Version MJC/6

EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 24th April 2018 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) (i) Define Scattering (S) parameters and Transmission (ABCD) parameters for a 2-port device. [20%]

(ii) Find the scattering parameters for the shunt load shown in Fig. 1 below for a reference impedance Z_0 and show that $S_{21} = 1 + S_{11}$.

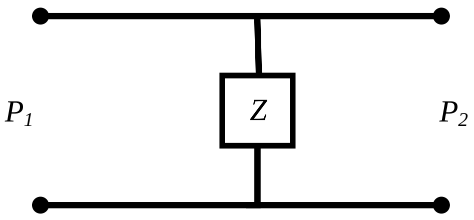

Fig. 1

[25%]

(b) (i) In the circuit shown below in Fig. 2 a load of Z_L=200+j100 Ω is to be matched to a 40 Ω line using a length *l* of lossless transmission line with characteristic impedance Z_1. Find *l* (in terms of λ) and Z_1.

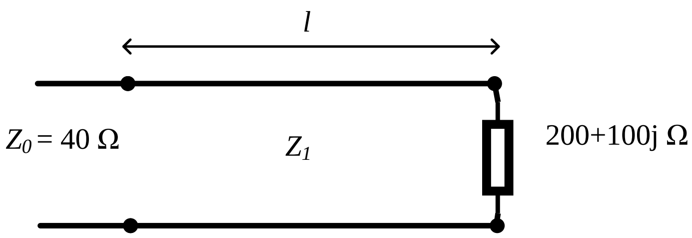

Fig. 2

[25%]

(ii) Determine what range of load impedances can be matched using the method in part (b) (i). [30%]

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

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

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

2 (a) (i) Briefly explain the concept of non-linear distortion in RF circuits and the problems produced in a narrowband transmitter. [20%]

(ii) The spectrum analyser output is shown below in Fig. 3 for an RF system when signals of equal amplitude and frequencies ω_1 and ω_2 are applied. Show that the 3rd order output intercept is given by $OIP_3 = P_{\omega_1} + (1/2)\Delta P$ where P_{ω_1} and ΔP are expressed in dBs.

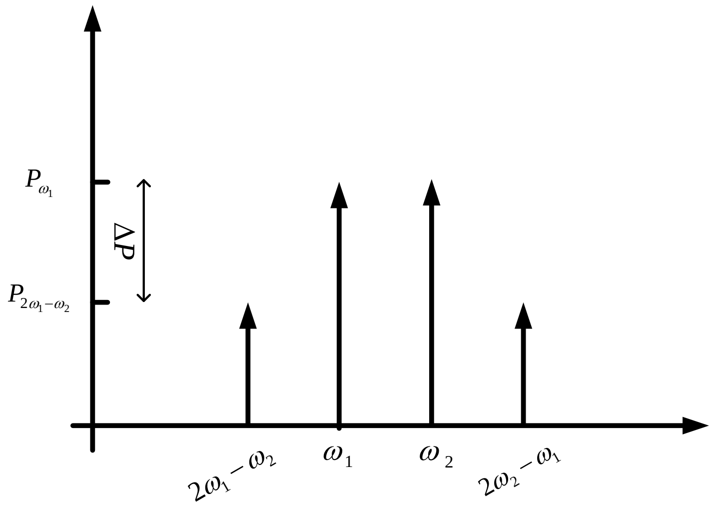

Fig. 3 [25%]

(iii) If $P_{\omega_1} = 5$ dBm, $P_{2\omega_1-\omega_2} = -27$ dBm, $P_{in} = -4$ dBm and the noise floor is found to be −90 dBm measured over a 100 kHz resolution bandwidth, what is the Spurious Free Dynamic Range (SFDR)? [10%]

(b) (i) Consider the radio receiver shown below in Fig. 4 where the bandwidth of the filter is 200 MHz centred at 5.2 GHz. If the system is at room temperature, find the overall system noise figure. What input signal level will result in an SNR of 3 dB?

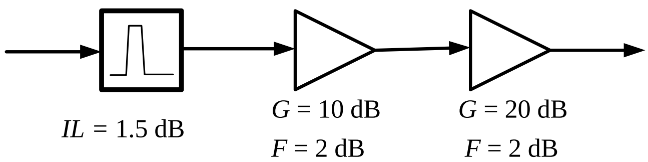

Fig. 4 [25%]

(ii) Show how the components can be re-arranged to improve the noise figure and calculate the new system noise figure. What additional considerations must be taken into account with the new design? [20%]

3 (a) Sketch roughly a plot of the expected received signal strength versus range assuming a flat earth model. Discuss the implications of antenna height and frequency choice for a point to point radio system. [20%]

(b) Describe the contributions to the antenna noise temperature of a directional antenna with the gain pattern shown in Fig. 5 if the radiation efficency is less than 1.

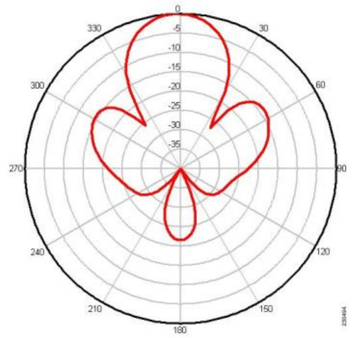

Fig. 5 [20%]

(c) A GPS satellite receiver is shown in Fig. 6. The minimum required SNR is defined as a Carrier to Noise ratio (C/N) over a 1Hz bandwidth.

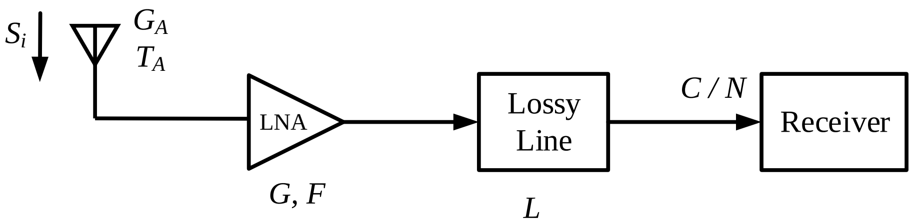

Fig. 6

(i) Determine an expression for the maximum allowable noise figure F of the LNA in terms of C/N assuming a power density of S_i impinging on the antenna, which has a gain G_a, and noise temperature T_a. The LNA has a gain G and the connecting line a loss L. [25%]

(ii) The system uses QPSK modulation with a symbol rate of 1 MHz and a carrier frequency of 1.575 GHz. Discuss the suitability of direct sampling, superheterodyne detection and direct conversion receivers for this application. [25%]

(iii) If the signal level as recorded by a 6 dBi gain antenna at ground level is −124 dBm, and the satellite transmit antenna has a gain of 14 dB and an altitude of 20,000 km, calculate the required conducted RF power to the antenna. [10%]

4 (a) Describe the terms *Power gain*, *Available Gain* and *Transducer Gain* as applied to an RF amplifier fed from a source impedance Z_S suppling a load impedance Z_L. State the conditions under which the Power gain, Available gain and Transducer gain will be identical. [30%]

(b) (i) An RF amplifier has S parameters at 1.8GHz: $S_{11} = 0.8\angle -160°$, $S_{21} = 4.25\angle 160°$ $S_{12} = 0.1\angle 9°$, $S_{22} = 0.707\angle -117°$ ($Z_0 = 50\ \Omega$). Determine the stability of the device, and plot stability circles on the attached Smith Chart if the device is potentially unstable, indicating stable and unstable regions. [30%]

(ii) Estimate the maximum stable gain of the amplifier. Explain why a simple conjugate match of S_{11} and S_{22} may not be desirable for this amplifier. [20%]

(iii) Estimate the bounds on error in the transducer gain which will result from assuming the device is unilateral. Explain the implications this has on the design for a specific gain. [20%]

END OF PAPER

Answers:

1. (b) (i) 0.288λ, Z_1=102.5Ω

2. (a) (ii) 107.3dB/Hz^2/3

   (b) (i) -86.5dBm

   (ii) F=2dB

3. (b) (ii) 7W

4. (b) (i) |Δ|=0.684, K=0.384,

   $C_L = 13.14\angle 66.4°, R_L = 12.7$, $C_s = 2.98\angle 125°, R_s = 2.45$

   (ii) 42.5

   (iii) 0.834< Gt/Gu < 8.91