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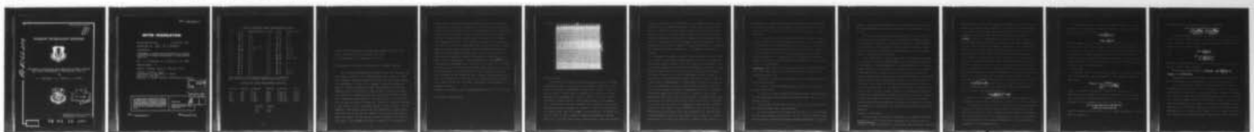

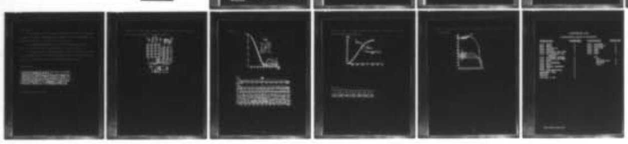

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EXPERIMENT OF DEVELOPING TWO-DIMENSIONAL ANTENNA LATTICES WITH RANDOM ARRANGEMENT OF TRANSMITTERS (PART II)

By

L. L. Bazerlyan, G. A. Inyutin, L. G. Sodin

FOREIGN TECHNOLOGY DIVISION

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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

EXPERIMENT OF DEVELOPING TWO-DIMENSIONAL ANTENNA LATTICES WITH RANDOM ARRANGEMENT OF TRANSMITTERS (PART II)

L. L. Bazerlyan, G. A. Inyutin, L. G. Sodin

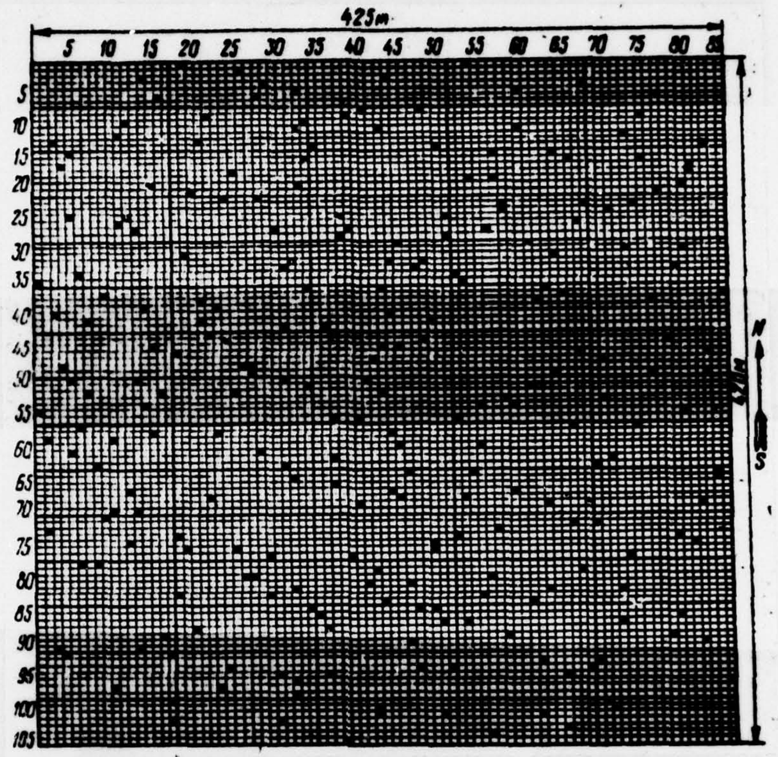
Configuration of lattice and arrangement of antenna elements

The rarefied antenna-lattice described below was developed with the purpose of using it in a radiotelescope with a range of 20-40 MHz. Wide-band vibrators, described in [1], are used in the antenna as transmitters. The beam of the antenna is guided electrically along two angular coordinates; along one coordinate (v) the beam swinging sector was selected as equal to ± 1, and along the second (u) - ± 0.707. In connection with this, we took the initial lattice with a distance between units of 4 m (along v) and 5 m (along u)[1]. This was done so that the antenna had a monolobe DN (voltage divider) on the shortest wave in the entire sector of beam swinging. The dimensions of the lattice along both axes were taken as nearly identical (425 and 420 m), and the number of units was, respectively, N_1=105 and N_2=85. The full number of units N_1N_2=8925. The level of side lobes of the antenna were taken as equal to 1% according to power (z=0.1). Here, we take these criteria for levels: the number of emissions in each cross section of the DN above level z=0.1 must average 5-10. In connection with this requirement, it was determined, according to the formulas in part I, that M=250 is sufficient. Actually, 256 transmitters are arranged in the area of the antenna. The arrangement was done in the following manner. All the units of the lattice are treated sequentially line by line from left to right. Here, the numbers from the table of random uniformly distributed numbers [2] are compared for each unit. If it turns out that for each unit the previously gathered combination of numbers was compared with the probability of its occurence near value $\frac{M}{N_1 N_2}$, then a vibrator is positioned in it. After all 256 transmitters were thus arranged, about 20% of them were removed, since several close groupings were formed in the distribution of the vibrators. They were again arranged on the lattice in such a manner that, wherever possible, the fluctuations of vibrators in the main and diagonal directions were smoothed out. The final distribution of transmitters is given in Figure 1.

Footnote: Coordinates u and v were determined in part I of the work.

See Figure 1 on next page.

Figure 1.



Antenna Scheme

Time systems of phasing, which permit accomplishing frequency-independent control of the beam, were developed in the use of antennas with regular arrangement of transmitters [3,4]. As shown in [5], the use of a tier scheme of addition and phasing of signals together with nonsynchronous change of phase in the tiers permits substantial simplification of the antenna scheme. Unfortunately, it is impossible to use the sequential tier structure of the scheme for non-equidistant antennas. An analysis of the many variations of the scheme showed that the optimal is the following. The entire lattice is split up into a number of identical rectangular sections (see Fig. 1), so that there were, on the average, about four elements in each of them. All the transmitters in a section were then added and phased to its geometric center. In other words, the scheme of phasing a section is accomplished so that, in any direction of the beam, the phase of its total signal equals the phase of the hypothetical transmitter installed in its center. After this, the entire antenna is equivalent to the system with regular arrangement of the transmitters, the number of which is equal to the number of sections, and phasing can be done according to the principles described in [3,4,5].

The number of sections equalled 75 (5 per u and 15 per v). Figure 2 gives the circuit of phasing signals in one of the sections. The circuit ensures control of the beam along two coordinates u and v, in which regard, along each of the coordinates, the beam is independently controlled. For this, there are separate phase shifters[1] for u and for v, each of which is dependent on a full sector of changing the corresponding coordinate. The phase shifter in Fig. 2a ensures addition and phasing of transmitters #'s 157, 158, 159, and 160, the arrangement of which in the section is shown in Fig. 2b. In the first stage, the phases of transmitters are fed by separate commutated delay lines to the phase of a vertical line, passing through the geometric center of the section. The corresponding delay lines have five binary digits, which gives 32 positions of the beam of a section in the sector $-0.707 \leq u \leq 0.707$. After phasing with respect to u, the signals of the transmitters Nos. 159 and 160 are added (these transmitters lie on one horizontal) and further three five-digit delay lines phase the section with respect to v. All the transmitters are joined with the phase shifters of the sections by oscillations of equal length, and the difference in average lengths of the phase shifters of the sections are compensated by the additional lengths of cable which are included at the outputs of the sections.

An alternative to that described can be the system of phasing without dividing the phase shifters along u and v. A phase shifter of a transmitter with coordinates (k, l) here must be controlled by a signal proportional to (ku+lv). This system gives some economy (by approximately 1.7 times) of the delay cable and commutating elements, although the complexity of the formation of the control signal (it depends on the transmitter's coordinates) makes the use of the system difficult.

Footnote 1: Phase shifters of the discrete-binary commutation type with cable delay lines use a high-frequency relay RES-8 as the switching elements [4].

Phasing of signals of the sections is move expediently done in the following manner:

a) groups of five contiguous sections along v are added and phased ("pentads");

b) groups of three "pentads", forming a column along coordinate v, are added and phased, and here the entire antenna leads to five columns along v;

c) two outer columns from the left and two outer columns from the right are added and phased together;

d) three sublattices are added and phased, two of which consist of two columns each, and the third - of one. Since all these systems are constructed according to those principles described in [3,4,5], there is no detailed information on them here; let us only note that the full number of phase shifters necessary for controlling a beam is 97.

We must note that since individual phasing of the signal from each transmitter is necessary in a nonequidistant lattice, the required amount of cable and switching relays depends on the selection of addition and phasing scheme. For the studied antenna, a delay cable of 22.5 km, a commutation cable of 13.4 km, and a commutation relay of 1915 pieces are required.

It is interesting to compare them with the corresponding values in equidistant T-shaped antenna which is most economical according to the number of antenna elements. A T-shaped antenna which is equivalent according to resolution must consist of an arm with 85x2=170 transmitters along coordinate u and an arm with 105 transmitters along coordinate v; in all, it must contain 275 elements. The optimal phasing system of this antenna must consist of 69 phase shifters. For that, a delay cable of 4.5 km, a commutation cable of 13.4 km, and a commutation relay of 1915 pieces are required. A comparison of the data shows that the phasing system of a nonequidistant antenna is much more complex than a system of phasing of a T-shaped (antenna). But this deficiency in a number of cases is not resolving since a nonequidistant lattice, according to several parameters (see below), has advantages in comparison with the maximally rarefied equidistant antennas.

Diagrams of Directivity

For the studied lattice, we computed, on a computer, six cross sections of a DN[1]: two main cross sections, two diagonal, and two

Footnote 1: Here, transmitters of the lattice are proposed as isotropic.

intermediate. The DN's (with respect to field) are given in Fig. 3a (field of main lobe) and 3b (field of side lobes). Along the x-axis we set sines of the angles between the direction in space and the normal to the lattice plane (for wave 10 m f=30 MHz), equal to $\sqrt{u^2+v^2}$. Each DN is constructed for half of its period (the DN is the odd function relative to the direction of the main maximum). On all the graphs we denote the average (according to the given realization) values of the level of the field (level z, fig. 3b). It is apparent that the main lobes of all cross sections coincide with high accuracy. In the region of side lobes, the DN's are approximated by the selective functions of the Rayleigh random process. In support of this, in Figure 4 we have constructed curves of accumulated frequencies for cross sections V and VI; also there, we give the integral curve of Rayleigh distribution. The selected dispersions $\hat{\sigma}_2$ for each cross section are computed according to the average quadrant and the average value of the DN. Both variations of calculations $\left(\bar{z}=\sqrt{\frac{\pi}{2}}\hat{\sigma};\ \bar{z}^2=2\hat{\sigma}^2\right)$ gave values $\hat{\sigma}$, differing by no more than 4%. We further used values $\hat{\sigma}$, determined by $\overline{z^2}$. Theoretical values for the antenna with $N_1N_2=8975$, $M=256$

$$\sigma=\left[\frac{N_1N_2-M}{2M(N_1N_2-1)}\right]^{1/2}=0{,}044.$$

A comparison of the selected dispersions with the theoretical values is given in Table 1 (index indicates the number of the cross section).

The dispersions which are low in comparison with the calculated data in the main and diagonal cross sections are explained by the fact that correction of the arrangement of transmitters was conducted so that the density of the transmitters in these cross sections was more uniform. On the whole, coincidence of σ with statistical calculation is sufficiently good.

The anticipated average number of emissions from the DN above level z=0.1 for each cross section is equal [see (12), Sodin article, part I, in this issue]:

$$\bar{n} = \sqrt{\frac{\pi}{12} N_1 N_2} \frac{z}{\sigma} \times$$
$$\times \exp\left(-\frac{z^2}{2\sigma^2}\right) \approx 8.$$

There are practically no emissions in cross sections I, II, and IV of the DN above level 0.1 (emissions with $u<0.06$ are connected with the average DN which has the first side lobe 0.21, the second - 0.14 with respect to field); in cross sections III, V, VI the number of emissions equals, respectively, 3, 8, and 7; these data also support the correctness of the basic hypotheses made with the conclusion of formulas of the preceding article.

Directive Gain

Directive gain of a nonequidistant antenna with random arrangement of transmitters can be calculated in the following manner. By determining

$$D(u_0, v_0) = \frac{4\pi F(u_0, v_0)}{\iint\limits_{u^2+v^2<1} F(u, u_0, v, v_0) \frac{du dv}{\sqrt{1-u^2-v^2}}},$$

where F - diagram of directivity according to power, u_0, v_0 - direction of main maximum of DN. Let us indicate $F_И$ for DN (according to power of the single transmitter, F_p for DN of lattice multiplier. DN of the antenna will be put in the form

$$F(u, v) = F_и(u, v) F_p(u-u_0, v-v_0) = F_и(u, v) \times$$
$$\times [\bar{F}(u-u_0, v-v_0) + \Delta F(u, v)].$$

Here $\bar{F}$ - average DN, equal to the DN of a filled lattice, ΔF - fluctuation component.

With respect to this expression for the DN we obtain

$$D = \frac{1}{\frac{\int \overline{F}_{\text{и}} \overline{F}_{p} \frac{du dv}{\sqrt{1-u^2-v^2}}}{4\pi F_{\text{и}}(u_0, v_0)} + \frac{\int \overline{F}_{\text{и}} \Delta F \frac{du dv}{\sqrt{1-u^2-v^2}}}{4\pi F_{\text{и}}(u_0, v_0)}}.$$

Without noticeable errors on the strength of the ergodicity of the DN (see Sodin article, part I of this issue)the averages, according to space and set, coincide, and in the second component we can denote ΔF by its average value

$$\overline{\Delta F} = \frac{N_1 N_2 - M}{M(N_1 N_2 - 1)}.$$

Then

$$D = \frac{1}{\frac{1}{D_0} + \frac{N_1 N_2 - M}{M(N_1 N_2 - 1)} \frac{1}{D_{\text{и}}}},$$

where $D_{\text{и}}$ - directive gain of a single transmitter, D_0 - directive gain of a fully filled antenna.

For strongly rarefied antenna $(N_1 N_2 \gg M)$ $D_0 \gg \frac{M(N_1 N_2 - 1)}{N_1 N_2 - M} D_{\text{и}}$ and $D \approx M D_{\text{и}}$. With $M \to N_1 N_2$ $D \to D_0$.

Physically, the latter equation is explained by the extremely weak interconnection of transmitters in the rarefied lattice.

For an illustration, Figure 5 gives the values of D for the developed antenna with λ=10 m. As a transmitter we took a dipole, positioned at a height of 2.92 m above the ideal screen. This figure also gives the directive gain values computed in [6] of the two arms of a T-shaped antenna with the same resolution power at the same elementary transmitter. As is known, in modulation conditions the directive gain of a T-shaped antenna is equal to the average geometric directive gain of the arms. From Figure 5 it is apparent that there are advantages of antenna with random arrangement of the elements.

Conclusions

1. Calculation of the DN of concrete realization of a rarefied antenna with random arrangement of elements showed coincidence with the theory given in the first part of the work.

2. The developed variation of phasing transmitters which is close to optimal permitted constructing an antenna scheme.

3. Directive gain of nonequidistant antenna proves to be higher than directive gain of a T-shaped antenna which is equivalent with respect to width of the beam by approximately two times.

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Submitted March 16, 1971

Figure 2. Key: 1 - transmitter; 2 - output; 3 - phase direction; 4 - control along u; 5 - control along v.

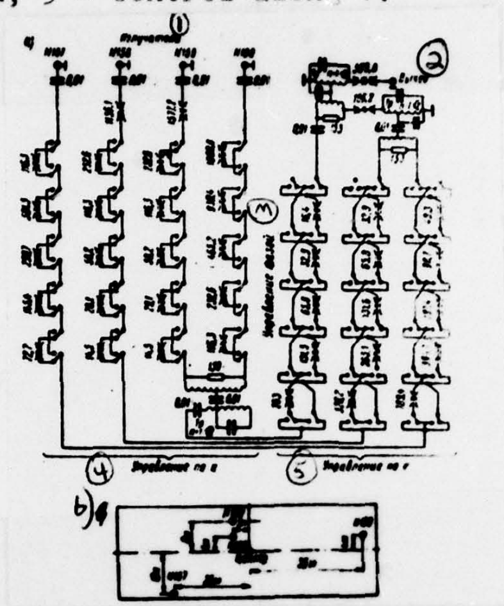


Figure 3.

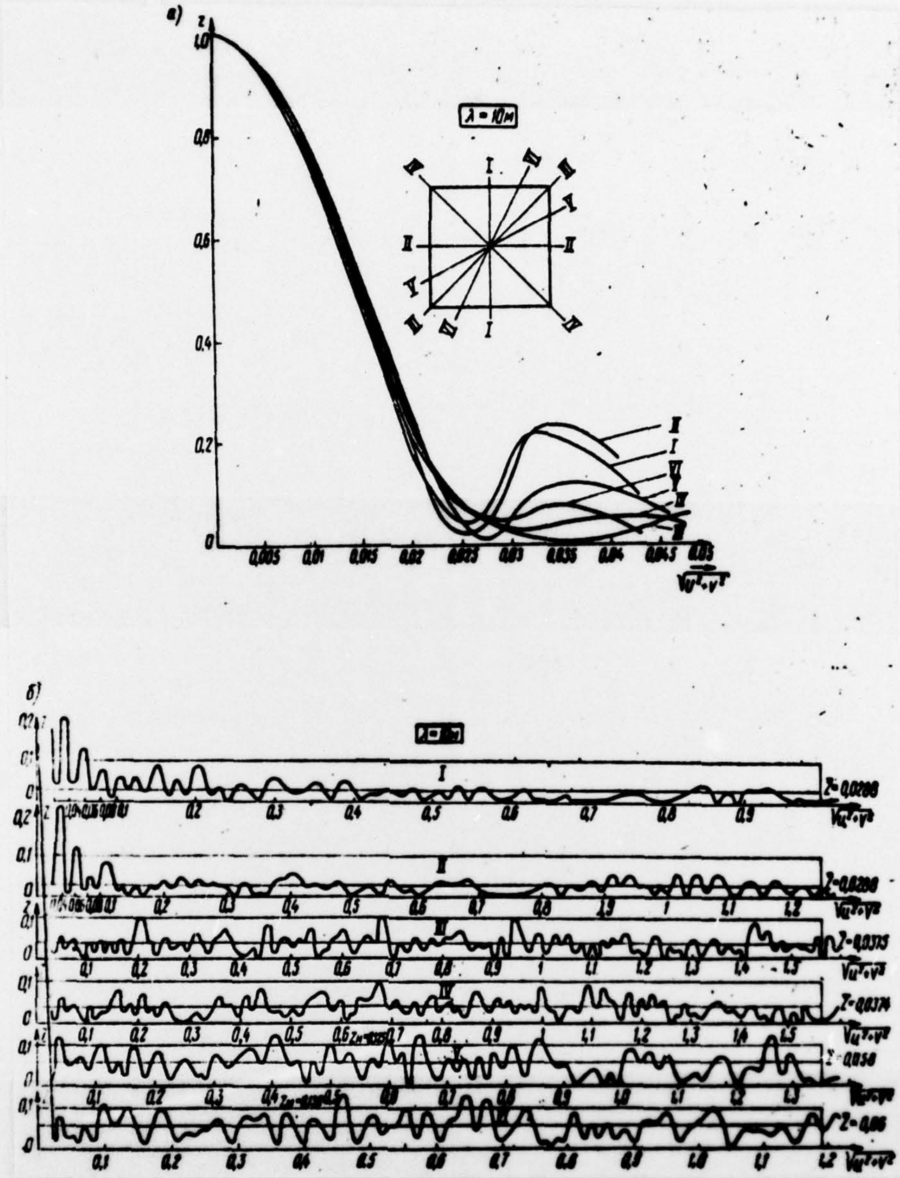


Figure 4. Key: 1 - cross section V; 2 - Cross section VI; 3 - Rayleigh distribution function.

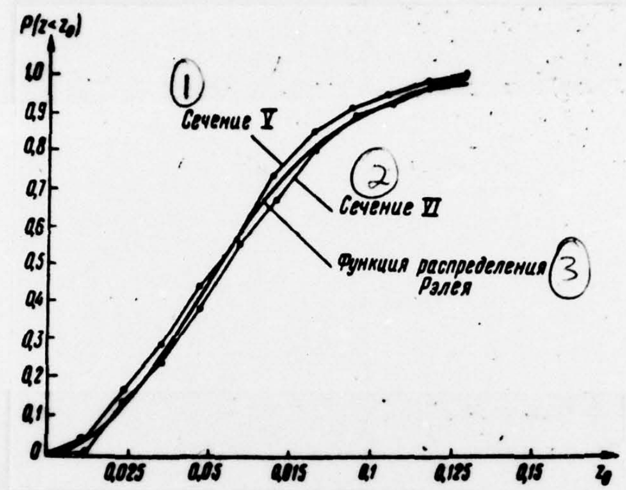
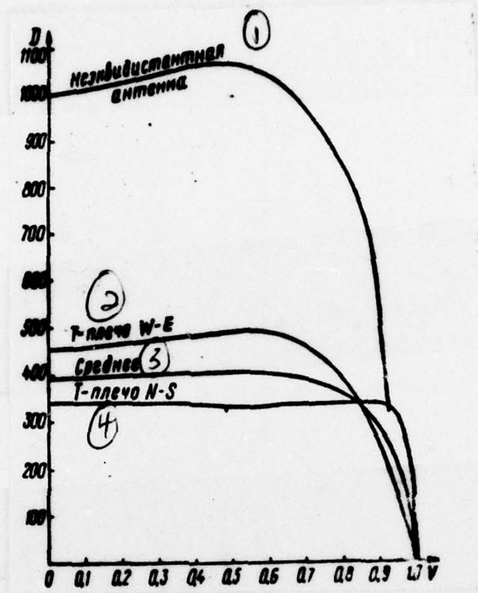


Table 1.

σ	$\hat{\sigma}_I$	$\hat{\sigma}_{II}$	$\hat{\sigma}_{III}$	$\hat{\sigma}_{IV}$	$\hat{\sigma}_V$	$\hat{\sigma}_{VI}$
0,044	0,028	0,027	0,030	0,029	0,047	0,046

Figure 5. Key: 1 - nonequidistant antenna; 2 - T-arm W-E; 3 - average; 4 - T-arm N-S.



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