ENGINEERING TRIPOS PART IA

Monday 12 June 2006 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 **(long)** (a) State the assumptions made when an op-amp is described as being 'ideal'. [4]

(b) For the circuit of Fig. 1(a) determine the voltage gain and the input resistance of the circuit, assuming that the op-amp is ideal. [8]

(c) If the op-amp has finite gain A = 10^4 but is otherwise ideal, determine the voltage gain and input resistance for the circuit of Fig. 1(a). [8]

(d) The circuit of Fig. 1(a) is used to amplify the signal from a voltage source of output resistance 600 Ω. The voltage source is connected to the amplifier using a length of coaxial cable as shown in Fig. 1(b). Determine the mid-band voltage gain, v_0/v_i and the 3 dB frequency of the circuit of Fig. 1(b). Assume that the op-amp is ideal in this case. [10]

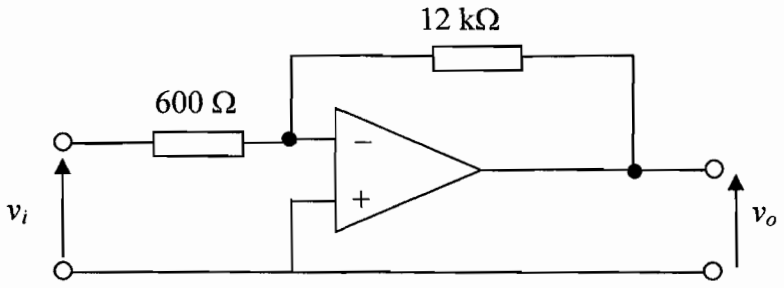


Fig. 1(a)

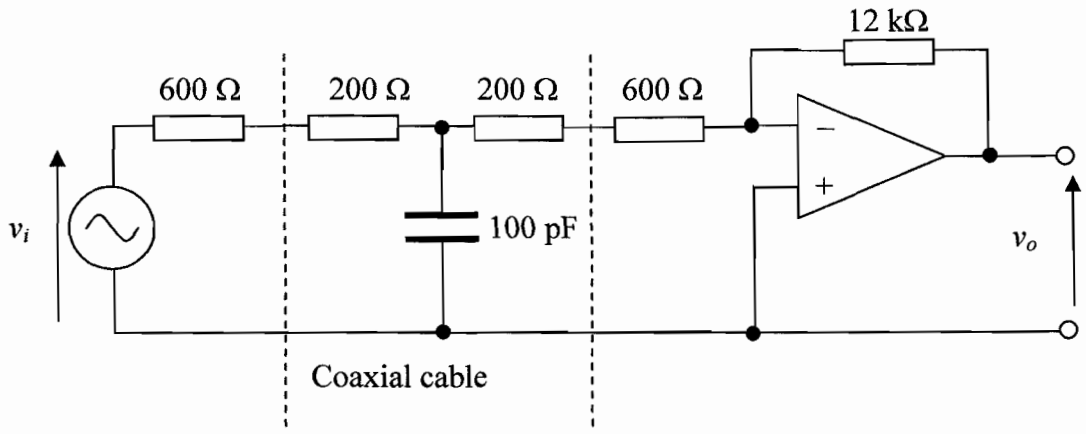


Fig. 1(b)

2 **(long)** (a) State Thevenin's and Norton's theorems. [5]

(b) Using Thevenin's and/or Norton's theorems, or otherwise, find the current in the resistor R shown in Fig. 2(a) for the two cases:

(i) R = 13 Ω;

(ii) R = 3 Ω. [10]

(c) For the ac circuit of Fig. 2(b) find:

(i) the current drawn from the 240 V rms supply if the frequency is 50 Hz; [7]

(ii) the supply frequency which maximises the current drawn from the 240 V rms supply, the capacitor voltage at that frequency and the Q factor of the circuit. [8]

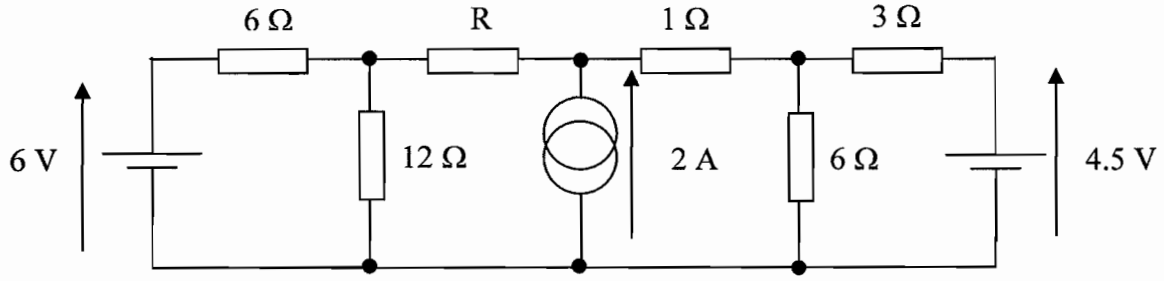


Fig. 2(a)

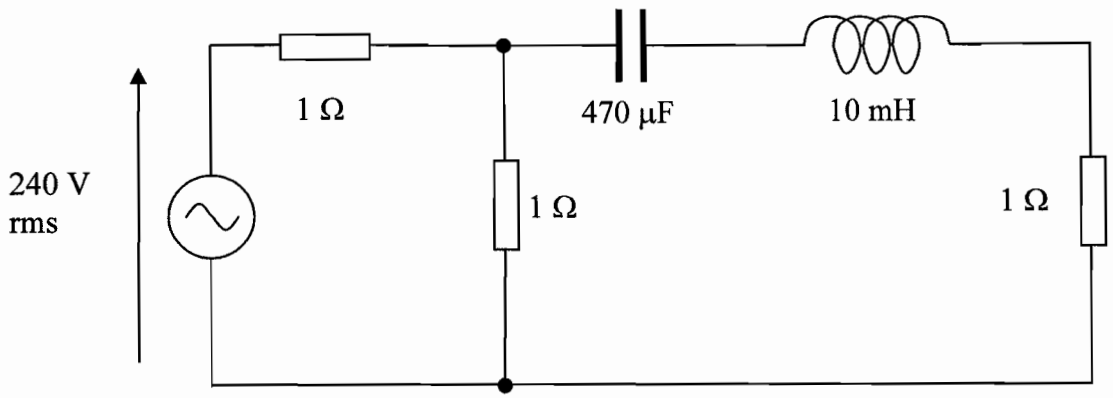


Fig. 2(b)

3 **(short)** The common source MOSFET amplifier shown in Fig. 3 is to be biased with V_{GS} = 4 V, V_{DS} = 10 V and I_D = 5 mA. At this operating point the small-signal parameters of the MOSFET are r_d = 30 kΩ and g_m = 5 mS.

(a) Find values for R_1 and R_2 to achieve this operating point. [4]

(b) Draw the small-signal circuit for the amplifier valid for mid-band frequencies, and find the mid-band small-signal gain, v_o/v_i. [6]

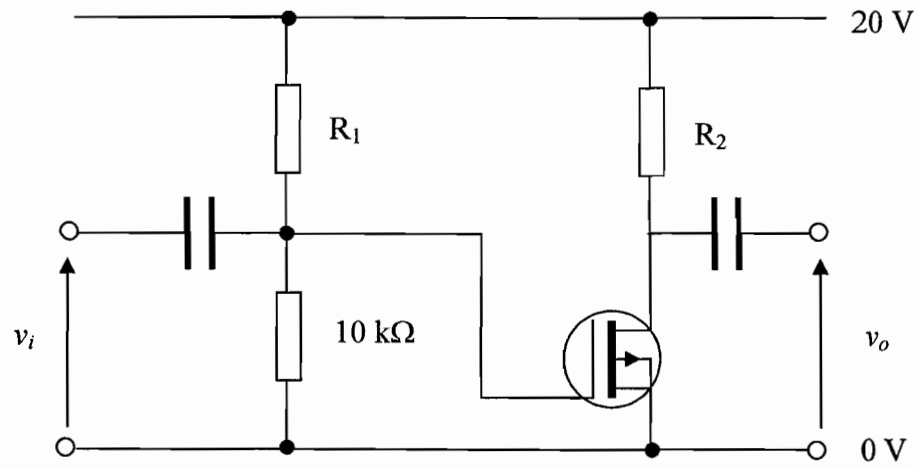


Fig. 3

4 **(short)** A transformer with a primary:secondary turns ratio of 10:1 has a load of impedance of (0.1 + j0.1) Ω connected to its secondary winding, and its primary winding is connected to a 240 V rms supply. The equivalent circuit parameters of the transformer referred to the primary are: R_1 = 2 Ω; R_2' = 1.5 Ω; X_1 = 3 Ω; X_2' = 2.5 Ω. The magnetising reactance and iron loss resistance are large enough to be ignored.

(a) Find the impedance of the load referred to the primary. [2]

(b) Determine the load current. [3]

(c) Find the load power and the transformer power losses and efficiency. [5]

5 **(short)** The ac circuit of Fig. 4 shows a (10 + j 5) Ω load connected to a 240 V rms ac supply via a feeder of impedance (0.5 + j2) Ω. Determine:

(a) the real and reactive power supplied to the load; [6]

(b) the value of the capacitor which, when connected in parallel with the 240 V supply, would improve the overall power factor to unity. [4]

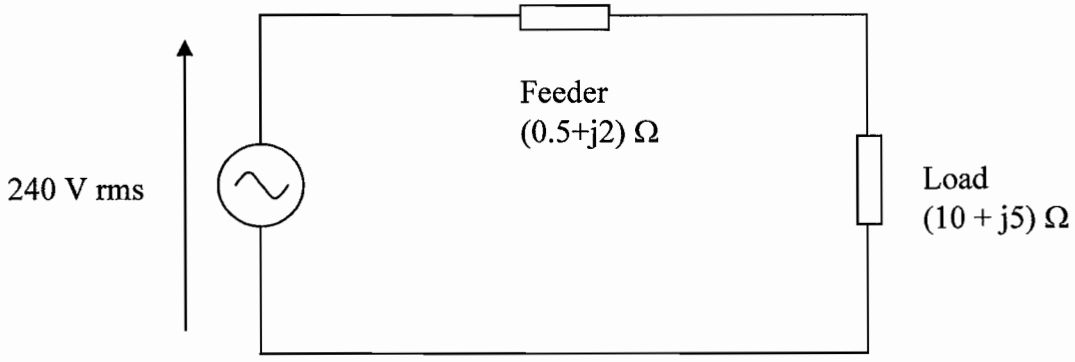


Fig. 4

SECTION B

6 **(long)** A logic circuit has four inputs and five outputs. The four inputs A_1, A_0 and B_1, B_0 represent two 2-bit unsigned binary numbers. The five bits of the output C are the result of the number A being raised to the power B.

(a) Express the logic function for each bit C_4, C_3, C_2, C_1, C_0 of the output on a Karnaugh map of the four input variables. [10]

(b) Hence design a calculation circuit using NOR and inverter gates only for C_0 and C_1, and NAND and inverter gates only for C_2, C_3 and C_4 [20]

Note: $A^0 = 1$ for all values of A.

7 **(short)** A system is to detect the sequence 10010 on an input carrying a stream of serial digital data. The system is only to respond to non-overlapping sequences. Draw the state diagram for this system. How many bistables are required to implement the system? [10]

8 **(short)** The following 6800 machine code is run

```
CLRA
CLRB
LDAA #$FC
LDAB #$3D
ABA
```

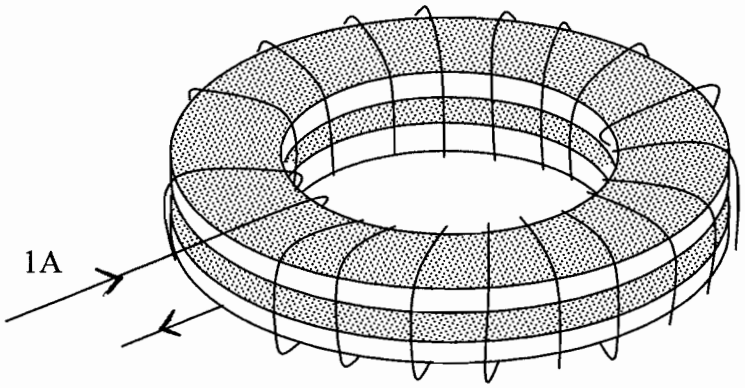
(a) What will be the contents of accumulators A and B and the state of flags N, Z, V and C after the code is executed? [5]

(b) Determine the time taken to execute the code assuming a 10 MHz clock. [5]

9 **(short)** The capital letters A to N are coded in sequence in binary with A represented by X_3, X_2, X_1, X_0 = (0001) and N by (1110). Find a simple sum of products expression in terms of X_3, X_2, X_1 and X_0 for the letters that can be written without curves (e.g. B and C have curves but A and F do not). [10]

SECTION C

10 **(long)** A pair of identical annuli with relative permeability $\mu_r = 100$ have an inner diameter of 20 mm, outer diameter of 30 mm and are 1 mm thick. They are placed face to face but 1 mm apart. The gap between the annuli is air. 100 turns of wire are wound symmetrically so that each coil contains a section of both annuli.



(a) If the current through the wire is 1 Amp, what is the magnetic flux through the iron? Do not assume that it is constant throughout the material. [10]

(b) Ignoring flux leakage, what is the magnetic flux through the air gap between the annuli? [8]

(c) What is the self-inductance of the coil? [4]

(d) Explain how your answer to part (c) would change if the current was increased or decreased and the annuli were made from Permalloy. How would it change if the material was Columax? [8]

11 **(short)** A balloon of diameter 10 cm is charged to a voltage of 100 kV then isolated and deflated to a diameter of 5 cm. Determine the new voltage on the balloon, and find the change in electrostatic stored energy. The capacitance of a sphere of radius r equals $4\pi\varepsilon_o r$. [10]

12 **(short)** The charge density within a sphere varies as a constant a times its radius. Find an expression for the direction and magnitude of the electric flux, **D**, within the sphere. [10]

END OF PAPER