Version MJC/4

EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 24 April 2019 9.30 to 11.10

Module 4B24

RADIO FREQUENCY SYSTEMS

*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
Attachment: 4B24 Radio Frequency Systems data sheet (1 page).
Supplementary page: Two Smith Charts to be detached and handed in with script if required.
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) Explain briefly the basic principles and use of network analysis in RF system design. [20%]

(b) (i) Define the ABCD parameters for a 2-port network and describe their use. [15%]

(ii) Find the ABCD parameters for the shunt and series elements shown in Figure 1.

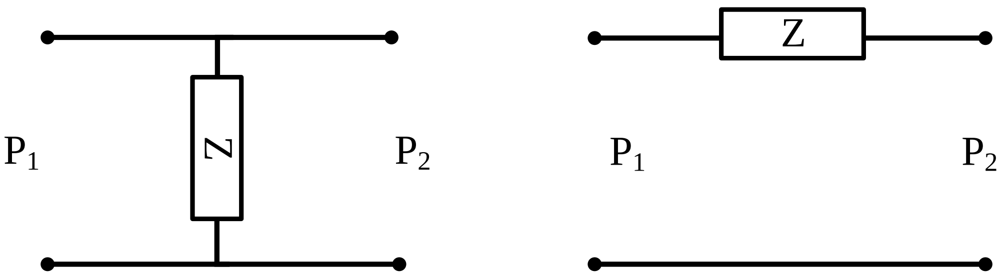

Figure 1 [15%]

(ii) Using the ABCD parameters found above, find the voltage V_{out} across the 100 Ω load resistor shown in Figure 2 below.

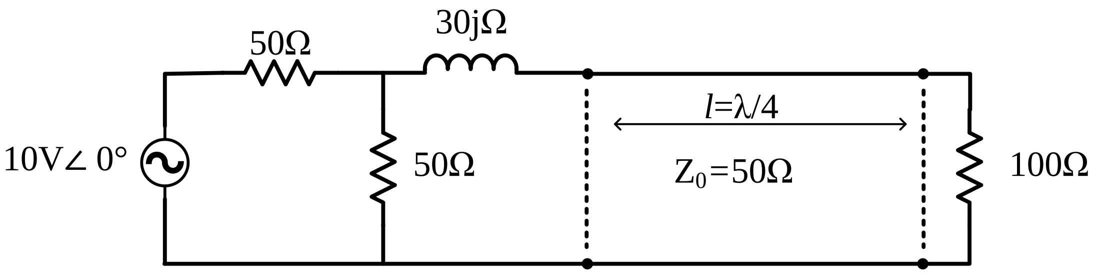

Figure 2

The ABCD parameters of a length of a transmission line of length *l*, characteristic impedance Z_0 and propagation constant β are given by:

$$\begin{bmatrix} \cos\beta l & jZ_0 \sin\beta l \\ j\,{}^{1}\!/_{Z_0} \sin\beta l & \cos\beta l \end{bmatrix}$$ [30%]

(c) For a three port network show that if port 2 is impedance matched to its load, impedance matching at port 1 can be achieved by generating a reflection Γ at port 3. Find the equation for Γ which results in impedance matching at port 1 in terms of the S-parameters of the three port network. [20%]

2 (a) (i) Compare the distortion requirements of a single band radio transmitter operating at 2.5 GHz with 25 MHz bandwidth with a radio repeater system operating with a bandwidth from 300 MHz to 3 GHz. [20%]

(ii) Find the power ratio between the third-order intermodulation products and the third-order harmonics of a non linear amplifier, if two equal power tones are applied [20%]

(b) A lossy power divider has the following S-parameters

$$S = \frac{1}{2}\begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix}$$

Port 3 is connected to a matched load.

(i) Find the available power gain between Ports 1 and 2 [10%]

(ii) Determine the noise figure between Ports 1 and 2 if the network is matched and at thermal equilibrium at temperature T [25%]

(iii) How will the noise figure change if Port 3 is connected to a perfect open circuit? [25%]

3 (a) The New Horizons space probe transmits data back to earth from a range of 6.5×10^{12} m. It uses a carrier frequency of 7 GHz, 12 W transmit power and a 42 dB gain antenna.

(i) Determine the required gain G of the ground station antenna assuming a brightness temperature of 4 K, if an SNR of 5 dB is required at the ground station antenna output over a 30 kHz noise bandwidth. The antenna pattern of the ground station can be modelled as:

$$D(\theta,\phi)=\begin{cases} G \text{ for } \theta,\phi \le \pi/\sqrt{G} \\ 0 \text{ for } \theta,\phi > \pi/\sqrt{G} \end{cases}$$

(Numerical iteration may be used to arrive at a solution) [30%]

(ii) Describe the additional contributions to the noise seen at the receive antenna output if the receive antenna is not ideal [15%]

(iii) Comment on the likely choice of modulation format for this application [10%]

(b) A backscatter communication system operates by switching an antenna load between a perfect match and perfect short as shown in Figure 3. The antenna has a 3 dB gain. A monostatic interrogator uses the same antenna to transmit a continuous tone signal at 2.5 GHz and receive the backscatter communication. The transmit power is 1 W and the antenna gain is 6 dB.

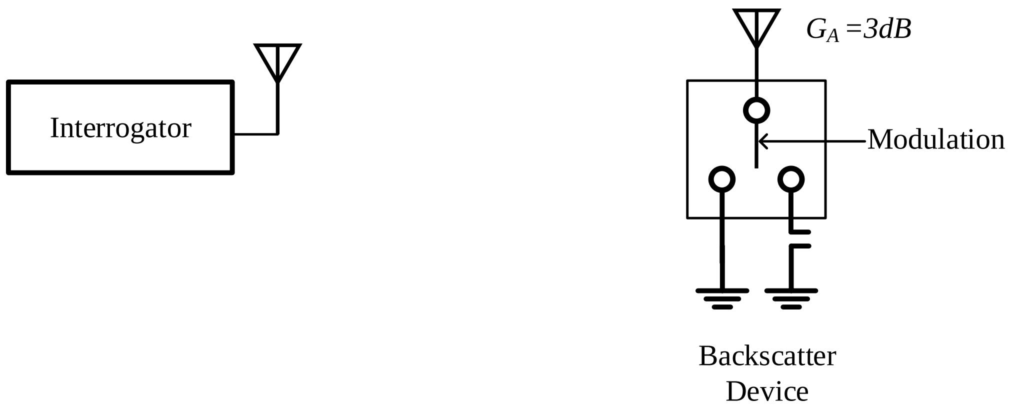

Figure 3

(i) Determine the differential radar cross section between the two modulation states and hence find the maximum range between the interrogator and backscatter device, if a minimum detectable signal level of −70 dBm is required at the output of the interrogator antenna to demodulate the backscatter signal. [30%]

(ii) In practice the reliable range is found to be much shorter than in (i). Comment on the assumptions made to arrive at the result in (i) and how they will differ in a realistic system. [15%]

4 (a) Describe the conditions for unconditional and conditional stability of an amplifier having input and output matching circuits in terms of the reflection coefficients Γ_{in} and Γ_{out} looking into the amplifier's input and output port respectively. [15%]

(b) State the condition to minimise the noise figure of a passive 2-port device. How is this different for an amplifier? [20%]

(c) A low noise amplifier is to be designed to achieve a gain of 8.5 dB with the minimum noise figure which is compatible with this gain. The device S-parameters are ($Z_0 = 50\ \Omega$):

$$S = \begin{bmatrix} 0.6\angle -60^\circ & 0.05\angle 25^\circ \\ 2\angle 80^\circ & 0.5\angle -60^\circ \end{bmatrix}$$

$$F_{\min} = 1.6\,\text{dB},\ \Gamma_{opt} = 0.6\angle 100^\circ\ R_N = 25\,\Omega.$$

(i) Determine the stability of the device [15%]

(ii) Assuming the device can be treated as unilateral, determine Γ_S and Γ_L for the input impedance matching and output impedance matching networks, and determine the value of the minimum noise figure with 8.5 dB gain. [50%]

END OF PAPER

Answers:

1. (b) (iii) $V_2=4.287\angle -120°$
2. (a) 9x (b) 0.25
3. (a) (i) 33dB (b) 8.47m
4. (b) $\Gamma_L = 0.5\angle 60°$ $\Gamma_S = 0.54\angle 88°$ NF=1.67dB