Version TDW/6

EGT1
ENGINEERING TRIPOS PART 1B

Tuesday 15 June 2021   13:30 to 15:40

Paper 5

ELECTRICAL ENGINEERING

This is an ***open-book*** *exam.*

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

Answer not more than ***two*** *questions 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.*

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

STATIONERY REQUIREMENTS
Write on single-sided paper.

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
You have access to the Engineering Data Book, online or as your hard copy.

10 minutes reading time is allowed for this paper at the start of the exam.

The time allowed for scanning/uploading answers is 20 minutes.

Your script is to be uploaded as a single consolidated pdf containing all answers.

SECTION A

*Answer not more than **two** questions from this section*

1 (a) The circuit in Fig. 1 (below) is an amplifier based on a single bipolar junction transistor and is to be designed using a BC182L as Q_1, with the base voltage set at 1.7 V and the following DC operating point

$$V_{CC} = 10\text{ V}, V_{CE} = 4\text{ V}, I_C = 2\text{ mA}, V_{BE} = 0.7\text{ V}, h_{FE} = 400.$$

(i) Calculate the values of R_3 and R_4 to achieve this operating point whilst maintaining maximum possible voltage swing at the output. [3]

(ii) Explain what other information is required in order to calculate values for R_1 and R_2. [2]

(b) Sketch the small signal model equivalent circuit for the circuit in Fig. 1 at mid-band frequencies, neglecting the effects of h_{re} and h_{oe}. Derive an expression for the small signal gain of the circuit. [4]

(c) Describe with a revised small signal model, what changes have to be made to part (b) in order to calculate the output impedance of the amplifier. [4]

(d) The input of the circuit (v_{in}) in Fig. 1 is connected to a voltage source v_s with an internal resistance R_S and in order to boost the gain of the amplifier at mid-band frequencies, a bypass capacitor is added in parallel with R_4. Unfortunately, due to the construction of the BC182L bipolar junction transistor, there is also an associated parasitic base to collector capacitance C_{CB}.

(i) Sketch the new small signal equivalent circuit for the revised amplifier. [3]

(ii) Derive an expression for the gain as a function of frequency due to the capacitance C_{CB}. Clearly state any assumptions you make. [7]

(iii) What other technique could be employed to calculate the effect of this capacitance on the amplifier? [2]

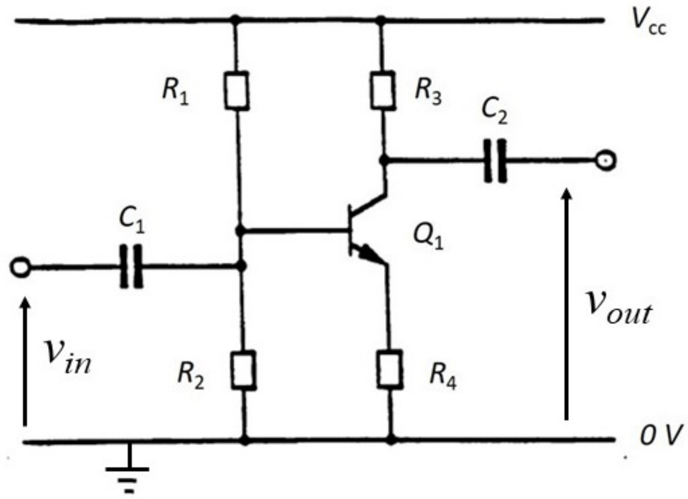

Fig. 1

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2 (a) Negative feedback is a technique that can be used to improve the overall performance of an electronic amplifier. Sketch a diagram to show how negative feedback can be applied to an amplifier with an open loop gain of A through a feedback network B. Derive an expression for the gain of the amplifier with negative feedback applied. [4]

(b) Two identical voltage amplifiers each have gains of A_0 but they can vary significantly by ΔA without any phase shift. If the two amplifiers are to be combined using negative feedback B, what configuration should be used in order to minimise the effects of this gain variation? Calculate the new gain variation of the combined amplifiers. [6]

(c) An amplifier has a mid-band gain of A_0, a low-frequency 3 dB cut-off f_1 and high-frequency 3dB cut-off f_2. Sketch a Bode plot of this frequency response and derive a mathematical equation for the overall gain of the amplifier as a function of frequency. State any assumptions made in this process. [5]

(d) An amplifier $A(f)$ has been designed with a lower frequency cut-off of $f_1 = 0$ Hz and upper frequency cut-off f_2. A negative feedback network $B(f)$ is used with this amplifier which contains a resistance R in parallel with a capacitance C.

(i) Obtain an expression for the overall gain of the circuit using this feedback network. [6]

(ii) Under what condition will the choice of R and C not dictate the upper frequency cut-off of the amplifier? [2]

(iii) What other consideration might have to be made when employing a frequency dependent feedback network? [2]

3 Consider a balanced star-connected 3-phase voltage supply with voltage V_{phase} at each phase and a balanced star-connected load with impedance $\bar{Z}_{phase}$ at each phase. The star point of the voltage supply and the star point of the load are connected with a conductor having impedance $\bar{Z}_c$. The power supply operates at 50 Hz with V_{phase} = 240 V and the load impedance is $\bar{Z}_{phase} = 100 + j20\ \Omega$.

(a) Derive the current flow through the conductor and describe the effect that $\bar{Z}_c$ has on the supply. [3]

(b) Calculate the power factor of the system and the line current. [5]

(c) Calculate the real and reactive power in the load. [5]

(d) Calculate the delta-connected inductance or capacitance required to alter the power factor of the system to 0.99 lagging. [8]

(e) The three separate phase outputs of the voltage supply are connected in series to achieve the single phase voltage $V_1 - V_2 + V_3$. Calculate the amplitude of this single phase voltage. [4]

SECTION B

*Answer not more than **two** questions from this section*

4 Three phase power generation is adopted throughout most of the modern world and is used to distribute electrical energy widely.

(a) Explain why 3-phase power generation is superior to other numbers of phases. Explain the difference between 3-phase 3-wire distribution and 3-phase 4-wire distribution for star connected systems and discuss which is better. [6]

(b) In modern power generation networks and grids, one of the key concepts is that of an infinite bus.

(i) What is an infinite bus? Give an example where an infinite bus assumption may not hold. [3]

(ii) A national grid system is supplied by 122 generators for a total of 56 GW. Suddenly, one of the stations operating at 7.4 GW fails. Does the infinite bus assumption still hold? Explain your answer. [2]

(iii) What could be done to restore the grid such that the infinite bus assumption could still hold? [2]

(c) A synchronous star-connected generator with 4 poles and a synchronous reactance of $X_s = 0.2\ \Omega$ is connected to a 50 Hz infinite bus with line voltage 33 kV.

(i) If the prime mover is set to 600 MW and the power factor at the terminals of the machine is 0.95 lagging, find the excitation voltage. [6]

(ii) If the power factor changes to 0.7 with line voltage and the excitation voltage obtained in (i) remaining unchanged, calculate the new prime mover power. [6]

5 The terminals of a pulsed voltage source are connected to an ideal transmission line which has specific inductance L $\mathrm{H\,m^{-1}}$ and specific capacitance C $\mathrm{F\,m^{-1}}$. The voltage source amplitude is V and $x = 0$ denotes the node where the transmission line connects to the source.

(a) Derive the Telegrapher's equations for the voltage $V(x)$ and current $I(x)$ in a lossless transmission line at a distance x for any given instant of time. [2]

(b) Find an expression for the characteristic velocity at which a voltage pulse would be transmitted in the transmission line. Give reasons for your answer. [5]

(c) What is the characteristic impedance Z_0 of the transmission line predicted by the Telegrapher's equations? [2]

(d) A twisted-pair transmission line has values of L = 1.0 x 10^{-6} $\mathrm{H\,m^{-1}}$, C = 2.5 x 10^{-11} $\mathrm{F\,m^{-1}}$ and is used to connect to a load impedance of 300 Ω located 2 m away from the voltage source.

(i) What is the time delay for a pulse originating at the voltage source to be received at the load? [3]

(ii) Considering the voltage source to be ideal, sketch the voltage variation with time at the load when a pulse of 10 V amplitude and 50 ns width is transmitted from the voltage source to the load. Your sketch should cover a period of at least double the pulse width duration at the load. [8]

(iii) How would you make the pulse received at the load be identical to that transmitted from the voltage source? [3]

(iv) Could the twisted-pair transmission line be used as a network data communication link at 100 mega bits per second (mbps)? Give reasons for your answer. [2]

6 (a) Show that Maxwell's equations predict electromagnetic wave propagation in free space. [3]

(b) Based on the results from (a) how can one conclude that radio waves in free space are a form of light? [3]

(c) Considering **E** and **H** fields to be plane waves in the $x - y$ plane:

(i) Show that the intrinsic impedance of free space is 377 Ω. [3]

(ii) Derive the intrinsic impedance for a medium which has a conductivity σ, permittivity ϵ and permeability μ. [4]

(d) An aircraft flying over the sea has to communicate with a submarine underneath the water. Sea water has parameters of conductivity $\sigma = 4\ \mathrm{S\,m^{-1}}$, relative permittivity $\epsilon_r = 81$ and relative permeability $\mu_r = 1$. The carrier frequency chosen for communication is 1 MHz. The antenna on the aircraft can be taken to transmit a plane wave with an electric field of $4000\ \mathrm{V\,m^{-1}}$ together with the corresponding magnetic field which lie in the plane of the surface of the sea.

(i) Calculate the intrinsic impedance of sea water at 1 MHz. [2]

(ii) Calculate the maximum electric field intensity within the sea water. [4]

(iii) If the antenna on the submarine has a collection area of 1 $\mathrm{m^2}$ and a detection power limit of 18 pW, calculate the maximum depth below sea level that the submarine can be at whilst maintaining communications with the aircraft above. [6]

END OF PAPER