ENGINEERING TRIPOS PART IIA

Tuesday 29 April 2008 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:

Optional chart for question 1, to be submitted with the solution if used.

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 test system for power amplifiers, used in equipment for detecting anti-theft tags at the exits from shops, comprises a precision sine-wave oscillator, to provide the input signal to the amplifier, and a variable electronic load for its output.

(a) Design a Wien Bridge oscillator circuit to produce a 100 kHz sine-wave from a source impedance of 100 Ω. Describe in outline how the output may be stabilised with an amplitude of around 5 V_{pp}. [35%]

(b) In order to simulate the effects of various different load impedances, particularly inductive loads, it is desired to construct an electronic reactive load which can be varied with an analogue control voltage. Show how an inductor can be synthesised from active and passive components and indicate how its value can be varied electronically. Give component values to synthesise an inductor with a nominal value of 1 - 10 mH. [30%]

(c) A power amplifier with an output impedance of 10 Ω is to drive the coils in a tag detection system, with impedance 25 + j40 Ω at 100 kHz. Using a Smith Chart, or by calculation, design an impedance matching circuit for this application. [35%]

State all assumptions and approximations made.

2 Radio frequency (RF) circuits are often limited in bandwidth by the Miller Effect and particular circuit techniques, such as the Cascode arrangement, are therefore utilised to mitigate this effect.

(a) Briefly describe the *Miller Effect* and how it originates in a circuit. [10%]

(b) Draw the circuit diagram for a Cascode circuit, configured as an amplifier with an output impedance of $100\ \Omega$ and a linear voltage gain of about $\times 10$ when connected to a matched load. Briefly explain in qualitative terms how the circuit operates. [25%]

(c) Show, by deriving the circuit small signal properties, how the Cascode circuit achieves an increase in bandwidth over using a single transistor. Calculate the approximate –3 dB roll-off frequency of the Cascode circuit from part (b) when it is driven by a source of impedance $100\ \Omega$ and the transistors are biased to a collector current of 50 mA d.c. [65%]

Bipolar transistors with the following properties are to be used:

$f_t = 250$ MHz , $h_{fe} = 500$, c_{oe} = negligible , $c_{cb} = 5$ pF

State all assumptions and approximations made.

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3 Last year, the radio transmitter for the national date/time synchronisation signal moved from Rugby (100 km from Cambridge) to somewhere in Cumbria (350 km from Cambridge). This signal is transmitted at 60 kHz with a power of 15 kW from an ideal dipole antenna.

(a) Calculate the reduction in the power density of this signal, as received in Cambridge, as a result of the move. What electric *(E)* and magnetic *(H)* field strengths would now be expected in Cambridge ? [20%]

(b) Calculate the signal amplitude which would be produced across a matched load of 4 kΩ from a 10 m straight length of wire dangling from a building in Cambridge assuming that the *Effective Aperture*, A_e , of such an antenna may be approximated by the area of a circle with a diameter equal to the length of the wire. What is the corresponding *Gain*, G , in dB and *Radiation Resistance*, R_r , of the antenna ? [35%]

(c) A rather more compact antenna comprises an air-cored induction coil with 500 turns of wire around an average diameter of 5 cm . If the coil antenna is wound using single-strand copper wire with a diameter equal to the *skin depth*, δ , at 60 kHz , what is the resistance of this coil ? Hence estimate the Q-factor of an LC tank circuit, resonant at 60 kHz , comprising the antenna coil and a 660 pF capacitor. [25%]

(d) What open-circuit signal voltage would you expect to be induced across the LC circuit when the coil is acting as a resonant antenna in Cambridge ? [20%]

The conductivity of copper may be taken to be 4×10^7 S m^{-1}.

State all assumptions and approximations made.

4 A new anti-collision system built into luxury cars employs a scanning radar beam operating at 6 GHz, implemented in planar transmission lines on a plastic substrate. In order to sweep the beam, a pair of patch antennas are used, each fed by an RF signal through a length of track, which introduces a time (and hence phase) delay.

(a) Sketch the construction of both microstrip and stripline transmission lines and briefly describe the relative advantages and disadvantages of each. [10%]

(b) To produce the variable time delays required, engineers are experimenting with a new 0.25 mm thick polymer substrate which has a relative permittivity, ε_r, variable between 2.5 and 3.5 by the application of a d.c. bias voltage. What should the track width be in the microstrip to create a characteristic impedance of 50 Ω when $\varepsilon_r = 3$, and by how much does the characteristic impedance vary over the extent of the relative permittivity range ? [40%]

(c) If the time-delay lengths of microstrip are each 50 mm long, what is the maximum relative phase shift that can be introduced between the feeds to the patch antennas ? [30%]

(d) If the patch antennas comprise squares of microstrip on a substrate with a constant relative permittivity of 3 , what size should these patches be ? How could the polarisation of the transmitted radio waves be controlled by using more time-delay sections ? [20%]

State all assumptions and approximations made.

END OF PAPER

Chart for question 1; to be detached and handed in with script.