Version MJC/4

EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 26th April 2022   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 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: 4B24 Radio Frequency Systems data sheet (2 pages).
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.

You may not remove any stationery from the Examination Room.

1 (a) Explain the differences between ABCD parameters and scattering parameters in the characterisation and modelling of two port and multi-port RF networks. [20%]

(b) An S_{11} of $0.5\angle 30°$ at 1 GHz is recorded looking into the port shown below in Fig. 1 with a reference impedance of 50 Ω. Determine the electrical length *l* and characteristic impedance Z_l of the connecting line, if the load is known to have an impedance of $100 - 100j$ Ω. [20%]

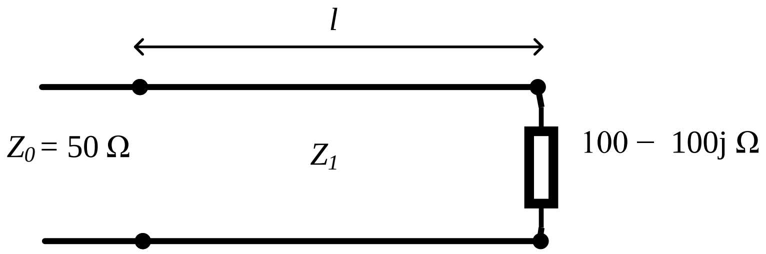

Fig. 1

(c) A 3-port device has a scattering parameter matrix given by (with a 50 Ω reference impedance):

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

(i) Find the two port S parameters for port 1 and 2 if a reflection Γ_3 is present on port 3. [20%]

(ii) Find the impedance which when applied to port 3 maximises the available gain between ports 1 and 2. What is the resulting impedance seen looking into port 1 if port 2 is terminated in a matched load? [20%]

(iii) Show that it is not possible to present a 50 Ω impedance at port 1 by applying an impedance on port 2 when port 3 is connected to a circuit which presents an impedance of $10 + 10j$ Ω. [20%]

2 (a) An amplifier has an IIP2 = 30 dBm, IIP3 = 25 dBm and a gain of 20 dB. Signals are applied at frequencies of 1 GHz, 1.5 GHz and 1.505 GHz such that the power at 1 GHz is 3 dB greater than each of the tones at 1.5 GHz and 1.505 GHz.

(i) Calculate the frequencies of all the resulting distortion products below 3.5 GHz (up to 3rd order including intermodulation). [15%]

(ii) What is the maximum output power of the wanted signals at 1.5 GHz and 1.505 GHz which give a fundamental power 30 dB greater than their 3rd order intermodulation products? [10%]

(iii) Under this condition, what would be the maximum possible harmonic power at 3GHz? [20%]

(iv) What would be the SFDR if the output SNR for the 1.5 GHz signal is 100 dB measured in a 1 MHz noise bandwidth? [15%]

(b) An amplifier shown below in Fig. 2 has S-parameters:

$$S = \begin{bmatrix} 0.5 & 100 \\ 0.001 & 0 \end{bmatrix}$$

The source (Z_S) and load impedance (Z_L) are both 50 Ω. The amplifier noise figure is 5 dB and may be assumed to be independent of the impedance seen by the amplifier.

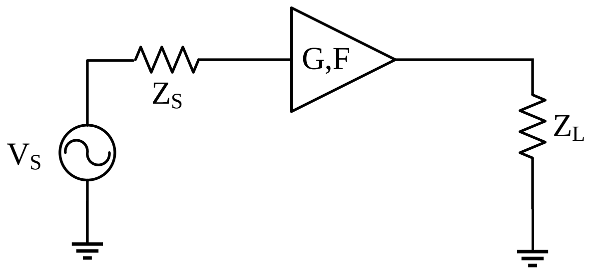

Fig. 2

(i) Determine the amplifier input impedance, reflection coefficient back to the source and noise temperature. [20%]

(ii) Explain how the noise figure of the system can be improved with impedance matching. Calculate the new noise figure. [20%]

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3 A backscatter communication system consists of an antenna connected to a single pole 4-way switch with each output terminated in a different load to allow multiple bits per symbol to be transmitted as shown in Fig. 3.

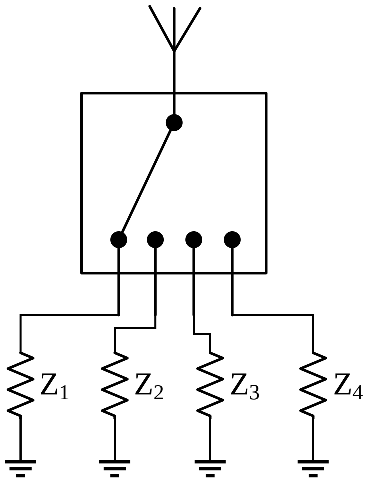

Fig. 3

The antenna impedance is $25 + 15j\ \Omega$, $Z_1 = 28.5 + 19j\ \Omega$, $Z_2 = 21.5 + 18j\ \Omega$, $Z_3 = 21.5 + 12j\ \Omega$ and $Z_4 = 28.5 + 11j\ \Omega$. The system operates with a carrier of 915 MHz, 3 dB gain antennas, a 30 dBm EIRP carrier power and a −70 dBm receiver sensitivity.

(a) (i) Describe the nature of the modulation. [15%]

(ii) Estimate the maximum communication range assuming free space propagation. State any other assumptions you make. [30%]

(iii) Propose a suitable receiver architecture for such a system justifying your choice. [10%]

(b) (i) The system is modified such that only impedance states Z_1 and Z_2 are used. Describe the resulting modulation. Hence calculate the required receiver sensitivity if the same maximum communication range, bit rate and bit error rate as in part (a), are to be achieved. [20%]

(ii) If the dominant noise source is phase noise from the transmitter, sketch the spectrum of the detected signals of both modulation systems at the input to the receiver. If the same receiver is used for both systems, which would likely have the longer range? Justify your answer. [25%]

4 (a) An RF amplifier has parameters $S_{11} = 0.6\angle 90°$, $S_{12} = 0.01\angle -45°$, $S_{21} = 5\angle 180°$, $S_{22} = 0.93\angle 20°$, and $Z_0 = 50\ \Omega$.

(i) Explain the meaning of Power Gain, Available Gain and Transducer Gain. For each explain the necessary conditions which would result in the gain being equal to $|S_{21}|^2$. How do the necessary conditions change if the amplifier is assumed to be unilateral? [25%]

(ii) Find the values of the source impedance Z_s and load impedance Z_L to maximise the power gain and available gain. [15%]

(iii) Determine the stability of the amplifier. [10%]

(b) The amplifier is connected in a cascade by following with a second amplifier which is unconditionally stable, but results in a $\Gamma_1 = 1.25\angle -90°$ as shown in Fig. 4 below.

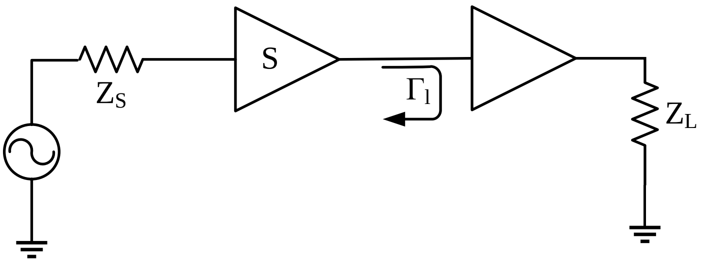

Fig. 4

Explain why the K Δ test is not valid to establish stability in this situation. Using an alternative method, show that the combination is potentially unstable. Propose a method to stabilise the combination. [50%]

END OF PAPER

Answers:

1) (b) $497\Omega, 0.053\lambda$

   (c) (i) open, (ii) 150Ω

2) (a) (i) 2GHz, 3GHz, 3.01GHz, 2.5GHz, 2.505GHz, 500MHz, 505MHz, (3.505GHz), 5MHz, 3GHz, 495MHz, 2.1GHz, 1.495GHz, 1.51GHz.

   (ii) 30dBm

   (iii) 23.1dBm

   (iv) 117dB/Hz^(2/3)

   (b) (i) 150Ω 627K

   (ii) 4.18dB

3) (i) $0.1\angle 45°, 135°, 225°, 315°$

   (ii) 9.8m

   (iv) -71.76dBm

4) (ii) $Z_L = 57.7 - 272j\ \Omega$

$$Z_s = 23.5 - 44.1\, j\ \Omega$$

   (iii) K = -0.38, Delta = 0.51