DESIGNING OF DUAL BANDPASS MICROWAVE FILTER

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By

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DECLARATION BY THE SCHOLAR

I hereby declare that the work reported in the M-Tech thesis entitled **“Designing of Dual Bandpass Microwave Filter”** submitted at **Jaypee University of Information Technology,Waknaghat India,** is an authentic record of my work carried out under the supervision of **Dr. Salman Raju Talluri**. I have not submitted this work elsewhere for any other degree or diploma.

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SUPERVISOR’S CERTIFICATE

This is to certify that the work reported in the M.Tech. project report entitled **“DESIGNING OF DUAL BANDPASS MICROWAVE** FILTER**”** which is being submitted by **Maneesh Kumar** in fulfillment for the award of Master of Technology in Electronics and Communication Engineering by the Jaypee University of Information Technology, is the record of candidate’s own work carried out by him under my supervision. This work is original and has not been submitted partially or fully anywhere else for any other degree or diploma.

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LIST OF ACRONYMS & ABBREVIATIONS

AWR	Applied Wave Research
CDMA	Code Division Multiple Access
CST	Computer Simulation Technology
DBR	Dual-Behavior Resonators
DBBSF	Dual-Band Band-stop Filter
GSM	Global System for Mobile
LPF	Low Pass Filter
MRT	Modified Richard’s Transformation
OLRR	Open-Loop Ring Resonators
PI-SIR	Pseudo-Inter-digital Stepped Impedance Resonators
SIR	Stepped Impedance Resonator
TSIR	Three-Mode Stepped Impedance Resonator
UWB	Ultra-Wideband

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CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION

Filter is a two-port network used to control the frequency response at a certain point in an RF or microwave system by providing transmission at frequencies within the pass-band of the filter and attenuation in the stop-band of the filter. Typical frequency responses include low-pass, high-pass, bandpass, and band-reject characteristics.

Filters are frequently used in a large number of fields of electrical and electronics engineering. The filter is a frequency selective device; it can be utilized for selecting a particular band of frequency from a wide range of frequency spectrum. In voice frequency telegraphy, multichannel communication is possible by utilizing a number of bandpass filters or simply a *multiband filter*. Many filters are used in various stages in TV receivers, where they can be used for producing intermediate combined sound and picture carrier frequency and then can separate sound carrier from the composite video signal.

In audio amplifiers, filters are used to reduce harmonic distortion and voice rejection.

Filters are mainly categorized into two categories:

1. Active Filters
2. Passive Filters

Active filters use amplifying elements, especially op amps, with resistors and capacitors in their feedback loops, to synthesize the desired filter characteristics.

The passive filters are made up of passive components: resistors, capacitors, and inductors. A passive filter is simply a filter that uses no amplifying elements (transistors, operational amplifiers, etc.). In this respect, it is the simplest implementation of a given transfer function.

1.1.1 DUAL BANDPASS FILTER

A dual bandpass filter is a single filter, which have two pass bands at two different resonating frequencies. The dual bandpass filter can be used in place of two single bandpass filters resonating at different pass bands. There is a great demand for the multiband filters. For example, a GSM-CDMA transceiver must be able to receive and transmit signals at 900 MHz and 1900 MHz. To obtain this multi-functionality, one can use separate filters for each standard, which means that each one must be separately designed, tested and packed and, thus, *an expensive solution*. To make the system cost efficient, compact sized and much more reliable (due to small number of components) dual bandpass filter is needed.

1.1.2 LOW PASS FILTERS

Low Pass Filters are simplest type of filter. An LPF allows all the frequencies upto a particular cut off frequency and attenuates all other frequencies above the cut off frequency. The cut off frequency marks the pass band and stop band of the LPF.

1.1.3 CHARACTERISTICS OF LPF

The low pass filters can be characterized using following properties:

i. **Filter Order:** One of the important characteristics of a filter is its order. Order of the filter is the number of reactive components in the filter, and therefore order of the filters contributes to its cost, its physical dimensions, and the design complexity. Therefore, higher-order filters are more costly, occupy more area, and are more difficult to design.

ii. **Gain:** Gain of a filter is the magnitude of ratio of the output to the input of the filter. The passive filters do not have any gain that means the magnitude of the output is always less than the input to the filter. The active filters provide a desired gain as there are active components involved in the design of the filters.

iii. **Attenuation:** If a filter is intended to reject a signal very close to cut off frequency, a sharp roll-off characteristic is desirable at cut off frequency. The attenuation is generally represented in ‘dB/decade’ or ‘dB/octave’.

S-parameters are used to observe the gain, phase and attenuation of an N port network quite efficiently at high frequencies.

1.1.4 S-PARAMETERS

S-parameter is an acronym for scattering parameter. *S-parameters* do not use open or short circuit conditions to characterize a linear electrical network; instead, matched loads are used and hence these terminations are much easier to use at high signal frequencies than open-circuit and short-circuit terminations. Moreover, the quantities are measured in terms of power.

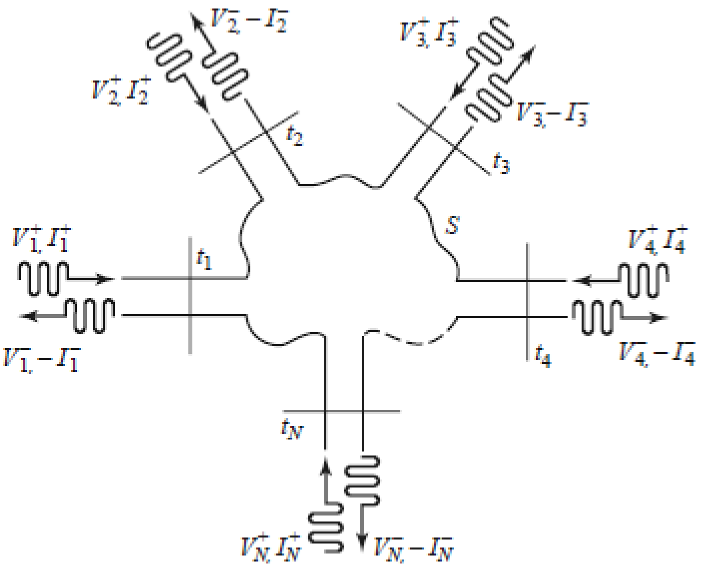


Figure 1.1: Any arbitrary N-port network

$$\begin{bmatrix} V_1^- \\ V_2^- \\ \vdots \\ V_N^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1N} \\ S_{21} & & & \vdots \\ S_{N1} & \cdots & & S_{NN} \\ \vdots & & & \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \\ \vdots \\ V_N^+ \end{bmatrix},$$

A specific element of S matrix is given by:

$$\mathrm{S}_{\mathrm{ij}} = \left.\frac{V_i^-}{V_j^+}\right|_{V_k^+ = 0 \; for \; k \neq j} \tag{1}$$

S_{ij} may be defined as the ratio of voltage reflected at i^{th} port when port j is driven by the incident voltage.

When $i \neq j$, then S_{ij} is called as the forward or reverse transmission coefficient depending of the values of i and j.

When $i = j$, then S_{ij} is called as the reflection coefficient at that port.

1.1.5 STEPPED IMPEDANCE LOW PASS FILTER

A stepped impedance low pass filter is a filter designed using alternate high and low impedance lines. The inductance is represented by a high impedance line and the capacitance by a low impedance line. The stepped impedance filter is easier to fabricate.

1.2 OBJECTIVE

Given the growth in daily demand of communication systems like satellite communication and mobile phones, a contemporary trend in microwave technology can be seen towards compact and small-sized circuits and lower prices. To achieve this objective, active and passive microwave circuits are designed in a compact, multi-band and frequency adjustable manner. After developing portable communication systems, multi-band systems have attracted great attention. Using this characteristic, results in smaller sizes and lower prices. The main idea behind this study is to design a dual bandpass filter or a multi bandpass filter using stepped impedance low pass filter.

1.3 LITERATURE REVIEW

Various designing techniques already available for the designing of the dual bandpass filter are studied and are given in the references.

A dual band filter is designed using the cascading of two bandpass filters resonating at different frequencies [1].

Modified Richard’s Transformations (MRT) can be used to design an asymmetric dual band filter with transmission lines of length **$\lambda/8$**. In the MRT method, an LC circuit can be transformed with each shunt lumped capacitor inductor being equivalently expressed by two sections of transmission lines connected by series cascading connection. With this technique, the bandwidths and center frequencies of the two passbands can be individually adjusted [2].

A miniaturized monolithic dual band filter can be developed for dual mode portable telephones. By using ceramic lamination technique, 1mm thick 900 MHz and 1.9 MHz filter are fabricated and stacked to be co-fired [3].

The short circuited stubs and shunt open stubs are building blocks of the dual-band resonators. A stepped impedance coupled line is used to design a dual-band filter. This type of filter has a very compact size [4].

By the use of different sized open-loop resonators, two bands of frequencies used for transmission can be excited. There are two resonators. One of them is main resonator and the other is sub resonator. The main resonator is used to control the passband of lower band and the sub resonator is used to control the frequency of second band. The performance of the filter can be improved by adding dual feeding structures [5].

A dual band filter can be designed using a stepped impedance resonator (SIR). But this design has a disadvantage that the resonant frequencies of SIR are dependent which complicate the filter design [6].

A dual bandpass filter was achieved by a cascaded connection of a bandpass filter and a band-stop filter, with the drawback of large circuit size [7].

Another dual-bandpass filter can be designed using three section stepped impedance resonator. The advantage of this type of filter is improved performance and compact size [8].

SIRs can be used to generate a dual bandpass filter. The SIRs generate the two resonant modes is the passbands [9].

By using two frequency transformations and apply them to the prototype LPF a dual bandpass filter can be obtained. Using this method, the dual band filter with desired passbands can be designed. Also the attenuation in the stop-band region can be controlled [10].

To design a bandpass filter, first of all formulae for parallel coupled strip-line SIR are derived. These formulae incorporate the effect of arbitrary coupling length and also quarter wavelength coupling. This filter has an advantage that it can control the spurious behavior of the filter by modifying the structure of resonator [11].

By the use of parallel coupled SIRs the bandpass filters can be designed. The passbands can be analyzed by using the concept of length ratio of high and low impedance parts [12].

PI-SIRs can be used to get a dual bandpass filter response. A good dual bandpass response can be achieved by adjusting the Impedance ratio (K) and physical lengths. By this approach a good separation between two bands can be achieved [13].

In a one-wavelength ring resonator there exist two resonant modes. The ports of the ring resonator are separated by an electrical length of $\pi/2$ and a perturbation is introduced within the resonator at a symmetrical location. If this perturbation is not used then there is no response at the output port whatever may be the conditions at the input port [15].

In [16], many topologies using DBR concept have been explained. All these topologies provide control over the bands. In this design the parameters like center frequency, BW can be controlled independently.

Planar wideband BPF can be synthesized using the multimode property of SIR [17]. The modal frequencies of SIR are calculated based on the dimensions of high and low impedance components.

An UWB filter can be designed using three Inter-digital edge coupled micro-strip lines which are used to increase the level of coupling. A stepped impedance stub is used to realize the transmission zeroes in the rejection bands. The advantage of this filter is its simplicity of design [18].

In order to achieve a dual-band branch line coupler stepped impedance stubs are used. This methodology improves the design. In [19], a method provides dual band performance and a small sized design.

A DBBSF which has two stop bands at desired frequencies have been designed in [20]. SIRs are used to realize the dual band reject response. Use of SIRs also reduces the size.

Another method to design UWB bandpass filter by using SIRs (stub-loaded) is proposed in [21]. This stepped impedance stub loaded resonator has the advantage that it gives the designer more parameters to control the resonant frequencies.

A microwave LPF is proposed in [22] which utilize the stepped impedance hairpin resonator. The benefit of such a filter is small size, less complexity in fabrication and better roll offs. Such filters find applications in several microwave systems [23].

A microwave filter using TSIR is proposed in [24]. This filter is very accurate in achieving the desired response. In this design a T-type stub is used in the miniaturized TSIR. This filter has quasi-elliptic response with sharp roll off and a wide band rejection region.

In [25], a technique to design a miniature dual-band filter is proposed. In this design technique, use of quarter wavelength stepped impedance resonator is done. To realize the passbands short and open stepped impedance resonators are coupled together. By using four resonators, the miniaturization is achieved.

By the use of folded OLRRs a dual-band filter can be designed [26]. This filter has a low loss. In this design technique, to achieve high performance, magnetic as well as the electric coupling structures are implemented. This filter has an advantage that the passbands of the filter can be shifted to any desired frequency by just modifying the dimensions of the OLRR.

A microstrip BPF can be designed using SIR and band-reject embedded resonators [27]. First of all, by designing a proper SIR the spurious harmonics may be eliminated by pushing them to the high frequencies. Then, a band reject filter is designed which eliminates the spurious harmonics in the high frequency region.

Stepped impedance BPF can be designed using an approach explained in [28]. Here, comb-filter topology [29] is used to get a dual-band response. Advantage of this design is that it saves more than half space as compared to switch type dual-band topology.

A technique to design a small sized dual BPF is presented in [30]. The passbands of the filter are controllable. This filter uses short SIR to achieve a dual wideband BPF.

A ring resonator BPF which has switchable passbands is presented in [31]. In this design technique inter-digital-coupled feed lines are used to obtain the harmonic suppression. By changing the characteristic impedances of the open stubs, mid-upper or mid-lower passband bandwidths can be separately varied.

The outline of this work is as follows:

In chapter 2 the basics of microwave filters have been explained, chapter 3 includes the designing of a dual-bandpass lumped element filter, in chapter 4 the distributed element filters and designing technique has been explained and chapter 5 includes the characterization of a stepped impedance LPF to dual bandpass filter.

CHAPTER-2

MICROWAVE FILTERS

2.1 DESIGNING OF THE LOW PASS MICROWAVE FILTER

An ideal filter has the values of insertion loss in the passband and attenuation in the stop band equal to zero and infinity respectively. Also an ideal filter should have a linear phase response in the passband so that it can avoid the signal distortion in the passband. Although such kind of filters cannot be realized practically. By using the insertion loss method of filter design, the passband and stop band of the filter can be controlled to a large extent. Also the phase characteristics of the filter can be controlled which allows the designer to get the desired response accurately. Although there are trade-off in various design parameters to best meet the designer’s requirement. If, for example, a minimum insertion loss is most important, a Chebyshev response would satisfy a requirement for the sharpest cutoff. If it is possible to sacrifice the attenuation rate, a better gain can be obtained by using a Butterworth filter. The filter performance can be improved in insertion loss method by just increasing the order of the filter . *The order of the filter is equal to the number of reactive elements.*

In the insertion loss method a filter response is defined by its insertion loss, or *power loss ratio*, P_{LR}:

$$P_{\mathrm{LR}} = \frac{P_{inc}}{P_{load}} = \frac{1}{1-|\Gamma(\omega)|^2} \qquad (2)$$

where P_{inc} and P_{load} are power available from the source and power delivered to the load respectively and $|\Gamma(\omega)|$ is the magnitude of reflection coefficient. Figure 2.1 explains the process of filter design by insertion loss method.

This quantity is the reciprocal of $|S_{12}|^2$ if both load and source are matched. The insertion loss (IL) in dB is

$$\mathrm{IL} = 10 \log (P_{\mathrm{LR}}). \qquad (3)$$

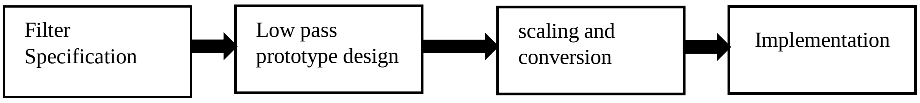


Figure 2.1: The process of filter design by the insertion loss method.

2.2 DIFFERENT TYPES OF FILTERS:

The microwave filters can be categorized mainly into two types of filters: Maximally flat filters (Butterworth filter) and Equal- ripple filters (Chebyshev filter) [32].

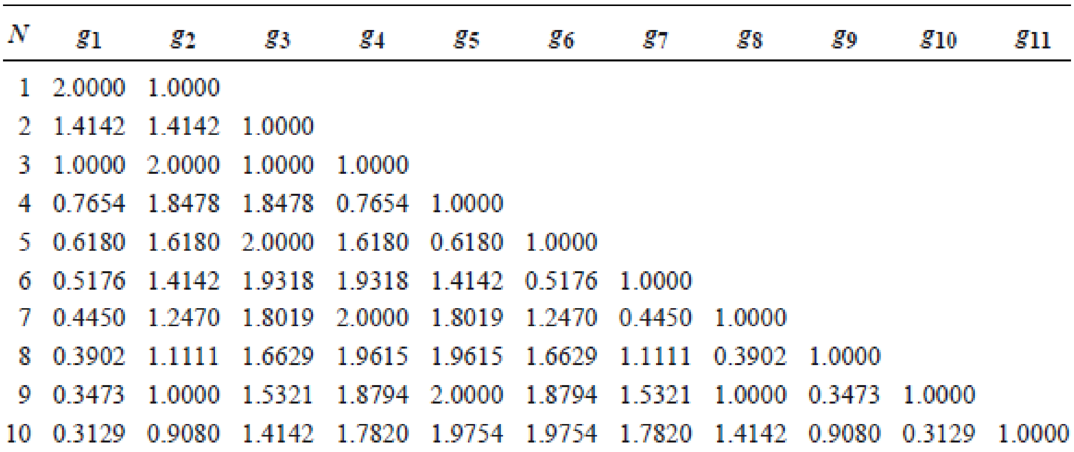
2.2.1 MAXIMALLY FLAT LOW-PASS PROTOTYPE FILTER

Prototype filter is a *normalized* filter which is designed for R_0 = 1 Ω and ω_c = 1 rad/sec. The standard table of values for different order filters is shown in Figure 2.2. First the order of the filter is decided on the basis of the required *insertion loss* and then a T or a Π design is opted for the design [32].

$$P_{LR} = 1 + k^2\left(\frac{\omega}{\omega_c}\right)^{2N} \qquad (4)$$

where k is a constant and is equal to 1 at -3 dB frequencies for maximally flat filter.

Once a prototype filter is designed at R_0 = 1 Ω and ω_c = 1 rad/sec, the filter with desired cut off frequency and desired load impedance can be obtained using *impedance and frequency scaling*.



N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

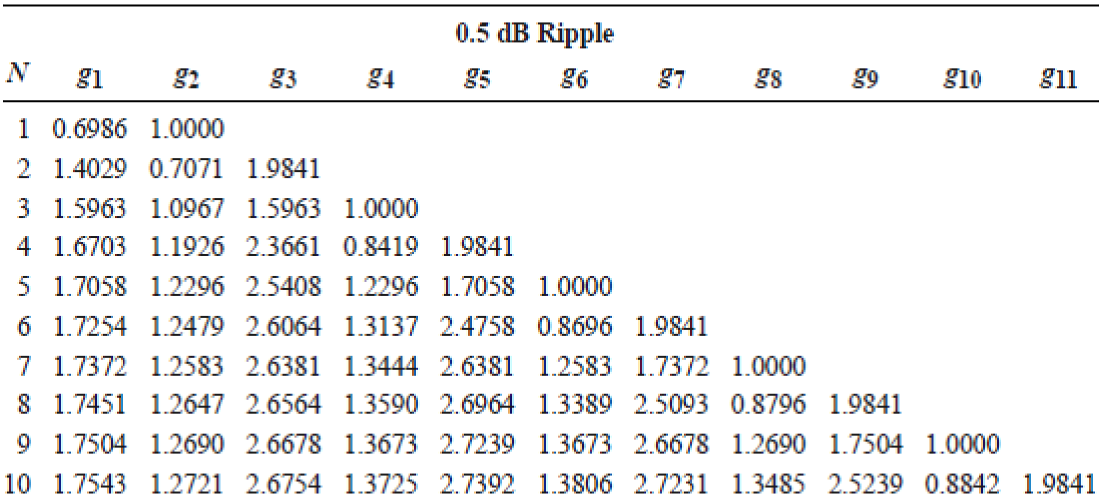
Figure 2.2: Element Values for Maximally Flat Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10).

2.2.2 EQUAL-RIPPLE LOW-PASS FILTER PROTOTYPE

The power loss ratio for the equal ripple Low Pass Filter prototype

$$P_{LR} = 1 + k^2T_N^2\left(\frac{\omega}{\omega_c}\right) \qquad (5)$$

where T_N is N^{th} order Chebyshev Polynomial and k is the constant that determines the ripples in the passband for the Chebyshev filter . The standard values for 0.5 dB ripple Chebyshev filter are shown in Figure 2.3.



	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

Figure 2.3: Element Values for Equal-Ripple Low-Pass Filter Prototypes ($g_0 = 1, \omega_c = 1$, $N = 1$ to 10, 0.5 dB ripple)

2.3 FILTER TRANSFORMATIONS

The prototype designs of LPF as explained in previous section were normalized designs i.e. they had a source impedance of $R_s = 1\Omega$ and a cutoff frequency of $\omega_c = 1$ rad/sec. In this section, the techniques to scale these normalized designs in terms of impedance and frequency are explained. Further the techniques to convert a prototype LPF high-pass, band-pass, or band-stop filter have been explained.

Impedance and Frequency Scaling

Impedance scaling: The values of source resistance and load resistance are taken equal to one in the prototype designs. By multiplying all the impedances of the prototype LPF by R_0, a source resistance equal to R_0 can be obtained. Thus, let primes denote impedance scaled quantities, the new filter component values are given by

$$L` = R_0 L \tag{6}$$

$$C` = \frac{C}{R_0} \tag{7}$$

$$R`_s = R_0 \tag{8}$$

$$R` = R_0 R_L \quad (9)$$

where L, C, and R_L are the values of the elements of the original prototype filter assumed.

Frequency scaling for low-pass filters: The cut off frequency of LPF prototype can be scaled from 1 rad/s to desired cut off frequency ω_c. For this the frequency dependence of the filter is scaled by the factor $1/\omega_c$, which can be done by replacing ω by $\omega/\omega c$:

$$\omega \leftarrow \frac{\omega}{\omega_c}$$

The new values for different elements can be obtained by applying the substitution to the reactances and susceptances, $j\omega L_k$, $j\omega C_k$, of the prototype LPF . Thus,

$$j\,X_k = j\frac{\omega}{\omega_c}L_k = j\omega L_k^{`} \quad (10)$$

$$j\,B_k = j\frac{\omega}{\omega_c}C_k = j\omega C_k^{`} \quad (11)$$

which shows that the new element values are given by

$$L_k^{`} = \frac{L_k}{\omega_c} \quad (12)$$

$$C_k^{`} = \frac{C_k}{\omega_c} \quad (13)$$

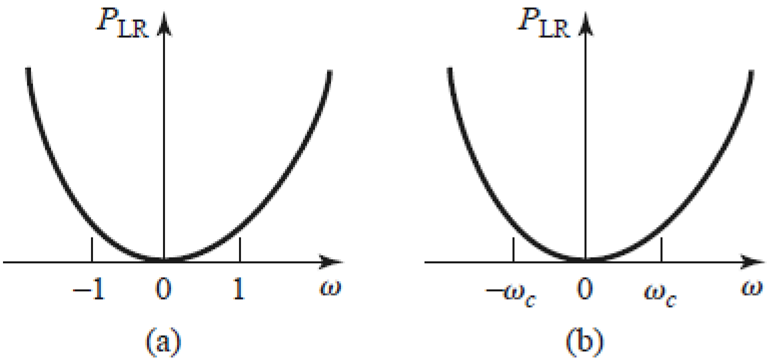


Figure 2.4: Frequency scaling for low-pass filters (a) Low-pass filter prototype response for ω_c = 1 rad/sec. (b) Frequency scaling for low-pass response.

A low pass filter can be transformed to a high pass filter, bandpass filter and a band-stop filter. The transformation formulae are given in the Figure 2.5.

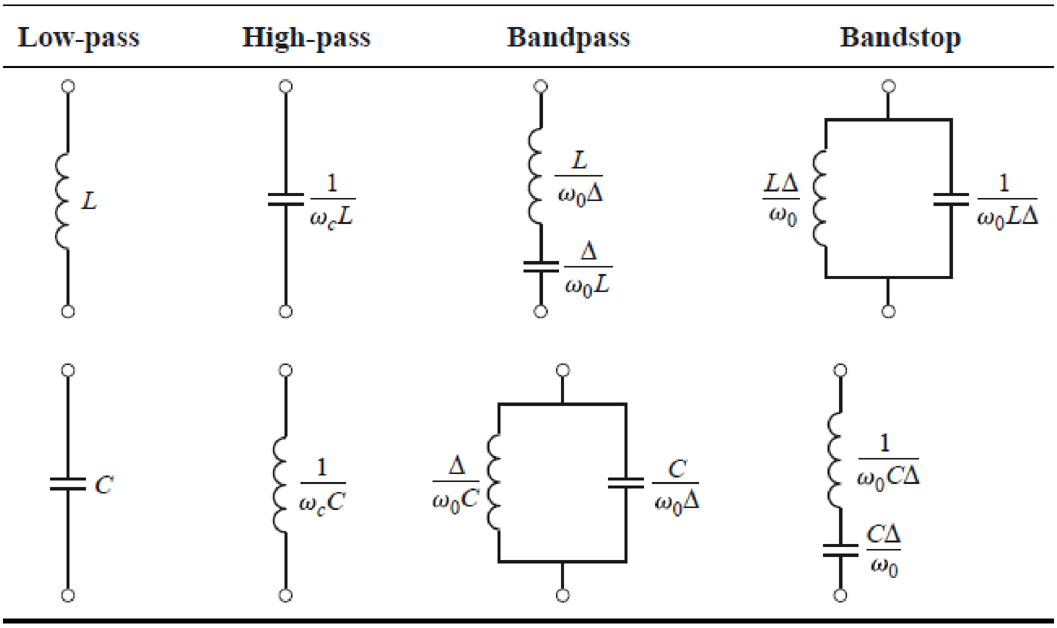


Figure 2.5: Summary of Prototype Filter Transformations $\left(\Delta = \frac{\omega_2-\omega_1}{\omega_0}\right)$

CHAPTER-3

DUAL BANDPASS LUMPED ELEMENT FILTER

3.1 DUAL BANDPASS FILTER

A lumped element filter is one in which the transit time effect for the travelling wave is not taken into the account.A dual band filter can be designed using many techniques like cascading two bandpass filters resonating at different frequencies or element- wise cascading of a wide pass band and one stop band which rejects some part of the wide pass band to make it a dual band filter. The second approach has been explained here.

- For the design that has been presented here, the frequencies 2.45 GHz and 5.8 GHz have been considered.
- First the bandpass filter whose band ranges from 2.3 GHz to 6 GHz is designed.
- Then a band-stop filter whose stop band ranges from approximately 2.5 GHz to 5.7 GHz is designed.

The bandpass filter is designed in Orcad PSpice [33]. The circuit result data are imported to Matlab and plotted [34]. Figure 3.1 represents the circuit corresponding to the bandpass filter which is transformed from low pass prototype filter.

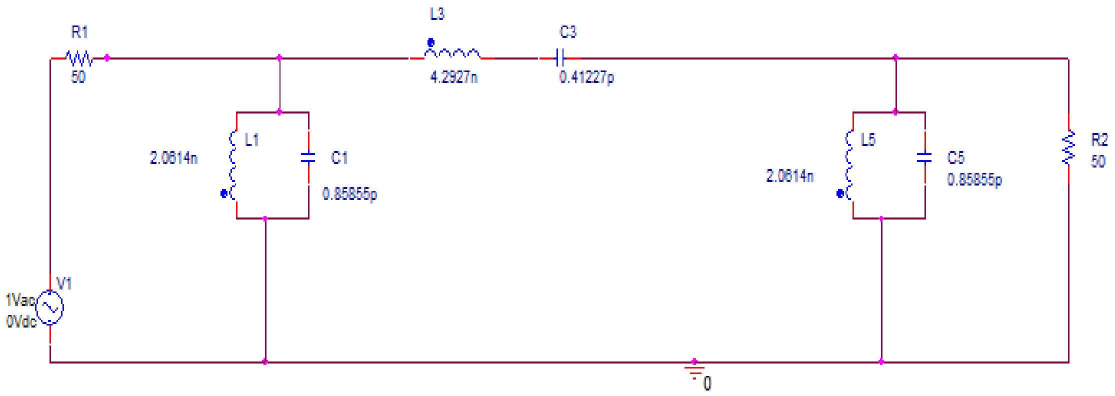


Figure 3.1: Transformation of low pass prototype filter to Bandpass filter.

To observe the pass band properly the above response in plotted in linear scale and hence the response is shown in Figure 3.2.

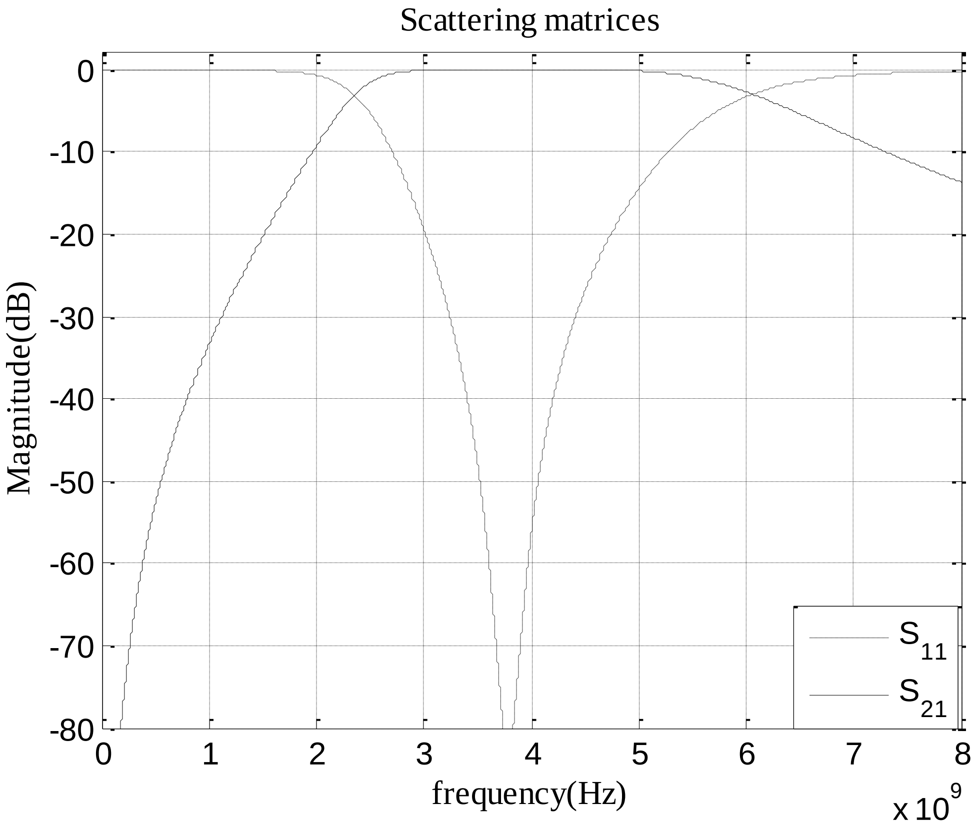


Figure 3.2: Response of the bandpass filter in the linear scale

After this a band-stop filter is designed which rejects the band of frequencies as mentioned in Figure 3.3.

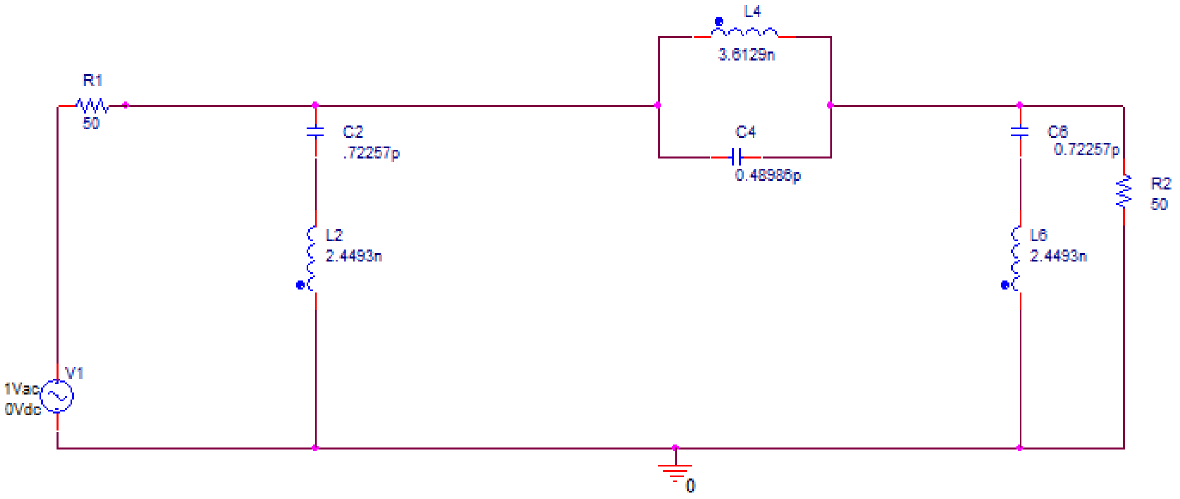


Figure 3.3: Transformation of low pass prototype to desired band-stop filter

The response of this filter is shown in Figure 3.4. It can be observed that a band reject filter which rejects the frequencies from 2.5 to 5.7 GHz.

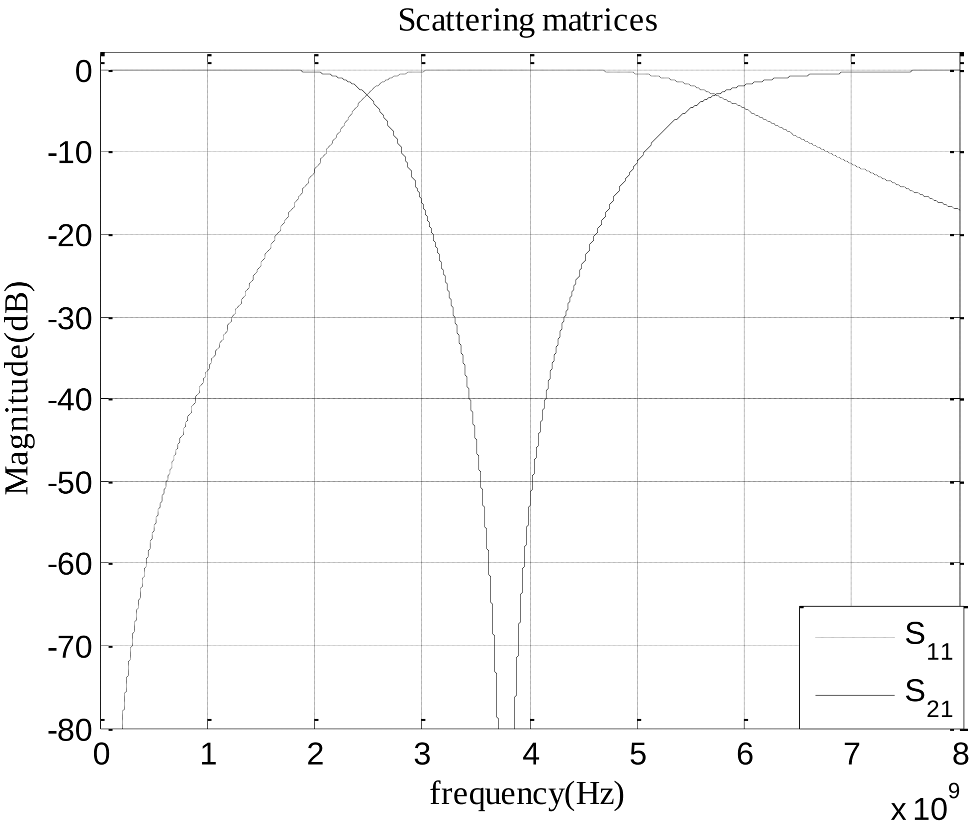


Figure 3.4: Response of the band-stop filter in the linear scale

- After this a circuit is designed by element wise cascading of the bandpass and band-stop. So that the part approximately from 2.5 GHz to 5.7 GHz can be rejected.
- And the rest of the remaining response will be that of a dual band filter with one band centered around 2.45 GHz and other band centered around 5.85 GHz.

The circuit diagram showing the element-wise cascading connection of a bandpass and a band-stop filter is shown in Figure 3.5.

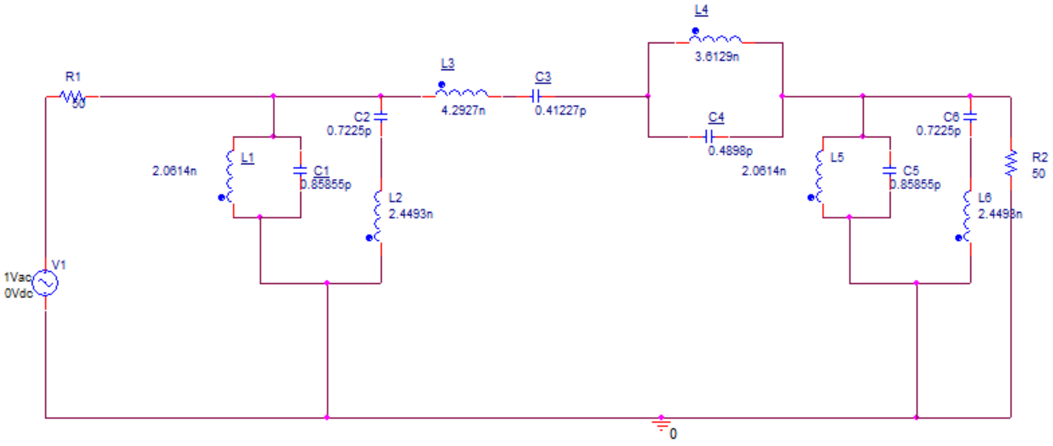


Figure 3.5: Circuit for the dual bandpass filter

The response, corresponding to this circuit, in logarithmic scale is shown in Figure 3.6. It can be observed from Figure 3.6 that the desired dual bandpass filter response is obtained. Figure 3.7 also describes the same dual bandpass filter but in logarithmic scale.

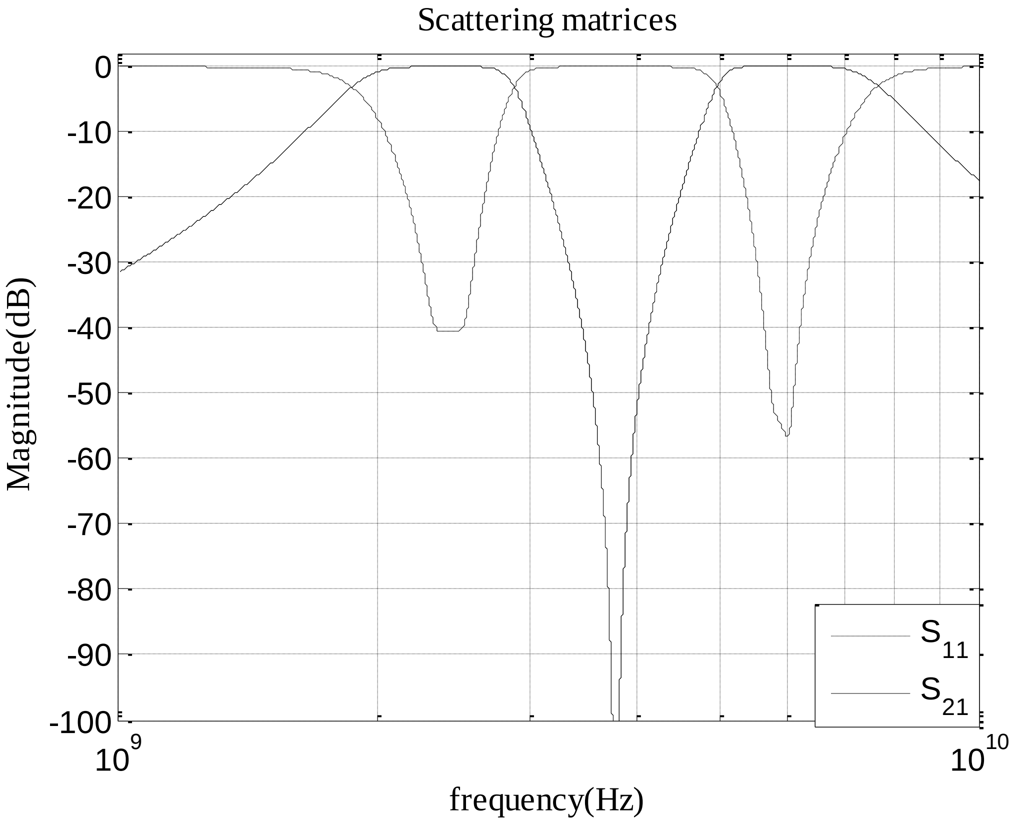


Figure 3.6: Response of the dual bandpass filter in logarithmic scale

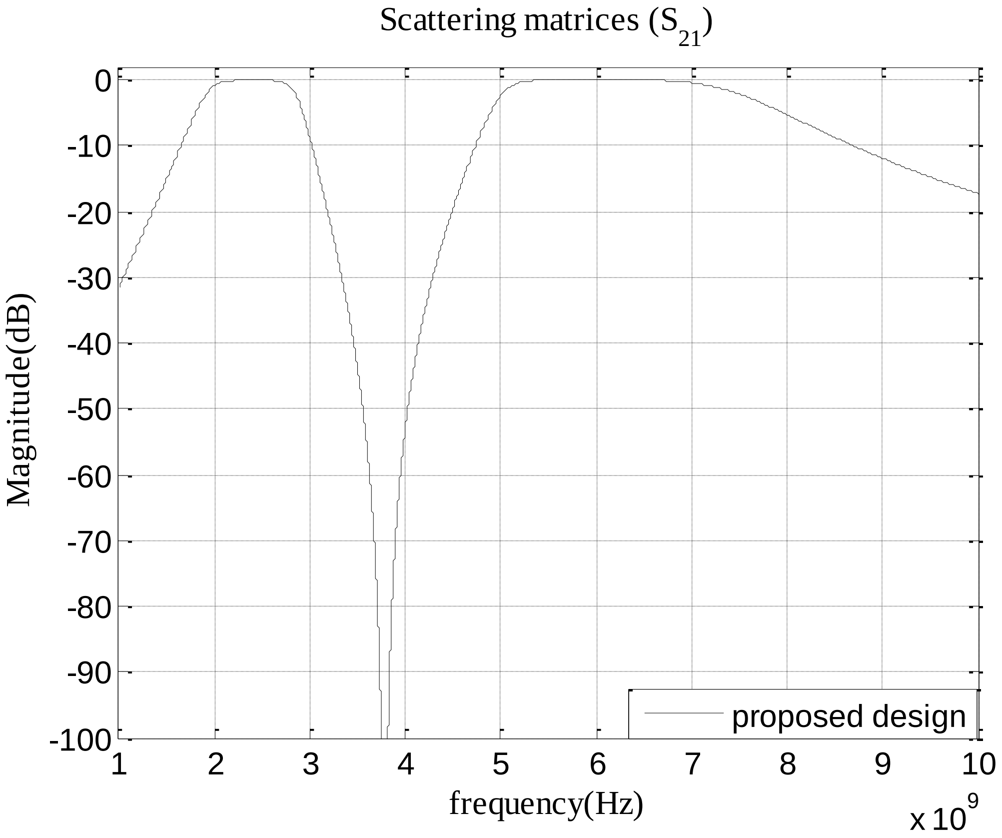


Figure 3.7: Response of the dual bandpass filter in linear scale

The design proposed here is compared with the design given in [1].The circuit given in [1] has been designed by using of element- wise cascading of two different pass-band filters with on pass band ranging from approximately 2.3 GHz to 2.5 GHz and other pass band ranging from 5.7 GHz to 5.9 GHz.

The dual-bandpass filter response is obtained for different values of quality-factor (Q-factor). As Q-factor is defined as

$$Q=\frac{\omega_0 L}{R}$$

So the value of Q can be achieved by varying the value of R. Different resistances corresponding to different value of desired Q are connected in series with each inductor.

To achieve the Q-factor equal to 10, a resistance equal to 0.777 Ω is connected in series with L_1 and L_5, a resistance of 0.9233 Ω is connected in series with L_2 and L_6, a resistance of 1.618 Ω in series with L_3 and a resistance of 1.3620 Ω in series with L_4 is connected.

For Q-factor equal to 100, a resistance of 0.0777 Ω in series with L_1 and L_5, a resistance of 0.09233 Ω in series with L_2 and L_6, a resistance of 0.1618 Ω in series with L_3 and a resistance of 0.13620 Ω in series with L_4 is connected.

The dual-band band-pass filter for different quality factors (Q) has been designed and the response (S_{21}) is shown in Figure 3.8.

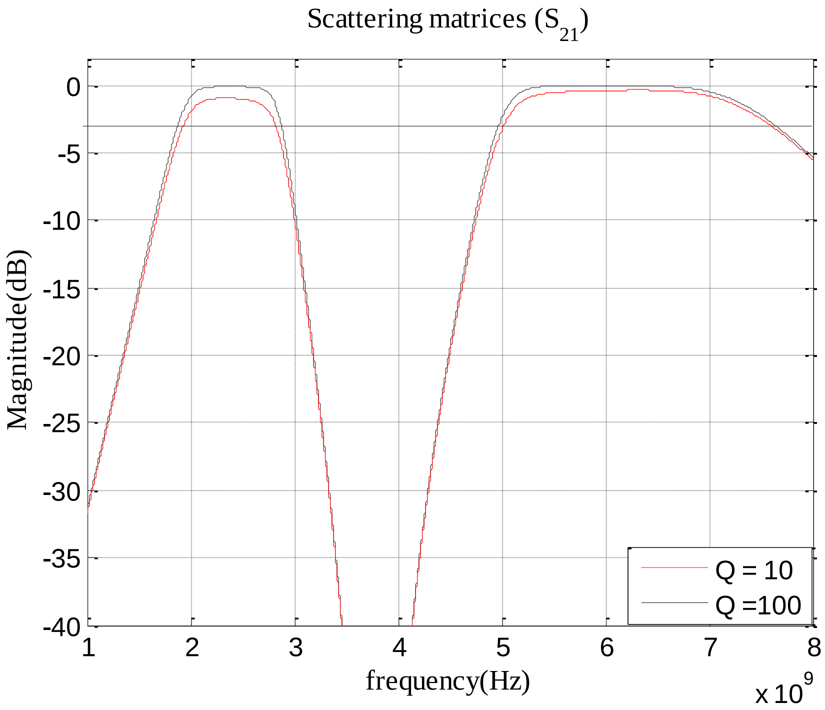


Figure 3.8: Response of the dual- bandpass filters design for different Q-factors.

The passbands and roll-off of the dual-bandpass filter proposed here can be varied slightly by varying the fractional bandwidths of passband and stop-band i.e. Δ_p and Δ_s respectively as shown in Figure 3.9. The bandwidths BW_1 and BW_2 for first passband and second passband have been shown in Table 3.1.

$$\Delta_p = \frac{\omega_{2p}-\omega_{1p}}{\omega_0} \tag{14}$$

$$\Delta_s = \frac{\omega_{2s}-\omega_{1s}}{\omega_0} \tag{15}$$

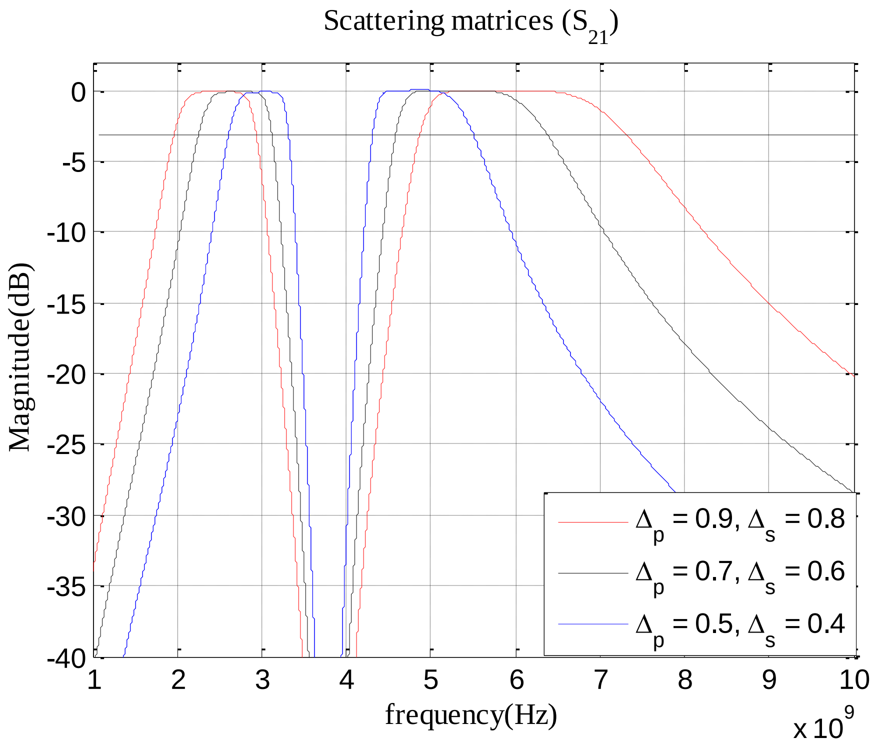


Figure 3.9: Response of the dual-band band-pass filter design for different values of fractional bandwidths.

Table 3.1: Bandwidth corresponding to different values of Δ_p and Δ_s

Fractional Bandwidths	-3dB Bandwidths for first and second passband
Δ_p= 0.9 ; Δ_s= 0.8	BW_1 = 0.965 GHz ; BW_2 = 2.424 GHz
Δ_p= 0.7 ; Δ_s= 0.6	BW_1 = 0.86 GHz ; BW_2 = 1.777 GHz
Δ_p= 0.5 ; Δ_s= 0.4	BW_1 = 0.701 GHz; BW_2 = 1.182 GHz

The circuit diagram for the design given in [1] is as shown in Figure 3.10:

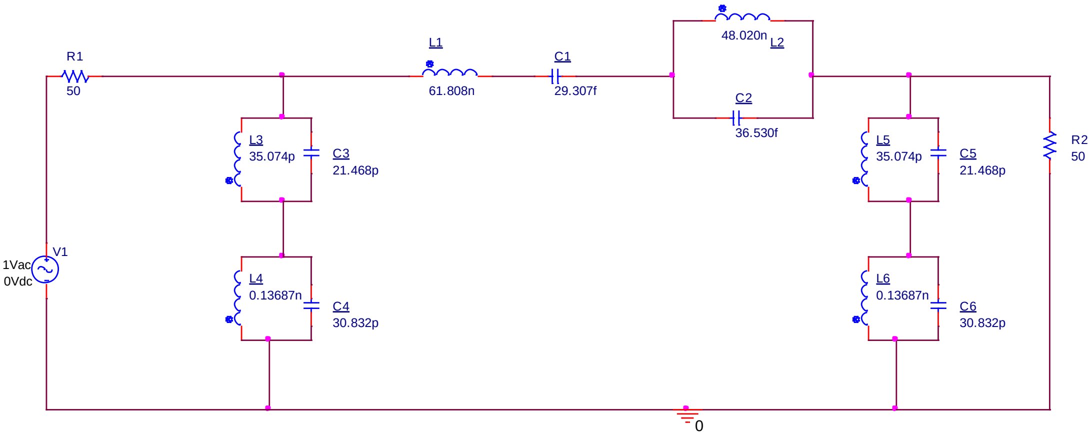


Figure 3.10: Circuit diagram for dual band filter given in [1]

The response i.e. S_{21} for this circuit is given as shown in Figure 3.11:

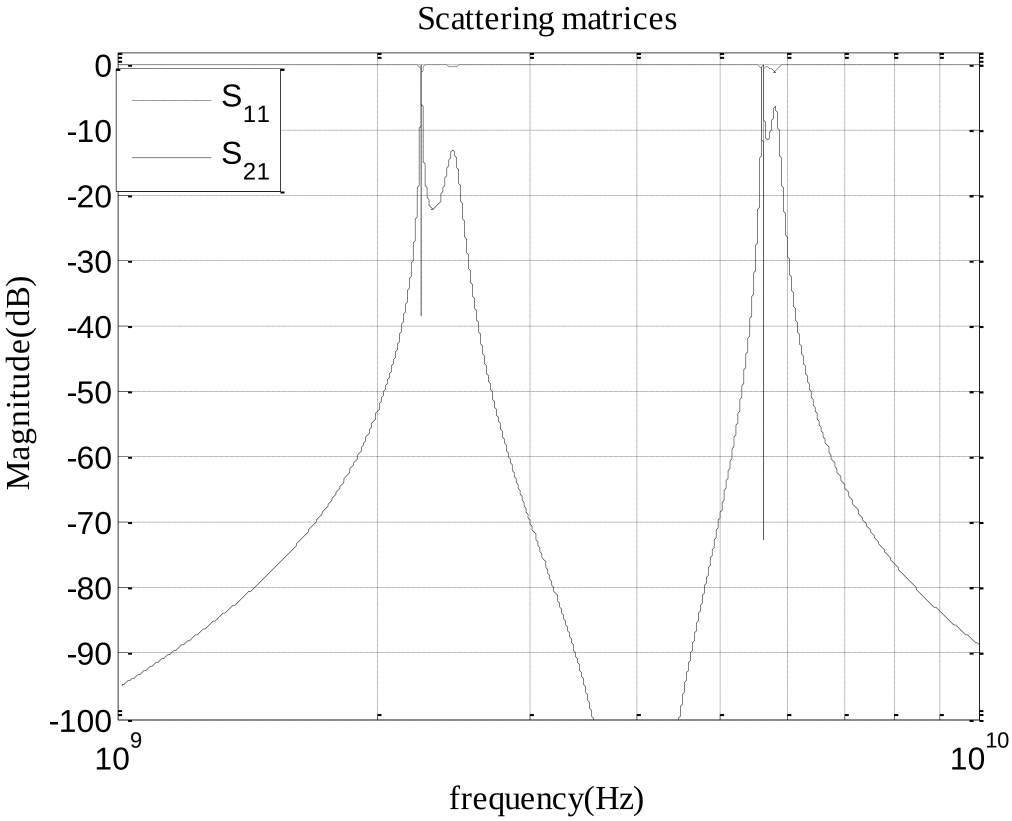


Figure 3.11: Response of the filter given in [1] in logarithmic scale

3.2 COMPARISON OF TWO DESIGNS

Responses of two different designs are compared and the results are shown in Figure 3.12. To see a clear picture of the difference between the two, the results are plotted in the logarithmic scale.

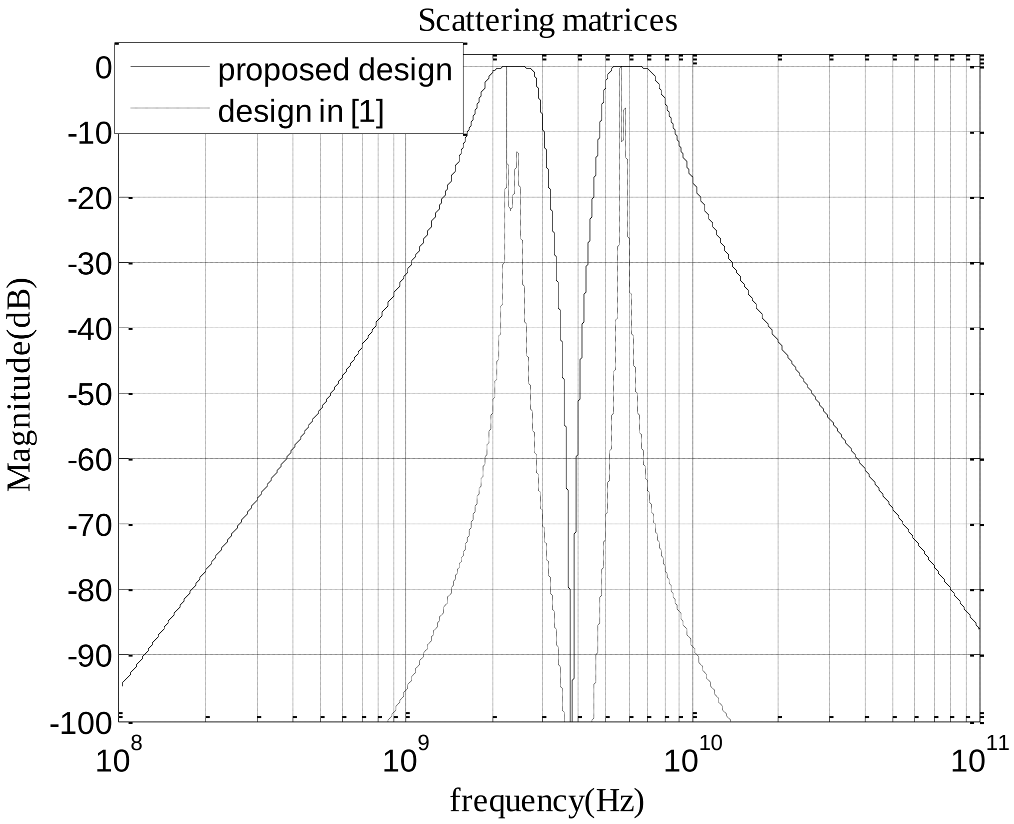


Figure 3.12: Comparison of responses

3.3CONCLUSION

In this chapter, a lumped element dual-bandpass filter using element-wise cascading of a BPF and a band-reject filter has been designed. The passbands and stop-band of the filter can be varied by varying a parameter i.e. fractional bandwidth (Δ_p and Δ_s). By increasing the values of Δ_s and decreasing the value of Δ_p the -3 dB bandwidths of the filter can be reduced.

CHAPTER-4

DISTRIBUTED ELEMENT FILTER

4.1 DIFFERENCE BETWEEN A LUMPED AND DISTRIBUTED ELEMENT FILTER

The lumped element filter is the one in which the components of the filter do not take into account the *transit time* for the current wave. In this type of filters, the size of the elements of the filter is fairly larger as compared to the wavelength of the signal travelling through it. Lumped element filters are well operated at low frequencies and hence they can be easily studied under conventional network and circuit theory.

The distributed element filters are those in which size of the elements is of the order of the wavelength of the signal travelling through them and this fact makes it to take into account the *transit time* effect. The distributed element filters cannot be studied under conventional network and circuit theory.

4.2 STEPPED IMPEDANCE LOW PASS FILTER

A relatively easy way to implement low-pass filters in microstrip or strip-line is to use alternating sections of very high and very low characteristic impedance lines. Such filters are usually referred to as *stepped-impedance,* or hi-Z, low-Z filters, and are popular because they are easier to design and take up less space than a similar low-pass filter using stubs.

A short transmission line section has an equivalent circuit as shown in Figure 4.1.

The series inductors of a low-pass prototype can be replaced with high-impedance line sections ($Z_0 = Z_h$), and the shunt capacitors can be replaced with low-impedance line sections ($Z_0 = Z_l$). The ratio Z_h/Z_l should be as large as possible, so the actual values of Z_h and Z_l are usually set to the highest and lowest characteristic impedance that can be practically fabricated.

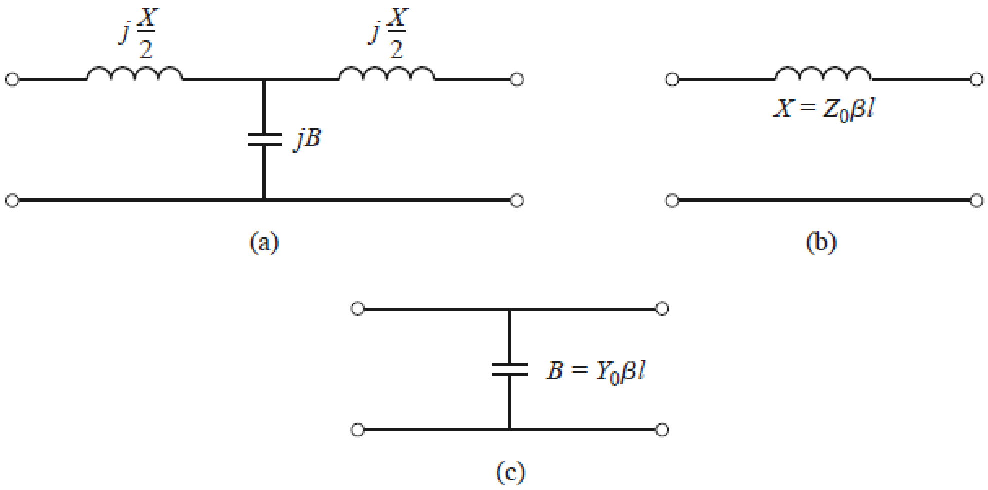


Figure 4.1: Approximate equivalent circuits for short sections of transmission lines. (a) T equivalent circuit for a transmission line section having $\beta l << \pi/2$. (b) Equivalent circuit for small β and large $Z0$. (c) Equivalent circuit for small β and small Z_0.

The electrical lengths of the inductor sections are calculated as [32]:-

$$\beta l = \frac{LR_0}{Z_h} \text{ (inductor)} \tag{14}$$

The electrical lengths of the capacitor sections are calculated as:-

$$\beta l = \frac{CZ_l}{R_0} \text{ (capacitor)} \tag{15}$$

where R_0 is the filter impedance and L and C are the normalized element values of the low-pass prototype.

4.3 DESIGN OF A STEPPED IMPEDANCE LOW PASS FILTER

In this section different order filters are implemented and compared to obtain the difference between their responses. The LPF is designed using CST studio suit 2016 [35] and the dimensions of the filter are calculated using AWR TXLine 2003.

4.3.1 THIRD ORDER LPF

In this design of third order LPF the substrate for the microstrip design is chosen to be RT Duroid 5880 which is having a dielectric constant of 2.2. The high impedance of the line is chosen to be 120 Ω and low impedance as 15 Ω. The cut off frequency is chosen to be 3 GHz.

Since the filter is third order LPF so the number of reactive elements will be three. The filter is designed for a desired frequency of 3 GHz. According to this frequency, the length and width and electrical lengths of the filter are calculated and the values are listed in Table 4.1.

Table 4.1: Table for the values of lengths for third order filter

Component	**Values**	**Z_l or $Z_h(\Omega)$**	**βl_i (degree)**	***w_i (mm)***	***l_i (mm)***
L_1	1.5963	120	38.1088	0.2921	8.0191
C_2	1.0967	15	18.85	7.30917	3.64426
L_3	1.5963	120	38.1088	0.2921	8.0191

This design of LPF with the values calculated in the table is shown in Figure 4.2.

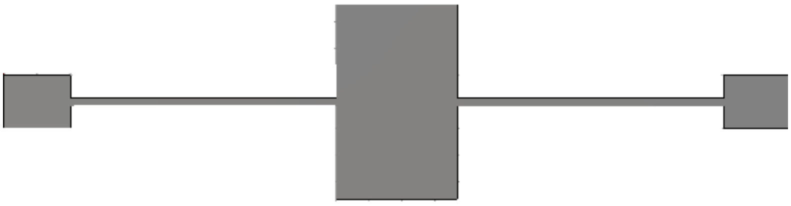


Figure 4.2: Third Order Stepped Impedance LPF

4.3.2 FIFTH ORDER LPF

On the similar basis, a fifth order LPF is designed and the corresponding calculated values are shown in the Table 4.2.

Table 4.2: Table for the values of lengths for fifth order filter

Component	Values	Z_l or $Z_h(\Omega)$	βl_i (degree)	*w_i (mm)*	*l_i (mm)*
L_1	1.7058	120	40.7229	0.29215	8.56863
C_2	1.2296	15	21.1352	7.31017	4.08593
L_3	2.5408	120	60.657	0.29215	12.763
C_4	1.2296	15	21.1352	7.31017	4.08593
L_5	1.7058	120	40.7229	0.29215	8.56863

The design of fifth order LPF corresponding to the values tabulated above is shown in Figure 4.3.

Figure 4.3: Fifth Order Stepped Impedance LPF

4.3.3 SEVENTH ORDER LPF

Table 4.3 lists the dimensions of seventh order stepped impedance LPF corresponding to 3 GHz cut off frequency.

Table 4.3: Table for the values of lengths for seventh order filter

Component	Values	Z_l or Z_h(Ω)	βl_i (degree)	w_i (mm)	l_i (mm)
L1	1.7372 H	120	41.4725	0.292105	8.72691
C2	1.2583 F	15	21.6285	7.30917	4.18142
L3	2.6381 H	120	62.9799	0.292105	13.2526
C4	1.3441 F	15	23.1033	7.30917	4.46655
L5	2.6381 H	120	62.9799	0.292105	13.2526
C6	1.2583 F	15	21.6285	7.30917	4.18142
L7	1.7372 H	120	41.4725	0.292105	8.72691

Figure 4.4 shows the design of seventh order stepped impedance LPF.

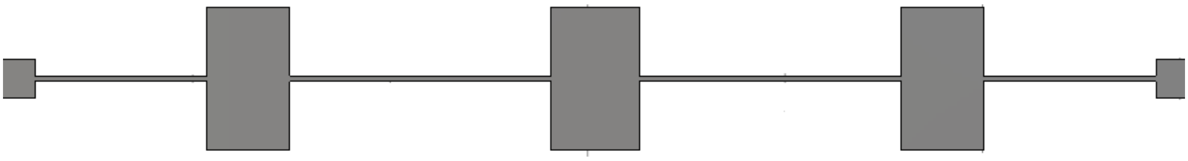


Figure 4.4: Seventh Order Stepped Impedance LPF

Comparison of different orders of Filters

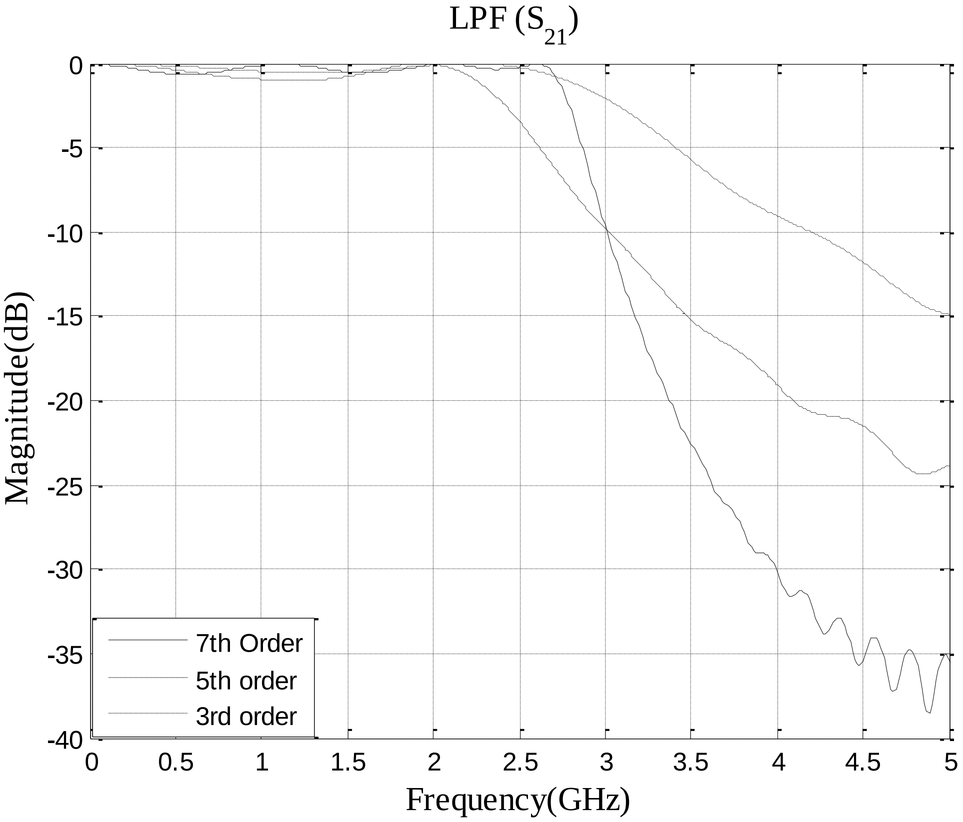


Figure 4.5: Comparison Stepped Impedance LPFs

4.4 MODIFIED DESIGN

It is observed that the above stated design consumes more space. So a new technique is tried. In this technique the inductor length is modified in micro-strip design so that it takes less space. The new design is given in Figure 4.6.

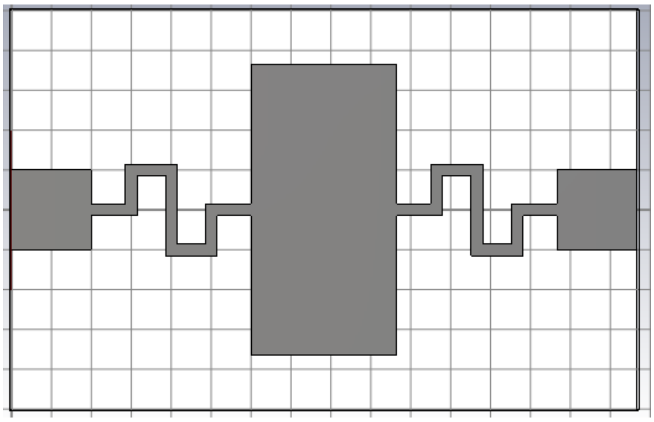


Figure 4.6: Modified design with $l_y = l_x$

In this design the length of the inductor is subdivided along Y axis and X axis. Along X-axis the length is assumed to be l_x and along Y-axis the length is l_y.

In first case the lengths are taken $l_y = l_x$ and S_{21} is obtained. Then in order to further reduce the space $l_y = 3l_x$ is chosen, and results are plotted.

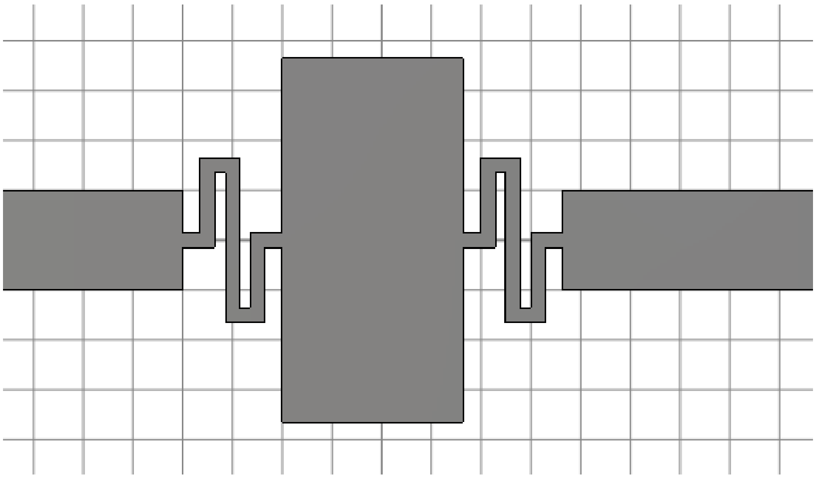


Figure 4.7: Modified design with $l_y = 3l_x$

It is observed in Figure 4.8 that the results in case of 1:1 are better than 1:3 ratio of length

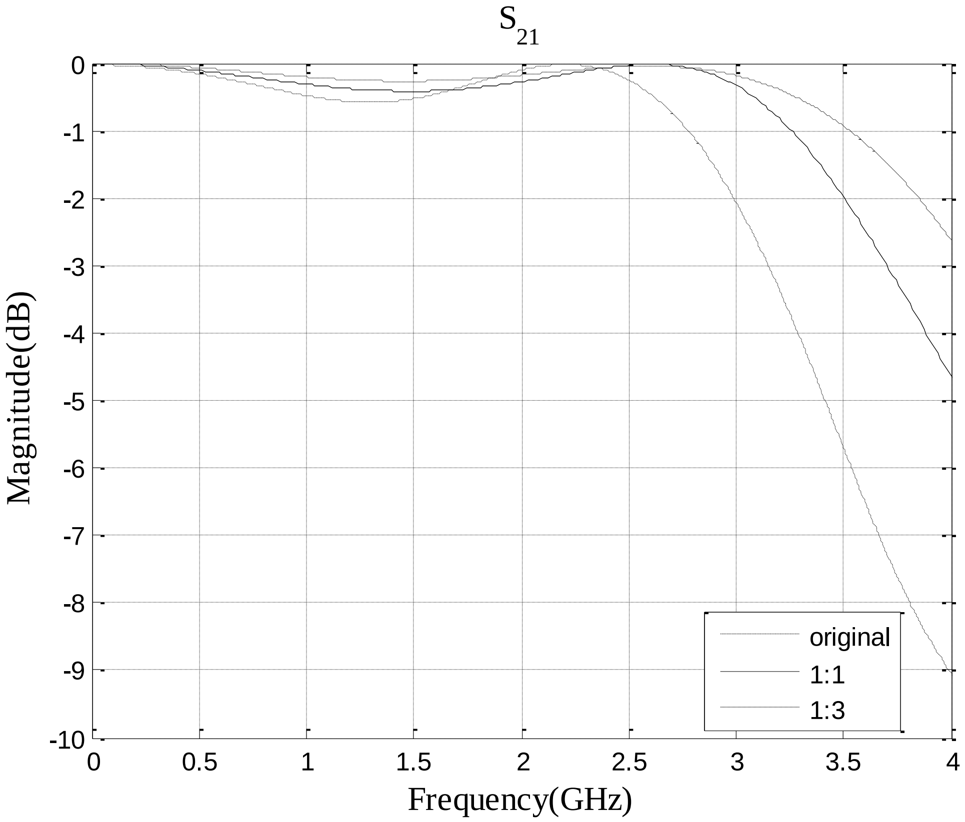


Figure 4.8: Comparison of two modified designs with the original

4.5 CONCLUSION

In this chapter, a technique to implement stepped impedance LPF has been explained. Stepped impedance LPF is designed for third, fifth and seventh order respectively. It is observed that the higher order filter gives better response in terms of the rejection in the pass band. After this, in order to reduce the circuit size some modifications are implemented. The length of the inductor is varied. The length cannot be modified by large amount as this would lead to deviation from the actual response.

CHAPTER-5

DUAL BANDPASS FILTER USING STEPPED IMPEDANCE LPF

5.1 CHARACTERIZING A DUAL BANDPASS FILTER USING A STEPPED IMPEDANCE LPF

A stepped impedance LPF can be used to achieve a dual bandpass filter response by certain modifications. Different order dual bandpass filters are characterized using stepped impedance LPF in the following sub-sections.

5.1.1 THIRD ORDER STEPPED IMPEDANCE FILTER

A dual bandpass filter can be designed using the stepped impedance LPF. As the stepped impedance LPF can give the periodic responses after certain modification so the design of the stepped impedance low pass filter is modified to get the response corresponding to the dual band filter. The stepped impedance LPF has been already designed, so the design of the stepped impedance LPF is modified. Keeping the length of the components fixed, the width of each component is modified according to the high or low impedance of the components of the stepped LPF. The design shown in the Figure 5.1 is for the third order stepped impedance LPF. In this stepped impedance LPF the width of alternative components is same.

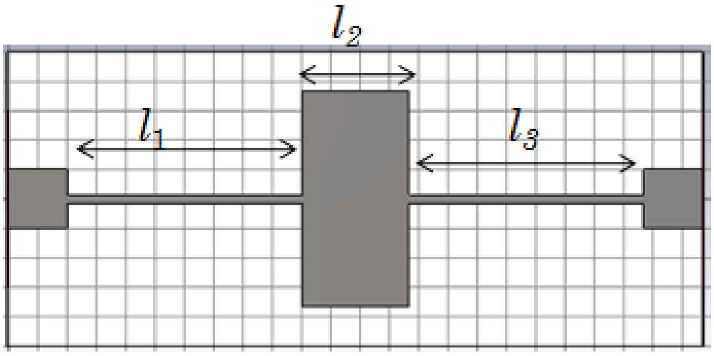


Figure 5.1: Third Order Stepped Impedance LPF

When this stepped impedance LPF is modified to get the stepped impedance dual bandpass filter, the length of each component is kept fixed, which makes the electrical length also constant as the frequency of operation is constant. The width of each component is changed in accordance to the high or low impedance of the component as shown is the Figure 5.2.

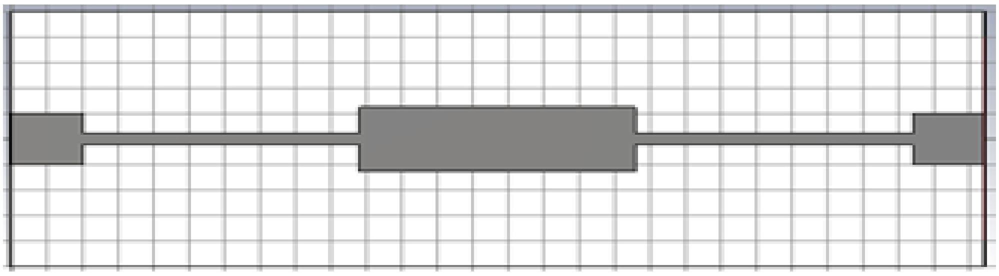


Figure 5.2: Third Order Stepped Impedance dual bandpass filter

The values of the lengths and widths for third order stepped impedance LPF and stepped impedance dual bandpass filters are shown in Table 5.1 and Table 5.2 respectively.

Table 5.1: Third order stepped impedance LPF

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.5963 H	120	0.2921	8.0191
C_2	1.0967 F	15	7.30917	3.64426
L_3	1.5963 H	120	0.2921	8.0191

Table 5.2: Third order stepped impedance dual bandpass filter

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.5963 H	101.623	0.444	8.4273
C_2	1.0967 F	35.8073	2.534	8.4273
L_3	1.5963 H	101.623	0.444	8.4273

The responses corresponding to the third order stepped impedance LPF and third order stepped impedance dual bandpass filter are compared and are shown in Figure 5.3.

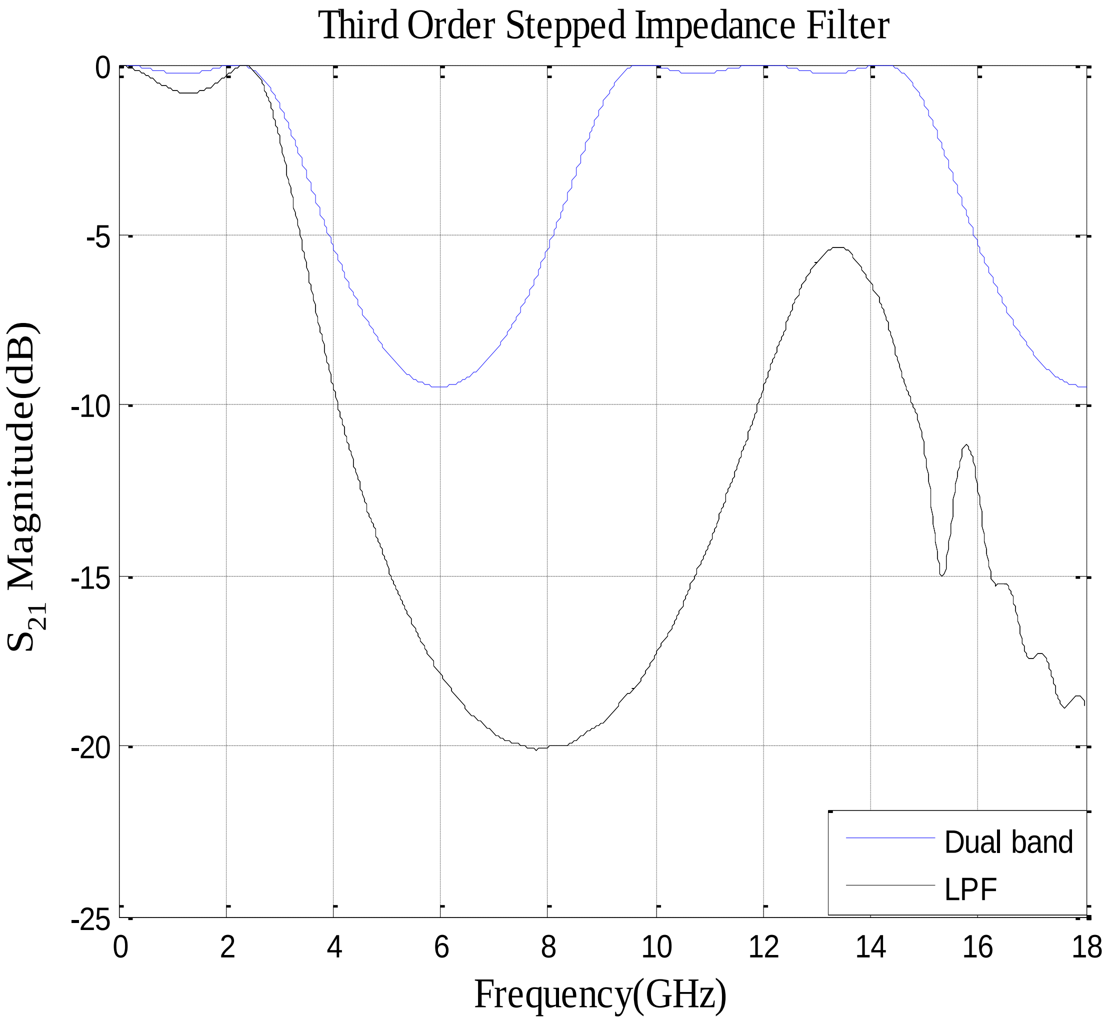


Figure 5.3: Comparison of responses of third order stepped impedance LPF and stepped impedance dual bandpass filter

From Figure 5.3 it can be clearly seen that the stepped impedance LPF is a periodic structure as the response tends to repeat but the gain is far below -3 dB and hence cannot be treated as a dual bandpass filter. After making the modifications the response is better as compared to the stepped impedance LPF in the second passband.

5.1.2 FIFTH ORDER STEPPED IMPEDANCE FILTER

As it has been analyzed in the above subsection that third order stepped impedance dual bandpass filter can be characterized using stepped impedance LPF, so similar modifications are applied to the fifth order stepped impedance LPF. Figure 5.4 and Figure 5.5 show the design corresponding to fifth order stepped impedance LPF and fifth order dual bandpass filter.

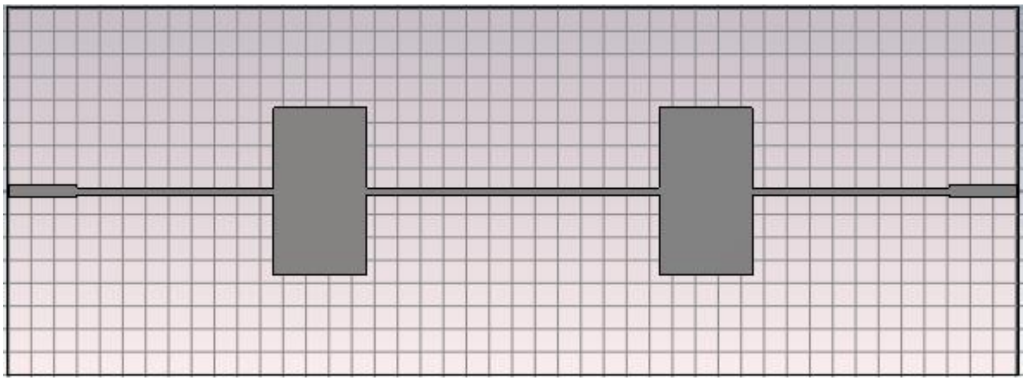


Figure 5.4: Fifth Order Stepped Impedance LPF

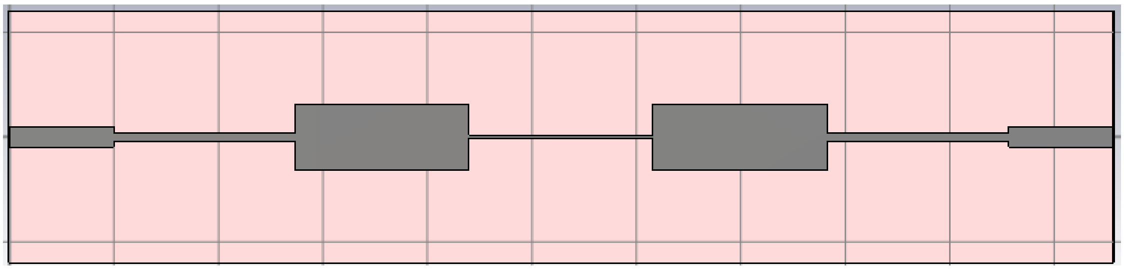


Figure 5.5: Fifth Order Stepped Impedance dual bandpass filter

Table 5.3 and Table 5.4 show the data corresponding to the fifth order stepped impedance LPF and fifth order stepped impedance dual bandpass filter.

Table 5.3: Fifth order stepped impedance LPF

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i* *(mm)***	***l_i* *(mm)***
L_1	1.7058 H	120	0.29215	8.56863
C_2	1.2296 F	15	7.31017	4.08593
L_3	2.5408 H	120	0.29215	12.763
C_4	1.2296 F	15	7.31017	4.08593
L_5	1.7058 H	120	0.29215	8.56863

Table 5.4: Fifth order stepped impedance dual bandpass filter

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.7058 H	108.5946	0.381	8.4273
C_2	1.2296 F	31.9371	2.95	8.4273
L_3	2.5408 H	161.7523	0.1221	8.4273
C_4	1.2296 F	31.9371	2.95	8.4273
L_5	1.7058 H	108.5946	0.381	8.4273

The responses of LPF and the dual bandpass filter are compared as shown in Figure 5.6

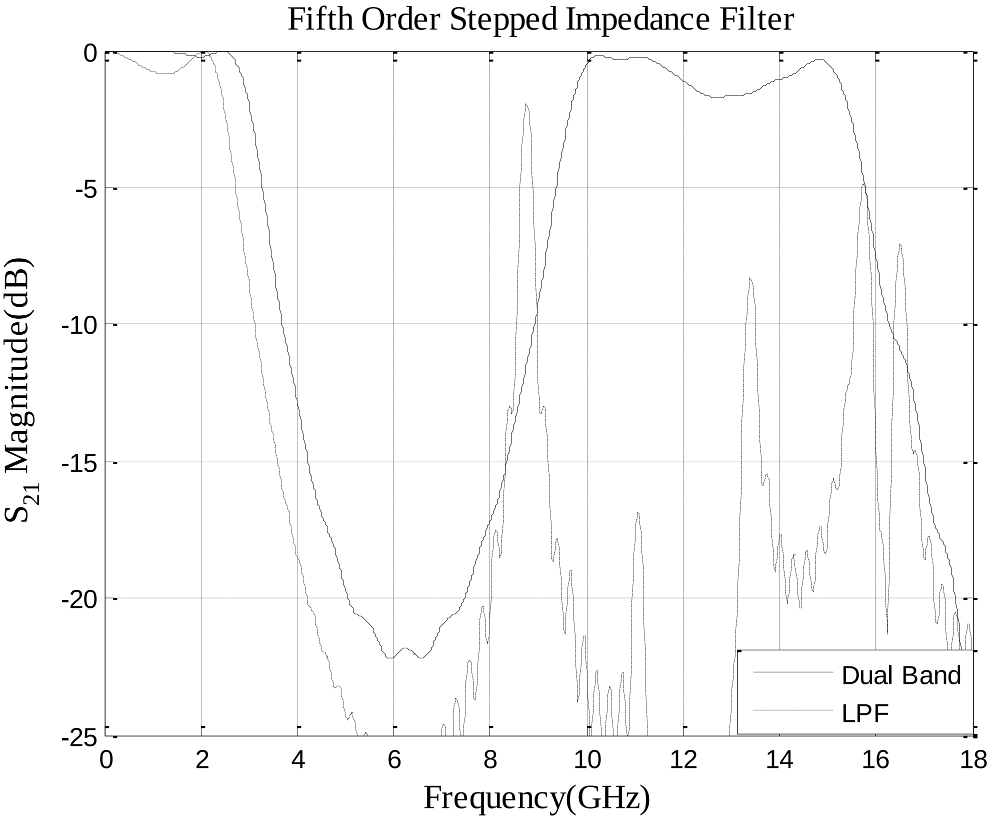


Figure 5.6: Comparison of responses of fifth order stepped impedance LPF and stepped impedance dual bandpass filter

As in case of the third order stepped impedance filter, similar results can be observed for fifth order stepped impedance filter also.

5.1.3 SEVENTH ORDER STEPPED IMPEDANCE FILTER

The seventh order filter is also realized using the same methodology as third order and fifth order. Figure 5.7 and 6.8 show the design of seventh order stepped impedance LPF and stepped impedance dual bandpass filter.

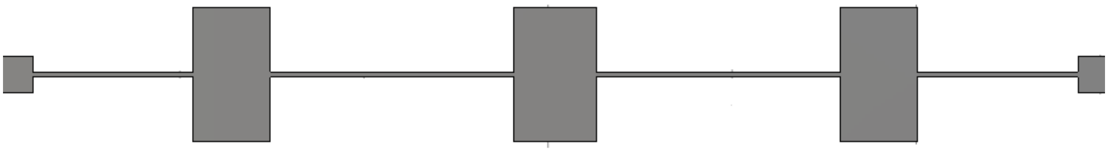


Figure 5.7: Seventh Order Stepped Impedance LPF

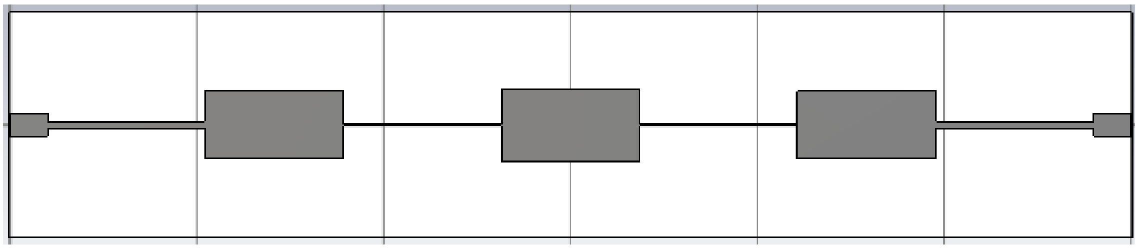


Figure 5.8: Seventh Order Stepped Impedance dual bandpass filter

Table 5.5 and Table 5.6 list the details of the components used in the seventh order stepped impedance LPF and seventh order stepped impedance dual bandpass filter respectively.

Table 5.5: Seventh order stepped impedance LPF

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i* (mm)**	***l_i* (mm)**
L1	1.7372 H	120	0.292105	8.72691
C2	1.2583 F	15	7.30917	4.18142
L3	2.6381 H	120	0.292105	13.2526
C4	1.3441 F	15	7.30917	4.46655
L5	2.6381 H	120	0.292105	13.2526
C6	1.2583 F	15	7.30917	4.18142
L7	1.7372 H	120	0.292105	8.72691

Table 5.6: Seventh order stepped impedance dual bandpass filter

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L1	1.7372 H	110.6074	0.359	8.4273
C2	1.2583 F	31.2048	3.001	8.4273
L3	2.6381 H	167.967	0.105	8.4273
C4	1.3441 F	29.212	3.265	8.4273
L5	2.6381 H	167.967	0.105	8.4273
C6	1.2583 F	31.2048	3.001	8.4273
L7	1.7372 H	110.6074	0.359	8.4273

Figure 5.7 shows the response comparison of seventh order stepped impedance LPF and seventh order stepped impedance dual bandpass filter.

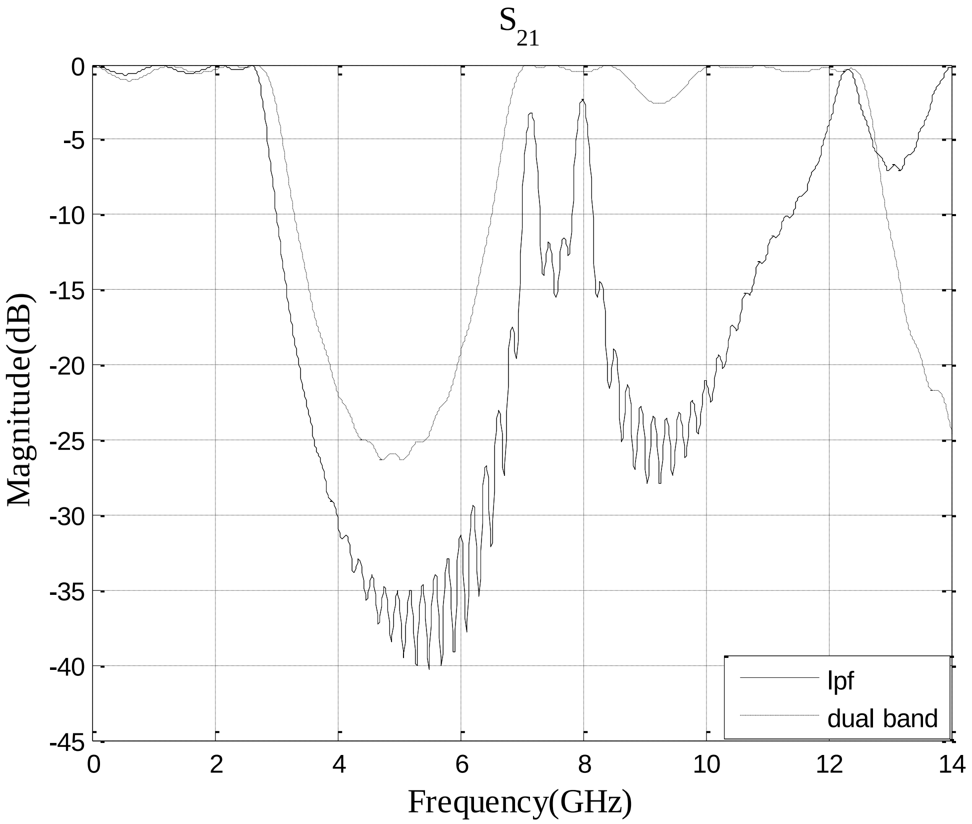


Figure 5.9: Comparison of responses of seventh order stepped impedance LPF and stepped impedance dual bandpass filter

5.2 DUAL BANDPASS FILTER OF DIFFERENT LENGTHS

5.2.1 THIRD ORDER DUAL BANDPASS FILTER OF DIFFERENT LENGTHS

Third order dual bandpass filter for different lengths i.e. for $\lambda/6$, $\lambda/8$, $\lambda/10$ and the results are then compared. The dimensions are mentioned in Table 5.7, 6.8 and 6.9 respectively.

Table 5.7: Third order stepped impedance dual bandpass filter for $l=\lambda/6$

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.5963 H	76.2177	0.793	11.2366
C_2	1.0967 F	47.743	1.695	11.2366
L_3	1.5963 H	76.2177	0.793	11.2366

Table 5.8: Third order stepped impedance dual bandpass filter for $l=\lambda/8$

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.5963 H	101.623	0.444	8.4273
C_2	1.0967 F	35.8073	2.534	8.4273
L_3	1.5963 H	101.623	0.444	8.4273

Table 5.9: Third order stepped impedance dual bandpass filter for $l=\lambda/10$

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.5963 H	127.0295	0.255	8.4273
C_2	1.0967 F	28.6458	3.39	8.4273
L_3	1.5963 H	127.0295	0.255	8.4273

The comparison of responses is shown in Figure 5.10.

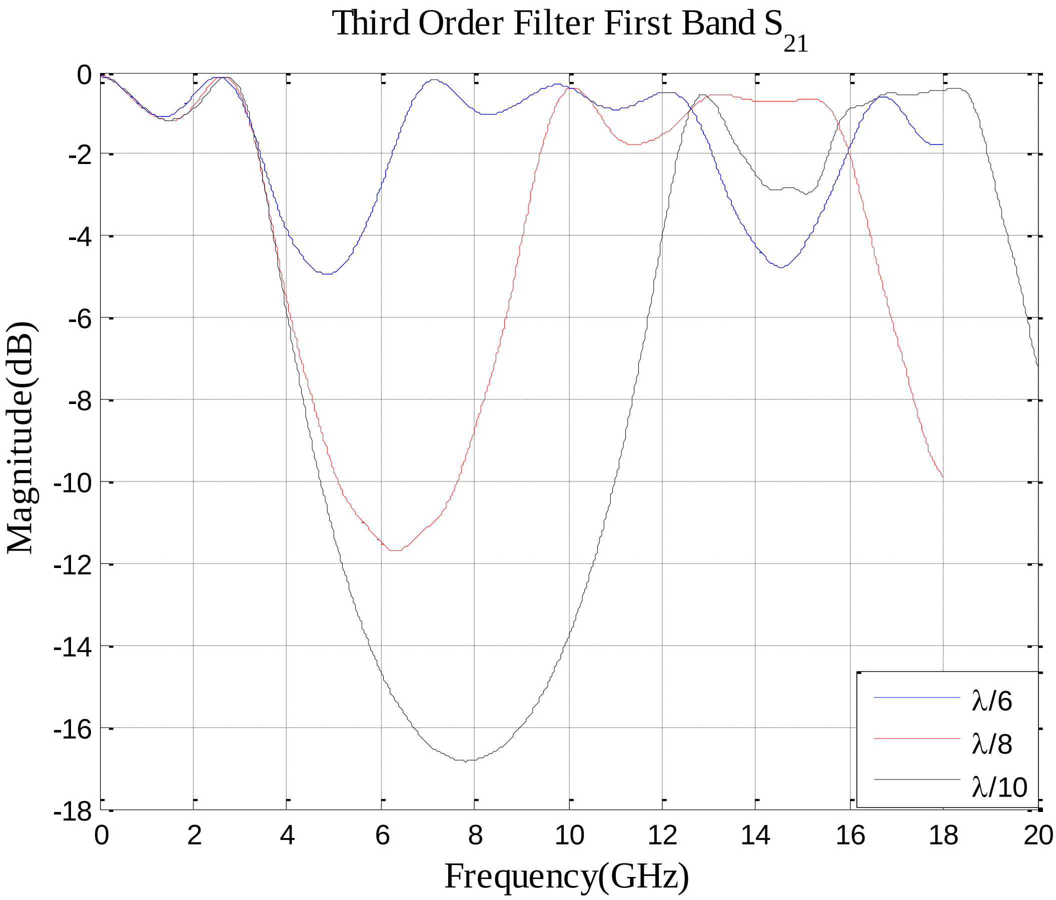


Figure 5.10: Comparison of responses of third order stepped impedance dual bandpass filter for different lengths

5.2.2 FIFTH ORDER DUAL BANDPASS FILTER OF DIFFERENT LENGTHS

Fifth order filter for different length is also realized and the values corresponding to *λ/6, λ/8, λ/10* lengths are listed in the Table 5.10, 6.11and 6.12 respectively.

Table 5.10: Fifth order stepped impedance dual bandpass filter for *l=λ/6*

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.7058 H	81.4459	0.70	11.2366
C_2	1.2296 F	42.5828	2.001	11.2366
L_3	2.5408 H	121.3142	0.2901	11.2366

C_4	1.2296 F	42.5828	2.001	11.2366
L_5	1.7058 H	81.4459	0.70	11.2366

Table 5.11: Fifth order stepped impedance dual bandpass filter for $l=\lambda/8$

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.7058 H	108.5946	0.381	8.4273
C_2	1.2296 F	31.9371	2.95	8.4273
L_3	2.5408 H	161.7523	0.1221	8.4273
C_4	1.2296 F	31.9371	2.95	8.4273
L_5	1.7058 H	108.5946	0.381	8.4273

Table 5.12: Fifth order stepped impedance dual bandpass filter for $l=\lambda/10$

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.7058 H	135.7432	0.212	6.7419
C_2	1.2296 F	25.5497	3.915	6.7419
L_3	2.5408 H	199.3256	0.055	6.7419
C_4	1.2296 F	25.5497	3.915	6.7419
L_5	1.7058 H	135.7432	0.212	6.7419

The response corresponding to these three designs is shown in Figure 5.11

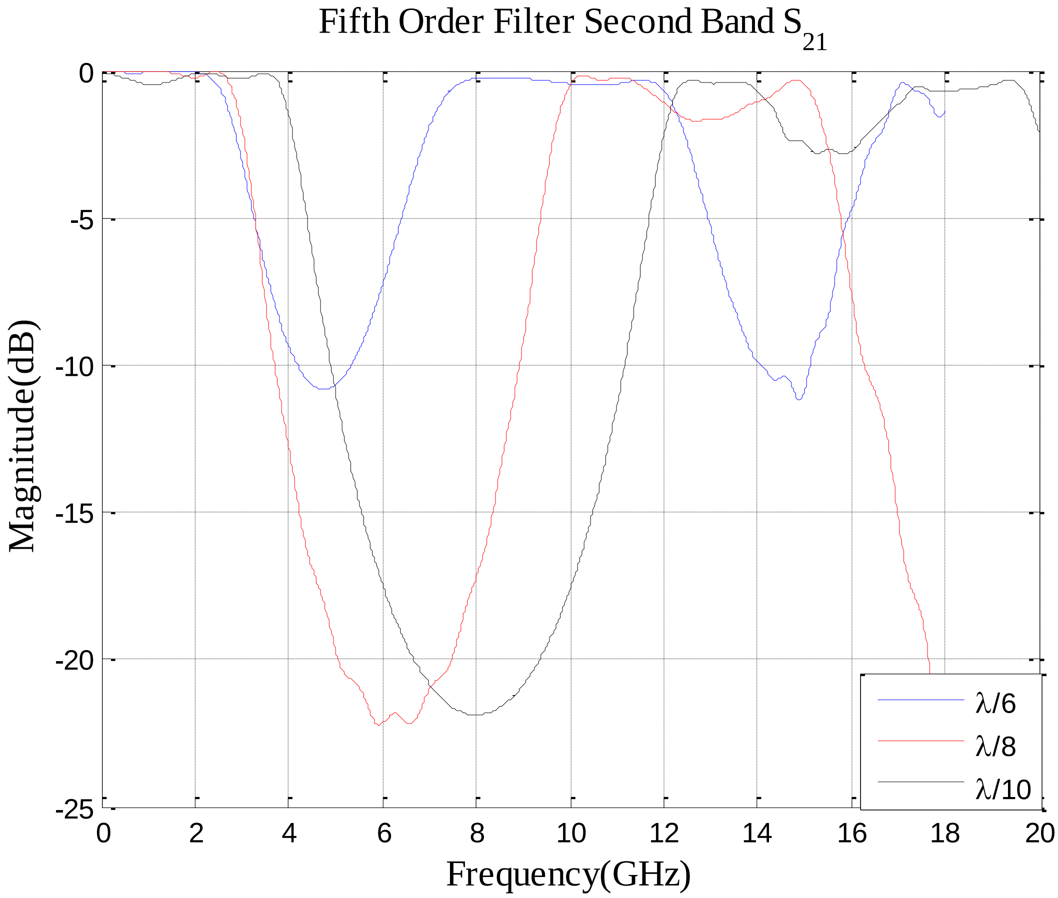


Figure 5.11: Comparison of responses of fifth order stepped impedance dual bandpass filter for different lengths

5.2.3 SEVENTH ORDER DUAL BANDPASS FILTER OF DIFFERENT LENGTHS

Seventh order filter for different length is also realized and the values corresponding to *λ/6, λ/8, λ/10* lengths are listed in the Table 5.13, 6.14and 6.15 respectively.

Table 5.13: Seventh order stepped impedance dual bandpass filter for l=***λ/6***

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L1	1.7372 H	82.944	0.667	11.2366
C2	1.2583 F	41.61	2.04	11.2366
L3	2.6381 H	125.959	0.257	11.2366
C4	1.3441 F	38.95	2.24	11.2366

L5	2.6381 H	125.959	0.257	11.2366
C6	1.2583 F	41.61	2.04	11.2366
L7	1.7372 H	82.944	0.667	11.2366

Table 5.14: Seventh order stepped impedance dual bandpass filter for $l=\lambda/8$

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L1	1.7372 H	110.6074	0.359	8.4273
C2	1.2583 F	31.2048	3.001	8.4273
L3	2.6381 H	167.967	0.105	8.4273
C4	1.3441 F	29.212	3.265	8.4273
L5	2.6381 H	167.967	0.105	8.4273
C6	1.2583 F	31.2048	3.001	8.4273
L7	1.7372 H	110.6074	0.359	8.4273

Table 5.15: Seventh order stepped impedance dual bandpass filter for $l=\lambda/10$

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L1	1.7372 H	138.2419	0.197	6.7419
C2	1.2583 F	24.9662	3.99	6.7419
L3	2.6381 H	209.9495	0.043	6.7419
C4	1.3441 F	23.3725	4.33	6.7419
L5	2.6381 H	209.9495	0.043	6.7419
C6	1.2583 F	24.9662	3.99	6.7419
L7	1.7372 H	138.2419	0.197	6.7419

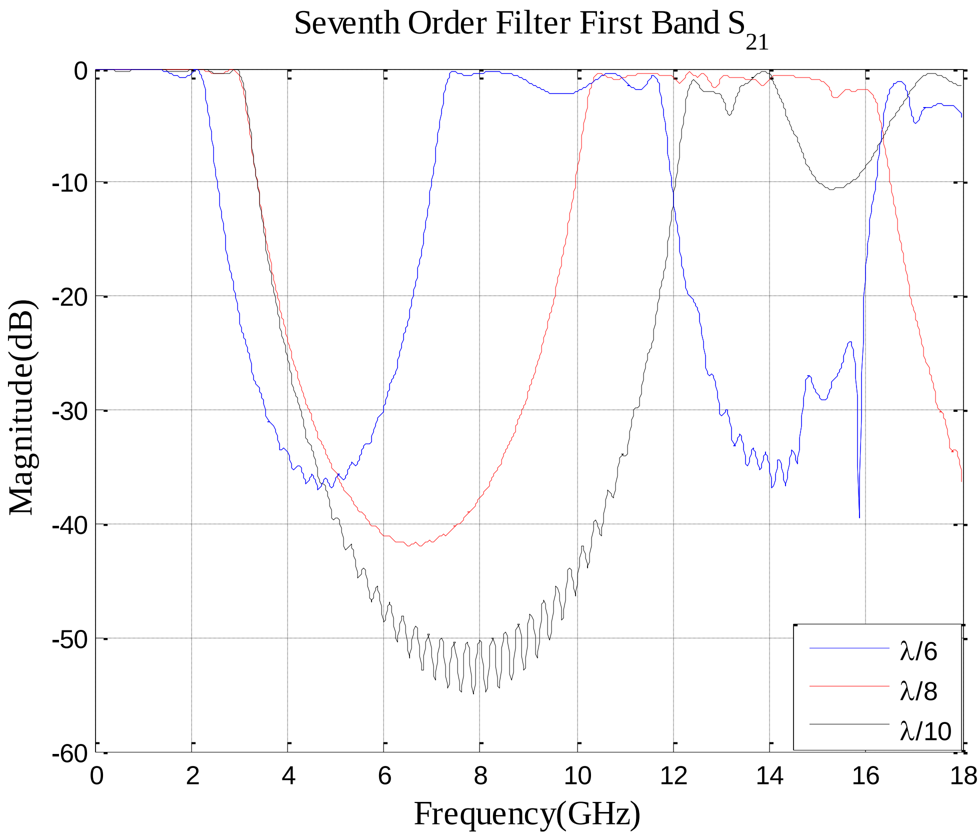


Figure 5.12: Comparison of responses of seventh order stepped impedance dual bandpass filter for different lengths

From Figure 5.10, 6.11 and 6.12 it can be observed that the filter design corresponding to length $l=\lambda/8$ gives better response as compared to others in terms of pass band gain and roll-off in the stop band. The details of this analysis are given in Table 5.16, 617 and 6.18

Table 5.16: Different order filters for $l=\lambda/6$

Filter Order	Bandwidth	Z_h/Z_l	**Roll-off**
Third	7.35 GHz	1.5964	-2.14 dB/GHz
Fifth	5.9245 GHz	2.848	-5.8 dB/GHz
Seventh	5.8204 GHz	3.9356	-18.11 dB/GHz

Table 5.17: Different order filters for $l=\lambda/8$

Filter Order	Bandwidth	Z_h/Z_l	**Roll-off**
Third	7.0848 GHz	2.838	-4.019 dB/GHz
Fifth	6.0137 GHz	5.06	-9.399 dB/GHz
Seventh	5.96 GHz	6.523	-21.840 dB/GHz

Table 5.18: Different order filters for $l=\lambda/10$

Filter Order	Bandwidth	Z_h/Z_l	**Roll-off**
Third	6.898 GHz	4.443	-4.019 dB/GHz
Fifth	8.18 GHz	7.80	-9.399 dB/GHz
Seventh	7.003 GHz	8.98	-21.840 dB/GHz

As the lengths of each component are modified, the values of inductance and capacitances of the lines are changed and which change the cut off frequency. In order to keep the cut off frequency same, the values of L and C are needed to be fixed. As

$$\beta l = \frac{LR_0}{Z_h}$$

Table 5.19 and 6.20 give the details of the designed dual bandpass filter and the modified dual bandpass filter in order to get the same cut off frequency.

Table 5.19: Designed third order dual bandpass filter

Component	**Values**	**Z_l or Z_h(Ω)**	**w_i (mm)**	**l_i (mm)**
L_1	1.5963 H	101.623	0.444	8.4273
C_2	1.0967 F	35.8073	2.534	8.4273
L_3	1.5963 H	101.623	0.444	8.4273

Table 5.20: Modified third order dual bandpass filter to get same cut-off frequency

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i* (*mm*)**	***l_i* (*mm*)**
L_1	1.5963 H	101.623	0.369	7.8
C_2	1.0967 F	35.8073	2.82	7.8
L_3	1.5963 H	101.623	0.369	7.8

According to these modified dimensions dual bandpass filter is designed. Figure 5.13 shows the comparison of the mathematical and simulated results according to new dimensions.

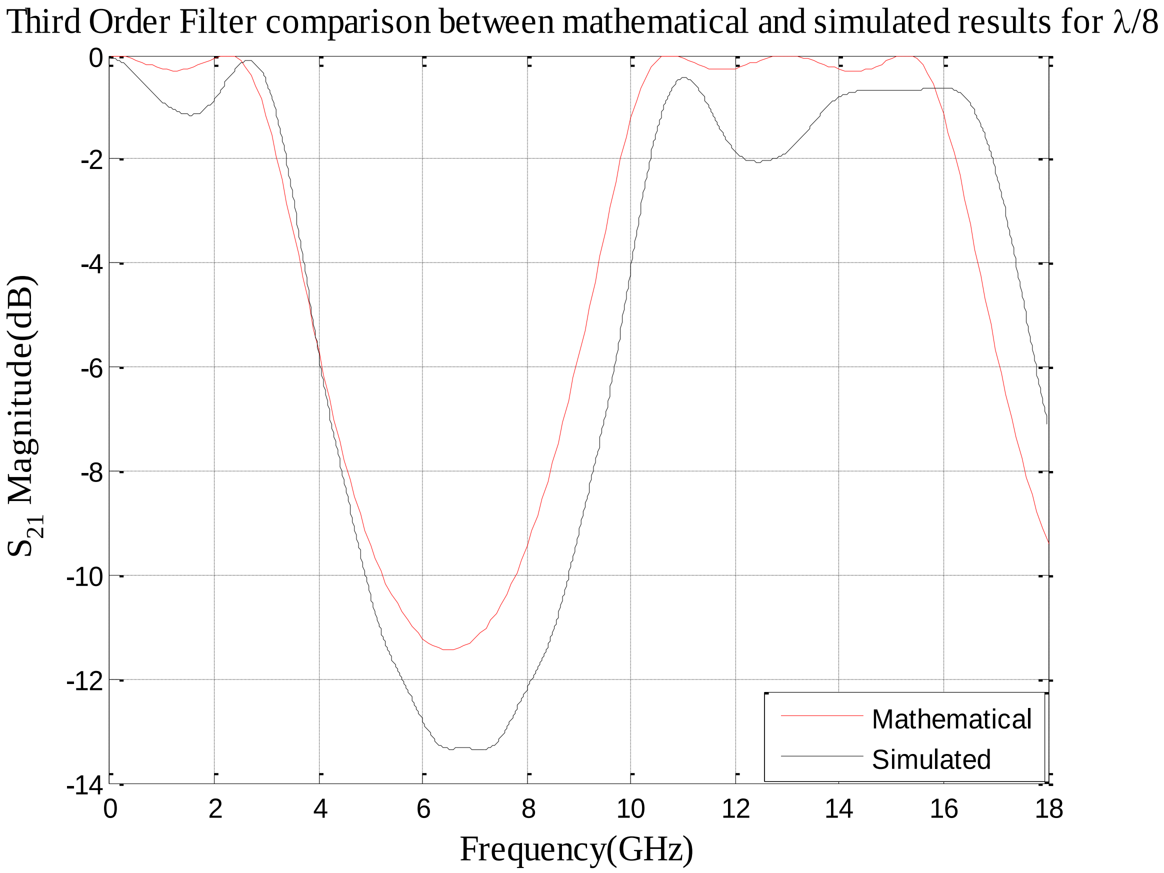


Figure 5.13: Comparison of mathematical and simulation results for third order dual bandpass filter

Similar analysis is done for the fifth order filter also.

Table 5.21: Designed fifth order dual bandpass filter

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.7058 H	108.5946	0.381	8.4273
C_2	1.2296 F	31.9371	2.95	8.4273
L_3	2.5408 H	161.7523	0.1221	8.4273
C_4	1.2296 F	31.9371	2.95	8.4273
L_5	1.7058 H	108.5946	0.381	8.4273

Table 5.22: Modified fifth order dual bandpass filter to get same cut-off frequency

Component	**Values**	**Z_l or Z_h(Ω)**	***w_i (mm)***	***l_i (mm)***
L_1	1.7058 H	105	0.41	8.7
C_2	1.2296 F	30	3.19	8.3
L_3	2.5408 H	158	0.132	8.8
C_4	1.2296 F	30	3.19	8.3
L_5	1.7058 H	105	0.41	8.7

Comparison of stimulated and mathematical response is shown in Figure 5.14

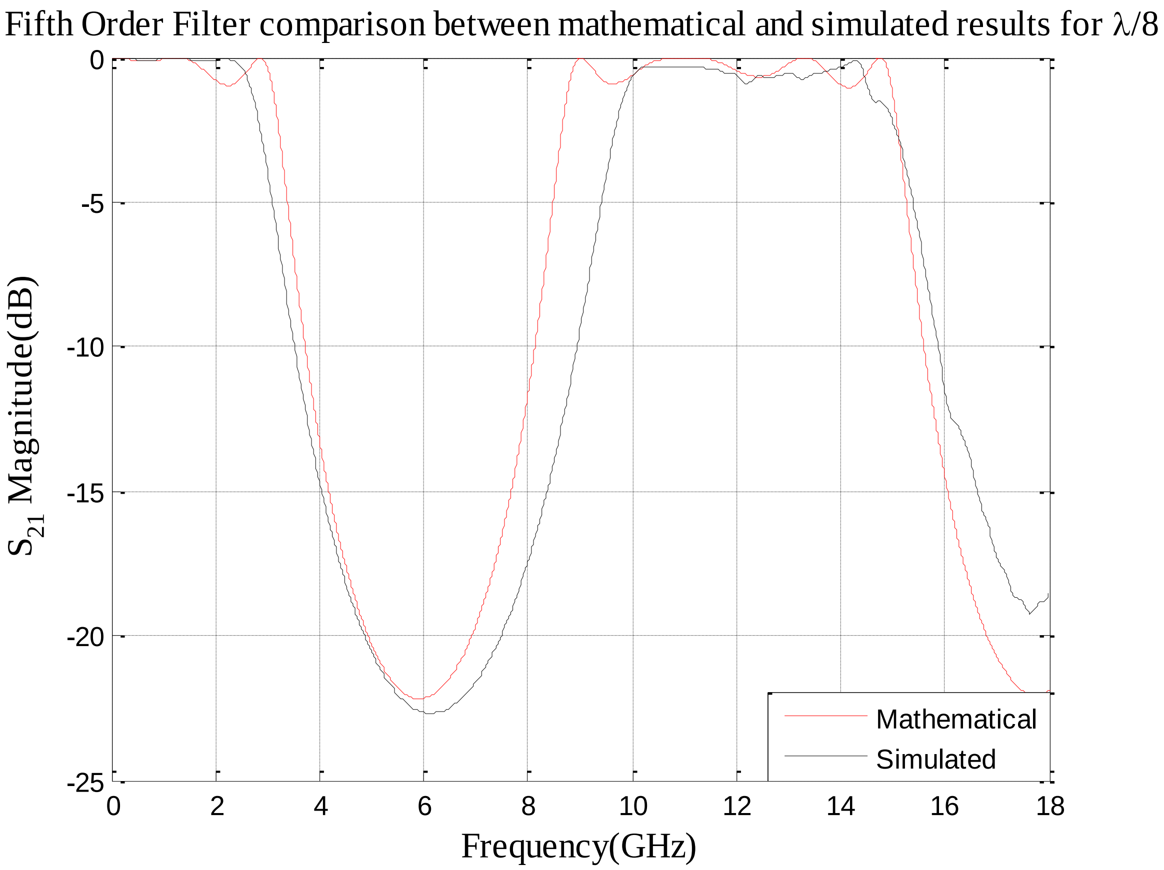


Figure 5.14: Comparison of mathematical and simulation results for fifth order dual bandpass filter

5.3 CONCLUSION

The dual band filter can be achieved from stepped impedance LPF by keeping the ratio of Z_h and Z_l less than 8. This is because increase in this ratio increases the discontinuities at the interface of high impedance and low impedance segments which can lead to the fringing effect and hence losses.

The dual bandpass filter is designed for different orders and for different lengths i.e. $\lambda/6$, $\lambda/8$ and $\lambda/10$. It is observed that the line length equal to $\lambda/8$ gives best result among $\lambda/6$, $\lambda/8$ and $\lambda/10$ in terms of gain in the pass band and roll off in the stop band.

The cut off is changed when the lengths of impedance lines are modified. By adjusting line lengths properly the cut off can be kept same.

Finally the optimal dual band filter is obtained by varying the impedances and line lengths slightly.

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