ELEN0037
Microelectronics
Tutorials

Pouyan Ebrahimbabaie, Vinayak Pachkawade,Thomas Schmitz

With special thanks to Vincent Pierlot

University of Liège - Montefiore Institute
EMMI Unit: Electronics, Microsystems, Measurements, and Instrumentation

Tutorial 5: Filters (BiQuad, Gm-C, MOSFET-C, etc)

Biquad filters (summary)

General form $$H(s) = \frac{k_2 s^2 + k_1 s + k_0}{s^2 + \left(\Omega_0/Q\right) s + \Omega_0^2}$$

Low Pass $$H(s) = \frac{\Omega_0^2}{s^2 + \left(\Omega_0/Q\right) s + \Omega_0^2}$$

Band Pass $$H(s) = \frac{\left(\Omega_0/Q\right) s}{s^2 + \left(\Omega_0/Q\right) s + \Omega_0^2}$$

Band Stop $$H(s) = \frac{s^2 + \Omega_0^2}{s^2 + \left(\Omega_0/Q\right) s + \Omega_0^2}$$

High Pass $$H(s) = \frac{s^2}{s^2 + \left(\Omega_0/Q\right) s + \Omega_0^2}$$

Exercise 1 (1st, P10.10/2nd, P14.18)

Using the bilinear transform, design a bandpass filter with a $Q = 20$ (in the continuous-time domain) and a peak gain of 1 at $f_0 = {}^{f_s}/_{100}$.[1] The (continuous) transfer function of the biquad bandpass filter is given by:

$$H(s) = \frac{k_1 s}{s^2 + \left({}^{\Omega_0}/_{Q}\right) s + \Omega_0^2}.$$

[1] $H(s) = \frac{0.00157s}{s^2+0.00157s+0.0009876}$, $\quad H(z) = \frac{0.00157z^2-0.00157}{1.0026z^2-1.998z+0.99942}$

Exercise 1 (frequency response)

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freqz([0.00157 0 -0.00157],[1.0026 -1.998 0.99942],100)
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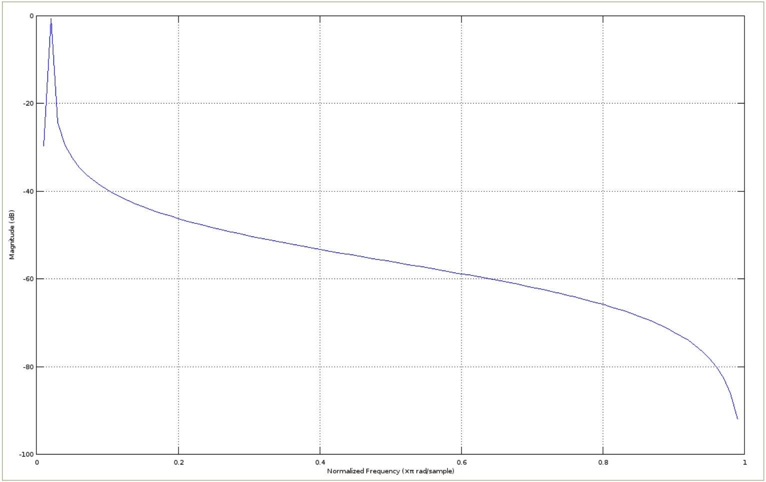
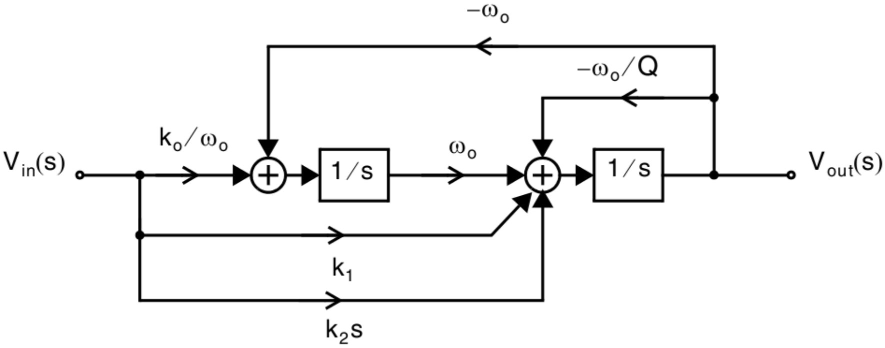


Peak gain = 0dB = 1.

Peak gain @ 0.02 of $f_s/2$, ⇒ peak gain @ $f_0 = f_s/100$.

Exercise 2 (2nd, P12.1)

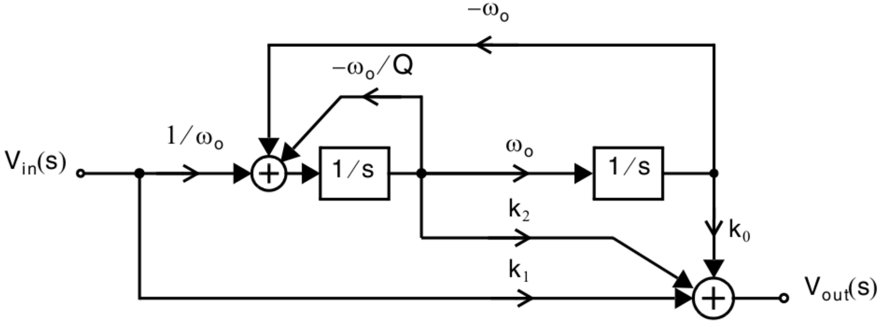
Find all of the signal path gains that are required in the general second-order (biquad) continuous-time filter to realize a bandpass filter with a center frequency of $\omega_0 = 2\pi \times 34\, MHz$, a Q-factor of 3, and a peak gain of 1.[2]



[2] $Q = 3,\ \omega_0 = 213.63\,10^6\ Hz,\ k_1 = 71.21\,10^6$

Exercise 3 (2nd, P12.2)

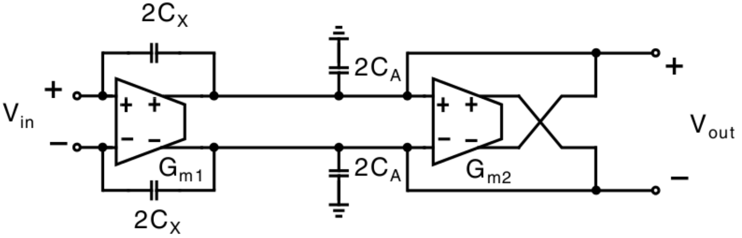
Find the transfer function of the general biquad signal flow graph represented hereafter.[3]



[3] $H(s) = \left[k_1 s^2 + \left(k_1 \frac{\omega_0}{Q} + \frac{k_2}{\omega_0}\right)s + \left(k_1 \omega_0^2 + k_0\right)\right] / \left[s^2 + (\omega_0/Q)s + \omega_0^2\right]$

Exercise 4 (1st, P15.2)

Based on the block diagram represented hereafter, find the transconductance values for a first-order filter with a DC gain of 10, a cutoff frequency of $15\,MHz$, and no finite zero. Assume the integrating capacitors are sized $C_A = 5\,pF$.[4]



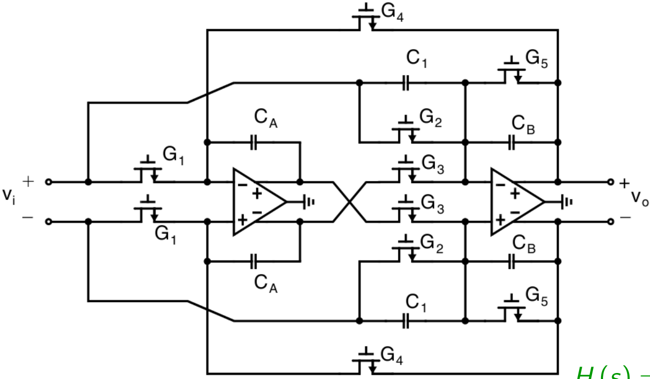
The transfer function is given by:

$$H(s) = \frac{\left(\frac{C_X}{C_A+C_X}\right) s + \left(\frac{G_{m1}}{C_A+C_X}\right)}{s + \left(\frac{G_{m2}}{C_A+C_X}\right)}$$

[4] $C_X = 0,\ G_{m1} = 4.71\,mA/V,\ G_{m2} = 0.47\,mA/V$

Exercise 5 (1st, P15.16)

Using two-transistors integrators, design a MOSFET-C second-order low-pass filter with a cutoff frequency of $1\,MHz$, $Q = 1$, and a DC gain of 2. Let $C_A = C_B = 10\,pF$, $V_C = 3\,V$, and $V_X = 0\,V$.[5][6]



$$H(s) = -\frac{\left(\frac{C_1}{C_B}\right)s^2 + \left(\frac{G_2}{C_B}\right)s + \left(\frac{G_1 G_3}{C_A C_B}\right)}{s^2 + \left(\frac{G_5}{C_B}\right)s + \left(\frac{G_3 G_4}{C_A C_B}\right)}$$

[5] $C_1 = G_2 = 0,\ G_5 = 63\,\mu A/V,\ G_3 G_4 = 3.95\,10^{-9},\ G_1 G_3 = 7.9\,10^{-9}$

[6] let $G_3 = 100\,\mu A/V,\ \frac{W_1}{L_1} = 0.39,\ \frac{W_3}{L_3} = 0.49,\ \frac{W_4}{L_4} = 0.2,\ \frac{W_5}{L_5} = 0.31$