rev. 2020-09-18/MS

EIT5/ITC5 Signal Processing, 4

Topics:
- OpAmps applied in active RC-filters
- Various designs of 2nd order Sallen-Key LP-filters
- MFB-filters
- HP, BP and BS filters
- In brief: Section allocation, effect of limited operational amplifier gain

Literature:
Kendal Su: "Analog Filters", Kluwer Academic Publishers, 2nd ed. 2002, ISBN 1-4020-7033-0
The book is available in electronic form at http://www.en.aub.aau.dk.

Topic	Pages ({*} ⇔ supplementary lit.)
Operational amplifier circuits	187-189, {190-196}, 206-208
Biquad circuits	204-206, 217-238
Higher order filters	253-260, 263-264

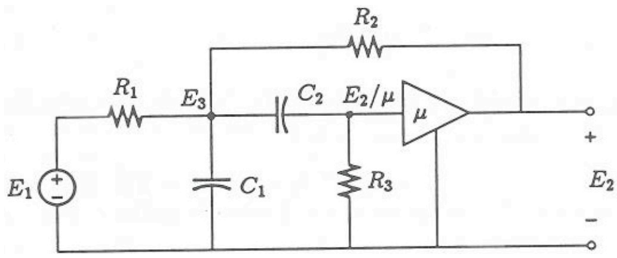
Supplementary: Lecture presentation "slides"

Preparation: I assume that basic operational amplifier circuits are well known to you. If you are in doubt, please read page 190-196.

Exercises:

4.1

The filter in Kendall Su: "Analog filters" Figure 8.4 has the transfer function given in (8.22). Component values are chosen as: $C_1 = C_2 = C$, $R_1 = R_2 = R$ and $R_3 = 2R$. In this case the transfer function can be reduced to:



$$H(s) = \frac{\frac{\mu}{CR}s}{s^2 + \frac{3-\mu}{CR}s + \frac{1}{(CR)^2}}$$

a. Find expressions for ω_0 and Q

b. Find an expression for S_μ^Q and its value for Q = 5

c. Find a simple expression for $H(j\omega_0)$ and for $S_\mu^{H(j\omega_0)}$ and their values for Q = 5

4.2

A 2nd order Butterworth normalized low-pass prototype filter is transformed to a BP-filter (4 poles) having:
- Lower passband edge (-3 dB) = 10 kHz
- Upper passband edge (-3 dB) = 15 kHz

The filter is made using 2 biquad filter sections of the type analyzed in exercise 4.1

a. Find the pole locations of the BP-filter. Hint: Use Matlab:

```
OrderLPP = 2;
Om = [10 15]*pi*2e3;
[Numpoly DenomPoly] = butter(OrderLPP,Om,'s'); % Bandpass since Om
is a vector
Poles = roots(DenomPoly)
```

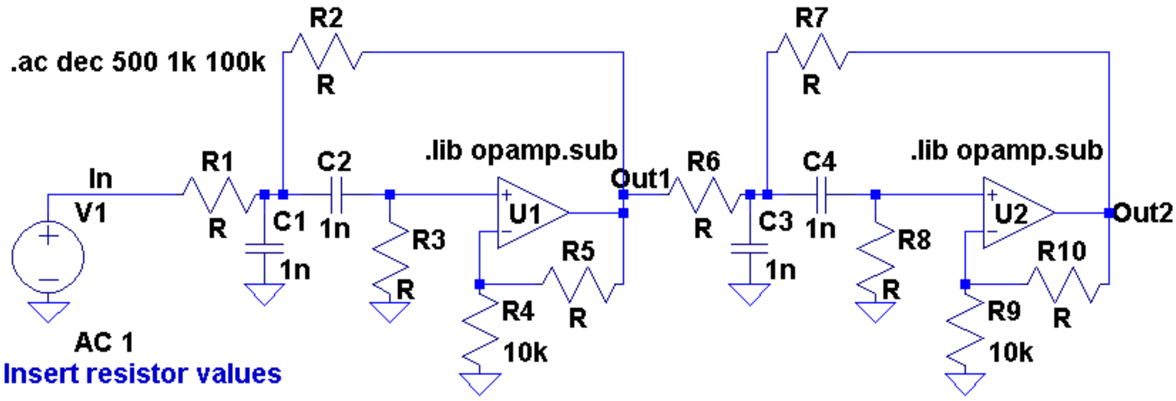
b. Find ω_0 and Q for each of the two sections. Hint:

```
omeg_0_biquad = abs(Poles)
Q_biquad = % some function of Poles
```

c. Using C = 1 nF, find the resistor values and μ in each section.

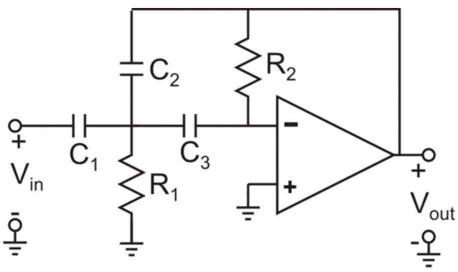
Section	*ω_0 [10^4 rad/s]*	*Q*	*$R = R_1 = R_2$*	*$R_3 = 2R$*	*μ*
1	*8.90*	*3.5*	*11.2 kΩ*	*22.5 kΩ*	*2.71*
2			*kΩ*	*kΩ*	

d. Option: Make a Spice-simulation to check the results (Hint: LT-Spice example):



4.3

The 2nd order MFB high-pass section shown has the transfer function:



$$H(s) = -\frac{\frac{C_1}{C_2}s^2}{s^2 + \frac{C_1 + C_2 + C_3}{R_2 C_2 C_3}s + \frac{1}{R_1 R_2 C_2 C_3}}$$

The capacitor values are chosen as:
- $C_1 = C_2 = 10$ nF
- $C_3 = 2C_1 = 2C_2 = 20$ nF

and it is required that:
- $\omega_0 = 2\pi \cdot 10^4$ rad/s
- Q = 5

a. Find the values of R_1 and R_2
b. Find the filter gain, $|H(j\omega_0)|_{dB}$, at ω_0.
c. Find the filter gain, $|H(j\omega)|_{dB}$, for $\omega \rightarrow \infty$

4.4

A 2^{nd} order Butterworth normalized low-pass prototype filter is transformed to a BP-filter (4 poles) having (same data as in ex. 4.2):

- Lower passband edge (-3 dB) = 10 kHz
- Upper passband edge (-3 dB) = 15 kHz

The filter is made using 2 biquad filter sections:

- An MFB low-pass section, for the poles with the largest ω_0, with $R_1 = R_2 = R_3 = R = 2\ k\Omega$.
- An SK high-pass section, for the poles with the smallest ω_0, with $C_1 = C_2 = C = 10$ nF and $\mu = 1$.

a. Find the pole locations of the BP-filter using Matlab
b. Find ω_0 and Q for each of the two sections from the pole locations.
c. Find the component values of the MFB-LP section
d. Find the component values of the SK-HP section.
e. Option: Make a Spice-simulation to check the results (Exerc5_2template.asc)

Section	ω_0 [10^4 rad/s]	Q
1 MFB-LP	*8.90*	*3.5*
2 SK-HP		

Results:

4.1

a.
b. *14*
c. *14, 15*

4.2

a. *-12710±j88077 and -9504±j65862*
b. *88989/66545 3.5/3.5*

4.3

a. *79.6 Ω, 15.9 kΩ*
b. *14 dB*
c. *0 dB*

4.4

a. *-12710±j88077, -9504±j65862*
b.
c. *59.0 nF, 535 pF*
d. *215 Ω, 10.5 kΩ*
e.