ENGINEERING TRIPOS PART IIA

Tuesday 2 May 2006 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.*

There are no attachments.

STATIONERY REQUIREMENTS

Single-sided script paper

SPECIAL REQUIREMENTS

Engineering Data Book

CUED approved calculator allowed

Supplementary page: Chart for question 4, to be submitted with the solution.

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 light aircraft intercom system provides an audio link connecting one or more headsets and the radio transceiver. The signal from the headset microphone needs to be amplified and limited in bandwidth (to reduce engine and airflow noise) before being fed into the radio.

(a) Draw a circuit diagram for a single-stage transistor amplifier and briefly describe the function of each component, giving approximate expressions for the gain and bandwidth of the circuit. You may neglect the high frequency limitation of the transistor itself, as this will not be significant at audio frequencies. [25%]

(b) The bandwidth required for the audio amplifier is 50 Hz - 2 kHz and the microphone output is 75 mV_{pp} from an impedance of 100 kΩ . The radio requires an audio input signal of 1 V_{pp} across its input impedance of 10 kΩ .

Design a suitable multi-stage transistor amplifer to meet these specifications, operating from a + 12 V DC supply. [40%]

(c) In order to minimise the background noise levels in the headset, particularly when no speech is present, an automatic muting system is proposed which will disconnect the audio signal from the radio input when its amplitude drops to less than about 0.5 $V_{pk\text{-}pk}$ for more than a second or so, but reconnect it when the level rises above 1 $V_{pk\text{-}pk}$ again.

Design some additional circuitry to achieve this noise muting function and indicate how it should be connected into your amplifier circuit from part (b). [35%]

State all assumptions and approximations made.

2 Many aircraft carry a radar transponder unit which transmits a series of data pulses, including altitude information, in response to a received radar pulse. One such device contains a radio receiver which uses a local oscillator (LO) locked to 1024 MHz.

(a) Draw a functional block diagram of a *Phase Locked Loop (PLL)* and briefly describe how the system operates. [25%]

(b) Show, by deriving the circuit small signal properties, how two transistors may be interconnected to achieve a negative resistance and design an LC oscillator circuit based on this principle to produce an output signal at around 1 GHz. Use an inductor of value 10 nH and assume its Q-factor to be about 30. You may ignore any high frequency limitations of the transistors. [55%]

(c) With the aid of a block diagram, explain how the output of the oscillator may be accurately fixed at 1024 MHz, using a reference signal at 8 MHz derived from a quartz crystal. What additional components would be required in your oscillator circuit and how should they be connected ? [20%]

State all assumptions and approximations made.

(TURN OVER

3 (a) A radio receiver for radar pulses operates with an Intermediate Frequency (IF) of 6 MHz. The bandwidth of the IF filter needs to be 2 MHz, with a sharp cut-off either side of the pass band. Design a suitable VCVS band-pass filter circuit for this IF filter, with a 4-pole high-pass and a 4-pole low-pass section, using a standard resistor value of 1 kΩ where appropriate. Justify your choice of filter type. A VCVS filter design table is given below. [40%]

(b) The radio frequency (RF) circuits of a receiver are to be fabricated using a combination of microstrip and stripline geometries on fibre-glass printed circuit board, generally based on a characteristic impedance of 33 Ω.

If the circuit board is 1 mm thick overall, with the insulation relative permittivity $\varepsilon_r = 3.8$, what track width is required in each case to realise the required characteristic impedance ? What are the relative merits of microstrip and stripline ? [35%]

(c) As part of a mixer circuit, it is required to produce a relative phase shift of 90° between two lengths of track fed in parallel from the same point, when carrying an incoming RF signal at 1030 MHz.

What length difference between the two tracks would be required to introduce this phase shift, assuming the circuit board properties as defined in part (b) above, and what should be the characteristic impedance of these particular tracks if they are to present a matched load at the feed point ? Should they be made in microstrip or stripline ? [25%]

State all assumptions and approximations made.

<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

4 An air traffic control radar system operating at 1030 MHz has a peak transmitter power of 25 kW and uses an antenna of gain G = 500 for both transmitting and receiving radar pulses. Transmitted radar pulses are received back again later as echos, when reflected from aircraft within range.

(a) What is the power density of radar pulses incident on an aircraft at a range of 20 km from the radar station and what electric and magnetic field strengths does this correspond to ? [20%]

(b) Assuming an aircraft to have a cross-sectional area of 20 m^2 and that it re-radiates all incident radar pulse energy isotropically, what is the voltage amplitude of the pulse echo signal detected back at the radar station antenna, when driving a matched load of 50 Ω ? [35%]

(c) A radar receiver pre-amplifier has an input impedance of 87 + j58 Ω at 1030 MHz. Using the Smith Chart provided, plot this point and determine the magnitude of the voltage reflection coefficient this device would produce when connected to a 50 Ω transmission line.

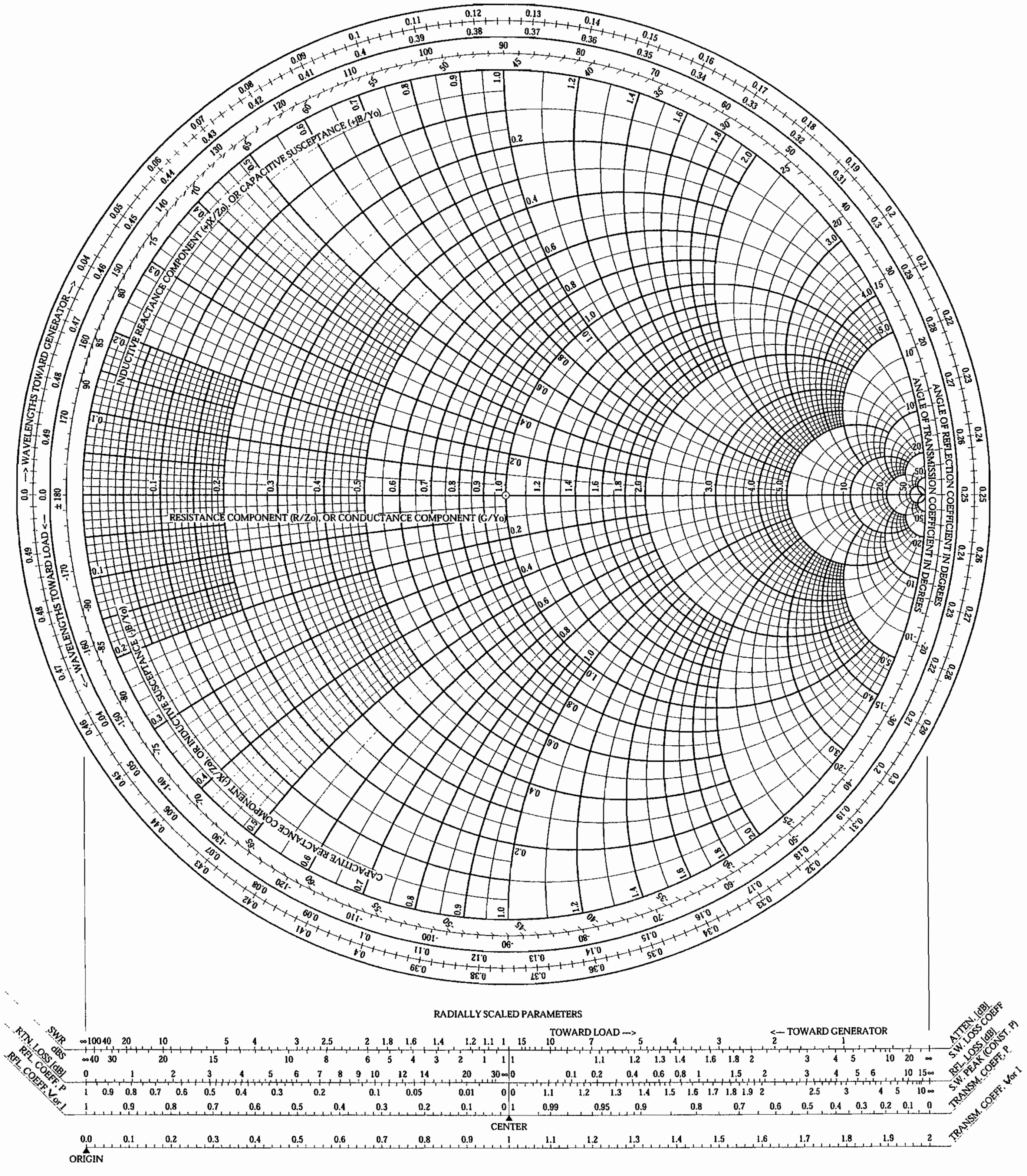
Design an impedance matching circuit using a parallel (shunt) capacitor and series inductor to match the pre-amplifier input to 50 Ω and draw the matching path on the Smith Chart.

Detach the Smith Chart from the question paper and hand it in with your answer. [45%]

State all assumptions and approximations made.

END OF PAPER

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



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(some numerical answers etc.)

1(b)

R1	R2	R3	R4	
1M2	150k	3k3	33k	stage 1
390k	47k	1k	10k	stage 2 100nF coupling caps, 15nF shunt cap.

1(c) Use diode demodulator and comparator to monitor signal level and MOSFET analogue switch to mute the signal when at low levels.

2(b) With L = 10 nH @ 1 GHz = j63 Ω, so Q factor = 30 gives shunt resistance of ~2 kΩ, hence choose transistor bias to give –R of LESS than this eg. -50 Ω to guarantee oscillation. C = 2.53 pF for LC resonance at 1 GHz.

3(a) Choose Chebyshev for sharp frequency cut-off. Low pass up to 7 MHz, high pass from 5 MHz gives cascaded bandpass 5-7 MHz.
C1 = 38 pF, C2 = 22 pF (low pass stages), (A-1)R = 580 or 1660 Ω
C3 = 19 pF, C4 = 33 pF (high pass stages), ditto

3(b) w = 3.85 mm microstrip, 0.46 mm stripline for 33 Ω.

3(c) 37 mm track length difference = 90 degrees.
For 66 Ω track, use microstrip 0.92 mm wide; not possible in stripline (-0.26 mm).

4(a) P = 2.5 mW/m^2, H = 3.6 x 10^{-3} A/m, E = 1.37 V/m.

4(b) P rec. = 33 pW, Vrec. = 58 μV into R = 50 Ω.

4(c) Normalise to 1.74 + j1.16. Voltage refl. coeff. = 0.46
Match with C = 2.3 pF and L = 9.4 nH.