental validation of models;
5. Analysis of experimental results of antenna control system;
6. Conclusions.

ACCURACY POINTING with Various Reflector Diameter

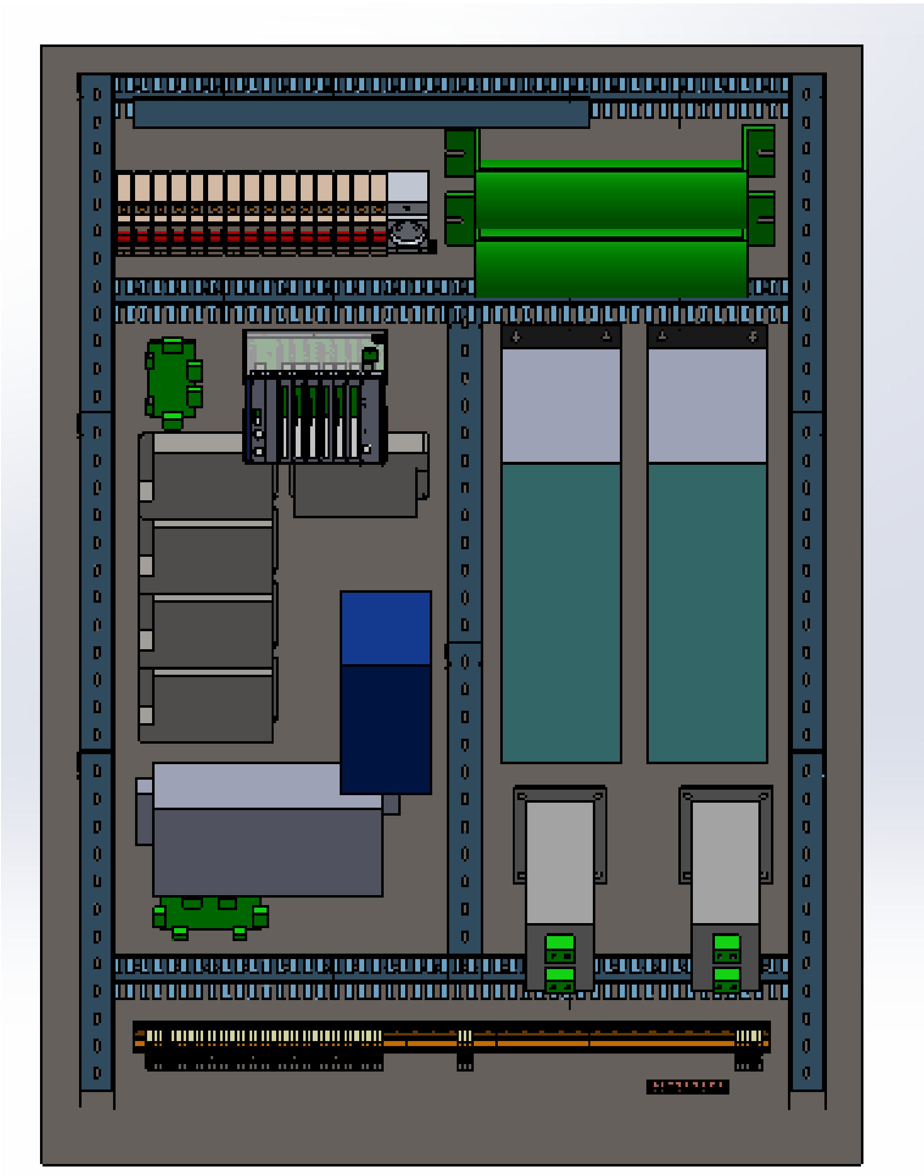
Necessary accuracy pointing of the antenna with various beams is:
(tenth (1/10) diagram of width antenna beam on level 3dB, units = angular minutes).

Admissible angles error for pointing of antenna beam (angular minutes) for different frequency ranges provided 1/10 diagram width									
Frequency	**Wave**	**The diameter of antenna reflector D, m**							
$f_{пр}./f_{пер}.$, ГГц	**$\lambda_{пр}/\lambda_{пер}$,мм**	**3,0**	**3,6**	**5**	**7**	**9**	**12,0**	**25,0**	**32,0**
L 0,8/1,0	375/300	35,0	28,8	21,1	15,0	11,7	8,75’	4,4’	**3,3’**
S 2,0/2,4	150/125	18,0	15	10,5	7,5	5,8	4,4’	2,2	**1,3’**
C 4,0/6,0	75/50	8,8	4,9	5,3	3,8	2,9	2,2’	1,1	**0,75’ (42”)**
X 8,0-8,4	30-36	3,5	**7,3**	**2,1’**	1,5’	1,17’	0,9’	0,44’	**0,35’ (22”)**
Ku/Ka 12,0/18,0	25/17	2,9’	2,4’	1,8’	1,3’	0,9’	43 sec.	21 sec.	**16 sec.**
Q 20,0/30,0	15/10	1,8’	1,46’	1,1’	45 sec.	35 sec.	26 sec.	13 sec.	**9,0 sec.**

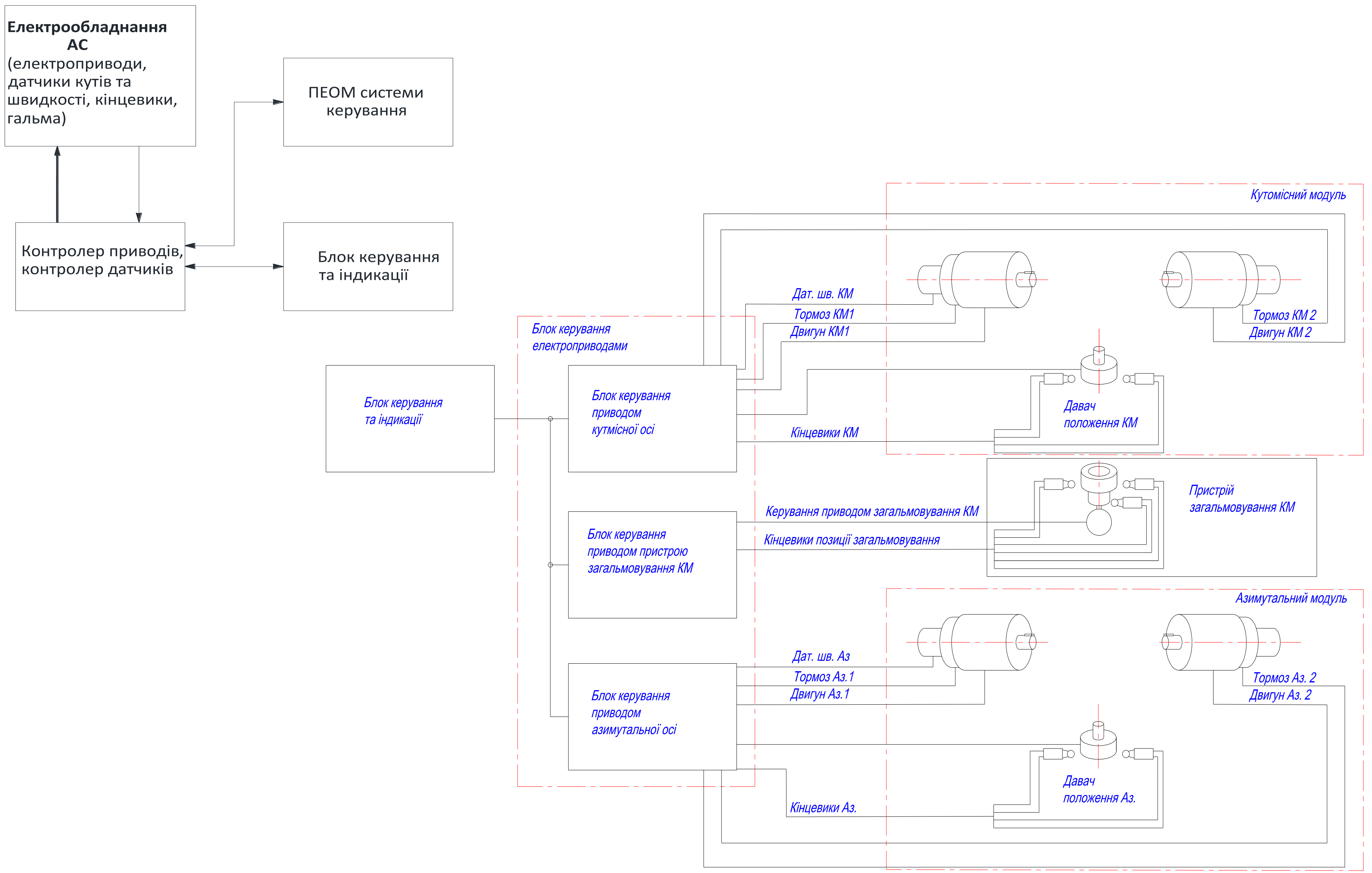
The Accuracy of static and dynamic tracking of satellites is provided by the antenna control system (AS).

Since the weight of such antennas ranges from one to tens of tons, the support-rotary platforms (SRP) has a significant influence on the accuracy of the guidance and the tracking of the trajectory.

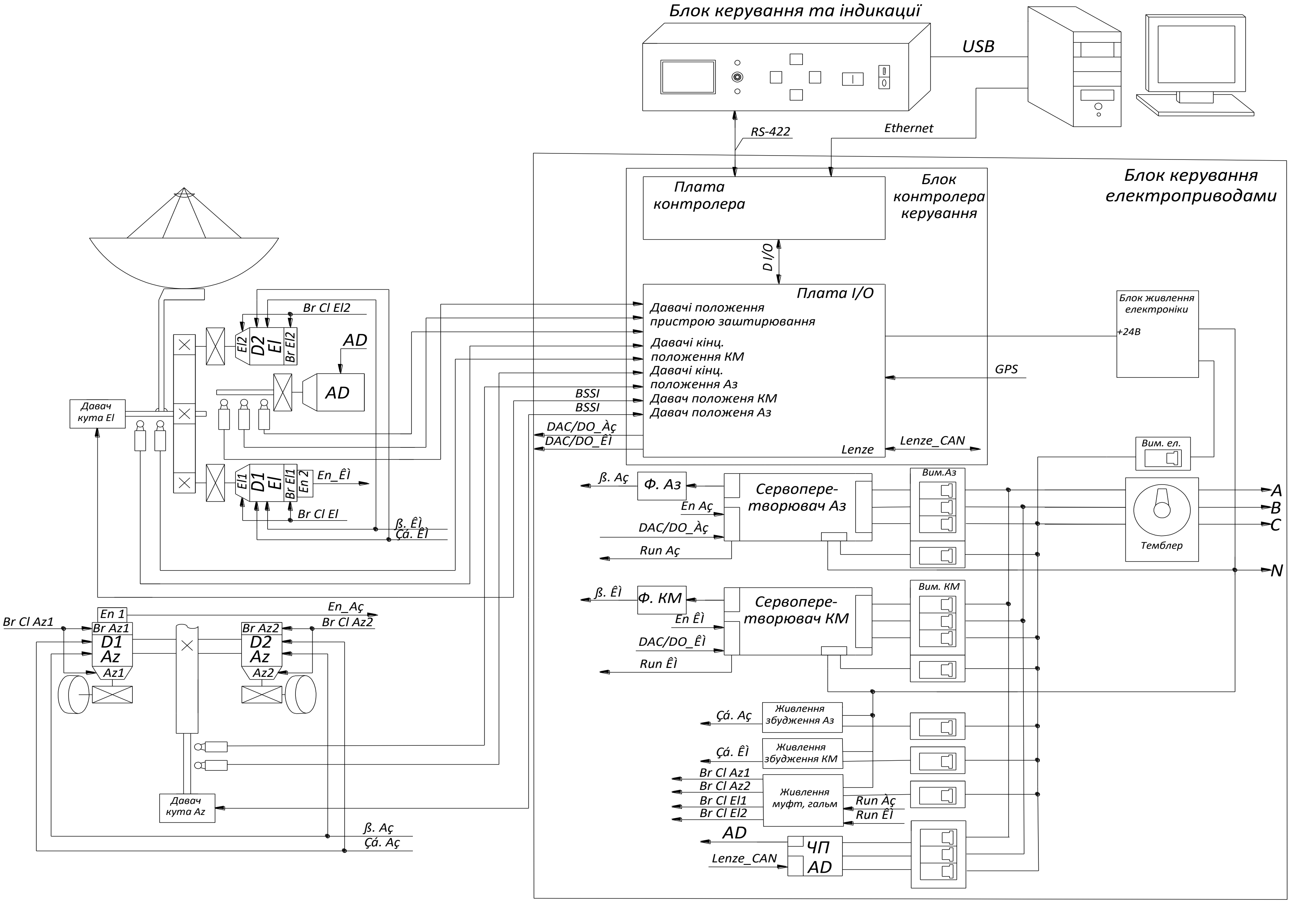
ANTENNA CONTROL SYSTEMS of AS MARK-4B



Block Diagram of ACS MARK-4B



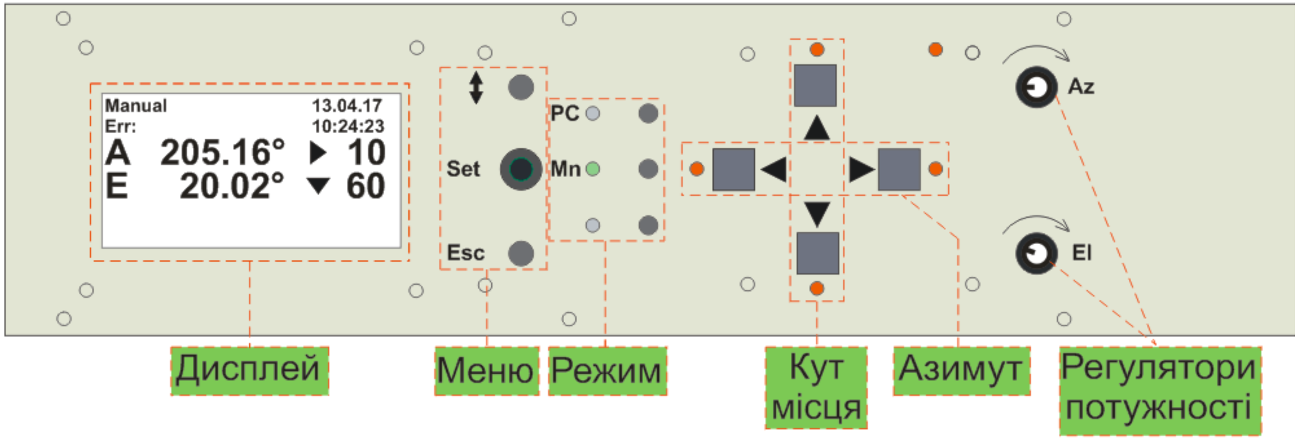
FUNCTIONAL SCHEME of ACS “MARK-4B”



PARAMETERS of ACS MARK-4B

Найменування	Значення параметру	Примітка
Кількість координат керування	2 шт.	
Діапазон обертання осей АС: **вість Азимута** **вісь Кута місця**	±180 град. 6…90 град.	
Потужність приводу **вість Азимута** **вісь Кута місця**	2*7,5 кВт 2*7,5 кВт	
Максимальна швидкість наведення **вісь Азимута** **вісь Кута місця**	0,7 град./с. 0,4 град./с.	
Макс. швидкість супроводження об`єктів за програмою не менше **по Азимуту** **по Куту місця**	0,6 град./с. 0,3 град./с.	
Максимальне прискорення гальмування руху антени **вісь Азимута** **вісь Кута місця**	0,3 град./с2. 0,3 град./с2.	
Характеристика регульованого електроприводу	- ручне та програмне регулювання частоти обертання двигуна; - програмований час розгону та плавного гальмування; - швидка зупинка двигуна при екстерній зупинці АС; - управління гальмами двигунів.	
Живлення системи керування	380 ±10% трьохфазна мережа	
Споживання електроенергії	40 кВт	
Маса блоків керування (без маси двигунів і трансформатора 380/220)	**30 кг**	

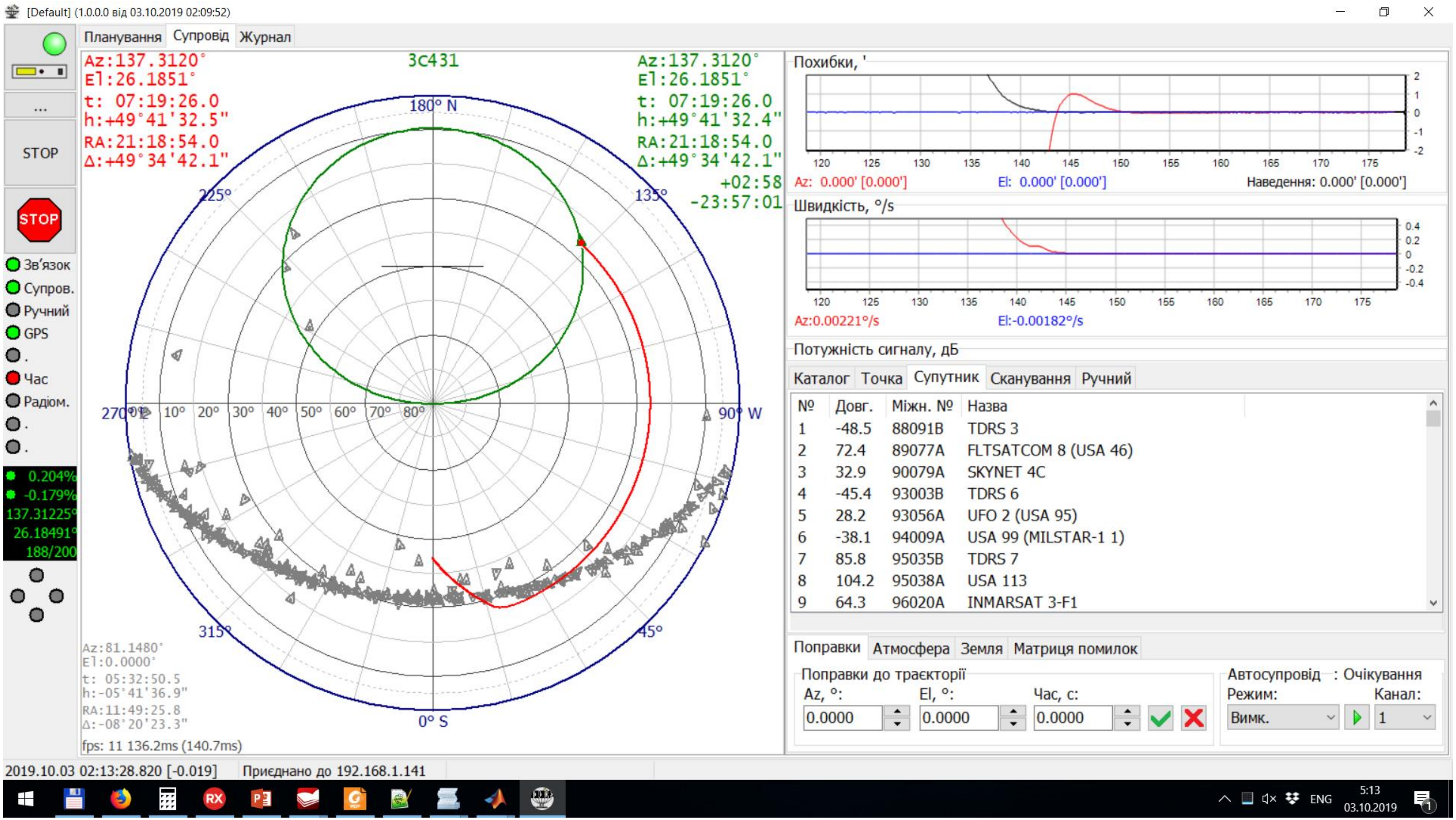
CONTROLS AND DISPLAYS. REMOTE CONTROL



Panel of the control block and control panel display

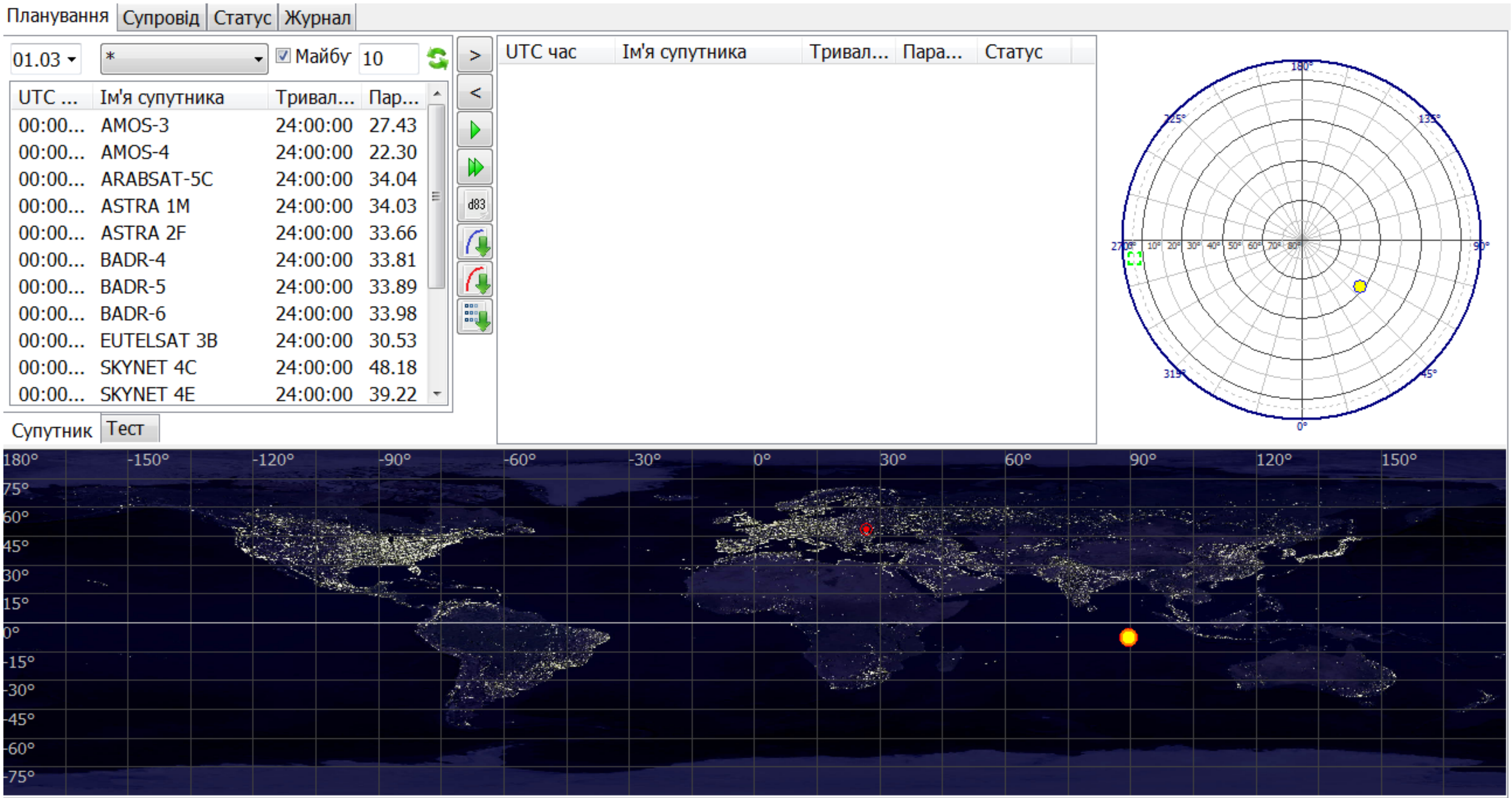
The control body	Assignment
Mode	Selection of control mode operation (indicated by LED). •PC - remote control from PC; •Mn - manual control.
Power regulators	In manual mode the speed of the axis of azimuth and elevation respectively are setted.
Elevation / Athimuth	Buttons for selecting the direction of travel with LED indicator of the limit switches (software or hardware).

The Software of Antenna Control System

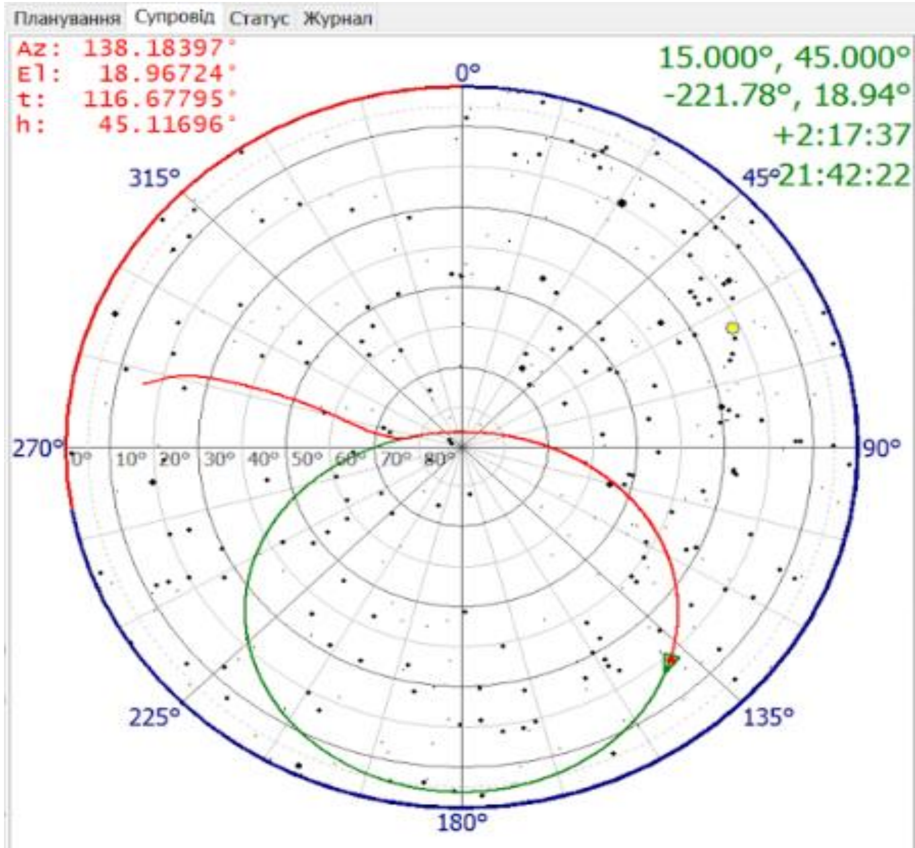


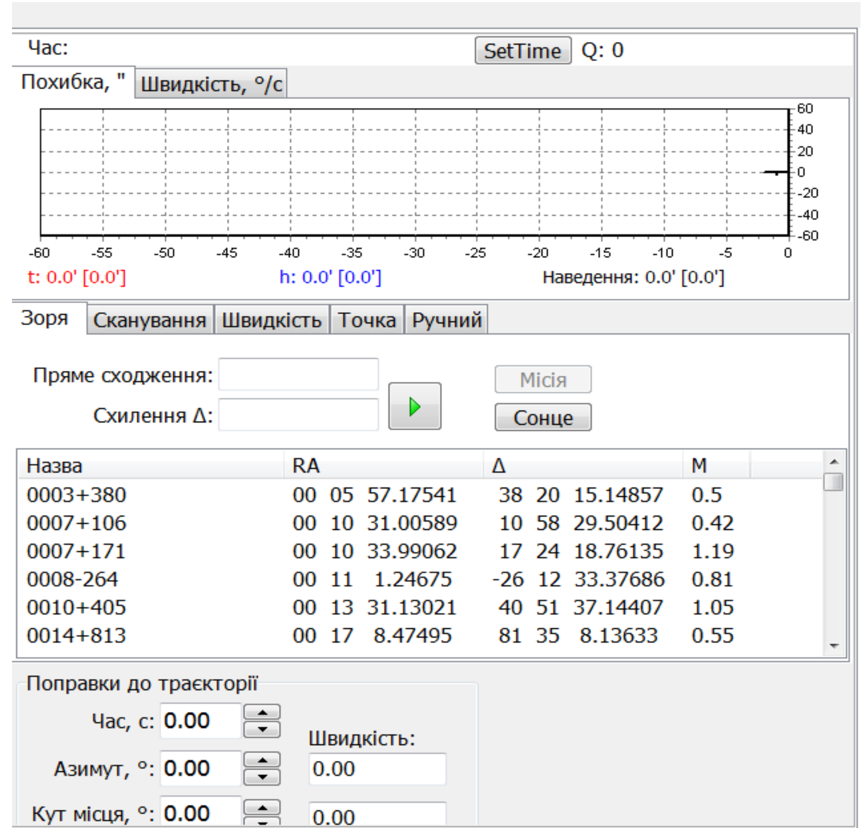
The Software of Antenna Control System

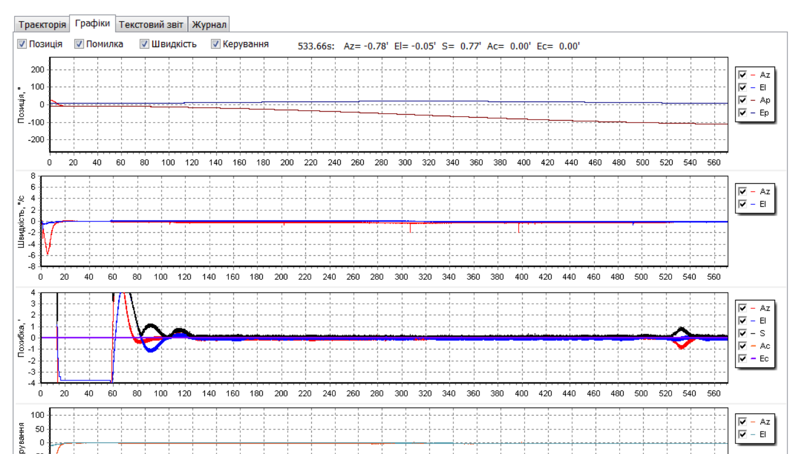
Space Object Planning Tab



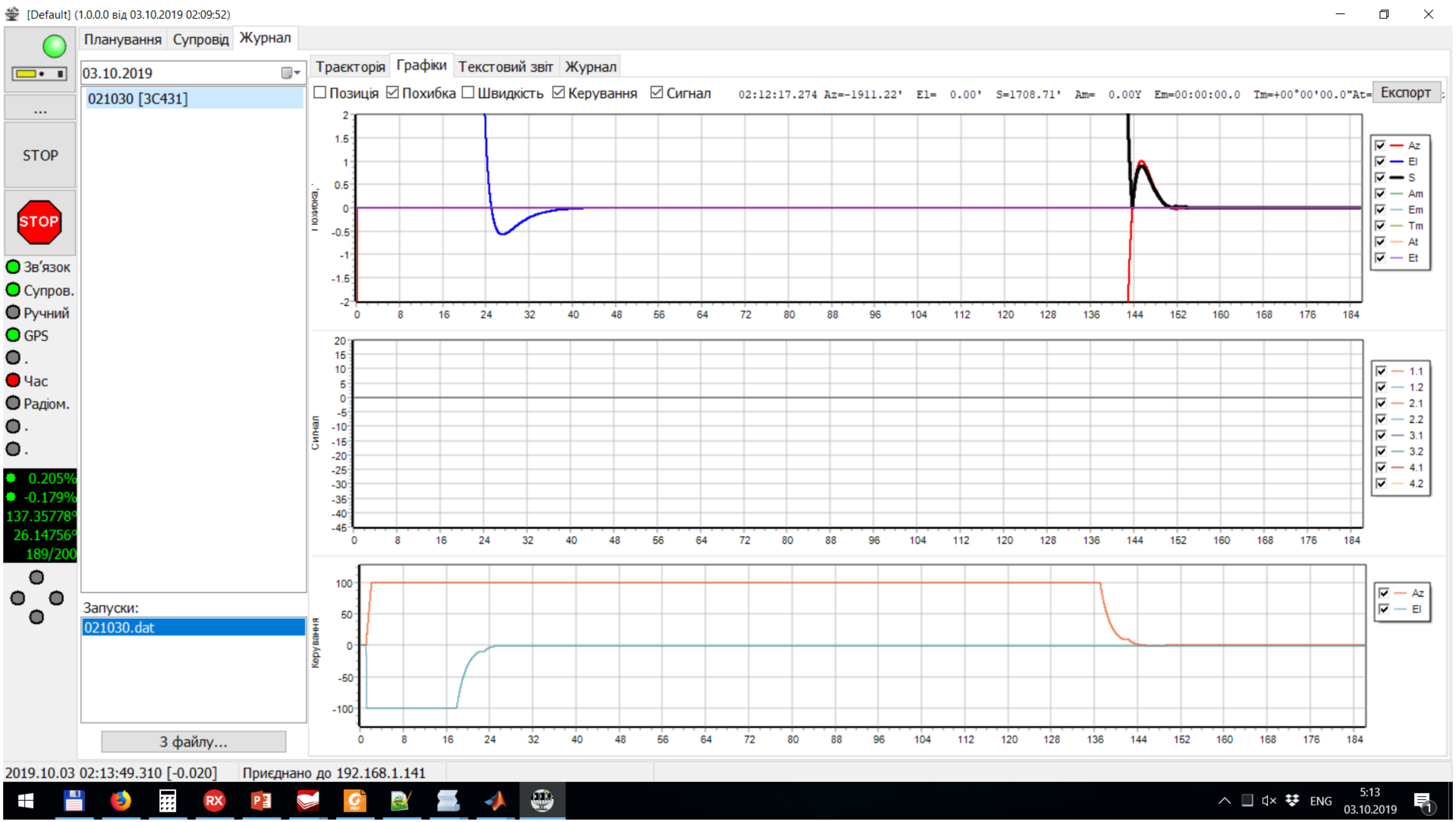
The Software of Antenna Control System



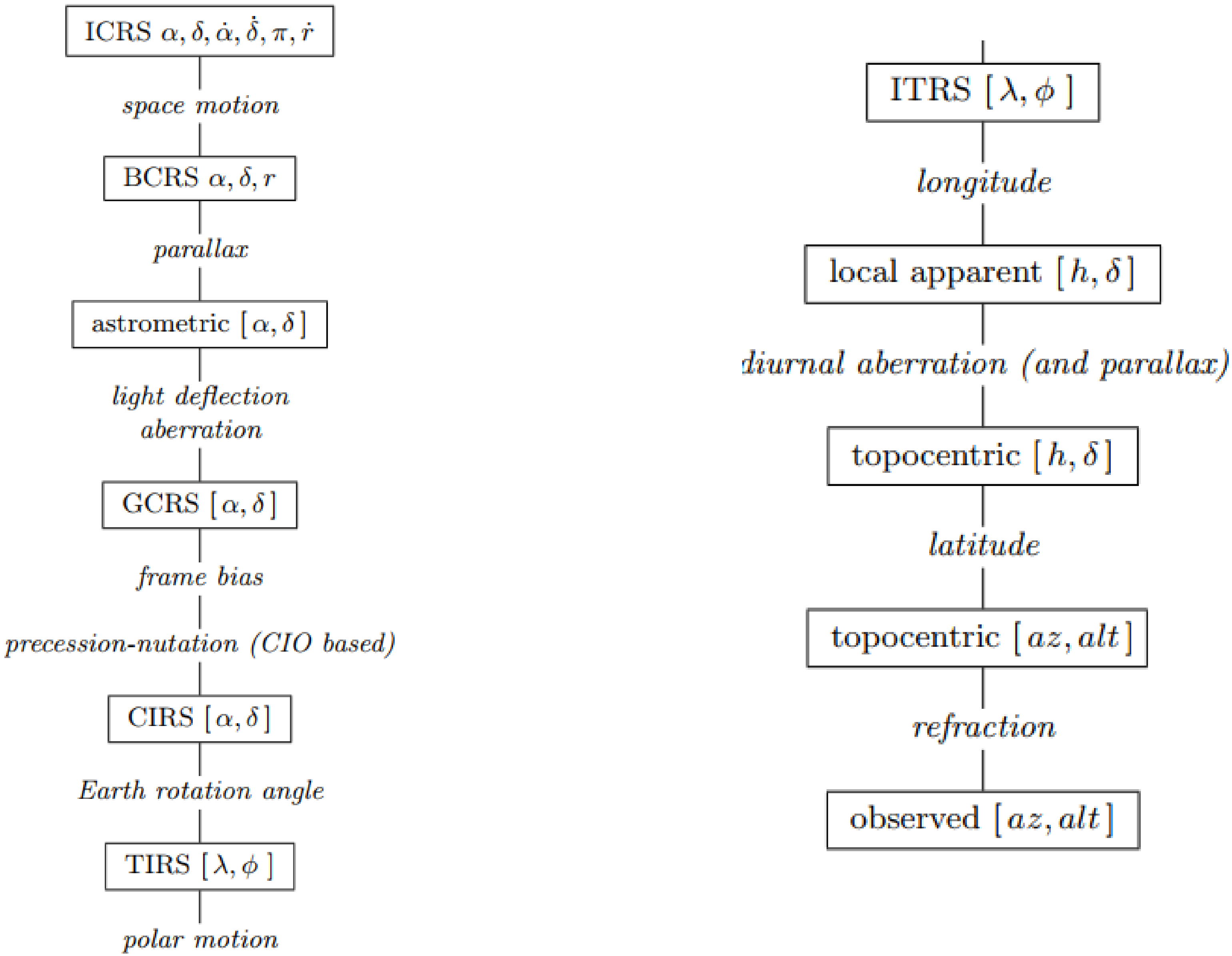




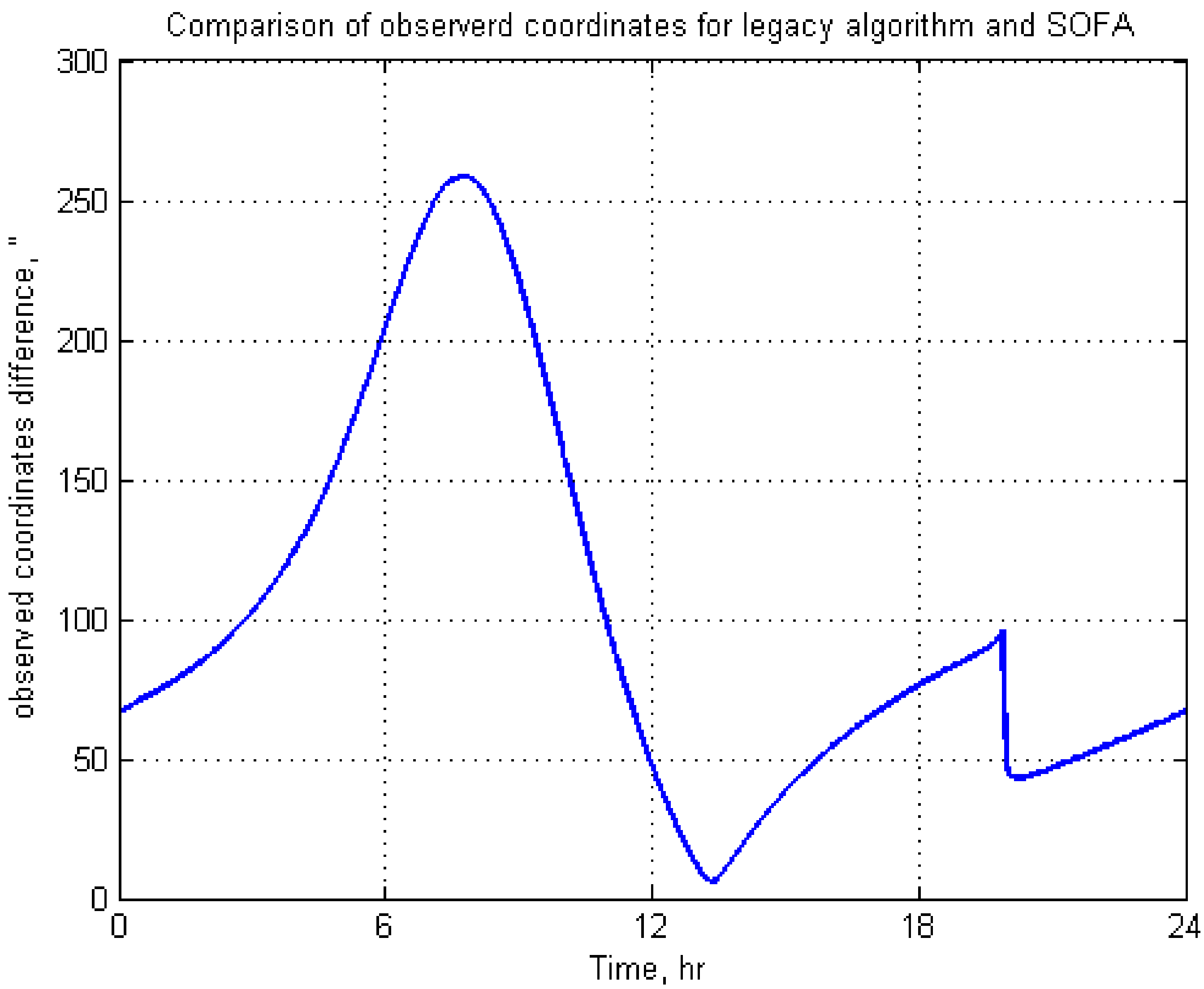
The Software of Antenna Control System



SOFA – Standards Of Fundamental Astronomy



Comparison of legacy algorithm and SOFA



ANTENNA CONTROL Methods and Devices Overview

An important element of Antenna control system is an executive electric drive of high power, which should provide a wide dynamic range of adjustment with high accuracy and stable point.

At the existing antenna systems precision control of power devices is provided by the use of **synchronous DC motors, special types of brushless DC (BLDC) engines or valve motors (Servo Drivers)**

Induction motors (IM) in squirrel cage, or asynchronous drive (AD), widely used at the industry, have a number of advantages compared with other types of drives. IM with frequency control are used in many technological processes.

However, induction motors inherently are not designed for speed control over a wide range without loss of torque and is used mainly in tasks that require constant rotational speed or slightly its regulation.

The use of IM in conjunction with frequency control devices in precision control systems of AS is a promising solution and will allow to reduce the cost of the AS and increase their reliability.

More research is needed on their use in accurate pointing and tracking systems.

ASSESSMENT FEATURES AS a CONTROL OBJECT

•Object features and management system structure:
the moments of inertia of the modules are dependent on the angles of inclination of the reflector and the ratio of positions of the modules of the antenna for different axes change;
• change of rigidity of mechanical transmissions;
• changes in friction resistance;
• the impact of backlash;,
• instability of the electric drives characteristics ;
• stochastic effect of wind loads, etc.

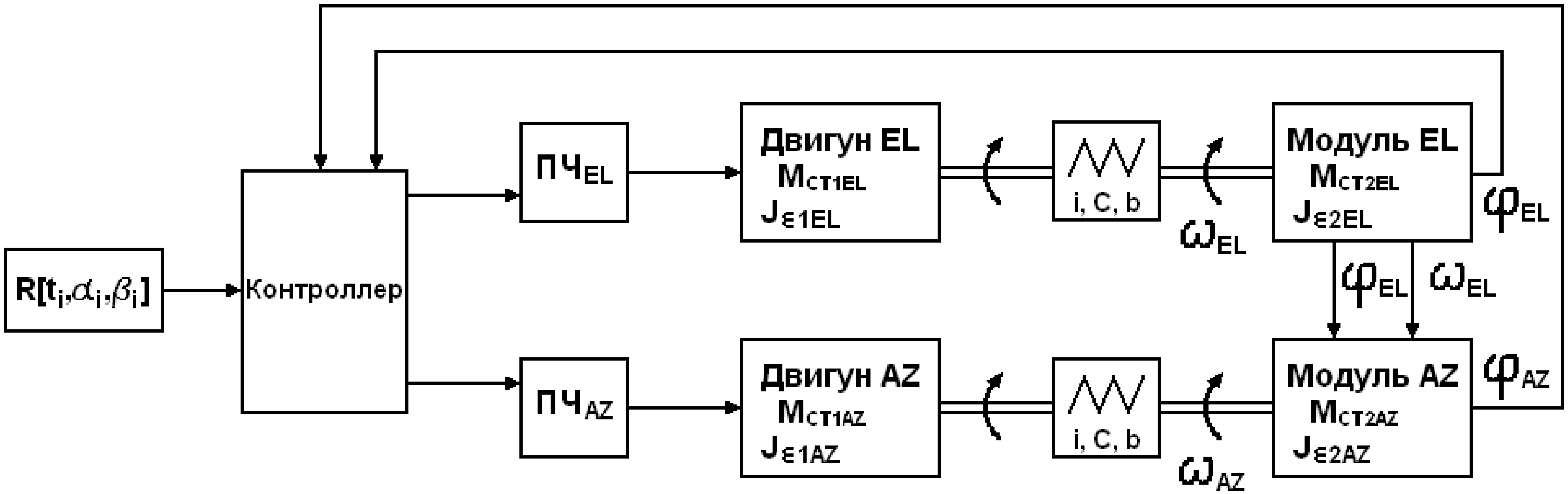
As a dynamic system the control object is non-linear.

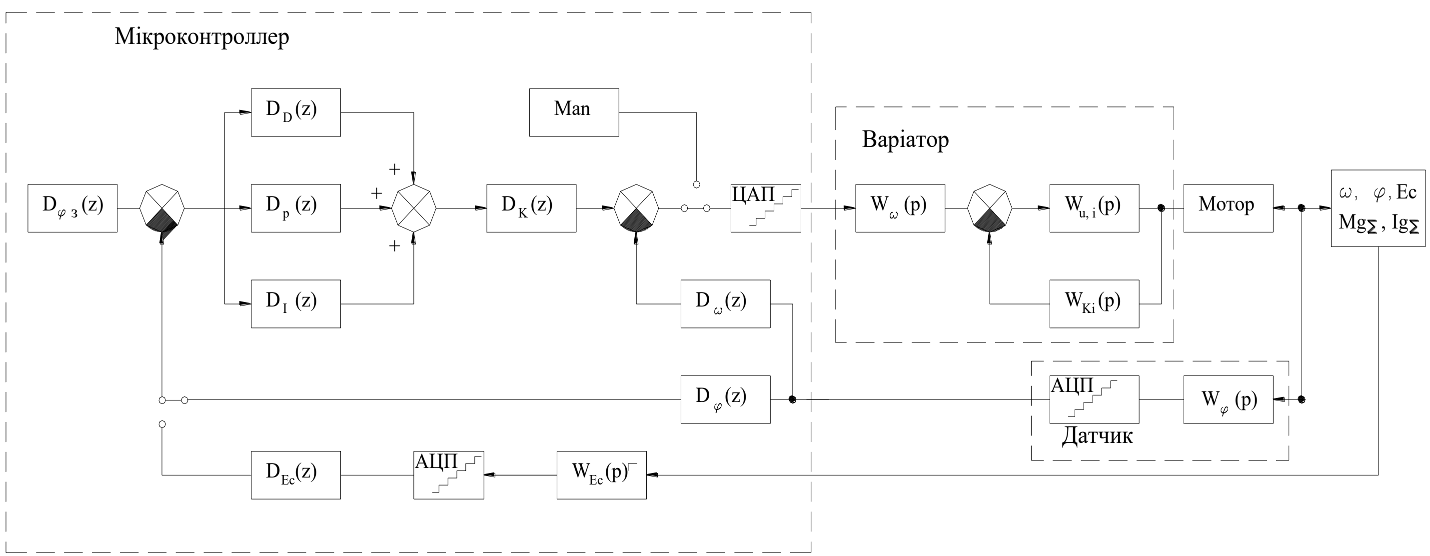
Substantiation of the choice of the topology of the ANN of the neurocontroller in the control circuit:

Recurrent NC, unlike other types of NC, are dynamic networks that convert inputs into sequences of reactions capable of producing effective control actions under uncertainty when managing complex systems.

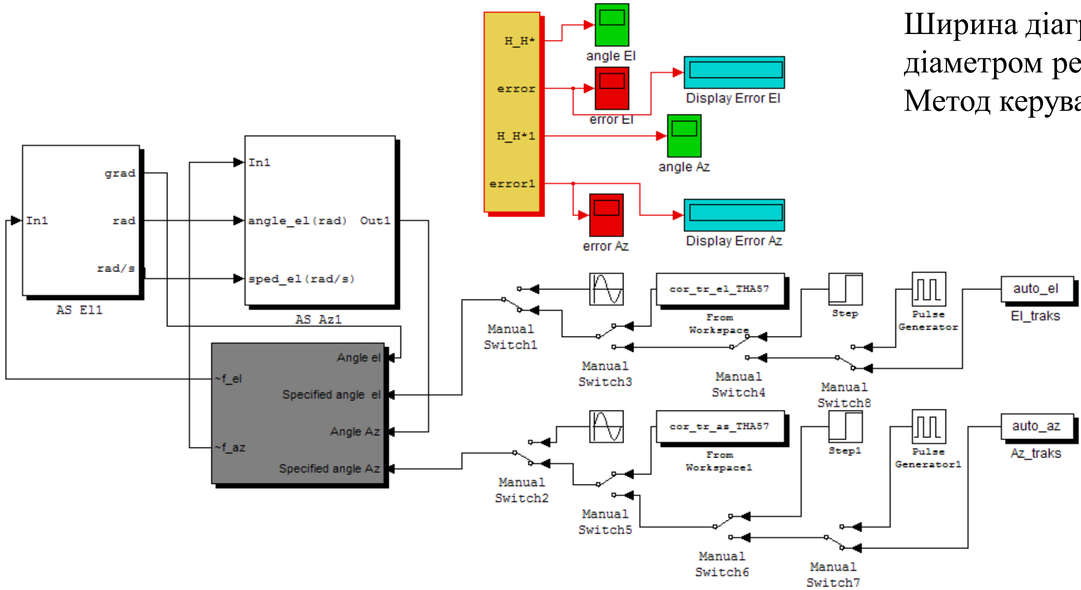
The neurocontroller of the control system is built on the basis of the of Elman NC [3], which is an advanced modification of the ANC of Jordan the feedbacks in it are brought from the outputs of internal neurons to additional inputs of the intermediate layer, and not to the primary inputs, which makes it more stable than other recurrent ones. .

AS control structure circuits

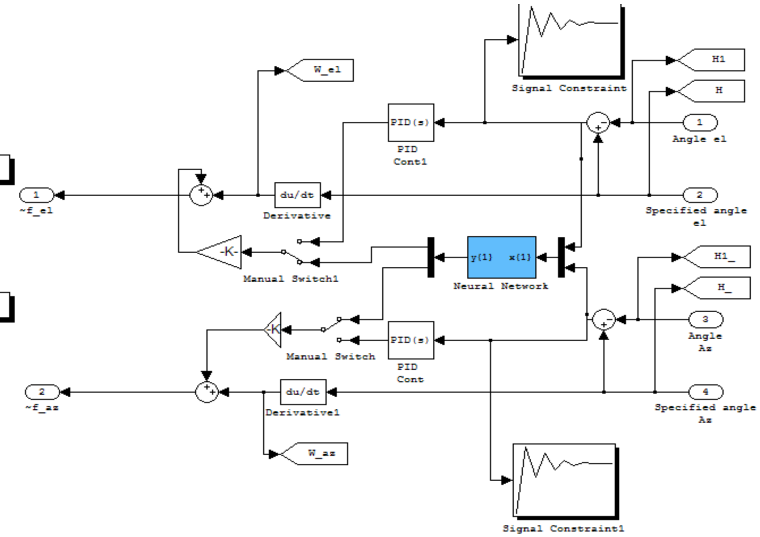




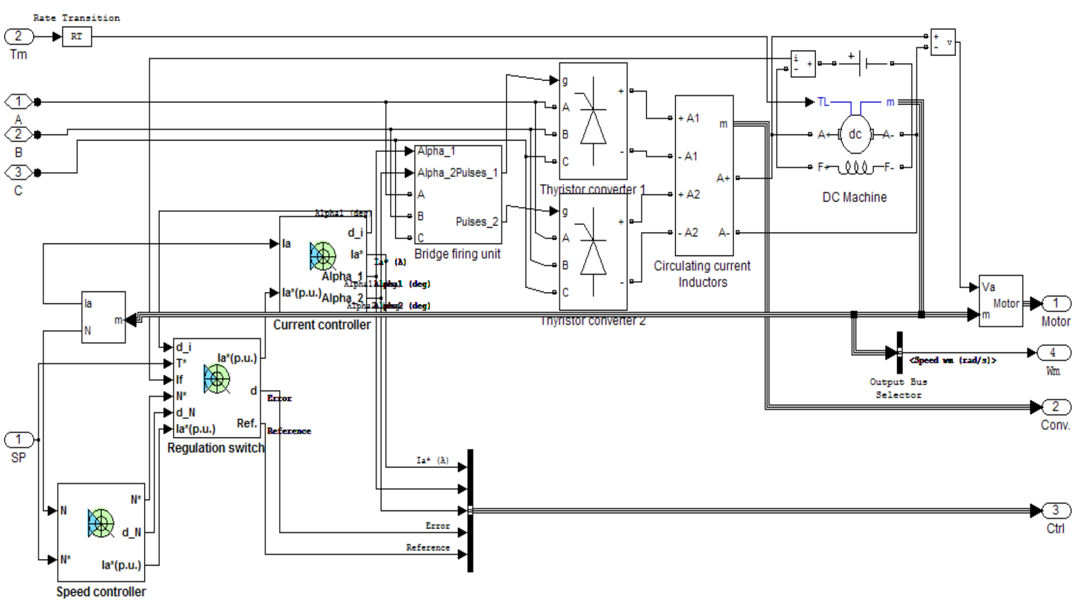
AS CONTROL SYSTEM SIMULATION MODEL



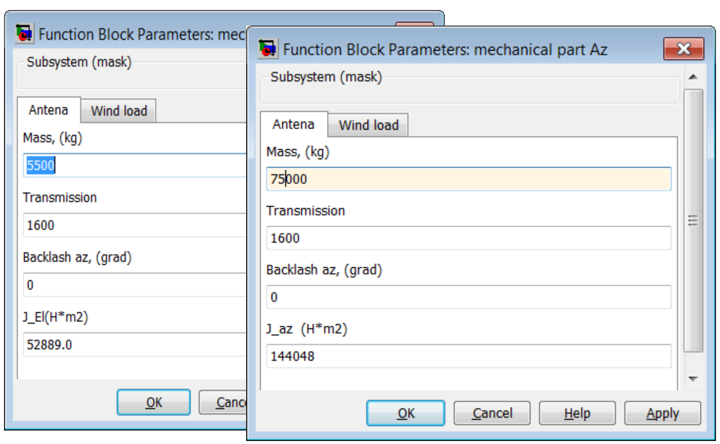
Ширина діаграми направленості АС = 14’, діаметром рефлектора 32 м, маса т
Метод керування на основі 2 ПІД, або ШНМ



Контролер керування АС

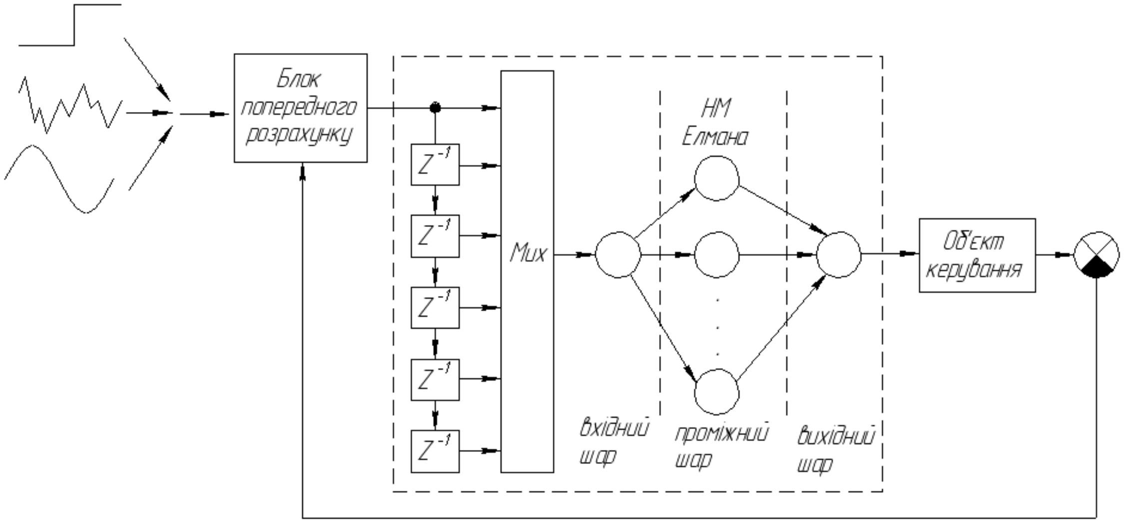


Модель регулятора швидкості двигунів СК АС



Параметри механічних модулів АС

Elman's Modified Recurrent ANN Model Synthesis in MatLab / Simulink



Стан нейронів рекурентного шару

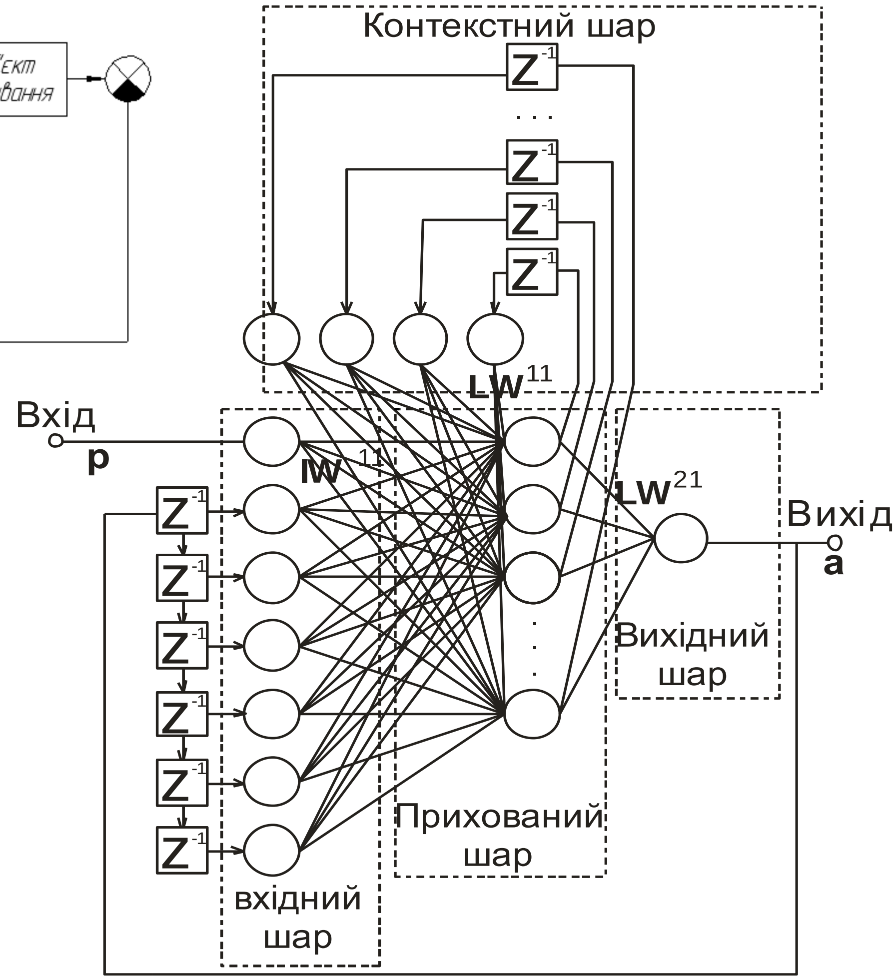
$$\begin{cases} \mathbf{n}^1(k) = \mathbf{LW}^{11}\mathbf{a}^1(k-1) + \mathbf{IW}^{11}\mathbf{p} + \mathbf{b}^1, \ \ \mathbf{a}^1(0) = \mathbf{a}_0^1; \\ \mathbf{a}^1(k) = tansig(\mathbf{n}^1(k)), \end{cases}$$

де **n** – виходи суматорів нейронів відповідного шару;
a – виходи нейронів після функції активації у *k-й* ітерації;
p – вектор вхідного сигналу;
b – вектор зміщень, що додаються до зважених входів нейронів.
IW, LW – матриці синаптичних ваг, що налаштовуються під час навчання

$$\begin{cases} \mathbf{n}^2(k) = \mathbf{LW}^{21}\mathbf{a}^1(k) + \mathbf{b}^2; \\ \mathbf{a}^2(k) = purelin(\mathbf{n}^2(k)). \end{cases}$$

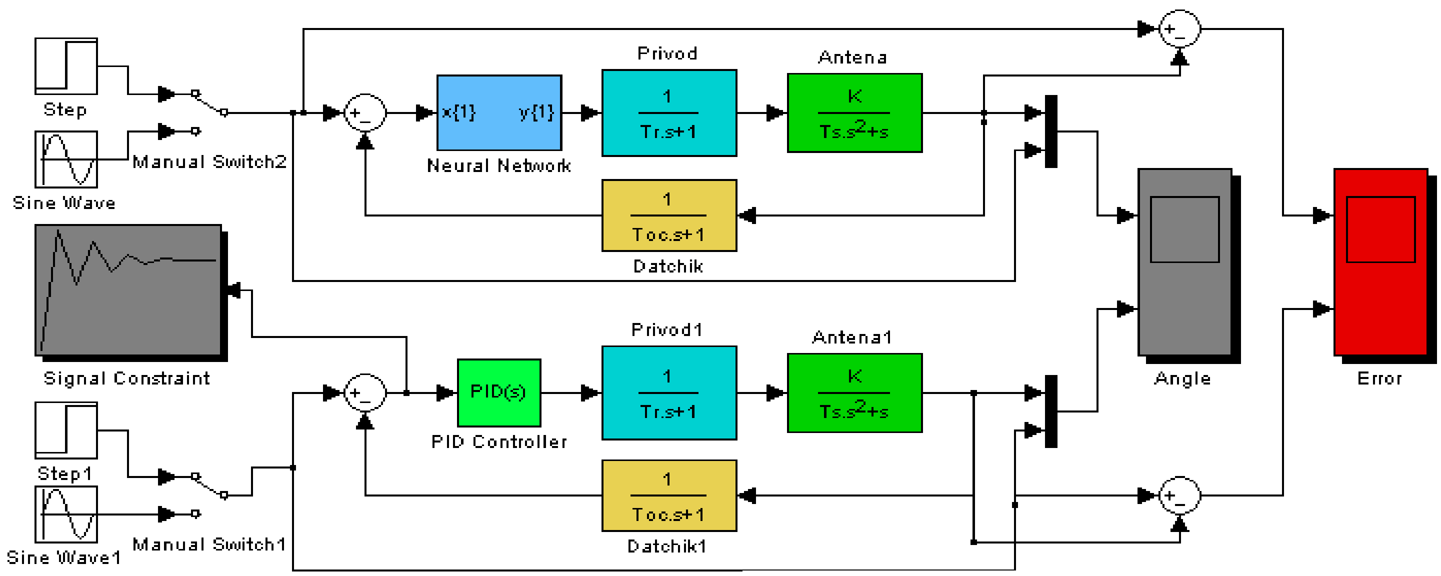
Вихідний шар ШНМ

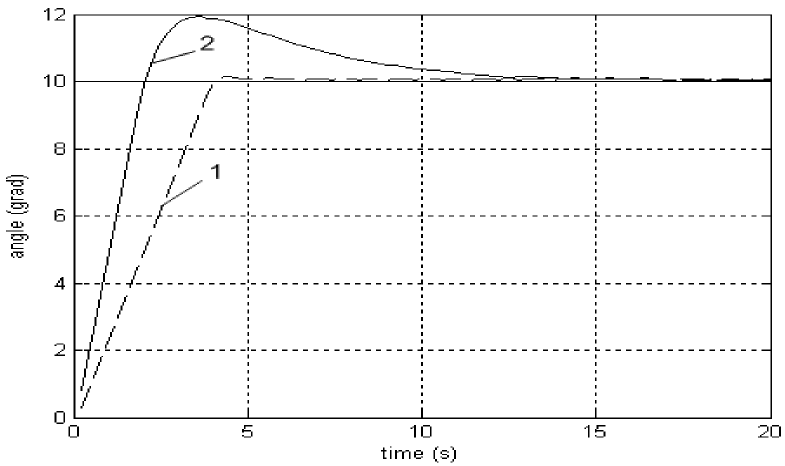
Використання зовнішніх зворотних зв'язків дозволяє зменшити вимоги до кількості нейронів внутрішнього шару ШНМ, детальніше враховувати передісторію процесів поведінки об'єкта і накопичувати інформацію для вироблення ефективніших керуючих дій



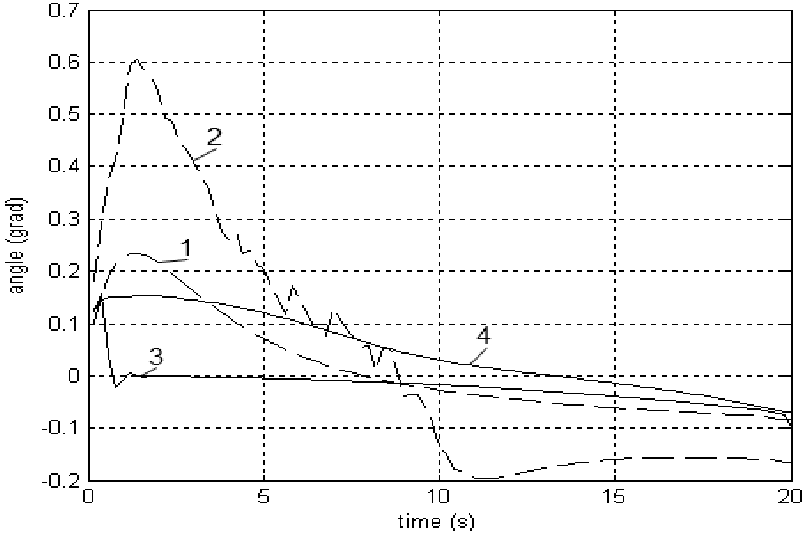
Структурна модель ШНМ Елмана із зовнішніми зворотними зв'язками

Comparison of the operation of the ANC and the PID when changing the dynamic parameters of the object





1 – модифікована НМ Елмана; 2 – налаштований ПІД- регулятор



Помилка регулювання при гармонічному характері зміни розбалансування: криві 1,2 – налаштований ПІД- регулятор з Ts = 1 та Ts = 2; криві 3,4 – модифікована НМ Елмана з Ts = 1 та Ts = 2

Advantages of CS using ANN

- Precise mathematical models of the control object do not need to be used in the control circuit;
- ANC can be effectively trained in adjusting dynamic objects with variable parameters;
- It is important for ANCs to choose an effective topology and training sequences that fully cover possible system behaviors;
- For control actions, it is efficient to use recurrent SNMs , particulary it is researched and substantiated the usage of Elman ANC with additional feedback, which increases the ANC's training capacity;
- It is rationaled the studying ANC trainings by gradient method (Fletcher-Reeves algorithm variant).
- The behavior of a control system with a neurocontroller in the mode of testing input trajectories with random perturbations is investigated.

The use of ANC allows us to adaptively adjust the parameters of the CS AS taking into account the peculiarities of the mechanical structures of the RD AS without detailed bulky calculations of the parameters of the actuators, and on the previously prepared training test trajectories of the AS.

ERROR SOURCES IN THE ANTENNA POINTING

The total errors for electrical axis pointing AS consist the following groups:

1. Methodical, astronomical *from inaccuracy coordinates determination* ()

2. Instrumental: angle measurement, influences of mechanisms angle sensors fastening, Support-Rotary-Device-constructions influences, influence of the reflector construction.

Behavior of them is unchangeable during a large period of time or changes according to the certain law.

Features of the object and structure of the control system:

The most significant sources of errors in control system is:

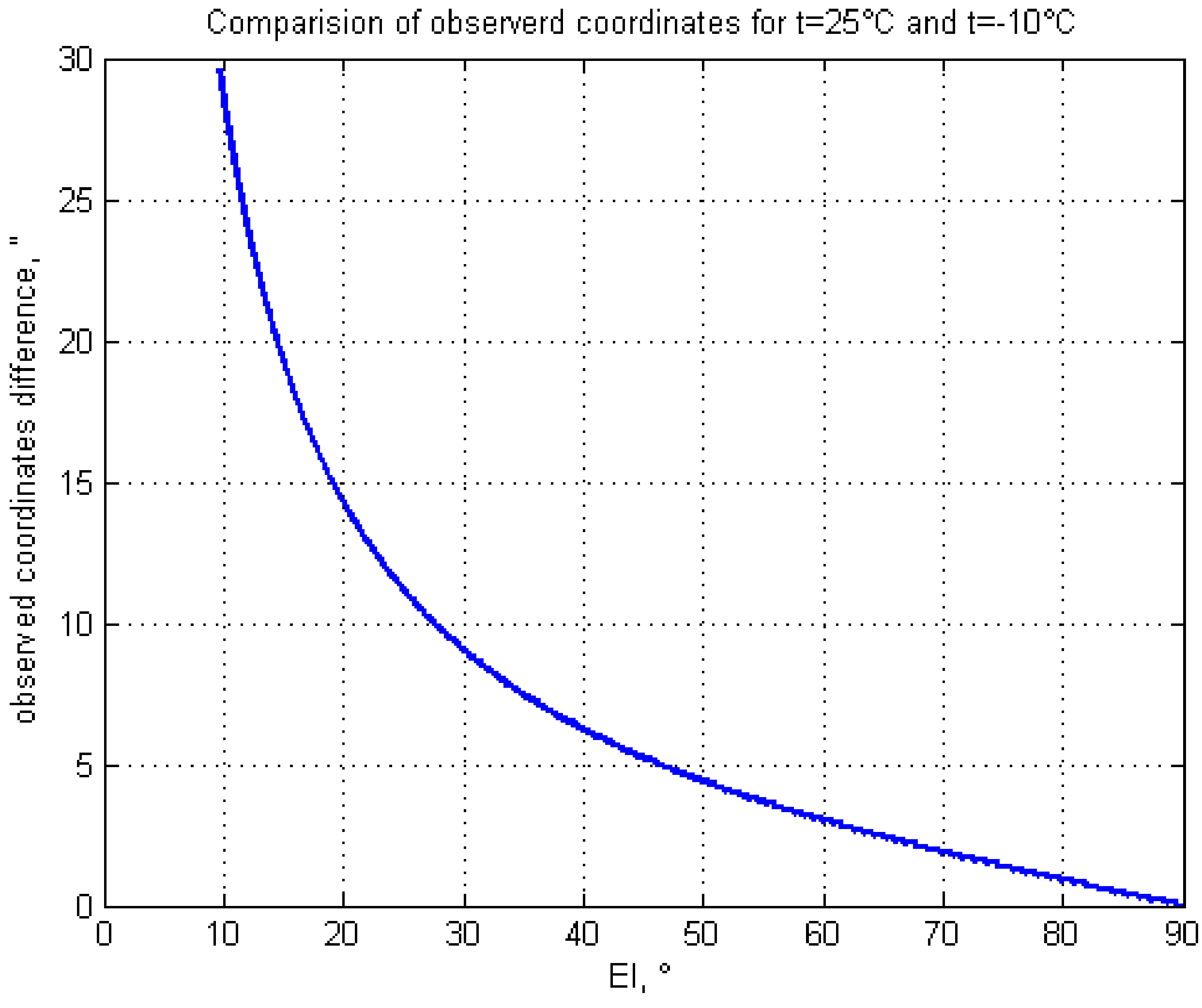
- the moments of inertia of modules vary from the angles of the reflector and the ratio of positions of the antenna modules for different axes,
- change in stiffness of mechanical gear
- changes in friction resistance,
- backlash
- Instability characteristics of electric drives,
- stochastic influence of wind loads, etc.

Such dynamic systems as management objects have a nonlinear character

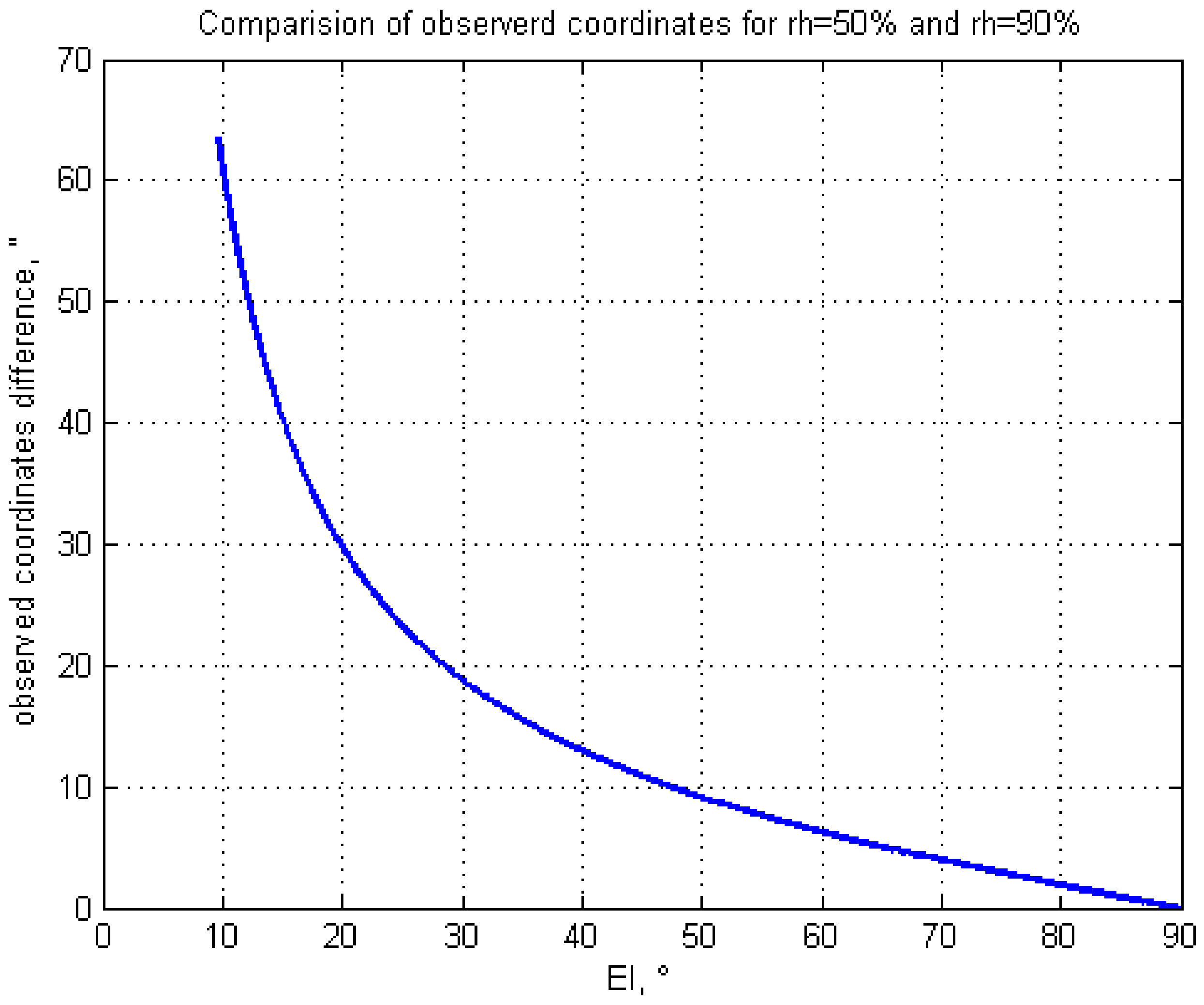
The error reducing methods based of constructive ways are complicate mechanical parts of SRD and lead to increase costs for their projecting, adjustment and maintenance.

ACS ERRORS ESTIMATED

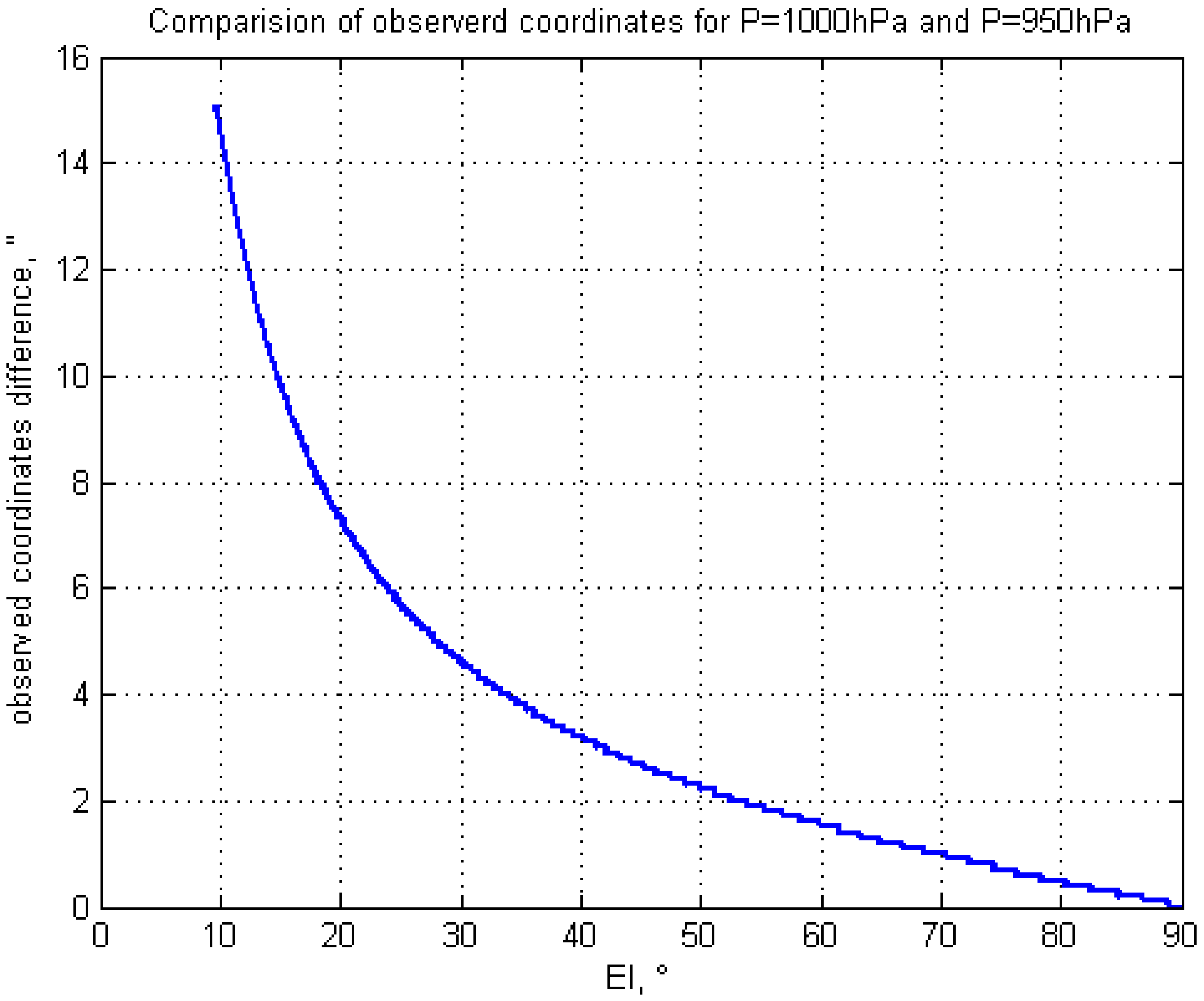
Effect of temperature on the refraction



Effect of humidity on the refraction



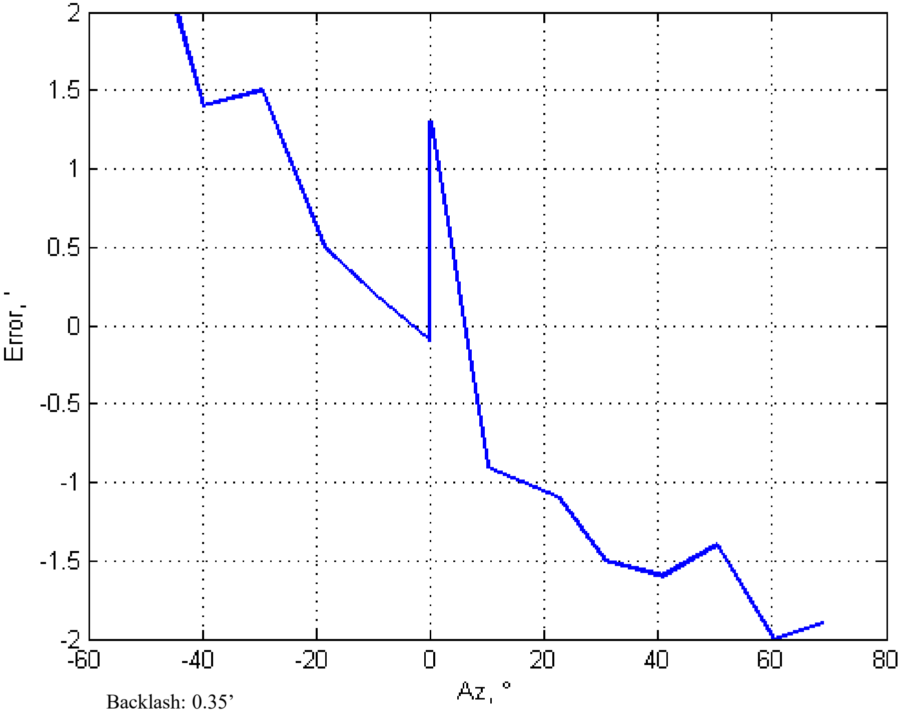
Effect of air pressure on the refraction



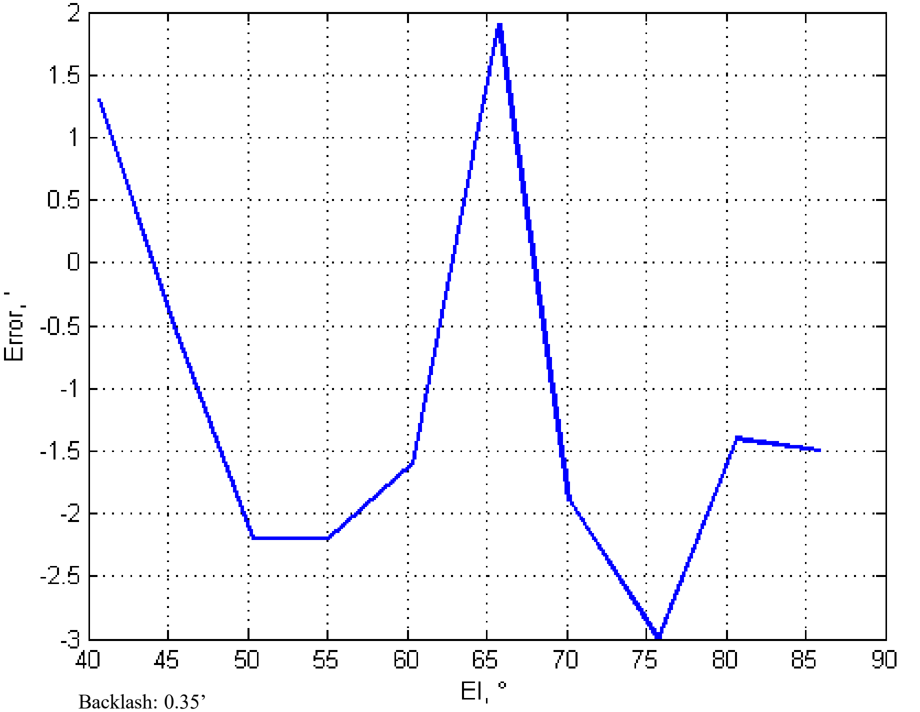
Effect of the Earth attitude and rotation

- UT1-UTC is less than 1s and affects observed coordinates for less than 15”
- Effect of polar motion xp, yp is less than 1”

Error measurement

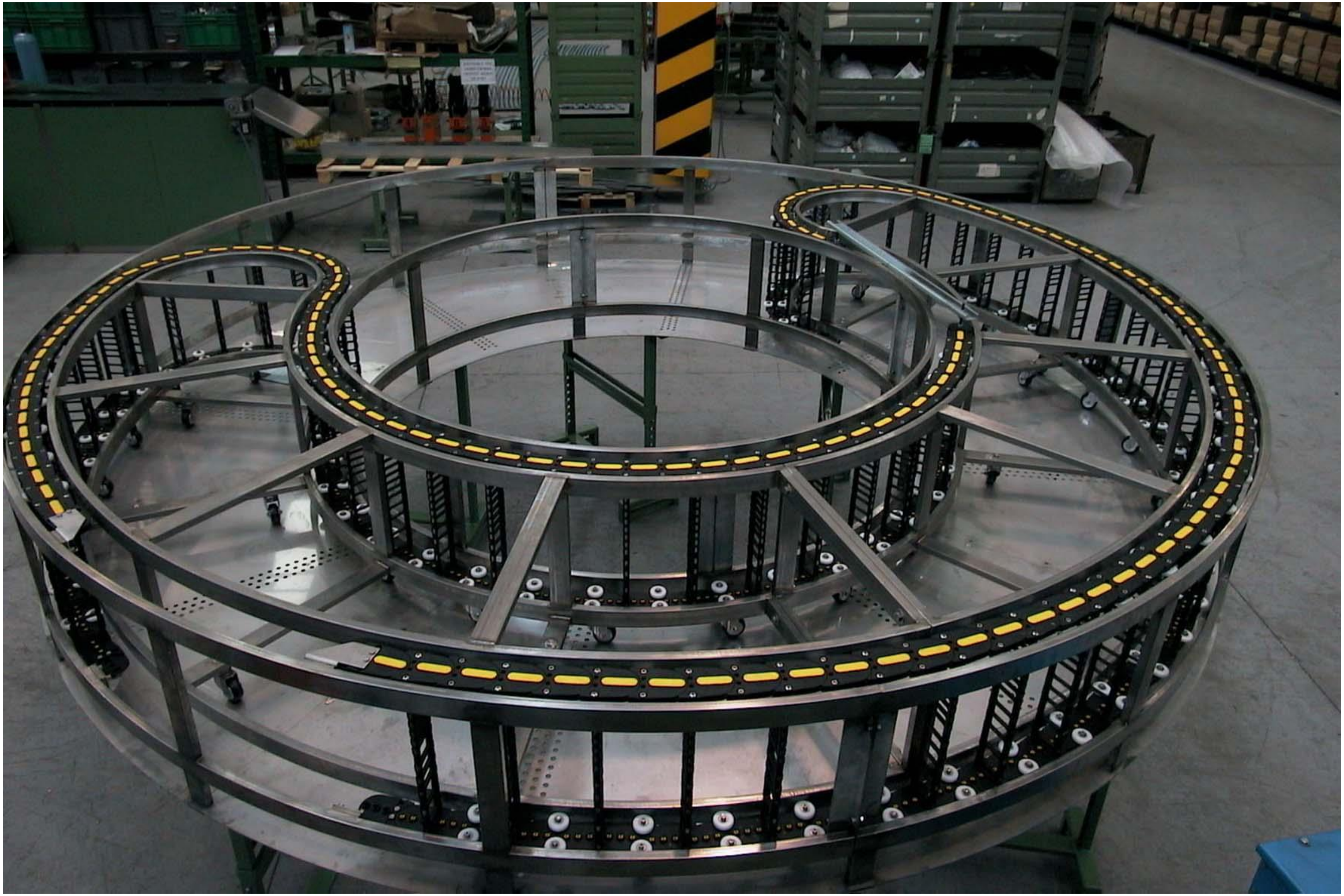


Backlash: 0.35’



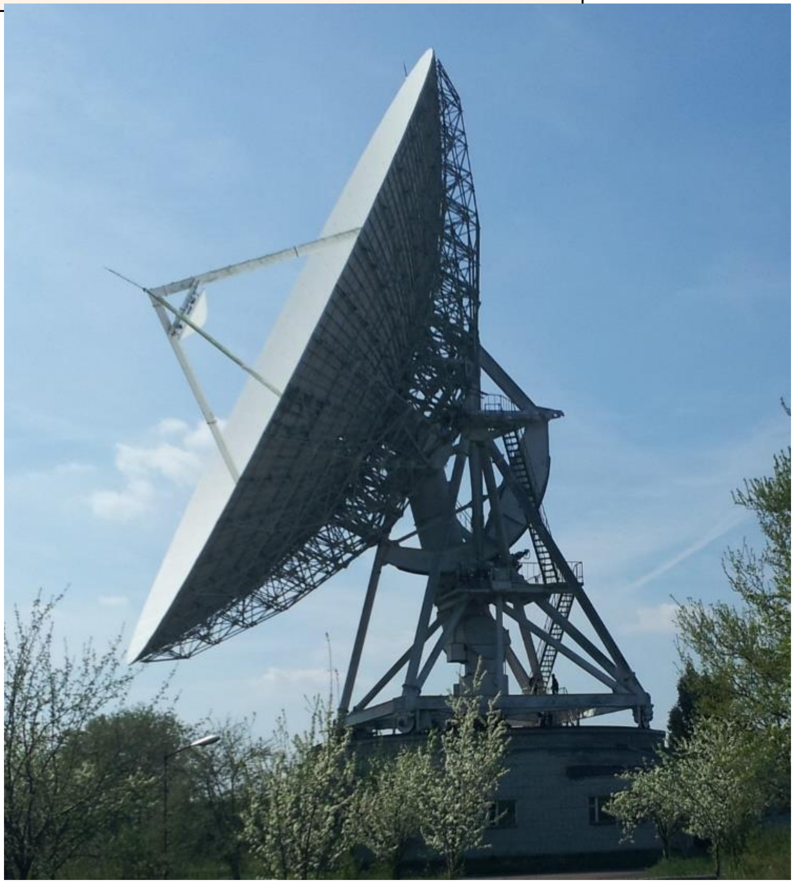
Backlash: 0.35’

CABLING ROUTING TO INCREASE as ROTATION RANGE



Laboratory studies of the cable chain

The report is finished



THANK YOU
for your attention!

UKRAINE
Ternopil,
Ruska str., 56
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kaf-pv.tntu.edu.ua
http://tntu.edu.ua/?p=uk/structure/research/labs/ndl-itis