EGT2
ENGINEERING TRIPOS PART IIA

Monday 29 April 2019 2 to 3.40

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: one copy of Smith Chart (Question 3)
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

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

1 A Mars lander utilises a Radio Frequency (RF) telemetry link to Earth operating at 11 GHz. The Earth base station uses a 35 m diameter dish to transmit and receive signals to/from the Mars lander, which is equipped with a quarter-wave antenna. The distance between Mars and the Earth was 145×10^{6} km when the lander touched down.

(a) Explain the terms *Radiation Resistance, Gain, Radiation Efficiency* and *Effective Aperture* as applied to antennas. [20%]

(b) If the lander transmits a radio signal with a radiated power of 75 W, what is the power density of this signal received on Earth ? [10%]

(c) (i) Given that the *Effective Aperture* of a dish antenna is approximately equal to the area of a circle with the same diameter as the dish, calculate the voltage amplitude of the received signal when the dish antenna drives a matched load of 150 Ω. [20%]

(ii) Calculate the gain of the dish antenna and estimate its beam angle. [20%]

(d) Estimate the radiation efficiency of the lander antenna if it is fabricated from non-magnetic stainless steel wire with a diameter of 0.5 mm, taking the electrical resistivity of stainless steel to be 6.9×10^{-7} Ωm. [15%]

(e) If the dish is also used to transmit control signals from Earth to Mars with a radiated power of 1 kW, calculate the voltage amplitude of the signal delivered into a 75 Ω matched load on the lander. [15%]

State all assumptions and approximations made.

2 (a) (i) Draw a schematic block diagram for a Phase Locked Loop (PLL) to produce a 1.52 GHz local oscillator signal in a GPS receiver, referenced to a 40 MHz quartz crystal oscillator, and briefly describe the function of each block. [15%]

(ii) If the phase comparator comprises a 3.3 V logic XOR gate with an output of 1.05 V rad^{-1}, the loop filter is a simple RC network and the VCO has an output of 1 GHz V^{-1}, derive an expression for the transfer function of the loop and hence determine values for R and C, if the loop transient response is to be critically damped. [50%]

(b) (i) If the RF system is to be constructed in stripline using a substrate with a total dielectric thickness of 1.2 mm and relative permittivity, $\varepsilon_r = 2.5$, what width should the tracks be to realise a characteristic impedance of 50 Ω ? [25%]

(ii) If the input impedance to an amplifier has been mistakenly specified as 75 Ω, instead of 50 Ω, what effect will this have on the RF signal magnitude and integrity ? [10%]

State all assumptions and approximations made.

3 (a) A radio control system for an industrial process operates at 868 MHz and contains a resonant coil inductor with parallel capacitor as a combined antenna and front-end filter. If the capacitor has a value of 3.3 pF and the coil has a resistance of 0.6 Ω, calculate the value of the inductor and the bandwidth of the resonant circuit. [20%]

(b) (i) The input impedance to a low noise amplifier is given by $S_{11} = 0.73\angle -67°$ when operating at a frequency of 868 MHz in a 50 Ω system. Plot this point on the Smith Chart provided at the back of this paper, and determine the equivalent series passive component values which would represent this impedance point. [15%]

(ii) Design an impedance matching circuit, comprising a pair of passive components, to match this amplifier input impedance to 50 Ω at the operating frequency. Plot the matching scheme on the Smith Chart and hence briefly describe how the matching is achieved. [25%]

(c) The radio receiver in an industrial controller operates with a Superheterodyne architecture and is to use an Intermediate Frequency (IF) of 1 MHz, realised with a VCVS band-pass filter circuit predominantly employing 1 kΩ resistors. The filter circuit is to have a bandwidth of 200 kHz with a sharp cut-off each side. Design a suitable IF filter using 4 operational amplifiers, giving the values of all passive components used. Table 1 gives the design parameters for 4-pole VCVS filters. [25%]

(d) The IF amplifier in a radio system is required to have variable gain, with a response time of around 10 ms, in order to normalise the IF signal amplitude before demodulation. Draw the circuit for a variable gain amplifier with a gain range of ×1 to ×100, for operation with 1 MHz signals, such that the output signal is maintained at an amplitude of approximately 1 V. [15%]

Table 1 4-pole VCVS 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

4 (a) A 2-stage RF amplifier for a radio telemetry system operating at 868 MHz comprises a pair of bipolar transistors configured to give 30 dB of power gain when connected into a 50 Ω system. The amplifier operates from a 10 V supply and you may assume that the transistors have the following properties: h_{fe} = 250, f_t = 12 GHz, c_{cb} = 0.15 pF, c_{oe} = 0.10 pF.

(i) Draw the circuit diagram for such an amplifier and briefly describe the function of each component. [20%]

(ii) Give suitable passive component values to realise the required gain with input and output impedances matched to approximately 50 Ω. [25%]

(iii) Calculate the − 3 dB high frequency cut-off for the amplifier circuit in operation. [25%]

(b) Design a Colpitts oscillator circuit to produce a sinusoidal output signal at 868 MHz using a transistor of the same type as given in part (a). Assume that the circuit operates from a 10 V supply, utilises an inductor of value 10 nH with a Q-factor of 35, and that its output feeds into a high impedance buffer. Draw the circuit diagram and give the values of all other components used. [30%]

State all assumptions and approximations made.

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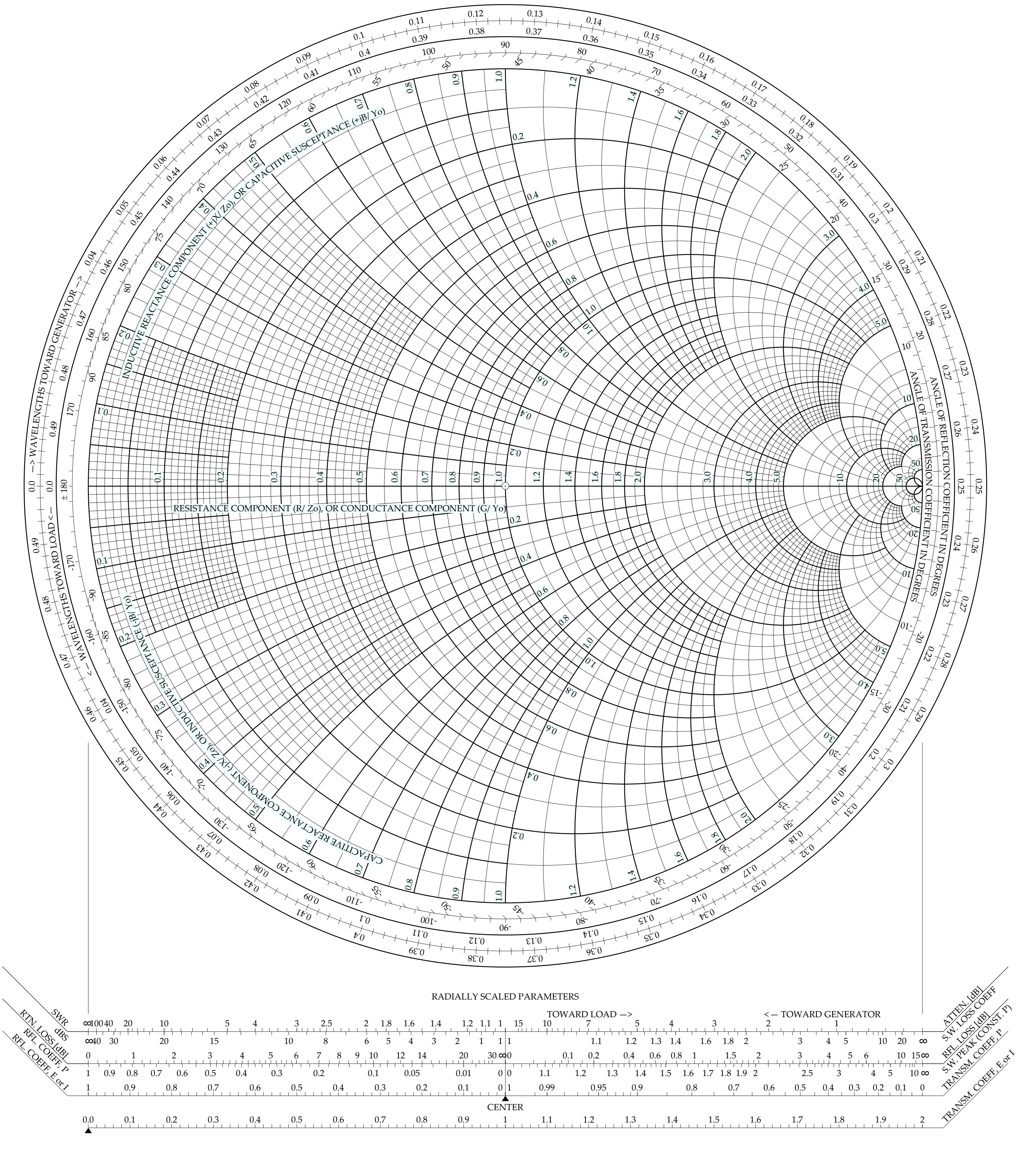
Candidate No.

Smith Chart to be detached and handed in with script if required



3B1 2019 – Numerical answers

1(b) 4.26×10^{-23} W m^{-2}

1(c)(i) 22.2 nV pk-pk

1(c)(ii) G = 16.2×10^{6}, full beam angle = 0.057°

1(d) 99%

1(e) 20.2 nV rms

2(a)(ii) CR = 1.44 ns, R = 100 Ω, C = 14.4 pF

2(b)(i) w = 0.23 mm

3(a) L = 10.2 nH, BW = 9.37 MHz

3(b)(i) Z = 25 – j70 Ω, C = 2.62 pF

3(b)(ii) 41.7 nH parallel + 17.4 nH series or 8.8 nH parallel + 2 pF series

3(c) Chebyshev C1 = 242 pF, C2 = 140 pF, R1 = 582 Ω, R2 = 1.66 kΩ (low pass)

C3 = 106 pF, C4 = 182 pF, R3 = 582 Ω, R4 = 1.66 kΩ (high pass)

4(a)(ii) R1 = 560 Ω, R2 = 68 Ω, R3 = 3.9 Ω, R4 = 50 Ω, C = 10 nF

4(a)(iii) f_{-3dB} = 1.4 GHz

4(b) R1 = 2.7 kΩ, R2 = 3.3 kΩ, R3 = 220 Ω, Rd = 150 Ω, Cfb = 1 nF, C = 6.72 pF