The University Of Sheffield.

Data Provided: useful definitions and equations at end of paper (after Q4)

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2010 - 2011 (2 hours)

ELECTRONIC DEVICES IN CIRCUITS 2

Answer THREE questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order in which they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1 (i) Write down the high frequency and low frequency gains of the circuit of figure 1 in terms of the circuit components. {*2*}

(ii) Show that the transfer function, v_o/v_i of the circuit is given by:

$$\frac{v_o}{v_i} = k\,\frac{\left(1+j\dfrac{f}{f_1}\right)}{\left(1+j\dfrac{f}{f_0}\right)},\ \text{where } k = 1,\ f_1 = \frac{1}{2\pi C\,(R_1+R_2)} \text{ and } f_0 = \frac{1}{2\pi C\,R_2} \qquad \{3\}$$

(iii) If $R_1 = 30\ \text{k}\Omega$, $R_2 = 1\ \text{k}\Omega$ and $C_1 = 1\ \mu\text{F}$, sketch the gain magnitude part of the frequency response that you would expect to observe. Label the low and high frequency gains, the frequencies f_1 and f_2 and the slopes of any gradients. {*5*}

The circuit of figure 1 with the component values specified in part **(iii)** is required to have an upper 3 dB corner frequency of 500 kHz or greater and at 500 kHz the amplifier must be capable of supporting a 10 V peak sinusoidal signal.

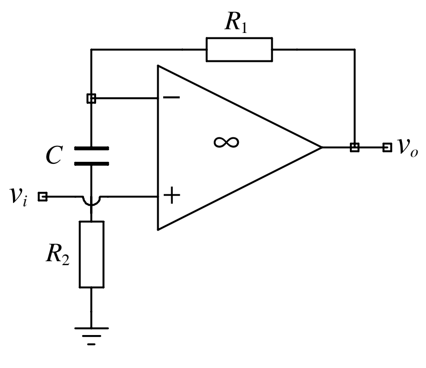

Figure 1

(iv) What minimum gain bandwidth product specification must the op-amp satisfy? {*2*}

(v) What minimum slew rate specification must the amplifier satisfy? {*3*}

(vi) The amplifier you have chosen has offset specifications, i_b = 100 nA, i_{os} = 100 nA and v_{os} = 4 mV. What is the worst case output offset voltage that you would expect? {*5*}

2 **(i)** Explain briefly why active filters are regarded as attractive alternatives to passive *L-C-R* filters, especially in cases where the filter cut-off frequency is low.

Which element in a typical active filter circuit topology is mainly responsible for placing an upper bound on the range of frequencies for which active filters are feasible?

Explain briefly how resistors and capacitors deviate at high frequencies from their ideal behaviour. **{*6*}**

During an upgrade of a particular piece of equipment, it is necessary to convert an existing *L-C-R* filter into an active filter form. Your boss gives you the job. The existing circuit is shown in figure 2.

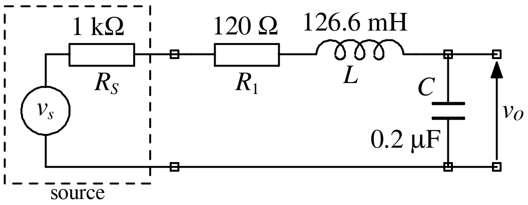

Figure 2

(ii) Show that the transfer function, v_o/v_s, of the existing filter circuit is $\frac{v_o}{v_s} = \frac{1}{1 + s\,C\,(R_S + R_1) + s^2 LC}$. **{*3*}**

(iii) Evaluate the undamped natural frequency and *q* factor of the existing circuit. **{*2*}**

(iv) Your boss tells you to use a low-pass Sallen and Key circuit with equal resistor values and a transfer function, $\frac{v_o}{v_i} = \frac{1}{1 + s\,2C_2R + s^2C_1C_2R^2}$ to replace the existing circuit. Find expressions for the undamped natural frequency, ω_n, and quality factor, q, of the Sallen and Key circuit and identify values of C_1/C_2 and RC_2 that will make the active circuit behave like the existing one. **{*4*}**

(v) You notice that the internal resistance of the source formed part of the existing filter. You decide that it would be safer to make the new filter independent of this source resistance. What op-amp circuit placed between source and filter could provide this independence without affecting gain. **{*2*}**

(vi) Sketch the complete circuit including the source. **{*3*}**

3 **(a)** Figure 3 shows a network consisting of noisy resistors and noise sources.

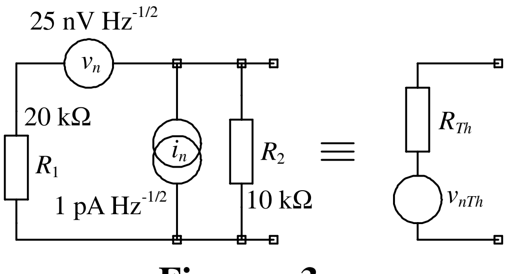

Figure 3

(i) Find the noise free resistance R_{Th} and the root - mean - square noise voltage v_{nTh} (in terms of V Hz$^{-1/2}$) which form the Thevenin equivalent of the noisy network. **{*8*}**

(ii) If a 50 pF capacitor is connected across the network terminals, what is the total rms noise voltage across the capacitor? **{*2*}**

QUESTION 3 IS CONTINUED ON THE NEXT PAGE

(b) **(i)** The noise factor of an amplifier in an impedance matched system is given by $F = 1 + \dfrac{N_A}{A_P\, kT\Delta f}$ where N_A is the amplifier added noise, A_P is its current gain and the other symbols have their usual meanings. Show that if two impedance matched amplifiers are connected in series, the overall noise factor of the system is $F = F_1 + \dfrac{(F_2 - 1)}{A_{P1}}$, where subscripts 1 and 2 refer to the first and second amplifiers in the cascade. **{*6*}**

(ii) Two amplifiers with noise factors and power gains of 2 and 6dB and 3 and 10dB respectively are to be connected in series to achieve a gain of 16dB. Which of the two should be placed at the front end to minimise noise factor? Evaluate the overall noise factor of your system. **{*4*}**

4 **(a)** **(i)** What is the main advantage of class D over class A or class B amplifiers?

(ii) What is the main advantage of class A or class B over class D amplifiers?

(iii) Draw a block diagram of a class D amplifier and describe the functions of the blocks using waveform diagrams where appropriate. **{*6*}**

(b) An integrated circuit Class B (IC) power amplifier is designed to drive peak currents of up to 3A into a resistive load. When supplied with ±35 V rails, the IC can drive peak output voltages of up to ±32V. All signal currents and voltages are sinusoidal.

(i) Identify the load resistance into which the amplifier will deliver the largest power and evaluate the magnitude of this power. **{*3*}**

(ii) If a load of 15 Ω is used with the amplifier, determine whether it is the peak current capability or whether it is the peak voltage capability that limits the maximum power delivered to the load. (Make sure you briefly state the reasoning behind your answer) What is the maximum power that can be delivered to the 15 Ω load? **{*3*}**

(iii) What average current must each rail of the power supply to the IC be capable of delivering if the amplifier is to be used with the 15 Ω load? **{*3*}**

(iv) Two identical amplifier ICs and a voltage regulator are to be mounted onto a single heatsink whose temperature must not exceed 90 ^{o}C. The amplifier ICs are bolted to the heatsink such that the overall junction to heatsink thermal resistance is 2 ^{o}C W^{-1}. The IC amplifiers incorporate a thermal protection shutdown circuit that triggers if the junction temperature reaches 125 ^{o}C. The regulator dissipates a constant 20 W. If the maximum ambient temperature is 35 ^{o}C, calculate the maximum thermal resistance allowed for the heatsink in order to avoid triggering of the thermal shutdown circuit. **{*5*}**

You may assume that the waveshapes involved are sinusoidal and that the maximum power dissipation in each amplifier IC is given by $P_{DISS} = \dfrac{2V_{CC}^2}{\pi^2 R_L}$, where V_{CC} is the supply voltage and R_L is the load resistance.

You may find some of the following relationships and definitions useful:

$I = C\dfrac{dV}{dt}$ $\quad\omega = 2\pi f\quad$ $V(t) = (V_{START} - V_{FINISH})\exp\left(\dfrac{-t}{\tau}\right) + V_{FINISH}$

$V_{AVE} = \dfrac{V_P}{\pi}$ for a half wave rectified sinusoid $\quad V_{rms} = \dfrac{V_P}{\sqrt{2}}$ for a sinusoid

$V_{AVE} = \dfrac{V_P}{4}$ for a half wave rectified triangular wave $\quad V_{rms} = \dfrac{V_P}{\sqrt{3}}$ for a triangular wave

$V_{AVE} = \dfrac{V_P}{2}$ for a half wave rectified square wave $\quad V_{rms} = V_P$ for a square wave

$\dfrac{v_o}{v_i} = \dfrac{Z_1 + Z_2}{Z_1}\qquad \dfrac{v_o}{v_i} = -\dfrac{Z_2}{Z_1}$

$v_o = A_v\,(v^+ - v^-)\qquad A_v = \dfrac{A_0}{1 + s\,\tau_0} = \dfrac{A_0}{1 + j\dfrac{\omega}{\omega_0}}\qquad \overline{v_n^2} = 4kTR\ \mathrm{V^2\,Hz^{-1}}$

$\overline{i_n^2} = 2eI\ \mathrm{A^2\,Hz^{-1}}\qquad \overline{v_n^2} = \dfrac{kT}{C}\ \mathrm{V^2}\qquad e =$ electronic charge $= 1.602 \times 10^{-19}$C

k = Boltzmann's constant = 1.38×10^{-23} J K^{-1} $\qquad$ Room temperature = 300 K

Second order standard forms are:

$$\frac{v_o}{v_i} = k\,\frac{1}{\left(1 + \dfrac{s}{\omega_n q} + \dfrac{s^2}{\omega_n^2}\right)}\qquad \frac{v_o}{v_i} = k\,\frac{\dfrac{s}{\omega_n q}}{\left(1 + \dfrac{s}{\omega_n q} + \dfrac{s^2}{\omega_n^2}\right)}\qquad \frac{v_o}{v_i} = k\,\frac{\dfrac{s^2}{\omega_n^2}}{\left(1 + \dfrac{s}{\omega_n q} + \dfrac{s^2}{\omega_n^2}\right)}$$

gain in dB = $20\log\left|\dfrac{v_o}{v_i}\right|$ for voltage ratios and $10\log\left|\dfrac{P_o}{P_i}\right|$ for power ratios.

unit multipliers: p = $\times 10^{-12}$, n = $\times 10^{-9}$, μ = $\times 10^{-6}$, m = $\times 10^{-3}$, k = $\times 10^{3}$, M = $\times 10^{6}$ G = $\times 10^{9}$

All the symbols have their usual meanings

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