Version PAR/2

EGT2
ENGINEERING TRIPOS PART IIA

Thursday 26 April 2018 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: Smith Chart (Question 2)
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 new electric airliner, flying directly between London and Paris (345 km apart), carries a radio telemetry system to send data to a monitoring ground station in London. The system has a transmitter power of 150 W and operates at a frequency of 913 MHz with a quarter-wave antenna on the aircraft.

(a) What is the signal *power density* and magnitude of the *electric field* seen in London when the aircraft is overhead Paris, assuming the antenna is ideal ? [15%]

(b) Define the terms *effective aperture*, *gain* and *radiation resistance*, as applied to antennas, and explain how they are inter-related. [20%]

(c) The London ground receiver uses a 2.5 m diameter fixed dish antenna pointing towards Paris, where the effective aperture of a dish antenna may be taken to be equal to the area of a circle with the same diameter as the dish, and it is connected to a matched load impedance of 75 Ω.

(i) What is the received signal amplitude produced across the load when the aircraft is overhead Paris ? [10%]

(ii) How much larger is the signal amplitude (expressed in dB) when the aircraft is only 5 km from the London receiver ? [10%]

(iii) What beam angle would you expect the dish antenna to have, and so how far off course sideways could an aircraft arrive near Paris before the received signal strength drops significantly ? [20%]

(d) Estimate the radiation efficiency of the aircraft antenna if it is made from a 1 mm diameter stainless steel rod with a resistivity of 6.92×10^{-7} Ω m. [25%]

2 Global Positioning System (GPS) signals are transmitted on two frequencies (denoted $L1$ and $L2$) from satellites in orbit; $L1 = 1575.42$ MHz and $L2 = 1227.60$ MHz. The reflection coefficient at the input to a pre-amplifier in a GPS receiver is given as $S_{11} = 0.71 \angle{-36}\,°$ for the $L1$ frequency, referring to a 50 Ω system.

(a) (i) Plot S_{11} on the Smith Chart and derive the values of the 2 series components which would represent an equivalent impedance at the $L1$ frequency. [25%]

(ii) With reference to the Smith Chart and appropriate calculation, determine what value for S_{11} would be expected for the same pre-amplifier when operated at the $L2$ frequency, assuming the equivalent passive components remain the same. [25%]

(iii) Design an impedance matching circuit using a length of transmission line and a series capacitor to match the pre-amplifier input to 50 Ω when operating on the $L2$ frequency. [25%]

A Smith Chart is attached to the back of this paper. It should be detached and handed in with your answers.

(b) The output of the pre-amplifier has an impedance of 15 + j25 Ω at the $L1$ frequency. Design an impedance matching circuit using a pair of discrete, passive components to match this to 75 Ω. Calculate the Q-factor for the matching circuit and hence comment over what frequency range you would expect the matching to be reasonable. [25%]

3 (a) A Superhet radio circuit used in a 3 GHz marine radar system operates with an Intermediate Frequency (IF) of 4 MHz. An IF bandpass filter with a bandwidth of 1 MHz and a steep cut-off each side is to be realised from a Voltage Controlled Voltage Source (VCVS) circuit employing a pair of 2-pole cascaded filters. Design a suitable circuit using 1 kΩ resistors where appropriate, giving the values of other passive components used. Justify your choice of filter type. A 2-pole VCVS filter design table is given below in Table 1. [35%]

(b) The 3 GHz Radio Frequency (RF) signals are routed around the radar system Printed Circuit Board (PCB) using a combination of microstrip and stripline copper tracks. If the PCB has an overall total dielectric thickness of 1.2 mm and is fabricated from a polymer material with a relative permittivity, $\varepsilon_r = 2.5$, what width of track is required to realise a characteristic impedance of 75 Ω in each case ? [35%]

(c) The 3 GHz transmitter oscillator is to be based on the negative resistance principle. Draw the circuit for a pair of transistors connected to create a negative resistance and hence design an oscillator circuit to feed a 3 GHz sine-wave into a 75 Ω load, when operating from a ±5 V d.c. supply. Assume an inductor value of 1 nH, with a Q-factor of 20, and give the values of other passive components used. [30%]

Table 1. 2-pole VCVS filter design table

Bessel		Butterworth		Chebyshev (0.5 dB)	
f_n	A	f_n	A	f_n	A
1.274	1.268	1	1.586	1.231	1.842

4 A radio receiver for telemetry requires a pre-amplifier operating at 913 MHz to amplify the incoming RF signal. The circuit is to operate from a +12 V d.c. supply and provide 20 dB of net power gain, in a circuit with a 75 Ω nominal input and output impedance.

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

(b) Calculate the values of passive components in the amplifier circuit to meet the performance characteristics required. You may assume that a suitable transistor is available for which $h_{fe} = 200$. [25%]

(c) Briefly describe the *Miller Effect* and how it can limit the bandwidth of RF amplifier circuits. What steps can be taken to mitigate this limitation ? [20%]

(d) If the selected transistor actually has the following properties:

$h_{fe} = 250, f_t = 22$ GHz, $c_{cb} = 0.14$ pF, $c_{oe} = 0.10$ pF , calculate the maximum frequency at which the amplifier circuit could operate before the gain drops by 3 dB. [35%]

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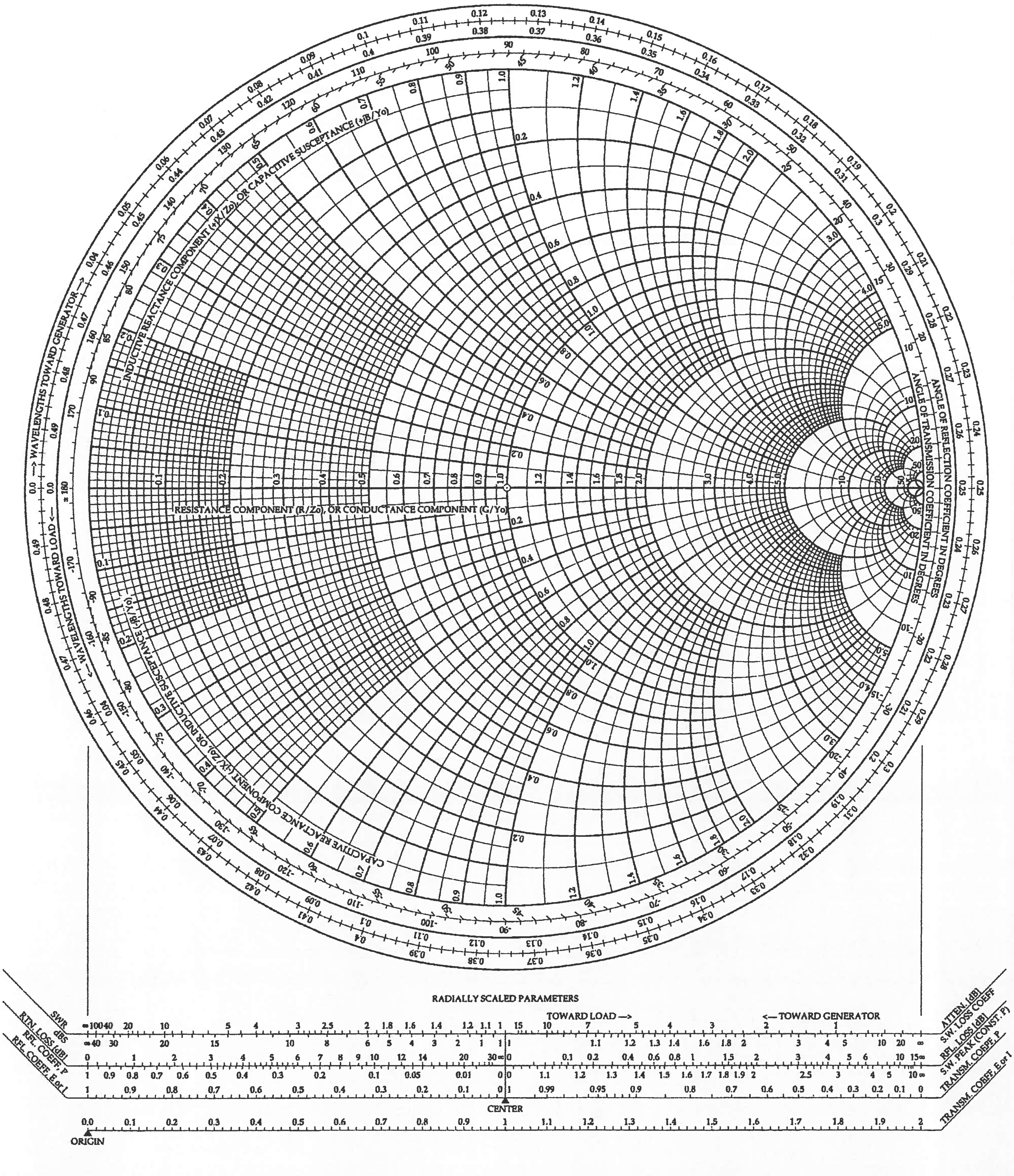
ENGINEERING TRIPOS PART IIA

Thursday 26 April 2018, Module 3B1, Question 2

Candidate No.

Smith Chart for Question 2 – to be detached and handed in with script.



3B1 Numerical answers 2018

1(a)	0.15 nW/m^2, 0.337 mV/m
1(c)(i)	235 μV rms
1(c)(ii)	36.8 dB
1(c)(iii)	29 km (± 4.8 ° beam angle)
1(d)	98.3 % for cosine current dist., or 97.4 % for linear
2(a)(i)	70 Ω + 0.84 pF
2(a)(ii)	0.80 ∠ -31 °
2(a)(iii)	line length 0.407 λ, C = 0.96 pF
2(b)	Q = 2, L = 3.79 nH, C = 1.84 pF
3(a)	Chebyshev, C1 = 28.7 pF, Rf = 842 Ω, C2 = 56 pF
3(b)	microstrip width = 1.40 mm, stripline width = -0.25 mm (not possible)
3(c)	L = 1 nH, C = 2.81 pF, Rb = Rt = 470 Ω to give -10 Ω say
4(b)	R1 = 750 Ω R2 = 91 Ω, R3 = 3.3 Ω, R4 = 75 Ω, C = 10 nF
4(d)	c_{ie} = 23.3 pF, f_{-3dB} = 1.10 GHz