FEATURES OF INTERACTION OF RESONATORS ON LUMPED ELEMENTS AND SECTIONS OF COUPLED STRIP LINES FORMING NON-REFLECTING FILTERS

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Abstract: *The results of a computational experiment on the effect of the length of a section of coupled strip lines on the frequency characteristics of a non-reflective band-pass filter are presented. Based on the data obtained, the following provisions are formulated: resonators on lumped elements are responsible for the formation of the central frequency f0; an increase in the length of coupled lines increases the steepness of the filter cutoff, while the bandwidth* Δf *changes insignificantly; a limit of the length of coupled lines is established when the operation of the non-reflective filter is disrupted, which occurs due to the resonant frequency of the oscillatory LC circuit falling into the stopband of the quarter-wave resonator on coupled lines. The data obtained will be useful in problems of optimization, synthesis and design of non-reflective filters.*

Keywords: *coupled strip lines, non-reflective bandpass filter, lumped elements, RLC-circuit, frequency characteristics.*

1. Introduction

Frequency-selective devices in the form of traditional band-pass filters on coupled lines [1–4] perform the important function of isolating signals in a certain frequency range. In the transparency band, such filters have low losses and reflection, measured by the coefficients $|S_{41}|$ and $|S_{11}|$ of the scattering matrix. At the blocking frequencies, band-pass filters have a maximum reflection $S_{11} \to 0$, which ensures the selectivity of the circuit, but at the same time leads to the generation of a large number of out-of-band interference signals.

This problem is especially acute in nonlinear circuits, where additional intermodulation products are generated due to the reflected signal, which subsequently leads to the appearance of destructive interference in the internal interface of the system [5, 6]. In addition, the presence of reflections leads to a mismatch between the frequency-selective device and external circuits. The problem of obtaining frequency selection devices while maintaining matching and absence of reflections in a wide frequency band developed in works [7–10], where the idea of creating non-reflecting or absorbing devices was proposed and considered. Part of the frequency spectrum of the signal arriving at the input is absorbed by the non-reflecting device itself and is not reflected back to the signal source. This provides a cleaner in-band spectrum, which is an important characteristic when designing any transceiver system.

The purpose of this work is to study the effect of the length of coupled strip lines (CSL) on the frequency characteristics of a non-reflecting bandpass filter (NBPF), which allows us to evaluate the nature of the interaction of lumped-element resonators and resonators on segments of coupled lines.

2. Study design

The device investigated in this paper is a non-reflective band-pass filter, the circuit of which was proposed in [11]. Fig. 1, a shows a three-dimensional image of the NRBF based on a section of the CSL and lumped RLC elements. The coupled lines are formed by connecting horizontal and vertical strips 1 and 2. The latter are obtained by installing a vertical dielectric substrate 3 metallized on both sides. Frequency-dependent loads in the form of RLC circuits 4-1 and 4-2 are connected to the diagonal arms through connecting strips 5 and are grounded on contact pads 6. To increase the self-capacitances of the horizontal conductors, substrate 1 is equipped with a grounded base 8 on the reverse side. The equivalent circuit of the NBPF is shown in Fig. 1, b with the designated length of the CSL l.

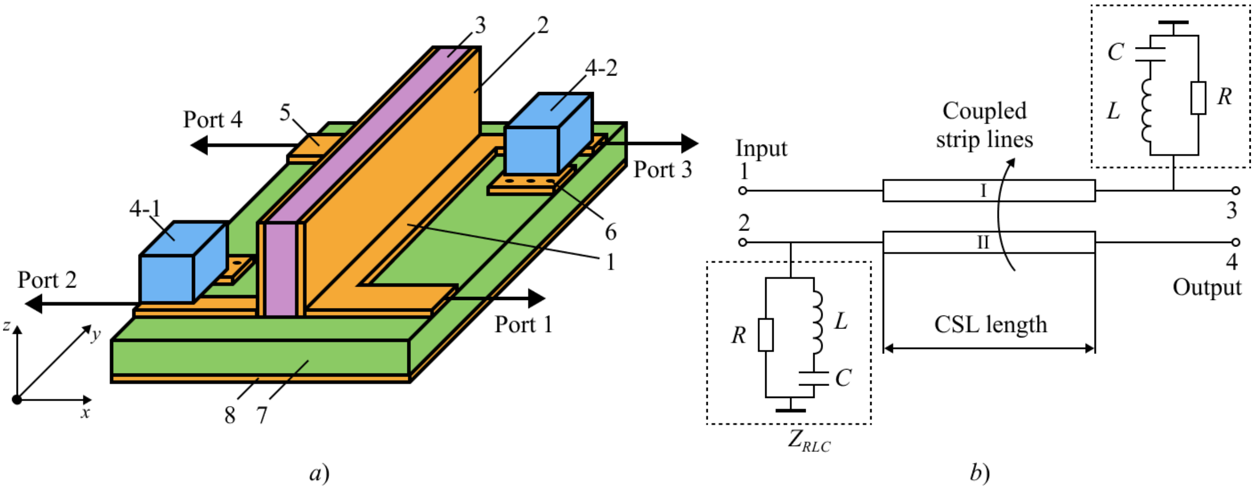

Fig. 1. Three-dimensional image and equivalent circuit of a non-reflective band-pass filter

The frequency-dependent load in the form of an RLC circuit has a single resonant frequency at which the minimum impedance is achieved $|Z_{RLC}| \to 0$ Ohm. At this frequency, the power in the CSL is distributed between ports 1 and 4, at other frequencies where $|Z_{RLC}| = R$ the power does not go to the device output, but is damped on the resistances R. As a result of such interaction of the distributed and lumped circuits, a single pass frequency with minimal return losses in a wide frequency range is formed on the frequency response, which is reflected in the graph in Fig. 2.

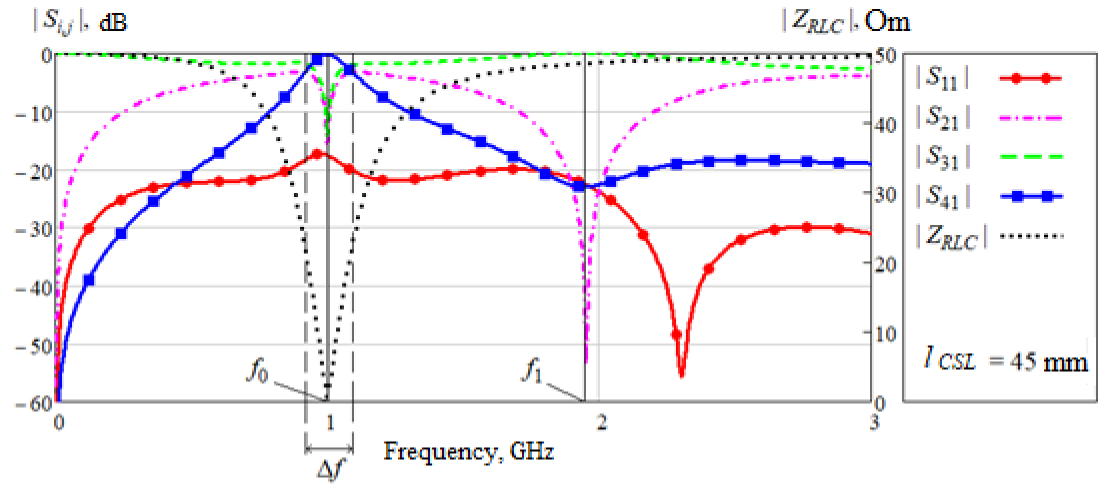

Fig. 2. Frequency dependence of the reflection and transmission coefficients of the NBPF with a length of coupled strip lines of 45 mm

3. The influence of the length of the CSL section on the frequency characteristics of the filter

To optimize the design and engineering of the NBPF, the influence of the CSL length (Fig. 1, b) on the frequency characteristics of the non-reflecting frequency selection device was studied. As a result of mathematical modeling, the graphs of the main dependencies were obtained, presented in Fig. 3–6. The range of the studied frequencies was from 10 MHz to 6 GHz, the range of the studied CSL lengths was selected from 0,1 mm to 100 mm. The upper value of the length was selected based on the consideration that the CSL is a quarter-wave resonator with periodically repeating passbands. With a decrease in the physical length of the CSL, the passband width decreases, and the central frequency of the first band shifts toward lower frequencies. Thus, the specified range of lengths allows us to sufficiently consider the interaction of lumped-element resonators and the CSL segment.

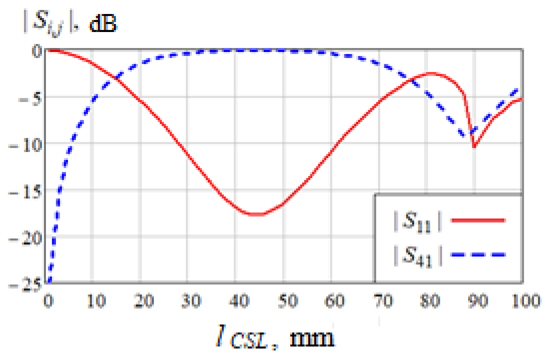

Fig. 3. Dependence of the reflection coefficients $|S_{11}|$ and transmission coefficients $|S_{41}|$ at the central frequency f_0 on the length of the CSL

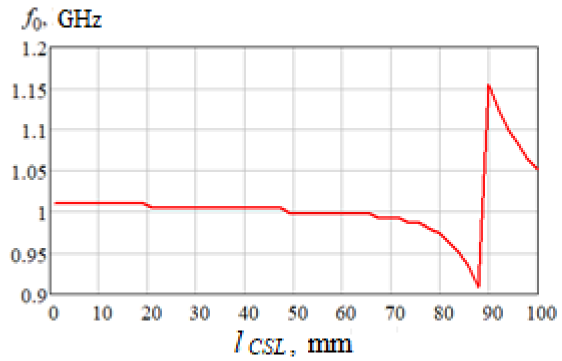

Fig. 4. Dependence of the central frequency f_0 on the length of the CSL

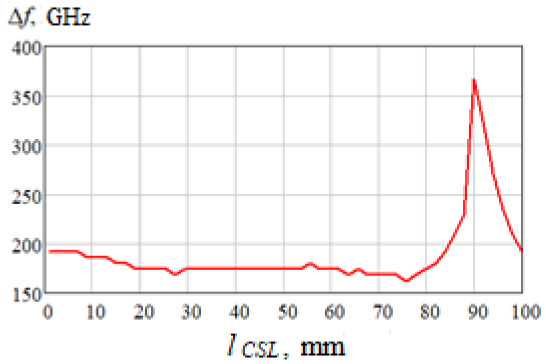

Fig. 5. Dependence of the bandwidth Δf on the length of the CSL

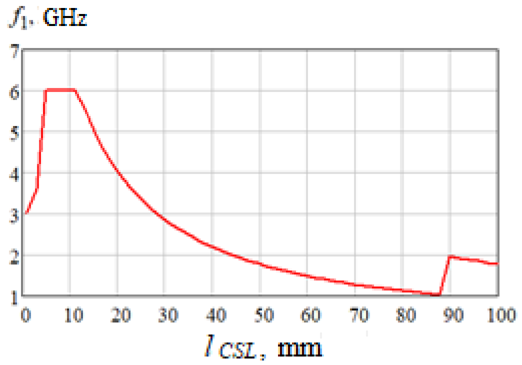

Fig. 6. Dependence of the frequency f_1 on the length of the CSL

From the graph of the return loss $|S_{11}|$ and the transmission coefficient $|S_{41}|$ at the central frequency f_0 on the length of the CSL (Fig. 3), an extreme point with the best characteristics is observed at l = 45 mm. Satisfactory values of $|S_{11}|$ and $|S_{41}|$ are maintained in the range of l = 30…60 mm, where $|S_{11}|$ does not exceed minus 10 dB, while the central frequency f_0 changes insignificantly in the interval from 1,004 to 0,998 GHz (Fig. 4). The bandwidth Δf also changes insignificantly, the values of which are in the range from 174 to 180 MHz (Fig. 5). The frequency f_1 (Fig. 2) with an increase in the length of the CSL l shifts towards lower frequencies (Fig. 6), thereby affecting the steepness of the cutoff of the NBPF.

In all the graphs presented, a point is observed after which the operation of the non-reflecting device is disrupted. It is evident that this occurs at a length of 90 mm, which is twice as long as the length l = 45 mm with the best characteristics. The failure of the NRBF operation occurs due to the resonant frequency of the *LC*-oscillatory circuit falling into the stop band of the quarter-wave resonator on coupled strip lines. The graph in Fig. 7 clearly shows the above-described effect of the CSL length on the frequency characteristics of the NBPF.

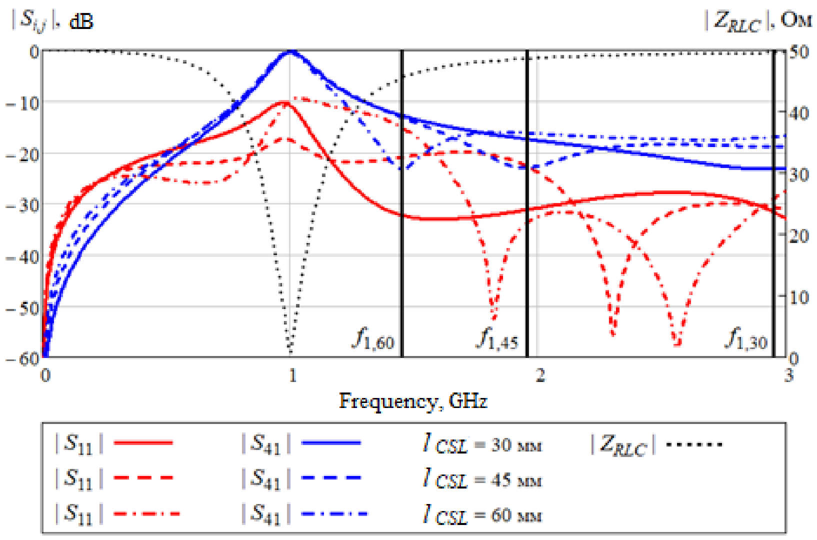

Fig. 7. Frequency dependence of the reflection coefficients $|S_{11}|$ and transmission coefficients $|S_{41}|$ for different lengths of coupled striplines

The graph in Fig. 7 shows that when the length of the CSL changes within the range from 30 to 60 mm, the main feature of the non-reflective filter is preserved – minimal return losses both in the passband with a central frequency of 1 GHz and in the stopband. The frequency $f_{1,30}$ at l = 30 mm is 2,925 GHz and shifts toward lower frequencies with increasing length. At a length of l = 45 mm, the frequency $f_{1,45}$ is 1,947 GHz. At the maximum length l = 60 mm, at which the absorption capacity of the device is preserved, the frequency $f_{1,60}$ is 1,5 GHz.

4. Conclusion

The article presents the results of a study of the effect of the coupled line segment length on the frequency characteristics of a non-reflective band-pass filter. Based on the data obtained, the following statements can be formulated:

– A change in the coupled line segment length has little effect on the central frequency f0 (changes in the range from 1,004 to 0,998 GHz), thus, lumped-element resonators are responsible for the formation of f0;

– An increase in the distributed circuit length increases the filter cutoff steepness, while the passband width Δf changes insignificantly within the range from 174 to 180 MHz for the CSL length values l = 30…60 mm;

– After the critical coupled line length (for the case under consideration, l = 90 mm), the non-reflective filter operation is disrupted, which occurs due to the resonant frequency of the LC oscillatory circuit falling into the stopband of the quarter-wave coupled-line resonator.

The obtained data allow us to conclude that there is a weak interaction between resonators on lumped elements and sections of coupled striplines in the range of electrical lengths of the CSL of 60º ÷ 120º. The results of the work will be useful in the problems of optimizing the design of the CSL, synthesis and design of the NBPF.

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