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Investigation of parameters of antenna settings for radioheliograph operation

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Abstract. Algorithms of calculation of the antenna settings and antenna patterns for RATAN-600 operation as a radioheliograph are considered in the paper. Results of modeling the number of panels in the antenna settings and the structure of the antenna patterns are presented.

Key words: radio telescopes — instrumentation: radioheliograph — parameters

1. Radioheliograph mode

The idea of observations of the Sun in the radioheliograph mode was put forward by G.B. Gelfreikh in cooperation with V.M. Bogod and A.N. Korzhavin, and appeared first in the paper by Bogod et al. (1988). This mode represents further development of the methods of observations without tautochronism of rays in the antenna system, some versions of which are considered in the papers by Parijskij, Shivris (1972); Gelfreikh et al. (1975), and the implementation of one of them is reported by Golubchina (1986).

The principal aim of the radioheliograph mode is the two-dimensional imaging of the Sun with high spatial and time resolution. This can be done owing to two possibilities which arise from broken tautochronism: 1) considerable increase in the aperture size through setting of a maximum number of elements (panels) of the main mirror for a given location of a source and 2) obtaining of a number of scans necessary for construction of the image during a short time, using significant differences of antenna patterns at close frequencies. As a rule, these possibilities are realized simultaneously — the settings with a great number of panels are characterized by a considerable difference of the ray paths, providing sufficiently fast change of the antenna patterns (AP) with frequency. By analogy with one of the ways of imaging at the Siberian solar radio telescope (Smol'kov et al., 1983) we will name the construction of images through the implementation of the APs at different frequencies "frequency scanning". The method of scanning with the aid of resetting of the antenna is also used in the radioheliograph mode, but it compares considerably unfavourably with the frequency scanning both in the speed of imaging and in the possibility of collecting a sufficient number of scans for mapping (Gelfreikh, Opeikina, 1992). This is why we pay primary attention to the method of frequency scanning.

In the majority of cases multilobe APs occupying a large solid angle have to be used for frequency scanning. Apart from the shortcomings of employing such APs there are some advantages. If each of the APs covers fully the source, then one can, firstly, obtain a rough source image from the results of its single transit accross the AP at one frequency, secondly, use data of a large number of frequency channels to construct an "instantaneous" image. Both possibilities are considered in the paper by Bogod and Grebinskij (1997).

To implement the radioheliograph mode, the main mirror of RATAN-600 is considered as a system of independent reflecting elements that collect the radiation of the source at the focus whose position can be varied over a wide range. A set of secondary reflectors, which consists of a conic and parabolic mirrors and gathers the radiation of the whole ring (a feed of type VI (Esepkina, Parijskij, 1972)), is placed at the focus of the main mirror. By varying the position of the focus, an antenna setting is chosen with a maximum number of panels and a considerable difference of the ray paths. With the aid of independent setting of the panels, phase distribution is set allowing an AP of a required shape to be formed. The multilobe APs can be obtained by specifying a random phase distribution. The lobes of such APs will be distributed randomly inside the large field of view restricted by an envelope whose size is defined by the size of one panel or of a group of panels operating in phase. The APs with the like properties will be obtained at all wavelengths, and because of this, one can construct images simultaneously at all wavelengths within the working range of the radio telescope using a multiwave feed with the single phase centre (Bogod et al., 1983) for illumination of the secondary parabolic mirror. The disadvantages of the method are as follows: decrease in sensitivity because of the reduced frequency bandwidth of the receiving channels; considerable diminishing of the amplitude of the AP lobes and a noticeable effect of the scattered pattern, difficulty of accurate calculation of non-cophasal APs; impossibility of applying this method for mapping the sources whose brightness distribution cannot be considered unchanged within the used interval of frequencies ($\sim 500\,\mathrm{MHz}$); necessity for data reduction which requires a great deal of computation.

To assess the capabilities of the radioheliograph and to choose the optimum variants of its performance, it is required to analyse a large number of antenna settings and characteristics appropriate to them. The aim of this paper is to solve part of these problems — the number of panels in settings is analysed, the procedures of calculation of antenna settings and APs are considered; examples are given of APs for settings with different phase distributions.

2. Computation of antenna settings

Khaikin et al. (1960) and Shivris et al. (1983) discussed in details the geometry of the antenna and derived the formulae for calculation of coordinates of the panels for the so-called standard modes of the telescope operation. Gelfreikh (1972) presented the formulae for calculation of coordinates for the case where each panel of the antenna is regarded as an independent flat mirror reflecting the radiation of a source in the direction of an arbitrarily specified focus. These formulae are more universal and suitable for calculations of settings of the radioheliograph.

The angular coordinates of the $k-th$ panel (i.e. the values of its inclination to the vertical and rotation in azimuth) are determined by the position of the normal to the panel, which is specified by the position angle of the normal, α_k, and by the azimuthal angle between the normal and the direction to the focus from the panel centre, a_{Nk}:

$$\sin \alpha_k = \frac{\sin h}{\sqrt{2(1+\cos h \cos a_{Mk})}}, \tag{1}$$

$$\tan a_{Nk} = \frac{\cos h \sin a_{Mk}}{1+\cos h \cos a_{Mk}}, \tag{2}$$

where h is the height of the source, a_{Mk} is the azimuthal angle between the directions to the source and to the focus from the panel centre.

The phase of the field in the aperture is defined by the length of the optical path the ray travels from the chosen plane of the wavefront to the focus. The optical path length can be varied by displacement of the panels along the radial coordinate, the quantity r_k is found from the expression for the optical path D_k:

$$D_k = r_k \cos h \cos a_{Sk} + \sqrt{r_k{}^2 + f^2 - 2r_k f \cos \phi_k}\,, \tag{3}$$

where f is the distance from the antenna centre to the focus, ϕ_k is the angle between the directions "antenna centre — panel" and "antenna centre — focus", $a_{Sk} = \pi + a - a_k$ is the azimuthal angle between the directions to the source and to the antenna centre from the panel centre, a is the azimuth of the source, a_k is the azimuth of the panel (the azimuths are reckoned from the point of the south to the west).

Expression (3) is reduced to a quadratic equation in r_k from the solutions of which the root is chosen that lies within the permissible displacements of the panel along the radius. It should be noted that the panel can be shifted by 1 m towards the centre from the outer circumference of radius r^*_{max}, where $*$ indicates that the radius is taken with allowance made for the correction caused by the design of the panel and dependent on its inclination (Shivris et al., 1983).

Based on the presented formulae, an algorithm of calculation of settings was developed. As in the cases of standard configurations, the computation of the radioheliograph setting consisted in sequential calculation of the coordinates of each element. The panel remains in the setting if all its coordinates are within the allowable limits. The algorithm calculates different antenna settings by varying, independent of one another, the parameters which are not interconnected rigidly: location of the source, position of the focus, relationship for the difference of the ray paths, etc. Such an approach to the calculation is more common and includes calculation of standard settings as a particular case. In the computations the necessary corrections associated with the panel design were taken into account, which permits the results of calculation to be used not only for modeling the operation of the radioheliograph, but also in tasks for setting of the antenna for observations.

3. Parameters of antenna settings

The variants of operation of the radioheliograph are determined by the properties of the antenna pattern: structure, angular dimensions of lobes, rate and character of its changes with frequency. These characteristics are connected with the parameters of settings by changing which one can form the AP with the desired properties. The most important of such parameters are as follows:

1. The relationship connecting the optical path lengths determines the antenna pattern structure.

a) The AP with one main lobe is formed provided that the relation

$$D_k = D_0 + n_k\lambda \quad (4)$$

is satisfied, where D_0 is the optical path length for the reference panel, n_k is the arbitrary integer. If one demands that $n_k = 0$ for all working panels and chooses the appropriate focal distance and the reference panel radius, the calculation of settings, using the algorithm described above, will then lead to standard settings. To increase the number of working panels in the mode of radioheliograph, n_k is chosen so that the panel radius falls within the permissible interval. For instance, the deviation of the radius from the middle of this interval (r^*) will be sufficiently small if n_k is chosen so that the difference between D_k and $D_k(r^*)$ does not exceed the wavelength. Here, as above, $*$ denotes allowance for the radial correction.

b) Multilobe non-cophasal APs with a random distribution of lobes are produced if

$$D_k = D_0 + n_k\lambda + \xi\lambda\,, \quad (5)$$

where ξ is the quantity distributed according to some random law. If ξ is distributed in the interval $[0;1]$, this, without violating the diversity of possible phase distributions, will then favour keeping the radius within the permissible limits. Note that the indicated simple ways of choosing n_k and ξ make it possible to find suitable radii for all panels when calculating practically useful settings of the radioheliograph for the centimetre range wavelengths.

c) Non-cophasal APs with regular arrangement of the lobes can be obtained, for instance, with the aid of the condition:

$$D_k = D_k(r_c)\,, \quad (6)$$

where the radius r_c is the same for all panels of the setting.
Regular non-cophasal APs will be obtained also in the settings in which different periodical phase distributions are set. For example, such as in the diffraction reflecting grating discussed by N.L. Kaidanovskij (1990), in which the rays from the neighbouring groups of panels arrive to the focus in antiphase.

d) By dividing the setting into parts, each of which operates in its own mode, one can optimize the stucture of the AP and its behaviour with frequency. For instance, if the working panels are divided into m groups for each of which the cophasal mode (in the general case with zoning) is realized at the given wave λ_m, then this will make it possible to form a set of APs with the given position of the main lobes on the sky and perform frequency scanning with single-lobe APs. In another case, if the parts of the setting with non-cophasal field distribution are pointed to different regions of the sky, the field of view can then be considerably widened as compared with the one that is derived when all panels are pointed to one region.

2. An important feature of the radioheliograph is the total number (N) of panels in the setting. A large number of panels suggests that high spatial resolution, good coverage of the (u, v) plane, a large collecting area, sufficient stochasticity of the AP for random non-cophasal modes will be realized. For the given location of the source the number of panels is defined by the position of the focus.

3. The distribution of panels over the ring can be both continuous and disrupted. This divides the settings by the character of coverage of (u, v) plane. It will be either filled completely within the region determined by the aperture size or it will have "holes". Among the settings consisting of several separate parts there will be also ones which with a small number of panels have high spatial resolution.

4. Each setting is characterized by its band of frequencies, whose width depends on the difference in ray paths in the antenna system. According to this characteristic, one can divide settings into broad-bandwidth and narrow-bandwidth, and choose from the latter such that can be used for frequency scanning. The usefulness for frequency scanning depends on the character of variations of the AP with frequency.

The principal difficulty in choosing an optimum setting is the necessity for simultaneous taking account of several parameters which may be related in an intricate manner to one another. Note also that the enumerated characteristics do not cover all the possible parameters of settings. To establish the optimum criterion that takes into account all the necessary parameters, one has to analyse, at first, each of them separately. Below we will discuss the variation of the number of panels depending on the location of the source and the focus and estimate the time interval of observations with a large number of panels.

4. The number of panels in the settings of the radioheliograph

In settings without tautochronism of rays one can increase considerably the number of panels as compared to the number of panels in cophasal settings without zoning (both standard and with the use of the feed of VI type (Kaidanovskij, 1982)). The greatest number of panels for each fixed position of the source and of the focus can be achieved provided that the setting of panels along the radial coordinate is not restricted by any requirements. In this case the inclusion of the panel in the antenna setting will be determined only by possibilities of its turning in angular coordinates.

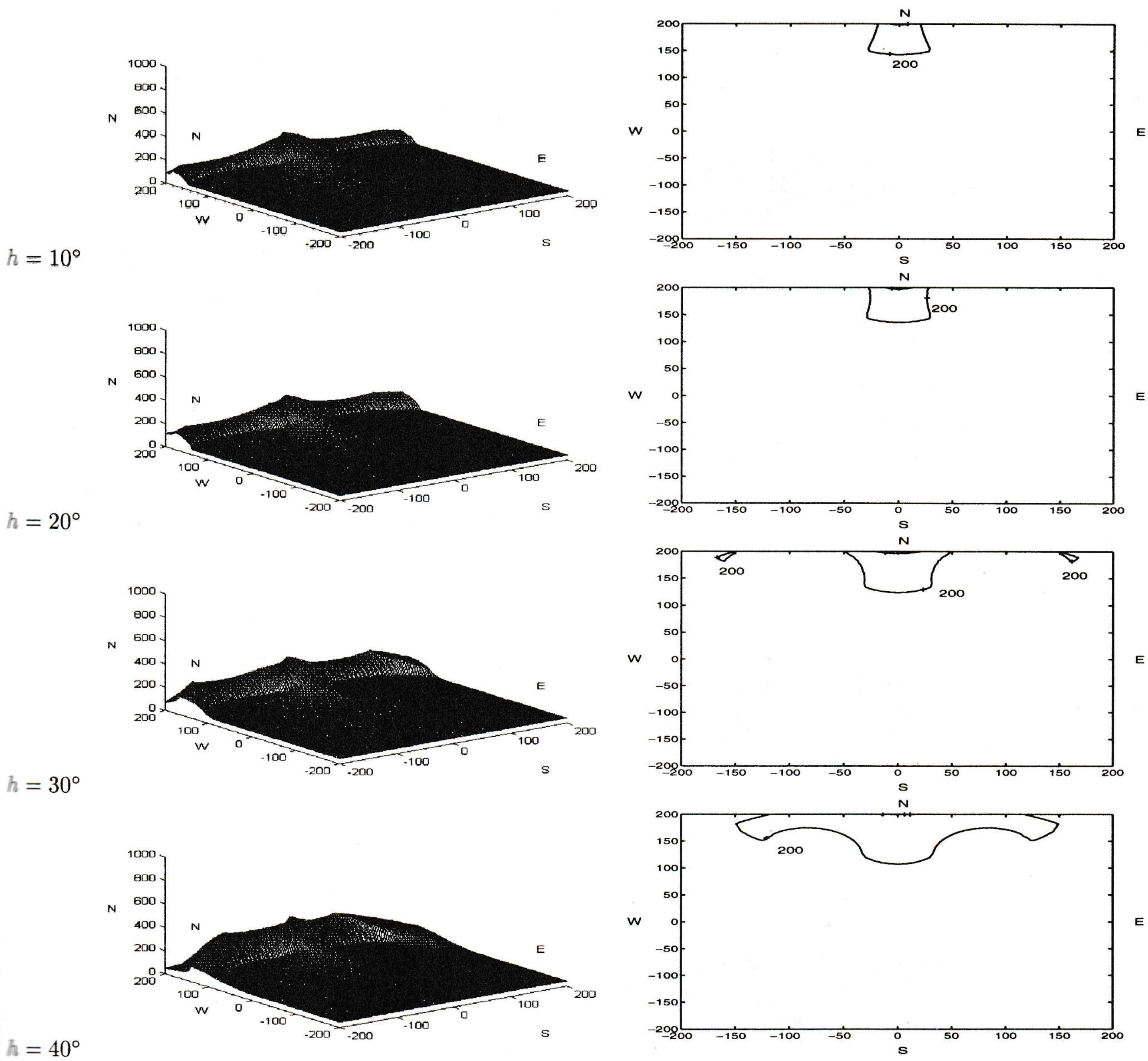


Figure 1: *The number of panels vrs the position of the focus for source heights* $10° - 40°$. *The numbers at the isolines on the right indicate the value of* $N_{0,h}$.

Let us examine the relationship between N and the variables that specify the position of the source and the focus (f is the distance from the focus to the antenna centre, a_f is the focus azimuth, (a, h) are the azimuth and height or (δ, t) are the declination and hour angle) and attempt to find the optimum location of the feed and estimate the duration of observations.

In order to imagine the behaviour of the multidimensional function $N(f, a_f, a, h)$, let us present different families of curves and surfaces which visually demonstrate the character of the relationships in question. For this purpose, construct a number of two-dimensional functions $N_{a,h}(f, a_f)$, where the position of the source (a, h) is fixed, while that of the focus (f, a_f) changes. By virtue of circular symmetry of this task one can restrict oneself to consideration of such functions $N_{a,h}(f, a_f)$ for which $a = 0$. Examples of the functions $N_{0,h}(f, a_f)$ for the heights $10° - 80°$ are shown in Figs. 1 and 2. The values of the functions are given in the nodes of the rectangular coordinate system located in the horizontal plane, the characters N, S, E, W indicate the northern, southern, easten and westen directions. In these figures and also in all the other figures of this section the values of the linear coordinates are given in metres, and those of angular coordinates in degrees. To illustrate the general character of the changes, we present the calculations of N within $x, y \in [-200m, 200m]$, which exceeds the

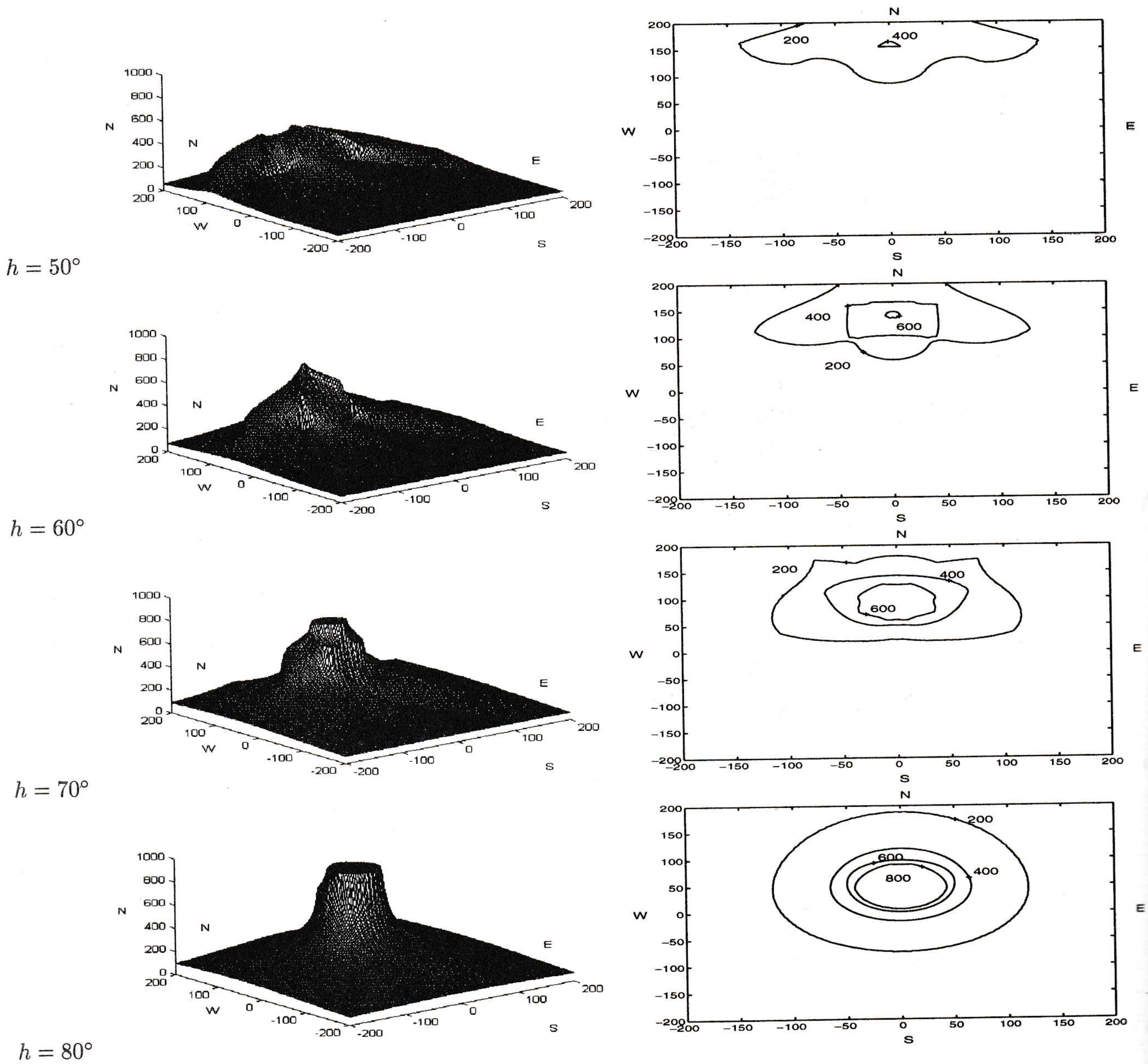
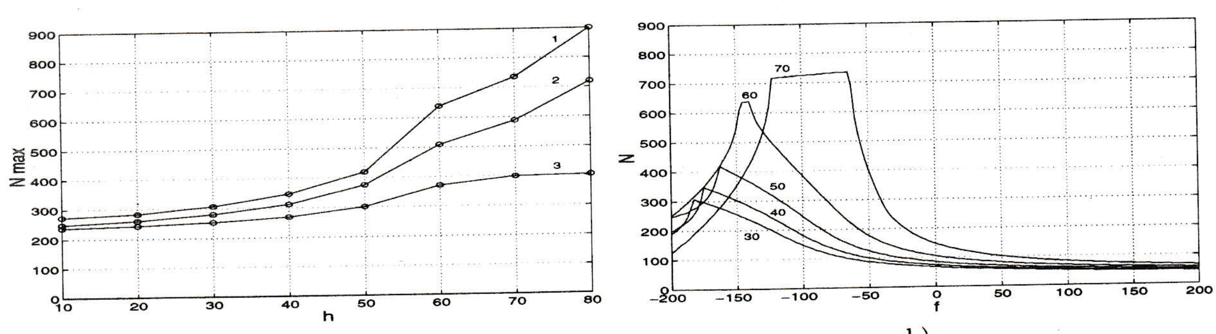


Figure 2: *The same as in Fig. 1 for source heights* $50° - 80°$.



a) b)

Figure 3: *a) The dependence of the maximum number of panels on the height of the source for different antenna models; b) The relationship between the number of panels and the focal distance for source heights* $30° - 70°$ *with the optimum azimuth of the focus.*

variations of f possible in practice (the length of the rails the feed cabin moves on is ~ 150 m).

Curve 1 in Fig. 3a shows how the maximum number of working panels N_{max} changes with height of the source. Note that the behaviour of the curve between the calculated points which are designated by circles may be somewhat different from that depicted in the figure. For instance, more detailed calculations show that sources, the height of which $\geq 75°$, can be observed with the full ring (900 panels). On the other hand, it can be seen from the figure that half and more of the panels of the ring will work simultaneously only for sources with $h > 50°$. In the case $h < 50°$ no variants of the mutual positions of the source and the focus will yield a great number of panels. For the radioheliograph, one should consider, first of all, the settings with a sufficiently large number of panels ($N \geq N_l$, where $N_l = 450$), then if only for one of the coordinates a maximum aperture is realized. That is why, taking into account that the height of the Sun at the latitude of RATAN-600 is not larger than 70°, we will be interested in the functions $N_{0,h}(f, a_f)$ in the interval $h \in [50°, 70°]$.

The function $N_{0,h}(f, a_f)$ for, at least, the height range of our interest points clearly enough to the optimum location of the feed, which corresponds to the maximum of the function N. In all the cases the maximum is in the azimuth opposite to that of the source ($a_f = a + \pi$). In Fig. 3b are displayed the curves showing the relation between the number of elements being set and f for the interval of heights 30°–70° and optimum for the $a = 0$ azimuth of the focus $a_f = 180°$. It is seen that the foci corresponding to N_{max} are located far from the centre of the circle ($f_{max} \sim 100$ m). One can also see from Figs. 1–3 that for $h = 50° - 70°$ the positions of the focus corresponding to a sufficiently large number of panels ($N \gtrsim N_l$) are such that their azimuths take a small range of angles near the optimum azimuth. This means that it is impossible to obtain a large N with the source azimuth largely different from the quantity $a'_f = a_f - \pi$. Thus, with great deviations of the focus azimuth from 180°, the number of panels in settings will be small for two reasons: 1) because of decreasing height of the source as it is receding from the meridian for the source azimuths close to a'_f; 2) because of the great difference between the source azimuth and a'_f for the source azimuths close to zero.

Let us treat, as an example, the variation of N_{max} in solar observations, which arises at deviations of a_f from 180°. The Sun has a declination $\delta \geq 11°$ in the period approximately from April 20 to August 25 (4 months), $\delta \geq 15°$ from May 1 to August 12 (3.5 months) $\delta \geq 19°$ from May 15 to July 28 (1.5 months) and is located near the maximum declination, $\delta_{max} \sim 23°$ from June 10 to July 1 (20 days). Now we give the results of calculations for these declinations. The variation of the maximum number of panels with increasing deviation of the feed azimuth from optimum ($da = 180° - a_f$) is presented in Fig. 4. To derive these relations, calculations in 4 azimuths, 180°, 150°, 120°, 100° were performed (note that the RATAN-600 design provides for the variation of the focus azimuth with a step of 30°). The value 100° was chosen for convenience in calculation since it is clear that for the actually existing $a_f = 90°$ the number of panels will be still smaller. In each case all possible hour angles and focal distances f were varied. It can be seen from Fig. 4 that the decrease in N_{max} in the azimuth 150° as compared to the azimuth 180° is modest. In the azimuth 120° the decrease is considerable, but for the declinations 23° and 19° a sufficiently large number (more than half) of panels still remains. In the azimuth 100° the number of panels differs only slightly from that in the standard settings for all declinations of the Sun.

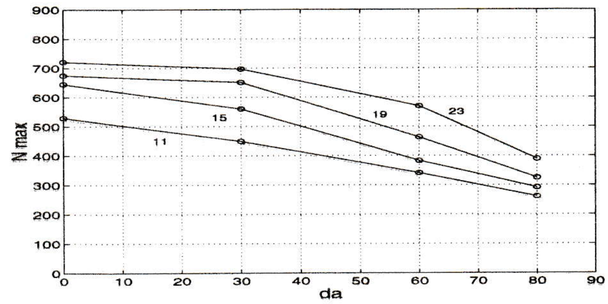


Figure 4: *The variation of the maximum number of panels with increasing da for different declinations of the Sun.*

Thus, to realize the radioheliograph mode, it is necessary to have a possibility of placing the feed on the northern railways ($a_f = 180°$) or on the railways closest to them "30" and "330" (from the names adopted at the radiotelescope).

If we suppose to observe the source with the stationary feed for some time, the optimum focus position for this case may then be different from the focus position corresponding to the maximum number of panels.

In Fig. 5 the number of panels is plotted as a function of hour angle t and focal distance f for the fixed feed azimuth $a_f = 180°$ and declinations 11°, 15°, 19°, 23°. Two isolines are shown in the figure one of which runs at the level $N = 450$, the other one near the function maximum. Thus, the region of the focal distances and hour angles, for which the number of panels in settings ≥ 450, is defined for each declination, and the focus position, at which the maximum number of panels is implemented, is shown. It is seen that the focus position, at which $N \geq 450$ keeps long to the utmost, does not coincide with the focus position at which the number of panels is a maximum (for

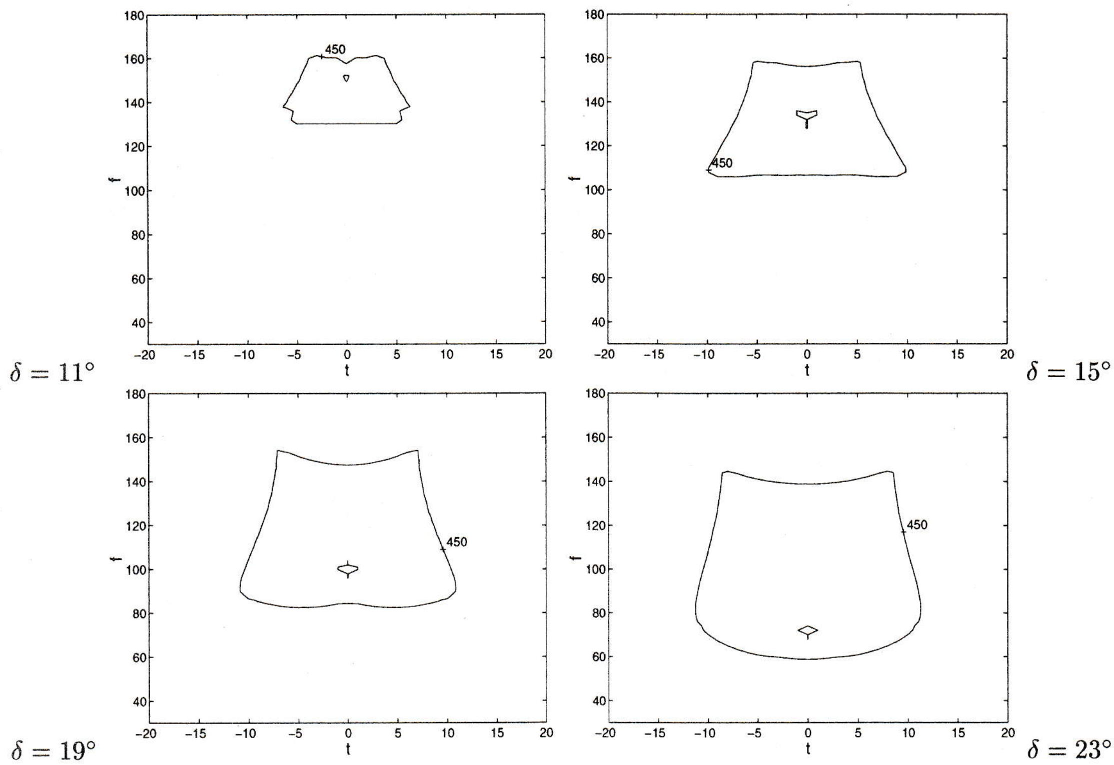


Figure 5: *The number of panels as a function of focal distance and hour angle for different declinations of the Sun.*

instance, the difference is well noticeable for $\delta = 15°$). It is also seen from the figure that the time interval for observations of the Sun with the number of panels ≥ 450 does not exceed $\sim 20°(1^h20^m)$.

The calculations discussed above were done for the design limits of changing the setting coordinates of panels. Their distinction from the results of the calculation performed for the actually existing limits on the antenna is determined chiefly by the considerable decrease in the limits of azimuthal rotations of the panels ($\pm 4.5°$ instead of $\pm 6.0°$). The decrease in the number of panels (N_{max}) associated with this is shown in Fig. 3a (curve 2). Besides, under the real observing conditions, part of the panels cannot work for a number of technical reasons (the southern part of the antenna is shaded by the flat reflector, the eastern sector is temporarily inoperative). The decrease in N_{max} due to the reduction of the rotation limits, shading and idle panels is displayed in Fig. 3a (curve 3).

We analysed only the summary number of panels in the setting. Part of the settings were solid, part of them consisted of separate parts. The width of the frequency band in them was also different. To choose the settings best suited to observations, a similar consideration of the bandwidth, distribution of panels over the ring and other characteristics is required.

5. Calculation of APs of the radioheliograph

The implementation of the radioheliograph depends on the ability to correctly calculate APs, on the knowledge of their properties and on the skills of choosing from the variety of APs the ones which are best suited to the tasks of mapping the Sun.

Calculation of APs for the radioheliograph operation has some essential distinctions as compared to that for the mastered variants of observations with RATAN-600.

1. The amount of calculations is by a few orders of magnitude larger since for each setting it is required to compute APs for a few hundred frequency channels, the settings being different both during one set of observations and from day to day. Besides, for non-cophasal modes of observations each AP must be calculated for a field whose size is hundreds of times the width of a separate lobe.

2. It is difficult to provide beforehand for all the distinctions of the antenna configuration at the moment of observations and to create a database of the necessary APs computed earlier. This is why APs must be calculated in the process of observations and their processing. For modeling, frequent calculation of APs is still more necessary. Thus, one should minimize the time of calculation of one AP.

3. Due to the lower level of energy of lobes and the large field of view, the demands on the accuracy of computations must be higher than for the standard conditions. It has also to be taken into account that experimental determination of the shape of such APs is difficult. This is why, special criteria are required to estimate the correctness of calculation of an AP.

So, the computation of the radioheliograph AP is a complicated task which is performed in this paper only in part.

To calculate the AP, we made use of the method suggested by Gelfreikh (1977). This algorithm allows taking easily into account the changes associated with a separate panel and varying different parameters of the antenna model. The algorithm is simple for programme implementation and has a sufficiently high speed of calculation. In the paper cited its fitness to calculation of the central part of the AP field was noted, and the algorithm was further used in the processing of observations and map restoration (Minchenko, 1979).

According to this algorithm, the main mirror of the antenna is treated as a multielement interferometer the elements of which are individual panels. For the calculation of the field pattern $F(a,h)$, in each of the polarizations, scallar addition of fields arriving to the focus from each panel is used taking into account their phases:

$$F(a,h) = \sum_k E_k \exp(2\pi i(D_k(a,h) - D_0(a,h))/\lambda)\,, \quad (7)$$

where E_k is the field amplitude on the $k-th$ panel; a, h are the azimuth and height which specify the direction of the computed point of the AP; D_k, and D_0 are the optical paths of rays for the $k-th$ and reference panels.

For model computations the field amplitude E_k was taken to correspond to the law of illumination of panels in the horizontal plane, and can roughly be estimated as

$$E_k = \cos(a_{Nk}) f(z)/\sqrt{(\rho_k)}\,, \quad (8)$$

where a_{Nk} is the azimuthal angle between the normal to the panel and the direction to the feed from the panel centre; ρ_k is the distance from the focus to the panel; $f(z)$ is the characteristic of vertical illumination of the panel.

In this paper we complemented the algorithm with a possibility of taking into account several points on the panel by analogy with taking account of the central point. This is necessary for correct calculation of the envelope of the AP and elimination of edge effects when estimating the AP within a large field of view. For the points that belong to the vertical line of the panel, the optical path ($D = D1 + D2$) is calculated by the formulae presented below. Here, the same as in the paper by Gelfreikh (1972), an ideal panel is considered. In this case the vertical line passing through the centre of the panel does not leave the vertical plane running through the centres of the panel and the antenna as the panel is turned.

Fix the rectangular coordinate system: the x axis is directed to the south, the y axis to the east, z to the zenith, the centre of the system is located at the centre of the antenna. Formula (3) for the optical path corresponds to the same system. After setting the panel in the operating position, the points of the vertical line locating at distance z from the panel centre have the following coordinates in the chosen system:

$$\begin{aligned} x' &= (r_k + z\sin\eta_k)\cos a_k \\ y' &= -(r_k + z\sin\eta_k)\sin a_k \\ z' &= z\cos\eta_k\,, \end{aligned} \quad (9)$$

where η_k is the inclination angle of the panel to the vertical, a_k is the azimuth of the panel, r_k is the panel centre radius.

The normal to the wavefront plane in the direction (a,h) is

$$\begin{aligned} n_x &= \cos h \cos a \\ n_y &= -\cos h \sin a \\ n_z &= \sin h\,. \end{aligned} \quad (10)$$

The distance from the points of the panel to the wavefront plane is then:

$$D1 = -(r_k \cos h \cos(a - a_k) + z(\cos h \sin\eta_k \cos(a - a_k) + \sin h \cos\eta_k)). \quad (11)$$

The distance from the panel points to the focus is found as the distance to the vertical plane passing through the focus point, and the normal to this plane coincides with the direction of rays reflected from the panel. The coordinates of the normal to the plane are indicated by:

$$\begin{aligned} a_x &= \cos\gamma \\ a_y &= \sin\gamma \\ a_z &= 0\,, \end{aligned} \quad (12)$$

where $\gamma = \pi - a_f - \psi_k$, a_f is the focus azimuth, ψ_k is the angle between the directions "focus — panel" and "antenna centre — focus". The distance to the focus is

$$D2 = -(a_x x' + a_y y')\,. \quad (13)$$

The power pattern is normalized either to unity at the maximum or so that a value proportional to the effective collecting area be obtained. The latter is more convenient for comparison of energy characteristics of APs of different settings with one another. In

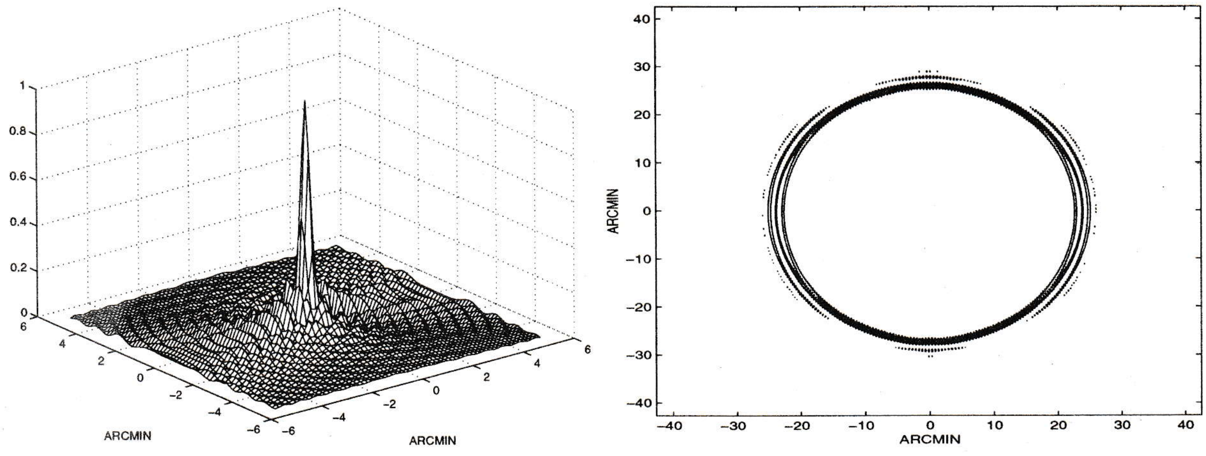


Figure 6: *The beam pattern in the cophasal (a) and "antiphase" (b) modes.*

this case the following quantity is calculated:

$$A(a,h) = FF^* / \sum_k E_k E_k^* \,. \tag{14}$$

To speed up the calculation of AP, interpolation of the argument from the azimuth in the calculations of complex components in formula (7) can be applied in the way described by Gelfreikh, Opeikina (1992). In this case the time of calculation of one point of AP related to one point of the panel is $\sim 0.2\,\mu$s on a computer with the processor Intel PII-330. The total time of the calculation of the AP for one frequency is proportional to the number of panels, the number of points on the panel and the number of points in the AP field. For instance, for the AP computed for a field of 512×512 points for a setting of 645 panels, taking account of one point per panel and without allowance for the frequency band, the time of computation is ~ 30 s. This is a reasonable speed for the mass calculation of APs needed both for modeling and for processing of observations.

Let us produce examples of APs formed with specification of different phase distributions. In all the cases the antenna configuration determined by the location of the source ($\delta = 15°, t = 0^h$) and the position of the focus ($a_f = 180°, f = 130$ m) is preserved. For all settings the number of panels ($N = 645$) and their distribution over the antenna are the same. The calculations were done for the wavelength of the received radiation $\lambda = 8$ cm. Fig. 6 shows examples of the AP for a setting with zoning (a) and of the AP for the case where the neighbouring groups, consisting of 3 panels each, operate in antiphase (b). The lobes of the "antiphase" AP are located far from the field centre and are weaker in power than the main lobe of the cophasal AP by a factor of 30.

The most important for the radioheliograph are non-cophasal settings with random phase distributions. In this case the APs are of complex multilobe structure. This kind of settings can be produced not only from separate panels, but also from groups consisting of a small number of panels arranged in phase. We will determine the number of panels in such a group by the parameter n_s. In Fig. 7 are displayd the examples of the APs for a random phase distribution specified by relation (5) with the uniformly distributed quantity ξ. The settings here are different in the value of the parameter n_s. The APs are computed for the field of 512×512 points with an interval between the points of $10''$. All the lobes whose amplitude is $\geq 30\,\%$ of the maximum value for the given AP are shown. The APs are presented in the rectangular coordinates oriented in right ascension and declination; the numbering of the scales is given in minutes of arc.

The smaller n_s, the larger region on the sky is covered by the AP. The maximum region that may be taken by a non-cophasal AP, provided that all panels of the setting are pointed to one point, is attained at $n_s = 1$. The AP envelope is associated with the sizes of an "in-phase" group of panels, but it differs from its AP since individual groups are projected onto the aperture in different ways.

In non-cophasal modes of operation a considerably smaller part of energy falls at each lobe as compared to the cophasal zoning condition. For our task it is important to know how energy is distributed between the lobes to choose a setting for observations in an optimum manner, taking into account the signal-to-noise ratio. Information about the variation of the AP with wavelengths of observations is still more important. Correlation characteristics of the AP are also of interest. These questions will be discussed in later papers.

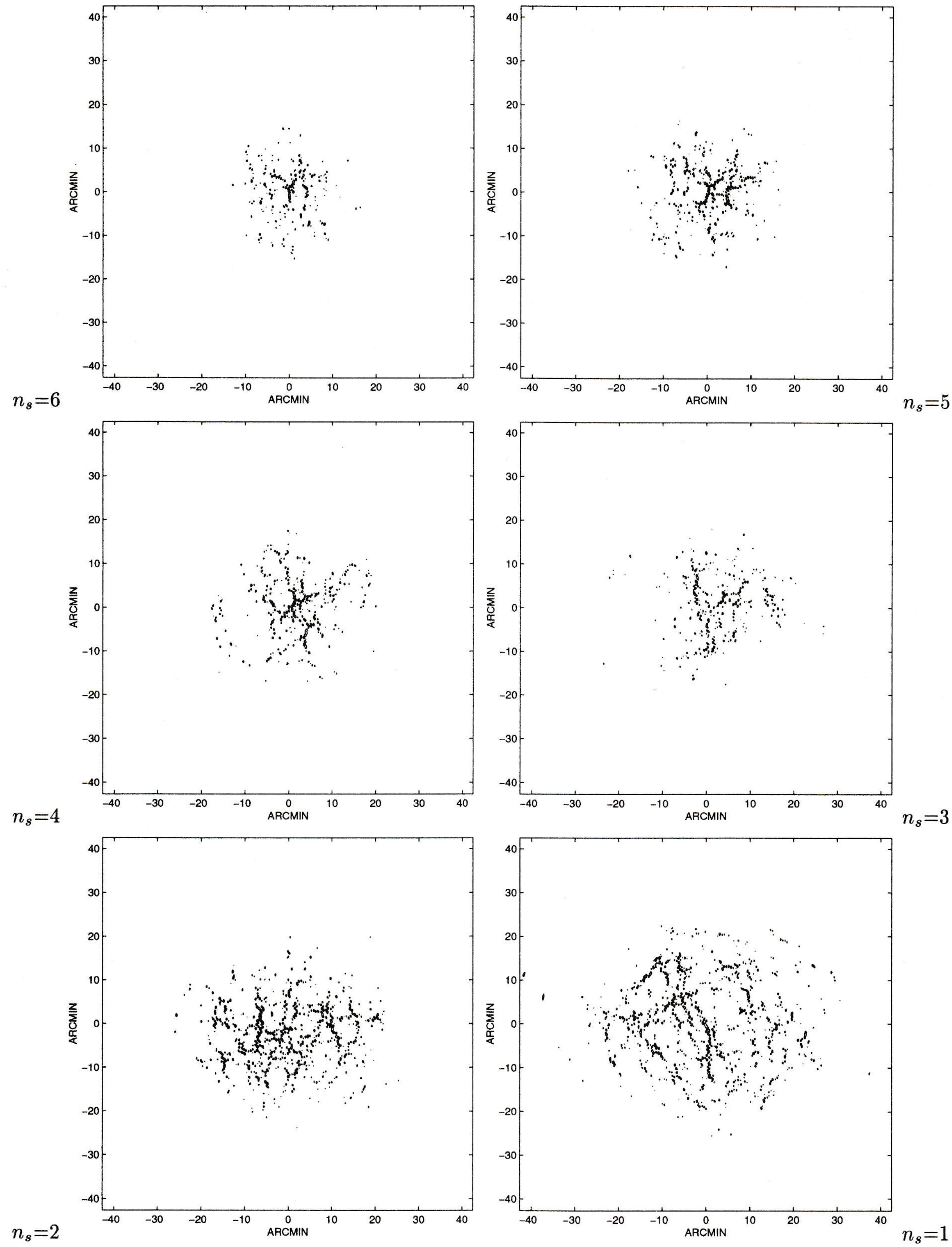


Figure 7: *The beam patterns for settings with a random phase distribution with different number of panels in phased groups.*

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