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CONSIDERATIONS FOR FAR-FIELD ANTENNAS TEST

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Abstract—*The theoretical foundations of testing antenna parameters and characteristics in the far radiation field are presented. A two-beam model of radio wave propagation was used, including a direct wave and a wave reflected from the earth's surface. This model meets the conditions for carrying out measurements on a signals training areas or in an anechoic chamber. It is shown that for a given distance between the antennas, it is necessary to control the dimensions of the aperture transmitting and receiving antennas for the compliance with the maximum permissible values. Formulas for determining the permissible dimensions of the antenna aperture are obtained. The influence of the antenna hanging heights on the measurement accuracy was also investigated. Recommendations for reducing the level of electromagnetic waves reflected from the earth's surface are given.*

Index Terms—Antenna; signals training areas; aperture dimension; wave interference.

I. INTRODUCTION

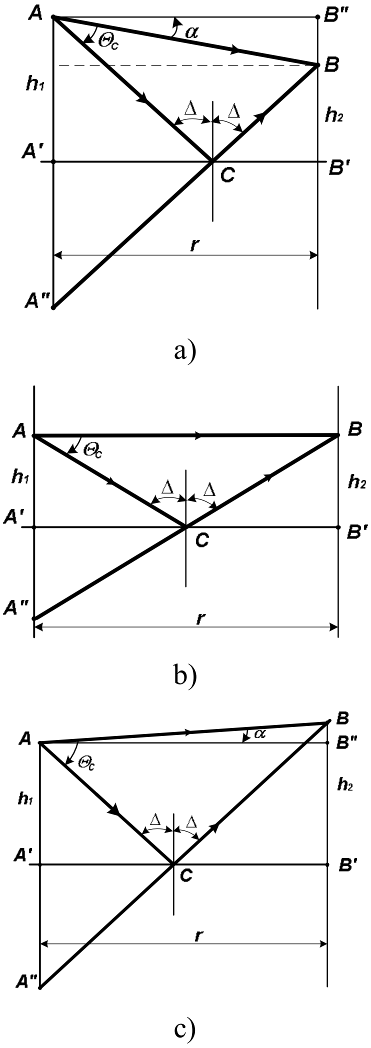
The rapid development of electronics and telecommunications has led to the emergence of many antenna devices and systems, which largely determine the efficiency of the communication, navigation and surveillance systems.

The test of antennas in the signals training areas makes it possible to define the parameters and characteristics of antennas with sufficient accuracy upon condition of the correct organization of experiments [1], [2]. The article discusses questions that affect the accuracy of research results.

II. PROBLEM STATEMENT

Signals training areas are free from any buildings, tall shrubs, trees and other possible reflectors of radio waves. Research on radio equipment, including antenna devices, reflective surfaces, etc., is carried out at radio training area. Under these conditions, it is necessary to take into account the possibility of radio waves propagation by two trajectories: direct beam and reflected from the earth's surface. There are three possible cases of radio wave propagation schemes, which differ only in the mutual hanging heights of the antennas (Fig. 1).

Suppose that at point *A* (Fig. 1) is a radiating antenna, and at point *B* is the studied antenna. The installation height of radiator in point *A* is denoted as h_1 and the height of the antenna at point *B* as h_2.



a)

b)

c)

Fig. 1. Two rays interference model

Mirror image at point A'' of transmitting antenna places on the distance $A'A''=h_1$. At point *C*, the beam is reflected from the earth's surface and propagates to the test antenna. It is obvious that the reflected beam interferences with direct beam causes undesirably changes in the field intensity at the receiving point.

The most radical way to get rid of this beam is to use an absorbent material with an area equals to the first few Fresnel zones. This method is costly but effective.

The second method is based on the guiding properties of the antennas. Let assume that the electromagnetic wave radiator is directed so that the pattern maximum coincides with the direction to the phase center of the studied antenna, that is with the beam *AB* (Fig. 1). Under this condition, at point *B*, error due to multipath can be avoided. The realization of second method is considered in article.

III. THEORETICAL BASIS

The intensity of the reflected wave depends on the pattern and angle θ_c in Fig. 1. Let consider cases of antenna mutual arrangement: $h_1>h_2$; $h_1=h_2$ and $h_1<h_2$. The distance between the antennas r at points *A* and *B* must meet the requirements for the formation of the antenna radiation field. At a given value r, can be found a limit to the maximum dimension of the transmitting antenna aperture.

Dependence of maximum aperture dimension from distance between antenna and reference point is found using known method [3] of antenna theory according to which aperture is represented as aggregate of elementary radiators. Each elementary radiator creates in reference point the field with density $d\dot{E}$, which phase factor is e^{-ikr_s}, where r_s is a distance from aperture element to reference point; $k=2\pi/\lambda$ is a wave number; λ is a wavelength.

Figure 2 shows the aperture AA' of the radiator and two rays *AC* and *OC*. The ray *AC* is formed by elementary radiator, placed on the aperture edge (distance $L/2$ from aperture center). The second ray represent radiation of the elementary radiator at point *O*. Let assume that all elementary radiators are fed in phase and amplitude distribution is uniform. At this the total field intensity vector in reference point is defined by phase relations, which is defined by rays lengths r and r_A.

Phase shift is equal to

$$\psi = k(r_A - r) = k\sqrt{\frac{L^2}{4} + r^2} - kr. \qquad (1)$$

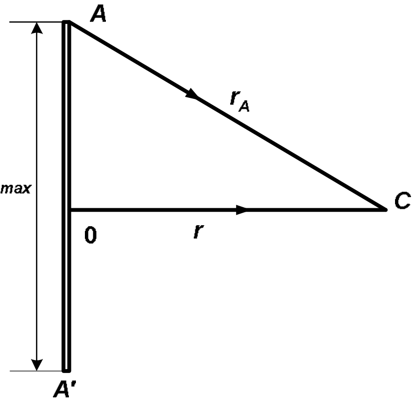


Fig. 2. To determine the maximum permissible size of the transmitting antenna aperture

Let assume that when the phase shift ψ is less or equal to a small value δ, the phase shifts can be neglected and the amplitude of the field intensity vector at point *C* is equal to the algebraic sum of the elementary intensities

$$\dot{E} = \sum_s d\dot{E}_s.$$

Substitution the selected small value δ in the equation (1) instead the phase shift ψ gives

$$\delta + kr = \frac{k}{2}\sqrt{L^2 + 4r^2}. \qquad (2)$$

The square of the right and left parts of the equation (2)

$$2kr\delta + \delta^2 = \frac{k^2L^2}{4}.$$

From the last equation, the maximum allowable dimension of the antenna aperture

$$L_{\max} \le 2\sqrt{2\frac{\delta r}{k} + \frac{\delta^2}{k^2}}. \qquad (3)$$

The value of the allowable phase shift

$$\delta = \frac{\pi}{n},$$

where *n* is a number that characterizes the maximum allowable phase shift.

Entering the number n in (3) gives

$$L_{\max} \le 2\sqrt{\frac{r\lambda}{n} + \frac{\lambda^2}{4n^2}}. \qquad (4)$$

In determining the Fraunhofer zone is often chosen $n=8$ [3]. If the second term under the root of formula (4) can be neglected, then at $n=8$ the known restriction of the minimum radius $r_{\min}$ of the Fraunhofer zone is obtained

$$r_{\min} \geq 2\frac{L^2}{\lambda},$$

here λ is a wavelength.

Since the receiving antenna at point *B* may have a significant aperture size, in this case it is necessary to make correction in the aperture dimension determined by formula (4).

If during antenna measurements the distance between antennas r is small, another effect occurs, which also influences on choice of the aperture dimension. In Figure 3 the relative position of the phase center of the transmitting antenna and the aperture of the receiving antenna L_B is shown.

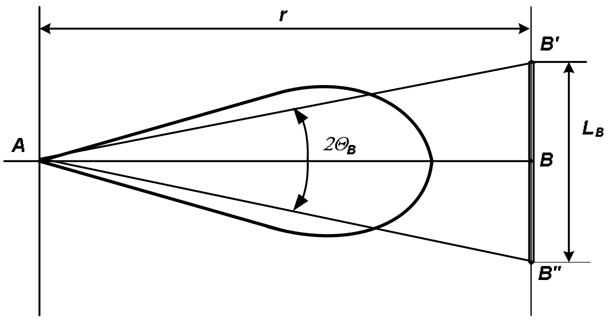


Fig. 3. To the choice of the size the receiving antenna aperture.

The limit points B' and B'' of the receiving antenna aperture are irradiated with rays at an angle θ_B to the direction of the pattern maximum. The field intensity at these points will be slightly lower compared to the aperture center L_B, that causes errors. Nonuniformity of irradiation is determined by the shape of the radiation pattern. Therefore, in the general case, the antenna pattern is written in the form of three factors

$$F_A(\theta) = F_1(\theta)F_A(\theta)F_S(\theta), \tag{5}$$

where $F_1(\theta)$ is a pattern of array element; $F_A(\theta)$ is an array factor (interference factor); $F_S(\theta)$ is a factor, which takes into account influence of a screen.

Since all the multipliers in (5) are normalized, the field intensity in point *B* is maximal and it's relative value is equal to one. Field intensity in points B' and B'' is calculated at $\theta = \theta_B$. The nonuniformity of irradiation is defined as

$$\delta_B = 1 - F_A(\theta_B).$$

If δ_B is less than the allowable value δ_{tol}, the aperture dimension determined by the formulas (3), (4) does not need to be adjusted. If $\delta_B > \delta_{\text{tol}}$ it is necessary to reduce value $F_A(\theta)$ using in the pattern product (5) the angle $\theta = \theta_B$. This reduction is achieved by choosing the aperture dimension L_A less than permissible value $L_{\max}$. If transmitting antenna is a single radiator, than exist opportunity to use the radiator with wider pattern.

This conclusion can be formalized as another requirement for the dimension of the radiator aperture

$$1 - F_1(\theta_B)F_A(\theta_B)F_S(\theta_B) \leq \delta_{\text{tol}}, \tag{6}$$

where $\theta_B = \operatorname{arctg}\frac{L_B}{2r}$.

In the engineering of antenna measurements [3], if there are no special requirements for accuracy, is chosen $\delta_{\text{tol}} = 0.01$.

Conditions (3), (4), (6) indirectly affect the possibility of reducing the intensity of the beam *ACB* reflected from the ground. Indeed, the smaller the distance r at constant heights h_1 and h_2, the greater deviation of the ray *AC* from the ray *AB* (Fig. 1).

If the ray *AB* coincides with the direction of maximum radiation, the ray *AC* will have, in any case, a lower power density than the direct ray *AB*. Therefore, the greater angle θ, the easier it is to ensure a low level of radiation in the direction of the reflection point *C* on the earth's surface.

In the first case $h_1 > h_2$ the angle θ is defined as

$$\theta = \frac{\pi}{2} - \Delta - \alpha, \tag{7}$$

where

$$\Delta = \operatorname{arctg}\frac{r}{h_1 + h_2}$$

and

$$\alpha = \operatorname{arctg}\frac{h_1 - h_2}{r}.$$

In the second case $h_1 = h_2$

$$\theta = \frac{\pi}{2} - \Delta. \tag{8}$$

And in the third case $h_1 < h_2$

$$\theta = \frac{\pi}{2} - \Delta + \alpha. \tag{9}$$

Comparing formulas (7), (8) and (9), it can be concluded that the third case of the antennas location is the most advantageous, because the angle θ at $h_1 < h_2$ obtains the greater values.

If the transmitting antenna is a low-element antenna array, its pattern is defined as the product of the radiation pattern of the array element and the array factor. When using near-omnidirectional elements of the antenna array, the intensity of the reflected wave depends to a greater extent on the array factor and the presence of the screen.

If in accordance with the formula (6) the three-element array can be used, then in the meridional plane, which coincides with the vertical plane, it is advisable to use the binomial distribution of a feed current and obtain array factor in the form

$$F_A(\theta) = \cos^2\left(\frac{kd}{2}\cos\theta\right),$$

where d is the distance between adjacent array elements.

At $d = \frac{\lambda}{2}$ the pattern of array factor has form of one major lobe without side lobes.

In a case when using conditions (3), (4), (6) the number of array elements is limited to only two elements, then as the elements of the array must be chosen radiators with a gain greater than that of a dipole. There may be Log-Periodic antenna or Yagi-Uda antenna.

The pattern factor of reflected beam in direction of reference point B (Fig. 1) is defined by the pattern of transmitting antenna and Fresnel reflection factor in point C

$$F_B(\theta_C) = F_A(\theta_C) R(\Delta, \tilde{\varepsilon}),$$

where Δ is incident angle of wave on the earth surface; θ_C is angle between direct and reflected rays; $\tilde{\varepsilon}$ is the complex dielectric permittivity of the ground in the first Fresnel zone with center in point C.

The relative value of reflected wave field intensity in point B with respect to direct wave can be found as

$$E_{\mathrm{ref}\,B} = F_B(\theta_C)\frac{\sqrt{r^2 + (h_1 - h_2)^2}}{\sqrt{r^2 + (h_1 + h_2)^2}}.$$

IV. CONCLUSIONS

Using interference model the main questions on conducting antennas far-field test in conditions of signals training area is considered.

It is shown that at given distance between antennas in order to minimize amplitude and phase errors of measurements it is necessary to compare the real apertures dimensions transmitting and receiving antennas with permissible values, which are determined by obtained formulas.

The correct choice of antenna hanging heights permits to decrease influence of direct and reflected waves interference.

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Л. Я. Ільницький, Л. В. Сібрук, І. І. Михальчук. Міркування щодо проведення дослідження антен в далекому полі випромінювання

Представлені теоретичні основи проведення досліджень параметрів і характеристик антенних пристроїв в далекому полі випромінювання. Використовувалася двопроменева модель поширення радіохвиль, що включає пряму хвилю і хвилю, відображену від земної поверхні. Дана модель відповідає умовам проведення вимірювань на радіополігоні або в безлунній камері. Показано, що при заданій відстані між антенами необхідно контролювати розміри апертури передавальної і приймальні антен на відповідність максимально допустимих значень. Отримано формули для визначення допустимих розмірів апертури антен. Також досліджено вплив висот підвісу антен на точність вимірювань. Дано рекомендації щодо зменшення рівня електромагнітної хвилі, відбитої від земної поверхні.

Ключові слова: антена; радіополігон; розмір апертури; інтерференція радіохвиль.

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Л. Я. Ильницкий, Л. В. Сибрук, И. И. Михальчук. Размышления о проведении исследования антенн в далеком поле излучения

Представлены теоретические основы проведения исследований параметров и характеристик антенных устройств в дальнем поле излучения. Использовалась двухлучевая модель распространения радиоволн, включающая прямую волну и волну, отраженную от земной поверхности. Данная модель отвечает условиям проведения измерений на радиополигоне либо в безэховой камере. Показано, что при заданном расстоянии между антеннами необходимо контролировать размеры апертуры передающей и приемной антенн на соответствие максимально допустимым значениям. Получены формулы для определения допустимых размеров апертуры антенн. Также исследовано влияние высот подвеса антенн на точность измерений. Даны рекомендации по уменьшению уровня электромагнитной волны, отраженной от земной поверхности.

Ключевые слова: антенна; радиополигон; размер апертуры; интерференция радиоволн.

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