International Journal of Advanced Science and Research
ISSN: 2455-4227
Impact Factor: RJIF 5.12
www.allsciencejournal.com
Volume 2; Issue 5; September 2017; Page No. 135-138

Frequency response of high pass Butterworth RC filters using operational amplifiers

Mantu Kumar Das
Department of Physics, Garhbeta College, Affiliated to Vidyasagar University, Paschim Medinipur, West Bengal, India

Abstract
This paper presents a detailed design of First Order and Second Order high pass Butterworth filters using operational amplifier. The frequency response of the filters showed agreement with the theoretical expectations.

Keywords: filter, Butterworth, 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). In this paper design and fabrication of active filters are presented. Operational amplifiers along with resistors and capacitors are used for fabrication of filters. The frequency response of the filters was studied.

2. Theoretical background and circuit diagrams of the filters
2.1 First order high pass Butterworth filter
High pass filter are often formed simply by interchanging frequency determining resistor and capacitors in low pass filter. That is a first order high pass filter is formed from a first order low pass type by interchanging components R and C. Figure- 1 shows a first order high pass Butterworth filter with a low cut off frequency of f_L. This is the frequency at which the magnitude of the gain is 0.707 times its pass band value. Obviously, all frequencies higher than f_L are pass band frequencies with the highest frequency determined by the close loop bandwidth of the OP-AMP.

The output voltage is given by**:**

$$v_o = \left(1+\frac{R_F}{R_1}\right)\frac{j2\pi fRC}{1+j2\pi fRC}v_{in} \qquad (1)$$

Or,
$$\left|\frac{v_o}{v_{in}}\right| = A_F\left[\frac{j\left(\frac{f}{f_L}\right)}{1+j\left(\frac{f}{f_L}\right)}\right] \qquad (2)$$

Where, $A_F = \left(1+\frac{R_F}{R_1}\right)$= Passband gain of the filter

f = frequency of the input signal

$f_L = \frac{1}{2\pi RC}$ = Low cut off frequency of the filter.

And magnitude of the voltage gain is:

$$\left|\frac{v_o}{v_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}} \qquad (7)$$

Figure-1 shows the circuit of first order high pass Butterworth filter using RC network and operational amplifier (OPAMP).

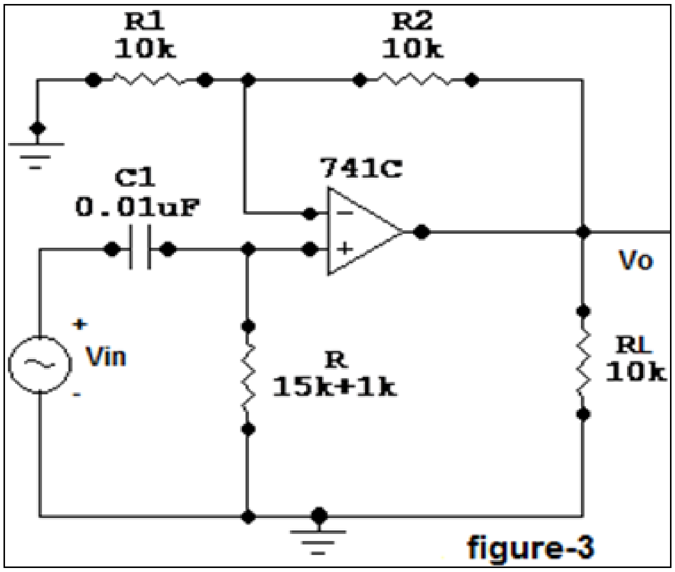

Fig 1: Circuit diagram of a first order high pass Butterworth filter

2.2 Second order high-pass Butterworth filter
As in the case of the first order filter, a second order high pass filter can be formed from a second order low pass filter simply by interchanging the frequency determining resistors and capacitors. Figure 4 shows a second order high pass filter.
The voltage gain magnitude equation of the second order high pass filter is as follows:

$$\left|\frac{v_o}{v_{in}}\right| = \frac{A_F}{\sqrt{1+(\frac{f}{f_L})^4}} \quad (8)$$

Where, $A_F = \left(1 + \frac{R_F}{R_1}\right)$= Passband gain of the filter

f = frequency of the input signal

f_L = Low cut off frequency.

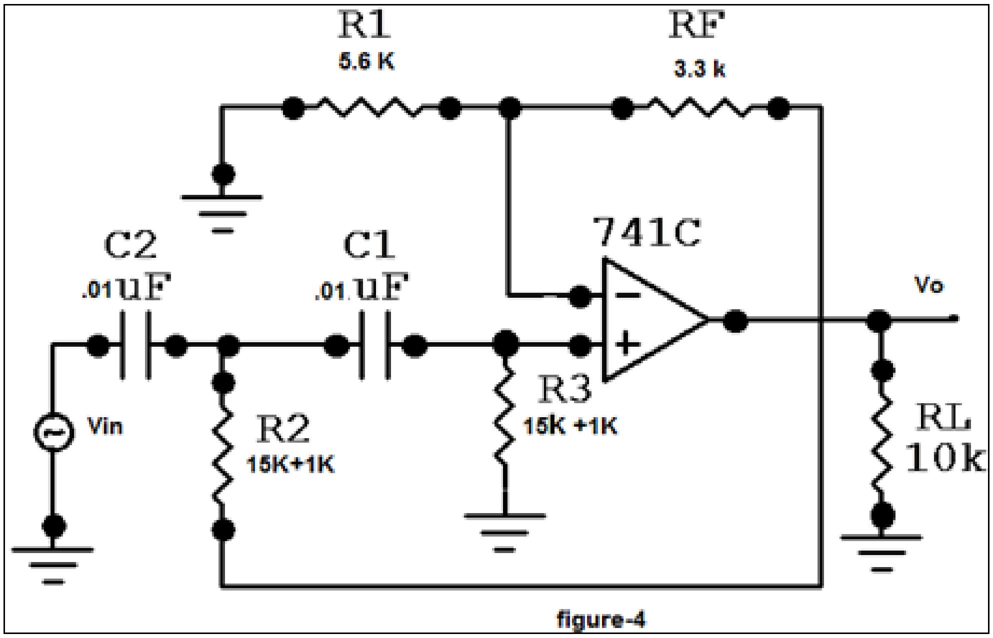

Fig 2: Circuit diagram of a second order high pass Butterworth filter

3. Calculation of circuit components
3.1 First order high pass Butterworth filter
For a high pass filter of cut off frequency 1KHz with a pass band gain 2

$f_L =$ 1KHz, C= 0.01μF and hence,\

$$R = \frac{1}{2\pi(10^3)(10^{-8})} = 15.9\ K\Omega$$

Resistance has been taken as, R= (15+1) KΩ

Since passband gain is 2, $R_F = R_1 = 10K\Omega$

3.2 Second order high-pass Butterworth filter
For designing a 2nd order high pass Butterworth filter of higher cut off frequency $f_L =$ 1KHz, the required components are taken as, $R_2 = R_3 = R$ and $C_2 = C_3 = C =$ 0.01 μF

Hence, $R = \frac{1}{2\pi(10^3)(10^{-8})} = 15.9\ K\Omega$. The chosen value of R= (15+1) KΩ

To guarantee Butterworth response gain must be equel to 1.586 and hence, $R_F = 0.586R_1$

Chosen values are $R_F = 3.3K\Omega$ and $R_1 = 5.6\ K\Omega$

4. Frequency Response Data and Results
4.1 First order high pass Butterworth filter
The data for frequency response of the 1st order high 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	0.08	0.08	-21.40
100	1.00	0.75	0.75	-02.50
200	1.00	1.25	1.25	01.94
500	1.00	1.80	1.80	05.10
700	1.00	1.94	1.94	05.74
800	1.00	2.00	2.00	06.02
1000	1.00	2.00	2.00	06.02

3000	1.00	2.00	2.00	06.02
7000	1.00	2.00	2.00	06.02
10000	1.00	1.90	1.90	05.58
100000	1.00	1.95	1.95	05.80

The frequency response curve for 1st order high pass filter is shown in figure-3.

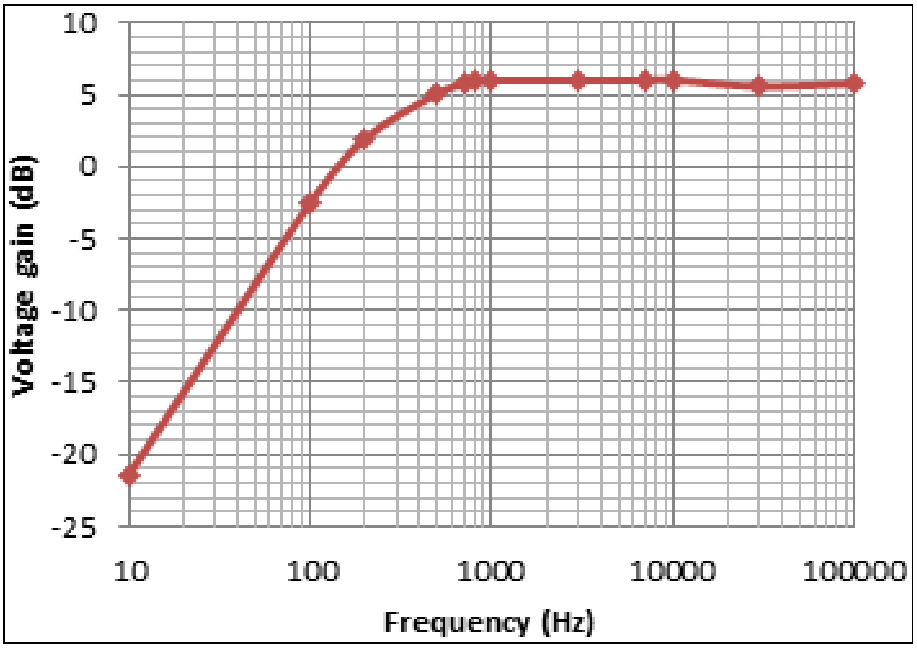

Fig 3: Frequency Response curve of 1st order Butterworth filter

4.2 Second order high pass Butterworth filter

The data for frequency response of the 1st order high pass 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	Gainmagnitude $\left\|\frac{v_o}{v_{in}}\right\|$	Magnitude (dB)= $20\log\left\|\frac{v_o}{v_{in}}\right\|$
30	1.00	0.01	0.01	-38.42
100	1.00	0.03	0.03	-30.46
200	1.00	0.06	0.06	-24.44
500	1.00	0.43	0.43	-07.33
600	1.00	0.54	0.54	-05.35
700	1.00	0.70	0.70	-03.09
800	1.00	0.80	0.80	-01.94
900	1.00	0.95	0.95	-0.44
1000	1.00	1.05	1.05	0.42
1200	1.00	1.25	1.25	01.94
1500	1.00	1.38	1.38	02.79
2000	1.00	1.45	1.45	03.23
3000	1.00	1.55	1.55	03.81
7000	1.00	1.60	1.60	04.08
10000	1.00	1.60	1.60	04.08
100000	1.00	1.45	1.45	03.23

The frequency response curve for 2nd order high pass filter is shown in figure-4.

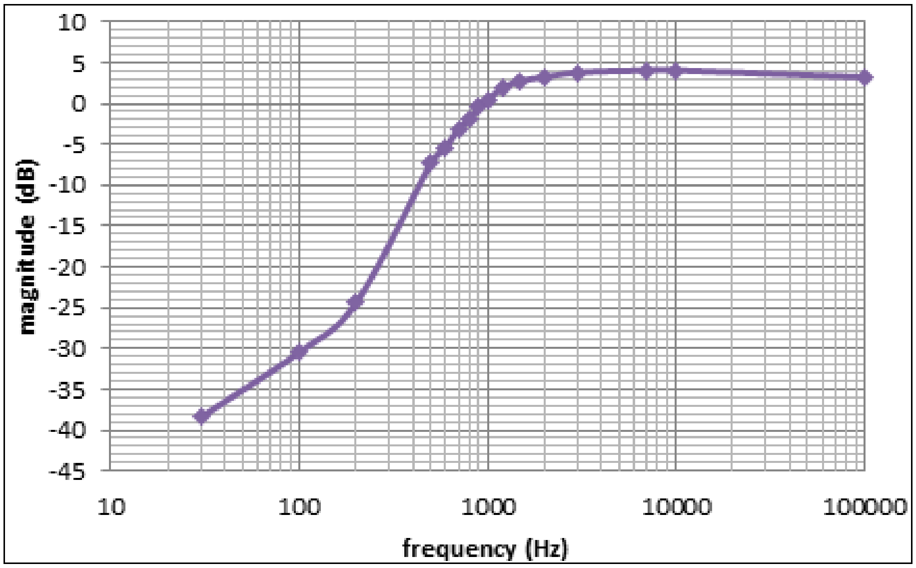

Fig 4: Frequency Response curve of 2nd order Butterworth filter

5. Conclusions

In this paper the low pass Butterworth filter of order 1 and 2 have been successfully implemented. The frequency response of the filter 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

I wish to express my heartfelt thanks to Mr. Chandan Pramanik, a student of Garhbeta College for his kind co-operation in taking experimental data.

7. References

1. Gayakwad RA, Opamp and Linear Integrated Circuit, Prentice Hall of India, New Delhi, India, 2008, 447-449.
2. Albert Paul Malvino. Electronic Principles, Tata McGraw Hill Publishing Company Limited, New Delhi, India, 1989, 535-541.
3. Robert Boylestad, Louis Nashelsky. Electronic Devices and Circuit Theory, Prentice Hall, New Jersey, 2011, 662-667.