LINKÖPING UNIVERSITY

Exam in TSTE14 Analog Filters

Exam code:	TEN1		
Date:	2016-06-09	**Time:**	14–18
Place:	TER4		
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 working days after the exam at http://www.commsys.isy.liu.se/en/student/kurser/TSTE14/		
Result:	Available by 2016-06-23		

1 **a.** What is a main difference between passive and active components? (2 p)

b. What is a Richards structure? (2 p)

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

d. Which of the following two filters requires most components (capacitors and inductors) in a ladder realization: an 11th-order Butterworth or a 7th-order Cauer? (2 p)

e. How are the poles and zeros related in an allpass filter? (2 p)

2 Synthesize a Cauer filter that meets the following specification: $\omega_c = 2\pi \times 2$ Mrad/s, $\omega_s = 2\pi \times 9.4$ Mrad/s, $A_{\max} = 0.01$ dB ($\rho = 5\%$), and $A_{\min} = 40$ 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 Butterworth filter that meets the following specification: $\omega_c = 2\pi \times 10$ Mrad/s, $\omega_s = 2\pi$ Mrad/s, $A_{\max} = 0.2$ dB, and $A_{\min} = 40$ dB. Use a T-type ladder structure. Determine the capacitor and inductor values assuming source and load resistors with the same value according to $R_S = R_L = 10$ kΩ. (10 p)

4 Two transfer functions are given as

$$H_1(s) = \frac{p_1}{s + p_1}, \quad H_2(s) = \frac{s}{s + p_2}$$

a. Determine the poles and zeros (expressed in terms of p_1 and p_2) of $H_3(s)$, as given below. (4 p)

$$H_3(s) = H_1(s) + H_2(s)$$

b. Determine the poles and zeros (expressed in terms of p_1 and p_2) of $H_4(s)$, as given below. (4 p)

$$H_4(s) = H_1(s)H_2(s)$$

c. Compute the magnitude responses of $H_3(s)$ and $H_4(s)$ for the angular frequencies $\omega = 0$ and $\omega = \infty$. (2 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

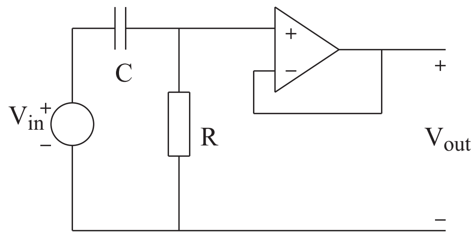
$$H_1(s) = \frac{sRC}{1 + sRC}, \quad H_2(s) = \frac{A(s)}{1 + A(s)}$$

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

b. Sketch the magnitude responses of $H_1(s)$, $H_2(s)$, and $H(s)$, and indicate their 3dB angular frequencies. Use reasonable approximations if necessary. (For a filter $H(s)$, the 3dB angular frequency, say ω_{3dB}, is defined by $|H(j\omega_{3dB})| = G/\sqrt{2}$ where G represents the maximum value of $|H(j\omega)|$). Assume that $R = 1$ 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)