THE OPEN UNIVERSITY OF SRI LANKA
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Final Examination – 2015/2016

ECX6250 – ANALOG ELECTRONIC SYSTEMS (Closed-Book Exam)

DATE: December 17, 2016 ***TIME: 09:30-12:30 hrs.***

ANSWER ANY FIVE (5) QUESTIONS ONLY (each question carries 100 marks)

Be neat and clear. Show all steps very clearly. Underline your final answer where possible.

Q1.

(a) Explain briefly using figure(s) as necessary, what is meant by the term hysteresis (5 marks). Provide an example situation where it is beneficially used (5 marks). (10)

(b) (i) For the Schmitt trigger circuit shown in Figure Q1, the positive and negative supply voltages are +15V and -15V respectively, and $V_{Ref} = +6V$. Find (1) the upper and lower trigger levels for the circuit (20 + 20 marks), and (2) the amount of its hysteresis (10 marks). (50)

(ii) Sketch neatly and clearly the V_{out} versus V_{in} transfer characteristics for the above, marking all key values and providing all necessary labels. (20 marks) (20)

(iii) Draw the output waveform that would result when the input is a 10V peak sine-wave. (20 marks) (20)

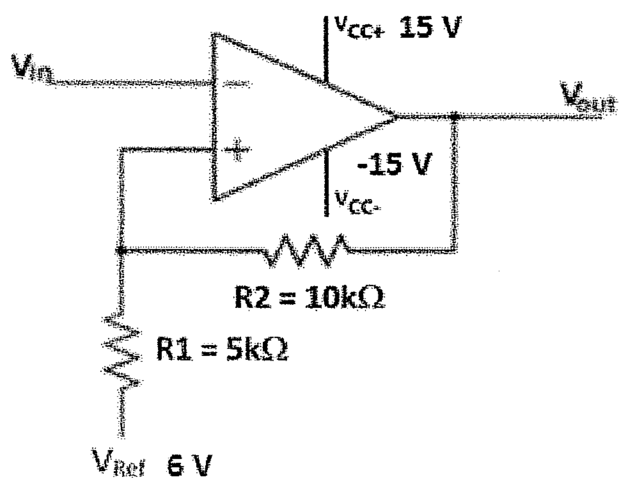

Figure Q1

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Q2.

(a) Starting from first principles, derive the Barkhausen criterion for oscillations to occur in a feedback oscillator circuit (15 marks). Also, provide separately the magnitude criterion (5 marks) and the phase criterion (5 marks). (25)

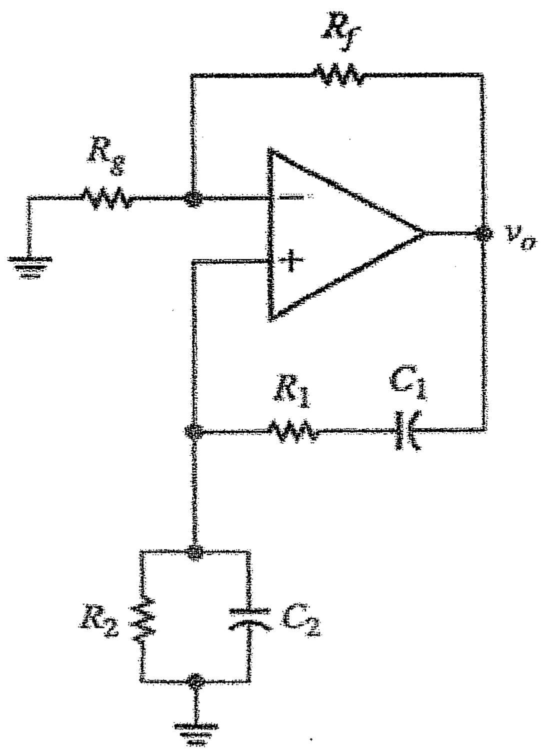

Figure Q2

(b) For the Wien-Bridge oscillator circuit shown in Figure Q2, derive the oscillation frequency in terms of its passive components (20 marks). What is the expression for the frequency of oscillation if both the resistors are of equal value (R) and both the capacitors are of equal value (C) (5 marks)? What is the value of its feedback ratio at this oscillation frequency (10 marks)? (35)

(c) If $R_g = R_1 = 10\ k\Omega$, and $C_1 = C_2 = 1$ nF, (Figure Q2), calculate the range of R_2 values (see Figure Q2) required to obtain oscillations in the range 10 kHz through 50 kHz (20 marks). Determine the R_f value (see Figure Q2) required for oscillations to occur at 10 kHz (20 marks). (40)

Q3.

For the circuit in Figure Q3, calculate the lower critical frequency due to

(a) the input RC circuit (30 marks),
(b) the output RC circuit (30 marks), and
(c) the bypass RC circuit (40 marks).

Use r-parameter model. Use a suitable transistor equivalent circuit model based on the problem and parameters given. Assume $r'_e = 9.6\ \Omega$, and $\beta = 200$. Show all steps and work clearly. (100)

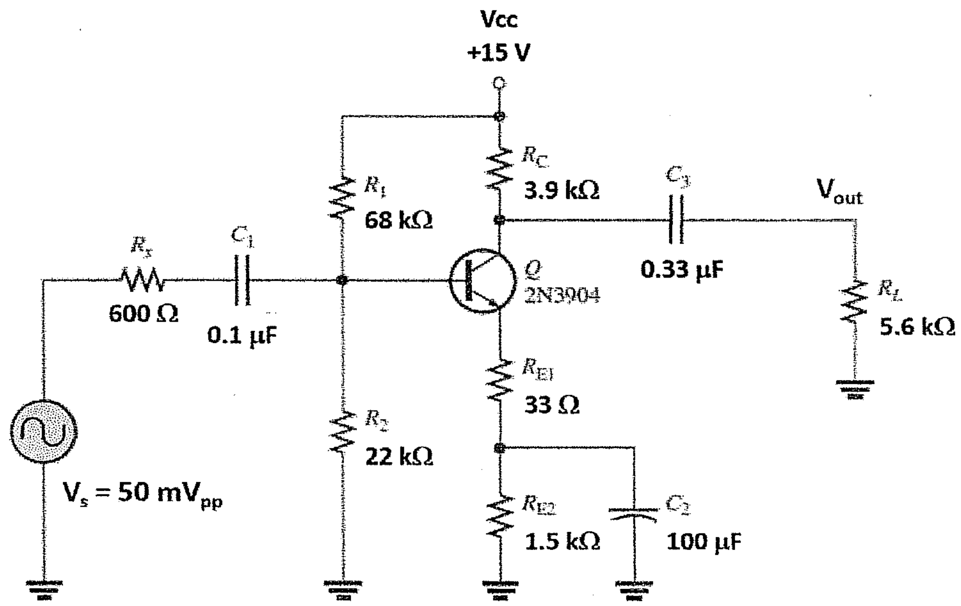

Figure Q3

Q4.

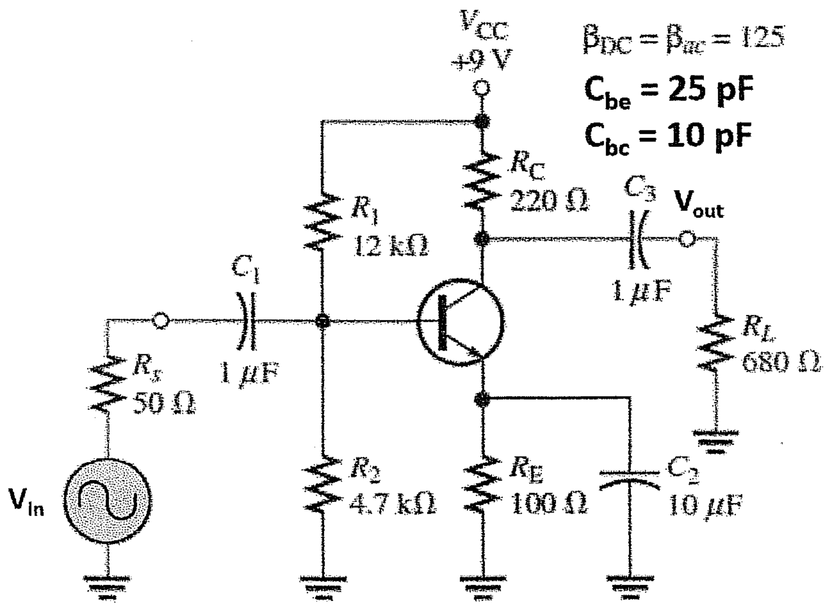

Figure Q4

(a) Explain Miller's theorem in connection with impedance decoupling between the input and the output of a two-port device (10 marks). (10)

(b) For the circuit shown in Figure Q4, perform the following:

(i) Calculate the mid-frequency voltage gain of the amplifier (30 marks).

(ii) Find the upper critical frequency due to (1) the input RC circuit (30 marks), and (2) the output RC circuit (30 marks).

Use the r-parameter model for the transistor. Assume $r'_e = 1.73\ \Omega$, and $\beta_{ac} = 125$. See Figure Q4 for other required parameters. (90)

Note: The formulas for computing $C_{in\ (miller)}$ and $C_{out\ (miller)}$ are as follows (usual notations):

$C_{in\ (miller)} = C_{bc}\ (1 + A_V)$, and $C_{out\ (miller)} = C_{bc}\ (1 + 1/A_V)$

Q5.

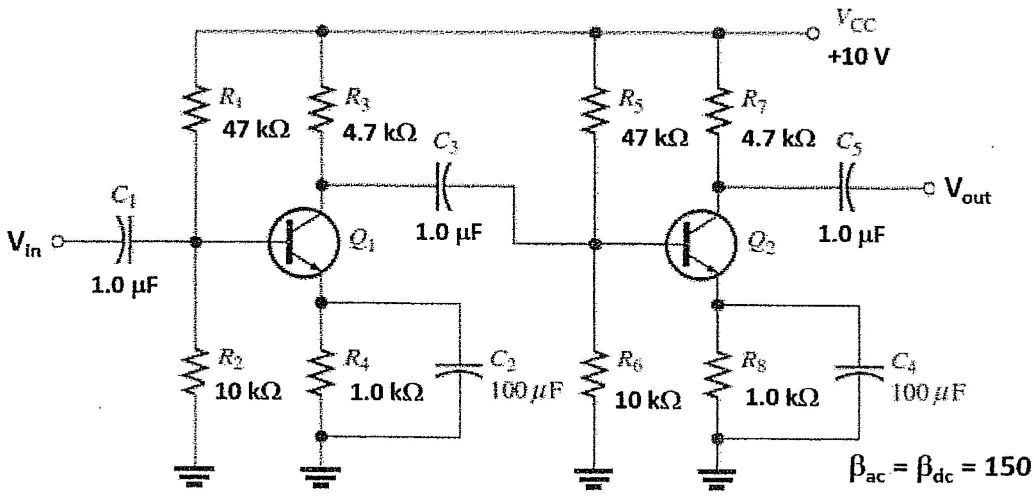

Figure Q5

For the two-stage amplifier shown in Figure Q5 (β for each transistor is $\beta_{ac} = \beta_{dc} = 150$),

(a) Determine the dc bias conditions (I_B, I_C, and V_{CE}) for each of the two stages of the two-stage amplifier circuit. Use the exact analysis technique. (20 marks) (20)

(b) Determine the value of the ac emitter-resistance parameter r'_e for each stage, based on their DC bias operating conditions. (10 marks) (10)

(c) Determine the mid-frequency voltage gain of each amplifier stage (30 + 30 marks) (60)

(d) Determine the overall voltage gain (mid-frequency) of the two-stage amplifier. (5 marks) (5)

(e) Express the voltage gains found in question 5(c) and (d) (above) in dB (5 marks) (5)

Use the r-parameter model. Assume $\beta_{ac} = \beta_{dc} = 150$ for each transistor. Also, assume that the bypass capacitors and the coupling capacitors all have negligible reactances at the frequencies in which the amplifier is operated.

Q6.

The transfer function of a first-order low-pass filter with a dc gain A, and a cut-off frequency ω_0 rad/sec, is given by $H(s) = A\frac{\omega_0}{s+\omega_0}$. And the transfer function of a second-order low-pass filter with dc gain A and cut-off frequency ω_0 rad/sec is given by $H(s) = A\,\frac{{\omega_0}^2}{s^2+b\omega_0 s+{\omega_0}^2}$ where "b" is a constant.

(a) Show that the transfer function H(s) of the first-order active low-pass filter circuit shown in Figure Q6 is given by $H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{RCs+1}$ (10 marks) (10)

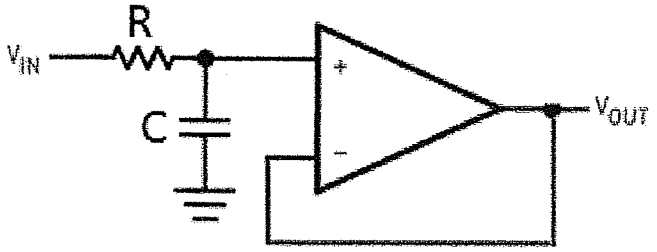

Figure Q6

(b) Using the "Low-Pass Butterworth Denominator Polynomial" given in Table 1 (below) (ω_0 = 1 rad/sec), determine the transfer function of a **fifth order**, low-pass Butterworth filter with a unity gain and a cut-off frequency of ω_0 rad/sec. Write in "standard" form. (10 marks) (10)

(c) Draw a neat circuit diagram of a second order low-pass Sallen-Key operational-amplifier based filter circuit having equal resistance values (R) and different capacitor values (C_1 and C_2). (10 marks) (10)

(d) The transfer function H(s) of a second order, low-pass, Sallen-Key active filter circuit having equal resistance values (R) and different capacitor values (C_1 and C_2) is given by

$$H(s) = \frac{1}{s^2R^2C_1C_2+2RC_2s+1}$$

By suitably cascading first and second order Sallen-Key operational-amplifier filter sections, design a **fifth-order**, unity gain, low-pass (active) Butterworth filter with a cut-off frequency of 3500 Hz. You are expected to determine suitable values for all circuit parameters to meet the requirements of the problem. Show all steps and work clearly.

For your design, use a suitable 1% tolerant standard values in the range 1KΩ through 1MΩ for the resistors, and a suitable 5% tolerant standard values in the range 100 pF through 100 nF for the capacitors. (70 marks)

(70)

n (order)	Normalized Denominator Polynomials in Factored Form
1	$(1+s)$
2	$(1+1.414s+s^2)$
3	$(1+s)(1+s+s^2)$
4	$(1+0.765s+s^2)(1+1.848s+s^2)$
5	$(1+s)(1+0.618s+s^2)(1+1.618s+s^2)$
6	$(1+0.518s+s^2)(1+1.414s+s^2)(1+1.932s+s^2)$
7	$(1+s)(1+0.445s+s^2)(1+1.247s+s^2)(1+1.802s+s^2)$
8	$(1+0.390s+s^2)(1+1.111s+s^2)(1+1.663s+s^2)(1+1.962s+s^2)$
9	$(1+s)(1+0.347s+s^2)(1+s+s^2)(1+1.532s+s^2)(1+1.879s+s^2)$
10	$(1+0.313s+s^2)(1+0.908s+s^2)(1+1.414s+s^2)(1+1.782s+s^2)(1+1.975s+s^2)$

Table 1: Low-Pass Butterworth Denominator Polynomial with Cutoff Frequency of 1 rad/sec and Different Filter Orders

Q7.

(a) (i) Give the general block-diagram representation of an amplifier with feedback (include various key feedback elements) (5 marks). Develop an expression for the gain of an amplifier (block represented) with feedback, in terms of its gain without feedback and other feedback system parameters (5 marks). (10)

(ii) Explain very briefly (but precisely) what is meant by (i) positive feedback (5 marks), and (ii) negative feedback (5 marks) in feedback systems. (10)

(iii) With the help of block diagrams, name and show the different types of feedback configurations (topologies) of electronic amplifiers. (20 marks) (20)

(b) Figure Q7 shows an RC Phase-Shift oscillator (with $R_1 = R_2 = R_3 = R$, and $C_1 = C_2 = C_3 = C$). Its loop transfer function is given by

$$T(s) = -\frac{R_F}{R}\frac{(RCs)^3}{1 + 5RCs + 6(RCs)^2 + (RCs)^3}$$

Using the above loop transfer function, derive the angular frequency at which oscillation can occur for this phase-shift oscillator (20 marks). What is the required relationship between R_F and R for oscillations to occur (5 marks)? (25)

(c) For the RC phase-shift oscillator circuit shown in Figure Q7, determine the value of R_f necessary for the circuit to operate as an oscillator (10 marks). Determine its frequency of oscillation (10 marks). (20)

(d) Design an RC phase shift oscillator that will oscillate at 250 Hz (i.e., determine suitable component values for its passive elements – R_f, R, and C). (15 marks) (15)

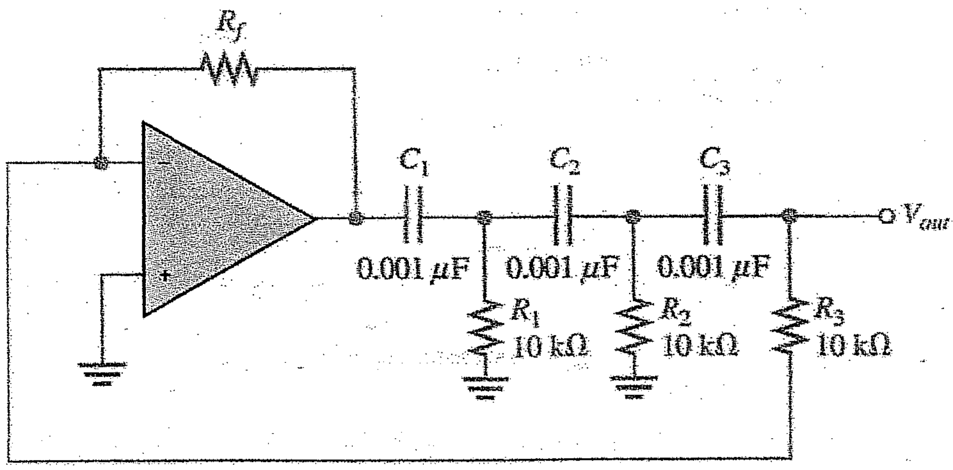

Figure Q7

Q8.

(a) Starting from the diode characteristic equation $I_D = I_S \exp[(v_D/\eta v_T) - 1]$ derive the expression for the intrinsic resistance, r_d of the diode junction as $\eta v_T/I_{DQ}$ (usual notations) (15 marks). (15)

(b) Figure Q8a shows a diode based log amplifier. Show that v_o is proportional to $\ln(v_{in})$ (15 marks) (15)

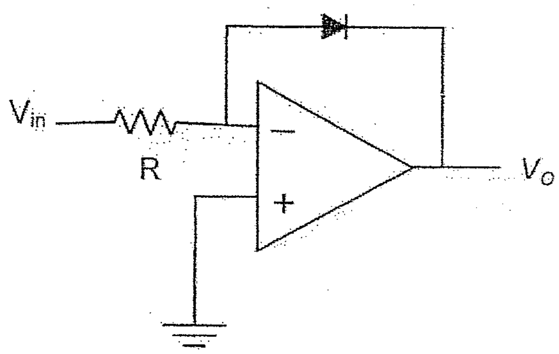

Figure Q8a

(c) Explain briefly but clearly the operation of the precision rectifier arrangement shown in Figure Q8b. (35 marks) (35)

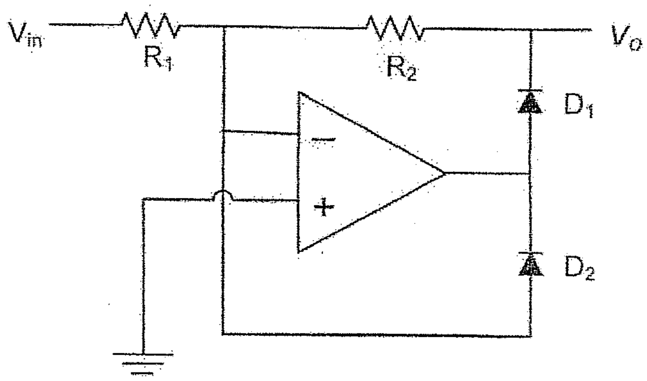

Figure Q8b

(d) Consider the circuit diagram of Figure Q8c.

(i) Assuming ideal diode and capacitor behavior, briefly explain the operation of the above circuit (20 marks). (20)

(ii) Hence draw the waveforms of V_1, V_2, and V_3 for an input signal of $v_{in} = 10 \sin 2\pi t$ (5 x 3 = 15 marks) (15)

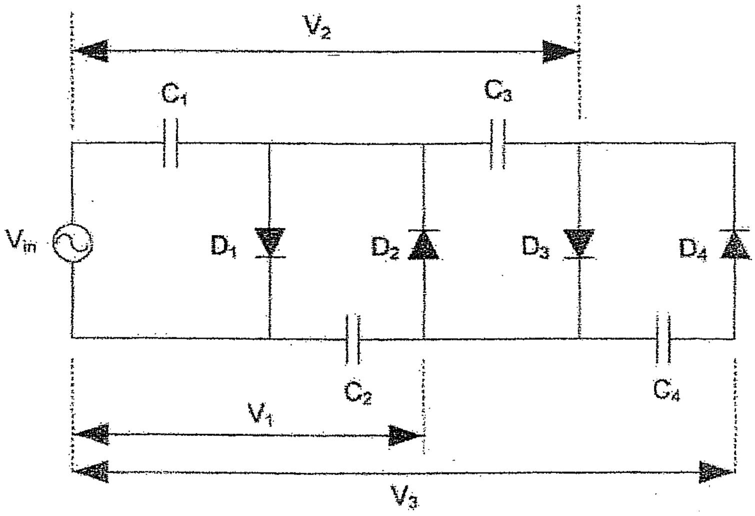

Figure Q8c