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Design of High Frequency Filters for RF Applications

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ABSTRACT

Filters are the significant Radio Frequency (RF) and Microwave component. It plays a vital role in RF/microwave applications especially in receiver system design. They are used to separate or combine different frequencies. Commonly lumped and distributed element filters are classified into Low pass filter (LPF), High pass filter (HPF), Band pass filter (BPF) and Band stop filter (BSF). The design and implementation of the lumped and distributed elements filter are proposed in this paper for RF applications. Low pass filter is a circuit which allows only the frequency below the cut off frequency. At the outset Low pass filter are designed using the lumped elements such as inductor and capacitor with the frequency range of 1-5GHz.The inductors and capacitors used are selected as 65.9nH, 58.5nH, 5nH and 42.7pF respectively. These specified lumped elements are not physically available. Distributed filters are the practical solution of RF filter design. Physical length and width of the inductors are 150mil and 100mil respectively. Similarly, physical length and width of the capacitors are 150mil and 50mil respectively. Numerical Analysis results with the estimation of Insertion loss as 0dB at 4GHz. High pass filter is a filter which passes only the frequency above the cut off frequency and attenuates the frequency below the cut off frequency. Here it was designed using the lumped elements with the frequency range of 1-5GHz. The value of the inductors and capacitors used are 65.9nH, 58.5nH, 5nH and 42.7pF, 60pF respectively. Corresponding physical dimension L:W of the inductors are 150mm and 100mm respectively. Similarly, physical length and width of the capacitors are 150mm and 50mm respectively. The insertion loss obtained for the High pass filter is 0dB at 2GHz. Band pass filter is a filter which passes only the desired band of frequency. As LPF and HPF, Band pass filter also designed using the lumped elements with the frequency range of 2.3-2.7 GHz. The inductors and capacitors value mentioned here is 102.618nH, 0.088nH and 0.0395pF, 45.892pF respectively. The insertion loss obtained for the band pass filter is 0dB at a bandwidth of 100 MHz finally, band stop filter are designed to eliminate the undesired band of frequencies. Here the band stop filter was designed using the same lumped elements such as inductor and capacitor with the frequency range of 1-10GHz. The value of the inductors and capacitors used are 12.214nH, 0.0769nH and 0.0819pF respectively. The insertion loss obtained for the band stop filter is 0dB at 300 MHz bandwidth. Novel Filter designs are identified and implemented for ideal RF and Microwave Applications.

Keywords : Filters, LPF, HPF, BPF and BSF

I. INTRODUCTION

FILTERS: Radio frequencies inhabited the range of electromagnetic spectrum designated communication. Filters are mean to select the signals from specific frequency bands while rejecting unwanted signals that hinder with the reception of the intended frequency. In a modern RF systems, there are more than 100 RF filters finding its application in the filtering the desire band. As the number of filters increases which intern increase the design challenge for the filter. Filter performance is important; failing design may lead to increase in power consumption and allows interference in the other hand makes RF system bulky.

II. ANALYSIS OF FILTERS

Filter analysis starts with the determination of the cut off frequency. Order of the filter plays a vital role in the ensuring the sharp cut off rate. Analysis is performed for LPF, HPF, BPF and BSP. High cut off frequency and wider bandwidth is the main goal of the design.

A. LOW PASS FILTER DESIGN:

LPF is one which permits the frequencies lower than the cut-off frequency and attenuates the frequency above the cut-off frequency. The attenuation arised in the circuit for all frequency range depends on the filter numerical solving. LPF is otherwise called a high-block filter in audio applications. The design of low pass filter involves cascading of inductance with shunt capacitance at the frequency range of 0.01-1 GHz.

$$LA(\omega) = 10\log_{10}\{1+\varepsilon(\omega/\omega_c)^{2N}\}.....(1)$$

Where,

$$\varepsilon = \{Anti\log_{10} LA/10\} - 1$$

Order of the filter N=3.

1) Numerical solving of the low pass filter:

The numerical values of the filter is calculated as given by,

$$g_0 = 1$$

,

$$g_k = 2\sin\{2k-1)\pi/2N\}.....(2)$$

Where k=1, 2,….N and

2) The circuit model of the filter:

The numerical values of the low pass filter after frequency and impedance calculations are given by

$$c_k' = c_k / R_0\omega_C$$

$L_K' = R_0 L_K / \omega_C$ Where R_0 is $50\,\Omega$

The resulting lumped by values are given by,

$$L_1 = L_4 = 65.9nH$$

$$L_2 = L_5 = 58.85nH$$

$$L_6 = L_3 = 5nH$$

$$C_1 = C_3 = C_5 = 60\,pF$$

$$C_2 = C_4 = C_6 = 42.7\,pF$$

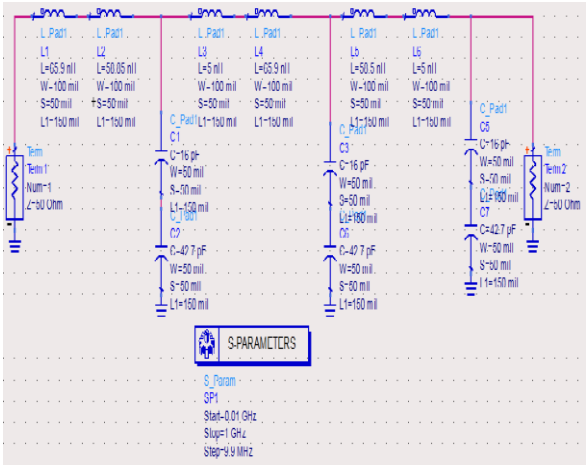

Figure1.Lumped element Low pass filter (N=3)

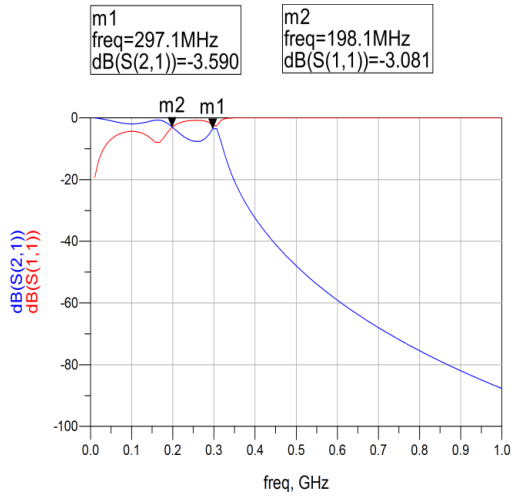

Figure2.Simulation response of lumped element circuit LPF at N=3

B.HIGH PASS FILTER DESIGN:

Generally, HPF is a filter which allows only the frequency above the cut-off frequency and attenuates the frequency below the cut-off frequency. High pass filters are designed by converting the LPF directly into HPF by changing the series and shunt elements. The value of the inductors and capacitors used are selected as 65.9nH, 58.5nH, 5nH and 142.7pF, 60pF respectively. The physical dimension of the inductors are 150mm and 100mm respectively. Similarly, physical dimension L:W of the capacitors are 150mm and 50mm respectively.

$$LA(\omega) = 10\log_{10}\{1+\varepsilon(\omega/\omega_c)^{2N}\}.....(3)$$

Where,

$$\varepsilon = \{Anti\log_{10} LA/10\} - 1$$

Order of the filter N=3.

1) Prototype values of the low pass filter:

The prototype values of the filter is calculated by,

$$g_0 = 1,$$

$$g_k = 2\sin\{2k-1)\pi/2N\}.....(4)$$

Where k=1, 2,….N and $g_{n-1} = 1$

2) The circuit model of the filter:

The numerical values of the high pass filter is given by

$$c_k' = c_k / R_0\omega_C$$

$$L_K' = R_0 L_K / \omega_C \text{ Where } R_0 \text{ is } 50\,\Omega$$

The resulting circuit values are given by,

$$L_1 = L_4 = 65.9nH$$

$$L_2 = L_5 = 58.85nH$$

$$L_6 = L_3 = 5nH$$

$$C_1 = C_3 = C_5 = 60\,pF$$

$$C_2 = C_4 = C_6 = 42.7\,pF$$

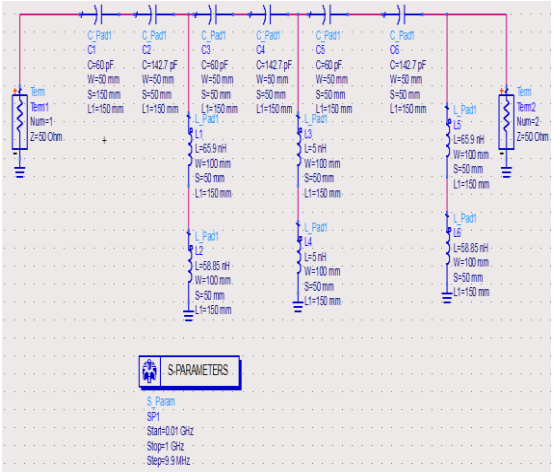

Figure 3 Lumped element High pass filter (N=3)

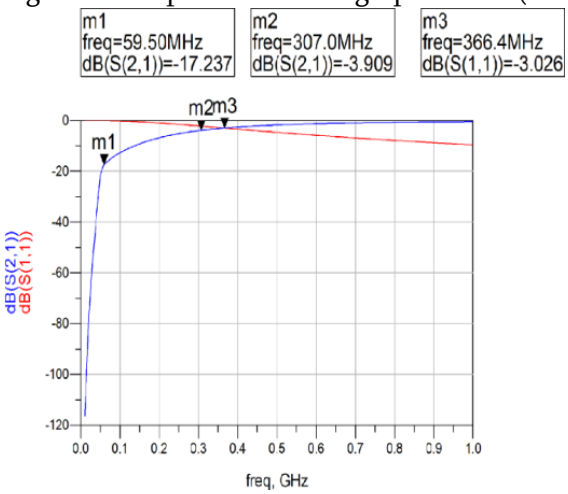

Figure 4 Simulation response of lumped element circuit LPF at N=3

From figure 4 it is inferred that the S(1,1)=Return loss=-3dB and S(2,1)=Insertion loss=-3dB for the cut off frequency 307MHz.

C BANDPASS FILTER DESIGN:

Band pass filter is a filter which passes only the desired band of frequency and it is a combination of both high pass filter and low pass filter. As HPF and LPF, Band pass filter designed using the lumped elements with the cut off frequencies of 2.3-2.7GHz. The inductors and capacitors value are selected as 102.618nH, 0.088nH and0.0395pF, and 45.892pF respectively.

1) Specification of Lumped model of the filter:

Lower cut-off frequency : 2.436GHz

Upper cut-off frequency : 2.556GHz

Band width : 0.1GHz

Order of the filter : 2

2) The circuital model of the filter:

The numerical values of the band pass filter after frequency are given by

Where, Z_0 is $50\,\Omega$

$L_1' = L_1 Z_0 / \omega_0 \Delta$.....(5)

$C_1' = \Delta / L_1 Z_0 \omega_0$.....(6)

$L_2' = \Delta Z_0 / \omega_0 C_2$.....(7)

$C_2' = C_2 / Z_0 \Delta \omega_0$.....(8)

$L_3' = L_3 Z_0 / \omega_0 \Delta$.....(9)

$C_3' = \Delta / L_3 Z_0 \omega_0$.....(10)

$\Delta = (\omega_2 - \omega_1) / \omega_0$.....(11)

The resulting lumped values are given by:

$L_1' = L_2' = L_3' = 102.618\,nH$

$L_4' = L_5' = 0.08879\,nH$

$C_1' = C_2' = C_3' = 0.0395\,pF$

$C_4' = C_5' = 45.8926\,pF$

The schematic window of the lumped element band pass filter is shown in the figure 5.

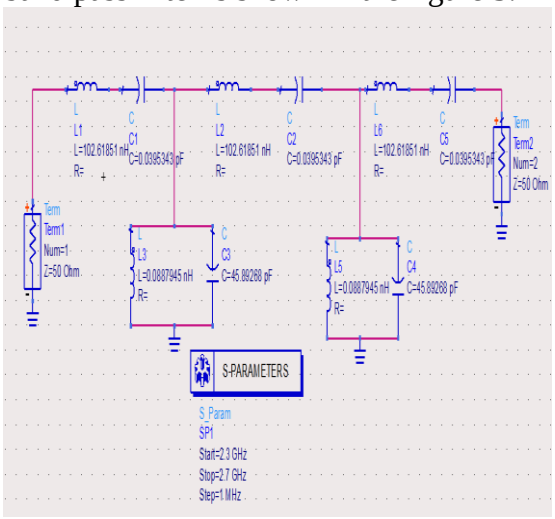

Figure 5 Lumped element Band pass filter

Fig. 6 shows the simulation result for N=2 of lumped element BPF. The return loss, S (1,1)= -4dB and Upper cut-off frequency 2.4 GHz, Lower cut-off frequency 2.5GHz.Hence bandwidth can be obtained as 0.1 GHz

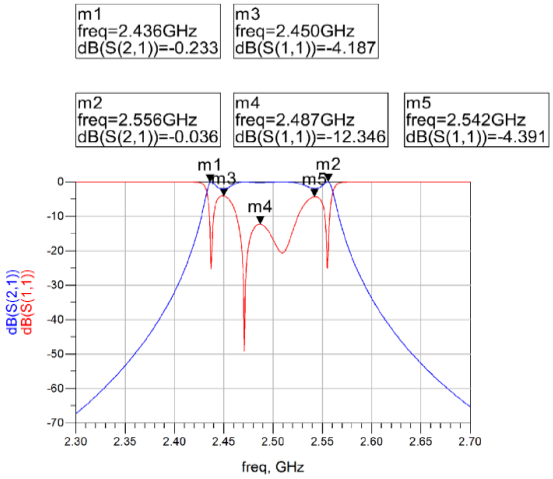

Figure 6 Simulation response of lumped element circuit BPF at N=2.

D BAND STOP FILTER

Band stop filter or band reject filters are designed to eliminate the undesired band of frequencies. Here the Band stop filter was designed with the frequency range of 1-10GHz to make is predominant in RF applications. The value of the inductors and capacitors used are selected as 12.214nH, 0.0769nH and 0.0819pF respectively.

1) Specification of Lumped model of the filter:

Lower cut off frequency : 4GHz

Upper cut off frequency : 6GHz

Band width : 2GHz

Order of the filter : 2

2) The Lumped model of the filter:

The lumped values of the band stop filter after frequency calculations done are given by

$\omega_0 = \sqrt{\omega_1 \omega_2}$.....(12)

$FBW = (\omega_2 - \omega_1) / \omega_0$.....(13)

$C_P = (1 / FBW\,\omega_0 \Omega_C) 1 / \gamma_0 g$.....(14)

$L_P = (\Omega_C FBW / \omega_0) \gamma_0 g$.....(15)

$L_S = (1 / FBW\,\omega_0 \Omega_C) \gamma_0 g$.....(16)

$C_s = (\Omega_c FBW / \omega_0) 1 / \gamma_0 g$.....(17)

The resulting lumped values are given by:

$L_1' = L_4' = 12.2124\,nH$

$L_2' = L_5' = 0.0764\,nH$

$L_3' = L_6' = 12.2124\,nH$

$C_1' = C_4' = 0.0819\,pF$

$C_2' = C_5' = 0.0819\,pF$

$C_3' = C_6' = 13.0075\,pF$

The schematic diagram of the lumped element band stop filter is shown in the figure 7.

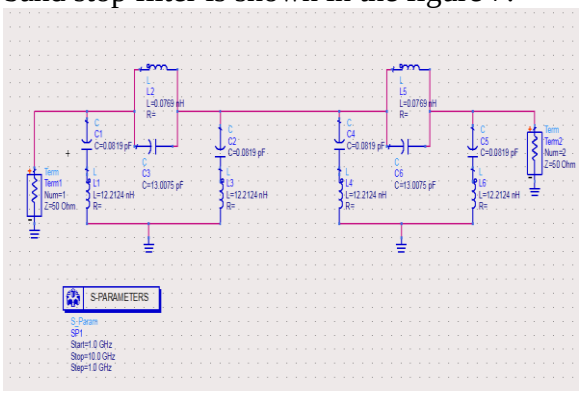

Figure 7 Lumped element Band stop filter (N=2*)*

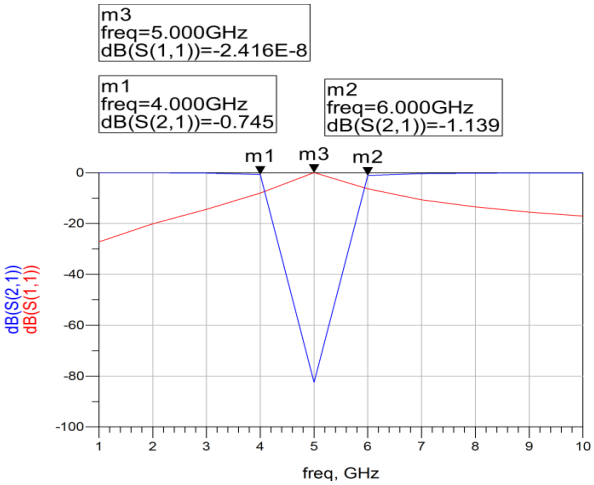

Figure 8 Simulation response of lumped element circuit BSF at N=2.

Fig. 8 shows the simulation result for N=2 of lumped element BSF. The return loss, S(1,1)=-2dB and Upper cut-off frequency 4 GHz, Lower cut-off frequency GHz. Hence bandwidth can be obtained as 2GHz

III. CONCLUSION

The numerical designing of lumped elements based filters like LPF, HPF, BPF and BSF are executed for RF frequencies. The theoretical calculation derived and found good agreement with the numerical simulation results. This paper explains the procedure for designing and numerical solving using ADS tool. It is also possible to generate layout of the above said filters using ADS tool and fabricate the same.

IV. REFERENCES

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