ENGINEERING TRIPOS PART IA

Tuesday 13 June 2000 9 to 12

Paper 3

ELECTRICAL AND INFORMATION ENGINEERING

Answer not more than **eight** *questions, of which not more than* **three** *may be taken from Section A, not more than* **three** *from Section B, and not more than* **two** *from Section C.*

The **approximate** *number of marks allocated to each part of a question is indicated in the right margin.All questions carry the same number of marks.*

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Answers to questions in each section should be tied together and handed in separately.

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SECTION A

Answer not more than **three** *questions from this section.*

1 In the circuit of Fig.1, R_1 has a value of 2 MΩ, and C_{out} may be assumed to be large. Transistor T_1 has small signal parameters $g_m = 5$ mS, and $r_d = 50$ kΩ. The operating point for T_1 is specified as $V_{ds} = 7$ V, $I_{ds} = 2.6$ mA, and $V_{gs} = -3$ V.

(a) What application might this circuit have? [2]

(b) Calculate values for R_2 and R_3. [4]

(c) Calculate the small signal gain, and also input and output impedances at mid-band frequencies. [7]

(d) If the output impedance of the signal source for this circuit may be regarded as small, calculate the value for C_{in} if the lower 3 dB point for the circuit is 159 Hz. [4]

(e) What is the approximate maximum signal power that the circuit could deliver into a 10 kΩ load resistor, R_{load}, at a single frequency in the mid-band region? [3]

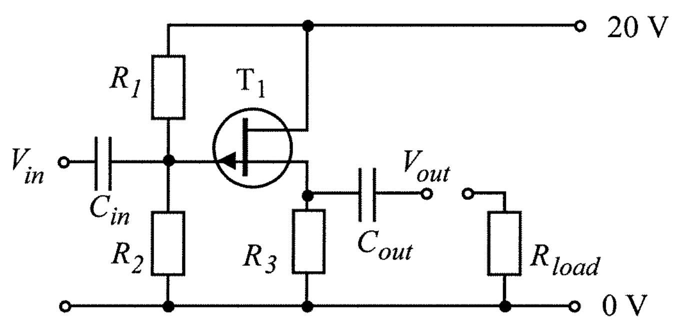

Fig.1

2 The amplifier shown in Fig.2 has voltage gain $A = 10^4$ and input impedance $R_i = 10^4\ \Omega$, but is otherwise perfect. $R = 10^3\ \Omega$, $R_f = 10^4\ \Omega$, $C_1 = 7.96\ \mu F$, and $C_2 = 31.8$ nF.

(a) Calculate the approximate voltage gain of the circuit at mid-band frequencies, assuming for this part of the question that the amplifier is perfect. [3]

(b) Find an expression for the mid-band voltage gain of the circuit in terms of R, R_f, A and R_i, and then calculate the gain of the circuit. [8]

(c) Sketch a Bode plot for the circuit, showing the 3 dB frequencies and the mid-band region. [5]

(d) What are the phase shifts between input and output of the circuit at the 3 dB frequencies, and also in the centre of the mid-band region? [4]

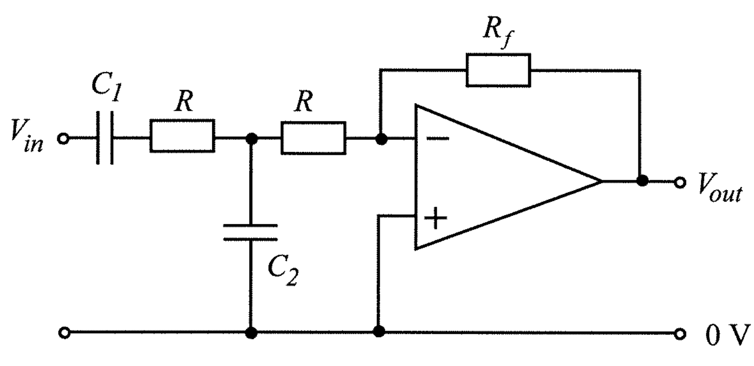

Fig. 2

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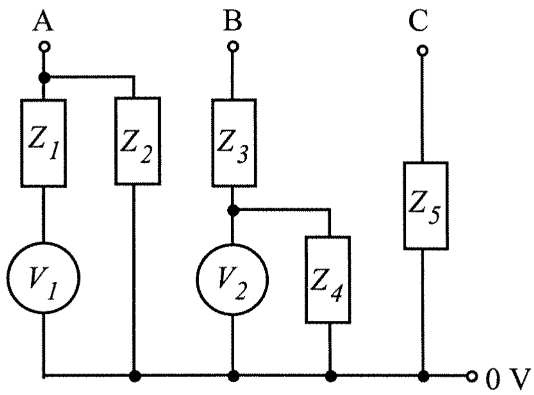
3 (a) For the circuit as shown in Fig. 3, calculate the real and imaginary parts of the voltages at terminals A and B (i.e. in the form $a + jb$). [5]

(b) Convert the circuits connected to terminals A and B to their Norton equivalents, again giving your answers as real plus imaginary parts. [5]

(c) If terminals A, B, and C, are connected together, calculate the voltage, V_{ABC}, between this node and ground. [6]

(d) What are the peak voltage and phase angle of V_{ABC} measured relative to V_1? [4]



$V_1 = 1.414\angle{-45°}$

$V_2 = 3\angle 90°$

$Z_1 = Z_2 = 1 + j2$

$Z_3 = Z_4 = Z_5 = 3 + j2$

Fig.3

4 (a) Explain why transformers are useful in a.c. power applications. Give another reason why a.c. is preferred to d.c. for such applications. [4]

(b) What are *copper loss* and *iron loss* in the context of power transformers? Indicate how each of these corresponds to elements of a simple transformer equivalent circuit, and also explain how each may be measured. [7]

(c) A transformer has losses of 2 kW and 2 kVAR when providing its full load of 50 kVA with a lagging power factor of 0.8 at 250 V and 50 Hz. Under these conditions it may be assumed that copper and iron losses are equal, and the supply has very low impedance. Calculate the output voltage under no-load conditions. [9]

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SECTION B

Answer not more than **three** *questions from this section.*

5 (a) Describe how Karnaugh maps can be used to find the simplest *sum of products* and *product of sums* forms for a logic expression. [5]

(b) A logic circuit has five inputs ABCDE and one output. Three of the inputs A, B, and C carry a weight of two and the other two carry a weight of one. The total value of the input to the circuit is defined as the weighted sum of the logic values for each of the five inputs. The output of the circuit is to be at logic 1 if the total input value is greater than 5.

(i) Draw two 4-variable Karnaugh maps for the circuit output (one for A = 0 and the other for A = 1). [5]

(ii) Express the output in a minimum product of sums form. [5]

(iii) Show how this logic function can be implemented using only 2-input and 5-input NOR gates and draw a circuit diagram. [5]

6 (a) What is the difference between asynchronous and synchronous sequential circuits, and give one advantage and disadvantage of each. [5]

(b) A modulo-6 synchronous binary counter is to be designed using only J-K bistables and 2-input NOR gates. The design should ensure that if an unused state occurs the counter is returned to the state 000 on the next clock pulse.

(i) Draw a state table for the counter. [4]

(ii) Find the required J-K logic inputs for each bistable. [4]

(iii) Draw the complete circuit. [4]

(iv) If other 2-input gates were also available, show how the design could be changed to use a smaller total number of gates, and list the gates used. [3]

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7 (a) Explain what is meant by a register in a microprocessor. What are the functions of the stack pointer and program counter in the 6800 microprocessor? [4]

(b) Two (unsigned) numbers in the range 1 to 15 are initially stored at locations 0201H and 0202H. Memory location 0203H is available for temporary storage. The following fragment of 6800 code is executed:

```
        LDAA  #8
        STAA  $0203
        CLRA
        LDAB  $0201
LOOP:   ASLA
        BITB  $0203
        BEQ   03
        ADDA  $0202
        ASR   $0203
        BNE   LOOP
```

(i) Copy the fragment and fully comment the operation performed by each line. [5]

(ii) Describe the overall operation of the program fragment and illustrate with a description of the operation when the value stored in 0201H is 9 and the value in 0202H is 7. [5]

(iii) If the value stored in 0201H is 9 and the value in 0202H is 7, calculate the time for the program fragment to operate if the microprocessor has an 8MHz clock frequency. [6]

8 (a) What is a dual in Boolean algebra? [2]

(b) Show using Boolean algebra that

$$A.\overline{B}.\overline{C} + \overline{A}.B.\overline{C} + \overline{A}.\overline{B}.C + A.B.C = A \oplus B \oplus C$$

where $A \oplus B$ represents the exclusive-OR of A and B. [5]

(c) What is the 2's complement representation of signed integers? Show how numbers can be converted to and from 2's complement form to decimal. [3]

(d) Give the 8-bit 2's complement representation of –7, –42, and 63 showing your working. Find the binary sum of the three 2's complement numbers and show how this is converted to a decimal quantity. [4]

(e) Define tri-state logic and explain how it is used in connecting multiple memory devices to a microprocessor system. [3]

(f) Two 128Kbit random access memory devices each organised for 8-bit data are to be connected to a 6800 microprocessor. Show the connections of the data and address bus. [3]

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SECTION C

Answer not more than **two** *questions from this section.*

9 (a) State Gauss' law for electrostatics, and hence derive an expression for the capacitance of an isolated conductive sphere in air. [4]

(b) Derive an expression for the electric field surrounding an infinitely long isolated straight wire of radius R in air. [3]

(c) Explain the principle of linear superposition for potential fields (or voltages in a network). Hence derive an expression for the capacitance per unit length between two parallel straight wires of radius R with centres separated by distance d (where $d >> R$) as shown in Fig. 4. [7]

(d) Two wires 10 mm in diameter with centre-to-centre separation 1 m in air are to be used to carry high voltage. What is the capacitance per unit length between the wires, and if the breakdown field of air is greater than 10^6 Vm^{-1}, estimate the maximum voltage which the wires could carry. [6]

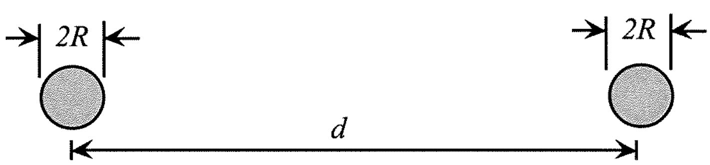

Fig. 4

10 A clamp type ammeter is constructed as shown in Fig. 5, for use at 50 Hz only. The hinge is perfect and does not disrupt the magnetic circuit.

(a) Find an expression for the peak flux, ϕ, in the yoke for current I threading the fully closed jaws (i.e. $t = 0$). [4]

(b) If the current to be measured, $I = 1$ A rms, $L = 100$ mm, $\mu_r = 1000$, and $N = 1000$ and the cross sectional area of the yoke, A, is 10^{-4} m^2, calculate the RMS voltage V at the voltmeter, assuming that it has infinite impedance. [7]

(c) If a spherical dust particle of radius 0.01 mm stops the jaws closing fully, estimate the percentage error resulting in the indicated current (assuming perfect calibration with the jaws fully closed). How would the error change if a different magnetic material with relative permeability $\mu_r = 100$ were employed for the yoke, and how else could the meter be made less sensitive to dust between the jaws? [6]

(d) What effect has moving the position, within the yoke, of the wire carrying the current to be measured? [3]

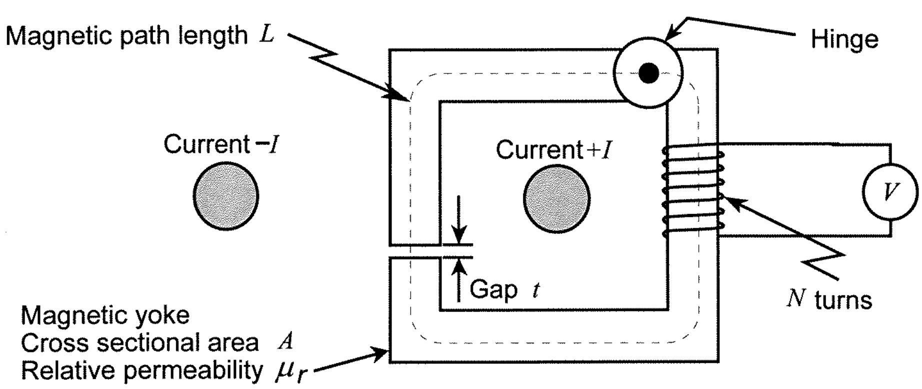

Fig.5

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11 Figure 6 shows a semi-circular permanent magnet of radius R, thickness δR (which is small) and depth, d, is constructed of Columax. The magnet has a soft iron keeper, which is of very high permeability, but which is prevented from touching the pole pieces by a plastic sheet ($\mu_r = 1$) of thickness t. The weight of the plastic and the keeper may be ignored.

(a) If $I = 0$, $R = 100$ mm, $\delta R = 10$ mm, $d = 10$ mm, and $t = 0.1$ mm, what is the flux density, B_c, in the magnet? [5]

(b) What force is necessary to pull the keeper from the magnet, with $I = 0$? [6]

(c) If $N = 10^4$ turns, what current, I_{rel}, is necessary for the force between the magnet and keeper to be zero? [5]

(d) Does the direction of the current matter, and what happens if I is increased beyond I_{rel}? [4]

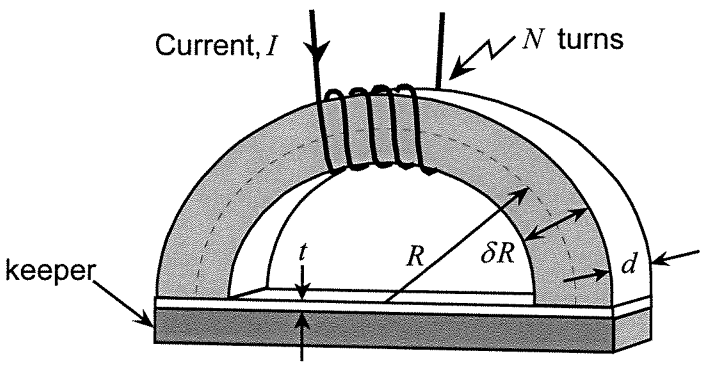

Fig. 6

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