LINKÖPING UNIVERSITY

Exam in TSTE14 Analog Filters

Exam code:	TEN1
Date:	2016-03-21 **Time:** 14–18
Place:	TER3
Examiner:	Håkan Johansson
Department:	ISY
Allowed aids:	Pocket calculator Wanhammar: Tables and formulas for analog and digital filters Söderkvist: Formler och Tabeller Ingelstam, Rönngren, Sjöberg: Tefyma Ekbom: Tabeller och Formler NT Nordling: Physics Handbook for Science and Engineering Strid: Formler och Lexikon Mathematical tables
Number of tasks:	7
Grading:	Maximum 70 points, 30 points required to pass the exam. **Note** that a **motivation/solution** is required to get the maximal number of points for a problem. **Note** that 10, 8, 6, 4, or 2 points obtained at the **seminars** means that you do not have to solve Problem 1, 1(a)-(d), 1(a)-(c), 1(a)-(b), or 1(a), respectively.
Solutions:	Will be published no later than three days after the exam at http://www.commsys.isy.liu.se/en/student/kurser/TSTE14/
Result:	Available 2016-04-04

1 **a.** Explain the meaning of a linear and time-invariant system (filter). (2 p)

b. What is the difference between second-order lowpass, highpass, and bandpass sections, regarding their zero locations? (2 p)

c. What are the potential drawbacks of using frequency transformations when designing bandpass and bandstop filters? (2 p)

d. Why is it important to use low-sensitivity filter realizations? (2 p)

e. Explain what the gain-bandwidth product of an OP amplifier is, and why it is desired to have a large gain-bandwidth product. (2 p)

2 Synthesize a Cauer filter that meets the following specification: $\omega_c = 2\pi$ Mrad/s, $\omega_s = 2\pi \times 2$ Mrad/s, $A_{\max} = 0.1$ dB ($\rho = 15\%$), and $A_{\min} = 50$ dB. Determine the poles and zeros, and indicate their locations in the s-plane. The filter order should not be higher than necessary. (10 p)

3 Realize a highpass Chebyshev-I filter that meets the following specification: $\omega_c = 2\pi \times 5$ Mrad/s, $\omega_s = 2\pi$ Mrad/s, $A_{\max} = 0.5$ dB, and $A_{\min} = 40$ dB. Use a π-type ladder structure. Determine the capacitor and inductor values assuming source and load resistors with the same value according to $R_S = R_L = 2$ kΩ. (10 p)

4 The transfer function of a second-order section can generally be expressed as

$$H(s) = \frac{as^2 + bs + c}{s^2 + ds + e}$$

a. Determine a, b and c (zero or nonzero constants) so that $H(s)$ corresponds to a bandpass filter and a bandstop (notch) filter, respectively. (4 p)

b. Assume that $a = b = 0$ and $c = e$ which makes $H(s)$ correspond to a lowpass filter with a DC gain of $|H(j0)| = 1$. When $e > d^2/2$, $|H(j\omega)|$ has a maximum value for $\omega = \omega_{peak}$, $0 < \omega_{peak} < \infty$. Determine ω_{peak} and $|H(j\omega_{peak})|$ when $e = 10$ and $d = 1$. (6 p)

5 **a.** Derive the transfer function $H(s) = V_{\text{out}}(s)/V_{\text{in}}(s)$ for the active filter below, and show that it can be written as $H(s) = H_1(s)H_2(s)$ where

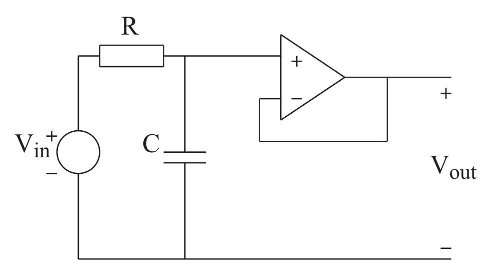
$$H_1(s) = \frac{1}{1+sRC}, \quad H_2(s) = \frac{A(s)}{1+A(s)}$$

with $A(s)$ being the transfer characteristics of the OP amplifier (that is, a non-ideal OP amplifier is assumed). (5 p)

b. Determine the 3dB angular frequency for $H_1(s)$, $H_2(s)$, and $H(s)$. Use reasonable approximations if necessary. For a lowpass filter $H(s)$, the 3dB angular frequency, say ω_{3dB}, is defined by $|H(j\omega_{3dB})| = G/\sqrt{2}$ when $|H(j0)| = G$. Assume that $R = 10$ kΩ, $C = 100$ nF, and

$$A(s) = \frac{A_0}{1+\frac{s}{\omega_0}}$$

with $A_0 = 10^5$ and $\omega_0 = 2\pi \times 10$ rad/s. (5 p)



6 For a lowpass-to-bandpass frequency transformation

$$S = s + \frac{\omega_I^2}{s}$$

where $\omega_I^2 = \omega_{c1}\omega_{c2} = \omega_{s1}\omega_{s2}$, show that:

a. The frequency responses are related as $H_{BP}(j\omega) = H_{LP}(j\Omega)$, where $\Omega = \omega - \omega_I^2/\omega$. (2 p)

b. The passband region of the lowpass filter, $\Omega \in [-\Omega_c, \Omega_c]$ is mapped to the two passband regions of the bandpass filter, $\omega \in [\omega_{c1}, \omega_{c2}]$ and $\omega \in [-\omega_{c2}, -\omega_{c1}]$ where $\Omega_c = \omega_{c2} - \omega_{c1}$. Note that the passband regions given above include the negative frequencies. (8 p)

7 For a doubly resistively terminated LC-filter, seen in the figure below, derive the transfer function, defined by $H(s) = V_{\text{out}}(s)/V_{\text{in}}(s)$, expressed in terms of R_S, R_L, $A(s)$, $B(s)$, $C(s)$, and $D(s)$, where $A(s)$, $B(s)$, $C(s)$, and $D(s)$ are the entries in the chain matrix of the two-port between R_S and R_L. (10 p)