ENGINEERING TRIPOS PART IIA

Friday 26 April 2013 2.00 to 3.30

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.*

There are no attachments to this paper.

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 The audio radio link for a free-fall parachutist requires substantial filtering and bandwidth limiting of the raw microphone signal to minimise wind noise and maximise intelligibility. It transpires that human speech can be carried well within a limited bandwidth of 250 Hz – 3 kHz , helped further by an automatic volume control to limit the dynamic range of the signal.

(a) Describe the frequency and time domain characteristics of 3 different filter types and discuss which type may be the most suitable for this application. [20%]

(b) Draw the circuit schematic for a VCVS band-pass filter circuit using 4 operational amplifiers and select suitable component values for the circuit, predominantly using 10 kΩ resistors. [40%]

(c) Draw the circuit diagram for a variable gain amplifier and briefly explain the function of the main components. [20%]

(d) Show how, with the addition of a few extra components, the variable gain amplifier circuit may be used to provide a normalised audio signal with an amplitude of around 1 or 2 V . Select suitable component values to give a gain range of 10 – 30 dB over the limited audio bandwidth in this application. The dynamic response time should be around 0.1 s . [20%]

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

2 (a) A phase locked loop (PLL) is used to reconstruct a square-wave clock waveform from a data bit stream.

(i) Draw a schematic block diagram for a PLL and briefly describe the function of the main components and the operation of the loop. [20%]

(ii) If the phase comparator comprises a 5 V logic XOR gate, an RC filter, and a VCO with an output frequency of 1 MHz V^{-1}, derive an expression for the transfer function of the loop, and hence determine the RC time constant required for the loop to have a step response transient overshoot of 10 % . [55%]

(b) An RF amplifier operating at 868 MHz comprises two gain modules cascaded together. The first has an output impedance of $30 + j40\ \Omega$ and the second has an input impedance of $80 - j60\ \Omega$. Design an impedance matching circuit using the minimum number of passive components to effectively couple the RF signal between the stages. [25%]

State all assumptions and approximations made.

3 The telemetry system for a high altitude capsule, from which a parachutist will jump to set a number of world records, uses a microstrip resonant patch antenna operating at 868 MHz to transmit the digital data with an RF power of 1.0 W .

(a) Briefly explain the terms *Gain* , *Effective Aperture* and *Radiation Resistance* as applied to an antenna, and describe how they are inter-related. [15%]

(b) If the microstrip patch antenna is fabricated on a 1.2 mm thick PTFE substrate with a *relative permittivity,* ε_r , of 2.0 , what length should the patch be for efficient operation and what width should the feed line track be for a matched *characteristic impedance* of 73 Ω ? [30%]

(c) The base-station at mission control has a receiving antenna with a *gain* of 20 dB, which points directly at the capsule as it ascends under a large helium balloon. If the receiving antenna has an impedance of 100 Ω , what is the amplitude of the RF signal at the antenna port when the capsule reaches an altitude of 37 km overhead ? [25%]

(d) If the transmitting antenna patch is made from copper foil, with a thickness of 18 μm and a width of 10 mm , estimate its *Radiation Efficiency.* You may assume that the resistivity of copper is 3.0×10^{-8} Ω m. [20%]

(e) Comment on how circular polarisation may improve the radio signal coupling and what adaptations can be made to an antenna to achieve this. [10%]

State all assumptions and approximations made.

4 A radio transmitter for a telemetry system operating at 868 MHz comprises a microstrip patch antenna, which behaves as an LC resonant circuit, connected to a negative resistance circuit such that the system oscillates at the resonant frequency.

(a) Draw a negative resistance circuit comprising a pair of identical bipolar transistors, and derive its electrical characteristics from a small-signal analysis. [40%]

(b) Select suitable passive component and supply voltage values for the circuit if the antenna has an impedance of 73 + j0 Ω at resonance and requires around 1 W of RF power. [20%]

(c) If the transistors have the following properties: $h_{fe} = 250$, $f_t = 22$ GHz , $c_{cb} = 0.15$ pF and c_{oe} = negligible , estimate the maximum frequency at which the negative resistance circuit would be effective in an oscillator, assuming the same antenna impedance as in part (b). [25%]

(d) The telemetry data is to be modulated onto the carrier by frequency modulation (FM) where a parallel LC circuit with a matching resonant frequency is connected across the patch feed, but the capacitor value is varied by electronic means. If the inductor has a value of 10 nH, suggest a suitable component for the capacitor and draw a circuit showing how the FM could be implemented in response to a 5 V logic data signal. [15%]

State all assumptions and approximations made.

END OF PAPER