Version MJC/5

EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 27 April 2021 9.00 to 10.40

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 (1 page).
You are allowed access to an electronic version of the Engineering Data Book.

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 (a) Define the scattering parameters of a multiport device in terms of the incident and reflected voltages at each port. Describe the physical meaning of each term in your definition in relation to a filter. Sketch a graph of the magnitude of the s-parameters of a bandpass reflective filter versus frequency. [20%]

(b) Derive the impedance Z parameters for the 2-port network shown in Figure 1. [20%]

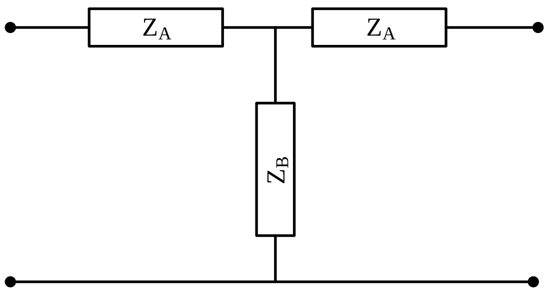

Fig. 1

(c) A 3-port device has a scattering parameter matrix given by:

$$\begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

Describe the function of the device if all ports are matched to the characteristic impedance. How would a mismatch of port 2 affect the transmission of signals between ports 1 and 3, and between 3 and 1? [20%]

(d) Find the S parameters for a series reactance jX connected between two transmission lines with characteristic impedances Z_{01} and Z_{02}, as shown in Figure 2. [40%]

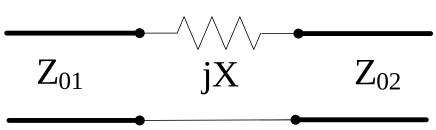

Fig. 2

2 (a) A two tone signal with frequency separation $\Delta\omega$ is applied to a multi-stage amplifier system. The output spectrum is shown in Figure 3 with the original tones having equal amplitudes, but different amplitudes in the new frequency components. Explain how the new frequency components arise and a possible cause of the amplitude imbalance.

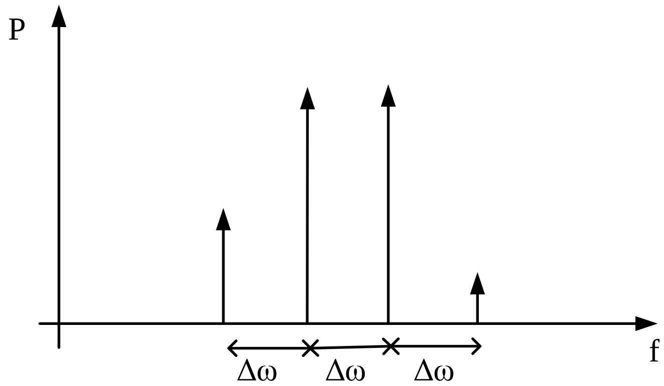

Fig. 3 [30%]

(b) A receiver's noise figure is measured by the Y-factor method. A cold source at 77 K and a hot source with an equivalent noise temperature of 46300 K are used. A power detector records a 15.83 dB increase in the power at the output for the hot source relative to the cold source. Determine the noise figure of the receiver and give the condition under which it is valid. [20%]

(c) Show that, for a transmission line with loss L at a temperature T, its noise temperature can be written as

$$T_e = (L-1)T.$$ [10%]

(d) A lossy transmission line with a characteristic impedance of 50 Ω, an electrical length of 360° and loss of 2 dB/λ is connected to a transmission line with a characteristic impedance of 30 Ω, an electrical length of 90° and loss of 4 dB/λ. For the cascaded arrangement determine:

(i) the reflection coefficient resulting from the impedance mis-match

(ii) the available gain

(iii) the noise figure at 330 K [40%]

3 (a) Describe the conditions which result in the path loss of a propagating RF signal between a transmission antenna and a receiving antenna increasing as R^4, where R is the separation of the antennas. For fixed antenna gains, consider the effect of carrier frequency on path loss in these conditions. [15%]

(b) A 4G mobile telephone receiver operates in a band which requires it to be able to tune between 3.4 and 3.8 GHz with each channel being 5 MHz wide. A complex modulation format is used.

(i) Sketch a superheterodyne and direct conversion receiver and describe the considerations for the choice of receiver for this application. Suggest and justify a suitable intermediate frequency (IF) for use in the superheterodyne receiver for this application. [20%]

(iii) The mobile telephone has an antenna with a radiation efficiency of 0.5. Calculate the resulting output noise power spectral density from the antenna into the receiver if the antenna is at a physical temperature of 55 °C and the brightness temperature is 350 K. [15%]

(c) (i) A backscatter communication system has been designed to operate using modulation of the antenna load impedance. The antenna has a characteristic impedance of 50 Ω and a gain of 3 dB. If two load impedances Z_1 = 5 Ω and Z_2 = 100 Ω are used to modulate the antenna, calculate the differential radar cross section of the antenna switching between the two loads with a carrier frequency of 3 GHz. Describe the nature of the modulation. [25%]

(ii) What loads should be chosen to maximise the radar cross section? Estimate the free space range improvement achieved for the optimum loads over the loads used in part (c)(i) above. [25%]

4 (a) An amplifier with s-parameters S is to be matched to provide maximum gain. Explain why setting $\Gamma_s = S_{11}^*$ and $\Gamma_L = S_{22}^*$ where Γ_S and Γ_L are the reflection coefficients looking into the input and output impedance matching networks, might not achieve the maximum gain. [15%]

(b) An RF amplifier has parameters $S_{11} = 0.6\angle 90°$, $S_{12} = 0.01\angle -45°$, $S_{21} = 5\angle 180°$, $S_{22} = 0.93\angle 20°$, $Y_{opt} = 0.1538 - 0.2308i$ S, $F_{min} = 2$, $R_N = 30\ \Omega$ and $Z_0 = 50\ \Omega$. The source and load impedances are 50 Ω

This question should be solved by calculation without drawing on a Smith Chart. Show your working.

(i) What is the maximum gain of the amplifier? Does the load match for this condition lie in the stable region? [25%]

(ii) If the input of the amplifier is directly connected to the 50 Ω source impedance with no matching network, calculate the resulting maximum gain and noise figure. [20%]

(iii) Find the required impedance looking into the output matching network to give an overall gain of 20 dB. You may assume that the amplifier is unilateral and you should minimise the impedance ratio of the output matching network. [30%]

(iv) Explain why there is no error in the gain resulting from the unilateral assumption where the amplifier is directly connected to the 50 Ω source impedance with no matching network . You may use the relationship:

$$G_T = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2)}{|1-\Gamma_S\Gamma_{in}|^2|1-S_{22}\Gamma_L|^2}$$

[10%]

END OF PAPER

Answers:

Q1)

Q2) (d)(i) -0.25 (ii) -3.28dB (iii) 3.34dB

Q3) (b)(iii) –173dBm/Hz (c)(i) 0.0042m^2 (ii) 32% increase

Q4) (b)(i) 24.6dB (ii) 4.34dB (iii) 150-120jΩ

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