Version CD/05

EGT1
ENGINEERING TRIPOS PART IB

Wednesday 4 June 2014 2 to 4

Paper 5

ELECTRICAL ENGINEERING

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

Not more than two questions may be answered from any one section and not more than one question from each of the other two sections.

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.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

SECTION A

1 Figure 1 shows a bipolar transistor amplifier circuit.

(a) If the direct current gain, h_{FE}, is infinite and the base-emitter voltage, V_{BE}, is 0.7 V, determine the voltages at the collector, V_C, and the emitter, V_E. [6]

(b) In reality, h_{FE} is finite, with a minimum value of 150. For this value of h_{FE}, determine the values of V_C and V_E. [8]

(c) Explain why the capacitor C_E is included when the circuit is used to amplify ac signals. [3]

(d) When the circuit is built, a transistor with h_{fe} = 200 is used. For this transistor, h_{ie} is 300 Ω and both h_{oe} and h_{re} can be neglected. Determine the input resistance and the voltage gain of the circuit, v_2/v_1 at mid-band frequencies. [8]

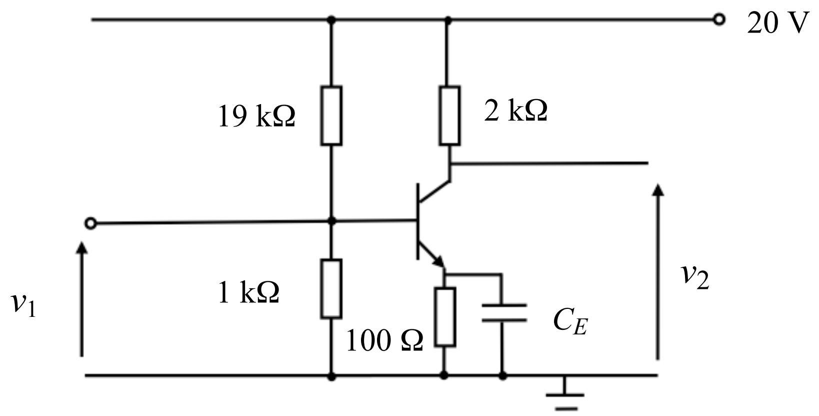

Fig. 1

2 (a) Explain what is meant by the *common-mode rejection ratio, CMRR* of a differential amplifier and why a large value is desirable. [3]

(b) Fig. 2 shows a differential amplifier circuit. Assuming that the two transistors are identical and that h_{oe} and h_{re} are negligible, draw the small-signal equivalent circuits for:

(i) common-mode input signals;

(ii) differential-mode input signals.

In each case, determine the gain. Using these results, derive an expression for the *CMRR* of the circuit. [9]

(c) We wish the circuit to have a *CMRR* of 10^4 and a differential gain of 200. The transistors are to operate with V_{CE} = 10 V and I_C = 20 mA. Given that h_{ie} = 200 Ω, h_{fe} = 200, R_C = 300 Ω and the voltage (in the absence of any input signals) at point A = 0 V, determine suitable values of R_B, R_T, V_{CC} and V_{EE}. [10]

(d) Comment on the values of dc supply voltage needed, and suggest a modification to the circuit that would lead to more desirable values of V_{CC} and V_{EE}. [3]

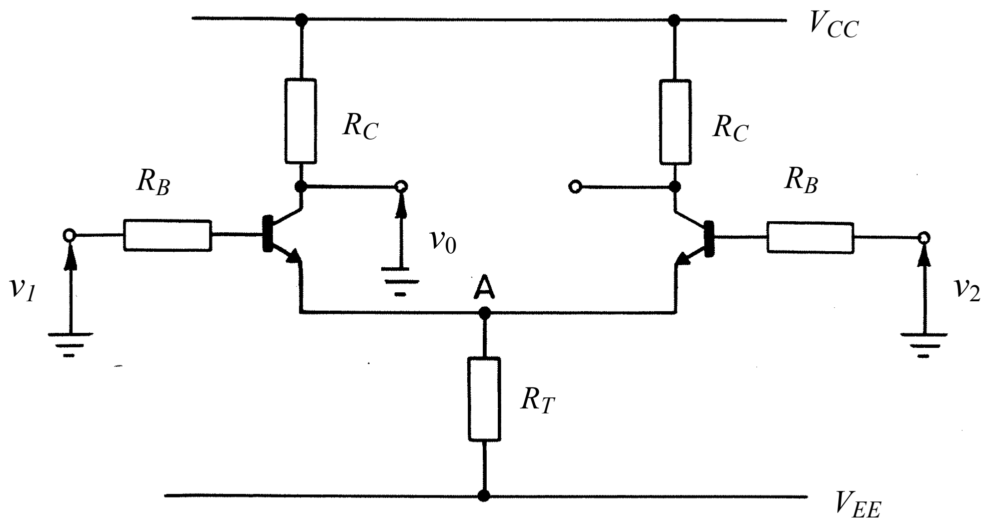

Fig. 2

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SECTION B

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

(i) lagging power factor of 0.6;

(ii) leading power factor of 0.6.

Clearly indicate the bus voltage, current and excitation phasors, as well as the load angle and the phase angle corresponding to the power factor. It may be assumed that the stator has negligible resistance. [6]

(b) Explain how the power factor and hence the reactive power delivered by a synchronous generator that is connected to an infinite bus may be varied while keeping the total power constant. Use a pair of sketches of the phasor diagram to illustrate your answer. [7]

(c) A 4-pole, star-connected 23 kV, 600 MVA synchronous generator with a stator reactance of 1 Ω per phase at 50 Hz delivers 200 MW to an infinite bus at a leading power factor of 0.6. Calculate:

(i) the line current;

(ii) the excitation voltage;

(iii) the load angle;

(iv) the synchronous speed. [7]

(d) The excitation is kept constant, but the prime-mover input power is increased to 250 MW. Calculate the new line current. [5]

4 (a) State the main advantage of the per-unit system for the analysis of electrical power systems. [4]

(b) A 200 MVA, 22 kV generator with a reactance of 0.1 per-unit is connected to a 250 MVA 22 kV/132 kV step-up transformer for transmission, with a reactance of 0.1 per-unit. The transmission line connected to the high-voltage side is 50 km long and has a reactance of 0.1 Ω/km and negligible resistance. The other end of the transmission line is then connected to a 200 MVA, 132 kV/11 kV step-down transformer with a reactance of 0.1 per-unit for local distribution. The low-voltage side of the transformer is connected to a distribution bus which supplies 140 MW at a power factor of 0.9 lagging to a town. The voltage at the distribution bus is 10 kV. Calculate:

(i) the generator excitation voltage; [8]

(ii) the generator line-current. [8]

(c) Determine the MVA rating of a circuit breaker which is to be installed between the step-down transformer and the distribution bus, and the short-circuit line current that would result from a short-circuit at the distribution bus. [5]

5 A 6-pole, three-phase, star-connected induction motor is connected to a balanced 50 Hz supply with a line voltage of 415 V. No-load and locked-rotor tests are performed on the motor with the following results:

Line voltage	Line current	Power in	Speed
415 V	5 A	1250 W	1000 rpm
100 V	80 A	6000 W	0 rpm

The stator winding resistance, R_1, is 0.15 Ω. The stator leakage reactance, X_1 is the same as the referred rotor leakage reactance, X_2' .

(a) Briefly explain the physical meaning of each of the components in the equivalent circuit of the induction motor as found in the databook and how we can relate them to those of the transformer. [9]

(b) Determine the values of the following components in the equivalent circuit of the induction motor:

(i) the iron loss resistance, R_i ; [3]

(ii) the magnetising reactance, X_m ; [2]

(iii) the rotor winding resistance referred to the stator, R_2' ; [3]

(iv) the stator leakage reactance, X_1 . [2]

(c) Calculate the maximum power that may be delivered by this motor when supplied at the rated voltage and the slip at which it occurs. [6]

SECTION C

6 (a) Define the characteristic impedance of a transmission line. [2]

(b) A 100 m long coaxial cable has a capacitance per unit length of 100 pF m^{-1} and an inductance per unit length of 0.25 μH m^{-1}. Calculate the characteristic impedance, Z_0 and the velocity of signals. Comment on this value of velocity. [6]

(c) The cable in Part (b) is used to carry signals between a 20 V voltage source with an internal resistance of 100 Ω and a load impedance, Z_L. Calculate the amplitude of the voltage of the first wave that travels from the source along the line. [4]

(d) Calculate the input impedance of the line plus the load for the following values of load impedance:

(i) $Z_L = 0$; [3]

(ii) $Z_L = \infty$; [3]

(iii) $Z_L = Z_0$. [3]

(e) Calculate the value of the first voltage wave to be reflected from the load for the case where the load impedance $Z_L = 25\ \Omega$. [4]

7 (a) Sketch the fields of a plane electromagnetic wave that is propagating in the z - direction, with the electric field in the x - direction. [4]

(b) What is the significance of the Poynting vector? For an electromagnetic wave with electric field strength 10^3 V m^{-1}, calculate the power per unit area carried by that wave. [5]

(c) The laser used in a blu-ray player has a power of 1 mW. If it is focused down to a spot of diameter 0.6 microns, calculate the magnitude of the electric field at the focus. If the breakdown strength of air is 2×10^6 V m^{-1}, calculate the maximum laser power that can be focused down to this size. [8]

(d) The diameter of the laser spot on the surface of a blu-ray disc is 0.5 mm, and the half-angle (in air) is 30^o, as indicated in Fig. 3. Given that the data layer is 0.3 mm below the surface, and the disc is made of polycarbonate with relative permittivity, ε_r of 2.25 and relative permeability, μ_r of 1, calculate the following quantities within the disc at the same depth as the data layer:

(i) the laser spot diameter; [3]

(ii) the laser power per unit area; [2]

(iii) the electric field strength. [3]

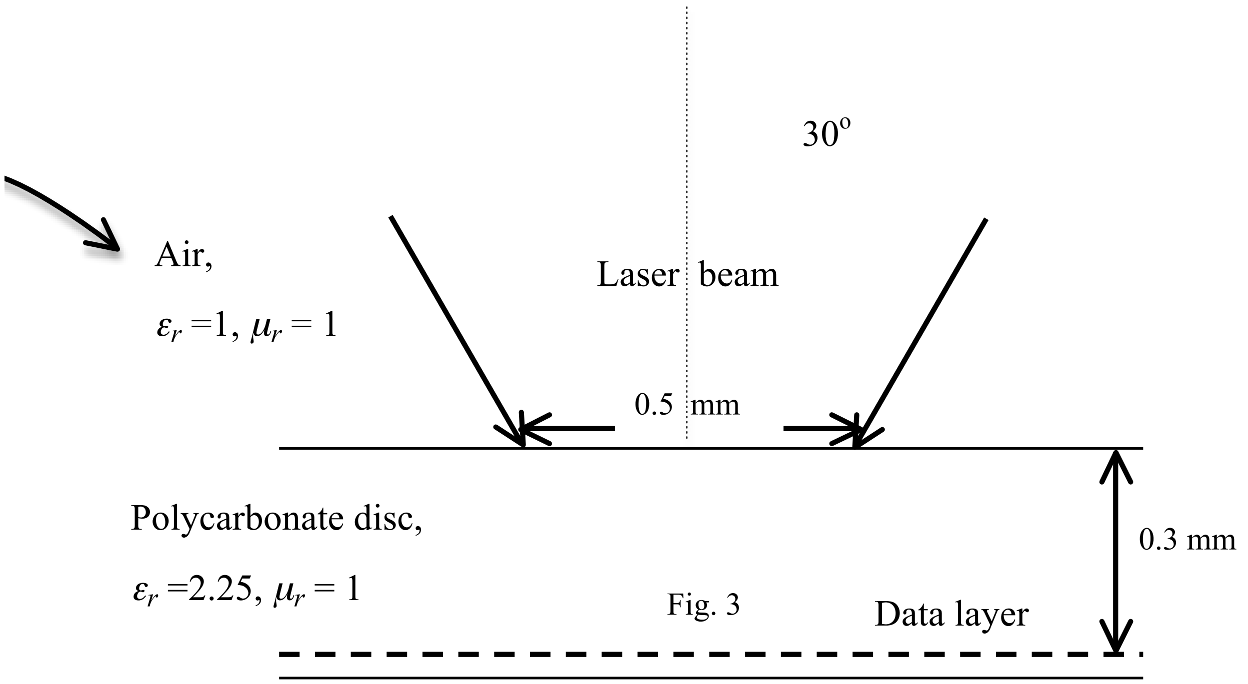

Fig. 3

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