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Mechanically controlled phase shifter on a gap-waveguide

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The paper is devoted to the study of the possibility of realisation of a phase shifter based on a gap-waveguide in the Ku-band of wavelengths. The results of modelling of the proposed phase shifter design are presented. The phase adjustment range exceeded 360° in the frequency range of more than 30% at a mechanical displacement of the decelerating line by 6 mm. The VSWR of the device was less than 1.1. The proposed phase shifter can be applied for construction of antenna arrays with mechanoelectric scanning.

Keywords: gap-waveguide, phase shifter, mechanoelectric scanning.

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In recent years, satellite communication systems have received a new round of active development. Both the renewal of geostationary and the deployment of new low- and medium-orbit satellite constellations are taking place. The development of the latter implies the use of scanning antenna systems even as part of fixed satellite ground terminals. The high cost of modern active element base and its availability put into question the creation of active phased antenna arrays for mass consumers, which fuels considerable interest in antenna systems with mechanoelectric type of scanning, in which the beam is controlled by mechanical control of the components of antenna system [1,2]. The most important element of a mechanoelectric scanning type antenna system is the phase shifter. The characteristics of the antenna system largely depend on its properties.

Often, phase shifters and delay lines are designed using strip technology [3], devices based on which have significant losses, especially at high frequencies. Waveguide phase shifters, although having relatively low loss [4], require high precision fabrication to maintain their electrical parameters. In addition, there are requirements for electrical contact between the constituent walls of the waveguide, which is not always sufficiently realizable. To level out the above disadvantages, more expensive fabrication and surface treatment techniques are required to efficiently assemble the parts, which also adds complexity to the manufacturing process.

The development of „gap-waveguide“ technology opens up a range of possibilities for creation of mechanically controlled microwave- components, since in this type of transmission line there is no need for contact between the constituent parts of the device.

The principle of operation of this transmission line was previously described in [5]. The intermittently placed pins simulate a high-impedance surface that prevents the wave from propagating within the structure. In this way, a barrier band [6] is formed, whose lower frequency is determined by the height of the pins h, which is approximately $\lambda/4$, and whose upper frequency is determined by the ratio $h+z=\lambda/2$, where z — the gap between the tops of the pins and the standoff wall of the waveguide.

A H–shaped gap- waveguide, the electric field in which is shown in Fig. 1, a, was taken as the basis for the mechanically controlled waveguide.

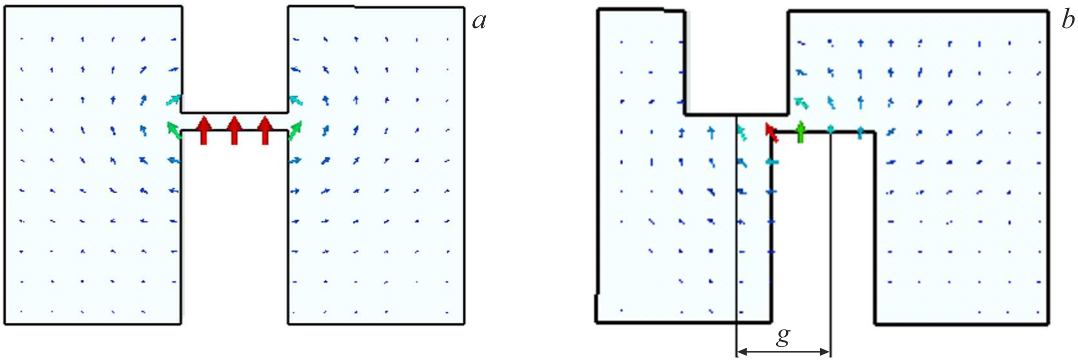

Figure 1. Waveguide with H-section. a — the field distribution in the H--section waveguide, b — the field distribution in the H--section waveguide when the crests are displaced relative to each other.

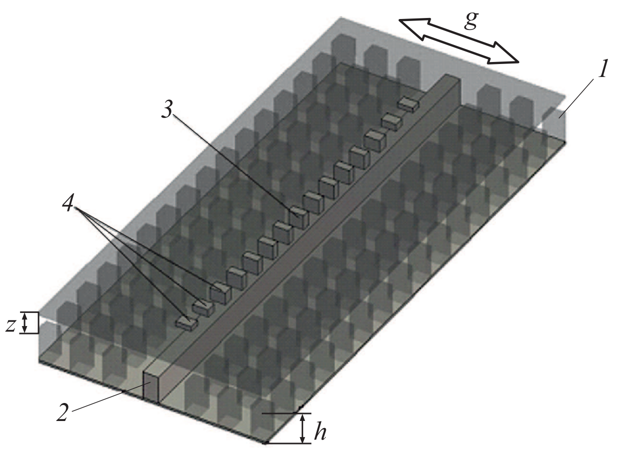

Figure 2. The structure of the phase shifter. *1* — gap waveguide pins, *2* — waveguide bottom crest, *3* — meander periodic retarding structure, *4* — matching elements.

The transverse components of the electromagnetic field concentrate mainly in the narrow gap where the field is close to the TEM- wave, similar to a microstrip transmission line that has a critical frequency of zero [7]. Consequently, a waveguide with this cross section has a lower critical frequency compared to a rectangular waveguide of the same dimension.

As a result, the periodically spaced crests act as a high-impedance structure that prevents the wave from propagating in an undesired direction, resulting in the wave propagating between the crests *H*- of the waveguide section without additional decay.

Additional phase delay in such a waveguide can be obtained by realizing one of the crests as a meander decelerating line [8].

Based on the considered waveguide and delay line, a mechanically controlled phase shifter (Fig. 2) was realized, which does not require direct contact of the surfaces, which greatly simplifies its practical realization. The dimensions of the device are 90 × 40 × 9 mm.

At the position where the crests are on top of each other, the field concentration in the gap is maximized (Fig. 1, *a*), and the wave interacts maximally with the delay line. Once the structure of the upper crest is shifted sideways by some amount *g* (to the left or right relative to the lower ridge), the influence of the decelerating line decreases (Fig. 1, *b*), and the propagating wave begins to acquire a smaller phase delay. This structure can provide 360--degree phase delay depending on the crest position. The calculated phase dependences are presented in Fig. 3, *a*.

To minimize the wave reflectance from the phase shifter, the height of the crests of the meander decelerating line is made smoothly increasing and decreasing. The voltage standing wave ratio (VSWR) of such a structure as a function of crest offset *g* is shown in Fig. 3, *b*. The calculated losses in the phase shifter when it is made of aluminum do not exceed 0.2 dB. The introduced time delay in the operating frequency range is linear (Fig. 3, *with*), which will allow the devices to be used in broadband antenna arrays with minimal frequency scanning. The maximum phase and time delays depend on the length of the decelerating line in the phase shifter.

The performed studies show the possibility of creating a mechanically controlled phase shifter based on gap-

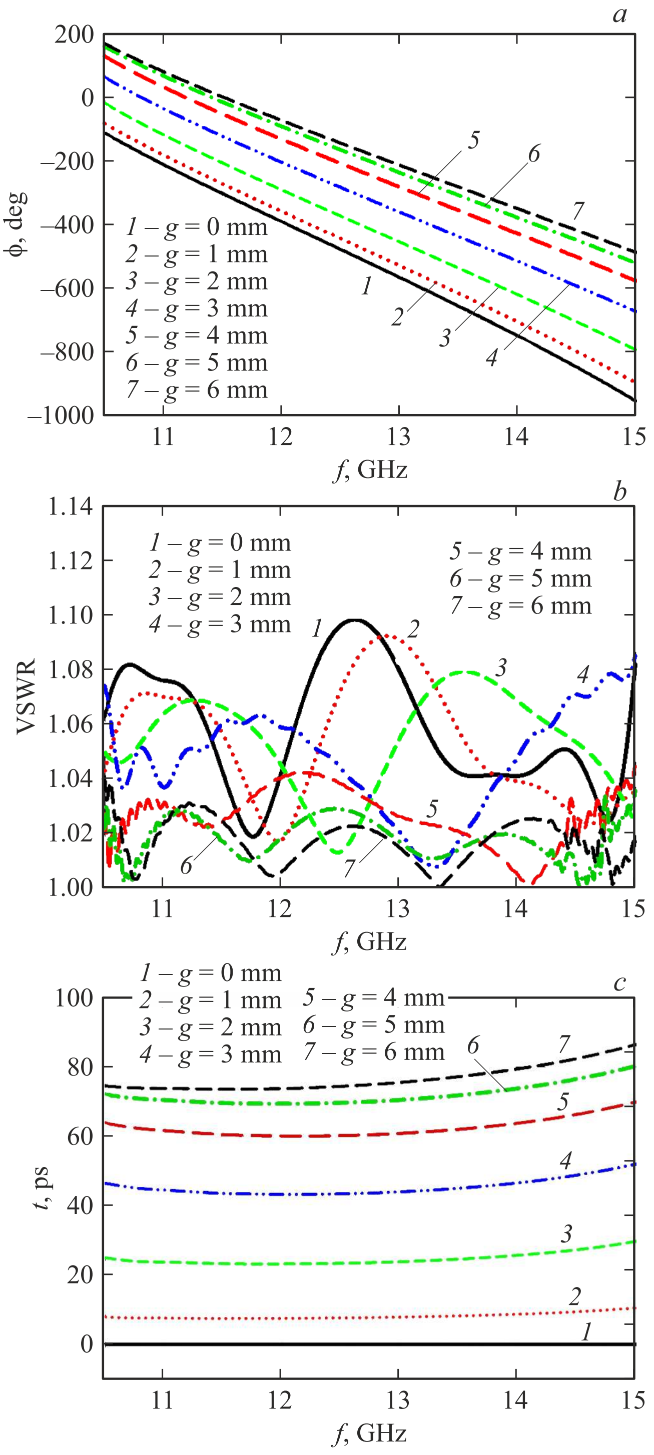

Figure 3. Frequency dependencies at different decelerating line shifts. *a* — gain phase, *b* — VSWR, *c* — delay time.

waveguide with phase shifting more 360° in the operating frequency range. The absence of requirements for electrical contact of the gap--waveguides walls gives a large technological advantage in the design of mechanical microwave-nodes.

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Conflict of interest

The authors declare that they have no conflict of interest.

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