Version MJC/3

EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 29 April 2025 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 is fed via a 50 mm long microstrip transmission line with a poorly designed impedance matching network as shown in Fig. 1. The frequency of operation is 400 MHz. The circuit board is arranged such that the RF ground plane (not shown) is 0.2 mm below the top copper, separated by the circuit board material.

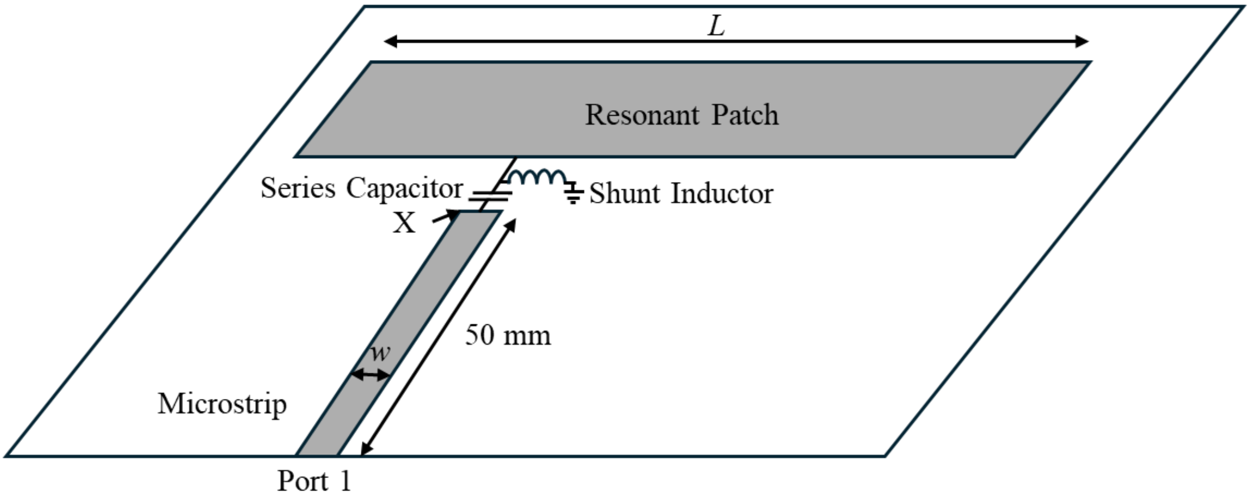

Fig 1. NOT TO SCALE

(a) The microstrip track width, $w = 0.4$ mm, is found to provide a characteristic impedance of 50 Ω. Calculate the dielectric constant of the circuit board material. [20%]

(b) A Vector Network Analyser (VNA) is used to measure the S_{11} at port 1 which is found to be $0.3 \angle -40°$. Find the impedance presented by the antenna and matching network at the other end of the 50 Ω microstrip (marked point X in Fig. 1). [30%]

(c) The impedance matching network consists of a 32 nH shunt inductor and 7.6 pF series capacitor. Find the impedance of the antenna. [30%]

(d) The antenna is to be a resonant microstrip patch. What length L should it have? Suggest how the lumped element impedance matching network could be eliminated while improving impedance matching between the antenna and 50 Ω microstrip. [20%]

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

2 (a) An antenna is measured in an anechoic chamber which has no reflections ensuring that propagation resembles free space. A fixed RF power at 2.4 GHz is transmitted from a reference antenna at a range of 3 m. This is detected by the antenna under test and a reference isotropic antenna which can be assumed to have an efficiency of 1. Both antennas are matched to the 50 Ω receiver and are vertically polarised.

(i) The reference antenna has a received power of 250 μW, and the antenna under test has a maximum received power of 1 mW as its orientation is varied, a radiation resistance of 30 Ω and an ohmic resistance of 20 Ω. Find the gain, directivity and efficiency of the antenna under test and the power density incident at the receive antenna location. [25%]

(ii) The antenna under test is to be used as the receive antenna in a telemetry system which has a receiver sensitive down to 10 μV. If the transmitted power is 2 mW with a gain of 30, what would be the maximum range in free space? [20%]

(b) A double balanced mixer circuit is partially shown in Fig. 2.

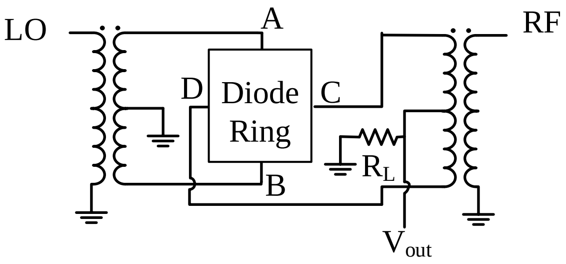

Fig. 2

(i) Draw the required configuration of the diode ring clearly marking points A, B, C and D. [10%]

(ii) Explain how the RF and LO inputs are well isolated from the output. Explain why this is important. Suggest imperfections which might cause each isolation to be reduced. [20%]

(c) The LO signal for the mixer in part (b) is to be driven by the output of a phase locked loop. The receiver is to tune over a 2.4 GHz to 2.5 GHz band with frequency steps of 5 MHz, and an intermediate frequency of 120 MHz. Sketch a block diagram of a suitable phase locked loop using a VCO with a maximum frequency of 2.5 GHz, and a stable crystal reference of 100 MHz. Find suitable divider values. [25%]

3 A satellite superheterodyne radio system works at a centre IF frequency of 70 MHz. The IF filter is to have a bandwidth of 10 MHz with no overshoot in the time-domain response.

(a) Draw the block diagram of the receiver and explain the roles of the oscillator and the IF filter. Explain how the system copes with a wide range of received signal strengths due to the rapid movement of the satellite. [20%]

(b) Design a suitable IF filter using 4 operational amplifiers, giving the values of all passive components used. Table 1 gives the design parameters for 4-pole VCVS filters. Use 100 Ω resistors where appropriate. [30%]

(c) Design a Colpitts oscillator circuit to produce the IF signal from the 1490 MHz incoming RF signal. Explain the choice of the oscillator frequency, knowing that it should be below 1.5 GHz. Assume that the circuit operates from a 3 V supply, utilises a transistor with the following properties: $h_{fe} = 250$, $f_t = 12$ GHz, $c_{cb} = 0.15$ pF, $c_{oe} = 0.10$ pF, and should provide 2 mW into a 500 Ω load. Where needed use an inductor of value 10 nH with a Q-factor of 45. Draw the circuit diagram and give the values of all other components used. [30%]

(d) Draw a negative impedance converter circuit using an op-amp and explain how it works. Use this to realise a 10 H inductor only using op-amps, resistors, and capacitors. Give an example on a use case of negative impedance converters. [20%]

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

4 An amplifier is required for a free space optical link to provide a modulating signal with a suitable amplitude to drive a laser. The modulating signal is at baseband with an upper frequency of 1 GHz. A gain of at least 36 dB is required. Impedances of source and load (i.e., laser) are both 50 Ω.

(a) Draw a single stage bipolar transistor amplifier. Briefly explain the role of each component and explain the function of the emitter resistor in the amplifier stability and gain. [20%]

(b) Design a suitable amplifier using a 10 V supply and transistors with h_{fe} = 250. Calculate the values of the passive components in the amplifier circuit. [30%]

(c) If the transistors have the following properties: f_t = 20 GHz, c_{cb} = 0.20 pF, c_{oe} = 0.10 pF, explain if it can handle the modulating signal by estimating the upper roll-off frequency of the amplifier designed in part (b). [30%]

(d) To increase the link capacity, higher modulation bandwidth is required. Explain how an amplifier with a cascode configuration could work better with a higher expected bandwidth. Draw the circuit diagram, configured as an amplifier with an output impedance of 50 Ω and a voltage gain of 16, when connected to a matched load. [20%]

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Tuesday 29 April 2025, Module 3B1, Question 1

Candidate No.

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