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11

Bipolarized X-band antenna array with an edge-decreasing field distribution

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The results of a for a bipolarized X-band antenna array is presented. A special feature of the design is the use of a milled base, which makes it possible to reduce the mutual influence between the microstrip lines of the feed network and thereby achieve the required a decreasing to the edges amplitude distribution in the antenna surface to reduce the level of the side lobes. Experimental studies on the layout of a common-mode, bipolarized antenna array with dimensions of $3\lambda_0 \times 6.7\,\lambda_0$ (where λ_0 corresponds to the center frequency of the operational range) have shown a relative operational frequency band of 12 %, with a standing wave ratio (SWR) < 2 and a decoupling between polarization channels of at least -27 dB. Side lobe levels in orthogonal planes do not exceed -18 dB.

Keywords: antenna array, bipolarized, side lobe level, X-band, decreasing amplitude distribution.

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An important requirement for antenna arrays (AAs) in various communication, ranging, and ranging system is the side lobe level (SLL) of the radiation pattern (RP). With certain processing algorithms, high SLL values may lead to the emergence of false targets and have a negative impact on the performance characteristics of a radar station [1–4]. In view of this, the formation of an amplitude distribution decreasing towards the edges, which ensures SLL minimization, remains critical for modern antenna systems. If there are no restrictions on overall dimensions, a parabolic aerial with proper parameters of the reflector and the feed may be used. However, the weight and size parameters are often subject to rather severe restrictions that make parabolic aerial inapplicable. Owing to this, slotted waveguide antenna arrays (SWAAs) [5], printed microstrip antenna arrays (MSAAs) [6], and printed AAs with a feed network based on the SIW technology [7–10] have become widespread.

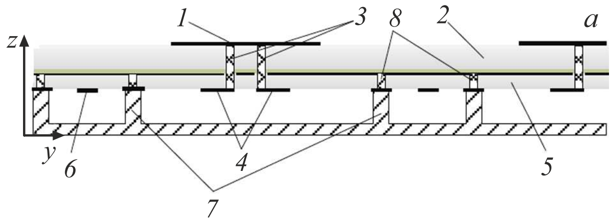
Operation in two polarizations allows for a significant expansion of functionality of radar systems. However, the need to combine two power divider systems makes it rather hard to design dual-polarized antennas with low SLL. For example, dual-polarized SWAAs are significantly more structurally complex than single-polarized ones [11], and their weight increases. It is much simpler to manufacture microstrip antennas, but their efficiency is lower due to thermal losses in the dielectric, and the radiated power is limited by heating of the strip transmission lines [12]. Nevertheless, if one considers a combination of factors (simplicity, weight, technological variability in production), they are still a viable option.

In contrast to single-polarized MSAAs [6,13,14], a dual-polarized MSAA requires a branched feed system (FS) for each polarization. For example, an antenna design with the power divider system for both polarizations located in one layer was presented in [15]. However, owing to the specific features of this architecture, the number of emitters is limited. FSs for each polarization may be positioned in separate layers, but the cost and complexity of the printed circuit board then increase significantly. FSs for different polarizations may also be positioned on separate boards [16,17]. However, the technological efficiency of the design is reduced in this case, since it becomes necessary to fix individual boards at different heights from the screen. One possible solution is to switch to a series-series or series-parallel FS. Series-feed arrangements are compact and easily scalable. Two series FSs for the required number of elements may be positioned in one layer of the printed circuit board. The operating frequency band is narrower in this case, since it is inversely proportional to the number of elements in series AAs [1]. However, this a promising option for narrow-band systems.

In the present study, we discuss a prototype of a narrow-band dual-polarized microstrip AA designed to test the engineering solutions that provide a low level of RP side lobes. The prototype features four lines of ten elements each. These lines are fed in the center and consist of two halves of five elements connected in series. The power is distributed between emitter lines in accordance with a parallel scheme. Having studied several FS designs, we found the following.

First, even individual FS elements should not be placed in the radiating aperture, since the level of radiation from them is commensurate with the field level in the region of RP side lobes.

Second, when the FS is arranged in one layer, additional measures must be taken to neutralize the mutual influence between its individual elements. The mutual influence of FS



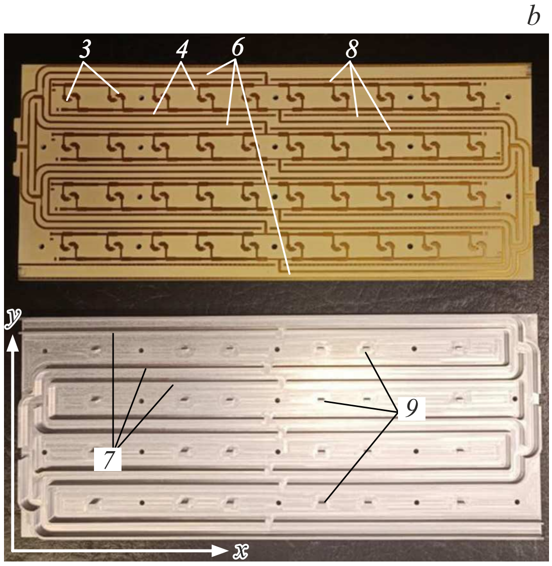


Figure 1. *a* — cross section of the AA element; *b* — elements of the subarray prototype.

elements leads to errors in the amplitude–phase distribution and, consequently, to RP distortion.

In the end, a disk emitter based on a multilayer printed circuit board secured to a milled base was chosen to be the basic AA element. The emitter diameter was $0.265\,\lambda_0$ (λ_0 corresponds to the center frequency of the operating range), and the cell size was $0.607\lambda_0 \times 0.678\,\lambda_0$. The overall view of the structure is presented in Fig. 1. Its elements are as follows: *1* — disk microstrip emitter; *2* — layer of WL-CT338 (equivalent to RO 4003) with a thickness of 1.524 mm; and *3* — metallized holes connecting the emitters with the FS of lines *4* printed on layer *5* (WL-CT338 with a thickness of 0.813 mm). The walls of milled base *7* together with metallized holes *8* form solid partitions that suppress the mutual influence between the power divider system of lines *4* and supply lines *6* (see also Fig. 1, *b*). If the FS was based on a symmetrical microstrip line, insulating walls could be made using the SIW technology [10]. However, this would reduce the antenna efficiency due an increase in losses per unit length in the feed circuit. This is the reason why we opted for the above design. Cavities in the milled base form sections of rectangular waveguides with a transverse dimension of $0.47\lambda_0$, which is equal to the maximum distance between walls *7*. With the dielectric layer of the printed circuit board taken into account, the cutoff frequency of such a waveguide turns out to be positioned below the lower operating frequency; therefore, there is a risk of its excitation. This may lead to errors in the amplitude–phase distribution, RP distortion, and a reduction in gain. To prevent the excitation of cavities in the milled base, spikes *9* (of the same height as walls *7*) are positioned between walls *7*. These spikes raise the cutoff frequency of waveguides. Since they do not come into contact with the FS elements, they do not affect the antenna characteristics.

A prototype of a dual-polarized printed AA was designed and fabricated in order to test the proposed engineering solutions. Its elements are shown in Fig. 1, *b*. To simplify the design, identical series power dividers (a splitting factor of -3.5 dB) were used, and the end of the line was terminated with a matched load. The printed circuit board and the milled base were tightened with M2.5 screws (mounting holes are visible in Fig. 1, *b*). The assembled prototype is shown in Fig. 2, *a*.

Full-wave FEM modeling of the antenna was performed, and the following characteristics at the center frequency were obtained as a result: the SLL for the first and second polarizations is -19.8 dB and -18 dB, respectively; thermal losses in the dielectric are -0.83 dB; load losses are -0.14 dB; the directivity is 22.4 dB; and the gain is 21.4 dB. Dielectric losses are the key factor characterizing the efficiency of the proposed solution. Load losses may be avoided, since they emerge due solely to the use of identical dividers (loads remove the jump in the amplitude distribution at the outermost elements). If the FS is designed more thoroughly with dissimilar dividers, they are not needed.

The prototype shown in Fig. 2, *a* was tested in the anechoic chamber at the St. Petersburg State Electrotechnical University „LETI“. The measurements revealed that the relative operating frequency bandwidth with a standing wave ratio (SWR) better than 2 and a decoupling between the polarization channels of at least -30 dB was 6 % (Fig. 2, *b*). If a weaker criterion is used (decoupling no worse than -27 dB at the same SWR level), the relative bandwidth exceeds 12 %. The bandwidth at the level of -1 dB from the maximum gain value was 4.6 %. The calculated and experimental RPs matched closely (see Fig. 3). The measured gain at the center frequency was 19.8 dB. The

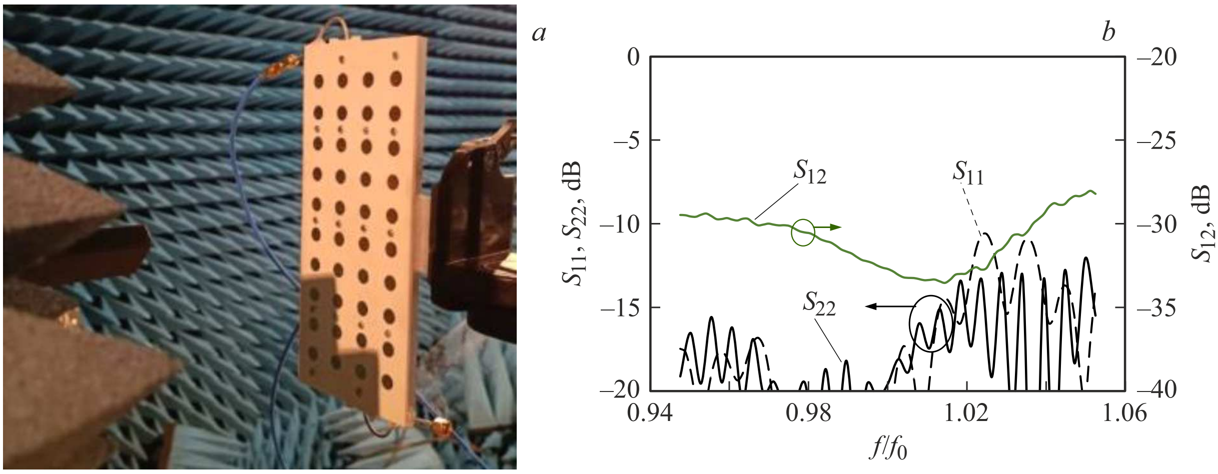


Figure 2. *a* — view of the experimental facility; *b* — measured *S*-parameters of the subarray prototype.

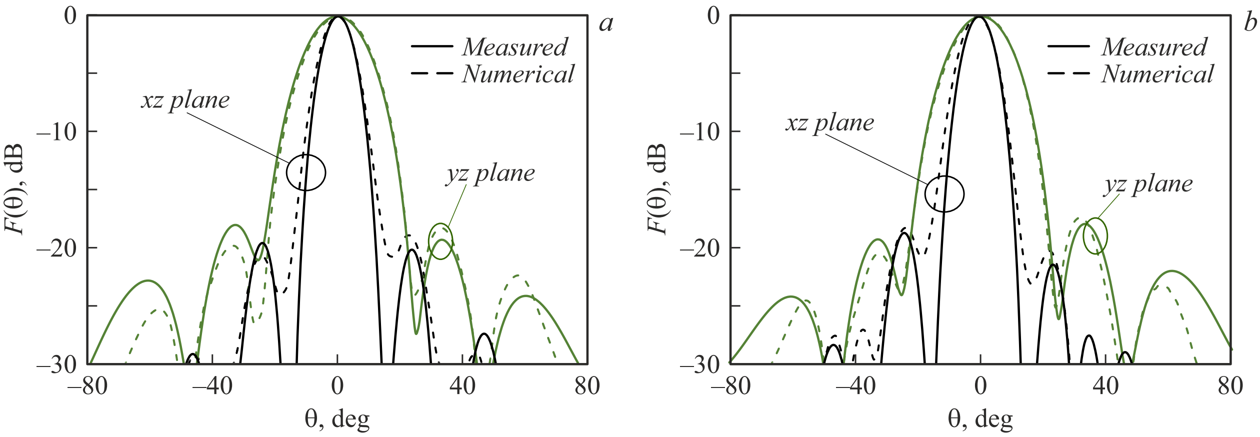


Figure 3. Radiation pattern (RP) at the operating frequency. *a* — first polarization; *b* — second polarization.

side lobe level at the center frequency was -20 dB for the first polarization and -18 dB for the second one.

The feasibility of a dual-polarized printed X-band antenna array design with low SLL was demonstrated. The discussed antenna array is a combination of a printed circuit board and a milled base. This design allows one to form the FS for both polarizations in one layer and thus minimize the number of PCB layers (two sintered cores are used). The proposed design is easily scalable, but it should be remembered that an increase in the number of elements leads to narrowing of the operating frequency band due to the use of the series feed circuit. A milled base is needed to suppress mutual influence between individual FS elements. The results of experiments are in close agreement with calculated data, which verifies the suitability of the chosen engineering solutions.

The closest counterparts are the antennas described in [11,16,17]. They are structurally more complex, but offer a wider operating frequency band. Thus, the proposed design is preferable for narrow-band antennas.

Conflict of interest

The authors declare that they have no conflict of interest.

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