ENGINEERING TRIPOS PART IA

Monday 9 June 2008 9 to 12

Paper 3

ELECTRICAL AND INFORMATION ENGINEERING

*Answer **all** questions.*

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

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

There are no attachments.

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

SECTION A

1 **(short)** In the circuit of Fig. 1, R_1 = 3 MΩ and capacitors C_{in} and C_{out} may be assumed to be large. Transistor T_1 has small signal parameters g_m = 7 mS and r_d = 60 kΩ. The operating point for T_1 is defined as V_{DS} = 7 V, I_{DS} = 2.8 mA, V_{GS} = -5.5 V.

(a) Calculate values for R_2 and R_3. [3]

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

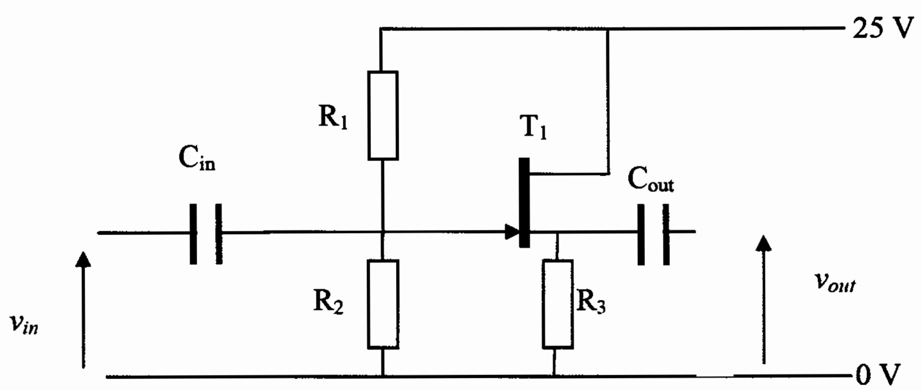

Fig. 1

2 **(short)** A small factory consumes 30 kW at 240 V, 50 Hz, with a lagging power factor of 0.8. The supply line has impedance Z_s = (0.03 + j0.02)Ω.

(a) Draw a circuit diagram and calculate the power lost in the line and the voltage supplied by the power station. [5]

(b) Calculate the required size of the capacitor connected across the factory terminals in order to correct the power factor to unity. [5]

3 **(short)** A transformer with a primary:secondary turns ratio of 10:1 has a load of impedance $(0.5 + j0.9)\Omega$ connected to its secondary winding, and its primary winding is connected to a 240 V supply. The equivalent circuit parameters of the transformer referred to the primary are:

$$R_1 = 3\Omega;\ R_2' = 2\Omega;\ X_1 = 4\Omega;\ X_2' = 3.5\Omega$$

The magnetising reactance and iron loss resistance are large enough to be ignored.

(a) Find the impedance of the load referred to the primary. [3]

(b) Determine the load current. [3]

(c) Find the load power and the transformer power loss and efficiency. [4]

4 **(long)** (a) Describe Thevenin's and Norton's Theorems. Illustrate these by deriving an equivalent model in each case for the circuit shown in Fig. 2(a). [5]

(b) Calculate the current in the link x-x for the circuit shown in Fig. 2(b), using Norton's and Thevenin's theorems to simplify the circuit. [10]

(c) If a resistor of value 1Ω is connected in place of the link x-x, what current would pass through it? [5]

(d) If a resistor of value 2Ω is connected in parallel to the current source in Fig. 2(b), what is the new value of current passing through the 1Ω resistor connected in x-x? [10]

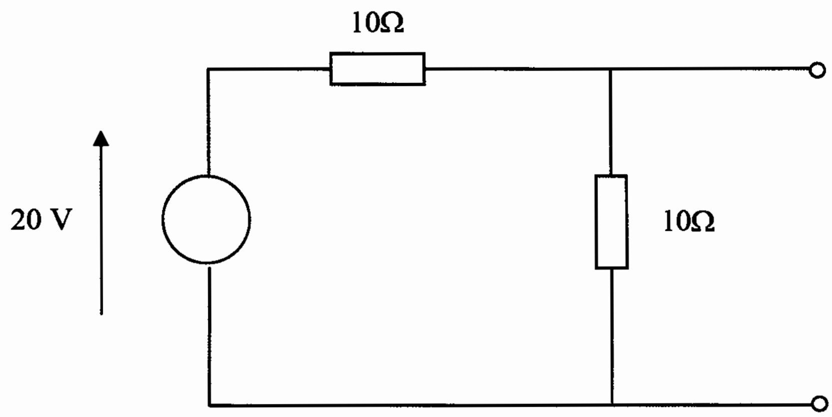

Fig. 2(a)

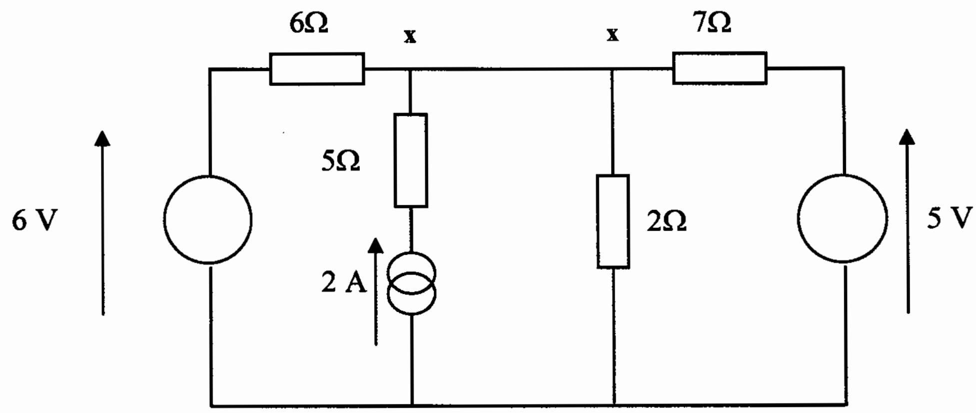

Fig. 2(b)

5 **(long)** (a) What are the parameters that describe an ideal operational amplifier and under what circumstances may real operational amplifiers be considered as ideal? [5]

(b) The op-amp in Fig. 3 may be assumed as ideal, except for the finite gain A of 200. Calculate the input impedance and voltage gain of the circuit, given that the signal source is not connected, and neglecting the effects of capacitor C_f. [10]

(c) What is the output voltage v_O in terms of v_S if the signal source in Fig. 3 is connected to the circuit? [10]

(d) With the signal source connected, and considering $C_f = 20$ pF, and treating the op-amp as ideal, what is the frequency at which the output voltage, v_O, falls to 70% of its low frequency value? [5]

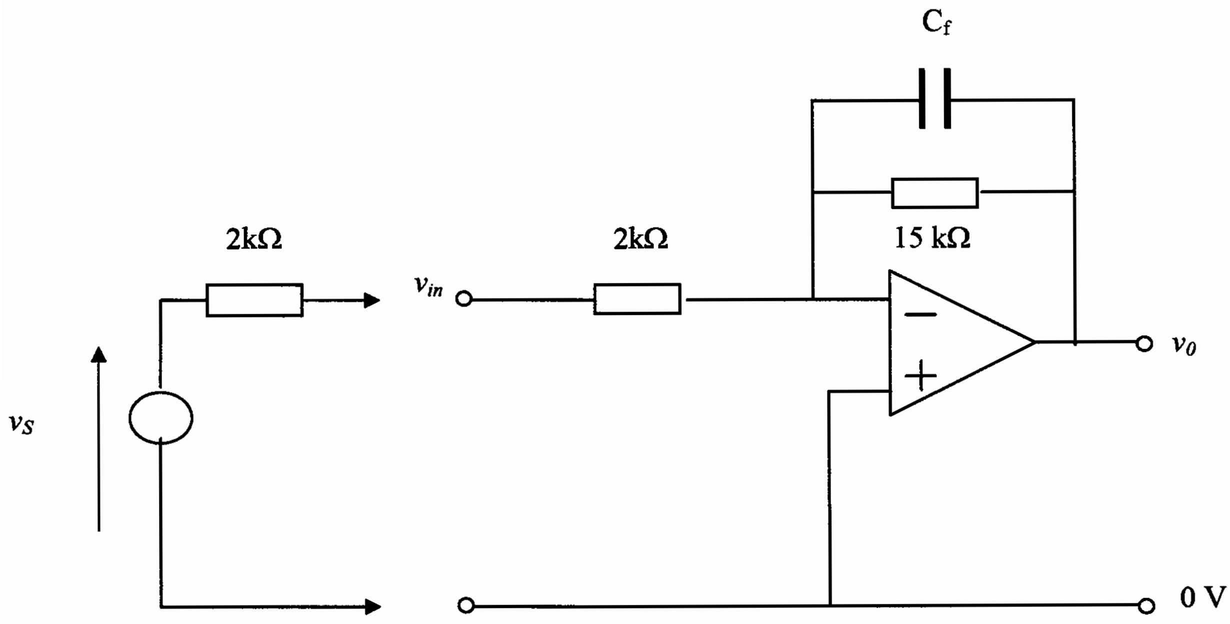

Fig. 3

SECTION B

6 **(short)** Two single-bit numbers, A and B, are to be added placing the result in the two-bit number S.

(a) Design a combinational logic circuit using 2-input NAND gates only to achieve this, and sketch the circuit. [8]

(b) How many gates are needed if any type of 2-input logic gate may be used? [2]

7 **(short)** A memory chip has 8 data lines and 14 address lines.

(a) Determine its capacity in bits. [3]

(b) The memory chip is located between addresses $8000 and $BFFF in the memory map of the 6800 microprocessor to which it is connected. Draw a circuit showing how the memory chip should be connected to the 6800 microprocessor. [7]

8 **(short)** The memory location $001B contains $4D, and accumulator B is set to $00 before the following sequence of 6800 microprocessor instructions is executed:

```
LDAA #$B3
LDAB $1B
ABA
STAA $001B
```

(a) List the contents of accumulators A and B, and memory location $001B after each instruction has been executed. [4]

(b) Write down the state of the H, N, V, C and Z flags of the condition code register after the ABA instruction has been executed. [4]

(c) Determine the number of clock cycles taken to execute the code. [2]

9 **(long)** A bread maker consists of a motor which drives a mixer to mix the dough, a heater to make the dough rise and bake the bread, and an alarm to alert the user that the process has finished. The motor, heater and alarm are to be controlled by a circuit made of J-K bistables. Initially the motor, heater and alarm are all off. When a push button P is pressed, switching its output from 0 to 1, the sequence shown below is initiated at the first rising clock edge.

State	Motor	Heater	Alarm
Start	0	0	0
Mixing	1	1	0
Baking	0	1	0
Bread ready	0	0	1

If push button P is pressed again (switching its output from 1 to 0) during the mixing stage the process is returned to the start to allow further ingredients to be added. It must also be pressed again (switching its output from 1 to 0) when the bread is ready in order to return the bread maker to the starting state. Otherwise it has no effect.

(a) Draw a state diagram for the system. [10]

(b) Determine the number of states and hence the minimum number of bistables needed. [2]

(c) Write out the state transition table for the system. [6]

(d) Draw a complete circuit diagram for the controller. [12]

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SECTION C

10 **(short)** In the magnetic circuit shown in Fig. 4 the permanent magnet material is Columax and the soft iron material may be taken to have infinite relative permeability. The air gap length is 2 mm, the total length around the magnetic circuit (excluding the air gap) is 278 mm and the permanent magnet length is 30 mm. The cross-sectional area throughout the magnetic circuit is 300 mm^2. Determine:

(a) The flux density in the air gap. [6]

(b) The total flux crossing the air gap. [2]

(c) The magnetic field intensity in the permanent magnet. [2]

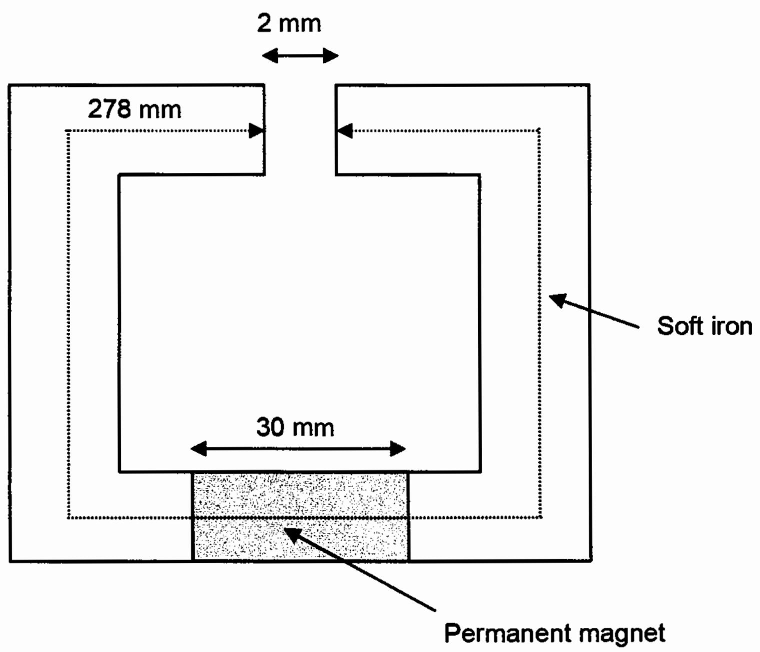

Fig. 4

11 **(short)** The cross-section of a coaxial cable, which may be taken to be infinitely long, is shown in Fig. 5. It consists of an inner conductor of diameter 2 mm, and an outer conductor which has an inner diameter of 4 mm and an outer diameter of 5 mm. The inner conductor carries a current of 1 A flowing in the positive z direction and the outer conductor carries a current of 1 A flowing in the negative z direction.

(a) Sketch the magnetic flux density, showing its direction. [3]

(b) Calculate the magnetic flux density at radii of 1.5 mm and 3 mm. [3]

(c) Sketch a graph showing the variation of the magnitude of the flux density with radius r from 0 mm to 2.5 mm. [4]

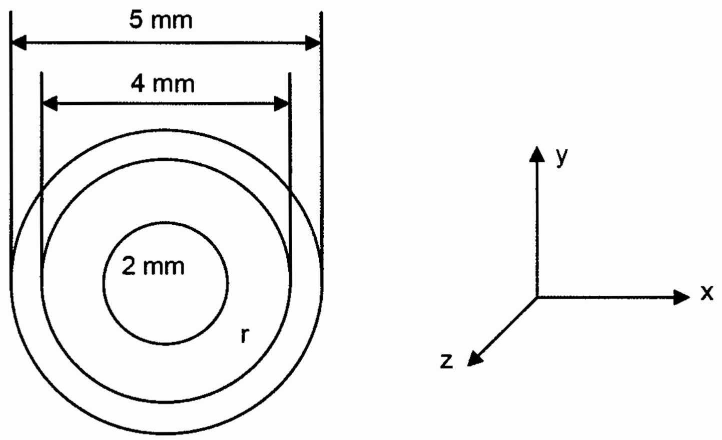

Fig. 5

12 **(long)** (a) Explain how the method of images may be used to solve electrostatic field problems involving a set of charges above a flat, infinite, conducting grounded plane. [6]

(b) Show that the capacitance of a conducting sphere of radius R situated with its centre at height h above an infinite, flat, conducting grounded plane is given by

$$C = \frac{4\pi\varepsilon_0}{\left(\frac{1}{R} - \frac{1}{2h-R}\right)}. \qquad [10]$$

(c) Explain the principle of virtual work for determining electrostatic forces, and show that the force acting in the x direction on a body charged to potential V with respect to another body, the pair of which form a capacitor with capacitance C(x), is given by

$$F = \frac{1}{2}V^2\frac{\partial C}{\partial x}. \qquad [4]$$

(d) Determine the electrostatic force acting on the conducting sphere of part (b) if R = 1 cm and h = 20 cm, and it is charged up to a voltage of 1000 kV with respect to the grounded plane. [10]

END OF PAPER