EGT2

ENGINEERING TRIPOS PART IIA

Tuesday 28 April 2026 14:00 to 15:40

Module 3B1

RADIO FREQUENCY ELECTRONICS

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage 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

Supplementary page: Smith Chart (Question 4)

Engineering Data Book

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

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

You may not remove any stationery from the Examination Room.

1 (a) A radio system is designed to receive signals with bandwidth 500 kHz at the 430 – 440 MHz band for an Internet-of-Things (IoT) application. An oscillator is required to enable the generation of the intermediate frequency (IF) signal.

(i) The circuit in Fig. 1 is used to create a negative resistance with an LC tank. Calculate the required values of R_b, R_T and the capacitor required to generate a 445 MHz tone feeding into a 75 Ω load, when operating from a ±6 V d.c. supply. Assume an inductor value of 10 nH, with a Q-factor of 20. State all assumptions. [20%]

(ii) Sketch how the LC tank should be connected to the circuit in Fig.1 and add needed components to tune the frequency of oscillation over the range 440 MHz to 450 MHz. [15%]

(iii) Transistors in Fig. 1 have $h_{fe} = 100$ and f_T of 50 GHz. Calculate the 3 dB roll-off frequency which leads to the loss of negative impedance, meaning that the oscillator is not effective anymore. Explain whether the design in (i) and (ii) above is still effective. [25%]

(b) The system above should be able to cope with high frequency noise. Design a suitable 4-pole VCVS filter using 4 operational amplifiers with a cut-off frequency of 460 MHz. It has been decided that a Chebyshev filter type would be suitable with $f_n = 0.597$ and 1.031, $A = 1.582$ and 2.660. Use $100\ \Omega$ resistors where appropriate and calculate the values of all passive components needed. Also, design another RC filter for the same purpose. Which one would be a better option? Briefly explain advantages and disadvantages of the two filters you designed. [40%]

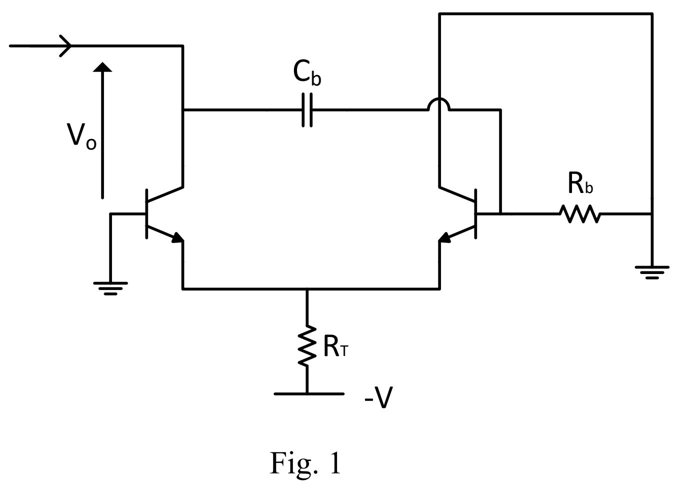

Fig. 1

2 (a) A radio frequency (RF) amplifier is required to boost the signal power from an antenna by 20 dB. The nominal frequency of operation is 200 MHz.

(i) Draw a circuit diagram for a single stage RF amplifier based on bipolar junction transistors and calculate the components values. The input and output impedances are matched to the source and load impedances of 50 Ω. The amplifier should operate from a 10 V d.c. supply and be able to provide up to 100 mW output power. Assume a suitable transistor with $h_{fe} = 250$ is available. [35%]

(ii) Two transistors are available. T1: $f_T = 5$ GHz, $C_{cb} = 0.3$ pF and T2: $f_T = 10$ GHz and $C_{cb} = 0.2$ pF. By calculation of the upper –3 dB frequency of your amplifier, justify which one would be suitable for your amplifier. (C_{oe} may be neglected) [35%]

(b) Consider a similarly designed amplifier with emitter resistance $R_E = 5$ kΩ. As shown in Fig 2., some components are used to control the gain of the amplifier. Explain the function of the given components and calculate the values of passive components to reduce the gain by 50%. Sketch the components which need to be added inside the dashed box to provide feedback from the output voltage and explain their functions. [30%]

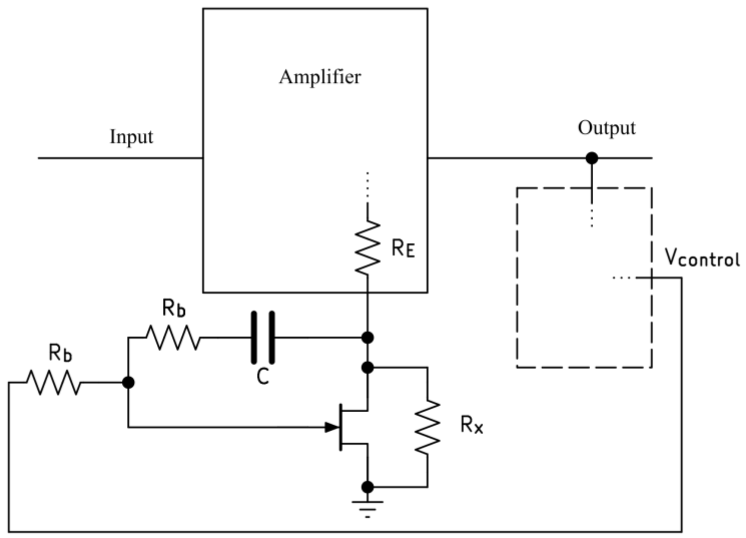

Fig. 2

3 A maritime search and rescue radar operates at a frequency of 9.4 GHz. The system uses a parabolic dish antenna to transmit signals and receive reflected signals. The transmitter has a peak output power of 10 kW and the antenna has a gain of 34 dB.

(a) Define the terms *Gain, Directivity* and *Effective Aperture* as applied to antennas and explain how they are inter-related. [20%]

(b) Given that the *Effective Aperture* of a dish antenna is approximately equal to 60% of the area of a circle with the same diameter as the dish, estimate the diameter of the parabolic dish antenna required to achieve the 34 dB gain. [10%]

(c) Estimate the beam angle of the antenna, given a *Radiation Efficiency* of 75%. [10%]

(d) Calculate the power density, the magnitude of the electric field strength, and the magnitude of the magnetic field strength, at a distance of 12 km from the radar. [15%]

(e) The radar tracks a small vessel at a range of 12 km. The vessel presents an effective area of 50 m^2, off which the signal is reflected isotropically. Calculate the power of the received signal at the parabolic dish antenna. [25%]

(f) The radar system includes a backup VHF dipole antenna fabricated from copper wire with a diameter of 1.0 mm. The antenna operates at 150 MHz. Estimate the radiation efficiency of this dipole. Assume the dipole radiation resistance as 73 Ω. [20%]

State all assumptions and approximations made.

4 A 2.45 GHz power amplifier module for a Wi-Fi transmitter requires specific impedance matching networks at its input and output. The circuit is to be fabricated on a PCB substrate with a relative permittivity $\varepsilon_r = 3.55$ and a dielectric thickness of 1 mm.

(a) Determine the width of the microstrip track required to realize a characteristic impedance of 50 Ω. You may use a standard approximation formula or estimate, stating any assumptions made. [20%]

(b) The output of the amplifier is connected to an antenna with an impedance $Z_L = 75 + j20\ \Omega$ via a 50 Ω transmission line. Calculate the voltage reflection coefficient (Γ) magnitude and phase, and the Return Loss in dB. [10%]

(c) The input impedance of the amplifier transistor is $Z_{in} = 20 - j40\ \Omega$. Design a matching network to match this impedance to a 50 Ω source using a series inductor and a shunt capacitor.

(i) Describe the procedure you would use on a Smith Chart to determine the component values. [10%]

(ii) Calculate the required reactance values and the corresponding inductance and capacitance values. [20%]

(d) The power amplifier output stage presents a real impedance of 12.5 Ω. A microstrip transmission line is used as an impedance transformer to match this output to a 50 Ω transmission line. Calculate the required characteristic impedance and physical length of the microstrip transmission line. [20%]

(e) Explain how a patch antenna with a notched corner implemented on a PCB can produce circularly polarised radiation. [20%]

State all assumptions and approximations made.

A Smith chart is attached to the back of the question paper. It should be detached and handed in with your answers.

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Tuesday 28 April 2026, Module 3B1, Question 4

Candidate No.

Smith Chart for Question 4 – to be detached and handed in with script.