OPERATIONAL TESTING OF THE RUSSIAN AVK UPPER-AIR RADARS USING TRACKING OF THE SUN RADIATION

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ABSTRACT

It is described an easy-to-use and efficient procedure of the operational testing of alignment and orientation and verifying overall angular tracking performance of the Russian AVK upper-air radars. The procedure is based on the well-known field-proven method of automatic tracking of the microwave radiation of the Sun. To facilitate the use of the method by operational stuff of an upper-air station it is developed a user-friendly software utilizing original evident representation of angular readings of a radar aerial and calculated trajectory of the Sun in elevation-azimuth coordinates. This allows a simple pointing of the aerial to the Sun and a visual control of locking and automatic tracking of its radiation and, in the same time, doesn't require too accurate time-synchronization of PC. 2-3 hours around noon tracking is enough to make with sufficient confidence a conclusion on satisfactory state of the aerial alignment and orientation and to verify visually the radar sensitivity and the angular tracking performance. The recorded data are supposed to be sent to regional service centers where they could be subject to a more sophisticated analysis.

The software is in operational use on several Russian upper-air stations, some test results are demonstrated.

Russian upper-air system AVK /1/ as any radar equipment /2/ is quite sensitive to proper aligning and positioning. For the rawindsonde observations, utilizing radar tracking of a rawindsonde, the proper alignment and positioning of the radar antenna has the comparable significance for ensuring the overall performance as an accuracy of radiosonde sensors. While accuracy of each radiosonde sensors is assured by a manufacturer, an accuracy of the AVK antenna alignment and orientation is secured episodically by laborious procedures and is subject to variation in time due to seasonal factors, structure aging etc., whereas utilized techniques are not very reliable.

Standard maintenance procedures prescribe periodic verification of angular accuracy of antenna. This is done by visual setting of the antenna with built-in optical viewing device towards well-defined local targets and testing their measured azimuth and elevation against known coordinates, accurately determined once by precise geodetic means during the system installation. For more comprehensive test a comparison with an optic theodolite should be organized at least once a year. Due to significant wind load and over harsh environment factors on many stations AVK antennas are covered by radio-transparent radome. In this case, the comparison with theodolite is the only available way for the check. These traditional methods have many shortcomings and the main is they require rather sophisticated technical staff with sufficient skill.

Therefore finding express and simple while accurate technique of checking the AVK angular tracking is quite actual for the present conditions of the Russian upper-air network operation. As early as in the 70-s in the Central Aerological Observatory it was investigated and proved in field conditions (first for the older Meteorite radars and later for the AVK) an idea of using automatic tracking of the own microwave Sun radiation. When the location coordinates and time are known the coordinates of the Sun movement across the sky could be calculated with very good precision and normal performance of antenna system should be sufficient for the automatic locking followed by the tracking of the Sun. However, the widespread usage of this method by operational staff of the Russian upper-air network was prevented by the necessity of complicated calculations, operators had to have sufficient skill to check proper locking of the Sun during tracking, printed results had to be processed using manual input and time synchronization requirements were quite rigorous.

Recent progress in upgrading the AVK with PC-based data-processing systems (see e.g. /3/) has removed the problems with the calculations and data registration. The advance towards the wide operational use of the method was made by the program "Sun tracking" included in the software package of ARM Aerolog workstation /3/.

The program visualizes the Sun movement across the sky using azimuth-elevation diagram, also known as the sunpath chart in heliostat and architecture design (see e.g. /4/). A pretty web-page of Solar Radiation Monitoring Laboratory from University of Oregon, making a good introduction to this sort of diagrams, is located at http://solardat.uoregon.edu/AboutSunCharts.html. The site contains also a page http://solardat.uoregon.edu/SunChartProgram.html, where one can get online an example of such diagrams for an arbitrary location (see Figure 1).

The whole verification is made in four stages. The first one consists in pointing the antenna towards the Sun position on the sky and locking it by the AVK automatic tracking system. During this stage the program in real time calculates (it uses astronomic calculus according to /5/) and plots one by one the actual Sun coordinates, thus forming the Sun trajectory, and outputs to the same diagram the current elevation (El) and azimuth (Az) of the antenna by a hair-cross.

A calculation error depends practically only on the accuracy of the station latitude and culminates at the solar noon where elevation error equals latitude one. Due to elimination of time in such kind of diagrams having the precise PC time (one minute accuracy necessary for routine operations is sufficient) and knowing the exact longitude are not very critical. They only affect the right pointing of the antenna towards the Sun. When the antenna angular errors are not too big, the hair-cross is located on the calculated Sun trajectory, leading or lagging the current Sun position. Therefore an operator directs the antenna to the expected Sun position with some advance (see Figure 2[1]). A successful pointing is indicated by the indicators of the AVK equisignal zone and signal level. Afterwards, the operator switches on the AVK automatic tracking and checks the successful locking. The capability of the antenna to track the Sun radiation is itself an evidence of the receiving system's sufficient sensitivity.

After successful locking and stabilizing of automatic tracking begins the next step of the recording of the observed antenna coordinates. Until this moment points with antenna direction are not remained on the diagram, eliminating big variation of the antenna position during the initiation of the automatic tracking. Since the start of the recording all the measured coordinates remain on the diagram forming the observed Sun trajectory, see Figure 3. It is recommended to perform the recording about 2-3 hours around the local noon. During this step the operator switches on the automatic adjustment of the diagram scaling and manages the locking of the Sun position by the AVK tracking systems, making pauses in recording and repeating the locking of the Sun if necessary as described above (as the Sun signal is much weaker than a radiosonde, local sources of radio-noise may sometimes interfere the tracking). One person from an upper-air operational staff, having a practical experience of tracking a radiosonde with the AVK, is enough to perform the observations. No additional equipment is required.

An in-place examination of differences between observed and calculated Sun coordinates is the next step. It could start immediately after completion of the recording or at any time later as all data are stored to a computer file (examples of such records are demonstrated on Figure 4 - Figure 6). The rough estimate could be done immediately. Interpretation of diagrams is rather simple - the horizontal offset between curves corresponds to the azimuth error while vertical offset corresponds to an error in the elevation. And the random scatter of observed points along the average path is a measure of precision. So, the positive result of test is visible instantly and obvious as on the Figure 4.

Nominal limits of the AVK elevation and azimuth systematic errors are 2 AVK units (i.e. 0.12°), therefore a shift between observed and theoretical curves should not exceed this value

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[1] One should note AVK traditionally uses its own angular units, 1 AVK angular unit is equal to 0.06°, i.e. 1500 units are equal to 90° and 3000 units are equal to 180°.

either in the azimuth or in the elevation. The scatter of observed points aside the mean path indicates random tracking errors, which are characterized by nominal limit in 3 AVK units. Therefore, the overall "thickness" of the observed sunpath should not exceed about 12 AVK units (i.e. 0.72°). Thus, a competence of station personnel is enough to make the express conclusion about sufficient performance of AVK angular tracking.

Recorded data are supposed to be sent for control and archiving to regional service centers. If a presence of errors is suspected they are subject to more sophisticated analysis. Background for further analysis is given in the Annex. The main task of the analysis is to determine the necessity to arrange remedial maintenance. This is the final phase of the verification.

The software is already in operational use on several Russian upper-air stations, equipped with the AVK and ARM Aerolog. At the moment more than 70% of Russian upper-air stations are equipped with PC-based data-processing systems and therefore there is a good potential to verify their pointing performance using either the described technique directly (where it is applicable) or the suggested approach.

References:

1. A. Ivanov at al, 1991. Radiosondes WMO International Radiosonde Comparison - Phase III, Dzhambul (USSR), 1989. WMO, Instruments and Obs. Methods Report No. 40.

2. WMO Guide to Meteorological Instruments and Methods of Observation, 1996: WMO-No. 8.

3. A. Balagurov, V. Grinchenko, A. Kats, 2000. New Instruments for Russian Upper-air Network. Papers Presented at the WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2000). Beijing, China, 23-27 October 2000. WMO, Instruments and Obs. Methods Report No. 74.
4. Edward Mazria, 1979. The Passive Solar Energy Book: A Complete Guide to Passive Solar Home, Greenhouse and Building Design. Rodale Press.
5. Jean Meeus, 1988. Astronomical Formulae for Calculators (Russian edition). Moscow, "Mir".

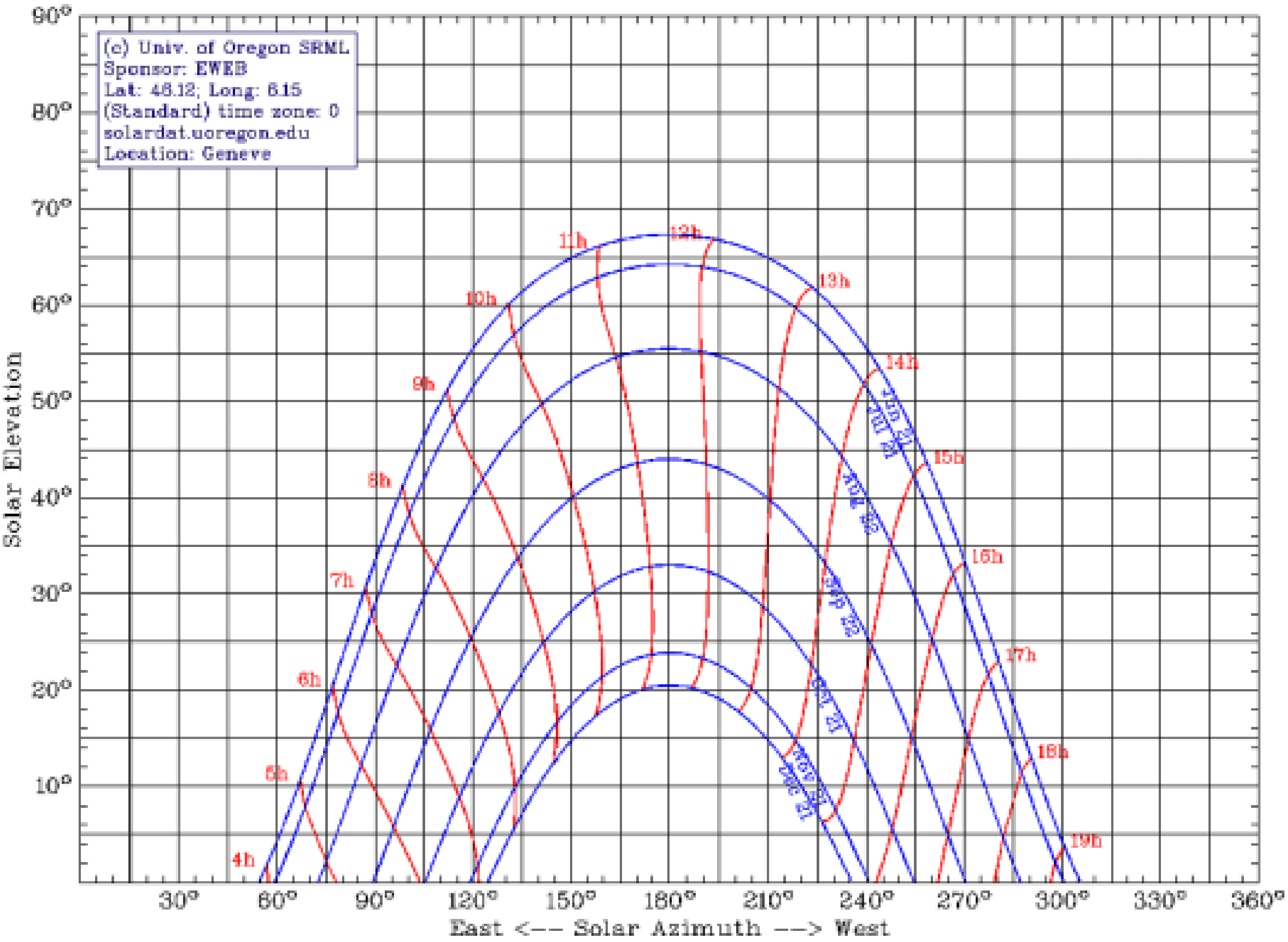

Figure 1. An example of the Sun azimuth-elevation diagrams (generated on the Web at http://solardat.uoregon.edu/SunChartProgram.html, Radiation Monitoring Laboratory, University of Oregon).

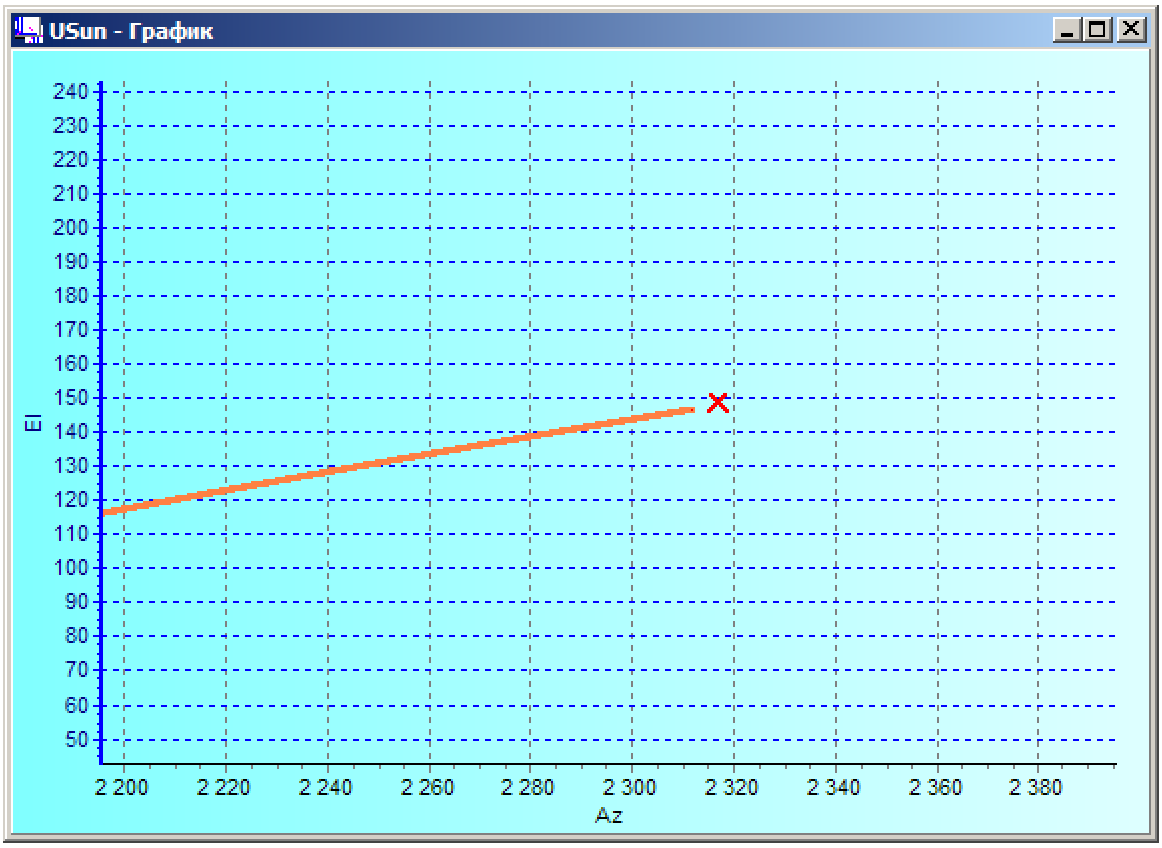

Figure 2. Pointing the antenna towards the Sun (orange points, forming the Sun trajectory, are updated in the real-time, red cross – current position of the antenna).

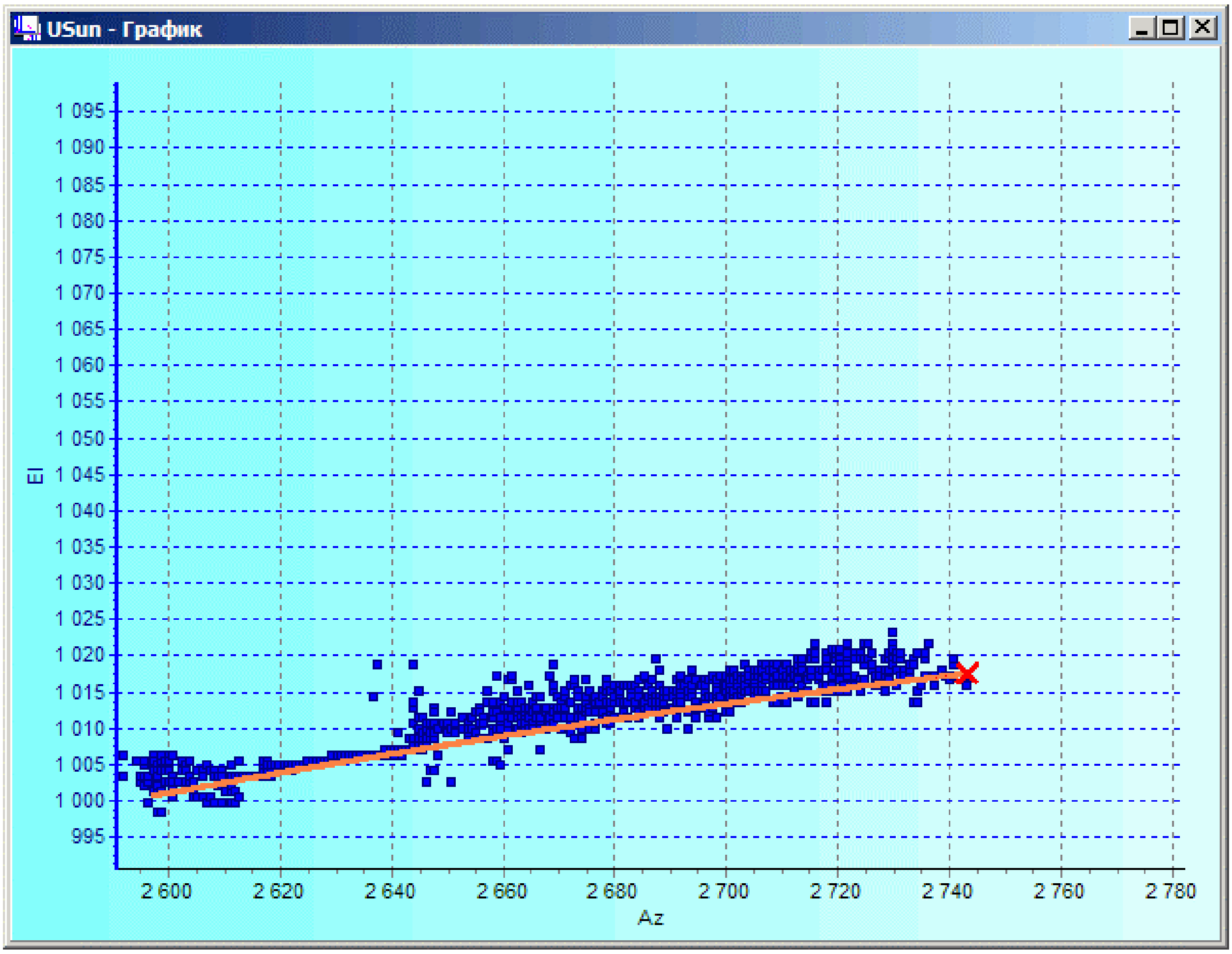

Figure 3. Automatic tracking of the Sun (the blue points are the successive coordinates of the antenna tracking the Sun trajectory).

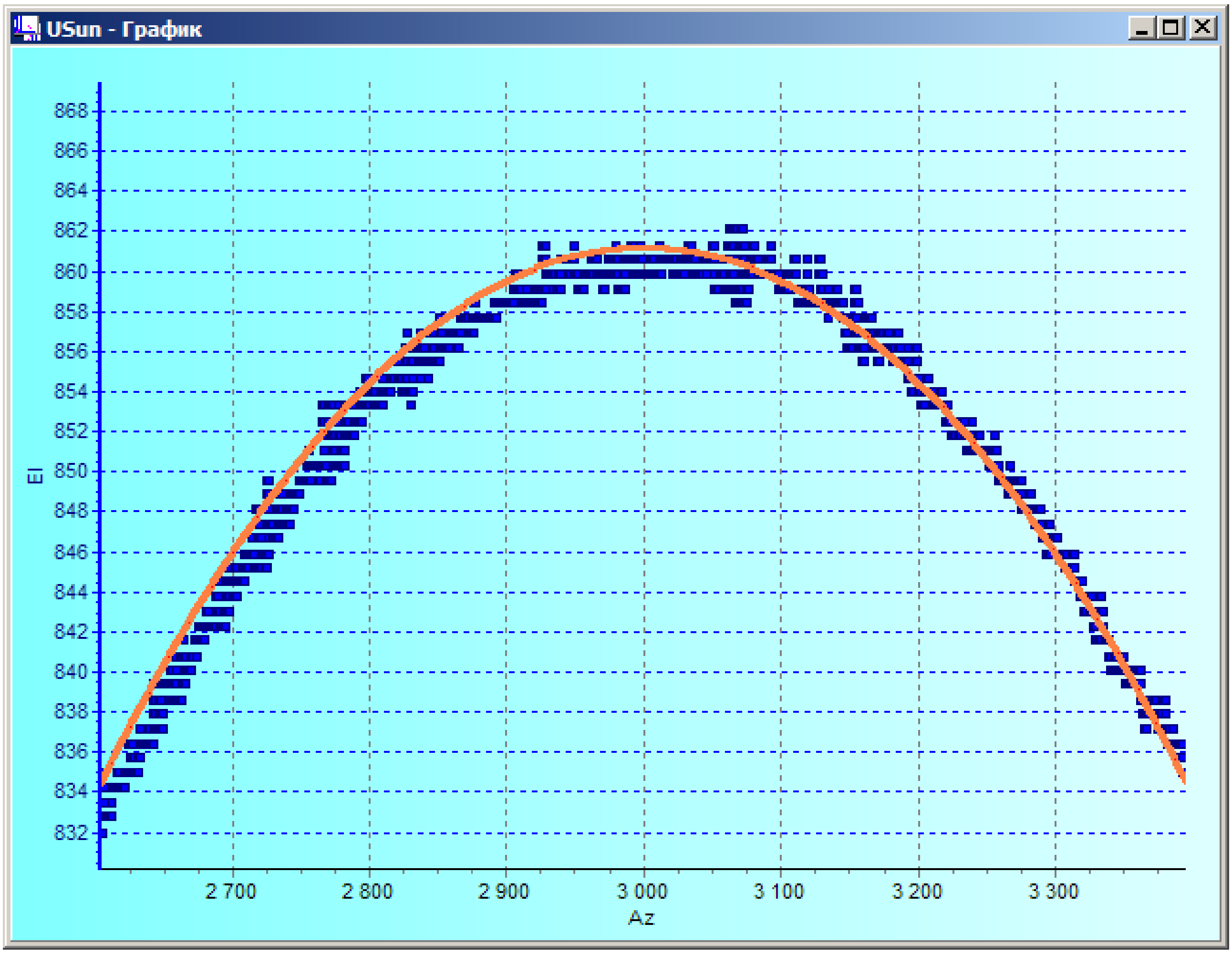

Figure 4. An example of a very good performance.

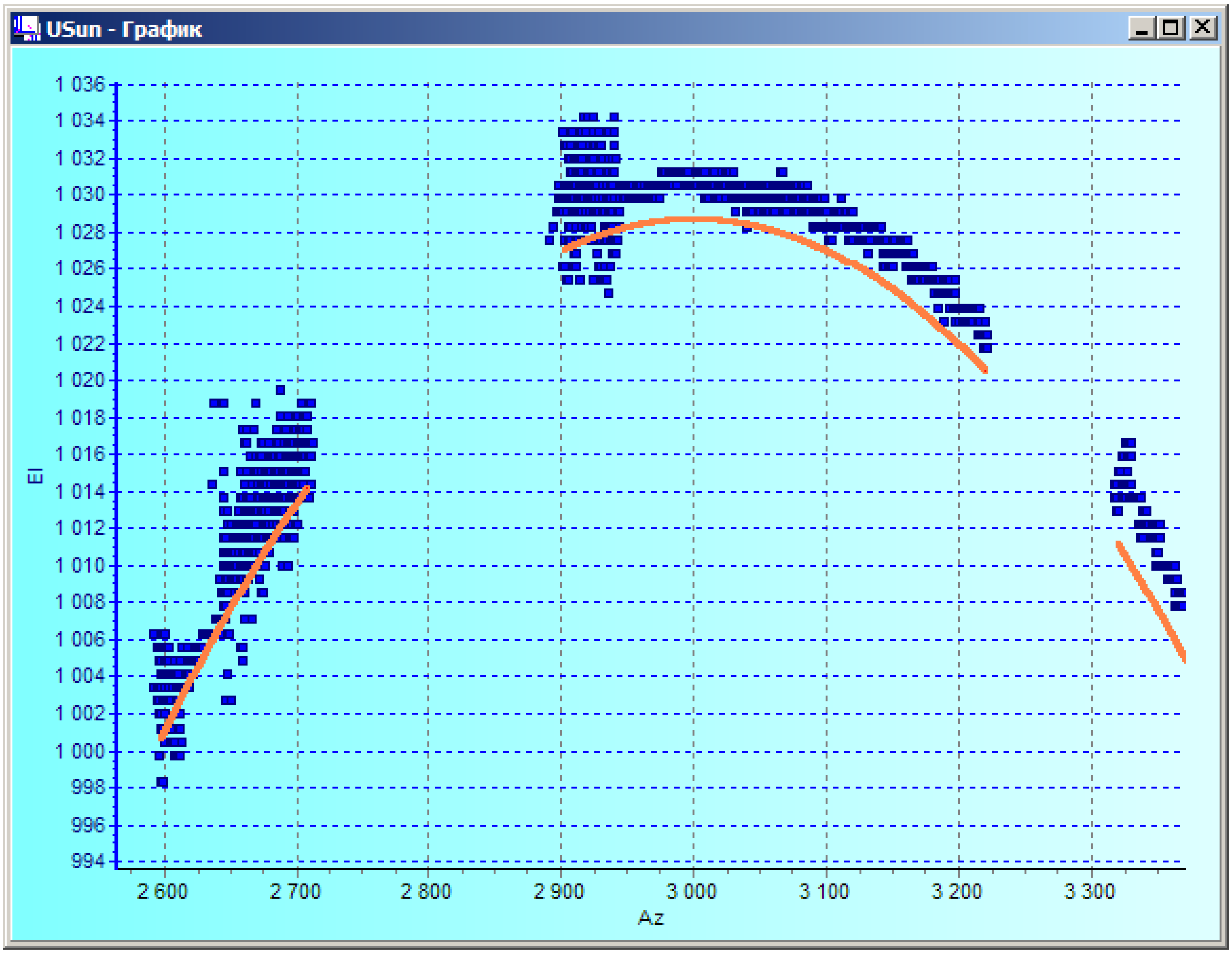

Figure 5. An example with minor systematic elevation error.

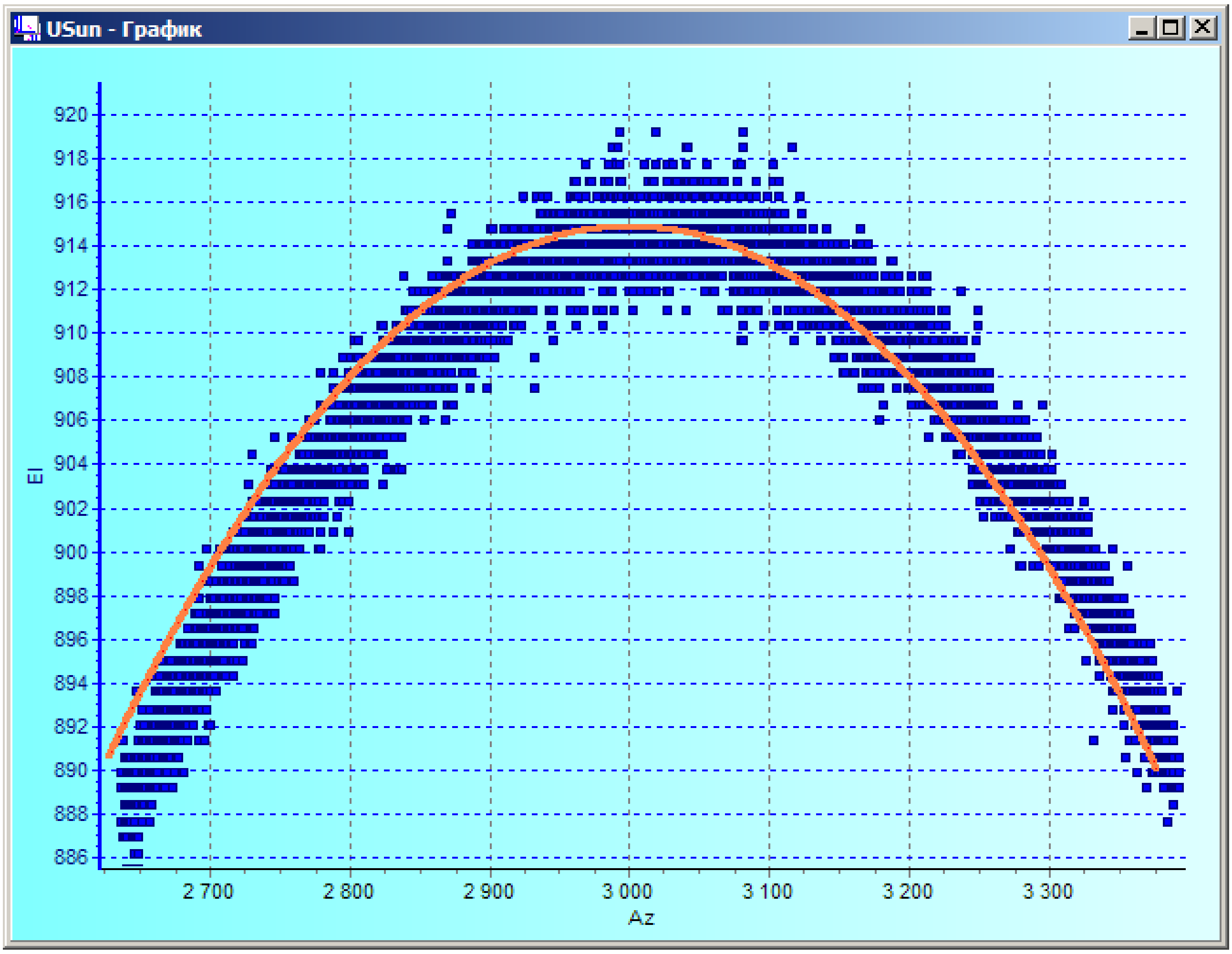

Figure 6. An example with systematic azimuth error and worse tracking precision.

ANNEX

To the analysis of disagreement between observed and calculated coordinates of the Sun.

Usually if a presence of errors is suspected there is a noise in the measurements which together with their limited resolution prevents the accurate determination of errors. Therefore some kind of statistical processing is necessary. Until horizontal alignment of antenna is OK and there is no misalignment between the electrical and the mechanical axes of the antenna the most simple is a model with constant azimuth and elevation errors.

Therefore the averages of differences between observed and calculated azimuth and elevation taken at the same time (the time of each point is also recorded to a file) may immediately give us estimates of the systematic errors. However, when the deviations between observed and calculated coordinates of the Sun are analyzed using time as independent variable, time error may influence the observations. The influence is in particular significant for the elevation – the observed position of sun elevation is shifted relative to the local noon:

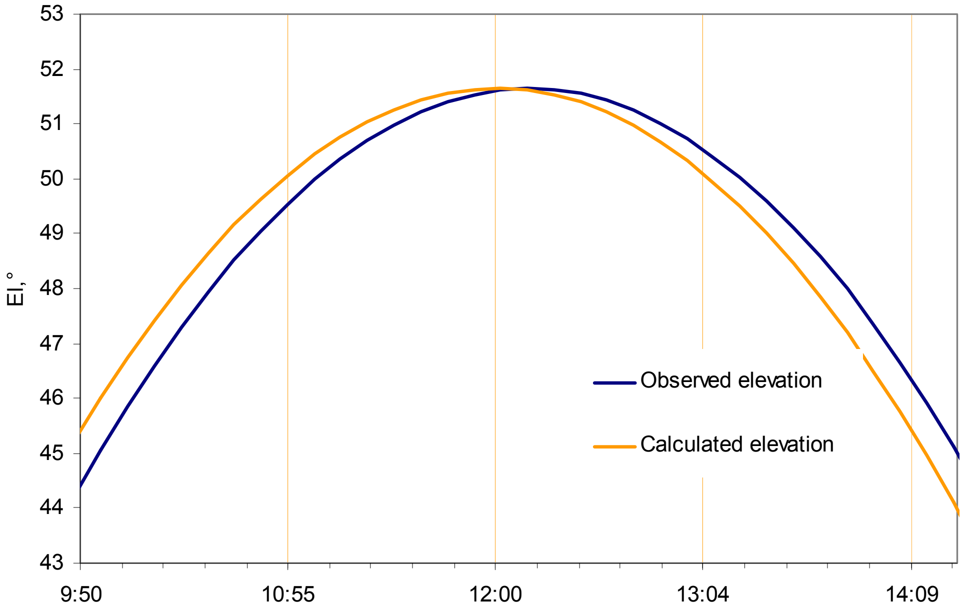

Figure A.1. Influence of time error on observation of the Sun trajectory (scheme).

Time error contributes to observed differences as follows:

$$El'-El \approx \boldsymbol{d}El/\boldsymbol{d}t \cdot \Delta t + \Delta El$$

$$Az'-Az \approx \boldsymbol{d}Az/\boldsymbol{d}t \cdot \Delta t + \Delta Az$$

where El' and Az' are the observed elevation and azimuth, $\boldsymbol{d}El/\boldsymbol{d}t$ and $\boldsymbol{d}Az/\boldsymbol{d}t$ are their time derivatives, t is time and ΔEl, ΔAz and Δt are their errors respectively.

For such cases may help the statistical processing of azimuth-elevation diagram. Under the same assumptions as above the systematic azimuth error is the horizontal displacement and the systematic elevation error is the vertical displacement between corresponding culminations, see Figure A.3.

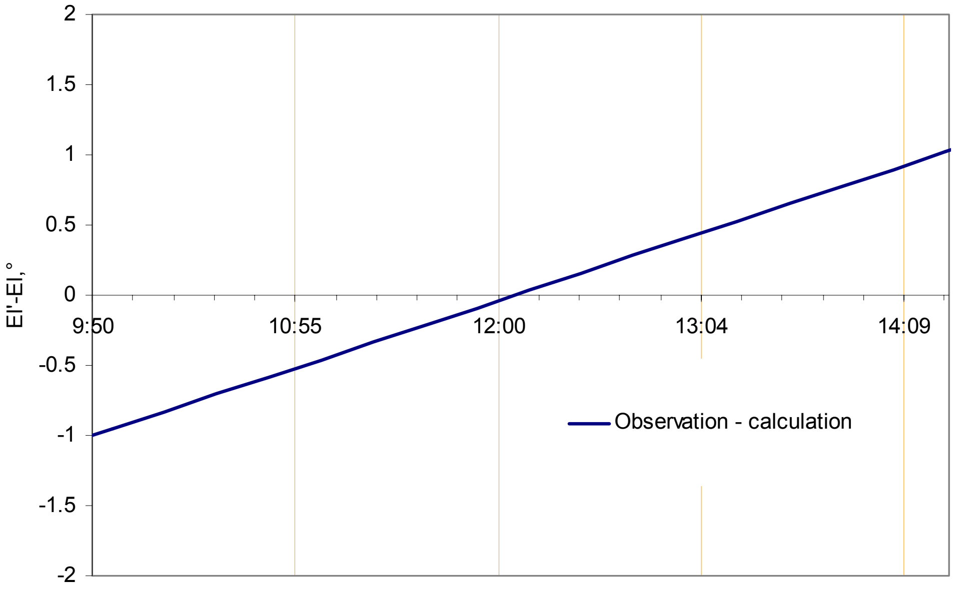

Figure A.2. Contribution of time error to the differences between observed and calculated elevation of the Sun (scheme).

The Sun coordinates at the local sun noon are well-known. So the task is reduced to the finding of a suitable fit to the observed coordinates. Because both the elevation and the azimuth depend on the Sun declination and hour angle finding an exact analytical form for fitting observed curve is not suitable. Fortunately for conditions of most locations of the Russian upper-air network the quadratic polynomial approximation of the Sun elevation versus azimuth has sufficient accuracy. So, to find the systematic errors it is enough to find from corresponding polynomial fit position and magnitude for the maximum of the observed curve and determine their differences from ones of the local noon.

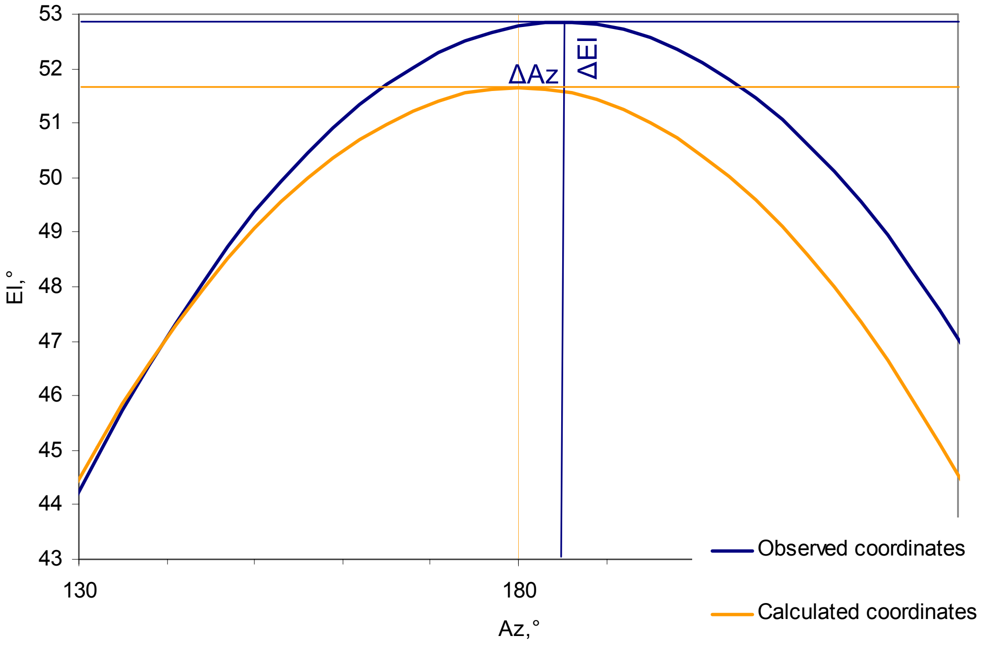

Figure A.3. Systematic errors of the Sun tracking (scheme).

To make sure of the adequacy of the made assumption about the constancy of the systematic errors it is necessary to plot differences between observed and calculated elevations versus azimuth. If the above assumption is adequate the differences are grouped around straight line.

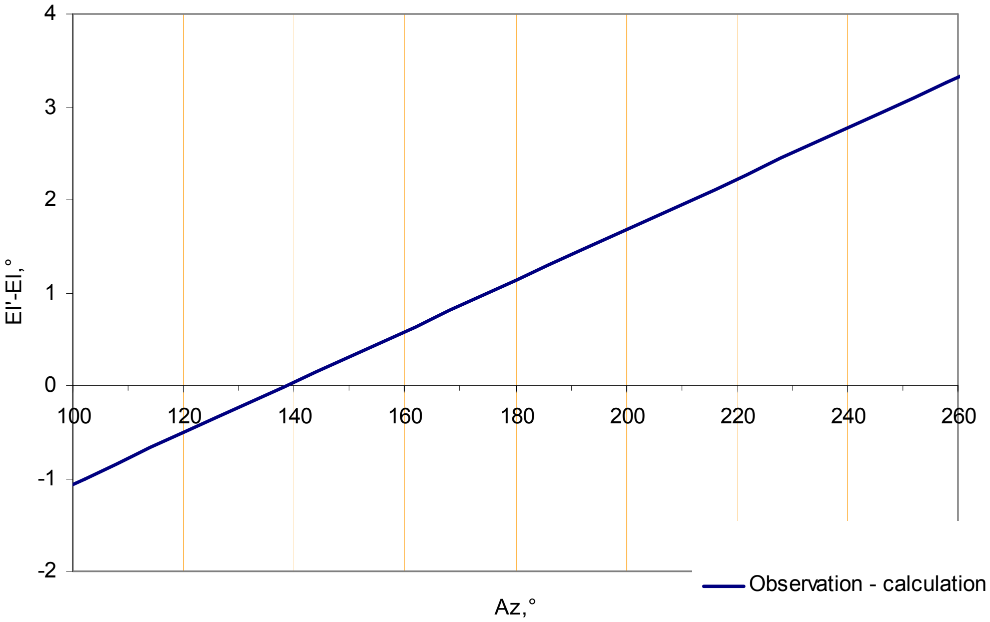

Figure A.4. Differences between observed and calculated elevations under assumption on the constancy of the systematic errors (scheme).

Systematic consistent deviation from such line is an indication of a serious problem with the antenna alignment. One such a problem could be unsatisfactory horizontal alignment of antenna foundation.

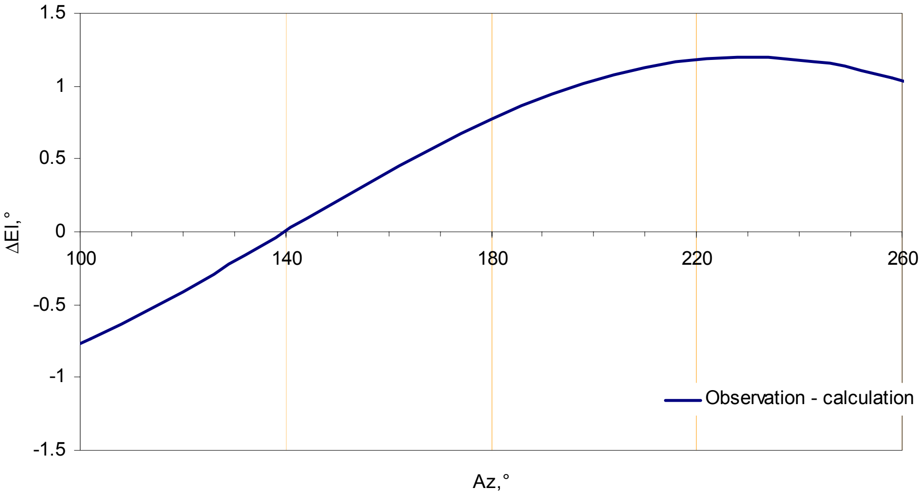

Figure A.5. Differences between observed and calculated elevations under horizontal misalignment of the antenna (scheme).

The characteristic indicator of a problem is also a tilt of observed trajectory relative to the theoretical one.

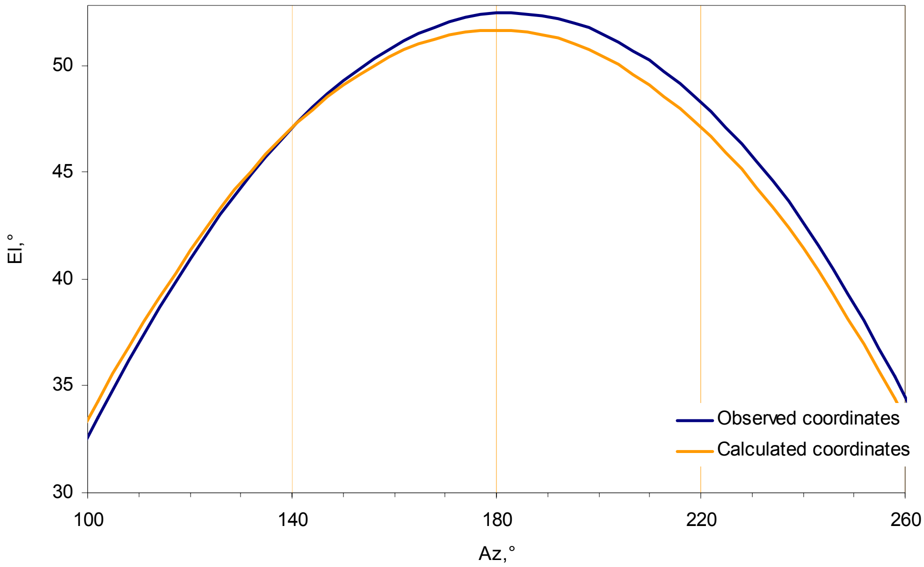

Figure A.6. Influence of horizontal alignment error on observation of the Sun trajectory (scheme).

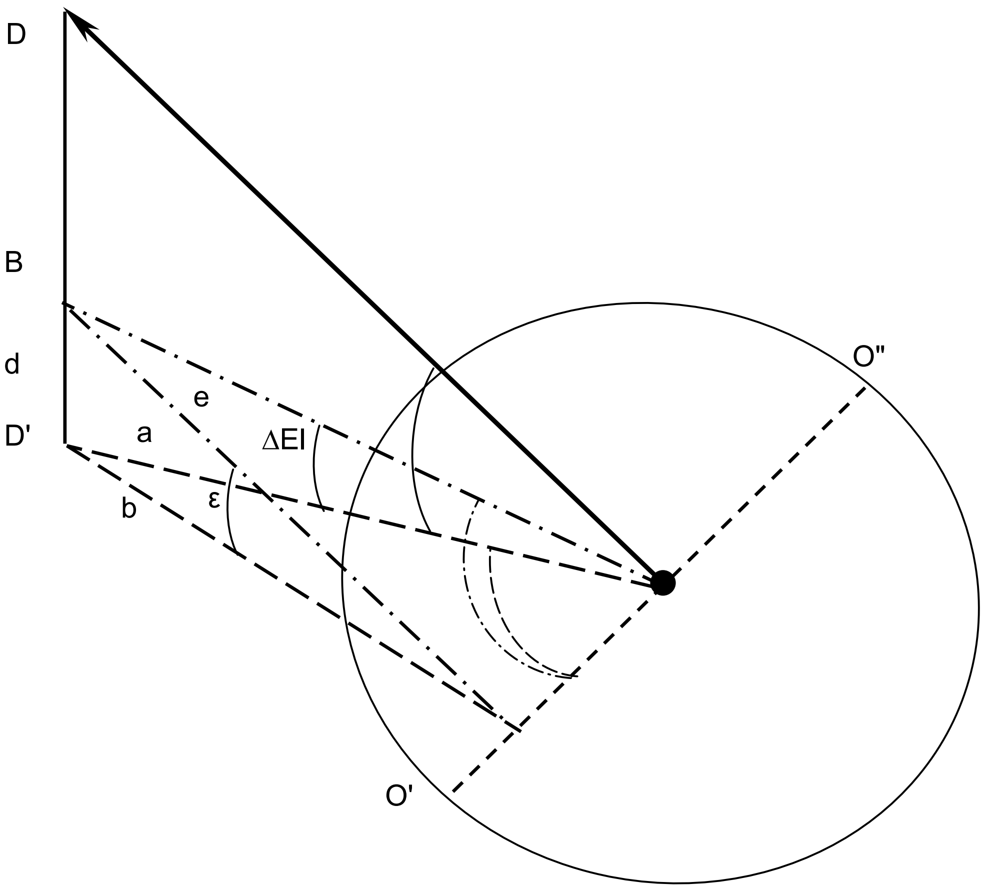

Figure A.7. To the analysis of the horizontal antenna misalignment (scheme).

Let us assume that antenna foundation plane is tilted related to the horizontal plane by the angle ε and crosses the horizonatl plane along O'AO" axis, for the sake of convinience we consider that AO' points to the North (this has no effect on following consideration as the choice of reference on the circle is arbitrary). For other cases Az could be replaced by Az-α, where α is the actual angle between AO' and the North. Lines, belonging to the antenna foundation plane, are shown as dash-dot. Lines, that lying in the horziontal plane are shown as dash, and axis O'AO", belonging to both planes, is shown as dot line.

AD is unitary vector directed from the antenna to a target D with azimuth Az and elevation El, AD' – its projection to the horizontal plane. D'C – normal from point D' to the axis O'AO". B – point of intersection DD' with the antenna foundation plane. Thereafter, the angle at BAD' is the sought elevation error ΔEl due to horizontal misalignment of the antenna ε, whereas the angle at BAC is the observed azimuth Az'. Indeed, as D'C and BC lie at the same plane, DD' and O'AO mutually perpendicular and the angle at D'CA is a right one, then the angle at BCA is also right. Therefore the angle D'CB is also the inclination ε of the antenna plane relative to the horizon.

Further we have

$$a = \boldsymbol{cos}\mathrm{El}$$

$$b = a \cdot \boldsymbol{sin}\mathrm{Az} = \boldsymbol{sin}\mathrm{Az} \cdot \boldsymbol{cos}\mathrm{El}$$

$$d = b \cdot \boldsymbol{tg}\varepsilon = \boldsymbol{sin}\mathrm{Az} \cdot \boldsymbol{cos}\mathrm{El} \cdot \boldsymbol{tg}\varepsilon$$

Therefore

$$\boldsymbol{tg}\Delta\mathrm{El} = d/a = \boldsymbol{sin}\mathrm{Az} \cdot \boldsymbol{tg}\varepsilon$$

A quick check – when a target is located in the direction normal to the axis O'AO" (Az=90°, ***sin***Az = 1), the error is maximal and is equal to ε, while for direction collinear to O'AO" it is equal to zero (Az=0°, ***sin***Az = 0).

Further:

$$e = b / \boldsymbol{cos}\varepsilon = \boldsymbol{sin}\mathrm{Az} \cdot \boldsymbol{cos}\mathrm{El} / \boldsymbol{cos}\varepsilon$$

$$c = a \cdot \boldsymbol{cos}\mathrm{Az} = \boldsymbol{cos}\mathrm{Az} \cdot \boldsymbol{cos}\mathrm{El}$$

$$\boldsymbol{tg}\mathrm{Az}' = e/c = \boldsymbol{tg}\mathrm{Az} / \boldsymbol{cos}\varepsilon$$

A numerical analysis of the latter formula shows that influence of the antenna horizontal misalignment onto the azimuth is not essential as for small angles cosine is close to 1.

So, to locate the problem it is necessary to determine the position of extrema of the elevation error from the diagram like Figure A.5. It may require performing additional observations after sunrise or before sunset.

Another possible problem is a misalignment between the electrical and the mechanical axes of the antenna. It has two components. One is vertical and makes purely systematic contribution to the systematic elevation error. Therefore it doesn’t require separate consideration. Another one is horisontal and influences only the azimuth error, but the contribution depends on elevation.

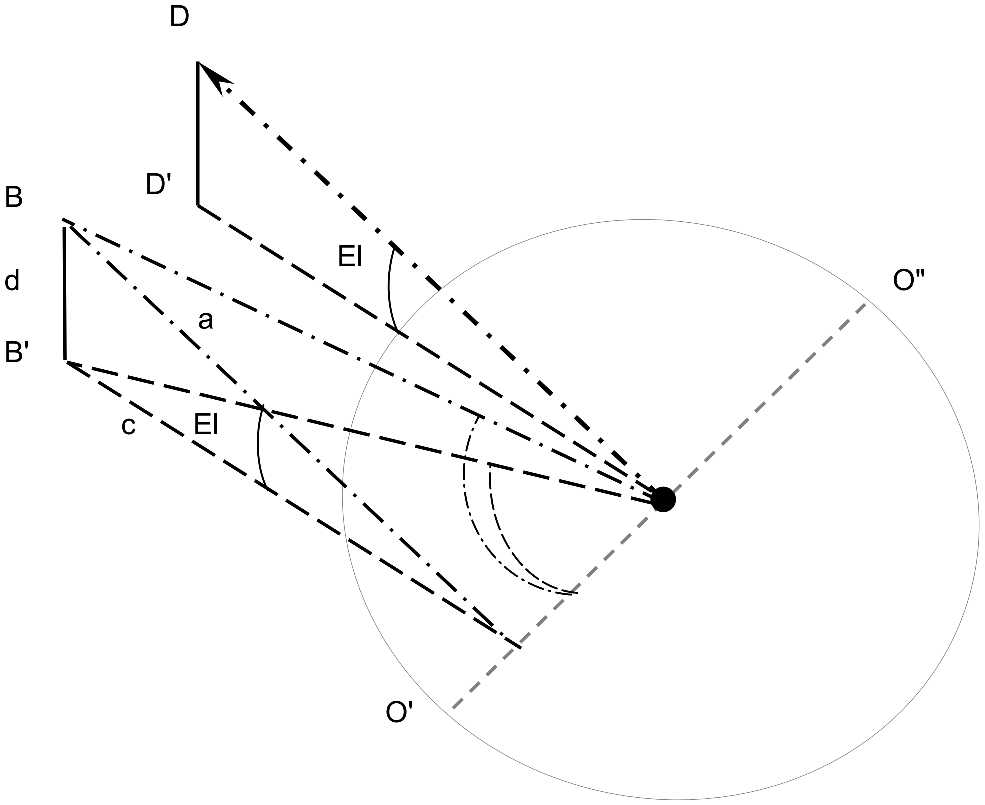

Figure A.8. To the analysis of misalignment between the electrical and the mechanical axes of the antenna (scheme).

Again, lines lie in the horziontal plane are shown as dash. Lines, belonging to the plane, passing through the antenna electrical axis and normal to it axis O'AO", are shown as dash-dot. And axis O'AO", belonging to both planes, is shown as dot line.

AD is unitary vector directed from the antenna A along the electrical axis to a target D with azimuth Az (not indicated for sake of brevity) and elevation El, AD' – its projection to the horizontal plane. AB is unitary vector directed from the antenna A along the mechanical axis, B'A – its projection onto the horizontal plane. BC is a normal from point B onto axis O'AO". The angle ά between AB and AD is the horizontal component of misalignment between the electrical and the mechanical axes. Respectively, the angle at B'AD' is also sought azimuth error ΔAz caused by the axes misalignment.

$$a=\cos \acute{\alpha}$$

$$b=\sin \acute{\alpha}$$

$$c=a \cdot \cos \mathrm{El}$$

$$\mathrm{tg}\Delta \mathrm{Az}=b/c$$

and finally

$$\mathrm{tg}\Delta \mathrm{Az}= \mathrm{tg}\, \acute{\alpha}/\cos \mathrm{El}$$

This relationship describes uneven distribution of azimuth errors depending on the elevation. Unfortunately, such problem if found could not be fixed and therefore replacement of the antenna or even of the ground system may be required. An alternative could be a possible programmatic correction of this error.