EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 19 April 2016 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
Engineering Data Book
Smith Chart for question 4

10 minutes reading time is allowed for this paper.

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

1 The International Space Station orbits the Earth every 93 minutes at a height of 375 km above the surface. A telecoms engineer wonders if it would be possible to make calls with a standard mobile phone onboard the space station if a suitable dish antenna has been set up on Earth, linked to a base-station. The dish would not be steerable, but would point directly upwards in a location which is periodically underneath the orbit path.

(a) Explain the terms *Gain* and *Effective Aperture* and give the formula showing how they are inter-related. What is the approximate gain of a small dipole antenna, such as that used on a mobile phone ? [15%]

(b) If the transmitted RF power from an astronaut's mobile phone is 4 W, at a carrier frequency of 2 GHz:

(i) What power density and electric field strength would be seen at the Earth's surface, ignoring any atmospheric attenuation of the signal ? [15%]

(ii) What is the required *Gain* of the dish antenna if the base-station requires a received signal strength of at least -100 dBm in order to operate ? [20%]

(iii) If the antenna drives a matched load of 75 Ω, what voltage signal amplitude does this correspond to ? [10%]

(c) Given the required *Gain* above, estimate the beam angle of the dish antenna and hence, how long a telephone call could last during each overhead orbit. [20%]

(d) If the base-station is actually intended to work with a 150 Ω rather than 75 Ω antenna, design an impedance matching circuit using passive components to match the two together, and describe the effects of not having this circuit in place. [20%]

2 An RF amplifier is required to boost the signal from an antenna receiving mobile phone signals, so that it can feed a distributed antenna array inside a road traffic tunnel, to prevent mobile calls from dropping out during transit. The RF carrier frequencies are around 2 GHz.

(a) Draw the circuit diagram for a single-stage RF transistor amplifier and briefly describe the function of each of the circuit components. [20%]

(b) Design an RF amplifier to provide a net gain of 20 dB in power, with an input impedance of 75 Ω and an output impedance of 50 Ω. The circuit should operate from a 15 Vdc supply and be able to provide up to 100 mW of output power. You may assume that a suitable transistor with h_{fe} = 250 is available. [30%]

(c) In order to narrow the response of the amplifier to a peak around 2 GHz, a parallel LC resonant circuit is connected between the input and ground. If this circuit uses an inductor of 0.47 nH with a series resistance of 0.1 Ω, what value of capacitor should be employed, and what is the expected resonant bandwidth of this arrangement when it is connected into the circuit ? [20%]

(d) A cheaper, new RF transistor with the following properties is to be considered for this application: h_{fe} = 300, f_t = 12 GHz, c_{cb} = 0.15 pF , c_{oe} = 0.12 pF. Calculate the expected bandwidth of this transistor in the circuit and hence comment on its suitability for this application. [30%]

3 (a) Draw the circuit for a 2-pole, low-pass *Voltage Controlled Voltage Source (VCVS)* filter and show how this circuit can be configured to produce a Butterworth filter response of the form:

$$\left|\frac{V_o}{V_i}\right| = A\left[1 + \left(\frac{f}{f_c}\right)^4\right]^{-\frac{1}{2}}$$

where the input and output voltage signals are V_i and V_o respectively and f_c is the cut-off frequency. How should the circuit be modified to obtain a high-pass response instead ? [40%]

(b) A serial digital data link operates at 16 Mbit/s, where the received data signal needs to be filtered in order to remove high frequency carrier components from the waveform. Design a suitable low-pass, 4-pole VCVS filter circuit with a reasonably sharp cut-off, in order to clean up the signal without introducing significant overshoot. [20%]

(c) Sketch the functional block diagram of a *Phase Locked Loop (PLL)* and briefly describe how such a circuit can be employed to recover the clock signal from serial data bits, in order to produce synchronised data and clock bit streams. [25%]

(d) The 16 Mbit/s serial data signals are routed around a passenger aircraft to provide entertainment and communication services. In order to save weight, the data cables comprise round polymer cores coated with a thin layer of copper, rather than solid copper cores. What thickness of copper is required to minimise weight without significantly increasing the effective resistance of the cables in operation ? [15%]

VCVS filter design table

	Bessel		Butterworth		Chebyshev	(0.5 dB)
n	fn	A	fn	A	fn	A
2	1.274	1.268	1.000	1.586	1.231	1.842
4	1.432 1.606	1.084 1.759	1.000 1.000	1.152 2.235	0.597 1.031	1.582 2.660

4 (a) A 1.5 GHz oscillator comprises a negative impedance transistor circuit connected to an LC resonant tank circuit, using an inductance of 3 nH. Show how a pair of transistors can be connected to realise a negative impedance, and select suitable circuit values for the oscillator if the inductor has a Q-factor of 30 and the circuit is to operate from ±5 Vdc supply rails. [35%]

(b) An RF amplifier module has a quoted input S-parameter value, $S_{11} = 0.35\angle 40°$ at a frequency of 2 GHz, when operated in a 50 Ω circuit.

(i) Plot this point on the Smith Chart and determine the input impedance of the module, expressing the result in the form $X \pm jY$ Ω. [20%]

(ii) Design an impedance matching circuit, using a length of transmission line with a dielectric *relative permittivity* of 2, and a series capacitor, to match the amplifier input impedance to 50 Ω. [20%]

(iii) Express the equivalent unmatched input impedance as two passive components connected in series, and hence determine the expected S_{11} value for the input at 1 GHz assuming the passive component values are constant. [15%]

(iv) What voltage reflection coefficient, at the input to the 2 GHz impedance matching circuit, would be expected when operating the circuit at 1 GHz ? [10%]

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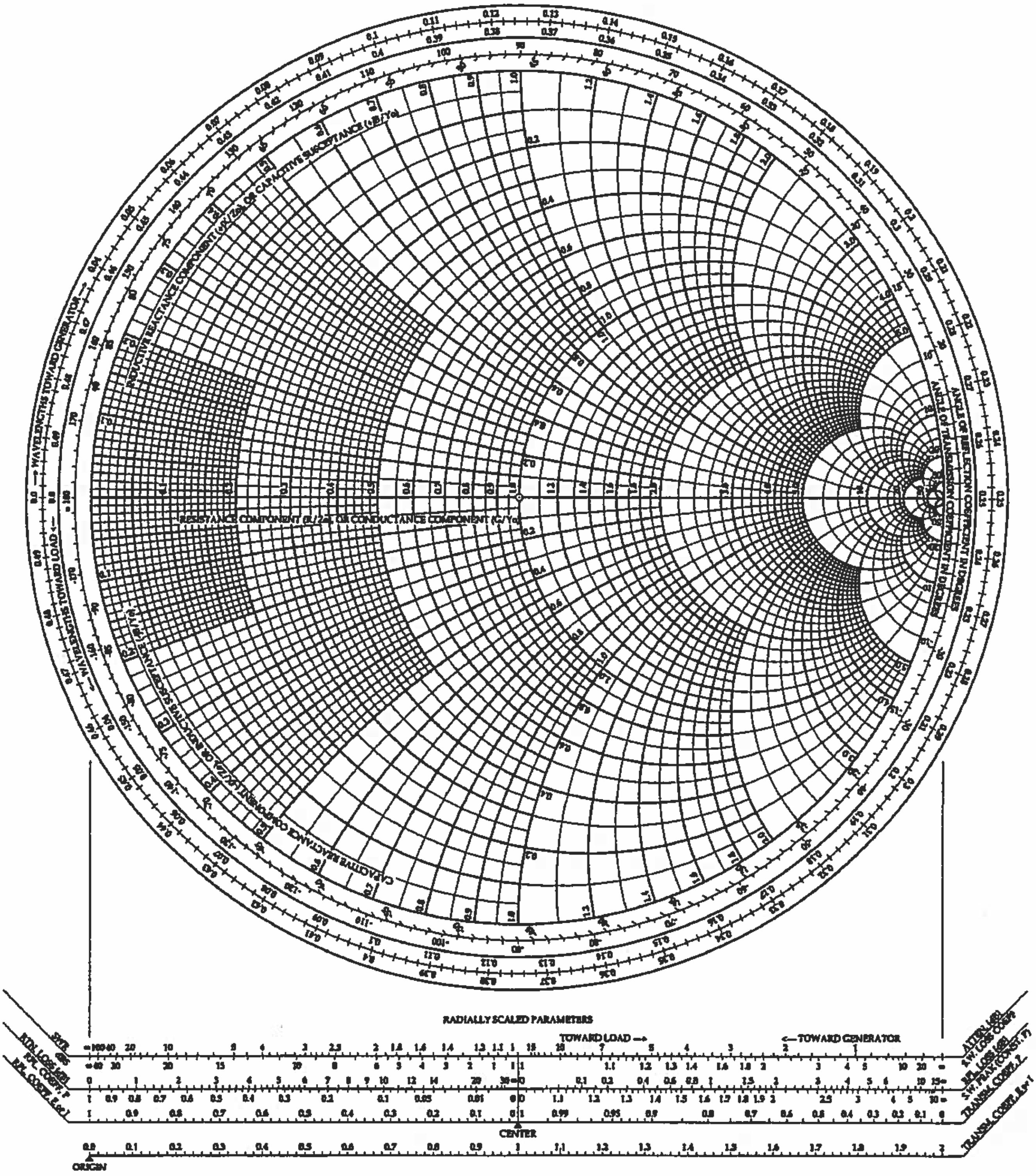
Candidate No. [ ]

Smith Chart for Question 4 – to be detached and handed in with script.



3B1 2016 – Numerical answers

1 (b)(i) 3.4 pW/m^2 , 50.6 µV/m
(b)(ii) G = 16.4 (12.2 dB)
(b)(iii) 2.74 µV rms
(c) 28 ° ½ angle, ~ 14 mins.
(d) C = 0.53 pF, L = 5.97 nH or 1.06 pF, 11.9 nH

2 (b) R1 = 1500 Ω, R2 = 110 Ω, R3 = 2.2 Ω, R4 = 50 Ω, Gain ×16.4 (×20) unloaded gain, coupling caps.10 nF
(c) 13.5 pF, Q total = 6.1, Δf = 328 MHz
(d) 538 MHz (not fast enough)

3 (b) Butterworth, R = 100 Ω, C = 133 pF, fc = 12 MHz
(d) skin depth δ = 16 µm, therefore use 50 µm to have minimal resistive losses

4 (b)(i) 75 + j40
(ii) 48.6 mm, C = 2.1 pF
(iii) 75 Ω in series with 3.18 nH = 1.5 + j40 normalised @ 1 GHz, ρ = 0.25
(iv) ρ = 0.74

1 (b)(i) 3.4 μW/m², 50.6 μV/m
(b)(ii) G = 16.4, 12.2 dB
(b)(iii) 2.74 pV rms
(c) 28°, angle = 14 mins
(d) C = 0.54 pF, L = 8.07 nH or 1.09 pF, 25.9 nH

2 (b) R1 = 1500 Ω, R2 = 110 Ω, R3 = 2.2 Ω, R4 = 50 Ω, Gain = 10.4 (= 20) unloaded gain
coupling caps 10 nF
(c) 15.5 pF, Q total ... 328 MHz
(d) 336 MHz (not fast enough)

3 (b) Butterworth, Z_0 = 100 Ω, C = 125 pF, f_0 = 12.7 MHz
(d) Skin depth δ = 16 μm therefore use 50 μm to have minimal resistive losses

4 (b)(i) $\Gamma = \rho_{10}$
(ii) 48.6 mm, C = 2.1 pF
(iii) 75 Ω in series with 3.18 nH, Γ = j50 normalised @ 1 GHz, ρ = 0.25
(iv) ρ = 0.71