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

Sirindhorn International Institute of Technology
Thammasat University

Midterm Exam Answers: Semester 1, 2012

Course Title: ITS323 Introduction to Data Communications

Instructor: Steven Gordon

Date/Time: Tuesday 14 August 2012; 13:30–16:30

Instructions:

- This examination paper has 15 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:

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

- Nyquist capacity:

$$C = 2B\log_2(M)$$

- Shannon capacity:

$$C = B\log_2(1 + SNR)$$

Prepared by Steven Gordon on 20 August 2012
ITS323Y12S1E01, Steve/Courses/2012/s1/its323/assessment/midterm-exam.tex, r2450

Question 1 [30 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.

accuracy	guided	omnidirectional
analog data	half-duplex	optical fibre
analog signal	hardware address	physical
analog transmission	header	point-to-point
application	HTTP	port number
attenuation	IEEE	simplex
coaxial cable	IETF	spectrum
data link	IP address	TCP
delivery	IPv4	timeliness
digital data	IPv6	trailer
digital signal	ISO	transport
digital transmission	isotropic	twisted pair
directional	LAN	unguided
frequency	multipoint	WAN
full-duplex	network	wavelength
gain	noise	-

Table 1: Possible answers for Question 1

(a) The application layer protocol used by web browsers to download web pages is *HTTP*.

(b) The most common network layer protocol in use today is *IPv4*.

(c) The standards organisation that develops and maintains standards for wired and wireless LANs is *IEEE*.

(d) When data is passed between layers it is often encapsulated in a packet, where the packet may contain a *header*, the data and a trailer.

(e) Comparing common guided transmission media, *optical fibre* allows for transmission of signals with a much greater bandwidth than coaxial cable.

(f) A home ADSL modem takes *digital data (or digital signal)* as input from your computer and transmits a/an *analog signal* across the telephone line.

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

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

(i) An example of *simplex* communications is when a computer can receive data from a server over a link, but that computer cannot send data to the server.

(j) In *analog transmission*, amplifiers are used to cover a long distance with multiple links.

(k) Wireless communication uses a/an *unguided* medium.

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

(m) 192.168.1.1 is an example Internet address. This type of address is part of the *network* layer.

(n) When a LAN card is manufactured it is normally assigned a/an *hardware address*, which is part of the data link layer.

(o) A common measure of an antenna characteristic is to consider the gain of its signal strength in one direction compared to when using a/an *isotropic* antenna.

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

(q) Increasing the size of a parabolic antenna will generally lead to an increase in *gain*.

(r) Satellite TV distribution involves two links: transmitting from TV station to the satellite and then from satellite to homes. The second link, from satellite to homes, has a *multipoint (or simplex)* configuration.

(s) As the distance a signal needs to propagate increases, the *attenuation* of that signal increases.

(t) The *transport* layer includes the task of reliable delivery of data between application processes.

Question 2 [10 marks]

An encoding scheme maps 10 bits of digital data into 1 signal element.

(a) In a noise-free environment with a bandwidth of 20MHz, what is the maximum theoretical data rate possible? [3 marks]

Answer. *With 10-bits to 1 signal element, 1024 different levels (signal elements) are needed to represent any sequence of bits. As it is assumed no noise is present, Nyquist capacity equation can be used to find the maximum theoretical data rate, C:*

$$\begin{aligned} C &= 2B\log_2(M) \\ &= 2 \times 20 \times 10^6 \times \log_2(1024) \\ &= 400Mb/s \end{aligned}$$

(b) If the level of noise was measured to be 26.877dBm and the received signal strength of 33dBW for a communications channel with bandwidth of 30MHz, what is the maximum theoretical data rate possible? [4 marks]

Answer. *A noise level of 26.877dBm is equivalent to $10^{2.6877}$ mW or $10^{-0.3123}$ W. A signal strength of 33dBW is equivalent to $10^{3.3}$ W. Given the signal and noise levels, Shannon's capacity equation can be used to find the maximum theoretical data rate, C:*

$$\begin{aligned} C &= B\log_2(1 + SNR) \\ &= 20 \times 10^6 \times \log_2(1 + \frac{10^{3.3}}{10^{-0.3123}}) \\ &= 360Mb/s \end{aligned}$$

(c) In the noisy channel of part (b) what is the number of bits per signal element needed to achieve the maximum theoretical data rate? [3 marks]

Answer. *Here we make some approximations. Even though we know the channel has noise, we will apply Nyquist's capacity equation to determine the number of levels needed.*

$$\begin{aligned} C &= 2B\log_2(M) \\ 360 \times 10^6 &= 2 \times 30 \times 10^6 \times \log_2(M) \\ 6 &= \log_2(M) \end{aligned}$$

Therefore $M = 64$. We need 64 levels, i.e. 6 bits per signal element.

Question 3 [10 marks]

You have a twisted pair Ethernet LAN cable connecting two computers directly together. The NICs in each computer support a data rate of 1Gb/s. You have a 100MB file to transfer from one computer to the other using TFTP (which uses UDP as a transport protocol). Assume protocols in each layer add a header (and/or trailer), as listed below, and introduce no other (non-header) overheads. Some protocols also limit the size of data in the packet, performing segmentation when the data is larger than the maximum allowed size.

- TFTP – header: 4 Bytes; maximum allowed data size: 512 Bytes
- IP – header: 20 Bytes; maximum allowed data size: 65,536 Bytes
- UDP – header: 8 Bytes; maximum allowed data size: 65,536 Bytes
- IEEE 802.3 Ethernet Physical – header: 4 bits
- IEEE 802.3 Ethernet Data Link/MAC – header 14 Bytes; trailer: 4 Bytes; maximum allowed data size: 1500 Bytes

Assume packets are sent as fast as possible (one immediately after another) and there are no other (non-header) overheads.

(a) Draw a protocol stack, labelling each layer, for one of the computers. [2 marks]

Answer.

TFTP

UDP

IP

IEEE 802.3 Ethernet DLL/MAC

IEEE 802.3 Ethernet PHY

(b) How much overhead is in each packet sent by the source computer? [2 marks]

Answer. *The overhead is the total of all headers/trailers added by the protocols at each layer to a packet. This totals 50 Bytes and 4 bits, or 404 bits per packet.*

(c) How many packets must be sent by the source computer to deliver the entire file to the destination (assuming perfect data transfer, i.e. no errors)? [2 marks]

Answer. *There are 404 bits of overhead per packet. The application layer protocol, TFTP, limits the data in each packet to 512 Bytes. That is, the 100MB file is segmented into 195,312 packets of 512 Bytes of data and one smaller packet with 256 Bytes of data. Even though the other layers have maximum data size limits, they are all much larger than 512 Bytes (meaning the 512 Bytes of data and header from the higher layers will be less than the maximum allowed size, i.e. no segmentation necessary). Therefore the source computer sends 195313 packets.*

(d) What is the total number of bits transmitted across the link from source to destnation? [2 marks]

Answer. *There are 195,312 packets with 512 Bytes of data plus 404 bits of overhead, giving a total size of 4,500 bits. There is 1 packet with 256 Bytes of data plus 404 bits of overhead, giving a total size of 2,452 bits. Therefore the total number of bits transmitted is 878,906,452.*

(e) What is the throughput as measured by the user on the destination computer? [2 marks]

Answer. *A total of 878,906,452 bits are transmitted at a rate of 1,000,000,000 bits per second, therefore taking 0.878906452 seconds. The amount of user data transferred is 100MB, giving a throughput of 910,222,013 b/s or approximately 910Mb/s.*

Question 4 [12 marks]

You are going to install a wireless LAN access point in a single-floor office building. Employees have tablets, with a wireless LAN interface, that will be used to connect to Internet via the access point. The following characteristics are common to both access point and the tablets:

- Transmit power: 0.1 W
- Receive power threshold: 2.77×10^{-6} mW
- Frequency: 2.4 GHz

You know the gain of the antenna on the access point is 6dBi. You want to measure the gain of the tablet antenna. To do so, you perform an experiment outdoors in an large open space (i.e. free space path loss), measuring the maximum distance at which a tablet can communicate successfully with the access point. You measure the distance to be 169m.

(a) What is the transmit power of the access point, measured in dBm? [1 mark]

Answer. *The transmit power is 0.1W or 100mW. Convert to dBm gives 20dBm.*

(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* $2.4 \times 10^9 Hz$*. Hence the wavelength is 0.125m.*

(c) What is the gain of the tablet antenna? [5 marks]

Answer. *As the experiment was performed in a free-space environment (or very close to free-space conditions), the free-space path loss model can be used:*

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

Considering the signal sent from access point to tablet (the other direction can also be considered, giving the same answer) the following values are known:

- *Transmit power,* P_t*: 100 mW*
- *Transmit antenna gain,* G_t*: 6dBi* $= 10^{0.6}$
- *Receive power threshold,* P_r*:* 2.77×10^{-6} *mW*
- *Wavelength,* λ*: 0.125 m*
- *Distance, d: 169 m*

The unknown is the receive (tablet) antenna gain, G_r. By substituting the known values into and re-arranging the free space path loss equation we find G_r:

$$\begin{aligned} G_r &= \frac{P_r(4\pi d)^2}{P_t G_t \lambda^2} \\ &= \frac{2.77 \times 10^{-6} \times 4^2 \times \pi^2 \times 169^2}{100 \times 10^{0.6} \times 0.125^2} \\ &= 2.008 \\ &= 3dBi \end{aligned}$$

Although the free-space path loss model is appropriate for outdoor experiments, it is inaccurate in indoor environments, as it does not consider obstructions such as floors, ceilings, walls and office furniture. A more accurate model of indoor environments is the ITU Indoor Propagation model, where the path loss between two antenna's is calculated as:

$$L_{dB} = 20\log_{10}(f) + N\log_{10}(d) + P_f - 28$$

where:

- L is the path loss measured in dB
- f is the signal frequency in Megahertz (MHz)
- d is the distance in metres (m)
- N is the distance power loss coefficient, with values depending on frequency and environment. For an office environment using signals at frequency of 2.4GHz, $N = 30$.
- P_f is floor penetration loss factor which depends on the number of floors and frequency. For a single floor office environment using signals at frequency of 2.4GHz, $P_f = 15$.

(d) Assuming the ITU Indoor Propagation model for your office building, what is the maximum distance at which a tablet can communicate successfully with the access point? [5 marks]

Answer. *The general form for path loss can be written as:*

$$P_r = \frac{P_t G_t G_r}{L}$$

where the path loss, L, depends on the model (e.g. free space or ITU Indoor). Alternatively, with all values expressed on a logarithmic scale, i.e. in dB:

$$P_{r_{dB}} = P_{t_{dB}} + G_{t_{dB}} + G_{r_{dB}} - L_{dB}$$

Assuming the ITU Indoor model, L is given by the equation in the question. The following values are known:

- *Transmit power, P_t: 100 mW = 20 dBm*
- *Transmit antenna gain, G_t: 6 dBi*
- *Receive antenna gain, G_r: 3 dBi*
- *Receive power threshold, P_r: $2.77 \times 10^{-6} = -55.58$ dBm*
- *Frequency, f: 2.4GHz = 2400 MHz*
- *Distance power loss coefficient, N: 30*
- *Floor penetration loss factor, P_f: 15*

The distance, d, is unknown. First re-arranging the general path loss equation to find L_{dB}:

$$\begin{aligned} L_{dB} &= P_{t_{dB}} + G_{t_{dB}} + G_{r_{dB}} - P_{r_{dB}} \\ &= 20 + 6 + 3 - (-55.58) \\ &= 84.58dB \end{aligned}$$

Now using the ITU Indoor propagation model:

$$L_{dB} = 20\log_{10}(2400) + 30\log_{10}(d) + 15 - 28$$

Substituting in for L_{dB} and re-arranging gives:

$$\begin{aligned} 30\log_{10}(d) &= 84.58 - 20\log_{10}(2400) - 15 + 28 \\ \log_{10}(d) &= \frac{29.976}{30} \\ d &= 10^{0.999} \\ &= 10m \end{aligned}$$

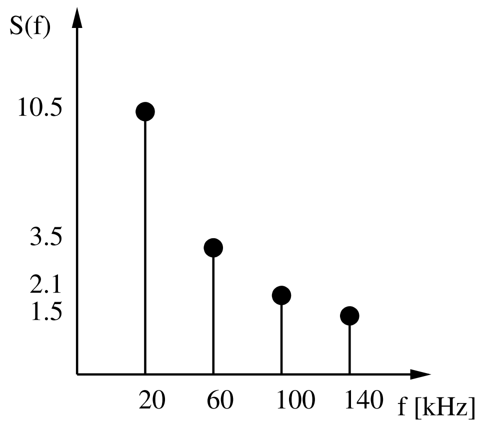
The distance is 10 metres.

Question 5 [10 marks]

Consider the signal, $s_1(t)$:

$$s_1(t) = 10.5\sin(40000\pi t) + 3.5\sin(120000\pi t) + 2.1\sin(200000\pi t) + 1.5\sin(280000\pi t)$$

(a) Plot signal $s_1(t)$ in the frequency domain, clearly labelling the values. [3 marks]



(b) What is the value of the absolute bandwidth of $s_1(t)$? [1 mark]

Answer. *The signal contains components with frequencies ranging from 20,000 Hz to 140,000 Hz. Therefore the absolute bandwidth is 120,000 Hz.*

(c) What is the value of the frequency of $s_1(t)$? [1 mark]

Answer. *The fundamental frequency of $s_1(t)$ is 20kHz (all components have frequencies which are integer multiples of 20kHz).*

(d) Figure 1 shows plots of eight different signals. Which of the plots do you think is the plot for $s_1(t)$? (Hint: only one of the plots is of $s_1(t)$). Explain your answer. [3 marks]

Answer. *The fundamental frequency of $s_1(t)$ is 20kHz. Therefore the period is 50 μs. Plots (e), (f) and (h) have a different period and therefore are not of $s_1(t)$. Plot (b) is for a sine wave (one component only), while Plot (d) is for a (almost) square wave with many more components than in $s_1(t)$ and therefore they are not of $s_1(t)$. Plots (a) and (g) have a amplitude of around 30, whereas its expected $s_1(t)$ will have an amplitude around 10.5, and therefore are not of $s_1(t)$. The remaining plot, (c), is most likely—and indeed is—of $s_1(t)$.*

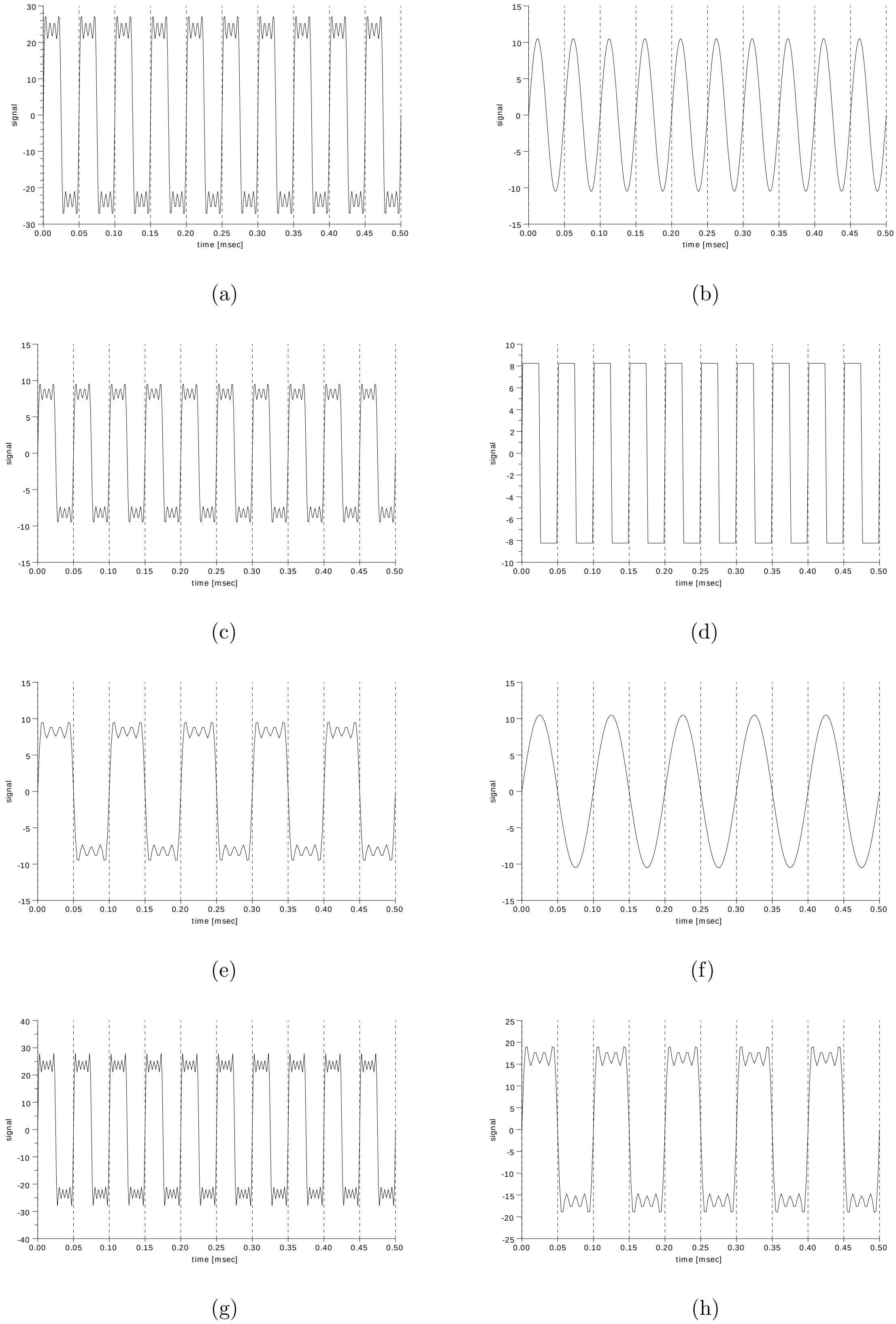


Figure 1: Different Signals

Now consider another signal, $s_2(t)$:

$$s_2(t) = 31.5\sin(40000\pi t) + 10.5\sin(120000\pi t) + 6.3\sin(200000\pi t) + 4.5\sin(280000\pi t) + 3.5\sin(360000\pi t)$$

Assuming both signals are to be used to transmit digital data, where a high level represents a bit and a low level represents another bit, compare $s_1(t)$ and $s_2(t)$.

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

Answer. $s_1(t)$ *occupies less bandwidth than* $s_2(t)$.

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

Answer. $s_2(t)$ *more accurately represents digital data (a square wave), therefore less chance of errors than* $s_1(t)$.

Question 6 [10 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 10μs processing delay; every packet received incurs 10μs processing delay; no queuing delay

Device B: no processing delay; every packet received is put into a queue, which incurs queuing delay of 200μs and then is transmitted

Device C: no processing delay; no queuing delay

Link 1: distance = 15km; data rate = 10Mb/s

Link 2: distance = 30km; data rate = 100Mb/s

(a) What is the transmission delay of a 125B packet from A to B? [2 marks]

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

$$\begin{aligned} t_{AB} &= \frac{datasize}{datarate} \\ &= \frac{125B}{10Mb/s} \\ &= 100\mu s \end{aligned}$$

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

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

$$\begin{aligned} p_{BC} &= \frac{distance}{speed} \\ &= \frac{30km}{3 \times 10^8 m/s} \\ &= 100\mu s \end{aligned}$$

(c) Consider a web browser on device A generates a 125B request packet to be sent to C. Device C responds with a 1,250B 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)? [6 marks]

Answer. *As the data rate of link 2 is 10 times that of link 1, the transmission delay is* $t_{BC} = 10\mu s$*. For the reverse direction, with the a packet 10 times larger we have:* $t_{CB} = 100\mu s$ *and* $t_{BA} = 1000\mu s$*.*

The propagation delay across link 1, which is half the length of link 2, is $p_{AB} = 50\mu s$*.*

Considering the processing delay at device A ($pr_A = 10\mu s$*), and the queuing delay at device B (*$q_B = 200\mu s$*), the total time to deliver the request from A to C is:*

$$\begin{aligned} req &= pr_A + t_{AB} + p_{AB} + q_B + t_{BC} + p_{BC} \\ &= 10 + 100 + 50 + 200 + 10 + 100 \\ &= 470\mu s \end{aligned}$$

And to deliver the response:

$$\begin{aligned} resp &= t_{CB} + p_{CB} + q_B + t_{BA} + p_{BA} + pr_A \\ &= 100 + 100 + 200 + 1000 + 50 + 10 \\ &= 1,460\mu s \end{aligned}$$

Hence the response time is 1,930μs or 1.93ms.

Question 7 [8 marks]

(a) Consider the NRZI transmitted signal in Figure 2. What is the value of the data? [2 marks]

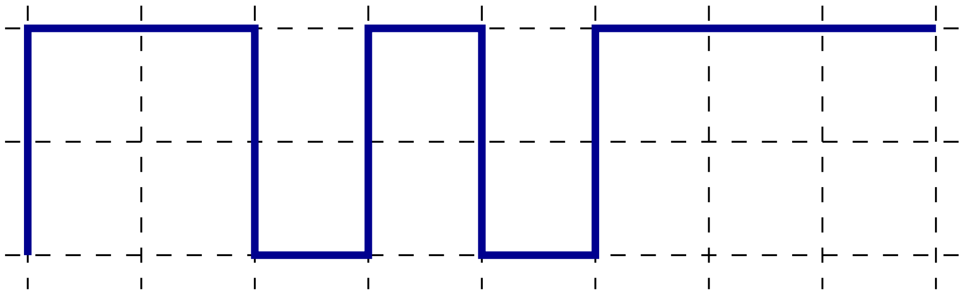


Figure 2: NRZI Signal

Answer. *10111100 (note, because the signal has a transition at the start, the first bit is a 1 - assuming it is 0 is incorrect)*

Manchester encoding is described as: 0 = transition from high to low in the middle of interval; 1 = transition from low to high in the middle of interval. Assume the signal is initially high.

(b) For the data 00101110, draw the Manchester signal on Figure 3. [3 marks]

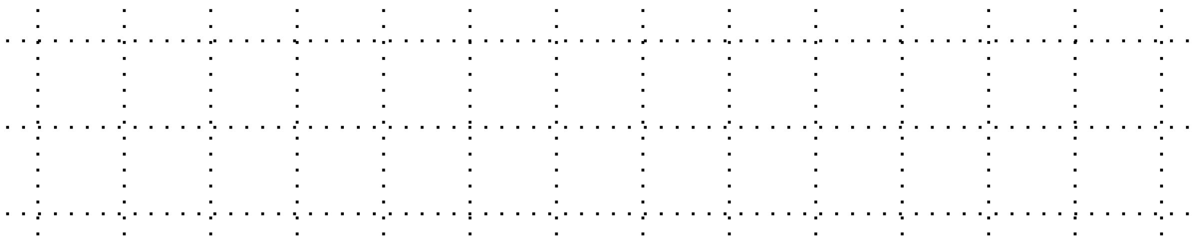
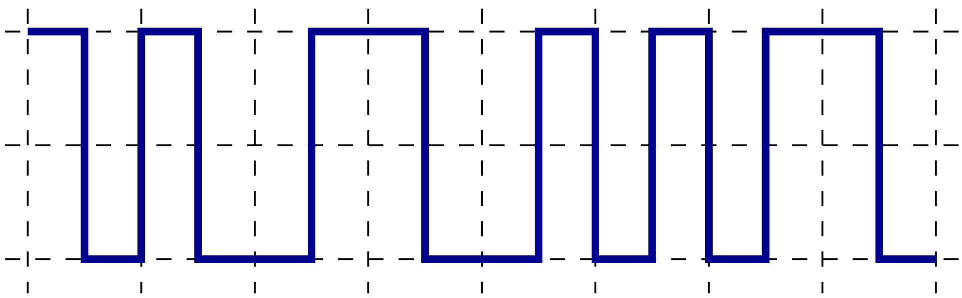


Figure 3: Draw the Manchester signal



An important feature of encoding schemes is *clock recovery* at the receiver. If there is no external clock source, for some encoding schemes it is possible for the receiver to use the received digital signal as a clock, and sychronise its clock with the transmitters. If the transmitter and receiver clocks are not synchronised, bit errors can occur at the receiver (because the receiver does not know exactly where one bit interval finishes and the next bit interval starts).

(c) Compared NRZI with Manchester encoding. Do either have the ability for clock recovery at the receiver? Explain your answer. [3 marks]

Answer. *Manchester has clock recovery, whereas NRZI does not. With Manchester encoding the transmitter will change levels every bit interval, no matter the value of the bit. Therefore the receiver, can recover a clock signal from the data signal. With NRZI with a long sequence 0's, the received signal will not change. In this case there is no indicator to the receiver where a bit interval starts or finishes. If the clock of the receiver is out-of-synch with the transmitter, the receiver will not be able to recover during that long sequence of 0's.*