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Design and study of frequency response of band pass and band reject filters using operational amplifiers

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Abstract
Filter circuits have very important applications in electronic communication systems. Depending on the requirement different types of filters have been developed. In this paper a detailed design of band pass and band reject filters using operational amplifier is presented. The frequency response of the filter showed good agreement with the theory.

Keywords: filter, band pass, band reject, frequency response, operational amplifier (OPAMP)

1. Introduction

A filter is a frequency- selective circuit that allows a specified band of frequencies and blocks or attenuates signal of frequencies outside this band. Thus a filter is an electrical or electronic network that alters the amplitude or phase characteristics of a signal with respect to the frequency. Filters are generally classified as (a) Analog or Digital (b) Passive or Active and (c) audio frequency (AF) or radio frequency (RF). Filters can be designed using passive elements like inductors, resistors and capacitors or their combinations. High performance filters can be designed using operational amplifier. In this paper design and fabrication of band pass and band reject filters using Operational amplifiers along with resistors and capacitors are presented. The frequency response of the filters is also studied.

2. Theoretical Background and circuit diagrams of the filters

2.1 Band Pass filters

Band pass filters can be constructed in by many different methods. In this design a first order high pass –first order low pass wide band pass filter is described, which is nothing but the series combination of the first order high pass and first order low pass filter. Since the overall gain will be the multiplication of the two gains of the series combination.
The gain of the filter is given by equation (1)

$$\left|\frac{v_o}{v_{in}}\right| = \frac{A_{FT}\left(\frac{f}{f_L}\right)}{\sqrt{\left[1+\left(\frac{f}{f_L}\right)^2\right]\left[1+\left(\frac{f}{f_H}\right)^2\right]}} \quad \text{.....................} \textbf{(1)}$$

Where, A_{FT} = Total pass band gain of the filter
f = frequency of the input signal
f_L = Lower cut off frequency.
f_H = higher cut off frequency.

The relationship between Q, the 3 dB band width and the center frequency f_c is given by

$$Q = \frac{f_c}{BW} = \frac{f_c}{f_H - f_L} \quad \text{........................} \textbf{(2)}$$

For the wide band pass filter the center frequency f_c can be defined by the relation

$$f_c = \sqrt{f_H f_L}$$

The circuit diagram of a wide band pass filter is shown in Fig. 1.

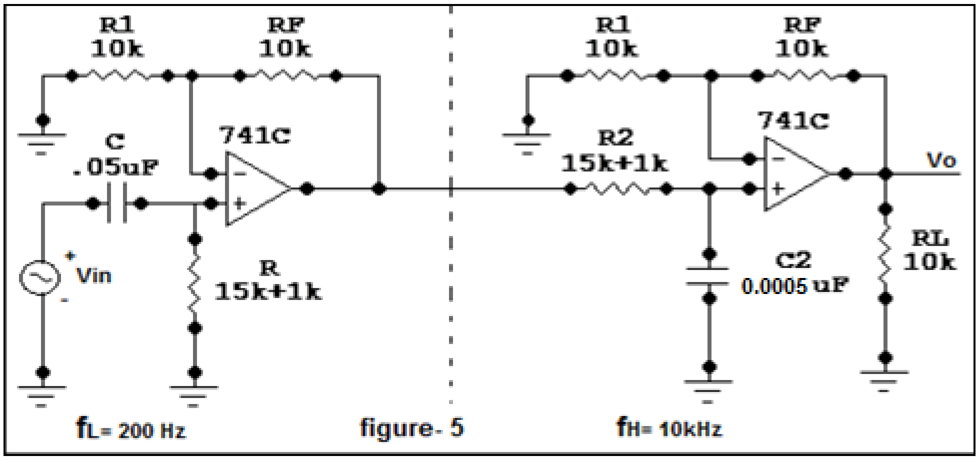

Fig 1: Circuit diagram of a Band Pass Filter

2.2 Band Reject Filter

The circuit diagram of a band reject filter using a low pass filter, a high pass filter, and a summing amplifier is shown in Fig. 2.

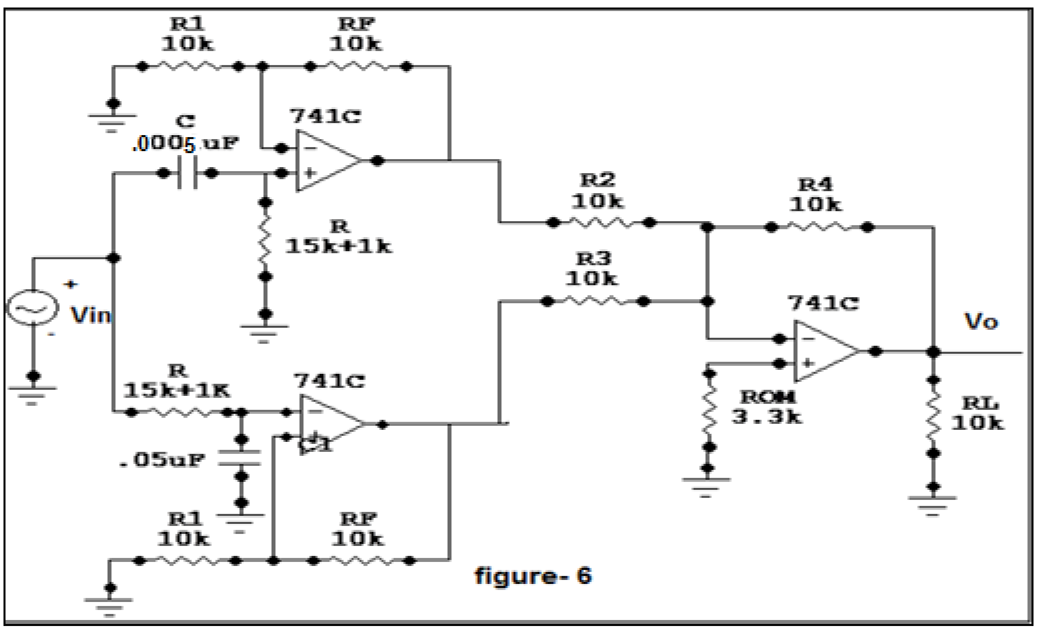

Fig 2: Circuit diagram of a Band Reject Filter

To realize a band reject response, the low cut off frequency f_L of the high pass filter must be larger than the higher cut off frequency f_H of the low pass filter. In addition the pass band gain of both the high pass and low pass section must be equal.

3. Calculation of Circuit Components

3.1 Band Pass filter

A wide band pass filter with lower cut off frequency, $f_L = 200Hz$, higher cut off frequency, $f_H = 20\ KHz$ and pass band gain = 4 is designed.

We choose, C=0.02μF (0.1$\mu F \| 0.1\mu F$)

Hence, $R = \frac{1}{2\pi(200)(5*10^{-8})} = 15.9\ K\Omega$. R is taken as (15+1) K$\Omega$

$For\ \ f_H = 20\ KHz$, C$'$ is taken as C$'$ = 0.0002μF ($(0.001\mu F \| 0.001\mu F)$

Hence, $' = \frac{1}{2\pi(10^4)(10^{-9})} = 15.9\ K\Omega$. R is taken as (15+1) K$\Omega$

For making overall gain 4, each section is designed with equal gain 2.

I took, $R_1 = R_F = R'_1 = R'_F = 10K\Omega$

Here $f_c = \sqrt{(200 * 20000)} = 2000\ Hz$

Hence $Q = \frac{2000}{(20000-200)} = 0.1$

As Q<0.56, so it can be concluded that it is narrow band pass filter.

3.2 Band Reject filter

A wide band reject filter with lower cut off frequency, $f_L = 200Hz$, higher cut off frequency, $f_H = 20\ KHz$ and pass band gain = 4 is designed.

So, each section have same gain=2

Let, $R_1 = R_F = R'_1 = R'_F = 10K\Omega$

Further the gain of the summing amplifier is set at 1, therefore, $R_2 = R_3 = R_4 = 10K\Omega$

And the value of $R_{OM} = R_2 \| R_3 \| R_4 \cong 3.3\ K\Omega$

$f_H = 200Hz$, C=0.05μF (0.1$\mu F \| 0.1\mu F$)

Then $R = \frac{1}{2\pi(200)(5*10^{-8})} = 15.9\ K\Omega,$ I took R= (15+1) KΩ

$f_L = 20KHz$, C$'$ = 0.0002μF ($0.001\mu F \| 0.001\mu F$)

Then $R' = \frac{1}{2\pi(10^4)(10^{-9})} = 15.9\ K\Omega$, I took R' = (15+1) K$\Omega$

4. Frequency Response Data and Results

4.1 Band Pass filter

The data for frequency response of the band pass filter is shown in Table-1.

Table 1

Input frequency (f) in (Hz)	Input voltage v_{in} in volt	Output voltage v_o in volt	Gain magnitude $\left\|\frac{v_o}{v_{in}}\right\|$	Magnitude (dB)= $20\log\left\|\frac{v_o}{v_{in}}\right\|$
10	1.00	0.18	0.18	-14.89
20	1.00	0.36	0.36	-8.87
30	1.00	0.53	0.53	-05.51
100	1.00	1.50	1.50	03.52
500	1.00	3.40	3.40	10.63
1000	1.00	3.80	3.80	11.59
1200	1.00	3.80	3.80	11.59
1400	1.00	3.90	3.90	11.82
1600	1.00	4.00	4.00	12.04
1800	1.00	4.00	4.00	12.04
2000	1.00	4.00	4.00	12.04
3000	1.00	3.80	3.80	11.59
5000	1.00	3.60	3.60	11.13
7000	1.00	3.40	3.40	10.63
10000	1.00	3.00	3.00	09.54
15000	1.00	2.40	2.40	07.60
20000	1.00	2.00	2.00	06.02
25000	1.00	1.70	1.70	04.61
30000	1.00	1.50	1.50	03.52
50000	1.00	0.90	0.90	-0.92
100000	1.00	0.30	0.30	-10.40

The frequency response curve for band pass filter is shown in figure-3.

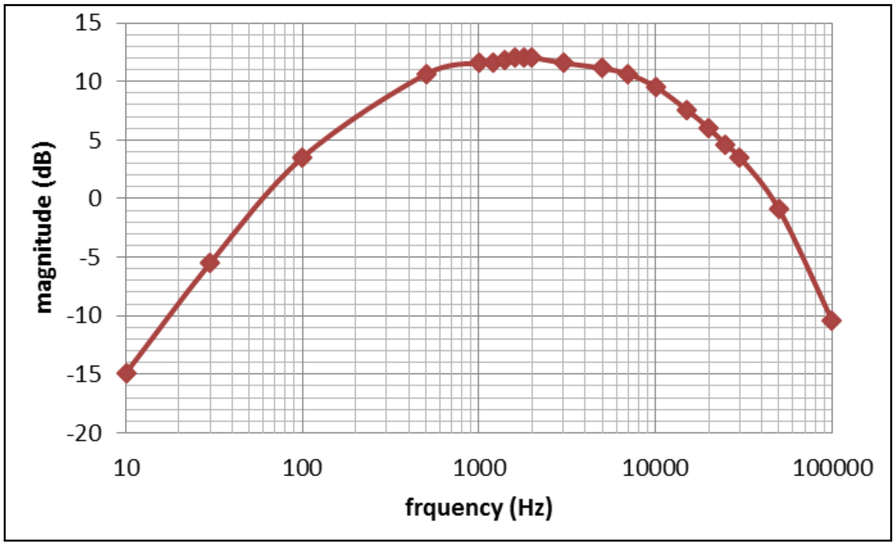

Fig 3: Frequency Response curve of a band pass filter

4.2 Band Reject filter

The data for frequency response of the band reject filter is shown in Table-2.

Table 2

Input frequency (f) in (Hz)	Input voltage v_{in} in volt	Output voltage v_o in volt	Gain magnitude $\left\|\frac{v_o}{v_{in}}\right\|$	Magnitude (dB)= $20\log\left\|\frac{v_o}{v_{in}}\right\|$
10	1.00	2.00	2.00	06.02
30	1.00	2.00	2.00	06.02
50	1.00	1.90	1.90	05.58
100	1.00	1.60	1.60	04.08
150	1.00	1.30	1.30	02.28
200	1.00	1.10	1.10	00.83
250	1.00	0.95	0.95	-00.44
300	1.00	0.80	0.80	-01.94
500	1.00	0.50	0.50	-06.02
1000	1.00	0.15	0.15	-16.47
1350	1.00	0.09	0.09	-20.92
3000	1.00	0.40	0.40	-07.96
4000	1.00	0.56	0.56	-05.04
5000	1.00	0.70	0.70	-03.10
7000	1.00	1.00	1.00	00.00
10000	1.00	1.25	1.25	01.94
20000	1.00	1.70	1.70	04.61
50000	1.00	1.90	1.90	05.58
100000	1.00	1.90	1.90	05.58

The frequency response curve for band reject filter is shown in figure-4.

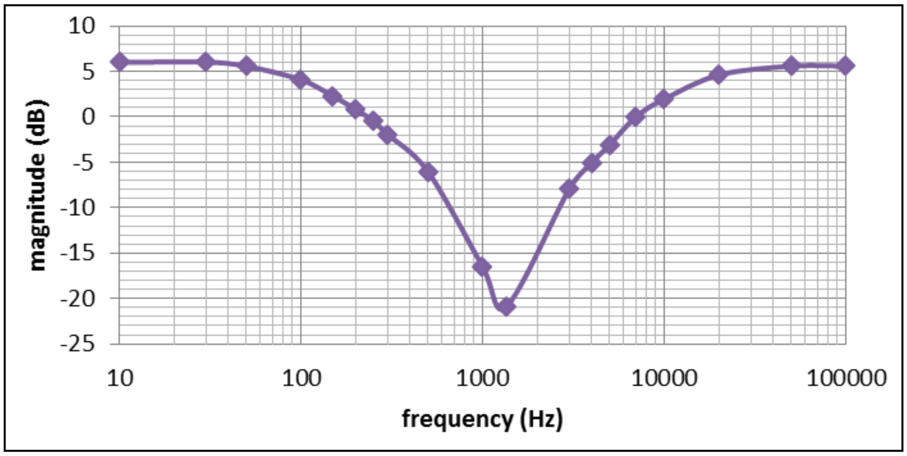

Fig 4: Frequency Response curve of band reject filter

5. Conclusions

In this paper a wide band pass filter and a wide band reject have been successfully implemented. The frequency response of the filter appears to be very closed to the ideal one. Each of these filters uses an OP-AMP as the active element and resistors and capacitors as the passive elements. Since, the OP-AMP is capable of providing high gain; the input signal is not attenuated as it is in passive filters. Because of the high input resistance and low output resistance of the OP-AMP, the active filter does not cause loading of the source or load.

6. Acknowledgements

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7. References

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