EXPERIMENT 3

THE FOUR OP-AMP BIQUAD CIRCUIT

(EXPERIMENTAL)

OBJECTIVE

To build different second order (biquad) filter circuits employing four operational amplifiers (OP-AMPs).

INTRODUCTION

A common practice in IC fabrication is to manufacture chips with multiple devices. A four op-amp biquad takes advantage of the availability of four op-amps on a single chip enabling generation of several different second order filter responses. The four op-amp biquad realizes the general biquadratic function and exhibits low-pass, band–pass, high-pass, band-stop and all-pass characteristics simultaneously.

THE FOUR OP-AMP BIQUAD CIRCUIT

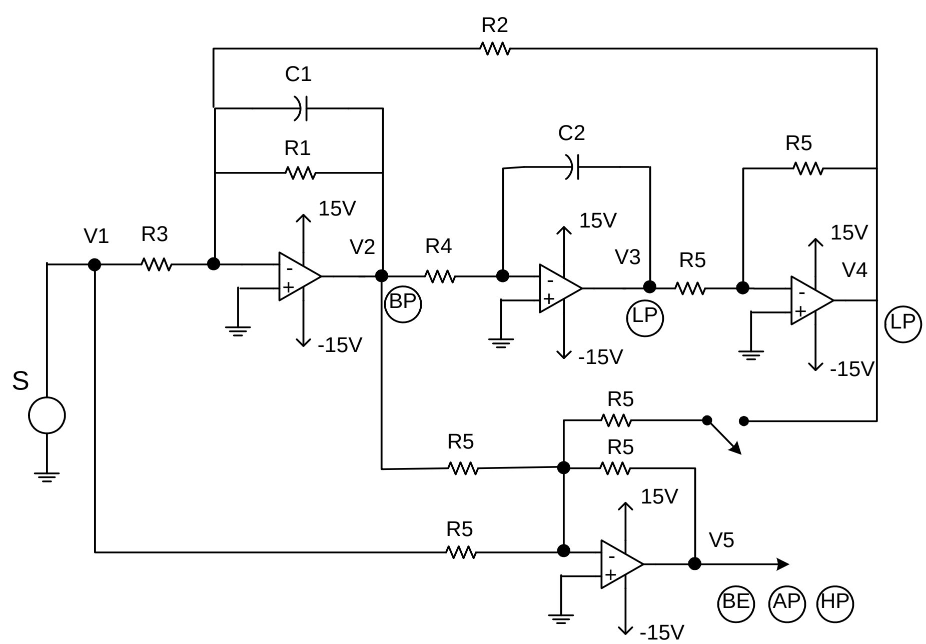

FIG. 1

The four opamp biquad shown in Fig. 1 can produce the general transfer function:

$$T_G(s) = \frac{k_1 S^2 + k_2(\frac{w_o}{Q})S + k_3 w_o^2}{S^2 + (\frac{wo}{Q})S + w_o^2}$$

The terms k_1, k_2 and k_3 in the general transfer function determine the type of filter. For example if $k_3 = 1$ and $k_2 = k_1 = 0$ the general transfer function reduces to:

$$T(s) = \frac{w_o^2}{S^2 + (\frac{wo}{Q})S + w_o^2}$$

which is the standard low-pass transfer function with $H_o = 1$.
Similarly, for $k_1 = 1$ and $k_2 = k_3 = 0$ we obtain a high-pass transfer function:

$$T(s) = \frac{S^2}{S^2 + (\frac{wo}{Q})S + w_o^2}$$

For $k_2 = 1$ and $k_1 = k_3 = 0$ we obtain a band-pass transfer function:

$$T(s) = \frac{(\frac{w_o}{Q})S}{S^2 + (\frac{wo}{Q})S + w_o^2}$$

For $k_1 = k_3 = 1$ and $k_2 = 0$ we have a band elimination (BE), also called a band-stop or notch, transfer function.

$$T(s) = \frac{S^2 + w_o^2}{S^2 + (\frac{wo}{Q})S + w_o^2}$$

with $k_1 = k_3 = 1$ and $k_2 = -1$ the transfer function represent an all-pass filter (APF).

$$T(s) = \frac{S^2 - (\frac{w_o}{Q})S + w_o^2}{S^2 + (\frac{wo}{Q})S + w_o^2}$$

PRE-LAB

1. Derive the transfer function V_2/V_1 in Fig.1, and identify the terms k_1, k_2, k_3, w_o and Q, in terms of the circuit elements (i.e., R_1, R_2, R_3, ..C_1, and C_2). What value of R_3 yields unity gain at the pole- frequency w_o? What is the type of the filter?

2. Derive the transfer function V_5 / V_1 with the **switch opened.** Compare your result with the general transfer function $T_G(s)$, and identify the design cases for (a) a BE filter (i.e., $k_2 = 0$), and (b) an APF (i.e., $k_2 = -1$ and, $k_1 = k_3 = 1$) in terms of the circuit elements (i.e., R_1, R_2, R_3, ..C_1, and C_2).
3. Derive the transfer function V_5 / V_1 with the **switch closed**, and compare it with the general transfer function $T_G(s)$ .What values of $R_1, R_{2,} R_3$ and R_4 will yield a *high pass* response (i.e., $k_2 = k_3 = 0$, and $k_1 = 1$)?

PROCEDURE

1. Calculate the value of $C = C_1 = C_2$ that yields a cut-off frequency, $f_o = 5KHz$, and a Q value of 1.5. Use resistance values between 1 kΩ and 1 MΩ.
2. Build the biquad circuit shown in Fig. 1 using the closest values of C available. If the value of C is not the same as obtained in part 1, recalculate the cut-off frequency f_o.
3. Apply 1V, peak-to-peak sinusoidal signal to the circuit, and sweep the frequency from 100 Hz to 15 KHz in step 500 Hz. Keep the switch **closed.** Measure voltages at the nodes for V_2, and V_5 (as shown in Fig.1). Take more readings at smaller intervals, around the cut-off frequency.
4. Plot graphs of $|V_2|$ and $|V_5|$ vs. frequency and validate the theoretical results expected in items #1 and #3 in the **pre-lab** practice.