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Modular Design of Micro/Nanosatellites

Electronic Laboratory Course

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Methodological guidelines are designed for laboratory work on the course "Modular design of micro / nanosatellites" in the form of calculated and experimental, virtual representation of the data elements of mathematical modeling and algorithms for on-board systems of micro / nano-satellites.

Interuniversity Space Research Department, Master Program Educational Content "Space Information Systems and Nanosatellites. Navigation and Remote Sensing" for education direction 010900.68 «Applied Mathematics and Physics»

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Laboratory Course

Modular Design of Micro/Nanosatellites

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Samara 2011

Introduction

Methodological guidelines are designed for laboratory work on the course "Modular design of micro / nanosatellites" in the form of calculated and experimental, virtual representation of the data elements of mathematical modeling and algorithms for on-board systems of micro / nano-satellites.

Teaching and material-technical base of works created under the National Project "Education" and the project CRIST «Reforming the educational programs in the field of space technologies in Kazakhstan, Russia, Ukraine" Tempus.

Technical base is the class of «CAD / CAM / CAE design," as well as Laboratory 'station control small satellites "and lab" Navigation ".

Computer Class «CAD / CAM / CAE design" is equipped with licensed software «ProEngineer», «Altium Designer» and «Satellite Tool Kit», as well as freely available within the programming Lazarus and Java.

In the class of «CAD / CAM / CAE design" in the course "Computer technology design and engineering micro / nano-satellites in medium ProEngineer» Students receive practical knowledge and skills of computer-aided design of structural elements of spacecraft (SC) model of the spacecraft motion, the decision support service tasks SC (calculating the route, line of sight, etc.).

Laboratory "Control Station for small satellites" with a set of equipment necessary for the reception and transmission of data on board the micro / nano-satellites Technical University of Berlin, and includes in its composition: receiving station, data ICOM, modems to connect to the satellites and Beesat Lapan-TUBSat .

In the laboratory, "The station control small satellites," students carry out radio communications with the micro / nano-satellite Technical University of Berlin. The aim is to get the radio telemetry data (temperature, voltage and current in solar cells, modules, on-board systems) on board the micro / nanosatellites.

Laboratory "Control Station for small satellites," equipped with the following software:

1. SatPC32 - Program for the movement of space objects on the data of NORAD.
2. Beesat GUI - a program reception and transmission of data on board nanosatellite Beesat.
3. Lapan GUI - a program reception and transmission of data on board the nano-satellite Lapan-TUBSat.
4. Arswin - a program for automatic control receiving and transmitting antennas.

Laboratory "Navigation" is equipped with a simulator signals of CH-3803M and a set of navigation receivers.

In the laboratory, "Navigation" students have the opportunity to work with signals as simulated by the simulator CH-3803M, and the real signals of GLONASS and GPS.

Laboratory "Navigation" is equipped with the following software:

1. A Nuvi - a program designed to process real signals, obtained using a set of navigation receivers.
2. GGhunter - a program designed to create scenarios for simulated signals of the CH-3803M.

LABORATORY WORK №1
Synthesis of scenarios for micro/nanosatellites navigation equipment testing

Purpose - to obtain the skills of ground testing of navigation equipment using simulated signals.
Objectives:

1. A study of the general method of synthesis scripts
2. Study methods microsatellite job movement, as a material point
3. Testing the navigational equipment on the simulator signals of CH-3803M.

Stages

Performing laboratory work carried out in two stages:
Stage 1. Scenario synthesis
Stage 2. The simulation using the simulator CH-3803M

Stage 1. Scenario Synthesis

If you select [Synthesis] menu (Figure 1.1), a dialog box presented below (Figure 1.2).

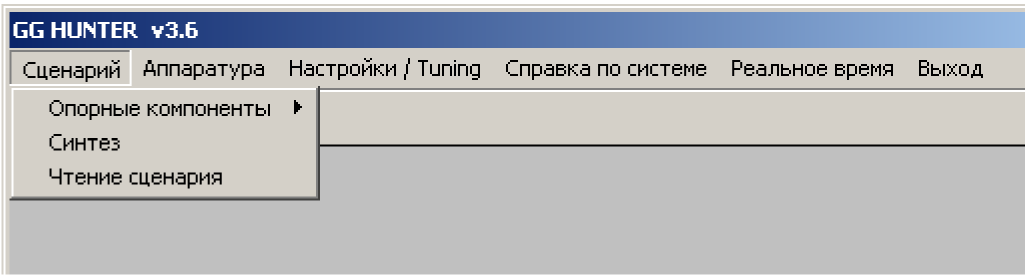


Figure 1.1 – [Synthesis] submenu

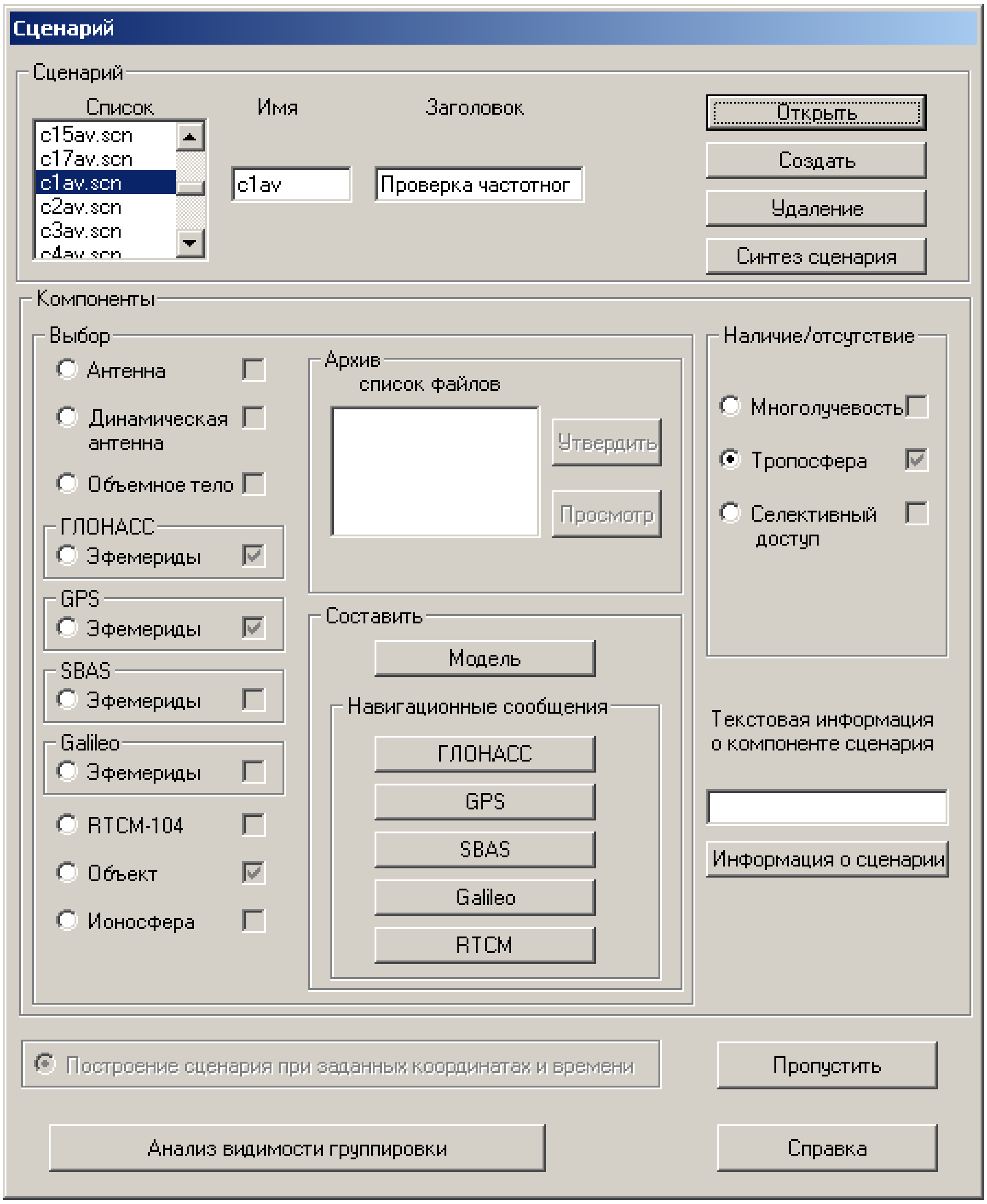


Figure 1.2 – The scenario menu

Synthesis of the scenario operational components

Operational components of the scenario are:

- navigation message of GLONASS, GPS, SBAS, GALILEO;
- object (a material point or three-dimensional body);
- model of the object;
- ionosphere;
- differential corrections;
- description of the antenna;
- GLONASS ephemeris, GPS, SBAS and GALILEO.

Considered the components are selected from the category archive or re-created, and joined a group called [Select].

Set parameters and calculation of visibility and groupings of values of geometric factors is similar to that described above for laying the [Constellation] calculator.

The operational elements, combined in a group called [The presence / absence], belong to the category established by the flag:

- presence or absence of multipath,
- presence or absence of selective access
- presence or absence of the troposphere.

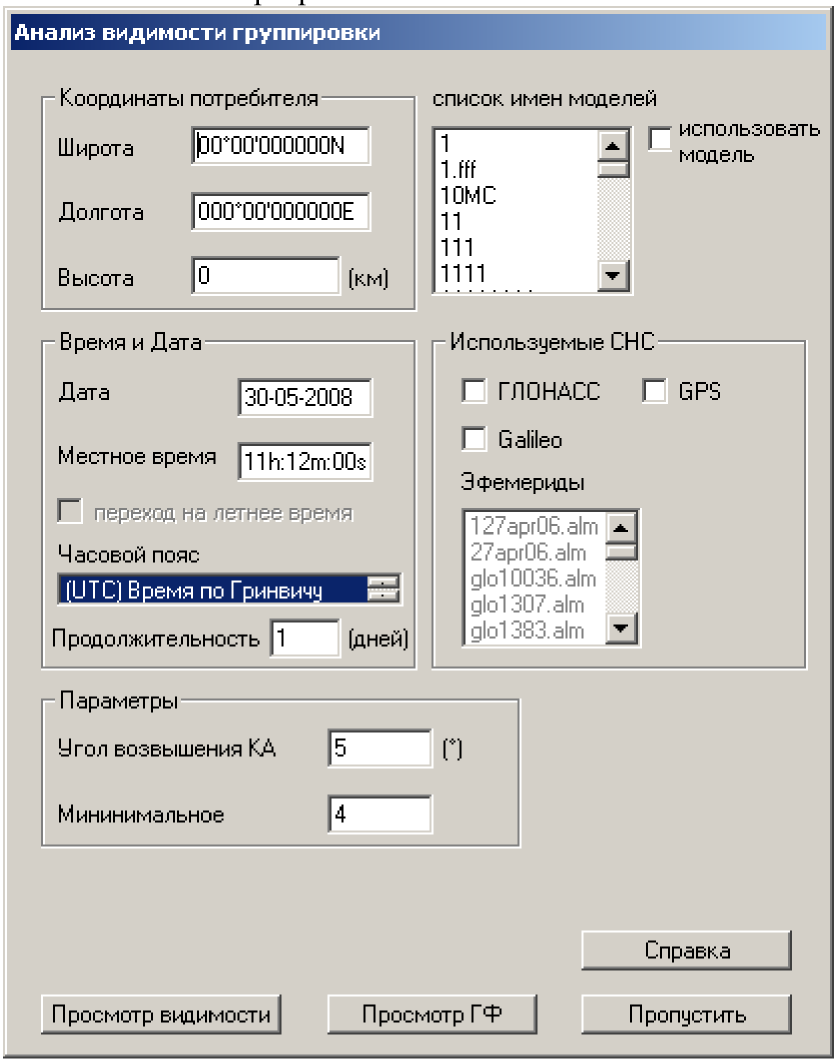


Figure 1.3

By the operational components that are created quickly, include the navigation message of GLONASS satellite, satellite SNA GPS, HCA SNA SBAS, satellite SNA GALILEO, a model of object motion and differential corrections.

Navigation Report Generation Transmitted by NS SNS GLONASS to GS

Overview

The navigation message is transmitted as a stream of digital information encoded on the Hamming code and transformed into relative code. Structurally flow of digital information generated in the form of continuously repeating superframes. Superframe consists of several frames, the frame consists of several lines of digital information. Superframe has a duration of 2.5 minutes and consists of 5 shots for 30 seconds.

Each frame consists of 15 rows of duration 2 seconds. Within each superframe transmitted a full range of non-operational information for all 24 GLONASS satellite.

The Initial Operations of Generation of GS GLONASS

For the formation of the GLONASS satellite to NC in the window (Figure), press [GLONASS] in the [Create] -> [Navigation messages]. A dialog box presented below (Figure). Before you set the required parameters, you first need to set time and date of commencement of the formation of satellite navigation message. When you set the start time should be considered temporary discipline forming superframes. The duration of each superframe is equal to 2.5 minutes and the number of days in srednesolnechnyh strictly fixed.

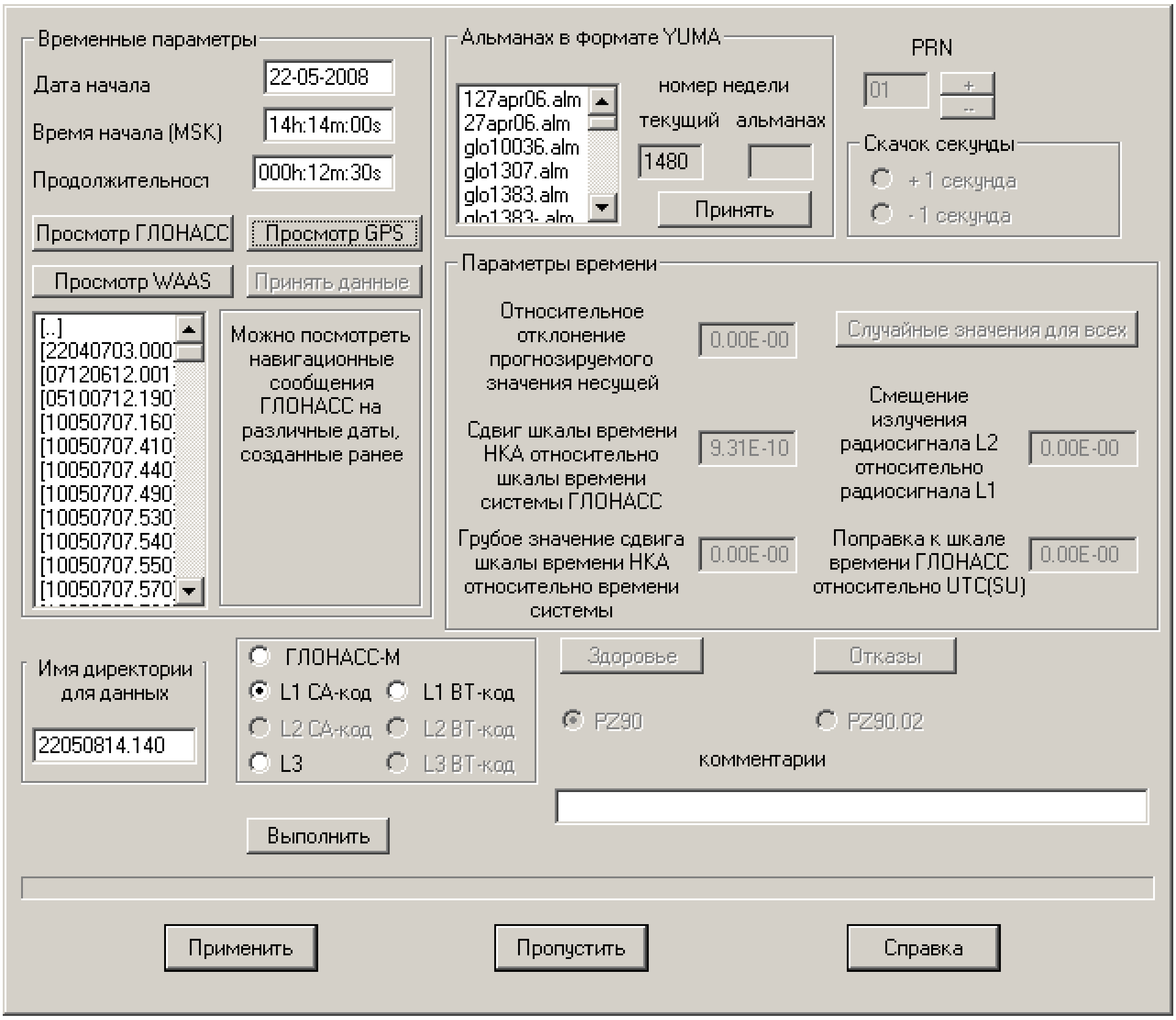


Figure 1.4 –The window of the formation of the GLONASS satellite to NC

Time Parameter Setting

Time parameters can be specified in the following ways:

1. The date and time provided by the CAS, are exhibited in the appropriate boxes by default;
2. correction of the time and date on display by default;
3. the adoption of time to the first superframe of already established cardiovascular system of navigation messages GPS, using the following buttons:

- [View GLONASS] - allows you to view the names of existing files of GLONASS navigation message;

- [View GPS] - allows you to view the names of existing files navigation message SNA GPS;
- [View WAAS] - allows you to view the names of existing files navigation message SNA SBAS.

Clicking on these buttons allows you to get information about the temporal parameters help you view the ephemeris.

Button [Accept data] is available after pressing the [View GPS] or [View WAAS] and allows us to take the date and time corresponding to the navigation message, adding 3 hours to GLONASS. The exact value to the date and time displayed in the navigation message is located next to the information window.

GLONASS, GPS works with a different starting point timing. This should be borne in mind when forming the navigation message of which will continue to create the script. If the script will get the navigation messages generated numerically at the same time, their time reading about the overall PIM UTC disperse at 3:00, leading to faulty navigation and temporal definitions of the NAM when you play this scenario for IP.

Setting of the GLONASS almanac parameters

The next step is a navigation message to the CAS becomes available Almanac groups. In the group [in the format Almanac YUMA] is a list of anthologies OG recorded as a result of treatment assignment orbit satellite system. The choice made by OG week number. The boxes under the name [week number]:
[Current] - shows the number of weeks, which holds the current date,
[Almanac] - shows the number of weeks of the anthology, selected by pressing [Accept].

In the inscription under [Settings time] can be introduced timing for each satellite, which by default is zero. System number of NCA, which introduces the parameters displayed in the window below the words [PRN]. The number can be changed by pressing the button [+][-].

In the left pane of the dialog box under the information about the establishment of the navigation message is the [name of the directory for the data]. This window is represented by the name of the directory in which to store the navigation message, and which can be changed by the operator. The default file name is formed according to the date and time of the posting:

ddmmyyhh.iis,

where dd - number, mm - month, yy - year, hh - hour, ii - minutes, s - 0 (0 seconds) or 1 (30 seconds).

Breagdown/Error Mode Setting

To enter the setting mode failures, failures in the navigation messages generated, press the [waiver]. Window view for job failures, failures navigation message is shown below (Figure 1.5). At the same time you receive access to the regime of job failure, caused by failures in the navigation messages of two types:

- Error in determining the sampling time of the radiation signal from the satellite (misrepresentation of the time);
- Error in determining the coordinates of the observation satellite.

All input values refer to system number that appears next to the appropriate inscription [system number]. Buttons located next to the edit box you can change the number of NCA and specify the required values of error.

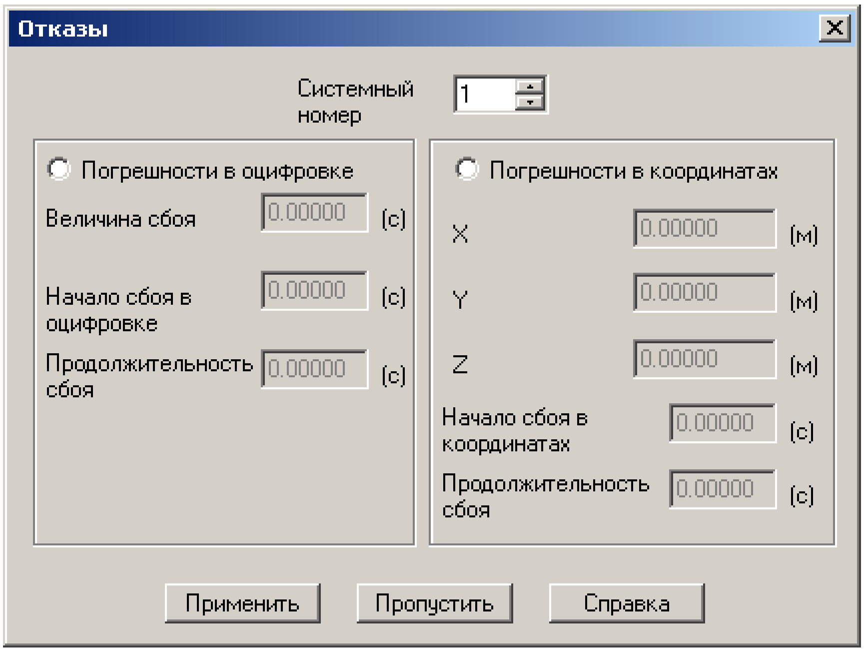


Figure 1.5 Window view for job failures, failures navigation message

If you put a black dot in the inscriptions [Errors in digitizing] then become available for editing window, located below, in which you enter values for each satellite separately:

[Top of failure in the digitization] - the time interval from the beginning of the script, which is manifested in failure to digitize (specified in seconds);

[The duration of failure] - time during which the failure manifests itself (specified in seconds);

[The value of failure] - value of the error in the digitization (specified in seconds).

If you put a black dot in the inscriptions [Errors in the coordinates], then become accessible windows, are located above and below, in which you enter values for each satellite separately:

- [Top of failure in the coordinates] - the time interval from the beginning of the script, from which there is an error in the coordinates (given in seconds);
- [The duration of failure] - time interval during which the manifest failure (given in seconds);
- [X] - error in the coordinates on the X, defined in meters;
- [Y] - error in the coordinates of the axis of Y, defined in meters;
- [Z] - error in the coordinates in Z, defined in meters.

For a single satellite can be given both types of error, each defined by their time. To do this, without changing the system number of NCA, switch the set of errors from one to another or successively, by changing the number of satellite system, ask for one error, then the other.
When you click [Save], the information about the crash is saved and the window closes.
When you click the [Skip] information is ignored and the window closes. The [Help] is intended to provide background information.

NS GLONASS Technical State Setting

Pressing the [Health] there is an additional window (Figure 3) which can be defined "health" of NFA in accordance with ICD for each satellite and each superframe. The choice of PRN [PRN], and [number superframe] by the buttons [+/-]. In this healthy companion to be marked a "black spot" radio button [health].

If you change the superframe displays the start time selected superframe [Time superframe]. The number of superframes generated depends on the duration of navigational messages. Began to create navigation message is displayed next to [Date] and [Time], and next to [Time] and [Number of superframes] The details of the length of messages.

The [Save] is designed to save the entered information and closes the window.
The [Skip] is designed to close the window, with the information entered is ignored.
The [Help] is intended to provide background information.

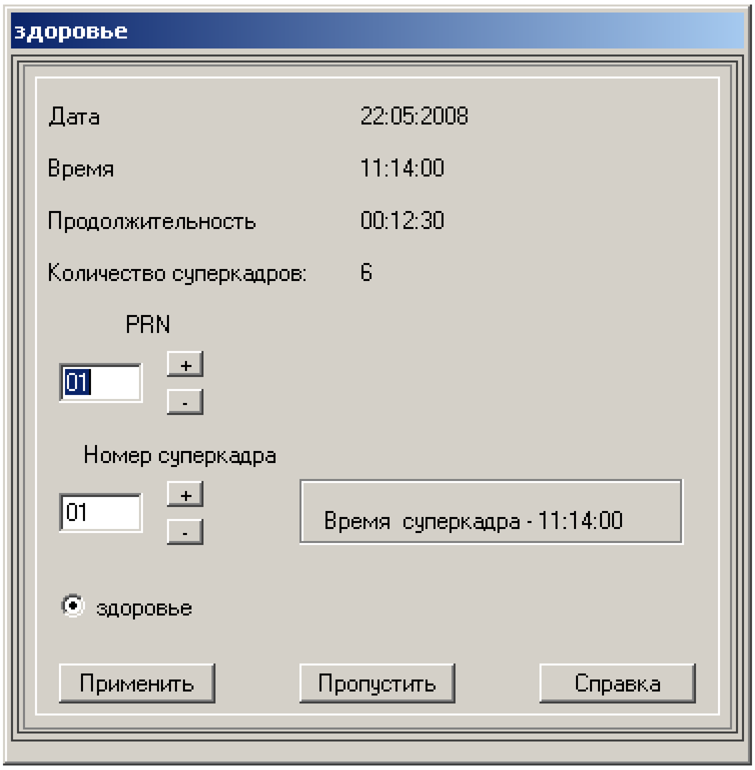


Figure 1.6

Conclusive Operations of GS SNS GLONASS Generation

The information line [comments], if necessary, the operator can enter information to describe the navigation messages generated.

If you enter or view the parameters of GLONASS ephemeris is completed, you must press the [Run]. The process of formation is controlled by changing color bar below the button and ends when it is full.

This creates 24 files (separate for each satellite SNA) with bit sequences corresponding to the navigation message of a given length.

Exit and save the ephemeris by pressing the [Apply].

Pressing the [Skip] all of the action of the synthesis of the GLONASS ephemeris CAS ignored and any data created is destroyed, then the operator can begin to create an ephemeris with "clean" list.

The [Help] is intended to provide background information.

Navigation Report Generation Transmitted by NS SNS GPS to GS Overview

Building exhaust SNA GPS, characteristics of the signals, the formation of the navigation message meets an ICD «INTERFACE CONTROL DOCUMENT. NAVSTAR GPS SPACE SEGMENT / NAVIGATION USER INTERFACES »ICD-GPS-200.

The format structure of the main messages is a frame consisting of 1,500 bits and composed of five subframes. Each subframe consists of 300 bits. The full message is required to transmit 25 frames.

Navigation data stream is transmitted RNA at 50 bits per second. Duration of the navigation message is 12.5 minutes.

The Initial Operations of Generation of GS GPS

For the formation of NC NCA SNA GPS to the window, presented above (Figure 1.6), press [GPS] in the [Create] -> [Navigation messages]. A dialog box presented below (Figure 1.7). The initial phase to set all the variables is time and date of beginning of formation of satellite navigation message. When you set this time in the CAS takes into account peculiarities of superframes in the SNA GPS.

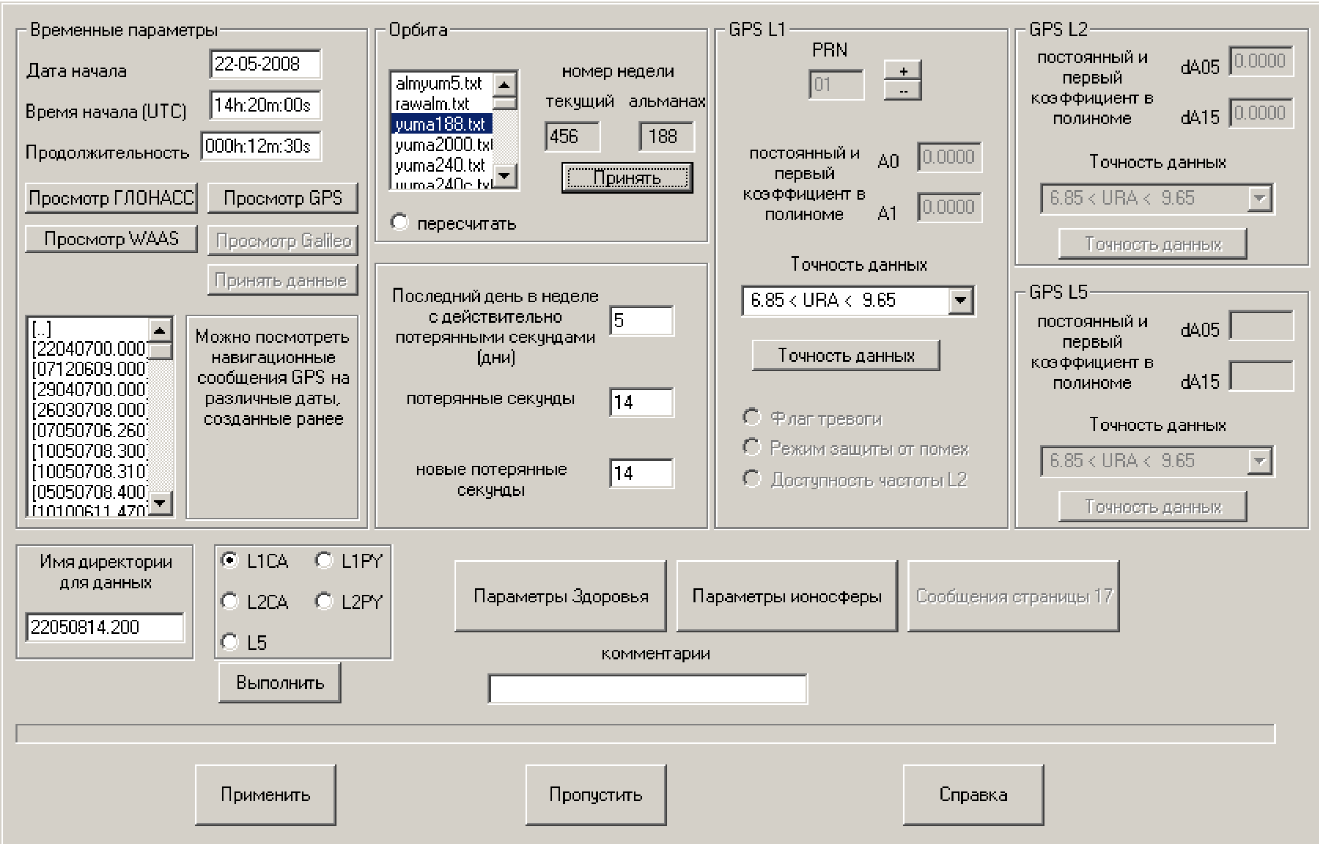


Figure 1.7

One element of the order of framing in the SNA is the alignment of superframe GPS modulo week, ie always the beginning of the week in the SNA GPS denotes the start of developing new superframes for all "healthy" satellite. Duration superframe is exactly equal to 750 seconds.

Time Parameter Setting

Time parameters can be specified ways:

1) The date and time provided by the SSA. Installed in the appropriate boxes by default.
2) Correction date and time provided by default.
3) The adoption of time to the first superframe of already established cardiovascular system of navigation messages GLONASS. For this purpose we click:

- [View GLONASS] - allows you to view the names of existing files of GLONASS navigation message;
- [View GPS] - allows you to view the names of existing files navigation message SNA GPS;
- [View WAAS] - allows you to view the names of existing files navigation message SNA SBAS;
- [Take data] - is available when you click one of the [View GLONASS] [View WAAS] and allows us to take the appropriate date and time of the navigation message for the navigation message of GLONASS system time corrected GPS SNA at 3:00.

Selecting the SNS GPS almanac

In the window under the name [orbit] is a list of anthologies OG recorded as a result of treatment assignment orbit satellite system. The choice made by OG week number. The boxes under the name of [number of weeks]:

[Current] - displays the number of weeks, which includes the current date;

[Almanac] - displays the number of weeks of the anthology, selected with [Accept].

Black radio button marked [count] provides data for recount display the time entered in the box [Timing].

Press [+] and [-] to change the number of NCA, which is displayed in the box located next to [PRN].

Located below the windows are some of the time parameters, as described in ICD-GPS-200 for each satellite, which by default is zero.

In the [lost seconds] a value of "lost" second of the SNA GPS.

In the [new lost seconds] the new value of "lost" seconds must occur if the "jump" (NCA change PIM an integer number of seconds).

The [last day of the week with really lost seconds (days)]. If you should happen "leap" seconds, then this window is available and it introduced last day of the previous value of "lost" seconds. The day number is valid for one week.

When editing the anthology can be set flags:

attribute data on the frequency of L2 - [Accessibility frequency L2];

synchronization feature (NCA model for the design of block-1) - [Flag of sync], or a sign of the regime, which provides protection against misleading interference (RNA for the construction of a model unit-2) - [mode of protection against noise];

sign since the loss of information (for Block-1) - [Flag of loss of information], or a sign of anxiety (for Block-2) - [Flag of anxiety].

Under the inscription [accuracy of the data] is given by the predicted accuracy of the distance to the consumer using a standard satellite channel for two-frequency method for determining. Here, for each satellite, you can choose any value from the list of URA for each satellite. In this case, each value from the list given by URA for the duration of messages. For a more detailed job, you must press the [accuracy of the data], then the window opens, presented below (Figure 2).

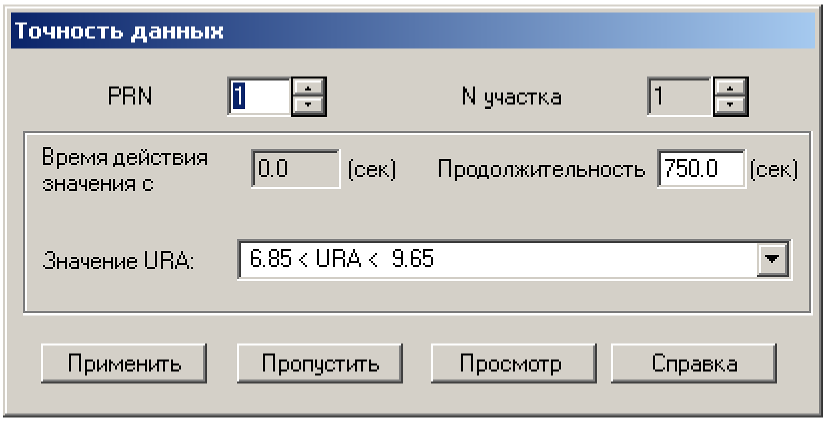


Figure 1.8

In the editing window [PRN] shows the system number (PRN) satellite GPS, which will be detailed to ask the accuracy of the data. The number can be changed manually, as well as using the scroll buttons to the right of the window.

Change the value of URA is given to areas identified by the time of their onset and duration of the site. In the [Time of values] displays the start time of a given value URA in seconds from the beginning of formation of the navigation message of GPS, selected in the main window. In the editing window [Time] is given by the duration of the selected value in seconds.

In the [value of URA] then the value of URA drop-down list.

In the [N-site] displays the serial number given by the plot. After choosing the values of URA and the duration of using the scroll buttons can proceed to the next job site.

While the job can be viewed on a graphical display of set value by pressing the [View], resulting in a window there, represented in the figure below (Figure 1.9).

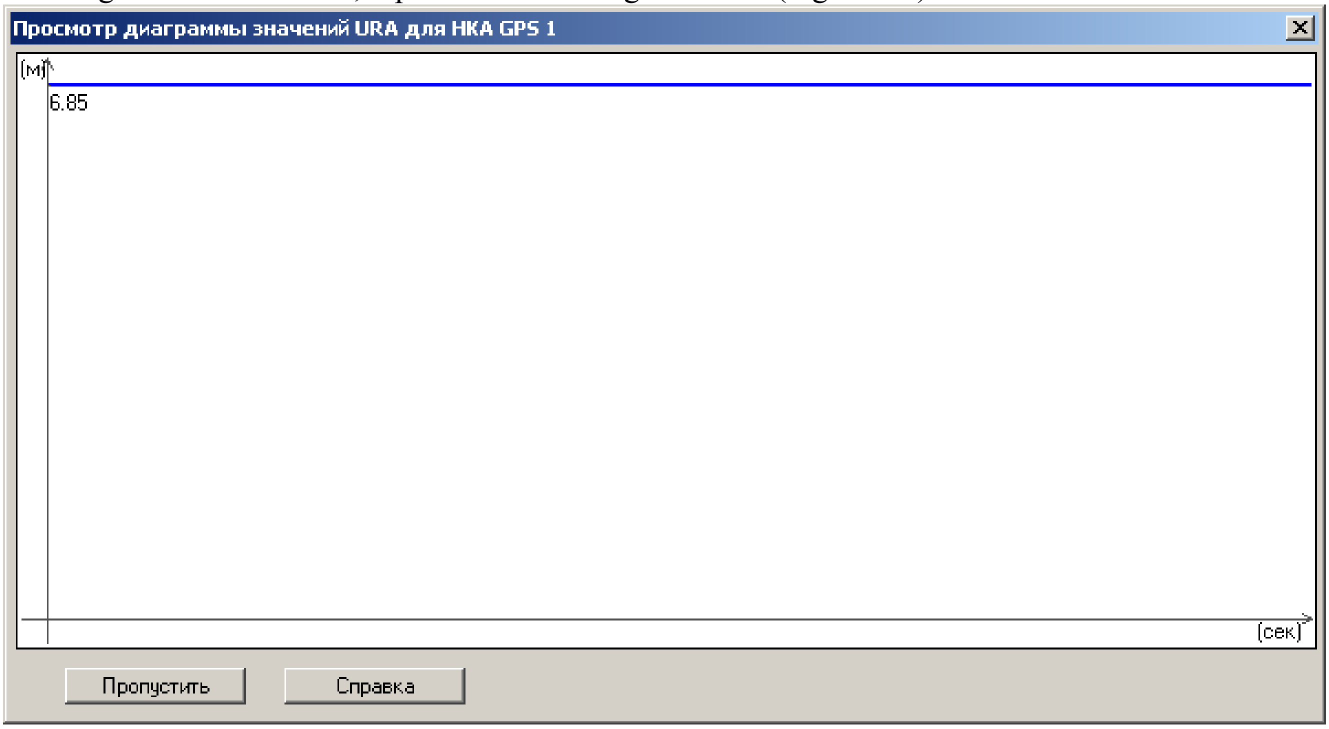


Figure 1.9

Completing the Found job keeping the values of URA data by pressing the [Apply]. In case of refusal to save, press [Skip]. The [Help] is intended to provide background information.

Pressing the [Options Health] there is an additional window (fig 1.10), which can be set operating parameters ("Health") in accordance with NCA ICDs for each frequency band, each satellite and each superframe. The choice of PRN [PRN], and [number superframe] by the buttons [+/-]. If you change the superframe displays the start time selected superframe [Time superframe]. The number of superframes generated depends on the duration of navigational messages. Functioning NFA without restrictions ("Health" NCA) formed by the described in ICD-GPS-2000 rule of the two parameters which are selected by opening the windows c parameters.

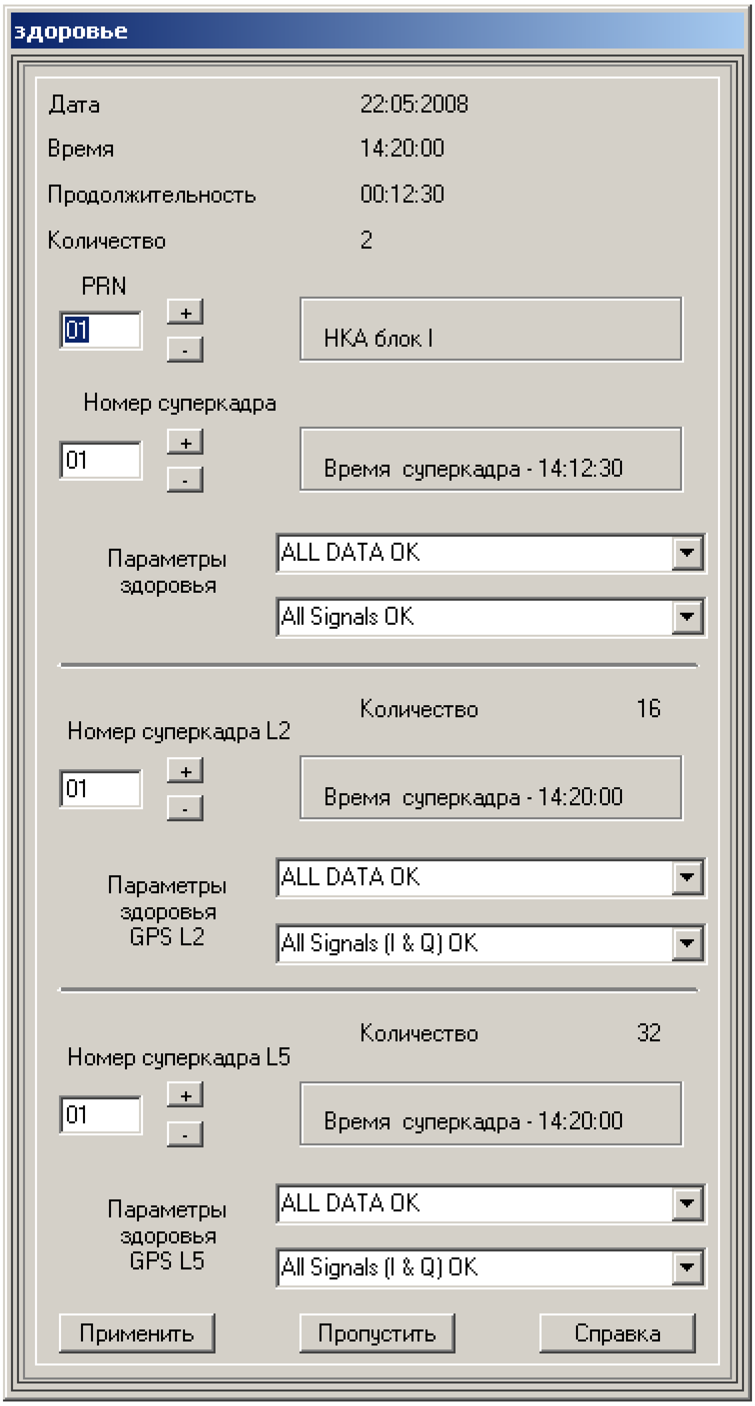


Figure 1.10

Description of Movement Model in the Geocentric Coordinate System as a File with a Table

If you select [table] in the (Error: the source of cross-references not found), there is a window (Figure 1.11) to select a file name that contains the values of the turning points in the Geocentric SC describing the motion of an object.

Описание модели движения в Геоцентрической СК в виде файла с таблицей

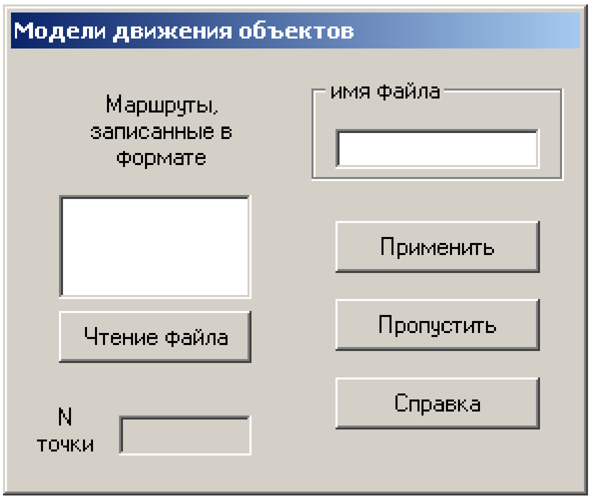


Figure 1.11

Chosen from a list that is directly under [Routes recorded in the format]. Also, reading from any computer disk and record the route in the list carried in a standard dialog box that opens with the [Reading from a file]. Data file must have a «xyz». After separation of the file name color, is decoding the contents of the file box labeled [N points] will be the serial number of the last point, which corresponds to the number of points in the table and in the window below the words [filename] displays the default file name, in which prompted to save the converted information. This file name can be changed.

Format of the formalized record route for conversion to route CCC:
(Along the lines written information through any number of spaces)
time in seconds;
X-coordinate value in meters;
Y-coordinate value in meters;
value of Z coordinate in meters;
speed X-axis in meters per second;
speed on the Y axis in meters per second;
speed along the Z axis in meters per second.
These transformations are not subjected to additional processing and, thus, no smoothing algorithm is not applicable.

In the [filename] the name of the file in which to store information about the entered values.

When you click [Apply] the information is saved and the window closes.

When you click the [Skip] information is ignored and the window closes.

The [Help] is intended to provide background information.

Ionosphere Parameter Setting

When you press the [ionosphere parameters] dialog box appears, represented by the following Figure 1.12. This window can be given the parameters used in the calculation of the ionospheric delay, four rate equations describing the amplitude of the vertical delay [Alfa] and four coefficients of the equation describing the period of the model [Beta]. Odds can be set arbitrarily by entering the relevant information (the [editor]) or selected types of ICDs for the simulated time of the year: [Winter] [Spring] [Summer] [Autumn].

If the effect of the ionosphere is not considered, then we can choose zero values - [Reset].

The [Apply] - confirmation of the information. If rates were set arbitrarily, while reaffirming the need to enter a filename in which they will be saved [list of files ionosphere].

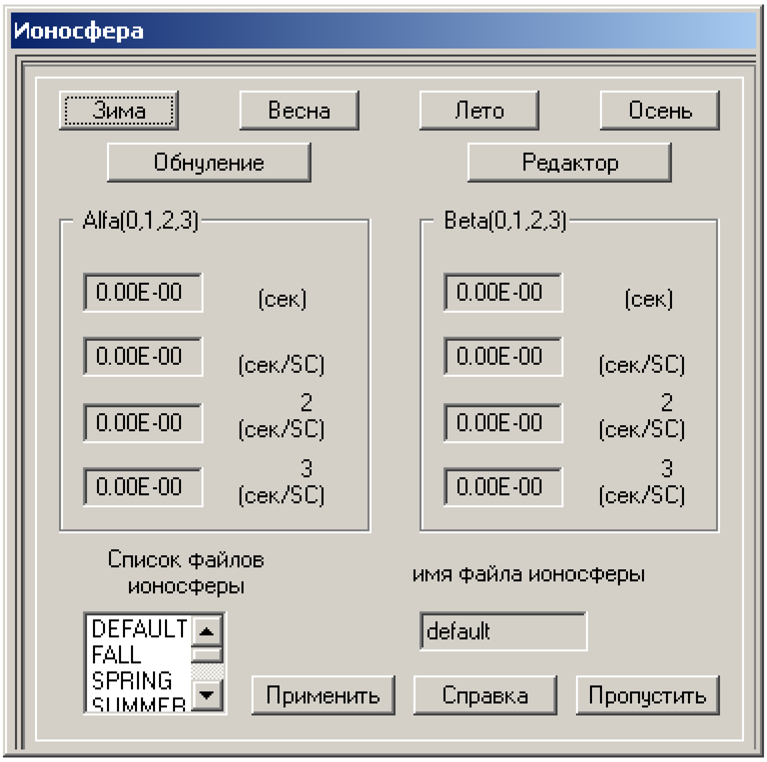


Figure 1.12

Stage 2. The simulation using the simulator CH-3803M

Modeling with the use of simulator CH-3803M

To perform simulation using the simulator CH-3803M, follow these steps:
1 Save the script on the flash card.
2 Insert the flash card into the simulator, the simulator and turn it to heat for 20 minutes.
3 Perform the actions described below

Equipment

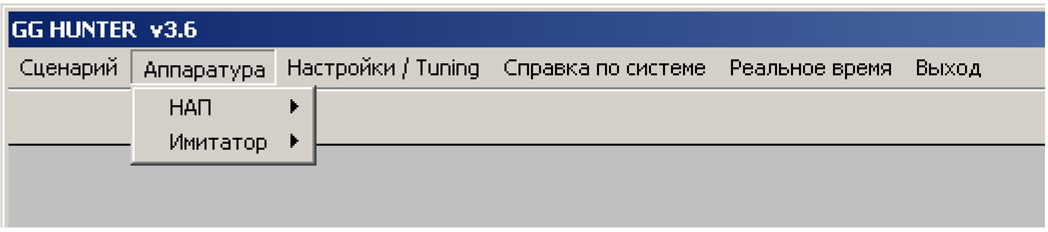


Figure 1.13

Implementation of Feedback with the Tested Equipment

When choosing the main menu, select [Hardware] popup menu appears, represented below (Figure 1.4).

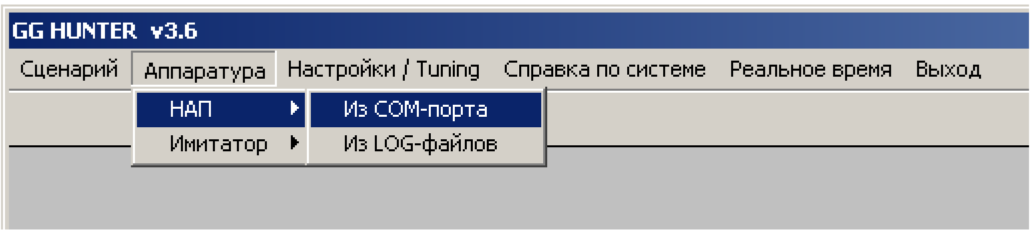


Figure 1.14

Implementation of the feedback with the test equipment connected to the PC, which is set CSI-SSS on the serial port (COM-port)

Access regime implemented by choosing the menu item [from COM-port] (fig. 1.14).

The dialog box shown below the considered mode (fig 1.15).

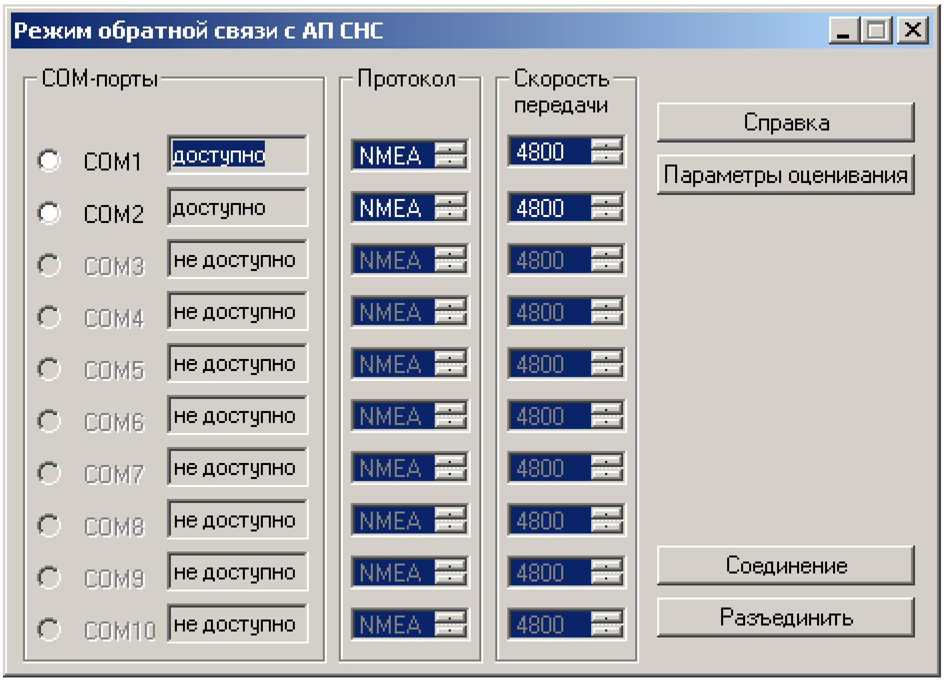


Figure 1.15

You must select COM-port number that is connected to the NAP of the available ([description]). You must configure the CSI-SSS on the communication protocol on that port. At present, the default protocol is NMEA. Can also be selected protocols BINR, ICD-153A, RINEX. In the [Baud rate] must enter the baud rate and "burn" it. The default rate is 4800.

To personalize the profile obtain estimates of the characteristics of the NAM in both graphical and tabular form, as well as the recording mode results in the file, click the button [Options Assessment]. You will then see a dialog box presented below (Figure 1.16).

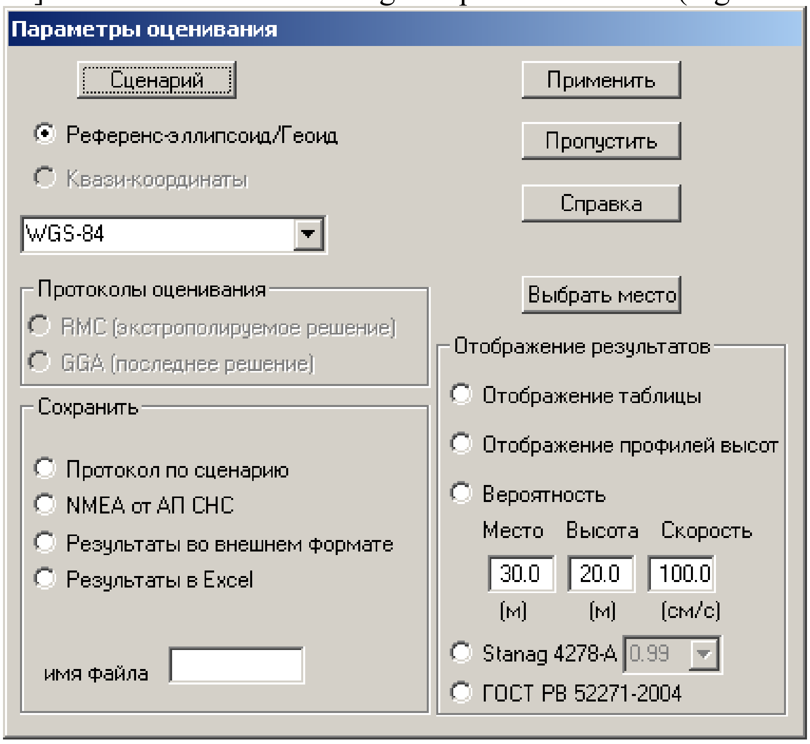


Figure 1.16

By default, the coordinates of the NAP test selected from the NMEA - offers GGA, but it is possible to obtain data from Proposition RMC ([Minutes of estimation]).

If the box that says [Referens-ellipsoid/Geoid] is a black dot, then the simulated coordinates will be provided on the reference ellipsoid. The default is - WGS-84. Another reference ellipsoid can be chosen from the list below. If the window to remove the point, the label will change [geoid / ellipsoid Reference] and modeled coordinates will be on the geoid.

To compare the results of the NAP with the simulated motion to open the script, running on the appropriate BI - the [script]. In this window appears (fig 1.17) with a list of scripts located on a PC. If the script name is enough to identify it, then when you select it from the list and pressing the [Apply] scenario thus adopted for use.

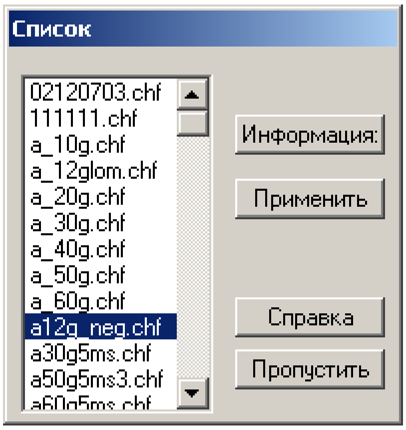


Figure 1.17

If necessary, you can save the data discrepancies between modeled and CAS derived from NAP navigation options in a file with a text format. To do this in the under the sign [Save] want to put a period next to the [Protocol on the script], [BINR from AP SNA] or [NMEA from AP SNA] or [RINEX from AP SNA] (depending on the selected communication protocol), [the results in an external format] or [the results in Excel] and enter the file name [file name]. When selecting a protocol RINEX, available in real time only operation with a record of data from the AP SNA.

For comparison, the results in Excel format, select the text file [the results in Excel]. The data relating to one point in time, are located in one row, ie ultimately the same name for different data points in time are in one column and therefore available for further processing Excel.

Example:

Title:

Time | Real data | Data of receiver | error | satellite

Represented data:

- time - hours, minutes, seconds, with the shares,
- model data - latitude, longitude, altitude, heading, velocity components (horizontal, latitude, longitude, altitude)
- data from the test receiver - latitude, longitude, altitude, heading, velocity components (horizontal, latitude, longitude, altitude)
- discrepancies between these data
- information about the reliability of data and proposals from the GSV, PORZD.

The file will have. .**exN**, where N - number of COM-port that is installed information link.

In addition, under the sign in the window [Display results of the comparison] is possible to configure the displayed information in the testing process. By default, always against the background of digital cartographic data are drawn trajectory modeling the movement and real movement of the object under test. The window with the map information is removed only with the interruption of the testing process, but it can be moved or minimized. You can order the display of the data described in writing to files, in tabular form in the testing process [Display table], and schedules change heights - [Display height profile]. It is possible to calculate the probability that a circle of given radius error of the velocity and location. For this purpose approved by the [probability] and in the windows under this sign are introduced to the radius of errors in meters and the place of the velocity in cm / sec.

Under [Display results of the comparison] is a radio button [Stanag 4278-A] is designed to display the error navigation measurements, calculated as - percentage points for a given value (). In the drop-down list below the radio button, then the value of probability level (0.3, 0.5, 0.68, 0.9, 0.95, 0.99). Details of the methods of calculation - percentage points in the document STANAG 4278. Three-dimensional error is calculated over all the coordinates (latitude, longitude and altitude), two-dimensional error in two coordinates (latitude, longitude) and one-dimensional error only in height.

Under [Display results of the comparison] is a radio button [GOST 52271-2004 PB] is designed to calculate the errors of navigational measurements of coordinates and velocities of the NAM on them imposed by the equipment in accordance with GOST 52271-2004 PB.

Save settings - [Apply], otherwise - [Skip]. Call reference information - the [Help].

To start the process of obtaining the navigation parameters on the protocol of the NAM, it is necessary in the window (Figure 1.15), click [Connect].

Next window will appear (Figure 1.18), which, in the window [BINR proposal] will show the incoming proposals, and in the rows corresponding to their name will indicate the number of proposals received. In addition to the amount of received data is displayed in the [number of bytes received].

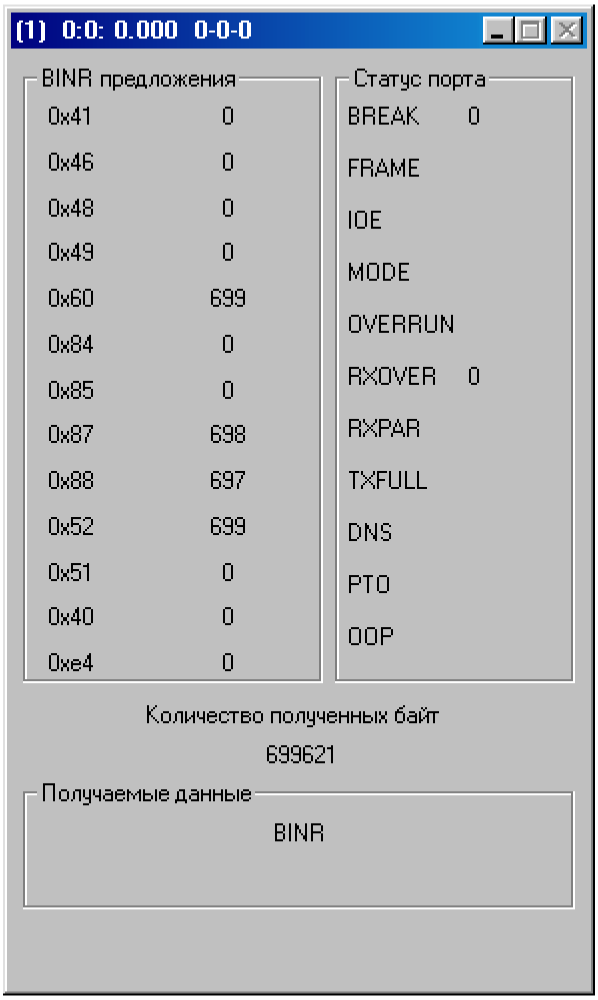


Figure 1.18

If the script is opened, the map background (Figure 1.19) will see two paths: the green - the simulated motion, the red - the movement of NAP. Otherwise, the map background will be only the red trajectory corresponding to a graphic display of the navigation parameters derived from the NAP.

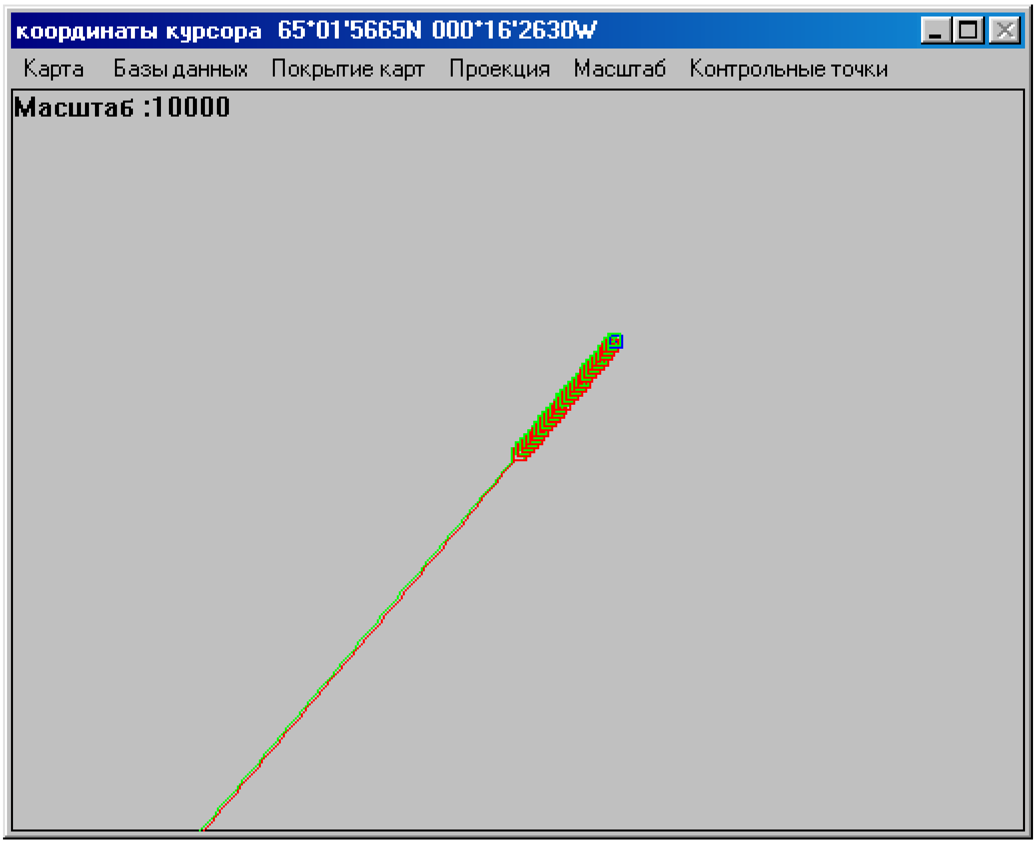


Figure 1.19

In addition, the window (Figure 1.20), if configured to output navigation parameters in tabular form:

Modeling ([Data Model]);

- Derived from the equipment under test ([Data from APSNS]);
- The difference between the above data ([Conflict of estimated data]);
- Statistical characteristics of differences ([Statistical characteristics]).

In the [observation], the point will appear when in NMEA-sentences transmitted data observation, in the [reliability], the point will come when the proposal RMC flag is passed, that data is reliable, in the [differential], the point will come when there is sign receiving differential corrections. Under these windows, in the form of a text line displays information about at some of the reference ellipsoid or geoid model derived coordinates. When you click [Update History] resets the values of statistical characteristics and statistics set begins anew.

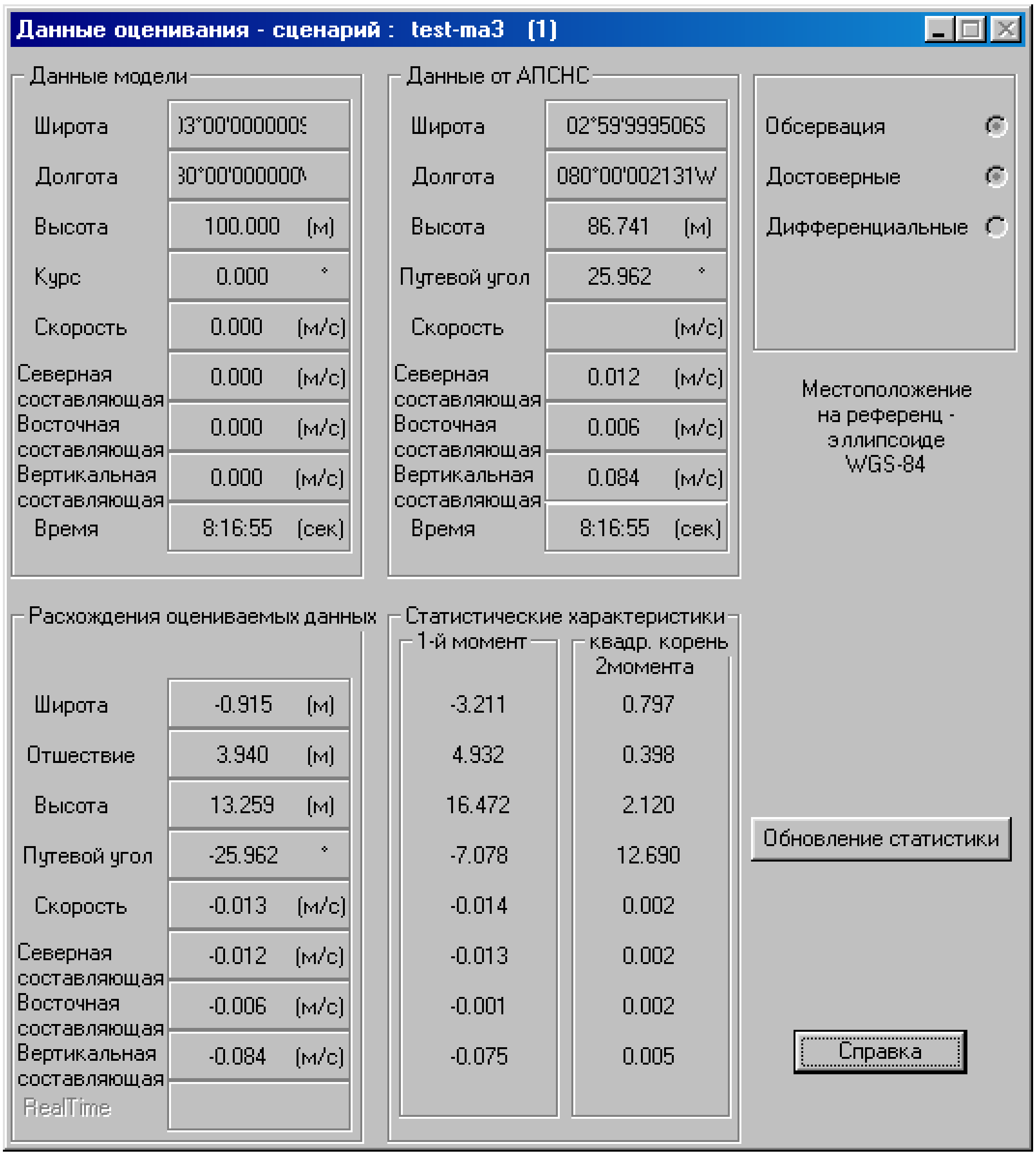


Figure 1.20

To exit test mode NAP to close the dialog box (Figure 1.13) by pressing the [Disconnect].

Report on laboratory work should include:

1. A detailed description of the conditions of the scenario: mode of movement (the file with the coordinates x, y, z), the error in pseudorange, the presence / absence of ionospheric, tropospheric errors, and so on. screenshots of windows, shown in Fig. 1.19 and Fig. 1.20.
2. Conclusions.

LABORATORY WORK №2
Scenario Synthesis for Micro/Nanosatellites Navigation Equipment Testing in a Spin-Up Mode

Objective and tasks of the laboratory work number 2 identical goals and objectives of the laboratory work number 1.

Stages

Performing laboratory work is similar lab number 1. The difference lies in the model of the satellite. In this lab as a model for traffic flow model is used by Euler angles.

Movement Model Description by Euler angles

When you select when you select Script → Support → Components → Object → Object of the material point Geocentric SC → Motion by Euler angles window appears for entering the parameters of motion using Euler angles in the geocentric coordinate system (Figure 2.1).

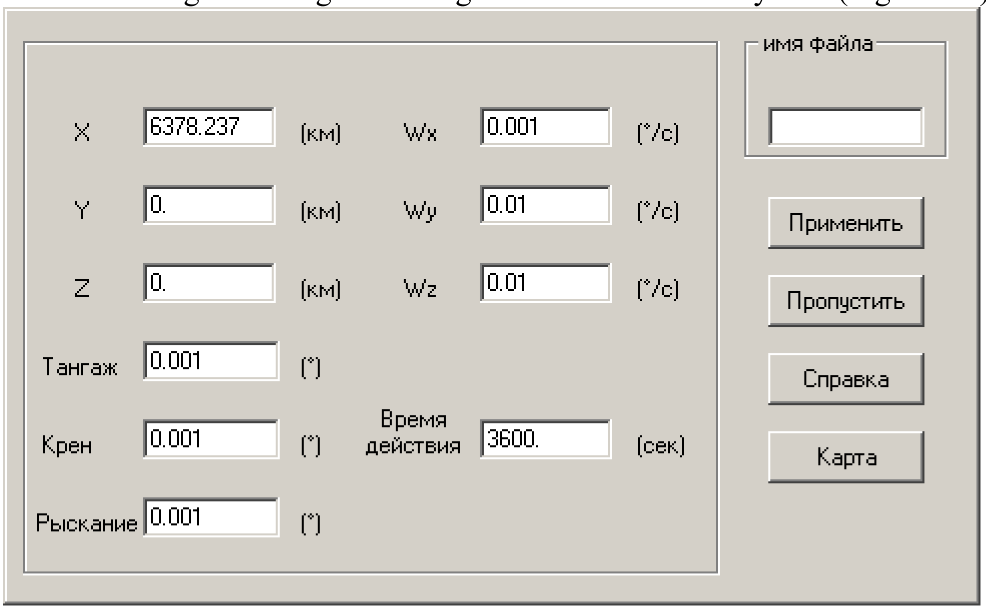


Figure 2.1

Model description of object motion in a tabular form, using the description of the Euler angles.

Introduced successively the values of rectangular coordinates in the geocentric coordinate system in windows [X] [Y] [Z], the values of the Euler angles [Wx], [Wy], [Wz], and time their actions in seconds.

In the [filename] the name of the file in which to store information about the entered values.

When you click [Apply] the information is saved and the window closes.

When you click the [Skip] information is ignored and the window closes.

Contents of the report the same lab number 1.

Laboratory Work №3
Micro/Nanosatellites Axis Orientation Determination by the Radionavigation Measurements

Purpose - to study the algorithm for determining the orientation of the axis of the micro / nanosatellite for radio navigation measurements.

Objectives - to define the orientation of the axis of the micro / nanosatellite for radio navigation measurements without use of additional information.

Theory

The algorithm for determining the spatial orientation of the axis of the micro / nano-satellite is based on the use of information on the spatial position of the GLONASS and GPS.

For definiteness, assume that the antenna is located along the longitudinal axis of the micro / nano-satellite (i = 1). The problem of determining the orientation of the longitudinal axis of the micro / nano-satellite is reduced to finding estimates of the vector of direction cosines of the phase center antenna NR $\hat{\mathbf{A}}_2 = (\hat{x}_2, \hat{y}_2, \hat{z}_2)^T$ located along the longitudinal axis of the micro / nano-satellite from the minimum of the objective function, $\Phi(x_2, y_2, z_2)$ reflecting the conditions of visibility / invisibility of the NS.

$$\begin{cases} \cos(\mathbf{a}_2, \mathbf{grad}_{B_i}) \geq \cos(\alpha), & (i = \overline{1, N_B}); \\ \cos(\mathbf{a}_2, \mathbf{grad}_{HB_j}) < \cos(\alpha), & (j = \overline{1, N_{HB}}), \end{cases} \tag{3.1}$$

where $\mathbf{grad}_i = \{x_{2i}, y_{2i}, z_{2i}\}$ - the unit vector of the distance to the i-th NS, the projections on the axis of OCS N_B, N_{HB} – the number of visible and invisible, respectively, of the NS; α - angle of the cone semi-shade, taking into account the normalization condition for the direction cosines of the antenna phase center of NS $x_2^2 + y_2^2 + z_2^2 = 1$.

The procedure for solving the problem of determining the orientation of the longitudinal axis of the micro / nanosatellite is the following:

1. The calculation of the ephemeris invisible navigation satellites GLONASS and GPS on the moments in time by definition.
2. Recalculation of the NS GLONASS ephemeris from the time the job ephemeris te to measure the moments of navigational parameters ti, where ($|\tau_i| = |t_i - t_э| \leq 15$ min) is carried out by numerical integration of differential equations of motion of the NS (see Interface control document GLONASS).

Equations are integrated in a rectangular absolute geocentric coordinate system $OX_aY_aZ_a$ and are as follows:

$$\begin{cases} \frac{dx_a}{dt} = Vx_a, \\ \frac{dy_a}{dt} = Vy_a, \\ \frac{da_a}{dt} = Vz_a, \\ \frac{dVx_a}{dt} = -\mu \times X_a - \frac{3}{2} \times J_2^0 \times X_a \times \rho^2 \times \left(1 - 5 \times Z_a^2\right) + Jx_a л + Jx_a c, \\ \frac{dVy_a}{dt} = -\mu \times X_a - \frac{3}{2} \times J_2^0 \times Y_a \times \rho^2 \times \left(1 - 5 \times Z_a^2\right) + Jy_a л + Jy_a c, \\ \frac{dVz_a}{dt} = -\mu \times Z_a - \frac{3}{2} \times J_2^0 \times Z_a \times \rho^2 \times \left(1 - 5 \times Z_a^2\right) + Jy_a л + Jy_a c, \end{cases} \tag{3.2}$$

where: $\mu = \mu / r^2,\ X_a = x_a / r,\ Y_a = y_a / r,\ Z_a = z_a / r,\ \rho = a_c / r,\ r = \sqrt{X_a^2 + Y_a^2 + Z_a^2}$;-

$Jx_a c, Jy_a c, Jz_a c$ – acceleration of the solar gravitational perturbations;

$Jx_a л, Jy_a л, Jz_a л$ – the acceleration of the lunar gravitational perturbations;

$a_c = 6378{,}136$ km - a constant gravitational field of the Earth;

$J_2^0 = 1082625{,}7 \times 10^{-9}$ – the coefficient of the second zonal harmonic expansion of Earth's gravity field in spherical functions.

Acceleration of the lunar and solar gravitational perturbations is given by:

$$\begin{cases} Jx_a k = \bar{\mu}_k \left[\left(\xi_k - \bar{X}_{ak}\right) / \Delta_k^3 - \xi_k\right], \\ Jy_a k = \bar{\mu}_k \left[\left(\eta_k - \bar{Y}_{ak}\right) / \Delta_k^3 - \eta_k\right], \\ Jz_a k = \bar{\mu}_k \left[\left(\zeta_k - \bar{Z}_{ak}\right) / \Delta_k^3 - \zeta_k\right], \end{cases} \tag{3.3}$$

where: k - index of the perturbing body, k = l for the moon, and k = s for the Sun - and the direction cosines of the radius vector of the perturbing bodies in the system at the time of te;

Appearing in (3.3) and the direction cosines of the radius vector are computed once at the time te and the entire breeding range (± 15 min) by the expressions:

$$\begin{cases} \xi_л = \sin\left(\upsilon_л + \Gamma'\right)\xi_{11} + \cos\left(\upsilon_л + \Gamma'\right)\xi_{12} - \textit{кси Луны} \\ \eta_л = \sin\left(\upsilon_л + \Gamma'\right)\mu_{11} + \cos\left(\upsilon_л + \Gamma'\right)\eta_{12} - \textit{эта Луны} \\ \zeta_л = \sin\left(\upsilon_л + \Gamma'\right)\zeta_{11} + \cos\left(\upsilon_л + \Gamma'\right)\zeta_{12} - \textit{дзета Луны} \\ \xi_c = \cos\upsilon_c \cdot \cos\omega_c - \sin\upsilon_c \cdot \sin\omega_c - \textit{кси Луны} \\ \eta_c = \left(\sin\upsilon_c \cdot \cos\omega_c + \cos\upsilon_c \cdot \sin\omega_c\right)\cos\varepsilon - \textit{эта Луны} \\ \zeta_л = \left(\sin\upsilon_c \cdot \cos\omega_c + \cos\upsilon_c \cdot \sin\omega_c\right)\sin\varepsilon - \textit{дзета Луны} \\ r_k = a_k\left(1 - e_k \cos E_k\right), \quad (к = л, c) \end{cases} \tag{3.4}$$

which $E_k = g_k + e_k \cdot \sin E_k$ is determined by solving the transcendental equation.

$$
\begin{cases}
\sin \upsilon_k = \sqrt{1-e_k^2} \cdot \sin E_k \cdot (1-e_k \cos E_k)^{-1}, \\
\cos \upsilon_k = (\cos E_k - e_k) \cdot (1-e_k \cos E_k)^{-1}, \\
\xi_{11} = \sin \Omega_л \cos \Omega_л (1-\cos i_л), \\
\xi_{12} = 1-\sin^2 \Omega_л (1-\cos i_л), \\
\eta_{11} = \xi^* \cos \varepsilon - \zeta^* \sin \varepsilon, \\
\eta_{12} = \xi_{11} \cos \varepsilon + \eta^* \sin \varepsilon, \\
\zeta_{11} = \xi^* \sin \varepsilon + \zeta^* \cos \varepsilon, \\
\zeta_{12} = \xi_{11} \sin \varepsilon - \eta^* \cos \varepsilon, \\
\xi^* = 1-\cos^2 \Omega_л (1-\cos i_л), \\
\eta^* = \sin \Omega \sin i_л, \\
\zeta^* = \cos \Omega \sin i_л, \\
g_k = g_{ok} + g_{1k} \cdot T, \\
\Omega_л = \Omega_{0л} + \Omega_{1л} \cdot T, \\
\Gamma' = \Gamma'_0 + \Gamma'_1 \cdot T, \\
T = (27392{,}375 + \Sigma_{ДН} + t_э / 86400) / 36525
\end{cases}
$$

where: $a_л = 3{,}84385243 \cdot 10^5$ - semi-major axis of the orbit of the moon; $a_c = 1{,}49598 \cdot 10^8$ km - semi-major axis "orbit" the Sun; $e_л = 0{,}054900489$ km - the eccentricity of the lunar orbit; $e_c = 0{,}016719$ km - solar orbit eccentricity; $i_л = 5°08'43'',4$ - inclination of the lunar orbit to the ecliptic plane; $\varepsilon = 23°26'33''$ - the average obliquity of the ecliptic to the equator;

$g_{ол} = -63°53'43'',414$; $g_{1л} = 477198°50'56'',79$; $\Omega_{ол} = 259°10'59'',79$;

$\Omega_{1л} = -1934°08'31'',23$; $\Gamma'_0 = -334°19'46'',40$; $\Gamma'_1 = -4069°02'02'',52$; $\omega_c = 281°13'15'',00 + 6189{,}03T$;

$g_{oc} = 358°28'33'',04$; $g_{1c} = 129596579'',10$;

T - time from the epoch 1900, 00 January, 12:00 (GMT) until the job ephemeris te in Julian centuries of 36 525 ephemeris days, 27392.375 - the number of days from the epoch of the year, 00 January, 12:00 (GMT) to period in 1975, 00 January, 12:00 (MDV) with a view of three hours in terms of Moscow standard time (MDV) te in Greenwich (GMT); - the sum of days from the epoch of 1975, 00 January, 00 hours (MDV) to 00 hours current date (MDV), to which the time te (counting the start date, Moscow time).

Initial conditions for integrating the system (3.2) are the coordinates of Greenwich and velocity components contained in the navigation frame, which are converted from Greenwich coordinates OXYZ (PZ-90) in the absolute by the formulas:

$$
\begin{cases}
X_a(t_э) = x(t_э) \cdot \cos S - y(t_э) \cdot \sin S \\
Y_a(t_э) = x(t_э) \cdot \sin S + y(t_э) \cdot \cos S \\
Z_a(t_э) = z(t_э) \\
Vx_a(t_э) = Vx(t_э) \cdot \cos S - Vy(t_э) \cdot \sin S - \omega_з Y_a(t_э) \\
Vy_a(t_э) = Vx(t_э) \cdot \sin S + Vy(t_э) \cdot \cos S + \omega_з Y_a(t_э) \\
Vz_a(t_э) = Vz(t_э)
\end{cases}
$$

where $S = S_0 + \omega_з\left(t - 3^h\right)$ - the sidereal time; ωz the angular velocity of the Earth, which is equal to 0.7292115· 10-4 s-1; S0-true sidereal time at Greenwich midnight ephemeris date set te.

To calculate the coordinates of the GPS navigation data on the operational information transmitted from satellites, an interface control document for the GPS provides the following algorithm.

The coordinates of the satellites in geocentric coordinate system fixed (ECEF) calculated as:

$$\begin{cases} x_k = x'_k \cdot \cos\Omega_k - y'_k \cdot \cos i_k \cdot \sin\Omega_k \\ y_k = x'_k \cdot \sin\Omega_k + y'_k \cdot \cos i_k \cdot \cos\Omega_k \\ z_k = y'_k \cdot \sin i_k \end{cases} . \quad (3.6)$$

Corrected longitude of ascending node (Ω_k) is defined by

$$\Omega_k = \Omega_0 + \left(\Omega - \Omega_e\right) \cdot t_k - \Omega_e \cdot t_{oe} . \quad (3.7)$$

The coordinates of the navigation satellite in the orbital plane:

$$\begin{cases} x'_k = r_k \cdot \cos u_k \\ y_k = r_k \cdot \sin u_k \end{cases} . \quad (3.8)$$

Corrected inclination orbit:

$$i_k = i_0 + \delta i_k + \left(IDOT\right) \cdot i_k . \quad (3.9)$$

Adjusted the radius of the orbit:

$$r_k = A \cdot \left(1 - e \cdot \cos E_k\right) + \delta r_k . \quad (3.10)$$

Adjusted argument of latitude:

$$u_k = \Phi_k + \delta u_k . \quad (3.11)$$

An amendment to correct the argument of latitude:

$$\delta u_k = C_{us} \sin 2\Phi_k + C_{uc} \cos 2\Phi_k . \quad (3.12)$$

Correction for the correction of the radius:

$$\delta r_k = C_{rs} \sin 2\Phi_k + C_{rc} \cos 2\Phi_k . \quad (3.13)$$

An amendment to correct the inclination of the orbit:

$$\delta i_k = C_{is} \sin 2\Phi_k + C_{ic} \cos 2\Phi_k . \quad (3.14)$$

The argument of latitude:

$$\Phi_k = \nu_k + \omega . \quad (3.15)$$

Eccentric anomaly

$$E_k = \arccos\frac{e + \cos\nu_k}{1 + e \cdot \cos\nu_k} . \quad (3.16)$$

True anomaly:

$$\begin{cases} \nu_k = arctg\left(\dfrac{\sin\nu_k}{\cos\nu_k}\right) = arctg\left\{\dfrac{\left(\sqrt{1-e^2} \cdot \sin E_k\right)/\left(1 - e \cdot \cos E_k\right)}{\left(\cos E_k - e\right)/\left(1 - e \cdot \cos E_k\right)}\right\} \\ \sin\nu_k = \left(\sqrt{1-e^2} \cdot \sin E_k\right)/\left(1 - e \cdot \cos E_k\right) \\ \cos\nu_k = \left(\cos E_k - e\right)/\left(1 - e \cdot \cos E_k\right) \end{cases} . \quad (3.17)$$

Kepler's equation for eccentric anomaly to be solved by iteration:

$$M_k = E_k - e \cdot \sin E_k . \tag{3.18}$$

Mean anomaly:

$$M_k = M_0 + n \cdot t_k . \tag{3.19}$$

Corrected mean motion:

$$n = n_0 + \Delta n . \tag{3.20}$$

Time measured from the reference epoch ephemeris:

$$t_k = t - t_{oc} , \tag{3.21}$$

where: t - GPS system time at time of message transmission (time corrected for the delay of the signal from the satellite to the consumer, equal to the ratio range to the speed of light) tc - the current time. This parameter must correspond to the true difference between the system time of GPS (t) and the reference time ephemeris set () and consider the moment of transition "begin / end" of the week. Accounting for the moment of transition "begin / end" of the week is this: if tc more "302 400" seconds, then subtracted from tc "604 800" seconds, if less "-302 400" seconds, then added to the tc "604 800" ("604 800" - Number of seconds in one week).

Estimated average Movement:

$$n_0 = \sqrt{\frac{\mu}{A^3}} , \tag{3.22}$$

where - the semi-major axis of the elliptical orbit satellite navigation.

In expressions (3.6) - (3.22) parameters: transmitted from navigation satellites in subframe 2 parameters: transmitted from navigation satellites in subframe 3 (the contents described in the interface control document GPS); options: m3/s2 and radians / sec there are elements WGS-84.

2. Recalculation of distances to visible / invisible from the National Assembly in SC USC absolute by the matrix

$$\mathbf{A} = \begin{bmatrix} -\sin u \cos\Omega - \cos u \sin\Omega \cos i & \cos u \cos\Omega - \sin u \sin\Omega \cos i & -\sin\Omega \sin i \\ -\sin u \sin\Omega + \cos u \cos\Omega \cos i & \cos u \sin\Omega + \sin u \cos\Omega \cos i & \cos\Omega \sin i \\ \cos u \sin i & \sin u \sin i & -\cos i \end{bmatrix} . \tag{3.23}$$

3. Exclusion from consideration of invisible satellites, the Earth shadow. The condition of shading the Earth:

$$z_{2k} < 0 \quad u \quad |z_{2k}| > \cos\left(\arcsin\left(\frac{R_з}{R_з + h}\right)\right), \quad k = \begin{cases} \overline{1, N_{Глонасс}} \\ \overline{1, N_{GPS}} \end{cases} . \tag{3.24}$$

4. Finding the assessment of the direction cosines of the vector antenna phase center by minimizing the objective function that reflects the conditions of visibility / invisibility of the NA (3.1) (Fig. 3.1)

$$\Phi(x_2, y_2, z_2) = \sum_{i=1}^{N_B} (x_{2i}x_2 + y_{2i}y_2 + z_{2i}z_2 - 1)^2 + \sum_{j=1}^{N_{HB}} (x_{2j}x_2 + y_{2j}y_2 + z_{2j}z_2 + 1)^2 . \tag{3.25}$$

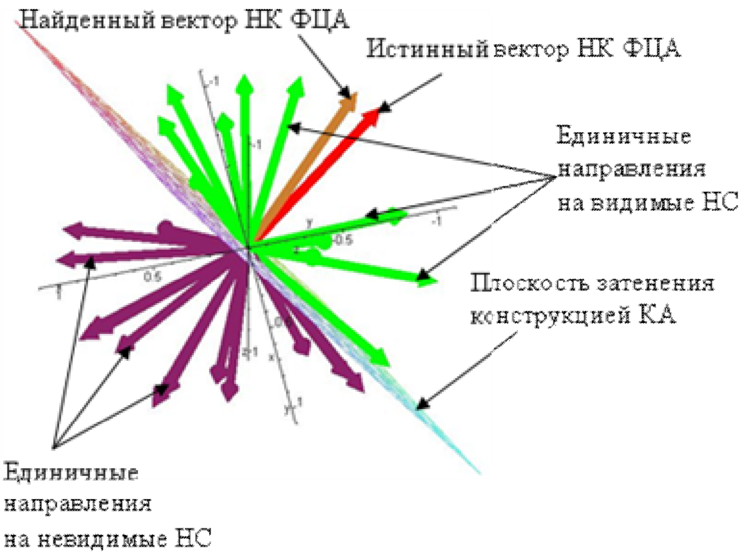
where - number of visible NA - NA number of invisible .

The procedure for minimizing the objective function (3.25) reduces to solving a system of three linear equations

$$
\begin{cases}
\left(\sum_{i=1}^{N_B} x_{2i}^2 + \sum_{j=1}^{N_{HB}} x_{2j}^2\right)\cdot x_2 + \left(\sum_{i=1}^{N_B} x_{2i}y_{2i} + \sum_{j=1}^{N_{HB}} x_{2j}y_{2j}\right)\cdot y_2 + \left(\sum_{i=1}^{N_B} x_{2i}z_{2i} + \sum_{j=1}^{N_{HB}} x_{2j}z_{2j}\right)\cdot z_2 = \sum_{i=1}^{N_B} x_{2i} - \sum_{j=1}^{N_{HB}} x_{2j};\\
\left(\sum_{i=1}^{N_B} x_{2i}y_{2i} + \sum_{j=1}^{N_{HB}} x_{2j}y_{2j}\right)\cdot x_2 + \left(\sum_{i=1}^{N_B} y_{2i}^2 + \sum_{j=1}^{N_{HB}} y_{2j}^2\right)\cdot y_2 + \left(\sum_{i=1}^{N_B} y_{2i}z_{2i} + \sum_{j=1}^{N_{HB}} y_{2j}z_{2j}\right)\cdot z_2 = \sum_{i=1}^{N_B} y_{2i} - \sum_{j=1}^{N_{HB}} y_{2j};\\
\left(\sum_{i=1}^{N_B} x_{2i}z_{2i} + \sum_{j=1}^{N_{HB}} x_{2j}z_{2j}\right)\cdot x_2 + \left(\sum_{i=1}^{N_B} y_{2i}z_{2i} + \sum_{j=1}^{N_{HB}} y_{2j}z_{2j}\right)\cdot y_2 + \left(\sum_{i=1}^{N_B} z_{2i}^2 + \sum_{j=1}^{N_{HB}} z_{2j}^2\right)\cdot z_2 = \sum_{i=1}^{N_B} z_{2i} - \sum_{j=1}^{N_{HB}} z_{2j},
\end{cases}
$$

Laboratory Work Steps

Step 1. Specifying the initial data and assumptions
Assumptions:
1) The antenna is NP-axis (the vector with coordinates);
2) orientation of the antenna is given by the angles (pitch), (yaw);
3) GLONASS and GPS are fully deployed;
4) navigation satellites GLONASS and GPS are considered "frozen";
5) provision of micro / nanosatellite in orbit is set at random by equiprobable law (from 0 º to 360 º);
6) an array of angles of orientation ϑ, ψ of the longitudinal axis of the micro / nanosatellite is randomly generated by equiprobable law orientation angles vary from 0 º to 360 º.
Background:
orbit micro / nanosatellite is circular, the height (h) 300 km, 400 km, 500 km, 650 km and 1000 km, inclination (i) 52 º, 63 º, 81 º.
Step 2. Modeling the problem of determining the orientation of the longitudinal axis
Modeling the problem of determining the orientation of the longitudinal axis of the micro / nanosatellite is carried out in four steps.
Step 1. Simulation of micro / nano-satellite in orbit.
Step 2. Formation of arrays of distances to visible / invisible in the National Assembly of absolute CK.
Step 3. Recalculation of distances to visible / invisible from the National Assembly in the absolute IC USC using the matrix (3.23). Exclusion from consideration of the National Assembly shaded Earth by relation (3.24).
Step 4. Direct determination of the direction cosines of the vector antenna phase center location at USC, is based on finding the minimum of objective functions (3.25) with respect to taking into account the normalization condition for the coordinates of antenna.
As the error estimates take values orientation.
To assess the effectiveness of the algorithm using the probability density function of probability of exceedance and the error estimates of orientation angles of the longitudinal axis of the micro / nanosatellite set value error.
To obtain estimates of the efficiency of processing a sample volume of 1000 realizations.
Report on laboratory work should include:
Baseline data for the selected option;
Block diagram of the algorithm;
Graphs of the probability density function of probability of exceedance and the error estimates of the orientation angles to the longitudinal axis;
Conclusions.



Найденный вектор НК ФЦА
Истинный вектор НК ФЦА
Единичные
направления
на видимые НС
Плоскость затенения
конструкцией КА
Единичные
направления
на невидимые НС

Figure 3.1

Laboratory Work №4
Micro/Nanosatellites Orientation Determination by Radionavigation and Magnetometric Measurements

Purpose - to study the algorithm for determining the spatial orientation of the micro / nano-satellite for radio navigation and magnetometric measurements.

Objectives - to define the spatial orientation of micro / nano-satellite for radio navigation and magnetometric measurements.

Theory

Aggregation scheme and satellite magnetometer navigation measurements

Complexing Scheme of Radionavigation and Magnetometric Measurements

In schema-based aggregation magnetometer and satellite measurements is the idea of using the measured data (the vector of the EMF) and psevdoizmerennoy (the vector of direction cosines of the phase centers of antennas) associated with micro / nano-satellites and the coordinates of the same information in the reference coordinate system (orbital system of coordinates) at the same point in space and in matching times.

Tightly-aggregation scheme Magnetometer and satellite navigation measurements.

Closely Coupled Complexing Scheme of Radionavigation and Magnetometric Measurements

Under a tightly-aggregation scheme under consideration of the measurement here refers to the scheme, in which the problem of determining the orientation is decided with the simultaneous use of all measuring data.

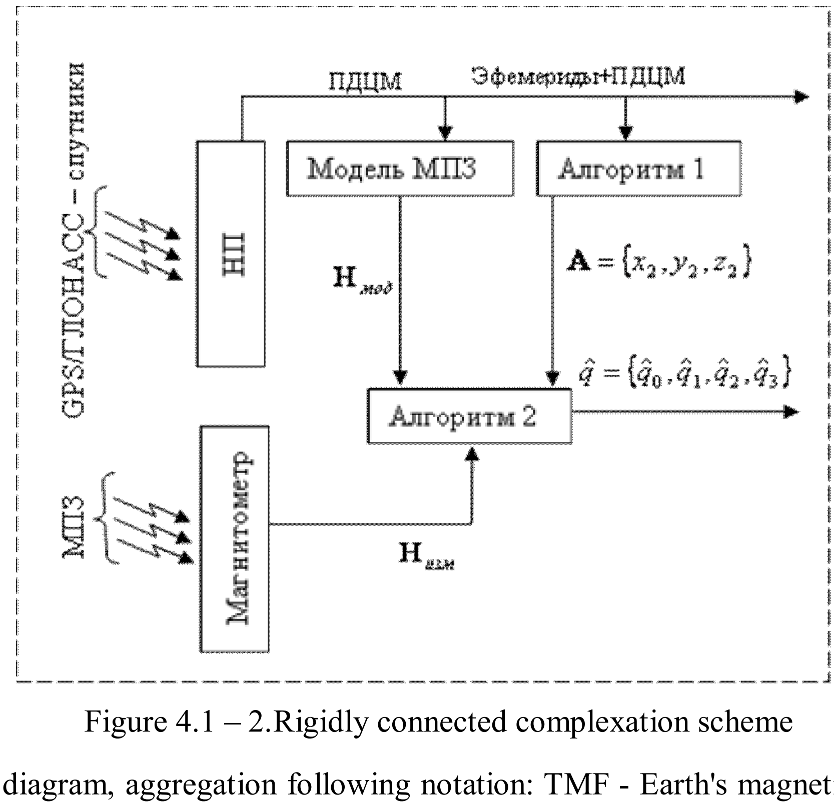


Figure 4.1 – 2.Rigidly connected complexation scheme

In the diagram, aggregation following notation: TMF - Earth's magnetic field; NP - navigation receiver; Algorithm 1 - Define the vector of direction cosines of the phase center antenna (see Lab number 3), Algorithm 2 - Definition of the orientation of micro / nano-satellite on the basis of the vector matching .Problem of determining the spatial orientation of micro / nano-satellite on the basis of a tightly-aggregation scheme is as follows.

Information from the NP is used for:

determine the spatial orientation of the longitudinal axis of the micro / nano-satellite (the definition of two angles of orientation in the presence of a single antenna);
calculate the vector of the MPD to USC.
To calculate the EMF strength vector to USC, the model of the dipole:

$$\begin{cases} H_{X_2} = \frac{\mu}{r^3}\sin i \cdot \cos u \\ H_{Y_2} = \frac{\mu}{r^3}\cos i \\ H_{Z_2} = -\frac{2\mu}{r^3}\sin i \cdot \sin u \end{cases}, \quad (4.1)$$

where $\mu = 8.1 \cdot 10^6$ T·km^3 - the magnetic dipole moment; i - inclination of micro / nanosatellite; u - the argument of latitude of micro / nanosatellite; r - radius vector of the micro / nanosatellite.

The orientation of the longitudinal axis of the micro / nanosatellite is described in this case by the vector NC antenna phase center.

Information from the triaxial magnetometer (the vector of the MPD in SSC), NDT vector phase center antenna or the antenna phase center to the input of Algorithm 2, which is based on the method of vector alignment.

In Algorithm 2 assumes that the orientation of the matrix is parameterized by quaternions.

$$\mathbf{M}_{X_1X_2} = \begin{bmatrix} v_0^2 + v_1^2 - v_2^2 - v_3^2 & 2\cdot(v_1v_2 + v_0v_3) & 2\cdot(v_1v_3 - v_0v_2) \\ 2\cdot(v_1v_2 - v_0v_3) & v_0^2 + v_2^2 - v_1^2 - v_3^2 & 2\cdot(v_0v_1 + v_2v_3) \\ 2\cdot(v_0v_2 + v_1v_3) & 2\cdot(v_2v_3 - v_1v_1) & v_0^2 + v_3^2 - v_2^2 - v_1^2 \end{bmatrix}$$

Mathematical Problem Statement

The problem of determining the orientation on the basis of a tightly-aggregation scheme is solved with the following measured data:

with a magnetometer:

$\mathbf{H}_1 = (h_{X_1}, h_{Y_1}, h_{Z_1})^{\mathrm{T}}$ – The vector of the MPD in the FCS;
as well as the result of Algorithm 1 (see Lab number 3):
$\mathbf{A}_2 = (x_2, y_2, z_2)^{\mathrm{T}}$ - Vector of direction cosines of the antenna phase center at USC;
EMF model (see relation 4.1):
$\mathbf{H}_2 = (h_{X_2}, h_{Y_2}, h_{Z_2})^{\mathrm{T}}$ - The vector of the MPD to USC;
$\mathbf{A}_1 = (x_1, y_1, z_1)^{\mathrm{T}}$ - Vector of direction cosines of the antenna phase center in the SSC;
reduced to estimating the spatial orientation of the micro / nano-satellite, ie evaluation matrix parameterized by the orientation quaternion, by minimizing the objective function $J(\hat{\mathbf{M}}_{X_1X_2}(\hat{q}_0, \hat{q}_1, \hat{q}_2, \hat{q}_3))$, taking into account the normalization condition for the elements of the quaternion $\hat{q}_0^2 + \hat{q}_1^2 + \hat{q}_2^2 + \hat{q}_3^2 = 1$.

The algorithm for determining the orientation of the spacecraft (Algorithm 2)

Spacecraft Orientation Determination Algorithm

In order to achieve maximum accuracy is advisable to use all available measurements directly in finding the matrix. To find the matrix orientation in the light of all available measurements was formulated by the so-called problem Wahba, which proposes to look for based on the minimization of the function, which is a weighted sum of the squares with the weights of the differences between the values of two vectors is given in two coordinate systems. Given this notation the cost function is written as

$$J(\mathbf{M}_{X_1X_2}) = \sum_{i=1}^{2} \alpha_i \left(\mathbf{U}_1^i - \mathbf{M}_{X_1X_2} \cdot \mathbf{U}_2^i\right)^T \left(\mathbf{U}_1^i - \mathbf{M}_{X_1X_2} \cdot \mathbf{U}_2^i\right), \tag{4.2}$$

Where $\mathbf{M}_{X_1X_2}$ - the matrix describing the relationship of USC and SSC, parameterized using quaternions;

$\mathbf{U}_1^i, \mathbf{U}_2^i$ - Vector of direction cosines of the antenna phase center and the vector of the MPD in SSC and USC, respectively;

$\mathbf{U}_1 = \mathbf{A}_1$ - Vector of direction cosines of the antenna phase center in the SSC;

$\mathbf{U}_2 = \mathbf{A}_2$ - Vector of direction cosines of the antenna phase center at USC;

$\mathbf{U}_1^2 = \mathbf{H}_1$ - The vector of the MPD in the FCS, as measured magnetometer;

$\mathbf{U}_2^2 = \mathbf{H}_2$ - The vector of the MPD to USC, calculated by the model, MSY;

α_i - Weighting factor () that takes into account the relative importance of satellite navigation and magnetometer measurements.

The task of minimizing the objective function (4.2) reduces to the problem of finding the four eigenvector of a symmetric matrix

$$\mathbf{B} = \sum_{i=1}^{k+1} \alpha_i \begin{bmatrix} \mathbf{I}\left(\left(\mathbf{U}_1^i\right)^T \mathbf{U}_2^i\right) - \mathbf{U}_2^i \left(\mathbf{U}_1^i\right)^T - \mathbf{U}_1^i \left(\mathbf{U}_2^i\right)^T & -\left(\mathbf{U}_1^i \times \mathbf{U}_2^i\right) \\ -\left(\mathbf{U}_1^i \times \mathbf{U}_2^i\right)^T & -\left(\mathbf{U}_1^i\right)^T \mathbf{U}_2^i \end{bmatrix}, \tag{4.3}$$

corresponding to its minimal eigenvalue.

In (4.3) I - identity matrix.

Steps of the laboratory work

Step 1. Specifying the initial data and assumptions

Assumptions:

1) The antenna is NP-axis (the vector with coordinates);

2) orientation of the antenna is given by the angles (pitch), (yaw), (roll);

3) GLONASS and GPS are fully deployed;

4) navigation satellites GLONASS and GPS are considered "frozen";

5) provision of micro / nano-satellite in orbit is set at random by equiprobable law (from 0 º to 360 º);

6) an array of angles of orientation of the longitudinal axis of the micro / nano-satellite is randomly generated by equiprobable law orientation angles vary from 0 º to 360 º;

7) error in the measurements of EMF absent.

Background:

orbit micro / nano-satellite is circular, the height (h) 300 km, 400 km, 500 km, 650 km and 1000 km, inclination (i) 52 º, 63 º, 81 º.

Step 2. Modeling the problem of determining the orientation of the longitudinal axis

Modeling the problem of determining the spatial orientation of the longitudinal axis of the micro / nano-satellite is carried out in five steps. Steps 1-4 are similar to the steps of the first laboratory № 3.

Step 5. We seek the eigenvector corresponding to the minimal eigenvalue of the matrix 4.3.

As the error estimates take values orientation.

To assess the effectiveness of the algorithm using the probability density function of probability of exceedance and the error estimates of the angles of the spatial orientation of micro / nano-satellite set value error

To obtain estimates of the efficiency of processing a sample volume of 1000 realizations.

Report on laboratory work should include:

1) Baseline data for the selected option;

2) Block diagram of the algorithm;

3) Graphs of the probability density function of probability of exceedance and the error estimates of the orientation angles to the longitudinal axis;

4) Conclusions.

Laboratory Work №5
Research of Accuracy of Determination of the Micro/Nanosatellites Orientation Angle with the Use of Strap Down Inertial Vertical

Purpose: To familiarize with the algorithm works Strapdown inertial vertical.

Guidelines for the preparation to the work Strapdown inertial designed to produce vertical orientation angles maneuvering objects (MO). The basis of the vertical is test set containing three linear accelerometers, which measure the components of the apparent acceleration and three angular velocity sensor (CRS), which measure the components of the angular velocity. Sensor outputs go directly to the device evaluation (PP), which defines the instantaneous direction of the axes of sensitivity accelerometers in reference coordinate system. The enlarged block diagram of the system is shown in Fig. 5.1. The dashed lines on the chart highlight the links that will continue to be artificially introduced to obtain a mathematical model suitable for the synthesis device evaluation.

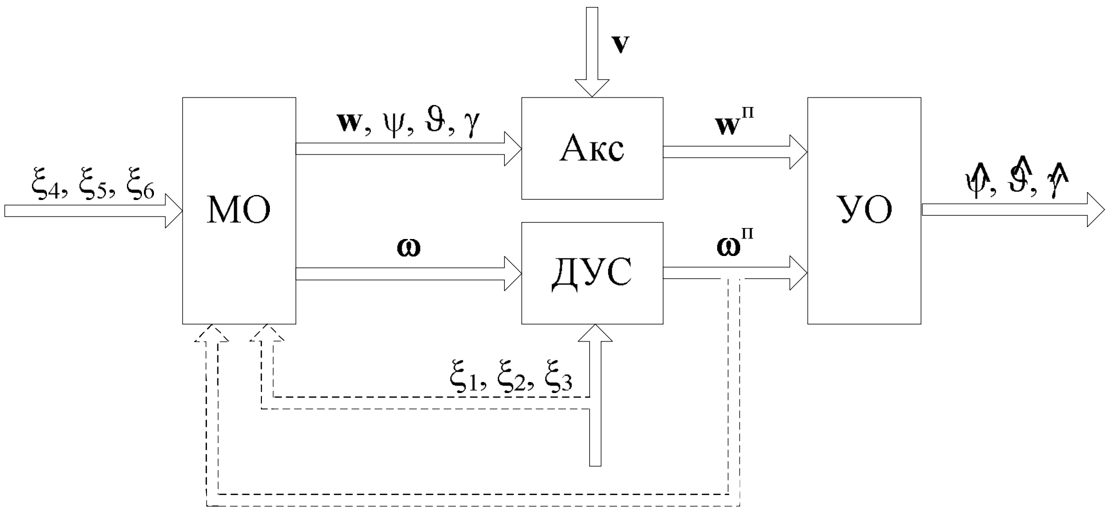


Figure 5.1 – The enlarged block diagram of the system

In constructing a computational algorithm Strapdown orientation system is taken as the basis of the Poisson equation describing the change in the matrix of direction cosines

$$\mathbf{C} = \begin{pmatrix} \cos\psi\cos\vartheta & \sin\vartheta & -\sin\psi\cos\vartheta \\ \sin\psi\sin\gamma - \cos\psi\sin\vartheta\cos\gamma & \cos\vartheta\cos\gamma & \cos\psi\sin\gamma + \sin\psi\sin\vartheta\cos\gamma \\ \sin\psi\cos\gamma + \cos\psi\sin\vartheta\sin\gamma & -\cos\vartheta\sin\gamma & \cos\psi\cos\gamma - \sin\psi\sin\vartheta\sin\gamma \end{pmatrix},$$

where ϑ - pitch, ψ - yaw angle, γ - roll angle.

In matrix form these equations are

$$\frac{d\mathbf{C}^{\mathrm{T}}}{dt} = \mathbf{C}^{\mathrm{T}}\boldsymbol{\omega}, \qquad (5.1)$$

where $\boldsymbol{\omega}$ - skew-symmetric matrix

$$\boldsymbol{\omega} = \begin{pmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{pmatrix},$$

in scalar form is the following system of differential equations:

$$\dot{C}_{11} = C_{21}\omega_z - C_{31}\omega_y, \quad (5.2)$$

$$\dot{C}_{21} = C_{31}\omega_x - C_{11}\omega_z, \quad (5.3)$$

$$\dot{C}_{31} = C_{11}\omega_y - C_{21}\omega_x, \quad (5.4)$$

$$\dot{C}_{12} = C_{22}\omega_z - C_{32}\omega_y, \quad (5.5)$$

$$\dot{C}_{22} = C_{32}\omega_x - C_{12}\omega_z, \quad (5.6)$$

$$\dot{C}_{32} = C_{12}\omega_y - C_{22}\omega_x, \quad (5.7)$$

$$\dot{C}_{13} = C_{23}\omega_z - C_{33}\omega_y, \quad (5.8)$$

$$\dot{C}_{23} = C_{33}\omega_x - C_{13}\omega_z, \quad (5.9)$$

$$\dot{C}_{33} = C_{13}\omega_y - C_{23}\omega_x. \quad (5.10)$$

Clearly, each triple of the Poisson equation (5.2) - (5.4) (5.5) - (5.7) and (5.8) - (5.10) can be integrated independently of the others. At the same time finding the nine direction cosines give redundant information to determine the orientation parameters, so in practice, in-flight calculators integrate, not all nine equations, but only the portion that allows the most simple way to calculate the angles of orientation. Further restrict ourselves to equations (5.5) - (5.10) with initial conditions

$$C_{12}(0) = \sin\vartheta_0,$$
$$C_{22}(0) = \cos\vartheta_0 \cos\gamma_0,$$
$$C_{32}(0) = -\cos\vartheta_0 \sin\gamma_0,$$
$$C_{13}(0) = -\sin\psi_0 \cos\vartheta_0,$$
$$C_{23}(0) = \cos\psi_0 \sin\gamma_0 + \sin\psi_0 \sin\vartheta_0 \cos\gamma_0,$$
$$C_{33}(0) = \cos\psi_0 \cos\gamma_0 - \sin\psi_0 \sin\vartheta_0 \sin\gamma_0.$$

Here ϑ_0, ψ_0, γ_0 - initial orientation angles.The missing elements of the matrix of direction cosines can be determined from the relations

$$C_{11} = C_{22}C_{33} - C_{23}C_{32}, \quad (5.11)$$

$$C_{21} = C_{13}C_{32} - C_{12}C_{33}, \quad (5.12)$$

$$C_{31} = C_{12}C_{23} - C_{13}C_{22}. \quad (5.13)$$

Then the parameters of orientation are computed from.

$$\vartheta = \operatorname{arctg}\frac{C_{12}}{\sqrt{C_{22}^2 + C_{32}^2}}, \quad \psi = -\operatorname{arctg}\frac{C_{13}}{C_{11}}, \quad \gamma = -\operatorname{arctg}\frac{C_{32}}{C_{22}}.$$

From (5.2) - (5.10) that for the calculation of orientation parameters requires knowledge of components of the angular velocity of the object. This information comes from the outputs of up to two-level measurement error:

$$\omega_x = \omega_x^{\text{п}} + \omega_x^{\text{др}}, \quad \omega_y = \omega_y^{\text{п}} + \omega_y^{\text{др}}, \quad \omega_z = \omega_z^{\text{п}} + \omega_z^{\text{др}},$$

where $\omega_x^{\text{п}}$, $\omega_y^{\text{п}}$, $\omega_z^{\text{п}}$ - measured (instrument) the values of the components of the angular velocity of rotation, which are the inputs of a dynamic system under study;
$\omega_x^{\text{др}}$, $\omega_y^{\text{др}}$, $\omega_z^{\text{др}}$ - angular velocity of the drift of the TLS. Methodological errors CRS will be considered here to be negligible.

Thus, the system of equations for the direction cosines Cij takes the following form:

$$\dot{C}_{12} = C_{22}\omega_z^{\text{ï}} + C_{22}\omega_z^{\text{äð}} - C_{32}\omega_y^{\text{ï}} - C_{32}\omega_y^{\text{äð}}, (5.14)$$

$$\dot{C}_{22} = C_{32}\omega_x^{\text{ï}} + C_{32}\omega_x^{\text{äð}} - C_{12}\omega_z^{\text{ï}} - C_{12}\omega_z^{\text{äð}}, \quad (5.15)$$

$$\dot{C}_{32} = C_{12}\omega_y^{\text{ï}} + C_{12}\omega_y^{\text{äð}} - C_{22}\omega_x^{\text{ï}} - C_{22}\omega_x^{\text{äð}}, \quad (5.16)$$

$$\dot{C}_{13} = C_{23}\omega_z^{\text{ï}} + C_{23}\omega_z^{\text{äð}} - C_{33}\omega_y^{\text{ï}} - C_{33}\omega_y^{\text{äð}}, \quad (7.17)$$

$$\dot{C}_{23} = C_{33}\omega_x^{\text{ï}} + C_{33}\omega_x^{\text{äð}} - C_{13}\omega_z^{\text{ï}} - C_{13}\omega_z^{\text{äð}}, \quad (5.18)$$

$$\dot{C}_{33} = C_{13}\omega_y^{\text{ï}} + C_{13}\omega_y^{\text{äð}} - C_{23}\omega_x^{\text{ï}} - C_{23}\omega_x^{\text{äð}}. \quad (5.19)$$

The angular velocity of the drift $\omega_x^{\text{др}}$, $\omega_y^{\text{др}}$, $\omega_z^{\text{др}}$ assume centered exponentially correlated random processes with standard deviation σ_1, σ_2, σ_3 and correlation time constants T1, T2, T3, respectively. Equation shaping filters for these processes are as follows:

$$\dot{\omega}_x^{\text{др}} = -T_1^{-1}\omega_x^{\text{др}} + \sqrt{2T_1^{-1}}\sigma_1\xi_1, \quad (5.20)$$

$$\dot{\omega}_y^{\text{др}} = -T_2^{-1}\omega_y^{\text{др}} + \sqrt{2T_2^{-1}}\sigma_2\xi_2, \quad (5.21)$$

$$\dot{\omega}_z^{\text{др}} = -T_3^{-1}\omega_z^{\text{др}} + \sqrt{2T_3^{-1}}\sigma_3\xi_3, \quad (5.22)$$

where ξ_i - uncorrelated with each other-centered white noises of unit intensity.

The components of absolute acceleration of the object w_{gx}, w_{gy}, w_{gz} also be represented as a centered exponentially correlated random processes with standard deviation σ_{gx}, σ_{gy}, σ_{gz} and constant correlation time Tgx, Tgy, Tgz respectively:

$$\dot{w}_{gx} = -T_{gx}^{-1}w_{gx} + \sqrt{2T_{gx}^{-1}}\sigma_{gx}\xi_4, \quad (5.23)$$

$$\dot{w}_{gy} = -T_{gy}^{-1}w_{gy} + \sqrt{2T_{gy}^{-1}}\sigma_{gy}\xi_5, \quad (5.24)$$

$$\dot{w}_{gz} = -T_{gz}^{-1}w_{gz} + \sqrt{2T_{gz}^{-1}}\sigma_{gz}\xi_6. \quad (5.25)$$

The output signals of accelerometers $w_x^{\text{п}}$, $w_y^{\text{п}}$, $w_z^{\text{п}}$ will be a noisy measurement of the apparent acceleration in their projections on the axis of sensitivity. When the subject is moving at a constant rate

$$w_x^{\text{ï}} = w_{gx}C_{11} + (w_{gy} + g)C_{12} + w_{gz}C_{13} + \upsilon_1, \quad (5.26)$$

$$w_y^{\text{ï}} = w_{gx}C_{21} + (w_{gy} + g)C_{22} + w_{gz}C_{23} + \upsilon_2, \quad (5.27)$$

$$w_z^{\text{ï}} = w_{gx}C_{31} + (w_{gy} + g)C_{32} + w_{gz}C_{33} + \upsilon_3, \quad (5.28)$$

where □ j - uncorrelated with each other and with ξ_i centered white noises with intensities given Rj; g - acceleration due to gravity.

The differential equations (5.14) - (5.25) and algebraic equations (5.26) - (5.28) represent a model of a dynamic system, which can be written in vector-matrix form:

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{u}) + \mathbf{B}\boldsymbol{\xi}, \quad (5.29)$$

$$\mathbf{z} = \mathbf{h}(\mathbf{x}) + \mathbf{v}, \quad (5.30)$$

where $\mathbf{x} = (C_{12}\ \ C_{22}\ \ C_{32}\ \ C_{13}\ \ C_{23}\ \ C_{33}\ \ \omega_x^{\text{др}}\ \ \omega_y^{\text{др}}\ \ \omega_z^{\text{др}}\ \ w_{gx}\ \ w_{gy}\ \ w_{gz})^{\mathrm{T}}$ – the state vector;

$\mathbf{z} = (w_x^{\text{п}}\ \ w_y^{\text{п}}\ \ w_z^{\text{п}})^{\mathrm{T}}$ - vector of measurements; u = (□ □ xn yp zp □) T - vector inputs; $\mathbf{u} = (\omega_x^{\text{п}}\ \ \omega_y^{\text{п}}\ \ \omega_z^{\text{п}})^{\mathrm{T}}$ - vector of disturbances; $\boldsymbol{\xi} = (\xi_1\ \ \xi_2\ \ \xi_3\ \ \xi_4\ \ \xi_5\ \ \xi_6)^{\mathrm{T}}$ - vector of measurement noise; B - matrix of perturbations of dimension 12×3, the nonzero whose elements are equal

$$B_{7,1}=\sqrt{2T_1^{-1}}\sigma_1,\ B_{8,2}=\sqrt{2T_2^{-1}}\sigma_2,\ B_{9,3}=\sqrt{2T_3^{-1}}\sigma_3,$$
$$B_{10,4}=\sqrt{2T_{gx}^{-1}}\sigma_{gx},\ B_{11,5}=\sqrt{2T_{gy}^{-1}}\sigma_{gy},\ B_{12,6}=\sqrt{2T_{gz}^{-1}}\sigma_{gz}.$$

The components of the vector function f (x, u) have the form

$$f_1(\mathbf{x},\mathbf{u})=x_2x_9-x_3x_8+x_2u_3-x_3u_2,$$
$$f_2(\mathbf{x},\mathbf{u})=x_3x_7-x_1x_9+x_3u_1-x_1u_3,$$
$$f_3(\mathbf{x},\mathbf{u})=x_1x_8-x_2x_7+x_1u_2-x_2u_1,$$
$$f_4(\mathbf{x},\mathbf{u})=x_5x_9-x_6x_8+x_5u_3-x_6u_2,$$
$$f_5(\mathbf{x},\mathbf{u})=x_6x_7-x_4x_9+x_6u_1-x_4u_3,$$
$$f_6(\mathbf{x},\mathbf{u})=x_4x_8-x_5x_7+x_4u_2-x_5u_1,$$
$$f_7(\mathbf{x},\mathbf{u})=-T_1^{-1}x_7,$$
$$f_8(\mathbf{x},\mathbf{u})=-T_2^{-1}x_8,$$
$$f_9(\mathbf{x},\mathbf{u})=-T_3^{-1}x_9,$$
$$f_{10}(\mathbf{x},\mathbf{u})=-T_{gx}^{-1}x_{10},$$
$$f_{11}(\mathbf{x},\mathbf{u})=-T_{gy}^{-1}x_{11},$$
$$f_{12}(\mathbf{x},\mathbf{u})=-T_{gz}^{-1}x_{12}.$$

The components of the vector function h (x) will have the form

$$h_1(\mathbf{x})=x_{10}(x_2x_6-x_3x_5)+(x_{11}+g)x_1+x_{12}x_4,$$
$$h_2(\mathbf{x})=x_{10}(x_3x_4-x_1x_6)+(x_{11}+g)x_2+x_{12}x_5,$$
$$h_3(\mathbf{x})=x_{10}(x_1x_5-x_2x_4)+(x_{11}+g)x_3+x_{12}x_6.$$

Obviously, the function f (x, u), h (x) are nonlinear, because Components contain products of state variables. To solve the problem of filtering (estimation of the components of the state) we use the generalized nonlinear Kalman-Bucy filter. Filter equations can be written as:

$$\dot{\hat{\mathbf{x}}}=\mathbf{f}(\hat{\mathbf{x}},\mathbf{u})+\mathbf{K}(\mathbf{z}-\mathbf{h}(\hat{\mathbf{x}})), \tag{5.31}$$

$$\mathbf{K}=\mathbf{P}\frac{\partial\mathbf{f}(\hat{\mathbf{x}},\mathbf{u})}{\partial\mathbf{x}^{\mathrm{T}}}\mathbf{R}^{-1}, \tag{5.32}$$

$$\dot{\mathbf{P}}=\frac{\partial\mathbf{f}(\hat{\mathbf{x}},\mathbf{u})}{\partial\mathbf{x}^{\mathrm{T}}}\mathbf{P}+\mathbf{P}\frac{\partial\mathbf{f}^{\mathrm{T}}(\hat{\mathbf{x}},\mathbf{u})}{\partial\mathbf{x}}-\mathbf{P}\frac{\partial\mathbf{h}^{\mathrm{T}}(\hat{\mathbf{x}})}{\partial\mathbf{x}}\mathbf{R}^{-1}\frac{\partial\mathbf{h}(\hat{\mathbf{x}})}{\partial\mathbf{x}^{\mathrm{T}}}\mathbf{P}+\mathbf{B}\mathbf{B}^{\mathrm{T}}, \tag{5.33}$$

where $\hat{\mathbf{x}}$ - the current estimate of the state vector; P - covariance matrix of the error vector $\boldsymbol{\varepsilon}=\mathbf{x}-\hat{\mathbf{x}}$; R - matrix of intensities of noise measurements (a diagonal matrix composed of the elements Rj); K - matrix gain filter.

Here $\frac{\partial\mathbf{f}(\hat{\mathbf{x}},\mathbf{u})}{\partial\mathbf{x}^{\mathrm{T}}}$ is a matrix of the form calculated at the point a - transposed matrix.

$$\frac{\partial \mathbf{f}(\mathbf{x},\mathbf{u})}{\partial \mathbf{x}^{\mathrm{T}}} = \begin{pmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \cdots & \frac{\partial f_1}{\partial x_{12}} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \cdots & \frac{\partial f_2}{\partial x_{12}} \\ & \cdots & & \\ \frac{\partial f_{12}}{\partial x_1} & \frac{\partial f_{12}}{\partial x_2} & \cdots & \frac{\partial f_{12}}{\partial x_{12}} \end{pmatrix},$$

Similarly we define the derivatives.

In this case,

$$\frac{\partial \mathbf{f}(\mathbf{x},\mathbf{u})}{\partial \mathbf{x}^{\mathrm{T}}} =$$

$$= \begin{pmatrix} 0 & x_9+u_3 & -x_8-u_2 & 0 & 0 & 0 & 0 & -x_3 & x_2 & 0 & 0 & 0 \\ -x_9-u_3 & 0 & x_7+u_1 & 0 & 0 & 0 & x_3 & 0 & -x_1 & 0 & 0 & 0 \\ x_8+u_2 & -x_7-u_1 & 0 & 0 & 0 & 0 & -x_2 & x_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & x_9+u_3 & -x_8-u_2 & 0 & -x_6 & x_5 & 0 & 0 & 0 \\ 0 & 0 & 0 & -x_9-u_3 & 0 & x_7+u_1 & x_6 & 0 & -x_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & x_8+u_2 & -x_7-u_1 & 0 & -x_5 & x_4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -T_1^{-1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -T_2^{-1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -T_3^{-1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -T_{gx}^{-1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -T_{gy}^{-1} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -T_{gz}^{-1} \end{pmatrix},$$

$$\frac{\partial \mathbf{h}(\mathbf{x})}{\partial \mathbf{x}^{\mathrm{T}}} =$$

$$= \begin{pmatrix} x_{11}+g & x_6x_{10} & -x_5x_{10} & x_{12} & -x_3x_{10} & x_2x_{10} & 0 & 0 & 0 & x_2x_6 & x_1 & x_4 \\ -x_6x_{10} & x_{11}+g & x_4x_{10} & x_3x_{10} & x_{12} & -x_1x_{10} & 0 & 0 & 0 & x_3x_4 & x_2 & x_5 \\ x_5x_{10} & -x_4x_{10} & x_{11}+g & -x_2x_{10} & x_1x_{10} & x_{12} & 0 & 0 & 0 & x_1x_5 & x_3 & x_6 \end{pmatrix}.$$

Initial conditions for the integration of the equations (5.31) - (5.33) are the a priori estimate of the state vector and covariance matrix of the a priori error vector P (0) = P0, where P0 - given a priori covariance matrix of the state vector (the diagonal matrix consisting of the variances of the components of the state) . Optimal a priori estimate of the state vector is its unconditional expectation, which for small angles ϑ_0, ψ_0, γ_0, we assume approximately equal to the diagonal elements of the vector of a priori covariance matrix P0 is defined as

$$\sigma_{01}^2 = \sigma_{02}^2 = \sigma_{03}^2 = \sigma_{04}^2 = \sigma_{05}^2 = 10^{-4};$$
$$\sigma_{06}^2 = 10^{-6};\ \sigma_{07}^2 = \sigma_1^2;\ \sigma_{08}^2 = \sigma_2^2;\ \sigma_{09}^2 = \sigma_3^2;$$
$$\sigma_{010}^2 = \sigma_{gx}^2;\ \sigma_{011}^2 = \sigma_{gy}^2;\ \sigma_{012}^2 = \sigma_{gz}^2.$$

1.1 Modeling Program Description

Lab runs in Matlab 6.5 using the package Simulink.

To analyze the accuracy of estimation of orientation angles formed Simulink-model according to Fig. 5.2. Model units Object (object) and the Kalman Filter (Kalman filter), formed as a subsystem (such as blocks Subsystem) in accordance with equations (5.14) - (5.25) and (5.31) - (5.33) are shown in Fig. 5.3 and 5.4, respectively.

Input data and initial conditions for the integration of systems of differential equations are placed in the m-file.

Perturbing effects of simulated wideband input processes with small time constant (0.01).

The motion of an object is defined by forming the components of the angular velocity varying sawtooth with a given amplitude Ω_x, $\bar{\Omega}_y$, $\bar{\Omega}_z$,, frequencies Ω_x, Ω_y, Ω_z and random initial phase.

In all versions of accepted values of the constants $R_1 = R_2 = R_3 = 10^{-5}$ m2/s3; T1 = T2 = T3 = 10; Tgx = Tgy = Tgz = 1, the period of change of the components of the angular velocity of the object 10 ($\Omega_x = \Omega_y = \Omega_z = \pi/5$ s^{-1}).

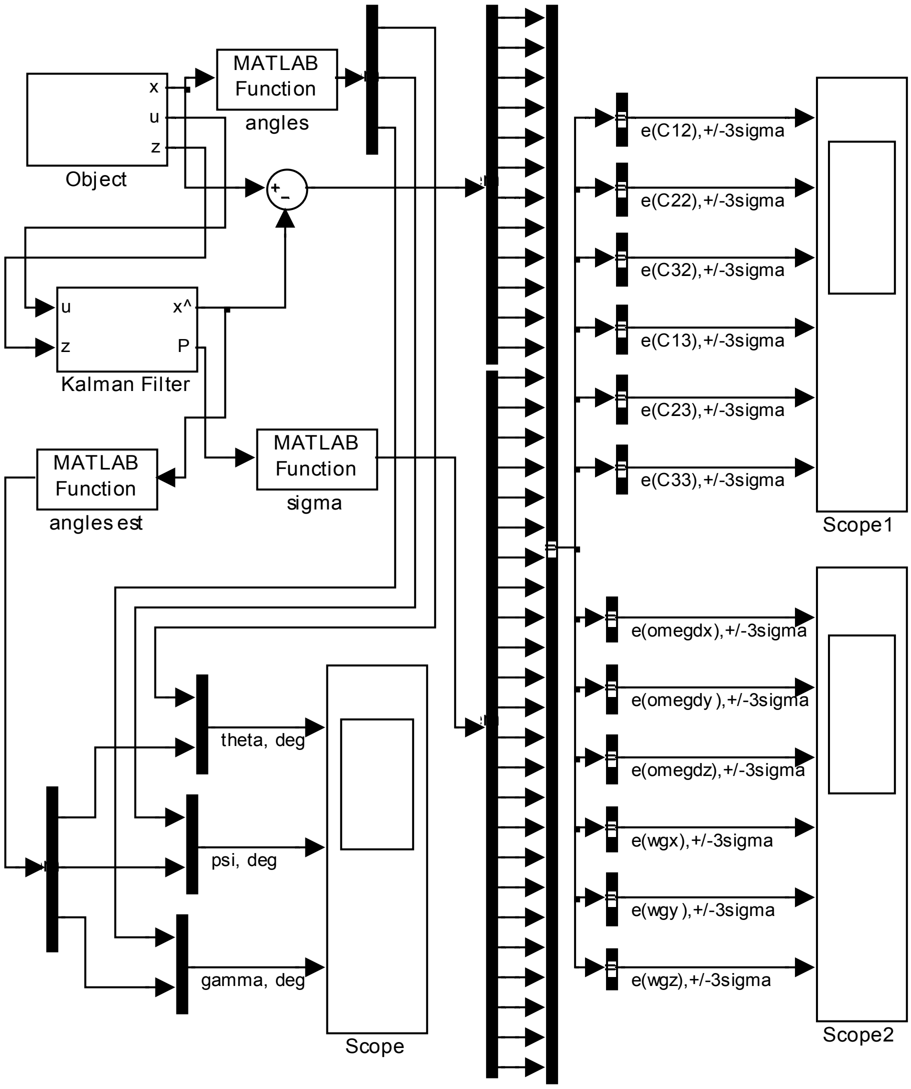


Figure 5.2 – Main windows

1.2 Procedure for laboratory work

1. Get a job at the option of the teacher.
2. Run Matlab, create a new mdl-file.
3. Generate Simulink-model according to Fig. 5.2. Embed:

angles to the block
Matlab Function: [atan (u (1) / sqrt (u (2) ^ 2 + u (3) ^ 2));
-atan (u (4) / (u (2) * u (6)-u (3) * u (5)));-atan (u (3) / u (2))] * 180/pi
Output dimensions: 3
to block angles est
Matlab Function: [atan (u (1) / sqrt (u (2) ^ 2 + u (3) ^ 2));
-atan (u (4) / (u (2) * u (6)-u (3) * u (5)));-atan (u (3) / u (2))] * 180/pi
Output dimensions: 3
to block sigma
Matlab Function: [-3 * sqrt (diag (u)); 3 * sqrt (diag (u))]
Output dimensions: 24
a Bus Creator block
Number of inputs: 36
in blocks Bus Selector (top down):

Selected signals: signal1 signal13 signal25
Selected signals: signal2 signal14 signal26
Selected signals: signal3 signal15 signal27
Selected signals: signal4 signal16 signal28
Selected signals: signal5 signal17 signal29
Selected signals: signal6 signal18 signal30
Selected signals: signal7 signal19 signal31
Selected signals: signal8 signal20 signal32
Selected signals: signal9 signal21 signal33
Selected signals: signal10 signal22 signal34
Selected signals: signal11 signal23 signal35
Selected signals: signal12 signal24 signal36
 Muxed output (in all blocks Bus Selector)
block in Scope (menu 'Scope' parameters)
Tab General:
Number of axes: 3
Time range: 50
Tab Data history:
 Limit data points to last:
in blocks Scope1, Scope2 (menu 'Scope' parameters)
Tab General:
Number of axes: 6
Time range: 50
Tab Data history:
 Limit data points to last:
In blocks Object and Kalman Filter to set the required number of inputs and outputs in accordance with Fig. 5.2.

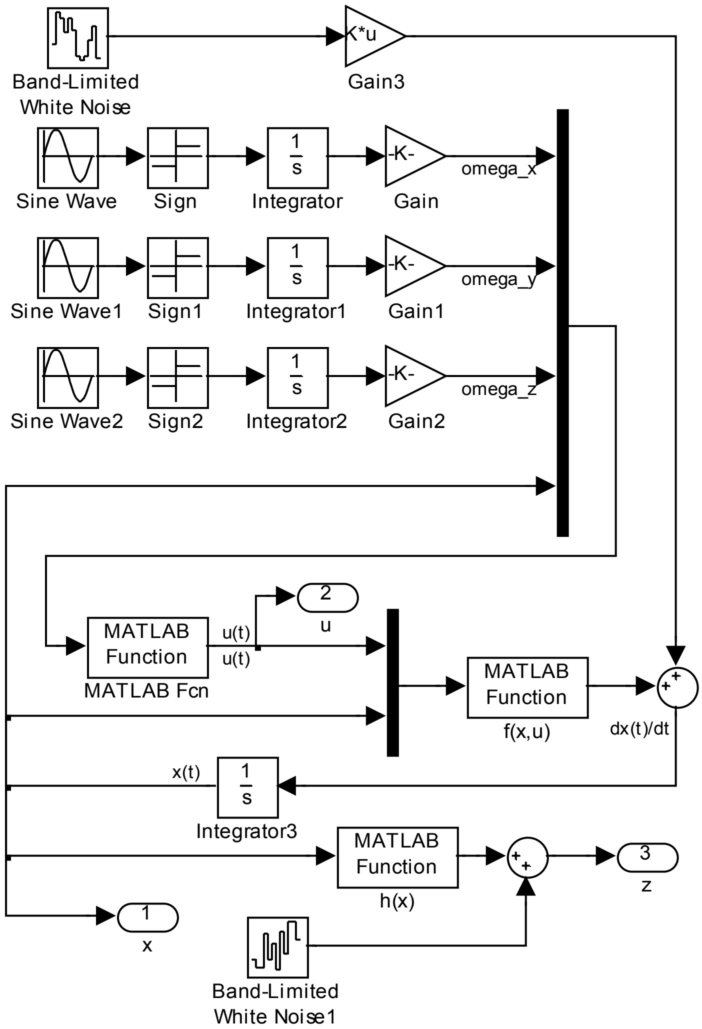


Figure 5.3 – The *Object* block

4. Expand Block Object. Generate Simulink-model according to Fig. 2.3. Embed:
block in Band-Limited White Noise
Noise power: 1
Sample time: 0.01
Sine Wave block in
Amplitude: 1
Bias: 0
Frequency (rad / sec): Omegx
Phase (rad): fi
Sample time: 0
to block Sine Wave1
Amplitude: 1
Bias: 0
Frequency (rad / sec): Omegy
Phase (rad): fi
Sample time: 0
to block Sine Wave2
Amplitude: 1
Bias: 0
Frequency (rad / sec): Omegz

Phase (rad): fi
Sample time: 0
in the block Integrator
Initial condition: (-0.5 + abs (fi / pi)) * pi / Omegx
to block Integrator1
Initial condition: (-0.5 + abs (fi / pi)) * pi / Omegy
to block Integrator2
Initial condition: (-0.5 + abs (fi / pi)) * pi / Omegz
Gain in power
Gain: Omeg_x * 2 * Omegx / pi
to block Gain1
Gain: Omeg_y * 2 * Omegy / pi
to block Gain2
Gain: Omeg_z * 2 * Omegz / pi
to block Gain3
Gain: B
Multiplication: Matrix (K * u)
MATLAB Fcn block in
Matlab Function: [u (1)-u (10); u (2)-u (11); u (3)-u (12)]
Output dimensions: 3
in block f (x, u)
Matlab Function: [u (5) * u (12)-u (6) * u (11) + u (5) * u (3)-u (6) * u (2);
u (6) * u (10)-u (4) * u (12) + u (6) * u (1)-u (4) * u (3);
u (4) * u (11)-u (5) * u (10) + u (4) * u (2)-u (5) * u (1);
u (8) * u (12)-u (9) * u (11) + u (8) * u (3)-u (9) * u (2);
u (9) * u (10)-u (7) * u (12) + u (9) * u (1)-u (7) * u (3);
u (7) * u (11)-u (8) * u (10) + u (7) * u (2)-u (8) * u (1); -1/T1 * u (10);
-1/T2 * U (11); -1/T3 * u (12); -1/Tgx * u (13); -1/Tgy * u (14); -1/Tgz * u (15)]
Output dimensions: 12
in block h (x)
Matlab Function:
[u (10) * (u (2) * u (6)-u (3) * u (5)) + (u (11) + g) * u (1) + u (12) * u (4);
u (10) * (u (3) * u (4)-u (1) * u (6)) + (u (11) + g) * u (2) + u (12) * u (5) ;
u (10) * (u (1) * u (5)-u (2) * u (4)) + (u (11) + g) * u (3) + u (12) * u (6)]
Output dimensions: 3
to block Integrator3
Initial condition: x0
block in Band-Limited White Noise
Noise power: diag (R)
Sample time: 0.01
Seed: [1111 2222 3333]
(the vector of three arbitrary integers)

1. Expand Block Kalman Filter. Generate Simulink-model according to Fig. 5.4.

Embed:
Constant block in
Constant value: R ^ -1
in blocks of Product, Product1, Product2, Product3
Multiplication: Matrix (*)
in the block Integrator
Initial condition: xo0
in block f (x ^, u)
MATLAB Function: [u (5) * u (12)-u (6) * u (11) + u (5) * u (3)-u (6) * u (2);

u (6) * u (10)-u (4) * u (12) + u (6) * u (1)-u (4) * u (3);
u (4) * u (11)-u (5) * u (10) + u (4) * u (2)-u (5) * u (1);
u (8) * u (12)-u (9) * u (11) + u (8) * u (3)-u (9) * u (2);
u (9) * u (10)-u (7) * u (12) + u (9) * u (1)-u (7) * u (3);
u (7) * u (11)-u (8) * u (10) + u (7) * u (2)-u (8) * u (1); -1/T1 * u (10);
-1/T2 * U (11); -1/T3 * u (12); -1/Tgx * u (13); -1/Tgy * u (14); -1/Tgz * u (15)]
Output dimensions: 12
in block h (x ^)
MATLAB Function:
[U (10) * (u (2) * u (6)-u (3) * u (5)) + (u (11) + g) * u (1) + u (12) * u (4);
u (10) * (u (3) * u (4)-u (1) * u (6)) + (u (11) + g) * u (2) + u (12) * u (5) ;
u (10) * (u (1) * u (5)-u (2) * u (4)) + (u (11) + g) * u (3) + u (12) * u (6)]
Output dimensions: 3
block in df (x ^, u) / dx '
MATLAB Function: [0;-u (12)-u (3); u (11) + u (2), 0, 0, 0, 0, 0, 0, 0, 0, 0;
u (12) + u (3), 0;-u (10)-u (1), 0, 0, 0, 0, 0, 0, 0, 0;-u (11)-u (2); u (10) + u (1);
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0;-u (12)-u (3); u (11) + u (2), 0 , 0, 0, 0, 0;
0, 0, 0, 0; u (12) + u (3), 0;-u (10)-u (1), 0, 0, 0, 0, 0, 0, 0, 0, 0, - u (11)-u (2);
u (10) + u (1), 0, 0, 0, 0, 0, 0, 0, 0; u (6);-u (5), 0; u (9);-u (8); -1/T1; 0, 0, 0;
0, 0;-u (6), 0; u (4);-u (9), 0; u (7), 0; -1/T2; 0, 0, 0, 0; u (5); -u (4), 0; u (8);
-U (7), 0, 0, 0; -1/T3; 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0; -1/Tgx; 0, 0; 0, 0, 0, 0;
0, 0, 0, 0, 0, 0; -1/Tgy; 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0; -1/Tgz]
Output dimensions: 144
to block Integrator1
Initial condition: P0
to block dh (x ^) / dx '
MATLAB Function: [u (11) + g;-u (6) * u (10); u (5) * u (10); u (6) * u (10);
u (11) + g;-u (4) * u (10);-u (5) * u (10); u (4) * u (10); u (11) + g; u (12) ; u (3) * u (10);
-U (2) * u (10);-u (3) * u (10); u (12); u (1) * u (10); u (2) * u (10);-u (1) * u (10);
u (12), 0, 0, 0, 0, 0, 0, 0, 0, 0; u (2) * u (6); u (3) * u (4); u (1) * u (5); u (1); u (2);
u (3); u (4); u (5); u (6)]
Output dimensions: 36
Reshape block in
Output dimensionality: Customize
Output dimensions: [12,12]
to block Reshape1
Output dimensionality: Customize
Output dimensions: [3,12]
blocks in Math Function, Math Function1
Function: transpose
to block Constant1
Constant value: B * B '
2. Simulation menu, choose Simulation Parameters and set the simulation time 50.
3. Create m-file in accordance with Annex 2. Enter the settings according to the embodiment set (Table 5.1), paying attention to their dimensions.

2. Pressing [F5] to run m-file for execution.
3. Back to the main window Simulink-model. Pressing the Start Simulation run mdl-file for execution.
4. Double-click on blocks Scope1, Scope2, Scope3 open windows under construction schedules: orientation angles □, □, □ and assessments;
Error estimates of state variables with the estimates of accuracy (□ 3 □).
5. Compare estimates of orientation angles from their true values. Record the maximum magnitude

of errors to report.
6. Make sure that the error estimates of state variables estimates of their accuracy (hit control the error values in the corridor □ 3 □). To conclude how the errors depend on the orientation of the object.
7. In blocks Band-Limited White Noise, Band-Limited White Noise1 establish the intensity of the input noise equal to zero. Repeat the procedure of modeling. Define the state variables, the transients are damped for which character. The duration of the transients to estimate the willingness to work Strapdown vertically.

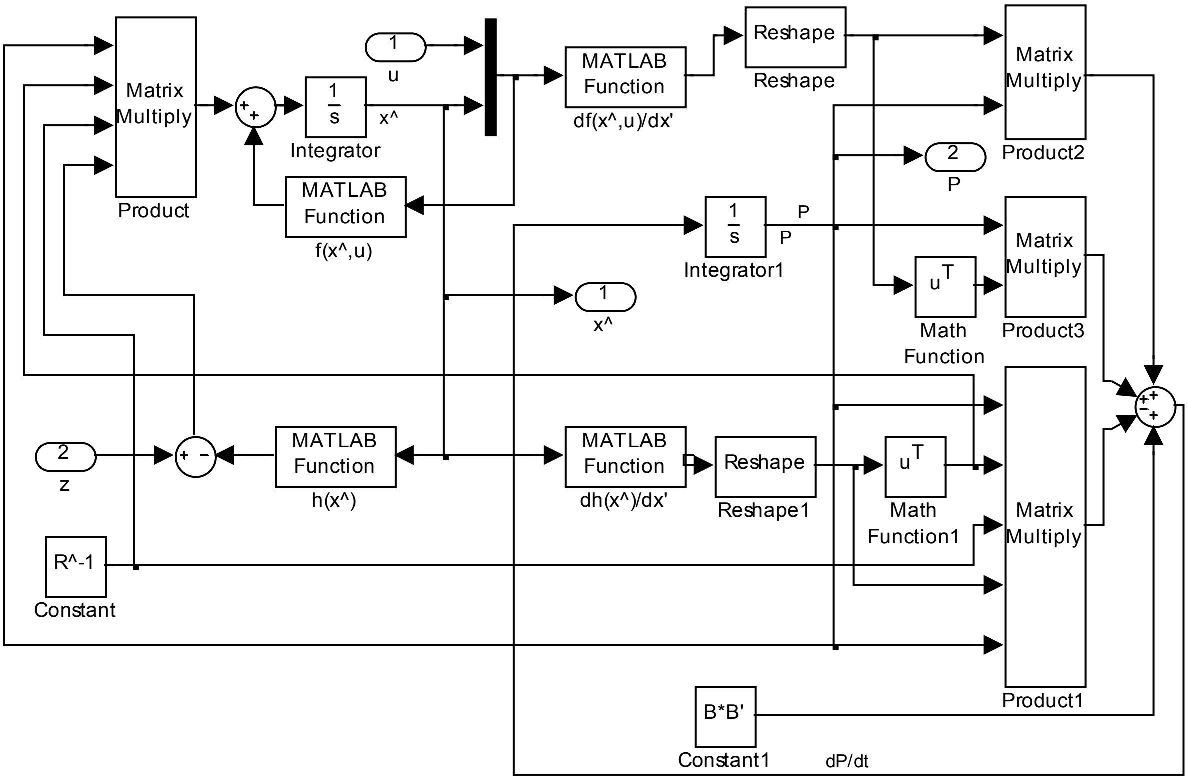


Figure 5.4 –*Kalman Filter*

1.3 Report Content

Report on laboratory studies should include:

block diagram of the system;

system of differential equations describing the behavior of the object;

values obtained for the experimental data;

conclusions of the work.

1.4 Test Questions

1. What sensors includes a measuring unit Strapdown vertically? What are the physical quantities they measure?

2. What type of correlation functions are components of the angular velocity of the drift of the TLS?

3. What are the components contain the outputs of accelerometers?

4. How many elements of the matrix of direction cosines give complete information about the angles of orientation of an object? What order is a dynamic system under study?

5. What signals are input and which - with respect to the output device evaluation?

6. What is the distribution of the initial phase of the law changes the angular velocity of an object?

7. In some of the blocks of Simulink model defined initial conditions for the integration of the dispersion equation?

8. In what units Simulink model by the variation of the components forming the angular velocity?

9. How are modeled by input disturbances such as white noise?

10. Is the system under investigation is fully observed? Why?

Laboratory Work №6
Calculation of the Micro/Nanosatellite Thermal Processes in an Orbit

The purpose of the

Getting the skills of calculation of thermal processes occurring on board micro / nano-satellites.

The objectives of the

1 Identify the orbital parameters needed to calculate the thermal processes on-board micro / nano-satellite.

2 Develop a software package for calculating and visualizing thermal processes of micro / nano satellites using programming environments Lazarus (or Java)

Brief theoretical information

It is known that virtually every satellite is a cube with six planes. It is therefore necessary to consider thermal regulation with each of these planes. Thermal energy is supplied to a satellite through three channels:

Direct sunlight

Reflected from Earth's sun

Infrared rays from the Earth's surface

Necessary equipment and materials:

1. Personal computer with an Internet connection.

2 Programming Environment Lazarus (Java)

Necessary formulas

1. Energy balance.

Considering the energy balance equation and heat flow we obtain:

$$\frac{dQ}{d\tau} = c*m*\frac{dT}{d\tau} = \dot{Q}_{abs_S} + \dot{Q}_{abs_{Fl}} - \dot{Q}_{EM} - \dot{Q}_{WL} + \dot{Q}_{Alb} + \dot{Q}_{Erd}$$

In our case it is known that heat and reflected sunlight from the Earth equal to 0:

$$\dot{Q}_{Alb} = 0 \qquad \dot{Q}_{Errd} = 0$$

2. The absorption of the sun.

Absorption from the sun is defined:

$$\dot{Q}_{abs_S} = \alpha * S * A_{abs}$$

where α-absorption coefficient, S-rays of the sun and Aabs-surface absorption.

To calculate the heat absorption from the Sun must be known surface absorption. It is determined by the vernal equinox and summer solstice:

In the spring he computed as:

$A(1) = l^2 * \cos(\varphi)$

$A(2) = l^2 * \sin(\varphi)$

$A(3) = 0$

$A(4) = 0$

$A(5) = -l^2 * \sin(\varphi)$

$A(6) = -l^2 * \cos(\varphi)$

And summer is calculated as follows:

$A(3) = l^2 * \sin(23.14°)$

$A(4) = 0$

$A(1,2,5,6) = A_{Frühjahr}(1,2,5,6) * \cos(23.14°)$

3. Solar Shade:

As we know the earth's axis is tilted 23 ° 14 'in consequence of that shade from the sun to the Earth at different times of the year falls unevenly. This should be considered in further calculations.

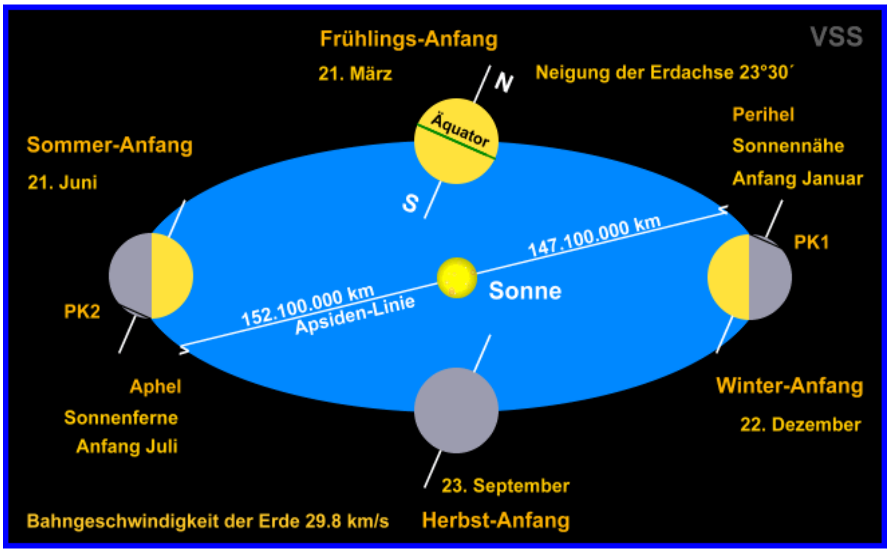


Figure 6.1 - Solar shade

Angle of incidence of the Earth's shadow on the moon α is defined as:

$$\frac{r_{Erde}}{r_{Sat}} = \sin(\alpha)$$

For φ > π- α and φ > π+ α because $\dot{Q}_{abs_S} = 0$

And also:

$$\varphi = \varphi_0 + \omega * dt$$

$$\omega = \frac{2\pi}{24h}$$

dt = 1 min

φ0=0 as the initial value

4. Heat Transfer:

For the law of heat we have:

$$\dot{Q}_{WL} = \sum_{j=1..6}^{i \neq j, i+j \neq 7} \dot{Q}_{Lij} \quad \text{and} \quad \dot{Q}_{Lij} = k * (T_i - T_j)$$

Where k-factor of heat transfer.

For example for the surface of a given formula becomes:

$$\dot{Q}_1 = k * \left[(T_1 - T_2) + (T_1 - T_3) + (T_1 - T_4) + (T_1 - T_5) \right]$$

5. Thermal radiation:

Heat radiation is electromagnetic radiation of the object when the object changes its temperature

For the radiated surface:

$$A_{EM} \approx 2 * l^2 \quad \dot{Q}_{EM} = \varepsilon * \sigma * T_i^4 * A_{EM}$$

where σ - Boltzmann constant.

6. Heat absorption

Heat absorption can be determined:

$$\dot{Q}_{ij} = \sigma * \alpha * A_{em} * \varepsilon * e_{ij} * T_j^4$$

where $A_{em} = l^2$ und σ - Boltzmann factor.

Ti-temperature of the surface

TJ-temperature rest

For example, for surface 1 we have:

$$\dot{Q}_1 = \sigma * \alpha * A_{em} * \varepsilon * e_{ij} * (T_2^4 + T_3^4 + T_4^4 + T_5^4 + T_6^4)$$

7. Determination of surface temperature by using the Runge-Kutta method.

The formula for determining the temperature of the form:

$$\frac{dT}{d\tau} = \frac{\dot{Q}_{abs_S} + \dot{Q}_{abs_{Fl}} - \dot{Q}_{EM} - \dot{Q}_{WL} + \dot{Q}_{Alb} + \dot{Q}_{Erd}}{c * m},$$

where $m = \rho * d * l^2$

This formula can be applied to all surfaces by changing the Ti, Tj:

$$\dot{T}_{i1} = f(\varphi(t); T_{i,alt}; T_{j,alt})$$

$$\dot{T}_{i2} = f(\varphi(t) + \omega\frac{dt}{2}; T_{i,alt} + \frac{T_{i1*\Delta t}}{2}; T_{j,alt})$$

$$\dot{T}_{i3} = f(\varphi(t) + \omega\frac{dt}{2}; T_{i,alt} + \frac{T_{i2*\Delta t}}{2}; T_{j,alt})$$

$$\dot{T}_{i4} = f(\varphi(t) + \omega dt; T_{i,alt} + \Delta t * T_{i3}, T_{j,alt})$$

Hence, the temperature for each surface is determined by:

$$T_{i,neu} = T_{i,alt} + \Delta t * \left(\frac{\dot{T}_{i1} + 2*\dot{T}_{i2} + 2*\dot{T}_{i3} + \dot{T}_{i4}}{6}\right)$$

Procedure:

1. Include a personal computer.
2. Download the Internet site www.celectrack.som characteristics of the satellite orbit (NORAD system) to determine the characteristics needed to calculate the satellite's orbit.
3. Upload a computer programming environment Lazarus (Java).
4. Using the above formula to make the program work in Lazarus (Java) according to the proposed algorithm in the example.
5. to debug the program.

Laboratory Work №7
Studying of onboard responders of satellite transfer systems

Purpose:

Study of principles of repeaters onboard systems for space communications.

Job

1. To view a block diagram of the onboard transmitter.
2. Learn from the base element used in high-output amplifiers.
3. To view the parameters of traveling-wave tubes.
4. Please see the structural schemes adding capacity.
5. familiar with the appointment of a receiver input board relay.
6. Draw up a report.

Brief theoretical information

The main parameter airborne transponder (BRTR) determining the resource and quality characteristics of the communication system is the power of the transmitter, the maximum value is limited by several factors:

maximum output of primary power sources PPE;

opportunity to challenge the limits of heat dissipated by the satellite;

reduced longevity and reliability of electronic devices with improved power factor:

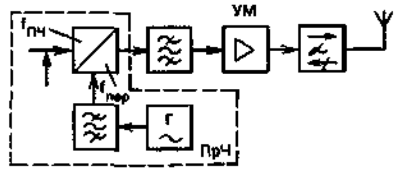


Figure 7.1 - Block diagram of the transmitter BRTR

Most transmitters BRTR heterodyne-type building on the traditional pattern (Fig. 7.1), consisting of high-power frequency converter and power amplifier with the necessary set of filters and matching elements. Most often, the transmitters amplify signals in the band of one trunk, but sometimes used for simultaneous amplification of the signals of several trunks.

The main element is a powerful transmitter output power (in the trunks of the direct transfer of a transmitter power amplifier to understand), since it falls on a significant part of total energy consumed BRTR, mass and volume. As the actual amplifying element, depending on the destination, the required power, bandwidth, weight, dimensions, efficiency, durability, etc. using various microwave devices, traveling wave tube (TWT), klystrons, solid-state devices (transistors, tunneling, avalanche-transit diodes, etc.).

TWT are the most abundant and rapidly growing class of microwave vacuum devices for airborne equipment are widely used in the field because they possess several advantages compared to other microwave devices: high-gain, broadband, the ability to work in pulsed and continuous modes in a wide range of output powers.

Used in different BRTR TWT, in addition, high efficiency, compactness, low weight, high durability (up to 100 ... 150 thousand hours) and reliability. These devices operate at voltages less than 6500, their design has enough stiffness and can withstand severe vibration and shock loads.

Virtually all of the TWT used in BRTR have the same structure, except for minor modifications related to the implementation of specific features of specific BRTR.

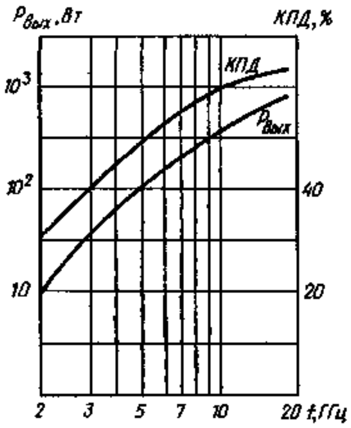


Figure 7.2

Figure 7.2 shows the curves showing the highest values of output power and efficiency achieved in the TWT of different types. For BRTR greatest interest TWT high power, and for this purpose create a special economical and compact TWTs. Based on the conditions of TWT on-board equipment unattended, they impose very high demands on efficiency, durability, reliability, overall dimensions and weight.

TWT for airborne equipment are made on the individual specially allocated frequency bands in the range 1.8 ... 12.7 GHz. Typical of the first samples were BRTR TWT with a capacity of 20 watts, and in some satellites used in the TWT output of 30 and 70 W in continuous mode. Currently, the most connected satellite TWT output power in continuous mode is 30 ... 75 watts, and broadcasters - 50 ... 150 watts. With the same design and receive a higher power. The most important factor when choosing a TWT output power is the power supply satellite. Already a small increase in efficiency results in a significant gain for the satellite as a whole - reduced the number of solar cells, batteries, overall dimensions and power supply simplifies the problem of heat dissipation. Almost all the main parameter for satellite TWT, defining all the other elements of the design is the required power consumption of on-board power source. Therefore, by increasing the efficiency of the TWT paid much attention.

These methods include:

- The change of the phase velocity of slow waves along the length of the lamp or correction sync speed;
- Formation of discrete features;
- Multistage-recovery in the reservoir (or reduction potential of the reservoir sequence headers to a value less than the potential slow-wave structure, which allows return of unused energy from the working of the electron beam).

Typically, the coefficient - the strengthening of the TWT is 40 ... 50 dB, and efficiency - 64 ... 50%.

Desired mode TWT output power level is set by selecting the level of input power. Amplitude characteristic of the TWT to distinguish between two distinct areas, corresponding to two modes of operation.

In the linear mode (small signal) gain is constant, and the power output varies in proportion to the input. Maximum output power TWT in the linear regime for smaller par 3 ... 6 dB.

In the saturation regime (large-signal regime), the linear dependence of output power on the input is violated, increase the input signal does not lead to a further increase in power output due to the limited power of the electron beam. In the saturation slope sharply fazoamplitudnoy TWT performance, which is the dependence of the phase shift introduced by the TWT, the amplitude of the input signal, which leads to the transformation of the amplitude modulation of the phase (amplitude-phase conversion). Thus, the parasitic AM, for example, frequency-modulated signal at the input of TWT leads to spurious FM and, therefore, to nonlinear distortion of signals.

The output of power amplifiers for TWT efficiency reasons it is desirable to use the lamp mode is close to saturation (nominal). When transmitting broadband signals in the saturation or near saturation regime must take into account emerging distortion. Acceptable levels of distortion depends on the type of modulation - odnosignalnaya FM or FM multi-carrier - and the type of multiple access - TDMA or FDMA.

Two phenomena that occur in a TWT - Amplitude nonlinearity and AM-PM conversion - are the reasons the appearance of interference in the amplification of multiple signals.

In the output amplifier and ATC using klystrons. Thus, the system developed in Russia, STV "Display" operating in the range 702 ... 726 MHz, used direct-flight klystron with an output of 200 ... 300 W with a bandwidth of about 24 MHz on the level of 2 dB. The use of the onboard devices, klystrons is limited because of their narrow band. The advantages include ease of klystron design, smaller in number compared to the TWT nominal supply voltages, high efficiency. The rest of klystron amplifiers are similar to TWT amplifiers, with all their advantages and disadvantages (nonlinear transfer characteristic, the amplitude-phase conversion, etc.).

Solid-state devices as the output of power amplifiers were used BRTR only in recent years due to the success of semiconductor electronics, can significantly increase the power of the transmitters. The development of microwave semiconductor transmitters for BRTR comes in two main directions: creation of new high-power microwave transistors and the addition of power semiconductor lasers with multi-pole circuits or adding capacity in space using phased antenna arrays (PAR).

The advantages of solid-state transmitters BRTR compared with an electrical as follows:

- usually much greater durability;
- low values of supply voltages (the first demand for power supply voltage is not more units or tens of volts, and only one or two denominations, the latter need to supply a range of different voltage ratings, a maximum value of several kilovolts, even at relatively low output power of the microwave signal);
- use of semiconductor devices can use the methods of microelectronics in manufacturing of various components and units included in the transmitters BRTR, which, in turn, causes a significant reduction in weight and dimensions of the latter;
- powerful semiconductor devices have near-instant readiness to work compared with an electrical, heating circuit which requires pre-heating.

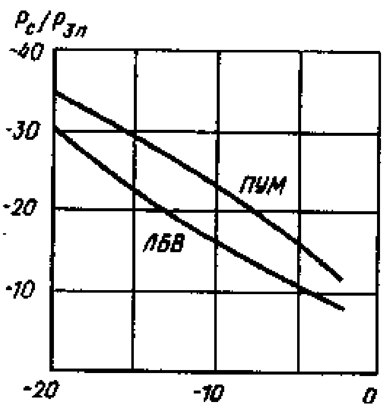


Figure 7.3

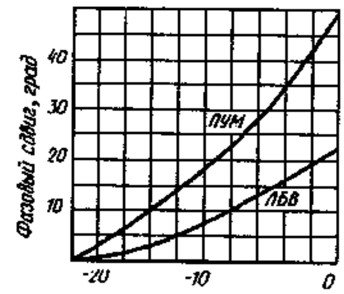


Figure 7.4

This makes the communication system more flexible and responsive.

According to some sources, a significant improvement in the parameters of the barrel BRTR achieved in the American system of satellites through the use of RSA Satcom semiconductor power amplifier (PIP). Replacing them in the TWT on PIP (on GaAs FET) has significantly improved performance and reliability of the transmission path BRTR. In addition, according to the same work, PUM has a high linearity performance especially in the operation near the saturation point.

Thus, to achieve the level of PIP intermodulation third order (in the transmission of two carriers), 3 ... 8 dB less than the TWT.

Figure 7.3 shows for comparison the dependence of the ratio of the relationship with - the signal power at the output of the device - a product of distortion third order in the output of the device - power input signal - signal at the entrance to the saturation regime. Here, for a given level of intermodulation distortion, such as -20 dB at the input of PIP required reduction in power by 5 dB less than that for the amplifier to the TWT. It provides a higher signal to noise ratio, resulting in increased throughput, improved industrial efficiency or BRTR.

These data are somewhat at variance with the findings of several authors, which is given to the advantage of TWT. The discrepancy is probably due to the fact that in the first case considered PIP field-effect transistor with a relatively large linear plot, while the second - bipolar transfer function which has a short linear portion and two typical fracture - in the initial region and saturation region.

In addition, a significant decrease in the phase of oscillations changes the signal level reduces parasitic AM-FM conversion for systems with FDMA and reduces the probability of symbol error for digital systems.

Phase characteristics of the PIP field-effect transistor and an amplifier for TWT are shown in Fig. 7.4.

The consequence of these advantages are significant reduction in weight and overall dimensions, increase efficiency, durability and reliability of solid-state transmitters BRTR compared with an electrical all other things being equal.

Along with the advantages and disadvantages should be noted these transmitters:

- semiconductor devices sensitive to deviations, even briefly, from the permissible operating conditions that can lead to breakdown of the pn junction and the complete failure of the device, so the transmitter has to take special measures to protect from accidentally occurring adverse factors;
- power semiconductor devices is limited, and most of them with increasing frequency / decreasing it by law.

There are three main ways of adding: using multi-pole circuits, phased arrays using multi-element, in the general cavity. In the first method to adder connected many of the same type of amplifiers, which power goes to the total output load, with the second method of adding capacity in the space of signals produced by the FAS, which includes a large number of irradiators oriented respectively, each of which is excited by a separate amplifier. The third method is used only for the addition of microwave power generating diodes located in the general cavity. In practice, the first method allows to increase the transmitter power vs. power per transistor by 15 ... 20 dB, the second method - a 30 ... 40 dB, the third - to 10 ... 13 dB.

The basic requirements to be met by the above methods of summation:

1. Signal power at the output of addition is equal to or close to the sum of individual power ratings of amplifiers n: $P_{ОБЩ} = nP_{НОМ}$.
2. All amplifiers have to be mutually independent, ie HN-decoupling from each other. The failure of any amplifier should not affect the operation and output of all other amplifiers.
3. In the event of failure of m amps total load power should fall to a lower value may, at best - no more than.

Most often, the addition of microwave power amplifiers is carried out using the so-called bridge devices, providing a pairwise addition of the signals. Mainly used bridge device belonging to the class of directional couplers (NO), ie this eight-intended to be branches of power, the distinctive feature of which is as follows: the excitation of one of the four channels BUT energy comes only in two channels. A similar but can be used to reverse the procedure - the division of power in half (ie, power reduction of 3 dB).

Different variants of transistor circuits of transmitters with the addition of power amplifiers based on the bridge devices. Thus the number of the added power amplifiers must be 2n, which is achieved by using (2n - 1) bridge device. Using a variety of options for multi-pole adder-dividers, power combiners implement a large number of microwave amplifiers. These devices consist of three main parts: power divider signal, n the same microwave amplifiers and power combiner.

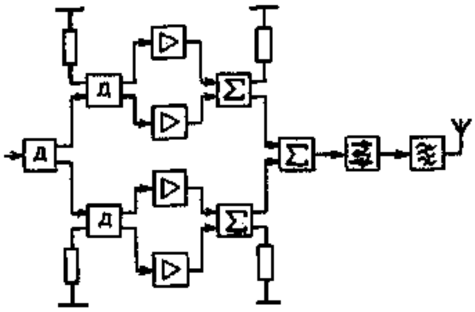


Figure 7.5

For example, Fig. 7.5 shows a diagram of adding capacity four amplifiers, built on the basis of the quadrature bridge devices made by the ballast loads. This scheme, which allows you to add signals to a sufficiently large capacity, easy to distribute and to a greater number of identical pairs the added amplifiers or amplifier unit.

An important factor in adding power schemes that separate amplifiers is the requirement for phasing of the added signals. For this purpose, identical in structure dividers (D) and adders (Σ), including its conjugate. In this case, no additional phase shifters. This scheme is typical of the transistor modules, built on hybrid integrated technology. Almost by multipolar adders by adding capacity 50 ... 100 of semiconductor devices, and usually first to unite the four transistors module, and then added power 8 ... 16 such modules, depending on the required output power amplifier.

In real terms in the summation of the signal power is inevitable losses associated with the spread parameters of the individual amplifiers (their non-identity), the deviation of the S-parameters of adders (scattering parameters) and the dividers from the optimal values of the bandwidth and the reflections in the signal propagation paths. Total power of all amplifiers in the total load in these cases is given by

$$P_H = \frac{P_{г.ср.ном.}}{n}\left|\sum_{k=1}^{n} a_k p_k s_k g_k e^{-j\varphi_k}\right|(1-|\Gamma н|^2)$$

where $\mathbf{a_k}$ - coefficient taking into account the reflection of the k-th channel (in good agreement close to 1); $\mathbf{P_{г.ср.ном.}}$ - average rating, the same for all amplifiers n; $\mathbf{p_k = \sqrt{P_{г.k.ном.} / P_{г.ср.ном.}}}$ - coefficient taking into account the deviation of the input signal amplitude, where $\mathbf{P_{г.k.ном.}}$ - the nominal capacity of k - th generator; $\mathbf{s_k}$ - ratio close to 1, taking into account the change in absolute value for a specific amplifier relative to the nominal value for identical amplifiers; $\mathbf{g_k}$ - ratio close to 1, taking into account the change in voltage amplitude of the incident wave in the general channel under the action of k - go generator due to the reflection in the ballast loads; $\boldsymbol{\varphi_k}$ - the resultant phase of the signal arriving at a common channel from the k - th amplifier, with good phasing $\varphi_k = 0$; $\Gamma_н$ - total load reflection coefficient, good agreement with $\Gamma_н$=0; n - the number of amplifiers connected to the adder.

The efficiency of the transmitter, built by the method of summation of power of individual amplifiers is determined by the transmission

$$\mathbf{k_п = P_н / \sum_{k=1}^{n} P_{г.k.ном.}}$$

Loss (dB) power combiner are

$$\mathbf{b_п} = 10\,\mathbf{lg(1/k_п)}$$

With the full transfer of power from all generators in the load $\mathbf{k_п} = 1$.

Fig. 7.6, and in the dependences, reflecting the influence of various factors on the loss of power in the summation signals using multi-pole adders.

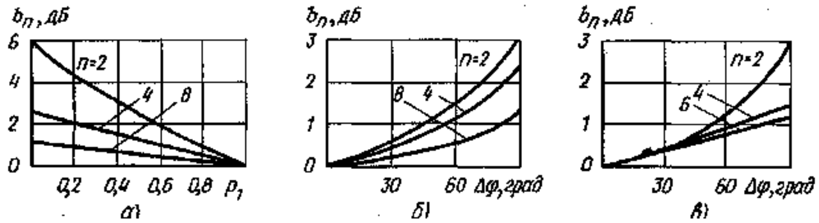


Figure 7.6 The dependence of loss of power adder of the unbalance in amplitude (a) and phase (b, c).

Fig. 6 and shows the dependence $\mathbf{b}_п$ of the change (imbalance) is the sum of signals in the amplitude under the condition that Г=0, $\varphi_k=0$, $\mathbf{a}_k=1$, $\mathbf{s}_k=1$, and all the nominal power amplifiers $\mathbf{P}_{г.k.ном.} = \mathbf{P}_{г.ср.ном.}$ for two special cases:

1. capacity of all generators are identical and constant, except for one of them, like the first;
2. amplitude of the added signal amplifiers are distributed from Pmin to Rmah.

Fig. 6, b and c, respectively, shows the imbalance of the added signals out of phase for two cases: the phase of signals from all amplifiers, except for one constant and equal to the nominal values, the phases of all signals from all amplifiers are distributed uniformly from φ_{min} to φ_{max}.

The analysis shows that for the power transmission coefficient KP transmitter with the addition of capacity is not less than 90 ... 95% is necessary to ensure the spread, the capacity of the individual amplifiers in the range 20 ... 30% and the difference in phase summed signal no more than 20 ... 30 °. This should be provided in a given frequency band changes in the scattering parameters (S-parameters) in the range 20 ... 30%, and the SWR on the part of each input should be no worse than the 1.4 ... 1.5.

The On-Board Responder Input Receivers

Background. The input receivers provide the necessary signal to noise ratio BRTR trunks. The minimum level of received signals is determined by its own fluctuation (thermal) noise of the receiver. In practice, the choice of the effective noise temperature are based on the one hand, the condition that the contribution of the noise section of the Earth-satellite in 5 ... 10 times quieter section of the satellite-Earth, but on the other hand, the minimum effective noise temperature of the satellite receiving system does not may be less than the equivalent T3 temperature of the Earth, as satellite receiving antennas are oriented in its direction.

Noise temperature, input receiver BRTR (reduced to the input of the receiving antenna the irradiator)

$$T_б = T_з + T_{атм} + bT_{косм} + T_{пр},$$

where T_{ATM} - equivalent noise temperature of the atmosphere, the antenna stationary satellites in the range 1 ... 20 GHz varies from 2 ... 25 °; $T_{косм}$ - the equivalent temperature of the cosmic noise - depending on the area of the sky, which is directed antenna, and can be determined by special maps of the sky, the maximum values at 1 GHz does not exceed 30 ° and decreases rapidly with increasing frequency; b - coefficient significantly less than unity, determines the fact of receipt of cosmic noise only the side lobes; $T_{пр}$ - the receiver noise temperature BRTR.

The bottom line regarding the selection of TB

$$T_б=(5...10)T_{пр3С},$$

where $T_{пр3С}$ - receiver noise temperature of the AP, working with the data of the satellite. The input receivers of modern AP using low-noise amplifiers in the range of different types of satellite communications are the total noise temperature of 40 ... 300 °. In these cases, respectively, the total noise temperature Tb may be in the range 400 ... 3000 K.

Test Questions

1. Explain block diagram BRTR.
2. What is the element base is used to build powerful output amplifiers BRTR?
3. What are the methods to improve the efficiency of the TWT?
4. How are the power output and efficiency of the TWT with the frequency?
5. Describe the basic parameters of the TWT.
6. What are the advantages of solid-state transmitters BRTR compared with an electrical?
7. Explain dependency relations Pin / Rnas for PIP and TWT.
8. Explain the amplitude and phase characteristics of the PIP and amplifiers based on TWT.
9. What are the disadvantages of transmitters using the PIP?
10. What methods are used to increase the output power BRTR?
11. Explain block diagram of the addition of even power amplifiers.
12. What determines the efficiency of the transmitter was built by the method of adding capacity?
13. What factors affect the loss but the summation of power?
14. What is provided a value of the transfer of power transmitter R 90 ... 95%?
15. Explain the purpose of input receivers BRTR?
16. Describe the basic parameters of low noise amplifiers (LNA).

In addition to the report content

Provides a block diagram of a transmitter BRTR (adding power) on the instructions of the teacher.

Laboratory Work №8
Receiving of the Telemetery Information from a Board of Micro/Nanosatellites

Purpose - to obtain the skills to work with the control stations of micro / nano-satellites.

Objectives of work - get on board telemetry micro / nano-satellites and Beesat Lapan-TUBSat.

Steps of work

Step 1. Turn your PC, receiving station, data transmission (see Fig. 8.1), an antenna controller (Figure 8.2)

Figure 8.1

Figure 8.2

Step 2. To work with the satellite Beesat run Beesat GUI (Figure 8.3), and for working with the satellite Lapan-TUBSat run Lapan GUI (Figure 8.4)

Step 3. The program Beesat GUI (Lapan GUI) to select ports connect to a PC (the default for CAT - 3 port for TNC - 1 port), see Fig. 8.3, 8.4.

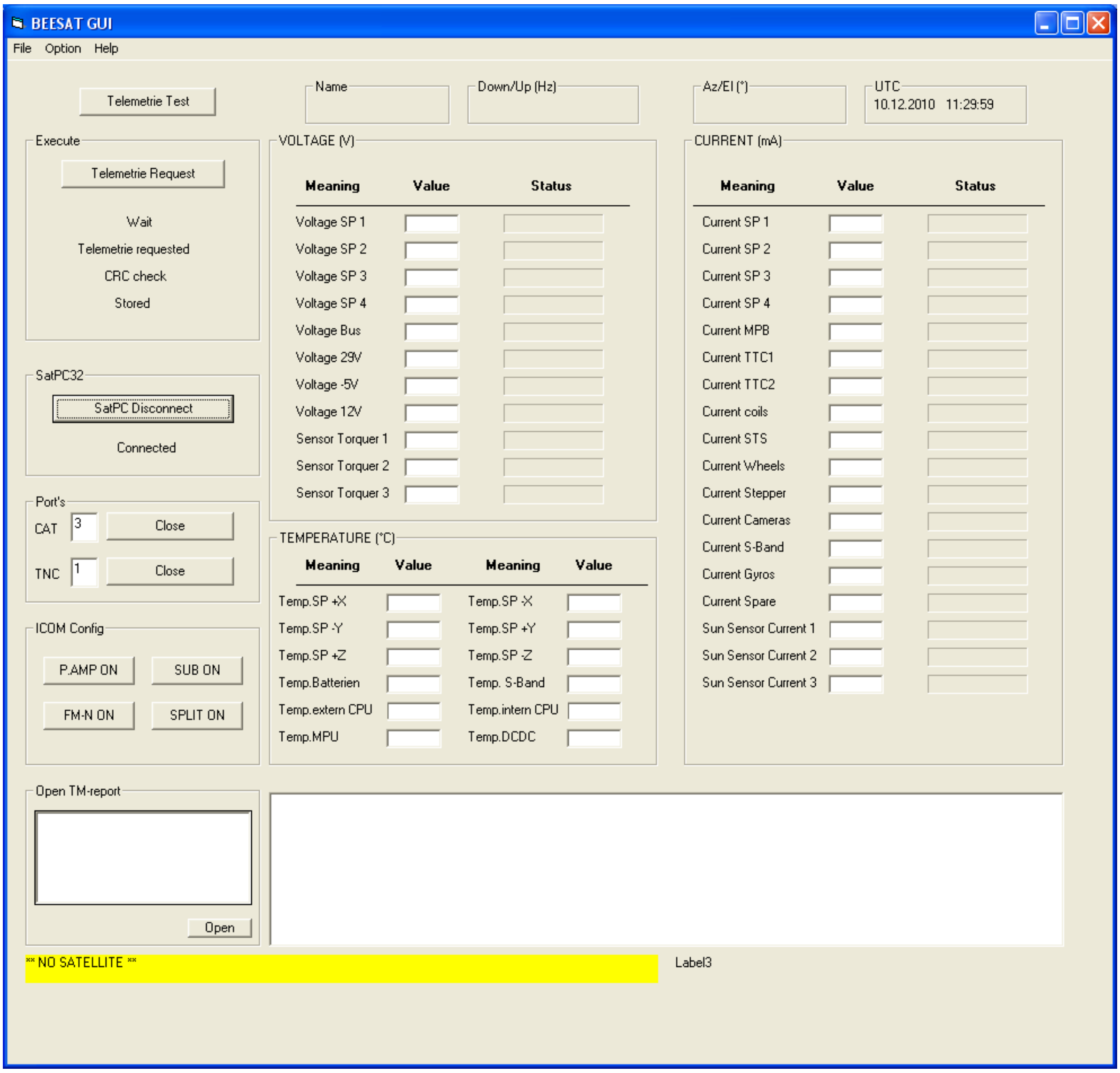


Figure 8.3

Step 4. Run this program SatPC-32-lk (see Fig. 8.5). Along with this program, the program starts Arswin (see Fig. 8.6).

Step 5. Update data about the elements of the orbits of satellites of interest, as shown in Fig. 6.7. The data obtained from the site http://www.celestrak.com/NORAD/elements.

Step 6. After entering the zone of the ground station program SatPC-32 through the program will automatically track Arswin moving satellite. To send commands to the issuance of telemetry to link the program BeeSat GUI (Lapan GUI) software with SatPC-32. To do this, press the button «SatPC Connect» Program .

BeeSat GUI (Lapan GUI). To directly send commands to the satellite press «PCU Telemetrie».

Telemetry reception result is shown in Fig. 8.4 and Fig. 8.8 (binary data).

The report should reflect the stages of laboratory work and the results (binary file with telemetry).

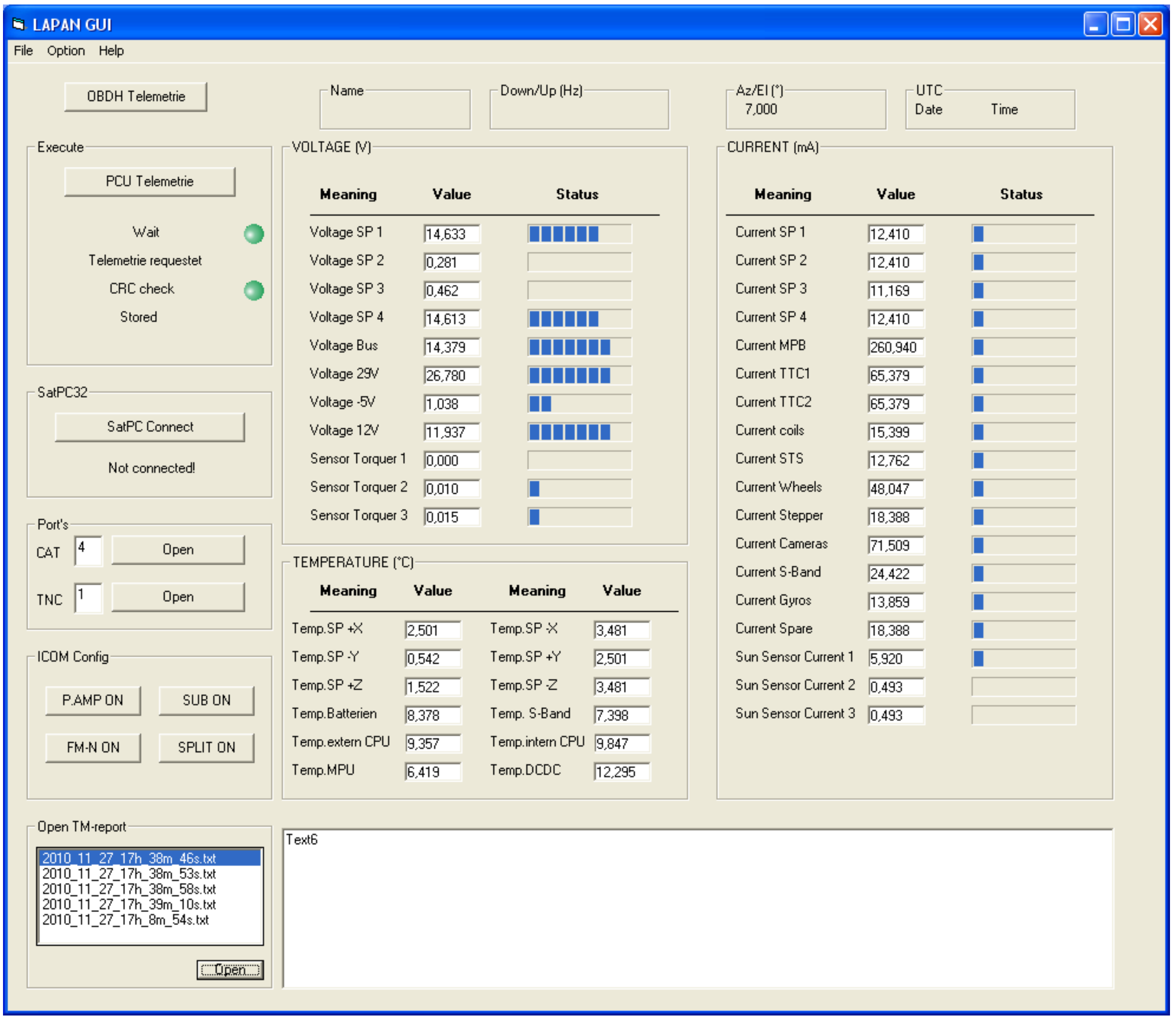


Figure 8.4

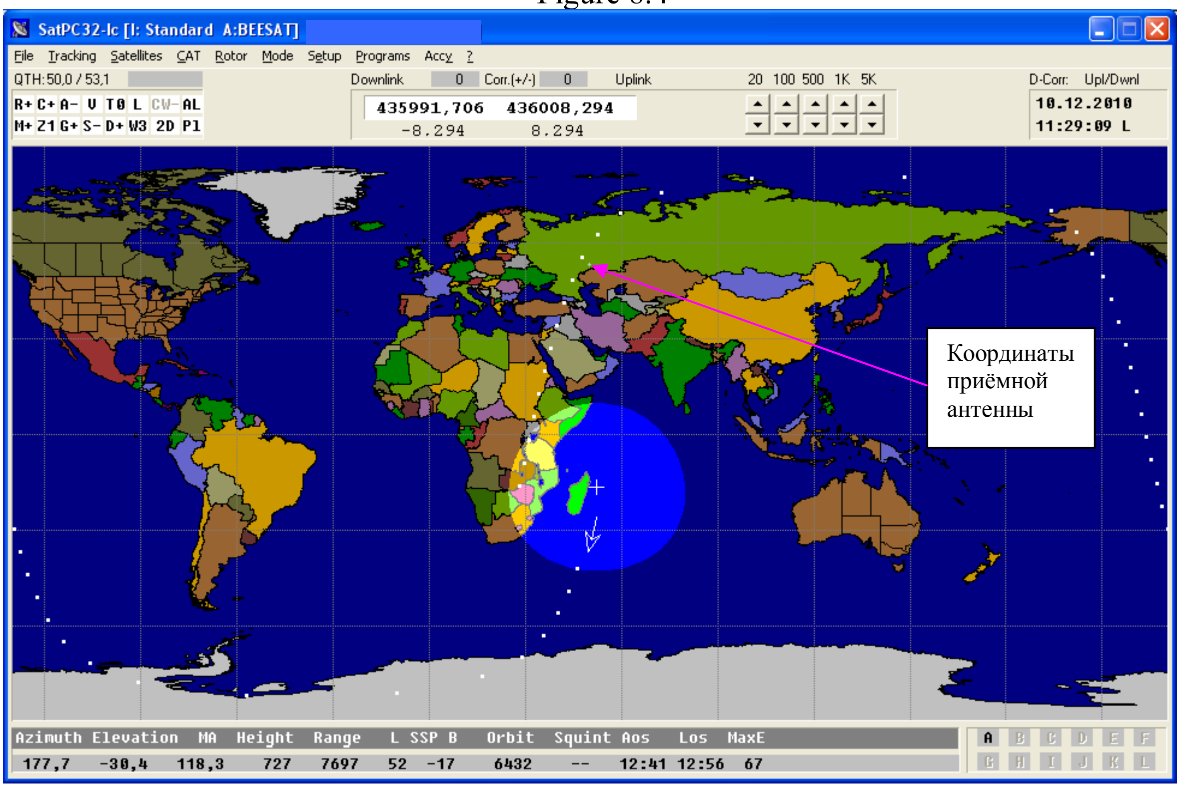


Figure 8.5

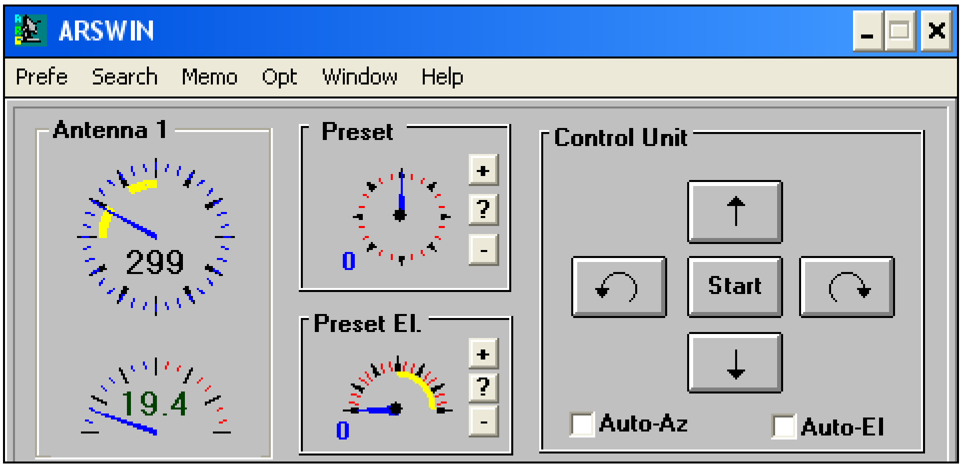


Figure 8.6

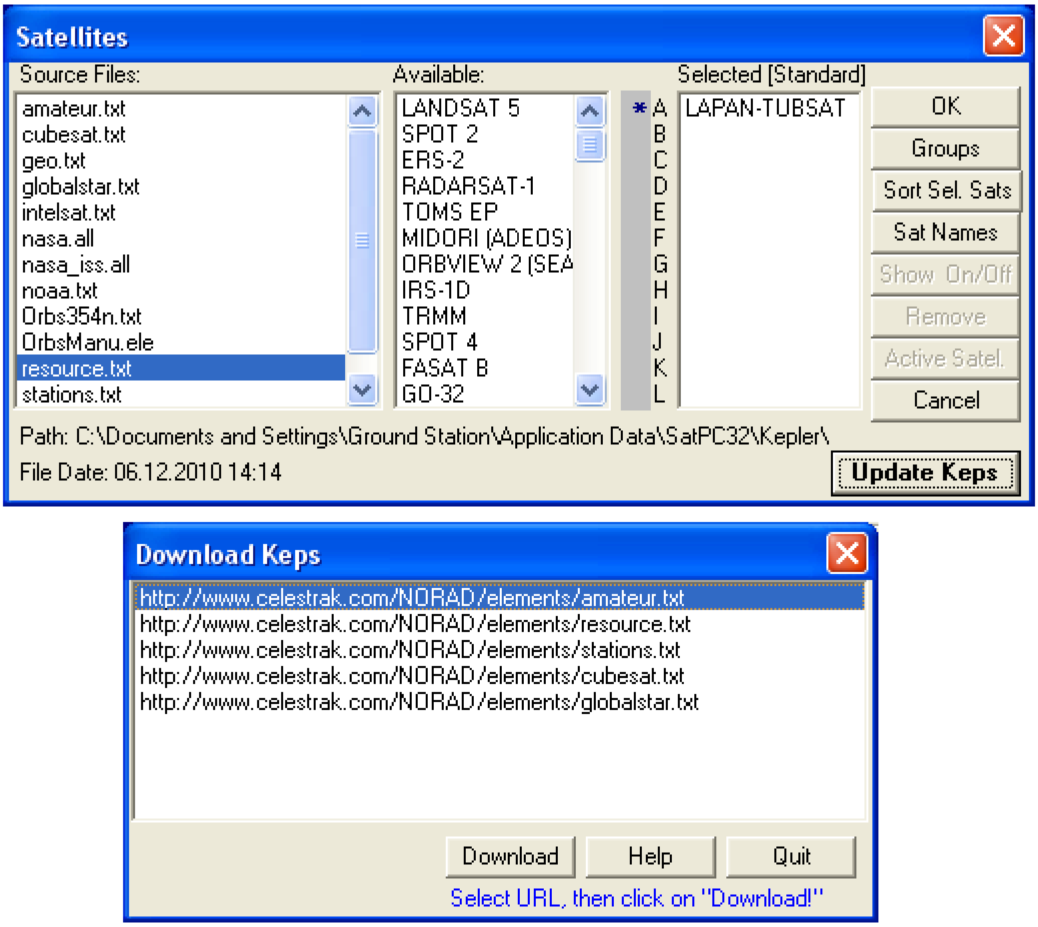
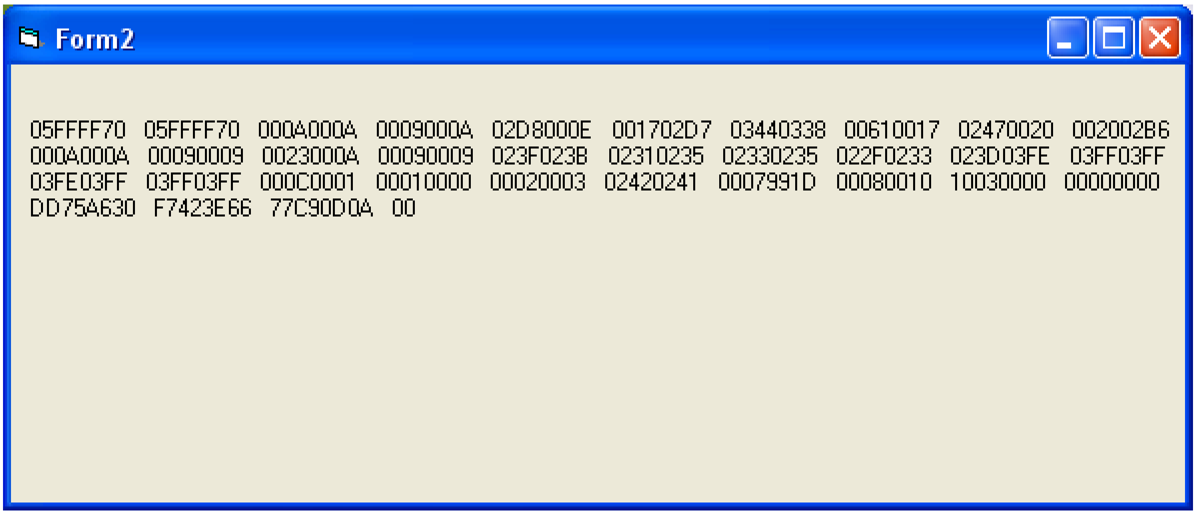


Figure 8.7


Form2
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03FE03FF 03FF03FF 000C0001 00010000 00020003 02420241 0007991D 00080010 10030000 00000000
DD75A630 F7423E66 77C90D0A 00

Figure 8.8

Laboratory Work №9
Calculation of Power Supply System of a Micro/Nanosatellites

Purpose - to obtain the skills to select elements of the system power supply micro / blower traveler.

Objectives - to calculate the capacity of batteries micro / nano-satellite.

Background:

The main modules of micro / nano-satellites are the navigation receiver, satellite modem GSP1620, three-axis magnetometer.

As the payload using remote sensing camera. Mode of the camera - the camera takes 20 minutes on each pass. In the shadow of the Earth does not remove the camera (in standby).

The remaining elements of the systems and the remaining modules, students choose their own.

Modes of micro / nano-satellite

A. Work with a payload
B. Expectations
C. Emergency

In all modes, always run by default:

- On-board computer;
- Telemetry;
- Navigation receiver.

Mode A mode with a payload.

Work: a system of orientation and stabilization system of telemetry control, satellite modem GSP1620, navigation receiver and a triaxial magnetometer.

Mode B. Standby

1 A magnetometer operates every 10 seconds;
2 satellite modem, only if the visibility zone of connected satellites;
3 The system of orientation and stabilization of the disabled.

Mode C. Emergency operation

1 A magnetometer is disabled;
2 satellite modem is disconnected;
3 The system of orientation and stabilization of the disabled.

Report on laboratory work should include:

1 The layout of micro / nanosatellite.
2 The effective area of solar panels.
3 The final composition of airborne systems.
Table 4 Energy components on-board systems
Scheme 5 junction solar cells.
6 Type of batteries and how they are charging.
When calculating the required battery capacity into account solar and shadow side of the orbit of micro / nanosatellite.

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