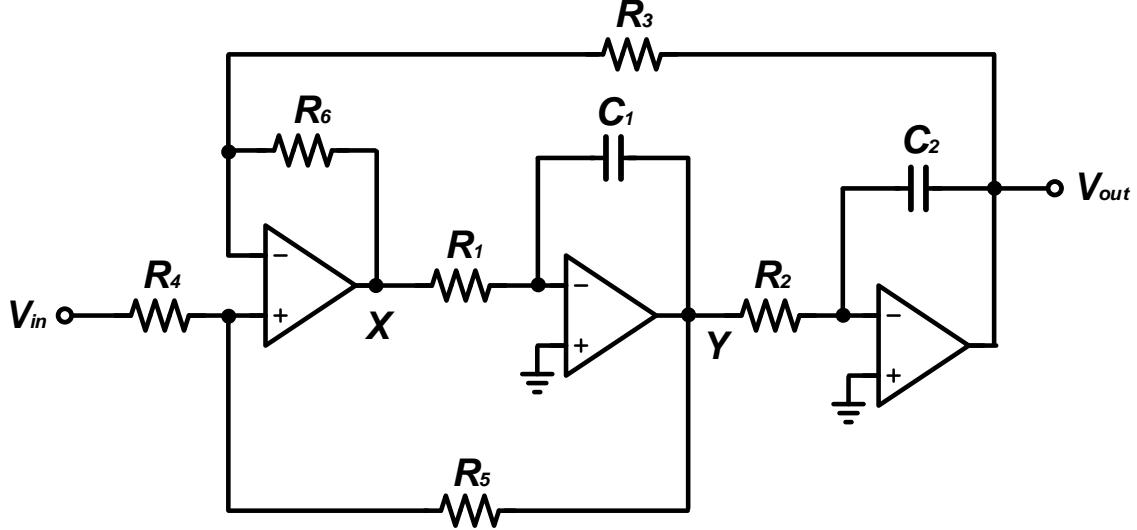


1. For the KHN biquad below, answer the following questions. Full credit will not be given without explanation. Assume that all amplifiers are ideal.



- (a) Find the transfer function of the filter. Specify the filter's function.

$$V_Y = -\frac{1}{R_1 C_1 s} V_X, V_{out} = -\frac{1}{R_2 C_2 s} V_Y = \frac{1}{R_1 R_2 C_1 C_2 s^2} V_X, V_X = \frac{V_{in} R_5 + V_Y R_4}{R_4 + R_5} \left( 1 + \frac{R_6}{R_3} \right) - V_{out} \frac{R_6}{R_3}$$

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{\frac{R_5}{R_4 + R_5} \left( 1 + \frac{R_6}{R_3} \right)}{s^2 + \frac{R_4}{R_4 + R_5} \frac{1}{R_1 C_1} \left( 1 + \frac{R_6}{R_3} \right) s + \frac{R_6}{R_3} \frac{1}{R_1 R_2 C_1 C_2}} \frac{1}{R_1 R_2 C_1 C_2}$$

☞ Low-Pass Filter

- (b) Derive Q and  $\omega_n$ .

$$\omega_n = \sqrt{\frac{R_6}{R_3 R_1 R_2 C_1 C_2}}, Q = \frac{\omega_n}{\left[ \left( \frac{R_4}{R_4 + R_5} \right) \left( \frac{1}{R_1 C_1} \right) \left( 1 + \frac{R_6}{R_3} \right) \right]} = \frac{1 + \frac{R_5}{R_4}}{R_3 + R_6} \sqrt{\frac{R_3 R_6 R_1 C_1}{R_2 C_2}}$$

- (c) Determine the sensitivities of the KHN biquad. ( $|S_{R_1, R_2, C_1, C_2, R_3, R_6}^{\omega_n}|$ ,  $|S_{R_4}^{\omega_n}|$ ,  $|S_{R_1, R_2, C_1, C_2}^Q|$ ,  $|S_{R_3, R_6}^Q|$ )

$$|S_{R_1}^{\omega_n}| = |S_{R_2}^{\omega_n}| = |S_{C_1}^{\omega_n}| = |S_{C_2}^{\omega_n}| = |S_{R_3}^{\omega_n}| = \left| \frac{d\omega_n}{dR_3} \frac{R_3}{\omega_n} \right| = \left| -0.5 \frac{1}{\sqrt{R_3^3}} \sqrt{\frac{R_6}{R_1 R_2 C_1 C_2}} \sqrt{\frac{R_3 R_1 R_2 C_1 C_2}{R_6}} R_3 \right| = 0.5$$

$$|S_{R_6}^{\omega_n}| = \left| \frac{d\omega_n}{dR_6} \frac{R_6}{\omega_n} \right| = \left| 0.5 \frac{1}{\sqrt{R_6}} \sqrt{\frac{1}{R_3 R_1 R_2 C_1 C_2}} \sqrt{\frac{R_3 R_1 R_2 C_1 C_2}{R_6}} R_6 \right| = 0.5$$

$$|S_{R_4}^{\omega_n}| = \left| \frac{d\omega_n}{dR_4} \frac{R_4}{\omega_n} \right| = 0$$

$$|S_{R_1, R_2, C_1, C_2}^Q| = |S_{R_1}^Q| = \left| \frac{dQ}{dR_1} \frac{R_1}{Q} \right| = \left| 0.5 \frac{Q}{R_1} \frac{R_1}{Q} \right| = 0.5$$

$$|S_{R_3, R_6}^Q| = |S_{R_3}^Q| = \left| \frac{dQ}{dR_3} \frac{R_3}{Q} \right| = \left| \left( -\frac{1}{R_3 + R_6} Q + \frac{1}{2} \frac{Q}{R_3} \right) \frac{R_3}{Q} \right| = \left| -\frac{R_3}{R_3 + R_6} + \frac{1}{2} \right| = \frac{1}{2} \frac{|R_6 - R_3|}{R_3 + R_6}$$

$|S_{R_3, R_6}^Q|$  은 Q를 풀어서 정리하지 않으면 0점