ENGINEERING TRIPOS PART IB

Thursday 5 June 1997 9 to 11

Paper 5

ELECTRICAL ENGINEERING

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

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

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.

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SECTION A

1 (a) The common-emitter amplifier shown in Fig. 1 employs a bipolar transistor with the following small-signal parameters: $h_{fe} = 100$, $h_{oe} = 10\ \mu S$, $h_{ie} = 1\ k\Omega$. The parameter h_{re} may be neglected. The reactances of the capacitors C_i and C_o are negligible at all frequencies of interest. The reactance of the capacitor C_e may be taken to be zero at mid-band frequencies. Draw a small-signal equivalent circuit for the amplifier valid for mid-band frequencies. [4]

Using the small-signal circuit, calculate:

(i) the small-signal voltage gain at mid-band frequencies;

(ii) the small-signal input resistance at mid-band frequencies;

(iii) the small-signal output resistance at mid-band frequencies. [7]

(b) With the capacitor C_e omitted from the circuit and neglecting the effect of h_{oe} calculate:

(i) the small-signal voltage gain;

(ii) the small-signal input resistance. [6]

What are the functions of the capacitor C_e and the resistor R_e in this amplifier? [3]

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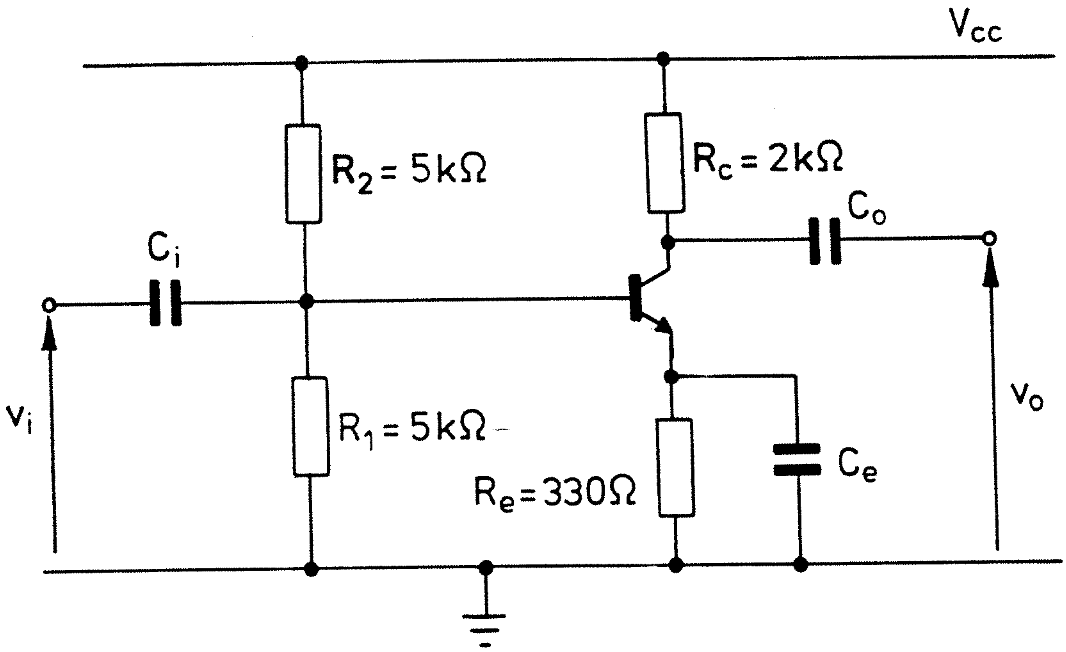

Fig. 1

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2 (a) Define the terms *common-mode gain* and *differential gain* for a differential amplifier. Briefly describe a practical example in which a high *common-mode rejection ratio* is required. [6]

(b) The amplifier circuit shown in Fig. 2(a) employs an operational amplifier.

(i) Assuming that the operational amplifier is *ideal*, calculate the value of R to give a closed-loop gain of 13. [4]

(ii) Now assume that the operational amplifier has an open-loop, low-frequency gain, A_0, of 4×10^4 and an open-loop, half-power bandwidth of 120 Hz. Assume also that the input resistance of the operational amplifier is infinite and its output resistance is negligible.

Write down an expression for the open-loop gain as a function of frequency. Hence derive a numerical expression for the closed-loop gain of the amplifier as a function of frequency for the value of R calculated above. At what frequency will the closed-loop gain be reduced by 3 dB? [3]

(c) The differential amplifier circuit shown in Fig. 2(b) employs ideal operational amplifiers. The first stage comprises the operational amplifiers A_1 and A_2 and the second stage comprises A_3. Calculate:

(i) the differential gain of the second stage, $v_0 / (v_x - v_y)$;

(ii) the overall differential gain of the amplifier, $v_0 / (v_a - v_b)$.

What is the main advantage of incorporating the first stage in this circuit? [7]

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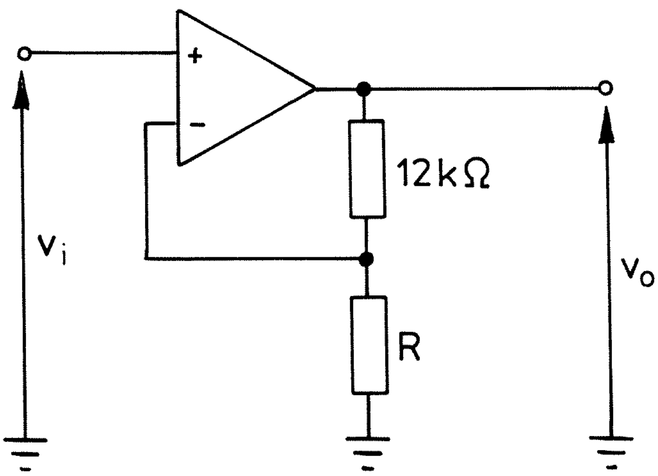

Fig. 2(a)

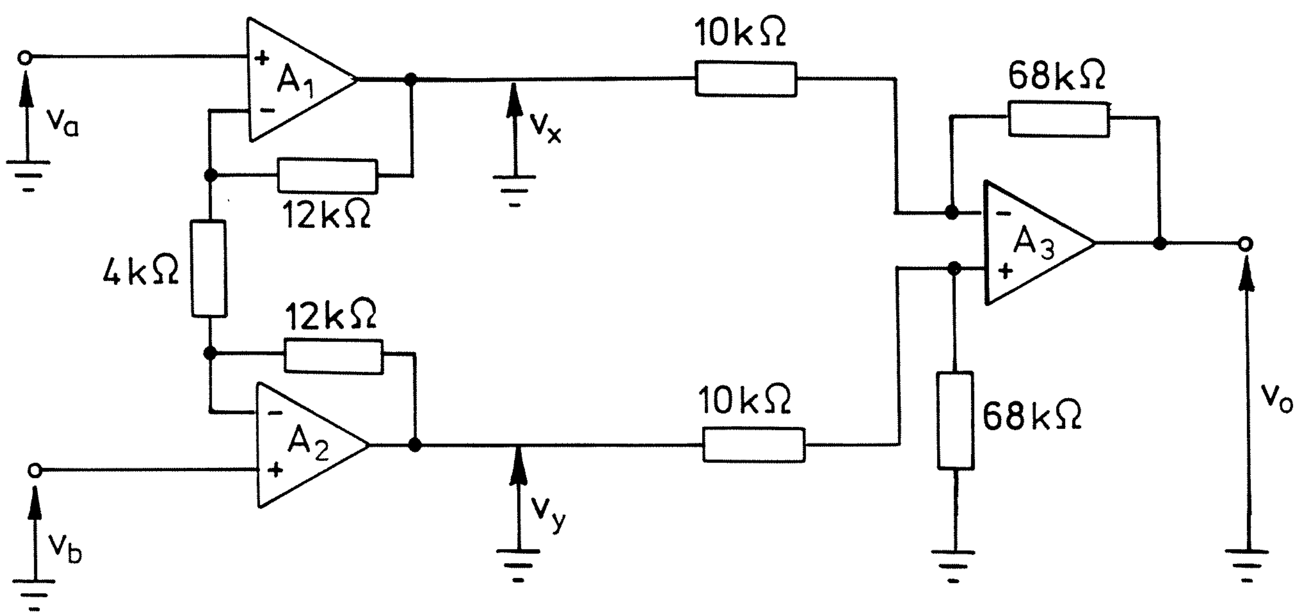

Fig. 2(b)

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SECTION B

3 (a) Sketch phasor diagrams for one phase of a synchronous generator when delivering power to an infinite bus under the following conditions:

(i) leading power factor of 0.8;

(ii) lagging power factor of 0.8.

Mark clearly the position of the generator current phasor on each phasor diagram. It may be assumed that the generator has negligible stator resistance. [6]

Explain how the reactive power delivered by the generator may be varied when delivering constant power to an infinite bus. Illustrate your answer by sketching a phasor diagram, indicating how the phasor diagram changes as the reactive power varies. [4]

(b) A 2-pole, star-connected, 22 kV, 1000 MVA synchronous generator has a synchronous reactance of 0.4 Ω per phase and negligible stator resistance. It delivers 300 MW to an infinite bus at a leading power factor of 0.6. Calculate:

(i) the stator line current;

(ii) the generator excitation phase voltage;

(iii) the load angle. [7]

The prime-mover input power is increased to 400 MW, but the excitation voltage remains unchanged. Calculate the new load angle. [3]

4 (a) List three desirable features of a protection scheme for a power distribution system, briefly explaining each. [5]

(b) Figure 3 shows a power distribution network in which a 100 MVA, 11 kV synchronous generator with a reactance of 30 % is connected via a circuit breaker to a 200 MVA, 11 kV/132 kV step-up transformer with a reactance of 5 %. The high voltage side of the transformer is connected to a transmission line that is 50 kilometres long. The line has a reactance of 0.2 Ω per kilometre and negligible resistance. At the end of the transmission line there is a second transformer rated at 150 MVA, 132 kV/33 kV, having a reactance of 8 %, which is used to step down the voltage. The low voltage side of the transformer is connected to a distribution bus that supplies a small town.

The generator excitation line voltage is maintained at 11 kV. If a symmetrical, three-phase fault to earth occurs at the 33 kV distribution bus, calculate:

(i) the fault current in Amps in the 33 kV distribution bus;

(ii) the fault current in Amps in the transmission line;

(iii) the required MVA rating of a circuit breaker placed at the generator terminals. [12]

What additional series-connected reactance (in Ohms) must be added at A in order to limit the fault current in the distribution bus to 3500 A? [3]

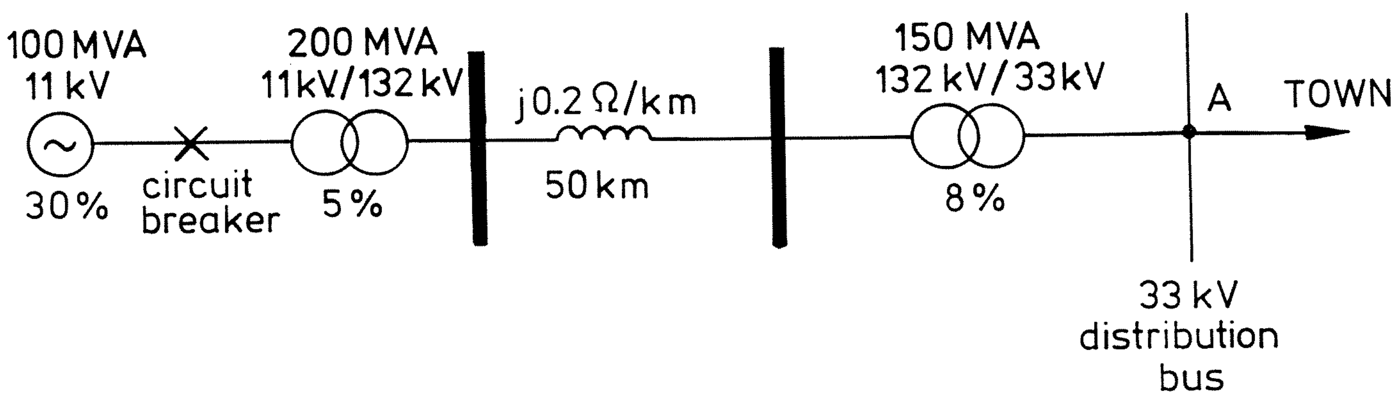

Fig. 3

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5 (a) *Very briefly* describe the physical significance of the six equivalent circuit parameters of a three-phase cage induction motor as depicted in Fig. 4. [5]

(b) Tests on a four-pole, three-phase, delta-connected induction motor yield the following results:

speed	**total input power**	**line current**	**line voltage**
1500 rpm	600 W	4 A	415 V
0 rpm	333 W	8 A	30 V

Given that the equivalent circuit parameter R_l is 2 Ω and assuming that $X_l = X_2'$, determine the five unknown equivalent circuit parameters, making any necessary assumptions. [6]

(c) A different four-pole, three-phase, delta-connected induction motor has the following equivalent circuit parameters:

$$R_l = 2\ \Omega, \quad R_2' = 2\ \Omega, \quad X_m = 100\ \Omega, \quad X_l = 1\ \Omega, \quad X_2' = 1\ \Omega.$$

R_i is large enough to be omitted from the equivalent circuit.

For a speed of 1480 rpm, calculate:

(i) the slip;

(ii) the complex input impedance per phase;

(iii) the stator line current;

(iv) the electromagnetic torque developed by the motor. [9]

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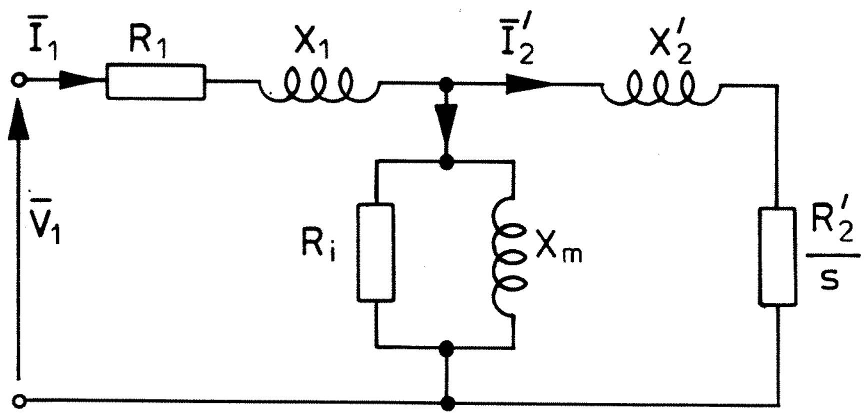

Fig. 4

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SECTION C

6 (a) Briefly define the characteristic impedance, Z_0, of a transmission line.

A 20 m long ethernet cable has a capacitance per unit length of 80 pF m^{-1} and an inductance per unit length of 0.2 μH m^{-1}. Calculate the characteristic impedance of the cable. Estimate the transmission frequency at which transmission line effects become significant. You may assume that transmission line effects become significant when the wavelength of waves propagating along the line is sixteen times the cable length. [5]

(b) The circuit shown in Fig. 5 includes a 32 V voltage source having an internal resistance of 150 Ω, an ideal switch and a 20 m long, lossless transmission line having a characteristic impedance of 50 Ω. The wave velocity along the line, v, is 2×10^8 ms^{-1}. The line is terminated with a load impedance Z_L. At time, $t = 0$ s, the switch is closed and remains closed thereafter. Calculate the magnitude of the voltage of the first incident wave that travels from the source to the load.

Calculate the power in Watts of the first wave reflected by the load for each of the following load impedances:

(i) $Z_L = \infty$ (open-circuited transmission line);

(ii) $Z_L = 0$ (short-circuited transmission line);

(iii) $Z_L = Z_0$.

Comment on the result for part (iii). [9]

For $Z_L = 150\ \Omega$, plot the variation with time of the voltage at a point half way along the transmission line for the first 0.4 μs after the switch is closed. Mark clearly on the plot the numerical values of time and voltage at the points when the voltage changes. [6]

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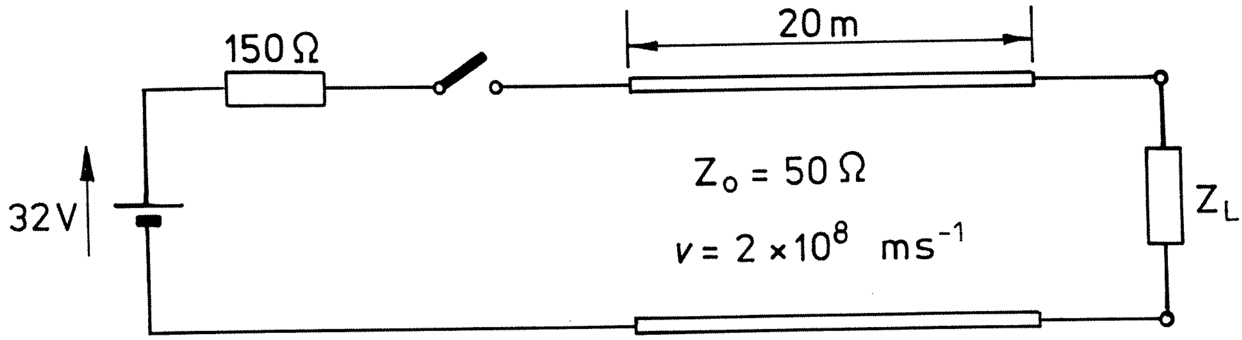

Fig. 5

7 (a) Define the *gain* of an antenna.

A satellite antenna transmits a radio wave through free space without any power loss. The peak power of the wave is 25 W. If the gain of the antenna is 2000, calculate the peak power intensity at a distance of 25,000 km from the antenna. [5]

A receiving antenna is placed 25,000 km away from the satellite antenna. The receiving antenna has a receiving area of $2\ \mathrm{m}^2$ and connects via $50\ \Omega$, lossless coaxial cable to an electronic receiver which is perfectly matched to the cable.

Calculate:

(i) the peak power received by the antenna;

(ii) the rms current that flows into the receiver. [6]

(b) The magnetic field strength of a plane electromagnetic wave propagating through free space is given by:

$$\mathbf{H}(z,t) = \mathbf{u}_y H_0 \exp[j(\omega t - \beta z)]$$

Using Maxwell's equations, show that the electric field of the wave is given by:

$$\mathbf{E}(z,t) = \mathbf{u}_x \eta_0 H_0 \exp[j(\omega t - \beta z)]$$

where η_0 is the intrinsic impedance of free space defined by [9]

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$$

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