GLASGOW COLLEGE UESTC

Main Exam

Wireless & Optical Transmission Systems (UESTC 4024)

Date: 5th Jan. 2021
Time: 09:30am - 11:30am

Attempt all PARTS. Total 100 marks

Use one answer sheet for each of the questions in this exam.
Show all work on the answer sheet.

Make sure that your University of Glasgow and UESTC Student Identification Numbers are on all answer sheets.

An electronic calculator may be used provided that it does not allow text storage or display, or graphical display.

All graphs should be clearly labelled and sufficiently large so that all elements are easy to read.

The numbers in square brackets in the right-hand margin indicate the marks allotted to the part of the question against which the mark is shown. These marks are for guidance only.

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Q1

(a) A CubeSat in a 220 km low earth orbit (LEO), carries a 3.7 GHz transmitter. Assuming the average radius of Earth is 6,370 km and Kepler's constant has the value 3.986004418 * 10^5 km^2/s^2, critically examine the following:

(i) Orbital velocity. [1]

(ii) Orbital period. [2]

(iii) Orbital angular velocity in radians per second. [2]

(b) A CubeSat in the Earth orbit has a semi-major axis of 7,400 km and an eccentricity of 0.1036. With the help of a comprehensively labelled diagram:

(i) Calculate the satellite's altitude at both perigee and apogee. [7]

(ii) Describe with aid of suitable diagrams the orbital behaviour of a CubeSat with an eccentricity of 1.00 and an eccentricity of 1.036. [3]

(c) A satellite communication system consists of 150 CubeSats. For any satellite system to be feasible, the communication capacity must be sold at a price that is attractive to customers. This question looks at the cost of the system over its lifetime and calculates a minimum cost per voice circuit.

(i) Each CubeSat carries 25 transponders. When fully loaded, what is the total number of speech channels that the CubeSat can support? Determine how many telephone circuits are needed given that it takes two channels to make a telephone circuit? [3]

(ii) Each CubeSat costs CNY 40 M in orbit and the CubeSat system costs CNY 100 M per year to run. The expected lifetime of the CubeSats is 10 years and the system requires a total of 10 spare CubeSats to be launched over the 10-year period. Determine the cost of operating the system for a ten-year period. Add a 27% factor to cover interest payments and dividends. Calculate the 10-year cost of the entire CubeSats satellite system. [7]

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Q2

(a) In a satellite communication system, it is a common practice to employ a dual reflector antenna system to improve the end-to-end performance. In this aspect, diagrammatically express two different types of dual reflector antenna systems. Make sure to label the figures appropriately. [6]

(b) A CubeSat satellite system constitutes a S-band Earth Station that has an antenna operating with a transmit gain of 27 dB. The output power of the transmitter is set to 50 W at a frequency of 3.050 GHz. The signal is received by a CubeSat at distance of 250 km. To ensure a reliable communication link, it is desired to receive the signal with a power of at least -50 dBW at the output port of the CubeSat. The signal is then routed to a transponder with a noise temperature of 200 K, a bandwidth of 18 MHz, and a gain of 55 dB. (Use Boltzman's Constant = 1.38×10^{-23} J/k)

(i) Calculate the required wavelength at 3.050 GHz given that the quality of the channel is restricted by a pathloss that is set at 100 dB. [3]

(ii) As a satellite communication system engineer, determine the value of receiver antenna gain. [3]

(iii) Analyse the noise power at the transponder input, in dBW, operating at a bandwidth of 18 MHz. [3]

(iv) Calculate the Carrier-to-Noise, C/N, ratio, in dB, in the transponder to guarantee a reliable communication link. [3]

(v) Determine the carrier power, in dBW and in Watts, at the transponder output of the CubeSat. [3]

(c) A CubeSat communication link has a transponder that is operated at an output power level of 60 W. The transponder is utilised in frequency division multiple access (FDMA) mode to transmit 1,500 binary phase shift keying (BPSK) voice channels with half-rate forward error correction (FEC) coding. The carrier-to-noise (C/N) ratio in clear air for an Earth base-station (BS) receiving one BPSK voice signal is set at 29 dB. Each coded BPSK signal has a symbol rate of 50 kbps and requires a receiver with a noise bandwidth of 50 kHz per channel. The Earth BSs utilised to receive the voice signals have antennas with a gain of 40 dB.

(i) Determine the power transmitted by the CubeSat in a single voice channel. [2]

(ii) Evaluate the margin over a coded BPSK threshold of 18 dB? [2]

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Q3

(a) One of the very important steps during the design process of orbital dynamics / mechanics (position in the sky / space) is to define the constellation(s). Subsequently, this requires setting up the celestial sphere. Describe the formation of celestial sphere with the help of a diagram. Make sure to highlight the two key parameters involved. [5]

(b) A CubeSat with a **circular** and **equatorial** orbit is orbiting the Earth at an altitude of 250 km in the **opposite direction** of the Earth's rotation. An airplane is flying just above the Earth's surface on the equator and in the **same direction** of the Earth's rotation at a speed of 200 m/s with respect to the Earth's surface. At **1300 (13:00 PM)**, the CubeSat passes exactly above the airplane. (***Assume:*** Duration of Earth's Day ≈ 24 Hours; Earth's Average Radius = 6,378 km; Kepler's Constant = $3.986 * 10^5$ km^3/s^2)

(i) Calculate the central angle γ at the Earth's centre separating the CubeSat's position from the airplane's position at **1500 (03:00 PM)**. [15]

(ii) Determine the distance (d) between the CubeSat and the airplane at **1500 (03:00 PM)**. [5]

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Q4

(a) This question relates to optical amplifiers.

(i) Explain how an Erbium doped fiber amplifier (EDFA) works. Your answer must include a sketch of the typical structure of an EDFA. [3]

(ii) Compare the advantages and disadvantages of a Raman amplifier and Erbium doped fibre amplifiers (EDFA). [4]

(iii) You are tasked with designing the amplification for an optical network operating in the O band. Which type of optical amplifier would you select? Your answer must be fully justified. [2]

(b) This question relates to dispersion in optical fibers. Questions (i) and (ii) are independent.

(i) An optical network is designed with a multimode fibre, which has the following dispersion coefficients (at 1550nm operating wavelength):
- Chromatic dispersion: D_{chrom} = 18 ps/nm.km
- Modal dispersion: D_{modal} = 60ps/km.
The fiber length is 200 km. The light source used to send data into the fiber is a laser with a linewidth of 0.1 nm.

Calculate the total dispersion experienced by a pulse propagating in this fiber. [2]

(ii) To correct the effects of chromatic dispersion of a SMF of length 150km and chromatic dispersion coefficient of Dc=17ps/nm.km (and laser linewidth 0.1nm), you decide to use a specially designed dispersion compensating fibre (DCF). This DCF has a dispersion coefficient of D_n = -100 ps/nm.km. Calculate the length, L_n, of DCF needed to compensate the chromatic dispersion introduced by the SMF used in the network. [3]

(c) This question focuses on WDM networks:

(i) Explain the main characteristics of WDM networks. [2]

(ii) What are the differences between CWDM and DWDM (your answer should include discussion on wavelengths, channel spacing, technical standards). [2]

(d) You are tasked with verifying the power margin of a passive optical network that has been designed to transmit 1 Gbit/s data over a distance of 50 km.

The current design has the following characteristics:
- Laser source at 1550 nm with a minimum emitted power of 0.5 mW

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- Single mode fibre with loss of 0.3 dB/km
- Receiver minimum sensitivity is -25 dBm and its maximum sensitivity is -3dBm.
- The fibre has 8 splices along its length. Each splice has a loss of 0.5 dB.
- Coupling between laser and fiber is assumed ideal (i.e. perfect coupling).
- Connector loss is estimated at 1dB per connector.

Answer the following questions:

(i) What is the power emitted by the laser in dBm? [1]

(ii) What is the span loss of this network [2]

(iii) What is power margin of the network. What can you conclude? [2]

(iv) Based on the Power Margin you have obtained in (iii), discuss the suitability of this design for long-term use. Justify your conclusion. [2]

End of question paper