Version MJC/5

EGT2
ENGINEERING TRIPOS PART IIA

Thursday 27 April 2017 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
Supplementary page: Smith Chart for Question 1

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 new positioning satellite system operates at 1.5 GHz. The satellite has a transmitter with an output power of 200 W at the output of its power amplifier. The transmit antenna has a gain of 10 dB and the output power amplifier of the transmitter, feeding the antenna, has a 50 Ω output impedance. Signals from the satellite are received by ground stations.

(a) Explain briefly the terms *gain*, *effective aperture*, *radiation resistance* and *polarisation* for an antenna. [20%]

(b) (i) The antenna is measured to have a S_{11} of $0.47\angle 45^{\circ}$ at 1.5 GHz using a 50 Ω impedance. Plot this point on the Smith Chart and determine the input impedance of the antenna expressing the result in the form $X \pm jY$ Ω. Find the corresponding power reflection co-efficient.

A copy of the Smith Chart is attached to the back of the paper. It should be detached and handed in with your answers. [20%]

(ii) The receiver has an antenna gain of 3 dB and requires a received signal strength of −100 dBm. What is the maximum link range if the transmit antenna is unmatched? How much could it be improved with matching? [30%]

(iii) Design an impedance matching circuit for the transmitter antenna to match the output impedance of the power amplifier, using a length of transmission line with a dielectric relative permittivity of 2 and a series capacitor. [20%]

(iv) Describe what other potential problems exist, besides reduced transmission range, if the impedance of the transmitter antenna is not well matched to the output of the power amplifier. [10 %]

State all approximations and assumptions made.

2 A radio frequency (RF) amplifier is required to boost the signal from an antenna receiving television signals for distribution around a building over 75 Ω coaxial cable. The RF carrier frequencies are between 450 and 850 MHz.

(a) (i) Design a single stage transistor amplifier to provide a net power gain of 10 dB. The input impedance should be 75 Ω and the output provide 5 V peak-to-peak into a 75 Ω load. It should operate from a 15 V supply. You may assume a suitable transistor with $h_{fe} = 250$ is available. [35%]

(ii) Two transistors are available. A low cost version has $h_{fe} = 250$, $f_t = 4$ GHz, $C_{cb} = 0.25$ pF and a more expensive version has $h_{fe} = 250$, $f_t = 16$ GHz, $C_{cb} = 0.25$ pF. By calculation of the upper −3 dB frequency of your amplifier, comment on their suitability for the application (C_{oe} may be neglected). [35%]

(b) (i) The receive antenna for the system has an impedance of 30 Ω. Calculate the required component values to match with 75 Ω using two passive components at a frequency of 650 MHz. [20%]

(ii) Estimate the useful bandwidth of the match designed in part (b)(i) and suggest a method to improve the rejection of unwanted out-of-band signals? [10%]

State all approximations and assumptions made.

3 (a) Describe the differences in the frequency and time domain responses of *Butterworth*, *Bessel* and *Chebyshev* filters. [20%]

(b) Design a voltage controlled voltage source (VCVS) filter using 4 operational amplifiers to pass a signal from 10 kHz to 200 kHz with the steepest possible roll off out of band. Use 1 nF capacitors in your design. You may assume that operational amplifiers with sufficient bandwidth are available. [40%]

(c) (i) The circuit diagram of an oscillator is shown in Fig. 1. Briefly explain the function of each component and principle of operation. Show how the circuit can be modified to give a variable frequency that is controlled by an external voltage V_b. [10%]

(ii) Select values for the other passive components to provide an output frequency of 1.5 MHz to 2 MHz and operate from a 10 V supply. It should drive a load of 15 kΩ with a low distortion sine wave. A 1N5476A varactor with a 10 pF to 300 pF tuning range is available. Your tank circuit should use the smallest C value to achieve the tuning range. [30%]

State all approximations and assumptions made.

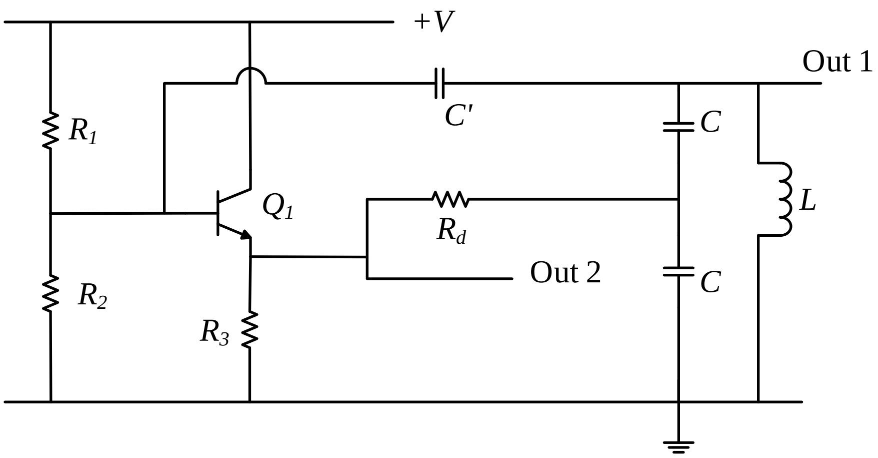

Fig. 1. Oscillator Circuit Diagram

Table 1: VCVS 4-pole normalised filter coefficients

Bessel		Butterworth		Chebyshev 0.5dB ripple	
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) Sketch a block diagram of a superheterodyne (superhet) radio receiver and briefly explain the function of each block. What are the advantages over a simple crystal set type receiver? [30%]

(b) A superhet radio has a local oscillator (LO) frequency of 90 MHz and an intermediate frequency (IF) of 455 kHz. What is the frequency of the tuned station? What is the image frequency? Under what conditions will the image frequency be suppressed? [10%]

(c) Draw a double-balanced diode ring mixer, and a field effect transistor-based mixer. Describe the principle of operation of each and discuss the merits of each for use in a low cost superhet receiver. [20%]

(d) The front end of a superhet receiver uses a resonant inductor-capacitor (LC) tank where L = 30 nH and C = 100 pF. If the inductor has a series resistance of 0.2 Ω and the capacitor can be considered to be ideal, what is the Q factor? [10%]

(e) If the RF signal is frequency modulated (FM), show how a phase locked loop can be configured to demodulate the intermediate frequency signal. [30%]

State all approximations and assumptions made.

END OF PAPER

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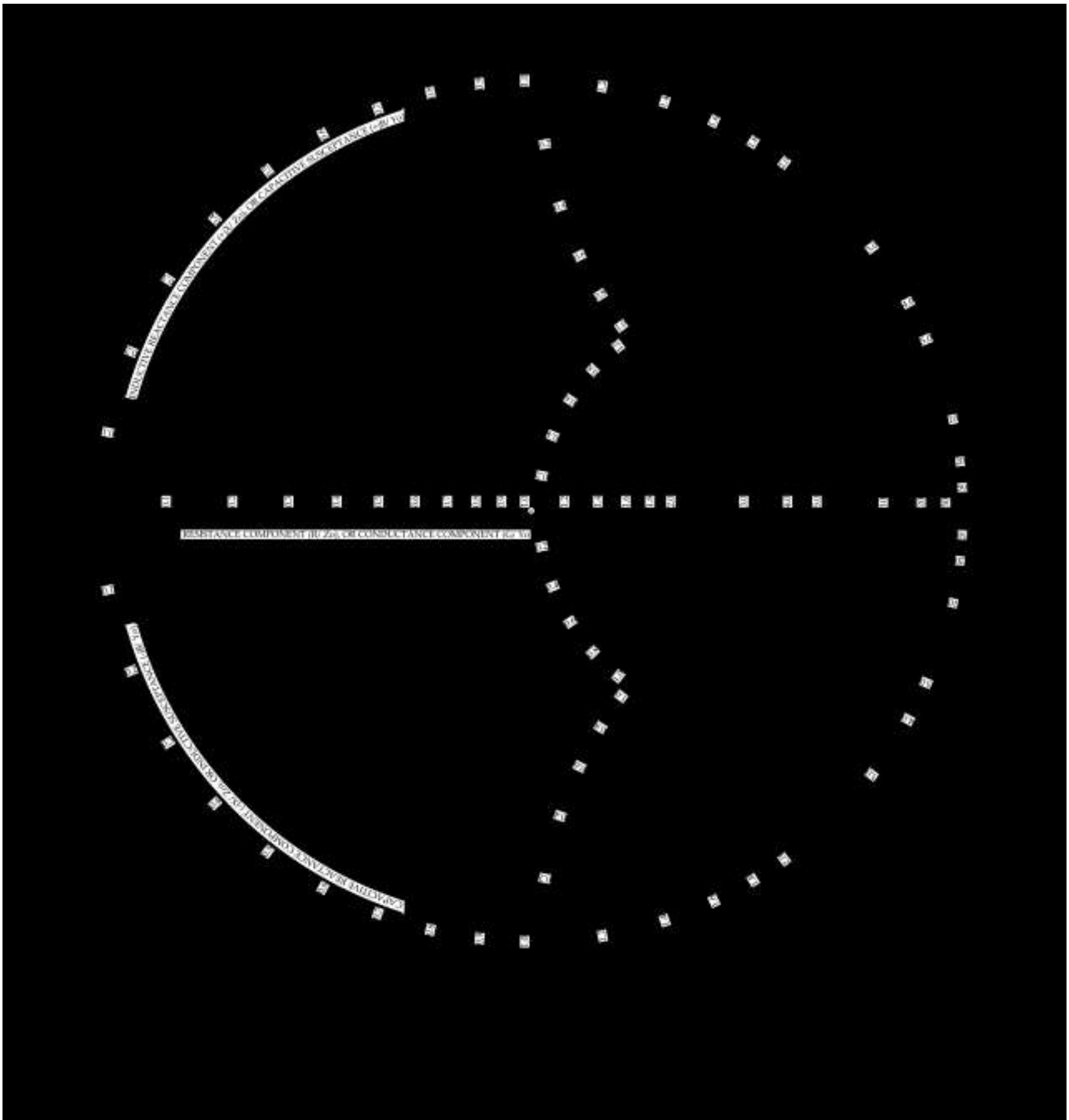
Candidate No.

Smith Chart for Question 1 to be detached and handed in with script



Numerical Answers:

1.

(b)(i) 70 + 60j Γ = 0.22

(b)(ii) r = 2811 km

(b)(iii) 67.3mm, C = 1.9fF

2.

(a)(i) R_1= 1650Ω R_2 = 150Ω, R_3 = 5.9Ω, R_4 = 75Ω , C=10nF

(b) (i) C=6.7pF, L=15nH

(b) (ii) 117MHz, 1182MHz

3.

(b) Pole 1: 1.33kΩ, 775Ω, Pole 2: 772Ω, 1.128Ω. Pole 3 9.5kΩ, 5.52kΩ, Pole 4: 16.4kΩ 27.3kΩ

(c)(i) L = 16 μH, R_1=1kΩ , R_2 = 12.7kΩ, Rd = 2k Ω, R_3 = 3.75kΩ

4.

(b) 89.545MHz, 90.455MHz

(d) 86.6