Lect. 20: Two-Integrator-Loop Biquad

(Razavi 14.4.2)

One circuit configuration for several different second-order filters?

➔ Two-integrator-loop biquad

Consider high-pass filter $$\frac{V_{hp}}{V_i} = \frac{Ks^2}{s^2 + s(\omega_0 / Q) + \omega_0^2}$$

$$V_{hp}s^2 + V_{hp}s(\omega_0 / Q) + V_{hp}\omega_0^2 = KV_i s^2$$

$$V_{hp} + \frac{1}{Q}\left(\frac{\omega_0}{s}V_{hp}\right) + \left(\frac{\omega_0^2}{s^2}V_{hp}\right) = KV_i$$

$$V_{hp} = KV_i - \frac{1}{Q}\frac{\omega_0}{s}V_{hp} - \frac{\omega_0^2}{s^2}V_{hp}$$

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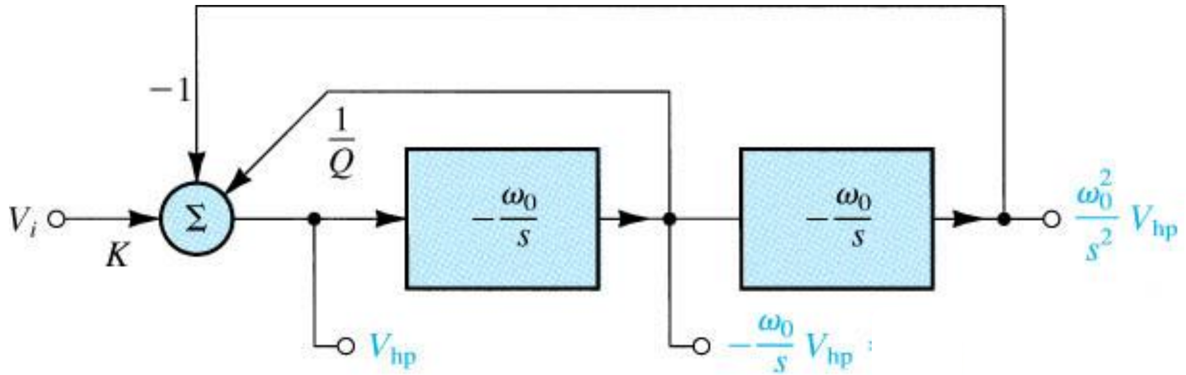
$$\mathbf{V}_{\mathrm{hp}} = K\mathbf{V}_i - \frac{1}{Q}\frac{\omega_0}{s}\mathbf{V}_{\mathrm{hp}} - \frac{\omega_0^2}{s^2}\mathbf{V}_{\mathrm{hp}}$$

Express the above equation using a block diagram



(c)

Biquad ➔ Universal Active Filter

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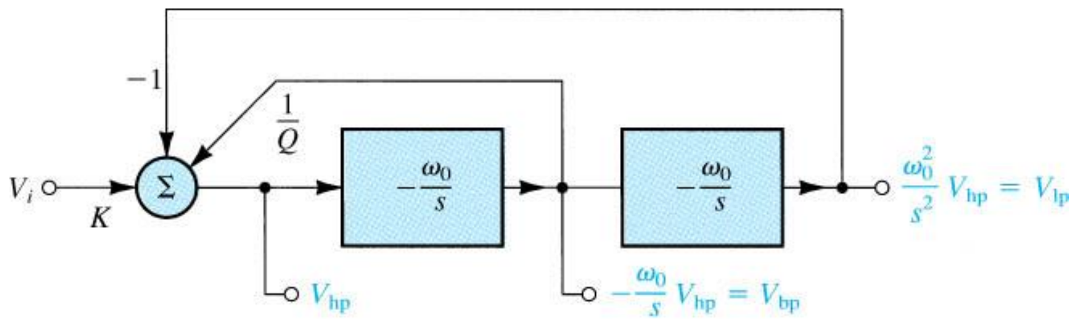
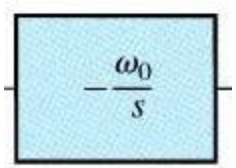
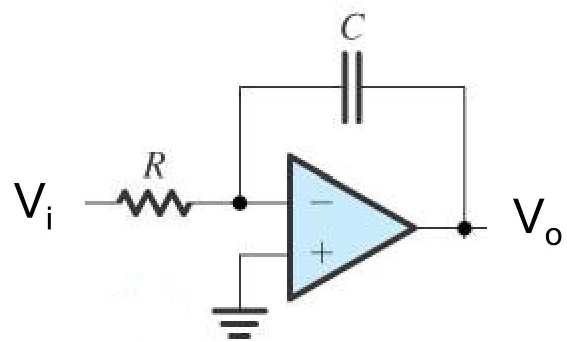


(c)

How to implement biquad?





$$V_o = -\frac{V_i}{R} \cdot \frac{1}{sC}$$

$$\frac{V_o}{V_i} = -\frac{1}{RCs} = -\frac{\omega_0}{s}$$

$$\omega_0 = \frac{1}{RC}$$

(Ignoring the op-amp offset)

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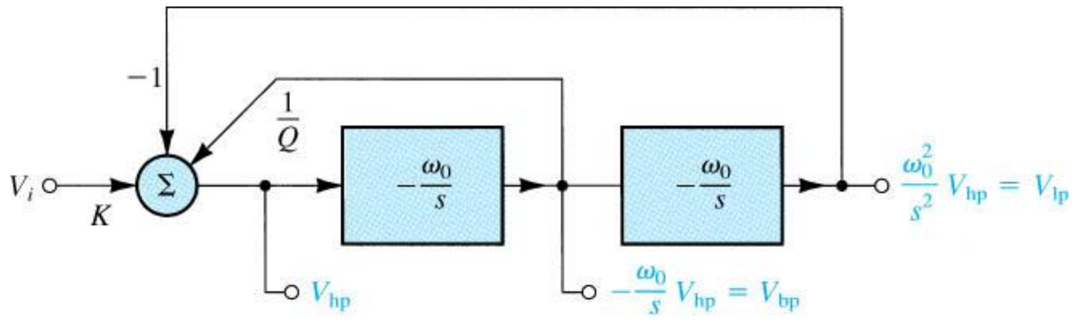
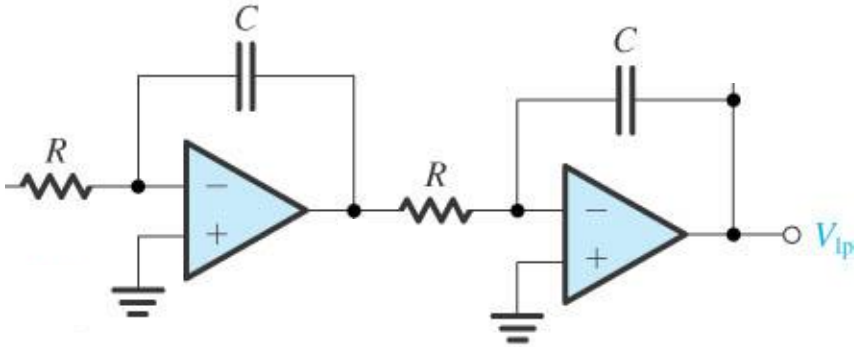


(c)



(a)

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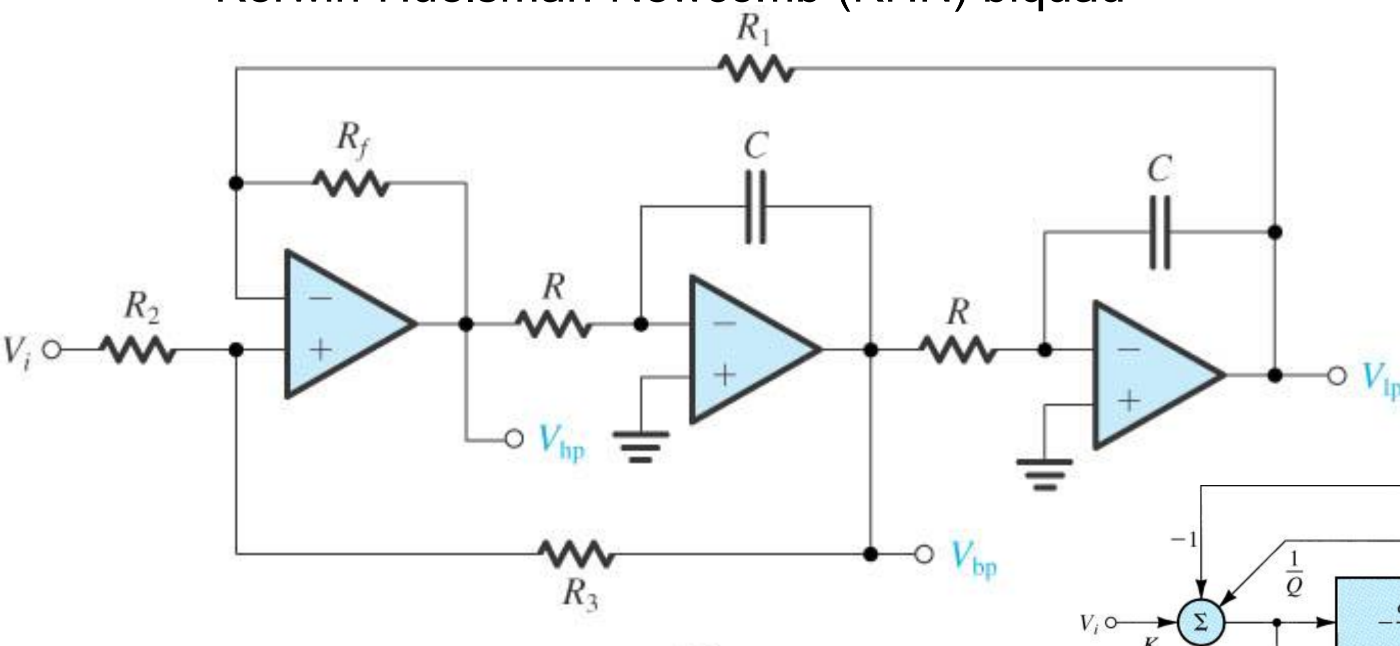
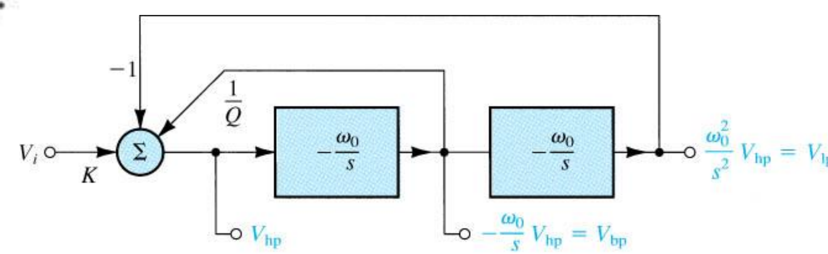
Kerwin-Huelsman-Newcomb (KHN) biquad



(a)



(c)

Use superposition (V_i, V_{bp}, V_{lp})

$$\mathbf{V}_{hp} = \frac{R_3}{R_2 + R_3}\left(\frac{R_1 + R_f}{R_1}\right)\mathbf{V}_i + \frac{R_2}{R_2 + R_3}\left(\frac{R_1 + R_f}{R_1}\right)\mathbf{V}_{bp} - \frac{R_f}{R_1}\mathbf{V}_{lp}$$

➔ Weighted sum of V_i, V_{bp}, V_{lp}

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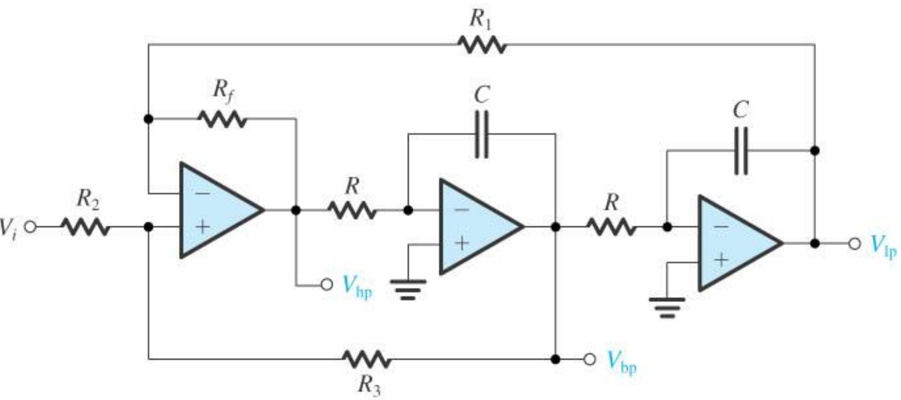
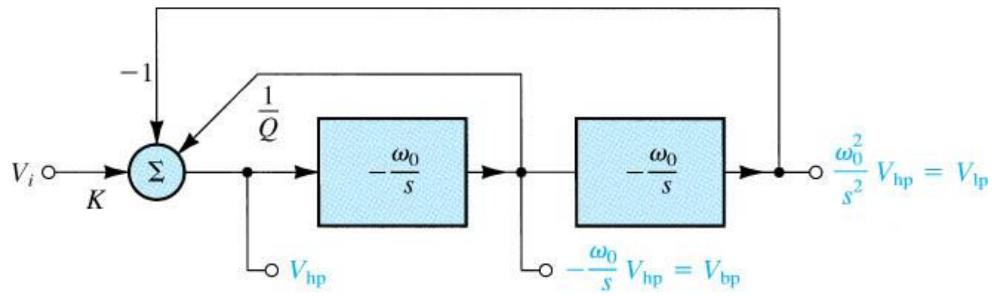
KHN



$$\frac{\mathbf{V}_{hp}}{\mathbf{V}_i} = \frac{Ks^2}{s^2 + s(\omega_0/Q) + \omega_0^2}$$



(c)

$$\mathbf{V}_{hp} = \frac{R_3}{R_2+R_3}\left(\frac{R_1+R_f}{R_1}\right)\mathbf{V}_i + \frac{R_2}{R_2+R_3}\left(1+\frac{R_f}{R_1}\right)\mathbf{V}_{bp} - \frac{R_f}{R_1}\mathbf{V}_{lp}$$

$$\mathbf{V}_{hp} = K\mathbf{V}_i + \frac{1}{Q}\mathbf{V}_{bp} - \mathbf{V}_{lp}$$

$$\therefore R_f/R_1 = 1 \qquad \frac{2R_2}{R_2+R_3} = \frac{1}{Q} \quad \therefore Q = \frac{R_2+R_3}{2R_2} \qquad K = \frac{2R_3}{R_2+R_3} \qquad \omega_0 = ?$$

All of HF, LP and BP characteristics can be obtained!

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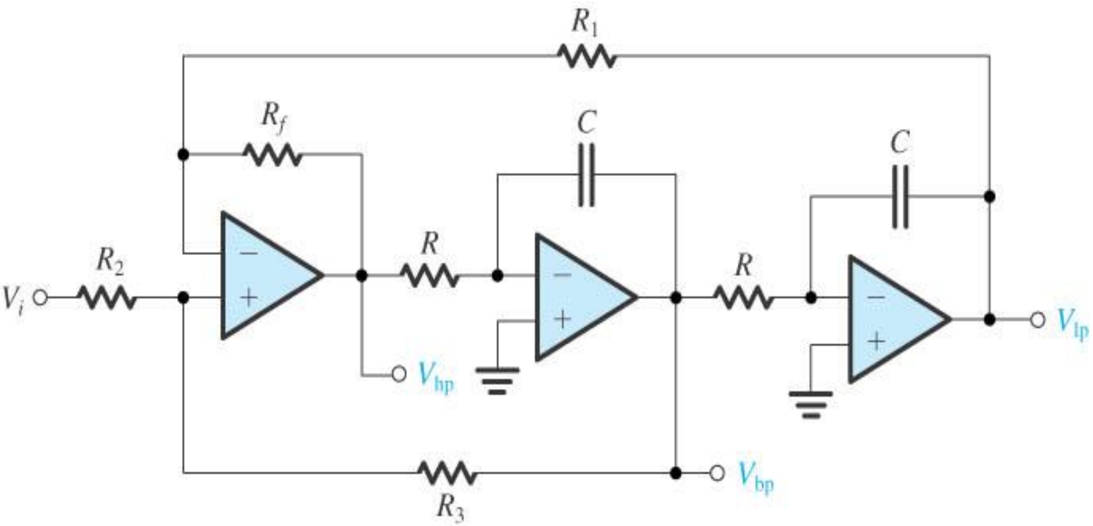
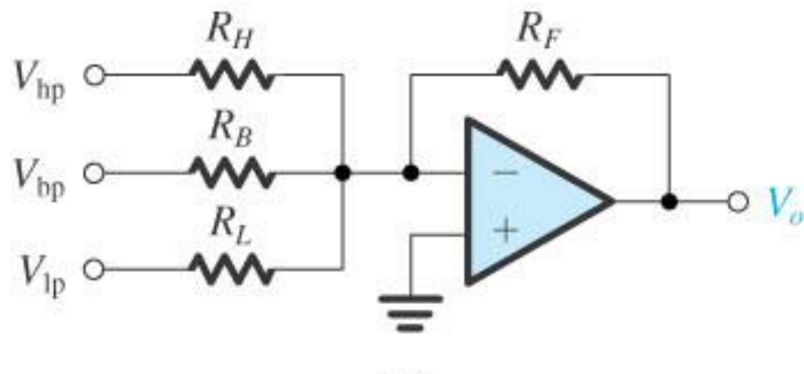
How about All-Pass Filter?

Can be realized by linear combination of V_{hp}, V_{bp}, V_{lp}



KHN



(b)

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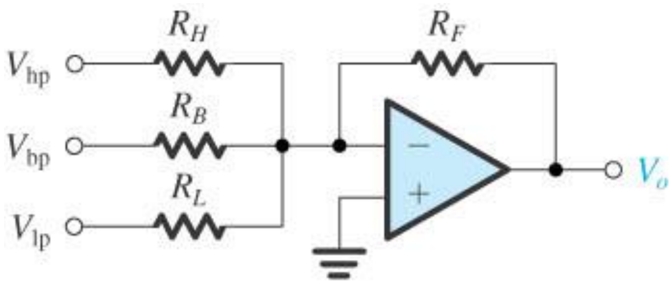
All-Pass Filters



(b)

$$\mathbf{V}_o = -\left(\frac{R_F}{R_H}\mathbf{V}_{\text{hp}} + \frac{R_F}{R_B}\mathbf{V}_{\text{bp}} + \frac{R_F}{R_L}\mathbf{V}_{\text{lp}}\right)$$

$$\mathbf{V}_{\text{hp}} = \frac{Ks^2}{s^2 + s(\omega_0/Q) + \omega_0^2}\mathbf{V}_{\text{i}}$$

$$\mathbf{V}_{\text{bp}} = (-\frac{\omega_0}{s})\mathbf{V}_{\text{hp}} = \frac{-K\omega_0 s}{s^2 + s(\omega_0/Q) + \omega_0^2}\mathbf{V}_{\text{i}}$$

$$\mathbf{V}_{\text{lp}} = (\frac{\omega_0{}^2}{s^2})\mathbf{V}_{\text{hp}} = \frac{K\omega_0{}^2}{s^2 + s(\omega_0/Q) + \omega_0^2}\mathbf{V}_{\text{i}}$$

$$\frac{\mathbf{V}_o}{\mathbf{V}_i} = -\frac{(R_F/R_H)Ks^2 - (R_F/R_B)K\omega_0 s + (R_F/R_L)K\omega_0^2}{s^2 + s(\omega_0/Q) + \omega_0^2}$$

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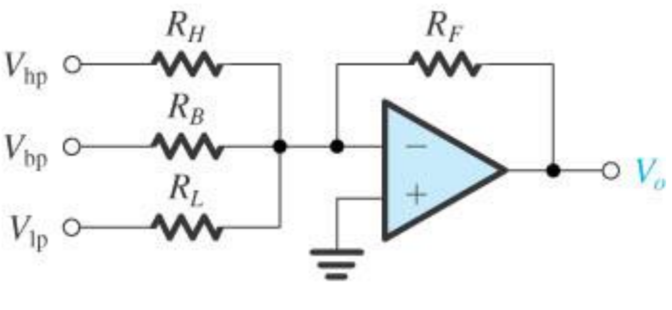
Lect. 20: Two-Integrator-Loop Biquad

How about All-Pass Filters?



(b)

$$\frac{V_o}{V_i} = -K\frac{(R_F/R_H)s^2 - (R_F/R_B)\omega_0 s + (R_F/R_L)\omega_0^2}{s^2 + s(\omega_0/Q) + \omega_0^2}$$

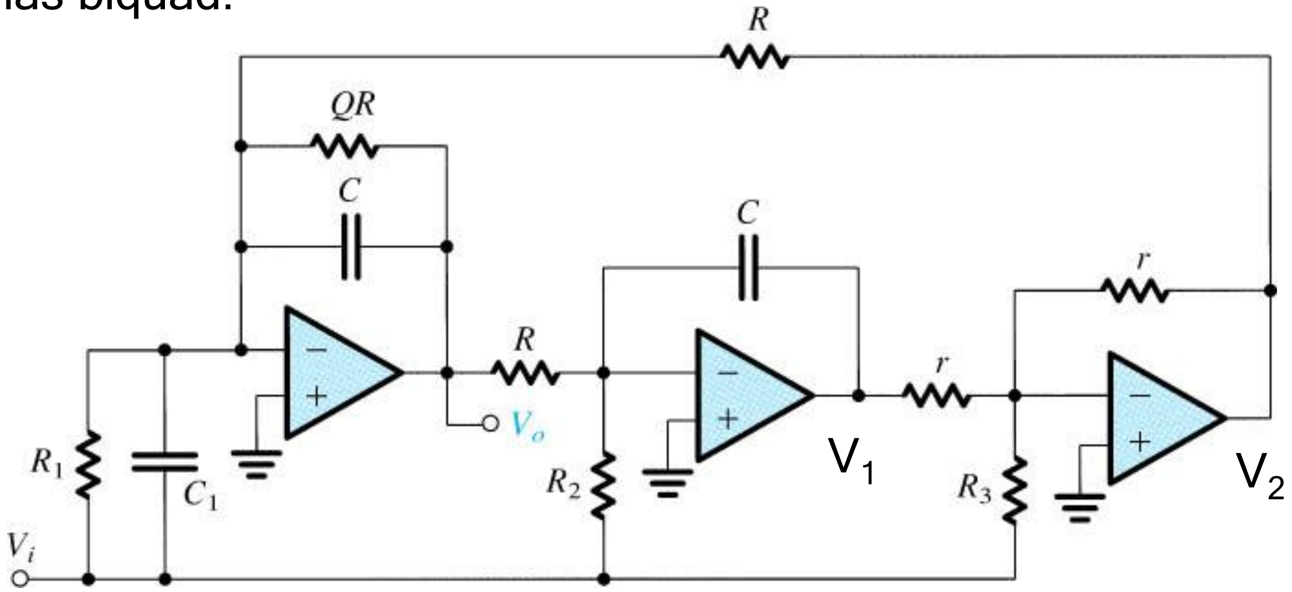
All-Pass Filter $T(s) = a_2 \dfrac{s^2 - s\dfrac{\omega_0}{Q} + \omega_0^2}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$

$$\frac{R_F}{R_H} = 1, \quad \frac{R_F}{R_B} = \frac{1}{Q}, \quad \frac{R_F}{R_L} = 1$$

Lect. 20: Two-Integrator-Loop Biquad

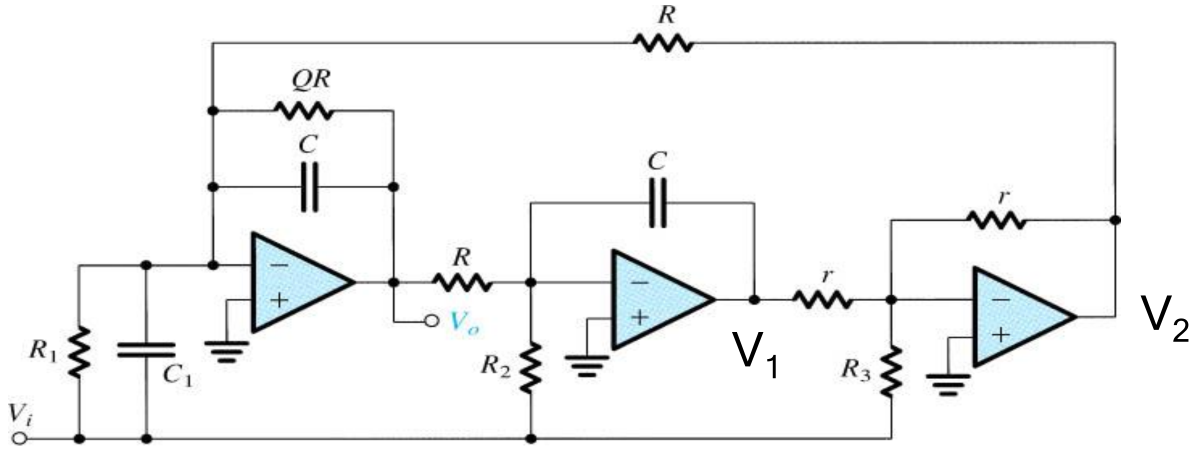
There are several Biquads

Tow-Thomas biquad:



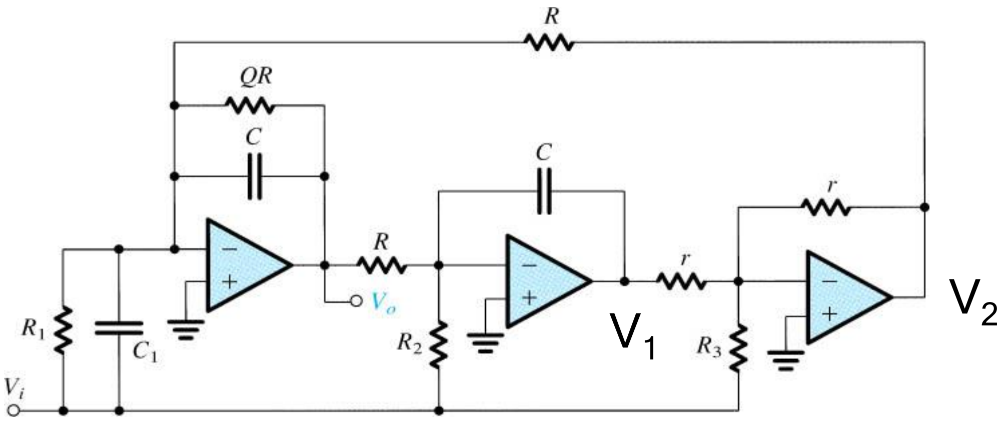
$$V_o = -\left(\frac{V_i}{R_1 // \frac{1}{sC_1}} + \frac{V_2}{R} \right) (QR // \frac{1}{sC}) \qquad V_1 = -\left(\frac{V_o}{R} + \frac{V_i}{R_2} \right) \frac{1}{sC} \qquad V_2 = -\left(\frac{V_i}{R_3} + \frac{V_1}{r} \right) r$$

Tow-Thomas biquad



$$\frac{\mathbf{V_o}}{\mathbf{V_i}} = -\frac{s^2\left(\frac{C_1}{C}\right) + s\frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right) + \frac{1}{C^2RR_2}}{s^2 + s\frac{1}{QCR} + \frac{1}{C^2R^2}} \qquad \omega_0 = \frac{1}{CR}$$

Lect. 20: Two-Integrator-Loop Biquad



For LP $$T(s) = \frac{a_0}{s^2 + s\frac{\omega_0}{Q} + \omega_0^2}$$

$$C_1 = 0 \qquad R_1 = \infty, \quad R_3 = \infty$$

DC Gain: $\frac{R}{R_2}$

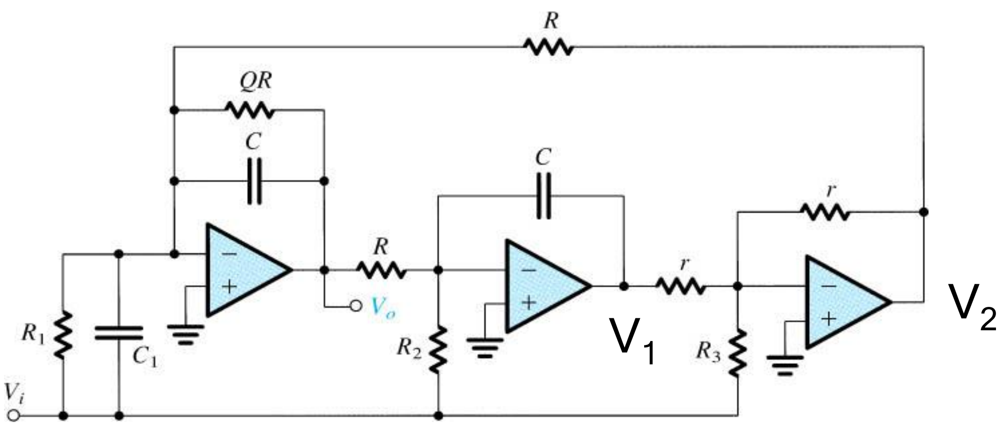
For HP $$T(s) = \frac{a_2 s^2}{s^2 + s\frac{\omega_0}{Q} + \omega_0^2}$$

$$\frac{V_o}{V_i} = -\frac{s^2\left(\frac{C_1}{C}\right) + s\frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right) + \frac{1}{C^2 RR_2}}{s^2 + s\frac{1}{QCR} + \frac{1}{C^2R^2}}$$

$$R_1 = \infty, \quad R_2 = \infty, \quad R_3 = \infty$$

HF Gain: $\frac{C_1}{C}$

Lect. 20: Two-Integrator-Loop Biquad



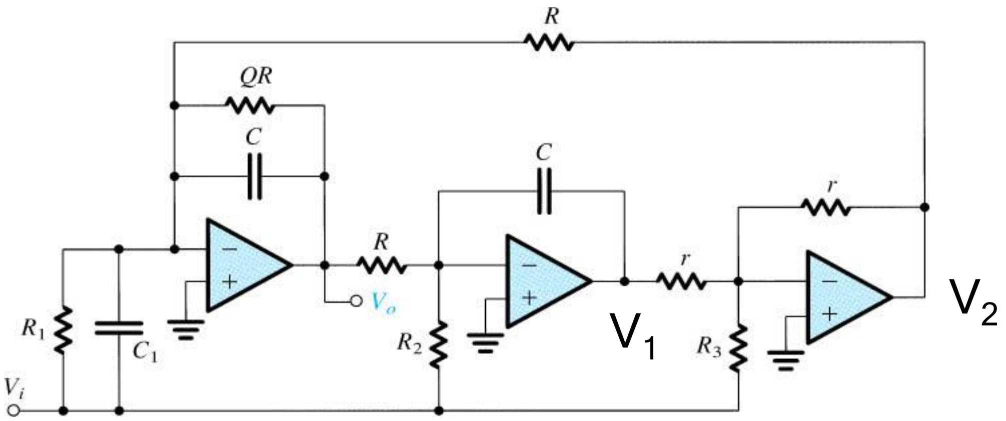
For BP $T(s) = \dfrac{a_1 s}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$

$$C_1 = 0 \qquad R_2 = \infty$$

$$a_1 = \frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right)$$

$$\frac{\mathbf{V}_o}{\mathbf{V}_i} = -\frac{s^2\left(\dfrac{C_1}{C}\right) + s\dfrac{1}{C}\left(\dfrac{1}{R_1} - \dfrac{r}{RR_3}\right) + \dfrac{1}{C^2RR_2}}{s^2 + s\dfrac{1}{QCR} + \dfrac{1}{C^2R^2}}$$

Lect. 20: Two-Integrator-Loop Biquad



For AP

$$T(s) = a_2 \frac{s^2 - s\frac{\omega_0}{Q} + \omega_0^2}{s^2 + s\frac{\omega_0}{Q} + \omega_0^2}$$

$$C_1 = C$$

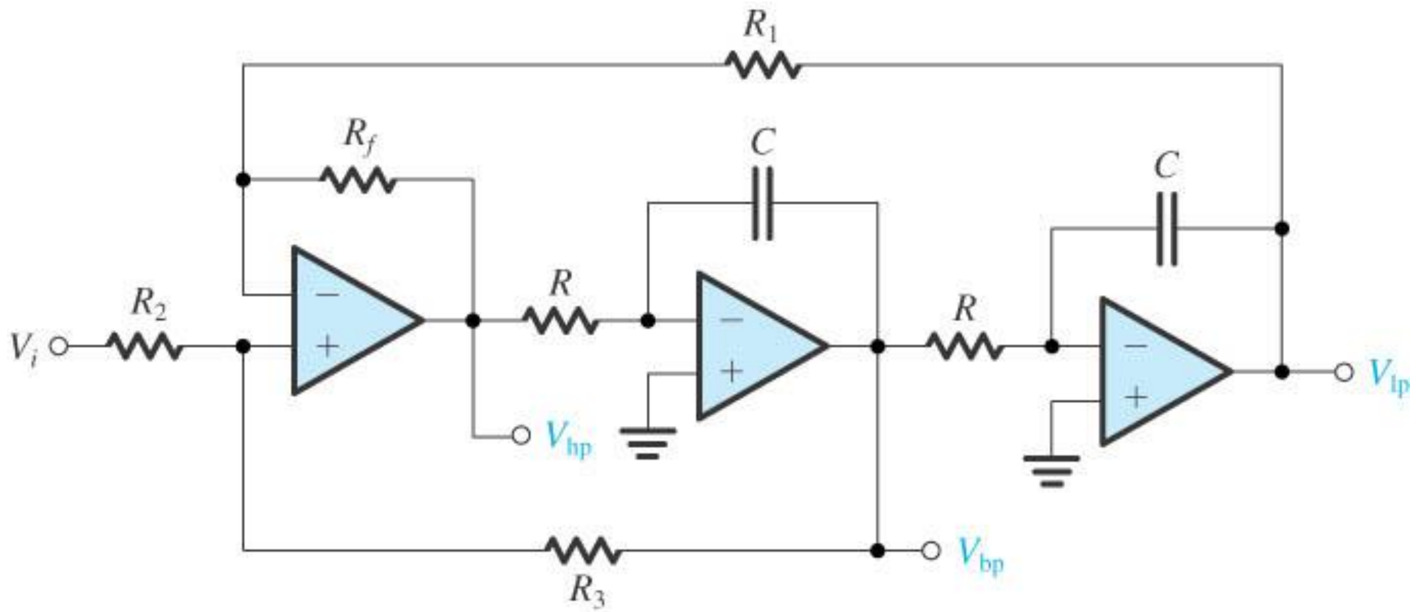
$$R_1 = \infty \qquad R_3 = Qr$$

$$R_2 = R$$

$$\frac{\mathbf{V}_o}{\mathbf{V}_i} = -\frac{s^2\left(\frac{C_1}{C}\right) + s\frac{1}{C}\left(\frac{1}{R_1} - \frac{r}{RR_3}\right) + \frac{1}{C^2RR_2}}{s^2 + s\frac{1}{QCR} + \frac{1}{C^2R^2}}$$

Lect. 20: Two-Integrator-Loop Biquad

Homework(1) Determine $V_{hp}(s)/V_i(s)$, $V_{bp}(s)/V_i(s)$, $V_{lp}(s)/V_i(s)$



(a)

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Homework(2): Determine $V_o(s)/V_i(s)$