Reduction of scattering cross section of path antennas

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Abstract. This report considers the possibility of reducing the scattering cross section of patch antennas when using emitters of various shapes and when using structures with non-zero surface resistance. The report presents the results of the influence of the choice of the shape of a emitter on the SCS in the region of resonant scattering frequencies. The scattering indicatrices of various emitters for the resonant scattering frequency are analyzed. Comparative analysis results of the decrease estimation for the SCS of the square path when using various forms of regions with impedance surface are presented.

1. Introduction

When reflecting microwave waves from aircraft, the scattering field is mainly determined by the sum of waves reflected from several local areas – antennas, the cockpit, air intakes, wing edges, the tail of an aircraft or a non-existent helicopter tail rotor [1-3].

The field scattered from the antenna system (AS) is divided into two components. The first component ("radiated") appears as a result of receiving an incident electromagnetic wave (EMW) and its partial reflection from an uncoordinated load of the antenna system [1]. Considering this component, we can talk about the connection of the radar and radio technical characteristics of antennas (about the connection of the scattering diagram with the radiation pattern). The second component ("structural") is not related to the antenna specifics and appears as a result of the fraction of incident EMW on the "external" elements of the antenna structure. In general, both components are simultaneously present in the scattered antenna field and both should be minimized. To reduce the visibility of the radar design elements that do not participate in the formation of the antenna radiation pattern, it is possible to cover their surface with light and relatively thin (up to 3 mm) radiation-absorbing materials, which usually have reflection coefficients from minus 10 dB to minus 30 dB in the radiation wavelength range from 30 cm to 1 mm. Such properties are possessed, for example, by multilayer radiation-absorbing coatings based on thin nanostructured films [4-6].

Thus, firstly, the problem of reducing the scattering cross section (SCS) of antennas is directly related to the complexity of reducing the constructive component of the scattering field from the effective opening of the antenna, especially in close proximity to the operating frequencies of the antenna that coincide with the frequencies of the transmitting radar. Outside of this range, it is possible to reduce the structural scattering by placing frequency-selective screens in front of the antenna in a convex fairing or by giving frequency-selective properties to the fairing walls thepatchelves. The placement of additional screens requires more space under the fairing, and this possibility should be taken into account already when designing it. Frequency-selective elements built into the fairing should provide a bandwidth for
both transmission and reception, and for signals outside a given frequency interval, the fairing should be reflective, then the SCS is relatively low due to the shape of the fairing [1,2]. If there is a single single-band antenna array under the fairing, this problem can be solved [1], but since there are almost always several speakers under the fairing, for many practical applications, the number of operating frequency bands used should be increased. This leads to the need to create multilayer frequency-selective surfaces or to the formation of a complex geometric configuration of the relative location of frequency-selective structures under the observer. This raises the following questions: whether such a separation is advisable in principle, since a change of antenna systems is possible during modernization, firstly, whether sufficiently sharp transmission boundaries (frequency ranges) can be achieved and, secondly, whether the characteristics of the transmission bands are acceptable in terms of amplitude and phase transmission coefficients and polarization properties. As already mentioned, the difficulty is caused by the adjustment of the SCS of the AS in its operating antenna band, since the task of reducing radio visibility becomes associated with the need to maintain the requirements for the characteristics of the antenna radiation. Obviously, in an ideal situation, the antenna should absorb the entire energy of the irradiation wave, but even a completely black body scatters electromagnetic waves [3], so it is impossible to create an absolutely absorbing antenna. But we can strive to increase the share of electromagnetic energy absorption of the AS. In the direction of the line of sight, this means that, excluding resistance losses in the path, the efficiency of the antenna should tend to 100%. Solutions are needed that would include such changes in the antenna design that would contribute to reducing the SCS in the field of vision of the greatest interest, would be affordable, would be simple to use and would not significantly worsen the radiation characteristics. In this article, the problem of choosing emitters for reducing the SCS of low-element patch antenna arrays is considered.

2. Methodology for assessing the influence of shape and surface impedance on scattering characteristics of patch antennas

The study of the scattering properties of patch antennas is becoming increasingly important lately due to the fact that, firstly, they have a significant impact on the SCS of the object with the antenna installed, and secondly, they can be used as reflective antenna arrays (RAA). In this case, RAA can be excited by the field of an incident plane wave and can be made as conformal arrays. Antennas made of patch emitters are characterized by low manufacturing cost and low weight and are used as antennas of the centimeter and millimeter ranges. The following is a solution to the problem of reducing the SCS of patch emitters by choosing the appropriate shape of the emitter with the possible implementation of impedance regions on its surface.

The geometric formulation of the problem of determining the SCS of a patch emitter of arbitrary shape with regions of non-zero surface resistance is shown in figure 1. The patch perfectly conducting emitter is located on a grounded dielectric substrate having a relative permittivity $\varepsilon$ and thickness $d$. We consider the incidence of a plane wave with a single amplitude of the electric component of the field, the direction of propagation of which is set by the angles of incidence $\theta, \phi$.

To determine the patch scattering field, it is necessary to solve a system of integral equations with respect to the Fourier components of the spatial spectrum of the vector function of the electric current distribution on the patch plate [7-10]. To determine the latter, the Galerkin method is used, based on the representation of the two-dimensional distribution of the surface current in the form of series along the coordinate components of the surface current in the nodes of the spatial grid. A rectangular spatial grid superimposed on the area is shown in figure 1.

The spatial grid has dimensions $2L_x$, $2L_y$ with the number of nodes $M+1$ along the $0X$ and $N+1$ along the $0Y$ axes. The grid is divided into discrete subfields, with dimensions $\Delta x$ and $\Delta y$ along the axes. The distribution of the components of the surface current vector on the path surface is given as follows [7]:

\[
J_x (x, y) = \sum_{m=1}^{M} \sum_{n=1}^{N+1} J_{mn} (x) \Pi_m (y) MPR_{mn}; \quad J_y (x, y) = \sum_{m=1}^{M+1} \sum_{n=1}^{N} J_{mn} (y) \Pi_m (x) MPR_{mn},
\]
where $I_{xmn}$, $I_{ymn}$ is the value of the coordinate components of the currents in the nodes of the spatial grid. The coordinates of the nodes are determined by the indices $m$ and $n$, $MPR_{mn}$ is an element of the matrix of belonging of the elements of the spatial grid to the path region.

![Figure 1. Determine the patch scattering field with the use of Galerkin method.](image)

The basic functions are selected based on the representation of a given linear current on a segment of a microstrip line, and are described by the following relations [7]:

$$
A_m(x) = \begin{cases} 
1 + \frac{x-x_m}{\Delta x} & \text{if} \quad x_m - \Delta x \leq x \leq x_m, \\
1 - \frac{x-x_m}{\Delta x} & \text{if} \quad x_m \leq x \leq x_m + \Delta x; \\
1 & \text{if} \quad \Pi(y) = 1 \quad \text{if} \quad y_n - \Delta y \leq y < y_n.
\end{cases}
$$

In the domain of spatial frequencies (1) is represented by the relations:

$$
J_x(K_x, K_y) = \sum_{m=1}^{M} \sum_{n=1}^{N} I_{xmn} F_{xmn} (K_x, K_y) MPR_{mn};
$$

$$
J_y(K_x, K_y) = \sum_{m=1}^{M} \sum_{n=1}^{N} I_{ymn} F_{ymn} (K_x, K_y) MPR_{mn};
$$

$$
F_{xmn} (K_x, K_y) = \Delta x \Delta y \frac{\sin(K_x \Delta y / 2)}{K_y \Delta y / 2} \left( \frac{\sin(K_x \Delta x / 2)}{K_x \Delta x / 2} \right)^2 \exp(-jK_x x_m - jK_y y_n + jK_y \Delta y / 2);
$$

$$
F_{ymn} (K_x, K_y) = \Delta x \Delta y \frac{\sin(K_y \Delta x / 2)}{K_x \Delta x / 2} \left( \frac{\sin(K_y \Delta y / 2)}{K_y \Delta y / 2} \right)^2 \exp(-jK_x x_m - jK_y y_n + jK_y \Delta x / 2),
$$

where $K_x = k \sin \theta \cos \phi$, $K_y = k \sin \theta \sin \phi$, $k = 2 \pi / \lambda$, $\lambda$ is the wavelength in free space. To determine the coordinate components of the surface current in the nodes of the spatial grid excited by an incident wave, it is necessary to solve the following matrix equation [8]:

![Diagram of a microstrip line with a patch and grid nodes.]
where \( p=1,2,\ldots,M+1,\ q=1,2,\ldots,N+1 \). The left vector is the vector of the values of the nodal excitation voltages created in the node of the spatial grid with coordinates \( p \) and \( q \) and the coordinate components of the current of the node with coordinates \( m \) and \( n \). The matrix is a matrix of resistances, the elements of which are determined through integral transformations from the Green functions for the dielectric layer over the metal screen in the region of spatial frequencies and Fourier transforms of the basic functions in the region of spatial frequencies [8]. After determining the values of the components of the surface current vector on the path surface in the nodes of the spatial grid, it is possible to find the components of the scattering field in the opposite direction according to the ratio [8]:

\[
E_{s(x,y)|\theta,\phi} = \sum_{m=1}^{M+1} \sum_{n=1}^{N+1} E_{s(x,y)|\theta,\phi} I_{s(x,y)|\theta,\phi} MPR_{m,n}.
\]

To assess the influence of the choice of the path form on the SCS, four forms of emitters were used, shown in figure 2. In figure 2 a) the patch is presented in the form of a square, in figure 2 b) in the form of a circle, in figure 2 c) in the form of an isosceles triangle, and in figure 2 d) in the form of a ring.

![Figure 2](image)

**Figure 2.** The studied forms of path emitters.

The following patch parameters were used for the study: the thickness of the dielectric substrate 0.08 cm, the dielectric permittivity of the substrate \( \varepsilon = 2.2 \). The dimensions of the spatial grid were \( L_x=L_y=0.7 \) cm. The inner radius of the ring corresponds to the value 0.5\( L_x \).

**3. Simulation results for evaluating the effectiveness of reducing the SCS of patch antennas**

In figure 3, there are the dependences of the SCS of patches (\( \sigma \) in dbm) for the above-mentioned studied forms on the frequency of incident radiation (\( f \) in GHz). The following system of notation is adopted on the graphs corresponding to the study of the scattering characteristics depending on the choice of the emitter shape.
Figure 3. Frequency response of SCS for different forms of emitters.

Curve No. 1 corresponds to the path in the form of a square, curve No. 2 corresponds to the patch in the form of a circle, curve No. 3 corresponds to the patch in the form of a triangle, curve No. 4 corresponds to the patch in the form of a ring, the frequency of incident radiation varies in the range from 6 to 15.5 GHz. The analysis of the dependencies shows that the maximum value of the SCS has the path in the form of a square (curve No. 1 at figure 3). The minimum value of the SCS has the patch in the form of a ring (curve No. 4 at figure 3).

Figure 4 shows the scattering indicatrices reduced to the total maximum depending on the angle of incidence of the wave $\theta$ (measured from the normal to the plane of the emitter in the $OXZ$ plane), built on the first resonant frequencies for each emitter under study.

It follows from the above dependencies that the maximum value of the width of the scattering indicatrix by level (-3 dBm$^2$) is achieved when using the path in the form of a triangle; the minimum value of the width of the indicatrix is achieved when using the path in the form of a ring.

Figure 5 shows a square MSE, for which the possibility of reducing its SCS was studied depending on the shape of the regions of impedance surface applied to the surface of the emitter (dark areas correspond to areas covered with resistance). The value of the surface resistance was chosen in such a
way that it corresponded to half of the maximum value of the intrinsic resistance of the emitter subdomains determined as half of the input resistance excited at the edge of a rectangular antenna.

![Figure 5](image)

**Figure 5.** The square path with different impedance regions.

Figure 6 shows the dependences of the SCS of the patch for the above-studied forms of regions of non-zero surface resistance on the frequency. The direction of the wave fall corresponds to the angles $\varphi_i = 0^\circ$, $\theta_i = 0^\circ$. The curve numbers correspond to the path number shown in figure 5.

![Figure 6](image)

**Figure 6.** Frequency response of path with different impedance regions on the surface of the emitter.

4. Conclusion

According to the results of a spatial-frequency study of the scattering characteristics of patch of various shapes, it follows that it is better to use ring emitters to realize the effect of reducing the SCS of path antennas. The SCS of antennas can also be reduced by introducing impedance regions with non-zero surface resistance of a certain geometric configuration.

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