ENGINEERING TRIPOS PART IIA

Thursday 3 May 2012 9 to 10.30

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.*

Attachment:

Chart for question 4, to be detached and submitted with the solution.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

FINAL version

1 A radio system to monitor the sounds of wildlife in the jungle, to locate groups of monkeys, includes a microphone connected to a transmitter. The transmitter operates at 172 MHz with a power of 30 mW and uses a quarter-wave dipole antenna.

(a) Explain the terms *Gain*, *Effective Aperture*, *Radiation Resistance* and *Polarisation* for an antenna. [20%]

(b) How long should each dipole element be, and what is the power density of the radio signal at a receiving antenna placed 2 km away ? [20%]

(c) What is the signal voltage created by a receiving antenna, which is similar to the transmitting antenna, when it is connected to a matched load of 50 Ω ? [20%]

(d) If the antennas are made from 3 mm diameter stainless steel tube with a wall thickness of 0.25 mm, estimate the radiation efficiency of the antennas in this application. [25%]

(e) What signal voltage do you get from multiplying the electric field at the receiving antenna by the antenna length ? Comment on this result. [15%]

The resistivity of stainless steel is $7.2 \times 10^{-7}\ \Omega$ m.

State all assumptions and approximations made.

2 A radio receiver is constructed with a superheterodyne architecture and includes automatic gain control in the IF signal path. The IF filter is to have a bandwidth of 20 kHz with a centre frequency of 500 kHz and is to comprise a VCVS filter circuit followed by a variable gain amplifier.

(a) Draw a schematic block diagram for a superheterodyne radio and briefly explain the function of each block. [20%]

(b) Design a variable gain amplifier/attenuator circuit with a gain range of magnitude ×0.1 to ×20 to maintain the IF signal amplitude at around 1 V. The circuit should include amplitude monitoring and feedback, with a control bandwidth of around 10 Hz. [35%]

(c) Design a VCVS circuit for the IF filter using 4 operational amplifiers. Justify your choice of filter type and give the value of all the resistors used, given that the capacitors should all be of value 1 nF. [35%]

(d) Explain the term *tracking* in the context of tuning the radio, and how this relates to the IF filter bandwidth and front-end resonant circuit *Q-factor*. [10%]

<u>VCVS 4-pole filter design table</u>

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

State all assumptions and approximations made.

(TURN OVER

3 The antenna of a 172 MHz transmitter circuit is to be driven by an RF amplifier, with a matched input and output impedance of 75 Ω, operating from a d.c. supply voltage of 10 V.

(a) Draw the circuit for a suitable single-stage transistor amplifier and select component values to give the required input and output impedance and approximately 10 dB of gain when loaded. Assume a bipolar transistor is available with $h_{fe} = 250$. [25%]

(b) Estimate the maximum useful operating frequency of the amplifier, when connected to a matched source and load, if the transistor has the following properties: $f_t = 18$ GHz , $c_{cb} = 0.20$ pF , c_{oe} = negligible. [35%]

(c) An alternative high gain antenna is to be evaluated, but this device has an impedance of 30 + j20 Ω . Design a suitable matching circuit, using a pair of passive components, to match the antenna impedance to 75 Ω at 172 MHz. [30%]

(d) An unrelated transmitter is operating nearby at a frequency of 200 MHz and it is desired to use a modified version of the antenna matching circuit as a filter to attenuate this nuisance signal. Indicate how this can be achieved. [10%]

State all assumptions and approximations made.

4 (a) The front end of a 172 MHz radio receiver comprises a resonant LC tank circuit, where the *Q-factor* is mainly determined by the losses in the inductor. If the inductor comprises a number of turns of copper wire, with a resistance of 2 Ω, calculate the *Q-factor* and *bandwidth* of the tank circuit if the capacitor has a value of 18 pF. [20%]

(b) Show how an operational amplifier and passive components can be connected to realise a negative resistance and explain if this could be useful in increasing the Q-factor of an resonant LC tank circuit. [15%]

(c) The input impedance of a mixer circuit in a mobile phone is represented by a resistance of 33 Ω in series with a 10 nH inductance and operates at 960 MHz. Plot this point, normalised to 50 Ω, on the Smith Chart provided at the end of this paper and design an impedance matching circuit, comprising a length of stripline and a capacitor, to match the mixer input to 50 Ω. What magnitude of voltage reflection coefficient would be expected if the signal frequency increases to 1060 MHz ? [40%]

(d) What should the width of the stripline track in part (c) be, if the relative permittivity of the dielectric is 3 and its total thickness is 2.8 mm ? What length of this stripline should be used in the matching circuit designed ? [25%]

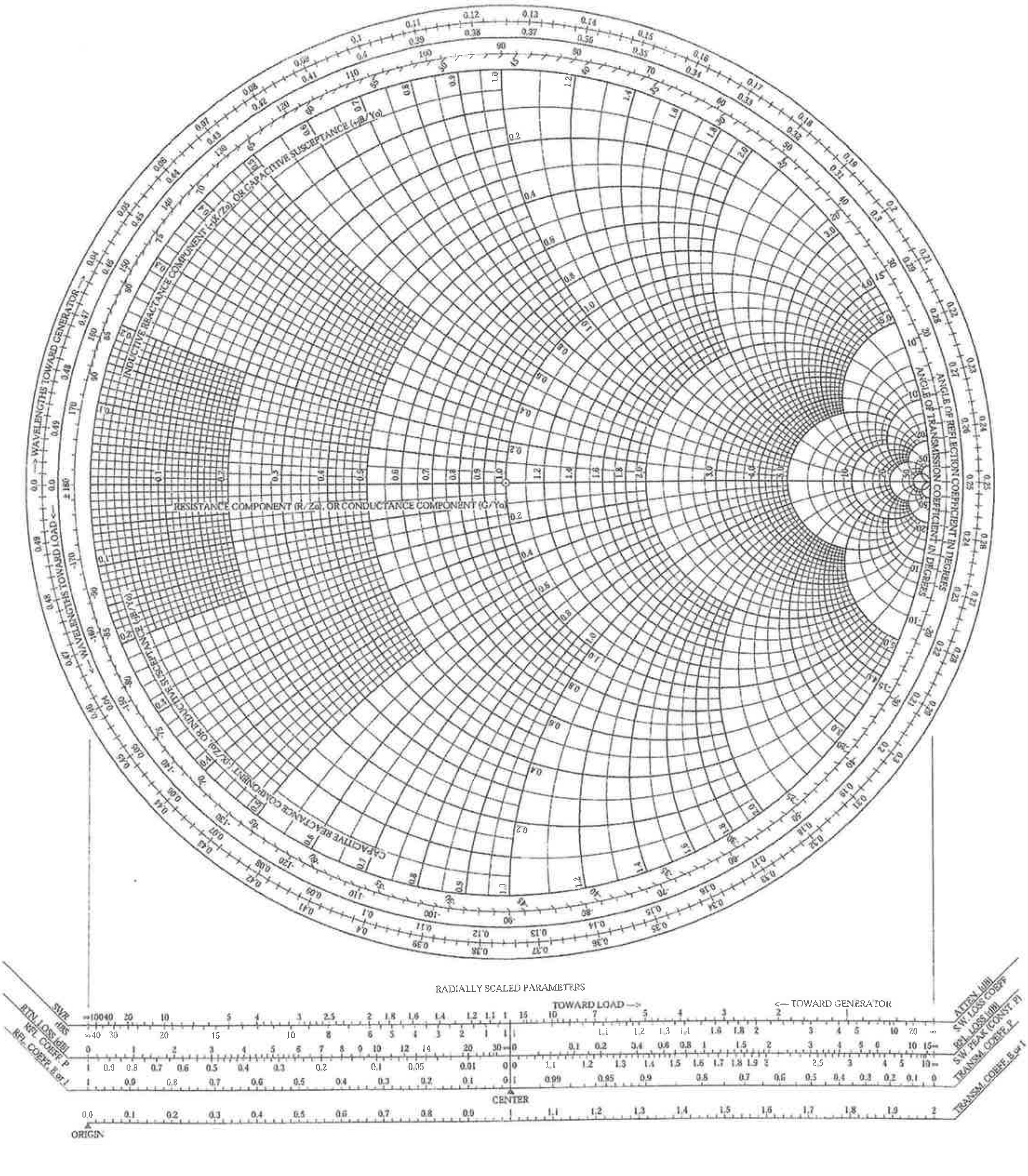
State all assumptions and approximations made.

END OF PAPER

THIS PAGE IS INTENTIONALLY BLANK

Candidate Number: ____________

Chart for question 4; to be detached and handed in with script.



3B1 2012 – Numerical answers

1 (b) 8.95×10^{-10} W m^{-2}
(c) 1.27×10^{-4} V rms
(d) 96 %
(e) 5×10^{-4} V rms

2 (c) 510 kHz, high pass, Rf = 1 kΩ
R1 = 523 Ω, (A-1)Rf = 582 Ω
R2 = 303 Ω, (A-1)Rf = 1.66 k Ω

490 kHz, low pass, Rf = 1 kΩ
R3 = 194 Ω, (A-1)Rf = 582 Ω
R4 = 335 Ω, (A-1)Rf = 1.66 k Ω

3 (a) R1 = 100 Ω , R2 = 560 Ω , R3 = 12 Ω , R4 = 75 Ω
(b) 2.72 GHz
(c) 57 nH, 16 pF

4 (a) Q = 25.7, B/w = 6.69 MHz
(c) 0.029 λ , 2.21 pF , ρ = 0.22
(d) w = 0.24 mm , l = 4.7 mm