ENGINEERING TRIPOS PART IB

Thursday 5 June 2003 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.

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 an amplifier based on an npn bipolar transistor.

(a) For the case where V_{cc} = 20 V, the operating point for this transistor is V_{CE} = 10 V, I_B = 100 μA, I_C = 40 mA and V_{BE} = +0.7 V. Find the values of R_2 and R_E which will allow this working point to be achieved. [6]

(b) The dc characteristics of the transistor in this circuit show that the Collector current I_C and base-emitter voltage V_{BE} are functions of both V_{CE} and I_B. Write down expressions for small variations in I_C and V_{BE} in terms of the small signal quantities v_{ce}, v_{be}, i_c, i_b and parameters h_{ie}, h_{fe}, h_{oe} and h_{re}. Hence, derive the small-signal equivalent circuit for the bipolar transistor. Do you think this is an accurate representation of a real transistor? If you had to add anything to this equivalent circuit to make it more realistic at high frequencies, what would it be? [6]

(c) For the circuit shown in Fig. 1, derive an expression for the mid-band voltage gain v_2/v_1, and show that it is equal to −1.46 when h_{ie} = 1 kΩ (Assume that the small signal current gain h_{fe} has the same value as the dc current gain, and that $1/h_{oe}$ and h_{re} can be neglected). Show that if h_{fe} is doubled, the gain does not change by very much, and explain why this might be an important consideration in circuit design. [5]

(d) What is the function of the coupling capacitors C_1 and C_2? Sketch *qualitatively* what effect they have on the gain of the circuit as a function of frequency. [3]
How do you think the operation of the circuit would be affected if they were omitted?

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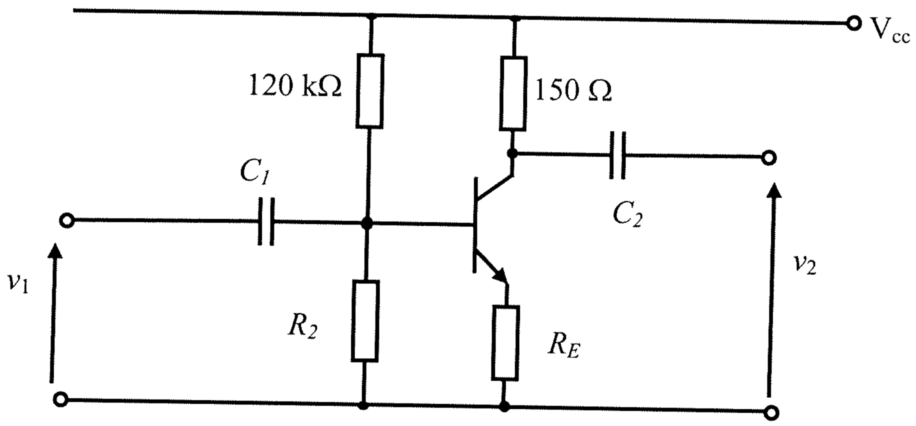

Fig. 1

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2 Figure 2 shows an emitter follower circuit.

(a) In what sort of situation is such an amplifier used? Is this a Class A or Class B amplifier? [2]

(b) For $R_L = 2$ kΩ, $h_{ie} = 1$ kΩ and $h_{fe} = 250$, calculate the voltage gain of this circuit. You may assume that $1/h_{oe}$ is negligible. [4]

(c) Define *power efficiency* for this type of amplifier. Calculate its value for this circuit. [6]

(d) What is the advantage of using a complementary emitter follower as shown in Fig. 3 rather than just a basic emitter follower? [2]

(e) Sketch the transfer characteristic of the circuit shown in Fig. 3, and discuss ways to reduce the main source of signal distortion. [6]

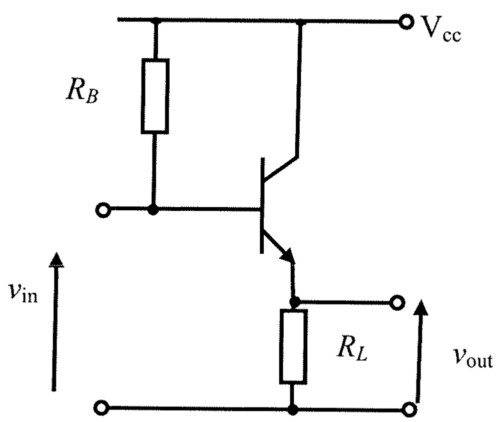

Fig. 2

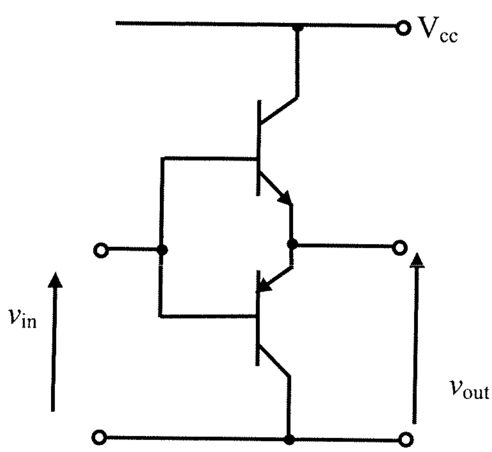

Fig. 3

SECTION B

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

3 (a) Discuss the reasons why electrical power is most commonly generated and transmitted as 3-phase AC rather than DC, with particular reference to the economic considerations of efficiency and capital cost of the generators used. [3]

(b) A town which is connected as a balanced 3-phase load to the national grid (at 50 Hz) consumes 50 MW of power at a power factor of 0.8 lagging. Find the line current and hence the line voltage at the start of the feeder lines which is required in order to provide a line voltage at the town of 132 kV, given that the feeder lines between the national grid and the town can be represented as a 10 Ω resistance in series with a 31.8 mH inductance. [7]

(c) What would be the power loss in the feeder if the town's power factor was improved to 0.9 lagging, assuming that the line voltage at the town remained at 132 kV? What will be the corresponding line voltage at the start of the feeder lines? [4]

(d) How would you improve the town's power factor to 0.9? State the circuit components required and calculate their values. [3]

(e) Given that the frequency of the national grid can vary up and down by 5%, determine the possible range of line currents assuming that the line voltage at the town remains at 132 kV, and the power factor remains at 0.9. [3]

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4 (a) State two advantages of the per-unit system for the analysis of electrical power systems. [3]

(b) A 100 MVA, 11kV generator with a reactance of 0.1 p.u. is connected to a 200 MVA 11 kV/132 kV step-up transformer with a reactance of 0.1 p.u. The high-voltage side of the transformer feeds a 20 km long feeder line which has a reactance of 0.1 Ω/km and negligible resistance. At the end of this line, there is a step-down transformer, rated at 150 MVA, 132 kV/22 kV, and with a reactance of 0.1 p.u. The low voltage side of this transformer is connected to a distribution bus which supplies 60 MW at a power factor of 0.97 lagging to a factory. The voltage at this distribution bus is 21 kV. Calculate the required generator line-line emf (excitation) and the line current at the generator. [9]

(c) Determine the MVA rating for a circuit breaker to be located between the last transformer and the distribution bus. Also calculate the short-circuit line current at this point. [5]

(d) What reactance must be added at this point to limit the fault rating to 170 MVA? [3]

5 (a) Briefly describe the principle of operation of induction motors, explaining why they produce no torque at synchronous speed. [4]

(b) A 4-pole, 3-phase, star-connected induction motor is connected to a balanced 3-phase supply at 415 V, 50 Hz. Using the equivalent circuit of the induction motor as found in the electrical and information data-book, find the iron loss resistance and the magnetising reactance of this motor, given the following no-load test information:

V_{line}	I_{line}	P_{in}	*Speed (rpm)*
415 V	3.2 A	850 W	1500

[3]

(c) A locked-rotor test is now carried out on the same motor. Given that the stator winding resistance is 0.7 Ω, and the ratio of stator to rotor leakage reactance is 2/3, find the rotor winding resistance and the rotor leakage reactance referred to the stator, and the stator leakage reactance using the locked-rotor test data below:

[4]

V_{line}	I_{line}	P_{in}	*Speed (rpm)*
200 V	60 A	5000 W	0

(d) Using information from the electrical and information data book, calculate the electromagnetic torque and efficiency of this motor at 1450 rpm, stating any assumptions made. [6]

(e) Sketch the relationship between torque and speed, clearly marking out the three regimes of operation of the motor. [3]

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SECTION C

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

6 (a) Consider a coaxial cable with outer diameter a and inner diameter b, where the space between these two conductors is filled with a dielectric. Starting from Ampere's law, derive an expression for the inductance per unit length. [7]

(b) Describe briefly what is meant by the characteristic impedance Z_0 of the coaxial cable. Given that the capacitance per unit length is given by the expression $C = 2\pi\varepsilon_0\varepsilon_r/\ln(a/b)$ where ε_r is the relative permittivity of the dielectric, find an expression for Z_0 and calculate its value for the case $a = 2$ mm, $b = 1$ mm, and $\varepsilon_r = 2$. [7]

(c) When the coaxial cable is terminated by a 50 Ω load, explain briefly what determines the fraction of the incident power that is reflected back from the load. For the case in part (b), calculate its value. In order to minimise this value, what size should the inner conductor have? [6]

7 (a) Consider a plane wave of light travelling through material 1 with refractive index η_1, relative permittivity ε_1 incident upon a planar interface to material 2 with refractive index η_2 and relative permittivity ε_2. If the angle of incidence is θ_i to the normal to the plate, draw a detailed diagram showing the reflected and refracted waves. Derive from the diagram the relationship between the angle of refraction, θ_t, and θ_i. [6]

(b) What are the boundary conditions on the electric field at the interface? If the electric field associated with the incident wave is E_i, write down an expression for the incident power per unit area at the interface. [4]

(c) For the case of a parallel polarised wave (i.e. where E_i is in the plane of incidence), derive an expression for the ratio E_r/E_i in terms of ε_1, ε_2 and E_i, where E_r is the electric field associated with the reflected wave. What is the minimum value of this ratio? Describe qualitatively what happens to the ratio E_r/E_i as the ratio $\varepsilon_2/\varepsilon_1$ is increased. [6]

(d) Explain briefly how Polaroid sunglasses reduce glare. [4]

END OF PAPER