ENGINEERING TRIPOS PART IIB

Monday 28 April 2008 9 to 10.30

Module 4B8

ELECTRONIC SYSTEM DESIGN

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Attachment: Data sheet (1 page).

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1 A "Chebychev" *high pass* filter with a 1 dB ripple in the passband is to have a gain ratio of output voltage v_2 / input voltage v_1 given by the equation:-

$$v_2 / v_1 = -20\, s^2 / (s^2 + 1.1\, s\, \omega_0 + 1.1\, \omega_0^2) \quad \text{where } s = j\,\omega$$

(a) Explain and sketch carefully the expected gain against frequency response for the filter if the turnover frequency is at $\omega_0 = 600\pi$ rad/sec. What will be the maximum gain in dBs in the passband? What effect will a gain times bandwidth product of 10^6 for the op-amp have on the response? [30%]

(b) Determine the gain magnitude when $\omega = \omega_0$. Is this the expected value at the turnover frequency? If it is not, then suggest reasons for the difference. [10%]

(c) The inverting circuit shown in Fig. 1 has a gain given by:-

$$v_2 / v_1 = -Y_1\, Y_3 / [\, Y_5\, (Y_1 + Y_2 + Y_3 + Y_4) + Y_3\, Y_4\,],$$

where Y_1 to Y_5 are the *admittances* of the passive components. What types of passive elements are needed to give the desired Chebychev response? Determine expressions for the numerator of value *20* and for the terms in the denominator of value $1.1\,\omega_0$ and $1.1\,\omega_0^2$ of the filter gain equation in terms of the admittances Y_1 to Y_5. [35%]

(d) A designer has capacitors of value 200 nF and resistors of value 100 kΩ available for components to form the admittances Y_1 and Y_5. Explain what is wanted for each. Determine the other component values needed for a low frequency turnover at 300 Hz for the required Chebychev response. [25%]

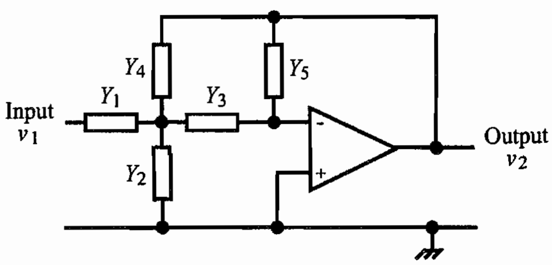


Fig. 1

2 (a) Draw the circuit and carefully explain the action of a *half-wave* precision rectifier circuit which is arranged to give a *negative* output voltage for a sine wave input voltage. Derive expressions for the output voltage for both positive and negative input voltages including any error terms due to the diode deficiencies using the normal diode model, [50%]

(b) The following specifications are to be met:-

(i) an input resistance of at least 40 kΩ

(ii) an output voltage of –10 V is desired for a alternating input of 1 V peak

(iii) output errors to be less than 0.01% of the 10 V output

(iv) the output should be smoothed so that it has less than a 2% droop with an input frequency of 10 Hz and when a load of 100 kΩ is connected across the smoothed output.

Determine the values and other requirements of the components to ensure that the circuit will perform as specified above. [40%]

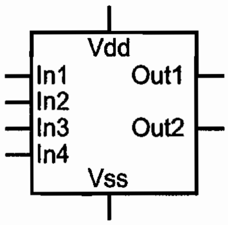
(c) Describe briefly one possible application for this type of circuit. [10%]

(TURN OVER

3 A 120 W digital dimmer lamp, running from 230 VAC/50 Hz mains, is to be implemented using a microcontroller and a sensitive gate-triac. Phase angle control is used to control the brightness of the lamp. The dimmer lamp will have 1 user input button for controlling its brightness. When the user holds down the button, the lamp brightness increases until it reaches its maximum value, and holding down the button further causes the lamp to decrease in brightness. If the user continues to hold down the button at its minimum brightness, the lamp increases in brightness again. The brightness is 'set' when the user stops pressing the button. From fully dim, the lamp takes 2.55 seconds to reach full brightness when the button is held down. From full brightness, the lamp takes 2.55 seconds to reach fully dim when the button is held down.

8-bit Microcontroller

Suggested circuit symbol (12C509):



- Supply voltage = 5 V
- Supply current = 400 μA
- Oscillator = internal/4 MHz
- 4 cycles per instruction
- Number of input pins = 4
- Number of output pins = 2
- Output current (max) = 25 mA
- 1 input interrupt (on change) and 1 timer interrupt

Triac (2N6071) turn on characteristics

- Gate trigger current = 2 mA
- Gate trigger voltage = 2.5 V
- Min gate pulse width = 1 μs

Light filament

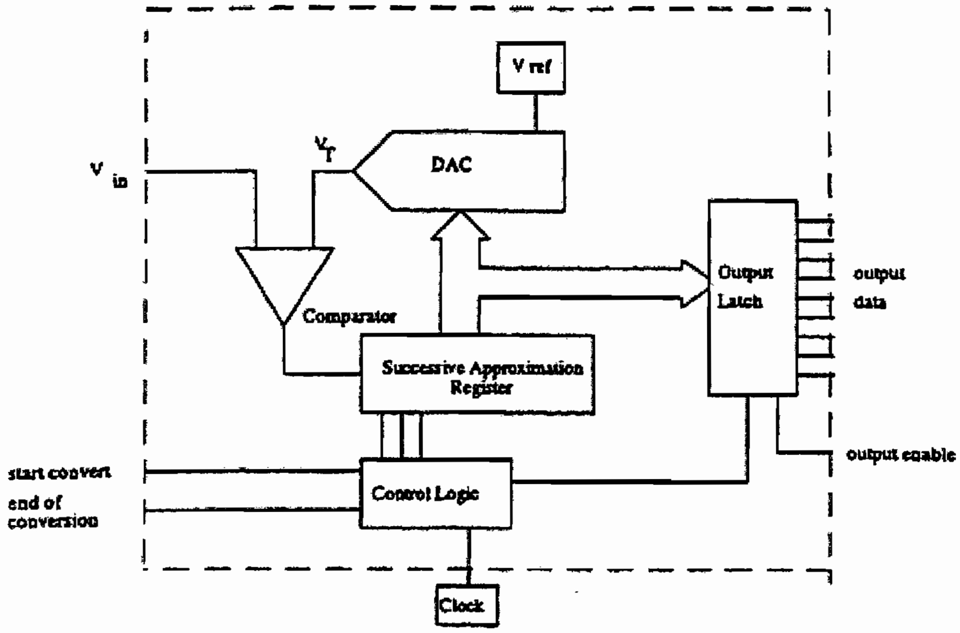
- Load type = purely resistive
- Power @ 230 V = 120 W

(a) Compare the Harvard and Von Neumann microcontroller architectures, with reference to memory maps, bottlenecks and potential errors. [15%]

(b) Draw a *complete* circuit diagram for the digital dimmer lamp, showing all inputs, components (including their values), and the lamp. [40%]

(c) With the aid of *flow diagrams*, describe the implementation of the digital dimmer using *interrupt service routines*. [45%]

4 The figure below shows a *Successive Approximation Analog to Digital Convertor* (SA-ADC)

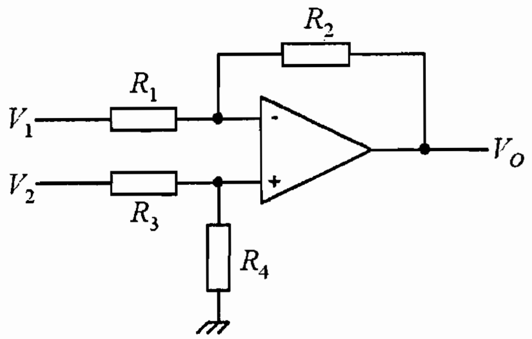


(a) Draw a *flow diagram* for the operation of the SA-ADC. [35%]

(b) Assuming the SA-ADC has 4-bits with a full scale voltage of 1.5 V, plot a timing diagram showing the evolution of V_T from start to end conversion with V_{in} = 1.05 V. [30%]

(c) Draw a block diagram of a *sigma delta modulator* which is used to convert an analog signal into a 1-bit stream. In tabular form where each column is the output of each block in your diagram, generate the first 5 bits (ie. t = 1 to 5) of the output stream for a 3 V dc analog input. The '0' level is 0 V and the '1' level is +5 V. At t = 0, assume the outputs at all blocks are 0 V. [35%]

5 (a) Assuming an ideal op-amp, show that the output of the differential amplifier below is given by: [20%]



$$V_O = V_2\left(\frac{R_4}{R_3+R_4}\right)\left(\frac{R_1+R_2}{R_1}\right) - V_1\left(\frac{R_2}{R_1}\right)$$

(b) This circuit is to be used to amplify the difference ($V_2 - V_1$) with a nominal gain of 100, where $R_2 = R_4$ and $R_1 = 1$ kΩ. Determine the common mode rejection ratio (CMRR) of the circuit if R_3 has an error of 1%. [25%]

(c) If the op-amp of the circuit above has an input offset voltage of 0.8 mV and input offset current of 200 nA, determine the magnitude of the error in the output voltage caused by these imperfections. [25%]

(d) Explain why the circuit above may not be appropriate for measuring the output of a bridge circuit with source resistance 10 kΩ and show how the above circuit may be improved by adding more components to enable it to do so. [20%]

(e) The INA114 instrumentation amplifier, configured with gain 100, is used instead. Using the datasheet provided, determine the magnitude of the error in its output voltage if the input of the INA114 has a common-mode voltage of:

(i) 2 V dc

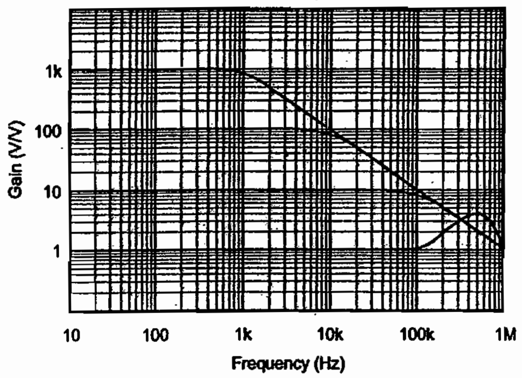
(ii) 2 V amplitude sinusoid at 50 kHz [10%]

END OF PAPER

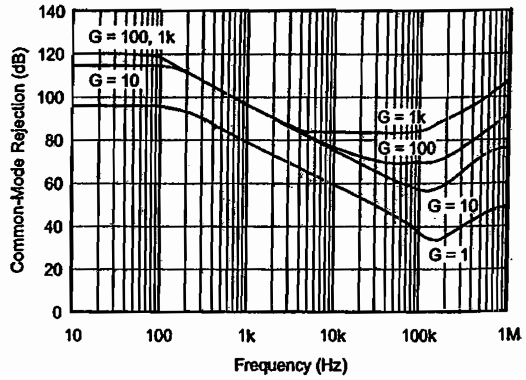
TYPICAL PERFORMANCE CURVES

At $T_A = +25°C$, $V_S = \pm15V$, unless otherwise noted.

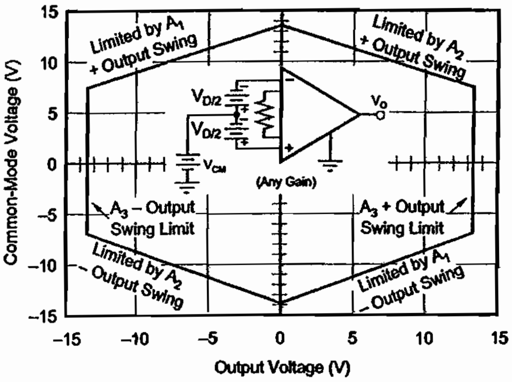
GAIN vs FREQUENCY



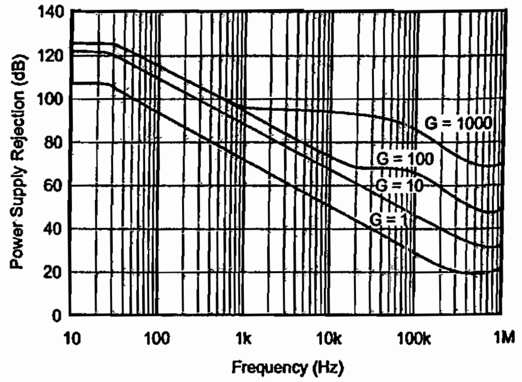
COMMON-MODE REJECTION vs FREQUENCY



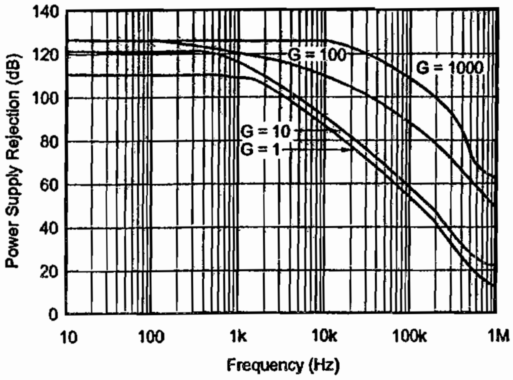
INPUT COMMON-MODE VOLTAGE RANGE vs OUTPUT VOLTAGE



POSITIVE POWER SUPPLY REJECTION vs FREQUENCY



NEGATIVE POWER SUPPLY REJECTION vs FREQUENCY



INPUT-REFERRED NOISE VOLTAGE vs FREQUENCY