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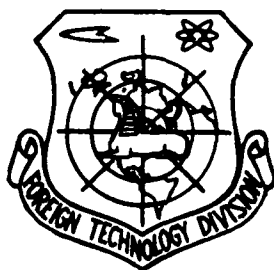# FOREIGN TECHNOLOGY DIVISION

ANTENNA ARRAYS WITH INCREASING ACCORDING TO ARITHMETICAL PROGRESSION
DISTANCES BETWEEN THE EMITTERS

by

Yu. M. Zhidko

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PARTIALLY EDITED MACHINE TRANSLATION

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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

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc.
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Antenna arrays with increasing according to arithmetical progression distances between the emitters [1].

FOOTNOTE [1]. Article is written on the base of the report, made at session of scientific-technical society of radio engineering and electronics im. A. S. Popov in June 1961. ENDFOOTNOTE.

Yu. M. Zhidko.

The results are analysed of the numerical computation of radiation patterns for the antenna arrays with the distances between isotropic radiators increasing from the antenna center to its edges according to arithmetical progression.

Antenna array from equidistantly arranged/located isotropic emitters, distances between which $d_0 \sim \lambda$ (λ - wavelength), has, as is known, number of deficiencies, connected with presence in its diagram of interference maximums of higher orders. The interference maximums of higher orders can be "suppressed", if we utilize the directed emitters. It is natural that the formation of single-lobe diagram thus is very undesirable, if antenna is intended for the wide-angle electrical scanning, since in this case the sector of scanning is limited to width of diagram of separate emitter. The greatest sector of scanning is reached in such a case, when the diagram of separate emitter is sector and is equal on the width to half of angular distance (to scale $\sin\theta$) between the neighboring interference maximums. Hence follows the known relationship/ratio between sector

of scanning Θ_c and a number of emitters N:

$$\Theta_c = (N - 1)\Delta\Theta_0,$$

where $\Delta\Theta_0$ - width of major lobe. The value of this sector with large d_0 can prove to be considerably less than π.

Since interference maximums of higher orders are caused by periodicity (equidistance) of array, then from them, and consequently, from limitation indicated it is possible in some degree to get rid of, disrupting periodicity, i.e., arranging/locating emitters nonequidistantly. This is easy to illustrate based on the example of the very simple nonequidistant array, which consists of two consecutive equidistant subarrays with an identical quantity of cophasal emitters, but with the different periods d_1 and d_2. The zero interference maximums of subarrays coincide, and rest diverge (if $d_1 \neq d_2$). As a result the minor lobes of total diagram are approximately two times less than the basis, while during the equidistant arrangement/position they are equal to fundamental.

Dividing/marking off array to larger number of subarrays with different periods and passing in limit to case, when number of subarrays coincides with number of emitters, we can even more strongly suppress minor lobes. In this case, naturally, the problem about the most optimum arrangement/position of emitters on the fabric of antenna arises.

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The criteria of optimality can be different. It is possible, for example, the problem about finding of optimum antenna array to formulate in the following form: is assigned size of line-source antenna L, it is required to place on it N identical cophasal emitters in such a way, that on the fixed/recorded side-lobe level in the assigned sector of angles [1] the width of major lobe would be minimum.

FOOTNOTE [2]. This sector can contain the part of the region of the complex angles |sin 0|>1 in the general case. Inclusion of the region of complex angles gives the possibility to pass from the known solution of problem with the cophasal distribution of the emitters (ray/beam is oriented perpendicularly to the axis of antenna) to the case, when the phases of emitters are changed according to the law of the traveling wave (ray/beam is inclined toward the axis of antenna). ENDFOOTNOTE.

Finding solution of similar problems, just as synthesized problems in the case, when variations in distances between emitters are allowed/assumed, is connected with great mathematical difficulties [1,2]. Problem to the optimum can be considerably simplified, by decreasing a number of independent parameters (after applying on them any connections/communications). If we, for example, place emitters then so that the distances d_i between them would be changed according to the law of the arithmetical progression

$$d_i = d_1 \left[1 + (i - 1) \frac{x - 1}{M - 1} \right],$$

where

$$i = 1, 2, \ldots, M; \quad N = 2M; \quad x = d_M'd_1.$$

then remain two independent parameters, and at fixed/recorded L altogether only one. To the examination of the diagrams of the antenna arrays of this class in the case, when the amplitudes of currents in all emitters are identical, is dedicated this work.

It is natural that diagram of antenna, optimum among this narrow class of antenna arrays, is worse in comparison with diagram of antenna, optimum among all types of antenna arrays. However, this loss with large N in a number of cases, apparently, is small. In more detail on this we will pause below.

Diagram of one of arrays with distances increasing according to the law of arithmetical progression between adjacent emitters is given in work [3]. However, by this diagram it is difficult to judge the possibilities of similar antenna arrays, since it is designed only for one value of the parameter κ and the comparatively small number of emitters in the array (for 15 radiators). In order to explain the dependence of the degree of the suppression of interference maximums on parameter of nonequidistance and number of emitters, we produced the numerical calculation of diagrams for the different values κ and N^2.

FOOTNOTE [2]. Calculation was conducted on BESM-2. ENDFOOTNOTE.

Diagrams were computed depending on parameter $\xi = k d_0 \sin\theta$ (where

$d_0 = L/(N-1)$ - average distance between the emitters, θ - angle,

calculated from the direction, perpendicular to the axis of antenna)

in the interval - $22 \leq \xi \leq 22$.

As showed calculation, with increase/growth of κ, i.e., increase

of degree of nonequidistance, side-lobe level in interval ξ in

question at first decreases, reaching minimum with $\kappa \sim 1.8$ and then it

grows/rises (see Fig. 1) [3].

FOOTNOTE [3]. Diagrams are depicted schematically in the form of the

lines, height and abscissa of which determine respectively level and

position of the maximums of minor lobes. ENDFOOTNOTE.

Radiation patterns according to the power for $\kappa = 1.8$ and three values

N=61, 101 and 161 are given in Fig. 2. Dotted lines here noted those

values ξ, at which fall the interference maximums of higher orders

during the equidistant arrangement/position of radiators on the same

aperture.

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Dependence of maximum side-lobe level R (in interval $-22 \leq \xi \leq 22$) on

number of emitters in array is given in Fig. 3. With N=61 side-lobe level does
not exceed -10 dB, with N+161 all minor lobes are below -12 dB.

To region of real angles ($-1 \leq \sin\theta \leq 1$) in Fig. 1, 2 correspond

values ξ, that lie at interval

$$- kd_{..} \quad \vdots \quad kd_{...}$$

During the scanning by changing phase displacement between the adjacent emitters this region is moved along the axis ξ and at the angle of the slope of ray/beam φ it falls to the interval

$$kd_{v}(1 - \sin\varphi) \quad \vdots \quad kd_{..}(1 + \sin\varphi).$$
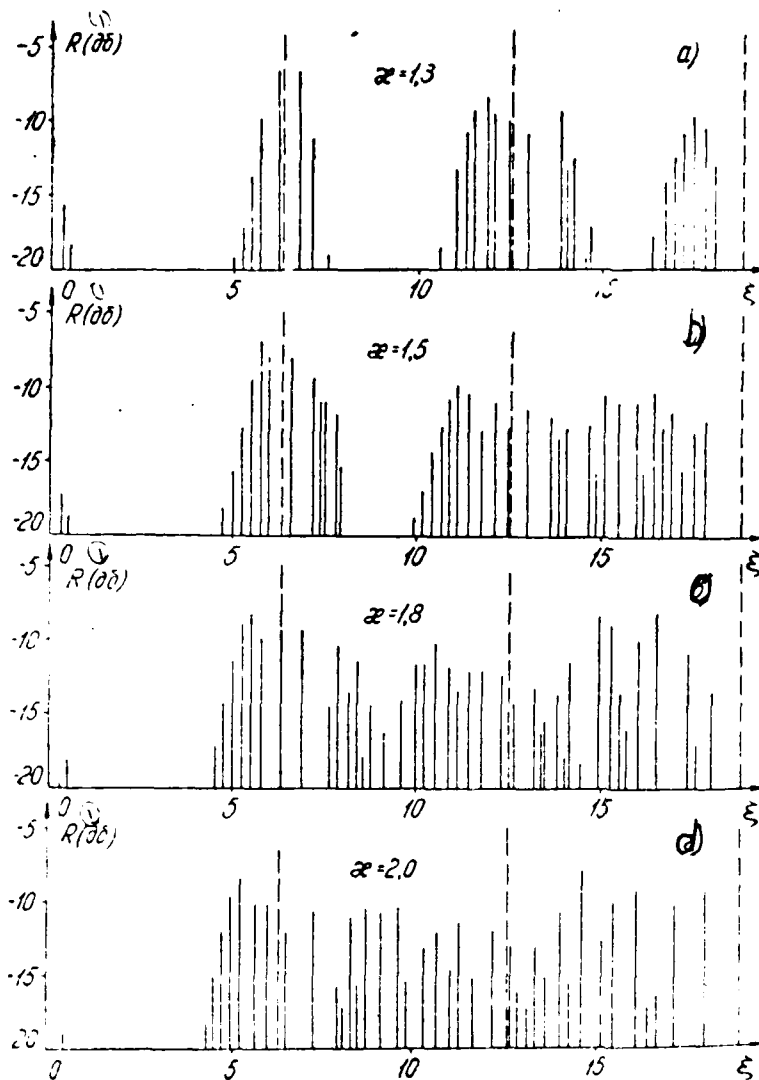
Fig. 1. Radiation patterns for different values of parameter of

nonequidistance κ at N=31.

Key: (1). dB.

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Since the graphs/curves Fig. 1 are designed for values ξ which lie

at the interval ±22, they give the possibility to determine the

diagram of cophasal array in the region of real angles for all

$d_o \leq 3.7\lambda$, and during the scanning on $\pm90°$ for all $d_o \leq 1.85\lambda$. Thus, for

example, with the cophasal emitters and $d_o = 1.85\lambda$ the region of real

angles falls to the interval $-11 \leq \xi \leq 11$, and with the beam deflection on

$90°$ to the interval $0 \leq \xi \leq 22$. Thus, with $d_o = 1.85\lambda$ Fig. 3 defines the

maximum value of the side-lobe level of diagram with beam swinging on

$\pm90°$; for example, with N=61 the side-lobe level in the sector of

oscillation $\pm90°$ does not exceed, as it follows from this graph/curve,

-10 dB. In the case of the equidistant arrangement/position of

emitters for providing the same level of side lobes (with identical

width of main beam) would be required 3.5 times more radiators. Such

gain in the number of radiators is very essential in the antennas,

intended for electric beam swinging, since with the decrease of number

of emitters the number of adjustable elements is decreased, and

consequently, is simplified control system of diagram.

Due to absence of large minor lobes nonequidistant arrays possess

one additional essential advantage in comparison with equidistant,

that consist in small change in directivity with beam swinging. This

is illustrated by Fig. 4, where is given the dependence of KND on the

angle of oscillation for the array of 101 emitters with two values of

average distance between them: 0.8λ and 1.3λ. Broken curves

correspond to the equidistant location of emitters, and continuous -

nonequidistant ($\kappa = 1.8$). As can be seen from these curves,

average/mean value of KND in the sector of oscillation $\pm90°$ is

identical with accuracy to several percent and is determined only by a
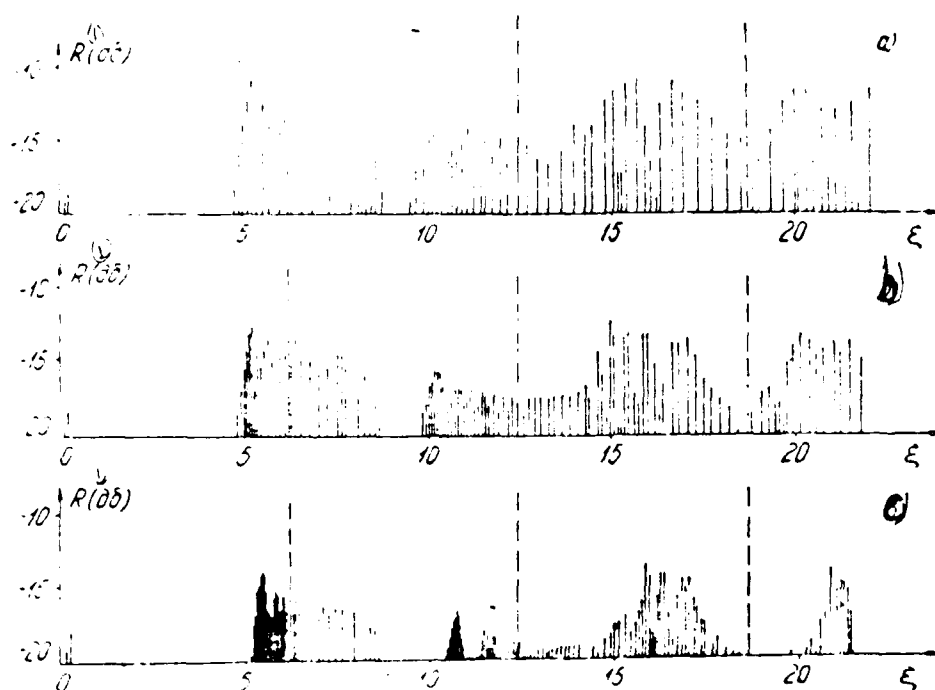
number of emitters in the array.

Fig. 2. Radiation patterns of nonequidistant antenna arrays with
N=61, 101 and 161 with optimum value κ=1.8.

Key: (1). dB.

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During nonequidistant location of emitters is smoothed dependence
of directivity on frequency (see Fig. 5). At first with an increase
in the frequency directivity increases, as it takes place also for the
equidistant array (dotted line); after achieving maximum, directivity
slightly falls to value, equal to a number of emitters in the array,
and then virtually it remains constant. During the equidistant
arrangement/position the directivity sharply is changed with a change
in the wavelength, which is connected with the advent in radiation
pattern of the interference maximums of higher orders.

One should note that during examined by us nonequidistant arrangement/position of emitters somewhat is expanded major lobe (in comparison with equidistant arrangement/position with the same L and N). This is explained by the fact that the averaged amplitude distribution during this arrangement/position drops to the edges of aperture and, consequently, decreases the effective size/dimension of antenna.
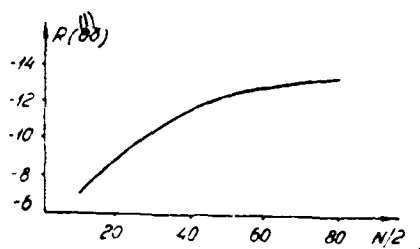
Fig. 3.   Fig. 4.

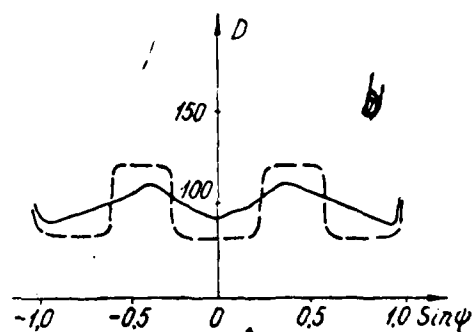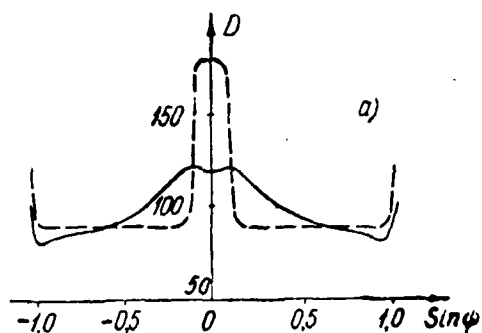Fig. 3. Dependence of maximum side-lobe level R on number of emitters
in array.

Key: (1). dB.

Fig. 4. Dependence of directivity on angle of slope of ray/beam of
equidistant (broken line) and nonequidistant (solid line) of antenna
arrays of 101 emitters: a) with average distance between emitters
$d_o=0.8\lambda$; b) with $d_o=1.3\lambda$.

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The dependence of the broadening of major lobe $\Delta\theta_i\Delta\theta_u$ (where $\Delta\theta$ and
$\Delta\theta_o$ - width of lobes along the level of half power during the
nonequidistant and equidistant arrangement/position respectively) for

N=21 is given in Fig. 6.

    With $d_0 < \lambda/2$ diagram of equidistant array does not contain interference maximums and side-lobe level is determined by first minor lobe.
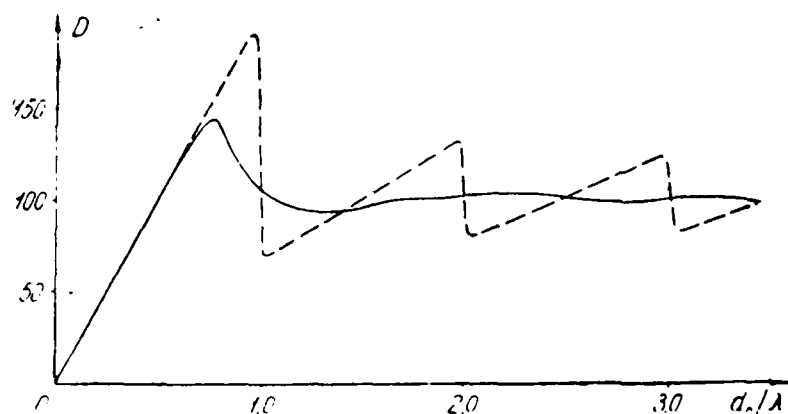
Fig. 5. Dependence of directivity on frequency for equidistant
(dotted line) and nonequidistant (solid line) antenna arrays of 101
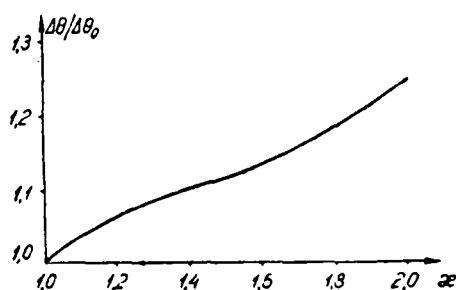emitters.

Fig. 6.

Fig. 7.

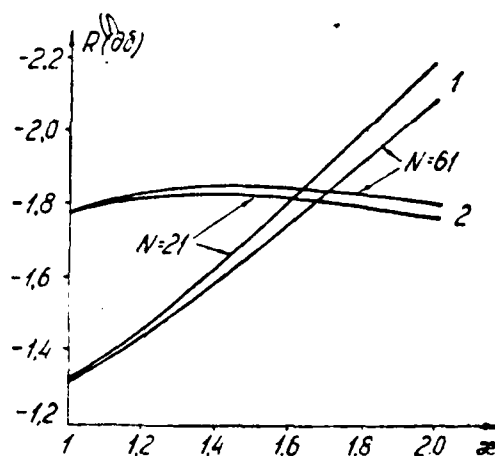Fig. 6. Dependence of broadening of major lobe on parameter κ.

Fig. 7. Dependence of levels of first two greatest minor lobes of
diagram on κ.

Key: (1). dB.

Page 1150.

With the increase/growth of κ the value of first minor lobe 1 rapidly
decreases (see Fig. 7), while second lobe 2 is almost unchanged. With
$\kappa \sim 1.6$ both lobes are located on the level -18 dB, which is 5 dB lower
than during the equidistant arrangement/position of emitters. Thus,
the nonequidistant location of emitters can be used for the
suppression of minor lobes not only for large d_0, when there is a
series/row of interference maximums, but also with $d_0 < \lambda/2$.

It is natural that arrangement/position of emitters according to
the law of arithmetical progression is not optimum, since diagram of
optimum array must contain N identical minor lobes of maximum level
[1]. However, with $\kappa \sim 1.8$ the diagrams of the antenna arrays in
question have with sufficiently large N and d_0 very large number
(order N) of close in level lobes. This gives grounds to assume that
the arrangement/position of radiators according to the law, closer to
the optimum with large N and d_0, will not lead to the considerable
(more than on 2-3 dB) decrease of side-lobe level.

Author is grateful to T. N. Fedoseyeva, who participated in
numerical calculation of diagrams, given in work.

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