Version PAR/4

EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 25 April 2023 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 1)
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 An antenna of impedance 250 + j100 Ω requires impedance matching to a transmitter circuit with an output impedance of 50 Ω, at an operating frequency of 250 MHz.

(a) Find the S_{11} of the antenna with a reference impedance of 50 Ω. [10%]

(b) The transmitter circuit is to be constructed on a printed circuit board with a relative permittivity, ϵ_r of 4.2, and a thickness of 1.6 mm. Determine the track width required for a microstrip to have a characteristic impedance of 50 Ω, stating any assumptions and approximations made. [30%]

(c) (i) Using the attached Smith Chart, design an impedance match between the antenna and transmitter using a length of microstrip as specified in part (b), and a series capacitor. How could the physical length be reduced ? [30%]

(ii) A manufacturing fault results in the microstrip having a relative permittivity, ϵ_r of 2.69. Determine the voltage reflection coefficient at the input to the matching circuit if the length and capacitor value are unchanged from part (b). [30%]

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

2 (a) (i) An antenna has a directivity of 23 dB and a gain of 21 dB. If the real component of its impedance is 120 Ω, find the radiation resistance and efficiency. [10%]

(ii) What would be the maximum power received by a matched half-wave dipole antenna placed 10 m away from the transmitter antenna of part (i), if the transmitter antenna is fed from a matched source with a power of 10 mW at a frequency of 868 MHz. [20%]

(b) (i) A PLL is required to control a VCO producing an output of 868 MHz in tuning steps of 200 kHz. Show using a block diagram how the VCO can be locked to a crystal reference with a 20 MHz output frequency. How does the output of the phase comparator relate to the phase of the VCO and reference ? [15%]

(ii) If the phase comparator of the PLL has an output of K_p V rad^{-1}, the VCO an output of K_o rad s^{-1} V^{-1} and uses the loop filter shown below in Fig. 1, derive an expression for the damping factor of the loop transfer function. [40%]

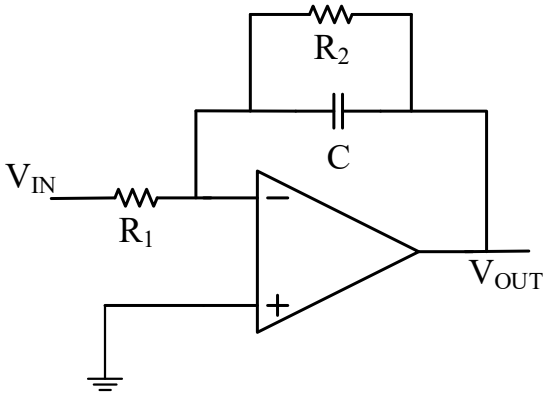

Fig. 1

(c) The output of the VCO has an output impedance of 50 Ω and will be used to drive both the transmitter mixer and receiver mixer, each having an input impedance of 75 Ω. Determine the characteristic impedance and electrical lengths of the transmission line elements of a Wilkinson splitter to achieve both splitting and impedance matching. [15%]

Note: antenna gain equation $G = (4\pi A_e) / \lambda^2$

3 A two-stage RF amplifier with a net gain of 33 dB is required to boost the signal from a 50 Ω source and drive a 50 Ω load, with matched input and output impedances. The amplifier is to operate at 860 MHz with a supply voltage of 12 V d.c.

(a) Draw the schematic circuit diagram of a suitable 2-stage transistor amplifier and briefly describe the function of each of the components used. [25%]

(b) Calculate the values of the passive components in the amplifier circuit to meet the performance characteristics required. You may assume that transistors are available with $h_{fe} = 200$. [20%]

(c) If the transistors also have the following properties:

$f_t = 22$ GHz, $c_{cb} = 0.20$ pF, $c_{oe} = 0.16$ pF , estimate the upper −3dB roll-off frequency for the loaded amplifier circuit and hence comment if the available transistors are suitable for this application. [35%]

(d) In order to minimise noise and interference, the frequency response of the amplifier is to be restricted by including a resonant LC circuit, with a Q-factor = 5, connected between the two transistor stages, such that the peak gain occurs at 860 MHz and drops off either side. Show how such a circuit should be connected and calculate suitable values for L and C. [20%]

4 (a) Electrocardiogram signals in the range 0.2 – 100 Hz are used to monitor the function of the heart, typically producing shaped electrical pulses at around 1 – 2 Hz repetition rate. The raw signals are quite small, at ~mV levels, and it is required to amplify and filter the electrical signals prior to digital processing.

(i) Design a 4-pole Voltage Controlled Voltage Source (VCVS) high-pass filter to remove electrical noise and drift at low frequency. Using 100 kΩ resistors where appropriate, give the values of other passive components used. Justify your choice of filter type. A 4-pole VCVS filter design table is given below in Table 1. [25%]

(ii) Design a suitable circuit to flash an LED with each pulse over 1 mV amplitude, so that the patient pulse rate can be quickly and easily seen when connecting the electrodes to the patient. A threshold which tracks recent pulse amplitudes should be employed to improve reliability with variable signal levels. [25%]

(b) A negative resistance oscillator circuit is required to produce a 1.58 GHz LO signal for a GPS receiver, which presents a 100 Ω load to the oscillator. Show how a pair of transistors can be connected to create a negative resistance and hence design an oscillator circuit for the required frequency. Assume an inductor value of 1 nH with a Q-factor of 20, and give the values of other passive components, assuming a ± 3 V supply. Indicate how the frequency of the circuit can be tuned electronically for other GPS bands at 1.13 GHz and 1.18 GHz, with the addition of a few extra components. [50%]

Table 1. 4-pole VCVS filter design table

Bessel		Butterworth		Chebyshev (0.5 dB)	
f_n	A	f_n	A	f_n	A
1.432	1.084	1.000	1.152	0.597	1.582
1.606	1.759	1.000	2.235	1.031	2.660

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ENGINEERING TRIPOS PART IIA

Tuesday 25 April 2023, Module 3B1, Question 1

Candidate No.

Smith Chart for Question 1 – to be detached and handed in with script.