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Analysis of the sensitivity of circular waveguide filter performance to manufacturing tolerances

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The electrodynamic properties of circular waveguide filters with complex-shaped resonant diaphragms have been studied. The dependence of the band-pass filter characteristics on the geometric dimensions of the central diaphragm and their slight deviations from the optimal values has been analyzed. Their influence on the device's amplitude-frequency response has been determined.

Keywords: band-pass filter, circular waveguide, resonant diaphragm, manufacturing tolerances.

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Introduction

Circular waveguides with inhomogeneities of complex cross-section have certain selective properties [1]. This makes them commonly used in microwave technology [2–4] and determines the relevance of solving the problem of studying their electrodynamic characteristics, which was successfully solved in Ref. [1].

When creating new microwave devices, not only numerical and analytical methods are used, but also various computer modeling packages, the role of which is very important in optimizing the electrodynamic characteristics of the projected selective microwave devices. However, it is known that the success of multiparametric optimization, which requires large, time-consuming computer calculations, depends on the initial approximation. The more accurately you can create a prototype filter and set its dimensions, the more effective the use of various computer-aided design packages will be.

It is also known that the characteristics of a microwave device depend on the accuracy of its manufacture. And the error in reproducing the design of a microwave device affects its actual electrodynamic parameters.

The geometric errors resulting from the size variation of the resonant diaphragms during manufacture lead to changes in the electrical parameters of the device, so the complex geometry of the resonant diaphragms used [5] imposes strict tolerances for their manufacturing.

All this makes it relevant to study the effect of precision manufacturing of microwave devices on their parameters. And when developing new devices, research should be conducted to determine the manufacturing requirements for the main components (for example, resonant diaphragms with complex cross-sectional shapes). This is especially important for microwave devices designed for mass production. Therefore, when designing various devices, it is necessary to determine not only the optimal manufacturing tolerances, but also to study their effect on the basic electrodynamic characteristics of the product.

In this paper, we continue to study the electrodynamic characteristics of band-pass filters based on a circular waveguide with radial inhomogeneities of complex cross-section [5], and focus on studying their electrodynamic characteristics with a slight change in the geometric dimensions of the diaphragms.

1. Problem statement

To achieve these goals, we will conduct an electrodynamic study of the filter characteristics with a slight deviation of its dimensions from the optimal ones. To do this, we will create the filter itself and study its electrodynamic characteristics.

We will use a filter model in this paper, which was designed using a previously proven technique [6,7] and included two stages [1]:

• study of the electrodynamic characteristics of resonant diaphragms [5,8] (selection of the type of inhomogeneity, study of the dependence of S-parameters and evaluation of their quality depending on the geometric dimensions);

• creation of a three-dimensional prototype filter model (determining its characteristics, the required number of links, and the geometric dimensions of the resonators) and optimizing its parameters using the CST STUDIO package.

Knowledge of the geometric dimensions that have a significant effect on the resonant frequency and quality of a single diaphragm with a complex cross-section [1,5] allows calculating a prototype filter, determine its geometric dimensions, synthesize it, and perform multiparametric optimization.

Next, the problem to be solved is reduced to investigating the dependence of the filter characteristics (its S-parameters) with a slight change in geometric dimensions (when they deviate from optimal values).

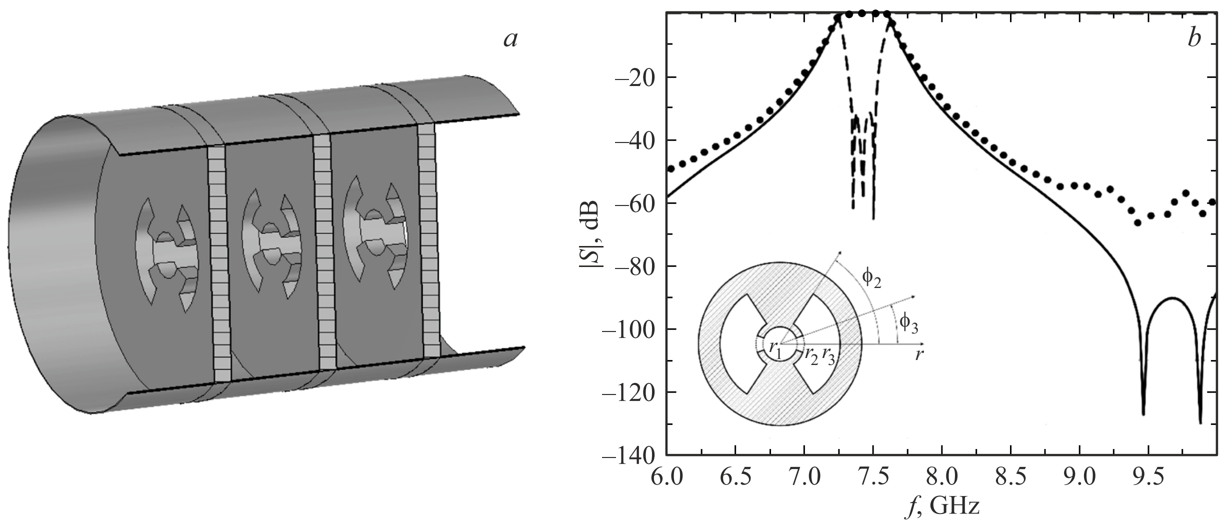

Figure 1. A model of a synthesized third-order band-pass filter: its topology (*a*) and frequency response (*b*).

2. The effect of the deviation of the geometric dimensions of the filter from the optimal ones on its characteristics

It should be noted that the complex profile of resonant diaphragms requires high precision in their manufacture. To study the effect of permissible deviations of the geometric dimensions of inhomogeneities from the optimal ones, we use the created models of designed filters of the third and fifth orders.

Fig. 1 shows the topology of the third-order filter and its amplitude-frequency response (frequency response). For this filter, the unevenness of the transmission coefficient in the bandwidth (7.22–7.62 GHz) reached ~ 0.7 dB with a reflection coefficient not worse — 33 dB. At the same time, its longitudinal size is slightly greater 26 mm. The comparison (The inset on Fig. 1, *b* shows the cross section of the resonant diaphragm) of the calculation results (solid line — $|S_{21}|$, dotted — $|S_{11}|$) with experimental data (markers — $|S_{21}|$, averaged values over two measurements using Agilent Technologies E8363B PNA Network Analyzer and Micran P4M-18) confirmed the high accuracy and reliability of the data obtained. The results are shown for a filter with dimensions from the table. Comparisons were made in Ref. [1] with experimental data for a fifth-order filter.

Let's consider the dependence of the frequency response of a band-pass filter with a slight deviation of the geometric dimensions of the diaphragm from the optimal ones (see the table).

Thus, Fig. 2, *a* shows the dependence of the reflection coefficient modulus upon a change in the outer radius of the annular segment r_2. It can be seen that the optimal value of $|S_{11}|$ is reached at $r_2 = 2.65$ mm, and its slight change affects the quality factor of the resonator, but does not lead to significant changes in the filter characteristics in the operating frequency band. It should be noted that, unlike changing the angle of the radial rib and the angle of the annular segment, changing the outer radius of the annular segment has the least effect on the frequency response of the filter.

Geometric dimensions of the studied filters

Sizes of diaphragms	ϕ_2, °	ϕ_3, °	r_1, mm	r_2, mm	r_3, mm
Optimal third-order filter sizes					
The first and the third	57.56	26.92	2.37	4.33	6.47
The second	61.19	23.04	2.16	4.24	6.06
Distance between the diaphragms: $l_{12} = l_{23} = 10.17$ mm					
Optimal fifth-order filter sizes					
The first and fifth	58.26	27.26	2.28	3.69	6.47
The second and fourth	61.28	23.34	2.08	4.11	6.06
The third	63.8	21.69	1.55	2.65	5.61

Distance between the diaphragms: $l_{12} = l_{45} = 7.92$ mm, $l_{23} = l_{34} = 8.91$ mm

Let us consider the effect of the size of the radial ridge ϕ_2 on the filter frequency response when it deviates from the optimal size of 63.8°. At the same time, the remaining dimensions of the waveguide structure are fixed and optimal. Thus, Fig. 2, *b* shows the dependence of the reflection coefficient modulus of a fifth-order band-pass filter with a slight change in the angle of the radial ridge ϕ_2. As can be seen in Fig. 2, *b* at $\phi = 63.8°$, the reflection coefficient modulus is approximately 20 dB, which corresponds to the optimal filter characteristic. Even with a slight change in the angle (within one degree), the filter characteristic begins to

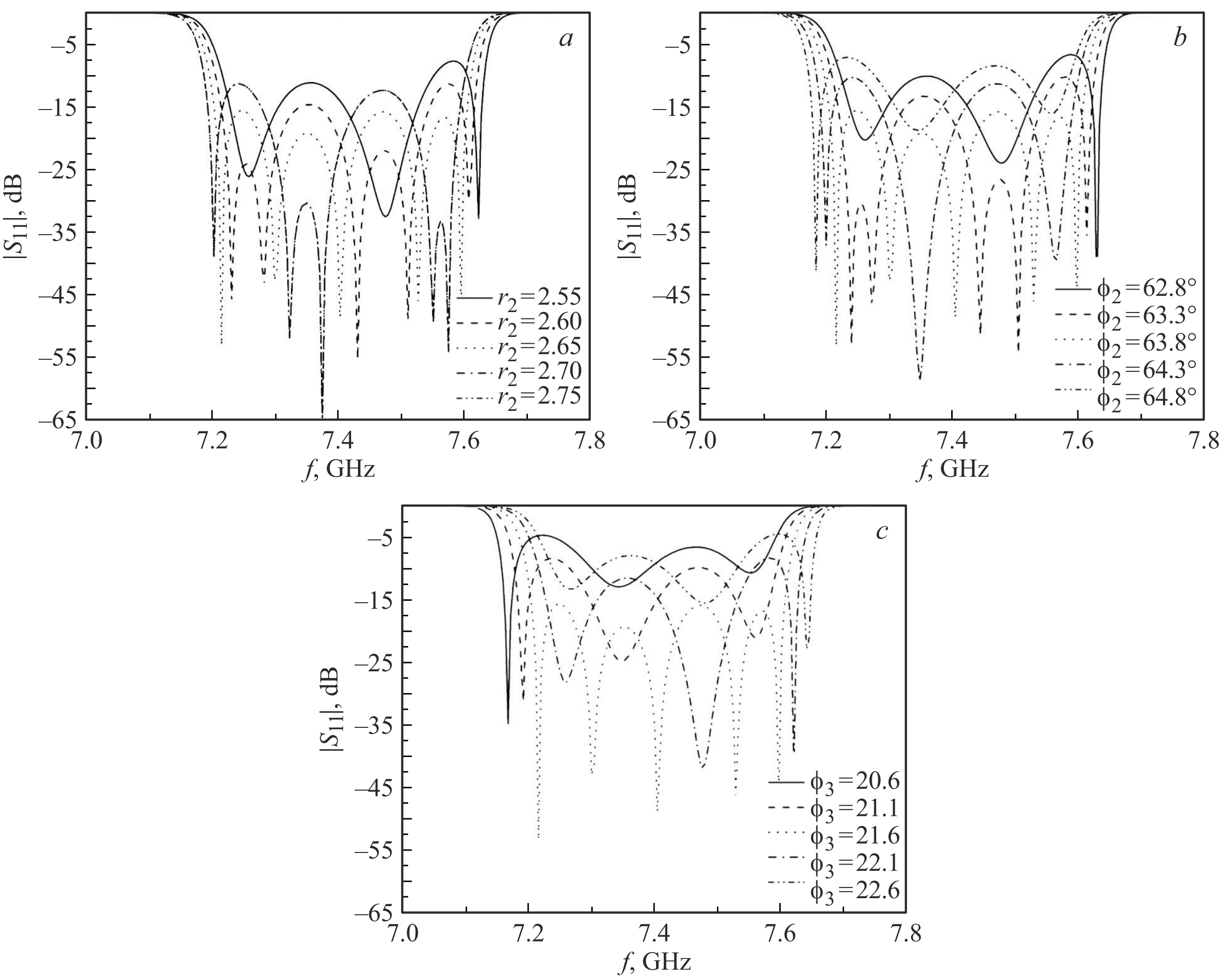

Figure 2. Dependence of the reflection coefficient modulus on the frequency and size of the aperture (explanations in the text).

fall apart, as this leads to a sharp and significant change in the resonant frequency and, as a result, the quality factor of the third diaphragm [5]. The frequency response is shifted to the high frequency range with a decrease in the angle value, and a similar shift in the opposite direction is observed with an increase in the angle.

Fig. 2, *c* shows the dependence of the filter characteristic when changing the angle of the radial annular segment ϕ_3. The following figure shows that the optimal filter characteristic is achieved at $\phi_3 = 21.60°$. As the value of the filter angle decreases, the frequency response of the filter shifts to the left, and as the angle increases, — to the region of higher frequencies. This is due to a significant change in the quality of the resonant diaphragm, which affects the electrodynamic characteristics of the filter.

Let us briefly consider the effect of minor ($\sim 2\%-3\%$) changes in geometric dimensions on the transmission coefficient modulus for a fifth-order filter. So, Fig. 3, *a* shows the dependence of $|S_{21}|$ on the frequency when the radius changes r_2. It is worth noting that changing the radius by 0.1 mm significantly distorts the filter characteristic, and manufacturing errors by 0.05 mm can be considered acceptable. The deviation of the radial ridge angle ϕ_2 has a more significant effect on the frequency response of the device. So, its change by only $0.5°$ leads to a shift in the center frequency (Fig. 3, *b*).

Fig. 3, *c* shows the dependence of $|S_{21}|$ on frequency when changing the distance (l) between the apertures for a third-order filter. The optimal frequency response of the filter is achieved at a distance between the diaphragms of 10.188 mm. Calculations have shown that when the distance between the apertures is changed by 0.05–0.1 mm, the change in $|S_{21}|$ is insignificant. But the deviation of the dimensions from the optimal ones by about 1 mm is already critical.

The calculations performed for a third-order band-pass filter showed a similar dependence of the electrodynamic characteristics on the size of the average resonator.

Conclusion

Thus, it can be concluded that during the manufacture of filters, the azimuthal dimensions of the inhomogeneity

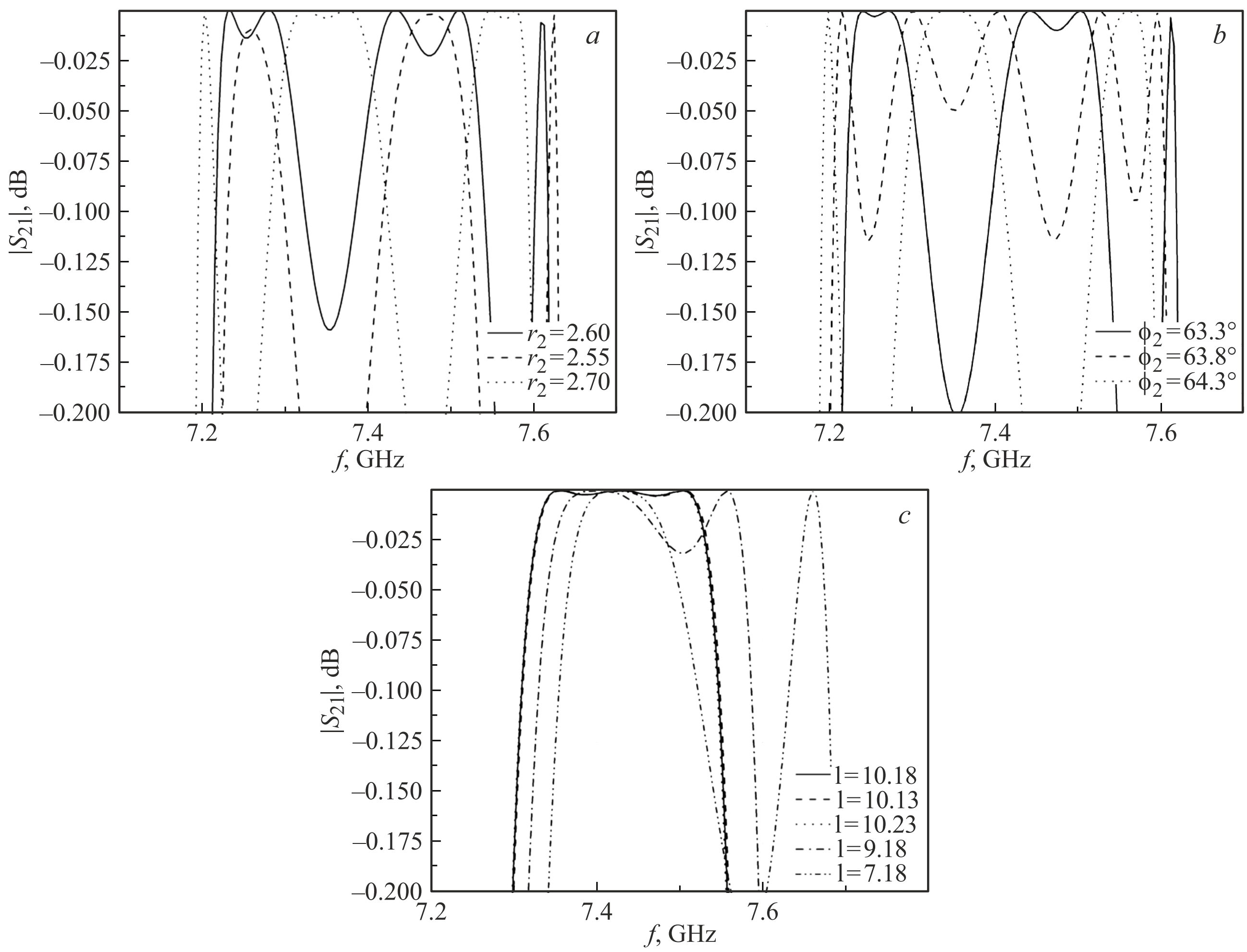

Figure 3. Dependence of the transmission coefficient modulus on the frequency and size of the aperture (explanations in the text).

should be controlled, as they have a significant effect on the frequency response of the device. In this case, a deviation of $\pm 0.5^\circ$ is allowed. The radial dimensions allow a deviation of $\sim 2\,\%–3\,\%$, in our case it is about 0.05 mm. The distance between the diaphragms has the least effect on the frequency response of the device and allows a deviation of up to 1 mm from the optimal size. It should also be noted that the complex geometry of resonant diaphragms and their number tighten the tolerance requirements for the manufacture and assembly of selective microwave devices.

The results obtained in the study can be used not only for designing and manufacturing microwave filters, but also for the development of various virtual laboratory projects [9].

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Conflict of interest

The authors declare that they have no conflict of interest.

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