

# Sirindhorn International Institute of Technology Thammasat University

## Midterm Exam Answers: Semester 1, 2014

**Course Title:** ITS323 Introduction to Data Communications

**Instructor:** Steven Gordon

**Date/Time:** Monday 6 October 2014; 13:30–16:30

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### 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.
- Turn off all communication devices (mobile phone etc.) and leave them at the front of the examination room.
- The examination paper is not allowed to be taken out of the examination room. A violation may result in score deduction.
- 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  $3 \times 10^8$  m/s
- Nyquist capacity:  $C = 2B \log_2(M)$
- Shannon capacity:  $C = B \log_2(1 + SNR)$
- Antenna gain:

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

- Path loss model:

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

- Free space path loss:

$$L_p = \frac{(4\pi d)^2}{\lambda^2}$$

Introduction to Data Communications, Semester 1, 2014

Prepared by Steven Gordon on 11 October 2014

ITS323Y14S1E01, Steve/Courses/2014/s1/its323/assessment/midterm-exam.tex, r3368

## Question 1 [18 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	fundamental	point-to-point
analog data	gain	processing
analog signal	guided	propagation
attenuation	half-duplex	queuing
carrier	harmonic	simplex
center	header	spectrum
coaxial cable	HTTP	timeliness
delivery	isotropic	trailer
digital data	LAN	transmission
digital signal	multipoint	twisted pair
directional	network	unguided
frequency	noise	WAN
full	omnidirectional	wavelength
full-duplex	optical fibre	-

Table 1: Possible answers for Question 1

**SG: I forgot to add “transmitter” and “receiver” to the table, so question (a) was marked correct for everyone, no matter what your answer was**

- (a) A model of a communication system consists of a source and *transmitter* in the source system, a transmission system, and a *receiver* and destination in the destination system. **SG: Marked correct for everyone**
- (b) Most applications require delivery of data for effective communications. Of the other requirements for effective communications, for multimedia (or real-time applications) usually *timeliness* is more important than *accuracy*.
- (c) The protocol used for web browsing is *HTTP*.
- (d) When all components in a signal have a frequency which is an integer multiple of one frequency, then that one frequency is called the *fundamental* frequency.
- (e) As the *noise* received at a receiver increases (compared to the received signal), the increased chance of errors.
- (f) For a device that has data arriving from multiple different sources, and then sends that data onto a single destination, as the data arriving increases, the *queuing* delay increases.
- (g) TV broadcasts are an example of simplex communications using an unguided media and in a *multipoint* configuration.
- (h) *Optical fibre* is a guided media that provides higher data rates and allows for transmission across larger distances than coaxial cable.
- (i) As the distance a signal needs to propagate increases, the *attenuation* of that signal increases.
- (j) *Twisted pair* is the most common guided media used within home LANs.
- (k) 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.
- (l) A LAN cable has multiple pairs of wires, with one pair used for transmission of signals in one direction, and another pair used for transmission of signals on the opposite direction. With respect to direction of communications, a LAN cable is considered to be *full duplex*.

## Question 2 [12 marks]

Consider a transmission system for which you have measured different characteristics. Figure 1 shows the received signal in the frequency domain. Figure 2 shows the measured signal power and noise power at the receiver.

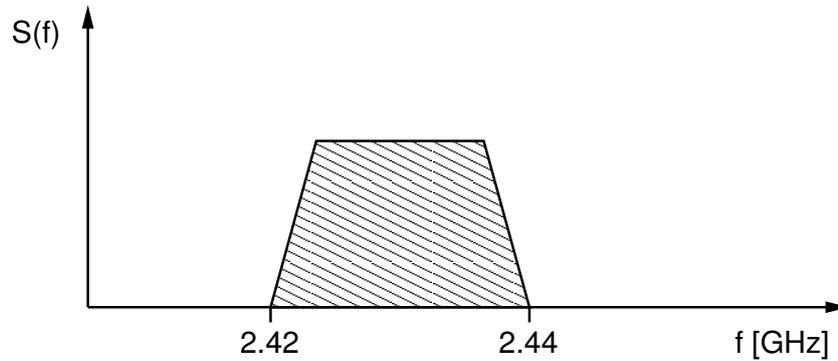


Figure 1: Signal in frequency domain

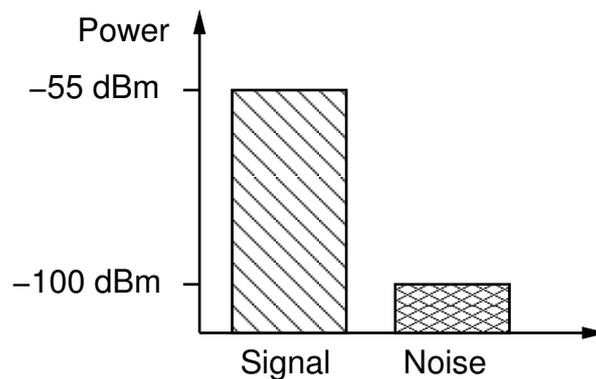


Figure 2: Receive signal and noise power

- (a) What is the bandwidth of the transmission system? [3 marks]

**Answer.** From the frequency domain plot the signal contains frequencies from 2.42 GHz up to 2.44 GHz. Therefore the bandwidth is 0.02 GHz or 20 MHz.

- (b) What is the SNR of the transmission system? [3 marks]

**Answer.** From the signal and noise power plots, the received signal is 45 dB higher than the noise power. Therefore the signal-to-noise ratio (SNR) is 45dB or  $10^{4.5}$ .

- (c) If the signal uses 8 bits per level, then what is the maximum theoretical data rate that can be achieved in this transmission system? (Show all calculations) [6 marks]

**Answer.** With 8 bits per level, there are 256 possible levels. According to the Nyquist capacity equation, the maximum data rate is limited by the bandwidth and number of levels,  $M$ :

$$\begin{aligned} C &= 2B \log_2(M) \\ &= 2 \times 20 \times 10^6 \times \log_2(256) \\ &= 320 \times 10^6 \text{ b/s} \end{aligned}$$

So assuming no noise, the maximum data rate is 320 Mb/s. But according to the Shannon capacity equation, the maximum data rate is limited by the bandwidth and the SNR:

$$\begin{aligned} C &= B \log_2(1 + \text{SNR}) \\ &= 20 \times 10^6 \times \log_2(1 + 10^{4.5}) \\ &= 299 \times 10^6 \text{ b/s} \end{aligned}$$

(or approximately 300 Mb/s).

So assuming an infinite number of levels, the maximum data rate is approximately 300 Mb/s. Since the number of levels is limited and noise is present, then in this system the maximum possible data rate is 300 Mb/s.

### Question 3 [11 marks]

Consider the network in Figure 3 where computer A has data to send to computer B. Link distances and data rates are shown for each link, and the processing delay for each device is shown below the device (e.g. the processing delay for each message at the satellite is 7 ms). The distance to the satellite from A is the same as the distance from the satellite to the gateway (GW): 36,000 km. Assume computer A has a 12,500 B message to send to computer B.

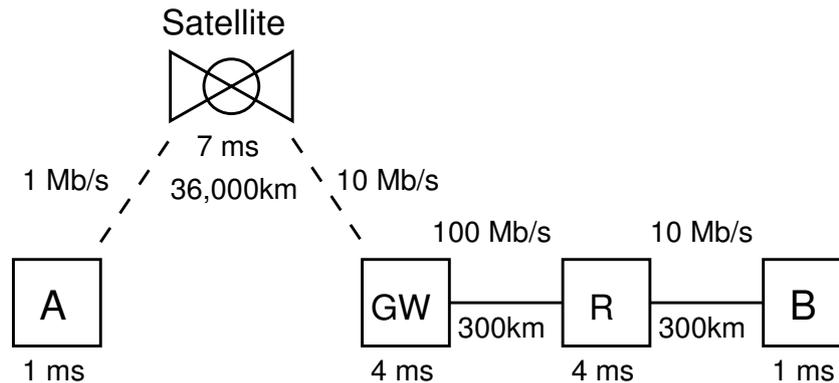


Figure 3: Satellite network

- (a) What is the transmission delay of the message from computer A up to the satellite? [2 marks]

**Answer.** *Transmission delay is data size divided by data rate:*

$$t_{1Mb/s} = \frac{12500 \times 8}{1 \times 10^6} = 100ms$$

- (b) What is the propagation delay of a signal from the satellite down to the gateway? [2 marks]

**Answer.** *Propagation delay is distance divided by signal speed:*

$$p_{36000} = \frac{36 \times 10^6}{3 \times 10^8} = 120ms$$

- (c) What is the total delay to deliver the message from computer A to computer B? [4 marks]

**Answer.** *The total delay is the sum of all the link transmission delays, link propagation delays and device processing delays. First the transmission delays:*

$$t_{1Mb/s} = 100ms$$

$$t_{10Mb/s} = 10ms$$

$$t_{100Mb/s} = 1ms$$

*The propagation delays:*

$$p_{36000} = 120ms$$

$$p_{300} = 1ms$$

*The total delay is therefore:*

$$1 + 100 + 120 + 7 + 10 + 120 + 4 + 1 + 1 + 4 + 10 + 1 + 1 = 380 \text{ ms}$$

- (d) If computer A has many messages of the same size to send to computer B (e.g. millions of messages ready to send from A, with each message 12,500 B in length), then if you ignore protocol overheads, what is the maximum throughput that can be achieved? Explain your answer. [3 marks]

**Answer.** *Computer A can send a new message directly after transmitting the previous. Therefore the transmission delay of the uplink to the satellite will be the largest component of delay, i.e. the satellite uplink is the bottleneck. With an uplink data rate of 1 Mb/s, ignore overheads, the throughput across the path will be 1 Mb/s.*

## Question 4 [16 marks]

Consider a communications signal,  $s(t)$ , given by the following general equation:

$$s(t) = A \left( \sin(2\pi ft) + \frac{1}{3} \sin(2\pi 3ft) + \dots + \frac{1}{2N-1} \sin(2\pi(2N-1)ft) \right)$$

where  $N$  is the number of components in the signal.

As an example, Figure 4 shows the signal in the time domain and Figure 5 shows the corresponding signal in the frequency domain when  $N=2$ . ( $T$  is the signal period).

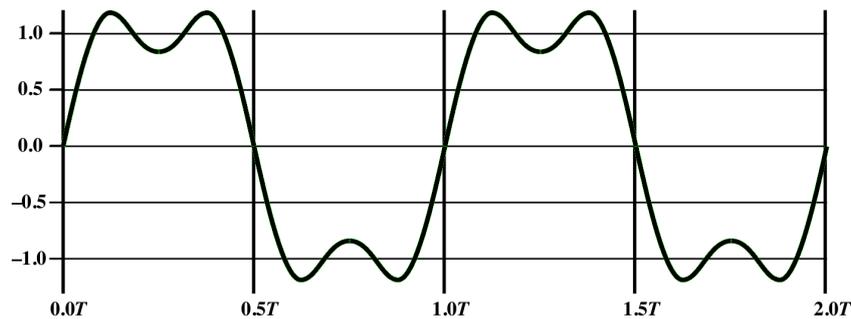


Figure 4: Signal in time domain,  $N = 2$

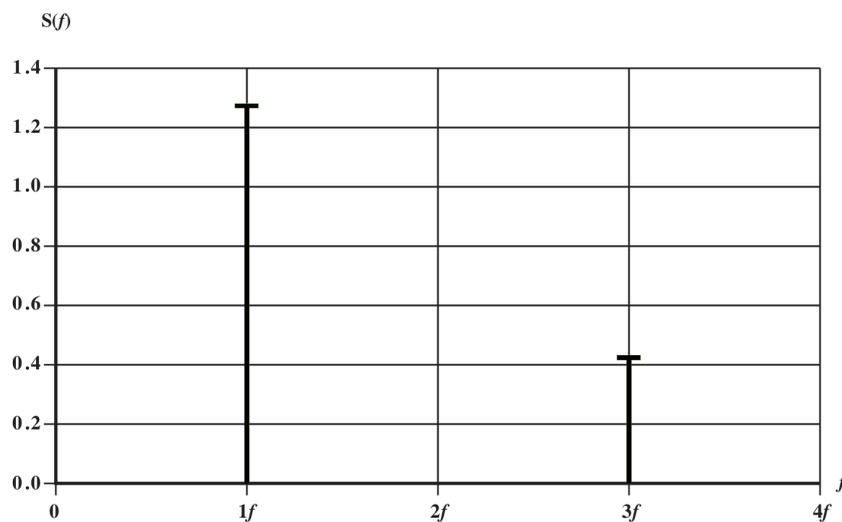


Figure 5: Signal in frequency domain,  $N = 2$

Answer the following questions assuming the general signal equation.

- (a) If the frequency of a signal with 3 components is 1 kHz, then what is the signal period? [1 mark]

**Answer.** *The period is the inverse of the frequency: 1 ms.*

- (b) If the frequency of a signal with 3 components is 1 kHz, and 2 bits can be transmitted per period, then what is the data rate? [1 mark]

**Answer.** With a period of 1 ms, the data rate will be 2000 b/s.

- (c) If the bandwidth of a signal with 3 components is 24 MHz, and 2 bits can be transmitted per period, then what is the data rate? [2 marks]

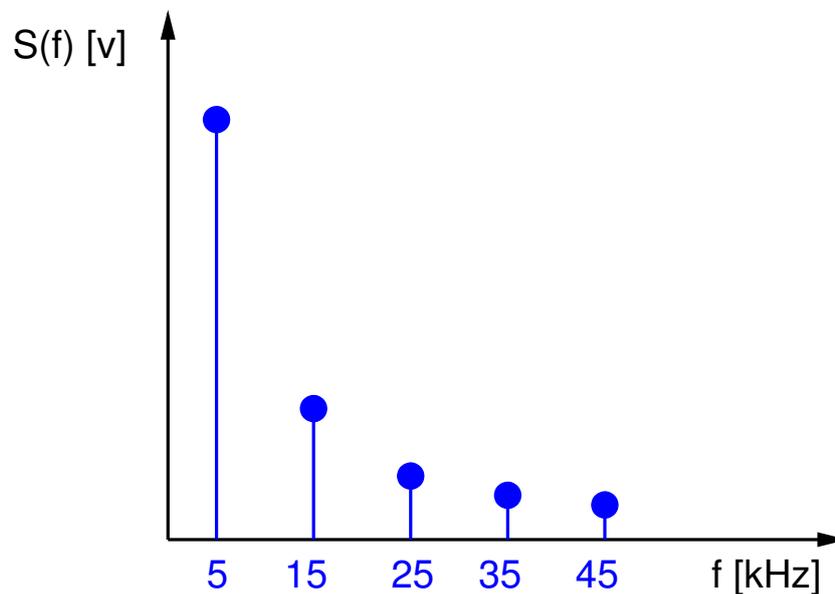
**Answer.** With 3 components, the bandwidth is  $4f$ . Therefore the frequency is 6 MHz, giving a period of 0.166  $\mu$ s and a data rate of 12 Mb/s.

- (d) If the bandwidth of a signal with 4 components is 24 MHz, and 2 bits can be transmitted per period, then what is the data rate? [2 marks]

**Answer.** With 4 components, the bandwidth is  $6f$ . Therefore the frequency is 4 MHz, giving a period of 0.25  $\mu$ s and a data rate of 8 Mb/s.

- (e) Consider a signal with 5 components that occupies a bandwidth of 40 kHz. Draw a plot of the signal in the frequency domain. [2 marks]

**Answer.** The plot should have five impulses, with amplitudes ranging from 1 (or  $A$ ) down to  $1/9$ . With a bandwidth of 40 kHz, the frequency should be 5 kHz. So the frequencies of the impulses should range from 5 kHz to 45 kHz.



When the signal frequency is fixed, the relationship between the number of components and the data rate can be described as:

*“increasing the number of components does not increase or decrease the data rate”*

Use a similar statement to describe the relationship in the following questions.

- (f) When the number of components is fixed, describe the relationship between the signal bandwidth and data rate. [2 marks]

**Answer.** *Increasing the bandwidth leads to increased data rate.*

- (g) When the bandwidth is fixed, describe the relationship between the number of components and the signal accuracy. [2 marks]

**Answer.** *Increasing the number of components increases the signal accuracy.*

- (h) When the data rate is fixed, describe the relationship between the number of components and the signal bandwidth. [2 marks]

**Answer.** *Increasing the number of components increases the signal bandwidth.*

- (i) Explain two disadvantages of increasing the bandwidth used by a signal or transmission system. [2 marks]

**Answer.** *Increasing the bandwidth increases the financial cost (e.g. license is more) and increases the chance of interfering with others (and be interfered with by others).*

**Question 5** [14 marks]

You have a wireless system with the following components:

- Transmitter with adjustable transmit power
- Transmit antenna with gain of 15 dBi
- Receive antenna is a parabolic antenna with radius of 0.4 m. Assume the effective area is 0.5 times the physical area (of a circle).
- Receiver with receive sensitivity of -60 dBm
- Distance between transmitter and receiver is 4500 m
- Signal frequency is 3 GHz

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

**Answer.**

$$\begin{aligned}\lambda &= \frac{c}{f} \\ &= \frac{3 \times 10^8}{3 \times 10^9} \\ &= 0.1 \text{ m}\end{aligned}$$

(b) What is the gain of the receive antenna in dBi? [3 marks]

**Answer.**

$$\begin{aligned}G_r &= \frac{4\pi A_e}{\lambda^2} \\ &= \frac{4 \times \pi \times 0.5 \times \pi \times (0.4)^2}{(0.1)^2} \\ &= 315.827 \\ &= 25 \text{ dBi}\end{aligned}$$

(c) What is the free space path loss, in dB, between the transmit antenna and receive antenna? [3 marks]

**Answer.**

$$\begin{aligned}
 L_p &= \frac{(4\pi d)^2}{\lambda^2} \\
 &= \frac{(4 \times \pi \times 4500)^2}{(0.1)^2} \\
 &= 3.197 \times 10^{11} \\
 &= 115 \text{ dB}
 \end{aligned}$$

- (d) What is the minimum transmit power, in dBm, needed to be able to successfully communicate between transmitter and receiver? [4 marks]

**Answer.**

$$\begin{aligned}
 P_t &= P_r - G_t - G_r + L_p \\
 &= -60 - 15 - 25 + 115 \\
 &= 15 \text{ dBm} \\
 &= 31.6 \text{ mW}
 \end{aligned}$$

Now consider the same wireless system, but using long cables: a 30 metre cable between transmitter and transmit antenna, as well as a 10 metre cable between receive antenna and receiver. With longer cables, the loss across those cables can become significant. Assume now the loss for each cable is 0.2 dB per metre.

- (e) What should the transmit power be adjusted to, in dBm, so that the cable loss is also considered? [3 marks]

**Answer.** *The total cable length is 40 metres. At 0.2 dB per metre, the total cable loss,  $L_c$ , is 8 dB.*

$$\begin{aligned}
 P_t &= P_r - G_t - G_r + L_p + L_c \\
 &= -60 - 15 - 25 + 115 + 8 \\
 &= 23 \text{ dBm} \\
 &= 200 \text{ mW}
 \end{aligned}$$

**Question 6** [8 marks]

Computer A is connected to computer B by a link with data rate 50 Mb/s. The user on computer A has 12.5 GB of data to send to B. The protocol used for sending the data splits the data into packets: each packet contains 1000 B of data plus 75 B of overhead information.

- (a) What is the maximum throughput that can be achieved in the data transfer? [4 marks]

**Answer.** To deliver the 12.5 GB, 12,500,000 packets containing 1000 B of data must be sent. Each packet contains an additional 75 B of data. Therefore each packet is 1075 B in size, and at a data rate of 100 Mb/s, takes 172  $\mu$ s to transmit. So 1000 B of useful data is received every 172  $\mu$ s, giving a throughput of 46.51 Mb/s.

- (b) What is the efficiency of the protocol? [2 marks]

**Answer.** The protocol introduces an overhead: of every 1075 B sent, 1000 B is useful data. Therefore the efficiency is 1000/1075 or 93.02%.

- (c) If, due to errors in the link, 5,000 packets that arrived at the receiver contained unrecoverable errors (i.e. the receiver cannot use the data), then what is the average packet error rate of the link? [2 marks]

**Answer.** There are 12,500,000 packets sent. If 5,000 contain errors, then the average packet error rate is 0.0004 or 0.04%.

## Question 7 [8 marks]

Assume Binary Frequency Shift Keying is used to transmit the data 01100101 across a link.

- (a) Draw the transmitted signal on Figure 6. [2 marks]



Figure 6: Draw the transmitted signal data

**Answer.** *Different frequencies need to be used for each bit. A simple approach is a low frequency for bit 0 and a higher frequency for bit 1. The opposite is also correct.*

Often PSK is combined with ASK. When used together they are called *Quadrature Amplitude Modulation*. The combination of amplitudes and phases is often drawn in a constellation diagram, as shown in Figure 7 for 16-QAM. The length of the line from centre to the dot indicates the amplitude to use in a signal element for a sequence of bits, while the angle indicates the phase.

- (b) If each signal element contains a signal constructed of a simple sine wave (i.e. single frequency component) with frequency 200 kHz, then write an equation for the signal element that produces data 1000. (Hint:  $s(t) = \dots$  and the only variable in the equation is  $t$ . You may write the angle in either radians or degrees). [2 marks]

**Answer.**  $s(t) = 4\sin(2 \times \pi \times 200 \times 10^3 \times t + \frac{\pi}{4})$

- (c) What signalling rate is needed to achieve a data rate of 20 Mb/s when using 16-QAM? [1 mark]

**Answer.** *5,000,000 signal elements (or symbols) per second. (Since there are 4 bits per signal element).*

- (d) Given a constant signalling rate, if 256-QAM was used, the data rate would be how many more times faster than if using BPSK? [1 mark]

**Answer.** *BPSK has 2 levels: 1 bit per signal element. 256-QAM has 256 levels: 8 bits per signal element. Therefore 256-QAM would be 8 times faster than BPSK.*

- (e) Explain two disadvantages of using 256-QAM compared to 16-QAM. [2 marks]

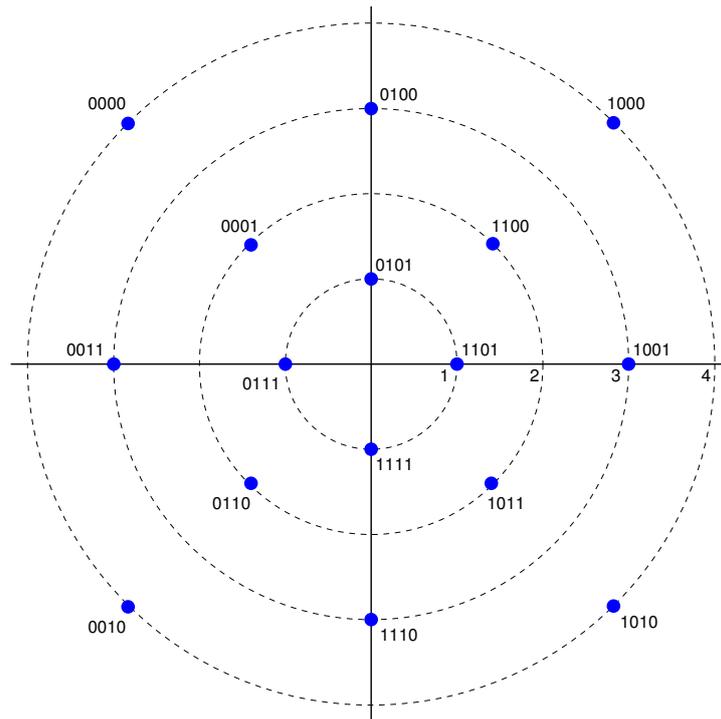


Figure 7: Constellation for 16-QAM

**Answer.** *More complex at transmitter and receiver; more chance of errors (i.e. more levels).*

## Question 8 [8 marks]

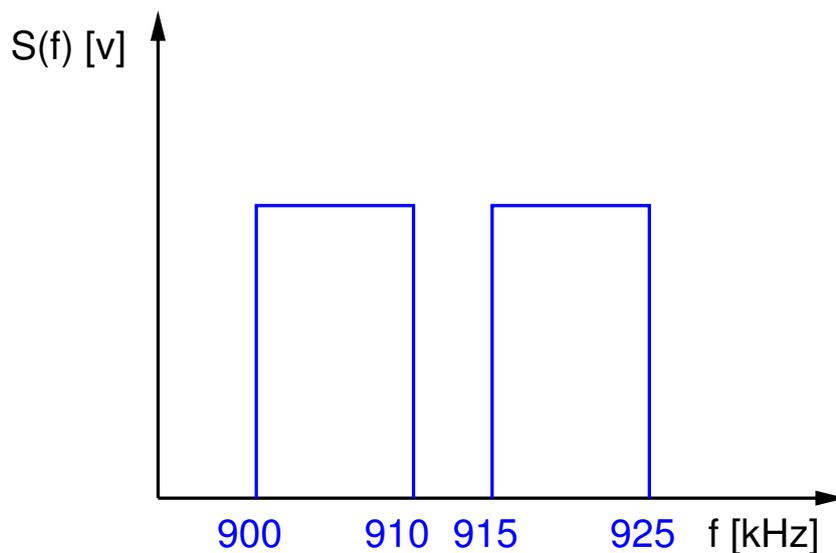
Consider two example AM radio channels; each channel uses a bandwidth of 10 kHz. Channel 1 uses a carrier signal with center frequency of 905 kHz, while channel 2 uses a carrier signal with center frequency of 920 kHz. Also consider an example FM radio channel with bandwidth 40 kHz and center frequency of 105.5 MHz.

- (a) NRZ is used to transmit digital data as a digital signal. What is AM (and FM) used for? [1 mark]

**Answer.** *Transmit analog data as an analog signal.*

- (b) Draw a single plot showing both AM radio channel signals in the frequency domain. [3 marks]

**Answer.** *The plot should show a signal with center frequency of 905 kHz and a bandwidth of 10 kHz, i.e. from 900 kHz to 910 kHz, for channel 1 and a signal from 915 kHz to 925 kHz for channel 2.*



- (c) Explain how an AM signal is generated. [2 marks]

**Answer.** *A carrier signal with center frequency of 905 kHz has its amplitude modulated (i.e. changed) according to the amplitude of the input analog data.*

Both AM and FM radio normally is used for voice and music. The spectrum of voice ranges from 100 Hz to 4 kHz, while the spectrum for music ranges from 10 Hz to 20 kHz.

- (d) Assuming the same music is being played on both AM radio and on FM radio, which one would sound better? Explain why. [2 marks]

**Answer.** *AM radio has a bandwidth of 10 kHz, while FM radio has a bandwidth of 40 kHz. Therefore all frequencies of the music, which has a bandwidth of 20 kHz, can be transmitted (and received) using FM, but not using AM. So FM will sound better because all of the original music frequencies can be received, whereas for AM some of the music frequencies will not be received (or heard).*

## Question 9 [5 marks]

Consider a transmitter with an attached antenna. Explain the direction in which a signal propagates, and at what strength, if using a:

- (a) Isotropic antenna [1 mark]

**Answer.** *The signal disperses in all directions at equal strength.*

- (b) Omni-directional antenna [1 mark]

**Answer.** *The signal disperses in one plane (e.g. horizontal) at equal strength, but weaker strength in the other plane (e.g. vertical).*

Assume if the antenna attached to the transmitter was isotropic, then the power received at a distance of 100 m away is 100 mW.

- (c) If instead the antenna is a parabolic dish antenna with a gain of 20 dBi, then what would the highest receive power be at a distance of 100 m away. [3 marks]

**Answer.** *A gain of 20 dBi is equivalent to a factor of 100. So the power received when using the dish would be 100 times that of using an isotropic antenna, i.e. 10,000 mW or 10 W.*