Lect. 17: Two-Integrator-Loop Biquad (S&S 12.7)

One circuit configuration for several different second-order filters?

➔ Two-integrator-loop biquad (biquad)

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

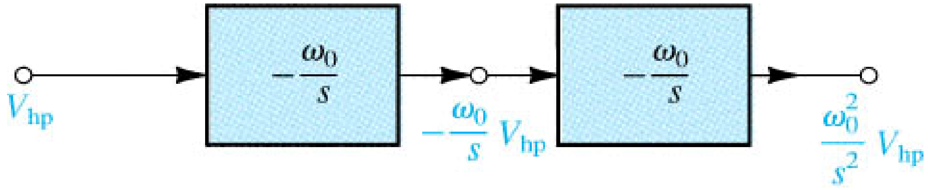
$$\mathbf{V}_{\text{hp}} + \frac{1}{Q}\left(\frac{\omega_0}{s}\mathbf{V}_{\text{hp}}\right) + \left(\frac{\omega_0^2}{s^2}\mathbf{V}_{\text{hp}}\right) = K\mathbf{V}_i$$

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

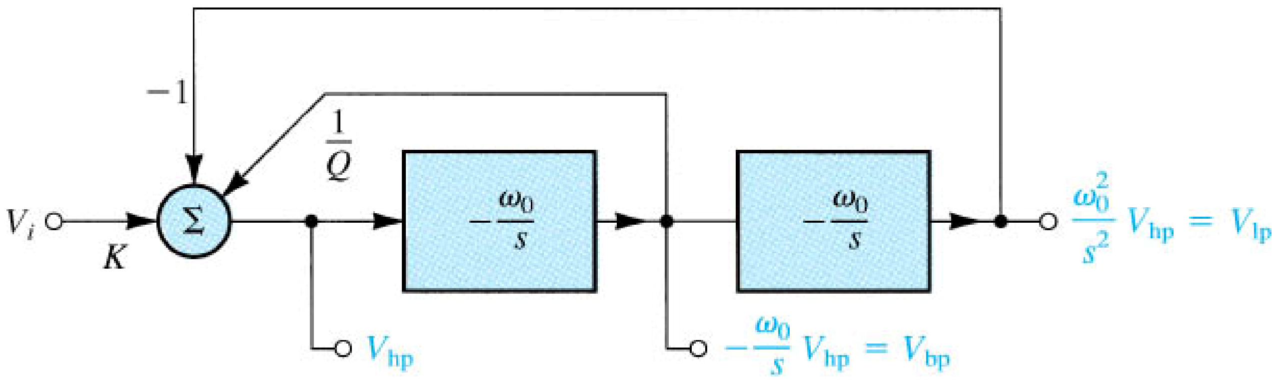
Lect. 17: Two-Integrator-Loop Biquad

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

Express the above equation graphically ➔ block diagram

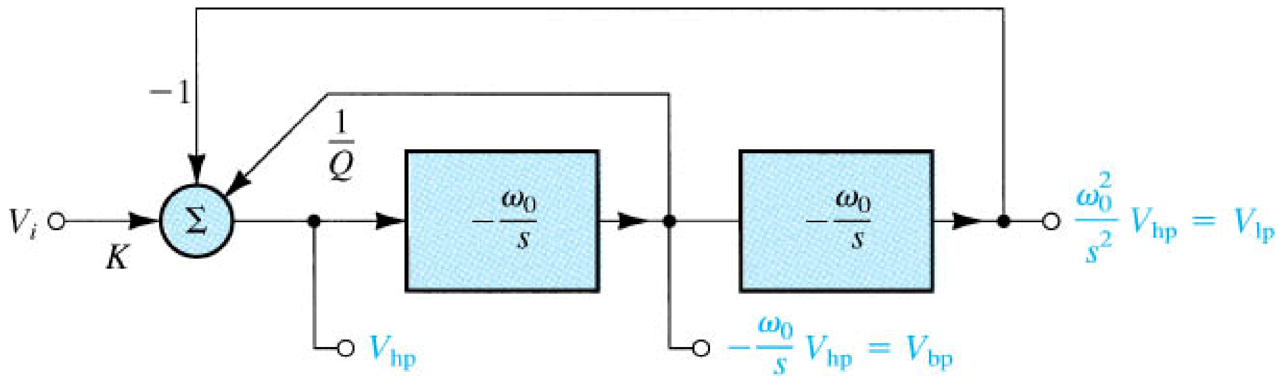


(a)



(c)

Lect. 17: Two-Integrator-Loop Biquad



(c)

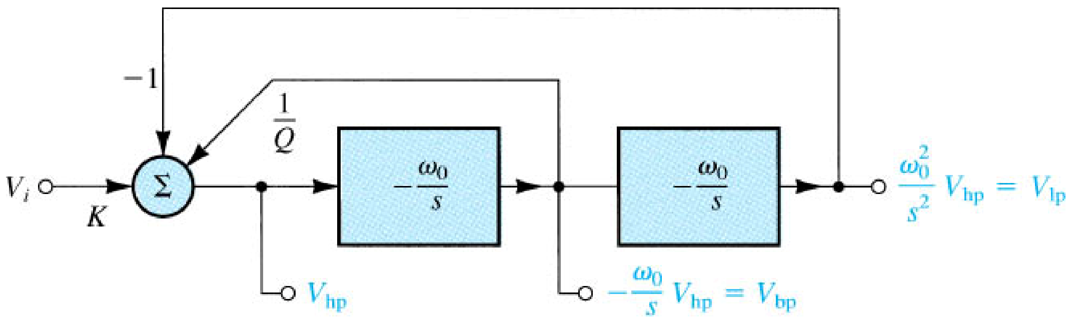
Since $$\frac{V_{hp}}{V_i} = \frac{Ks^2}{s^2 + s(\omega_0/Q) + \omega_0^2},$$

$$(-\omega_0/s)\frac{V_{hp}}{V_i} = -\frac{K\omega_0 s}{s^2 + s(\omega_0/Q) + \omega_0^2} \quad \text{BP}$$

$$(\omega_0^2/s^2)\frac{V_{hp}}{V_i} = \frac{K\omega_0^2}{s^2 + s(\omega_0/Q) + \omega_0^2} \quad \text{LP}$$

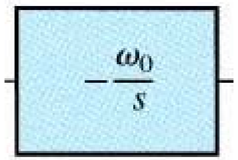
Biquad ➔ Universal Active Filter

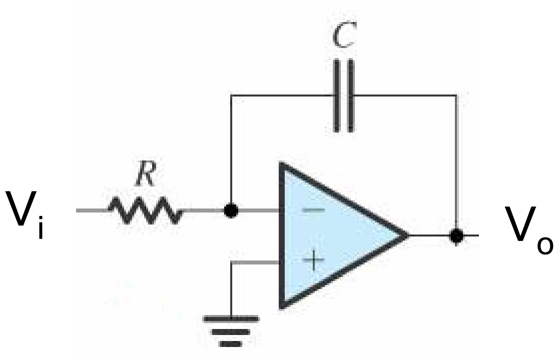
Lect. 17: Two-Integrator-Loop Biquad



(c)

How to implement biquad?



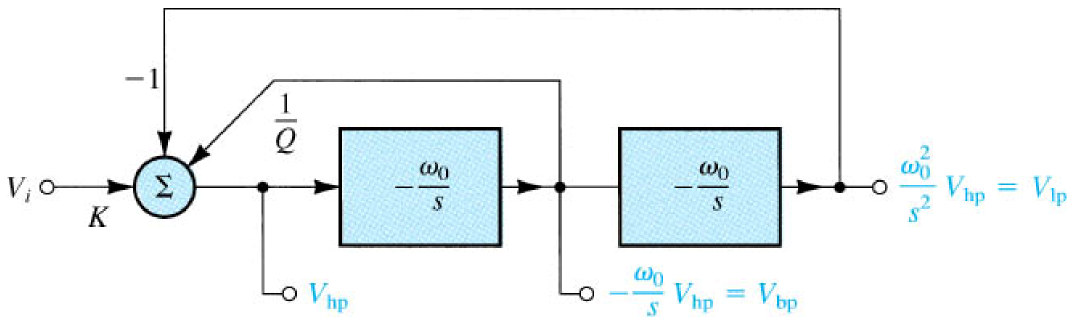


$$V_o = -\frac{V_i}{R} \cdot \frac{1}{sC}$$

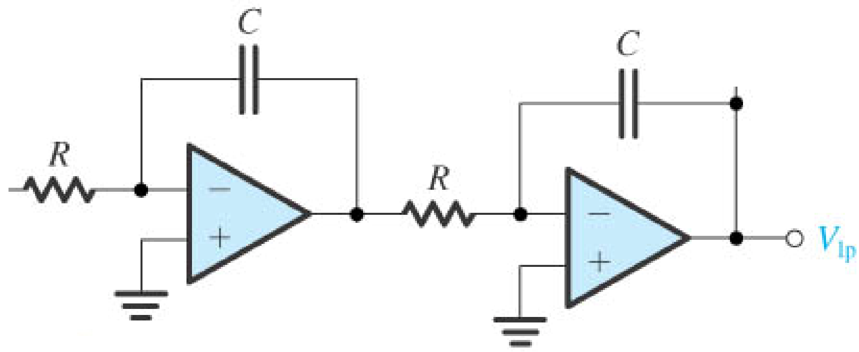
$$\frac{V_o}{V_i} = -\frac{1}{RCs} = -\frac{\omega_0}{s}$$

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

Lect. 17: Two-Integrator-Loop Biquad



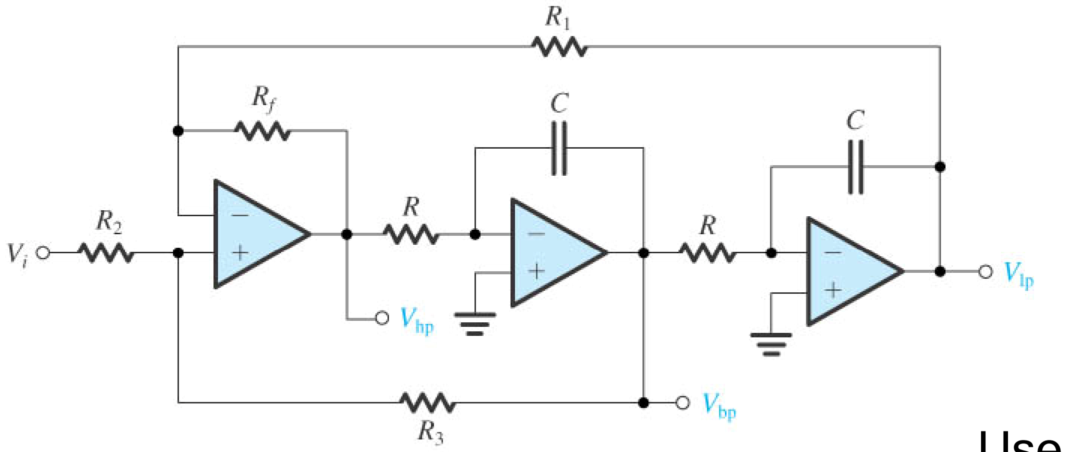
(c)



(a)

Lect. 17: Two-Integrator-Loop Biquad

Kerwin-Huelsman-Newcomb (KHN) biquad



(a)

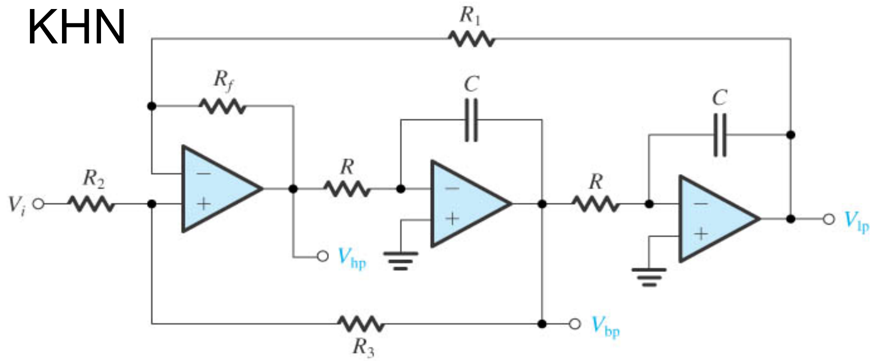
Use superposition (V_i, V_{bp}, V_{lp})

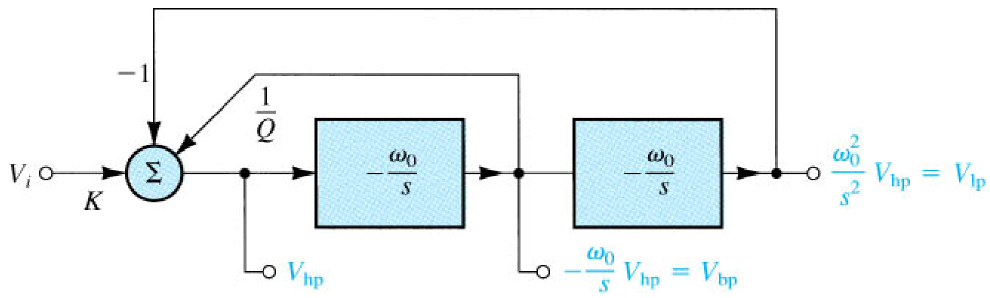
$$\mathbf{V}_{hp} = \frac{R_3}{R_2 + R_3}\left(\frac{R_1 + R_f}{R_1}\right)\mathbf{V}_i + \frac{R_2}{R_2 + R_3}\left(1 + \frac{R_f}{R_1}\right)\mathbf{V}_{bp} - \frac{R_f}{R_1}\mathbf{V}_{lp}$$

➔ Weighted sum of V_i, V_{bp}, V_{lp}

Lect. 17: Two-Integrator-Loop Biquad

KHN





(c)

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

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

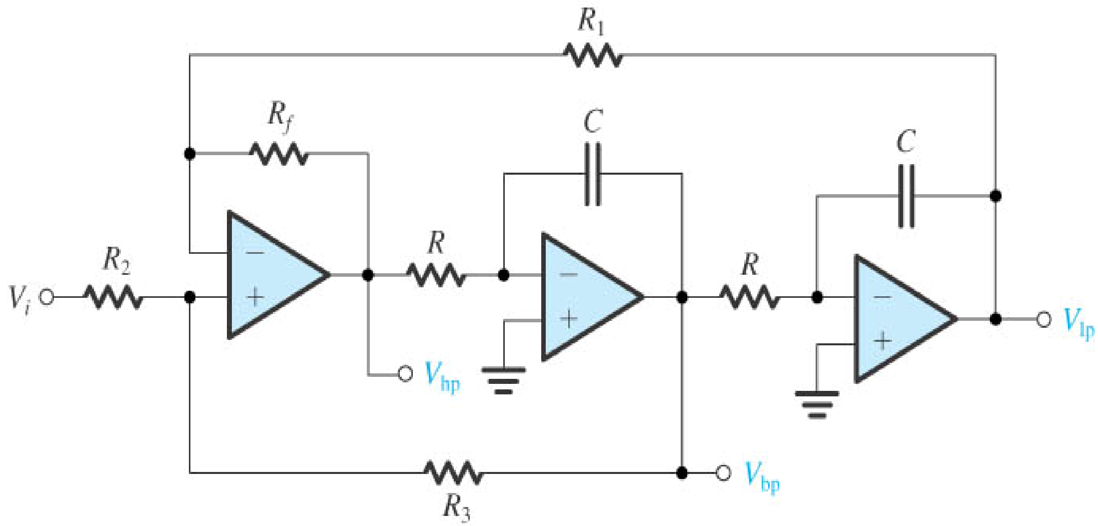
$$= \frac{R_3}{R_2+R_3}\left(\frac{R_1+R_f}{R_1}\right)\mathbf{V}_i + \frac{R_2}{R_2+R_3}\left(1+\frac{R_f}{R_1}\right)\left(-\frac{\omega_0}{s}\right)\mathbf{V}_{hp} - \frac{R_f}{R_1}\left(-\frac{\omega_0^2}{s^2}\right)\mathbf{V}_{hp}$$

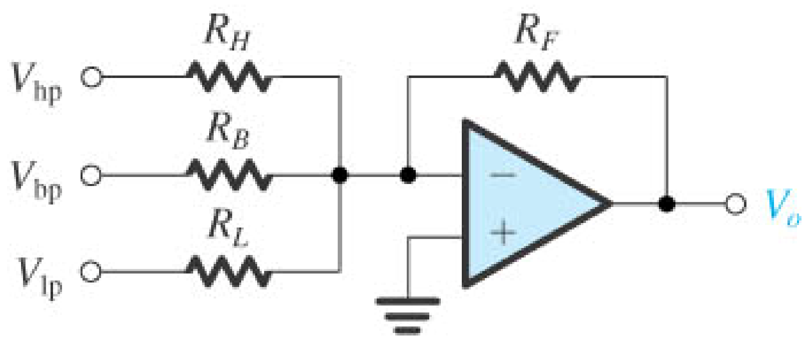
$$\therefore R_f/R_1 = 1 \qquad \frac{2R_2}{R_2+R_3} = \frac{1}{Q} \qquad \therefore Q = \frac{R_2+R_3}{2R_2} \qquad K = \frac{2R_3}{R_2+R_3} = 2 - \frac{1}{Q}$$

ω_0=?

Lect. 17: Two-Integrator-Loop Biquad

How about Notch, All-Pass Filters?

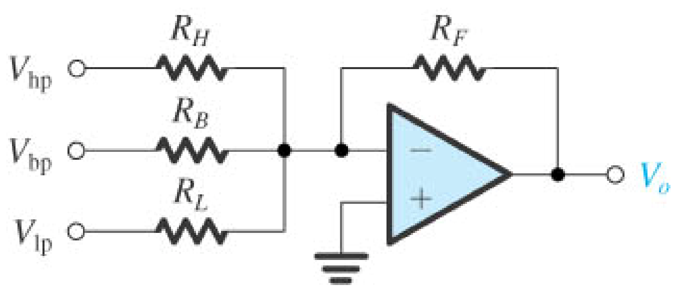




(b)

Lect. 17: Two-Integrator-Loop Biquad

How about Notch, All-Pass Filters?



(b)

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

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

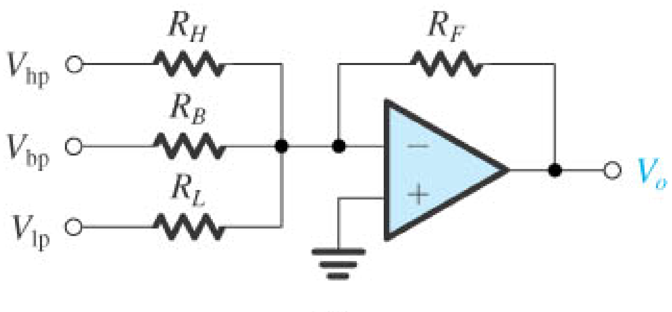
$$\mathbf{V}_{bp} = (-\frac{\omega_0}{s})\mathbf{V}_{hp} = \frac{-K\omega_0 s}{s^2 + s(\omega_0/Q) + \omega_0^2}\mathbf{V}_i$$

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

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

Lect. 17: Two-Integrator-Loop Biquad

How about Notch, All-Pass Filters?



(b)

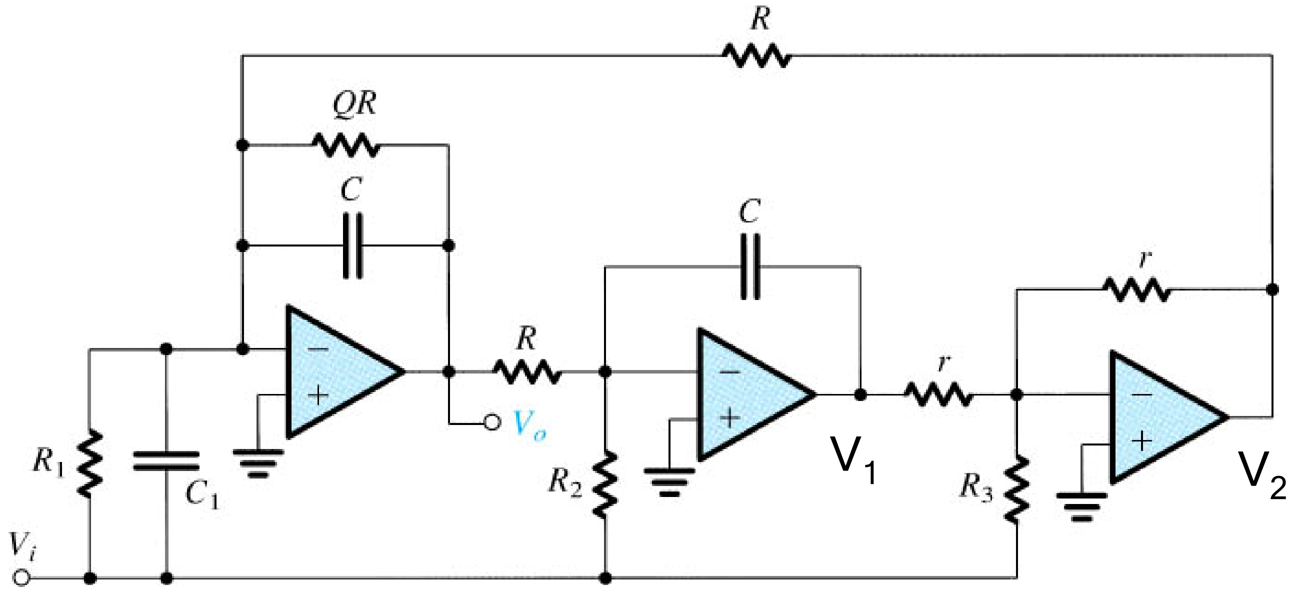
$$\frac{\mathbf{V}_o}{\mathbf{V}_i} = -K\frac{(R_F/R_H)s^2 - (R_F/R_B)\omega_0 s + (R_F/R_L)\omega_0^2}{s^2 + s(\omega_0/Q) + \omega_0^2}$$

Notch Filter: $T(s) = a_2 \dfrac{s^2 + \omega_0^2}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$ $\qquad \dfrac{R_F}{R_H} = 1, \quad R_B = \infty, \quad \dfrac{R_F}{R_L} = 1$

All-Pass Filter $T(s) = a_2 \dfrac{s^2 - s\dfrac{\omega_0}{Q} + \omega_0^2}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$ $\qquad \dfrac{R_F}{R_H} = 1, \quad \dfrac{R_F}{R_B} = \dfrac{1}{Q}, \quad \dfrac{R_F}{R_L} = 1$

Lect. 17: Two-Integrator-Loop Biquad

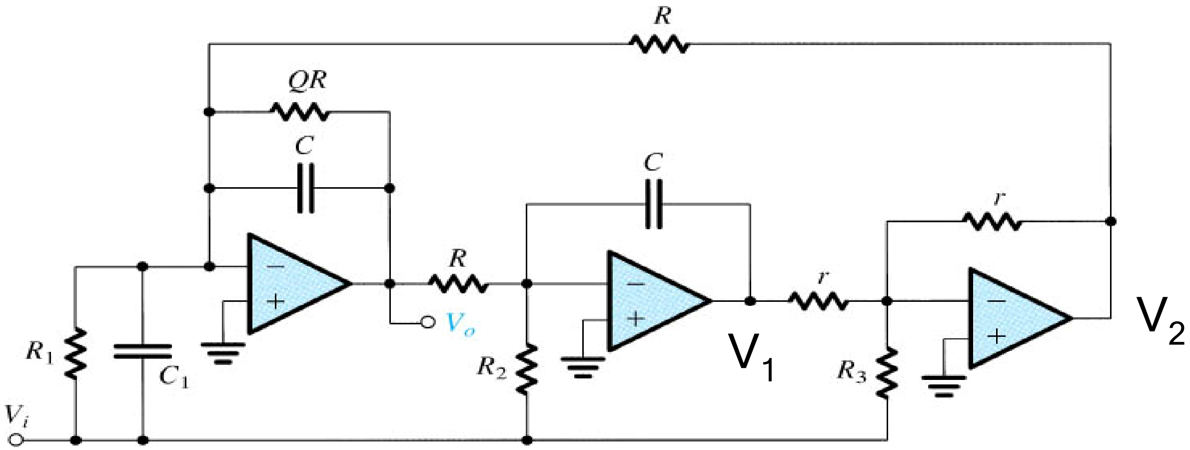
Other types of biquads? One type of Tow-Thomas biquad



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

Lect. 17: Two-Integrator-Loop Biquad

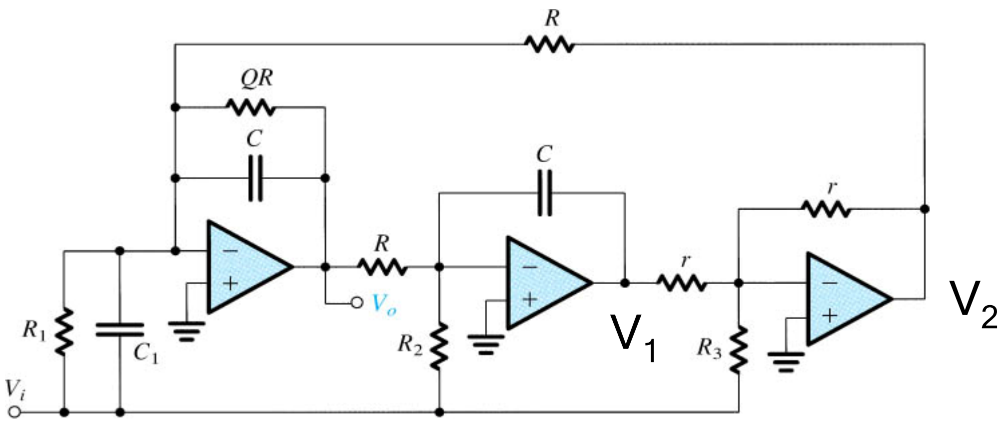
Tow-Thomas biquad



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

$$\omega_0 = CR$$

Lect. 17: Two-Integrator-Loop Biquad



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

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

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

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

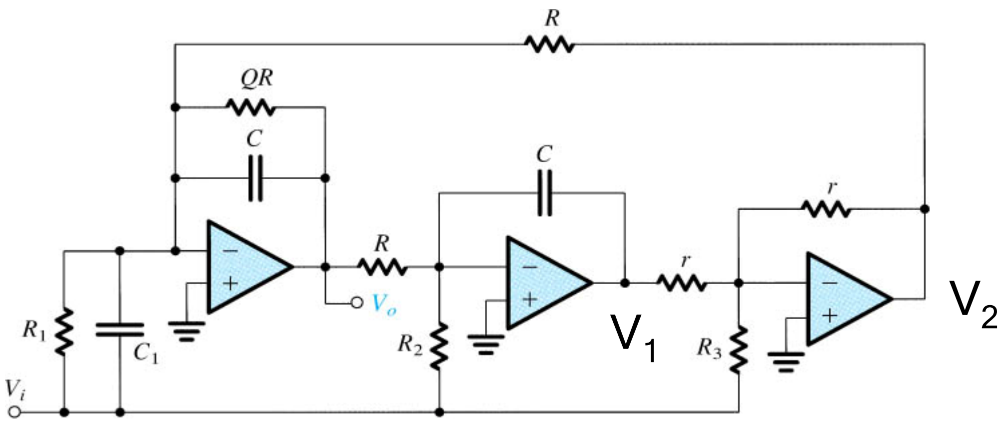
For HP $T(s) = \dfrac{a_2 s^2}{s^2 + s\dfrac{\omega_0}{Q} + \omega_0^2}$

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

HF Gain: $\dfrac{C_1}{C_2}$

W.-Y. Choi

Lect. 17: Two-Integrator-Loop Biquad



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

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

$$\text{HF Gain: } \frac{C_1}{C_2}$$

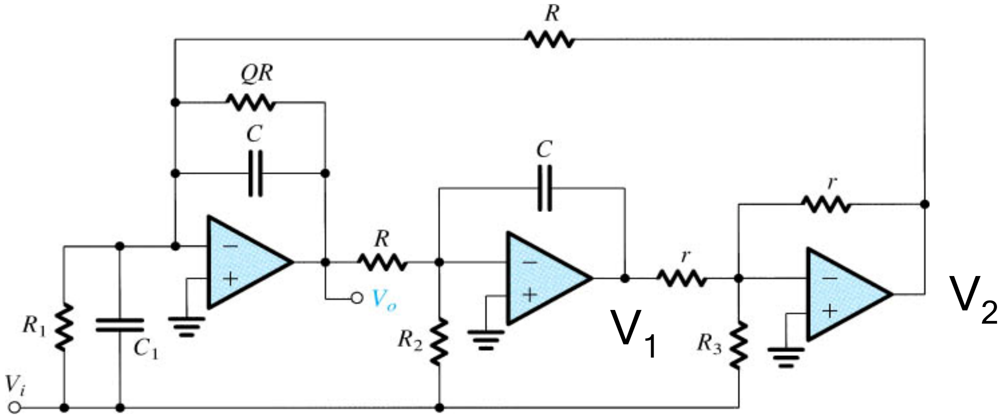
$$\frac{\mathbf{V}_o}{\mathbf{V}_i} = -\frac{s^2\left(\dfrac{C_1}{C}\right) + s\dfrac{1}{C}\left(\dfrac{1}{R_1} - \dfrac{r}{RR_3}\right) + \dfrac{1}{C^2RR_2}}{s^2 + s\dfrac{1}{QCR} + \dfrac{1}{C^2R^2}}$$

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

$$R_1 = \infty, \; R_3 = \infty$$

W.-Y. Choi

Lect. 17: Two-Integrator-Loop Biquad



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

(For the case of a_2=1)

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

$$C_1 = C$$

$$R_1 = \infty \quad R_3 = Qr$$

$$R_2 = R$$