Technical Physics Letters, 2022, Vol. 48, No. 10

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Slot transition from gap waveguide to symmetrical strip transmission line in millimeter wavelength range

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Received July 21, 2022
Revised August 18, 2022
Accepted August 19, 2022

The work is devoted to the investigation of a possible realization of the transition from a waveguide transmission line to a strip line in the millimeter wavelength range. The structure of slot transition from gap waveguide to strip line transmission is developed. Determined the working dimensions of the structural parts of the transition for use in the excitation systems of antennas in the millimeter wavelength range. Simulation of the obtained structure was performed, and conclusions about its applicability in communication systems were drawn.

Keywords: gap waveguide, radiating slot, strip transmission line.

DOI: 10.21883/TPL.2022.10.54791.19319

The constant strengthening of requirements imposed on the capacity of radio channels motivates the exploration and utilization of progressively higher-frequency ranges, which include the millimeter wave band.

Owing to low losses, classical rectangular waveguides are transmission lines that are the best suited for this wavelength range. They are commonly produced in a split design, which impairs the quality of electric contact at joints. Inaccurate assembling induces strong distortion of the electric characteristics in the millimeter wave band. A new type of transmission lines, which is known as a gap waveguide and offers better flexibility in modular assembly [1,2], was proposed in order to solve this problem. The key advantage of such waveguides consists in the possibility of their application without a direct contact between top and bottom faces [3]. This provides an opportunity to produce cheap and efficient structures for the millimeter wave band. The technology of gap waveguides allows one to relax the requirements on the fabrication accuracy and time and utilize less costly manufacturing techniques.

A gap waveguide is formed by two parallel metal plates. A periodic structure on one of these plates (Fig. $1, a$) establishes a rejection band to constrain the propagation of plane-parallel modes and surface waves in unwanted directions. If a periodic structure is located at a distance shorter than $\lambda/4$ from a smooth surface, the structure as a whole acts as a high-impedance surface, establishing a rejection band in a certain frequency range. The width of this band increases with decreasing height g of the air gap [4]. With ridge period $d > \lambda/4$, the upper boundary of the rejection band shifts lower due to the propagation of higher modes.

A periodic structure may assume various shapes: ridge with rectangular (circular) rods [5], mushroom-like [6], helical [7], etc. The optimum number of ridge rows of a periodic structure providing the needed rejection was determined in the present study. Specifically, S-parameter curves for a gap waveguide with a channel $a \times b$ in size were obtained (see Fig. $1, b$). These curves demonstrate that coefficient S_{11} does not exceed -20 dB, while coefficients S_{31} and S_{41} do not exceed -55 dB in the studied frequency band (with losses in metal being neglected). This is attributable to minimized reflectance and fine isolation of channels.

Transitions between gap waveguides and other transmission lines are central to the design of microwave devices. It is known [8] that a transition from a gap waveguide to a microstrip line may be established by exciting a quasi-TEM mode in both structures.

The only thing left to enhance the interface matching is to fulfill the requirement as to conversion of the electric field propagating in the substrate dielectric into the waveguide electric field. To achieve this, one may narrow the channel down in transition from a classical gap waveguide to a Π-shaped one [9]. This is exactly what was done in the present study. A method for converting a TEM mode propagating in a microstrip line into an H_{10} waveguide mode with the use of a slot line is known [10]. However, the aim of the study was to design a transition from a gap waveguide to a symmetric strip transmission line to be used further in excitation systems for antenna arrays. In view of the foregoing, the option of conversion of the mode of wave propagation in a gap waveguide into the mode of a strip transmission line via a radiating slot was implemented. This slot was cut in the upper smooth face of a gap waveguide, which also acts as a metallization layer of the printed board containing a symmetric strip line (Fig. $2, a$). The slot was made approximately two times shorter than the wavelength to ensure operation at

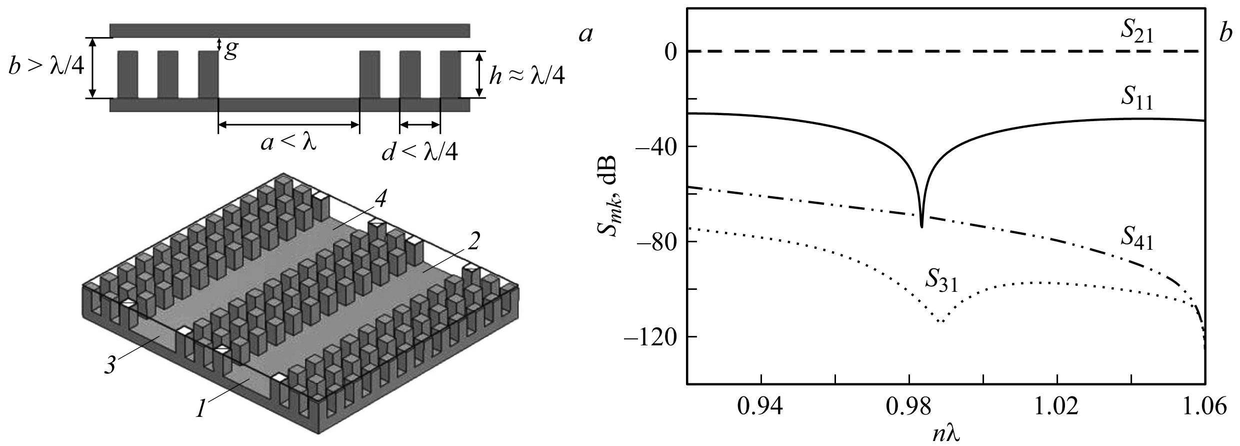

Figure 1. *a* — Structure of a ridge gap waveguide; *1–4* — port numbers. *b* — Frequency dependence of the S-parameters of the studied model.

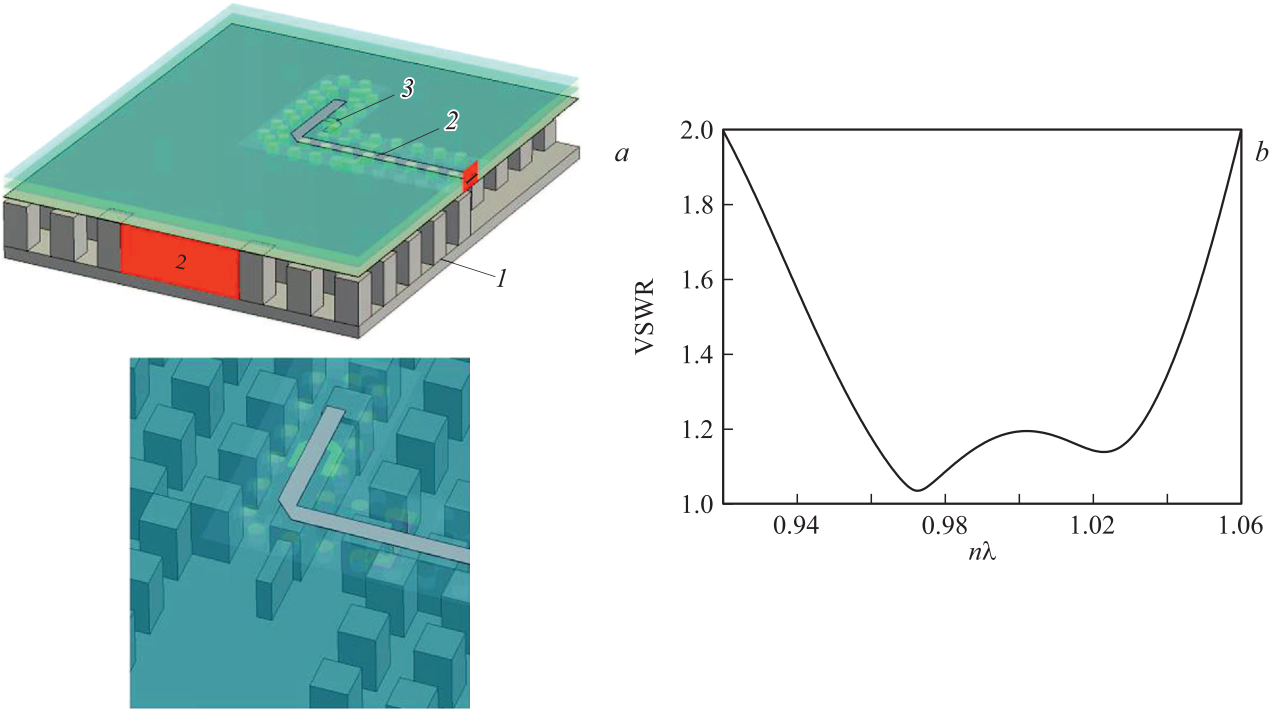

Figure 2. *a* — Transition from a gap waveguide to a strip transmission line: *1* — gap waveguide, *2* — strip transmission line, *3* — radiating half-wave slot. *b* — Frequency dependence of the voltage standing-wave ratio (VSWR) of the studied model.

the fundamental resonance frequency. It then serves as a purely active load for the gap waveguide. The symmetric board was fabricated from the Isola Astra MT77 material with a thickness of 0.254 mm and permittivity $\varepsilon = 3$.

The strip transmission line was shielded by plated-through holes in order to prevent the propagation of an electromagnetic wave along the dielectric material. The obtained multilayer printed board structure is somewhat similar to a substrate integrated waveguide [11]. in order to suppress the excitation of higher modes, the width of the waveguide formed by plated-through holes should not exceed a certain value. With that and size considerations in mind, a U-shaped radiating slot was designed. Matching was achieved through the use of a waveguide quarter-wave transformer in the gap waveguide with the channel narrowing down via the transition to the Π-shaped waveguide. The obtained structure was optimized with respect to the minimum voltage standing-wave ratio (Fig. 2, *b*). The presented data are indicative of fine matching of the designed transition in the required frequency range.

Thus, research indicates that an efficient transition from a gap waveguide to a strip transmission line may be constructed. This structure provides an opportunity to design excitation systems for antenna arrays operating in the millimeter wave band with low losses and with the strip system being integrated into the upper outer face of a gap waveguide. Since gap waveguides have no requirements imposed on the quality of electric contact between their faces, they are well-suited for mass production.

Funding

This study was supported financially by the Russian Foundation for Basic Research, the Government of Krasnoyarsk Krai, and the Krasnoyarsk Krai Foundation of Science as part of scientific project No. 20-47-240003.

Conflict of interest

The authors declare that they have no conflict of interest.

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