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

**DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING**

**Autumn Semester 2011 - 2012 (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 relevant circuit components. **{*2*}**

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

$$\frac{v_o}{v_i} = k\,\frac{\left(1+j\dfrac{f}{f_1}\right)}{\left(1+j\dfrac{f}{f_0}\right)},\ \text{where}\ k = \frac{R_1+R_2}{R_1},\ f_1 = \frac{R_1+R_2}{2\pi C\,R_1R_2}\ \text{and}\ f_0 = \frac{1}{2\pi C\,R_2} \qquad \{3\}$$

**(iii)** If $R_1 = 2\ \text{k}\Omega$, $R_2 = 10\ \text{k}\Omega$, $C = 100$ nF and $v_i$ is a step input changing from $-2$V to $+2$V at $t = 0$, sketch the shape of $v_o$ that you would expect to observe in response to the step input. Label your sketch with values of $v_o$ at $t = 0^-$, $t = 0^+$ (ie, just before and after the step respectively) and $t \Rightarrow \infty$ and give the value of the response time constant. **{*6*}**

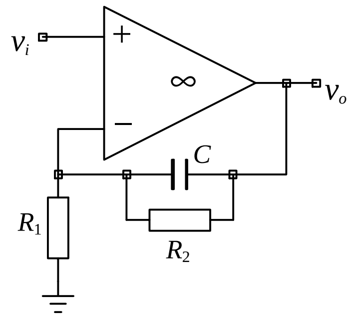


**Figure 1**

**(iv)** Using the component values in part **(iii)** find the gain magnitude, $|\,v_o/v_i|$, and the phase shift, $\angle|\,v_o/v_i|$, for the circuit of figure 1 at a frequency, $f$, of 400 Hz. **{*5*}**

**(v)** A second circuit, identical to that of figure 1, is placed in series with the circuit of figure 1 to form a cascade in which both amplifiers use the components defined in part **(iii)**. What is the overall gain magnitude and phase of the cascade at a frequency of 400 Hz? **{*2*}**

**(vi)** What gain-bandwidth product is required of the amplifier in the circuit of figure 1 if the circuit gain must be within 3dB of the value expected on the basis of the values of $R_1$, $R_2$ and $C$ defined in part **(iii)** for all frequencies up to 100 kHz? **{*2*}**

**2** **(i)** What is "parasitic" second order behaviour? In circuits dealing with signals containing fast transitions, such as pulses or steps, what behaviour would make one suspect that parasitic second order effects were present? **{*3*}**

A particular digital to analogue converter (DAC) provides an output current that is proportional to the digital input code applied to it. The current output is to be converted to a voltage by using the trans-impedance amplifier of figure 2. $C_P$ is the capacitance in parallel with the current source output of the DAC, $R_f$ defines the low frequency trans-impedance gain and $C_f$ is a compensating capacitor.

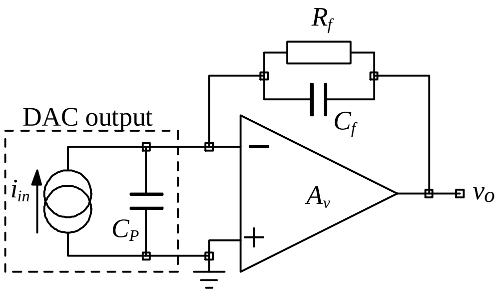


**Figure 2**

**(ii)** Show that the trans-impedance gain of the circuit of figure 2 is

$$\frac{v_o}{i_{in}} = -\frac{R_f}{1+\dfrac{1}{A_v}+sR_f\left[C_f\left(1+\dfrac{1}{A_v}\right)+\dfrac{C_P}{A_v}\right]}. \quad \{5\}$$

**(iii)** The op-amp gain is described by a first order behaviour $A_v = {}^{v_o}/_{i_{in}} = {}^{A_0}/_{(1+s\,\tau_0)}$ and when this is combined with the result of part **(ii)**, the result after some approximation is

$$\frac{v_o}{i_{in}} \approx -\frac{R_f}{1+s\left(\dfrac{1}{GBP}+C_f R_f\right)+s^2\dfrac{C_P R_f}{GBP}}$$

, where $GBP$ is the amplifier gain-bandwidth product (or unity gain frequency) in radians per second. Show that the $q$ factor of the system is given by

$$q = \frac{\sqrt{C_P R_f GBP}}{1+C_f R_f GBP}. \quad \{5\}$$

**(iv)** Sketch the magnitude response you would expect to observe for an underdamped response of the type given in part **(iii)**. **{*2*}**

**(v)** If $C_P = 50$ pF, $R_f = 10$ kΩ and the op-amp unity gain frequency is specified as 4 MHz,

**(a)** evaluate $q$ when $C_f = 0$. **{*2*}**

and

**(b)** find the value of $C_f$ required to give a maximally flat (Butterworth) response with a $q$ of 0.707. **{*3*}**

3 **(a)** Figure 3 shows a network consisting of noisy resistors and noise sources. The circuit is in thermal equilibrium at a temperature of 300 K.

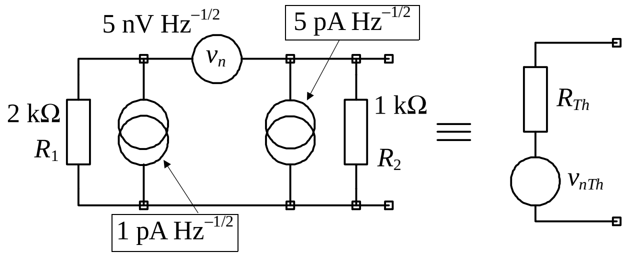


**Figure 3**

**(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)** At what temperature would the noise expected from a noisy $R_{Th}$ be the same as $v_{nTh}$? **{*2*}**

**(b)** The amplifier manufacturer for whom you work is characterising the noise performance of a new amplifier product and you have been asked to take the measurements. The amplifier has a voltage gain of 20 and a very high input resistance. All your noise measurements are made using a true rms voltmeter with a noise equivalent bandwidth of 2.5 kHz. Your log book record notes that when the input is connected directly to ground, the reading on the true rms meter is 8 μV but when the input is connected to ground by a 3.9 kΩ resistor the reading changes to 13 μV. Your readings were taken at room temperature.

**(i)** What is the value of the amplifier's equivalent input noise voltage generator expressed in terms of nV Hz$^{-1/2}$ ? **{*3*}**

**(ii)** What is the value of the amplifier's equivalent input noise current generator expressed in terms of pA Hz$^{-1/2}$ ? **{*4*}**

**(iii)** What signal source internal resistance will minimise the noise factor of the amplifier? **{*3*}**

**4** **(i)** Define what is meant by the terms Class A and Class B in the context of power amplifiers. ***{2}***

**(ii)** A Class B output stage is supplied by voltage rails $\pm V_S$ and feeds a load resistance $R_L$. Assuming that the waveform across the load is sinusoidal, show that the power dissipation in the output devices is maximum when $V_{LP}$, the peak load voltage, is $2V_S/\pi$ and that the dissipation at this condition is $\dfrac{V_S^2}{\pi^2 R_L}$ W per output device. ***{5}***

A power amplifier is required to deliver up to 1 kW into an 4 Ω loudspeaker system. Assuming a sinusoidal signal,

**(iii)** Suggest a suitable value of $V_S$ assuming that the condition $V_{LP} \approx V_S$ is achievable. ***{2}***

**(iv)** Evaluate the peak and the average current demands that the amplifier will impose on its power supply. ***{3}***

**(v)** What is the largest current through, voltage across and power dissipation in each of the output devices? ***{3}***

**(vi)** Each output device actually consists of three transistors connected in parallel with local circuitry to ensure that each transistor takes one third of the total output device load. Each output device is mounted on a single heatsink and each of the three transistors comprising the output device is insulated from the heatsink by an insulating washer with a thermal resistance of 0.6 $^{o}$C W$^{-1}$. The junction to case thermal resistance of the transistors is 0.5 $^{o}$C W$^{-1}$ and their specified maximum junction temperature is 150 $^{o}$C. If the amplifier may have to work in an ambient temperature as high as 35 $^{o}$C, find the maximum heatsink thermal resistance that can be used in this application. ***{5}***

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

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

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

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

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

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

$k =$ Boltzmann's constant $= 1.38 \times 10^{-23}\ \mathrm{J\,K^{-1}}$ $\qquad$ 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 = $\times10^{-12}$, n = $\times10^{-9}$, μ = $\times10^{-6}$, m = $\times10^{-3}$, k = $\times10^{3}$, M = $\times10^{6}$ G = $\times10^{9}$

All the symbols have their usual meanings

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