Version PAR/2

EGT2
ENGINEERING TRIPOS PART IIA

Monday 28 April 2014 2 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.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Supplementary page: Smith Chart (Question 3)
Engineering Data Book

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 The national German time signal is broadcast from a radio transmitter in Mainflingen, about 650 km from Cambridge. The signal is transmitted at 77.5 kHz with a power of 50 kW from a dipole antenna.

(a) Calculate the power density of this radio signal in Cambridge. What electric (E) and magnetic (H) field strength does this power density correspond to ? [15%]

(b) Calculate the expected *Radiation Resistance*, R_r, and *Efficiency* of a car aerial (antenna) of length 0.8 m and diameter 2 mm, fabricated from non-magnetic stainless steel rod, which has a conductivity of 1.2×10^6 S m^{-1}. [25%]

(c) Estimate the *Effective Aperture*, A_e , of the car aerial assuming it to have a *Directivity* of 1.5 . Hence estimate the matched electrical resistance of the aerial, assuming the received open-circuit signal voltage may be approximated by the electric field at the aerial multiplied by its length. What is the *Gain* of the antenna expressed in dB ? [40%]

(d) The radio receiver for the time signal employs a resonant LC tank circuit at its front end, as a bandpass filter. If the aerial has a series impedance represented by a 100 pF capacitance, what value of additional shunt capacitance is required for the circuit to be resonant at the required frequency with an inductance of 100 μH ? Given the inductor has a parasitic series resistance of 0.5 Ω, what is the *Q-factor* and *bandwidth* of the filter circuit ? [20%]

State all assumptions and approximations made.

2 A pair of high purity sine-wave oscillators is required for testing the linearity of high quality audio amplifiers. In the test system, two closely spaced audio tones are input to the amplifier and the output is examined for the products of unwanted frequency mixing; in particular the difference frequency between the two tones.

(a) Design a Wien Bridge oscillator circuit to produce a 10 kHz sine wave with an amplitude stabilised output of around 5 V_{pp}. [30%]

(b) A band-pass filter from 100 Hz – 500 Hz is required to select the potential mixing tone from the output signals. Design an appropriate VCVS filter circuit, using a total of 4 operational amplifiers and predominantly 10 kΩ resistors, to select this frequency range from the output signal with minimal signal transient distortion. Justify your choice of filter type. A design table for VCVS filters is given below. [35%]

(c) The effect of the load impedance on the amplifier performance is to be evaluated by using a variable inductive load. Show how the circuit properties of an inductor can be synthesised with a pair of operational amplifiers and associated passive components, and indicate how its value can be varied electronically. Give the values of the passive components required to synthesise an inductor from 20 – 100 μH. What are the possible limitations of using such a circuit for the application described ? [35%]

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

3 A microwave Doppler speed sensor built into a road traffic sign uses a pair of square *microstrip* patch antennas fed by *stripline* feed tracks, operating at 10.6 GHz. The system is fabricated using a sandwiched pair of 1.6 mm thick PTFE PCBs with a *dielectric permittivity*, $\varepsilon_r = 2.3$.

(a) Briefly explain the difference between *microstrip* and *stripline* geometries for the fabrication of transmission lines, and compare the relative advantages and disadvantages of each. [10%]

(b) What size should the microstrip antenna patches be for efficient operation and what width should the stripline feed track be for a matched *characteristic impedance* of 50 Ω, if the feed-lines are fabricated in stripline using a pair of PCBs sandwiched together ? [35%]

(c) The pre-amplifier for the receiver patch has an input scattering parameter $S_{11} = 0.66 \angle{-39°}$. Plot this point on the Smith Chart and derive the complex impedance values which it corresponds to, assuming a 50 Ω system. [15%]

(d) Design an impedance matching circuit using a length of transmission line and a series capacitor to match the input of the pre-amplifier to 50 Ω. Give the capacitor value and physical length of the transmission line required if it is to be realised using *microstrip* or *stripline* on the PCB. [20%]

(e) Design an alternative impedance matching network using several passive components, which still offers DC isolation along the signal path. [20%]

State all assumptions and approximations made.

4 A radio transmitter for a remote control system operates at 27 MHz, with amplitude modulation (AM) carrying a binary digital code at 10 kbit/s. The transmitter oscillator operates from a 9 V DC battery and delivers 10 mW of RF power into a 300 Ω load.

(a) Draw the circuit for a Colpitts oscillator and briefly describe the function of each of the components. [25%]

(b) Select suitable passive component values for the oscillator to meet the requirements above, given an inductor value of 100 nH, and indicate how a 5V logic signal could be coupled to the circuit to realise the digital modulation. [25%]

(c) The output of the oscillator is to be boosted by 10 dB with the addition of a single transistor amplifier stage. Design an amplifier circuit for this application, assuming a suitable NPN transistor is available, and give the values of all passive components used. [25%]

(d) If the booster amplifier transistor has the following electrical properties: $h_{fe} = 250$, $f_t = 1.2$ GHz , $c_{cb} = 1.5$ pF and $c_{oe} = 1$ pF , estimate the maximum frequency at which the amplifier circuit could operate effectively with a 300 Ω source impedance. [25%]

State all assumptions and approximations made.

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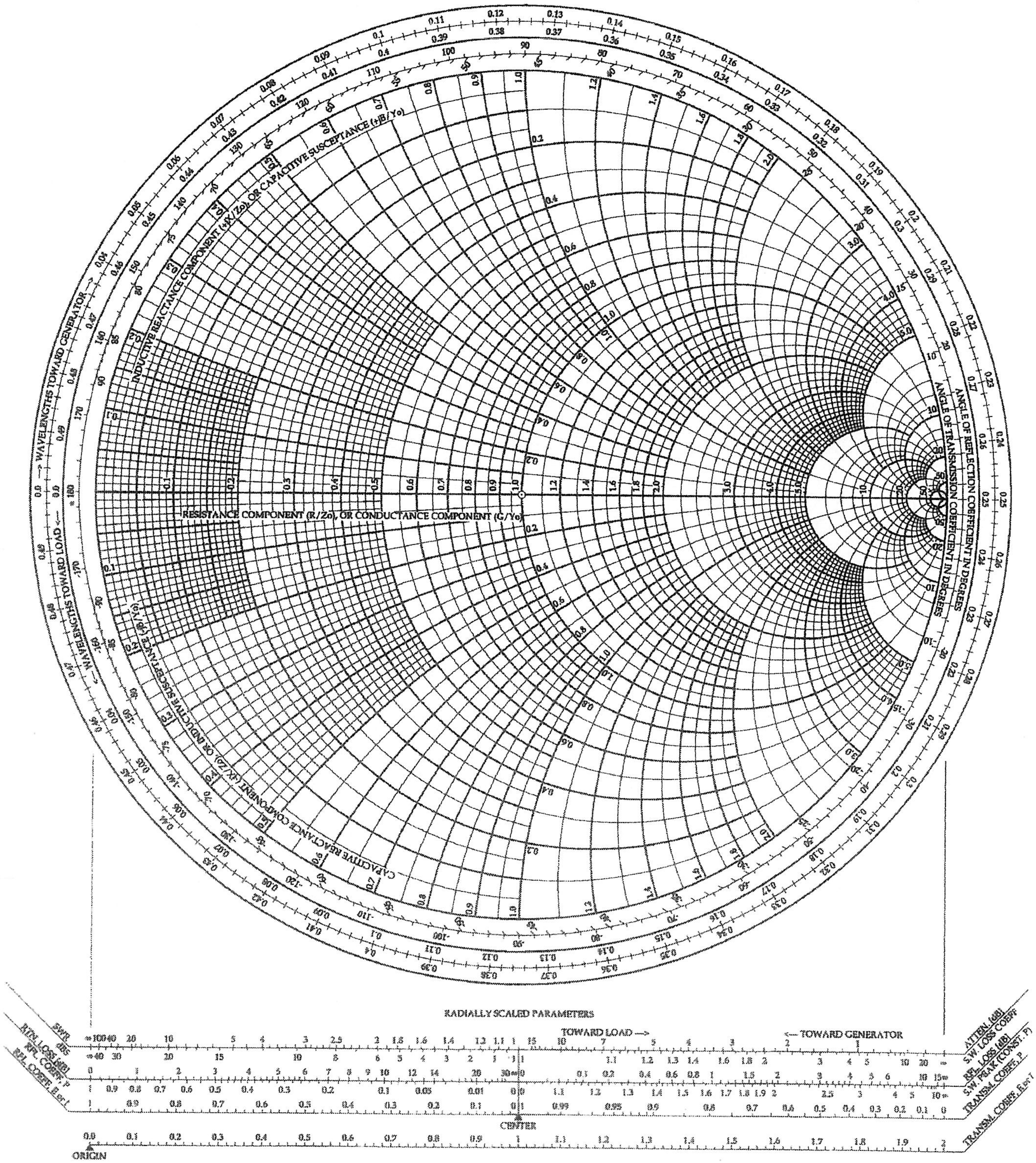
Candidate No. _____________

Smith Chart for Question 3 – to be detached and handed in with script.



3B1 2013 – Numerical answers

1 (a) 2.83×10^{-8} W m^{-2}, E = 4.62×10^{-3} V m^{-1}, H = 1.23×10^{-5} A m^{-1}
(b) $R_r = 8.43 \times 10^{-6}\ \Omega$, e = 0.004 %
(c) $A_e = 71.5$ m^2, $R_m = 0.84\ \Omega$, G = -42.2 dB
(d) Q = 97.4, B/W = 796 Hz

2 (b) Chebyshev, LP 500 Hz, C1 = 22.2 nF, R1 = 840 Ω, C2 = 19.8 nF, R2 = 7590 Ω
HP 100 Hz, C3 = 228 nF, R3 = 840 Ω, C4 = 256 nF, R4 = 7590 Ω

3 (b) $\lambda/2 = 9.33$ mm, w = 0.77 mm
(c) 1.4 – j2 on Smith chart = 70 – j100 Ω
(d) $0.378\ \lambda = 7.07$ mm, C = 0.172 pF

4 (b) L = 100 nH, C = 695 pF, R3 = 300 Ω, Cfb = 10 nF, R2 = 3.3 kΩ, Rd = 150 Ω
(c) R1 = 11 kΩ, R2 = 2.2 kΩ, R3 = 47 Ω, R4 = 300 Ω, C = 1 nF
(d) 70.3 MHz
(e) Lm = 1.5 nH, Cs = 0.47 pF, Lp = 1.66 nH