ENGINEERING TRIPOS PART IA

Monday 13 June 2005 9 to 12

Paper 3

ELECTRICAL AND INFORMATION ENGINEERING

*Answer **all eight** short questions and **not more than four** long 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.

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

(TURN OVER

SECTION A

1 **(short)** Using Thevenin's theorem or Norton's theorem, or otherwise, determine the current flowing in the 2 Ω resistor in the circuit shown in Fig. 1. [10]

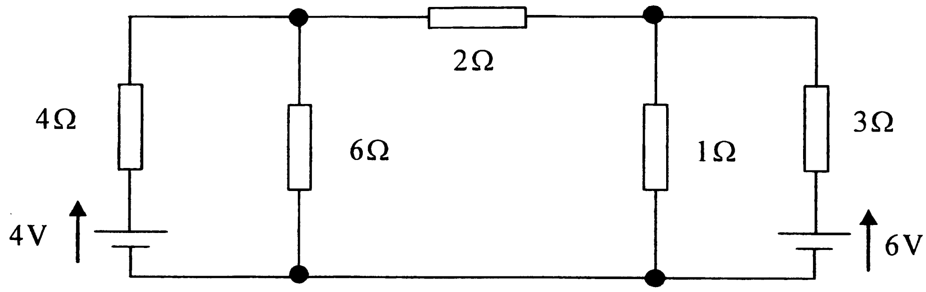

Fig. 1

2 **(short)** In the op-amp circuit of Fig. 2, the op-amp is ideal except for its finite gain, A. Derive an expression for the gain of the circuit, v_0 / v_i, and show that as A tends to infinity, the gain of the circuit tends to:

$$\frac{v_o}{v_i} = 1 + \frac{R_1}{R_2}$$

[10]

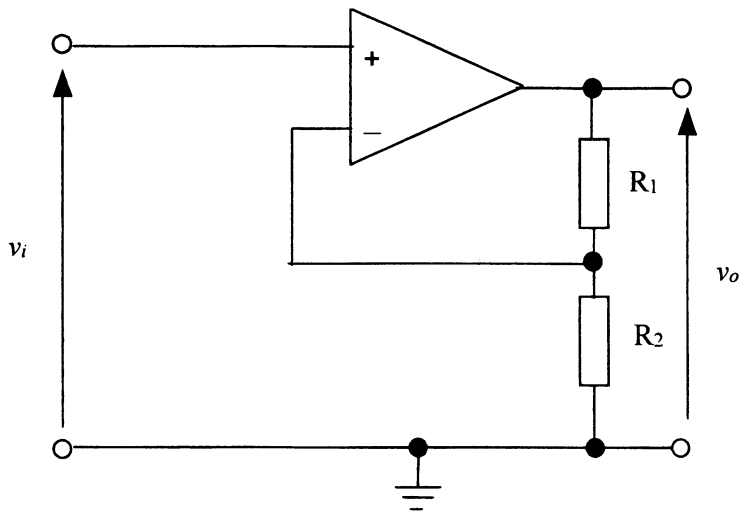

Fig. 2

3 (**short**) The ac circuit shown in Fig. 3 is connected to a 240 V, 50 Hz power supply. Determine the total complex impedance of the circuit and hence find the magnitude, and phase with respect to the voltage source, of the input current. [10]

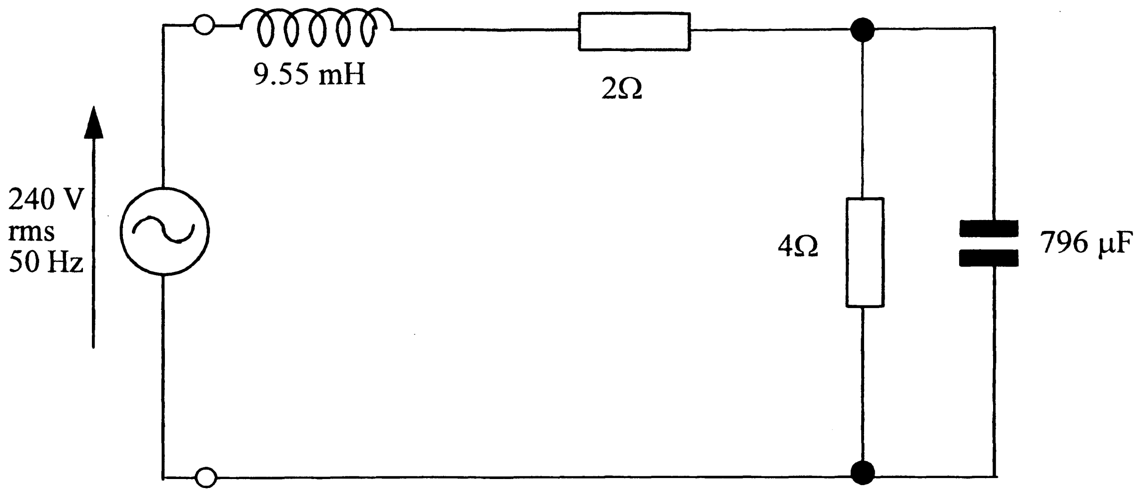

Fig. 3

4 (**long**) The FET amplifier of Fig. 4 is to be biased so that $V_{GS} = -4$ V, $V_{DS} = 8$ V and $I_D = 4$ mA. At this operating point the FET has small-signal parameters $g_m = 5$ mA/V and $r_d = 10$ kΩ.

(a) Explain how the 1 MΩ resistor ensures that the dc voltage at the gate of the FET is held at 0 V, and hence explain the principle of self-biasing. [4]

(b) Determine values for R_1 and R_2 to achieve the desired operating point. [6]

(c) Draw a small-signal equivalent circuit for the amplifier circuit shown in Fig. 4, valid for mid-band frequencies i.e. the reactances of all capacitors may be taken as zero. Hence determine the small-signal gain and output impedance of the circuit. [10]

(d) The low frequency half-power frequency of the amplifier is dominated by the effect of C_0, and is to be 10 Hz with a load resistance of 5 kΩ connected between the points A and B in Fig. 4. Determine the value of C_0. [6]

(e) Given the choice of gate-source voltage of –4 V, explain why $V_{DS} = 8$ V is the optimal choice for the drain-source voltage. [4]

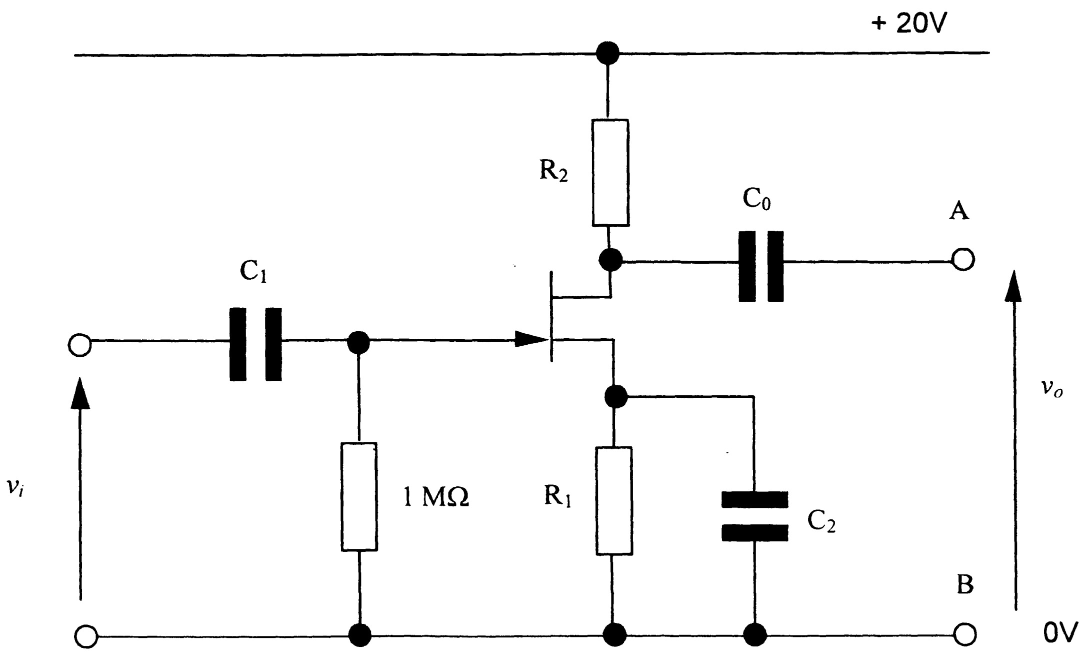

Fig. 4

5 (**long**) Figure 5 shows a factory which consumes 100 kW of real power at a lagging power factor of 0.85 when a 1 kV, 50 Hz voltage supply is connected directly across it. The factory is connected to a 50 Hz voltage source via a feeder of impedance (0.5 + j 1.5) Ω.

(a) If the factory voltage, V_{factory}, is 1 kV, determine the feeder current, the feeder power loss, and the voltage at the supply end of the feeder, V_{supply}. [10]

(b) A power factor correction capacitor is connected in parallel with the factory in order to improve the factory power factor to unity. Determine the value of the capacitor, and the new values of feeder current and power loss, assuming that the factory voltage is maintained at 1 kV. [10]

(c) Give two benefits of correcting the load power factor to unity. [3]

(d) With the power factor correction capacitor still connected, determine the factory voltage if the voltage at the supply end is 1 kV. [7]

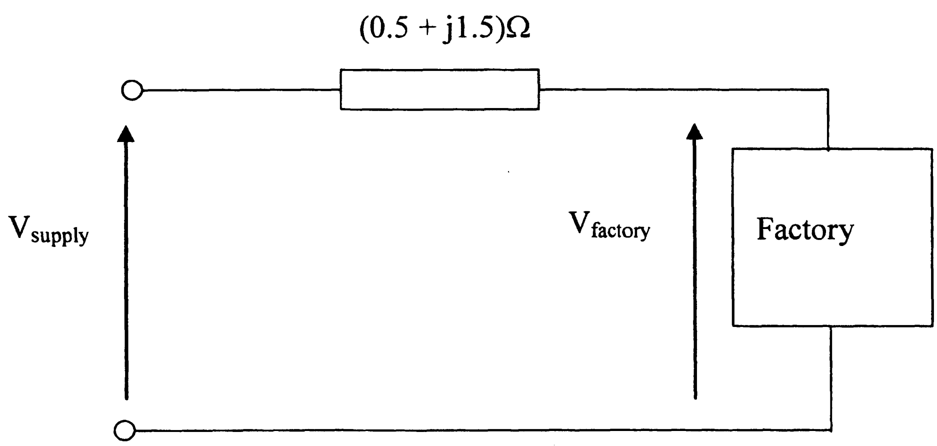

Fig. 5

SECTION B

6 (**short**) A 6800 microprocessor executes the following program segment:

LDAA	#3
ADDA	#6
LDAB	#8
STAA	$30
INCB	

What are the contents of accumulators A and B? Assuming a 1 MHz clock, how long does the program segment take to execute? [10]

7 (**short**) A segment of program code for the 6800 microprocessor contains the instruction $20 at address $001A. What should be the contents of address $001B if the next instruction is to be read from address $0004? Show your working. [10]

8 (**short**) Complete the truth table for the logic circuit in Fig. 6. [10]

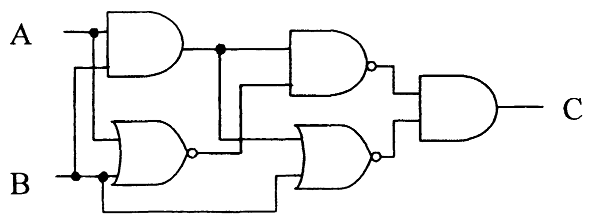

Fig. 6

9 **(long)** Figure 7(a) shows a circuit incorporating a field effect transistor whose properties are shown in Fig. 7(b). The input voltage, V_1, has a steady state value of 2 V, the impedance, R, equals 2500 Ω and the output voltage is V_2.

(a) Find V_2 when $V_1 = 2$ V. [7]

(b) Sketch on a graph the power dissipated by the circuit as a function of V_1. [10]

(c) The resistor is replaced by a PMOS transistor as shown in Fig. 7(c). The properties of the PMOS transistor are shown in Fig. 7(d). For the circuit in Fig. 7(c), sketch V_2 as a function of V_1. [10]

(d) How does power dissipation differ from before? [3]

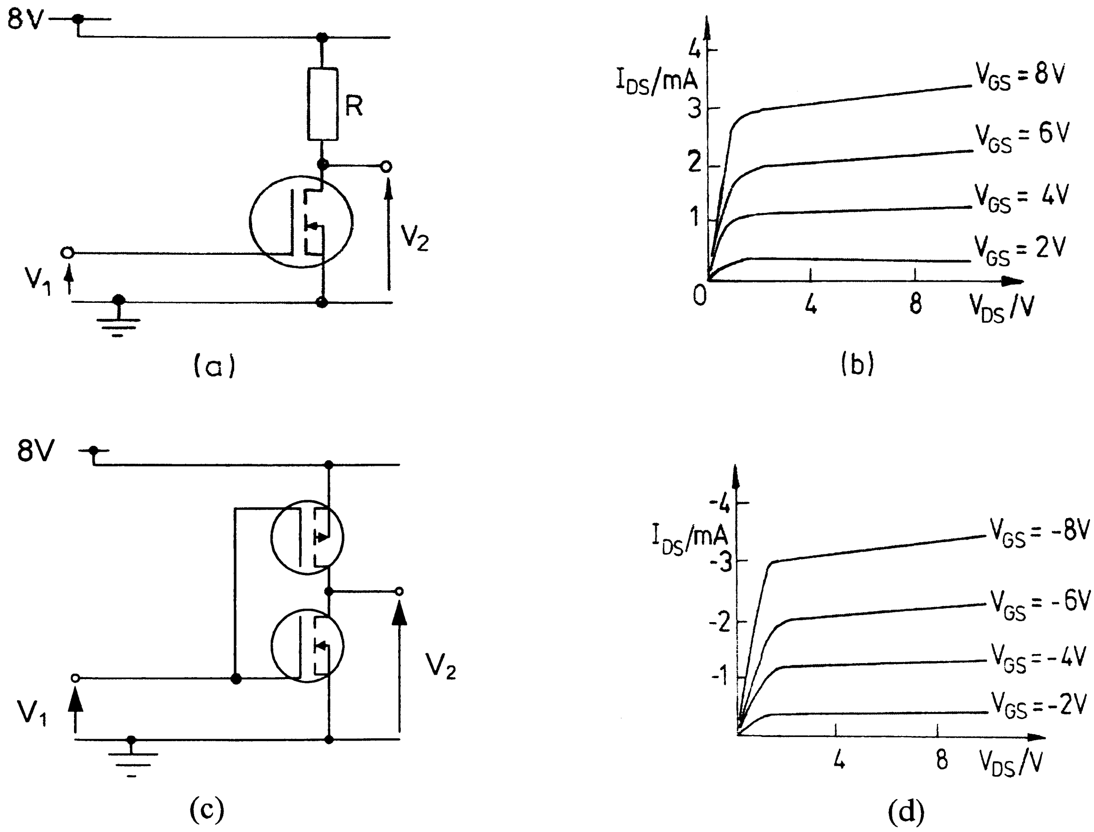

Fig. 7

10 **(long)** The controller of a painting machine is made of J-K bistables and is designed to produce the following sequence:

Heater	Spray	Fan
0	0	0
1	0	0
0	1	0
1	0	1
0	0	0

The sequence starts at the first rising clock edge following the pressing of a button B, switching its output to 1. If B is pressed while the fan is on, then both fan and heater are switched off and another coat of paint is sprayed. Otherwise B has no effect until the sequence is complete.

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

(b) What is the minimum number of bistables required? [2]

(c) Find a state transition table for the system. [9]

(d) Draw a complete circuit diagram. [9]

SECTION C

11 **(short)** A straight wire carries a current of 1 A. Find the direction and strength of the magnetic flux density, B, at a distance of 20 mm perpendicular to the wire, showing your answer on a diagram. [10]

12 **(short)** A large current is suddenly passed through a helical spring of finite length. State if the spring will extend, contract or do neither, briefly giving your reasons. [10]

13 **(long)** The electric flux density within an insulator varies as $\mathbf{D} = x\mathbf{i}$, as shown in Fig. 8, and the relative permittivity of the insulator is ε_r.

(a) Find the voltage between the points (½,0,0) and (−½,0,0). [10]

(b) Find the charge stored within a unit cube centred on the origin. [10]

(c) Find the energy stored within the cube. [10]

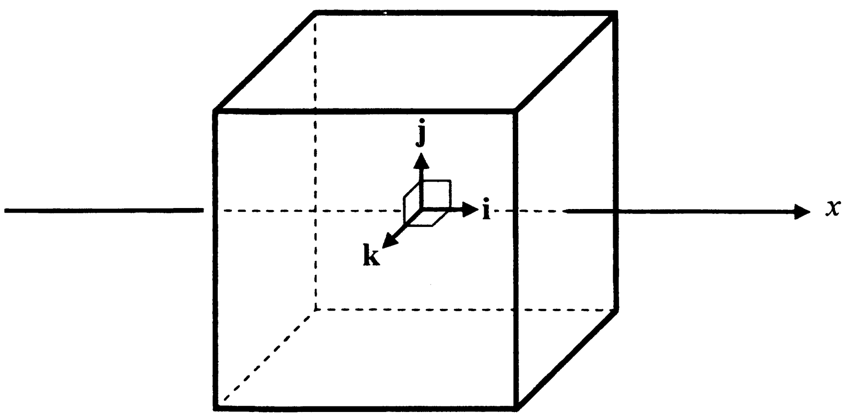

Fig. 8

END OF PAPER