MARCH 5, 2009 ECE 615 Mixed-Signal

BOISE STATE UNIVERSITY

Lecture 1 ! Extra !

Sec. 4.3, Analog & digital Filtering.

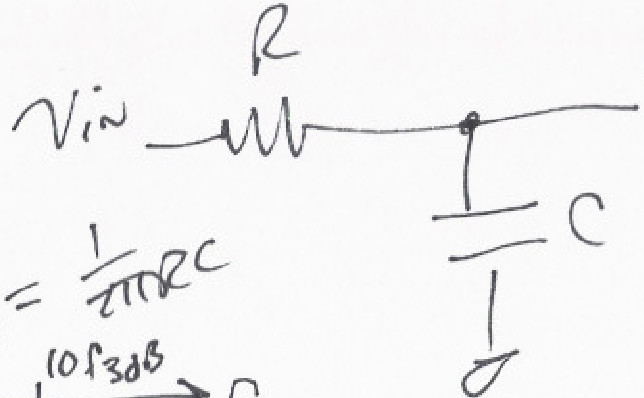
1.2 KHz → 2.4 KHz (1 oct)

Low pass RC

$-6dB \rightarrow \frac{1}{2}$

$+6dB \rightarrow \times 2$

oct → × ÷ 2



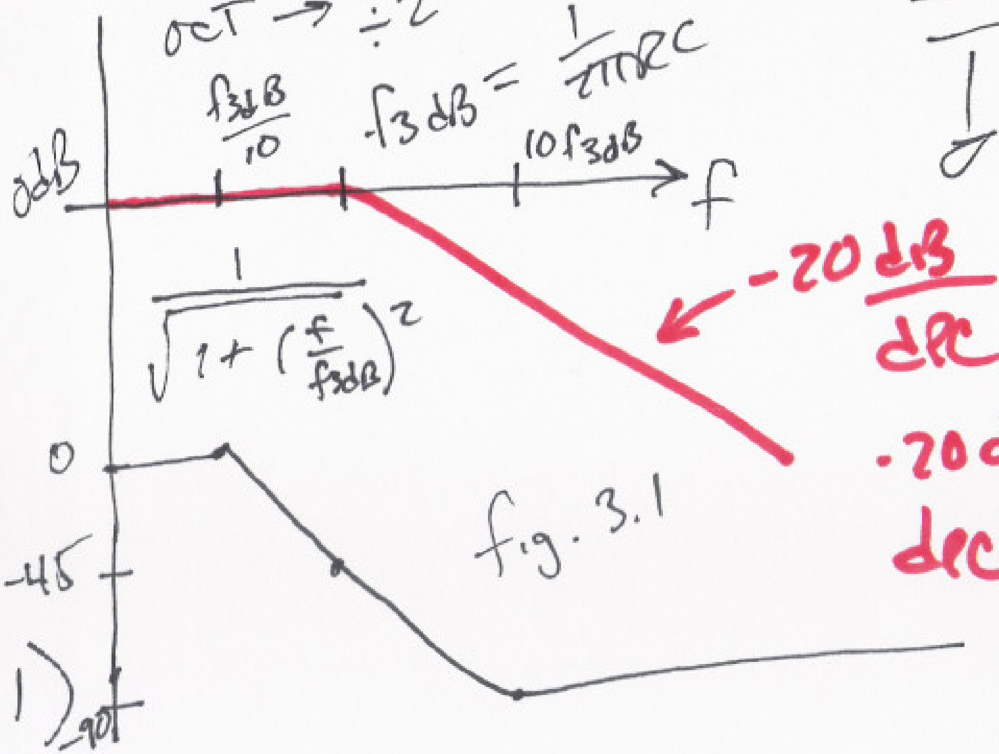
$$v_{out} = \frac{v_{in} \cdot \frac{1}{j\omega C}}{1/j\omega C + R}$$

$$\frac{v_{out}}{v_{in}} = \frac{1 + j0}{1 + j\omega RC}$$

$$\left|\frac{v_{out}}{v_{in}}\right| = \frac{1}{\sqrt{1 + (2\pi fRC)^2}}$$

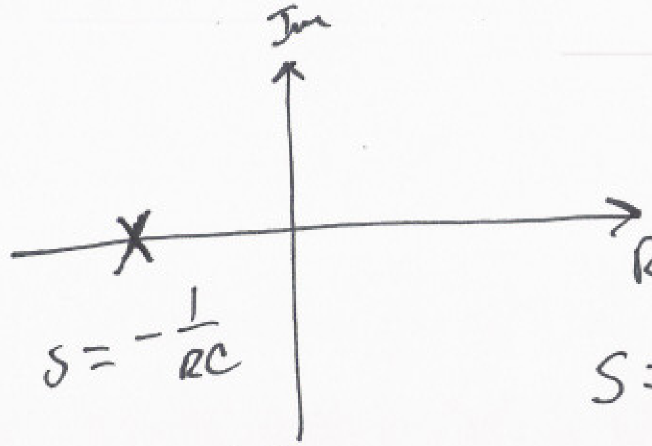
$$\angle \frac{v_{out}}{v_{in}} = 0 - \tan^{-1}\frac{2\pi fRC}{1}$$

$f_{3dB} = \frac{1}{2\pi RC}$



$-20 dB \rightarrow \frac{1}{10}$

dec → × ÷ 10

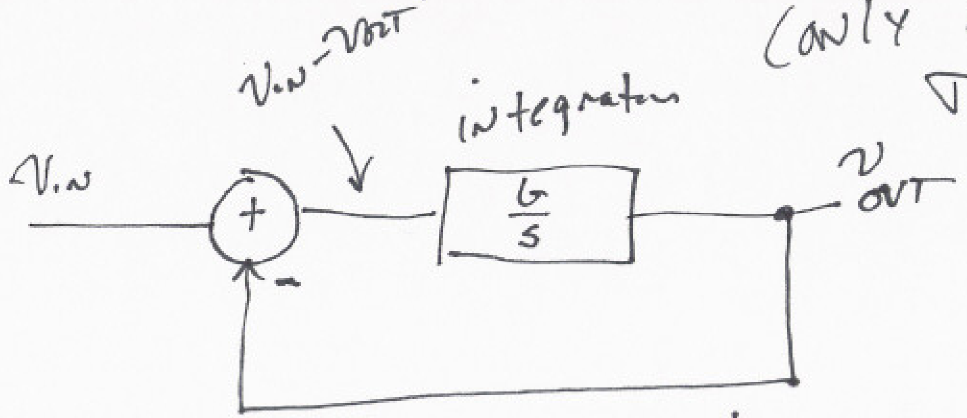


$$\frac{1}{1 + j\omega RC} = \frac{1}{1 + sRC}$$

$s = \sigma + j\omega$

(only sinusoids $\sigma = 0$, $s = j\omega$)

where is the pole? $s = -\frac{1}{RC}$

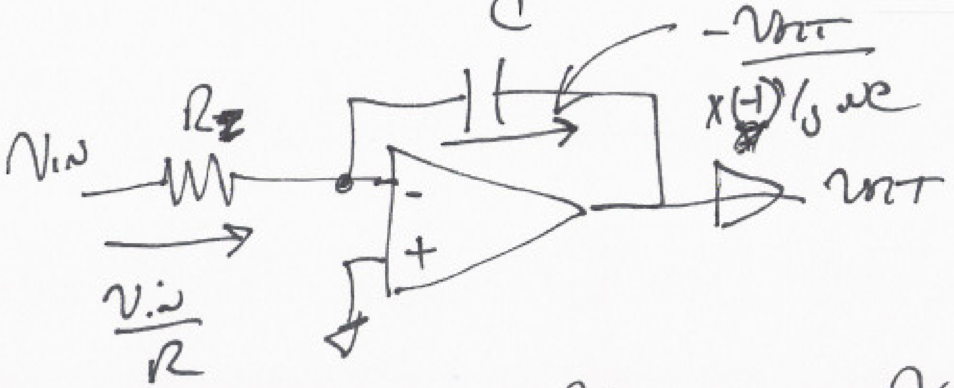


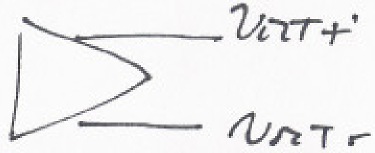
$$V_{OUT} = (V_{IN} - V_{OUT}) \cdot \frac{G}{s}$$

$$V_{OUT}\left(1 + \frac{G}{s}\right) = V_{IN} \cdot \frac{G}{s}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{\frac{G}{s}}{1 + \frac{G}{s}} = \frac{1}{1 + \frac{s}{G}}, \quad G = \frac{1}{RC}$$

Miller integrator, active RC integrator, etc.





$$v_{out} = v_{out+} - v_{out-}$$

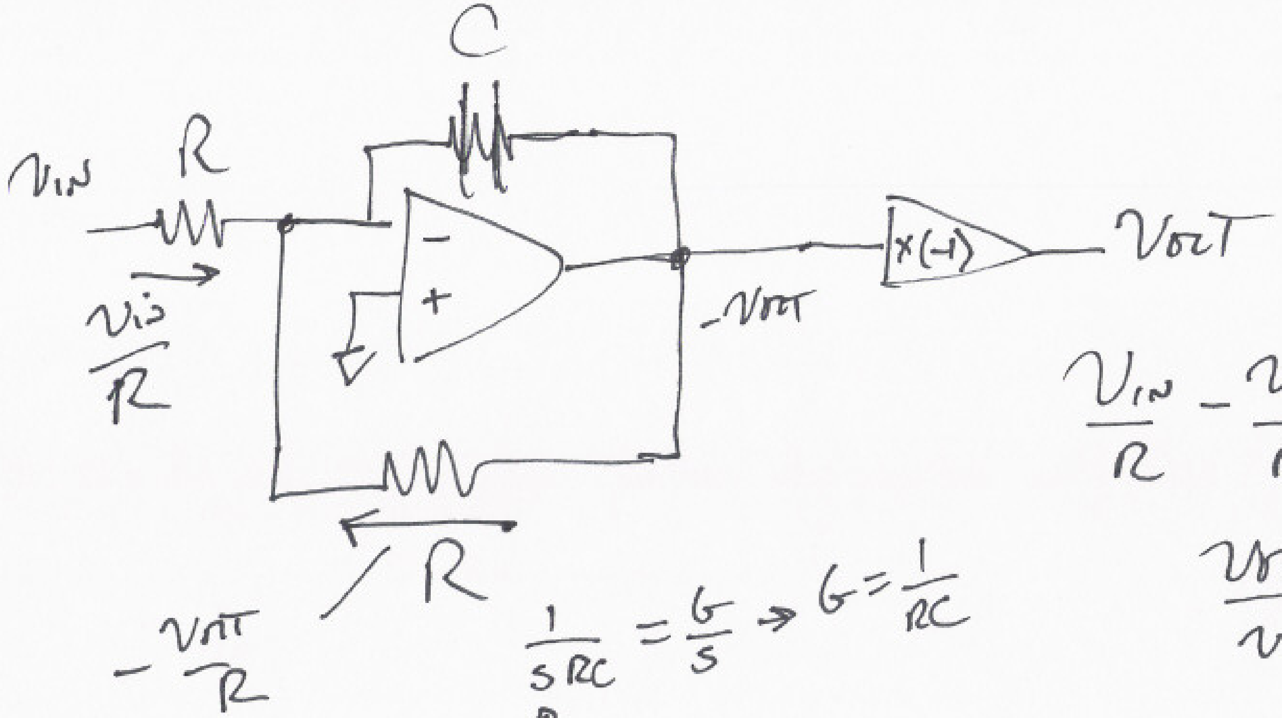
$$\frac{v_{in}}{R} = -v_{out} \cdot j\omega C$$

$$\frac{v_{out}}{v_{in}} = -\frac{1}{j\omega RC} = \frac{-1}{sRC}$$

$$\left|\frac{v_{out}}{v_{in}}\right| = \left|\frac{1}{j\omega RC}\right| = \left|\frac{1}{sRC}\right|$$

$$\frac{G}{s} = \frac{1}{sRC}$$

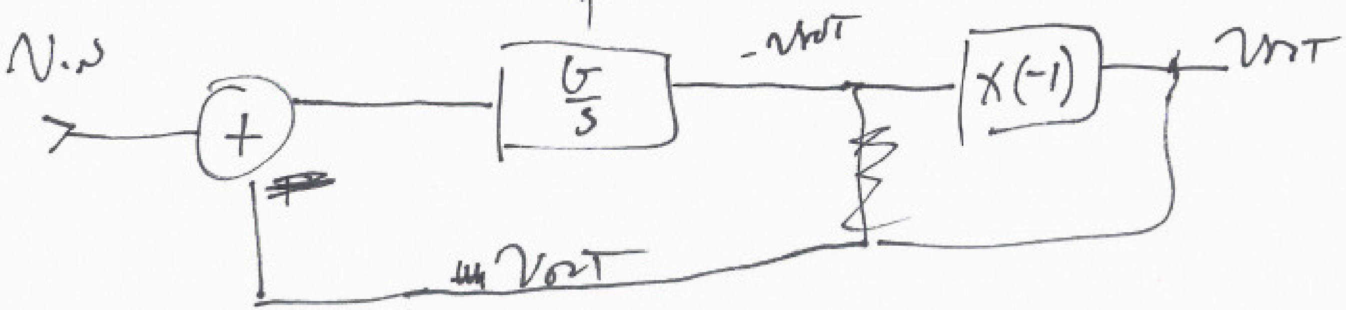
$$\boxed{G = \frac{1}{RC}}$$

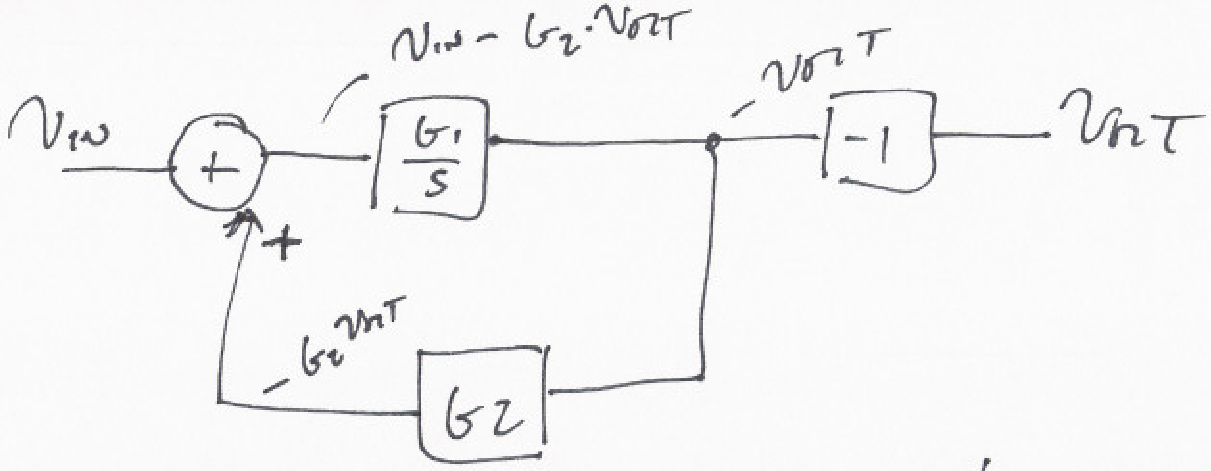


$$\frac{V_{IN}}{R} - \frac{v_{OUT}}{R} = -V_{OUT} \cdot j\omega C$$

$$\frac{v_{OUT}}{v_{IN}} = \frac{1}{1 + j\omega RC}$$

$$\frac{1}{sRC} = \frac{G}{s} \rightarrow G = \frac{1}{RC}$$





$$+v_{OUT} = \frac{G_1}{s}\left(v_{in} - G_2 v_{OUT}\right)$$

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

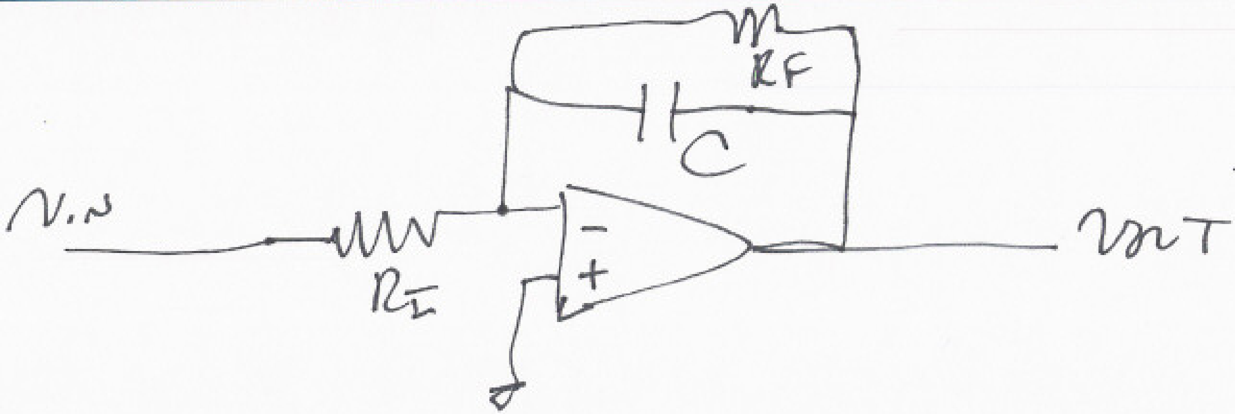
$$\frac{v_{OUT}}{v_{in}} = \frac{\frac{G_1}{s}}{1 + \frac{G_1 G_2}{s}}$$

$$f_{3dB} = \frac{G_1 G_2}{2\pi}$$

Low frequency Gain $= \frac{1}{G_2}$

$$= \frac{\frac{1}{G_2}}{\frac{s}{G_1 G_2} + 1}$$

5)



$$\frac{-\frac{1}{G_2}}{\frac{s}{G_1G_2}+1} = \frac{v_{out}}{v_{in}}$$

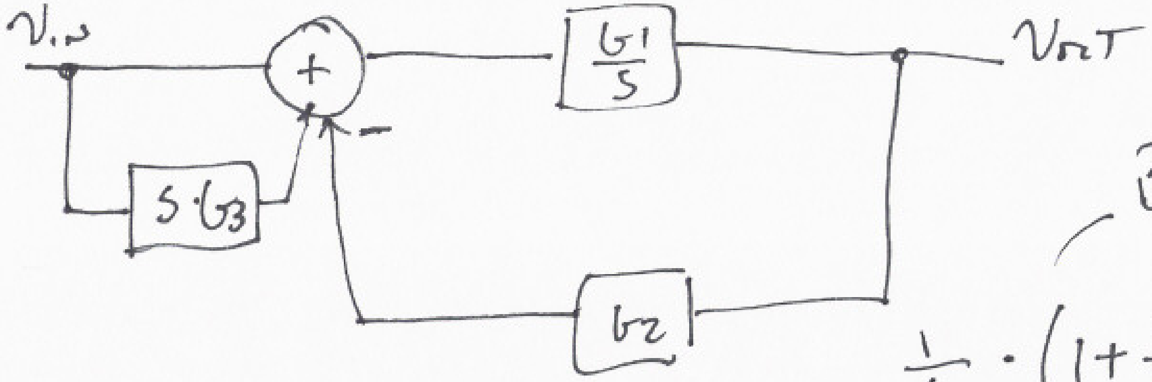
$$\frac{R_F \cdot \frac{1}{j\omega C}}{R_F + \frac{1}{j\omega C}} = \frac{R_F}{1 + j\omega C R_F}$$

$$\frac{v_{out}}{v_{in}} = \frac{-\frac{R_F}{1 + j\omega C R_F}}{R_I} = \frac{-\frac{R_F}{R_I}}{1 + j\omega C R_F}$$

$$G_2 = \frac{R_I}{R_F} \qquad \frac{1}{G_1 G_2} = s C R_F$$

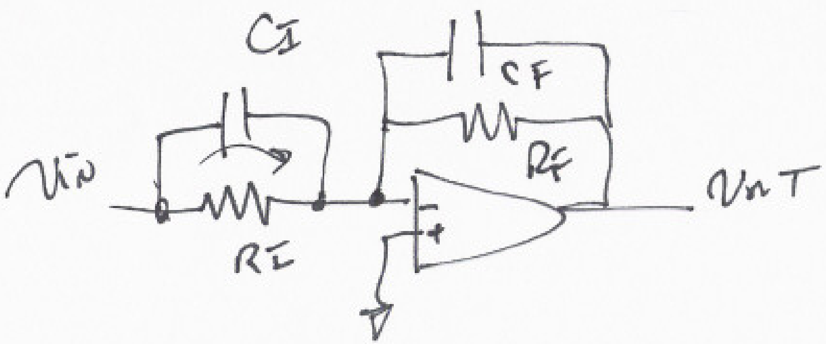
$$G_1 = \frac{1}{R_I \cdot C}$$

6)



Bilinear

$$\frac{\frac{1}{G_2} \cdot \left(1 + \frac{S}{1/G_3}\right)}{1 + \frac{S}{G_1 G_2}} = \frac{V_{OUT}}{V_{in}}$$



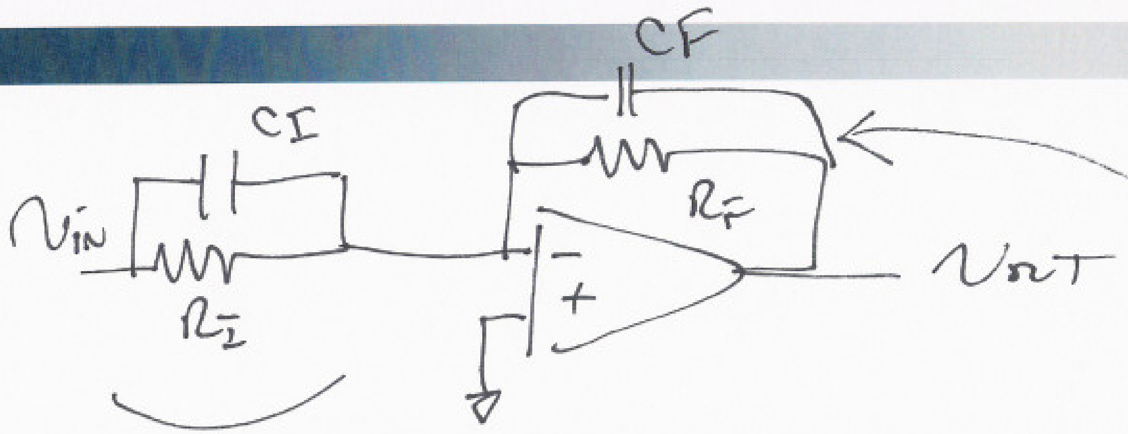
$$G_1 = \frac{1}{R_I \cdot C_F}$$

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

$$\frac{V_{in}}{1/j\omega C_I} = j\omega C_I \cdot V_{in} = V_{IN} \cdot S \cdot C_I$$

$$\frac{V_{in}}{R_I} \longrightarrow V_{IN}\left(\frac{1}{R_I} + SC_I\right)$$

$$G_3 = R_I \cdot C_I$$



$$\frac{R_I}{1+j\omega R_I C_I}$$

$$\frac{R_F}{1+j\omega R_F \cdot C_F}$$

$$\frac{v_{OUT}}{v_{IN}} = -\frac{\dfrac{R_F}{1+j\omega R_F C_F}}{\dfrac{R_I}{1+j\omega R_I \cdot C_I}}$$

$$= -\frac{R_F}{R_I} \cdot \frac{1+j\omega R_I C_I}{1+j\omega R_F C_F} = \frac{R_F}{R_I} \frac{1+\frac{jf}{f_z}}{1+j\frac{f}{f_p}}$$

$$f_z = \frac{1}{2\pi R_I C_I}$$

$$f_p = \frac{1}{2\pi R_F C_F}$$

Biquad

$$\frac{v_{OUT}}{v_{IN}} = \frac{a_2 s^2 + a_1 \cdot s + a_0}{s^2 + \left(\frac{2\pi f_0}{Q}\right)s + (2\pi f_0)^2}$$

Fig. 3.35

Fig. 3.39

lowpass

$a_2 = a_1 = 0$

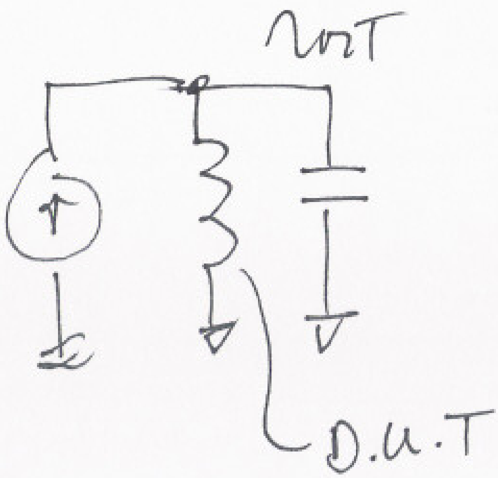
Bandpass

$a_2 = a_0 = 0$

highpass

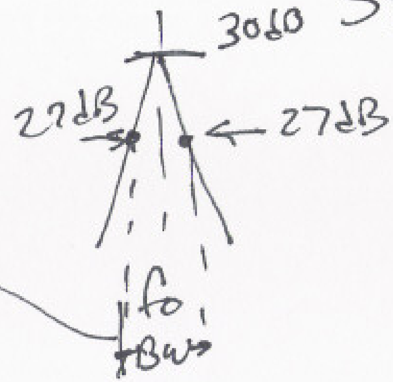
non-zero

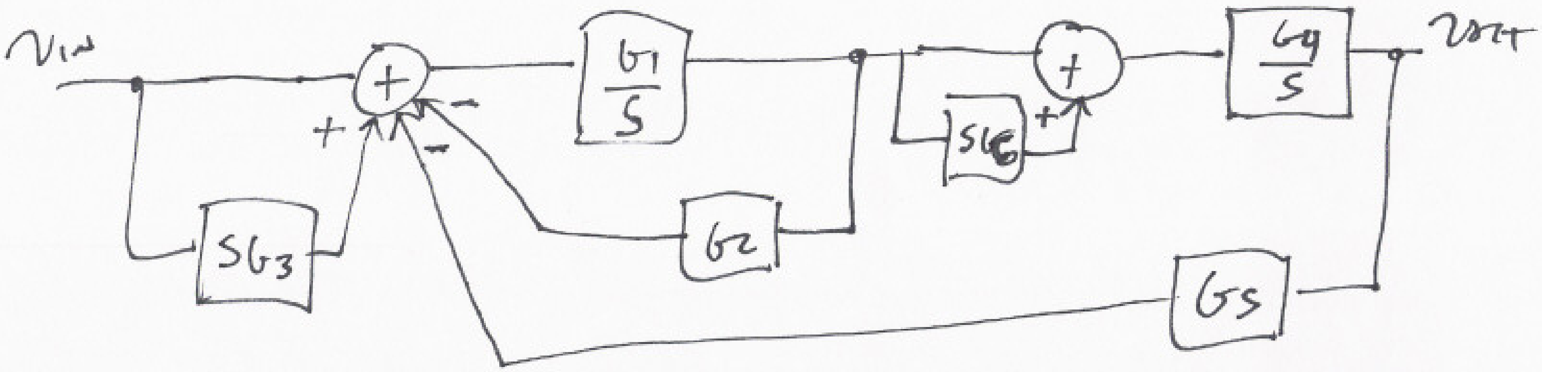
Know Q!



$$\frac{\text{energy stored}}{\text{energy lost}}$$ — in a resonant system

$$Q = \frac{f_0}{BW}$$





a2 Biquad, a1, a0

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

$\frac{2\pi f_0}{Q}$ $\quad (2\pi f_0)^2$

$$Q = \frac{f_0}{BW}$$