MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

ODESSA NATIONAL ACADEMY OF TELECOMMUNICATIONS
n.a. A.S. Popov

METHODICAL INSTRUCTIONS

for implementation of laboratory work

«Studying of the antenna pointing methods of satellite television broadcasting receiver»

on discipline

«Satellite communication, broadcasting and navigation systems»

for students of full-time forms of education
on infocommunications department

Odessa 2013

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Composers: M.B. Protsenko, I.Yu. Rozhnovskaya

Reviewers: assoc. prof. of ONAT Boyko N.F.
assoc. prof. Bukhan D.Yu.

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Goal of the methodical instructions is to help students during independent study of theoretical principles of discipline «Satellite communication, broadcasting and navigation systems» and in the performance of laboratory work «Studing of the antenna pointing methods of satellite television broadcasting receiver».

Methodical instructions are intended for students of full-time forms of education on infocommunications department.

The methodical instructions reviewed and approved at a meeting of the TED and SRC Department. (Protocol № 6 from January 22, 2013)

Approved methodical council of ONAT n.a. A.S. Popov. (Protocol № 3/14 from April 9, 2013)

CONTENTS

1 GENERAL REQUIREMENTS TO THE IMPLEMENTATION OF LABORATORY WORK

Contents of the lab work has to be pre-studied on the basis of methodical instructions with the involvement of theoretical material from the lecture course, relevant literature.

Laboratory work is done by groups consisting of 2-3 students, each of whom performs individual assignments.

Input data for the research assignments (see Appendix A) are chosen by each student in accordance with the next to last (m) and the last (n) digits of the student's credit book.

Report is prepared and defended by each student individually. Report on laboratory work should contain the following points.

1) Title page according to example.
2) Laboratory work goal.
3) Home task results.
4) Results of laboratory task.
5) Conclusions.

Conclusions of laboratory work should include both general part reflecting the main results and analysis, comparative analysis of theoretical and experimental studies, as well as an explanation of the results.

2 LABORATORY WORK

«Studying of the antenna pointing methods of satellite television broadcasting receiver»

2.1 Goal of the work

The goal of the laboratory work is to deepen the theoretical knowledge on the topic «Satellite television broadcasting», particularly the studying of general block diagram and construction features of receiver antennas of satellite television broadcasting and the antennas pointing methods.

2.2 Key points

General block diagram of satellite television broadcasting receiver

Satellite television broadcasting (STB) receivers are the complex of hardware intended for the reception of radio signals radiated by television broadcasting artificial Earth satellites (AES) in the assigned frequency bands, processing of these radio signals and transmission on the output of television receiver.

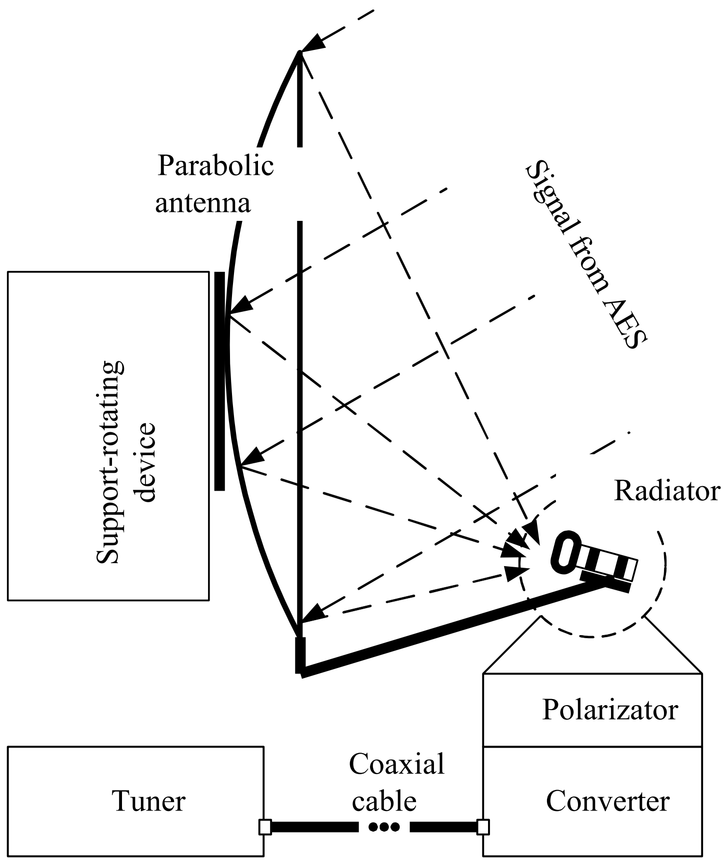

Figure 1 – General block diagram of STB receiver

STB receivers consist of three basic parts (see fig. 1):

– antenna (parabolic reflector antenna) arranged on a support-rotating device;

– SHF (super high frequency) module combined with the radiator of parabolic antenna and including the polarizator and SHF inverter block (converter);

– block of signal processing (tuner).

Antenna of STB receiver is intended for the reception of radio signals and arranged on the support-rotating device being by antenna system suspension and allowing to realize the antenna beam pointing to AES. SHF converter block in literature is named the converter (also use *Low Noise Blockconvertor – LNB*), and block of signal processing – the tuner.

Antenna realizes the directed reception of electromagnetic waves with the set polarization structure and selection of radio signal in the required frequency band. The primary amplification of incoming from antenna signal and spectrum transfer of this signal downward on frequency for the further signal processing in a tuner is realized in a converter. Taking into account the low levels of the received signals and high demands to the noise characteristics of STB receiver converter is disposed in immediate proximity from antenna (usually directly after the radiator of parabolic antenna). The intermediate-frequency amplifier in which a radio signal additionally amplifies for the transmission to the tuner input through a coaxial cable with length to 20…30 meters is also used composed of a converter.

Considered block diagram is traditional therefore antenna with a converter is often named by the external block (arranged, for example, on the roof of building), and tuner – by the internal block of STB receiver because it is arranged in immediate proximity from a television receiver.

Antennas of STB receiver

Antennas used in STB receivers are high-directed. Basic attention is attended the questions of technology, availability of a mass production, cost, stability to influence of environment at their design.

In accordance with the requirements of WACR-77 (World administrative conference of radio communication, 1977) antennas with the width of antenna pattern (AP) on the half-power level of $2\Delta\theta_{0,5} = 2$ deg. should use for the devices of individual reception and $2\Delta\theta_{0,5} = 1$ deg. – for the devices of collective reception in the STB receivers.

Basic types of antennas used today in the STB receivers are parabolic (single- and double-reflector) antennas. Single-reflector parabolic antennas: *axial-symmetric* (*prime focus*) and *offset* find widely use.

Axial-symmetric parabolic antennas (fig. 2) are the paraboloid of revolution with a radiator in its focus combined with the SHF module. Because the radiator is arranged on an axial line in a paraboloid center it and its fixation elements shade part of parabolic reflector surface that results in diminishing of coefficient of antenna surface use. However with growth of antenna diameter this effect becomes less considerable.

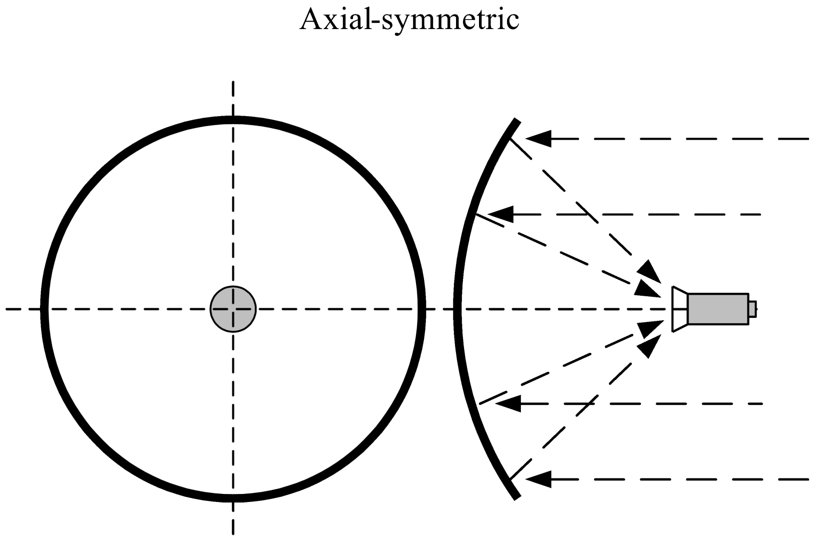

Figure 2 – Axial-symmetric parabolic antenna

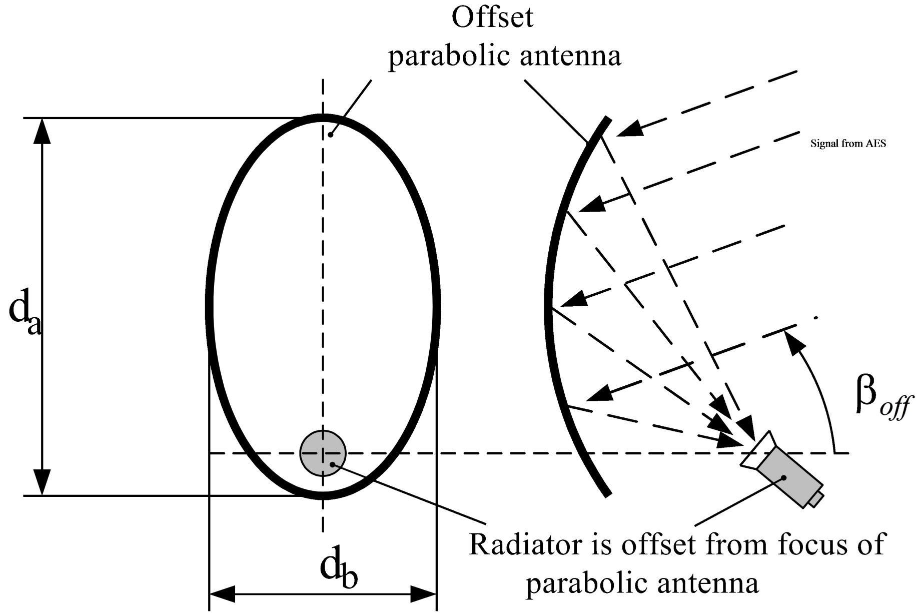

Figure 3 – Offset parabolic antenna

Offset parabolic antennas (fig. 3) are an asymmetrical slice of the paraboloid of revolution as a result their focus (place of radiator location combined with the SHF module) is displaced downward from the center of reflector. Exactly as a result of displaced focus in the case of offset antenna pointing to AES it is necessary to take into account that direction to satellite in offset antennas is higher than perpendicular to the plane of antenna on some angle (angle of offset).

The parabolic double-reflector antennas (Cassegrain, Gregorian, with the additional modified reflectors) are used in professional STB receivers. Lately more application is found a plane phase array with possibility of beam electronic scanning for pointing to one or another AES.

The basic geometrical and electrodynamics characteristics of antennas of STB receivers executed as parabolic reflector antennas are:

– d is an antenna diameter (for circular apertures), $d_à$ and d_b – large and small overall sizes of antenna (for elliptic apertures).

– S_{geom} is a geometrical area of antenna aperture:

$$S_{geom} = 0{,}25\pi d^2 \text{ — for circular apertures;}$$

$$S_{geom} = 0{,}25\pi\, d_à d_b \text{— for elliptic apertures.}$$

– β_{off} is an angle of offset – for offset parabolic antennas.

For evaluation calculations taking into account the ellipticity of aperture of offset antenna this angle can be defined on the formula

$$\beta_{off} = \arccos\left(d_b / d\right).$$

Note that the angle of offset isn't determined by this method for all of offset antennas. The value of an angle of offset is specified in an antenna passport.

– Coefficient of antenna surface use is a dimensionless value which is equal to ratio of the effective aperture of an antenna to the physical aperture. A value of this coefficient usually is within the limits of $\eta_{\grave{a}} = 0{,}55\ldots0{,}8$ and depends on the amplitude-phase distributing of the field in the antenna aperture (maximal value of coefficient of antenna surface use is $\eta_{\grave{a}} = 1$ when uniform and in-phase field distribution in antenna aperture is used).

– Effective aperture of an antenna

$$S_{ef} = S_{geom}\eta_{\grave{a}}.$$

– Directivity of an antenna (D) is a ratio of square of the field intensity created by antenna in specified direction to the mean value of square of the field intensity on all of directions. Directive gain is a dimensionless quantity.

Usually the value of D_0 is used in the direction of a maximum radiation of an antenna. Thus the directivity of an antenna becomes the measure of antenna ability to concentrate energy of electromagnetic radiation in a narrow beam. According to definition the directivity related to the form of antenna pattern (AP) (with the form of directional characteristic of an antenna).

– Gain of an antenna (G) is a ratio of power at the standard antenna input to the input power of the examined antenna on condition that both antennas create in one direction on identical distance the equal values of the field intensity or the same power flux density. Gain of an antenna is a dimensionless quantity.

Usually the value of G_0 is used in the direction of a maximum radiation of an antenna. Thus the gain of an antenna becomes the measure of antenna ability to concentrate energy of electromagnetic radiation in a narrow beam subject to the energy losses in antenna elements and objects located in near-field region .

The gain of the antenna is related to the directivity of the antenna and the efficiency factor of antenna η

$$G = D\eta .$$

When the efficiency factor is determined the losses on a reflection from mismatch between impedances at the antenna input and source of excitation are not taken into account.

Support-rotating devices

One of elements of STB receiver is a mechanism of antenna fixation (support-rotating device) which is intended for the suspension of antenna and pointing of its beam to satellite-retransmitter. Thus antenna can be set as stationary and receive radio signals only from one broadcasting AES which it is orientated on so on the special rotating device for possibility of re-pointing of antenna from one AES on other.

Support-rotating devices are classified on the construction of the reflector suspension. Taking into account the construction features of a pointing to geostationary broadcasting AES there are the azimuthally elevation suspensions and the polar suspensions.

Azimuthally elevation suspension is used for antennas with the fixed direction to satellite (fig. 4) or for antennas with large sizes.

Figure 4 – Azimuthally elevation suspension

This suspension has vertical primary (stationary) and horizontal secondary axes. The vertical axis is called azimuthal and horizontal – elevation. Antenna turns about the primary axis.

For pointing of the antenna to the satellite it is necessary to set two coordinates: the azimuth α and the elevation angle β .

Parameters of the antenna pointing. Broadcasting AES arranged as a rule on the geostationary orbit which from any point of earth surface can be visible only partly (see fig. 5 and 6).

For the calculation of antenna pointing parameters notably angle of elevation β and azimuth α it is necessary to have the next data:

– nominal satellite location on the orbit;

– AES deviation from nominal location during a day;

– exact coordinates of the antenna location;

– information about affixment of antenna beam axis to angular coordinates on the azimuth and the elevation angle.

The affixment of antenna beam axis can be realized either on the Pole Star or on the compass subject to magnetic declination in place of antenna location.

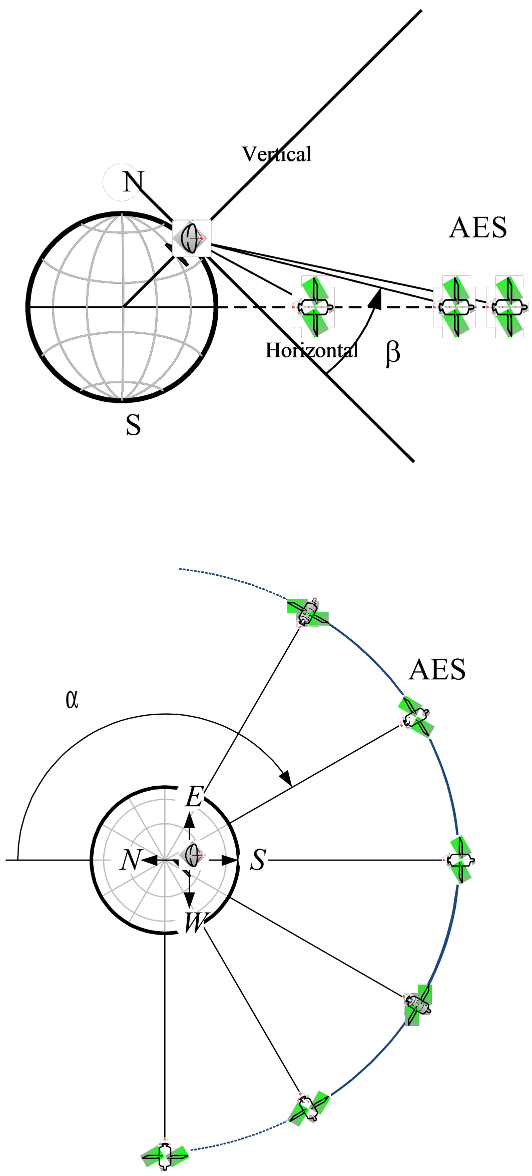

Figure 5 – AES location on the geostationary orbit

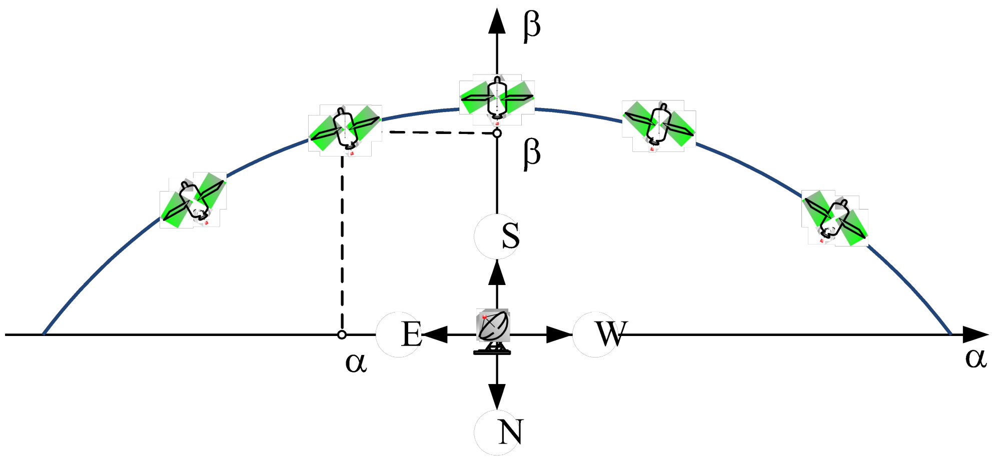

Figure 6 – Visibility part of the geostationary orbit arc

Calculation of the elevation angle for antenna beam axis pointing to AES can be realized on the formula

$$\beta = \operatorname{arctg}\left[\frac{\cos(\lambda_R - \lambda_P)\cos(\varphi_R) - \dfrac{R_E}{R_E + H}}{\sqrt{1 - \cos^2(\lambda_R - \lambda_P)\cos^2(\varphi_R)}}\right], \qquad (1)$$

where λ_P is the longitude of the subsatellite point of AES;

λ_R, φ_R are the longitude and latitude of the antenna location;

R_E is the Earth radius ($R_E = 6\ 378{,}16$ km);

H is the geostationary orbit height ($H = 35\ 786$ km).

When $\beta < \beta_{min}$, where β_{min} is the minimum elevation angle, AES goes out of the visibility zone of STB receiver located in the point with coordinate λ_R, φ_R.

The formula for calculation of antenna beam axis azimuth is of the form:

$$\alpha = \pi - \operatorname{arctg}\left[\frac{\operatorname{tg}(\lambda_R - \lambda_P)}{\sin(\varphi_R)}\right]. \qquad (2)$$

Positive direction of the azimuth is defined when the antenna moves from direction on the Noth pole clockwise.

Polar suspension has the special popularity in STB because it has important advantage: if it is turned in one plane then it is possible to look over visible part of the geostationary orbit (see fig. 6). Such type of suspension got the name from the Pole star because the axis of rotation of this construction at tuning must be parallel the axis of the Earth rotation and directed on the Pole star. Often it is the motorized suspension. Motors and devices which able to set antenna to motion divided by two kinds: motor suspension and actuator.

Motor suspension is the device in which an electric engine and polar suspension is integrated in one unit (see fig. 7*a*). In most cases motor suspensions high-quality work with satellite antennas the diameter of which is not exceeded by a 1,2 meter.

Actuator is an electric engine (see fig. 7*b*). Due to rotation through a forcing screw tightener a motor accomplishes linear motions up and down driving antenna to motion and forcing into rotation. Besides the actuator it is set the positioner which executes the role of controlling of actuator and its feeding. Mainly antennas with actuator have the diameter of 1,2 meter and more.

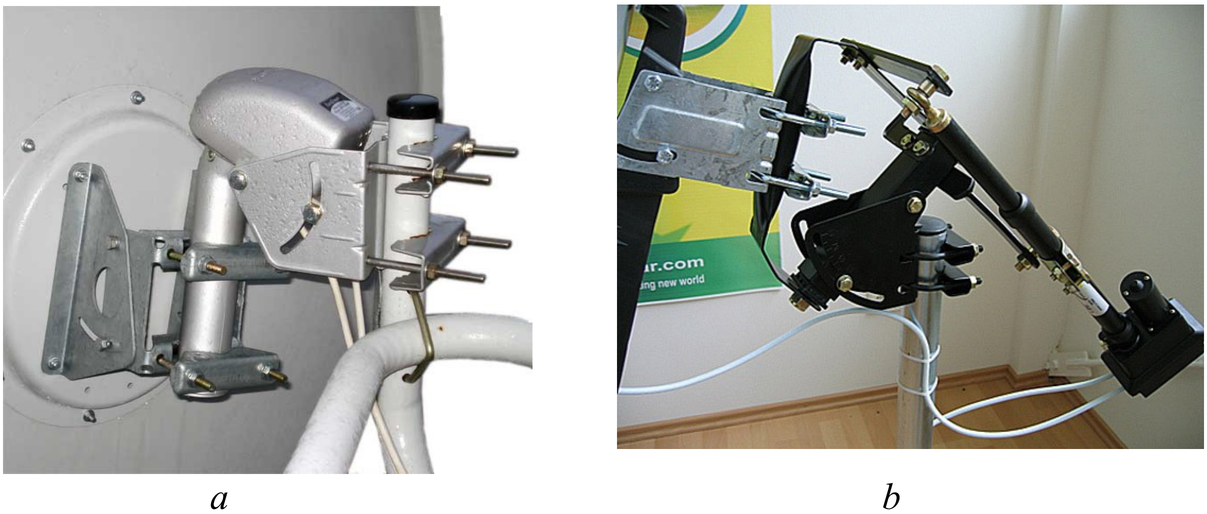

Figure 7 – Polar suspension with motor suspension *a* and actuator *b*

As the basic pointing angles of polar suspension are used: an elevation, a declination, a correcting angle and a rotation angle (see fig. 8).

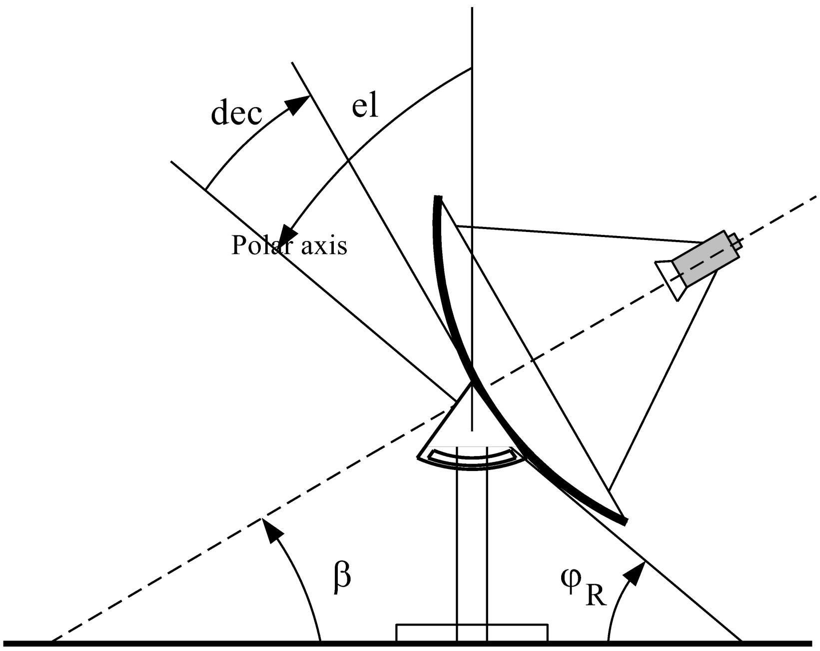

Figure 8 – Pointing angles of the polar suspension

Elevation el is the angle between vertical and polar axes in the place of STB receiver antenna location. Polar axis is a line parallel of axis of Earth rotation. The angle of polar axis is equal to the latitude of place of STB receiver antenna location.

Thus, elevation is equal

$$el = \pi/2 - \varphi_R, \quad (3)$$

where φ_R is the latitude of place of STB receiver antenna location.

Declination dec is the angle between the polar axis and plane of STB receiver antenna aperture (for axial-symmetric antennas). Taking into account that for axial-symmetric antennas the plane of aperture is perpendicular to the direction on AES declination can be calculated on a formula

$$dec = \operatorname{arctg}\left(\frac{\cos(el)}{\frac{R_E + H}{R_E} - \sin(el)}\right), \qquad (4)$$

where R_E is the Earth radius (km);

H is the geostationary orbit height ($H = 35\ 786$ km).

For offset antennas taking into account that direction to AES is displaced from normal line to the antenna aperture on *the angle of offset* declination will be equal

$$dec_{off} = dec - \beta_{off},$$

where β_{off} is the angle of offset.

On the calculation angles of elevation and declination antenna by its beam will be describe in sky an arc different from the arc of the geostationary orbit because the Earth does not have a spherical form ideally. For this account *the correcting angle* which does not exceed one degree is used. The elevation is decreased and the declination angle is increased on the value of correcting angle.

Rotation angle of the polar suspension $\alpha_Đ$ is the angle on which must be turned antenna about the polar axis with respect to the South for antenna pointing to set AES. For definition of the rotation angle of the polar suspension $\alpha_Đ$ can be used the formula

$$\alpha_Đ = \operatorname{arctg}\left(\frac{\sin(\lambda_P - \lambda_R)}{\cos(\lambda_P - \lambda_R) - \frac{R_E}{R_E + H} \cdot \sin(el)}\right), \qquad (5)$$

where λ_P is the geographical coordinate of subsatellite point (longitude) of AES;

λ_R is the geographical coordinate of place of antenna location (longitude);

R_E is the Earth radius ($R_E = 6\ 378{,}16$ km);

H is the geostationary orbit height ($H = 35\ 786$ km).

The negative value of angle $\alpha_Đ$ is meant the turn of the polar suspension clockwise, positive value – anticlockwise.

2.3 Key Questions

Questions for admittance to the implementation of laboratory work:

1 Draw the general block diagram of STB receiver. Explain its basic parts. What is part of general block diagram structure the external block and the internal block named?

2 Explain the purpose and features of STB receiver antenna operation.

3 What are types of antennas in STB systems used? Explain their construction features.

4 Enumerate the basic geometric and electrodynamics characteristics of STB receiver antenna. Explain the parameter «aperture» and write the formula for calculation of geometric areas of circular and elliptic apertures.

5 Enumerate the basic geometric and electrodynamics characteristics of STB receiver antenna. Explain the parameter «angle of offset» and write the formula for valuation calculation of angle of offset of the elliptic aperture.

6 Enumerate the basic geometric and electrodynamics characteristics of STB receiver antenna. Explain the parameters «effective aperture of an antenna», «coefficient of antenna surface use».

7 Enumerate the basic geometric and electrodynamics characteristics of STB receiver antenna. Explain the parameter «directivity of antenna». How is the directivity with the form of antenna pattern connected?

8 Enumerate the basic geometric and electrodynamics characteristics of STB receiver antenna. Explain the parameter «gain of an antenna». How is the gain of an antenna with the directivity of an antenna connected?

Questions to defend a laboratory work:

1 Explain the purpose and features of STB receiver converter operation.

2 What is antenna offset named? Enumerate its advantages and disadvantages. How can offset antenna be pointed on the elevation angles?

3 What is support-rotating device (suspension) azimuthally elevation named? Enumerate the basic parameters (pointing angles) of azimuthally elevation suspension and its advantages and disadvantages.

4 What is the geostationary orbit? Enumerate its basic advantages and disadvantages. What is definition «visibility part of the geostationary orbit arc» meant?

5 What is support-rotating device (suspension) polar named? Enumerate the basic parameters (pointing angles) of the polar suspension and its advantages and disadvantages.

6 Explain the parameters «elevation», «declination». How can be declination in offset antennas defined?

7 How can be exact antenna pointing on polar suspension carried out?

Questions of extra complexity*:

1 Derive the formula (1).
2 Derive the formula (2).
3 Derive the formula (4).
4 Derive the formula (5).

* A reasonable answer to any question of increased complexity is counted as the implementation and defend of a laboratory work with a maximum mark.

2.4 Home task

1 Study theoretical information (key points) using the methodical instructions, summary of lectures and recommended literature.
2 Prepare answers to key questions (questions for admittance to the implementation of laboratory work).
3 Prepare the report on laboratory work which includes the title page formatted according to example, the goal of the work, home task solution.
4 Explore the algorithm and the features of the program.
5 Solve a problem (the result of solving the problem relates to the input data to perform laboratory work).

Problem.

Define the basic parameters (pointing angles) for the azimuthally elevation and the polarsuspension for say location of STB receiver antenna. Input data for calculation is given in Table A.1 (Appendix A).

2.5 Laboratory Task

1 Start the personal computer and run of "SATTV" software environment.
2 Compare the result of home task solution with the "SATTV" program results, the one’s own variant input data must be entry in a program.
3 Changing the coordinates of receiving place when other components are not changing look in the testing screen how will be change the quality of receiving television signal from given satellite. Analyze the results and make the conclusions.

3 RECOMMENDED LITERATURE

1. Системы радиосвязи: учебник для вузов / Н. И. Калашников, Э. И. Крупицкий, И. Л. Дороднов, В. И. Носков; под ред. Н. И. Калашникова. – М.: Радио и связь, 1988. – 352 с.

2. Немировский А. С. Радиорелейные и спутниковые системы передачи: [учебник для вузов] / А. С. Немировский, О. С. Данилович, Ю. И. Маримонт и др.; под ред. А. С. Немировского. – М.: Радио и связь, 1986. – 392 с.

3. Каменский Н.Н. Справочник по радиорелейной связи / [Каменский Н.Н., Модель А.М., Надененко Б.С. и др.]; под ред. С.В. Бородича. – [2-е изд., перераб. и доп.] – М.: Радио и связь, 1981 – 416 с.

4. Нарытник Т. Н. Радиорелейные и тропосферные системы передачи: [учебн. пос.] – К.: Концерн «Видавничий Дім» Уж Юре, 2003. – 336 с.

5. Лукьянчук А. Г. Спутниковые системы связи, вещания и навигации: учебн. пос. / А. Г. Лукьянчук, Ю. П. Михайлюк, А. А. Савочкин; под ред. А. Г. Лукьянчука. – Севастополь: Изд-во СевНТУ, 2002. – 335 с.

6. Цифровые и аналоговые системы передачи: [учебник для вузов] / [В.И. Иванов, В.Н. Гордиенко, Г.Н. Попов и др.]; под ред. В.И. Иванова. – [2-е изд.] – М.: Горячая линия – Телеком, 2005. – 232 с.

Appendix A
Input data for implementation of researches

Table A.1 — Input data

n	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
City *	Kiev	Donetsk	Zaporozhye	Lviv	Sevastopol	Kharkiv	Cherson	Chmelnitskiy	Chernigov	Yalta
Latitude, N	50°26′	48°0′	48°13′	49°50′	44°37′	49°59′	46°40′	49°24′	51°28′	44°28′
Longitude, E	30°31′	37°46	35°24	24°0′	33°33′	36°13′	32°37′	26°59′	31°15′	34°12′
m	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Name and coordinates of AES	36° E Gals,	13° E Hot Bird 1,	5,2° E Sirsus 1,	0,8° W Thor 1,	3° W Telecom 2C,	4° W Amos,	Tele X, 5° E	Kopernikus 2, 28,5°E	7° E Eutelsat II-F4,	19,2° E Astra,

n is the last digit of the credit-book number;
m is the next to last digit of the credit-book number;
* – information from http://travel.org.ua/sunrise

Appendix B

Ministry of Education and Science of Ukraine
Odessa National Academy of Telecommunications n.a. A.S. Popov

Department of Technical Electrodynamics
and Systems of Radio Communications

REPORT

on laboratory work

“Studying of the antenna pointing methods of satellite television broadcasting receiver”

Done by: student of IC 3.401
Petrov Pyotr Petrovich
Credit book number: 000000

Checked by: prof. TED & SRC Dep.
Protsenko M.B.

Odessa 2013

Appendix C
Description of the algorithm and features of the program

In this laboratory work the research of the methods of satellite TV-broadcasting (STB) receiver antenna pointing with the help of the program model on PC. The laboratory facility is the specialized program "SATTV", a program interface is shown on a figure 1.9, allowing to estimate quality of reception of TV-program from certain satellite depending on the different parameters: signal power in the receiving point, diameter of receiving antenna, noise factor of converter, width of frequency band of video path, angles of antenna pointing to satellite.

Results of calculation of satellite antenna pointing angles for the azimuthally elevation suspension are shown in the right lower corner of basic window of the program "SATTV" (see fig. 1.9). The angles of polar suspension require you to pass to the proper menu in the basic window of the program, as a result to appear other dialog window with the parameters of polar suspension (see fig. 1.10).

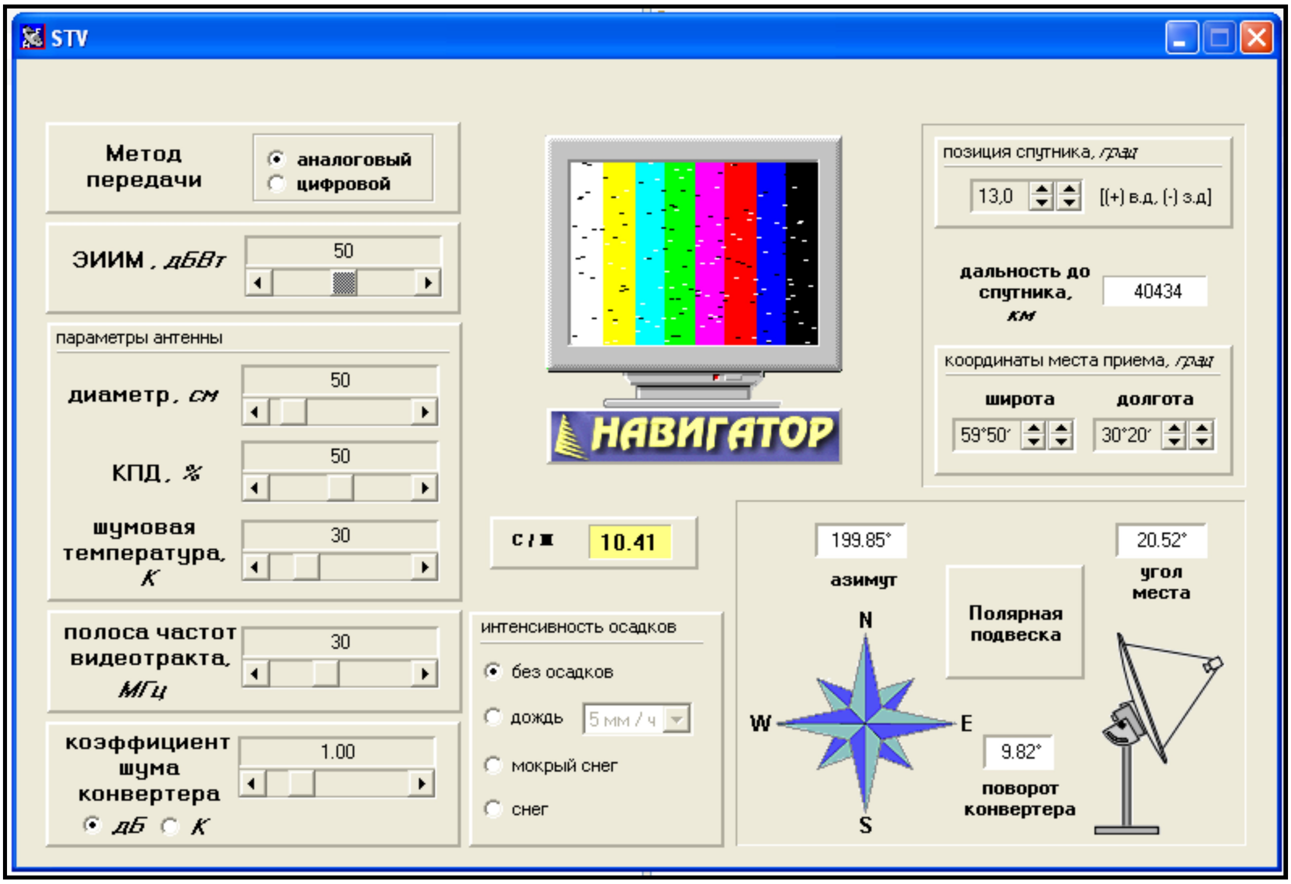

Figure C.1 – Interface of "SATTV" program

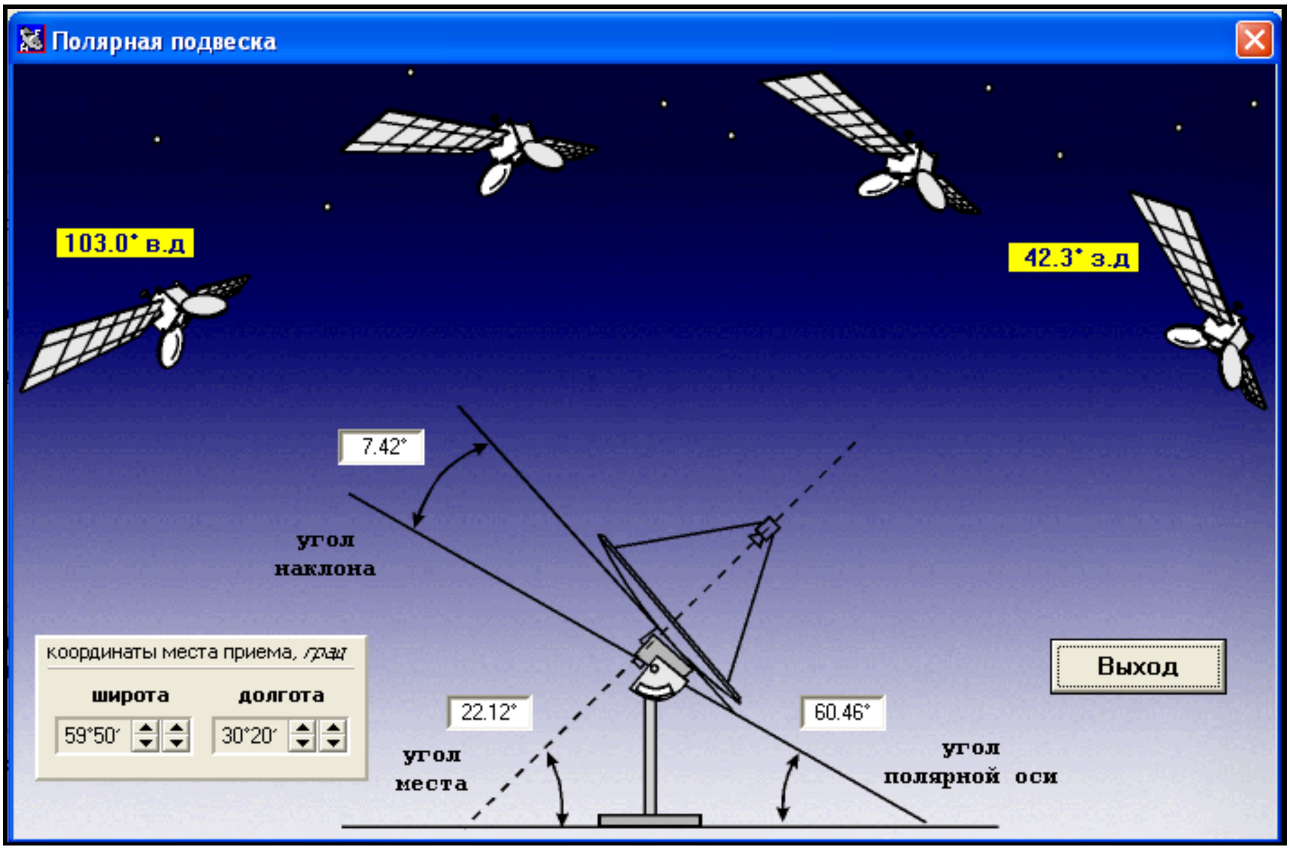

Figure C.2 – Dialog window with the parameters of polar suspension