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Performance Analysis of IIR Digital Band Stop Filter

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Abstract— **IIR Band-stop filter is recursive in nature i.e. the present output sample depends on the past input sample, past output samples and the present input samples. If the past and present inputs and output are varied the resulting present output will be changed. The Band-stop filter rejects one band of frequency and allows all other frequency band to pass. In this paper, the performance analysis of Band-stop filter is done using the Modified Analog-to-Digital Mapping technique and simulated in Matlab7. The response of the filter can be modified by changing the value of the components. The coefficients that are essentially required to design a IIR Digital Band-stop filter, are also calculated using the above mentioned algorithm and finally the magnitude response and the stability of the filter are determined using Matlab7 with satisfying results. The pole-zero plot of a system, filter in this case, determines the stability of the predesigned IIR Band-stop filter.**

Index Terms— **IIR filter, Digital filter, Band-stop filter, filter design, Modified Analog-to-Digital Mapping algorithm, coefficient.**

I. INTRODUCTION

Filter is a very essential device in signal processing. Actually filter circuit is applied in a system for the filtration of the input signal from noise and producing the output with least amount of noise. In Digital Signal Processing (DSP), there are mainly two types of filter available depending upon the impulse response and they are the Infinite Impulse Response(IIR) filter and another is the Finite Impulse Response(FIR) filter[1][2][12][26][27]. IIR filter is recursive type filter as the present output is dependent on the present input, past inputs and past outputs. The response of the IIR filter is of infinite duration whereas the response of FIR filter is of finite duration. There are many types of filter available for different applications. Band-stop filter is one of them and plays an important role in signal processing and filtering operation.

IIR Band-stop filter stops one specific band of frequency and allows all other frequency bands to pass. With a small variation of IIR Band-stop filter, the Notch filter can also be designed which is capable of eliminating only one frequency if proper specification is chosen [12][26][28][30].

Filter is of two types, analog filter and digital filter. The analog filter can be designed by resistors, capacitors, inductors and voltage source [7][12][28][29]. If an analog filter is constructed by using passive elements such as the resistors, capacitors and inductors, this analog filter is known to as the passive filter, and if the same is designed by active elements such as the voltage source along with the passive elements, the designed filter is known to as the active filters[28][29]. In our practical use, the filter is generally constructed by the OpAmp along with the passive and active elements. The reason behind this design is that the OpAmp shows the recursive effect which is necessary for an IIR filter [7][15].

There are various methods available to design the digital filter. The digital filter can be designed after constructing the analog filter and with the application of analog to digital mapping technique with the introduction of frequency transformation[1][3][7][22][27][31]. The basic target to design the digital filter is to obtain the transfer function in digital domain so that one can understand the stability of the filter. The digital filter have several characteristics like high accuracy, sensitivity, smaller physical size, reduced sensitivity to component tolerance and drift[1][2][3][7][8][12][14].

In this paper, the design and performance analysis of IIR Digital Band-stop filter is shown using the Modified Analog-to-Digital Mapping Technique(MADM) on a predesigned IIR Analog Band-stop filter[3][12].

II. TYPES OF FILTERS

There are basically two types of filter as follows:

1. Infinite Impulse Response(IIR) filter
2. Finite Impulse Response(FIR) filter

Filter can be classified into two types, depending upon the construction as follows:

1. Analog filter
2. Digital filter

There are various types of filters we can have for different applications. In this application view, the filter can be categorized as follows[18][21][26][27][31]:

1. Low pass filter
2. High pass filter
3. Band pass filter
4. Band stop or Notch filter
5. All pass filter
6. Comb filter

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The Band-stop filter is applied to reject one specific frequency band. Notch filter is the variation of Band-stop filter and used to stop only one frequency[5][6][30]. In the next section, the design of IIR Band-stop is shown.

III. DESIGN OF ANALOG IIR BANDSTOP FILTER

As discussed earlier, the band-stop filter can be designed by passive elements, passive and active elements or with OpAmp chip. The design of Twin-T analog band-stop filter is shown in Fig.1 using the passive components like Inductor and the capacitors[12][28][29].

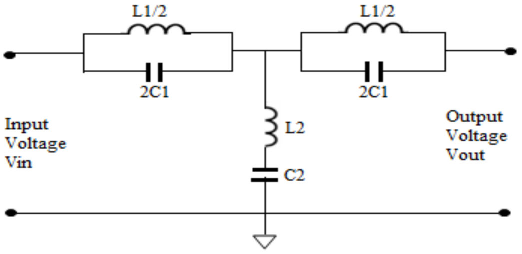

Fig.1 Twin-T passive Band stop filter(RC)

The parameter required for designing the T-section Band stop filter is given below[28][29],

$$f_m = \frac{1}{2\pi\sqrt{L_1 C_1}} = \frac{1}{2\pi\sqrt{L_2 C_2}} \quad \text{…..(1)}$$

$$R_k = \sqrt{L_1/C_1} = \sqrt{L_2/C_2} \quad \text{….(2)}$$

$$C_1 = \frac{1}{2R_k(\omega_2 - \omega_1)} \quad \text{….(3)}$$

$$L_1 = \frac{2R_k(\omega_2 - \omega_1)}{\omega_2\omega_1} \quad \text{….(4)}$$

$$C_2 = \frac{2}{R_k}\frac{(\omega_2 - \omega_1)}{\omega_2\omega_1} \quad \text{….(5)}$$

$$L_2 = \frac{R_k}{2(\omega_2 - \omega_1)} \quad \text{….(6)}$$

Where,

R_k = Nominal characteristic impedance
f_m = Geometric mean of two cut-off frequencies
ω_1 = Low cut-off frequency
ω_2 = High cut-off frequency

This filter can also be design in form of RC circuit i.e. the construction is done using the resistors and the capacitors.

Now, the construction of Band-stop filter using OpAmp is shown below in Fig.2[12][28][29].

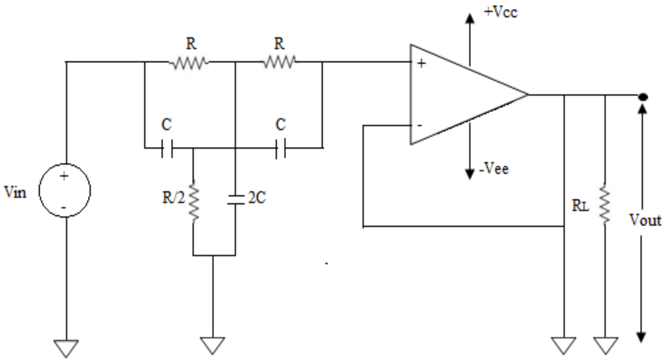

Fig.2 Active IIR Band stop filter using OpAmp

The circuit shown in Fig.2 is constructed using OpAmp chip and hence shows the recursive effect, essential to design the IIR filter. Hence the circuit is for IIR Band-stop filter which stops a specified band of frequency. The proper design of IIR Digital Band-stop filter can be done by applying Modified Analog-to-Digital Mapping Technique, an algorithm which efficiently design the digital filter and hence the IIR Digital Band-stop filter in this case.

IV. DESIGN OF DIGITAL IIR BANDSTOP FILTER

An analog Band-stop filter can be constructed using the passive components such as the resistor, capacitor and inductor or by using OpAmp chip. The stability of the constructed filter can be determined by obtaining the transfer function. If the transfer function of the analog filter can be mapped into its equivalent digital filter i.e. the transfer function will be mapped from *s*-domain to digital or *z*-domain, the stability can easily be found out. The corresponding pole-zero plot also determines the stability of that filter.

Now, to design a digital filter, there are many algorithms are available which can design the digital filter in different ways. The Modified Analog-to-Digital Mapping Algorithm is such a algorithm which provides with the mapping fundamentals for suitable design of the digital filter. This algorithm also helpful to evaluate the performance of the designed digital filter.

A. *Passive component value modification*

The analog filter is designed using the passive components, the value can be modified. After each modification, the output values will also be changed because if the values of the passive components will be changed, the stopband frequency, the passband frequency, the stopband ripple and the passband ripples will be modified[1][3][9][12][16].

Sometimes it is seen that, after successful modification of the values of the passive components, the order of the filter will remain unchanged. This indicates that, though the values are changed, the order will remain unchanged by a little bit variation of the passband and stopband ripple or with the variation of the passband or stopband frequency. After crossing the limit of the modification, the order will be changed. That means, for a set of values of modification, the order remain unchanged. So, there obviously a set of passband frequency and stopband frequency as well as stopband ripple and passband ripple for which the order of the filter will remain fixed[7][17][26][31].

Now, within the specified set of frequencies and ripples, the magnitude response will be varied. The magnitude response we can get for the highest limiting condition of the values of the above mentioned factors, will be considered as the perfect designed filter for the specified order of the filter.

B. *Modified Analog-to-Digital Mapping Algorithm*

This algorithm efficiently design the IIR Digital filter. Hence in this paper, the design methodology of IIR Band-stop filter is discussed. This algorithm is basically used for frequency transformation. It is also essentially required for s-plane to z-plane mapping i.e. analog-to-digital mapping technique through which the digital filter can be designed from an analog filter[1][12][19][21][25][26][27].

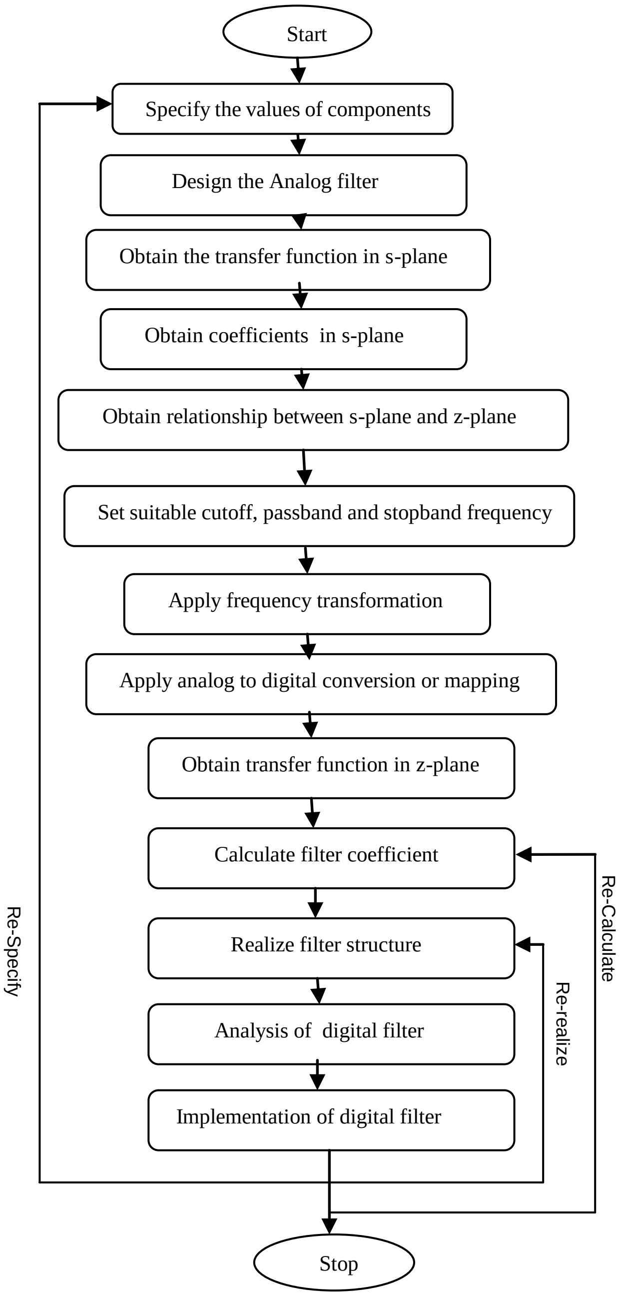

Fig 3 Modified Analog-to-Digital Mapping Algorithm

This algorithm basically used design the transfer function in digital domain of a filter that is previously designed in the analog domain. After successful calculation of transfer function in digital domain i.e. in z-plane, the digital filter can be designed with predefined specifications.

The performance of a digital filter can be enhanced by modifying the values of resistor and capacitors. The response of a filter of a particular order can be enhanced or modified by varying the values of passive components, i.e. resistors and capacitors.

C. *Design of analog IIR Band-stop filter by TinaPro9*

The analog IIR Band-stop filter is designed in TinaPro simulation tool. With help of this design, the digital IIR Band-stop filter can be designed and with the variation of the values of passive components, the modified digital filter can be constructed. The design is shown in Fig 4.

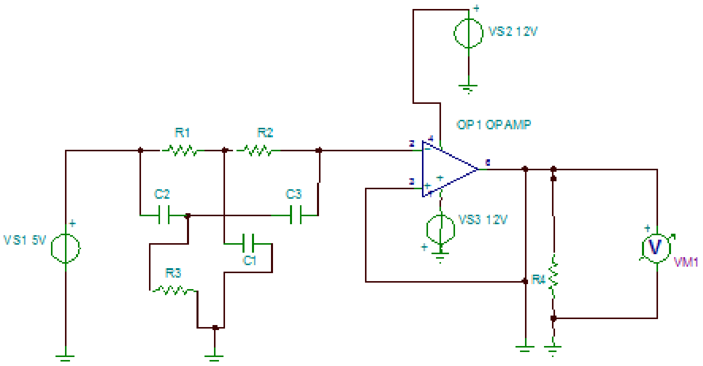

Fig 4. IIR Band-stop filter design using TinaPro9 simulation tool

D. *Transfer function of IIR Band-stop filter in digital plane*

The transfer function of IIR Digital Band-stop filter can be given by[1][12][13][20][23][24][26][27][31],

$$H(z)=\frac{\sum_{n=0}^{M} b(n)z^{-n}}{1+\sum_{n=1}^{N} a(n)z^{-n}} \quad \dots(7)$$

$$=\frac{B(z)}{A(z)}=\frac{b(0)+b(1)z^{-1}+b(2)z^{-2}+\dots\dots+b(M)z^{-M}}{1+a(1)z^{-1}+a(2)z^{-2}+\dots\dots\dots+a(N)z^{-N}} \quad \dots(8)$$

Where,

H(z) = Transfer function and Z-transform of impulse response h(n)
b(n) = Numerator coefficient
a(n) = Denominator coefficient

Now, from equation (7) and (8), it is found that the transfer function H(z) deals with the numerator coefficient b(n) and denominator coefficient a(n)[2][4][10][11][12]. If the value of the coefficients can be determined, the proper design of digital filter is possible. The value of the coefficients is dependent upon the order of the filter. The order of the filter is again determined by the values of the passive components.

So, if the value of the passive components is will be modified maintaining the proper order of the filter, the performance of the filter with same order will be modified either increased or decreased. So, the perfect specification must be choosen so that the high performance can be obtained.

E. Performance modification using modified values of passive components

The passive components of the circuit shown in Fig.4 are the capacitor and the resistor where,

R1=R2=R
C2=C3=C
C1=2C; R3=R/2

If the values will be modified accordingly to obtain the valus of the stopband frequency, the modified result such as the magnitude response, impulse response, the pole-zero plot can be well observed.

Let we start the calculation of the values of the passive components with two fixed values of the capacitors, one for C=470 nF and second for C=100 nF . So it is clear that if the value of the capacitance will be fixed, certainly the value of the resistor will be changed. So, the response will be modified.

Let we concider the passband frequency will be ωp=400 rad/sec. The stopband frequency will be determined on the basis of the passive component values. If the values will be changed , the corresponding stopband frequency will also be changed by maintaining the same order of the filter. The following tables, Table-1 and Table-2 describes the values of the stopband frequency and the notch frequency of a same ordered filter.

TABLE-1

Value of capacitor (nF)	Value of resistor (calculated) (KΩ)	Roundoff Value of resistance (available) (KΩ)	Passband frequency ωp (rad/sec)	Stopband frequency ωs (rad/sec)	Notch frequency ωn (rad/sec)	Order of the Bandstop filter
470	2.300	2.4	400	1450	925	10
470	2.360	2.4	400	1400	900	10
470	2.430	2.4	400	1350	875	10
470	2.520	2.7	400	1300	850	10
470	2.570	3.0	400	1250	825	10
470	2.650	3.0	400	1200	800	10
470	2.661	3.0	400	1199	799.5	10
470	2.662	3.0	400	1198	799	10

TABLE-2

Value of capacitor (nF)	Value of resistor (calculated) (KΩ)	Roundoff Value of resistance (available) (KΩ)	Passband frequency ωp (rad/sec)	Stopband frequency ωs (rad/sec)	Notch frequency ωn (rad/sec)	Order of the Bandstop filter
100	10.800	11	400	1450	925	10
100	11.110	11	400	1400	900	10
100	11.420	11	400	1350	875	10
100	11.760	12	400	1300	850	10
100	12.120	13	400	1250	825	10
100	12.500	13	400	1200	800	10
100	12.507	13	400	1199	799.5	10
100	12.515	13	400	1198	799	10

From the above two tables, it is clear that to construct a bandstop filter of order 10 with passband frequency ωp=400 rad/sec , there are some set of resistance, that will be used to vary the the Notch frequency as well as the stopband frequency keeping the same order of the filter. The set of resistance are given below in Table-3 and Table-4 with there corresponding preferrable notch frequency.

TABLE-3

Value of capacitor (nF)	Value of Resistance (KΩ)	Notch frequency ωn(rad/sec)	Order of Bandstop Filter
470	2.4	925	10
470	2.7	850	10
470	3.0	799	10

TABLE-4

Value of capacitor (nF)	Value of Resistance (KΩ)	Notch frequency ωn(rad/sec)	Order of Bandstop Filter
100	11	925	10
100	12	850	10
100	13	799	10

So, in order to evaluate the performance of the Bandstop filter, three frequency can be selected that is ωn=925 rad/sec, ωn=850 rad/sec and ωn=799 rad/sec. Among those frequencies, ωn=925 rad/sec is the first frequency of order=10 and after that frequency the order will be decreased and ωn=799 rad/sec is the last frequency for the Bandstop filter of order=10 and before that frequency the order of the filter will be increased for ωp=400 rad/sec.

V. SIMULATION

The simulation results for the Bandstop filter of order=10 with notch frequency ωn=925 rad/sec, ωn=850 rad/sec and ωn=799 rad/sec respectively are shown below from Fig.5 to Fig. 13. The simulation results include the magnitude response, impulse response and the pole-zero plot which determines the stability and performance of the preconstructed Bandstop filter.

A. *Simulation for ωn=925 rad/sec*

I. *Magnitude response*

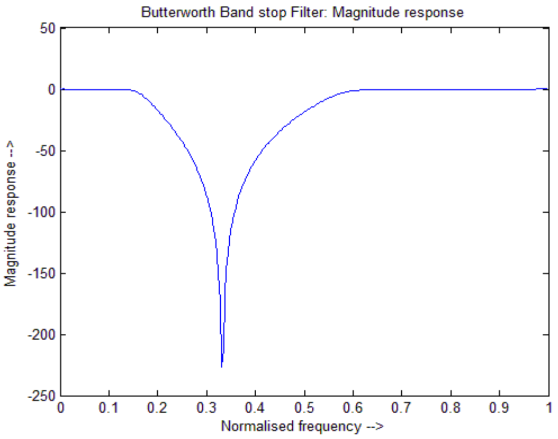

Fig.5 Magnitude response

II. *Impulse response*

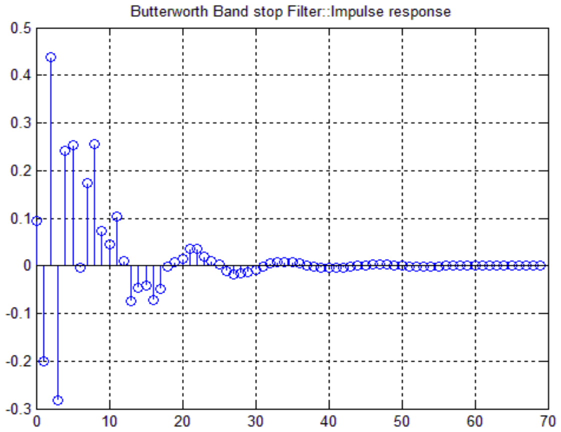

Fig.6 Impulse response

III. *Pole-Zero plot*

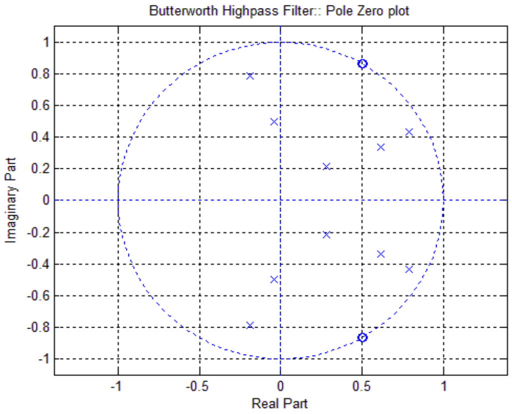

Fig.7 Pole-Zero plot

B. Simulation for ωn=850 rad/sec

I. Magnitude response

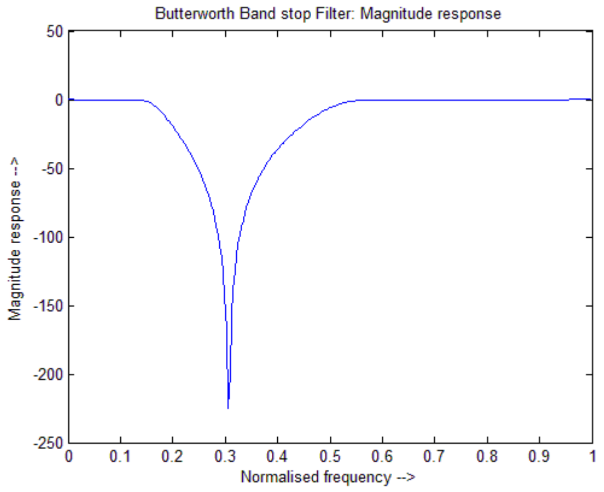

Fig.8 Magnitude response

II. Impulse response

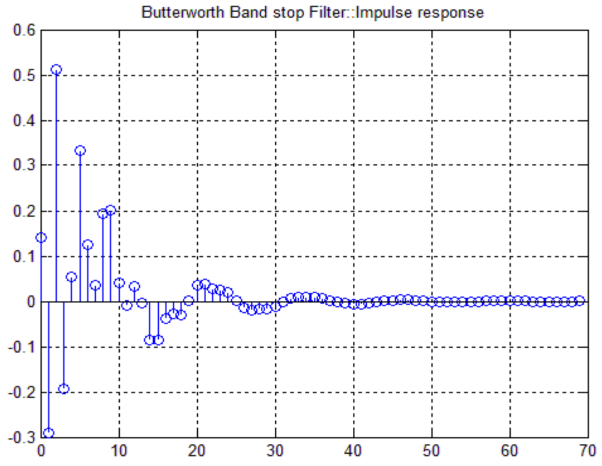

Fig.9 Impulse response

III. Pole-Zero plot

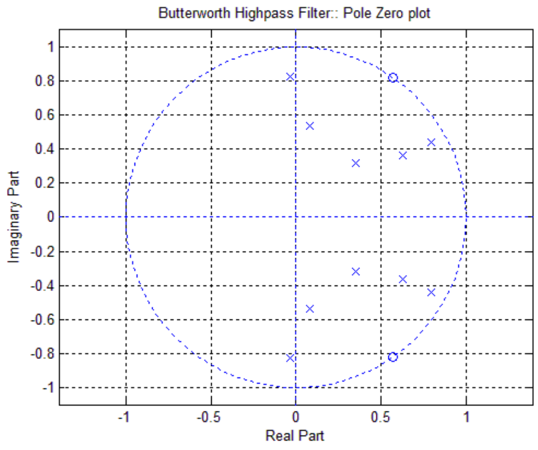

Fig.10 Pole-Zero plot

C. Simulation for ωn=799 rad/sec

I. Magnitude response

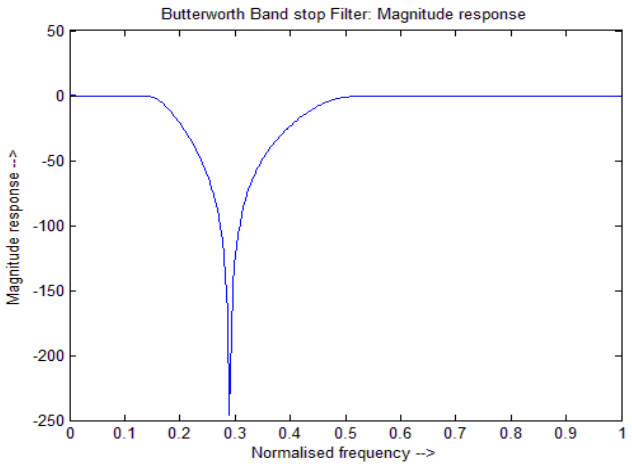

Fig.11 Magnitude response

II. Impulse response

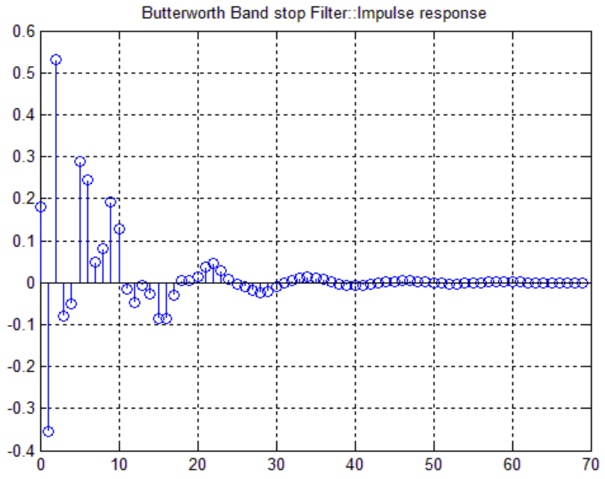

Fig.12 Impulse response

III. Pole-Zero plot

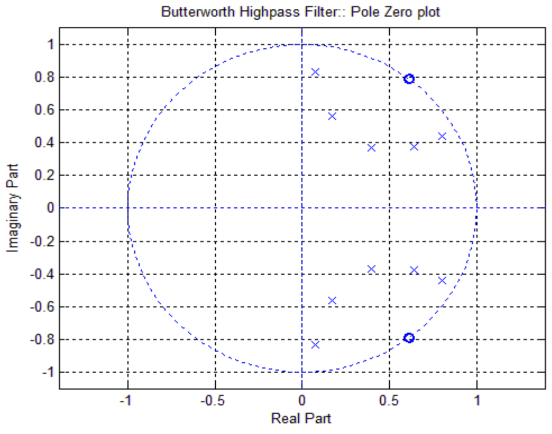

Fig.13 Pole-Zero plot

VI. CONCLUSION

The simulations, performed in Matlab7(R2008a), shown above from Fig.5 to Fig.13 are showing the responses of same the Bandstop filter with modified value of its passive components. Particularly the pole-zero plot shows that the designed filter is stable as all the poles and the zeros are inside the unit circle. Now if we observe Fig.5, Fig.8 and Fig.11 properly, it can be said that the magnitude response of Fig.11 is much more better than that of other two. The pole-zero plot of Fig.13 is also perfectly stable with respect to the pole-zero plot in Fig.7 and Fig.10. So, it is clear that using the parameters C=470 nF and R=3 KΩ or C=100 nF and R=13 KΩ is the perfect one when the design is for 10th order Bandstop filter. So, to design a Digital Bandstop filter from a predesigned Analog Bandstop filter by applying the Modified Analog-to-Digital Mapping Technique, the above mentioned specification can be used to achieve far good result in performance and achieving the goal of good stability.

VII. ACKNOWLEDGEMENTS

In this paper, the design methodology of a Bandstop filter is shown where the digital filter is constructed from a predesigned analog filter. The Modified Analog-to-Digital Mapping Technique is introduce for analog to digital mapping of a bandstop filter to increase the performance as well as to descrease the computational time for the design. This is reflected in the simulations. The idea of the paper is taken from the list of references given below.

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