Narrow-Band, Band-Stop Filter Designs with Different Numbers of L-Resonators

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Abstract: - Filters have an important place in RF and microwave engineering. Filtering certain frequencies is one of the most basic needs in receiver and transmitter systems. Today, microstrip filters are used in many areas of microwave engineering such as radar systems, cellular communications, test/measurement systems, wireless modems, radio and television receivers, and remote control systems. In these filter structures; high performance, low loss, small size, and low-cost requirements are sought. In this study, narrow-band, band-stop filter designs with different numbers of L-resonators at a frequency of 2.45 Hz were realized. The main goal of this study is to design filters with higher performance, lower return loss, and more compact and useful sizes. Thanks to these filter designs, undesirable signals are filtered and targeted signals are transmitted appropriately.

Key-Words: - 2.45 GHz, L-Resonator, Band-Stop Filter, Microwave Systems, Advanced Design System (ADS), RF Engineering.

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1 Introduction

Filters are a signal processing circuit that changes the amplitude and/or phase characteristics of a signal on the transmission line depending on the frequency. They are frequently included in electronic circuit designs to eliminate the unwanted frequency component in a transmitted signal and to ensure the transmission of desired frequency values, [1], [2]. Filters may consist of passive circuit elements such as resistors, capacitors, and inductors, or may contain amplifying elements such as transistors. Filters called passive filters, which consist only of passive circuit elements, do not require any power supply and can operate properly even at very high frequencies. They also have very low noise compared to active filters. Their disadvantage is that they cannot provide signal gain, [3], [4].

Microwave filters are of great importance in RF and microwave applications. They combine or separate different frequencies from each other. Filter structures are frequently used in microwave systems, especially in satellite and mobile communication systems. In general, in devices such as oscillators and mixers; to block unwanted signals, band-stop filters are added to the structures. Many microwave systems such as these include band-stop filter structures. To meet the requirements in this context, filters are designed as lumped element and discrete element circuits, [5], [6], [7], [8], [9].

In an ideal band-stop filter, the attenuation in the pass band is zero, the attenuation in the stop band is infinite, and the transition from the pass band to the stop band is extremely sharp. Although such ideal filters are theoretically possible, they are not possible in practice. Passband insertion losses are desired to be as small as possible and stop band attenuations are as high as possible, [10].

The authors designed a bandstop filter using L-shaped resonator structures to be used in WLAN applications. They made their design at 2.45 GHz frequency and achieved -60 dB attenuation. They simulated their designs in the ADS program using FR4 material, [11].

They designed a wideband band-stop filter to be used in the X band in their study. They created their design by making 5 pairs of L-shaped studs on, microstrip line. The operating frequency of the created filter was controlled by changing the dimensions of the L-shaped studs. Simulation results and experimental results showed excellent agreement, [12].

The authors designed a microstrip band-stop filter in their study. They used L and T -shaped studs together in the design and connected the T-shaped resonator to the transmission line between two identical L-shaped resonators. They calculated the structure according to ABCD matrix analysis. With this method, they designed two different filters and worked in the X and Ku bands, [13].

In their study, they designed a narrow-band

band-stop filter based on microstrip resonators connected to the transmission line in an L-shape. Three loosely coupled microstrip resonators are cascaded to form a bandstop filter circuit. They produced the designed circuit on Rogers RO4350B substrate material. As a result, a narrow-band absorber band-stop filter with a three-stage resonator was designed for the 2.23 GHz center frequency. They measured a return loss of better than 30 dB at the center frequency and in the 20 MHz band, [14].
In this study, narrow-band, band-stop filter designs with different numbers of L-resonators will be made.

2 Narrow-Band, Band-Stop Filter Designs with Different Numbers of L-resonators

FR4 material was chosen as the substrate in the designed circuits. The purpose of choosing FR4 material is that it is easily accessible and has low cost. The relative permeability coefficient of this material at 1 MHz is 4.5, the loss tangent is 0.022 and the material height is 1.6 mm. In these designs, the center frequency was chosen as 2.45 GHz. f_1 and f_2 frequencies, band-stop filter response frequency points were selected as 2.40 GHz and 2.50 GHz, and -3 dB partial bandwidth was calculated according to these values using the equation $KBG = \frac{\omega_2 - \omega_1}{\omega_0}$ Transmission lines are λ/4 long. Scattering parameters, center frequencies and bandwidths were calculated in the simulation environment using the ADS (Advanced Design System) program, which can perform two-dimensional microwave circuit analysis. Values for Chebyshev low pass filters are given in Table 1. In the designs, x/Z_0 slope parameter values were calculated using $x_i = \omega_0 L_i = \frac{1}{\omega_0 C_i} = Z_0 \left(\frac{Z_U}{Z_0}\right)^2 \frac{g_0}{g_i \Omega_c KBG}$ according to the values of Table 1.

Table 1. Values for Chebyshev low pass filters (g_0=1.0, Ωc=1)

n	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}
1	0.3052	1.0								
2	0.8431	0.6220	1.3554							
3	1.0316	1.1474	1.0316	1.0						
4	1.1088	1.3062	1.7704	0.8181	1.3554					
5	1.1468	1.3712	1.9750	1.3712	1.1468	1.0				
6	1.1681	1.4040	2.0562	1.5171	1.9029	0.8618	1.3554			
7	1.1812	1.4228	2.0967	1.5734	2.0967	1.4228	1.1812	1.0		
8	1.1898	1.4346	2.1199	1.6010	2.1700	1.5641	1.9445	0.8778	1.3554	
9	1.1957	1.4426	2.1346	1.6167	2.2054	1.6167	2.1346	1.4426	1.1957	1.0

3 Narrow-Band, Band-stop Filter Design with Single L-Resonator

The circuit with a single resonator is designed and shown in Figure 1. S_{21} values of the design are shown in Figure 2.

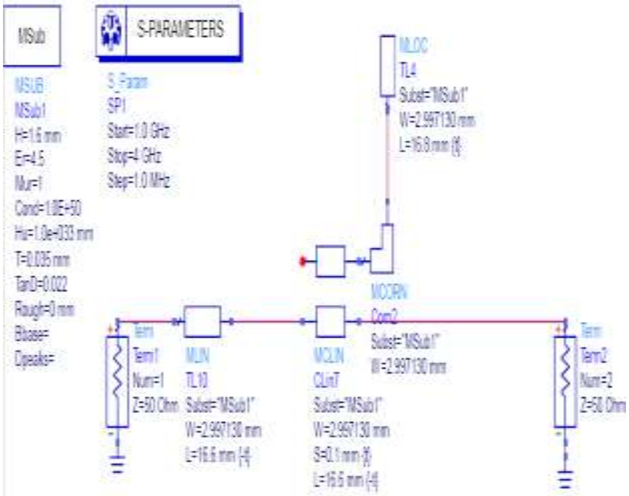

Fig. 1: Single resonator narrow-band band-stop filter design

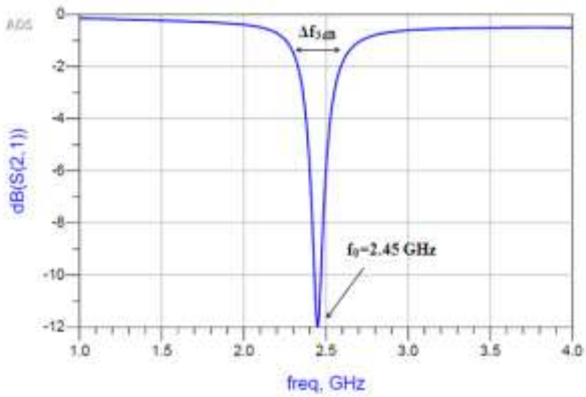

Fig. 2: Simulation result of single resonator narrow-band band-stop filter S_{21} value

By changing the gap value between the two transmission lines shown in Figure 1 between 0.05 mm and 0.5 mm, the X/Z_0 slope parameter curve was optimized according to the gap value and is given in Figure 3. Considering this curve in the designs, gap values were calculated according to the x/Z_0 slope parameter value.

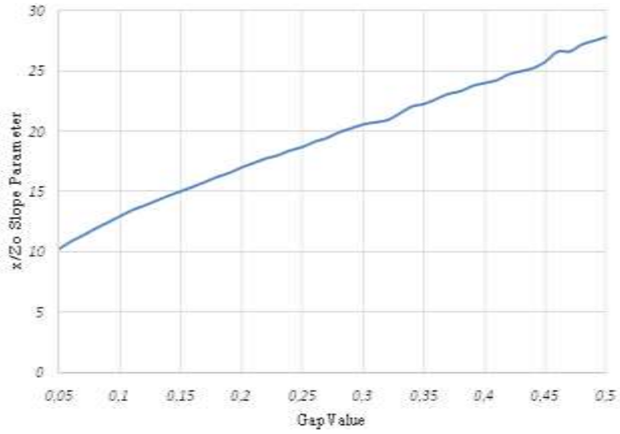

Fig. 3: x/Z_0 slope parameter curve according to gap values

4 Narrow-band, Band-stop Filter Design with Five L-Resonators

First, a circuit with five resonators was designed. The design center frequency was selected as 2.45 GHz and the -3 dB partial bandwidth was calculated as 0.0408 using $KBG = \frac{\omega_2 - \omega_1}{\omega_0}$. While designing, firstly the slope parameters for each resonator were calculated using equation $x_i = \omega_0 L_i = \frac{1}{\omega_0 C_i} = Z_0 \left(\frac{Z_U}{Z_0}\right)^2 \frac{g_0}{g_i \Omega_c KBG}$ here, Table 1 is looked at for the element values of the low-pass prototype. Then, the gap values corresponding to the calculated slope parameter values were obtained according to Figure 3. Design values for the five-resonator circuit are given in Table 2.

Table 2. Design values for five-resonator circuit

Slope Parameter	Slope Parameter Value	Clearance (mm)
X_1/Z_0	21.37	0.33
X_2/Z_0	17.87	0.21
X_3/Z_0	12.41	0.09
X_4/Z_0	17.87	0.22
X_5/Z_0	21.37	0.33

Considering the design values for the five-resonator circuit given in Table 2, the circuit given in Figure 4 was designed. The designed circuit was simulated, scattering parameter values were calculated and shown in Figure 5.

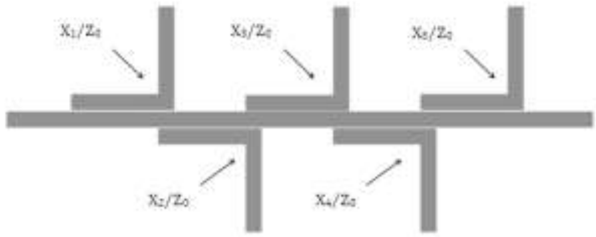

Fig. 4: Narrow-band bandstop filter design with five resonators

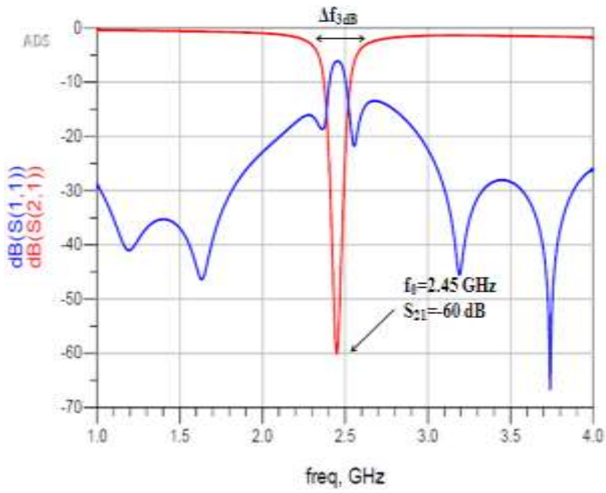

Fig. 5: Narrow-band band-stop filter with five resonators S-parameter values simulation result

When the simulation result of the circuit design with five resonators is examined in Figure 5, the S_{21} value is observed to be -60 dB with a center frequency of 2.45 GHz. In the design, -3 dB bandwidth is calculated as 13.9%. Then, after the design shown in Figure 4 was produced, the scattering parameters of the design were measured using the Rohde & Schwarz ZVA 24 vector network analyzer as shown in Figure 6. The measurement results are given in Figure 7.

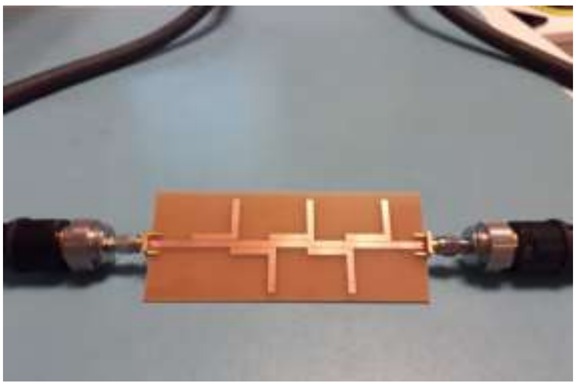

Fig. 6: Narrow-band L-resonator band-stop filter measurement setup

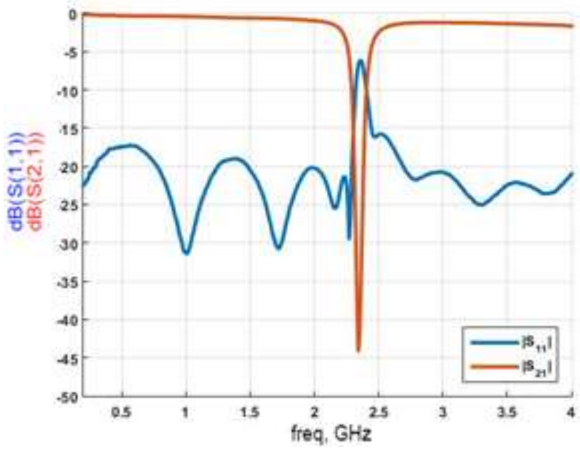

Fig. 7: Narrow-band L-resonator band-stop filter measurement results

The measurement results shown in Figure 7 were compared with the simulation results shown in Figure 5. When this comparison was examined, it was seen that the scattering parameters were quite compatible with each other in the simulation and measurement results. As a result of the simulation, it was seen that the center frequency was exactly 2.45 GHz, while the center frequency of the measurement result was 2.35 GHz.

According to these results, the deviation between the center frequencies was calculated to be 4%. This frequency deviation; It is due to the fact that the relative permeability coefficient of the dielectric material used depends on the frequency; this is a very acceptable value considering the connector, cable and solder losses.

5 Narrow-band, Band-stop Filter Design with Nine L-Resonators

A circuit with nine resonators has been designed. The design center frequency is 2.45 GHz and the -3 dB partial bandwidth is calculated as 0.0408 using equation $BG = \frac{\omega_2 - \omega_1}{\omega_0}$ while designing, firstly the slope parameters for each resonator were calculated using equation $x_i = \omega_0 L_i = \frac{1}{\omega_0 C_i} = Z_0 \left(\frac{Z_U}{Z_0}\right)^2 \frac{g_0}{g_i \Omega_c KBG}$ here, Table 1 is used for the element values of the low-pass prototype. Then, the gap values corresponding to the calculated slope parameter values were obtained according to Figure 3. Design values for the nine-resonator circuit are given in Table 3.

Considering the design values for the nine-resonator circuit given in Table 3, the circuit design given in Figure 8 was made. The designed circuit is simulated and the scattering parameter values are shown in Figure 9.

Table 3. Design values for a nine-resonator circuit

Slope Parameter	Slope Parameter Value	Clearance (mm)
X_1/Z_0	20.49	0.3
X_2/Z_0	16.99	0.2
X_3/Z_0	11.48	0.07
X_4/Z_0	15.16	0.16
X_5/Z_0	11.11	0.07
X_6/Z_0	15.16	0.16
X_7/Z_0	11.48	0.07
X_8/Z_0	16.99	0.2
X_9/Z_0	20.49	0.3

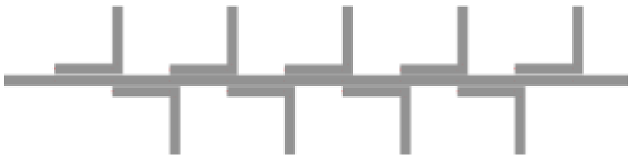
Fig. 8: Narrow-band bandstop filter design with nine resonators

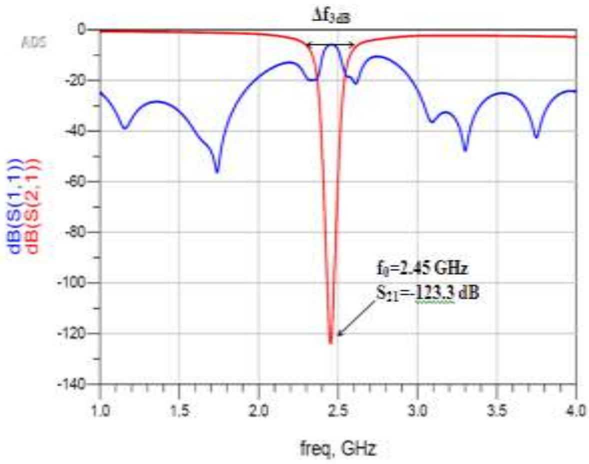

Fig. 9: Narrow-band band-stop filter with nine resonators

S-parameter values simulation result. When the circuit design with nine resonators is examined in Figure 9, the S_{21} value is observed to be -123.3 dB, with a center frequency of 2.45 GHz. In the design, -3 dB bandwidth is calculated as 27.8%.

6 Conclusions

In this study, three different band-stop filter structures were examined at the 2.45 GHz center frequency. While designing the narrow-band band-stop filter, L-shaped resonators were magnetically connected to the main transmission line. The dimensions of the gaps between the main transmission line and each L-shaped resonator had to be calculated individually. Then, the gap value between the two was optimized, starting from 0.01 mm and increasing by 0.01 mm steps, up to 0.5 mm. After this, designs with 1, 5 and 9 L-shape resonator connections were made and the slope parameter values for each L-shape were calculated one by one. From the previously drawn curve, the necessary gaps between the transmission line and the L-shaped resonator were found, the designs were created in this way and the results were interpreted. Then, a circuit was randomly selected among narrow-band band-stopping designs and produced. The measurement results of the produced circuit were compared with the results of the design simulated in the computer environment, and the results were interpreted.

When the design results by adding L-resonators one by one are examined, an improvement in the S_{21} value is observed as the number of L-resonators increases, while the bandwidth increased between 13.9% and 27.8% between the five-resonator design and the nine-resonator design. While bandwidth is generally preferred depending on the place of use; It should be noted that each time an L-resonator is added to the circuit, the length of the circuit increases. Considering these results, the desired narrow-band band-stop filter design can be selected according to the place of use, the length of the design and the desired bandwidth.

Even though the filters used today meet the current needs, the gain and return loss in filter characteristics are not at the desired level. This requires that the filters available are always better. In this way, it is aimed to advance the rapidly developing sector at the national and international level by contributing to the studies in this field.

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