ENGINEERING TRIPOS PART IB

Thursday 3 June 1999 9 to 11

Paper 5

ELECTRICAL ENGINEERING

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

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

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.

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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 has an effectively infinite direct current gain, h_{FE}, and the operating base emitter voltage, V_{BE}, is 0.7 V, determine the quiescent voltages at the emitter, V_E, and at the collector, V_C. [4]

(b) In fact, the transistor is specified to have a minimum value for h_{FE} of 100. Determine the two voltages V_E and V_C with this value of h_{FE} and the same value of V_{BE}. [6]

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

(d) The transistor has the small signal parameters h_{fe} equal to 150 and h_{ie} equal to 200 Ω. Both h_{oe} and h_{re} may be taken as zero. Determine the gain of the amplifier, v_2/v_1, both as a numerical ratio and expressed in decibels, assuming the frequency of the operation is such that C_E behaves as a short circuit. [7]

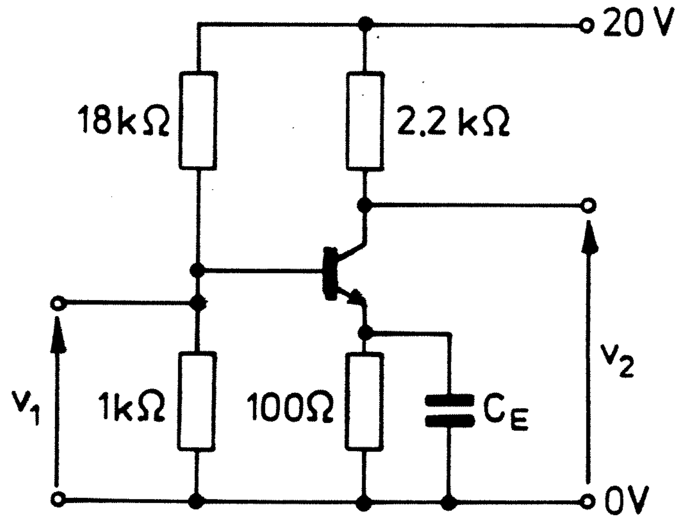

Fig. 1

2 (a) Describe briefly the advantages which result from the use of negative feedback in amplifier circuits. [5]

(b) An internally compensated operational amplifier has a voltage gain which varies with angular frequency according to the expression

$$A(\omega) = \frac{A_0}{1 + \mathrm{j}\omega T}, \text{ where } A_0 \text{ is a real number.}$$

The amplifier is otherwise ideal.

Obtain an expression for the 3dB bandwidth of the amplifier when negative feedback is not used in terms of the time constant T. [3]

(c) This operational amplifier is used in a non-inverting configuration in which a fraction βV_0 of the output voltage, V_0, is fed back to the inverting input. Obtain an expression for the gain of the circuit, v_2/v_1, in terms of A_0, ω, T and β. Hence, or otherwise, estimate the upper 3 dB frequency of the system when the value of β is:

(i) 0.1,

(ii) 0.001.

Take A_0 to be 10^5 and T as 0.01591 s. [4]

(d) The supply voltage to the amplifier is ±10 V and the maximum slew-rate at its output is 1 V/μs. Estimate the maximum peak to peak input voltages which may be used at the two frequencies calculated in part (c). [8]

SECTION B

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

3 (a) Outline the reasons why three phase systems are used for the large-scale generation and distribution of electricity. [6]

(b) A balanced three phase load consists of three star-connected impedances each of $10 + j10\ \Omega$ connected in parallel with three delta-connected impedances each of $15 - j20\ \Omega$. The load is supplied from a 415 V three phase generator through lines of negligible impedance. Determine the power consumed by the load, its power factor and the line current supplied. [10]

(c) The lines in fact have an impedance of $1 + j3\ \Omega$. If the load voltage remains at 415 V, determine the voltage at the sending end of the line. [4]

4 (a) Show that the power transferred between two alternating voltage sources E_1 and E_2, each of the same frequency, which are linked by an inductive reactance X is equal to:

$$\frac{E_1 E_2 \sin\delta}{X}$$

where δ is the phase angle between the two sources. [6]

(b) A star-connected synchronous generator has a synchronous reactance of 1 Ω per phase and has negligible stator resistance. It delivers 300 MW with unity power factor to a 33 kV infinite bus. Determine the generated e.m.f. (excitation voltage) and the load angle. [6]

(c) The excitation current is increased by 15% and the power delivered to the bus increases to 360 MW. Assuming a linear model for the machine, calculate the load angle, the stator current and the power factor. [8]

5 (a) The open circuit armature voltage, V_a, of a separately excited dc machine is measured as a function of the field current, I_f, at a speed of 1200 rpm, giving the results shown in the following table.

I_f (A)	0	2	4	6	8	10	12
V_a (V)	0	150	300	420	510	570	600

Calculate the torque developed when the machine is used as a motor at a speed of 1200 rpm with the field current set to 4 A and when it is connected to a 350 V supply. The armature resistance of the machine is 1 Ω. [6]

(b) The load torque remains the same as in part (a) and the field current is increased to 7 A. Estimate the new operating speed. [6]

(c) Estimate the minimum speed at which the motor can operate with the same load torque and supply voltage. Suggest how the speed could be reduced further for the same load torque. [8]

SECTION C

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

6 (a) A lossless transmission line has series inductance of 300 nHm^{-1} and shunt capacitance of 75 pFm^{-1}. Calculate the velocity of propagation of electromagnetic waves down the line and its characteristic impedance. Estimate the relative permittivity of the insulation, stating any assumptions that you make. [6]

(b) This line is terminated with a short circuit and is driven by a voltage generator with an output resistance equal to the characteristic impedance of the line. At a frequency of 300 MHz, calculate the shortest lengths of line which will:

(i) present an open circuit at its input, and

(ii) present a short circuit at its input. [4]

(c) The line of part (b) (ii) is bridged exactly half way along its length by an ideal 100 Ω resistor. Determine the reflection coefficient at the resistor and the voltage standing wave ratio (VSWR) in the line on the input side of the resistor. [4]

(d) The e.m.f. of the generator is 100 V. Determine the power developed in the resistor. [4]

(e) Describe how the voltage and current on the line vary with distance in the region between the resistor and the short circuit. [2]

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7 (a) A plane polarised electromagnetic wave travelling in air in the z–direction has a vertical electric field described by:

$$E_y = E_0 \exp\left[\mathrm{j}(\omega t - \beta z)\right] \ \mathrm{Vm^{-1}}\ (\mathrm{rms}).$$

Obtain an expression for the corresponding magnetic field, $H(z,t)$, and for the average power density in $\mathrm{Wm^{-2}}$ carried by the wave. [6]

(b) A circular wire loop of diameter d which is oriented in the y-z plane is immersed in the wave. Obtain an expression for the e.m.f. induced in the loop assuming that d is small compared to the wavelength of the radiation. [5]

(c) A colour television broadcasting station radiates electromagnetic waves at a frequency of 600 MHz. The power emitted is 1 kW and may be assumed to be uniformly distributed over a hemisphere.

The loop of part (b) has a diameter of 150 mm and is connected to a receiver which requires a minimum power of 4×10^{-9} W for adequate reception. If the receiver has an input resistance of 75 Ω and is power-matched to the loop, estimate the maximum distance between the transmitter and receiver if satisfactory performance is to be obtained. [7]

(d) The minimum power of 4×10^{-9} W quoted in part (c) may be reduced to 10^{-9} W for black and white reception. Estimate the maximum angle that the plane of the loop may make to the y–axis before such a signal cannot be successfully detected. [2]

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