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Interdigital annular shape filter design

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Abstract

The design of a small-size band-pass filter of an annular shape on interdigital rods has been developed. The results of experimental studies, which have shown that the developed filter has an acceptable quality index and can be successfully used for frequency selection of signals in multichannel microwave receivers with parallel spectral analysis are presented.

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1. Main body

The design of modern radio equipment is constantly associated with the complexity of optimizing the characteristics of elements and assemblies, improving the manufacturability of their implementation and meeting the requirements of electromagnetic compatibility. Frequency-selective and electrically controlled microwave devices are essential elements of modern radio engineering systems. They are widely used in communication systems, in phased antenna arrays of radar stations, as well as in various measuring and special radio equipment. Among the wide variety of frequency selective devices used in modern radio engineering complexes and systems, the most popular are microwave band-pass filters, as well as amplitude and phase modulators. So, in the onboard phased antenna arrays of the latest generation, the number of such devices can reach several hundreds, therefore exactly they very often determine the metrological characteristics of individual hardware parts, and also often the tactical and technical characteristics of the entire system. The most important requirements for such devices are compactness and simplicity of design, manufacturability in production, low cost and high electrical characteristics. By the combination of the listed requirements, the optimal are devices based on strip and microstrip transmission lines, which are created using planar technology. Search for new approaches and principles for the construction of such devices that have improved weight, size and electrical characteristics undoubtedly is an important and urgent task of modern radio engineering. Band-pass filters on opposite rods, which have a number of well-known advantages, are widely used in microwave technology. There are several technical solutions that make it possible to reduce the size of interdigital filters [1]. However, such filters are of limited practical use due to the complexity of their implementation. Therefore, in general, inter-rod filters of a typical design, which have a rectangular cross-section and are

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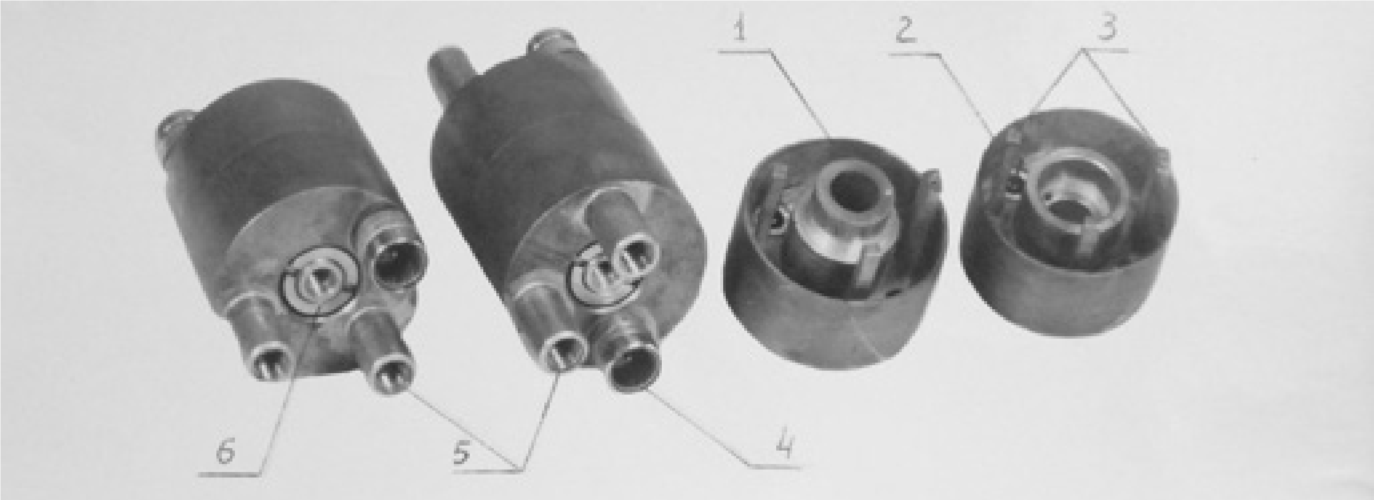

Fig. 1. *Filter design*
1, 2 – similar filter halves; 3 – rods of a comb structure; 4 – hyperboloid connectors; 5 – setting elements; 6 – fastening elements

made on a symmetrical air-strip line with rectangular internal conductors are used [2, 3].

This paper presents the results of the development of a small-sized strip band-pass filter of an annular shape on opposing rods, which makes possible reducing the weight and size characteristics of such filters and simplifying the technology of their manufacturing. Also, the evaluation of the filter's compliance with the quality criterion for uncontrolled band-pass filters was carried out.

The new design solution is based on folding a strip bandpass filter of a typical design into a closed ring [1]. Structurally, the filter is an assembly consisting of two similar halves of an annular shape and fastening elements (the design of the developed filter is shown in Fig. 1).

Each half with similar comb structures is milled from a cylindrical blank. The opposing arrangement of two such comb structures gives a compact filter configuration. The rods of the comb structure, located in a circle in the center of the empty screen, according to the preliminary calculation, have the shape of a sector in cross-section. At the same time, it was additionally experimentally established that the value of Δx (the width of the rods or the distance between them) in a filter analog of a rectangular section should correspond to the difference in central angles $\Delta\theta$ in a ring structure (1).

$$\Delta\theta(rad) = \Delta x / (r - t/2) \quad (1)$$

Where,

$r = (l + s)/2\pi$ – the radius of the middle circle of the ring, mm;

l – the length of the analog filter without taking into account the structural dimensions: the thickness of the body wall and the distance s between the extreme rod and the inner surface of the body, mm;

t – the thickness of the rod, mm.

Let us note that in this filter design, in contrast to the analogue, proper electrical contact of each resonator with the filter housing is guaranteed, because they are made from one piece of a blank (that is, soldering of the resonators to the housing is excluded). The filter is adjusted using adjusting screws located in a circle in the walls of the housing opposite the ends of the rods. Three mock-ups of four resonator interdigital filters of an annular shape for different sections of the S-band were manufactured and experimentally investigated using a complex transmission coefficient meter R4-23.

The filters are equipped with hyperboloid connectors [4, 5, 6]. This type of connectors surpasses all existing electrical circuit switching schemes in terms

[1] The design of the filter was proposed by V. V. Kartashev, and the design of the filters and their experimental study were carried out by A. V. Starunskii and L. M. Olshanskii.

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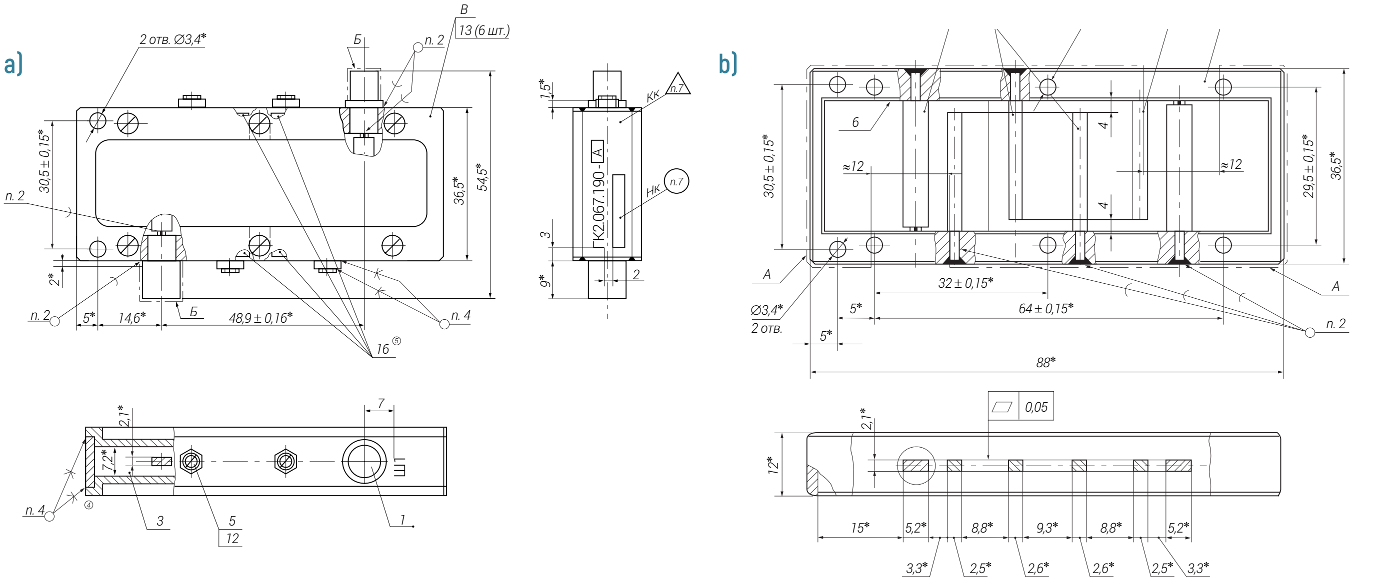

Fig. 2. *Drawings of the analog filter design:*
a) – *general view;*
b) – *internal view*

of reliability, duration of operation, resistance to external influences and ease of use. The mass and dimensions of the developed filters are approximately 1,5 times less than those of analogs, while the electrical parameters of the latter are preserved. It should be noted that the analog filter was produced commercially and was used in a multichannel frequency separating device (the design of the analog filter is shown in Fig. 2). Therefore, replacing analog filters with developed filters in such a frequency-separating device significantly reduces its weight.

The frequency response of the developed filter is shown in Fig. 3. Each filter has the following characteristics: insertion loss is α_o = 1,2 dB; bandwidth at the level 3 dB is $\Delta f \approx$ 55 MHz; the range of operating frequencies in which the filter's frequency response is possible is about 350 MHz; signal rejection is α_r = 27,5 dB when detuning from the center frequency f_o by the amount of bandwidth; VSWR ≤ 1,7; volume $\upsilon \approx$ 33,5 cm^3; mass ≈ 150 g.

The filter decoupling, which is determined by direct signal leakage through the coupling elements, is 50 dB.

To compare the design quality of bandpass filters, a number of expressions are proposed in the literature [7, 8], which take into account the electrical characteristics of the filter and its dimensions, including volume. The most successful known analytical expression (2) for the quality index (QI) of uncontrolled bandpass filters is given in [9]:

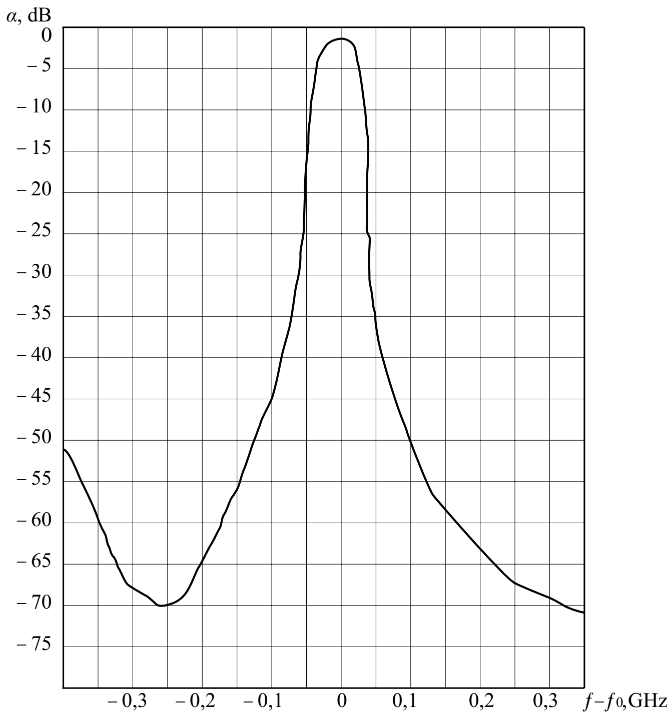

Fig. 3. *Frequency response of the filter:*
α – loss level;
f_o *– center frequency of filter*

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$$QI = \frac{10}{\lambda}\left[\frac{\alpha_0 (\Delta f / f_0) \upsilon}{(\alpha_r / 20)^2}\left(\log\frac{\Delta f_r}{\Delta f}\right)^2\right], \qquad (2)$$

Where,

α_o, dB – level of the minimum insertion loss in the bandpass;

Δf – bandwidth at the level 3 dB;

Δf_r – bandwidth at the level of rejection α_r;

$\Delta f / f_o$ – relative bandwidth, %;

υ, cm³ – physical volume of the filter;

λ, cm – working wavelength.

Theoretical and experimental studies of many filters on sections of transmission lines of various types have shown that for canonical filters with high-quality manufacturing QI = 3,0 – 3,5 [9]. By expression (2), when substituting the characteristics of the developed filter, we have QI = 3,5 (3).

$$QI = \frac{10}{10,17}\left[\frac{1,2 \cdot 1,86 \cdot 33,5}{(27,5/20)^2}\left(\log\frac{110}{55}\right)^2\right] = 3,5. \quad (3)$$

This testifies to the acceptable quality of the developed filter.

2. Conclusion

The developed small-sized bandpass filter has an acceptable quality index and can be used in modern microwave equipment, since it is competitive in terms of its design and technological parameters and deserves further development.

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