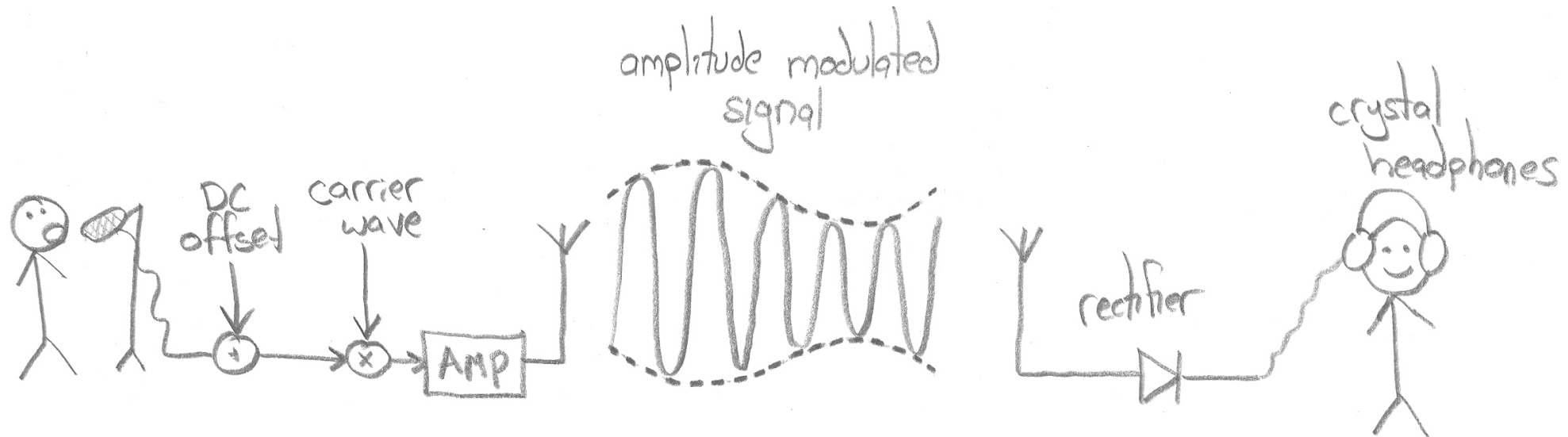


# ELEC1011 Communications and Control

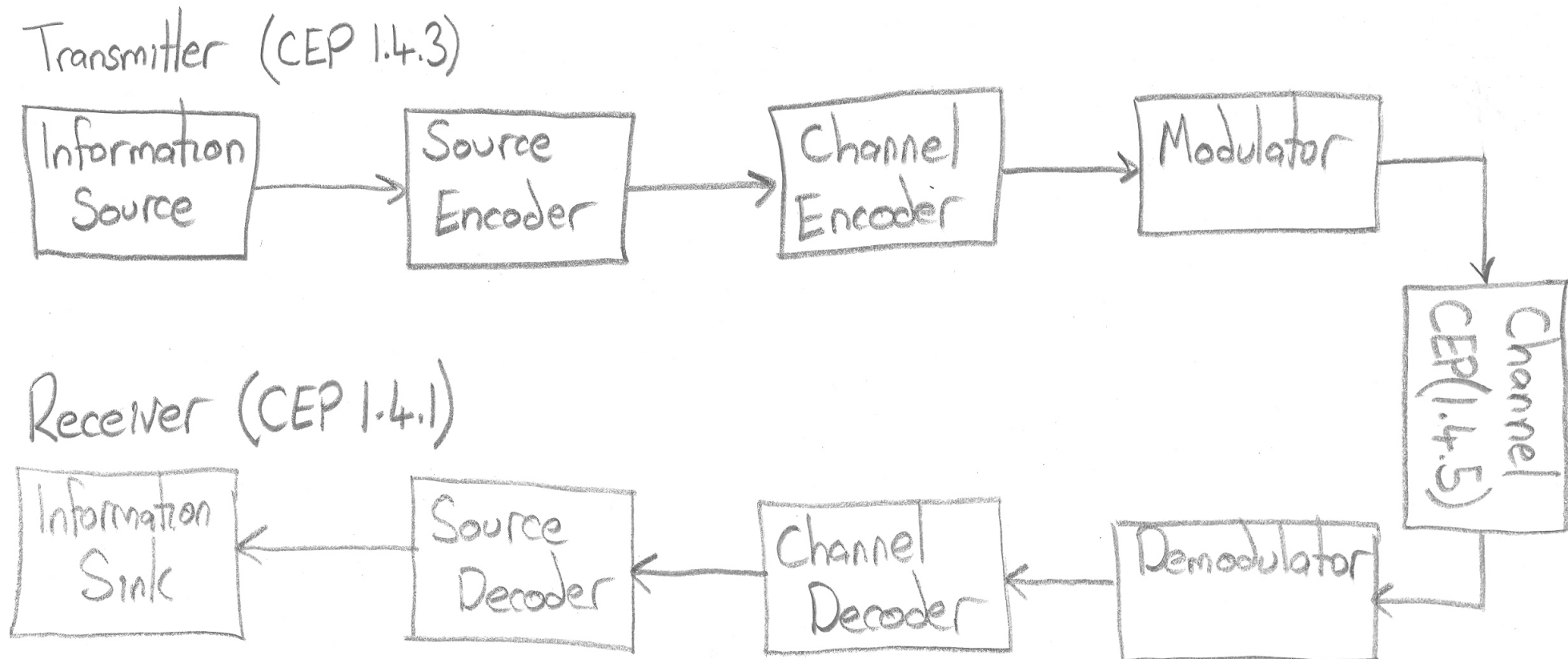
(1/11) Overview of  
Communication Systems

## A really simple communications scheme



- Many disadvantages (more on these in lecture 2):
  - Not resilient to **noise** (it is analogue and doesn't use error correction)
  - Not very **power** efficient (it uses amplitude modulation)
  - High **bandwidth** requirement (it doesn't use compression)
  - Doesn't allow **multiple access** (other signals cause interference)
- As a result, it only works if the receiver is very close to the transmitter (like two cans and a piece of string!)

## General communication schemes



- Three options:
  - Analogue information and analogue modulation.
  - Analogue information and digital modulation.
  - Digital information and digital modulation.

## Information source and sink (CEP 1.4.1)

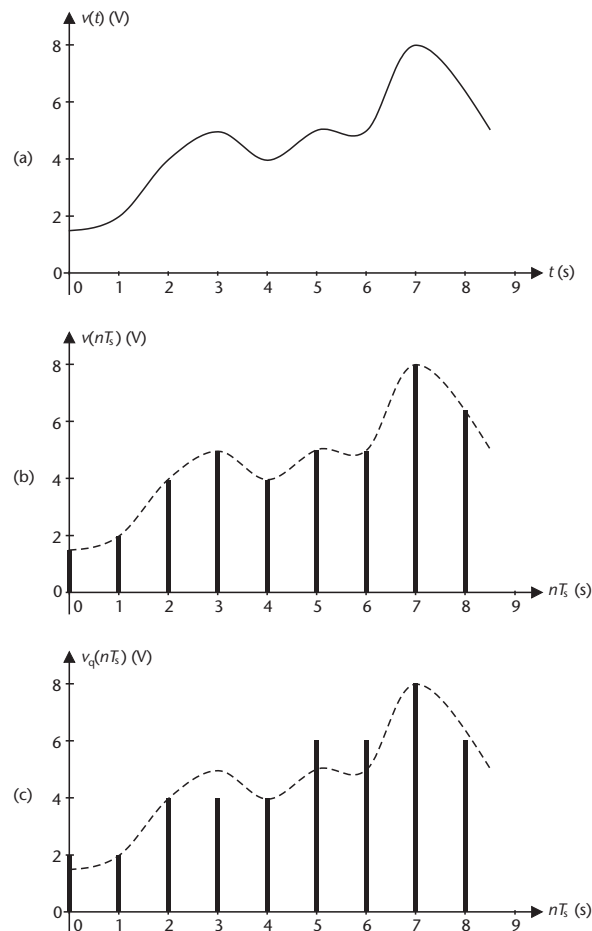
- An **information source** captures information for transmission.
- An **information sink** uses the received information.
- Many types of information:
  - Measurement - **temperature sensor**, **pressure sensor**, **any other type of sensor**, recording, **screen**, **speaker**, **controller**
  - Audio - **microphone**, **musical instrument**, recording, **speaker**
  - Speech - **microphone**, recording, **speaker**
  - Video - **camera**, **animation**, recording, **screen**
  - Image - **camera**, **computer imagery**, recording, **screen**, **printer**
  - Vector graphics - **camera**, **stylus**, recording, **screen**, **printer**
  - Writing - **camera**, **stylus**, recording, **screen**
  - Text - **keyboard**, **character recognition**, **speech recognition**, recording, **screen**, **printer**, **speech synthesis**
  - Data - computer program

## Analogue and digital information (CEP 1.5.2 – 1.5.2.2)

- Analogue information is **continuous in time** (or space) and **continuous in value**
  - e.g. the temperature in this room has a value at every possible time and that value can be anything above  $-273.15^{\circ}\text{C}$ .
  - Other types of analogue information include pressure, audio signals, images captured on film (these are **continuous in space** rather than in time).
- Digital information is **discrete in time** (or space) and **discrete in value**
  - e.g. a 1080p30 video signal displays 30 frames per second, each comprising  $1920 \times 1080$  pixels.
  - A 1080p30 video signal is **discrete in time and space** because it does not have a value in between pixels and in between frames.
  - A 1080p30 video signal is **discrete in value** because each pixel has a colour selected from a limited set of (only!) 16.7 million.
  - Other types of digital information include Binary digITs (bits)  $\{0, 1\}$ , decimal digits  $\{0, 1, 2, \dots, 9\}$  and letters  $\{a, b, c, \dots, z\}$ .

# Analogue to Digital Conversion (ADC)

Figure 1.18



Taken from *Communication Engineering Principles*, © Ifiok Otung, published 2001 by Palgrave

- (a) An analogue signal  $v(t)$ , which is **continuous in time** and **continuous in value**.
- (b) **Sampling** makes the signal **discrete in time** by only retaining the value of the signal at time instants  $t$  that are integer multiples of the sampling period  $T_s = 1$  s. Sampling can be reversed by using a Low Pass Filter (LPF). To avoid aliasing distortion, Nyquist theory states that the sampling frequency  $f_s = 1/T_s$  should be at least double the highest frequency in the signal  $v(t)$ .
- (c) **Quantisation** makes the signal **discrete in value** as well. This rounds each sample to the nearest value from the limited set  $\{2V, 4V, 6V, 8V\}$ .

## Source enCOder and DECoder (codec) (CEP 1.4.3.1 – 1.4.3.2)

- Source encoder converts the information to a format that is suitable for transmission.
- Source decoder converts it back again.
- e.g.
  - Multiplexing combines several signals into one. e.g. the left and right channels of stereo audio, the red, green and blue components of component video or the audio and video of a television signal.
  - Low Pass Filtering (LPF) to limit the bandwidth of the signal in order to avoid aliasing or to reduce the amount of spectrum required. (More on this in lecture 6)
  - Analogue-to-Digital Conversion (ADC) if we want to use digital modulation to transmit an analogue signal. This uses sampling and quantisation, as described on the previous slide.

## Source enCOder and DECoder (codec) continued

- More examples of source codec functions
  - **Compression** to reduce the amount of information we have to transmit. Video, image and audio codecs typically use **lossy compression**, which discards information that we (hopefully) won't notice too much. Quantisation and LPF can be considered to be lossy compression techniques. Data such as computer programs must be compressed *losslessly* so that they can be exactly reconstructed by the source decoder. **Lossless compression** only discards **redundant** information in the message. e.g. run-length coding, Morse code, Huffman coding, zip files. Sampling is lossless so long as the sampling period is short enough. (More on compression in lecture 7)
  - **Encryption** to protect the information from being decoded by an unauthorised receiver. Decoding is performed using a key that is built in to authorised receivers or SIM cards.
  - **Watermarking** to prove that the information has not been tampered with or sent from an unauthorised transmitter. The source decoder compares the received watermark with one that it has built in.



## Channel codec (CEP 1.4.3.3)

- **Channel encoder** protects the information against channel distortion, which causes transmission errors. This is achieved by inserting (carefully chosen) **redundant** information into the message.
- **Channel decoder** corrects the transmission errors by considering the redundant information.
- Repetition, Hamming, BCH and convolutional codes are examples.
- (More on channel coding in lecture 8)

## MOdulator and DEModulator (modem) (CEP 1.4.3.4 – 1.4.3.6)

- **Modulator** places the message onto the channel. With *baseband modulation* this may be performed directly, in carrier modulation a carrier wave is modulated with the message before being placed onto the channel. (More on this in lecture 2)
- **Demodulator** recovers the message from the channel.
  - In **coherent modulation** schemes, demodulation is sensitive to the timing and phase of the signal, requiring channel estimation, equalisation, carrier recovery and synchronisation.
  - **Non-coherent modulation** schemes don't require these complex techniques, but cannot achieve the same performance as coherent ones.
- Antennas are used for radio schemes, while lasers and Light Emitting Diodes (LEDs) are used for optical fibre and Infra-Red (IR) schemes.

## Digital vs analogue modulation (CEP 1.5.2.3)

- Advantages of digital modulation:
  - **Noise immunity, error correction and regeneration:** An analogue demodulator can never be sure if a particular component of a received signal is information or noise. A digital demodulator knows that the transmitted signal has a value chosen from a limited set of possibilities - the demodulator chooses the signal value that is most likely and (more often than not) this removes the noise. Even when the noise is strong enough to cause the demodulator to choose the wrong signal value, digital error correction techniques can be used to fix the mistake. Relays can use these methods to regenerate a digital signal before passing it on.
  - **Flexibility and integration:** A particular digital modulation scheme can be used to transmit any type of digital information and can integrate lots of different types into a single signal.
  - **Privacy and security:** Data encryption can be easily applied to digital information.
  - **Low cost:** Digital processing is typically much cheaper than analogue processing.
  - **Low dynamic range:** Digital signals typically have a constant transmission power, allowing power efficient transmitters and receivers to be built.

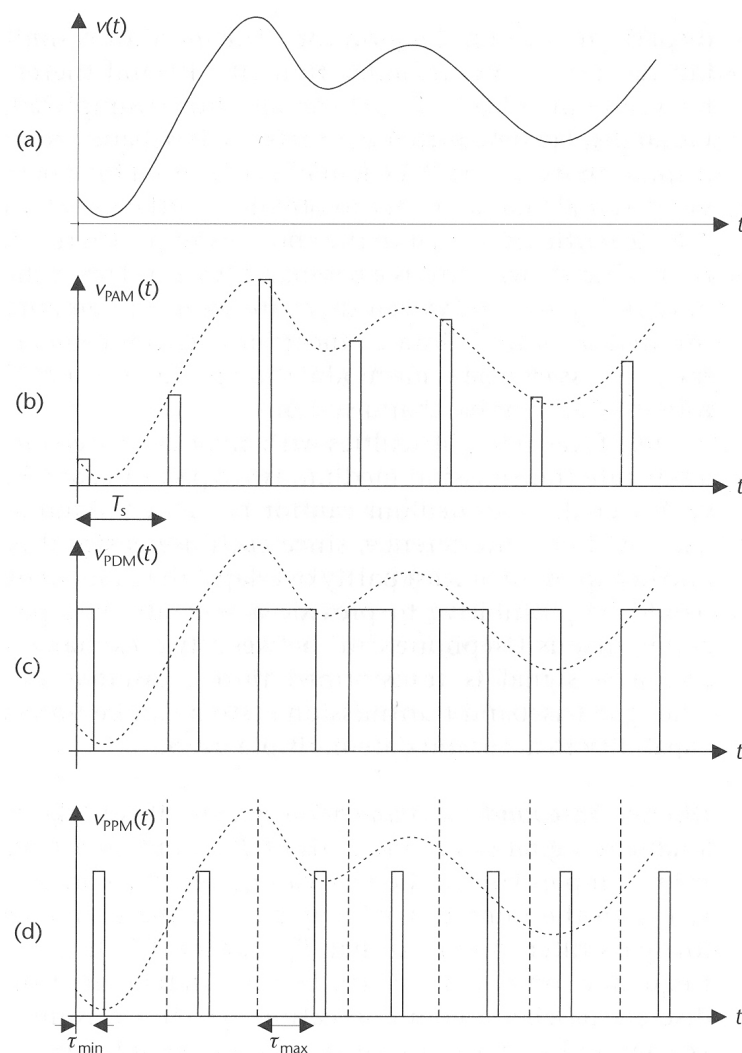
## Digital vs analogue modulation (CEP 1.5.2.4)

- Disadvantages of digital modulation:
  - **High bandwidth**: Digital modulation schemes require more bandwidth than analogue ones unless complex compression algorithms are used.
  - **Complexity**: Digital modulation schemes have a higher complexity than analogue ones because they perform more processing and require synchronisation.
  - **Quantisation distortion**: Quantisation is necessary for analogue-to-digital conversion, but it is inherently lossy and degrades the quality of the transmitted information.

## Baseband vs carrier modulation (CEP 1.5.3)

- We are typically interested in transmitting low frequency signals such as audio (20 Hz – 20 kHz).
- However, low frequencies don't propagate in some channels (more on this later).
- We can modulate our low frequency onto a high frequency **carrier** (e.g. 1 GHz) and transmit that instead (more on this in lecture 2).
- In other channels, **baseband** signals propagate fine and we don't need a carrier.
- **Analogue baseband modulation** is as simple as amplifying our analogue signal and putting it onto the channel directly, like in intercoms and CCTV.
- However, analogue baseband modulation does not support **multiple access** - the channel can only carry one signal.

## Discrete baseband modulation (CEP 1.5.3.1)



**Figure 1.21** Analogue signal and its discrete representation as PAM, PDM and PPM.

- (a) Discrete baseband modulation samples an **analogue** signal  $v(t)$  at time instants  $t$  that are integer multiples of the sampling period  $T_s$ .
- (b) **Pulse Amplitude Modulation** represents each sample with a pulse having the same amplitude. The analogue signal can be reconstructed using a LPF. Susceptible to additive **noise**.
- (c) **Pulse Duration Modulation** represents the amplitude of each sample with the duration of the corresponding pulse. Wasteful of **power**.
- (d) **Pulse Position Modulation** represents the amplitude of each sample with the position of the corresponding pulse.

## Discrete baseband modulation continued

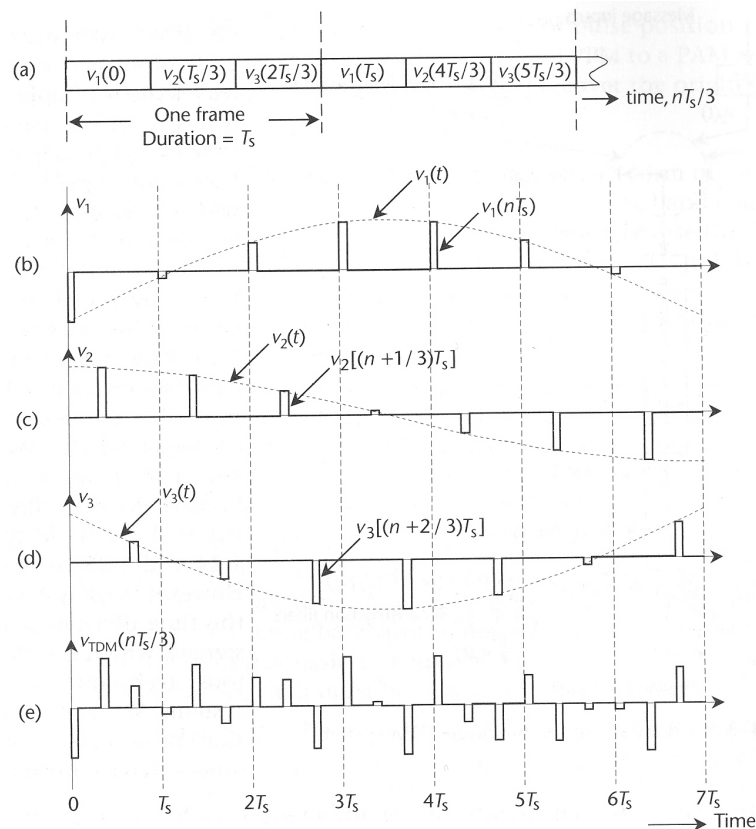


Figure 1.25 Three-channel TDM.  $n$  is an integer = 0, 1, 2, 3, ....

- (a) **Multiple access** can be achieved by dividing each sampling period  $T_s$  into a number of timeslots.
- (b), (c) and (d) A different PAM signal can be transmitted in each time slot.
- (e) The transmitted signal comprises all of the individual PAM signals. The receiver must be synchronised with the transmitter to tell the signals apart.

## Digital baseband modulation (CEP 1.5.3.1 and 6.5)

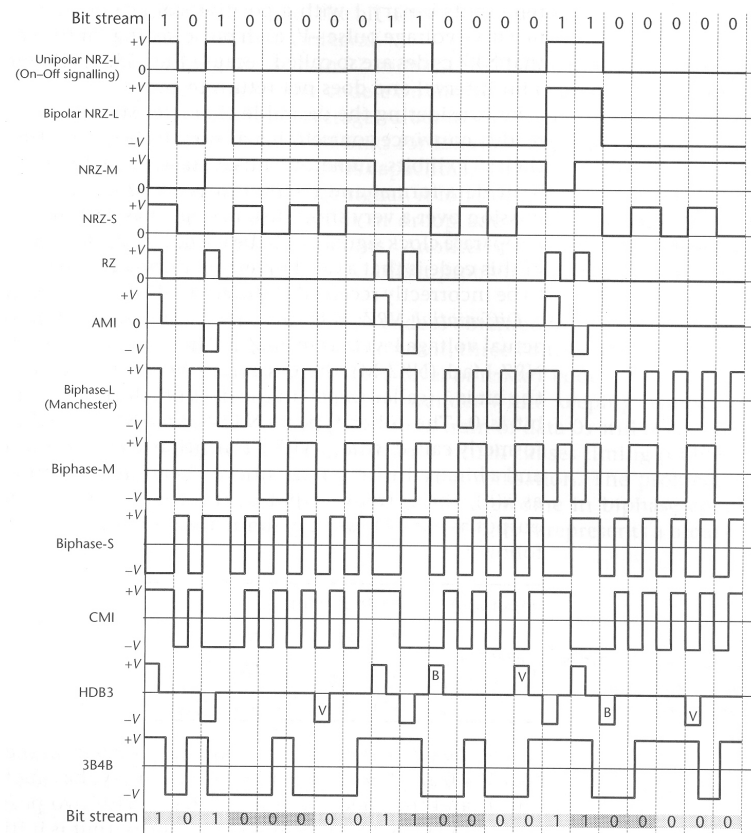


Figure 6.22 Common line codes.

- Digital signals can be converted into bit sequences using **Pulse Code Modulation (PCM)**. e.g. the sampled and quantised signal from before  $[2V, 2V, 4V, 4V, 4V, 6V, 6V, 8V, 6V]$  used a sampling period of  $T_s = 1$  s and  $N = 4$  quantisation levels. Each quantisation level can be mapped to  $\log_2(N) = 2$  bits according to  $2V \rightarrow 00$ ,  $4V \rightarrow 01$ ,  $6V \rightarrow 10$  and  $8V \rightarrow 11$ . We get the bit sequence  $[00, 00, 01, 01, 01, 10, 10, 11, 10]$  and a bit rate of  $k/T_s = 2$  bits per second.

- Line codes** can be used to transmit a bit sequence. They combine data and timing information into a single signal. They may allow error detection, by having some illegal sequences (e.g. in the sign of bipolar signals).

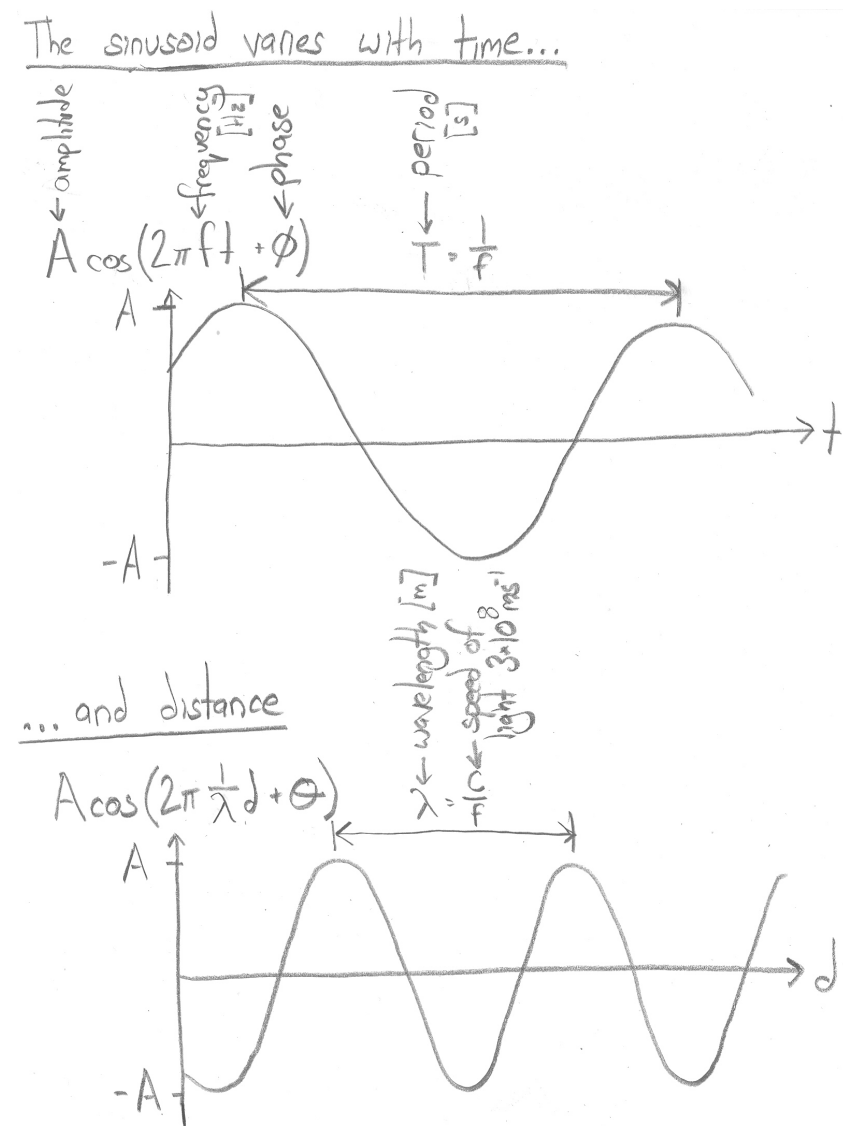


## Channel (CEP 1.4.5 - 1.4.5.3)

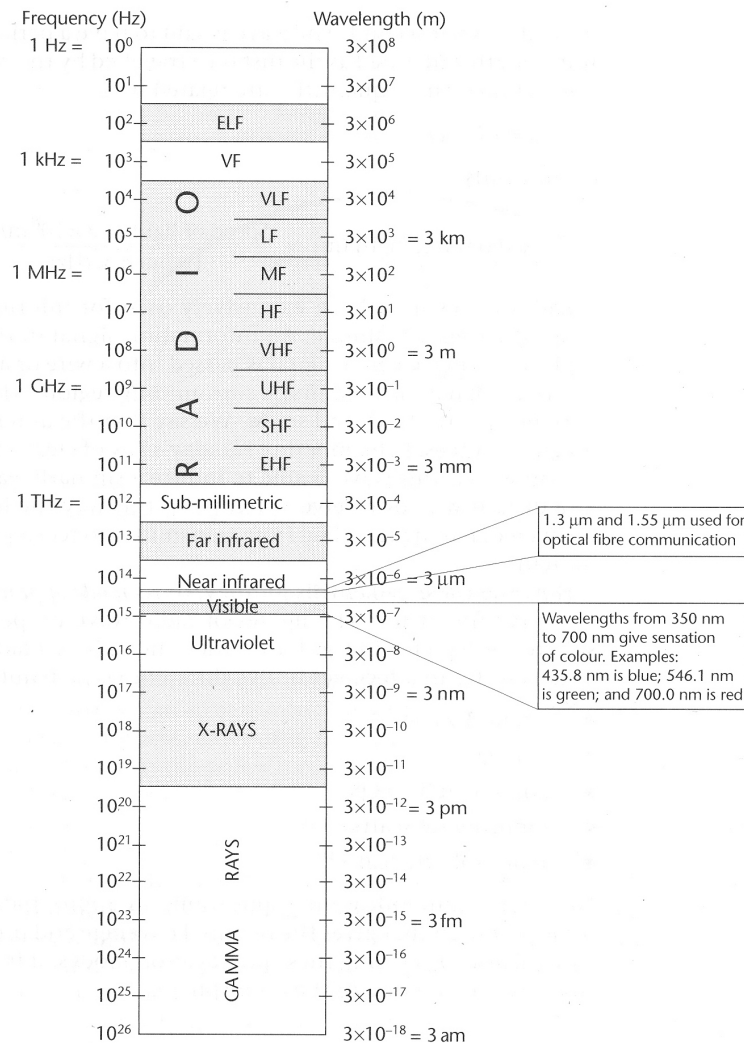
- **Closed channels** use a physical connection between the transmitter and the receiver.
- e.g.
  - **Twisted pair** uses two wires twisted together that convey a voltage differential. Used for telephone, Ethernet and ADSL.
  - **Coaxial cable** uses a conductor within an earthed sheath. This has a longer range and higher data rate than twisted pair, but has been mostly replaced by optical fibre.
  - **Waveguides** are metallic tubes in which radio waves are guided by reflection.
  - **Optical fibres** are waveguides for light. They are made of glass and the light reflects off the interface with the surrounding sheath, which is made of glass having a lower refractive index. Optical fibres allow very high data rates and are used as the backbone of the Internet and telephone networks. They are immune to electrical interference and cross talk. Also they insulate the transmitter from the receiver and are small and cheap.

## Radio (CEP 1.4.5.4)

- Radio is an open channel, allowing broadcast and mobility.
- It comprises electromagnetic waves, which propagate in free space as sinusoidal fluctuations in the electric and magnetic fields.
- It suffers from noise, shadowing, fading, multipath propagation and interference.



# Electromagnetic spectrum



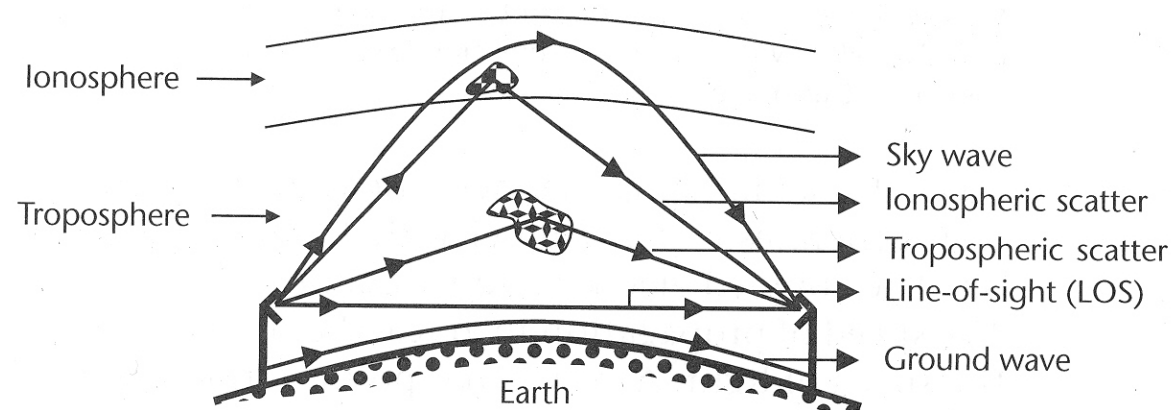
**Figure 1.14** The electromagnetic spectrum. ELF = extremely low frequencies (30–300 Hz); VF = voice frequencies (300–3000 Hz). For the abbreviations in the radio band see Table 1.6.

**Table 1.6** Typical services in various radio frequency bands.

Frequency band	Typical services
VLF (3–30 kHz)	1. Long-range navigation
Very low frequency	2. Submarine communication
LF (30–300 kHz)	1. Long-range navigation
Low frequency	2. Marine communication
	3. Radio beacons
MF (300–3000 kHz)	1. AM broadcast (550 kHz–1.6 MHz)
Medium frequency	2. Direction finding
	3. Maritime radio
HF (3–30 MHz)	1. Amateur radio
High frequency	2. International broadcasting
	3. Long distance aircraft and ship communication
	4. Military communication
	5. Telephone, telegraph and fax
VHF (30–300 MHz)	1. Aircraft navigational aid
Very high frequency	2. AM aircraft communication
	3. FM radio broadcast (88–108 MHz)
	4. VHF Television (54–88 MHz for channels 2–6; and 174–216 MHz for channels 7–13)
UHF (0.3–3 GHz)	1. Cellular telephone
Ultra high frequency	2. Microwave links
Sub-bands:	3. Navigational aids
L band = 1–2 GHz	4. Personal communication systems (PCS)
S band = 2–4 GHz	5. Radar
	6. UHF TV (470–890 MHz for channels 14–83)
SHF (3–30 GHz)	1. Satellite communication
Super high frequency	2. Radar
Sub-bands: C = 4–8; X = 8–12; Ku = 12–18; K = 18–27 GHz	3. Microwave links
EHF (30–300 GHz)	1. Experimental
Extra high frequency	2. Radar
Sub-bands: Ka = 27–40; V = 40–75 GHz	3. Satellite communication
Sub-bands above 300 GHz: Sub-millimetric (300 GHz–3 THz); far-infrared (3–30 THz); near-infrared (30–430 THz) used for optical fibre communication; and visible light (430–860 THz)	

## Radio propagation (CEP 1.4.5.4)

- Different frequencies propagate in different ways.
  - Diffraction causes **ground wave** propagation for frequencies below 2 MHz, like AM broadcast signals.
  - Varying refractive indices in the layers of atmosphere cause reflection for frequencies between 2 and 30 MHz. The Earth and the atmosphere create an **atmospheric waveguide**, allowing very long range communications when the weather permits.
  - Frequencies above 30 MHz will only propagate using **line of sight**.



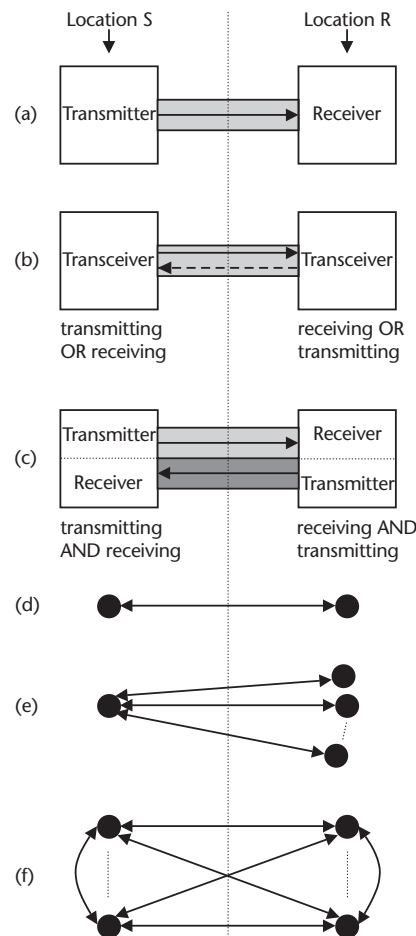
**Figure 1.15** Different radio wave propagation modes in the atmosphere.

## Relaying techniques (CEP 1.4.5.4)

- **Satellites** allows broad-area coverage and can act as **relays** for round-the-world communication.
  - Satellites at an altitude of 35874 km will have **geostationary orbits**, having a period equal to that of the Earth's rotation. They can therefore stay above any fixed point on the equator. The long distance imposes a 0.24 s round-trip delay and weak signals. This doesn't matter for broadcast TV, which uses directional satellite dishes.
  - **Low and medium Earth orbits** are used when stronger signals and lower delays are required, like in GPS. When used for communications, the satellites must be able to **hand calls over** to each other when they disappear over the horizon.
- **Cellular** communications uses a network of geographically separated basestations, which communicate with each other using closed channels. Mobile handsets communicate with each other via the nearest basestations, which act as **relays**. Basestations must be able to **hand calls over** to each other when the mobile handset moves out of range.

## Simplex and duplex (CEP 1.5.1)

Figure 1.17

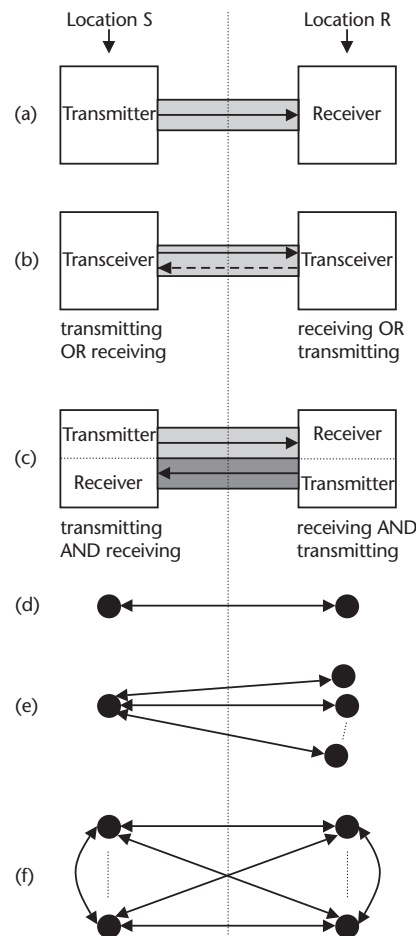


Taken from *Communication Engineering Principles*, © Ifiok Otung, published 2001 by Palgrave

- (a) **Simplex** channels pass information in only one direction from **transmitters** to **receivers**, like with audio/television broadcast, pagers, IR remote controls, radar.
- (b) **Half-duplex** channels pass information in both directions between **transceivers**, but only one direction at a time, like with walkie-talkies.
- (c) **Full-duplex** channels can pass information between **transceivers** in both directions at the same time by using different frequencies or time slots, for example. Telephone and data networks are full-duplex.

## Point-to-point (CEP 1.5.1.3)

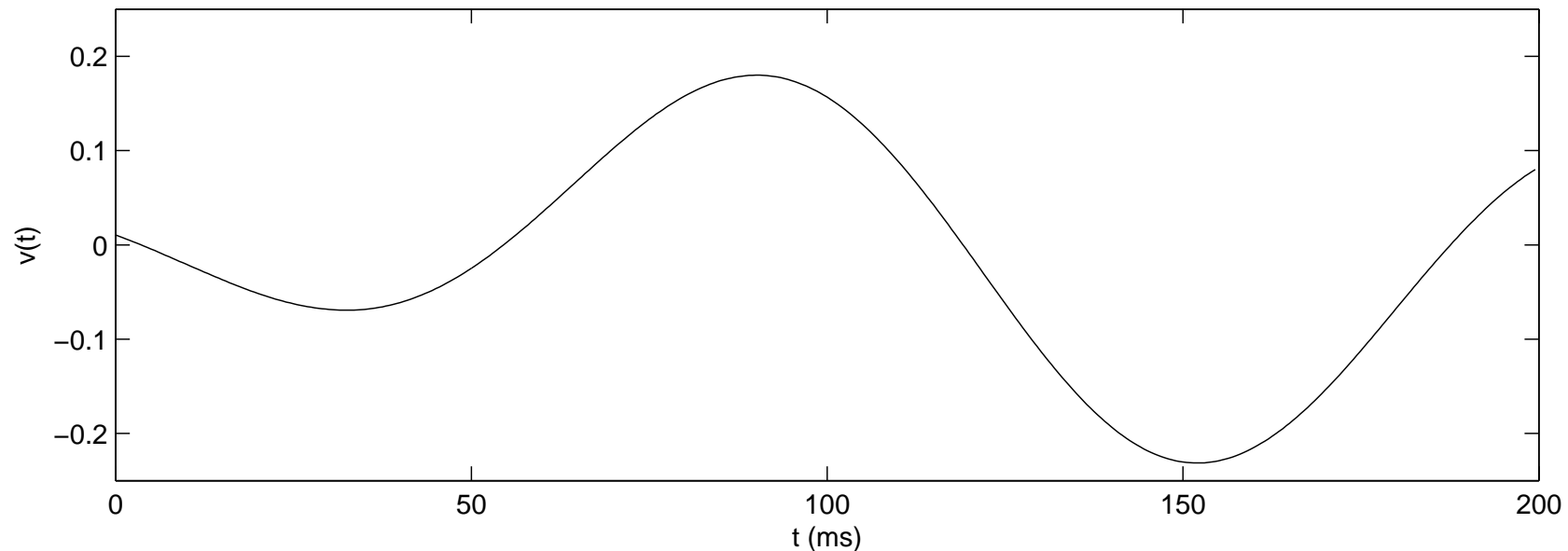
Figure 1.17



Taken from *Communication Engineering Principles*, © Ifiok Otung, published 2001 by Palgrave

- (d) The above channels are **point-to-point** if there is only one **transmitter** and one **receiver** (or a pair of **transceivers**).
- (e) **Point-to-multipoint** channels have one **transmitter** and many **receivers**, like in audio/television broadcast.
- (f) **Multipoint-to-multipoint** channels have many interconnected **transceivers**, like in local area networks.

## Exercise



1. This analogue signal is already suitable for **analogue baseband modulation**. However, in order to use **discrete baseband modulation**, we need to sample it. Sketch the impulses that would be obtained if a sampling period of  $T_s = 100$  ms was used. What is the problem here? Draw the corresponding sketch for a sampling frequency of  $f_s = 40$  Hz. Is this okay? Given that the maximum frequency in this signal is  $f_{max} = 10$  Hz, what is the lowest acceptable sampling frequency?



## Exercise continued

2. Sketch PAM, PDM and PPM representations of the analogue signal for a sampling period of  $T_s = 25$  ms.
3. In order to use [digital baseband modulation](#), we need to quantise our sampled signal. Choose  $N = 4$  appropriate quantisation levels and sketch the result of applying these to the signal after it has been sampled with a period of  $T_s = 25$  ms.
4. Choose a mapping from quantisation levels to bits and convert your quantised signal into a bit sequence. What is the bit rate?
5. Sketch Non-Return to Zero (NRZ), Non-Return to Zero Mark (NRZ-M) and Manchester representations of your quantised signal, remembering to annotate the time axes.