Name .... ID .... Section ...... Seat No ......

Sirindhorn International Institute of Technology Thammasat University

Midterm Exam Answers: Semester 1, 2011

Course Title: ITS323 Introduction to Data Communications

Instructor: Steven Gordon

Date/Time: Monday 1 August 2011; 9:00–12:00

Instructions:

- This examination paper has 17 pages (including this page).
- Conditions of Examination: Closed book; No dictionary; Non-programmable calculator is allowed
- Students are not allowed to be out of the exam room during examination. Going to the restroom may result in score deduction.
- Students are not allowed to have communication devices (e.g. mobile phone) in their possession.
- Write your name, student ID, section, and seat number clearly on the front page of the exam, and on any separate sheets (if they exist).
- Assume bits are ordered from left to right. For example, for the data 00001111, the first (1st) bit is 0 and the last (8th) bit is 1.
- Assume the speed of transmission is 3×10^8 m/s
- Free space propagation path loss:

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{G_t G_r \lambda^2}$$

- Antenna gain for parabolic antenna with effective area A_e:

$$G = \frac{4\pi A_e}{\lambda^2}$$

Question 1 [24 marks]

For each question fill in the blank space with the most appropriate term from Table 1. For each blank space you must give only one answer. However, there may be more than one correct answer. You may use a term from the table in more than one question. You must not use terms that are not in the table. Each correct answer is worth 1.5 marks.

No.	Term	No.	Term	No.	Term
1	accuracy	15	full-duplex	29	physical
2	amplitude modulation	16	guided	30	point-to-point
3	amplitude shift keying	17	half-duplex	31	port number
4	application	18	hardware address	32	pulse code modulation
5	coaxial cable	19	IP	33	simplex
6	codec	20	IP address	34	spectrum
7	CRC	21	LAN	35	TCP
8	data link	22	modem	36	time domain
9	data rate	23	multipoint	37	timeliness
10	delta modulation	24	network	38	transport
11	frequency	25	optical fibre	39	twisted pair
12	frequency domain	26	parity check	40	unguided
13	frequency modulation	27	phase modulation	41	WAN
14	frequency shift keying	28	phase shift keying	-	-

Table 1: Possible answers for Question 1

(a) Three important measures of effective data communications are: delivery, timeliness and *accuracy*.

(b) A *WAN* covers a large geographical area, whereas a LAN typically covers a campus, building or home.

(c) Two important protocols in the Internet, and from which the Internet stack gets its name, are *TCP* and IP.

(d) HTTP is a protocol for requesting and receiving web pages. It is part of the *application* layer.

(e) In a *multipoint* configuration more than two devices share the transmission medium.

(f) A transmission medium that allows transmission in both directions, but only one direction at a time, is called *half-duplex*.

(g) *Phase modulation* can be described as varying the phase of the output carrier signal as the amplitude of the input data changes.

(h) Protocols in the *data link and physical* layer are normally implemented in hardware on network interface cards.

(i) *Twisted pair* is the most common guided media used within home and building LANs.

(j) A *port number* is used to identify application processes running on a computer.

(k) For multimedia or real-time applications, *timeliness* is usually more important than accuracy.

(l) A *modem* takes digital data as input and transmits an analog signal.

(m) *Optical fibre* is a guided media that provides higher data rates and allows for transmission across larger distances than coaxial cable.

(n) *CRC or parity check* can be used to detect errors.

(o) The *data link* layer includes the task of reliable deliver across a single link.

(p) Routing protocols, which are used to select the most appropriate path across the Internet, are most often part of the *network* layer.

Question 2 [12 marks]

Table 2 shows the list of codewords for a Hamming-distance based Forward Error Correction (FEC) scheme.

Data	Codeword
000	011011
001	100110
010	100111
011	010000
100	111100
101	001010
110	100101
111	001011

Table 2: Hamming-based FEC

(a) For the following cases, explain the steps taken by the receiver (showing any calculations where necessary), and summarise the outcome by answering the following questions. [6 marks]

i. The data 001 is to be sent from transmitter to receiver. The last bit transmitted is in error.

Steps taken by receiver:

Answer. *Data 001 maps to codeword 100110. The codeword is transmitted, however because of the bit error the receive codeword is 100111. The receiver has received a valid codeword (and hence no error detected). It assumes the received data is 010, which is incorrect.*

Codeword received by receiver: _____ _____ _____ _____ _____ _____

Error detected by receiver? YES or NO

Data received: _____ _____ _____ (if applicable)

Is the correct data received? YES or NO

ii. The data 010 is to be sent from transmitter to receiver. The 1st bit transmitted is in error (that is, the 1st bit transmitted is different from the 1st bit received).

Steps taken by receiver:

Answer. *Data 010 maps to codeword 100111. The codeword is transmitted, however because of the single bit error the receive codeword is 000111. The receiver detects an error, and compares the received codeword to the valid codewords. The valid codeword with unique minimum Hamming distance to 000111 is 100111 (distance = 1). Therefore the receiver assumes the data received is 010. This is the correct assumption.*

Codeword received by receiver: _____ _____ _____ _____ _____ _____

Error detected by receiver? YES or NO (circle the correct answer)

Data received: _____ _____ _____ (if applicable)

Is the correct data received? YES or NO

iii. The data 100 is to be sent from transmitter to receiver. The 1st and 2nd bits transmitted are in error.

Steps taken by receiver:

Answer. *Data 100 maps to codeword 111100. The codeword is transmitted, however because of the bit errors the receive codeword is 001100. The receiver detects an error (the received codeword is invalid), and compares the received codeword to the valid codewords. There is no valid codeword with minimum Hamming distance (both 111100 and 001010 have distance of 2). Therefore error correction is not attempted, and the correct data is not received.*

Codeword received by receiver: ____ ____ ____ ____ ____ ____

Error detected by receiver? YES or NO

Data received: ____ ____ ____ (if applicable)

Is the correct data received? YES or NO

(b) Assuming you must use a FEC with 3 bits of data and 6-bit codeword, explain how the scheme in Table 2 could be changed to reduce the possibility of single-bit errors being undetected. [2 marks]

Answer. *Choose a different set of code words. For example, codewords for data 001 and 010 differ only by a single bit. Therefore if data 001 is transmitted, a single-bit error will be undetected if the received codeword matches that for 010. The codewords should have large Hamming distance between each other.*

(c) If using a link with data rate of 20Mb/s, what is the maximum possible throughput using the encoding scheme in Table 2? [2 marks]

Answer. *To send 3 bits of data, 6 bits actually have to be transmitted, representing 50% efficiency. Throughput is 10Mb/s.*

(d) Explain one advantage and one disadvantage of using an 5-bit codeword (instead of 6-bit codeword as in Table 2). [2 marks]

Advantage:

Answer. *Increases the throughput*

Disadvantage:

Answer. *Decreases the chance to detect and correct errors*

Question 3 [13 marks]

Consider a terrestrial microwave link between SIIT Bangkadi and SIIT Rangsit. The distance between the two campuses is 10km. Each campus uses the same equipment. The specification of the equipment is: antenna gain = 18.95dBi; receive power threshold (or sensitivity) = -70dBm; frequency = 3GHz.

(a) What is the minimum power at which the receiver at Bangkadi can successfully receive, measured in Watts? [2 marks]

Answer. *The minimum power is -70dBm. Convert to* mW *gives* $10^{-7}mW$*, which is* $10^{-10}W$*.*

(b) What is the wavelength of the transmitted signal? [1 mark]

Answer. *Wavelength,* $\lambda = \frac{c}{f}$*. The speed of light,* c *is* $3 \times 10^8 m/s$*, while the frequency,* f*, is* $3 \times 10^9 Hz$*. Hence the wavelength is 0.1m.*

(c) What is the absolute gain of one antenna? [2 marks]

Answer. *A gain of 18.95dBi is equivalent to an absolute gain of* $10^{1.895} \approx 78.54$*.*

(d) Assuming free-space path loss, what is the minimum transmit power required for the signal to be successfully received? [5 marks]

Answer.

$$\begin{aligned}
\frac{P_t}{P_r} &= \frac{(4\pi d)^2}{G_t G_r \lambda^2} \\
P_t &= \frac{P_r (4\pi d)^2}{G_t G_r \lambda^2} \\
&= \frac{10^{-10}(16 \times \pi^2 \times 10000^2)}{78.54 \times 78.54 \times 0.1^2} \\
&= \frac{16 \times \pi^2}{78.54^2} \\
&= 0.0256W \\
&= 25.6mW
\end{aligned}$$

(e) Assuming both antennas are parabolic antennas where the effective area is $\frac{1}{\pi}$ of the physical area of the antenna, what is the diameter of the dish? [3 marks]

Answer.

$$G = \frac{4\pi A_e}{\lambda^2}$$

$$A_e = \frac{1}{\pi}\pi r^2$$

Re-arranging the above two equations gives:

$$\begin{aligned} r^2 &= \frac{G\lambda^2}{4\pi} \\ &= \frac{78.54 \times 0.01}{4\pi} \\ &= 0.0625 \end{aligned}$$

Therefore the radius of the antenna is 0.25m and the diameter is 0.5m or 50cm.

Question 4 [7 marks]

The frame rate of a web camera attached to your computer is 24 frames per second, where each frame is an image of 1600 x 1200 pixels. Each pixel uses a 24 bit value to represent a single colour.

(a) What is the data rate required to send the raw (uncompressed) video from camera to computer? [3 marks]

Answer. *Each frames consists of* $1600 \times 1200 \times 24$ *bits. There are 24 frames sent per second, and therefore* $24 \times 1600 \times 1200 \times 24 = 1,105,920,000 b/s$ *(or approximately 1.1Gb/s).*

(b) Assuming the camera compresses the video before transmission, such that the compressed data is 1% of the original data size, what is the data rate required to send the compressed video from camera to computer? [1 mark]

Answer. *1% of the previous answer gives a required data rate of 11,059,200b/s or 11Mb/s.*

(c) With the compressed video, what is the minimum bandwidth required on the cable (connecting web camera to computer) if there was a signal-to-noise ratio of 27.08dB? [3 marks]

Answer. *An SNR of 27.08dB is equivalent to an absolute SNR of 510.5. Using Shannon's capacity theorem, we know the capacity (*$C = 11 Mb/s$*):*

$$11 \times 10^6 = B \log_2(1 + 510.5)$$

gives a bandwidth, B*, of approximately 1.22MHz.*

Question 5 [12 marks]

Consider a network with two links: Link 1 is between devices A and B, while Link 2 is between devices B and C. The link and device characteristics are:

Device A: every packet transmitted incurs 100μs processing delay; every packet received incurs 100μs processing delay; no queuing delay

Device B: no processing delay; every packet received is put into a queue, which incurs queuing delay of 10ms and then is transmitted

Device C: every packet transmitted incurs 100μs processing delay; every packet received incurs 100μs processing delay; no queuing delay

Link 1: distance = 30km; data rate = 1Mb/s

Link 2: distance = 60km; data rate = 10Mb/s

(a) What is the transmission delay of a 1000B packet from A to B? [2 marks]

Answer. *Let transmission delay of link 1 be t_{AB}:*

$$\begin{aligned} t_{AB} &= \frac{datasize}{datarate} \\ &= \frac{1000B}{1Mb/s} \\ &= 8000\mu s \end{aligned}$$

(b) What is the propagation delay from B to C? [2 marks]

Answer. *Let propagation delay of link 2 be p_{BC}:*

$$\begin{aligned} p_{BC} &= \frac{distance}{speed} \\ &= \frac{60km}{3 \times 10^8 m/s} \\ &= 200\mu s \end{aligned}$$

(c) Consider a web browser on device A generates a 1000B request packet to be sent to C. Device C responds with a 10,000B web page (including headers) in a single packet. What is the response time for the web browser (i.e. the time between when the browser initiates the request until the page is received)? [5 marks]

Answer. *As the data rate of link 2 is 10 times that of link 1, the transmission delay is* $t_{BC} = 800\mu s$. *For the reverse direction, with the a packet 10 times larger we have:* $t_{CB} = 800\mu s$ *and* $t_{BA} = 80000\mu s$.

The propagation delay across link 1, which is half the length of link 2, is $p_{AB} = 100\mu s$.

Considering the processing delays at device A and C ($pr_A = pr_C = 100\mu s$)*, and the queuing delay at device B* ($q_B = 10000\mu s$)*, the total time to deliver the request from A to C is:*

$$\begin{aligned} req &= pr_A + t_{AB} + p_{AB} + q_B + t_{BC} + p_{BC} + pr_C \\ &= 100 + 8,000 + 100 + 10,000 + 800 + 200 + 100 \\ &= 19,300\mu s \end{aligned}$$

And to deliver the response:

$$\begin{aligned} resp &= pr_C + t_{CB} + p_{CB} + q_B + t_{BA} + p_{BA} + pr_A \\ &= 100 + 8,000 + 200 + 10,000 + 80,000 + 100 + 100 \\ &= 98,500\mu s \end{aligned}$$

Hence the response time is 117,800μs or 117.8ms.

(d) Consider an application on device A is transferring a 1GB file to device C. The protocol stack on device A splits the file into 10,000B segments, sending each segment as data in a packet. Every packet contains 200B of header. Assuming no errors in the network, what is the maximum throughput of the file transfer? [3 marks]

Answer. *Note that from A to C, the bottleneck link is from A to B. Although B can send to C at 10Mb/s, the file transfer is going to be limited by the 1Mb/s data rate from A to B. For each 10,000B of application data transferred, there is 200B of overhead. That is an efficiency of* $\frac{10{,}000}{10{,}200} = 98.0392\%$. *Hence the maximum throughput is 980,392b/s.*

Question 6 [9 marks]

Consider the following communications signals:

$$s_1(t) = 30\sin\left(2\times10^3\pi t\right) + 10\sin\left(6\times10^3\pi t\right) + 6\sin\left(1\times10^4\pi t\right) + 4.37\sin\left(1.4\times10^4\pi t\right)$$

$$s_2(t) = 30\sin\left(2\times10^3\pi t\right) + 15\sin\left(4\times10^3\pi t\right) + 10\sin\left(6\times10^3\pi t\right) + 7.5\sin\left(8\times10^3\pi t\right)$$

$$s_3(t) = 15\sin\left(2\times10^3\pi t\right) + 5\sin\left(6\times10^3\pi t\right) + 3\sin\left(1\times10^4\pi t\right)$$

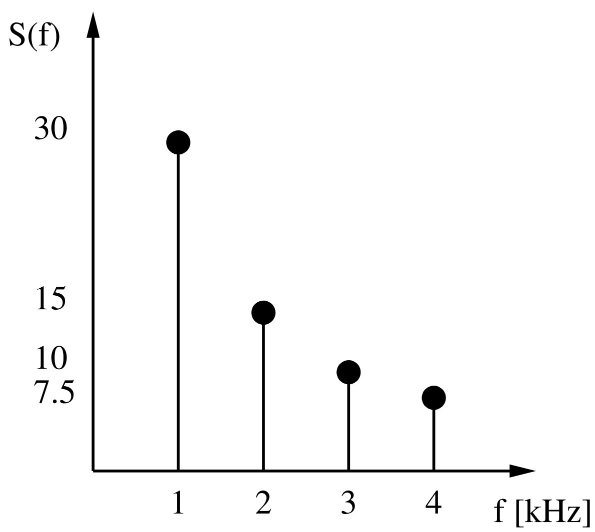
(a) What is the absolute bandwidth of $s_2(t)$? [2 marks]

Answer. *Maximum frequency component is 4000Hz, and the minimum is 1000Hz, hence the bandwidth is 3000Hz.*

(b) What is the period of $s_1(t)$? [2 marks]

Answer. *The components have frequencies 1KHz, 3KHz, 5KHz and 7KHz. All multiples of 1KHz, hence the fundamental frequency is 1KHz. The period is therefore 1ms.*

(c) Draw a plot of $s_2(t)$ in the frequency domain. [2 marks]



(d) Comparing signals $s_1(t)$ and $s_3(t)$ for transmitting digital data, what is an advantage of $s_1(t)$? [1.5 marks]

Answer. $s_1(t)$ *can produce a more accurate representation digital data, hence less errors.*

(e) Comparing signals $s_1(t)$ and $s_3(t)$ for transmitting digital data, what is an advantage of $s_3(t)$? [1.5 marks]

Answer. $s_3(t)$ *requires less bandwidth to transmit.*

Question 7 [8 marks]

(a) Consider the NRZI transmitted signal in Figure 1. What is the value of the data? [3 marks]

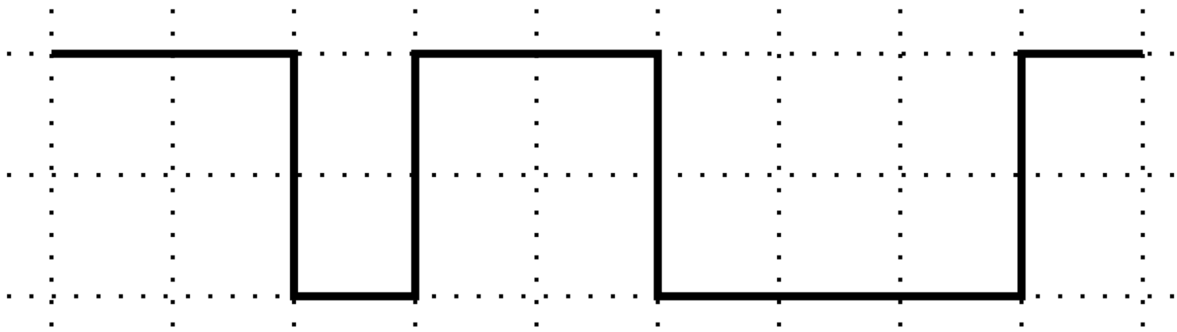


Figure 1: NRZI Signal

Answer. *001101001 (or the first bit as 1 is acceptable)*

(b) Bipolar-AMI is described as: 0 = no line signal; 1 = positive or negative level, alternating for successive ones. Consider the data 010011100. Draw the Bipolar-AMI signal on Figure 2. [3 marks]

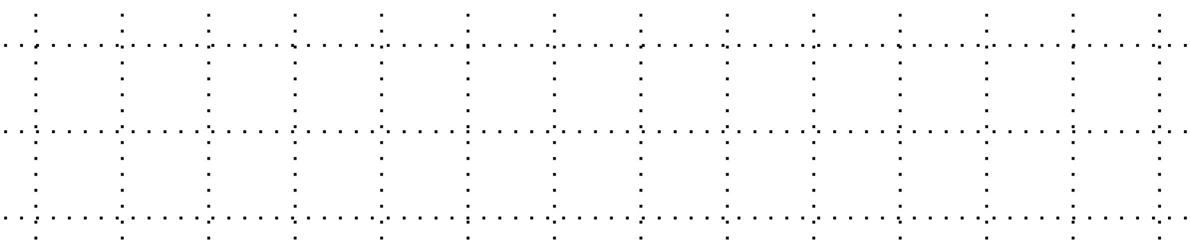
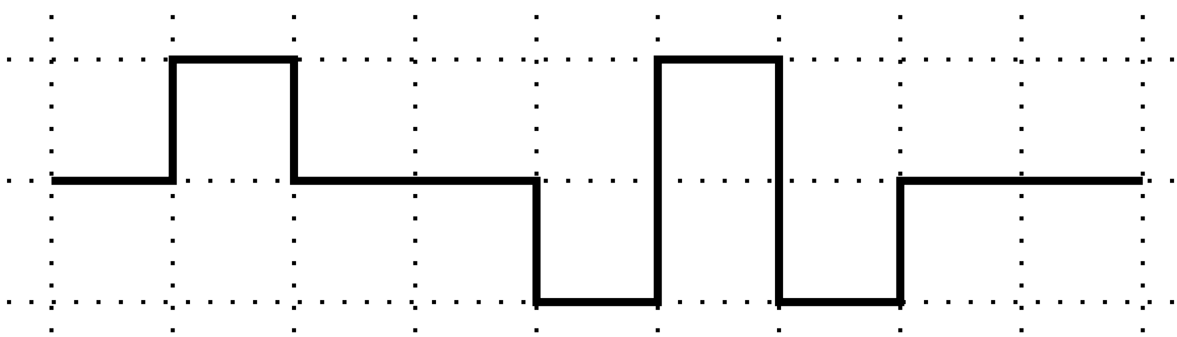


Figure 2: Draw the Bipolar-AMI signal

Answer. *The first bit 1 could be low or high (answer below uses high).*



(c) Explain how Bipolar-AMI provides error-detection, whereas NRZI does not. [2 marks]

Answer. *In Bipolar-AMI if a signal is received with two consecutive high (or low) levels, then an error is detected because the transmitted will never transmit with two consecutive high (or low) levels—it must always alternate between high and low.*

Question 8 [15 marks]

An audio recording application on Computer A used 4-bit PCM with a sampling rate of 10KHz to create the data: 101101100011010110011100. The data was sent to computer B.

(a) Draw the reproduced data at computer B on Figure 3. [5 marks]

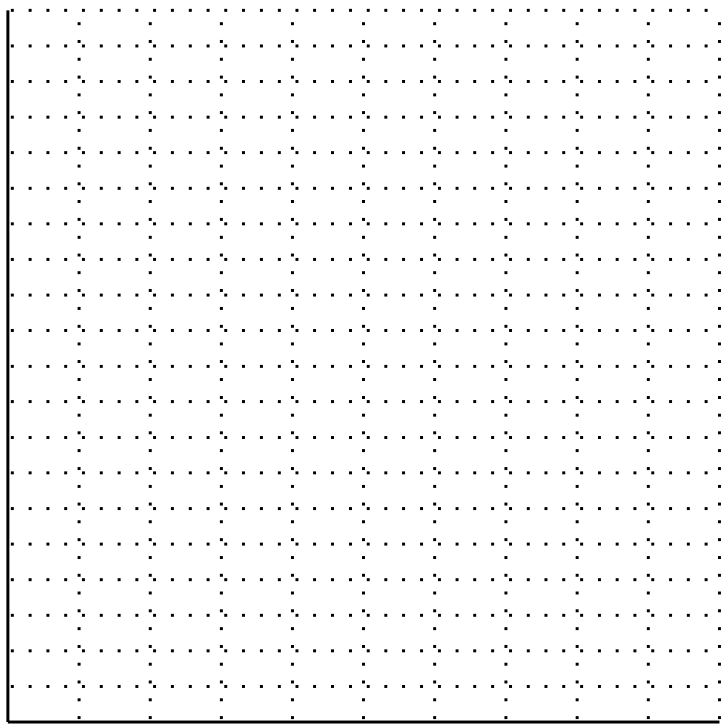


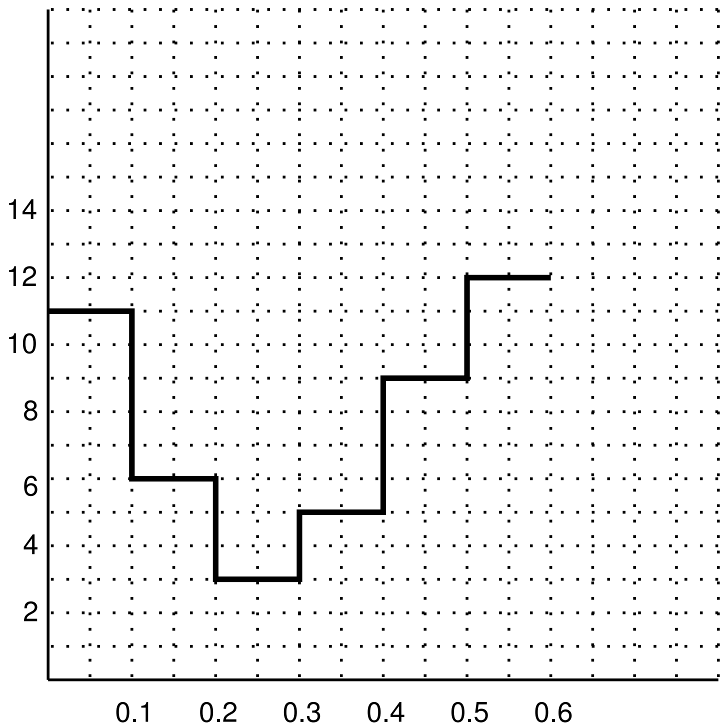
Figure 3: Draw the reproduced data

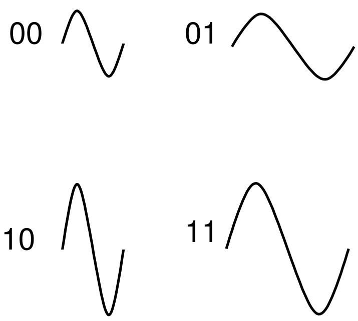
(b) To transmit the data from A to B, a combination of ASK (2 levels) and FSK (2 levels) are used. Design an appropriate shift keying scheme by selecting and drawing a possible combination of mapping signal elements to data. [3 marks]

Answer. *There are four signal elements: amplitude low, frequency low; amplitude low, frequency high; amplitude high, frequency low; amplitude high, frequency high. Each element is mapped to one of the four possible 2-bit values: 00, 01, 10, 11. One possible answer, and the answer used in part (c) is drawn below.*

(c) What is the ideal sampling rate if the original audio input signal is as shown shown in Figure 4? [2 marks]

Answer. *The input audio has a maximum frequency component of 8KHz. According to the sampling theorem, the sampling rate should be twice the maximum frequency component which is 16KHz.*





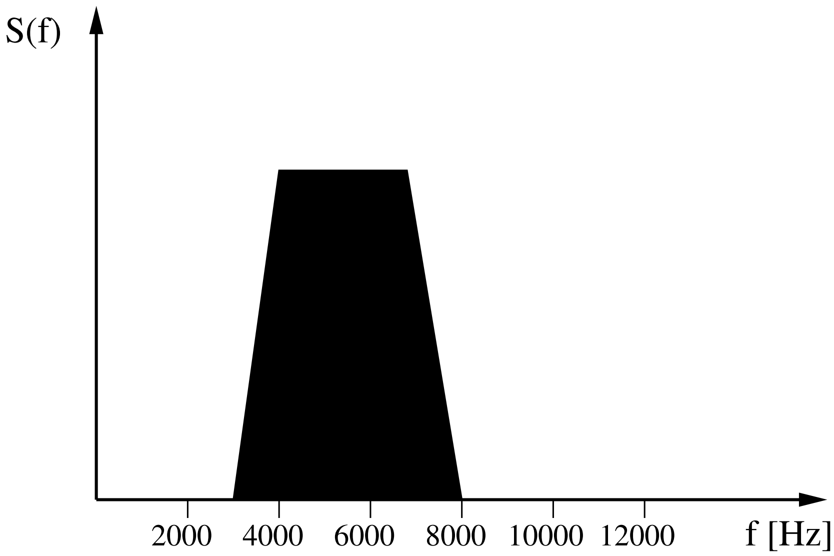


Figure 4: Frequency domain plot of original audio input

(d) If instead of sending to B, the application on computer A saved the data to a file, how large would the file be for a 10 minute recording? [3 marks]

Answer. *Each sample is 4 bits, there are 10,000 samples per second, therefore 40kb/s. 10 minutes is 600 seconds, meaning the file will be 24Mbits or 3MB.*

(e) What are the two methods that the application on computer A use to increase the quality of the reproduced audio? [2 marks]

Answer. *Increase the sampling rate and increase the number of bits per sample*