Modelling of a Four-Beam Antenna System Based on a Mirror Antenna

Aqeel Lateef Khudhair Attaby*1, Ahmed Sabri Ghazi Behadili2, Maytham Khudhair Abbas3

1Department of Material Engineering, University of Al-Qadisiyah, Al-Diwaniyah, Iraq
2Al-Karkh University of Science, Baghdad, Iraq
3Chemical Engineering Department, University of Al-Qadisiyah, Al-Diwaniyah, Iraq

* Aqeel.attaby@qu.edu.iq

Abstract. In this paper, the simulation of the four-beam antenna system of the centimeter range based on a mirror antenna, whereas the central frequency of the working range was considered 10 GHz. Besides, the comparative analysis was conducted for various antenna systems. Also, the terraced arrangement of four irradiators (feedhorns) was used in a reflector antenna because it showed an improvement in the energy characteristics compared to a flat design. The simulation of a two-mirror antenna presented decreasing in the directional coefficient and increasing in the level of side lobes as result of multipath using case.

Keywords: mirror antenna, hornfeed, radiation pattern, multi-beam antenna, Cassegrain antenna, lobes, directional coefficient

1. Introduction

The narrow-beam directional antenna is used to increase the range of communication and the number of subscribers. Unlike, the short-range omnidirectional antennas that has a circular radius of action and single-beam antenna. As a result, it can be used only in one direction, which reduces its functionality. Therefore, we combined all advantages of both types of antennas in one system, and then, we obtained a multi-beam antenna with a multilobe radiation pattern. The scanning of space takes place in parallel, at each moment of time, the several rays are formed, each discretely located in its scanning sector. Each beam refers to independent input / output [5].

If the multi-beam antenna is in a range of several signals from different directions, then the control unit distributes them to different antenna ports. The space is conditionally divided into sectors. At an angle of 360° there are usually three such sectors for omnidirectional antennas. A multi-beam antenna uses a larger number of sectors as shown in Fig. 1 (for example, forty-eight), and reuses the available frequencies in different sectors, which significantly increases the number of simultaneously served subscribers. Increasing the range of reliable reception reduces operating costs, improves the quality of communication and its reliability [6,7].
2. Materials and methods

Structurally, the multi-beam antenna consists of the antenna itself and the beam forming device. The focused element located in the phase center (focus) of a parabolic antenna or the focal plane is called a feedhorn or irradiator. The irradiator forms the radiation pattern (RP) and the polarization of the antenna. Structurally, the irradiator are made in the form of round or rectangular conical horns that form the radiation pattern, the same in the E and H planes (see Fig. 2).

Fig. 2. Horn antennas: a) H-plane, b) E-plane, c) pyramidal, d) conical

Hornfeed aperture usually has dimensions comparable to its working wavelength. In the same antenna can operate several different hornfeeds. Let’s choose a pyramid horn (Fig. 3) with the following characteristics:

a) the width of the main lobe of the RP:
- in the E-plane: \(2θ_{0.5} = 0.40 \text{ rad} = 23°\);
- in the H-plane: \(2θ_{0.5} = 0.55 \text{ rad} = 31°\);

b) directional gain and power gain: \(K_d = 15.0 \text{ dB}; K_p = 13.5 \text{ dB}\) respectively.
The pyramid horn

Demand radiation pattern of horn antenna in E- and H plane is shown in fig. 4. To form it a phase shifter in the feeder path was used.

Phase shifters (PS) are the most important part of the antenna, controlling the signal phase and the direction of the beam. Phase shifters come in various versions, but are generally divided into four types: PS with time delay, reflective / quadrature PS, vector IQ modulator, PS on HF / LF filters. We use the simplest PS with a time delay (see Table 1). The phase shift is formed by switching the signal between the transmission lines of a given length. Switching is performed by pin-diodes [1].

| Parameter                          | Value |
|------------------------------------|-------|
| Operating frequency, kHz           | 1,01  |
| Range of phase regulation, %       | ±4    |
| Number of digits                   | 2     |
| Rated power, W                     | 10    |
| Attenuation, dB                    | 1.1   |
3. Results and dissection

The simulation results showed that the selected design provides $K_d = 17.8 \text{ dB;} K_p = 16.0 \text{ dB}$. (see fig. 5)

![Fig. 5 – Results of four-beams antenna simulation](image)

This antenna can be implemented on a lattice base with a cascade arrangement of radiators (see Fig. 6) [2], arranged in a certain way. This allows high accuracy of the amplitudes and phases setting. The advantage of such a scheme is the possibility of using electrical scanning, increased gain, the possibility of forming the radiation pattern at of the required shape, optimization of the use of the energy potential of the antenna in distance. The disadvantages include the complexity of the design and electrical parameters calculation, high requirements for the element base, relatively high cost.

![Fig. 6. Cascade Scheme of hornfeeds array](image)

Mirror antennas are one of the most common narrow-band antennas of the VHF range. In antennas of this type, a wider radiation pattern at of the hornfeed is transformed into a narrow radiation pattern at
of the antenna itself. A feature of mirror antennas is the formation of an electromagnetic field in the aperture due to the reflection of an electromagnetic wave from the metal surface of a special mirror (reflector). The source of the wave is a small hornfeed located in the focus of the mirror. Any other antenna with a phase center emitting a spherical wave can play its role. The following types of mirrors are common: parabolic, spherical, flat and with a special profile. The mirror is usually made of a dielectric base on which a layer of conductive material is worn (foil, conductive paint, etc.).

Often the conductive layer is not a continuous system, but a grid or other perforated structure. This solution reduces the weight of the antenna, but slightly reduces its efficiency. Let us analyze the antenna with a mirror in the form of a symmetrical cut from a full paraboloid (Fig. 7) with dimensions Lx = 1.03 m; Ly = 1.75 m.

During simulation, the array is mixed relative to the mirror for a given distance (see Fig. 8). The calculated radiation pattern of a single-mirror antenna is shown in Fig. 9.
For a multidimensional array, as in our example, you can use an array consisting of lines of strip hornfeeds or it is also called a “terrace structure”. These lines are parallel to the focal line of the secondary mirror and are shifted relative to each other in the vertical plane by a certain value. This design is not only easier to implement, but also turns out to be more optimal in terms of energy characteristics. When using the "terrace" design, the decrease in the maxima of the radiation pattern of the individual rays is less than in a flat structure. With the same distances between the elements and their quantity, the signal attenuation in the extreme elements of the array is about 40% in the case of a flat structure, while for a “terraced” array it is no more than 15%. The mutual influence of elements in the "terraced" design is significantly less compared to a flat array. The simulation results of the antenna with a flat and terraced arrays are [3]:
- with a flat grid: Kd = 26.0 dB; KP = 23.5 dB;
- with a terrace grating: Kd = 28.5 dB; KP = 25.7 dB.

The disadvantages of mirror antennas are related to the design of the irradiators (feedhorn). This is manifested in the form of undesirable effects of parasitic polarization. The disadvantage of single-mirror antennas is the low resulting utilization ratio of the aperture area, which is eliminated in two-mirror antennas.

Let us analyze a two-mirror Cassegrain-type antenna. In the simplest case, a two-mirror antenna (Fig. 10) consists of a main parabolic mirror, an auxiliary mirror in the form of a hyperboloid of rotation, and an irradiator (feedhorn). This antenna is often called the Cassegrain antenna [4]. The focus of the auxiliary mirror F1 coincides with the focus of the main (parabolic) mirror. The focus of the second branch of the hyperbola lies, as a rule, on the axis of the parabolic mirror. In particular, it may coincide with its top. Studied model has the following parameters:
- dimensions of the reflector: Lx = 1.03 m; Ly = 1.75 m;
- size of a small mirror: Dm = 0.5 m
Fig. 10. Two-mirror antenna

Simulation result:
- the calculated radiation pattern is shown in fig. 11;
- \( K_d = 18 \text{ dB}; \quad K_p = 16 \text{ dB} \).

Both single-mirror design and two-mirror design have their advantages and disadvantages, which determine their areas of application. Consider the possibility of changing the operating frequency range.
Because the working frequency range is set by the irradiator (feedhorn), its change is associated with a change in the irradiator. The operating frequency of the above-considered horn radiator is 8-12 GHz. At high frequencies, it is recommended to use a tongue-shaped horn or a horn on the basis of an H-shaped waveguide (Fig. 12 and 13). As an alternative to the comb design, you can use a waveguide-slot input power divider, horns, Vivaldi antennas, spiral antennas use a different antenna design, for example, a flat antenna of a flowing wave with central power, built on the basis of structures with periodic arrays of metal strips.

Fig. 12 The design of the ridge horn

Fig. 13 - the radiation pattern of the horn H-shaped cross-section in three dimensions

By simulating a cascade array of feedhorns from tongue-shaped horns we obtained a radiation pattern, shown in fig. 14.

Fig. 14 - Radiation pattern of a cascade hornfeeds array of ridge horns

4. Conclusion

The terraced arrangement of the four radiators in the reflector antenna showed an improvement in the energy characteristics in comparison with the flat design.
The use of a comb horn has shown the efficiency of the antenna in the frequency range from 4.5 to 19.0 GHz, with a coefficient of directional action equal to 14.5 dB. The level of side lobes decreased to -32 dB.

Simulation of a two-mirror antenna showed a decrease in the directional coefficient and an increase in the level of side lobes in the case of its use as a multipath.

5. References

[1] Parameters of semiconductor phase shifters [Electronic resource] / information portal "Scientific library of selected natural science publications." Access mode http://stu.scask.ru/book_tmv.php?id=35. Date of request 01.04.2019

[2] Rusov, Yu.S., Budkin, A.A., Krehtunov, V.M., Shevtsov, O.Yu., Artyushchev, A.V. Modernization of elements of a phased antenna array of a millimeter wave band [Electronic resource] / Vestnik MGTU im. N.E. Bauman, 2014. Access mode http://engjournal.ru/articles/328/328.pdf

[3] Muravev V.V., Tamelo A.A., Lebedev V.M., Stepuk A.A. Simulation of multipath antennas for telecommunication systems. Science and Technology, No. 4, 2014 p. 49-53

[4] Shishlov A.V. Theory and practice of multi-mirror antennas. [Electronic resource] / Information resource "DocPlayer". Access mode http://docplayer.ru/31478868-Teoriya-i-tehnika-mnogozerkalnyh-antenn.html

[5] A.P. Pudovkin, Yu.N. Panasyuk, A.A. Ivankov The basics of antenna theory. Tambov: Publishing house of Tambov State Technical University, 2011. 92 p. - 100 copies. - ISBN 978-5-8265-0981-4.

[6] A.V. Shishlov, B.A. Levitan, S.A. Topchiev, V.R. Anpilogov, V.V. Denisenko. Multi-Beam Antenna For Systems Radar And Communications. Journal of Radio Electronics, ISSN 1684-1719, N7, 2018. DOI 10.30898 / 1684-1719.2018.7.6

[7] S. Dinges, E. Khasyanova. Multipath Antennas: ETI company solutions. Journal "Electronics: Science, Technology, Business". №2 (00116) 2012, pp.106-110