ENGINEERING TRIPOS PART IB

Thursday 7 June 2001 9 to 11

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 the question is indicated in the right margin.*

Answers to questions in each section should be tied together and handed in separately.

(TURN OVER

SECTION A Answer at least one question from this section.

1 Consider the npn bipolar junction transistor circuit shown in Fig. 1 below.

(a) For the case where the direct current gain, h_{FE}, is assumed to be essentially infinite, calculate the value of the Collector (and also the Emitter) current for the situation where R_1 = 20 kΩ, R_2 = 1.5 kΩ, R_C = 3 kΩ, R_E = 150 Ω, V_{CC} = 15 V and V_{BE} = 0.85 V, stating any approximations made. [6]

(b) Now consider the more realistic case that the current gain is not infinite, but has some finite value, say h_{FE} = 150. What will the emitter current now be? Remember that the base current will no longer be zero (assume that V_{BE} remains the same as before). [6]

(c) Given that the small signal parameters h_{oe} and h_{re} can be neglected, that $h_{fe}R_E >> h_{ie}$, and that the resistors have the same values as in part (a), show that the maximum value of the voltage gain for this circuit is approximately 20. [6]

(d) What simple addition would you make to this circuit in order to increase the voltage gain for ac signals? [2]

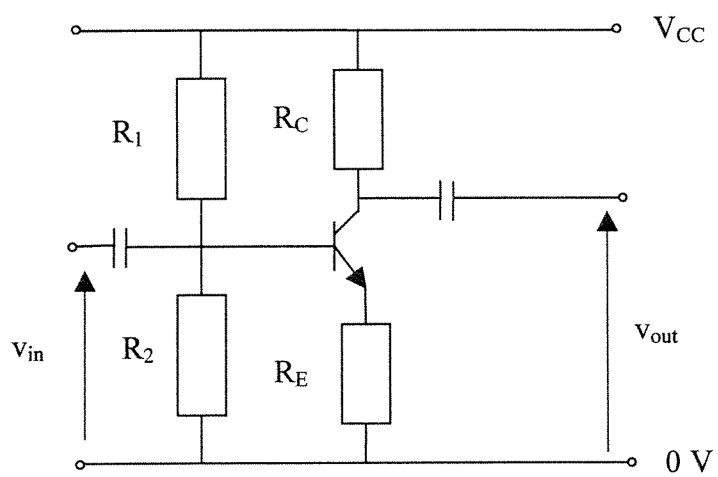


Fig. 1.

2 (a) When operating an op-amp circuit, what is meant by

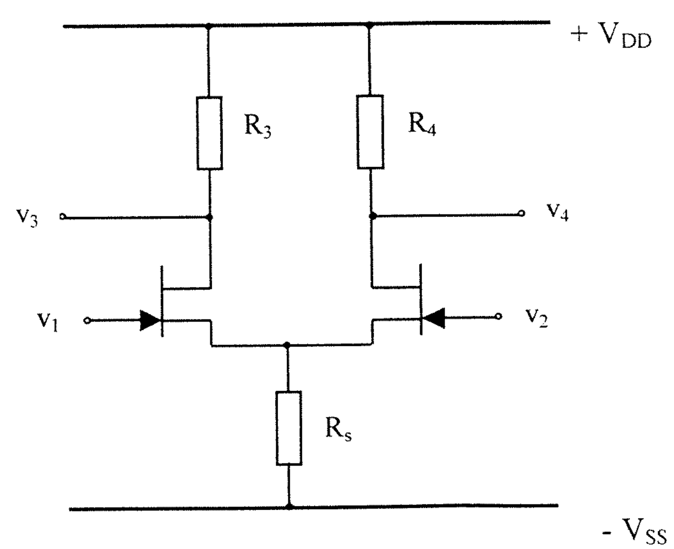
(i) differential, and
(ii) common-mode operation [4]

(b) What is the definition of the common-mode rejection ratio (CMRR) for an op-amp? [2]

(c) The circuit shown below in Fig. 2 is known as a "long-tailed pair". It consists of two equal JFET circuits back-to-back. v_1 and v_2 are the inputs and v_3 and v_4 are the outputs. Using the half-circuit approach, calculate the common-mode and differential-mode gains for this circuit and hence deduce an expression for the CMRR. Assume that r_d is large enough for its effect to be neglected. [10]

(d) Calculate the values of the differential gain and the CMRR for the situation where the circuit elements have the following values: g_m = 7 mS, R_s = 15 kΩ and $R_3 = R_4$ = 2 kΩ. [2]

(e) The standard differential output of this circuit is the voltage between the output terminals, i.e. v_3-v_4. If you wanted to get an output from the circuit, which is relative to ground instead, how would you do it? How would this affect the CMRR? [2]



(TURN OVER

Fig. 2

SECTION B Answer at least one question from this section.

3 (a) Describe briefly the merits of using high voltage three-phase ac electric power transmission rather than dc power from a power station to a town. What is the relationship between the line voltage and the phase voltage in an ac system? Explain what is meant by the statement that the town is a balanced load on the transmission line. [4]

(b) Consider a town which takes a balanced load of 50 MW at a power factor of 0.8 lagging. The line voltage is 33 kV at the town as shown in Fig. 3. Calculate the line current per phase. [4]

(c) If each feeder line has an impedance of 0.01 + j0.1 ohm per kilometer, calculate the maximum length of feeder line if the feeder losses are 10% as large as the power delivered to the town. In this case, what is the line voltage V_S at the sending end of the feeder if the voltage at the town is 33 kV? [8]

(d) Outline briefly how the characteristics of the load could be modified to reduce the power loss in the feeder. In practice what measures can be taken to increase the maximum feasible distance of the load from the power station? [4]

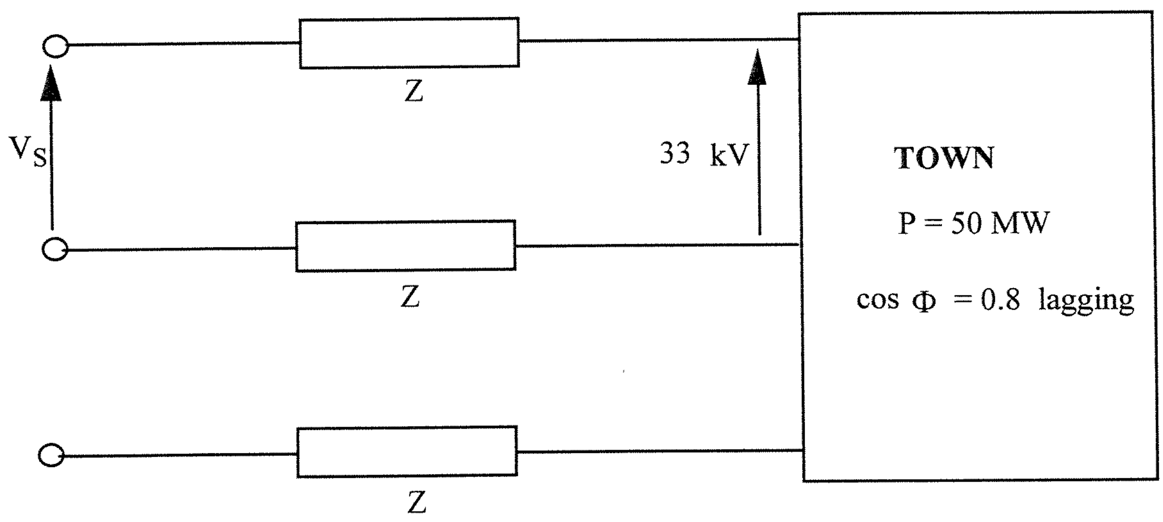


Fig. 3

4 (a) Sketch a phasor diagram for one phase of a synchronous ac generator when delivering power with a leading power factor of 0.7 to an infinite bus. Label the phasors and angles clearly on the diagram. How can you adjust the amount of reactive power delivered to the load? [6]

(b) A star-connected 2-pole, 33 kV, 2000 MVA synchronous generator has negligible stator resistance and a synchronous reactance of 0.5 ohm per phase. If it is delivering 500 MW to an infinite bus at a leading power factor of 0.7, calculate

(i) the generator excitation phase voltage, and

(ii) the load angle. [8]

(c) Sketch the torque vs load angle characteristic for fixed excitation emf of a typical machine and indicate on the diagram where it is generating and where it is motoring.

(i) Which angles correspond to maximum torque?

(ii) Find the maximum torque possible for the excitation determined in part (b). [6]

(TURN OVER

5 (a) Explain with reference to the torque versus slip curve sketched in Fig. 4 which ranges of values of slip correspond to motoring, generating and braking. The value of the slip at point A is 1. State the value of the slip at point B and explain what is happening to the machine at that point. What is a typical motor operating point on the curve? [4]

(b) State the physical significance of each of the six components of the equivalent circuit for an induction motor shown in Fig. 5. [4]

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

$R_1 = 4$ ohm, $R_2' = 3$ ohm,
$R_2 = 1000$ ohm, $X_m = 500$ ohm
$X_1 = 2$ ohm and $X_2' = 2$ ohm.

If the machine speed is 735 rpm calculate the following:

(i) the slip,

(ii) the approximate complex input impedance per phase stating the approximations made,

(iii) the stator line current,

(iv) the electromagnetic torque developed by the motor.

Explain qualitatively how the machine is behaving when the speed is 765 rpm. [12]

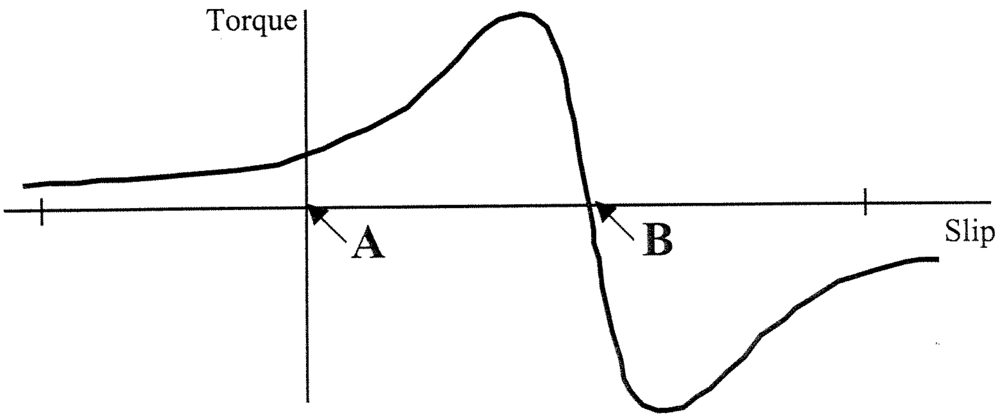


Fig. 4

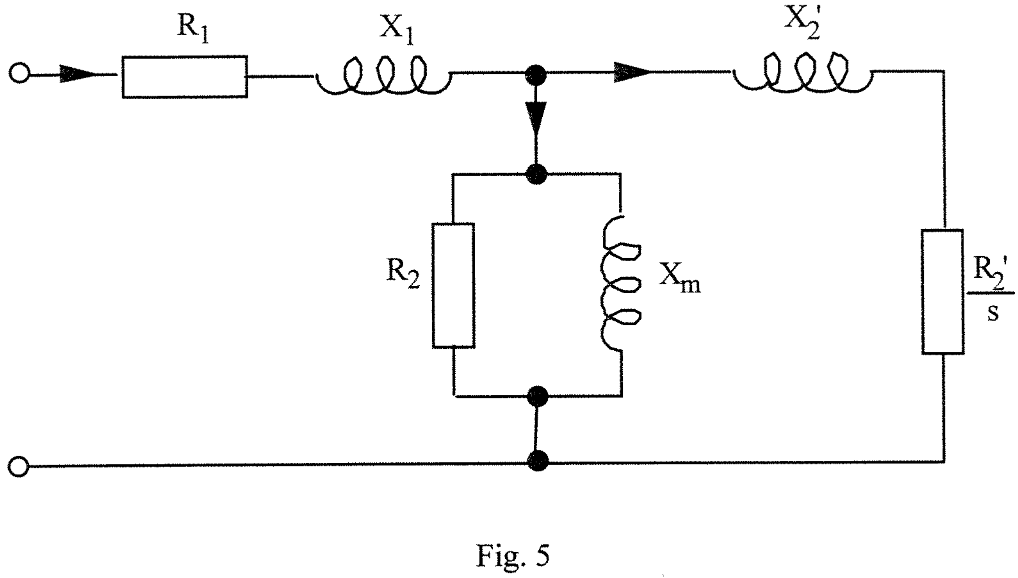


Fig. 5

(TURN OVER

SECTION C Answer at least one question from this section.

6 (a) Explain briefly why a transmission line is used for the propogation of high-frequency signals between electronic devices. What is meant by the characteristic impedance of a transmission line? Explain the significance of using a matched load. Why can a simple lumped-element circuit model be used to describe a short line if the length is less than one sixteenth of the wavelength of the relevant signal? [6]

(b) Consider the propogation of 1 GHz signals along a lossless transmission line with capacitance 80 pF m^{-1} and inductance 200 nH m^{-1}. Estimate the maximum length of line for which transmission line effects can be ignored. [4]

(c) Consider the 15 m length of transmission line shown in Fig. 6. The driver device has an output impedance 100 ohm and it switches from 3 volt to zero. The load device has an imput impedance 10,000 ohm.

(i) Estimate the magnitude of the voltage of the first wave that travels from the source to the load.

(ii) State qualitatively what then happens later to the voltage at the input to the load device. [10]

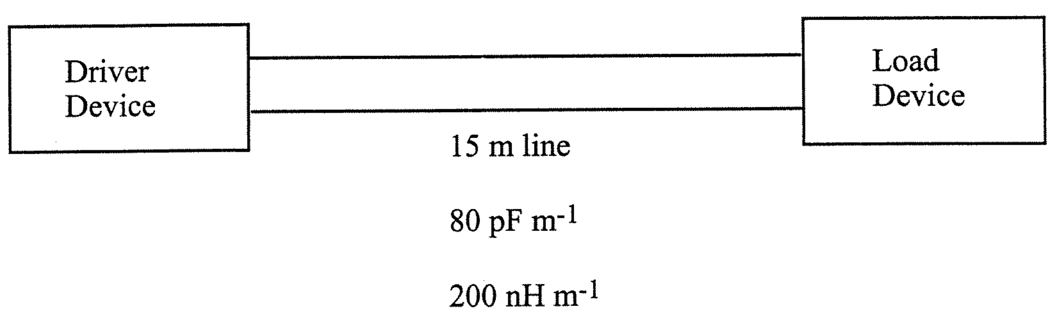


Fig. 6

7 (a) Identify the terms in the following equation for wave propogation in free space where the symbols have their usual meanings:

$$\frac{\partial^2 E}{\partial z^2} - \varepsilon_o \mu_o \frac{\partial^2 E}{\partial t^2} = 0$$

Show that the following function corresponds to a plane electromagnetic wave propogating in the z direction, and find an expression for the speed of propogation of the wave. [6]

$$u_x E_o e^{j(\omega t - \beta z)}$$

(b) Show that the power per unit area of a plane electromagnetic wave is given by $\frac{1}{2}\mathbf{E} \times \mathbf{H}^*$ [6]

(c) Consider an antenna with a gain of 1000 which transmits a radio wave signal with peak power 20 W through free space without any power loss. A receiving antenna is 20,000 km away and at the optimum location and orientation with respect to the transmitter. For the case where the receiver has an effective receiving area of 0.5 m^2, calculate the peak power received by the antenna. [8]

END OF PAPER