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Low-profile scanning antenna array based on an aperture-coupled radiator

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A low-profile antenna array based on an aperture-coupled element with wide-angle mechanoelectric scanning is considered. The scanning sector of the developed antenna array is 0−60° by the criterion of the gain degradation by no more than 3 dB at the whole antenna profile of 48 mm. The developed aperture-coupled antenna element with two linear orthogonal polarizations has a multilayer structure and gain of more than 7 dB in the frequency band of 10.7−12.75 GHz. The presented antenna array consists of eight identical subarrays each consisting of 16 aperture-coupled radiators. Modeling and analysis of the directional characteristics of the antenna array based on an aperture-coupled radiator are performed. Conclusions are made about the applicability of the proposed antenna array based on the aperture-coupled element in ground terminals of satellite communication, including those for low-orbit and medium-orbit systems.

Keywords: antenna array, microstrip aperture-coupled radiator, wide-angle scanning, satellite communication.

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Accessibility of telecommunication services is restricted by the consumerś geographical location. In areas with well-developed infrastructure, consumers are provided with broadband access to information services (telephony, TV, radio, Internet) via ground-based communication networks. However, in difficult-to-reach remote regions one of the most accessible modes of communication with the outside world is still satellite communication. New-generation satellite communication systems employing low-altitude highly elliptical and geosynchronous spacecraft enable access to telecommunication services independently of the consumerś location [1–3]. The most important functional unit of such systems is a ground-terminal antenna system that should be characterized by a wide scanning-angle sector, high efficiency, small dimensions, fast response, and low cost. Papers [4,5] have proposed a microstrip antenna array (AA) of the „Louver" type with mechanoelectric scanning. AA consists of eight subarrays mechanically rotating in the elevation plane about their own axes. The AA beam is spatially displaced in the scanning plane due to rotation of the subarrays and introduction of a linear phase delay along the subarrays. The AA profile amounts to no more than 50 mm with retention of the directivity characteristics in the scanning sector of 0−60° by the criterion of directivity degradation by no more than 2.5 dB. However, the operating band of the developed AA does not exceed 5% due to realization of the beam-forming subarray scheme in the form of a serial-parallel power divider and band-narrowness of the microstrip element itself.

The goal of this work was to create a small-dimension, low-profile and easy-to-manufacture „Louver" antenna system with mechanoelectric wide-angle scanning and two orthogonal polarizations.

In view of achieving a wide operating wavelength range, most promising are multilayer aperture-coupled antennas which, having minimal dimensions, provide a wider frequency band than antennas with two metallization layers [6–8].

This paper proposes to use a multilayer microstrip aperture-coupled antenna element in „Louver" AAs with mechanoelectric scanning. The developed antenna element has two orthogonal polarizations and consists of eight layers (see the top panel of Fig. 1, *a*). In dielectric layers *1* and *2* there are passive microstrip radiators intended for extending the operating frequency band. In the metallic layer *3* there is a cruciform radiating slot excited by microstrip lines with vertical and horizontal polarizations; the slots are located in layers *4* and *5*, respectively [9,10]. The microstrip exciting lines are fork-shaped, which allows improvement of the element reflection parameter to −14 dB in the band of 10.7 to 12.75 GHz (Fig. 2, *a*) [11]. Microstrip lines exciting the slots are fed from the microstrip feeding lines located in layer *7*. Layer *6* is needed for reducing mutual effect of the microstrip lines located in layers *4*, *5* and *7*, and also for improving the matching. Layer *8* is a screening one. The layer-to-layer transitions procced through the metallized holes. It is necessary to mention the proposed metal pins I coupling layers *3*−*6*, which are necessary to compensate the inductance of metallized holes (Fig. 1, *b*). Dielectric materials used in the aperture-coupled antenna element, namely, Rogers RT5880 (between layers *1* and *2*, layers *2* and *3*, layers *7* and *8* 1.575 mm thick) and Rogers RO4003C (between layers *3* and *4*, layers *4* and *5*, layers *6* and *7*

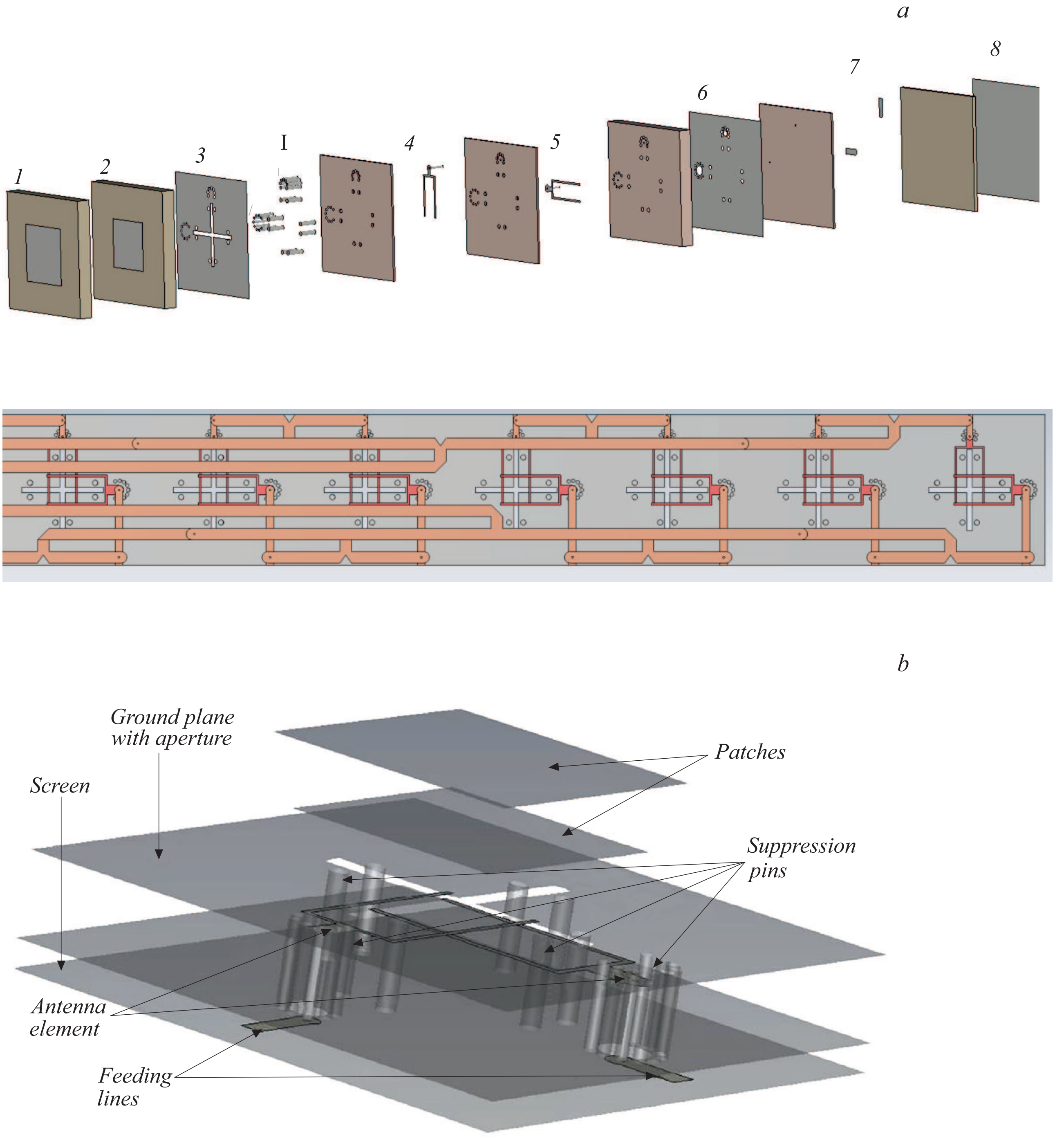

Figure 1. *a* — a layer-by-layer model of the developed aperture-coupled radiator with two orthogonal linear polarization (top panel) and a segment of the subarray power divider model (bottom panel). *b* — main components of the radiator.

0.203 mm thick and between layers *5* and *6* 1.524 mm thick) have dielectric permittivities $\varepsilon = 2.2$ and 3.55, respectively.

Reflection parameters for each port of the aperture-coupled antenna element under study do not exceed -14 dB in the frequency band of 10.7–12.75 GHz (Fig. 2, *a*), isolation between the ports is below -19 dB for two orthogonal polarizations. Simulated radiation patterns of the aperture-coupled element are presented in Fig. 2, *b* for two orthogonal polarizations. The gain of the studied aperture-coupled element exceeds 7 dB in the frequency band of 10.7–12.75 GHz.

Based on the aperture-coupled antenna element with two orthogonal polarizations, a subarray consisting of 16×1 elements was developed. To excite 16 radiators, in the subarray there were used binary microstrip dividers with a parallel power division circuit (lower panel of Fig. 1, *a*).

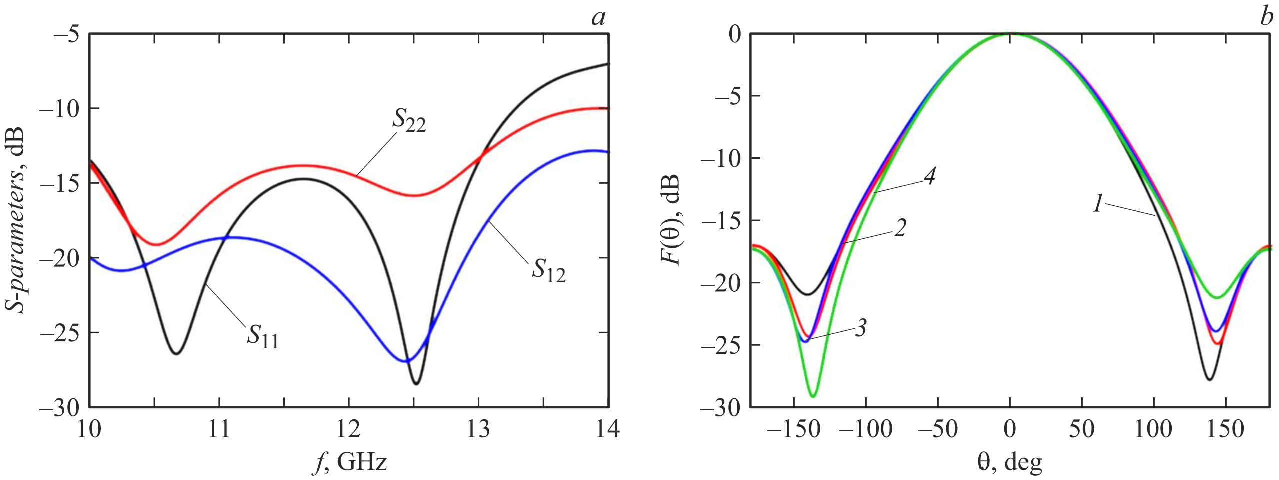

Figure 2. *a* — frequency dependences of the S-parameters of the aperture-coupled antenna element under consideration. *b* — radiation patterns of the aperture-coupled antenna element at the frequency of 11.75 GHz for two orthogonal polarizations (lines *1* and *2* in the E— and H-planes for the vertical polarization, respectively, lines *3* and *4* in the E— and H-planes for the horizontal polarization, respectively).

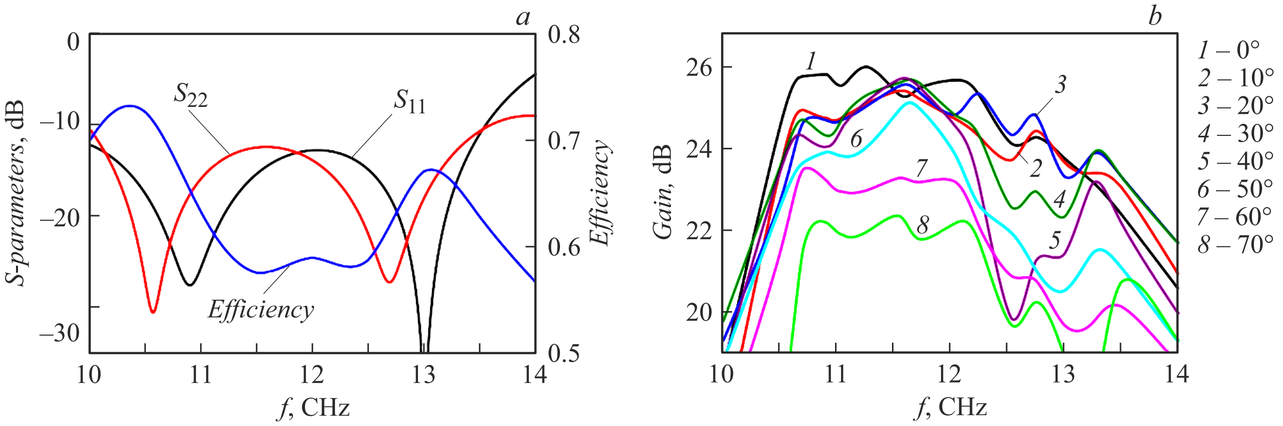

Figure 3. *a* — frequency dependences of the S-parameters and aperture efficiency of the studied subarray based on the aperture-coupled radiator. *b* — frequency dependences of the gain of the antenna array based on the aperture-coupled radiator at different scanning angles θ.

To reduce the subarray size in the scanning plane, the subarray power dividers are located in the printed circuit board layers underlying the radiators. Transition from the microstrip lines exciting the radiators to microstrip dividers also proceeds through metallized holes. The AA subarray size was 208 × 14 × 9 mm. The reflection parameter of the subarray developed based on the aperture-coupled element does not exceed −10 dB for two orthogonal polarizations. The subarray aperture efficiency was higher than 60% in the frequency band of 10.7 to 12.75 GHz (Fig. 3, *a*); the aperture efficiency of the microstrip subarray in the previously developed AA with mechanoelectric scanning [4,5] did not exceed 30% in the frequency band of 11−11.6 GHz because the subarray size was increased to accommodate the power divider. Mismatch losses in the subarray and materials do not exceed 2 dB in the operating frequency band.

Based on the presented subarray, a „Louver“ AA with mechanoelectric scanning was created. AA consists of eight identical subarrays; the total dimensions are 208 × 152 × 9 mm. The aperture efficiency of the array under consideration was higher than 50% in the frequency band of 10.75−12.5 GHz at the zero beam deflection. Scanning in the elevation plane is performed via the subarrays rotation about their own axes and introduction of a linear phase delay along the subarrays. Fig. 3, *b* presents the frequency dependences of the studied AA gain at different subarray rotation angles. Gain degradation of the antenna array based on the aperture-coupled element appeared to be no more than 1 dB in the scanning angle sector of 0−40° in the frequency band of 10.75−12 GHz; the gain decreases by 2.2 dB with turning the subarrays by 50° and by 3 dB with turning by 60°. When the subarrays turn by an angle more than 70°, the antenna gain decreases by 4 dB and more. A decrease in the gain of AA based on the aperture-coupled element at the scanning angles exceeding 40° is mainly caused by mutual shading of subarrays. Narrowing of the AA operating band relative to that of the proposed aperture-coupled element occurs due to an increase in the level of grating lobes at the highest operating band frequencies because the array pitch (the distance between the centers of neighboring arrays) exceeds 0.9λ. Notice that the scanning sector of the previously developed microstrip „Louver"-type AA is $0-70^\circ$ by the criterion of directivity degradation by no more than 3 dB; the reduction of the proposed AA scanning sector is associated with specific features of arrangement in the subarray of the radiators and power divider ensuring excitation of two orthogonal linearly polarized signals. However, the developed AA based on the aperture-coupled radiator is assumed to be used in ground terminals of low-orbit and medium-orbit satellite systems for which the beam scanning sector of $0-60^\circ$ is sufficient.

All the presented investigation results were obtained via numerical simulation by the methods of finite integration in the time domain and finite elements in the frequency domain.

Thus, this paper proposes an antenna array (AA) based on an aperture-coupled radiator and presents the results of studying the AA radiation characteristics. There is shown the possibility of using microstrip aperture-coupled radiators in antennas with mechanoelectric scanning (of the „Louver"type) in order to extend the operating frequency band and reduce the antenna dimensions. The obtained results may be used in creating low-profile AAs for ground terminals of low-orbit and medium-orbit satellite communication networks.

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Conflict of interests

The authors declare that they have no conflict of interests.

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