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Increasing the gain of an antenna array based on Fabry–Perot cavities at high scanning angles

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An approach for increasing the gain of an antenna array based on Fabry–Perot cavities with mechanoelectrical scanning in the 60–90° angle sector by using a radio-absorbing material on the shading subarray is described. Simulation and analysis of the directional characteristics of the antenna array based on Fabry–Perot cavities with a radio-absorbing material have been performed, and the characteristics have been compared with those of the antenna array without an absorber. Conclusions on the applicability of the proposed configuration of the antenna array based on Fabry–Perot cavities in mobile satellite terminals are made.

Keywords: antenna array, Fabry–Perot cavity, wide-angle scanning, radio absorber.

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The progress in telecommunications dictates the need to provide access to information services for all consumers regardless of geographical location. To establish connection on the go, an antenna array installed in a mobile satellite terminal should have proper mass and dimensions parameters, a high efficiency, and a wide scan sector. Traditional reflector antennas with mechanical scanning and planar phased antenna arrays with electronic scanning have significant drawbacks that make it impossible to perform wide-angle scanning at a high rate or operate at high geographic latitudes [1,2]. Satellite networks with low-altitude and medium-altitude spacecraft, where low-profile antennas with wide-angle scanning and a high efficiency are needed to establish a connection to a satellite, are also advancing rapidly at present [3,4]. An antenna element and an antenna array (AA) based on Fabry–Perot cavities with mechanoelectrical scanning for operation in the Ku frequency band were proposed in [5]. The proposed AA consists of two identical subarrays and features a 0–90° scan sector with an aperture efficiency in excess of 30% at beam deflection by 90°. To perform scanning in the elevation plane, subarrays are rotated mechanically, and a linear phase delay is introduced between them. The AA based on Fabry–Perot cavities was $740 \times 485 \times 185$ mm in size (Fig. 1, *a*). Microstrip power dividers with a fixed linear phase incursion for subarrays, which corresponded to a certain subarray rotation angle (θ), were used as phase-shifting devices to deflect the antenna beam by angle θ. The developed AA based on Fabry–Perot cavities provides a gain of 35.5 dB within a scan angle sector of 0–50° at frequencies of 11.9–12.5 GHz; with the AA beam deflected by 60°, 70°, and 80°, the gain decreased by 1.2, 2.2, and more than 3 dB (Fig. 1, *b*).

Since the AA based on Fabry–Perot cavities with mechanoelectrical scanning was designed for operation at geographic latitudes of 50–80°, one needs to minimize the loss at high scan angles and preserve its directional characteristics if this AA is to be used for communication with such satellites as Express-AM5 and Express-AMU7. The key factors exerting a negative effect on the directional characteristics of AAs based on Fabry–Perot cavities are mutual shadowing of subarrays, rereflections between subarrays, and the admission of radiated energy from the backward subarray to the cavity volume of the forward subarray (this impairs the operation of cavities and reduces their efficiency).

The aim of the present study is to find a solution for enhancing the gain of the above-described AA based on Fabry–Perot cavities in the region of scanning above 70° in the elevation plane.

Radio-absorbing materials are used widely in antenna engineering [6] (including phased antenna arrays) as a radome segment to suppress the cross coupling between reception and transmission paths [7], reduce polarization distortion [8], eliminate parasitic fields in multilayer microstrip AAs [9], etc. The novelty of the proposed solution for gain enhancement in the region of high scan angles consists in the application of a radio-absorbing material in an AA with mechanically rotating subarrays and a radiator in the form of a Fabry–Perot cavity.

A radio-absorbing material was proposed to be used on the back surface of the shading subarray to reduce the level of reflections in the AA based on Fabry–Perot cavities. A number of radio-absorbing materials with different electrophysical properties (permittivity ε and dielectric loss tangent $\tan\Delta$) were examined with the aim of enhancing the AA gain in the sector of high scan angles [10]. A material with the following parameters was chosen to be used on the back surface of the shading AA subarray: $\varepsilon = 1.1$, $\tan\Delta \approx 10^{-2}$, and a thickness of 10 mm. The absorber was

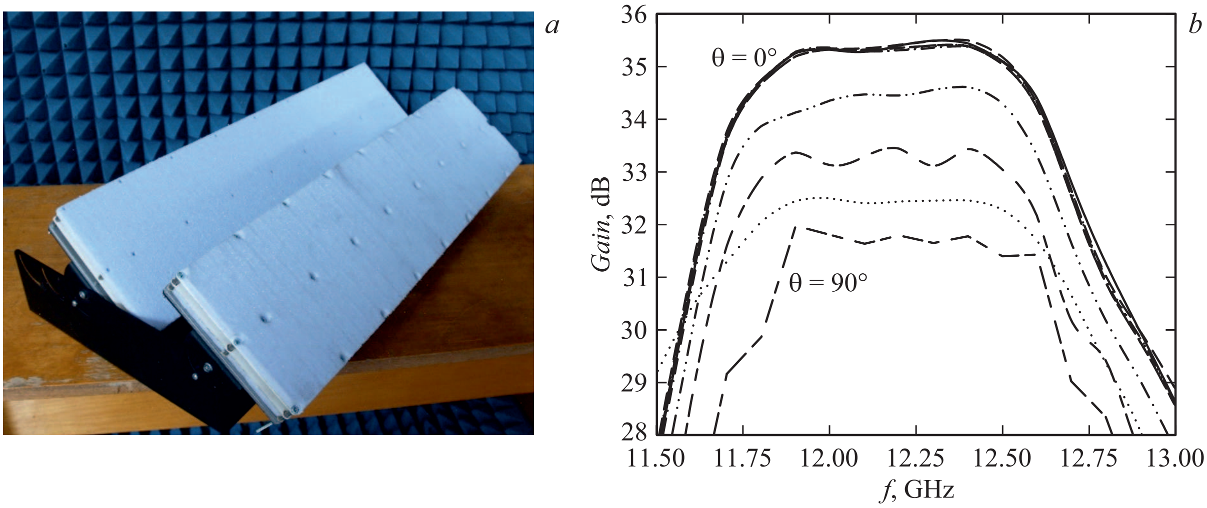

Figure 1. *a* — Model of the AA based on Fabry–Perot cavities with mechanoelectrical scanning; *b* — frequency dependence of the gain of this AA based on Fabry–Perot cavities at scan angles θ from 0 to 90°C (with a pitch of 10°).

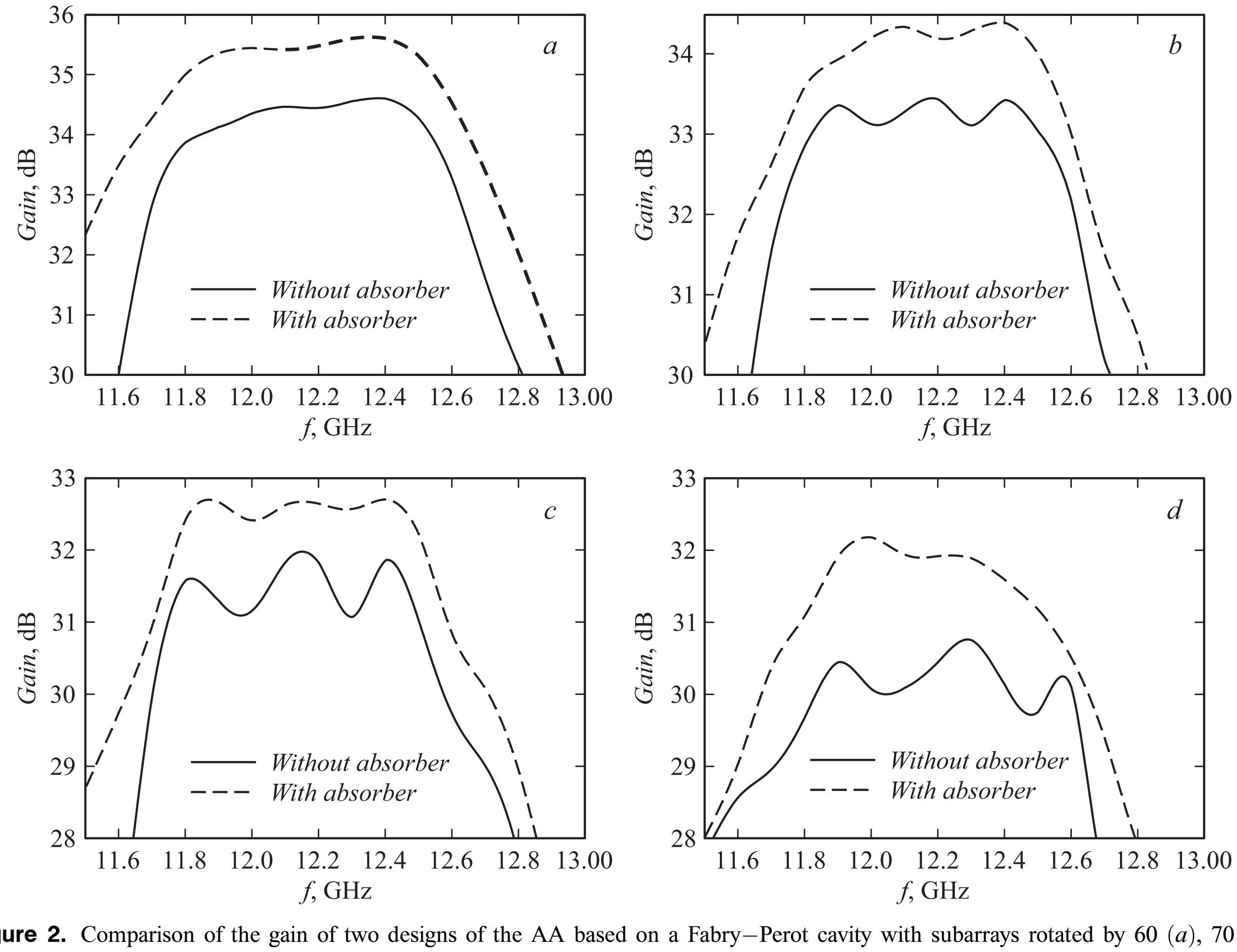

Figure 2. Comparison of the gain of two designs of the AA based on a Fabry–Perot cavity with subarrays rotated by 60 (*a*), 70 (*b*), 80 (*c*), and 90° (*d*).

positioned directly on the subarray surface and had the same shape as the subarray itself. These parameters and size of the absorber were chosen so as to minimize the reflection coefficient (RC) throughout the entire sector of scan angles while preserving the initial small antenna dimensions. It was found in the study of directional characteristics of the

AA based on Fabry−Perot cavities that the gain of this AA with an absorber exceeds the gain of a similar array without the absorber in the sector of high scan angles (60−90°). The gain values with and without the absorber differ insignificantly when subarrays are rotated by an angle of 0−50°. When the beam is deflected by 60° and 70°, the gain of the AA with the absorber in the frequency band of 11.9−12.5 GHz becomes more than 1 dB (Fig. 2, *a*) and 1.2 dB (Fig. 2, *b*) higher than the gain of the AA without the absorber.

If the beam of the AA with the absorber is deflected by more than 80°, its gain exceeds the one of a similar array without the absorber by more than 1 dB (Figs. 2, *c*, *d*).

The increased directionality of the proposed AA is attributable in part to a reduction in the subarray RC due to the presence of an absorber at the back surface of the shading subarray. Comparing the calculated RCs of AAs based on Fabry−Perot cavities with and without a radio-absorbing material, we found that the RC of the AA without the absorber is more than 2 dB higher than the one corresponding to the AA with the absorber in the frequency band of 11.8−12.5 GHz; however, the reflection level remained low and did not exceed −12 dB in the operating band. The examination of amplitude and phase distributions of the AA without the absorber in the elevation plane revealed that a standing resonant wave emerges between subarrays rotated by more than 60°. The energy of this wave enters the cavity volume of the shading subarray, thus reducing its efficiency. When an absorber is present on the back surface of the shading subarray, this standing resonant wave between subarrays is almost nonexistent and does not affect the directional characteristics of the array. Different methods of electrodynamic modeling (finite element and finite integration techniques) of emitting structures were applied in the present study. The frequency characteristics of gain of the examined AA determined using these two methods agreed well throughout the entire operating frequency band of the developed AA in a scan sector of 0−90°.

Thus, it was proposed to enhance the gain of AAs based on Fabry−Perot cavities in the region of high scan angles with a radio-absorbing material. Different candidate radio-absorbing materials were examined. It was demonstrated that the gain may be increased by more than 1 dB in a scan sector of 60−90°. The obtained results may be applied in the design of low-profile AAs with the considered mechanoelectrical type of scanning to preserve the directionality of antennas at high angles.

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Conflict of interest

The authors declare that they have no conflict of interest.

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