Investigation of 3D ultra-wideband bandpass filter model based on microstrip multimode resonators

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Abstract. Here are the results of theoretical studies of microstrip multimode resonators with a short-circuited section of a strip conductor and ultra-wideband filter based on five-mode resonators. Electrical characteristics of microwave devices were obtained by means of numerical electrodynamic analysis of their 3D models. Substrates with dielectric constant of \( \varepsilon = 80 \) and \( \varepsilon = 9.8 \) were used in calculations. A synthesized filter with a 100% bandwidth has high frequency-selective properties and can be used in radio equipment of tropospheric and space communication with the advanced information transfer.

1. Introduction

Rapidly developing space and air space exploration is impossible without continuous improvement of frequency selective devices used in data-transmission systems. At the same time, it is well known that microwave bandpass filters are traditionally used in radio equipment closets, including those used in tropospheric and space communications. However, today, along with continuous improvement of electric filters characteristics and reduction of their dimensions, significant extension of working bandwidth, due to the need to expand data-transmission channels to increase the volume and/or speed of data-transmission significantly are required. In terms of basic parameters, such as miniature size, reliability, manufacturability and prime cost, filters based on microstrip resonators [1-3] are currently the most optimal; the important advantage of which is the fact that simulation results obtained by electrodynamic numerical analysis of their 3D models are in good agreement with the results of experimental samples measurements [4]. This allows us to limit structural studies using only numerical experiments.

Quite often, bandpass filters are made using lumped elements [4, 5], but such frequency-selective devices have relatively low central working bandwidth frequencies (not more than 2 GHz), that does not allow their use in S, C, X, Ku, K and Ka microwave sub-bands. Filters on acoustic waves surface [6, 7] have similar disadvantage, moreover, they do not have strong power suppression in stopbands.

Filters based on waveguides have low losses at passband frequencies [8-12], but they do not compete with filters on microstrip resonators in terms of their overall dimensions and manufacturability.

The use of cascade connection of microstrip lines segments of different widths allows to create filters or reflective coatings with ultra-wide, up to 100%, working bands [13]. It is known that such structures are analogues of single-dimension electromagnetic crystals, however, ultra-wideband filters
based on them do not have high frequency-selective properties, because when the working passband extends, the stopbands narrow significantly due to the expansion of parasite passband.

The use of multimode (n-mode) resonators in frequency-selective devices is a way to reduce the size of these microwave structures without compromising their filtering properties. In filters based on such resonators, by means of original strip conductor topology, it is possible to approach the resonance frequencies of n lowest oscillation modes which form the passband [14]. Thus, n-mode resonator in frequency-selective device replaces n single mode resonators, thereby reducing its size. Moreover, the use of such resonators in filters allows to expand the passband due to substantial «repulsion» of these oscillation modes resonances due to their strong interaction.

2. Microstrip three-mode resonator

Figure 1a shows microstrip resonator investigated using numerical electrodynamic analysis of its 3D model. There are segments (3)-(5) that make up the strip conductor in such microwave device on the substrate (1). At the same time, narrow extended parallel segments (3) are connected to each other through a wide segment (4), which is joined to orthogonally located narrow extended segment (5), free end of which is connected to the base (2) by round hole (6) filled with copper, diameter of which is \( d \approx 0.45 \text{ mm} \) and the depth equal to the thickness of the substrate \( h = 1.00 \text{ mm} \). Input and output 50-\( \Omega \) ports are conductively connected to conductors (3). Substrates made of traditional materials for microwave technology (TBNS, polycor) with thickness of \( h = 1 \text{ mm} \) with dielectric permeability of \( \varepsilon = 80 \) and \( \varepsilon = 9.8 \), respectively, were used in calculations.

The amplitude-frequency resonator characteristics are shown in Figure 1b.

![Figure 1. 3D model of microstrip resonator (a) and its calculated amplitude-frequency characteristics (b). Lines – substrate with dielectric permeability of \( \varepsilon = 9.8 \) was used, and dots, \( \varepsilon = 80 \) are used in calculations.](image)

It can be seen that resonator passband \( \Delta f \) is formed by its three lowest resonances. To be definite, the central passband frequency of all microwave devices presented in this work was fixed at \( f_0 = 1.55 \text{ GHz} \), while, measured at level of -3 dB, relative width \( \Delta f/f_0 = 100\% \) was also fixed.

It should be noted that the change in dielectric penetration of \( \varepsilon \) substrate of three-mode resonator has significant effect on the formation of high-frequency stopband. Thus, a decrease in \( \varepsilon \) parameter in calculations is accompanied by a decrease in frequencies of power attenuation pole, from the upper boundary of high-frequency stopband to the lower one. Therefore, high-frequency passband slope is much steeper for resonator realized on «polycor» substrate, but in terms of dimensions, it is approximately four times larger than the resonator realized on «TBNS» substrate.

Construction dimensions of segments forming three-mode resonator are shown in table 1.
### Table 1. The sizes of strip conductor segments

| Number of the strip conductor segment | Substrate with dielectric permittivity $\varepsilon = 9.8$ | Substrate with dielectric permittivity $\varepsilon = 80$ |
|---------------------------------------|--------------------------------------------------------|-------------------------------------------------------|
|                                       | The dimensions of the segments are along x-axis (mm) | The dimensions of the segments are along y-axis (mm) |
|                                       | $0.65$ | $14.50$ | $0.25$ | $6.00$ |
|                                       | $4.80$ | $8.15$  | $2.30$ | $1.50$ |
|                                       | $0.40$ | $4.45$  | $0.40$ | $3.90$ |

3. **Microstrip five-mode resonator**

Frequency-selective properties of the considered resonator can be improved by increasing the number of roll-up of its strip conductor, i.e. supplementing additional segments of the strip conductor to the device, indicated by (3) and (4) in Figure 2a. For objective comparison of simulation results in calculations the same substrates (1) with thickness of $h = 1.00$ mm with relative permittivity of $\varepsilon = 80$ and $\varepsilon = 9.8$ were used. Conductor segments sizes were selected in such a way that five lowest oscillation modes of modified resonator formed its passband with relative width $\Delta f / f_0 = 100\%$ (Figure 2b). As a result of synthesis, segments (3) in this resonator are narrow and extended, and segments (4) are wide.

![Figure 2. 3D model of modified microstrip resonator (a) and its calculated amplitude-frequency characteristics (b). Lines – substrate with dielectric permeability of $\varepsilon = 9.8$ was used, and dots, $\varepsilon = 80$ are used in calculations.](image)

It can be seen that amplitude-frequency characteristics of such resonator are already located at a pair of attenuation poles. Similarly, as in case of three-mode resonator considered above, high-frequency passband slope of five-mode resonator becomes much steeper when using a substrate with dielectric permittivity of $\varepsilon = 9.8$. However, as can be seen from Figure 2b, additional roll-up of strip resonator conductor is accompanied by reduction in the length of high-frequency stopband, which becomes significant with the decrease in dielectric permittivity of modified resonator substrate.

Therefore, while studying five-mode resonator filter, one can restrict oneself only to a substrate with permittivity $\varepsilon = 80$ in calculations.

Construction dimensions of segments forming 5-mode resonator are shown in table 2. Open-end hole (8) with diameter of $d = 0.45$ mm grounded to the base (2).
**Table 2. The sizes of strip conductor segments**

| Number of the strip conductor segment | Substrate with dielectric permittivity $\varepsilon = 9.8$ | Substrate with dielectric permittivity $\varepsilon = 80$ |
|--------------------------------------|----------------------------------------------------|----------------------------------------------------|
|                                      | The dimensions of the segments are along x-axis (mm) | The dimensions of the segments are along x-axis (mm) |
| (3)                                  | 0.35                                               | 0.10                                               |
| (4)                                  | 7.55                                               | 2.60                                               |
| (5)                                  | 4.90                                               | 1.20                                               |
| (6)                                  | 13.20                                              | 3.10                                               |
| (7)                                  | 0.40                                               | 0.40                                               |

|                                      | The dimensions of the segments are along y-axis (mm) | The dimensions of the segments are along y-axis (mm) |
| (3)                                  | 14.5                                               | 5.60                                               |
| (4)                                  | 3.30                                               | 1.10                                               |
| (5)                                  | 10.45                                              | 4.00                                               |
| (6)                                  | 9.30                                               | 2.00                                               |
| (7)                                  | 1.00                                               | 2.40                                               |

4. **Microstrip ultra-wideband filter based on five-mode resonators**

It is not difficult to develop ultra-wideband bandpass filters with high electrical characteristics cascading the presented microstrip resonators. So, using only two resonators in the design, it is possible to realize bandpass filters of the sixth or tenth order. Obviously, the tenth-order filter (Figure 3) is of the greatest interest, therefore, we restrict ourselves describing the research results only of this design.

![Figure 3. 3D microstrip ultra-wideband filter model of tenth-order.](image)

When calculating electrical characteristics of such filter, we used substrate parameters of $\varepsilon = 80$ and $h = 1$ mm, as well as the diameter $d$ of the holes in it with the same values as in 3D models of resonators considered above. The arrangement of five-mode resonators on substrate was opposite directed.

The sizes of strip conductor resonator segments and their extension regarding each other, as well as clearance between the pair of segments (9), were chosen in such a way that relative filter bandwidth formed by ten resonances had the following value $\Delta f/f_0 = 100\%$ (Figure 4).

At the same time, high frequency-selective properties of ultra-wideband filter are caused by steep passband slopes and significant power suppression in low-frequency stopband (more than 80 dB).

Construction dimensions of filter conductor segments $(x \times y)$ in mm are: (3) −0.20×5.90, (4) −2.40×0.90, (5) −1.40×3.90, (6) −4.15×2.45, (7) −1.75×3.85, (8) −2.50×1.10, (9) −0.05×7.25, (10) −0.40×1.55. The clearance between the segments (9) are 0.05 mm. Filter dimensions, taking into account 1 mm indentation between conductors and the edge of the substrate is 13.85×15.15×1.00 mm$^3$. 


Consequently, original three- and five-mode microstrip resonators conductor topology is proposed. On the basis of five-mode resonators, ultra-wideband filter of tenth-order was designed; it has showed high frequency-selective properties having relative bandwidth of $\Delta f/f_0 = 100\%$. Theoretical studies of microwave devices were carried out using numerical electrodynamic analysis of their 3D models on substrates with dielectric permeability of $\varepsilon = 80$ and $\varepsilon = 9.8$.

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7. References
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