Version PAR/3

EGT2:IIA
ENGINEERING TRIPOS PART IIA

Friday 24 April 2015 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 A space craft exploring a remote comet carries a radio telemetry system to relay data back to Earth over a distance of 507 x 10^6 km. The data link operates at a frequency of 10.7 GHz, has a transmitter power of 750 W, and uses a 2.2 m diameter steerable dish antenna on the space craft.

(a) Explain the terms *Gain* , *Radiation Resistance* , *Radiation Efficiency* and *Effective Aperture* when referring to antennas and describe how they are inter-related. [20%]

(b) If the telemetry data signal is received on Earth using a radio-telescope dish antenna of diameter 70 m and the *Effective Aperture* of a dish antenna may be assumed to be equal to the area of a circle of the same diameter:

(i) What is the received signal voltage amplitude across a matched load of 50 Ω, assuming that the geometric alignment is ideal ? [15%]

(ii) What is the *Gain* and corresponding cone / beam angle of the transmitting dish antenna ? [20%]

(c) The space craft receives data from a small lander probe which has settled on the comet surface via a second radio link which operates at 2.7 GHz and uses low gain, half-wave dipole antennas fabricated from 1 mm diameter stainless steel rods. Estimate the *Radiation Efficiency* of these antennas and the factor by which this could be improved by coating the rods with a 2 μm layer of copper. [20%]

(d) The radio detector placed at the focus of the dish antenna comprises a low-noise amplifier linked to small dipole elements by microstrip tracks. If the circuit is fabricated on a 0.8 mm thick PTFE substrate with a *relative permittivity*, ε_r, of 2.0 what should the track width be to realise a characteristic impedance of 50 Ω ? [25%]

State all assumptions and approximations made.

2 An aircraft-band radio receiver works over a range of carrier frequencies from 120 MHz - 135 MHz using a Superheterodyne architecture and a Phase-Locked Loop (PLL) in the local oscillator circuit. The radio channel spacing is 25 kHz and there is a 10 MHz quartz crystal reference oscillator in the radio.

(a) Sketch a schematic diagram of a Superheterodyne radio and briefly explain how it operates, and in particular, how the radio is tuned. [20%]

(b) Draw a schematic diagram of the local oscillator circuit implemented with a Phase-Locked Loop, using an *Intermediate Frequency* of 20 MHz for this application. Include a circuit diagram for the reference crystal oscillator. [20%]

(c) (i) Design a transistor amplifier circuit, operating from a 12 V d.c. supply voltage to provide 30 dB of gain when inserted in a 50 Ω system, to amplify the radio carrier signal. Transistors with the following properties are available: $h_{fe} = 250$, $f_t = 6$ GHz, $c_{cb} = 0.20$ pF, c_{oe} = negligible. [35%]

(ii) What is the upper –3 dB frequency expected for this amplifier circuit ? [25%]

State all approximations and assumptions made.

3 (a) An instrument to measure the mass spectra of dust samples from the surface of a comet outputs a transient signal which needs to be band-pass filtered over the range 100 Hz - 7.5 kHz, to remove noise and drift, whilst still retaining the basic waveform shape. Design a suitable 4-pole VCVS filter circuit using 4 operational amplifiers and capacitors of value 100 nF throughout. [35%]

(b) In order to accommodate signals over a wide range of amplitudes, a variable-gain amplifier with a bandwidth of 1 MHz is required which can change gain from 0 - 40 dB, in response to a control voltage of 0 - 5 V. Design a suitable amplifier circuit for this application, giving the values of passive components and relevant properties of active components used. [25%]

(c) Draw the circuit diagram for a Colpitts oscillator and briefly explain the function of each component. Using 10 nF capacitors throughout, select values for the other passive components if the circuit to oscillate at 2 MHz, and operate from a 10 V d.c. supply. It should drive a load impedance of around 1 kΩ with a low distortion sinewave. [20%]

(d) Show by analysing the small signal model how a pair of bipolar transistors can be connected together to realise a negative resistance. [20%]

State all approximations and assumptions made.

VCVS 4-pole filter design table

Bessel		Butterworth		Chebyshev	
fn	A	fn	A	fn	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 resonant LC circuit is to be used in a filter to select the *Intermediate Frequency* signal after a mixer where the local oscillator signal is set at 2.49 GHz and the RF carrier frequency is 2.50 GHz.

(i) What value of capacitor should be chosen for the filter if a 100 nH inductor has been used ? [10%]

(ii) If the inductor has a series resistance of 0.4 Ω, what bandwidth is expected for the filter ? [10%]

(b) The input impedance to an amplifier used in a 2.5 GHz radio communication system is to be matched to the 75 Ω impedance of the receiving antenna. The amplifier has an input impedance represented by a 1.2 pF capacitance in series with a 47 Ω resistance.

(i) Design an impedance matching circuit using two passive components to match the amplifier input to 75 Ω. [20%]

(ii) Plot the impedance point for the amplifier input on a Smith Chart and determine the scattering parameter, S_{11}, for this port when operating at 75 Ω. [20%]

(iii) Design an alternative impedance matching circuit using a length of 75 Ω coaxial cable and a series capacitor. If the *relative permittivity* of the dielectric in the coaxial cable is 2.2 , determine the physical length of the cable required in the matching circuit. [20%]

(iv) It is proposed to operate the system at an additional frequency of 2.9 GHz to increase the data capacity. What is the voltage reflection coefficient for signals at this higher frequency if the matching circuit from part (iii) is retained ? [20%]

State all assumptions and approximations made.

END OF PAPER

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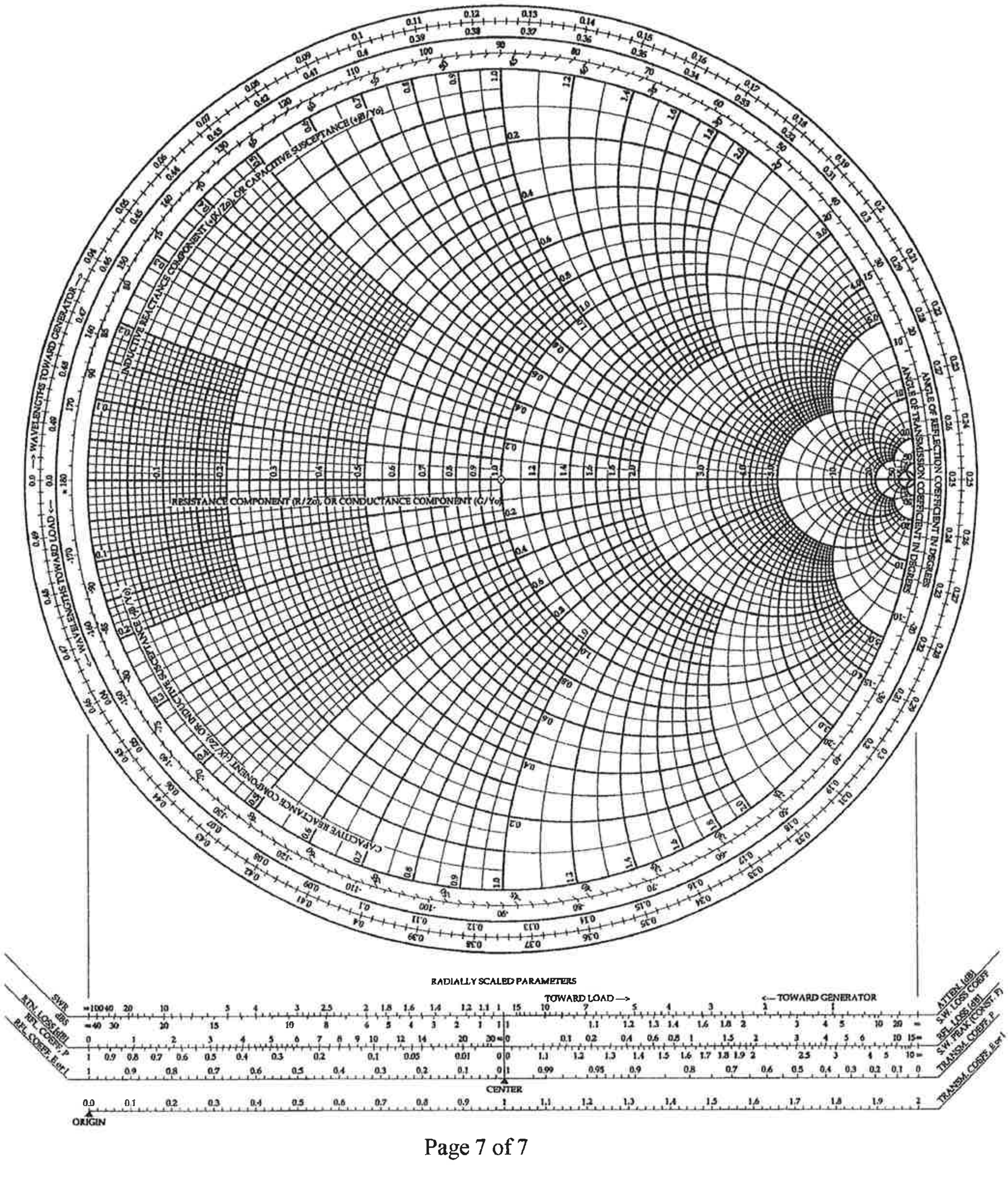
ENGINEERING TRIPOS PART IIA

Friday 24 April 2015, Module 3B1, Question 4

Candidate No.

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



3B1 2015 – Numerical answers

1 (b)(i) 1.6 μV
(b)(ii) 60.9×10^3, 0.46 degrees ½ angle
(c) 98% to 99.7%
(d) 2.66 mm

2 (b) PLL: N= 400, M = 5600 – 6200
(c)(i) 2 transistors, x12 per stage unloaded, R1 = 910 Ω, R2 = 100 Ω, R3 = 3.9 Ω, R4 = 50 Ω
(c)(ii) 646 MHz

3 (a) Bessel, LP 7500 Hz, R1 = 148 Ω, R2 = 132 Ω, Rf = 840 Ω, 7590 Ω for R = 10 kΩ
HP 100 Hz, R3 = 22.8 kΩ, R4 = 25.6 kΩ, Rf = 840 Ω, 7590 Ω for R = 10 kΩ
(b) 1 – 100 X linear gain, op-amp GBW > 100 MHz
(c) L = 1.27 μH, R1 = R2 = 2.2 kΩ, Rd = 300 Ω, R3 = 450 Ω

4 (a)(i) 2.53 nF
(ii) 637 kHz
(b)(i) 5.7 nH, 0.66 pF
(ii) $0.47\angle -95°$
(iii) 23 mm + 0.82 pF
(iv) 0.35