ENGINEERING TRIPOS PART IB

Wednesday 5 June 2013 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.

*The **approximate** percentage 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

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

SECTION A

1 (a) What Class of amplifier is shown in Fig. 1? Typically, how large does the voltage difference between the base and emitter need to be before the transistor can be said to be “switched on”? Explain your answer. [4]

(b) Given that the dc operating point of the transistor is at $V_{CE} = 7.5$ V, $V_{BE} = 0.7$ V, $I_C = 1$ mA, $h_{FE} = 200$, determine appropriate values of R_1 and R_2. With these values of resistors, calculate the base current flowing into the transistor. [6]

(c) The small-signal parameters of this transistor are $h_{ie} = 10$ kΩ, $h_{fe} = 200$, $h_{oe} = 25$ µS, $h_{re} = 0$. Derive expressions for the mid-band voltage gain, v_2/v_1, and the output resistance of this circuit, and determine their numerical values. [6]

(d) What value of load resistance is needed in order to maximise the output power of this circuit? Assuming that a suitable load resistor is chosen and added to the circuit, how much power will be dissipated in it, given a sinusoidal input voltage of amplitude 0.01V? [4]

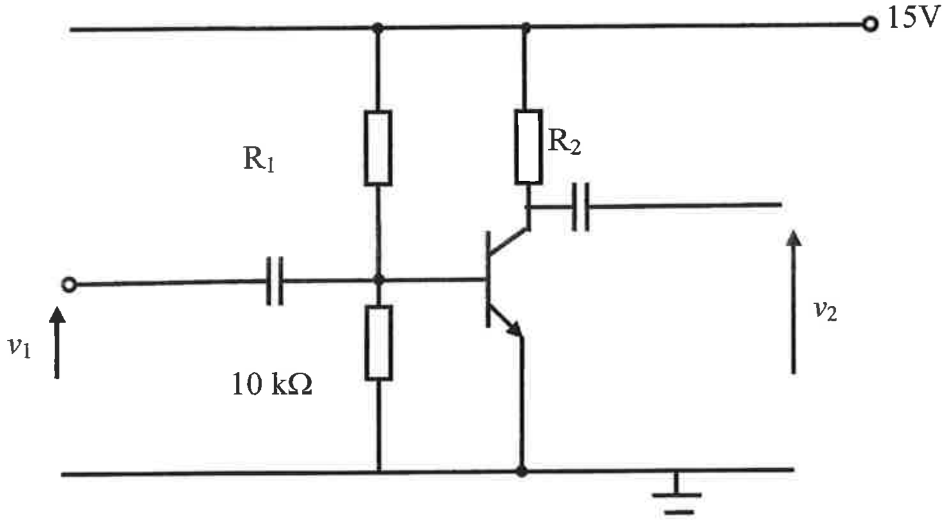

Fig. 1

2 (a) Briefly discuss the advantages and disadvantages of using negative feedback in Op-Amp circuits. [2]

(b) Assuming that a proportion, B, of the output of an Op-Amp of open-loop gain, A is fed back to the input, as illustrated in Fig. 2, derive an expression for the gain of this circuit. [3]

(c) Now consider the non-inverting amplifier shown in Fig. 3. The Op-Amp has an open loop gain of 10^5, internal input and output resistances of 10 MΩ and 100 Ω, respectively, and a bandwidth of 10 kHz. Using the result of part (b), estimate the input resistance, output resistance, gain and bandwidth of the circuit as a whole, for R_1 = 10 kΩ and R_2 = 40 kΩ, stating any assumptions made. [5]

(d) Considering the equivalent circuit of an Op-Amp, now calculate the output resistance and gain of the circuit in Fig. 3, assuming that the internal input resistance is infinite. [8]

(e) If we replace R_1 and R_2 with resistors that are 100 times smaller, how would the gain be affected? [2]

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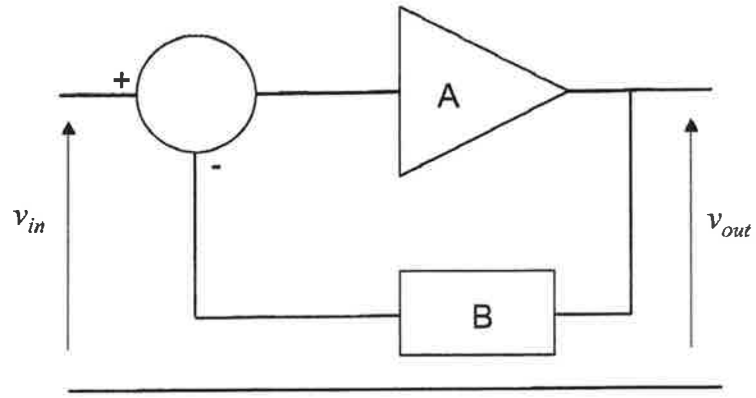

Fig. 2

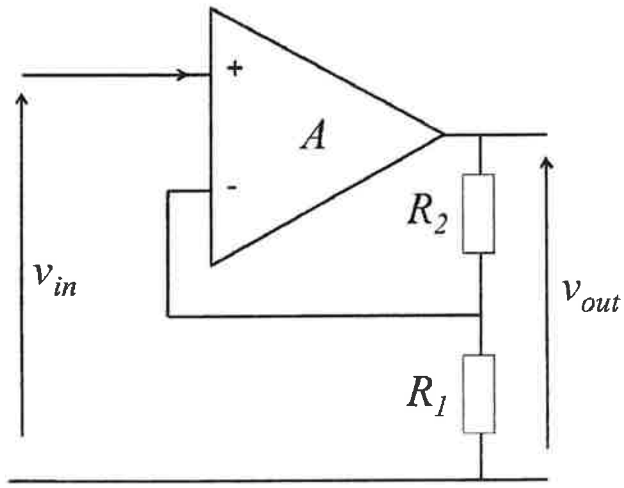

Fig. 3

SECTION B

3 (a) Give three reasons why electricity is generated and distributed as three-phase alternating currents. [3]

(b) The phase voltages coming from a three-phase star-connected generator are V_1, V_2 and V_3, which are all equal in magnitude at 6.35 kV. Sketch the corresponding voltage phasors and hence, or otherwise, determine the magnitude of the line voltage (the voltage difference between any two of the phases). [4]

(c) A three-phase generator operating at 50 Hz supplies 12 MW of power at a power factor of 0.75 lagging to a factory. The feeder lines each have a series resistance of 3 Ω and inductance of 15.92 mH, and the line voltage at the factory is 11 kV. Determine the line voltage produced by the generator and the line current. [7]

(d) In an attempt to increase the power factor, capacitors are connected line to line at the factory end. If their capacitance is 25 μF, calculate the new power factor of the factory. Determine the reduction in power loss in the feeder lines. [6]

4 (a) Explain the basic principle of operation of the ac synchronous generator. Your answer should include a sketch of the relevant fields and the equivalent circuit of the machine. What are the physical significances of the load angle and the excitation, *E*? [5]

(b) A star-connected, 6-pole synchronous generator that is rated at 800 MVA is used to deliver 500 MW of power at a power factor of 0.9 lagging to the infinite bus at a line voltage of 33 kV at 50 Hz. The synchronous reactance is 1.3 Ω per phase and the stator resistance can be neglected. Calculate:

(i) the prime mover torque; [3]
(ii) the excitation, *E*; [5]
(iii) the load angle. [2]

(c) The excitation is increased by 10%. Calculate the new load angle. What is the maximum excitation that this machine can sustain? [5]

5 (a) Sketch the torque-speed relationship for an ac induction motor, indicating the regions where motoring, generating and plugging occur. Explain why induction motors do not produce any torque at the synchronous speed. [6]

(b) A four-pole star-connected, three-phase induction motor is operated at 1350 rpm when driven by a line voltage of 600 V at 50 Hz. Calculate the value of slip. [4]

(c) In the equivalent circuit of the induction motor, the circuit parameters are: $R_1 = 2\ \Omega$, $R_2' = 3\ \Omega$, $R_0 = 500\ \Omega$, $X_m = 200\ \Omega$, $X_1 = X_2' = 0.5\ \Omega$. Briefly describe the physical origin of each of these terms. The machine has friction and windage losses of 400 W. Calculate the referred rotor current, and hence, determine the value of torque developed by the motor and the efficiency when it is operated at 1350 rpm. [10]

SECTION C

6 (a) Define the term *characteristic impedance,* and briefly discuss its physical meaning in the context of (i) a transmission line and (ii) a wave in free space. [3]

(b) A lossless coaxial cable has a capacitance per unit length of 40 pFm^{-1} and inductance per unit length of 400 nHm^{-1}. Calculate the characteristic impedance of the cable and the phase velocity that an electromagnetic wave will have in the cable. Comment on this value of phase velocity. [4]

(c) If we were to use this cable to connect a computer to an Ethernet hub operating at 100 MHz, determine the maximum length of cable that can be used before transmission line effects need to be considered, stating any assumptions made. Comment on this length. [5]

(d) The hub itself has an internal impedance of 50 Ω and generates a voltage of 5 V. Determine the magnitude of the first voltage pulse that propagates along the cable towards the computer. If the computer has an internal input resistance of 60 Ω, calculate the amplitude of the first reflected wave. Sketch the voltage at the computer as a function of time for the first 130 ns, assuming the cable is 10 m long. [8]

7 (a) Define the term *gain* of an antenna. [2]

(b) The Galileo satellite navigation system currently in development will operate at 1.2 GHz, using a series of satellites at an orbital height of 23,220 km. The receiving antennae (in the shape of a loop) have an effective area of 10^{-5} m^2 and an input resistance of 75 Ω. Calculate

(i) the wavelength of the electromagnetic waves emitted from these satellites [2]

(ii) the transmitted power if the satellites have a gain of 4,000 and the receiver needs at least 10^{-15} W to operate, assuming that the receiving antenna is oriented so as to maximise the signal. [8]

(iii) the voltage that will be developed in the receiver antenna if the received power is 10^{-15} W. [4]

(c) The relative permittivity of a dense cloud that is 1 km thick is 1.5. Estimate the power collected by the receiving antenna, assuming that the decay constant of the electromagnetic wave in the cloud is 0.001 m^{-1}. [4]

END OF PAPER