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

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2008 - 2009 (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 (a) (i) Write down the high frequency and low frequency gains of the circuit of figure 1 in terms of the circuit components. {*2*}

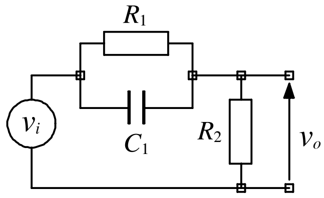

Figure 1

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

$$\frac{v_o}{v_i} = k\frac{\left(1+j\dfrac{f}{f_1}\right)}{\left(1+j\dfrac{f}{f_0}\right)}, \text{ where } k = \frac{R_2}{R_1+R_2},\ f_0 = \frac{R_1+R_2}{2\pi C_1 R_1 R_2} \text{ and } f_1 = \frac{1}{2\pi C_1 R_1} \qquad \{4\}$$

(iii) Using a dB scale for |gain| and a logarithmic scale for frequency, sketch the amplitude response that you would expect from the circuit of figure 1. Label the high and low frequency gains, the corner frequencies and the slope of any gradient. {*4*}

(iv) If C_1 = 1nF, R_1 = 10kΩ and R_2 = 1kΩ, what value of capacitor should be placed in parallel with R_2 in order to make v_o/v_i independent of frequency? {*2*}

(b) Two op-amps with a gain bandwidth product of 20MHz connected as non-inverting amplifiers each with a gain of 50. The amplifiers are connected in cascade - ie, in series.

(i) What total gain would be provided by the series combination? {*1*}

(ii) What is the -3dB frequency of each op-amp and of the cascade? {*5*}

(iii) If each amplifier has a slew rate of 70V μs^{-1}, what is the maximum frequency at which a 10V peak sinusoid can be supported at the output of the cascade? {*2*}

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 two.

(i) Show that the transfer function describing the circuit of figure 2 is given by:

$$\frac{v_o}{v_i} = \frac{2}{1 + s\,(2C_2 - C_1)R + s^2 C_1 C_2 R^2}$$ {*7*}

(ii) 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"?

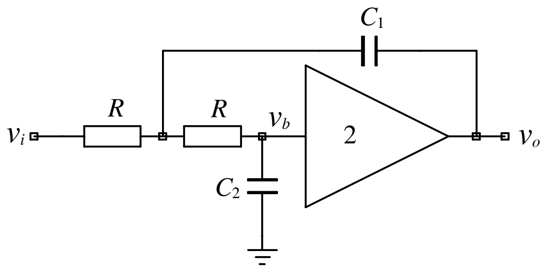

Figure 2

(*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*}**

(iii) By comparison with the appropriate standard form given in the useful information box after Q4, find expressions for the system constants k, ω_0 and q . **{*5*}**

(iv) Find a relationship between C_1 and C_2 that must be satisfied if the circuit is to be stable. **{*3*}**

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

(i) Find the noise free resistance R_{Th} and the root - mean - square noise voltage v_{nTh} (in terms of V $\text{Hz}^{-1/2}$) which form the Thevenin equivalent of the noisy network. **{*7*}**

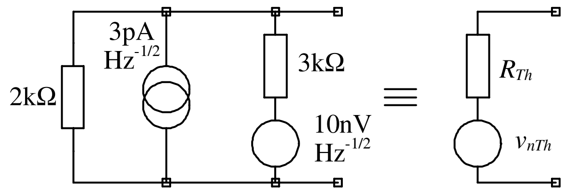

Figure 3

(ii) If a 10pF capacitor was placed across the output terminals of the network of figure 3, what would be the total rms noise voltage across the capacitor? **{*3*}**

Q3 CONTINUED ON NEXT PAGE

3 **(b)** Define "signal to noise ratio" and "noise factor". Why is noise factor useless as a measure of signal quality? **{*4*}**

(c) The ouput from an amplifier with a gain of 50V/V is measured using a true rms voltmeter with a noise equivalent bandwidth of 5kHz. When the input terminal of the amplifier is connected directly to ground the voltmeter reads 45μV and when the input terminal is connected to ground via a noisy 8.2kΩ resistor the reading changes to 84μV. Draw a noise equivalent circuit of the system and evaluate the equivalent input voltage and current noise generators that will account for these measurements. You may assume that the amplifier input resistance is infinitely large and that the experiment was performed at room temperature. **{*6*}**

4 **(a)** In figure 4 the voltages $+V_S$ and $-V_S$ are measured with respect to ground and V_I is a sinusoid of amplitude 2V with a mean value of ground potential.

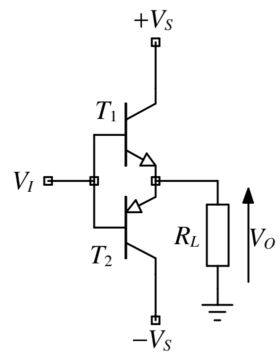

Figure 4

(i) Sketch V_I and V_O on the same axes, taking care to label peak values in your sketch. Explain briefly why V_O has the shape you have drawn. Your sketch should cover at least one complete cycle. **{*5*}**

(ii) Draw a circuit diagram to show how two 0.7V batteries could be added to the circuit of figure 4 to make the shape of V_O more similar to that of V_I. **{*2*}**

(iii) The addition of the 0.7V batteries in part **(ii)** makes the circuit vulnerable to "thermal runaway". Explain briefly what is meant by thermal runaway and why it happens. Draw a circuit diagram to show how two resistors could be added to the circuit to control thermal runaway. **{*5*}**

(b) An integrated circuit (IC) power amplifier is designed to drive peak currents of up to 3A into a resistive load. When supplied with ±18 V rails, the IC can drive peak output voltages of up to ±15V. All signal currents and voltages are sinusoidal.

(i) What is the maximum power that could be delivered to a 4Ω resistive load if the load voltage waveform must remain sinusoidal? **{*3*}**

(ii) Two of these amplifier ICs are to be used as a stereo amplifier with a 4Ω resistive load on each channel. The IC amplifiers, which incorporate a thermal protection shutdown circuit that triggers if the junction temperature reaches 120°C, are mounted on a single heatsink together with a regulator IC that dissipates a continuous 5W. The junction to heatsink thermal resistance for each IC is 2.5°C W^{-1}. The maximum ambient temperature is 35°C. What is the maximum heatsink thermal resistance that can be used if thermal shutdown circuit activation is to be avoided? **{*5*}**

The maximum power dissipation in each amplifier IC is given by $P_{DISS} = \dfrac{2V_S^{\,2}}{\pi^2 R_L}$, where V_S is the supply voltage and R_L is the load resistance.

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

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

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

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

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

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

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

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

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