Version MJC/3

EGT3
ENGINEERING TRIPOS PART IIB

Friday 2 May 2025 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
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).
Supplementary Page: Two copies of a Smith Chart (Question 4).
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) (i) Find the ABCD parameter matrix for the shunt resistor shown in Fig. 1. [20%]

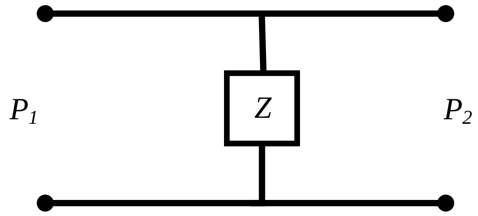

Fig. 1

(ii) Hence find the reduction in gain if a shunt resistor of 25 Ω is inserted before a device with S-parameters given below (Z_0=50 Ω) in a 50 Ω system if no impedance matching is employed. [35%]

$$S = \begin{bmatrix} -4 & -1 \\ -1 & 0 \end{bmatrix}$$

(iii) Are the original device and resulting combination lossless or reciprocal? [15%]

(b) A 3-port device has a scattering parameter matrix given by (Z_0=50 Ω):

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

(i) Port 3 is terminated with an open circuit to create a new 2-port device. Find the S_{11} and S_{21} parameters of the new 2-port device by drawing signal flow graphs. [20%]

(ii) Express the available gain between ports 1 and 2 in terms of the signal flow graph nodes. [10%]

The following relationships between S-parameters and ABCD-parameters may be used in this question:

$$S_{11} = \frac{A + \frac{B}{Z_0} - CZ_0 - D}{A + \frac{B}{Z_0} + CZ_0 + D}, \quad S_{12} = \frac{2(AD - BC)}{A + \frac{B}{Z_0} + CZ_0 + D}$$

$$S_{21} = \frac{2}{A + \frac{B}{Z_0} + CZ_0 + D}, \quad S_{22} = \frac{-A + \frac{B}{Z_0} - CZ_0 + D}{A + \frac{B}{Z_0} + CZ_0 + D}$$

$$A = \frac{(1 + S_{11})(1 - S_{22}) + S_{12}S_{21}}{2S_{21}}, \ B = Z_0 \frac{(1 + S_{11})(1 + S_{22}) - S_{12}\,S_{21}}{2S_{21}}$$

$$C = \frac{1}{Z_0}\frac{(1 - S_{11})(1 - S_{22}) - S_{12}\,S_{21}}{2S_{21}}, \ D = \frac{(1 - S_{11})(1 + S_{22}) + S_{12}S_{21}}{2S_{21}}$$

2 (a) A 2-tone test is performed on an amplifier at 2 per-tone input power levels. The output frequencies and corresponding power levels are given in the table below:

Frequency	Input power - 20 dBm per tone	Input power - 23 dBm per tone
905 MHz	−27 dBm	−18 dBm
910 MHz	0 dBm	3 dBm
915 MHz	0 dBm	3 dBm
920 MHz	−27 dBm	−18 dBm

(i) Sketch the measurement set up of a 2-tone test and explain the precautions which should be taken to ensure an accurate measurement. Explain the origin of each frequency component found at the output. [15%]

(ii) Find the IIP3 and OIP3 of the amplifier. [15%]

(b) A satellite receiver front-end is shown in Fig. 2. The entire system is at a physical temperature of 300 K and has a bandwidth of 1 MHz.

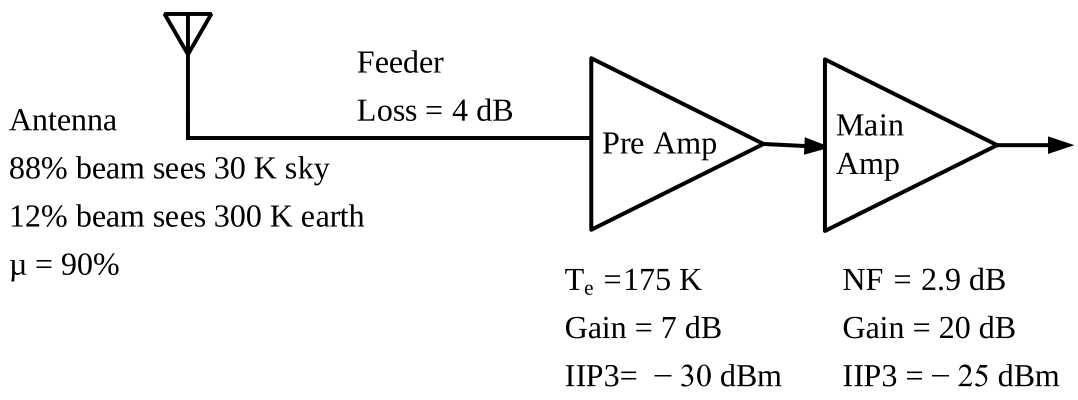

Fig. 2

(i) Find the antenna noise temperature. [15%]

(ii) Find the system noise temperature, noise figure and output noise power. [30%]

(iii) What is the maximum SFDR of the system, and the maximum tone power at the antenna output which does not produce observable intermodulation products at the receiver output (assume the worst case). [25%]

3 (a) A general purpose amplifier has an S-parameter matrix (Z_0=50 Ω):

$$S = \begin{bmatrix} 0.77\angle 47° & 0.18\angle -52° \\ 1.41\angle -66° & 0.46\angle 38° \end{bmatrix}$$

Find the maximum transducer gain of the amplifier if used in a 50 Ω system with conjugate matching. The amplifier can be assumed to be unilateral. How reasonable is the unilateral assumption? [20%]

(b) The amplifier in part (a) is connected between a source with impedance 30 Ω and load with impedance 70 Ω. Determine and explain the meaning of:

(i) the operating power gain in dB, [10%]

(ii) the available power gain in dB and [10%]

(iii) the transducer gain in dB. [10%]

(iv) Find the error in the transducer gain under the unilateral assumption. [5%]

(c) A monostatic pulsed radar system operates at 20 GHz with a per-pulse power of 1 W, a pulse repetition interval of 1 μs and uses an antenna with a gain of 30 dB. Determine the minimum target radar cross section which can be identified at the maximum unambiguous range if the receiver has a sensitivity of −90 dBm. [25%]

(d) An antenna with a gain of 6 dB and 50 Ω impedance is terminated with a 25 Ω resistor. What would be the resulting radar cross section in the direction of the main beam if the frequency of operation is 20 GHz. [20%]

Note: Unilateral figure of merit

$$u \equiv \frac{|S_{11}S_{12}S_{21}S_{22}|}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$$

4 (a) A FET has the following scattering and noise parameters at 4 GHz (Z_0=50 Ω): $S_{11} = 0.86\angle-78°$, $S_{12} = 0.04\angle 43°$, $S_{21} = 2.37\angle 112°$, $S_{22} = 0.74\angle-35°$, $F_{min} = 0.6$ dB, $\Gamma_{opt} = 0.45\angle 90°$, $R_N = 20\ \Omega$. The source and load impedances are 50 Ω.

(i) Determine the maximum gain of the amplifier and the required impedances to be presented by the matching networks to achieve this. You should consider stability and plot stability circles on the Smith Chart if they are required, clearly showing the stable and unstable regions. [20%]

(ii) Calculate the noise figure of the amplifier with matching circuits to achieve maximum gain. [15%]

(iii) Design with the aid of a Smith Chart the input impedance matching network for maximum gain, using a shorted transmission line stub. Give the lengths required in wavelengths and provide a sketch clearly showing their arrangement. [25%]

(b) A passive 2 port device has S-parameters:

$$S = \begin{bmatrix} 0.1 & 0.3 \\ 0.3 & 0.5\angle 45° \end{bmatrix}$$

(i) Determine the noise figure without any impedance matching networks stating any assumptions made. [25%]

(ii) Suggest Γ_S and Γ_L values for input and output impedance matching networks which would reduce the overall noise figure and find the resulting available gain and noise figure for the device including the matching networks. [15%]

Two Smith Charts are attached at the end of the question paper. They should be detached and handed in with your answers.

END OF PAPER

Answers:

1 a) (ii) 6dB

(b) (i) $S_{1,1} = 1.707, S_{2,1} = 0.707$

2 a) (ii) IIP3 = 33.5dBm OIP3 = 13.5dBm

(b) (i) 86.2K

(ii) 1114K, 6.8dB, -85.1dBm

(iii) SFDR = 92 $\mathrm{dBm/Hz}^{\frac{2}{3}}$, -69 dBm

3 a) 6.2

(b) (i) 6.6dB, (ii) 2.84dB, (iii) 2.01dB (iv) 0.04dB

(c) 4.5×10^{-3} m^2

(d) 3.15×10^{-5} m^2

4 a) i) 16.9dB

(ii) 3.2dB

0.1 λ line with 0.047λ stub

(b) (i) 9.21dB

(ii) 9.16dB