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

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2007 - 2008 (2 hours)

ELECTRONIC DEVICES IN CIRCUITS 2

Answer **THREE** questions. Solutions will be considered in the order in which they are presented in the answer book and **no marks will be awarded for an attempt at a fourth question.** 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 (a) (i) Write down the high frequency and low frequency gains of the circuit of figure 1 in terms of the circuit components. **{*3*}**

(ii) Show that the transfer function, v_o/v_i of the circuit of figure 1 is given by:

$$\frac{v_o}{v_i} = k\,\frac{j\dfrac{f}{f_1}}{\left(1+j\dfrac{f}{f_1}\right)},\ \text{where}\ k = \frac{C_1}{C_1+C_2}\ \text{and}\ f_1 = \frac{1}{2\pi(C_1+C_2)R_1}\qquad \{3\}$$

(iii) On logarithmic gain and frequency axes, sketch the amplitude reponse that you would expect to observe from the circuit of figure 1. Label the high frequency gain, the corner frequency and the slope of any gradient. **{*4*}**

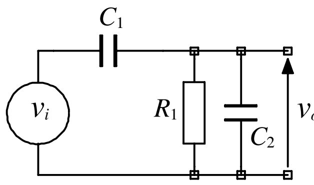

Figure 1

(iv) If C_1 = 1nF, C_2 = 2nF and R_1 = 10kΩ, what value of resistor should be placed in parallel with C_1 in order to make v_o/v_i independent of frequency? **{*2*}**

(b) A particular op-amp with a gain bandwidth product of 10MHz is connected in a non-inverting amplifier circuit. Resistor values are chosen to give an ideal circuit gain of 100.

(i) What risetime would you expect to measure at the amplifier output in response to a step input voltage change from -50mV to +50mV? **{*4*}**

(ii) If the output voltage waveshape for the conditions of part **(b) (i)** is to be unaffected by slew rate limiting, what is the minimum slew rate that the amplifier can have? Make sure you clearly state the reasoning that leads to your answer. **{*4*}**

2 The amplifier in figure 2 has an infinite input resistance, zero output resistance, infinite bandwidth and a well defined gain, v_o/v_b, of unity. The transfer function describing the circuit of figure 2 is given by:

$$\frac{v_o}{v_i} = \frac{1}{1 + sC_2(R_1 + R_2) + s^2 C_1 C_2 R_1 R_2}$$

(i) Which five of the following terms could be applied correctly to the circuit of figure 2 or its transfer function:-

"first order"
"second order"
"third order"
"analogue"
"low pass"
"band pass"
"high pass"
"Butterworth"
"digital"
"passive"
"active"
"conditionally stable"
"unconditionally stable"?

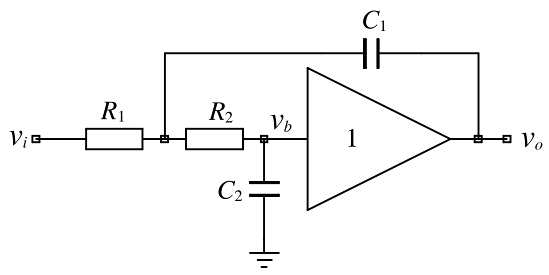

Figure 2

(*If you write down five terms or less from the above list, one mark will be given for each correct answer. If you write down more than five terms, only the first five terms in your list will be marked.*) **{5}**

(ii) By comparison with the appropriate standard form on page 5, find expressions for the system constants k, ω_n and q in terms, where appropriate, of the circuit components. **{*6*}**

(iii) Show that the q factor of the circuit is maximised when $R_1 = R_2$.
(Hint: remember that it is easier mathematically to solve this problem by seeking a minimum in 1/q than by seeking a maximum in q) **{5}**

(iv) Using the condition $R_1 = R_2 = R$ identified in part **(iii)** suggest suitable component values to achieve a q factor of 3 and an undamped natural frequency of 4kHz. The values you choose should be appropriate for a typical operational amplifier. **{*4*}**

3 **(a)** Figure 3a shows a network consisting of noisy resistors, a noise voltage generator and a noise current generator.

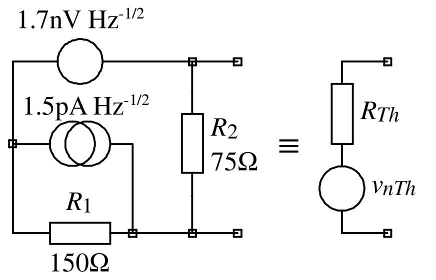

Figure 3a

(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) What noise temperature must be assigned to R_{Th} in order to account for the total output noise, v_{nTh} ? {*2*}

(b) The low noise amplifier of figure 3b has an equivalent input noise voltage, v_n, of 5nV Hz$^{-1/2}$, a negligible input current noise generator, and noisy resistors R_1, R_2 and R_S. The noise at the inverting input due to R_1 and R_2 is:

$$\overline{v_{nf}^2} = 4kT \frac{R_1 R_2}{R_1 + R_2} \ \mathrm{V^2\,Hz^{-1}}$$

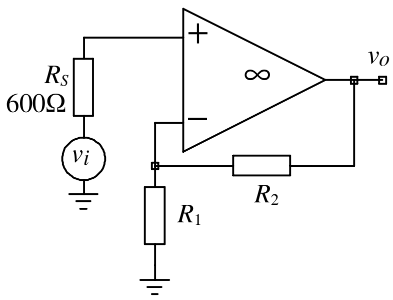

Figure 3b

(i) If the noise power at the output of the amplifier due to R_1 and R_2 must not exceed 10% of that due to v_n, what are the maximum values of R_1 and R_2 that can be used to achieve an amplifier gain of 50? {*6*}

(ii) A true rms voltmeter with a bandwidth of 10kHz is connected to the amplifier output. What reading would you expect it to display if $v_i = 0$ and R_1 and R_2 are as calculated in part **(b)** **(i)**? {*4*}

Assume throughout this question that the components used are at room temperature, ie., 300 K.

4 **(i)** Show that the maximum power dissipation in the output stage of an ideal class B amplifier driving a sinusoidal voltage, $V_P \sin\omega t$, across a resistive load, R_L, occurs when:

$$P_{DISS} = P_{LOAD} = \frac{2V_{CC}^2}{\pi^2 R_L}$$

where V_{CC} is the magnitude of the positive and negative supply rails. **{*6*}**

A particular class B power amplifier is required to deliver up to 75W into an 8Ω resistive load. Assuming that the waveshape is sinusoidal and that the output voltage can swing all the way between $+V_{CC}$ and $-V_{CC}$,

(ii) What power supply voltages, $\pm V_{CC}$, are necessary? **{*2*}**

(iii) Sketch the waveform of the current drawn from the positive supply when the peak output voltage is V_P, labelling times and amplitudes as appropriate. **{*3*}**

(iv) The output transistors, whose junction temperatures, T_J, must not exceed 150°C, have a junction to case thermal resistance of 2.5°C W^{-1} and are both mounted on the same heatsink using insulating washers with a thermal resistance of 1°C W^{-1}. A regulator IC providing power for the preamplifier stages of the system is also bolted to the heatsink and dissipates a constant 5W. If the heatsink temperature, T_S, must not exceed 100°C, and the worst case ambient temperature is 35°C, work out

1 the worst case (ie, largest) difference in temperature between T_J and T_S
2 the maximum heatsink thermal resistance that can be tolerated. **{*5*}**

(v) What would the worst case power dissipation in the output transistors be if the load was changed to an ideal 8Ω inductance? You should briefly justify your answer. **{*4*}**

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

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

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

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

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

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

$\overline{i_n^2} = 2eI\ \mathrm{A^2\,Hz^{-1}} \qquad \overline{v_n^2} = \dfrac{kT}{C}\ \mathrm{V^2} \qquad e =$ 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:

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

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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