ENGINEERING TRIPOS PART IIA

Tuesday 28 April 2009 2.30 to 4.00

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

1 A new electric aircraft is fitted with a radio telemetry system to transmit data back to a base station at the airfield. The transmitter operates at 433 MHz with a power of 10 mW and uses a small isotropic (unity gain) antenna. In order to achieve good reception range, the base station uses an antenna with a *Gain* of 30 , which is pointed in the direction of the aircraft to maximise the signal.

(a) Define the terms *Gain*, *Effective Aperture, Directivity* and *Radiation Resistance* for an antenna and explain how they are inter-related. [20%]

(b) If the telemetry system receiving antenna is connected to a matched impedance of 75 Ω and the receiver input circuitry is sensitive down to 10 μV , what is the maximum aircraft range that can be achieved for the data to be received ? [40%]

(c) In an attempt to improve performance, the engineer decides to change the transmitter antenna for a quarter-wave dipole. How long should the new antenna be and by how much will this increase the working range ? Are there any disadvantages to using it ? [15%]

(d) It is also proposed to use the same quarter-wave antenna for the aircraft's radio-telephony, which operates at 175 MHz. If the *Radiation Efficiency* at 433 MHz is 90 % , and the antenna comprises a large diameter piece of wire, what is its *Radiation Efficiency* at 175 MHz ? [25%]

State all assumptions and approximations made.

2 A digital radio telemetry system uses a diode ring mixer in its receiver to mix the incoming RF signal with that from a Local Oscillator (LO), to produce the Intermediate Frequency (IF) signal. Another diode ring mixer is also used in the Local Oscillator, to double the frequency produced by a quartz crystal oscillator.

(a) Draw the circuit for a diode ring mixer and briefly explain how it operates for frequency mixing and doubling. What provisions could be made to ensure that the mixer output does not contain a DC component ? [25%]

(b) After demodulation the telemetry receiver outputs an analogue square-wave signal, which is unfortunately subject to substantial higher frequency interference and voltage spikes. If the maximum data rate is 4800 bits/second , design a suitable 4-pole VCVS filter, using 10 kΩ resistors, to clean up the signal prior to it being fed into a comparator to reconstruct the digital data stream. Justify your choices of filter type and cut-off frequency. A filter design table is given below. [40%]

(c) The front-end of the receiver uses a resonant LC tank circuit, where $L = 10\ \mu H$ and $C = 330$ pF. If the inductor has a series resistance of 3 Ω, estimate the *Q-factor* of the tank circuit. How could a *Negative Impedance Converter* (NIC) be used to increase the *Q-factor* to 100 ? [35%]

VCVS 4-pole 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

State all assumptions and approximations made.

(TURN OVER

3 A low cost data transmission system comprises a microstrip patch antenna, with two feed points, linked to an amplifier in a feedback configuration such that it oscillates and radiates at 1.5 GHz. The amplifier supply voltage is modulated 0 – 10 V by the data signal to give an *Amplitude Modulated* (AM) carrier wave.

(a) Draw the circuit for a suitable single stage transistor amplifier and select component values to give input and output impedances of approximately 100 Ω and 10 dB of gain when loaded. Assume a bipolar transistor is available with $h_{fe} = 200$. [25%]

(b) Estimate the bandwidth of the amplifier, when connected to a matched source, if the transistor has the following properties: $f_t = 22$ GHz , $c_{cb} = 0.15$ pF , c_{oe} = negligible. [30%]

(c) Briefly describe the mode of operation of a microstrip patch antenna and calculate the length of a 1.5 GHz resonant patch, assuming the dielectric substrate has a *Relative Permittivity* of 3 . [15%]

(d) How should the patch be connected with the amplifier to realise an oscillator circuit ? [15%]

(e) If the substrate dielectric is 1.6 mm thick, what width should the microstrip feed lines be to give a *Characteristic Impedance* of 100 Ω ? [15%]

State all assumptions and approximations made.

4 A digital set-top box produces an RF signal at 500 MHz , to be plugged into an old fashioned analogue TV set with an aerial socket impedance of 75 Ω . The amplifier within the set-top box has an output impedance represented by a resistance of 165 Ω in series with an inductance of 28.6 nH .

(a) By calculation, design an impedance matching circuit, using three passive components, for this application. [20%]

(b) Using the Smith Chart, design impedance matching circuits comprising the following components:-

(i) an inductor and a capacitor

(ii) a capacitor and a length of 75 Ω coaxial cable

(iii) an inductor and a length of 75 Ω coaxial cable [45%]

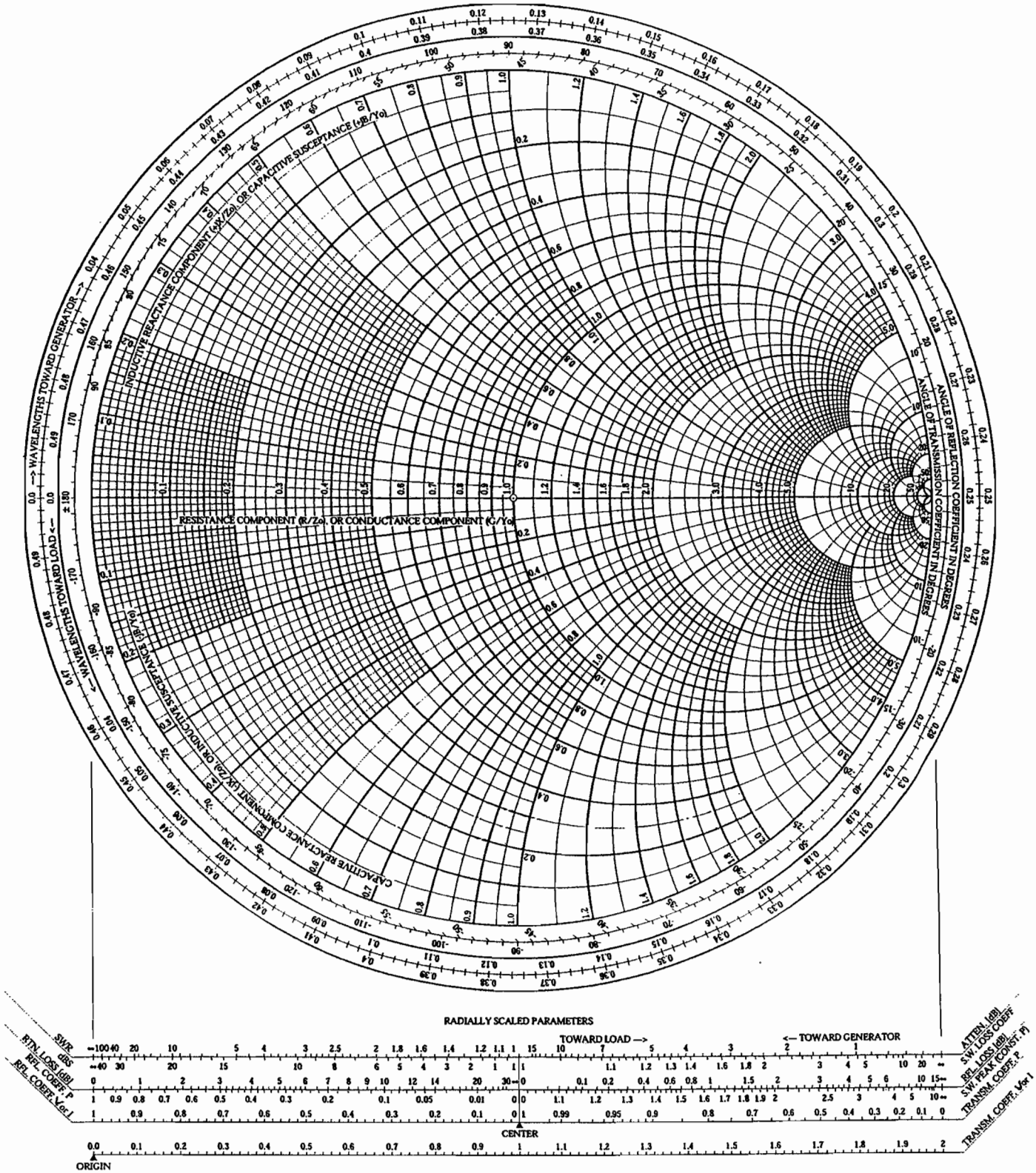
(c) If the coaxial cable dielectric has a *Relative Permittivity*, $\varepsilon_r = 2.2$ and costs 20 pence per metre, a capacitor costs 2 pence and an inductor 10 pence , which matching circuit would be the cheapest ? [15%]

(d) Considering the matching circuit which comprises an inductor and a length of coaxial cable, if the set-top box output frequency is changed to 420 MHz but the matching circuit is left unchanged, estimate the magnitude of the *Voltage Reflection Coefficient* which would result from such a frequency change. [20%]

State all assumptions and approximations made.

END OF PAPER

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



3B1 – 2009 Numerical answers

1 (b) 26.2 km (1.33 pW)

1 (c) 17.3 cm each half. Range increases to 32.1 km

1(d) 70%

2 (b) Use a low pass Bessel filter (for pulse shape) @ 9600 Hz. C1 = 1.16 nF, C2 = 1.03 nF

2(c) Q = 58 with equiv. R = 10.1 kΩ. For Q=100, R' = 17.4 kΩ, hence shunt with –24 kΩ

3 (a) R4 = 100 Ω, R3 = 15 Ω, R2 = 120 Ω, R1 = 680 Ω

3 (b) 1.46 GHz (or 2.9 GHz incl. source impedance of 100 Ω)

3 (c) 57.7 mm

3 (e) 0.28 mm

4 (a) Cseries = 3.54 pF, C = 3.9 pF, L = 48 nH

4 (b) (i) series 3.03 pF, parallel 85.3 nH
(ii) 26.3 nH and 0.118 λ
(iii) 3.79 pF and 0.449 λ

4 (c) coax. + C = 5.6 pence

4 (d) Voltage refl. coeff. = 0.15