Design and characteristics of ultra-wideband single-layer frequency-selective surface

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Abstract. The paper presents the design of the developed single-layer frequency-selective surface. Frequency characteristics of reflection and transmission coefficients are given. The operating frequency band of the surface on the level of reflection coefficient less than minus 20 dB is in the frequency range from 8.89 to 11.22 GHz. The operating bandwidth is 2.33 GHz or 23.3% relative to 10 GHz. The surface is ultra-wideband in terms of reflection coefficient less than minus 10 dB, and its operating frequency band is in the frequency range from 6.77 to 14.22 GHz.

1. Introduction
Frequency-selective surfaces are often used in the development of antenna system fairings. They are a perforated metal surface and are designed to transmit electromagnetic fields only a certain frequency range [1–7]. Outside this frequency range, it is the equivalent of a solid metal surface. These surfaces are needed, for example, in order to reduce the mutual influence of closely spaced antenna systems or are used as components of antennas to improve their radiation characteristics [8–10].

The main parameters of frequency-selective surfaces are their transparency (appreciated by the coefficient of transmission or reflection). It quantifies the proportion of electromagnetic energy that can pass through a surface.

According to the width of the operating frequency range there are three types – narrowband [1, 2], wideband [3–5] and ultra-wideband [6, 7]. The simplest to design and manufacture are narrow-band frequency-selective surfaces. Broadband and, especially, ultra-wideband frequency-selective surfaces are often multiresonant and their development is usually carried out by numerical method using CAD.

The aim of this work was to develop a single-layer frequency-selective surface with a low reflection coefficient (less than minus 20 dB) in a wide frequency band (more than 10 %). The resonant frequency should be at 10 GHz. At the same time, if there are parasitic resonances in the studied frequency range, the reflection coefficient should be more than minus 10 dB outside the main resonance region.

2. Design of frequency-selective surface
Figure 1 show the design (one period) of the 3D model of the frequency-selective surface, which was taken as a basis for the development of the frequency-selective surface. Its overall dimensions: 10×10 mm. The surface is developed of a dielectric substrate Rogers RO4003 (ε=3.55; μ=1; tgδ=0.0027). The thickness of substrate is 0.203 mm and has one-sided metallization. The metallization of thickness is 35 µm.
Figure 1. The design of the frequency-selective surface taken as a basis:
   a) general view and b) top view

It will be shown below that the frequency-selective surface shown in Figure 1 did not provide the required operating bandwidth. For this reason, it was modified and took the form shown in Figure 2. The overall dimensions of the surface increased to the following value: 18 × 18 mm.

The modification consists in the fact that two orthogonally arranged rectangles with the width of the small side \( w_2 \) were cut from the central element of the surface taken as a basis. As a result, instead of one central element, there are four smaller elements with a side \( w_1 \). The remaining parameter \( w_3 \) is the width of the closed strip within which the centre elements are located.

Figure 2. The design of the developed frequency-selective surface:
   a) general view and b) top view

3. The characteristics of the frequency-selective surface and their analysis

The characteristics of the frequency-selective surface (reflection and transmission coefficient) were studied in the frequency range from 0.1 to 25 GHz and were carried out for the case when the electromagnetic wave falls along the \( z \) axis and its vector \( E \) is parallel to the \( y \) axis. The studies were conducted using the HFSS software [11].

Figure 3 shows the frequency characteristics of the reflection coefficient and the transmission coefficient of the frequency-selective surface taken as a basis.

Frequency characteristics have one resonance in the entire studied frequency range. Resonance is observed at a frequency of 10 GHz. The operating frequency band of the surface on the level of the reflection coefficient less than minus 20 dB is in the frequency range from 9.52 to 10.50 GHz. The operating bandwidth is 0.98 GHz or 9.8% relative to the central frequency 10 GHz. By this parameter, the surface does not fulfill the aim of the work.
Figure 3. The frequency characteristics of the reflection and transmission coefficients of the frequency-selective surface taken as a basis

Due to dissatisfaction with the required operating bandwidth, the surface design was modified and took the form that was shown in Figure 2. The frequency characteristics of the reflection and transmission coefficients of the developed frequency-selective surface are shown in Figure 4.

Figure 4. The frequency characteristics of reflection and transmission coefficients of the developed frequency-selective surface

Figure 4 show that the frequency response has one main resonance at 10 GHz and several parasitic. In the regions of parasitic resonances, the change in the reflection coefficient is small (not less than -6 dB) and satisfies the established requirement (more than -10 dB). This characteristic was obtained by optimizing the values of the parameters $w_1$, $w_2$ and $w_3$. This parameter has the next value: 4.5; 4.4 and 1.0 mm.

The operating frequency band of the surface on the level of reflection coefficient less than minus 20 dB is in the range from 8.89 to 11.22 GHz. Bandwidth has increased more than 2 times and is 2.33 GHz or 23.3% relative to the central frequency 10 GHz. According to this parameter, the developed frequency-selective surface fully meets the established requirement (not less than 10%). The level of the reflection coefficient less than minus 10 dB bandwidth is the frequency range from 6.77 to 14.22 GHz.
and the coefficient of overlapping (the ratio of $f_{\text{max}}/f_{\text{min}}$) is approximately 2.1. That is, the level of reflection coefficient less than minus 10 dB surface is ultra-wideband.

4. Conclusion
In the course of the research work was developed and studied frequency-selective surface. Frequency characteristics of reflection and transmission coefficients were obtained and studied.

The developed frequency-selective surface fully meets the established requirements. The operating frequency band of the surface on the level of reflection coefficient less than minus 20 dB is in the frequency range from 8.89 to 11.22 GHz. The bandwidth is 2.33 GHz or 23.3% relative to the central frequency 10 GHz.

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