EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 27 April 2021 1:30 to 3:10

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 and at the top of each answer sheet.*

STATIONERY REQUIREMENTS
Write on single-sided paper.

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed.
Attachment: Smith Chart (1 page) to use when displayed on your computer screen.
You are allowed access to the electronic version of the Engineering Data Books.

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

The time taken for scanning/uploading answers is 15 minutes.

Your script is to be uploaded as a single consolidated pdf containing all answers.

1 Air traffic control radar operates at a frequency of 2800 MHz for primary surveillance, where the radio waves are directly scattered back from the aircraft. A new system with a peak transmitted power of 16 kW and a 33 dB gain antenna, which both transmits and receives, is being installed at an airport. The system is based on 50 Ω characteristic impedance and commissioning tests are being conducted with a target aircraft at a range of 80 km.

(a) What is the radar signal *power density* and magnitude of the *electric field* at the aircraft ? [15%]

(b) Calculate the *effective aperture* of the antenna, and the diameter of the dish which this would correspond to if the *effective aperture* is 80% of the dish frontal area. [20%]

(c) If the target aircraft is assumed to isotropically scatter the power in the radio wave that it intercepts, where the effective aperture of the aircraft is 25% of its actual surface area of 50 m^2:

(i) What is the received signal amplitude produced across a matched load at the antenna when the aircraft is at the designated range ? [20%]

(ii) How much larger is the signal amplitude (expressed in dB) when the aircraft is only 8 km from the airport ? [10%]

(d) What *beam-angle* would you expect the radar antenna to have ? [10%]

(e) A radar detector is carried on board the test aircraft to check the incident signal strength. It includes a microstrip patch antenna, fabricated on a PTFE substrate of *relative permittivity* = 2.3 and thickness 1.6 mm. What length should the patch be for efficient operation, and what width of microstrip track should be used to create a *characteristic impedance* of 50 Ω ? How does the antenna patch impedance change with track feed-point position along its length ? [25%]

Note: antenna equation, $G = 4\pi A_e / \lambda^2$

2 The input to a radio receiver circuit is linked to a connector mounted on the side of its casing by a 12 cm length of 75 Ω coaxial cable. The receiver operates at a frequency of 1060 MHz and the coaxial cable has a capacitance of 65 pF m^{-1}.

(a) Calculate the wavelength in the coaxial cable, at the frequency of operation. [15%]

(b) The reflection coefficient measured at the input connector on the casing is given by: $S_{11} = 0.68 \angle 85\,^{o}$ at the operating frequency, referring to a 75 Ω system. With the aid of the Smith Chart, determine the impedance values this corresponds to and the actual impedance seen at the receiver input, removing the effects of the cable. [30%]

(c) If the input impedance at the connector is to be matched to 75 Ω, how could the cable length be modified to achieve this with the addition of a series capacitor at the connector ? What value should this capacitor be ? Make a rough sketch of the key points, lines and values taken from the Smith Chart. [25%]

A Smith Chart is attached at the end of this paper for reference. You should use a rule, or make marks along the straight edge of a piece of paper, to measure dimensions from the chart scales and to read off values from the chart displayed on your screen. It is not necessary to print out the chart.

(d) The output of the receiver has an impedance of 5 + j25 Ω at the operating frequency. Design an impedance matching circuit using a pair of discrete, passive components to match this to 50 Ω. Calculate the Q-factor for the matching circuit and hence comment if you would expect the matching to still be reasonable at the second harmonic of the design frequency. [30%]

Note: matching equation, $Q = R_{hi}/X_p = X_s/R_{lo} = (R_{hi}/R_{lo} - 1)^{1/2}$

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3 (a) A digital radio receiver uses a 23-27 MHz band-pass filter at its front end to define the range of signals for reception, prior to digital sampling and processing. The filter is to be realised from Voltage Controlled Voltage Source (VCVS) filters producing sharp cut-offs each side of the pass band. Design a suitable circuit, using 100 Ω resistors where appropriate, giving the values of other passive components used. A 4-pole VCVS filter design table is given below in Table 1. [40%]

(b) The power output from an oscillator is to be divided equally between a pair of antennas, where all components have 75 Ω impedance. Briefly describe the construction and operation of a *Wilkinson power divider* suitable for this application. [20%]

(c) Show how a pair of transistors can be connected to create a negative resistance and hence design an oscillator circuit to feed a 2800 MHz sine-wave into a 50 Ω load, when operating from a ±5 V d.c. supply. Assume an inductor value of 1.5 nH, with a Q-factor of 25, and give the values of other passive components used. Indicate with the addition of a few extra components how the frequency of the circuit can be tuned electronically over the range 2600 MHz to 3000 MHz. [40%]

Table 1. 4-pole VCVS filter design table

Bessel		**Butterworth**		**Chebyshev (0.5 dB)**	
f_n	**A**	f_n	**A**	f_n	**A**
1.432	1.084	1	1.152	0.597	1.582
1.606	1.759	1	2.253	1.031	2.660

4 The front end of an aircraft radio receiver, operating at 1030 MHz, utilises a low noise transistor pre-amplifier circuit to boost the signals from the antenna. The system impedance is 50 Ω and it operates from a +12 V d.c. supply. A net power gain of 35 dB is required from the pre-amplifier.

(a) Draw a schematic diagram for a suitable transistor amplifier circuit, including values for the passive components, and briefly describe the function of each of the components shown. [35%]

(b) Briefly describe the *Miller Effect* and how it limits the bandwidth of RF amplifier circuits. [15%]

(c) Given that the low noise transistors available for this application have the following properties:

h_{fe} = 250, f_t = 15 GHz, c_{cb} = 0.15 pF, c_{oe} = 0.10 pF , calculate the upper cut-off frequency for the amplifier circuit. [30%]

(d) The power of received radio signals varies significantly with aircraft range from the radio ground station (an inverse square law relationship).

(i) What additions to the amplifier circuitry can be made to compensate for this variation ? Include a circuit sketch of the key elements.

(ii) If the compensation of received signal powers is limited to 30 dB in magnitude, what is the net ratio of signal amplitudes remaining when the aircraft range varies from 100 km down to 1 km ? [20%]

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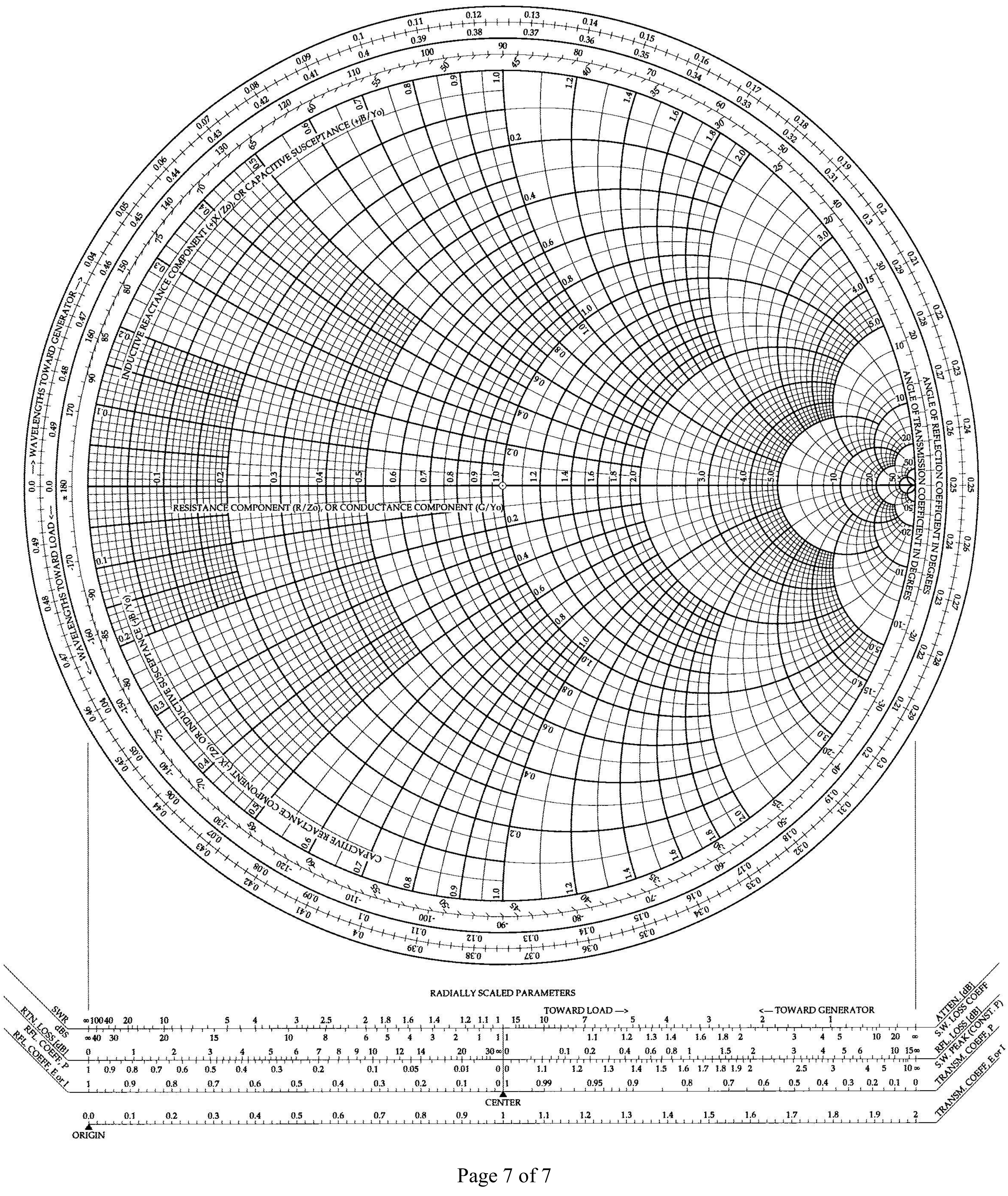
ENGINEERING TRIPOS PART IIA

Tuesday 27 April 2021, Module 3B1, Smith Chart for reference in Question 2



3B1 2021 – Numerical answers

1(a) 0.397 mW/m^2, 0.547 V/m

1(b) Ae = 1.82 m^2 , D = 1.70 m

1(c)(i) 2.37 µVrms

1(c)(ii) 40 dB

1(d) 5.13 °

1(e) l = 3.53 cm, w = 4.76 mm

2(a) 0.194 m

2(b) 30 + j75 Ω at connector, 14.3 + j6 Ω at receiver input

2(c) length = 130 mm (extra 10 mm from original case) + 1.07 pF series capacitor

2(d) Q = 3, L = 2.51 nH, C = 3.75 pF

3(a) R1 = R3 = 58 Ω, C1 = 99 pF, R2 = R4 = 166 Ω, C2 = 57 pF, C3 = 41 pF, C4 = 71 pF (Cheby.)

3(b) Choose say Rb = RT = 1 kΩ for -31 Ω

4(a) 2-stage, R1 = 510 Ω, R2 = 75 Ω, R3 = 3 Ω, R4 = 50 Ω, C = 1 nF

4(c) 1.2 GHz

4(d)(ii) x3.16 , 10 dB