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

Sirindhorn International Institute of Technology
Thammasat University

Midterm Examination: Semester 1/2008

Course Title : ITS 323 – Introduction to Data Communications

Instructor : Dr Steven Gordon

Date/Time : Thursday 31 July 2008, 13:30 – 16:30

Instructions:

- This examination paper has __ pages (including this page).
- Condition 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.
- Turn off all communication devices (mobile phone etc.) and leave them under your seat.
- Write your name, student ID, section, and seat number clearly on the answer sheet.
- The space on the back of each page can be used if necessary.
- Assume bits are ordered from left to right: 1st bit, 2nd bit, 3rd bit, … nth bit
- Unless stated in the question, you can assume the speed of transmission is 3 x 10^8m/s
- Free space propagation loss equation:

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

- Antenna gain for parabolic antenna with area A:

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

Part A - Multiple Choice Questions [26 marks]

Select the most accurate answer (only select one answer). Each correct answer is worth 2 marks.

1. Which of the following three acronyms refer to organizations that create telecommunications and Internet standards?
   a) ISO, IEEE and IP
   b) ISO, IEEE and IETF
   c) ICT, IEEE and IP
   d) OSI, IEEE and IP
   e) OSI, IEEE and IETF
   f) IETF, OSI and IP

2. ~~Computer A sends 6 bits of data plus a single odd parity bit (as the first bit) to Computer B. A single bit error occurs during the transmission. Computer B receives the bits 0011010. Which of the following statements can you be certain are true?~~
   ~~a) The original 6 bits of data was 011010~~
   ~~b) The original 6 bits of data had an even number of 1's~~
   ~~c) The original 6 bits of data had an odd number of 1's~~
   ~~d) The parity bit was transmitted as a 1~~
   ~~e) The receiver can detect the error~~
   ~~f) None of the above~~

3. Which technique is designed for transmitting analog data as analog signals:
   a) Pulse Code Modulation
   b) Binary Frequency Shift Keying
   c) Phase Modulation
   d) Manchester Encoding
   e) Quadrature Amplitude Modulation
   f) Non Return to Zero Invert on Ones

4. A multiplexer using FDM has 20 input lines each using a bandwidth of 40kHz. Which of the following statements can you be certain are true?
   a) Each input signal is assigned a time slot for transmission on the output line
   b) The bandwidth of the output line must be greater than or equal to 800kHz
   c) All input signals must be modulated to the same carrier frequency for transmission on the output line
   d) The bandwidth of each input signal must be reduced to 2kHz to be transmitted on the output line
   e) All of the above
   f) None of the above

5. Unshielded twisted pair:
   a) Is used in many fixed line telephone networks and LANs
   b) Provides higher data rates than coaxial cable
   c) Is no longer used because of the low data rates
   d) Is affected less by interference from other twisted pairs, than optical fibre

e) Carries light waves across glass fibres
f) Can be used to transmit over longer distance than optical fibre
g) None of the above

6. A transmission system that provides half-duplex communications between A and B:
   a) If A is sending to B, then B cannot send to A at the same time
   b) Only allows A to send to B
   c) Only allows B to send to A
   d) If A is sending to B, then B can send to A at the same time
   e) Allows both A and B to transmit to each other at the same time

7. If a signal has a wavelength of 6000km, then what is that signals period:
   a) 200 ms
   b) 50000 Hz
   c) 2 ms
   d) 20 ms
   e) 2 s
   f) 50 Hz
   g) 0.05 Hz

8. The Internet Protocol (IP) would normally be implemented:
   a) In an Ethernet or Wireless LAN card
   b) As part of web browser (e.g. Firefox, Internet Explorer)
   c) As part of a new application (such as file sharing or instant messaging)
   d) As part of the operating system
   e) In hardware to perform transmission of bits as analog or digital signals
   f) None of the above

9. What is the minimum bandwidth required to transmit at 500kb/s if the signal power level is 93mW and the noise power level is 3mW? (The answer is in the nearest kHz)
   a) 50 kHz
   b) 100 kHz
   c) 17 kHz
   d) 125 kHz
   e) 415 kHz
   f) 200 kHz

10. If a transmission system uses 16 signal levels, and has a signaling rate of 200 signals per second, then what is the maximum possible data rate?
    a) 100 bps
    b) 200 bps
    c) 600 bps
    d) 800 bps
    e) 1000 bps
    f) 3200 bps

11. What layers are in the OSI layered model, but not in the Internet layered model:
    a) Presentation, Session

b) Transport, Session
c) Hardware, Presentation
d) MAC, Presentation
e) Hardware, Transport
f) Hardware, Session
g) MAC, Session
h) MAC, Transport
i) Hardware, MAC

12. If ten packets sent in a computer network experience the delays as given below, then the jitter is (rounded to the nearest millisecond):

Packet	1	2	3	4	5	6	7	8	9	10
Delay (ms)	14	5	7	7	8	8	9	12	12	10

a) 1 ms
b) 2 ms
c) 3 ms
d) 4 ms
e) 8 ms
f) 9 ms
g) 10 ms

13. Which of the following is an example of a MAC address:
a) www.siit.tu.ac.th
b) steve@siit.tu.ac.th
c) 00:17:31:7E:50:7D
d) 125.61.3.28
e) Port 80
f) None of the above

Part B – General Questions [94 marks]

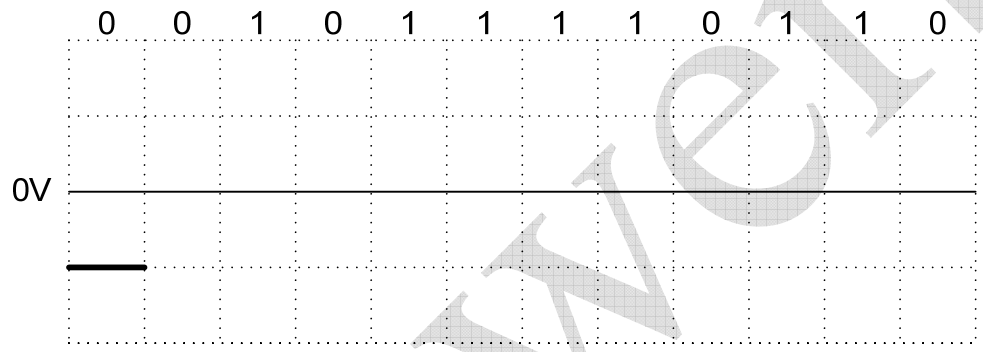
Question 1 [15 marks]

The following sequence of bits are to be transmitted across a link.

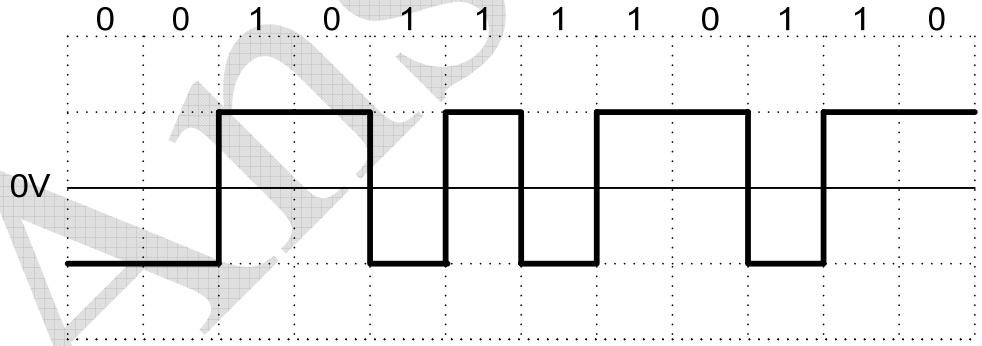
0 0 1 0 1 1 1 1 0 1 1 0

Consider the following options for transmitting the bits.

a) The bits are to be sent over a digital signal using Non-Return to Zero Invert on Ones (NRZI) encoding. Complete the digital waveform below. The value of the first bit is shown. [3 marks]



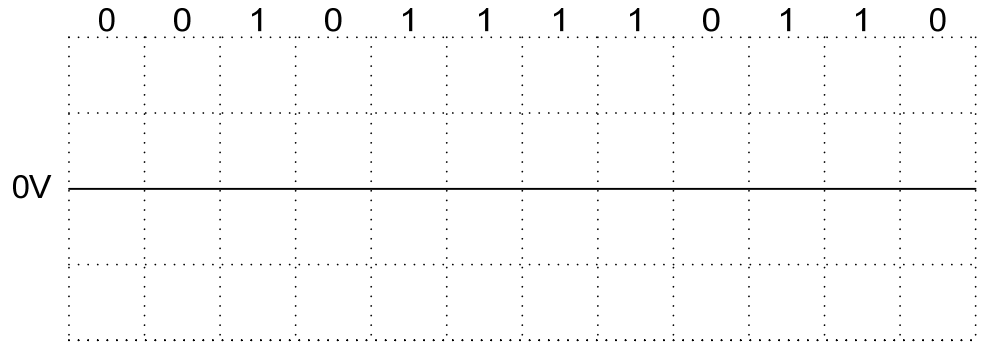
Answer



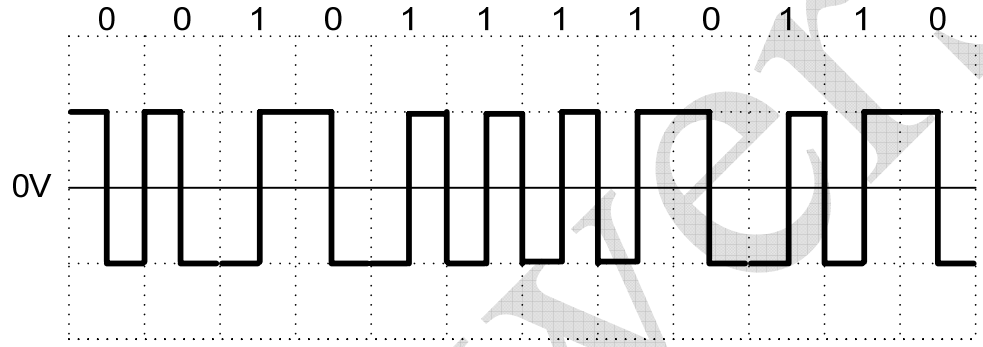
b) The bits are to be sent over a digital signal using Manchester encoding. Manchester encoding has the following rules:

0 = transition from high to low in the middle of the interval
1 = transition from low to high in the middle of the interval

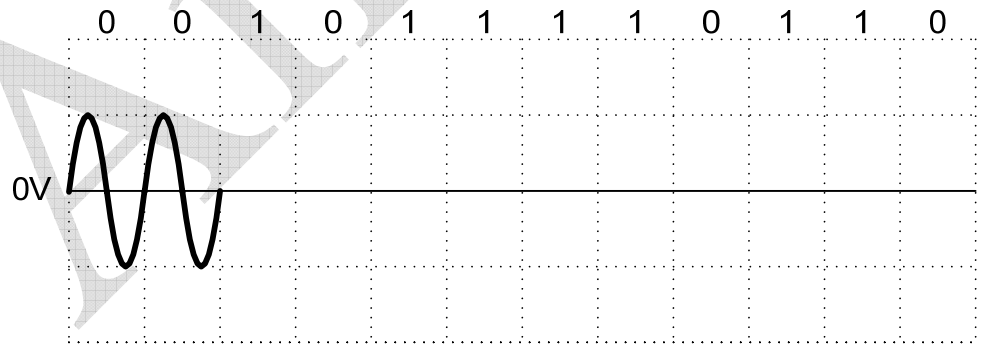
Complete the digital waveform below. [5 marks]



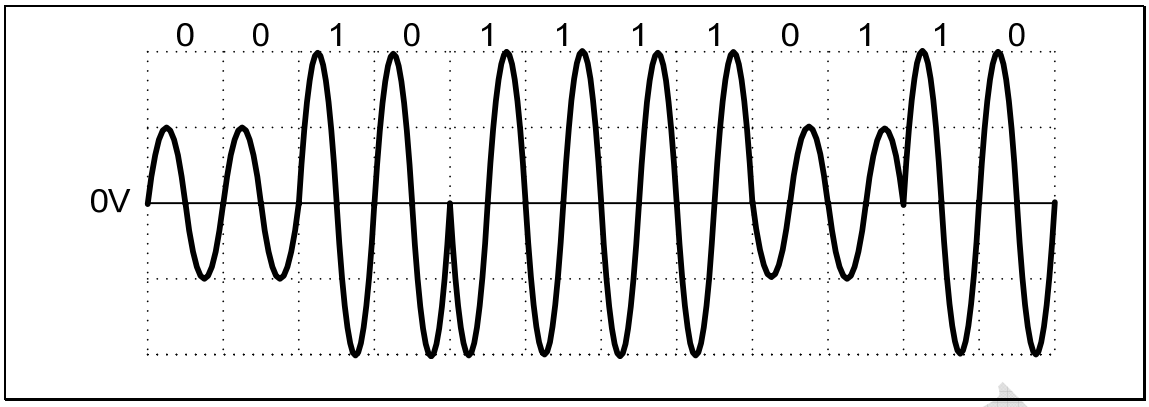
Answer



c) The bits are to be transmitted over an analog signal using a Quadrature Amplitude Modulation (QAM). QAM uses a combination of Binary Amplitude Shift Keying and Binary Phase Shift Keying (where the phase is shifted by 90 degrees). Complete the analog waveform below. The signal for the first two bits is shown. [5 marks]



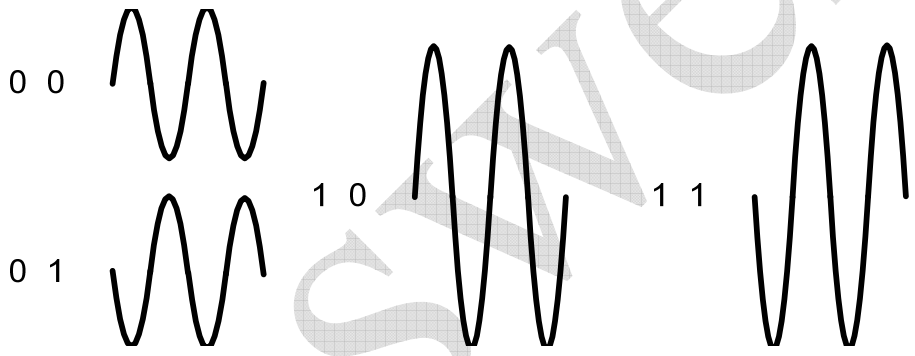
Answer



d) Explain the encoding scheme you used in part (c). [2 marks]

Answer

The mapping from pairs of digits to signals follows this scheme:



Question 2 [8 marks]

You are asked to design a point-to-point wireless link between two buildings. The location of the antenna's on the buildings are fixed (cannot be moved) and are separated by a distance of 2 km. The transmitting antenna is parabolic with a radius of 50cm and the receiving antenna is parabolic with a radius of 25cm. The receiving device has a receive power threshold of -40dBmW. Assume the wireless link uses a frequency of 300MHz.

a) Assuming free space propagation (see front page), calculate the minimum required transmit power to establish the link. [5 marks]

Answer

$$P_r = 10^{-40/10}$$
$$= 10^{-4}\, mW$$
$$P_t > P_r \frac{(4\pi d)^2}{G_t G_r \lambda^2}$$
$$= P_r \cdot \frac{16.\pi^2.4\times 10^6}{\frac{4\pi^2(0.5)^2}{\lambda^2}\cdot\frac{4\pi^2(0.25)^2}{\lambda^2}.\lambda^2}$$
$$= P_r \cdot \frac{64\pi^2\times 10^6}{\frac{16\pi^4\ 1/4\ 1/16}{\frac{(3\times 10^8)^2}{(3\times 10^8)^2}}}$$
$$= P_r \cdot \frac{256}{\pi^2}\times 10^6$$
$$= 10^{-7}\times 10^6 \times \frac{256}{\pi^2}$$
$$= 2.594W$$

b) After tests, you determine with the calculated transmit power level connectivity can still not be maintained (that is, receive power is not above the threshold). What is a practical option for maintaining the link? Explain a disadvantage of the option. [3 marks]

Answer

Option 1: Increase the transmit power (which will increase receive power). The disadvantage is that by using more power, there will be a higher cost for electricity (or for example, battery drainage occurs faster).

Option 2: Increase the antenna sizes. Disadvantage is that you will need to by larger antennas.

Option 3: change the receiver so it has lower receive power threshold. Again, you need to buy a new, better receiver (higher cost).

Question 3 [21 marks]

Figure 1 shows analog data to be converted to digital data using Pulse Code Modulation (PCM). The sampling times are shown as vertical lines (that is, there are 10 samples, since there are 9 dotted vertical lines plus the initial sample at time 0).

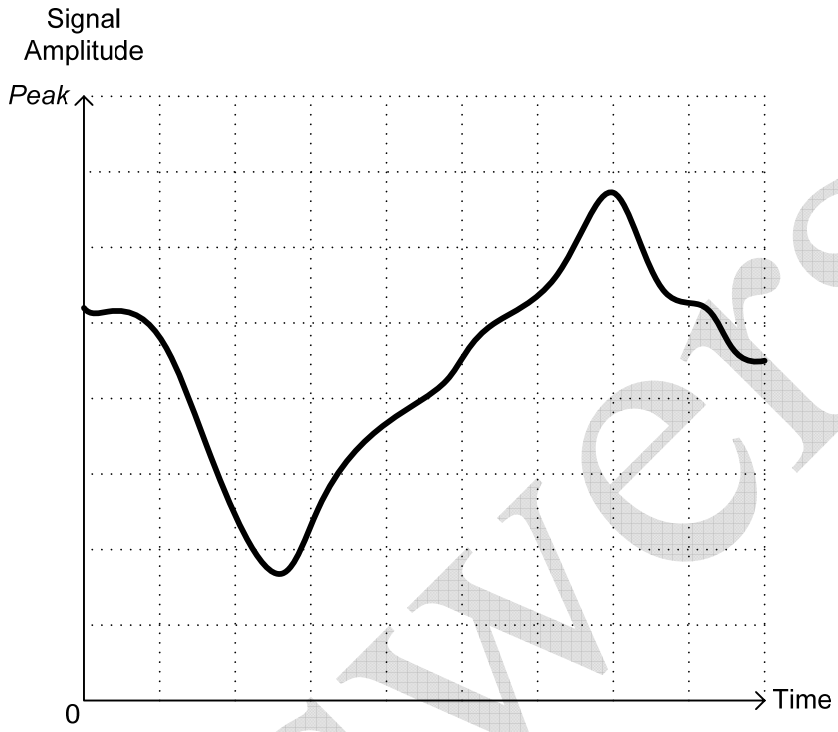


Figure 1: Analog data

a) Assuming each sample will be represented by a 3-bit code, what is the digital data to be transmitted for the signal in Figure 1 if using PCM? Assume the signal amplitude may range between 0 and *Peak*. [4 marks]

Answer

With a 3-bit code, the levels range from 0 to 7. There are 8 "rows" in Figure 1 (row0, row 1, …, row 7), so if the signal lies in a row at the start of the sample period, then the row number is used for the output code. At time 0, the sample lies in the 6th row, hence code 5 is used. The output data will be:

Code	5	4	2	2	3	4	5	6	5	4
Binary	101	100	010	010	011	100	101	110	101	100

b) On Figure 2, draw the analog output at the receiver. (Hint: the first portion of the data is already given; also, you only need to draw the output from the first 9 samples). [4 marks]

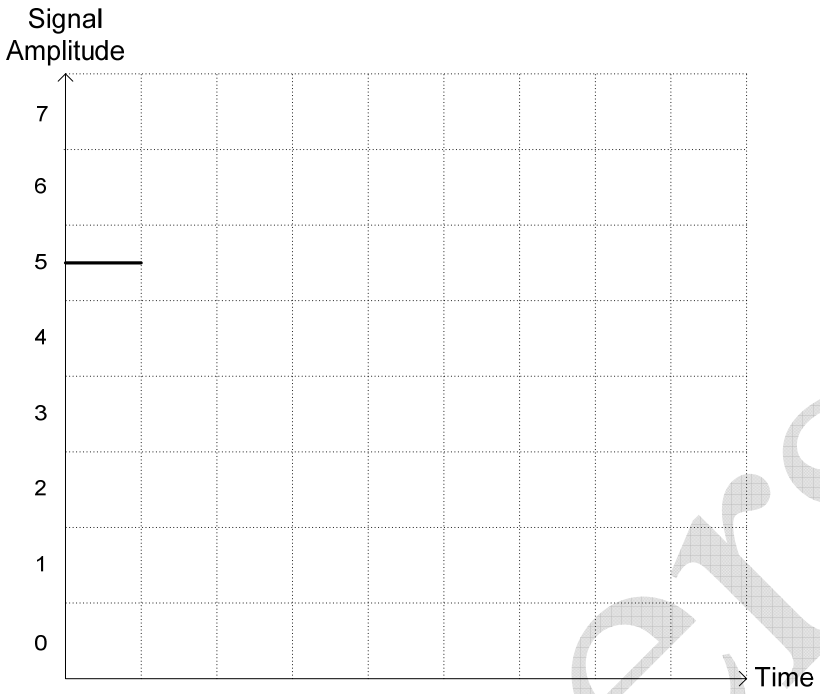
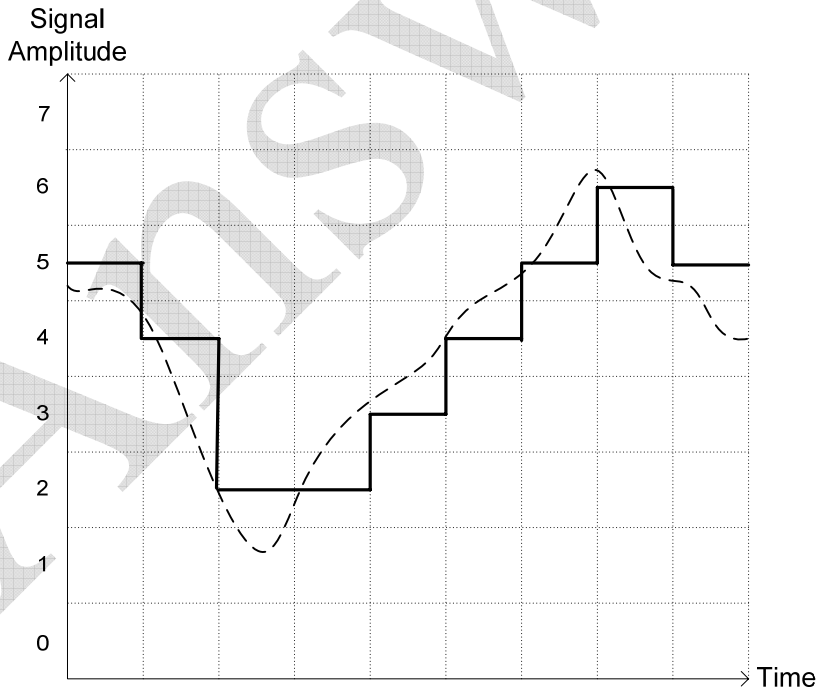


Figure 2: Draw the analog output at the receiver if PCM is used

Answer



An alternative to PCM is Delta Modulation (DM). In DM, a "staircase" function is created based on the analog input data. When the analog input is sampled, if the analog input value is greater than the previous staircase value, then the staircase goes up one level; else, the staircase goes down one level. The digital output is derived

directly from the staircase function: if the staircase level goes down, a bit 0 is output; if the staircase level goes up, a bit 1 is output. The step size of the staircase is called delta, δ. Figure 3 gives an example of Delta Modulation. Assume that the first staircase level is the level below the sampled analog input at time 0, and produces a bit 0 as output.

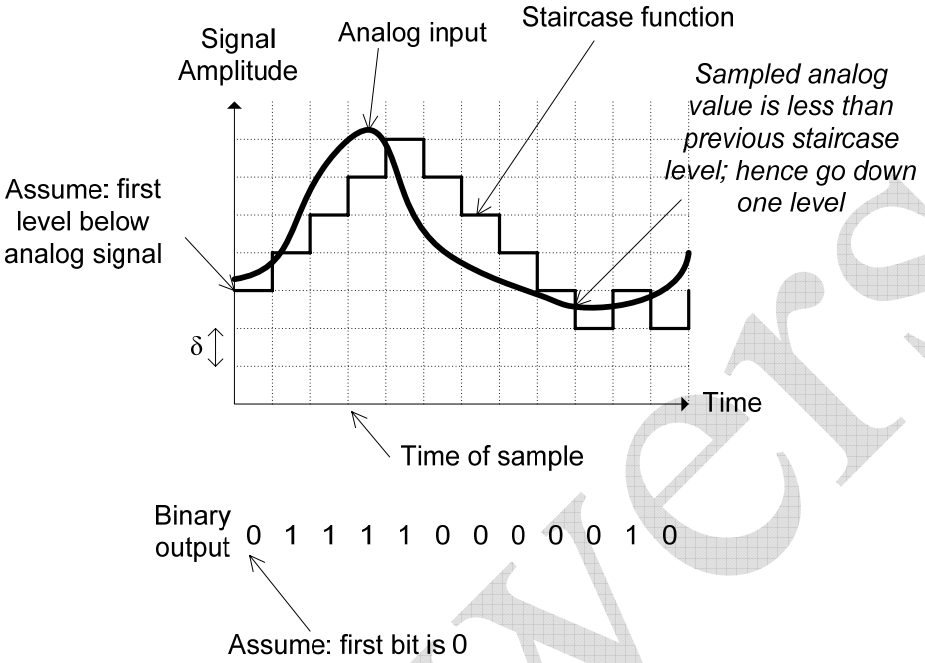


Figure 3: Delta Modulation example

c) For the analog data in Figure 1, draw the staircase function if Delta Modulation is used. (Hint: the first level is already given). Note that this staircase function will be equivalent to the analog output at the receiver. [4 marks]

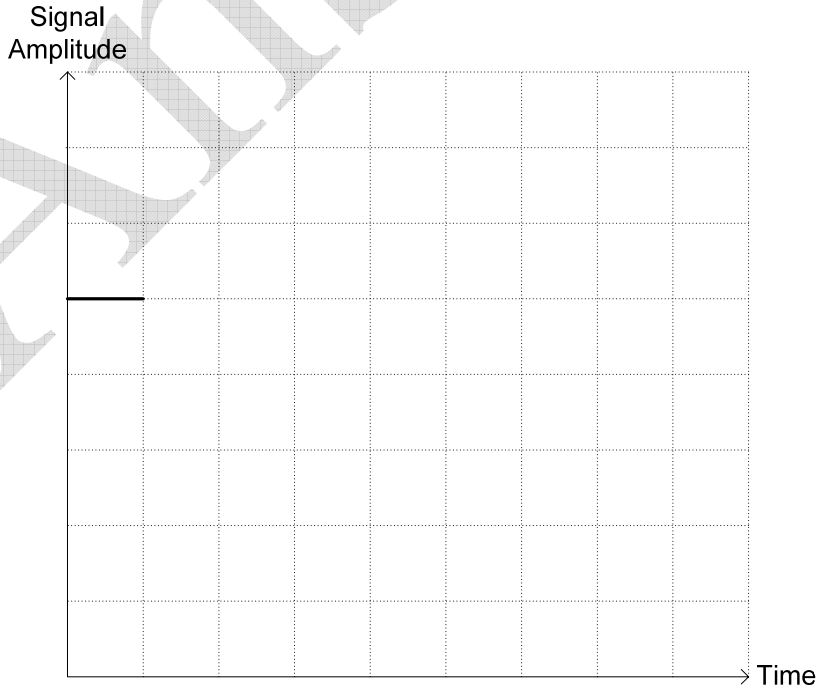
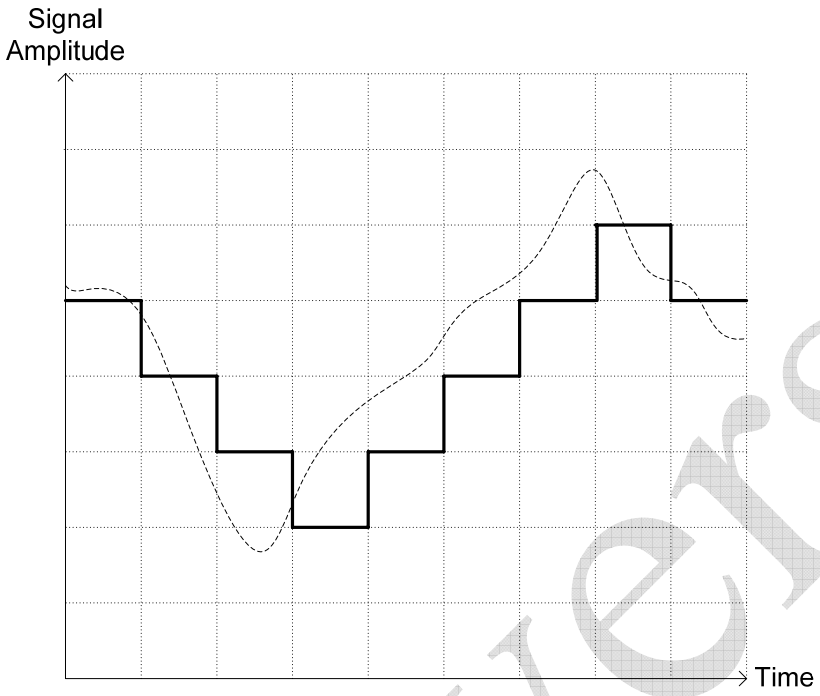


Figure 4: Draw the staircase function for Delta Modulation

Answer



d) What is the digital data to be transmitted if using DM? [3 marks]

Answer

0 0 0 0 1 1 1 1 0

Assume the original analog data in Figure 1 has a bandwidth of 50kHz.

e) What is the minimum sampling interval (that is, time between samples) to accurately sample the analog data? [1 mark]

Answer

According to the sampling theorem, the sampling rate should be twice the bandwidth, that is 100,000 samples per second. Therefore the sampling interval should be 10μs.

f) What data rate is required for the following schemes to send the data:
   i. Pulse Code Modulation [1 mark]
   ii. Delta Modulation [1 mark]

Answer

PCM: 100,000 samples per second. Each sample is 3 bits. 300kb/s.
DM: 100,000 samples per second. Each sample is 1 bit. 100kb/s.

g) Increasing the sampling rate is one method for increasing the accuracy of a PCM signal. Explain another approach to increasing the accuracy, referring to the PCM encoder in part (a) as an example. Also indicate any disadvantages of this approach. [3 marks]

Answer

Increasing the number of levels can increase the accuracy. That is, each level is represented by more bits, say a 4-bit code (16 levels) provides a more accurate signal than a 3-bit code (8 levels). The disadvantage is the data rate required is increased. A 4-bit code requires 400kb/s (as opposed to 300kb/s).

Question 4 [15 marks]

Consider a link between A and B using Selective Reject ARQ. The link has the following characteristics:

- Distance: 10km
- Data rate: 1Gb/s
- Transmission speed: 2 x 10^8 m/s
- All DATA frames contain 9900 bits of data and 100 bits of header
- All ACK frames contain 100 bits of header
- The receiver sends an ACK for every frame successfully received
- There is no processing or queuing delay
- There are full duplex lines between the nodes.

For parts (a) and (b) assume there are no errors, and the maximum window size W_{max}=8:

a) How many bits of the header are used for the sequence number? [1 mark]

Answer

With W_{max} = 8 with Selective Reject, the number of bits (k) for the sequence number is 4, since $W_{max} = 2^{k-1}$.

b) What is the maximum throughput that can be achieved from A to B? [5 marks]

Answer

Propagation time: 50µs
Data transmission time: 10µs
ACK transmission time: 0.1µs

To send the Window size of frames, it takes 8 x 10µs = 80µs. However, the time to receiver the first ACK is: 10 + 50 + 0.1 + 50 = 110.1µs. Therefore, after sending W_{max} frames, the source must wait for the first ACK before sending the next frame. The maximum throughput is then:
8 x 9900 bits / 110.1µs = 719.34Mb/s

For part (c) assume there are no errors, and the maximum window size W_{max} = 16:

c) What is the maximum throughput that can be achieved from A to B? [5 marks]

Answer

To send the Window size of frames, it takes 160μs. Therefore, the source can send 16 frames, and it will receive an ACK before the 16th frame is sent, and hence can immediately transmit subsequent frames after the 16th. Therefore the maximum throughput is:
16 x 9900 / 160μs = 990Mb/s

d) Discuss what happens to the maximum throughput if W_{max} is increased to values larger than 16. Include a discussion of the most appropriate value of W_{max} (including your reason why it is most appropriate). [4 marks]

Answer

For W_{max} >= 16, the source can always send the W_{max} frames, receive ACKs before the last of the W_{max} frames are sent, therefore immediately sending the next frames. The throughput will be:

W x 9900 / W x10μs = 990Mb/s

That is, the throughput will not change.

Therefore, a W_{max} of 16 is most appropriate as it deliver maximum throughput. A larger value will not increase throughput but increases the buffer needed at receiver. A smaller value requires a small buffer, but decrease the throughput.

Question 5 [10 marks]

Assume a Time Division Multiplexer (TDM) is used with 5 input lines from users A, B, C, D and E, and a single output line. The time slot is 4μs and blocks of data on the input lines are 1 byte per time slot.

a) If synchronous TDM is used, what is the data rate required of the output line? Assume the output frame has no overheads. [1 mark]

Answer

The maximum amount of traffic generated by each input line is 2Mb/s. Hence the output data rate required for Synchronous TDM is 10Mb/s.

Assume each user (on average) utilises the input links at the following rates:

User	*Input link utilisation*
A	60%
B	70%
C	50%
D	50%
E	70%

Table 1: Utilisation of input links for each user

(For example, user A only sends data in 60% of the time slots on the input line).

b) With synchronous TDM, what is the utilisation (efficiency) of the output link? [4 marks]

Answer

User A generates 60% of 2Mb/s = 1.2Mb/s
Users B and E generate 70% of 2Mb/s = 1.4Mb/s each
Users C and D generate 50% of 2Mb/s = 1Mb/s each
Total sent over the 10Mb/s output line is 6Mb/s. Efficiency is 60%.

c) If Statistical TDM was used instead of Synchronous TDM, what is the minimum data rate of the output link required? Assume that there is an overhead incurred, which is 10% of the total amount of data to be transmitted by the users (remember, Table 1 indicates the amount of data a user transmits).[3 marks]

Answer

Total data generated is 6Mb/s. There is a 10% overhead when using Statistical TDM, therefore output data rate should be 6.6Mb/s.

d) In general, when the input data traffic varies over time (and users to do not fully utilise their input line data rate) when using Statistical TDM a lower output data rate can be used (compared to Synchronous TDM). Explain a disadvantage of Statistical TDM. [2 marks]

Answer

When the input data peaks (e.g. over a short period the combined input traffic is say 8Mb/s), then either some data will be dropped (not sent) or data will have to be buffered (requiring extra memory, and incurring delays).

Question 6 [9 marks]

Figure 5 and Figure 6 show a portion of the signals $s_1(t)$ and $s_2(t)$, respectively.

a) For each signal, calculate the maximum data rate that can be achieved if the system bandwidth is limited to 36MHz. You can assume only 2 signaling levels are used. [8 marks]

$$s_1(t) = \sin(2\pi ft) + \tfrac{1}{3}\sin(2\pi 3ft) + \tfrac{1}{5}\sin(2\pi 5ft)$$

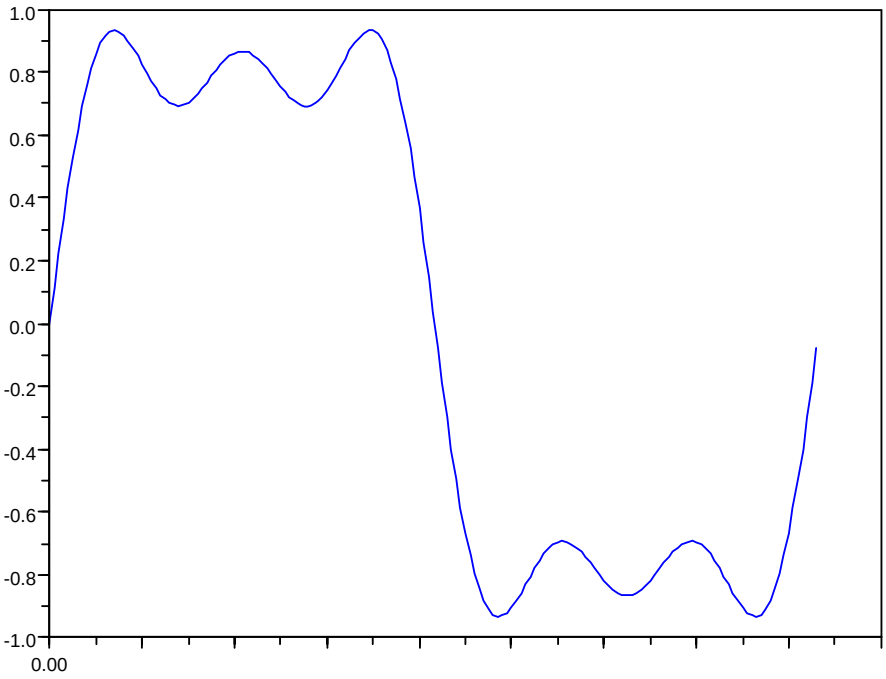


Figure 5

Answer

The bandwidth of s_1 is 4f = 36MHz, and hence the frequency must be 9MHz. Therefore the period of the signal is 1/9μs. Assuming a high level is 1 bit and a low level is another bit, there can be two bits sent per period. That is, 2 bits per 1/9μs. Therefore maximum data rate is 18Mb/s.

$$s_2(t) = \sin(2\pi ft) + \tfrac{1}{3}\sin(2\pi 3\,ft) + \tfrac{1}{5}\sin(2\pi 5\,ft) + \tfrac{1}{7}\sin(2\pi 7\,ft) + \tfrac{1}{9}\sin(2\pi 9\,ft)$$

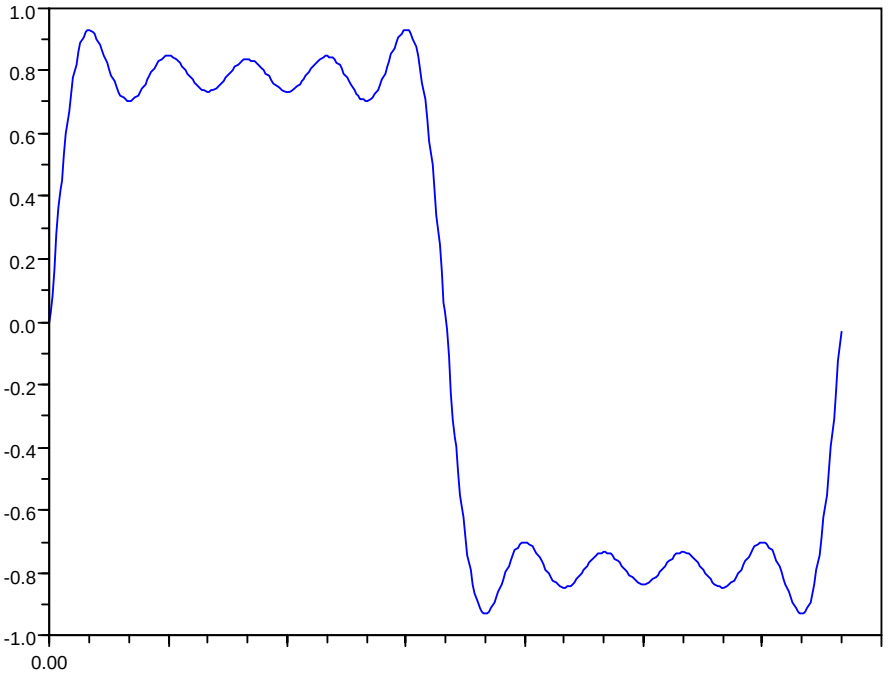


Figure 6

Answer

The bandwidth of s_2 = 8f = 36MHz, hence frequency is 4.5MHz. Following same calculations as previous signal, the data rate is 9Mb/s.

b) What is an advantage of $s_2(t)$ compared to $s_1(t)$? [1 mark]

Answer

Although offering a lower data rate, less errors are likely to occur if $s_2(t)$ is used.

Question 7 [6 marks]

The frame rate of a web camera attached to your computer is 24 frames per second, where each frame is an image of 640 x 480 pixels. Each pixel uses a 16 bit value to represent a single colour. Before sending the video data from the web camera to your computer (e.g. via a USB cable), the web camera software compresses the video data, so that the compressed data is 1% of the original data size.

a) What is the data rate required to transmit the (compressed) video from the web camera to your computer? [3 marks]

Answer

Original data rate = 24 frames x 640 x 480 pixels x 16 bits
= 117,964,800 bps
Compressed data rate = 0.01 x 117,964,800 bps
= 1.179 Mb/s

b) What is the minimum bandwidth required on the USB cable (connecting web camera to computer) if there was a signal-to-noise ratio of 20dB? [3 marks]

Answer

According the Shannon's theorem:

Data rate = Bandwidth x $\log_2 (1 + SNR)$

SNR $= 10^{20/10}$
$= 100$

Bandwidth = 1.179Mb/s / (6.658)
= 177kHz

Question 8 [10 marks]

Consider a simple communications system that uses only three layers: Physical layer, Data Link layer and Application layer. The protocols at each layer perform the following operations:

- Application layer: receives a photo (as digital data) from the user, divides the photo into segments no larger than *X* bytes, and then attaches a 25 byte header to each segment. Each resulting message (*X* byte segment plus 25 byte header) is sent one at a time to the Data Link layer. *X* is called the *segment size.*
- Data Link layer: receives a message from the Application layer, adds a 10 byte header and a 5 byte trailer (which includes a CRC code for error detection), and sends the resulting frame to the Physical layer.
- Physical layer: receives a frame from the Data Link layer, and encodes every 4 bits in a single signal element, sending the signal elements over the link to the destination.

Assume the signalling rate used by the Physical layer is 1,500,000 signal elements per second.

a) If the segment size (*X*) is 1000 bytes, what is the throughput if a 100,000 byte photo is sent? [6 marks]

Answer

Note that the data rate is 6Mb/s (1.5Msignals/sec, where each signal is 4 bits).
With segment size of 1000 bytes, the Application layer will divide the photo into 100 messages, each with 25 byte header. For each message, the Data Link layer adds an extra 15 bytes of overhead. Total bytes to be sent are:

100 x (1000 + 25 + 15)	=	104000 bytes
Amount of real data	=	100000 bytes
Throughput	=	(100,000/104,000) * 6Mb/s
	=	5.769Mb/s

b) What is the impact of the segment size on the throughput? That is, explain what happens to the throughput if the segment size is increased or decreased, and the reason why. [2 marks]

Answer

Increasing the segment size will increase the throughput. This is because the overhead (40 bytes) will be a smaller percentage of the total data sent in each segment.

c) Explain a good reason for using a small segment size. [2 marks]

Answer

Reduce impact of errors. If there is a bit error rate, then the smaller the packet, the less that needs to be retransmitted in case that packet contains an error.
Fairness. Using small packets gives other users an opportunity to send. User A sends a small packet, then user B sends a small packet (one user cannot steal the transmission medium for a long time).
Smaller buffers needed. The receiver can handle multiple small packets in a buffer, but may not be able to store a very large packet in the same sized buffer (thereby limiting the use of flow and error control mechanisms).