ENGINEERING TRIPOS PART IB

Wednesday 4 June 2008 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.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book

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

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

1 (a) The circuit in Fig. 1 represents a Class B amplifier. In what circumstances would it be used, and what are its advantages for amplifying alternating signals? [2]

(b) By considering the circuit connected to the external load resistor R_L, of resistance 8 Ω, estimate (i) the maximum peak output voltage and (ii) the maximum peak output current. Hence determine the maximum ac output power that could be supplied to the load by this amplifier. [5]

(c) Determine the average dc power consumed from the supplies V_{CC} and V_{EE}. State any assumptions made. Hence estimate the efficiency η of the amplifier, defined as:

$$\eta = \frac{ac\ output\ power}{dc\ input\ power}$$

Comment on the value obtained. [5]

(d) Transistors T_1 and T_2 have h_{fe} of 50 and h_{ie} of 50 Ω. Parameters h_{oe} and h_{re} may be ignored. Using the standard small-signal equivalent circuit for the bipolar transistor, draw a small-signal equivalent circuit for the amplifier and determine the voltage gain v_2/v_1. [6]

(e) Explain why small signal models may not be appropriate for this type of amplifier. [2]

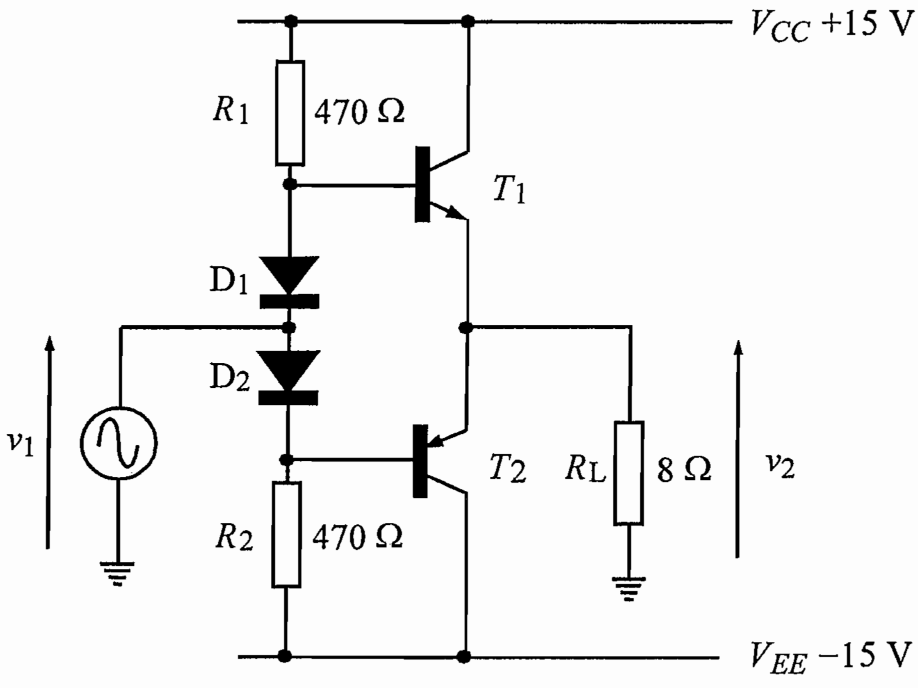

Fig. 1

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2 (a) List the advantages of using *negative feedback* in voltage amplifier circuits. [4]

(b) An internally-compensated operational amplifier has a frequency-dependent voltage gain which varies according to the expression:

$$A(\omega) = \frac{A_0}{1 + j\omega T} .$$

A_0 is a real number, ω is the angular frequency of operation and T is a time constant determined by the components within the operational amplifier. In the amplifier being considered, $A_0 = 10^5$ and $T = 1/(20\pi)$ s. The amplifier is otherwise ideal.

Write down an expression in terms of T for the upper -3 dB frequency of the amplifier when negative feedback is not used, and evaluate the expression for this amplifier. Comment on the result. [4]

(c) This operational amplifier is used in the circuit of Fig. 2. Show that the gain $G(\omega)$ of the circuit v_2/v_1 is of the form:

$$G(\omega) = \frac{A_0/k}{1 + j\omega T/k}$$

where k is a function of A_0, R_1 and R_2. [6]

(d) Hence estimate the upper -3 dB frequencies of this circuit when R_1 is 1 kΩ and R_2 is:

(i) 10 kΩ ;

(ii) 500 kΩ. [4]

(e) Explain the significance of the results in part (d). [2]

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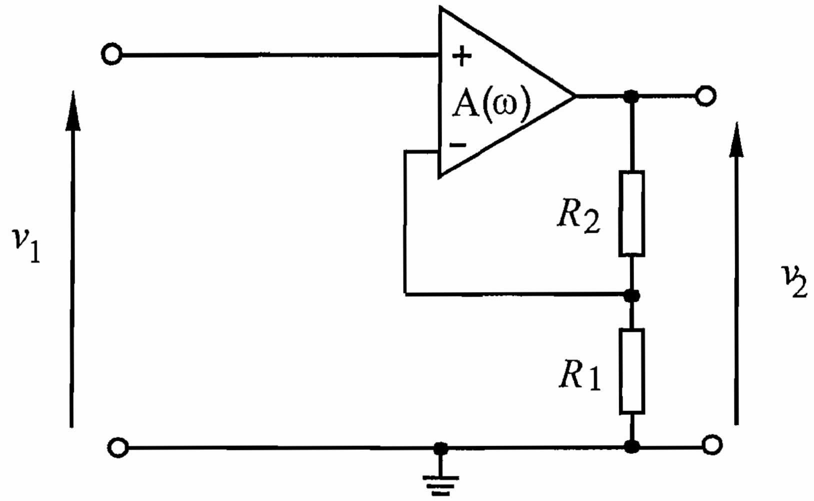

Fig. 2

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SECTION B

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

3 (a) Draw a phasor diagram for one phase of a synchronous machine delivering power to an infinite busbar for a leading power factor of 0.6. [2]

(b) Describe how the operating chart can be obtained from the phasor diagram. [2]

(c) A star-connected 1000 MVA rated, 60 kV synchronous generator has a reactance of 3 Ω per phase. It is driven by a turbine at 640 MW to supply a load of lagging power factor 0.8. Calculate the stator current and the line excitation voltage. [6]

(d) The excitation voltage is increased by 20% with the turbine power remaining unchanged. Calculate the new stator current. [4]

(e) The turbine has a maximum power of 800 MW and the maximum excitation voltage is 100 kV. Over what range of power factor can the rated MVA be delivered? [6]

4 (a) A 415 V, 50 Hz, 3-phase supply feeds two loads connected in parallel. Load 1 is delta-connected and consists of a 12 Ω resistor in parallel with a 8 Ω inductive reactance. Load 2 is star-connected, with a 10 Ω resistor in series with a 5 Ω capacitive reactance. Calculate:

(i) the power dissipated in each load and the power factors;

(ii) the total line current;

(iii) the power factor of the combined load. [10]

(b) The power factor of the combined load can be altered by placing 3 identical, star-connected capacitors in parallel with the load. Determine the value of the capacitors required to correct the power factor to:

(i) 0.95 lagging;

(ii) unity. [6]

(c) Calculate the reduction in line current for each capacitor value. Hence explain why it is not always desirable to correct the power factor to unity. [4]

(TURN OVER

5 (a) Identify on a copy of the torque versus angular velocity curve shown in Fig. 3 which ranges correspond to motoring, generating and braking. Label the values of slip at A and B. What situation does B correspond to, and where is a typical motor operating point? [3]

(b) Give the physical significance of each of the six components of the equivalent circuit of the induction motor shown in Fig. 4. [2]

(c) Consider an 8-pole, 3-phase delta connected induction motor driven by a line voltage of 415 V at 50 Hz. The equivalent circuit parameters are :

$R_1 = 2.5\ \Omega$, $R'_2 = 3\ \Omega$, $R_m = 1200\ \Omega$, $X_m = 560\ \Omega$, $X_1 = 2\ \Omega$ and $X'_2 = 2\ \Omega$.

If the machine speed is 720 rpm, calculate the following:

(i) the slip; [3]

(ii) the approximate complex input impedance per phase, stating any assumptions made; [4]

(iii) the stator line current; [4]

(iv) the torque developed by the motor. [4]

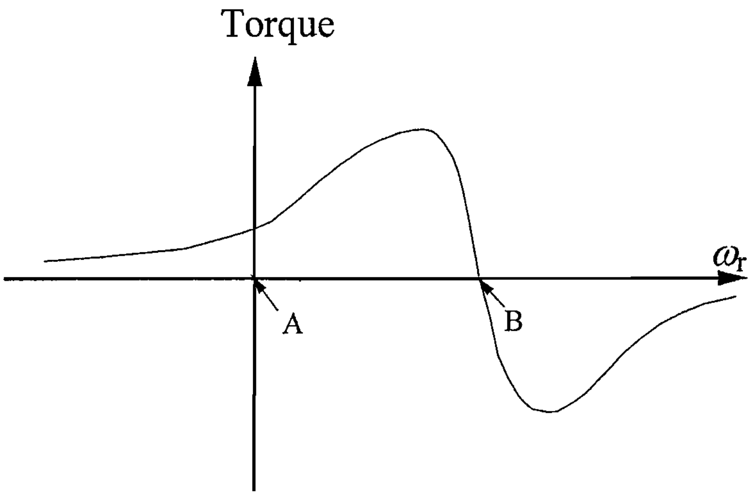

Fig. 3

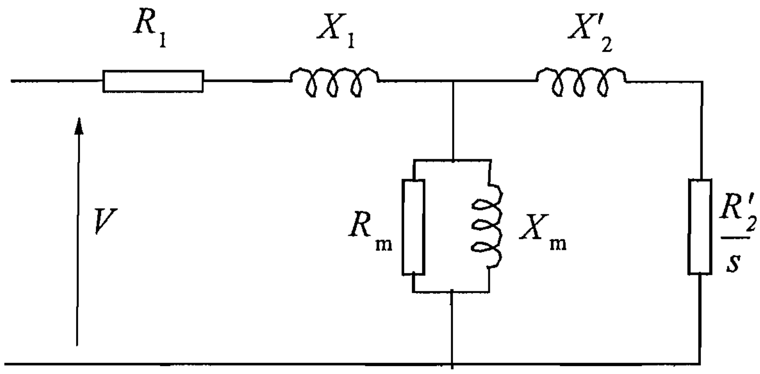

Fig. 4.

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SECTION C

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

6 (a) The electric field strength of an electromagnetic plane wave travelling through free space is given by

$$\mathbf{E} = \mathbf{u}_x E_0 \exp \mathrm{j}(\omega t - \beta z)$$

where $\mathbf{u}_x$ is unit vector in the x direction. Find the condition on ω and β for this wave to satisfy the wave equation:

$$\frac{\partial^2 E}{\partial z^2} - \varepsilon_0 \mu_0 \frac{\partial^2 E}{\partial t^2} = 0$$

and hence show that the speed of propagation of the wave in free space is $1/\sqrt{\mu_0 \varepsilon_0}$. [5]

(b) Sketch the relationship between the direction of propagation and the electric and magnetic fields of this plane electromagnetic wave, and define the impedance of free space, η_0. Hence, write down an expression for the corresponding magnetic field strength. Using the vector $\frac{1}{2}\boldsymbol{E} \times \boldsymbol{H}^*$ show that the power per unit area transmitted by the wave is $\dfrac{E_0^{\,2}}{2\eta_0}$. [5]

(c) The light from a 1 mW laser pen can be modelled as a plane wave with circular cross-section of diameter 1 mm travelling through free space. Determine the magnitude of its electric and magnetic field strengths. [5]

(d) The light impinges normally on a loss-less material of permittivity $4\varepsilon_0$ and permeability μ_0. By analogy with transmission line theory or otherwise, find the power per unit area propagating into the material, and the magnitude of the electric field there. [5]

(cont.

7 (a) A transmission line has a series inductance of 360 nH m^{-1} and a shunt capacitance of 80 pF m^{-1}. Calculate the velocity of propagation of electromagnetic waves down the transmission line and its characteristic impedance. Estimate the relative permittivity of insulation of the line, stating any necessary assumptions. [6]

(b) This line is terminated by a short circuit and is driven by a voltage generator with an output resistance equal to the characteristic impedance of the line. At a frequency of 300 MHz, calculate the shortest length of lines which will:

(i) present an open circuit at its input;

(ii) present a short circuit at its input. [4]

(c) The line of part (b)(ii) is bridged exactly half way along its length by a 100 Ω resistor. Calculate the reflection coefficient at the resistor, and the voltage standing wave ratio (VSWR) in the line on the input side of the resistor. [6]

(d) The generator emf is 100 V. Determine the power developed in the resistor. [4]

END OF PAPER