UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IB

Thursday 3 June 2004 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 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 the circuit of a bipolar transistor amplifier.

(a) If the transistor can be considered to have an effectively infinite direct-current gain, h_{FE}, and $V_{BE} = +0.7$ V, find the value of R_E which will provide the circuit with a small-signal voltage gain of 10. The small-signal parameters for this transistor are $h_{ie} = 1$ kΩ, h_{oe} is negligible, h_{re} is negligible, and $h_{fe} = h_{FE}$. [5]

(b) Consider the case where h_{fe} for the transistor has a finite value $h_{fe} = 200$. Determine the new value for R_E to achieve the same voltage gain, assuming the other small signal parameters are the same as before. Using this value of R_E, find the resulting value for V_{CE}, and hence determine the maximum peak to peak voltage amplitude of an ac input signal that can be faithfully amplified at mid-band frequencies. Comment on the choice of dc operating point. [6]

(c) A capacitor C_E is introduced as shown dotted in Fig. 1. Determine the input impedance of this circuit at mid-band frequencies, assuming that C_E effectively by-passes R_E. [5]

(d) What will be the effect of the capacitor C_E on the performance of the circuit? [4]

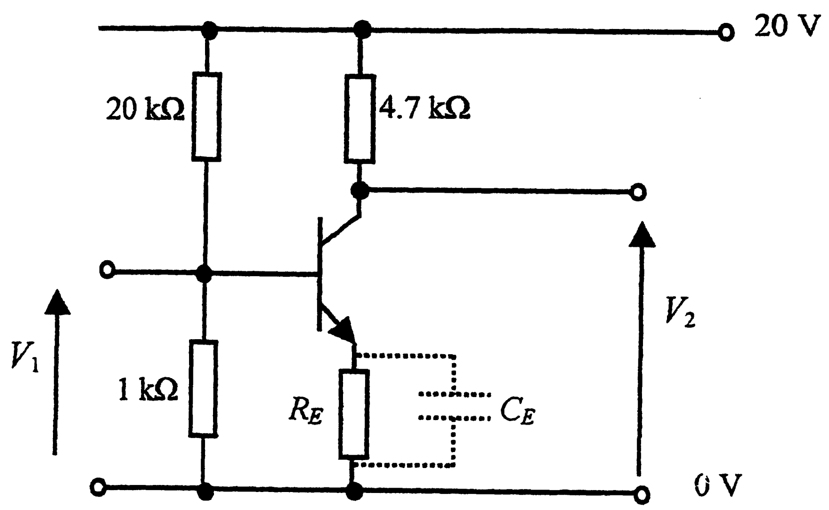

Fig. 1

2 (a) A transducer has a differential output signal of 2 mV at 1 kHz superimposed on an unwanted common-mode signal of 50 mV at 50 Hz. Explain why a differential amplifier is the amplifier of choice for this type of signal, and determine the common-mode rejection ratio (*CMRR*) required if the 1 kHz component at the amplifier output is to be 40 dB greater than the 50 Hz component. [4]

(b) Figure 2 shows a long-tailed pair circuit. Derive an expression for the *CMRR* by considering the small-signal equivalent circuits for both differential and common-mode signals. Hence, determine appropriate values of R_T and R_C which will give a differential voltage gain of 177.8 and a *CMRR* of 50 dB. Assume the following small-signal parameters for both transistors: h_{ie} = 1 kΩ, h_{fe} = 150, h_{oe} and h_{re} are negligible. [7]

(c) Given that the operating points for both transistors are V_{CE} = 10 V, I_C = 10 mA, V_{BE} = 0.7 V and the base voltage V_B = 0 V, determine the values for V_{CC} and V_{EE} required in order for this circuit to have a *CMRR* of 50 dB. State any assumptions made. [5]

(d) Describe one way in which the *CMRR* of this circuit could be increased, and one way in which the supply voltage can be reduced without decreasing the *CMRR*. [4]

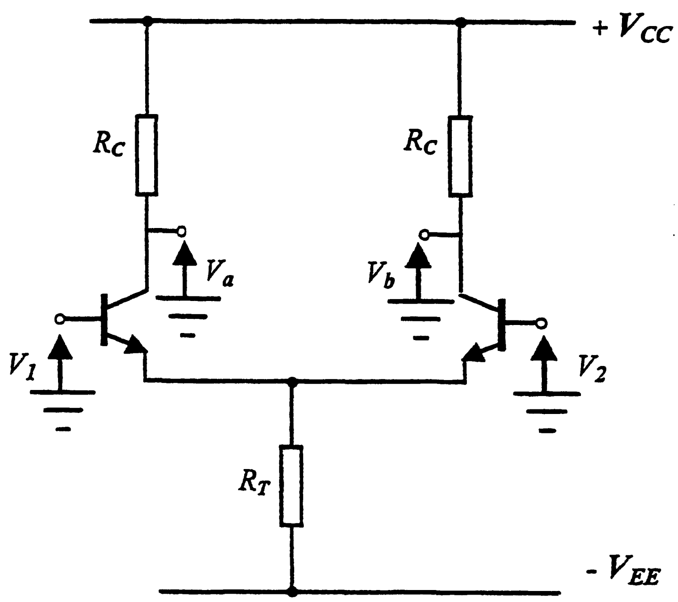

Fig. 2

SECTION B

Answer at least one question from this section.

3 (a) Give three reasons why electric power is transmitted long distances over a grid rather than generated locally where needed. List the main sources of electric power in the United Kingdom and comment on their relative importance. [5]

(b) A city is supplied by 3-phase electric power at 50 Hz with a line voltage of 50 kV as shown in Fig. 3. If the city presents a balanced load of 120 MW with a power factor of 0.9 lagging, calculate the line current per phase. [5]

(c) Each feeder line to the city has an impedance of $0.02 + j0.1\ \Omega\ \text{km}^{-1}$. If the power loss in the feeder is to be kept below 5%, calculate the maximum length of feeder line in kilometers, and the corresponding impedance Z in Fig. 3. In this case what is the line voltage at the sending end? [7]

(d) Outline briefly what measures could be taken to enable the use of a longer feeder line to the city. [3]

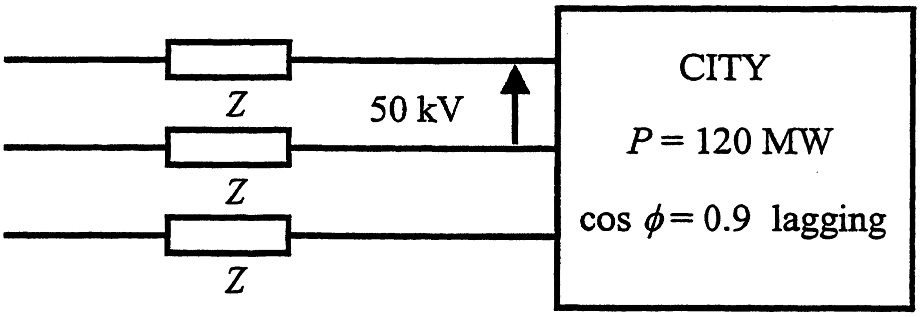

Fig. 3

4 (a) Outline the requirements for an ac synchronous machine to supply power to the 50 Hz national grid. Calculate the rotational speed in radians per second for (i) a 2-pole machine, and (ii) a 20-pole machine. State the kind of application where a machine with a large number of poles is used. [4]

(b) Figure 4 is a partially drawn equivalent circuit for a synchronous ac generator. Label a sketch of the figure with the voltage and current, and explain the use of the generating convention with regard to the direction of current flow. Draw and label a phasor diagram for one phase of a synchronous ac generator when delivering power with a power factor of 0.7 lagging to an infinite bus. [4]

(c) A star-connected 2-pole, 50 kV, 600 MVA synchronous generator delivers 300 MW to an infinite bus with a power factor of 0.7 lagging. Taking the synchronous reactance to be 1 Ω per phase and the stator resistance to be negligible, calculate the generator excitation voltage. [7]

(d) Explain how to adjust the amount of reactive power delivered to the load in case (c), maintaining the real output at 300 MW. Determine the maximum reactive power that the generator can deliver, assuming that it is limited by stator heating. [5]

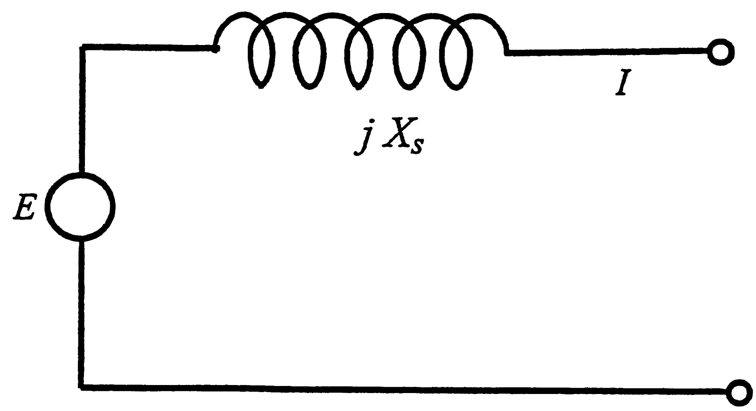

Fig. 4

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5 (a) Explain the principle of operation of a three-phase ac induction motor. Under what operating conditions is no torque generated? [4]

(b) An eight-pole, three-phase, delta-connected induction motor runs at 738 rpm when driven by a line voltage of 600 V at 50 Hz. Calculate the slip, s. [4]

(c) In the equivalent circuit in Fig. 5, the circuit parameters are: $R_1 = 3\ \Omega$, $R'_2 = 2\ \Omega$, $R_o = 800\ \Omega$, $X_m = 250\ \Omega$, X_1 and X'_2 negligible. For the case described in (b) calculate:

(i) the complex input impedance per phase;
(ii) the stator line current;
(iii) the approximate electromagnetic torque developed by the motor. [8]

(d) Describe the construction and the relative merits of:

(i) a wound rotor induction motor;
(ii) a cage rotor induction motor. [4]

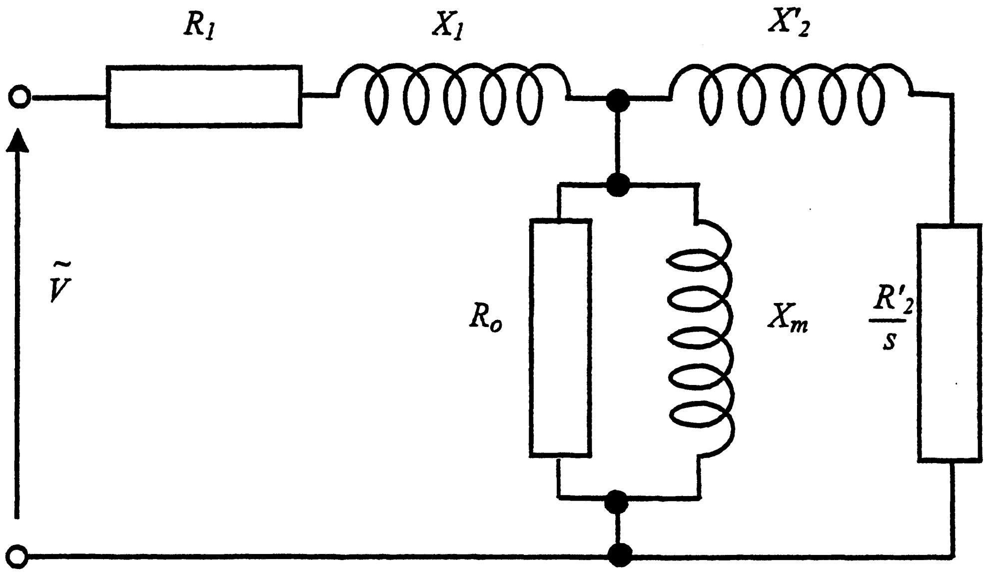

Fig. 5

SECTION C

Answer at least one question from this section.

6 (a) Explain briefly what is meant by:

(i) the characteristic impedance;

(ii) the wave velocity of a transmission line. [3]

(b) Consider a pair of overhead cables on the 50 Hz national power grid that have capacitance 3.5 pF m^{-1} and mutual inductance 3.17 μH m^{-1}. Calculate the wave velocity, wavelength and characteristic impedance. Comment on the practical significance of the numbers. [4]

(c) Consider a pair of wires in a local communications network running at 10 MHz. If the capacitance per unit length is 90 pF m^{-1} and the inductance is 0.2 μH m^{-1}, calculate the wave velocity, the wavelength and the characteristic impedance. Comment on how the wave velocity compares with the value found in part (b). [4]

(d) Figure 6 shows a driver device with output impedance 80 Ω and a load device with input impedance 1000 Ω. They are connected by a pair of wires of length 20 m having capacitance 90 pF m^{-1} and inductance 0.2 μH m^{-1}. If the driver device switches abruptly from 0 V to 5 V output, calculate the magnitude of the voltage of the first wave that travels from the source to the load and the value of the reflection coefficient at the load. Calculate the voltage at a point half way along the line 0.2 μs after the driver device has switched. State qualitatively what happens later. [9]

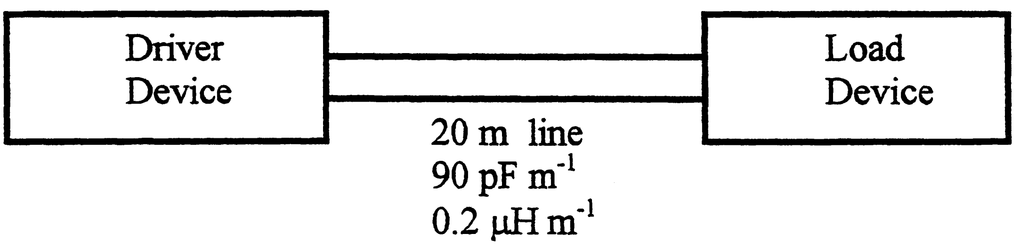

Fig. 6

7 (a) Explain briefly what is meant by the characteristic impedance of an EM wave in air. Calculate a value for the characteristic impedance of air, stating any approximations made. [5]

(b) The output of an infrared laser with wavelength $1\ \mu m$ is focused to a spot as shown in Fig. 7. Taking the maximum electric field in air before electrical breakdown to be $2\ MVm^{-1}$, and the laser output power to be 1 W, calculate the minimum focus spot size necessary to avoid dielectric breakdown in the air, stating the approximations made. For this minimum spot size, calculate the value of the associated magnetic flux density. [9]

(c) Now consider the use of a lower power laser with an output of 1 mW. Taking the minimum spot diameter achievable to be the wavelength of the laser output, calculate the corresponding electric field, and comment on the likelihood of electrical breakdown of the air. [6]

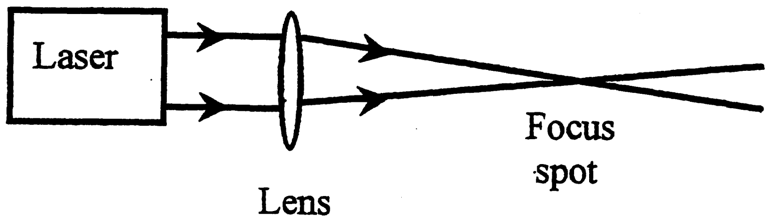

Fig. 7

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