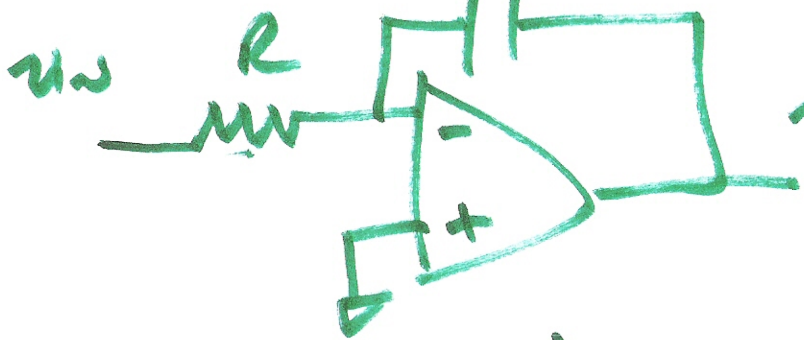
ECE 615 CMOS mixed-signal circuit design

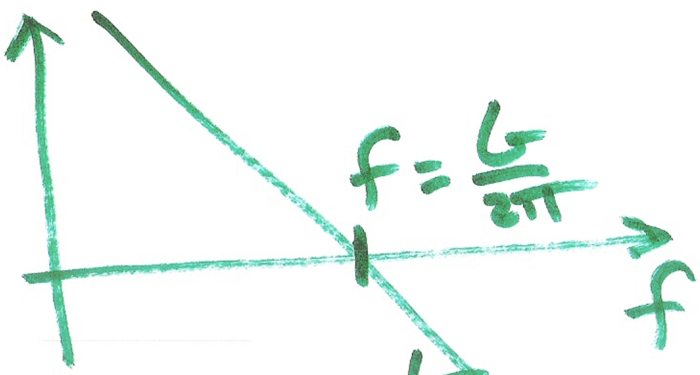
Lecture 9

Sept. 22, 2010

$$G = \frac{-1}{RC}$$

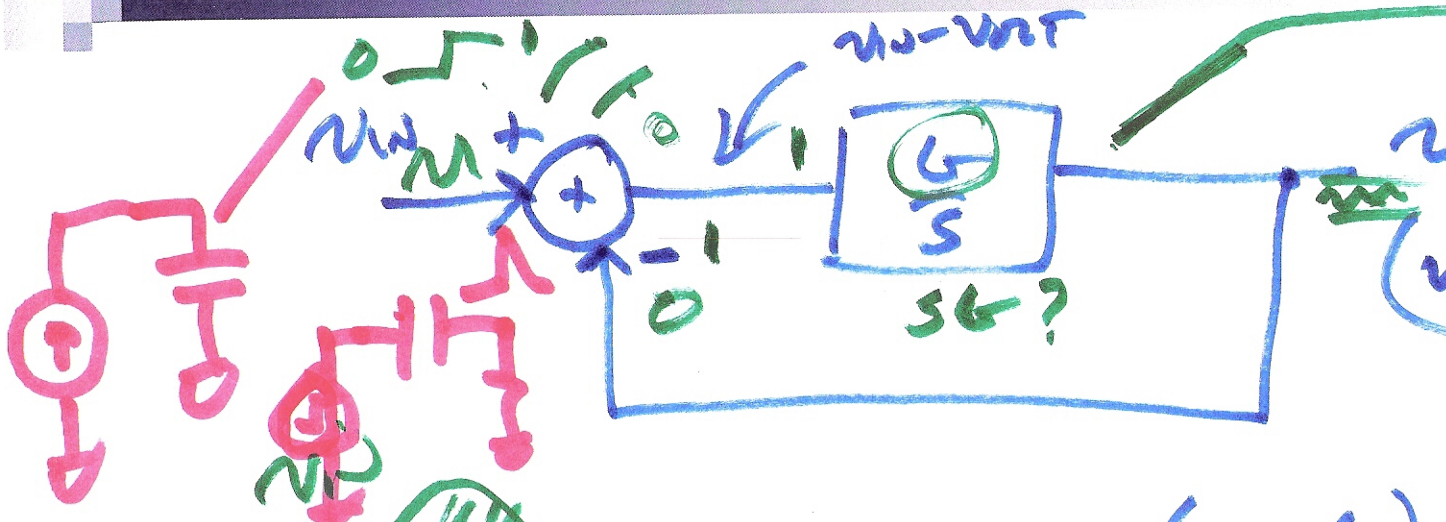


$$20\log\left|\frac{G}{j2\pi f}\right| = \left|\frac{G}{s}\right| = \left|\frac{G}{j\omega}\right|$$

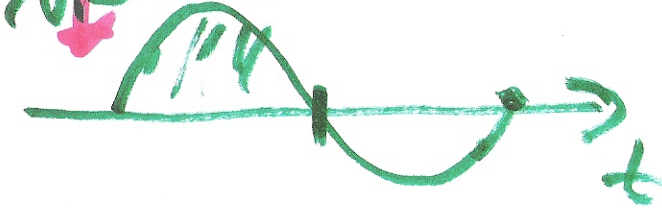


$$1 = \frac{G}{2\pi f}$$

$$\frac{v_{OUT}}{v_{IN}} = \frac{-\frac{1}{j\omega C}}{R} = \frac{-1}{j\omega RC}$$



$$v_{out} = (v_{in} - v_{out})\frac{G}{s}$$



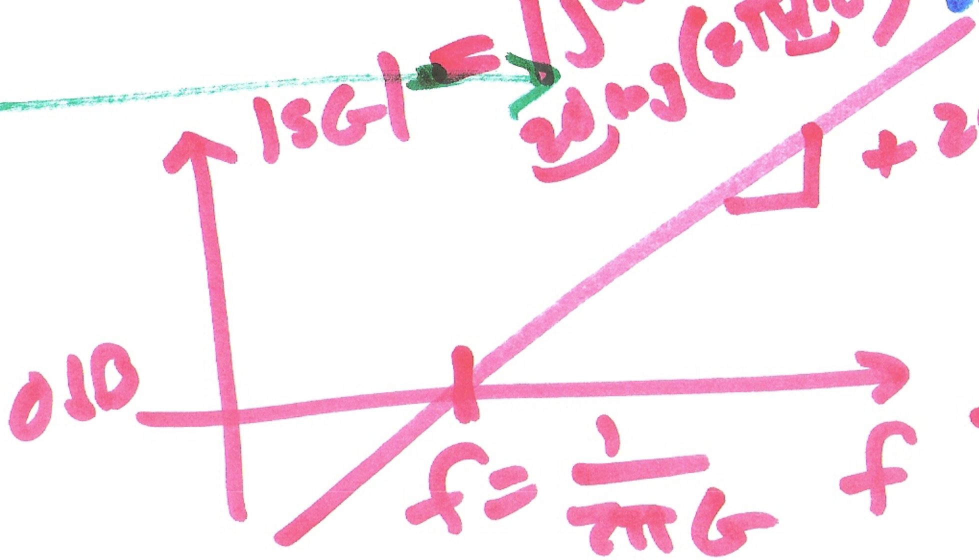
$$v_{out}\left(1 + \frac{G}{s}\right) = v_{in} \cdot \frac{G}{s}$$

$\int v_{in}\,dt$

$$\frac{v_{out}}{v_{in}} = \frac{\frac{G}{s}}{1 + \frac{G}{s}} = \frac{1}{1 + \frac{s}{G}}$$

$|sG| = |j\omega G|$

$20\log(2\pi f \cdot G)$



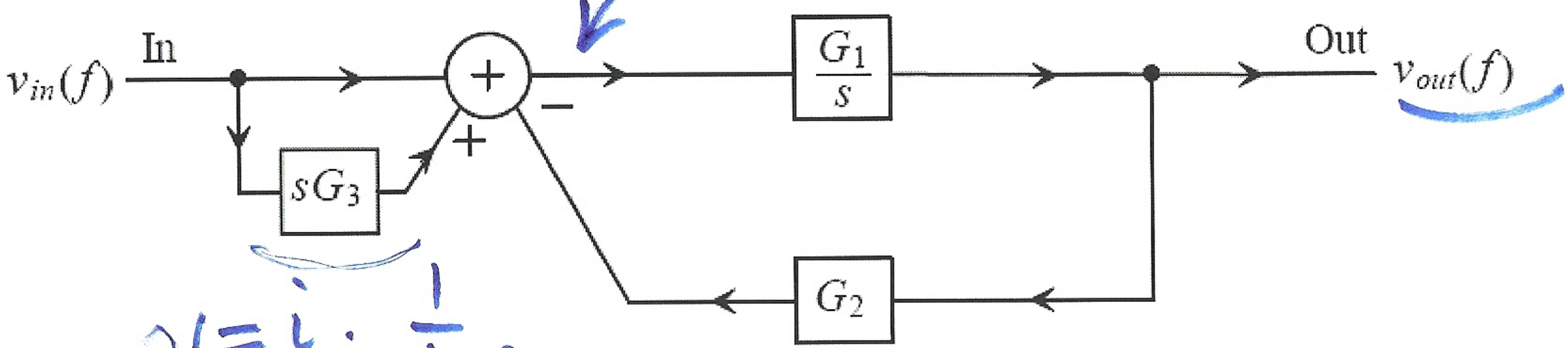
$f = \frac{1}{2\pi G}$

$2\pi f \cdot G = 1$

$f = \frac{1}{2\pi G}$

2)

$v_{in} + sG_3 v_{in} - v_{out} G_2$



$v = i \cdot \frac{1}{j\omega c}$

$sCv = i$

Figure 3.29 Implementation of a bilinear transfer function using an integrator.

$$v_{out} = \frac{G_1}{s}\left(v_{in}(1 + sG_3) - v_{out} \cdot G_2\right)$$

$$v_{out}\left(1 + \frac{G_1 G_2}{s}\right) = v_{in}\left(\frac{G_1}{s} + \frac{\cancel{s} G_1 G_3}{\cancel{s}}\right)$$

$$\frac{v_{out}}{v_{in}} = \frac{\frac{G_1}{s} + G_1 G_3}{1 + \frac{G_1 G_2}{s}} = \frac{1}{G_2} \frac{\frac{G_1}{s} + G_1 G_3}{\frac{1}{G_2} + \frac{G_1}{s}}$$

3)

$$\frac{v_{out}}{v_{in}} = \frac{1 + s/\frac{1}{G_3}}{1 + \frac{s}{G_1 G_2}} \cdot \frac{1}{G_2}$$

$$j2\pi f_{zero} = s_{zero} = -\frac{1}{G_3}, \quad f_{zero} = \frac{1}{2\pi G_3}$$

$$s_{pole} = -G_1 G_2 \qquad f_{pole} = \frac{G_1 G_2}{2\pi}$$

bilinear filter!

4)

$R = \frac{1}{fC}$

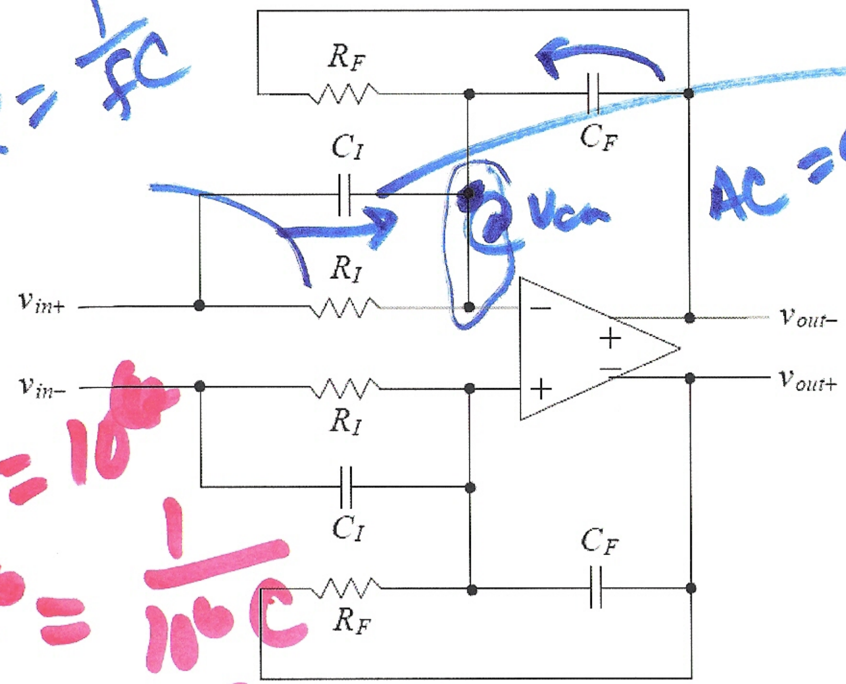


Figure 3.30 Implementation of an active-RC bilinear transfer function filter.

$$G_1 = \frac{1}{R_I C_F}$$

$$\boxed{G_2 = \frac{R_I}{R_F}}$$

$$G_3 = R_I C_I$$

$AC = 0$

$$i = SC_I \cdot V_{in}$$

$$\frac{V_{in}}{R_I} + V_{in} \cdot SC_I + \frac{V_{out}}{R_F} = -V_{out} \cdot SC_F$$

$$V_{out}\left(\frac{1}{R_F} + SC_F\right) = -V_{in}\left(\frac{1}{R_I} + SC_I\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{-\left(\frac{1}{R_I} + SC_I\right)}{\frac{1}{R_F} + SC_F} = -\frac{R_F}{R_I} \cdot \frac{1 + SC_I R_I}{1 + SC_F R_F}$$

$$A_{CL} = \frac{R_F}{R_I} = \frac{1}{G_2}$$

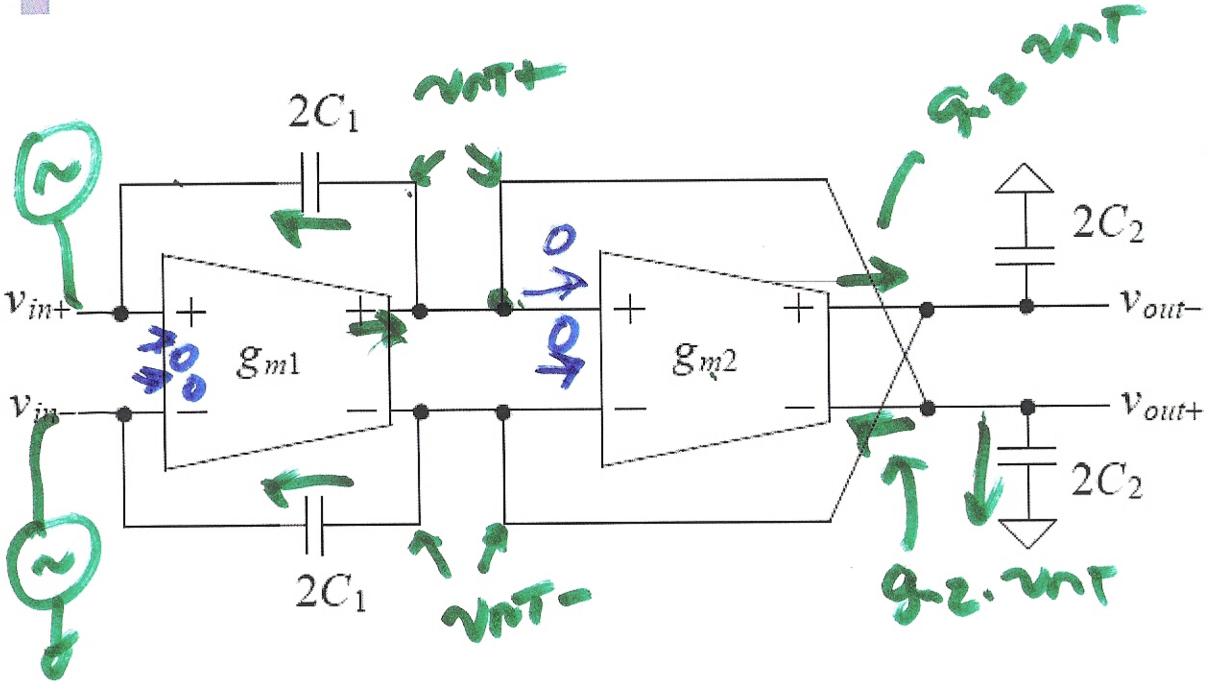
$$f = 10^6$$

$$10^6 = \frac{1}{10^6 C}$$

$$C = 1\,\text{pF}$$

$$f_{zero} = \frac{1}{2\pi R_I C_I}$$

5) $$f_{pole} = \frac{1}{2\pi R_F C_F}$$



$$G_1 = g_{m1}/(C_1 + C_2)$$

$$G_2 = \frac{g_{m2}}{g_{m1}}$$

$$G_3 = \frac{C_1}{g_{m1}}$$

Figure 3.31 Implemention of a bilinear filter using transconductors.

$(v_{out} - v_{in}) \cdot 2C_1 \cdot s = g_{m1} \cdot v_{in} + g_{m2} v_{out}$

$+ \; v_{out} \cdot 2C_2 \cdot s +$

$g_{m2} v_{out}$

RC = time

$C \cdot f = \frac{C}{T} = \frac{1}{R}$

$sC \rightarrow \frac{1}{R}$

$$v_{OUT}\left(2C_1 s + 2C_2 s + g_{m2}\right) = v_{in}\left(2C_1 s + g_{m1}\right)$$

$$\frac{v_{OUT}}{v_{in}} = \frac{2C_1 s + g_{m1}}{(C_1+C_2)2s + g_{m2}} = \frac{g_{m1}}{g_{m2}}\left(\frac{1 + s\cdot\frac{2C_1}{g_{m1}}}{1 + s\cdot\frac{2(C_1+C_2)}{g_{m2}}}\right)$$

2 drops out with fully-diff. signal paths

$$G_2 = \frac{g_{m2}}{g_{m1}}$$

$$G_1 G_2 = \frac{g_{m2}}{2(C_1+C_2)}$$

$$f_{un} = \frac{g_m}{2\pi C_c} = \frac{1}{2\pi \frac{1}{g_m} C_c}$$

$$G_3 = \frac{2C_1}{g_{m1}}$$

$$S_{pole} = \frac{-g_{m2}}{\cancel{2}(C_1+C_2)}$$

$$G_1 = \frac{g_{m1}}{2\cancel{g_{m1}}(C_1+C_2)}$$

$$= \frac{-1}{1/g_{m2}(C_1+C_2)}$$

2)

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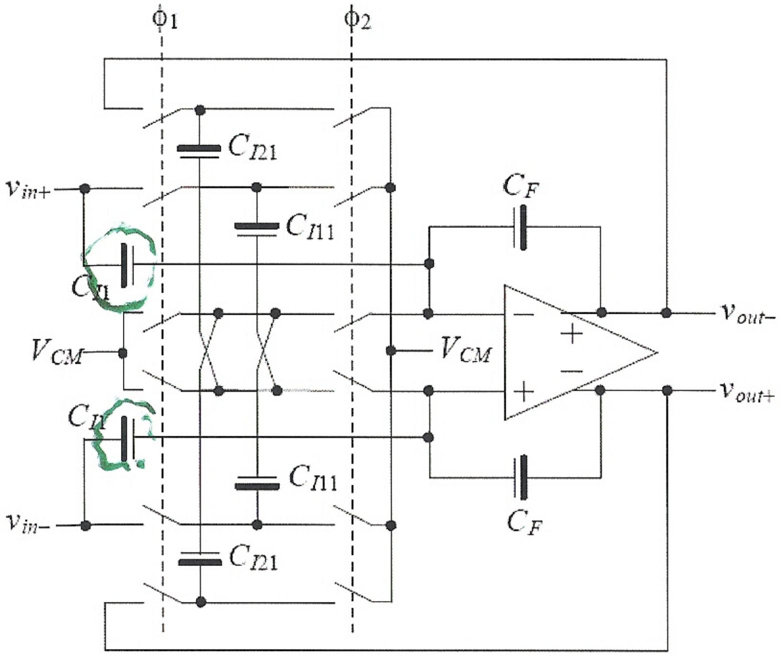


$$G_1 = \frac{C_{I11}}{C_F} \cdot f_s = \frac{1}{C_F \cdot R_{I11}} \qquad R_{I11} = \frac{1}{f_s C_{I11}}$$

$$G_2 = \frac{C_{I21}}{C_{I11}}$$

$$G_3 = \frac{C_{I1}}{C_{I11} \cdot f_s}$$

$$\frac{v_{out}(f)}{v_{in}(f)} = \frac{1}{G_2} \cdot \frac{1 + \frac{s}{1/G_3}}{1 + \frac{s}{G_1 G_2}}$$

Figure 3.32 Implemention of a bilinear filter using switched capacitors.

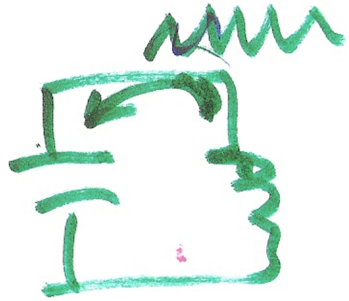
8)

BiQuad

$$\frac{V_{out}}{V_{in}} = \frac{a_2 s^2 + a_1 s + a_0}{s^2 + \left(\frac{2\pi f_0}{Q}\right)s + (2\pi f_0)^2}$$

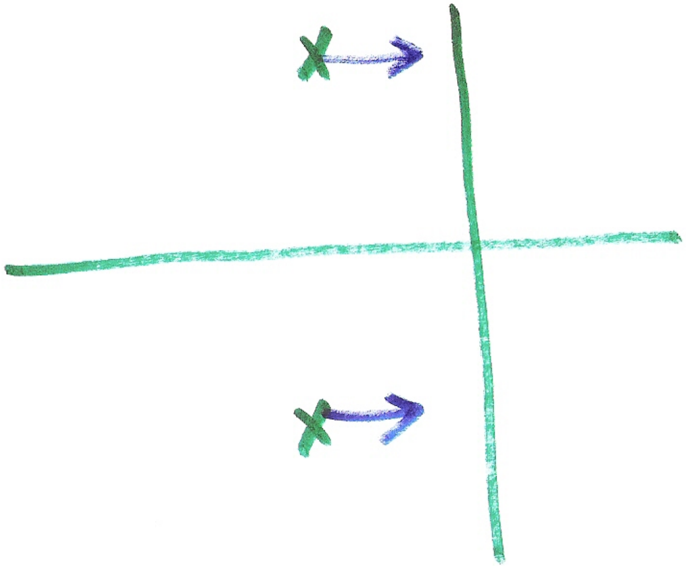
$\omega_0 = 2\pi f_0$

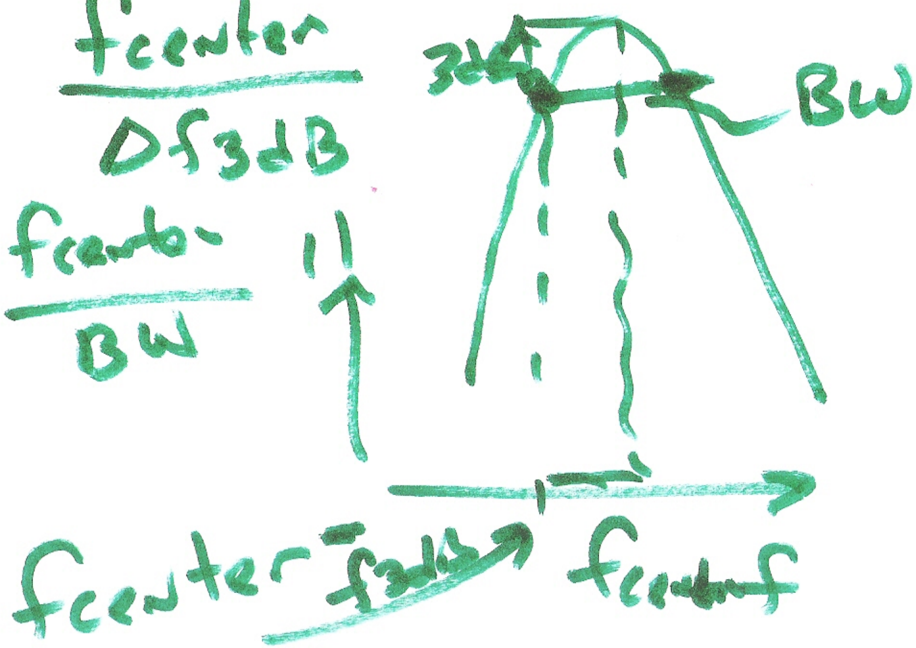
$$Q = \frac{\text{energy stored}}{\text{energy lost}}$$



$$= \frac{f_{center}}{\Delta f_{3dB}}$$

$$= \frac{f_{center}}{BW}$$





$$p_1, p_2 = -\frac{\pi f_0}{Q} \pm \frac{1}{2}\sqrt{\left(\frac{2\pi f_0}{Q}\right)^2 - 4\left(2\pi f_0\right)^2}$$

$$= -\frac{\pi f_0}{Q} + j 2\pi f_0 \sqrt{1 - \left(\frac{1}{2Q}\right)^2}$$

$$\frac{1}{2Q} \geq 1$$

$$1 \geq 2Q$$

$$Q \leq \frac{1}{2}$$

(a)

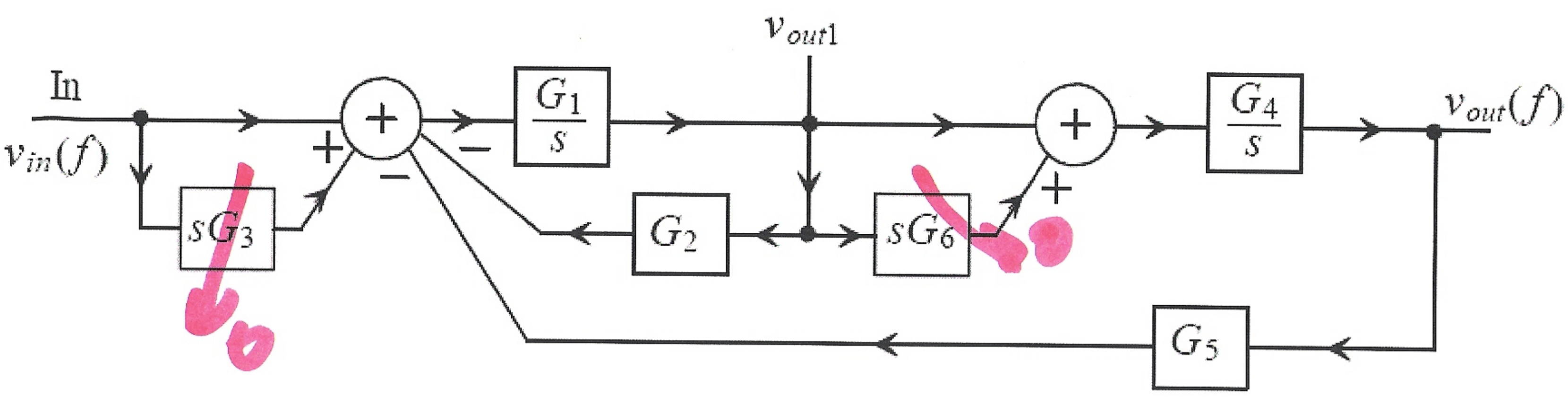
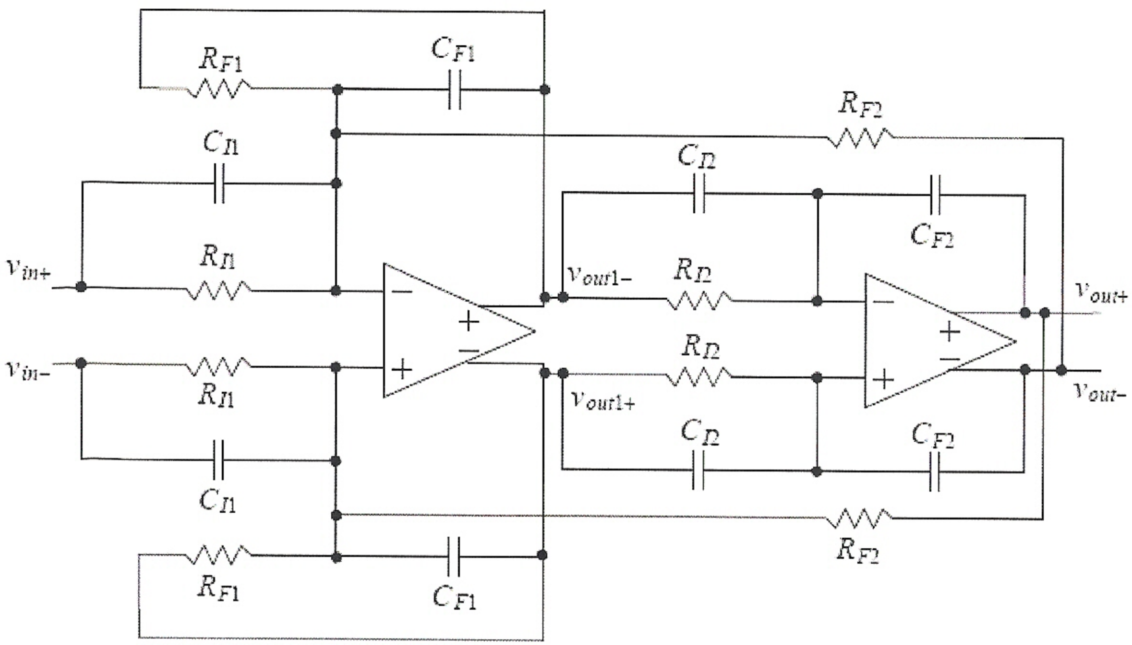


Figure 3.33 Implementation of a biquadratic transfer function using two integrators.

$$(3.70)\qquad \frac{v_{out}}{v_{in}} = \frac{\cancel{s^2 G_1 G_3 G_4 G_6} \to 0 + s(G_1 \cancel{G_3} G_4 + G_1 \cancel{G_4 G_6}) + G_1 G_4}{s^2 + s(G_1 G_2 + G_1 G_4 \cancel{G_5 G_6}) + G_1 G_4 G_5}$$

$$(2\pi f_0)^2 = G_1 G_4 G_5$$

11)



$$G_1 = \frac{1}{R_{I1} C_{F1}} \quad G_2 = \frac{R_{I1}}{R_{F1}} \quad G_3 = R_{I1} C_{I1} \quad G_4 = \frac{1}{R_{I2} C_{F2}} \quad G_5 = \frac{R_{I1}}{R_{F2}} \quad G_6 = R_{I2} C_{I2}$$

$$a_2 = \frac{C_{I1} C_{I2}}{C_{F1} C_{F2}} \qquad a_1 = \frac{C_{I1}}{R_{I2} C_{F1} C_{F2}} + \frac{C_{I2}}{R_{I1} C_{F1} C_{F2}} \qquad a_0 = \frac{1}{R_{I1} C_{F1} R_{I2} C_{F2}}$$

$$\frac{\omega_0}{Q} = \frac{2\pi f_0}{Q} = \frac{1}{R_{F1} C_{F1}} + \frac{C_{I2}}{C_{F1} R_{F2} C_{F2}} \qquad f_0 = \frac{1}{2\pi} \cdot \sqrt{\frac{1}{C_{F1} R_{I2} C_{F2} R_{F2}}}$$

Figure 3.34 Implementation of the active-RC biquadratic transfer function filter.

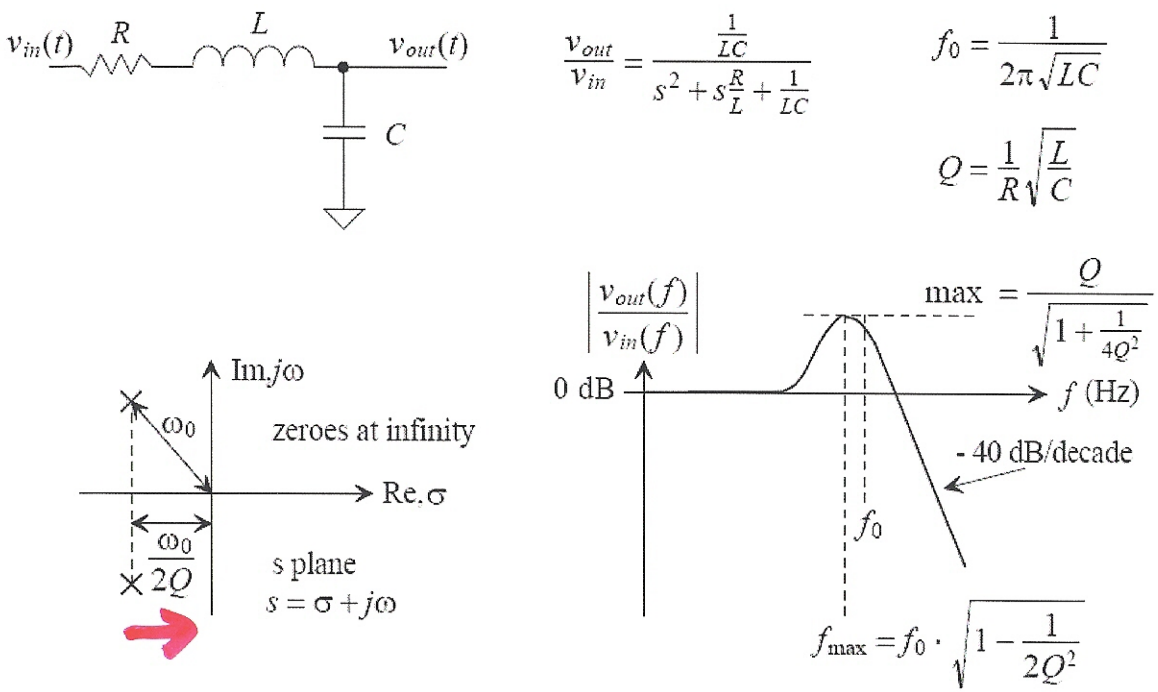


Figure 3.35 Second-order lowpass filter.

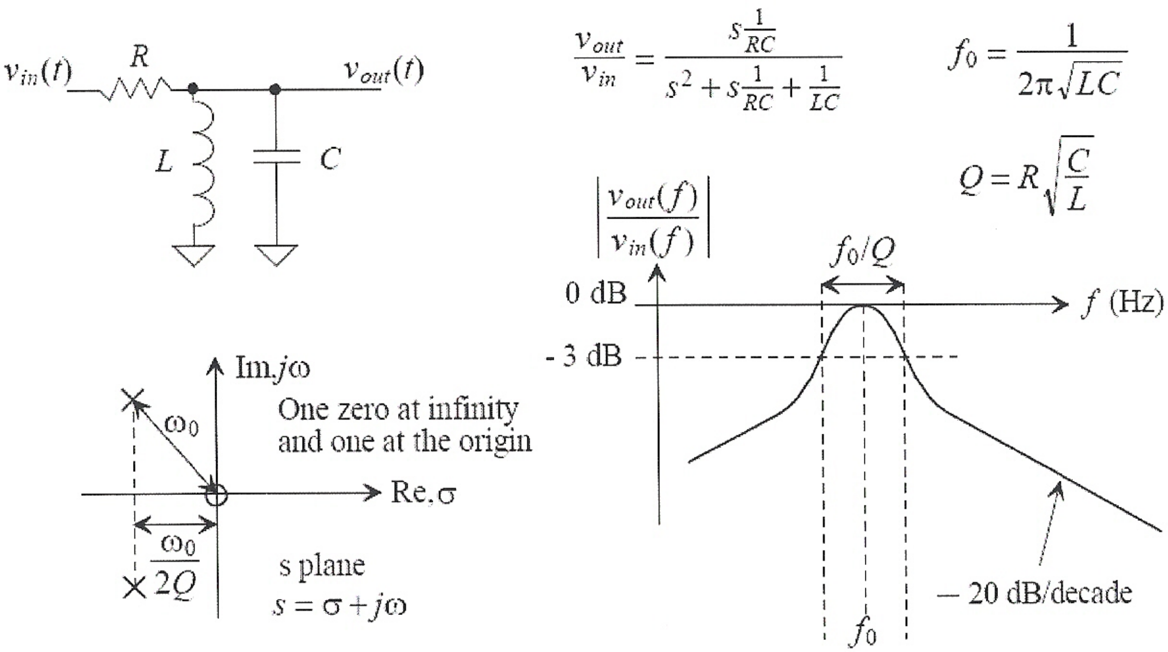


Figure 3.39 Second-order bandpass filter.

14)