## ELEC50001 EE2 Circuits and Systems

## **Problem Sheet 2**

(Operation Amplifier Applications – Lectures 4 to 6)

- 1. Figure 1 shows the macro model of AP431i voltage reference in SPICE format.
  - (i) Sketch the part of the circuit involving R1, R2 and I1 only.
  - (ii) What is the meaning of the line for E1?
  - (iii) Figure 1b) is a partially completed full model circuit for AP431i. Complete the circuit by filling in the missing component.



- 2. Based on information provided in the datasheet of the MCP601 op-amp (see Problem sheet 1),
  - draw only the input stage of the macro model for this op-amp.
  - 3. Use the datasheet for MCP601 again, complete the missing component values in this model that specify: (i) the open-loop gain, (ii) the gain-bandwidth product, (iii) the slew-rate, (iv) output impedance, and (v) maximum output current, of this op-amp as shown in Figure Q3. (Input stage not shown here.)



Figure Q3

4. Derive an equation for the closed-loop gain G = Y/X for the circuit shown in Figure Q4 below assuming that the open-loop gain of the op-amp is A<sub>1</sub> and the feedback factor is K.



5. Figure Q5 shows two different analogue comparators with hysteresis (also known as Schmidt Trigger circuits) that compare the input voltage  $V_{IN}$  to some switching thresholds. Calculate the switching thresholds for each circuit in terms of  $V_{REF}$ ,  $R_1$  and  $R_2$ .



6. For the circuit shown in Figure Q6, derive the transfer function  $H(s) = V_{out}(s)/V_{in}(s)$ .



7. *Figure Q7* shows a function generator that produces a square wave and a triangular wave. Calculate the amplitudes of and frequency of the signals.



- 8. Using the method described in Lecture 6 slide 11, design a Butterworth lowpass filter with a cutoff frequency of 5kHz and an attenuation rate of -80dB per decade.
- 9. Figure Q9 shows a 2<sup>nd</sup> order lowpass filter implemented using an op-amp configured as a unity gain amplifier. Assume that C1 = C2 = C and that R1 = R2 = R, derive the transfer function  $H(s) = V_{out}(s)/V_{in}(s)$ . If C = 100pF, determine the value of R such that the corner frequency is 10kHz. What is the Q of the filter?



10. The triangular signal from Q7 is connected the negative input of an op-amp and an analogue voltage Vin is applied to the positive input as shown in Figure Q10. Derive an equation relating the average voltage of V<sub>pwm</sub> to V<sub>in</sub> and the conditions under which this equation applies. Design a circuit to extract the average voltage from V<sub>pwm</sub>.

