ENGINEERING TRIPOS PART IB

Wednesday 8 June 2005 2 to 4

Paper 5

ELECTRICAL ENGINEERING

Answer not more than **four** *questions.*

Answer at least **one** *question from each section.*

All questions carry the same number of marks.

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 to this paper.

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

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SECTION A

*Answer at least **one** question from this section*

1 Figure 1 shows an *emitter-follower* amplifier operating in Class A.

(a) Describe briefly the main characteristics of the emitter-follower circuit and suggest typical applications for it. [2]

(b) The DC current gain of the transistor h_{FE} is specified by the manufacturer to lie within the range 100 to 500. Assuming that the base-emitter voltage is V_{BE} = 0.7 V when the transistor is active, deduce an expression for the base current that flows. Hence determine the upper and lower limits of the dc emitter voltage V_E with no input signal applied. [4]

(c) In the same circuit the transistor has small-signal parameters h_{ie} = 1 kΩ, h_{fe} = 150 and h_{oe} = 0.1 mS. The capacitors C1 and C2 may be assumed to have negligible reactance at the signal frequencies in use. Derive expressions for:

(i) the small-signal voltage gain;

(ii) the output resistance for small signals. [9]

(d) Sketch the principal elements of a complementary emitter-follower output stage for use in a power amplifier, with each output transistor operating in Class B. Explain why such a configuration can deliver several times greater signal power to a given load, and with greater efficiency, than the circuit of Fig. 1. [5]

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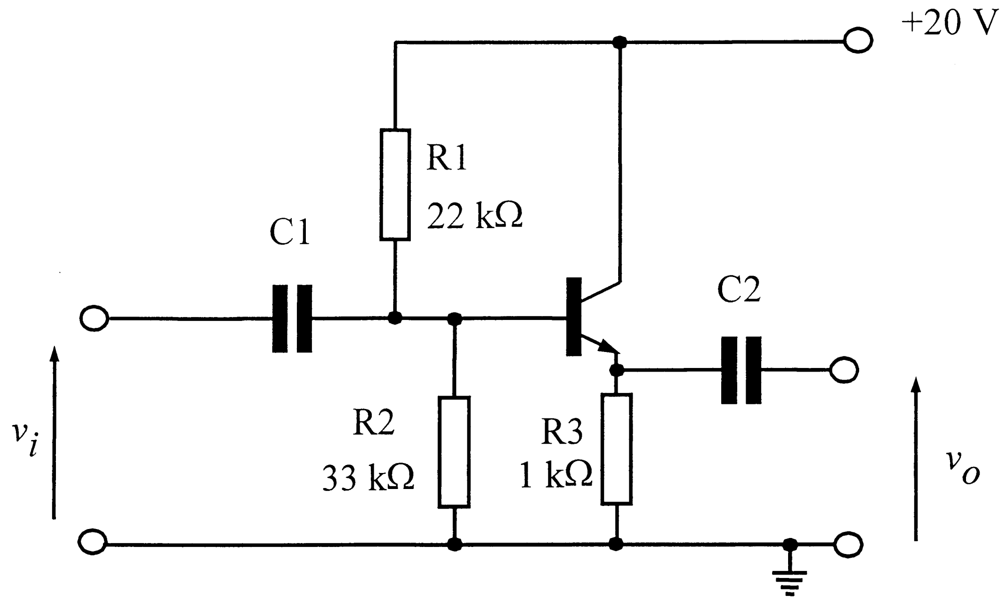

Fig. 1

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2 (a) In certain circumstances, an amplifier with negative feedback applied will behave as an oscillator. If the amplifier has forward gain A, and a fraction B of the output signal is fed back to the input, state the conditions necessary for oscillation to occur. [2]

(b) The circuit in Fig. 2 represents a *phase-shift RC oscillator.* The amplifier shown produces an inverted output and has a fixed gain G. It has infinite input resistance and zero output resistance. The feedback network is formed from three identical capacitors C and three identical resistors R.

The network has been annotated with loop currents i_1, i_2, and i_3. Using the method of loop current analysis, or otherwise, show that the signal v_i at the amplifier input can be expressed as a function of angular frequency ω as:

$$v_i = v_o \frac{R^3}{R^3 - \dfrac{5R}{\omega^2 C^2} + j\left(\dfrac{1}{\omega^3 C^3} - \dfrac{6R^2}{\omega C}\right)}$$ [7]

(c) Hence show that at a certain frequency ω_0, dependent upon R and C, the conditions for the circuit to oscillate may be met, and determine the relation linking R, C and ω_0. What must be the gain G of the amplifier to sustain oscillation? [5]

(d) If $R = 10\ \text{k}\Omega$ and the required frequency of oscillation is 130 Hz, determine the corresponding value for C. [2]

(e) It is necessary to realise the amplifier for the 130 Hz oscillator of Part (d) using integrated circuit operational amplifiers with input resistance of approximately 50 kΩ, but whose other characteristics may be assumed ideal. Sketch a suitable circuit diagram. [4]

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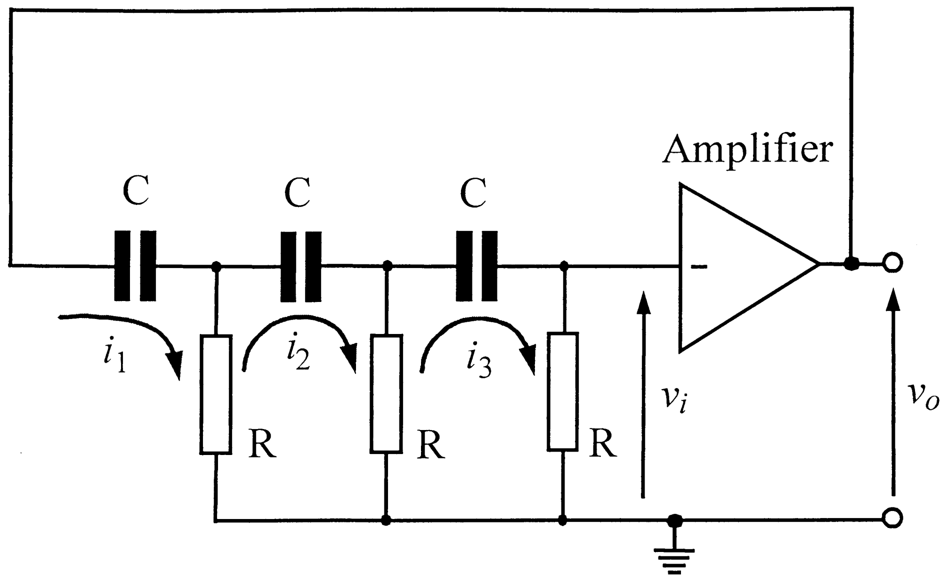

Fig. 2

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SECTION B

*Answer at least **one** question from this section*

3 (a) Explain how a three-phase supply creates a rotating magnetic field in an AC generator. [2]

(b) Sketch phasor diagrams for one phase of a synchronous machine delivering power into an infinite busbar at

(i) unity power factor
(ii) a leading power factor of 0.707
(iii) a lagging power factor of 0.707 [3]

(c) A star-connected 22 kV 500 MVA synchronous generator has a reactance per phase of 0.4 Ω. Determine the excitation voltage (phase) when the generator delivers 60% of the rated MVA at a leading power factor of 0.6 . Determine also the line current and load angle. [9]

(d) The prime mover power is increased by 20% with the excitation voltage held constant. Determine the new values of power and VARs delivered. [6]

4 (a) What is the synchronous speed of a synchronous machine in terms of the number of poles ? [2]

(b) Show how the transformer model is used to give an equivalent circuit for an induction motor. [2]

(c) Figure 3 shows a simplified equivalent circuit per phase of an induction motor, in which the magnetising reactance and iron loss resistance are ignored. Show that the output mechanical power of the motor is given by

$$P = \frac{3V^2}{(R_1 + R_2'/s)^2 + (X_1 + X_2')^2} R_2'\left(\frac{1}{s} - 1\right)$$ [6]

(d) Show that the maximum output power occurs for a slip of

$$s = R_2'/(R_2' + Z) \quad \text{where} \quad Z^2 = (R_2' + R_1)^2 + (X_1 + X_2')^2 .$$ [6]

(e) For a three phase 4-pole induction motor connected in delta to a 415V, 50Hz supply, with parameters $R_1 = 5\Omega$, $R_2' = 3.5\Omega$, $X_1 = 4\Omega$, $X_2' = 8\Omega$, calculate the maximum output power and rotation speed for maximum power. [4]

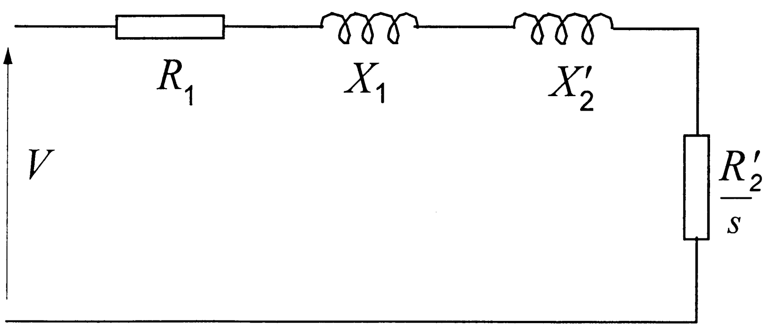

Fig. 3

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5 (a) Outline the reasons why three-phase systems are used to generate and distribute electric power. [2]

(b) Draw a labelled phasor diagram for a balanced 3-phase supply and hence derive the relationships between the line and phase voltages for a delta-connected load and line and phase currents for a star-connected load. [3]

(c) A 415V 50Hz 3-phase power line supplies two separate loads, one of which is delta-connected with an impedance of (40 + j30) ohms in each arm, and the other is star-connected with an impedance of (15 + j20) ohms in each arm.

Calculate the power supplied and the power factor for each load separately. Also calculate the total power and power factor for the combined loads. [9]

(d) A transmission line from the sub-station supplies these combined loads and has an impedance of (0.4 + j1.6) ohms per line. Calculate the power loss in the line and the new loss if the power factor of the loads is corrected to unity. Assume that the voltage at the load is maintained at 415V. [6]

SECTION C

*Answer at least **one** question from this section*

6 (a) Consider a coaxial cable with outer radius a and inner radius b. Starting from Ampere's law, derive an expression for the inductance per unit length. [6]

(b) When the coaxial cable acts as a transmission line, it has a characteristic impedance of 50Ω and a wave velocity of 2×10^8 m/s. Determine the capacitance and inductance per unit length. If the relative permittivity of the insulator is 1, calculate the radius ratio of the cable, a/b. [6]

(c) A transmission line as specified in Part (b), of length 10 m, is terminated by a resistor of 100Ω. A sharp pulse signal of 1V is fed from a source of internal impedance 10Ω. After how many reflections has the pulse's power fallen to less than 0.1% of its initial value inside the line? [8]

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7 (a) Use the expression for the electric field of a point charge to illustrate Gauss' law of electric flux density. [5]

(b) Which of the following two expressions for a plane wave is consistent with Maxwell's equations and why?

$$E_x = E_0 \exp(j(\omega t - \beta x))$$

$$E_y = E_0 \exp(j(\omega t - \beta x)) \qquad [2]$$

(c) Use the differential form of Maxwell's equations in free space to derive the corresponding expression for H and its direction. Thereby evaluate the power flux density in the wave, in terms of E_0 and the impedance of free space. [8]

(d) A TV transmitter radiates a mean signal power of 4 kW in an isotropic manner. If a receiver requires a minimum mean power of 1 nW delivered to an antenna of effective area 0.1 m^2 for adequate reception, estimate the useful range of the transmitter, stating any assumptions made. [5]

END OF PAPER