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FRESNEL FLAT REFLECTOR WITH FOCUSING CAPABILITY [1]

Theoretical modeling of a Fresnel flat reflector for focusing radiation in the point near the reflector is discussed in this paper. It shows that the reflector calculated for one frequency and one focus position can also be used for other frequencies, but a focusing point should be shifted along a focusing line. Fresnel reflector can be used for a space-frequency filtration in a wide frequency range.

Keywords: *a flat reflector, focusing, Fresnel zone, broadbandness.*

Introduction

The reflectors in the satellite dish for receiving TV signals have usually the shape of a paraboloid, which is the surface obtained by rotating a parabola around its axis of symmetry [1] Usually most of the difficulties in calculations and production are compensated by high quality of an antenna. At the same time changing the frequency does not affect the focusing ability of a reflector. It is known that a flat reflector based on the band theory can also have good focusing capability [2–4]. But there is a significant drawback – it can be used effectively only at the operating frequency. The fact that the in-phase addition of the partial frequencies from alternate Fresnel's bands depends on frequency, leads to changing both a size and a form of the reflector.

For example: there is a problem of maintaining a strict parabolic form with the increase of geometric dimensions of space self-extracting antennas. It's much easier to maintain a flat form of Fresnel reflector. In this connection the question arises, what to do with the high bandwidth requirement of space communication systems, navigation and radiolocation [3–5]. It will be reported in thiswork.

Reflector's shape calculation

Let a flat wave propagates in free space with a given Decart coordinate system. It falls at a certain angle to the axis z; $k = (-k\sin\alpha, 0, -k\cos\alpha)$ – a wave vector, $k = 2\pi f/c$ – a module (Fig. 1).

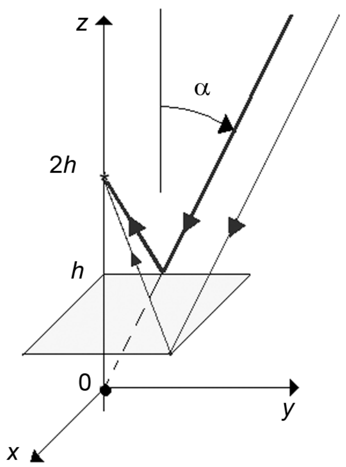

Fig. 1. Object's geometry.

The origin of the coordinates is combined with a mirror imaged point of expected focus $r_0 = (0, 0, 0)$. The reflector is located on height h. A phase shift of a center line of the reflector is zero: $\varphi_0 = kr_0 = 0$. The phase shift of the reflected wave at an arbitrary point $r = (x, y, h)$ is determined as

$$\varphi = kr + kr = k\left(\sqrt{x^2 + y^2 + h^2} - x\sin\alpha - h\cos\alpha\right).$$

Formula [3]

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$$\Delta\varphi = \varphi - \varphi_0 = m\pi\,,\ m = 0, 1, 2, \ldots$$

determines the location of Fresnel bands.

Even values correspond to in-phase zones, the odd m correspond to the antiphase ones. The shape of the zones represents ellipses. Changing the contribution of antiphase components to the opposite sign would lead to in-phase addition of all Fresnel's band. It can be done by profiling the reflector's surface (Fig. 2). It helps to increase the field intensity by 4 times in a point of focus. The focusing ability can be observed even if the antiphase zones are deleted.

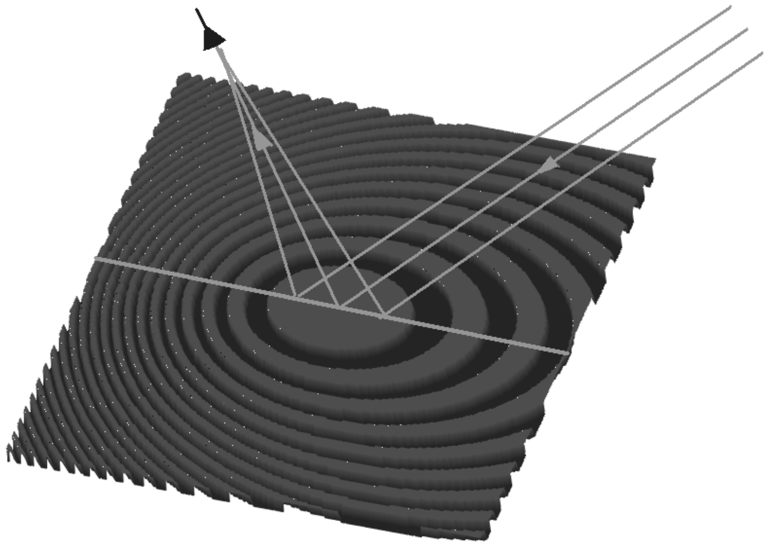

Fig. 2. The profile of the reflector.

The example of longitudinal distribution of the field intensity $F = |E(r)|^2$ in the plane of focus is presented in Fig. 3. This distribution is shown in the background of the corresponding Fresnel's zones. The point of focus is located at the origin of the coordinates. The calculations are performed for the frequency $f = 24$ GHz and the incident angle $\alpha = 45^\circ$, the height of the focus h = 15 cm. Ten zones were enough to get good focusing capability and the width of the focus area is close to wavelength $\lambda = c/f =$ 1.25 cm.

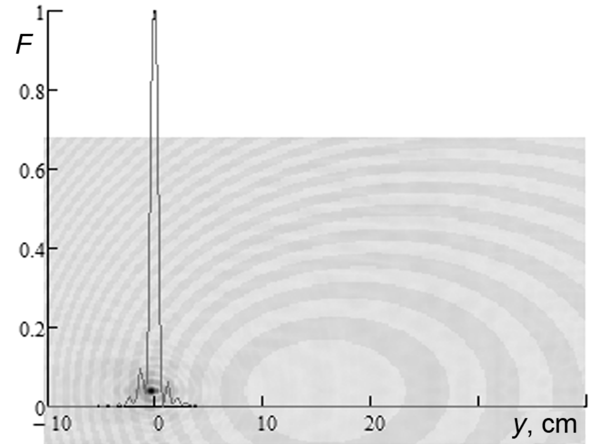

Fig. 3. Longitudinal distribution of the field intensity.

The calculation of field in the focus plane was made by a sequence of the following transformations:

The complex amplitude of the incident wave

$$E_0(r_s) = \exp\{ikr_s\}$$

was multiplied by the modulating factor $w(r_s)$ of the Fresnel reflector. If the point r_s lies within the even zones – $w(r_s) = 1$; if it lies within the odd zones – $w(r_s) = -1$; if it's outside the reflector – $w(r_s) = 0$. Then the received distribution was calculated on the observation plane by Kirchhoff formula:

$$E(r) = 2\iint_S E_0(r_s)w(r_s)\frac{d}{dz_s}G(r - r_s)dS\,, \qquad G(r - r_s) = -\exp\{ik\}/4\pi|r - r_s|\,.$$

The field intensity decreases rapidly by shifting a point of observation from the plane of focus. (Fig. 4). This shows that this device has a good spatial focusing ability.

The studied reflector is calculated for the incident angle $\alpha = 45^\circ$. If it is used for other angles, the focusing ability does not change, but a point of the focus shifts to a corresponding side (Fig. 5).

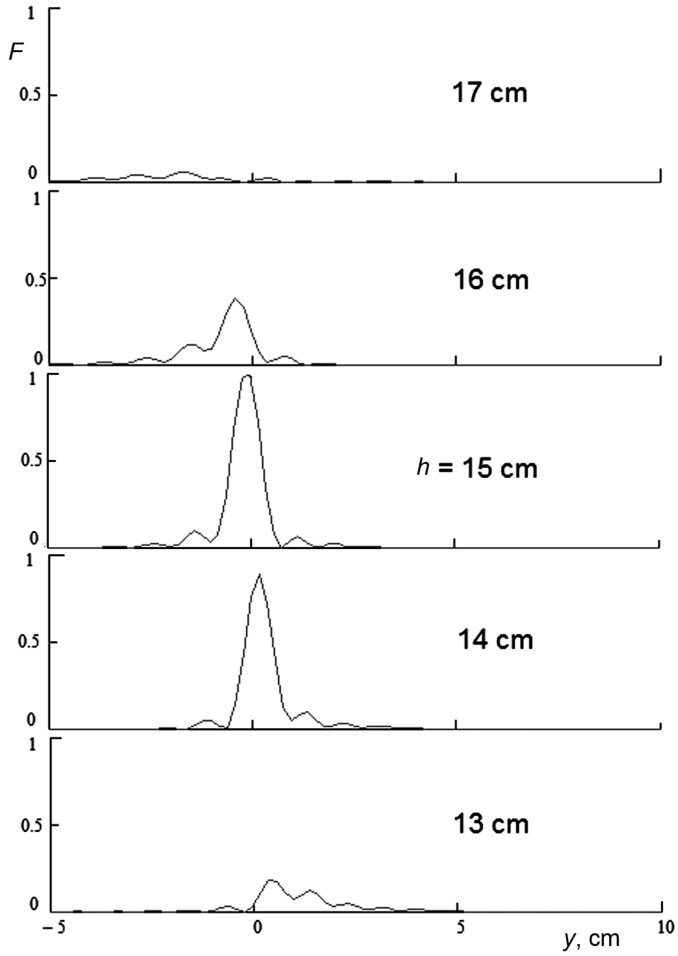

Fig. 4. Intensity distribution depending on the height above the reflector.

The spatial behavior of a focus point is similar to a parabolic analogue. The difference lies in the frequency dependence of focus. The location of a focus is determined only by reflector's geometry and doesn't depend on frequency. Changing radiation frequency f leads to a shift of focus along a focus line for the calculated reflector. On the one hand the geometrical dimensions of the first Fresnel's zone will be reduced by increasing the frequency; on the other hand the real dimensions of the zone cross section must remain constant. This is connected with the calculation of the reflector, which was made for average frequency $f =$ 24 GHz. Obviously it can be done by increasing the height of the focus above the surface. If the operating frequency is increased, the height of the best focus will be increased and vive versa. This is shown in Fig. 6 for three different frequencies. For $f = 26$ GHz height increases to $h = 17$ cm, and for $f =$ 22 GHz the height of the best focus reduces to $h = 13$ cm.

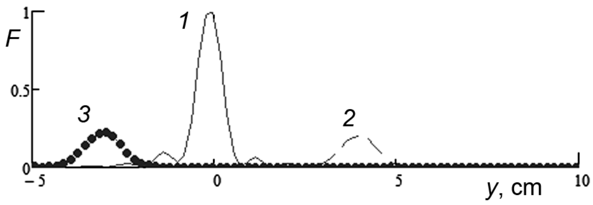

Fig. 5. Longitudinal distribution of the field intensity for different angles: *1* – 45°, *2* – 30°, *3* – 60°.

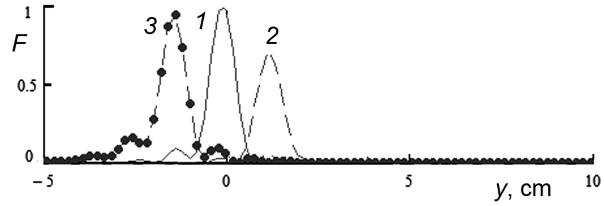

Fig. 6. Longitudinal distribution of the field intensity for different frequencies: *1* – 24 GHz, *2* – 20 GHz, *3* – 26 GHz.

The same result is illustrated in Fig. 7, which shows the dependence of height of the focus above the reflector surface according to the frequency of incident radiation. We can see that one Fresnel reflector calculated for set parameters has capability to focus different frequencies. The location of the focus should be shifted along the focus line of the reflector at a given angle of incidence to change frequency of radiation.

The calculations were made for $f = 24$ GHz, $h = 15$ cm, $\alpha = 45^\circ$.

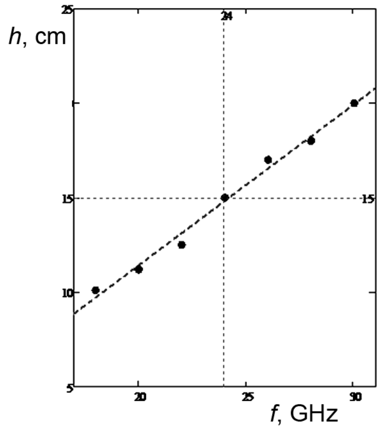

Fig. 7. Dependence of the height of the focus on frequency.

Conclusions

The conducted research showed that a flat reflector can be used for focusing monochromatic radiation. It is shown that one reflector can be used for different frequencies but a point of the focus should be shifted along the focus line. Thus small deviations from the calculated form can be compensated by optimizing the position of the focus. On the one hand, parabolic reflectors have a good focusing quality and ability to focus radiation in a wide frequency range. On the other hand, it is more difficult to manufacture them than their flat analogue.

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