Low-Pass Filter That Can Exploit Full Open Loop Gain Of Op-amp

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***Abstract*—Low pass filters are essential components in electronic circuits used to remove high-frequency noise and unwanted signals from a system. When such filters are not used, the system can suffer from issues such as signal distortion and instability. The design of a low pass filter that exploits the full open loop gain of an operational amplifier is particularly important as it ensures that the maximum voltage gain of the amplifier is achieved. This report presents the design of such a low pass filter with a gain of 3V/V, a 3dB cut frequency at 12 kHz, and a quality factor of 3.**

***Keywords* - high-frequency noise, signal distortion, open loop gain**

I. INTRODUCTION

Low-pass filters are a fundamental component of electronic circuits used to attenuate high-frequency signals and noise. The design of low-pass filters has gained significant attention due to its broad application in various fields of electronic engineering, such as signal processing, telecommunications, and power electronics.

The use of low pass filters that exploit the full open loop gain of an op-amp offers several advantages as it allows for maximum voltage gain, which in turn improves the signal-to-noise ratio of the system. Secondly, it reduces the noise introduced by the op-amp and other components in the system. Thirdly, it allows for precise control of the filter's parameters, making it possible to achieve the desired cut-off frequency and gain.

When low-pass filters are not appropriately designed, the system can suffer from various issues, such as signal distortion and instability. High-frequency noise can also affect the accuracy and reliability of the system, leading to erroneous measurements and incorrect results. These problems can be particularly pronounced in applications where the signal of interest is weak or the noise is strong gain.

The design presented in this report provides an effective solution to the problem of high-frequency noise. One possible improvement is the use of active filters to achieve sharper cutoffs and improved attenuation of higher-frequency noise.

II. BASIC THEORY

A. Second-Order Low-Pass Butterworth Filter

The practical response of the Second Order Low Pass Butterworth Filter must be very close to an ideal one. In the case of a low pass filter, it is always desirable that the gain rolls off very fast after the cut-off frequency, in the stop band. A first-order filter can be converted to a second-order type by using an additional RC network as shown in Fig.2.1 .The cut-off frequency $\mathbf{f_H}$ for the filter is now decided by $\mathbf{R_2}$, $\mathbf{C_2}$, $\mathbf{R_3}$, and $\mathbf{C_3}$. The gain of the filter is as usual decided by op-amp i.e. the resistance $\mathbf{R_1}$ and $\mathbf{R_f}$.

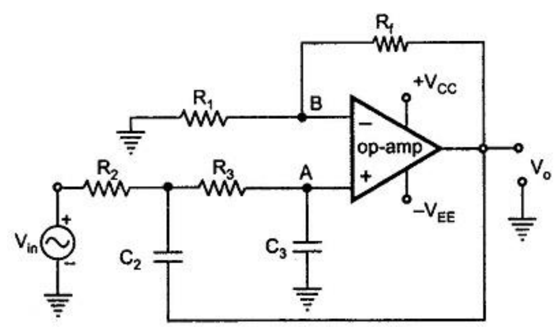


Fig. 1.1

B. Second-Order Low-Pass Butterworth Filter Transfer Function

$$\frac{V_o(s)}{V_{in}(s)} = \frac{A}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

Where,
A = overall gain
ξ = damping of system
ω_n = natural frequency of oscillations

$$f_H = \frac{1}{2\pi\sqrt{R_2 R_3 C_2 C_3}}$$

f_H is the required cut off frequency.

$$\frac{V_o}{V_{in}} = \left|\frac{V_o}{V_{in}}\right| \angle \phi$$

Where,

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^4}}$$

And,
A_f = gain in filter in pass band
f = input frequency in Hz
f_H = high cut-off frequency in Hz

The frequency response is shown in Fig. 2.2

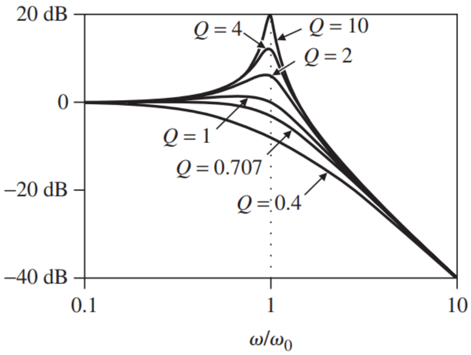


Fig.1.2

$$\omega/\omega_0 = \sqrt{1 - 1/2Q^2}$$

III. Design

Given Specification
$A_f = 3$
$Q = 3$
$3db\ cutoff\ frequency\ f = 12\ KHz$

Transfer function

$$\frac{V_0(s)}{Vin(s)} = \frac{\frac{A_f}{R_2R_3C_2C_3}}{s^2 + \left(\frac{R_3C_3 + R_2C_2 + R_2C_3 - R_2C_2A_f}{R_2R_3C_2C_3}\right)s + \frac{1}{R_2R_3C_2C_3}}$$

Using equal component method, we get

$R_1 = R_2 = R_3 = R;$

$C_2 = C_3 = C;$

$$\frac{V_0(s)}{Vin(s)} = \frac{\frac{A_f}{R^2C^2}}{s^2 + \left(\frac{3 - A_f}{R^2C^2}\right)RCs + \frac{1}{R^2C^2}} = \frac{\frac{A_f}{R^2C^2}}{s^2 + \left(\frac{3 - A_f}{RC}\right)s + \frac{1}{R^2C^2}}$$

$$w = \frac{1}{RC} \Rightarrow f = \frac{1}{2\pi RC}$$

$$R = \frac{1}{2\pi f C}$$

$Let\ C = 10nF$

$$R = \frac{1}{2\pi * 12 * 10^3 * 10 * 10^{-9}} = \frac{10^5}{2 * 12\pi} = 1.3K\Omega$$

$\boldsymbol{R_1 = R_2 = R_3 = R = 1.3K\Omega}$

$\boldsymbol{C_3 = C_2 = C = 10nF}$

$$1 + \frac{R_f}{R} = 3$$

$\boldsymbol{R_f = 2R = 2 * 1.3K\Omega = 2.6K\Omega}$

Practical Values
$C_3 = C_2 = 10nF$
$R_1 = R_2 = R_3 = 1.2K\Omega$
$R_f = 2.7K\Omega$

IV. Observation and Frequency Response

a) Observation Table: It contains Data of output voltage in dB(Decibel) vs Frequency in Hz.

Frequency (Hz)	Gain(db)
100	9.54
200	9.54
300	9.5
400	9.5
500	9.49
600	9.49
700	9.49
800	9.49
1000	9.49
2000	9.49
3000	10
4000	10
5000	10.61
7000	12.13
8000	12.7
10000	14.27
11000	16.44
12000	20.13

13000	18.27
14000	18.06
15000	18.02
16000	17.13
17000	16.75
18000	9.54
20000	7.47
30000	2.733
40000	-0.5
50000	-1.9

V. Acknowledgment

I would like to express my sincere thanks to Prof. Jignesh Sarvaiya Sir for his guidance and support throughout this project.

I would also like to thank Rashmi Ranjan sir, Kapil Sir, Rajesh Sir for their support, Department of Electronics and Communication Engineering for providing resources and facilities, and my teammates for their unwavering support.

Thank you all for your valuable contributions and encouragement throughout this project.

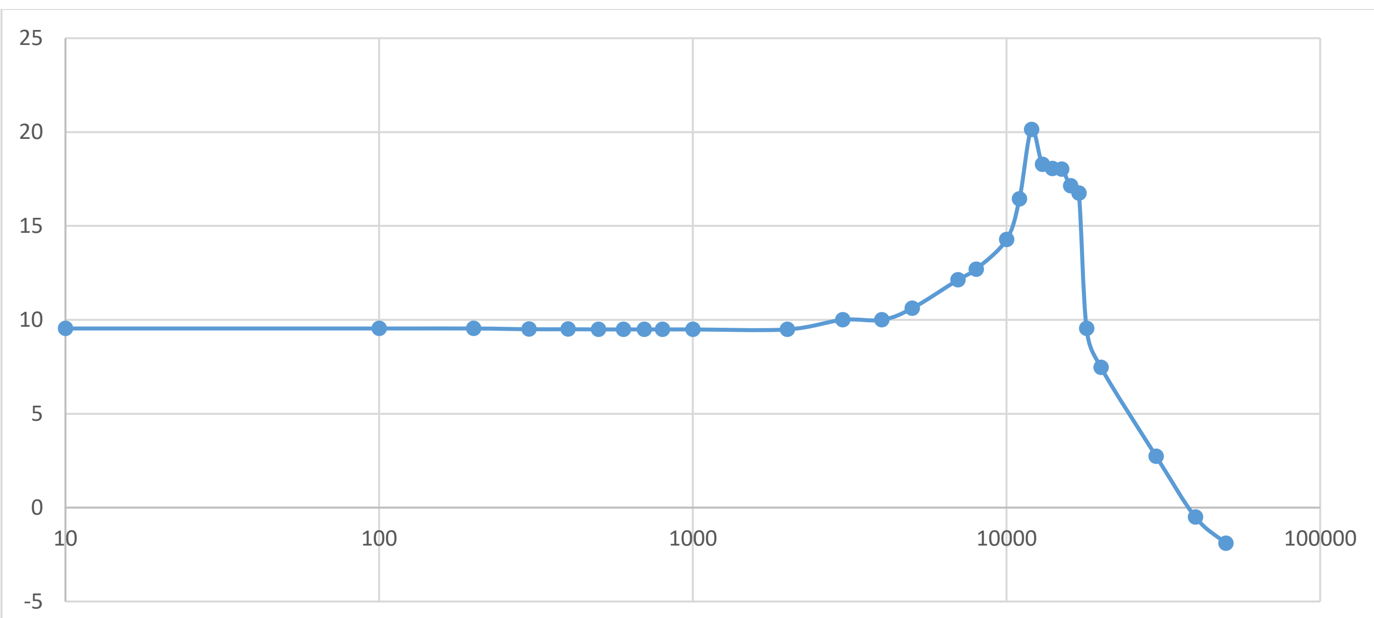
VI. References

[1] Sergio Franco, Professor at San Francisco State University, "Design with Operational Amplifiers and Analog Integrated Circuits", Fourth Edition

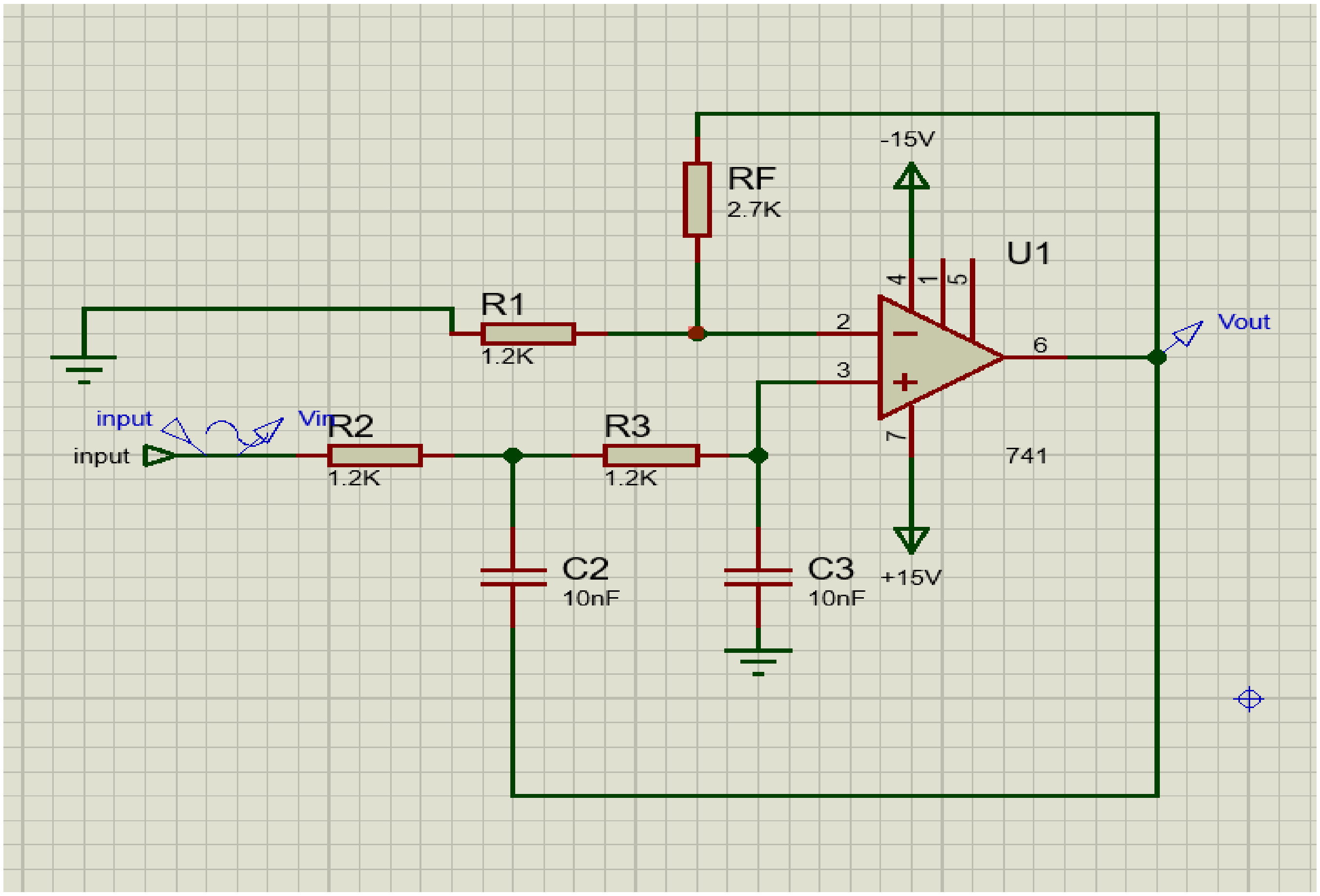
[2] Prof. Jignesh N. Sarvaiya, Department of Electronics and Communication Engineering at Sardar Vallabhbhai National Institute of Technology

RESULTS AND CONCLUSIONS

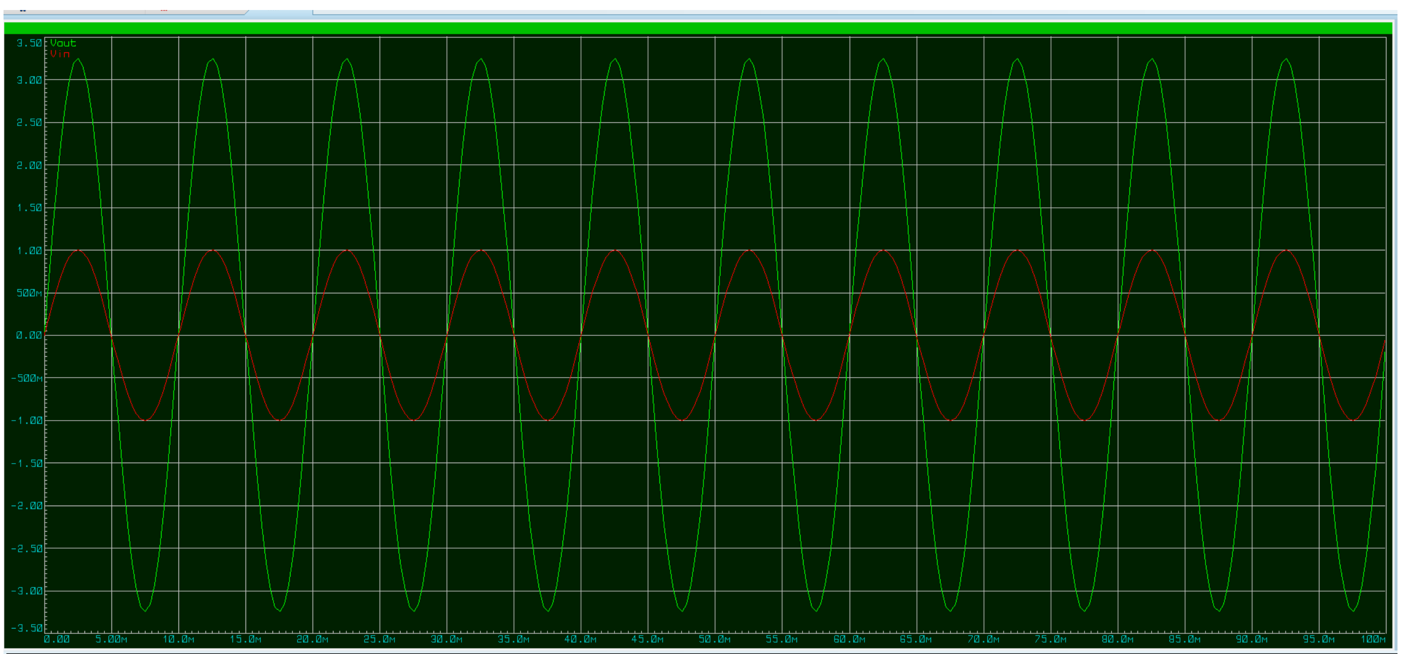
1. Frequency Response



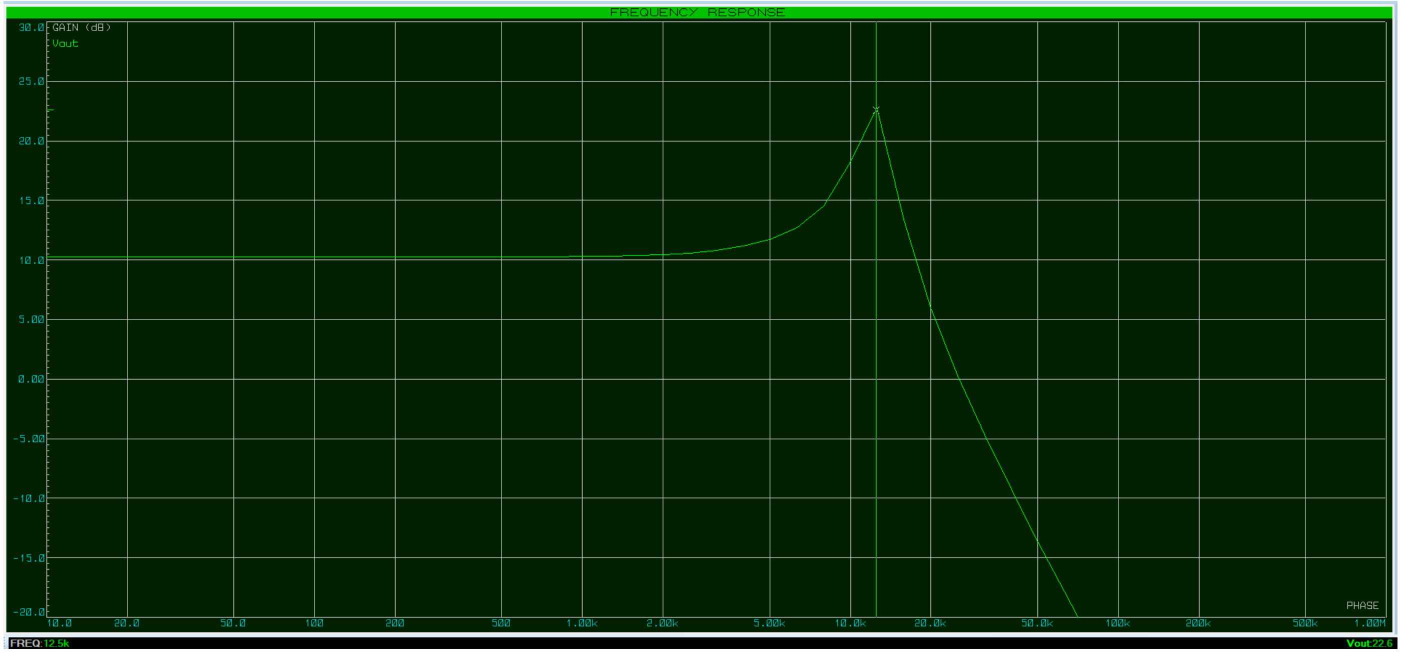
2. Simulation Results



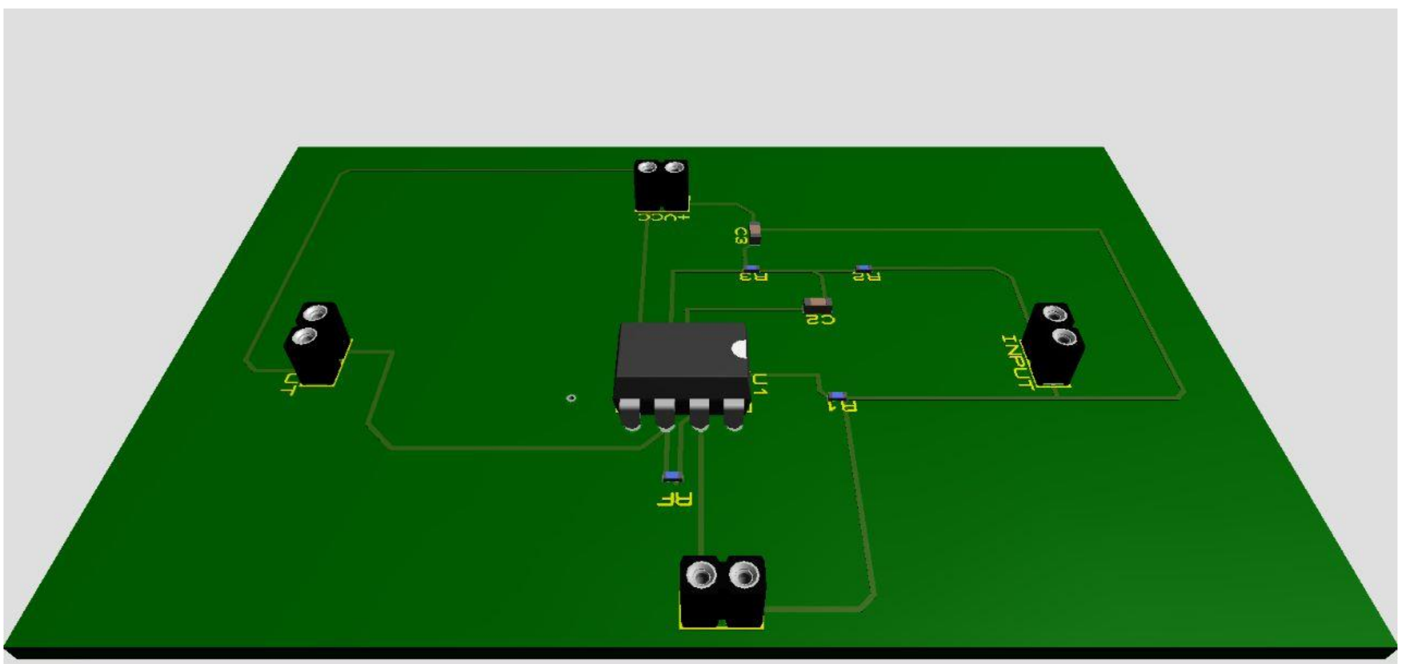
Schematic in Proteus



Output



Frequency Response



PCB Design Output

CONCLUSION: Using Equal Components method, we are able to design second order Butterworth low pass filter having specifications: gain of 3V/V, a 3dB cut frequency at 4 kHz, and a quality factor of 4. The designed low pass filter is verified by proteus simulation and the frequency response is approximately similar to the practically plotted frequency response. The PCB schematic also attached for better understanding.