

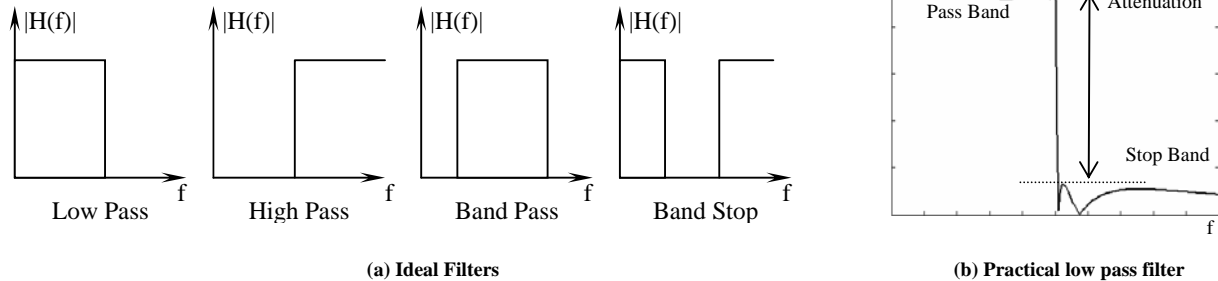
## Experiment #1 Design and Verification of a Biquad Active Filter

**Goal:**

Design and verification of a constant Q, tunable frequency band pass filter to be implemented using Biquad circuit.

**Introduction:**

Filters, as their name indicates, are used to allow certain range of frequencies to pass and reject the remaining. They are often classified into the four broad categories viz., low pass, high pass, band pass and band stop filters. The ideal characteristics of these filters are shown in Fig. 1a.



(a) Ideal Filters (b) Practical low pass filter

Practical filters try to approximate these ideal characteristics as closely as possible depending on the application. A practical filter is more likely to have characteristics as shown in Fig. 1b.

The important filter specifications are pass band frequency range, stop band frequency range, minimum attenuation in the stop band, maximum allowable ripple in the pass band, required phase characteristics, required transient characteristics, input and output impedances and noise characteristics etc.

Mathematically, filters are commonly described using transfer functions. The general expression for the second order or bi-quadratic transfer function is usually expressed in the standard form as:

$$H(s) = \frac{a_2s^2 + a_1s + a_o}{s^2 + s\left(\frac{\omega_o}{Q}\right) + \omega_o^2}$$

The type of filter functions, viz., low pass (LP), high pass (HP) and band pass (BP) filter, can be realized by proper choice of the numerator coefficients as shown in the following equations.

$$H_{LP} = \frac{a_o}{s^2 + s\left(\frac{\omega_o}{Q}\right) + \omega_o^2} \quad H_{HP} = \frac{a_2s^2}{s^2 + s\left(\frac{\omega_o}{Q}\right) + \omega_o^2} \quad H_{BP} = \frac{a_1s}{s^2 + s\left(\frac{\omega_o}{Q}\right) + \omega_o^2}$$

In this experiment we are interested in studying the properties of the second order band pass filter. The magnitude response of the band pass filter peaks at  $\omega = \omega_o$ , and is called the centre frequency of the filter. Gain of the filter at the centre frequency is given by  $G_o = \frac{a_1Q}{\omega_o}$ . The 3dB bandwidth, difference between the two frequencies ( $\omega_{1,2} = \omega_o \sqrt{1 + \frac{1}{4Q^2} \mp \frac{\omega_o}{2Q}}$ ) at which the gain is 3dB below the maximum gain, is used to quantify the selectivity of

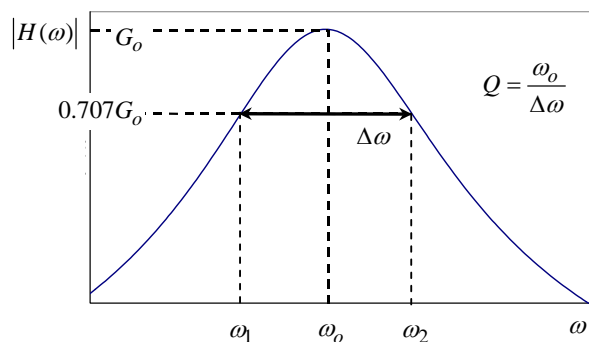


Figure 2: Characteristics of a band pass filter

the filter. Therefore, the 3dB bandwidth,  $\Delta\omega$  is given by,  $\Delta\omega = \omega_2 - \omega_1 = \frac{\omega_o}{Q}$  (Fig. 2).

One of the popular circuits used to realize a second order filter is shown in Fig. 3. This is popularly known as KHN filter after their inventors (Kerwin-Huelsman-Newcomb). This realization offers low pass, high pass and band pass outputs simultaneously. In this experiment, the band pass filter is of specific interest. Two of the most important characteristics of a band pass filter are its center frequency and Q factor (Fig. 2). The appropriate values for these two parameters depend on the applications, which are highly diverse in nature. As a result, any manufacturer of a band pass filter who wishes to sell his circuits in large volume thus finds it necessary to allow users the flexibility of modifying the filter characteristics, in other words make the filter tunable or programmable.

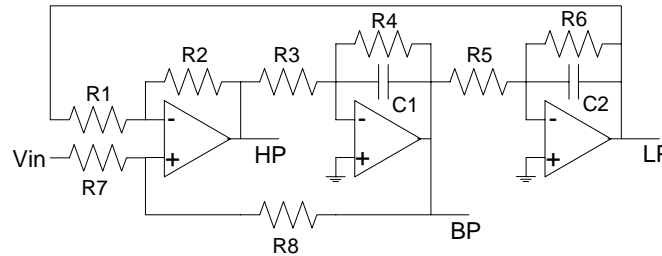


Figure 3: Schematic of a Biquad filter

**Specifications:**

Design a constant Q (choose a value between 5 and 20), tunable frequency band pass filter to be implemented using a Biquad circuit.

Implement your design using the Biquad circuit whose schematic is shown in Fig. 3. Fix the values of all the components except a few convenient ones that a user can vary to tune the centre frequency ( $f_o = \frac{\omega_o}{2\pi}$ ).

Provide an analytical expression or a graph using which the user can select the component values so that the filter is tuned to the desired centre frequency.

Describe also the range of frequencies for which the design would work satisfactorily.

**Verification:**

Verify your design through PSPICE simulations and through experimental measurements in the laboratory.

Plot a graph of centre frequency and Q (designed, simulated and measured) as a function of tunable element value.

Explain any discrepancies observed.

**Reference:**

A.S. Sedra and K.C. Smith, *Microelectronic Circuits*, Fourth Edition, Oxford University Press, 2003.

**Design Equations:**

For the band pass filter, the following design equations are obtained by assuming that the opamps and the integrators are ideal.

$$H_{BP} = \frac{s \left( \frac{R_8}{R_7 + R_8} \right) \left( 1 + \frac{R_2}{R_1} \right) \frac{1}{R_3 C_1}}{s^2 + s \left( \frac{R_7}{R_7 + R_8} \right) \left( 1 + \frac{R_2}{R_1} \right) \frac{1}{R_3 C_1} + \frac{R_2}{R_1} \frac{1}{R_3 C_1} \frac{1}{R_5 C_2}}$$

$$\omega_o = \sqrt{\frac{R_2}{R_1} \frac{1}{C_1 C_2} \frac{1}{R_3 R_5}} \quad Q = \sqrt{\frac{R_2}{R_1} \frac{C_1}{C_2} \frac{R_3}{R_5}} \times \frac{1}{1 + \frac{R_2}{R_1}} \times \left( 1 + \frac{R_8}{R_7} \right) \quad G_o = \frac{R_8}{R_7}$$