Bandpass Filter Design Using Lumped Elements for RF Applications

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1. Abstract

In this article, we have discussed the complete method to design an RF Bandpass filter using coupled lines topology. The article includes the detailed techniques of entire design process, its schematics, outputs, and all relevant design issues. On hardware that is appropriate for the circumstances, Band pass filters in particular will be constructed, and VNA findings will be attached. We'll also talk about the differences between both software and hardware.

2. Introduction

A microstrip bandpass filter is a type of radio frequency (RF) filter that is made using microstrip transmission lines on a printed circuit board (PCB). It is used to pass a specific range of frequencies while rejecting frequencies outside of this range.

Microstrip bandpass filters are widely used in a variety of applications, including wireless communication systems, satellite systems, radar systems, and more [1, 2]. They have several advantages over other types of RF filters, such as low cost, low insertion loss, and small size.

To design a microstrip bandpass filter, the designer must first specify the center frequency and bandwidth of the desired passband. The filter can then be designed using a combination of microstrip transmission lines, resonators, and other components. The transmission lines and resonators can be either open- or short-circuited, depending on the desired frequency response.

One of the main challenges in designing microstrip bandpass filters is achieving a steep transition between the passband and the stopband, as well as good out-of-band rejection. This requires careful analysis and optimization of the filter design.

Microstrip bandpass filters are an important component in a variety of RF systems, and their design requires a combination of engineering knowledge and expertise in RF circuit design.

3. Band Pass Filter

3.1. Specifications

Design a band pass filter at 10.5 GHz. The filter is designed on RO3010 substrate with a dielectric thickness of 0.025 inches. The fitter should have a pass band of 9.98 to 11.03 GHz. It should achieve at least 20 dB rejection at 9.65 GHz.

$F_o = 10.5$ GHz

$F_1 = 9.98$ GHz

$F_2 = 11.03$ GHz

IL = 20 dB

F = 9.65 GHz

3.2. Design

We have used the following equations to calculate the order of the filter.

- $P_{LR} = 1 + k^2\, Tn^2 \left(\frac{\omega}{\omega c}\right)^{2N}$
- $P_{LR} = 1 + \frac{k^2}{4} \left(\frac{2\omega}{\omega c}\right)^{2N}$

- IL = 10 log(P_{LR})
- 20 = 10 log(P_{LR})
- P_{LR} = 100
- $100 = 1 + \frac{1^2}{4}\left(\frac{2(6.6*10^{10})}{6.06*10^{10}}\right)^{2N}$
- N = 3.85
- Choosing N = 5 for 0.5dB equal ripple response

Table 1: Normalized impedance values for 0.5 dB equal ripple response

0.5 dB Ripple											
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.9841

Using above table, we have taken these values

$g1 = 1.7058$, $g2 = 1.2296$, $g3 = 2.5408$, $g4 = 1.2296$, $g5 = 7058$, $g6 = 1.0$

3.2.1. Lumped Elements

After choosing values of g we can proceed further. To convert a low pass into band pass filter a capacitor can be changed into a parallel combination of inductor and capacitor and an inductor can be changed into series combination of inductor and capacitor as shown in figure below.

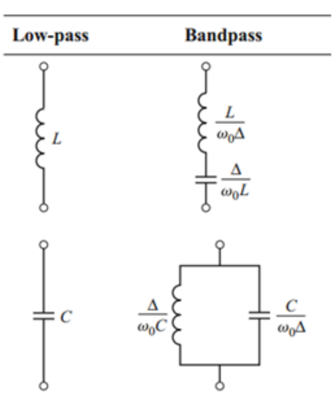


Figure 1: Low pass to band pass conversion

Where delta = $\frac{\omega 2 - \omega 1}{\omega o}$

3.2.1.1. Calculations

- Zo = 50; fc = 10.5*10^9; f1 = 9.98*10^9; f2 = 11.03*10^9; N = 5;
- gn = [1.7058 1.22296 2.5408 1.2296 1.7058 1.0]; delta = (f2-f1)/fc;
- for i = 1:N
- if(mod(i,2) ~= 0)
- C(i) = gn(i)/(delta*Zo*2*pi*fc); L(i) = (Zo*delta)/(gn(i)*2*pi*fc);
- end
- if(mod(i,2) == 0)
- L(i) = (Zo*gn(i))/(delta*2*pi*fc); C(i) = delta/(Zo*gn(i)*2*pi*fc);
- end
- End

After running this code, we get following results

- C =
- 1.0e-11 *
- 0.5171 0.0025 0.7702 0.0025 0.5171
- L =
- 1.0e-08 *
- 0.0044 0.9269 0.0030 0.9319 0.0044

3.2.1.2. Schematics

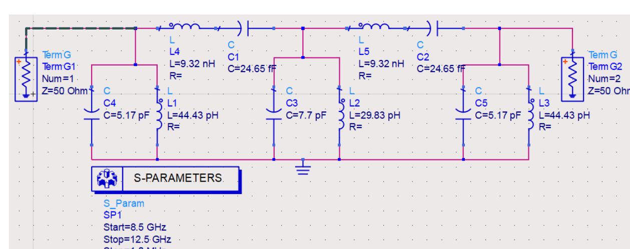


Figure 2: Schematic for band pas filter using lumped elements

3.2.1.3. Results

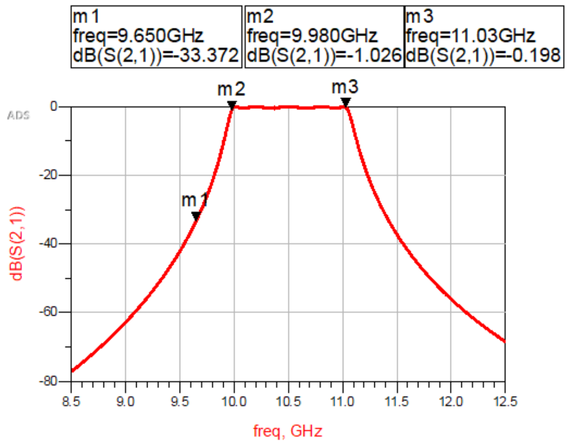


Figure 3: Results of band pass filter using lumped elements

3.2.2. Stub Technique

We know that band pass filter is a combination of series and parallel resonators so these resonators can be transformed into open and short circuit stubs. Band pass filter can also be designed by using short circuit stubs.

3.2.2.1. Calculations

- Zo = 50;
- fc = 10.5*10^9;
- f1 = 9.98*10^9;
- f2 = 11.03*10^9;
- gn = [1.7058 1.2296 2.5408 1.2296 1.7058 1.0];
- delta = (f2-f1)/fc;
- Zon = (pi*Zo*delta)./(4*gn)

After running the code, we get the following results

- Zon =
- 2.3021 3.1937 1.5456 3.1937 2.3021 3.9270

3.2.2.2. Schematics

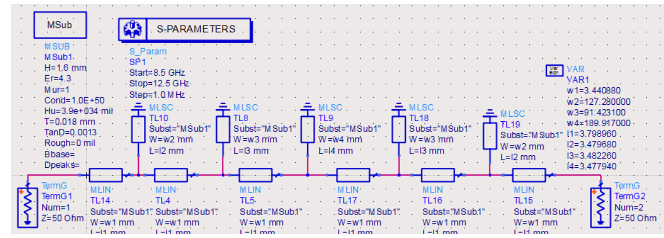


Figure 4: Schematics of band pass filter using stubs

3.2.2.3. Results

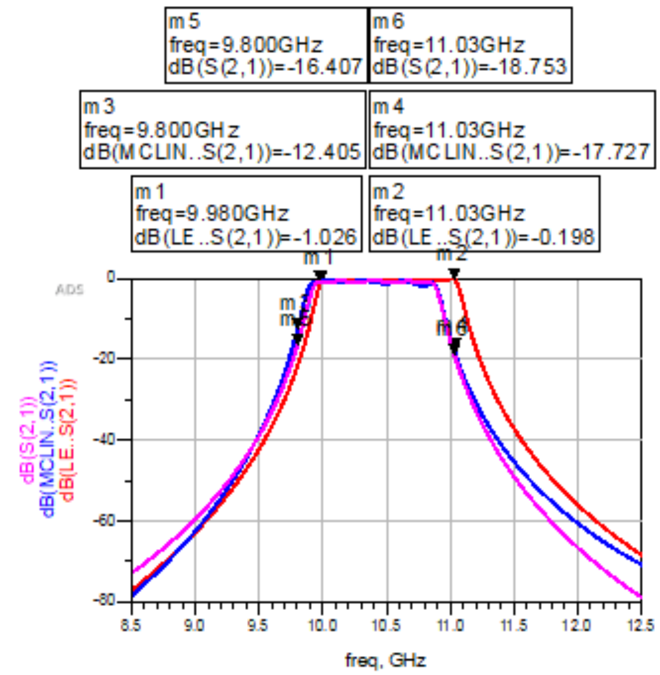
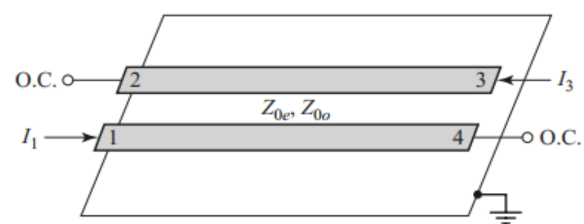


Figure 5: Results of band pass filter using stubs

3.2.3. Coupled Lines



$$Z_0 J_1 = \sqrt{\frac{\pi \Delta}{2 g_1}},$$

$$Z_0 J_n = \frac{\pi \Delta}{2\sqrt{g_{n-1} g_n}} \quad \text{for } n = 2, 3, \ldots, N,$$

$$Z_0 J_{N+1} = \sqrt{\frac{\pi \Delta}{2 g_N g_{N+1}}}.$$

$$Z_{0e} = Z_0[1 + J Z_0 + (J Z_0)^2],$$

$$Z_{0o} = Z_0[1 - J Z_0 + (J Z_0)^2].$$

3.2.3.1. Calculations

- Zo = 50; fc = 10.5*10^9; f1 = 9.98*10^9; f2 = 11.03*10^9; N = 5;
- gn = [1.7058 1.22296 2.5408 1.2296 1.7058 1.0];
- delta = (f2-f1)/fc; ZoJ(1) = sqrt((pi*delta)./(2*gn(1)));
- for i = 2:N
- ZoJ(i) = (pi*delta)./(2*sqrt(gn(i)*gn(i-1)));
- end
- ZoJ(N+1) = sqrt((pi*delta)./(2*gn(N+1)*gn(N)));
- for i = 1:N+1
- Zoe(i) = Zo.*(1+ZoJ(i)+(ZoJ(i))^2);
- Zoo(i) = Zo.*(1-ZoJ(i)+(ZoJ(i))^2);
- end
- ZoJ
- Zoe
- Zoo

After running the code, we get the following results

- ZoJ =
- 0.3035 0.1088 0.0891 0.0889 0.1085 0.3035
- Zoe =
- 69.7771 56.0291 54.8526 54.8384 56.0112 69.7771
- Zoo =
- 39.4315 45.1536 45.9415 45.9514 45.1651 39.4315

3.2.3.2. Schematics

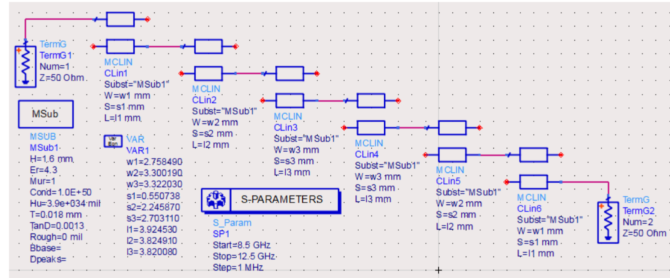


Figure 6: Schematics of band pass filter using coupled lines

3.2.3.3. Results

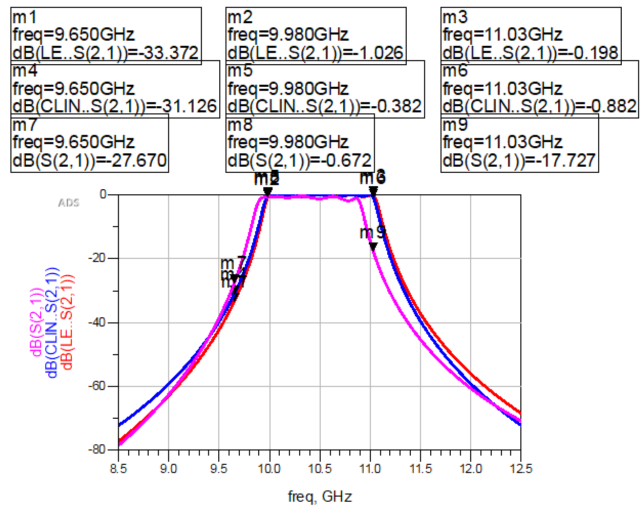


Figure 7: results of band pass filter using coupled lines

3.2.3.4. Problems

At low frequencies lengths of transmission lines can be very high that they are difficult to fabricate. Also, for low impedances width can be very low that it is difficult to fabricate.

3.3. Hardware Design

Since every design have some limitations so it was appropriate to design band pass filter using coupled lines.

3.3.1. Hardware

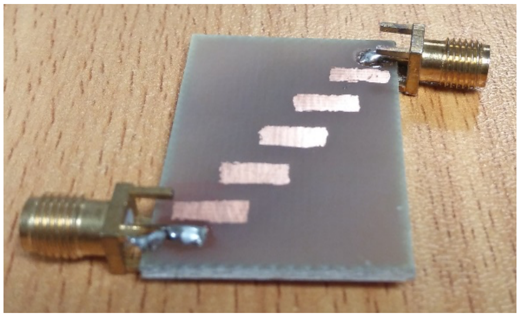


Figure 8: Hardware of band pass filter using coupled lines

3.3.2. Results

Our design was at center frequency 10.5 GHz but maximum frequency in VNA available is 6 GHz so it is impossible to test this hardware at VNA available.

4. Conclusion

In this paper, a bandpass coupled line filter is designed and fabricated. A complete design calculation method and designed flow have been discussed. The filter is designed on RO3010 substrate and then tested using VNA. It is shown that results are quite promising, and this could be used in many RF applications.

5. References

1) S. Li, L. D. Xu, and S. Zhao, "The internet of things: a survey," *Information systems frontiers,* vol. 17, no. 2, pp. 243-259, 2015.

2) K. Rose, S. Eldridge, and L. Chapin, "The internet of things: An overview," *The internet society (ISOC),* vol. 80, pp. 1-50, 2015.