Microwave Filters with Superwide Pass Transmission Band Based on Transmission Lines with Metamaterials Application

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***Abstract* — The broadband microwave filter based on prototype with an original circuit design and topological solution was developed. The synthesizing procedure for microwave filter with additional zero transmission is proposed, based on composite transmission line using metamaterial. All parameters of the equivalent filter circuit can be calculated using the synthesis procedure. The software to search for optimal parameters of the microwave filter has been developed. Design variants of microwave filters with application of multilayer technology are proposed.**

***Keywords* — microwave filter, superwide pass transmission band, transmission line, metamaterial, LTCC (Low Temperature Co–Fired Ceramic), related half–wave resonators.**

I. Introduction

In recent times, there has been significant increase in interest to the development of superwide broadband (SWB) band-pass transmission (BPT) microwave filters [1]. Such filters must respond to the strict requirements: small dimensions, low insertion losses and high selectivity. For filter synthesis, the traditional design technique using special prototype filter is used. Implementation of the design as an integrated circuit meets a number of difficulties associated with the inability to perform filter elements with the required rating values. To solve the problem, it is necessary to complicate the design and construction, and to modify the configuration of the filter circuit. Transition to symmetrical topological structure of the filter is successful variant. The attempt to implement the superwide band-pass transmission microwave filter with application of symmetric structure was undertaken in the publication [2].

The research was carried out at the expense of grant from the Russian science Foundation (project 18-79-10109).

II. Proposed Architecture

The filter design represented of connected half-wave resonators separated by two-mode stub providing the additional transmission zeros to increase the steepness (transconductance) of the filter characteristic. The stub is constructed as compact microstrip cell with two resonant responses [3]. The filter structure contains enough large number of topological elements that require the adjustment. The purpose of this research is to investigate the possibility of the application the symmetrical structure of broadband band-pass transmission microwave filter, which represent the simpler configuration compared to the structure described in the work [4], which makes it quite suitable for the industrial production. Symmetrical circuit of the similar broadband band-pass transmission microwave filter has been developed (Fig.1) with central frequency f_0 = 9.4GHz, relative pass transition band by level of -3dB 65%, and pulsations level in the pass transmission band of 0.04dB. In this connection, the filter synthesis passes through the following stages [5]:

1) Traditional synthesis procedure of band-pass transmission filter with prototype filter application with the Chebyshev characteristics;

2) Transition to the circuit of band-pass transmission filter with application of parallel circuits (contours) and inductive inverters;

3) Transformation the circuit described in the paragraph 2 (band-pass transmission filter using parallel circuits and inductive inverters) to the symmetrical circuit (Fig.1).

978-1-6654-3941-1 @2021 IEEE

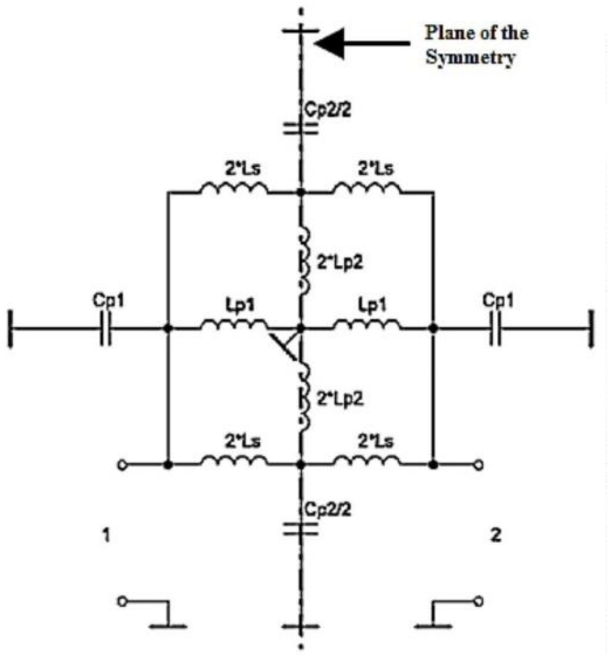

Fig 1. Symmetrical circuit of broadband band–pass transmission microwave filter (C_{P1} =0.677 pF; C_{P2} =2.32 pF; L_{P1} =1.165 nH; L_{P2} =0.164 nH; L_s =0.5 nH).

Application of such circuitry transformation, the new opportunity opens up to increase by 2 times the inductance values of L_S and L_{P2}. This allows reducing also the values of C_{P2} of capacitances by 2 times in the circuit described in paragraph 2, which simplifies the structure implementation with multi-layer ceramic technology LTCC (Low Temperature Co-Fired Ceramic) application [6]. The developed filter is implemented as multi-layer strip structure, represented in Fig.2. Four layers of DuPont Green Tape™ 951 ceramics (ε_r=7.8; tg(δ)=0.0015) with thickness of 216μm (microns) each were used. The topology of the conducting pattern is implemented by silver-containing paste with thickness of 8μm (microns). The filter area is 7×7 mm^2, which corresponds to the linear dimensions of 0.6 λ_g, where λ_g is the wavelength at the central frequency.

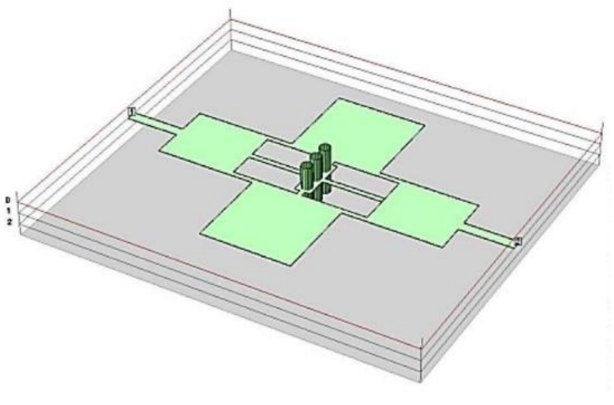

Fig 2. LTCC - structure of superwide broadband band - pass transmission microwave filter (Four layers DuPont Green Tape™ 951, each layer thickness 216μm, structure dimensions 7×7 mm^2).

III. Result of Electrodynamic Modeling

The results of electrodynamic modelling using Sonnet Suites CAD are shown in the "Fig.3". Dashed lines represent the calculated frequency dependencies of the transmission coefficients (S_{21}) and reflection coefficients (S_{11}) of the prototype circuit (Fig.1), and solid lines represent the result of electrodynamic modelling. The reflection coefficient S_{11} within the pass transmission band is better than 20dB.

The traditional transmission line using metamaterials-special composite materials (composites) obtained by artificial modification of elements embedded in them, is an artificial structure that can be applied in the design of superwide transmission band-pass filters of the microwave range [7].

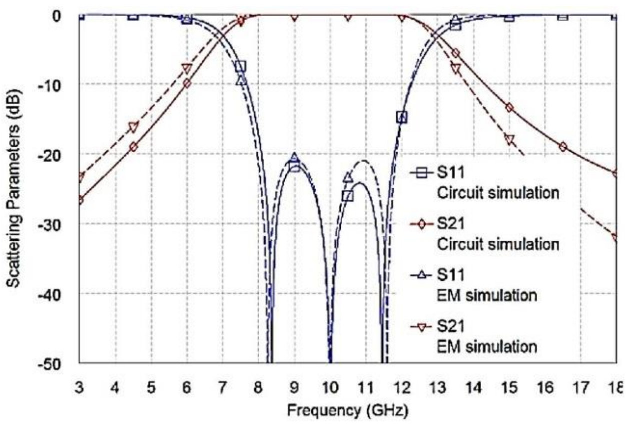

Fig 3. Characteristics of superwide broadband band-pass transmission microwave filter: Circuitry modelling (dashed lines) and electrodynamic modelling (solid lines).

On the ground on this circuit, due to the presence in it of elements that has the properties of low-pass filter (LPF) - "right hand" (RH) components C_r and L_r , and high-pass filter (HPF) - "left-handed" (LH) components C_l and L_l (Fig.4), it is possible to obtain the band–pass transmission characteristics.

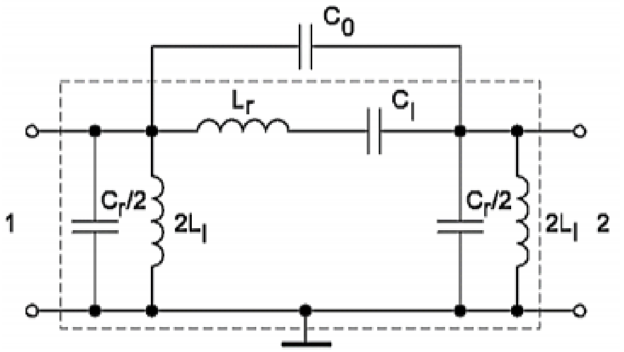

Fig 4. Circuit of superwide broadband band-pass transmission microwave filter based on the single section of the balanced transmission line using composite metamaterials.

When designing and constructing the real filters, in accordance with certain specific technical specification, it is proposed to use the synthesis procedure that differs from the traditional one. In the presence of low-frequency (LF) and high-frequency (HF) elements, the synthesizing begins from the application of the following formulas:

$$f_l = \frac{1}{2\pi\sqrt{L_l C_l}}\ ;\ f_r = \frac{1}{2\pi\sqrt{L_r C_r}}\ ; \qquad (1)$$

where f_l and f_r - are, respectively, the lower and upper frequencies of the transmission line cutoff with using composite metamaterials of balanced transmission line, used in the design of superwide broadband band-pass transmission microwave filter in the first approximation, as the band edges of pass transmission band at the level of -3dB.

In the case of balanced transmission line application, using the composite metamaterials, the frequencies of sequential (f_{se}) and parallel (f_{sh}) resonances are equal, and they are defined by the following expressions:

$$f_{se} = \frac{1}{2\pi\sqrt{L_r C_l}};\ f_{sh} = \frac{1}{2\pi\sqrt{L_l C_r}};\ f_{se} = f_{sh} = f_0, \quad (2)$$

here f_0 - is the central frequency of the pass transmission band. These formulas are used to determine the values of the right-hand and left-hand elements that forming the transmission band-pass characteristics (Fig.5, dashed lines).

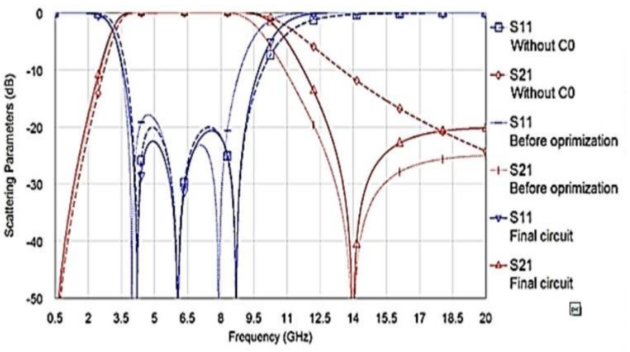

Fig 5. Characteristics of superwide broadband band–pass transmission microwave filter: without capacitive connection between input and output (dashed lines); with capacity C_0 before optimization (dotted lines); and after optimization (C_r =0.845pF; L_r =1.43nH; C_l =0.4pF; L_l =0.72nH; C_0 =0.117pF, solid lines).

For increasing the discrimination (selectivity) of the filter under development, one or more additional elements are appended to the original source balance circuit:

1) Inductance of the connection between the input and output for appending zero of transmission to the left from the pass transmission band;

2) Capacity of the connection between input and output, for appending zero of transmission to the right from the pass transmission band;

3) Low-pass filter for increase the discrimination (selectivity) on the right edge;

4) High-pass filter for increase the discrimination (selectivity) of the left edge;

5) band-pass band elimination (band-stop) filter for increase the discrimination (selectivity) for both left and/or right front, etc.

To illustrate the application of transmission line using composite metamaterials as ultra-, or superwide band-pass microwave filter, the procedure of the filter synthesizing was performed with central frequency of f_0 = 5.7GHz, with relative pass transmission band by level of -3dB 96%. It is American standard UWB, ultra-wide, or superwide band, 3.1÷10.6GHz [8]. The pulsations (ripple) level in the pass transmission band is about 0.04dB. To increase the discrimination (selectivity) of the filter on the right edge, the capacity C_0 is appended between the input and output (Fig.4).

When appending additional element (C_0) that determines position of additional transmission zero f_{C0}, the general synthesizing procedure is performed as follows: it is necessary to find the ABCD matrix; and then to define the S-parameters of the quadrupole (four-pole, Fig.4). After analyzing the resulting equations, it is required to find five characteristic frequencies: 0, f_l, f_0, f_r and f_{C0}, expressed in 5 variables: C_r, L_r, C_l, L_l and C_0 (f_l, f_0 and f_r - are zeros of reflection in the pass transmission band; f_{C0} - is transmission zero, providing high steepness (transconductance) of right edge).

By fixing the position of the frequency f_{C0} (having previously obtained the value of the frequencies f_l, f_0 and f_r, according to the formulas presented above), it is possible to determine precisely the rating values of all elements of the circuit shown in Fig.4, solving the system of five equations for five characteristic frequencies finding.

To define the parameters of the circuit of the superwide broadband band-pass transmission microwave filter with additional transmission zero, the software was developed in the programming language C++ for solve the system of equations for characteristic frequencies determining by the user-defined source data [9].

The developed software was used to find the optimal parameters of the circuit of superwide broadband band-pass transmission microwave filter.

The component rating values and characteristics are shown in Fig.5 (solid lines) in comparison with the characteristics of the circuit without additional zero of transmission (dashed lines) and characteristics of the filter with additional transmission zero before the optimization procedure (dotted lines).

Fig.4 and Fig.5 represents that circuit containing only six elements and the connection element between the input and output, obtained because of synthesizing, can implement the rational superwide band characteristic. Small number of circuit elements contributes to its compact implementation, which can be performed using the technology of multilayer printed circuit boards or other, more advanced multilayer technologies of constructioning, accepted in the modern radioelectronics [10]. It is proposed to use microstrip structure implemented on the technology of multilayer printed circuit boards [11], shown in Fig.6, as hardware realization of the superwide broadband band-pass transmission microwave filter under developed.

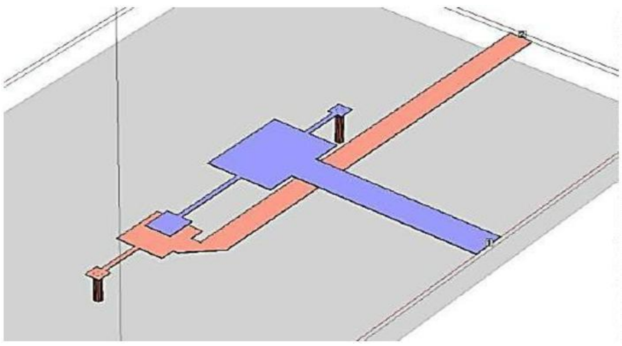

Fig 6. Structure of multilayer printed circuit board of the filter: the lower dielectric layer is the core RO3210™ with thickness 635µm, the upper dielectric layer is pre–preg RO3010 ™ with thickness 127µm, and the dimensions of the structure are 15×10 mm².

To ensure the small outer dimensions of the sequential capacitance C_l and to implement the capacity of connection C_0 between the input and output, two layers of dielectrics "Rogers ™ 3000 ® series" are used. The lower layer is the core RO3210™ with thickness of 635μm (microns), ε_r=10,2; tg(δ)=0,0022, the upper layer is pre-preg RO3010™ (abbr. from "pre-impregnated"), this is composite material-semiproduct) with thickness of 127μm (microns), ε_r=10,2; tg(δ)=0,0022.

The topology of conducting pattern (picture) of each layer is made from the copper with thickness of 18μm (microns). The filter area is 15×10 mm^2, which corresponds to the linear dimensions of 0.75 λ_g , where λ_g is wavelength at the central frequency.

The results of preliminary electrodynamic modelling using Sonnet Suites CAD are represented in the Fig.7. Dashed lines show the calculated frequency dependencies of the transmission coefficients (S_{21}) and reflection coefficients (S_{11}) of prototype circuit (Fig.4), and solid lines represent the result of electrodynamic modelling.

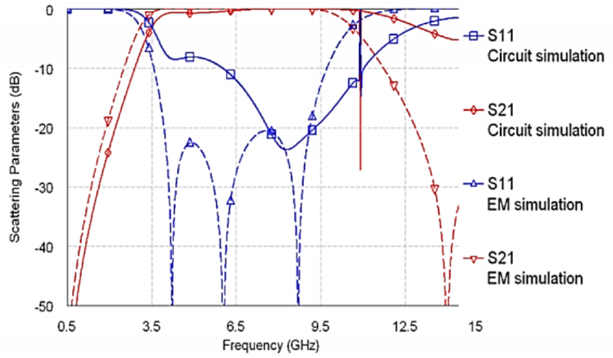

Fig 7. Characteristics of superwide broadband band–pass transmission microwave filter: schematic circuitry (dashed lines) and electrodynamic modelling (solid lines).

For successful implementation of the filter under develop, it is necessary to optimize additionally the geometry of the multilayer structure of the printed circuit board [12].

CONCLUSION

The article proposes and investigates the procedure for designing and constructioning of superwide broadband band-pass transmission microwave filters grounded on the transmission line using composite metamaterials. New method for synthesizing of superwide broadband band-pass transmission microwave filters based on ransmission line using composite metamaterials has been developed.

Such developed filter with additional zero of the transmission has demonstrated the high discrimination (selectivity), despite the fact that it contains only seven elements, which ensures its compact Implementation. In the case of cascading activation of the several transmission lines using composite metamaterials, the discrimination (selectivity) of the filter can be improved significantly.

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