Design of a Printed Antenna Array in Rectangular Corner Reflector with Cosecant Square-Shaped Beam Pattern

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Abstract – **The preliminary design and simulation results of printed antenna array with cosecant square-shaped beam pattern, using Orchard Elliott's and genetic algorithm methods, has been presented. The four wideband radiating elements operating at a second resonance are axially placed. The corner reflector is at distance $\lambda_0/4$ from antenna array providing increases in both antenna parameters: gain and side lobe suppression. At the centre frequency of 10 GHz the obtained simulation results clearly show expected advantages of presented antenna.**

Keywords – **Printed antenna array, Cosecant square radiation pattern, Side lobe suppression.**

I. Introduction

The crucial part of every radar system is antenna. Its main function is to transmit energy to space with the required pattern and to receive intercepted signal by reflecting object. Thus radar antenna enables detection and location of objects.

The coverage of a simple fan beam is usually inadequate for targets at high altitudes close to the radar [1]. The simple fan-beam antenna radiates very little of its energy in this direction. However, there are a few techniques for modifying the antenna pattern to radiate more energy at higher angles. One of them is employing a fan beam with a shape proportional to the square of the cosecant of the elevation angle. Cosecant-squared antenna produces a constant echo-signal power for a target flying at constant altitude, if certain assumptions are satisfied. Search radars generally employ this type of pattern.

There are many algorithms and methods for design cosecant-squared antennas [2-4]. Although the expected radiation pattern is achievable using adequate feeding coefficients for array elements [3], it is recommended to improve the others antenna parameters as gain, side lobe suppression (SLS), bandwidth … [4].

Cosecant-squared antennas are widely used for radars in lower microwave frequency, especially in L frequency range. This paper will present the antenna array in X range around 10 GHz. In this range, the functional antenna model will be realized to economize material and space. Certainly, the presented concept can be used in every UHF and microwave frequency ranges, relevant for Cosecant-squared antennas, using dimensions scaling.

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II. Pentagonal Printed Dipoles

Presented cosecant-squared antenna array is with printed dipoles (Fig. 1) of pentagonal shape [5-7] (one half of them on one side and another half on the opposite side of the substrate).

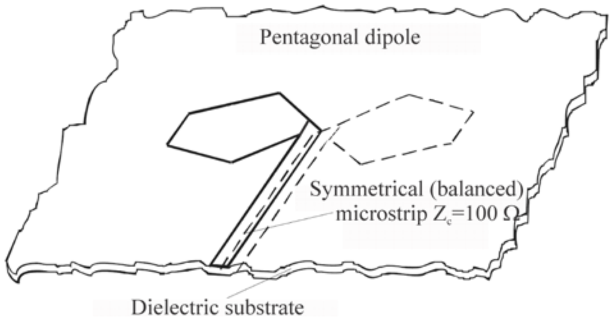

Fig. 1 Pentagonal dipole

They are fed by a symmetrical (balanced) microstrip line. The presented antenna array as well as its radiating element is with rectangular corner reflector at distance $\lambda_0/4$ from antenna array. Differently from conventional dipoles that operate on the first resonance, these dipoles operate on the second resonance [5-7]. The dipole's impedance varies with frequency very slow (Fig. 2).

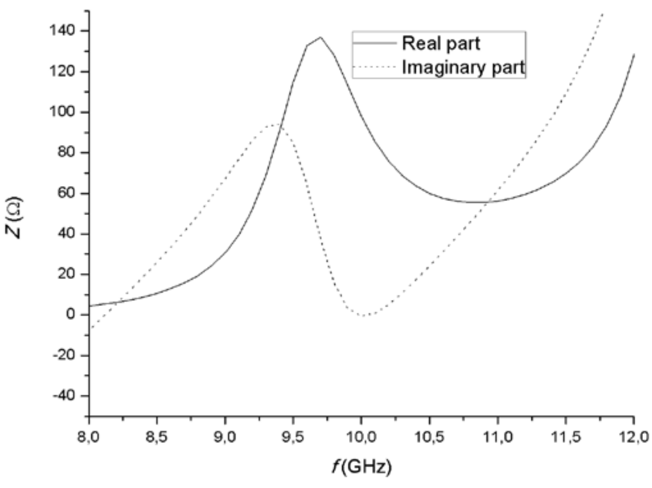

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Fig. 2. Real and imaginary part of pentagonal dipole's impedance

Modification of pentagonal dipole's dimensions enables us to change impedance on the second resonance in a relatively wide range (Fig. 2). In our case, we have adjusted dimensions of pentagonal dipoles in order to obtain dipole impedance of Z_d=100Ω at the centre frequency (10 GHz) taking into consideration the reflector influence and symmetrical microstrip feeding line of impedance $Z_c=Z_d$.

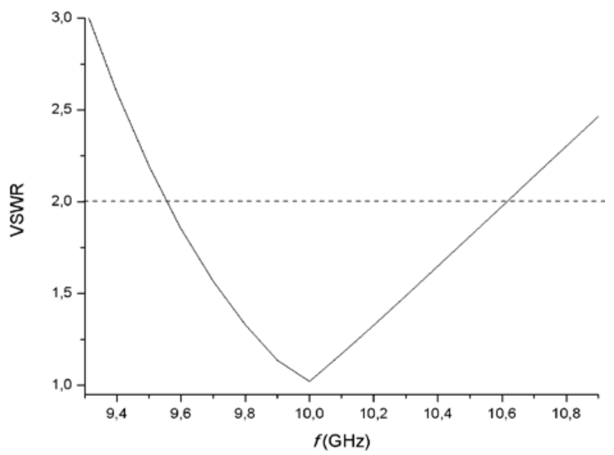

Fig. 3. VSWR of pentagonal dipole

The Fig. 3 presents Voltage Standing Wave Ratio (VSWR) of pentagonal dipole. VSWR is below 2 in the range from 9.6 GHz to 10.6 GHz that is 10% of central frequency. It is certain that the frequency range with VSWR below 2 will be wide if the dielectric substrate is with less height.

III. Antenna Array with Cosecant Squared Radiation Pattern

Cosecant function of angle ϕ is defined as:

$$\csc\phi = \frac{1}{\sin\phi}. \qquad (1)$$

In the cosecant-squared antenna, the gain as a function of elevation angle is given by [1]:

$$G(\phi) = G(\phi_0)\frac{\csc^2\phi}{\csc^2\phi_0} \quad \text{for } \phi_0 < \phi < \phi_m \qquad (2)$$

where $G(\phi)$ is the gain at elevation angle ϕ. ϕ_0 and ϕ_m are angular limits between which beam follows cosecant-squared shape**.**

Antennas with cosecant squared pattern are special designed for the airborne search radar observing ground targets as well as ground-based radars observing aircrafts targets. From ϕ=0 to $\phi=\phi_0$, the antenna pattern is similar to a normal antenna pattern, but from $\phi=\phi_0$ to $\phi=\phi_m$, the antenna gain varies as $\csc^2\phi$. Ideally, the upper limit ϕ_0 should be 90°, but it is always much less than this with a single antenna because a practical difficulties. The cosecant-squared pattern may be generated with an array-type antenna.

The presented antenna array consists of four parts (Fig. 4): (1) the axial array of four radiating elements, (2) feeding network and (3) bal-un – part (1), (2) and (3) are printed on the same dielectric substrate and (4) rectangular corner reflector.

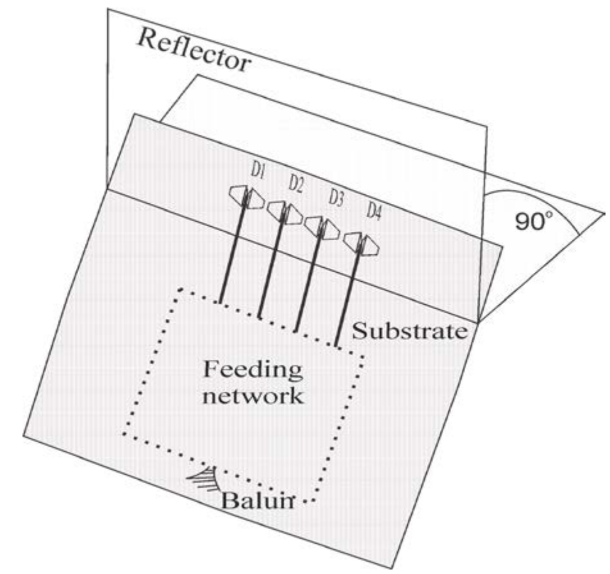

Fig. 4. Antenna array with cosecant squared radiation pattern

Along axis there is an array of four axially placed radiating elements. The dipoles are axially placed decreasing their mutual impedance. Radiating elements are printed on a dielectric substrate of 0.508 mm thickness end ε_r=2.17. Symmetrical (balanced) microstrip line is used as a feeding structure, because dipoles are electrically symmetrical elements. Distance between the dipoles is $0.8\lambda_0$=24 mm (at the centre frequency).

The normalized amplitude, u_i and phase shifts φ_i, i=1,2,3,4 for four radiating elements are shown in Table I [2,3].

TABLE I
The distribution coefficients for antenna array with cosecant squared radiation pattern

Dipoles number	1	2	3	4
Normalized amplitude u_i	0.4038	0.567	1	0.725
Phase shifts φ_i [°]	0	14	0	-36

IV. Simulation results

The simulation model [8] of antennas with cosecant squared pattern is shown in Fig. 5.

The gain is 17 dBi that is significantly improved than in antenna array with U-slot rectangular patch element [3] where gain is around 10 dBi. Further, the SLS is also better and it is equal 19.35 dB that is greater than 13 dB corresponding SLS from antenna array with U-slot rectangular patch element [3].

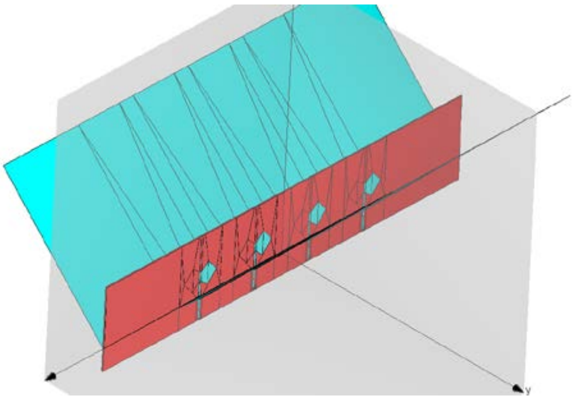

Fig. 5. The simulation model of antennas with cosecant squared pattern

The most important is that radiation pattern in E-plane does not vary a lot from theoretically simulated cosecant square radiation pattern for a four-element linear array [3] (Fig. 6).

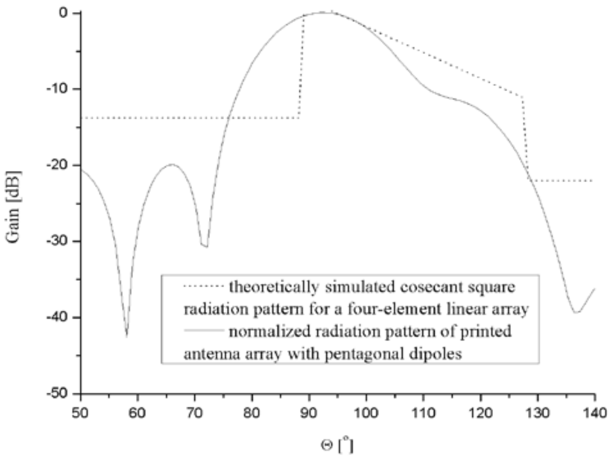

Fig. 6. The normalized radiation pattern of printed antenna array with pentagonal dipoles versus theoretically simulated cosecant square radiation pattern

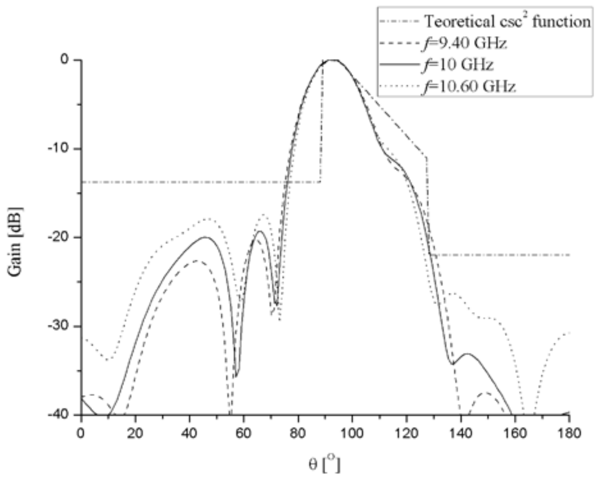

Fig. 7. The normalized radiation pattern of printed antenna array with cosecant squared pattern at 9.4 GHz, 10 GHz and 10.6 GHz

The Fig. 7 presents the normalized radiation pattern of proposed antenna array in wide frequency range. Considering results shown in Fig. 7, it can conclude that the antenna array with csc2 radiation pattern can be applied in frequency range 0.6 GHz from the central frequency of 10 GHz.

Also, the radiation pattern of presented antenna array in H-plane depends considerably on parameters of corner reflector: its angle, its dimensions and the distance of radiating elements from its apex. For rectangular corner reflector that is at distance λ0/4 from antenna array, the radiation pattern in H-plane is shown in Fig. 8. The adjusting the parameters of corner reflector, the wide frequency range of antenna array can be obtained.

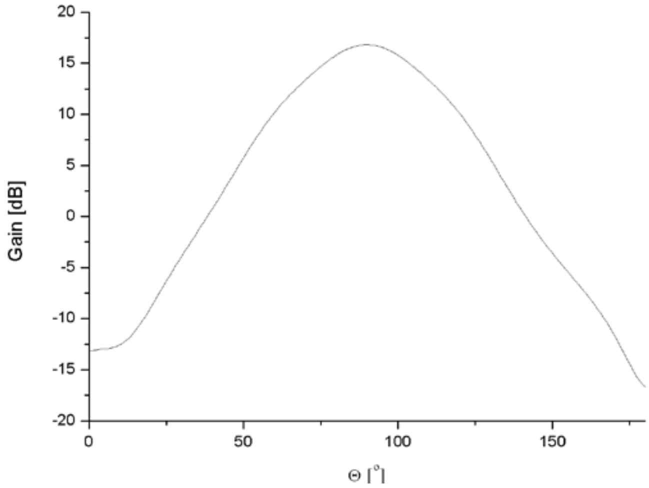

Fig. 8. The radiation pattern in H-plane of antenna array with rectangular corner reflector's apex at distance $\lambda_0/4$ from antenna array

V. Conclusion

The paper presents the printed antenna array with four radiating elements in corner reflector whose radiation pattern in E-plane has shape of cosecant square function. The pentagonal dipoles fed by a symmetrical (balanced) microstrip line are used as radiating elements. They have a few advantages over recently used radiating elements of antenna with cosecant square-shaped radiation pattern. Besides their simple structure, they have significantly wide frequency range (for VSWR<2, BW=10 %).

The simulation model consists of dipoles fed by generators with distribution coefficients calculated by Orchard Elliot's and genetic algorithm methods. The obtained radiation pattern very little varies from theoretical radiation pattern. Further, it is possible to adjust the of antenna beam width in H-plane changing parameters of corner reflector. Antenna gain is 17 dBi. The central frequency of simulation models is 10 GHz. The further research will be modeling feeding network that enables required distribution, in the same dielectric substrate as antenna array, as well as complete realization of antenna.

Acknowledgement

This work was supported by the Ministry of Education, Science and Technological Development of Republic Serbia within the projects No. III44009.

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