The University Of Sheffield.

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

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2009 - 2010 (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*}**

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

$$\frac{v_o}{v_i} = k\,\frac{\left(1+j\dfrac{f}{f_1}\right)}{\left(1+j\dfrac{f}{f_0}\right)},\ \text{where}\ k = 1,\ f_0 = \frac{1}{2\pi C_1(R_1+R_2)}\ \text{and}\ f_1 = \frac{1}{2\pi C_1 R_2}\qquad \{3\}$$

(iii) If $R_1 = R_2 = 10\text{k}\Omega$ and $C_1 = 10\text{nF}$, sketch the response you would expect to observe in response to an ideal 10V step input occurring at $t = 0$. Label the starting and aiming voltages of the response shape and evaluate its time constant. **{*5*}**

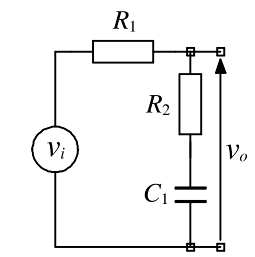

Figure 1

(b) An op-amp with a gain-bandwidth product of 20MHz is connected as a non-inverting amplifier with a gain of 50.

(i) What is the -3dB bandwidth of the amplifier and its associated time constant? **{*2*}**

(ii) What is |gain| and the phase of the output signal with respect to the input signal at a frequency of 1MHz? **{*5*}**

(iii) If the amplifier has a slew rate of $70\text{V}\,\mu\text{s}^{-1}$, what is the maximum frequency of 10V peak symmetrical triangular waveform that the amplifier can support at its output? **{*3*}**

2 **(i)** Briefly describe, with the aid of sketches if appropriate, the main features of Butterworth and Chebychev low-pass filter amplitude responses. Point out two main differences between Butterworth and Chebychev low-pass filter behaviour, one in the pass-band and one in the cut-off region of their responses. What makes the Butterwoth response attractive from a practical point of view? **{5}**

(ii) Draw a circuit diagram to show how a second order, low-pass Sallen and Key circuit can be realised using an operational amplifier, two resistors and two capacitors. (*no other components may be used.*) **{3}**

(iii) The transfer function of the second order, low-pass Sallen and Key circuit of part **(ii)**, made with equal resistor values, is

$$\frac{v_o}{v_i} = \frac{1}{1 + s\,2C_2R + s^2C_1C_2R^2}\,.$$

Find expressions for the undamped natural frequency, ω_n, and quality factor, q, of the circuit. **{3}**

(iv) A third order, 3dB ripple, Chebychev low-pass filter with a cut-off frequency of 20kHz is required for a particular application. The frequency normalised transfer function of the required filter is

$$\frac{v_o}{v_i} = \frac{1}{(s^2 + 0.299s + 0.839)\,(s + 0.299)}\,.$$

Rearrange the factors into standard forms and hence identify the q and ω_n required for the second order factor and the time constant required for the first order factor. **{7}**

(v) If the second order factor of part **(iv)** is to be realised using the Sallen and Key transfer function of part **(iii)**, what ratio of C_1 to C_2 is neccessary? **{2}**

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

(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 all of v_{nTh} is considered as originating in R_{Th}, what is the noise temperature of R_{Th}? **{2}**

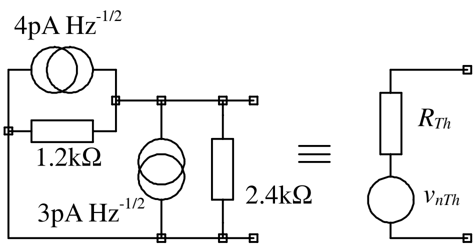

Figure 3

(b) Derive an expression for noise factor, F, in terms of N_I, N_A and A_P, the input and added noise powers and the amplifier power gain respectively. Briefly justify key steps in your derivation. **{4}**

Q3 continued overleaf

Q3 CONTINUED ...

(c) A particular amplifier has equivalent input noise voltage and current generators of 12nV $\mathrm{Hz}^{-1/2}$ and 2pA $\mathrm{Hz}^{-1/2}$ respectively. The amplifier has a voltage gain of 50 and its output is passed through a filter with a noise bandwidth of 20kHz. What is the signal to noise ratio at the filter output when the input signal is a 30μV rms sinusoidal source that has a noisy Thevenin resistance of 10kΩ. Assume that the temperature is 300K, that the filter generates no noise and that the frequency of the sinusoid lies within the filter bandwidth. **{*6*}**

4 **(a)** Figure 4 shows the output and output biasing stages typically found in operational amplifiers and power amplifiers. The voltages $+V_S$ and $-V_S$ are measured with respect to ground and V_I is has a dc component appropriate to make the dc component of V_O equal to zero.

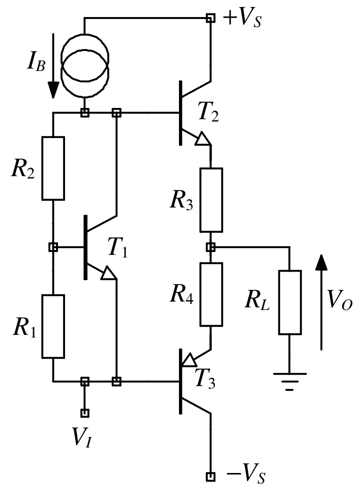

Figure 4

(i) Briefly explain the reason for the inclusion of T_1, R_1 and R_2 between the two output transistor bases. **{*2*}**

(ii) Why do designers aim to ensure that a small but finite current flows through the output transistors, T_2 and T_3, when the output signal current is zero? **{*2*}**

(iii) What two purposes are satisfied by R_3 and R_4? **{*2*}**

(b) **(i)** Show that the maximum power dissipated within each output device in a class B amplifier, such as that in figure 4, is given by

$$P_{DMAX} = \frac{V_S^2}{\pi^2 R_L} \quad \{5\}$$

A particular class B amplifier is designed to deliver power to a 4Ω resistive load. If the power supply voltage, V_S = 40V, the peak load voltage can reach V_S and the signal waveshape is sinusoidal,

(ii) What is the maximum power that could be delivered to the 4Ω resistive load if the load voltage waveform must remain sinusoidal? **{*1*}**

(iii) Sketch the waveshape of the current that you would expect to be drawn from the positive power supply for the conditions of part **(b) (ii)**. What is the peak value of this supply current waveform? **{*3*}**

(iv) Both output devices are mounted on a single heatsink but are electrically insulated from it by mica washers with a thermal resistance of 1°C W^{-1}. The maximum junction temperature of the transistors is specified as 150°C and their junction to case thermal resistance is 0.75°C W^{-1}. The ambient temperature may reach 35°C and the heatsink temperature must not exceed 85°C. What is the maximum heatsink thermal resistance that can be used if neither of the limiting temperature conditions is to be violated? **{*5*}**

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

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

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

$k =$ Boltzmann's constant $= 1.38 \times 10^{-23}$ 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

END OF PAPER

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