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Investigation of Band-Pass Filters of K-Range on Rectangular Concentric Resonators

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Abstract

Introduction. Simple-shaped cavity resonators: rectangular, cylindrical and coaxial, are widely applied in modern microwave engineering in design of different functional devices of middle and high power levels. Parameters of resonators can be obtained analytically by using expressions from literature. Concentric resonators, performed on the basis of classical simple-shaped cavities with a central metallic core represent a new class of electrodynamic systems of microwave range, the properties of which remain poorly studied. One of these structures, named a rectangular concentric resonator (RCR) is proposed in the paper as a basic unit of K-band bandpass filters (18...26 GHz).

Aim. To study potential possibilities of RCR for creation electromagnetic signals filtration devices of micro wave range.

Materials and methods. The finite element method implemented in the package COMSOL was used to investigate electrodynamic characteristics of RCR and scattering matrix parameters of the microwave filters on RCR-basis.

Results. Simple polynomial expressions for computation of normalized resonant wavelengths of RCR were obtained at the first stage of modeling. Next, two models of passband microwave filters by RCR with different sizes were built and their EM characteristics were studied. Cavities sizes were determined numerically and practical recommendations on the realization of a new type bandpass microwave filters were formulated.

Conclusion. New results of the finite-element analysis of spectral characteristics of two models of bandpass K-range filters on rectangular concentric resonators were represented. The advantages of the filters were indicated. Simple analytical expressions for calculation of the resonance wavelengths of the considered concentric resonators were obtained.

Keywords: microwave filter, band pass, rectangular concentric cavity, numerical modeling

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Электроника СВЧ

Оригинальная статья

Исследование полосовых фильтров K-диапазона на прямоугольных концентрических резонаторах

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Аннотация

Введение. Объемные резонаторы простой формы – прямоугольные, цилиндрические и коаксиальные – широко применяются в современной микроволновой технике при проектировании различных функциональных устройств среднего и высокого уровня мощности. Параметры таких резонаторов можно установить аналитически, используя соотношения, взятые из литературы. Концентрические резонаторы, выполненные на основе классических объемных резонаторов простой формы с центральным металлическим ядром, представляют собой отдельный класс электродинамических систем, свойства которых остаются малоизученными. Одна из таких структур, а именно прямоугольный концентрический резонатор (ПКР), предложена в настоящей статье в качестве базового элемента полосовых фильтров K-диапазона (18...26 ГГц).

Цель работы. Изучение потенциальных возможностей ПКР для создания устройств фильтрации электромагнитных сигналов микроволнового диапазона.

Материалы и методы. Собственные электродинамические характеристики ПКР и параметры матрицы рассеяния СВЧ-фильтров на его основе исследуются с помощью метода конечных элементов, реализованного в пакете программ COMSOL.

Результаты. На первом этапе моделирования получены простые полиномиальные соотношения для расчета нормированных резонансных длин волн ПКР. Далее построены две модели полосовых СВЧ-фильтров на ПКР с разными размерами и исследованы их электродинамические характеристики. В ходе численного анализа установлены размеры резонаторов и сформулированы практические рекомендации по реализации полосно-пропускающих и полосно-заграждающих СВЧ-фильтров нового типа.

Заключение. Приведены результаты конечно-элементного анализа амплитудно-частотных характеристик двух моделей полосовых фильтров K-диапазона на ПКР, впервые предложенных для этих целей. Указаны основные преимущества таких фильтров. Получены аналитические соотношения для расчета собственных резонансных длин волн рассматриваемых в работе концентрических резонаторов.

Ключевые слова: СВЧ-фильтр, полоса пропускания, прямоугольный концентрический резонатор, численное моделирование

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Introduction. One of the priority tendences of MW-devices for various applications improvement is their mass-overall dimension figures reduction and transmitted power level rise that is especially significant for board radiocommunication electronic equipment in the field of aeronautical and space technology [1–3]. Application of wave-guides and resonators of complex configuration as the basic elements enables to find admissible engineering solutions in a number of cases. In particular rectangular resonators (RR) with heterogeneous metallinslator filling are increasingly employed in order to expand functional feasibilities of high and middle power MW-Filters. As an example, band-pass filters with helical resonators of 200...500 NHz are performed for board electronic system complexes of space communication [4, 5].

More often in literature one can come across filter structures with RR having simpler inclusions. In particular, in [6, 7] some stage band-pass filters of various frequency ranges with metal axial-simmetrical pins of various topology are described. In [8, 9] one can find another example of similar construction for electromagnetic signals filtering based on RR and having metal pins and coaxial communication elements, as well as MW-Filter constructions of L- and X-ranges. Finally, in [10, 11] the results of numerical computations and measurements of small size band-pass filters (BpF) on ridged resonators of various ranges with wave-guide and coaxial communication elements are given.

The common feature of all MW-Filters construction described in [4–11] is interior inclusions (helixes, pins or ribs) mounting to one of RR walls. An alternative approach to metal inclusion housing inside a resonator is implemented in so-called concentric resonators, one of the most well-known is spherical concentric resonator (SCR) [12]. In such structures in the center of resonator of any shape a metal sphere of diameter less than the determining resonator size is housed. In [13] SCRs are shown to be adapted for compact band-pass MW-Filters of K-range.

The researches represented in [13] illustrated that spherical shape of base resonators doesn't always suit stage MW-Filters design. RRs used in [4–11] seem to be more admissible. In this connexion the goal of this paper is the search of engineering solutions for filtering devices on the base of rectangular concentric resonator (RCR) (Fig.1). A special case of such resonator having dimensions $a=a_x=a_y=a_z$=const is considered in the paper, a metal sphere of b – diameter being in the centre of resonator.

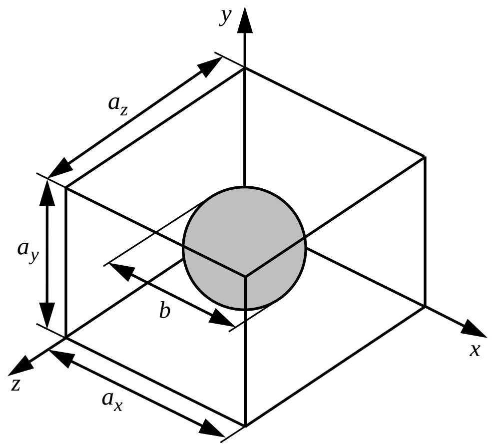

Рис. 1. Прямоугольный концентрический резонатор
Fig. 1. Rectangular concentric resonator

Numerical analysis method. Taking into consideration the complexity of implementation of boundary conditions on a curvilinear surface of spherical construction element in RCR (Fig.1). 3D-metod of the finite elements (FEM) was chosen as the basic numerical simulating tool and the general-purpose programs package COMSOL on its base. This method convergence was traced by an example of experimental data for RR ($x \times y \times z$ = 50 × 50 × 51 mm) having cylindrical insertions of 15.8 mm height and 14 mm diameter housed on resonator lower wall diagonal, the resonator having coaxial communication elements. Its measurements made in 2.5...4 GHz – range were described in [14]. The peculiarity of multi-mode filter construction offered in [14], is coaxial ports housing in the centre of lateral walls at an angle of 90° with each other. The results of simulating and measuring for this case are given in the table.

Коэффициент отражения прямоугольного резонатора
с двумя цилиндрическими вставками

Reflection coefficient of rectangular resonator
with two cylindrical insertions

f, ГГц	S_{11}, дБ	
	Измерения [14]	Модель на МКЭ
2.50	–0.073	–0.054
2.75	–11.1	–12.3
3.00	–19.3	–21.1
3.25	–12.6	–15.2
3.50	–14.8	–17.1
3.75	–0.37	–0.42
4.00	–0.11	–0.13

The testing of this filter numerical model constructed with the help of COMSOL – package gave the possibility to ascertain the close-packing of Whitney second order tetrahedral finite elements lattice that provides the necessary computational accuracy.

Modelling results. At the first stage of researches RCR electrodynamical parameteres ligenvalues were obtained (Fig.1) depending on standardized *b/a* dimension. The results of ligenvalues numerical simulating (resonant wavelength) of the fundamental *H*-mode oscillations were approximated by the third power polynomial with the aid of math-computations system MatLab for dimensions variation interval of $0.1 \le b/a \le 0.9$:

$$\lambda/a = -0.4961(b/a)^3 + 1.9722(b/a)^2 - -0.1278(b/a) + 1.4115, \quad (1)$$

where λ – the resonant wavelength.

The correlation of numerical simulation results and approximation by the least squares method is defined by the value R^2=0.9991, where *R* is coefficient of correlation.

In [15] the eigenvalues of quality factor (*Q*) in consideration of (1) were obtained for RCR with a wall made of copper having the size *a* = 10 mm and electric conductivity $\sigma = 5.8 \cdot 10^7$ Sm/m. The computations showed that unloaded *Q*-factor of RCR for the lowest *H*-mode oscillations attains the values Q_c = 16 000…18 000 at dimension variations $0.2 \le b/a \le 0.5$, whereas unloaded *Q*-factor for the lowest *E*-model oscillations is Q_c = 15 000…17 000 at dimensions $0.3 \le b/a \le 0.6$.

On the analogy of [13], 3D-model of RR was supplemented by standard coaxial communication elements (*D/d* = 3.5/1.52, where *D* and *d* are the diameters of external and internal conductors of coaxial line respectively, mm). The wall dimension of the resonator was chosen *a* = 13.5 mm. A cylindrical rod being the extension of coaxial line internal conductors (Fig. 2, *3*) was used for housing of interior spherical element inside the RR. Filter structure comprises thin polytetrafluorethilene (PTFE) washers 4, their dimensions having been chosen in order the wave impedance of washer section should be equal to coaxial line wave impedance.

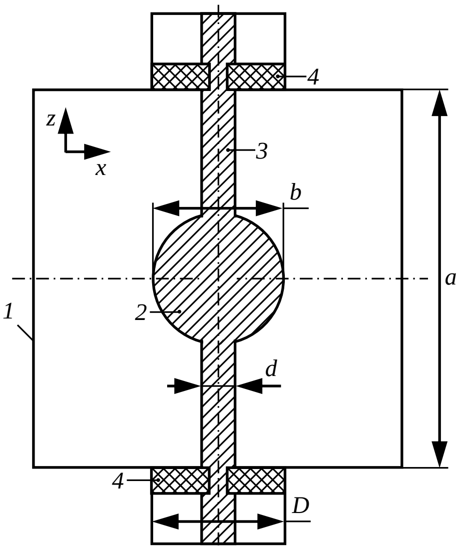

Рис. 2. Однорезонаторный полосовой фильтр:
1 – прямоугольный резонатор ; *2* – сферический элемент ;
3 – цилиндрический стержень ; *4* – опорная шайба

Fig. 2. Single -resonator bandpass filter: *1* – rectangular cav ity;
2 – spherical element; *3* – cylindrical rod; *4* – bead

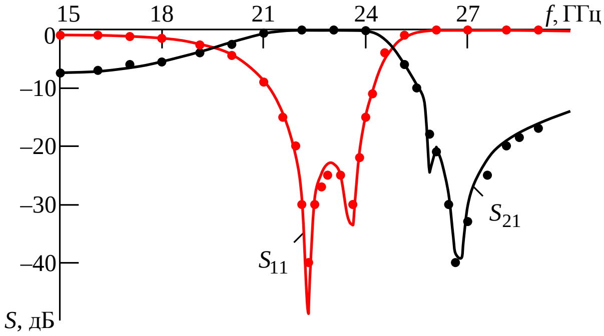

Рис. 3. S-параметры однорезонаторного фильтра .
Линии – модель на основе трехмерного метода конечных элементов; маркеры – модель на основе трехмерного метода конечных разностей

Fig. 3. S-parameters of single -resonator filter .
Lines – model b ased on 3D -merhod of the finite elements;
markers – model based on 3D -merhod of finite differences

The conditions of TEM-wave propagation with a unit amplitude for 15...30 GHz frequency range were preassigned at the input of MW-quadripole under the question. At the output absorbing boundary conditions imitating idealized matched load were preassigned. The only varied parameter of MW-Filter 3D-model was sphere diameter *b*.

Researches carried out with the help of this model enabled to define two resonances to the left and to the right from the central frequency f_0 = 23 GHz forming passband 24% at *b/a* = 0.4148. The results of numerical analysis for this case are illustrated in Fig. 3. For the results verification an analogous Filter 3D-model based on finite differences method (FDM) implemented in QuickWave3D Programs Packet was constructed in time domain, the frequency relationship of reflection coefficient and transmission factor of such quadripole were determined as well. As one can see from Fig. 3 good coincidence of numerical data obtained by two independent computational methods were determined in the course of verification.

From the illustrated in Fig. 3 amplitude – frequency characteristic (AFC) one can realize that signal attenuation in the longwave section of rejection band at frequencies less than 21 GHz appears insufficient. For this draw-

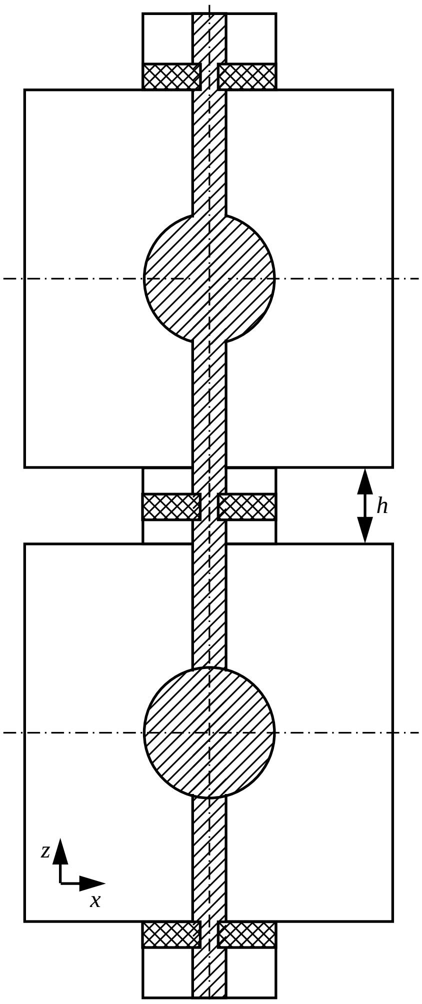

Рис. 4. Двухрезонаторный полосовой фильтр
Fig. 4. Double-resonator bandpass filter

back elimination one more numerical model of bandpass filter based on two RCR with wall dimension a = 15 mm in each one was constructed, both resonators being linked by coaxial diaphragm of h = 1 mm thickness, Spherical insertions as well as in SCR [13] filter construction are connected by a metal rod being the extension of internal coaxial line conductors. The diameter of through hole between the resonators was chosen equal to diameter of external conductor D (see Fig. 2).

In the course of numerical analysis and optimization of the structure under consideration in frequency range of 18...24 GHz the filter dimensions were determined as b/a = 0.2533, that provides the passband no more than 6.3% at the central frequency 19.9 GHz and rejection band 10.4% in 20.5...22.7 GHz range. Modelling results for this case are illustrated in Fig. 5. One can realize from the fig. than for stage filter construction based on RCR signal attenuation of ~20 db may be successful in the passband and in the longwave section of rejection band more

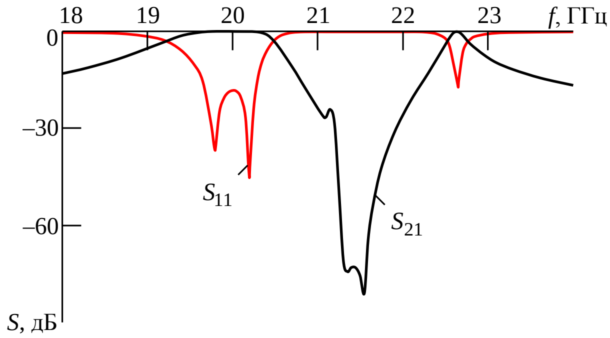

Рис. 5. S-параметры двухрезонаторного фильтра
Fig. 5. S-parameters of double-resonator filter

admissible AFC transconductance may be more successful than earlier as well (see Fig. 3). Besides, owing to one more resonance observed at the frequency of 22.6 GHz a section of AFC with central frequency 21.5 GHz is being formed which can be used for band elimination filter construction of 20.2...22.6 GHz range.

Results discussion. The researches represented in the paper under consideration showed that in oneresonator filter with coaxial communication elements (see Fig. 2) in 15...30 GHz range one can observe two resonances conditioned by the lowest even and odd H-oscillations of RCR with wall dimension a = 13.5 mm. As to the double-resonator filter (Fig. 4) based on RCR with a = 15 mm the analogous AFC is being formed in a more narrow range, namely, 18...22 GHz (Fig. 5), where as some additional narrow band resonance corresponding to the lowest E-oscillation of RCR arises at 22.6 GHz frequency.

Thus, in spite of lower unloaded Q-factor values in comparison with other concentrical resonators [15], RCR may be successfully adapted for constructing of narrow bandpass and band elimination filters. One more advantage of constructing such filters based on RCR is in their simpler design and fabrication than that of analogous filter construction based on SCR [13]. Owing to higher values of fundamental oscillation resonant wavelength in comparison with classical RR, functional MW-devices on the base of RCR appears to be more compact. In addition, such devices possess higher electric strength than analogous elements with metal insertions [6, 10, 16] based on RR do, because there are no regions of very high electric intensity.

Conclusion. Two versions of compact Bandpass Filters (BpF) of K-range based on RCR with coaxial communication elements are represented in the paper. Electrodynamical characteristics analysis of these devices was carried out by Finite-elements Method. The preliminary phase of modelling with the aid of experimental data taken from literature enabled to ascertain the close-packing of tetrahedral elements lattice providing high computation accuracy with minimal computational expenses. Supplementary verification of numerical data for one of the filters was carried out with one more numerical approach – Finite – differences Method (FDM) in time domain.

The results of numerical modelling confirmed the prospect of employing RCR for MW-Filters implementation, their AFC are formed in the passband by two resonances of high-quality corresponding to the lowest *H*-oscillations of RCR. The structures considered in the paper (see Fig.2 and 4) are the utmost simple and do not comprise adjusting elements such as additional pins, though their application enables to improve MW-devices parameters in a number of cases [7]. One of the priority tendences of future researches of MW-Filters based on concentric resonators is the analysis of such structures having adjusting elements.

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