VISIBILITY ZONE IMPROVEMENT OF DECIMETRE BAND RADAR USING SCANNING OF DIAGRAM DIRECTING

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Abstract

The paper demonstrates the theoretical possibilities for using the diagram of the control of a reflector antenna by a decimeter band far detection radar, trying to avoid the deficiencies in accompanying low-flying targets. In accordance with the theoretical part, the authors suggest practical resolutions contributing for the stable accompanying of targets flying low in the whole near-distance zone. An original method for defining the characteristics of horn feeding with plate diffusion and Fresnel's integral solution is suggested.

1. INTRODUCTION

Some of the radar's systems (RS) are used for low-flying and small-sized targets detection and tracking [3]. When creating this tape of RS the advantages of the radar's from the meter-wave band and radar's from the centimeter-wave band are taken into consideration, and at the same time lots of their disadvantages are avoided: 1) RS is compact, with a highly mobile small antenna system; 2) the position requirements of RS from the very meter-wave band are not so strict; 3) high efficiency of the system for moving targets selection; 4) small number of machines which are easy for maintenance.

These condition's, are used in the systems and mechanisms of RS of the decimeter-wave band [2, 4].

Although all the advantages of the centimeter-wave band and very meter-wave band RS, the tactical parameters of the RS from the decimeter-wave band can be improved still further and that is what we suggest and argument here.

2. PROBLEM FORMULATION

As the RS is from the decimeter-wave band, the directivity diagram (DD) is formed with the help of the ground surface. As a result of this it becomes multibeam and has

missing areas in the vertical plane. In this way at definite a miss in air targets tracking will occur. In order to avoid this, some RS antenna systems give the opportunity for controlling DD in such a way, that the missing's would be covered by the new diagram. The diagram will also have missing's, but at other distances and altitudes.

In the antenna system construction are opportunities for making some improvements that will result in changing the DD and will enforce the scanning effect. This will lead to a higher efficiency in detecting low-flying targets when all the other conditions are equal.

2.1. Mathematical hypothesis.

The construction of the antenna system of the decimeter-wave band RS with a double-floor mirror antenna is shown on fig. 1.

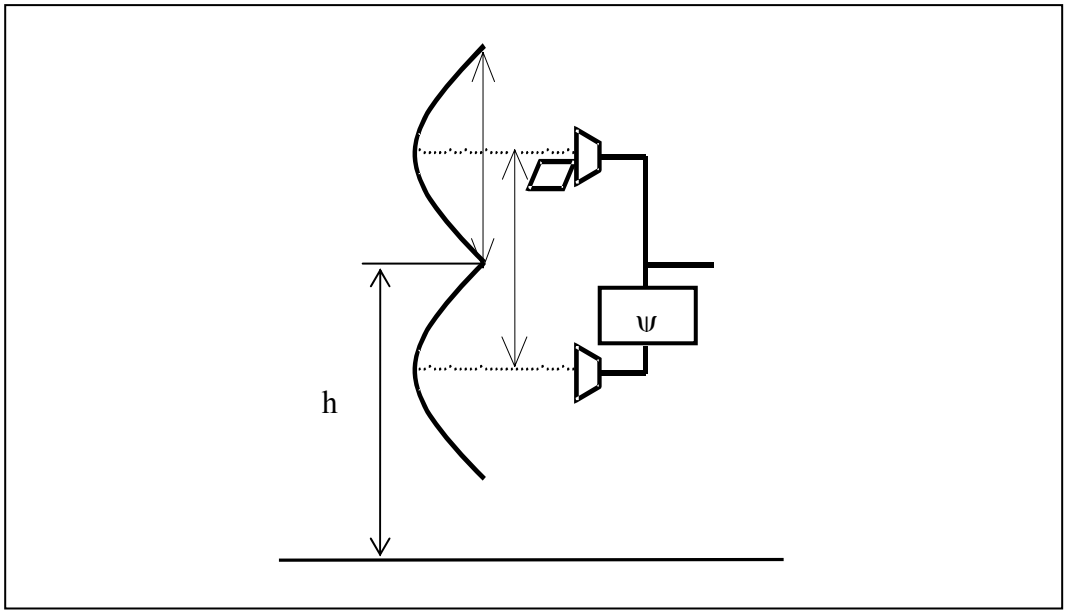

Figure 1. Antenna system of the decimeter-wave band RS with a double-level mirror antenna.

The directional characteristics (DC) of RS is expressed like this:

$$F(\theta) = \left|\left\{F_2(\theta) + F_1(\theta)\exp[j(kd_p \sin\theta - \psi)]\right\}F_3(\theta)\right| \qquad (1)$$

where $F_1(\theta)$ is the DC of the lower antenna mirror, $F_2(\theta)$ is the DC of the upper antenna mirror, d is the distance between their centers, ψ is the difference of the phases between the feeding voltages of the upper and lower antenna, $k = \frac{2\pi}{\lambda}$ is the reciprocal wavelength and λ – is the operating wavelength.

In a horizontal polarization, horizontal positioning of the antenna system focal axis and an axis-symmetric DD of the reflectors for the earth factor, the following equation is obtained [2,3]:

$$F_3(\theta) = 2\sin\left(kh\sin\theta\right) \quad , \tag{2}$$

where h is the altitude at which the reflector is situated.

Following the methodics, exposed in [2] for the DC of the lower dish antenna with horn feeding, is obtained the following mathematical equation

$$F_1(\theta) = \int_0^{R_0} \rho A_1(\rho) \int_0^{2\pi} \exp(jk\rho\sin\theta\cos\xi)\, d\xi\, d\rho \quad , \tag{3}$$

where

$$A_1(\rho) = F_p(\theta)\frac{1+\cos\theta}{2} \tag{4}$$

is the amplitude-phase field distribution in the lower reflector aperture, $\frac{1+\cos\theta}{2}$ is the multiplier of the parabolic reflector ρ and ξ are the current polar coordinates of any point of the reflector aperture with a radius R (Figure 2).

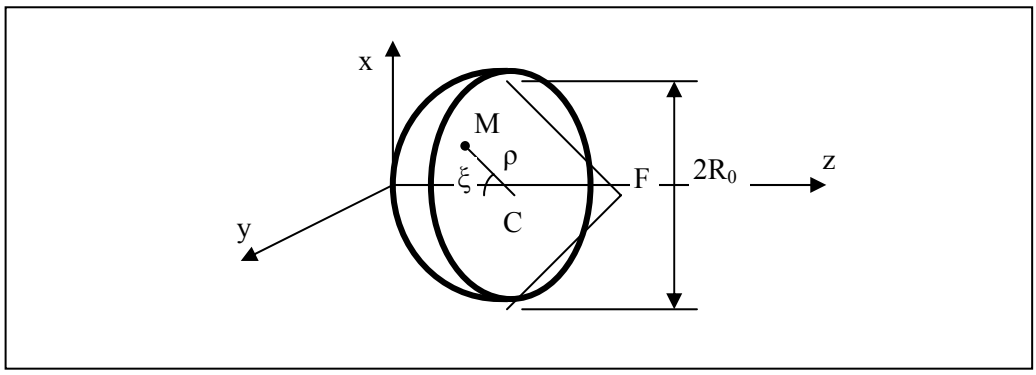

Figure 2. On defining DC of the reflector`s, composing the double-level mirror antenna.

$$F_p(\theta) = \frac{1+\cos\theta}{2} \cdot \frac{\cos\left(\frac{\pi a_p}{\lambda}\sin\theta\right)}{1-\left(\frac{2a_p}{\lambda}\sin\theta\right)^2} \tag{5}$$

is the DC of a single horn in a vertical plane (in case of horizontal polarization this is H-plane). a_p are the dimensions of the aperture in H-plane.

The DC of the upper dish antenna with horn feeding is defined by the equation

$$F_2(\theta) = \int_0^{R_0} \rho A_2(\rho) \int_0^{2\pi} \exp(jk\rho \sin\theta \cos\xi) d\xi d\rho \ , \tag{6}$$

where

$$A_2(\rho) = F_{\text{ph}}(\theta) \frac{1+\cos\theta}{2} \tag{7}$$

is the amplitude-phase field distribution in the upper reflector aperture.

DC of the horn feeding with a plate diffusion, following the methods in [1], is

$$F_{\text{ph}}(\theta) = F_{\text{p}}(\theta) + \frac{1}{\pi} \int_0^d \int_0^\alpha F_{\text{P}}(\theta).P(\theta).\exp[-jkx\sin(\theta+\alpha)] d\theta dx \ . \tag{8}$$

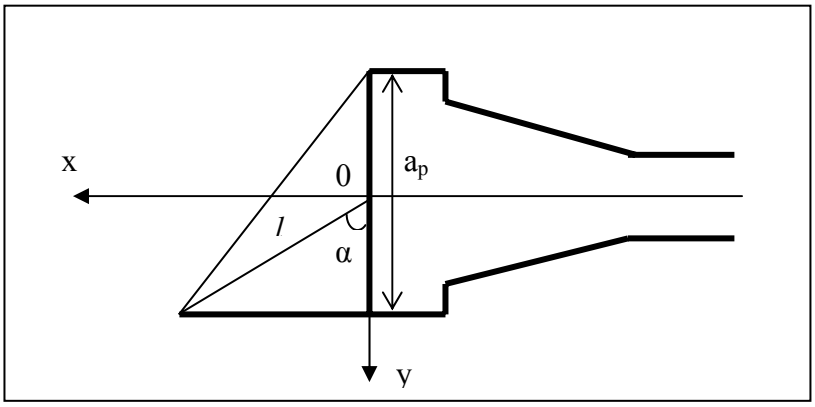

Figure 3. Horn feeding with plate diffusion.

It counts the interference of the wave, directly emitted by the horn and the wave reflected because of the interaction of the horn and the plate ; $x = 0 \div d$ is the coordinate of an arbitrary point from the plate surface (fig. 3); α - is the angle between the horn aperture plane and the line, linking its center and the farthest plate end ; l - is the distance between the horn's center and the farthest plate's end.

The characteristics of the plate diffusion, considering the interaction, is as follows

$$P(\theta) \approx -F_{\text{p}}(\theta).\Phi(u) \cdot \frac{e^{j\frac{\pi}{4}}}{\sqrt{\pi}} e^{jkl\cos(\theta-\alpha)} + \sqrt{\frac{2}{\pi kl}} \cdot P(\theta,\alpha)\left[F_{\text{p}}(\theta) - F_{\text{p}}(\pi+\alpha)\right] e^{-j\left(kl+\frac{\pi}{4}\right)} \tag{9}$$

$$P(\theta,\alpha) = \frac{1}{4\cos\frac{\theta-\alpha}{2}} \tag{10}$$

- plate's diffusion characteristics of a single plane wave, acting in direction α;

$$\Phi(u) = \int_u^{\infty} \exp(-jz^2)dz \tag{11}$$

- Fresnel's integral; $u = -\sqrt{2k\rho}\cos\frac{\theta-\alpha}{2}$ – Fresnel's integral argument.

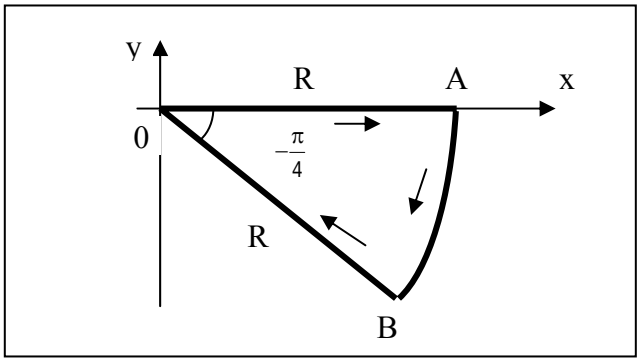

Figure 4. Method for Fresnel's integral solution.

2.2. Fresnel's integral solution.

What we suggest is an original method for Fresnel's integral solution. We use the substitution $z = v + u$, where $z = u \div \infty$, $v = 0 \div \infty$ then

$$\Phi(u) = \int_u^{\infty} \exp(-jz^2)dz = \int_u^{\infty} e^{-j(v+u)z^2} d(v+u) = \int_0^{\infty} \exp(-jz^2)dz, \tag{12}$$

where $z \in (0,\infty)$ (fig. 4).

According to the basic Cauchy's theorem for the analytical functions, applied for the closed contour OAB

$$\int_{OABO} \exp(-jz^2)dz = \int_{OA} \exp(-jz^2)dz + \int_{AB} \exp(-jz^2)dz + \int_{BO} \exp(-jz^2)dz = 0 \ . \tag{13}$$

The compound integrals have the following solutions.

For the first, considering $y = 0$ and $z = x + jy = x$, we obtain

$$J_1 = \int_{OA} \exp(-jz^2)dz = \int_0^R \exp(-jx^2)dx \tag{14}$$

For the second and third integrals we apply polar coordinates. The arc AB is defined by the equation $z = R.e^{j\varphi}$; $-\frac{\pi}{4} \le \varphi \le 0$. Then

$$J_2 = \int_{AB} \exp(-jz^2)dz = \int_0^{-\frac{\pi}{4}} \exp(-jR^2 e^{j2\varphi}).jR.\exp(j\varphi)d\varphi =$$
$$= jR\int_0^{\frac{\pi}{4}} \exp\left[R^2 \sin 2\varphi + j(\varphi - R^2 \cos\varphi)\right]d\varphi \quad . \tag{15}$$

Considering that $|j| = 1$ and $\cos 2\varphi > 0 > \frac{4\varphi}{\pi}$ when $-\frac{\pi}{4} \le \varphi \le 0$ we obtain

$$J_2 \le R\int_0^{-\frac{\pi}{4}} \exp\left(-jR^2 \cos 2\varphi\right)d\varphi < R\int_0^{-\frac{\pi}{4}} \exp\left(-j\frac{4R^2\varphi}{\pi}\right)d\varphi =$$
$$= \frac{j\pi}{4R}\exp\left(-j\frac{4R^2\varphi}{\pi}\right)\Bigg|_0^{-\frac{\pi}{4}} = \frac{j\pi}{4R}\left(e^{-jR^2} - 1\right) \tag{16}$$

The line BO is defined by the equation $z = re^{-j\frac{\pi}{4}}$; $0 \le r \le R$. Consequently

$$J_3 = \int_{BO} \exp(-jz^2)dz = -e^{-j\frac{\pi}{4}} \int_0^R \exp(-r^2)dr \tag{17}$$

and when $R \to \infty$ we apply Poisson's integral.

Considering (12) ÷ (17) we obtain

$$\lim_{z\to\infty}\left(\int_{OABO} \exp(-jz^2)dz\right) = \lim_{z\to\infty}\left(J_1 + J_2 + J_3\right) =$$
$$= \int_0^\infty \exp(-jz^2)dz + 0 - \exp\left(-j\frac{\pi}{4}\right).\int_0^\infty \exp(-jr^2)dr = F(u) - \frac{\sqrt{\pi}}{2}\exp\left(-j\frac{\pi}{4}\right) = 0 \quad , \tag{18}$$

and consequently

$$\Phi(u) = \frac{\sqrt{\pi}}{2}\exp\left(-j\frac{\pi}{4}\right) . \tag{19}$$

Substituting (19) in (9) and after reordering we obtain

$$P(\theta) \approx \sqrt{\frac{2}{\pi kl}} \cdot \left[F_{\mathrm{p}}(\theta) - F_{\mathrm{p}}(\theta-\alpha)\right] P(\theta,\alpha) \exp\left[-j\left(kl + \frac{\pi}{4}\right)\right] - \frac{1}{2} F_{\mathrm{p}}(\theta) \exp\left[jkl\cos(\theta-\alpha)\right]. \quad (20)$$

As a result of the double integral solution in the plate borders, the equation (8) looks as follows

$$F_{\mathrm{ph}}(\theta) \approx F_{\mathrm{p}}(\theta) - \frac{e^{-j2kl}}{2\pi kl} \cdot F_{\mathrm{p}}\left(\frac{\pi}{2} - \alpha\right) P(\theta,\alpha) \quad . \quad (21)$$

3. CONCLUSION

The developed theory allows F_1 (θ) = F_2 (θ) and F_1 (θ) ≠ F_2 (θ). This is acquired either by taking off the plate, which is situated under the upper reflector or by rotating it at a definite angle to the reflector. Besides, having the ability to feed the energy to the lower antenna with gradually changing difference phase, and thus we shall obtain gradual scanning of the DD. These are the advantages that we mentioned before.

The mathematical analyses shows that when we change the radiation angle of the plate α (for example by its rotation round its axis) and when we change the dephase between the feeding voltages of the two components, DD's $F_1(\theta)$ and $F_2(\theta)$ of both upper and lower antennas will change.This will result in scanning the sum DD of RS in a vertical plane and as a final result – mutual covering of the missing's for definite distances and altitudes.

Using this mathematical method a software is designed. The numerical modeling will be investigated in the future. What is interesting is investigating of DD in the borders $\theta = -10^0 \div 90^0$, that define the real positioning angles of the air targets in the observation range of a single RS.

Practical experiments are done [4], which prove the validity and worthiness of the developed theory. What is left for investigation is finding of those optimums of the variables, for which RS tracks the low-flying air targets much more efficiently.

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