ENGINEERING TRIPOS PART IIA

Tuesday 3 May 2011 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: Smith Chart (1 page)

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

Ver 4

1 A telemetry system is being designed to communicate engine data from a racing car to a base station via an AM radio link operating at 468 MHz. The data receiver has a Superhet architecture and uses a low noise pre-amplifier between the antenna and receiver input.

(a) Draw a block diagram of a Superhet receiver and briefly explain the function of each block and how the system operates; include a description of how the circuit is tuned and the significance of *tracking* and *image rejection*. [30%]

(b) Draw the circuit for a 2-stage antenna pre-amplifier and select the component values to produce a net gain of 24 dB when connected to a 75 Ω matched source and load. A pair of transistors with $h_{fe} = 150$ is to be used with a d.c. collector bias current of 60 mA for each stage, when operating from a supply voltage of 10 V. [30%]

(c) Calculate an estimate of the upper cut-off frequency for the amplifier circuit designed in part (b) if the transistors have the following properties:

$$f_t = 24 \text{ GHz} \ , \ c_{cb} = 0.30 \text{ pF} \ , \ c_{oe} = 0.20 \text{ pF}$$ [40%]

State all assumptions and approximations made.

2 A microstrip patch antenna is to operate at 468 MHz for transmitting and receiving radio signals in a telemetry system. The circuit board has a relative permittivity, ε_r, of 4.2 .

(a) Briefly explain, giving two reasons, why it is important for an RF system to use matched impedances in a circuit. [15%]

(b) Derive the characteristic impedance of a microstrip transmission line and determine the width of the microstrip antenna feed line required to realise an impedance of 75 Ω, if the board is 1.6 mm thick. [25%]

(c) What length of patch antenna should be used to realise an efficient antenna at 468 MHz, and how should the position of the patch feed-point be determined ? [15%]

(d) If a pair of these identical antennas was spaced 2 km apart, what would be the magnitude of the received signal across a 75 Ω matched load if the transmitting antenna is driven from a matched source, which has an amplitude of 10 V_{rms} ? [25%]

(e) In an attempt to reduce costs, the microstrip patch antenna is to be printed in a conductive ink rather than using copper track. Estimate the radiation efficiency of the antennas if they are made from an ink layer 20 μm thick, assuming a resistivity of 3×10^{-5} Ω m and the patch is 30 mm wide. [20%]

State all assumptions and approximations made.

(TURN OVER

3 An oscillator is to be designed for operation at 468 MHz based on a Colpitts circuit, and needs to provide 7 dBm of power into a 75 Ω load when operating from a 5 V d.c. supply.

(a) Draw a circuit diagram for a Colpitts oscillator and briefly explain the function of each component. Describe where outputs can be drawn from the circuit and what implications this has for harmonic distortion and any effects of loading the output. [25%]

(b) Select component values for the circuit to oscillate at 468 MHz assuming a tank circuit inductance of 10 nH is to be used. You may assume that a suitable high frequency NPN transistor is available. Estimate the power drawn from the supply by the circuit, and hence estimate its efficiency. [40%]

(c) Explain how additional components may be added to the oscillator circuit to make it suitable for incorporation into a phase-locked-loop (PLL), in order to stabilise its frequency with reference to a 10 MHz crystal oscillator. Draw a schematic block diagram for the complete PLL. [20%]

(d) If instead the output is to drive an impedance of 300 Ω, at the same power level, design a suitable passive matching circuit to insert between the oscillator and load to achieve this. [15%]

State all assumptions and approximations made.

4 (a) Prior to transmission by a telemetry system, the signal from an engine pressure sensor needs filtering to remove high frequency noise due to vibration. The signal bandwidth extends up to 1 kHz, and noise above this value should be attenuated such that the signal waveform shape is not distorted.

Design a 4-pole filter to achieve the required filter characteristics and justify your choice of filter type. [35%]

(b) The input stage of an RF power amplifier has an impedance represented by the scattering parameter $S_{11} = 0.44 \angle 32°$ at 468 MHz for a 75 Ω line. With the aid of a Smith Chart, design a matching circuit using a length of coaxial cable and a capacitor to match the input impedance to 75 Ω. If the relative permittivity, ε_r, of the coaxial cable insulator is 1.5, what physical length of coaxial cable is required in the matching circuit? [35%]

(c) Show how a number of operational amplifiers, resistors and a capacitor can be inter-connected to synthesize an inductor by drawing the circuit required. Indicate the capacitor value required to realise a 10 mH inductor if all the resistor values are 10 kΩ. What are the relative merits of actual versus synthesised inductors ? [30%]

State all assumptions and approximations made.

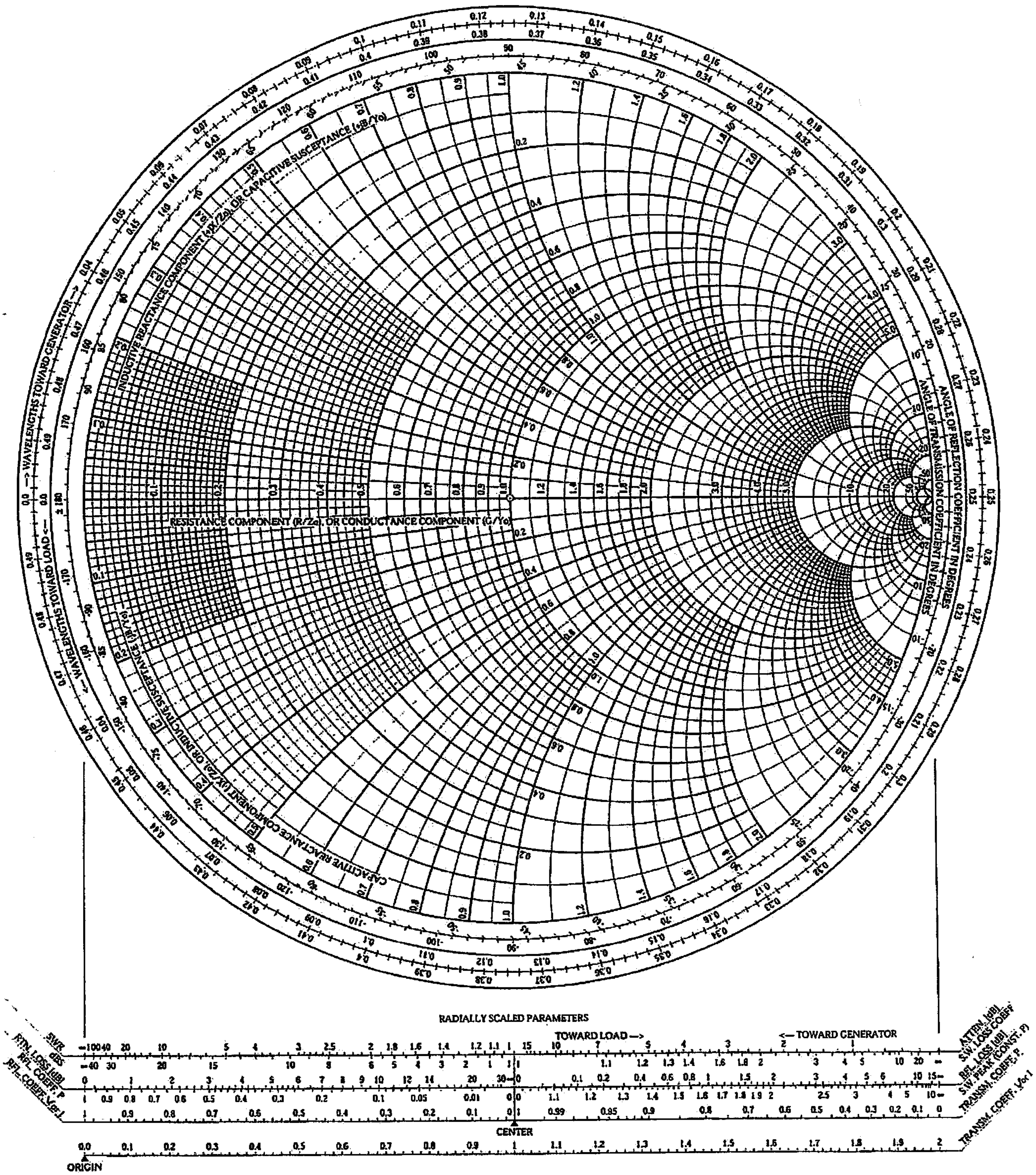
VCVS 4-pole filter design table

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

END OF PAPER

THIS PAGE IS INTENTIONALLY BLANK

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



3B1 Radio Frequency Electronics 2011 – Numerical Answers

1(b) R1 = 920 Ω, R2 = 120 Ω, R3 = 9 Ω, R4 = 75 Ω, C = 10 nF

1(c) R' = 43 Ω, C' = 1.6 pF, f_{-3dB} = 2.31 GHz / stage

2(b) w = 0.72 mm

2(c) $\lambda/2$ = 15.6 cm

2(d) Pr = 3.9 nW, Vr = 0.54 mVrms

2(e) η = 90 %

3(b) C = 23.1 pF, R3 = 150 Ω, R2 = 18 kΩ, R1 = 10 kΩ, Rd = 1 kΩ, η = 6 %

3(d) Xs = 130 Ω, Xp = 173 Ω so, L = 59 nH & C = 2.6 pF OR L = 44 nH, C = 2 pF

4(a) Bessel, C1 = 11 nF, R1' = 840 Ω, C2 = 9.9 nF, R2' = 7590 Ω with R = 10 kΩ

4(b) T/line length = 0.233 m (= 0.446 λ), C = 4.8 pF

4(c) $L = CR^2$ hence for R = 10 kΩ, C = 100 pF