CS1011: 數位電子導論

Signals and Data Transmission

Outline

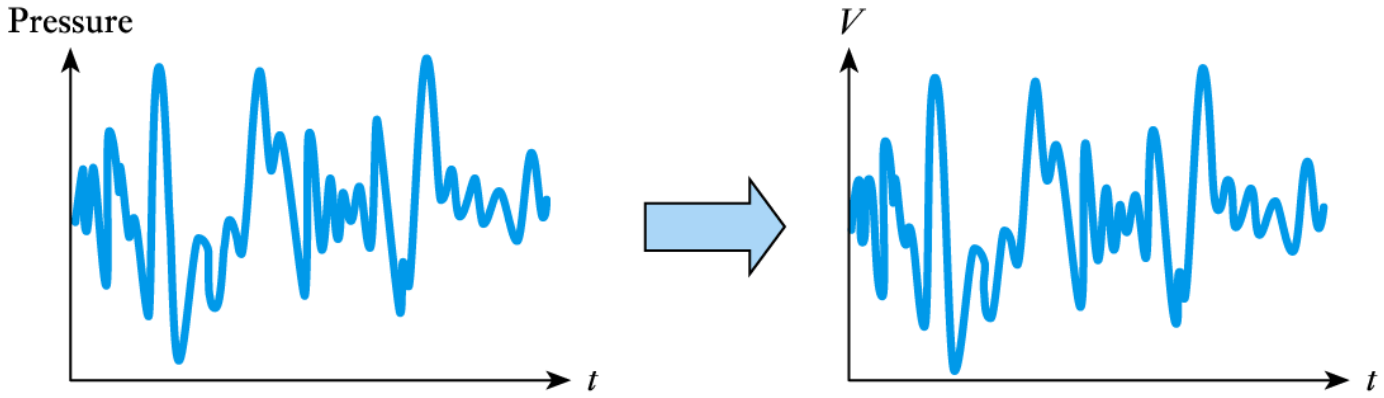
- Introduction
- Analog Signals
- Digital Signals
- Signal Properties
- System Limitations
- Communication Channels
- Modulation
- Demodulation
- Multiplexing
- Distortion and Noise

Introduction

- Earlier we looked at physical quantities
  - E.g., temperature, pressure, humidity
- It is often convenient to represent these by signals
  - Sensors *produce* signal from physical quantities
  - Actuators *take* signals and affect external quantities
- Signals can be analog or digital in nature
- In this lecture, we will look at examples of electrical signal of various forms

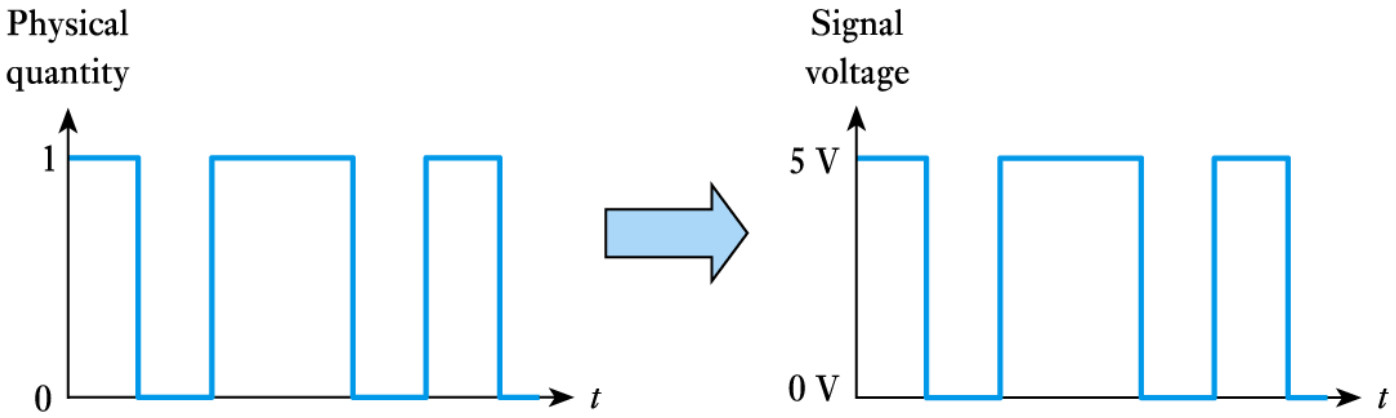
Analog Signals

- Analog signals are free from discontinuities and can take an infinite number of values
- They have been used since the 19th century
  - E.g., in telephone and wireless communication
- Perhaps the simplest form is where a voltage represents the amplitude of some physical quantity



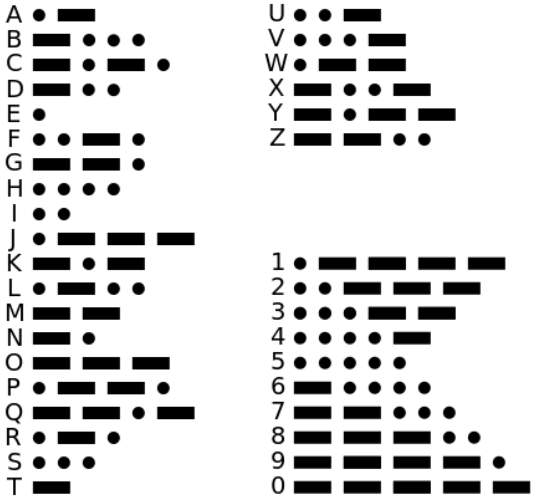
Digital Signals

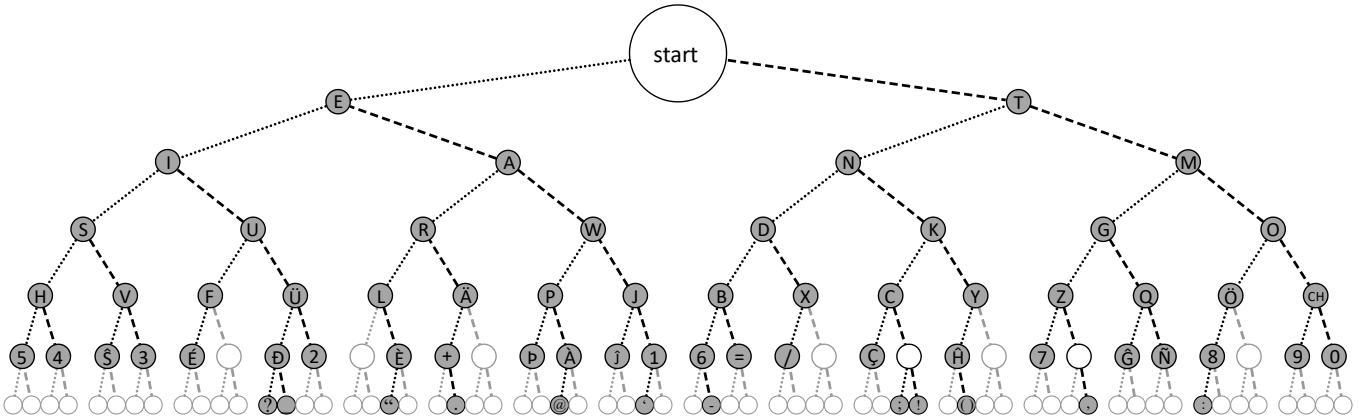
- Most applications use two values (binary signals)
- The two states are often represented by 2 voltages



Digital Signal Example – Morse Code

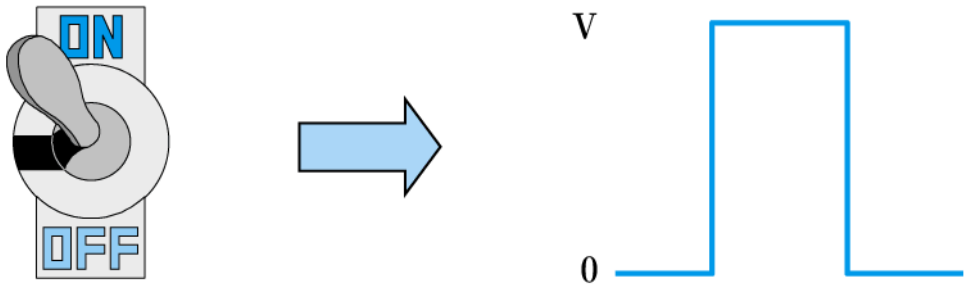
- **Digital signals have also been used since the 19th century**
  - **E.g., in telegraphy using Morse code**





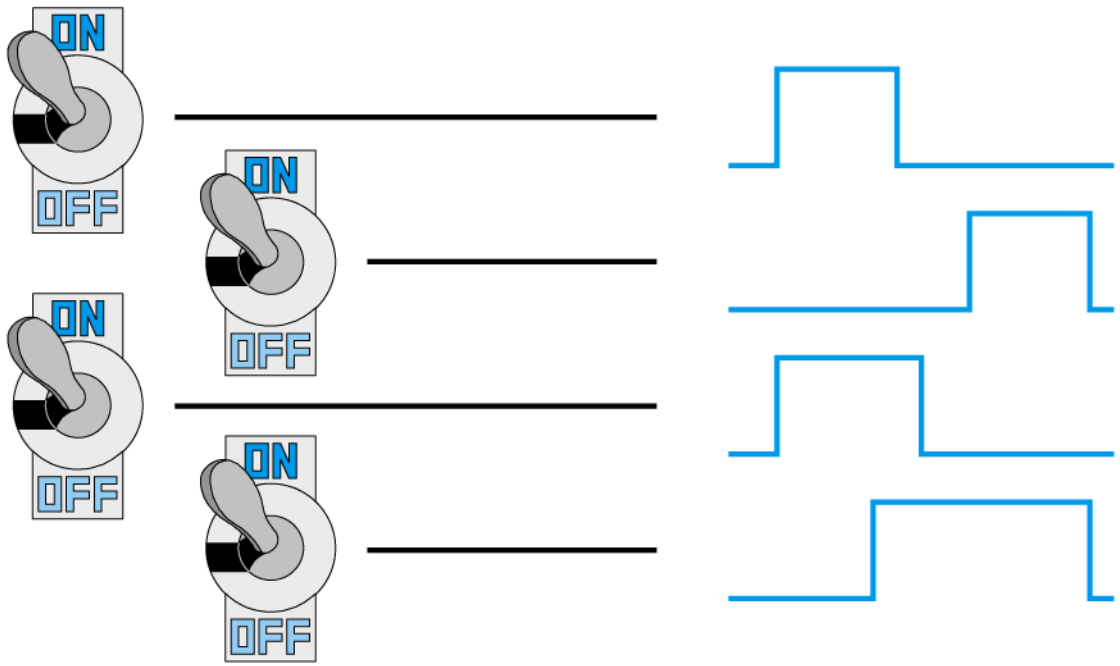
Single-bit Information

- **A single digital signal can represent the state of a single binary quantity**
  - **The information represented by such a signal can be represented by a single binary variable or binary digit**
  - **A binary digit is usually referred to as a bit**



Multiple-bit Information

- **Bits can be grouped together to form digital words**
  - **The multiple-bit can represent several signals or many values**



Multiple-bit Information Example

- A digital variable of *n* bits can take 2^n values
  - An 8-bit word can take $2^8 = 256$ values
  - A 16-bit word can take $2^{16} = 65{,}536$ values
  - A 32-bit word can take $2^{32} = 4{,}294{,}967{,}296$ values
- Therefore
  - An 8-bit word gives a resolution of 1 part in 256 or 0.39%
  - A 16-bit word gives a resolution of 1 part in 65,536 or 0.0015%
  - A 32-bit word gives a resolution of 1 part in 4,294,967,296 or 0.000000023%

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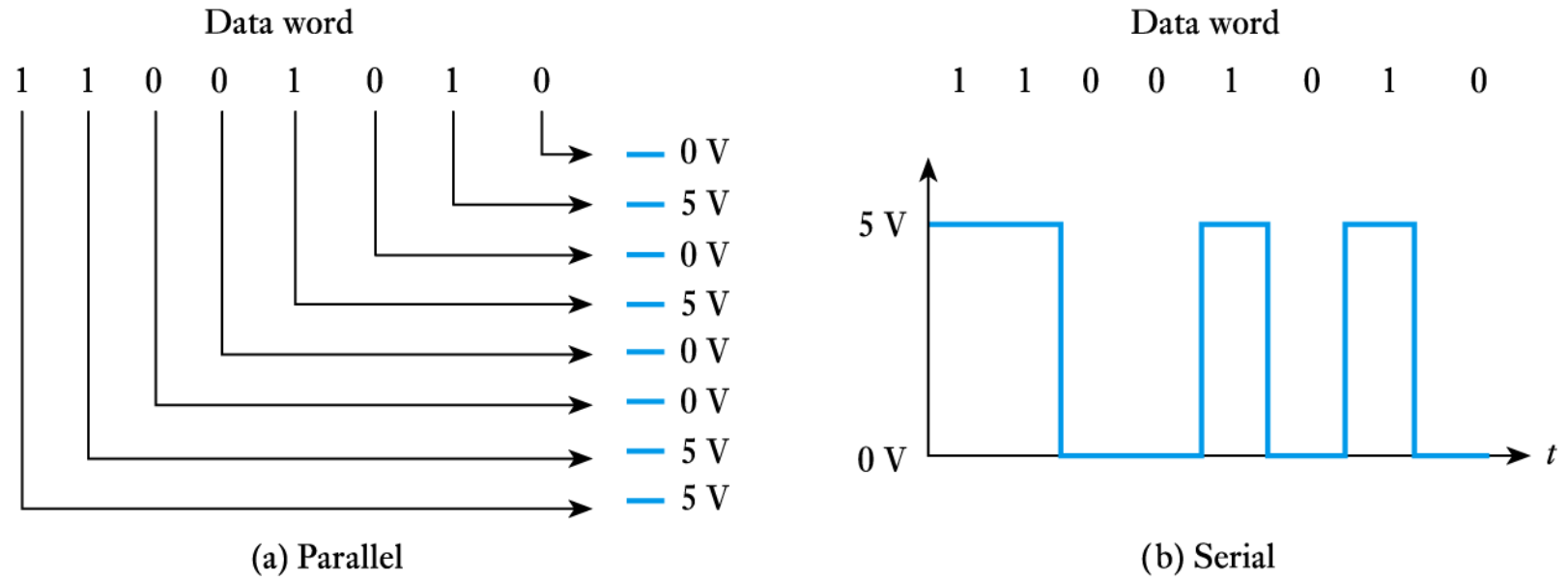
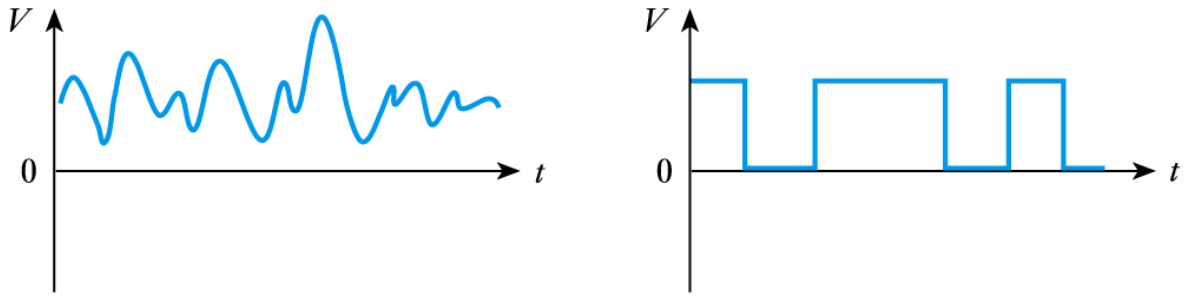
Parallel and Serial Data

- **Digital words can be communicated in either parallel or serial form**

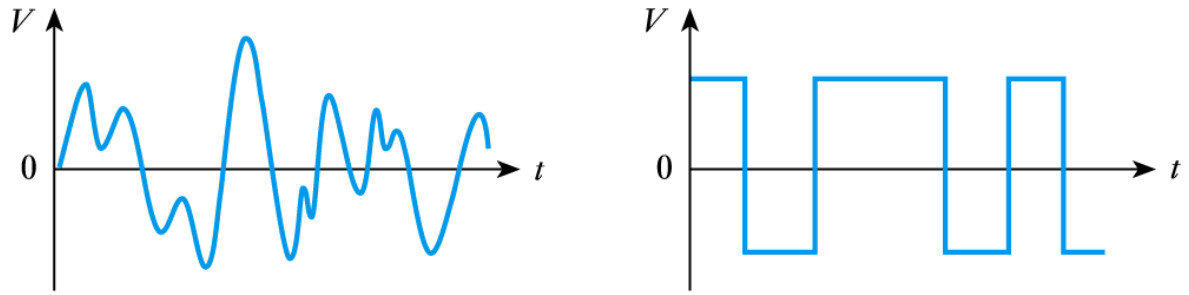


Signal Properties

- **Signals may be unipolar or bipolar**



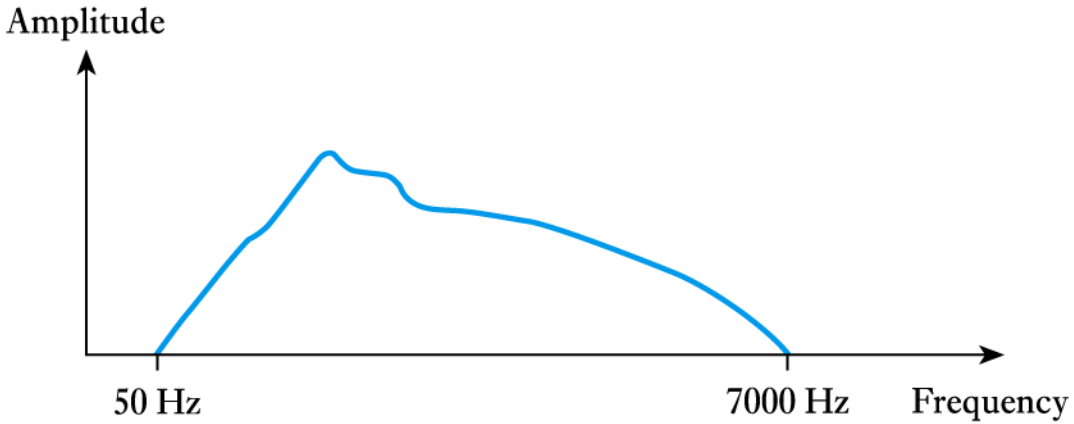
(a) Unipolar



(b) Bipolar

Frequency Spectrum

- **Signals vary in their frequency range**
  - **E.g., the human voice has a range from 50 Hz – 7 kHz**
- **The range can be described by a frequency spectrum**
  - **Shows the magnitude of the frequency components**

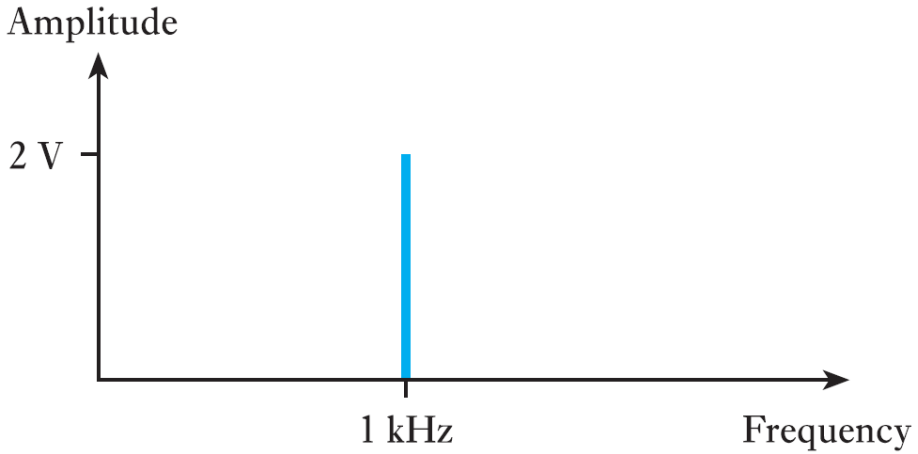


A frequency spectrum for a speech waveform

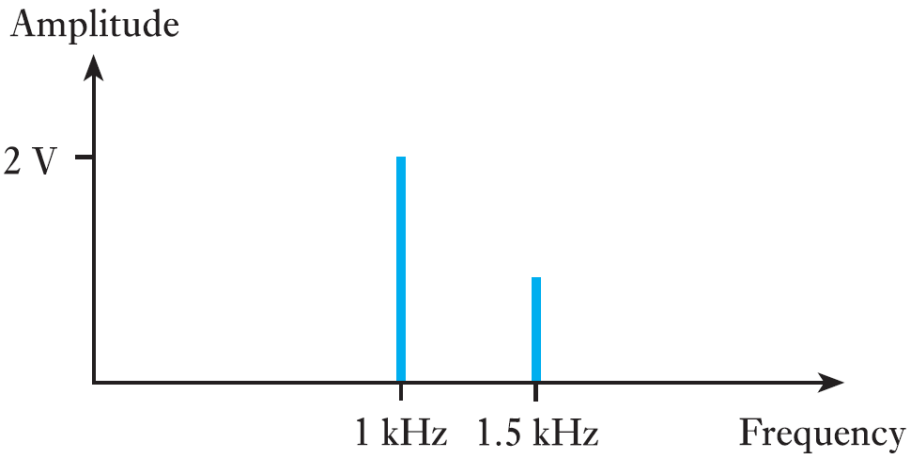
Bat: 1 kHz – 120 kHz
Dolphin: 150 Hz – 100 kHz
Cat: 60 Hz – 65 kHz
Dog: 40 Hz – 50 kHz
Human: 20 Hz – 20 kHz

Frequency Spectrum Examples

- **A signal consists of a sinusoidal voltage with a frequency of 1 kHz and a magnitude of 2 V**



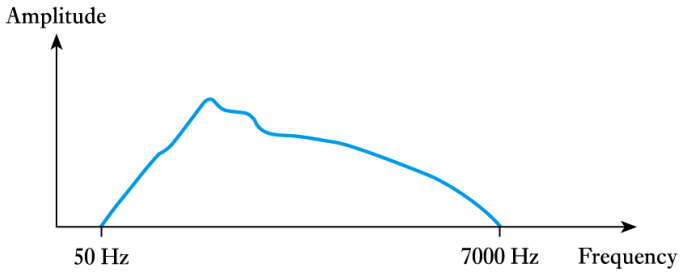
- **A signal is formed by adding two sinusoidal voltages. The first has a frequency of 1 kHz and a magnitude of 2 V. The second has a frequency of 1.5 kHz and a magnitude of 1 V.**



Bandwidth

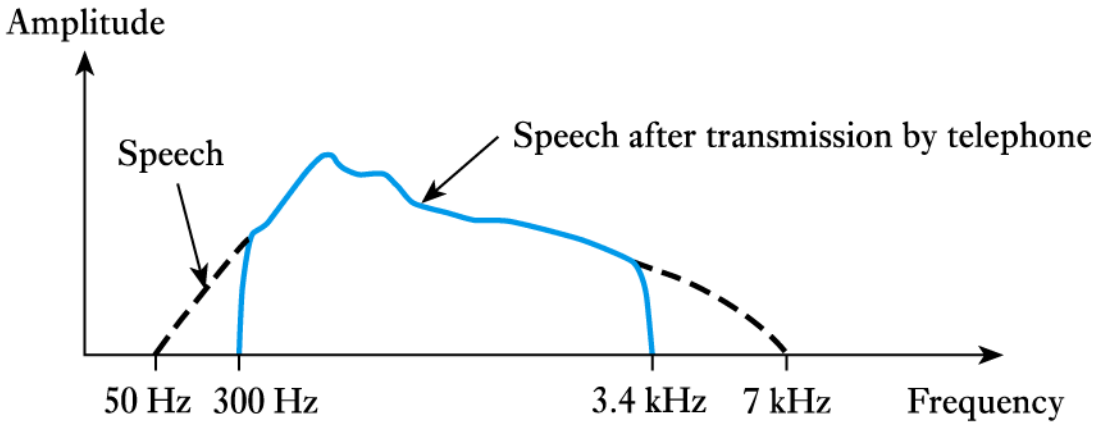
- **The difference between the highest and lowest frequencies in a signal is termed its bandwidth**
- **For example:**
  - **A typical human speech voice might have a frequency range from about 50 Hz to about 7 kHz. Therefore**

$$\text{Bandwidth} = 7\ \text{kHz} - 50\ \text{Hz}$$
$$= 6.95\ \text{kHz}$$
$$\approx 7\ \text{kHz}$$



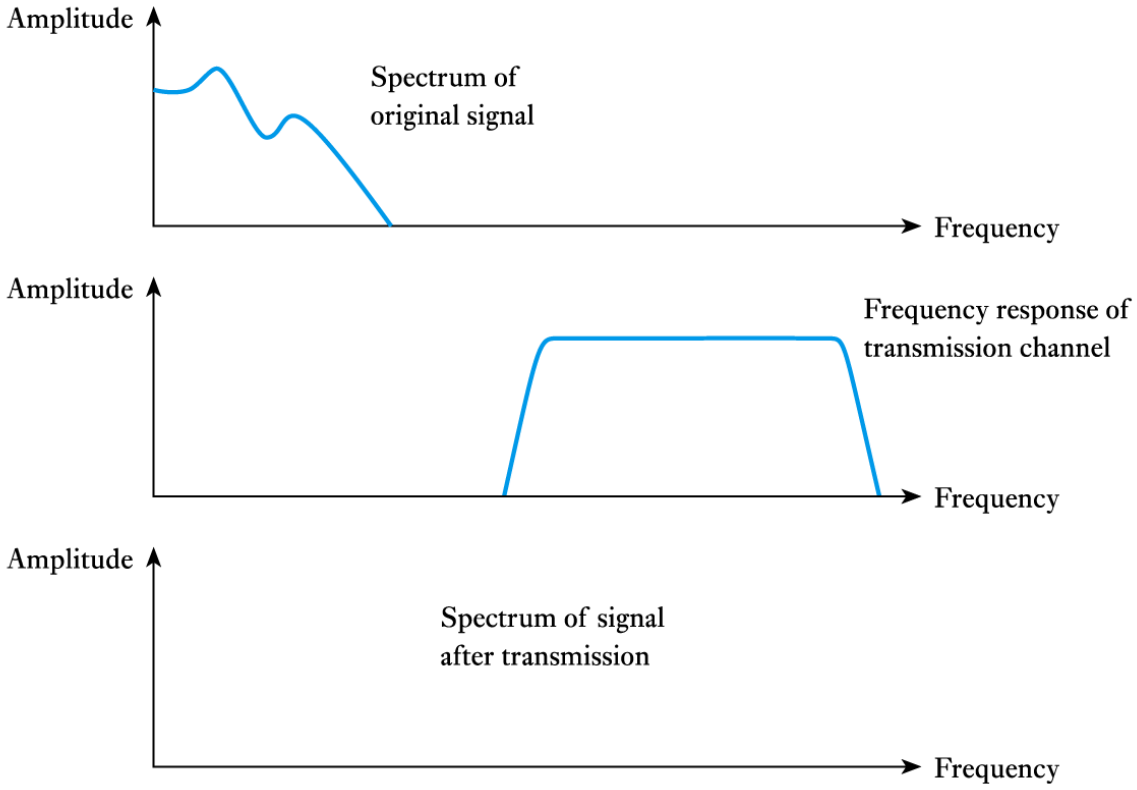
System Limitations

- **All systems impose restrictions on the signals that can be used with them**
  - **E.g., limits to the magnitudes of the inputs and outputs, limits to the range of frequencies that can be used**
  - **Usable frequency range is determined by the frequency response of the system**



Problem of Mismatched Frequency Range

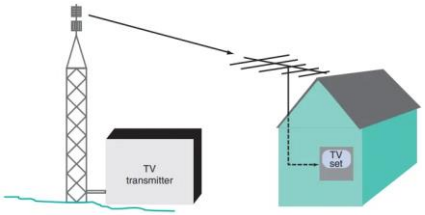
- Problems can occur if the frequency response of the system is not appropriate
- We can use modulation (調變) to overcome such problems



Communications

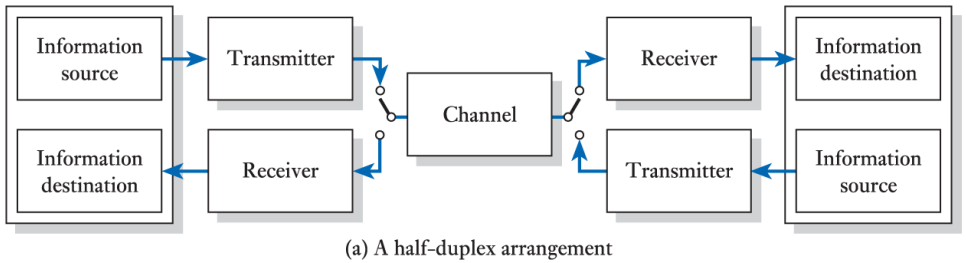
- The term *communication* relates to the transmission of information from one place to another
- This can refer to the exchange of information by way of speech or written material
- Here we are concerned with *communication systems*
- The basic elements of such a system are shown here

Simplex and Duplex Communication

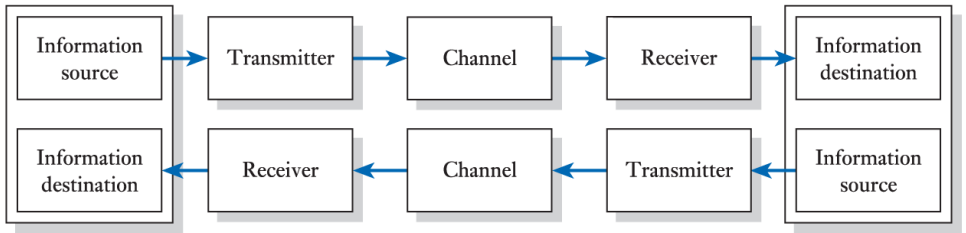


Simplex and duplex communication

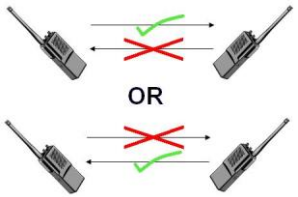
- A ***simplex*** system communicates in only one direction
- A ***duplex*** system communicates in both directions
- Duplex systems may be divided into two forms:
  - ***Half-duplex*** systems can communicate in both directions but only in one direction at any one time
  - ***Full-duplex*** systems allow simultaneous communications in both directions



(a) A half-duplex arrangement

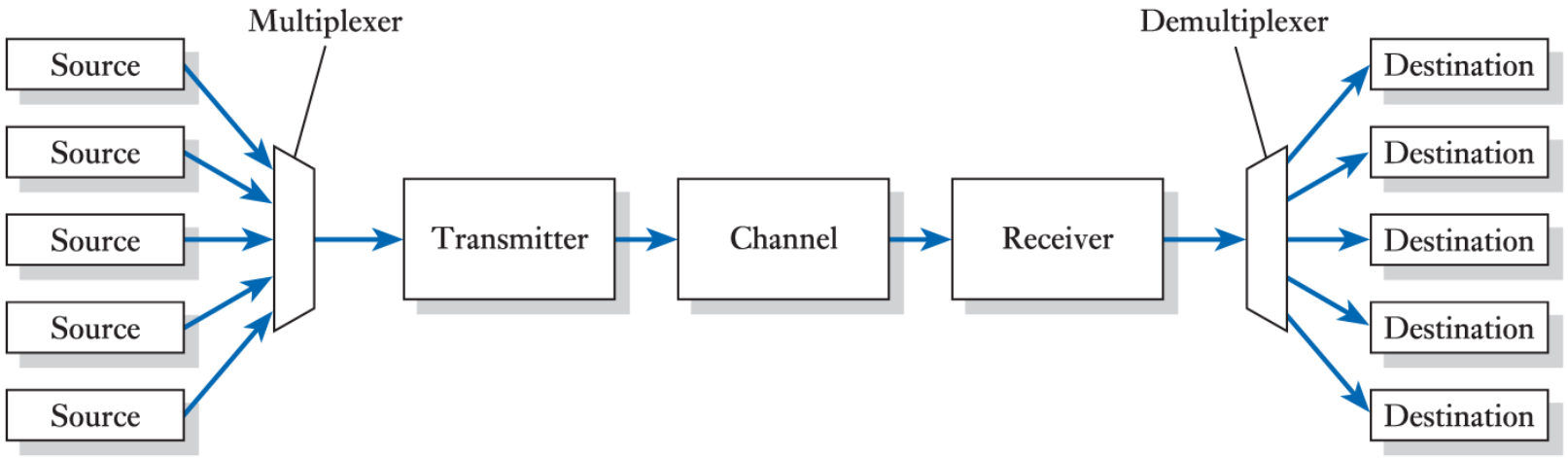


(b) A full-duplex arrangement



Multiplexing

- **Many communications systems are required to link several sources to several destinations over a single channel. This is achieved using some form of multiplexing. Techniques will be discussed later.**

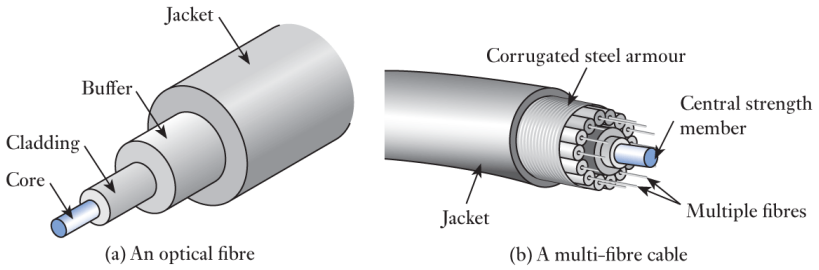


Communication Channels

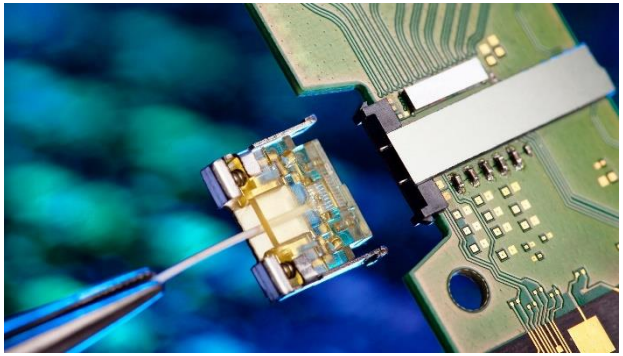
- Communication channels can take many forms
- Some use physical connections
  - Wires
  - Waveguides
  - Fiber-optic cables, etc.
- Others use "free space"
  - Light
  - Radio waves

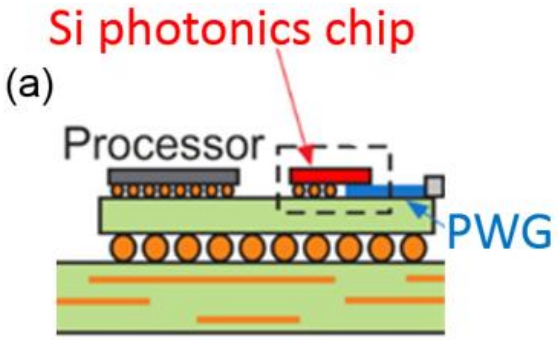
Fiber-optic Communication

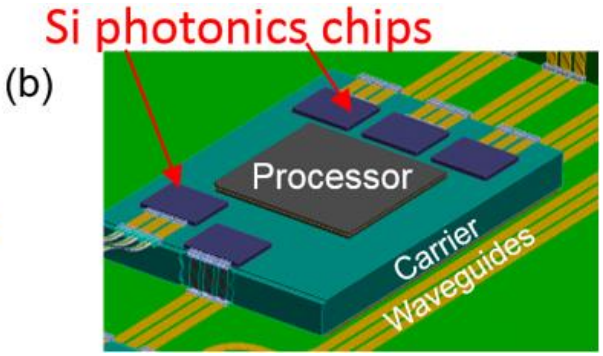
- Used for long-distance communication
- Removes the effects of ambient light
- **Fibre-optic cables** can be made of:
  - **Optical polymer**
    - Inexpensive and robust
    - High attenuation (衰減), therefore short range (up to about 20 meters)
  - **Glass**
    - Much lower attenuation (衰減) allowing use up to hundreds of kilometres
    - More expensive than polymer fibers
- Light source would often be a **laser diode**

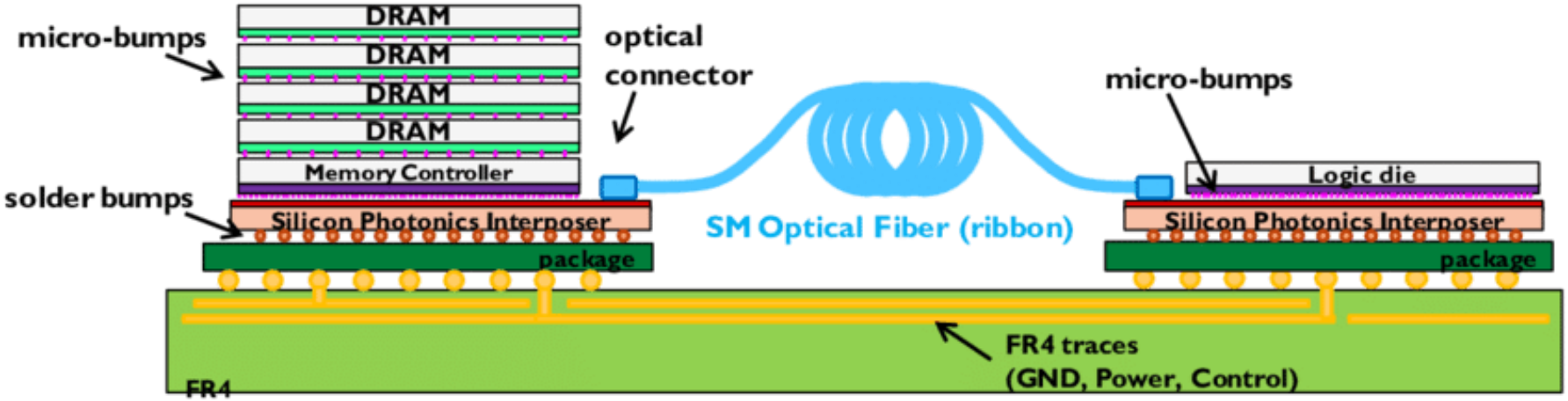


Silicon Photonics









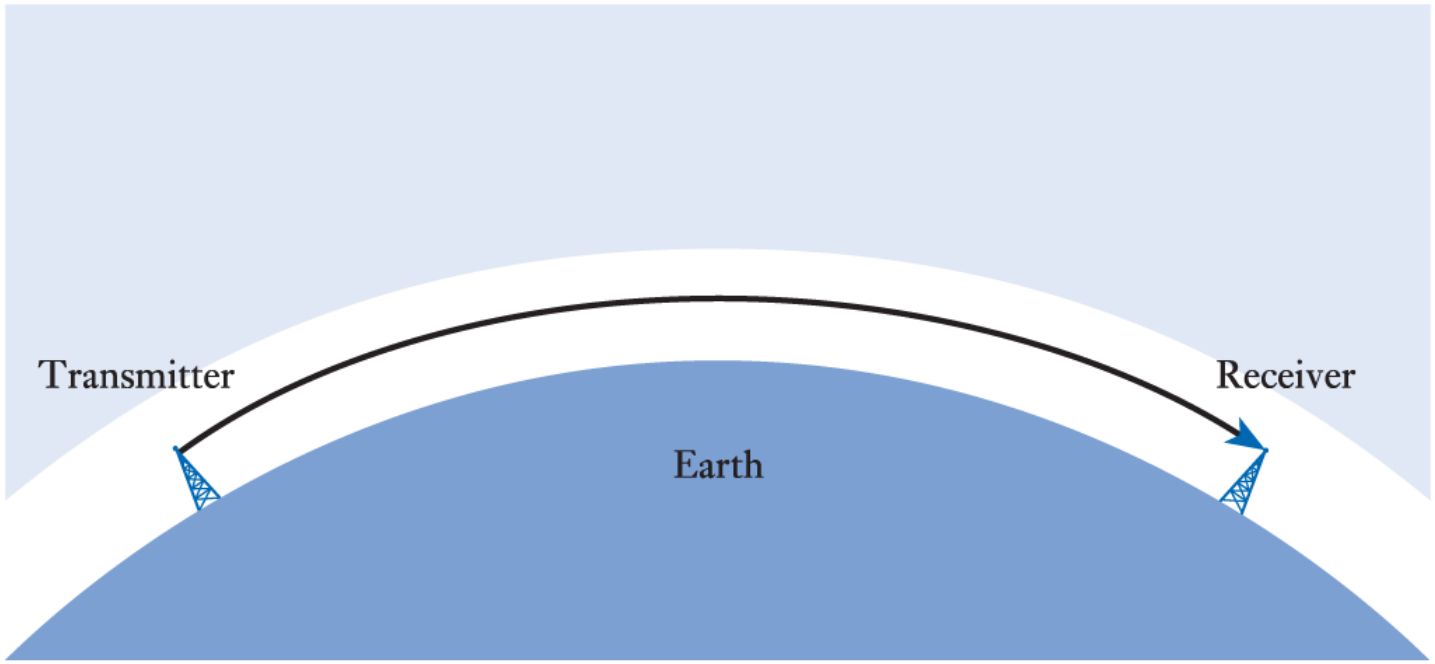
What is silicon photonics: https://www.youtube.com/watch?v=gsTl2qkWnp0

矽光子點亮光通訊未來: https://www.eettaiwan.com/20200317nt01-ofc/

Radio Wave Propagation

- **Radio signals of different frequencies differ in the way that they propagate from their source**
- **There are three basic forms of propagation:**
  - ***Ground wave propagation***
    - **Relatively low frequencies – up to a few megahertz**
  - ***Sky wave propagation***
    - **The high-frequency (HF) band – from 3 to 30 megahertz (short-wave band)**
  - ***Line-of-sight propagation***
    - **The very-high-frequency (VHF) band and above – above 30 megahertz**

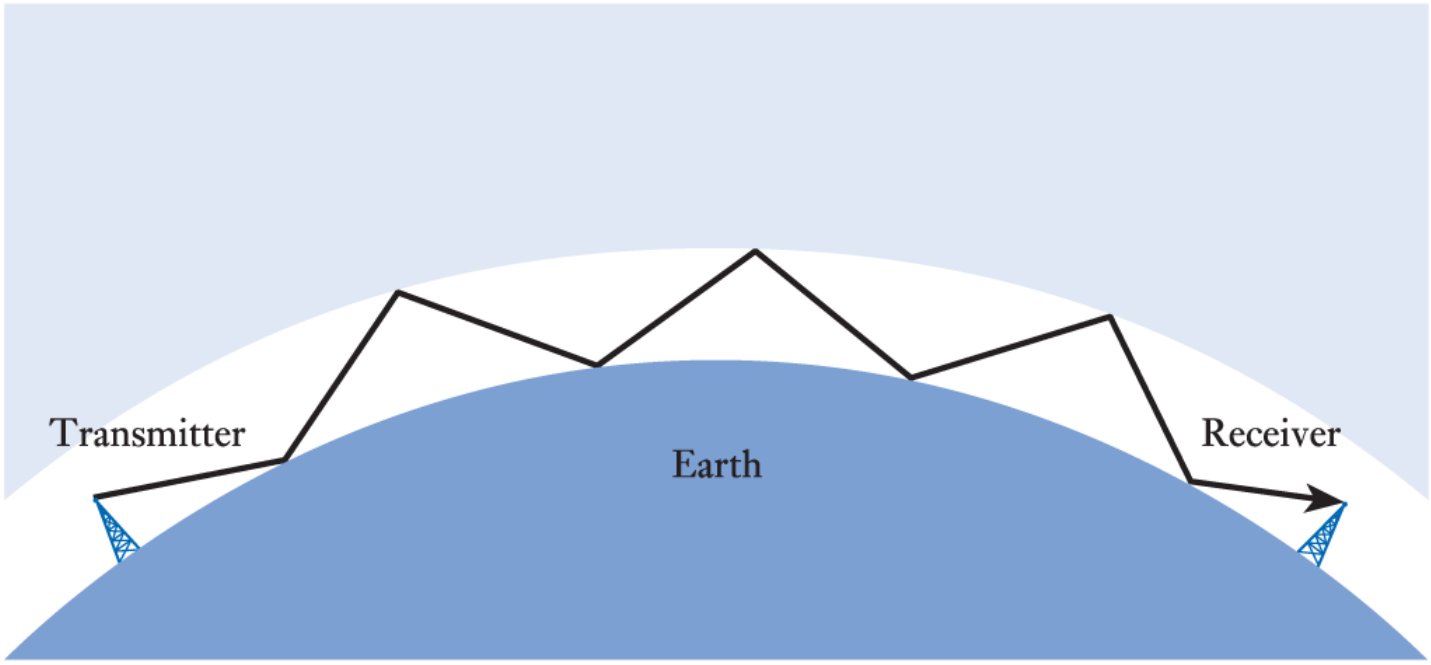
Ground Wave Propagation



(a) Ground wave propagation

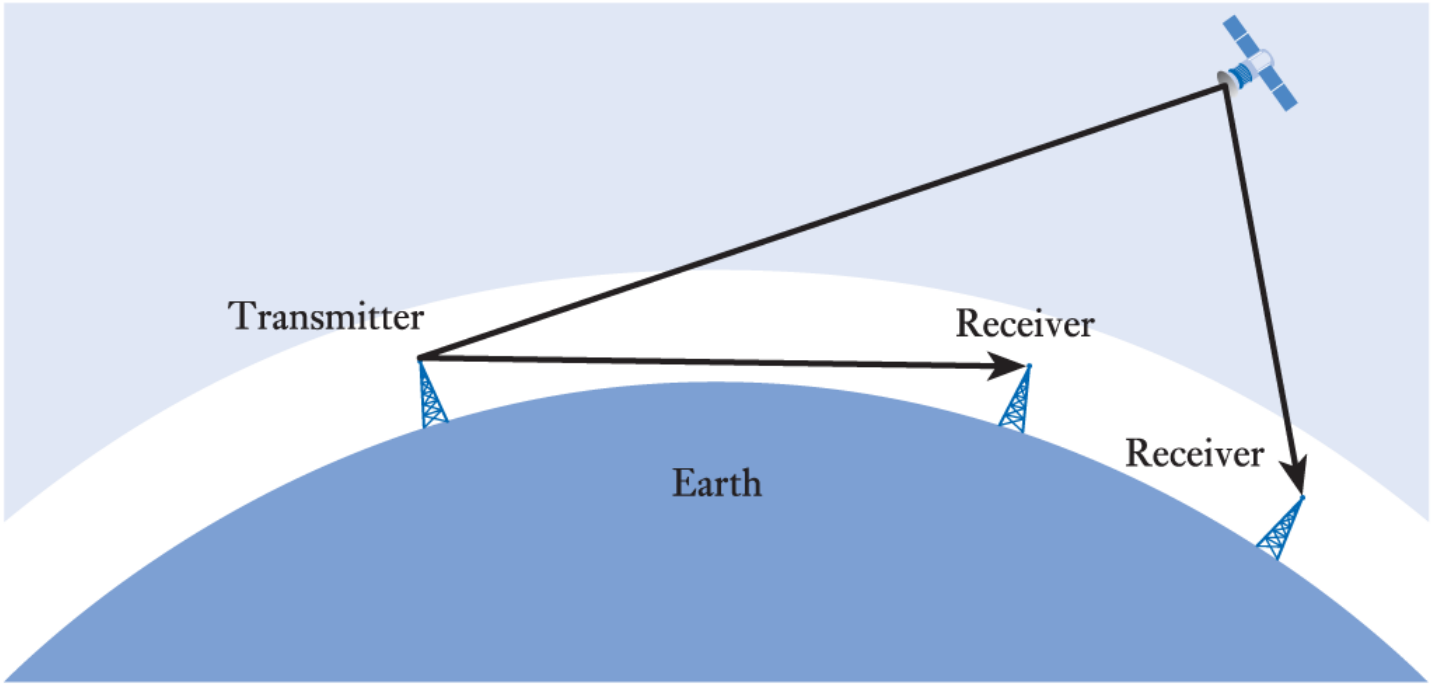
Bending a laser beam: https://youtu.be/zTx7UoPXvr4

Sky Wave Propagation



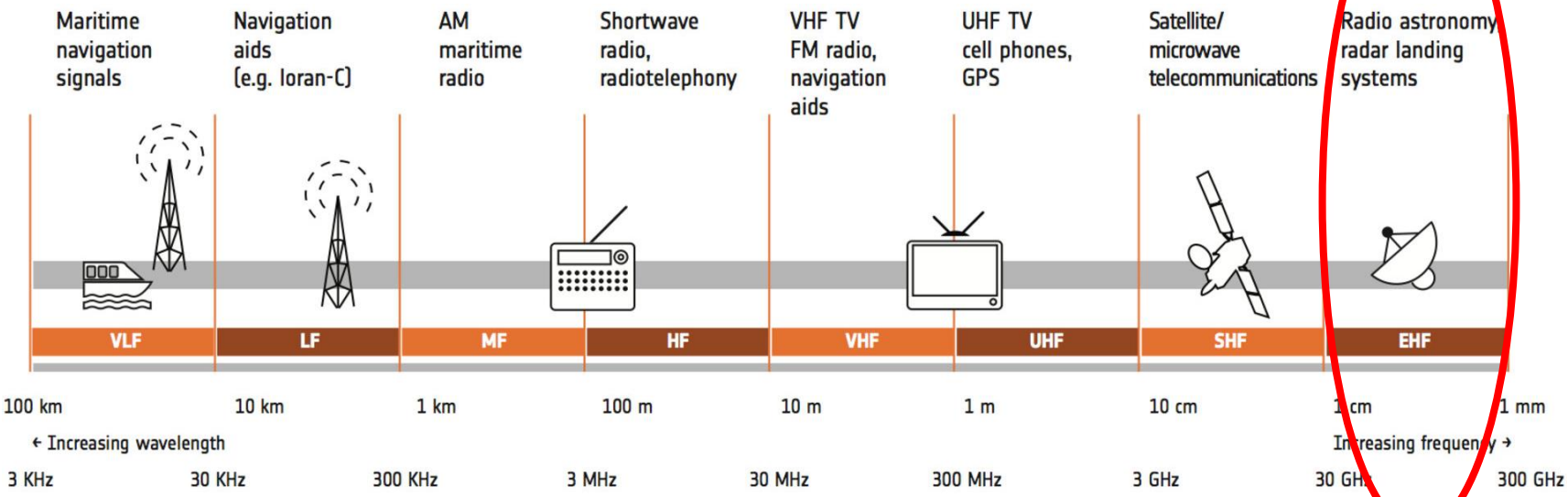
(b) Sky wave propagation

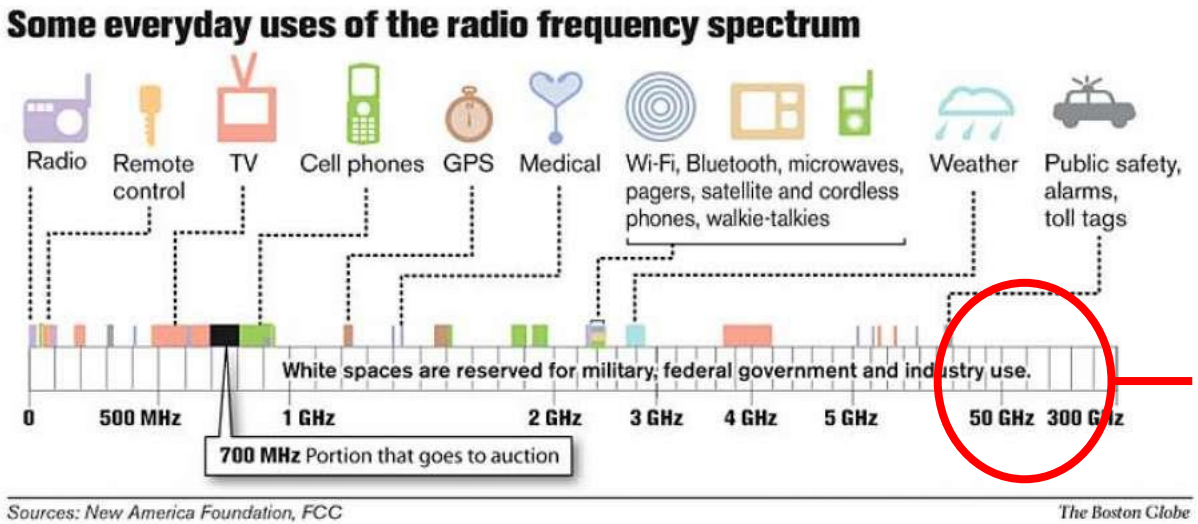
Line-of-sight Propagation



(c) Line-of-sight propagation

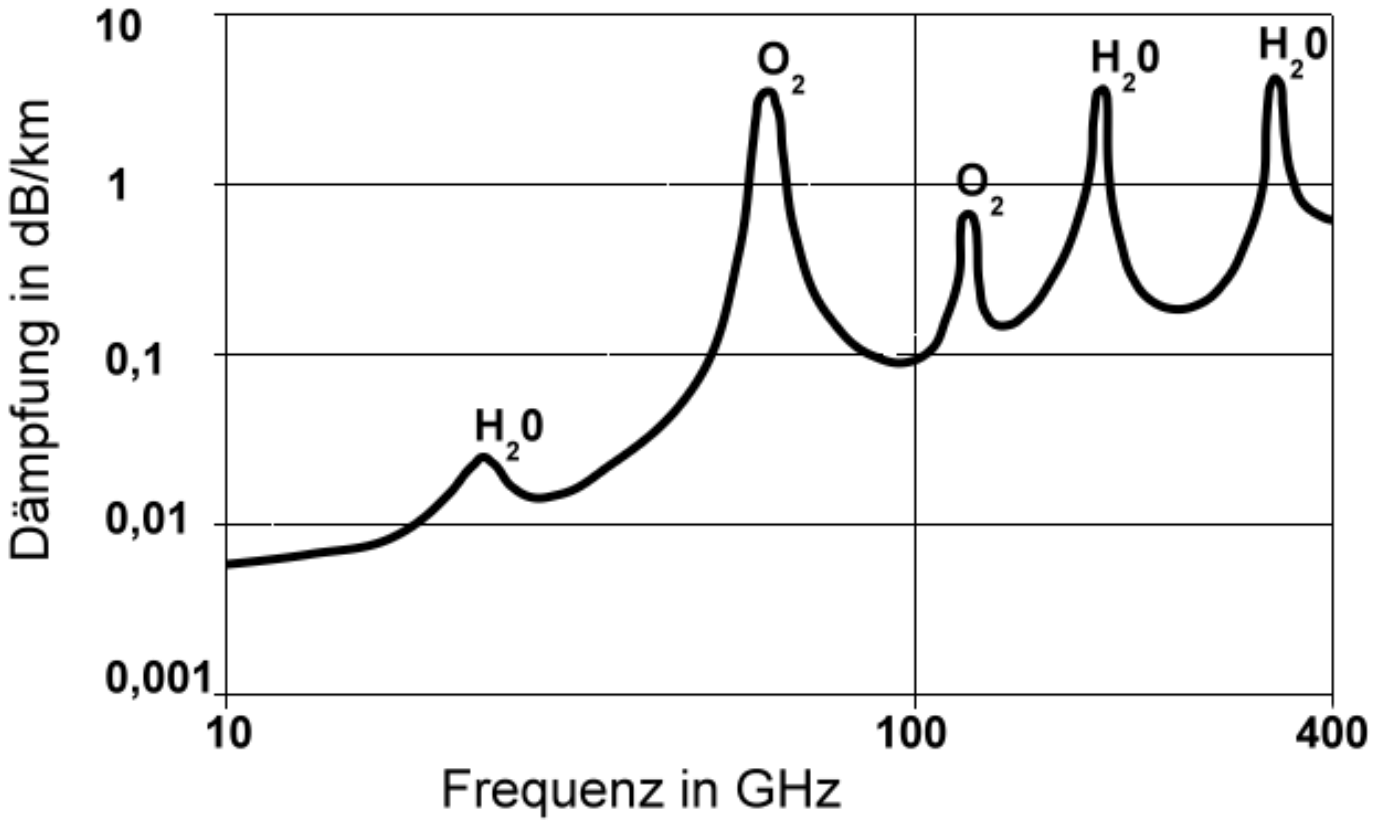
Radio Frequency Spectrum



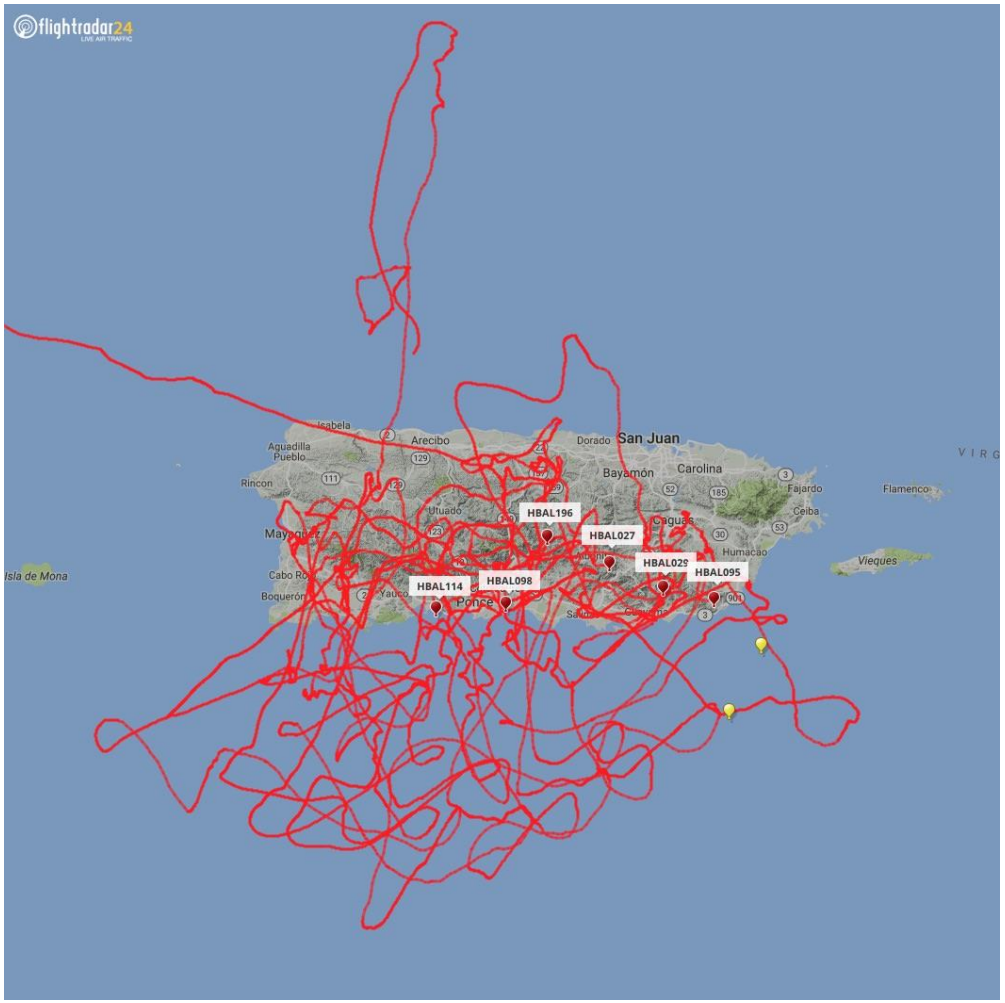


5G

Atmospheric Attenuation

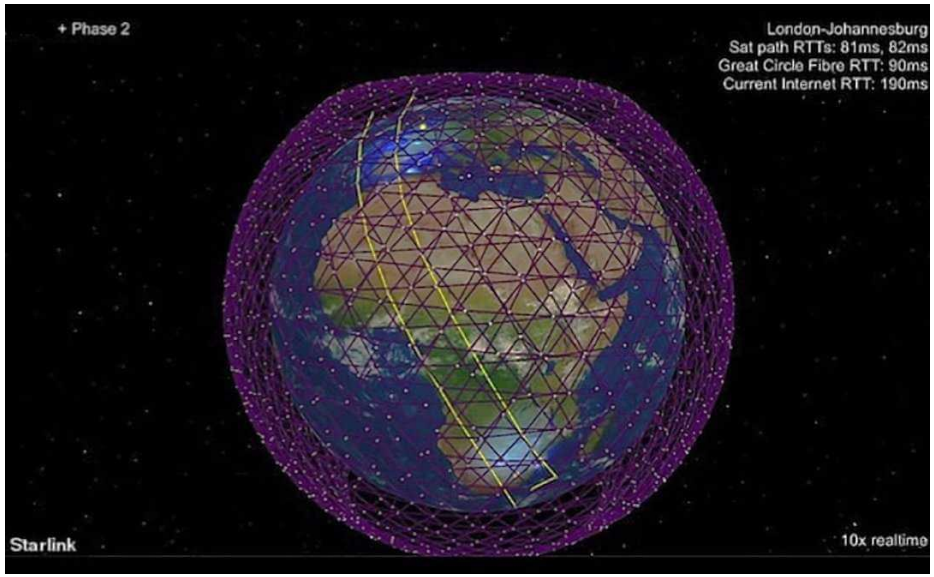


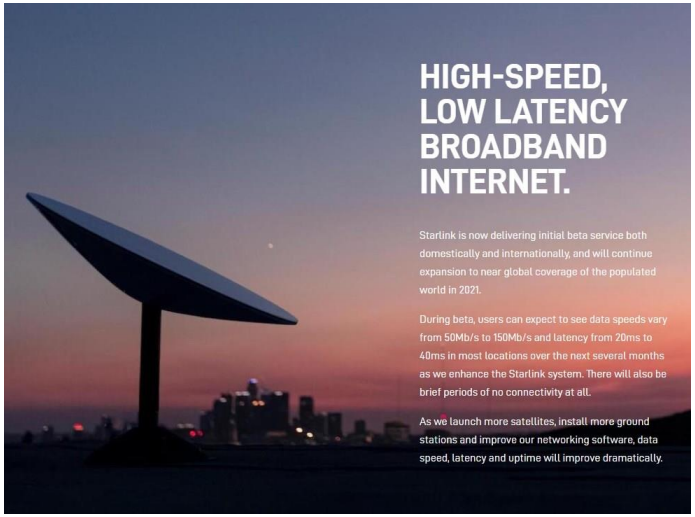
Google Project Loon

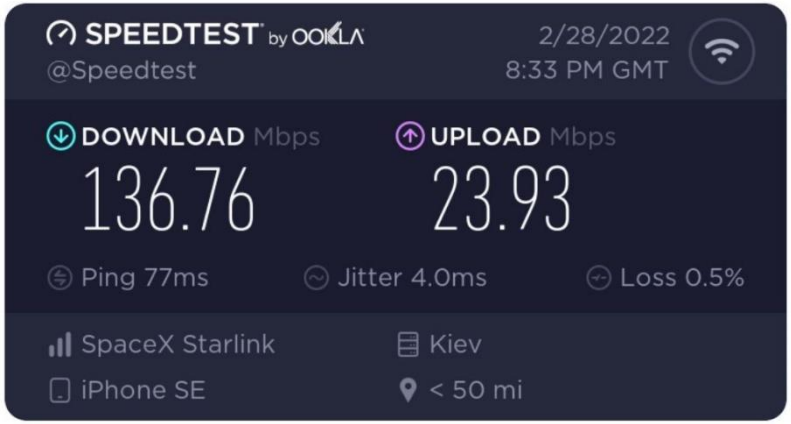


Project Loon: https://loon.com/

Starlink

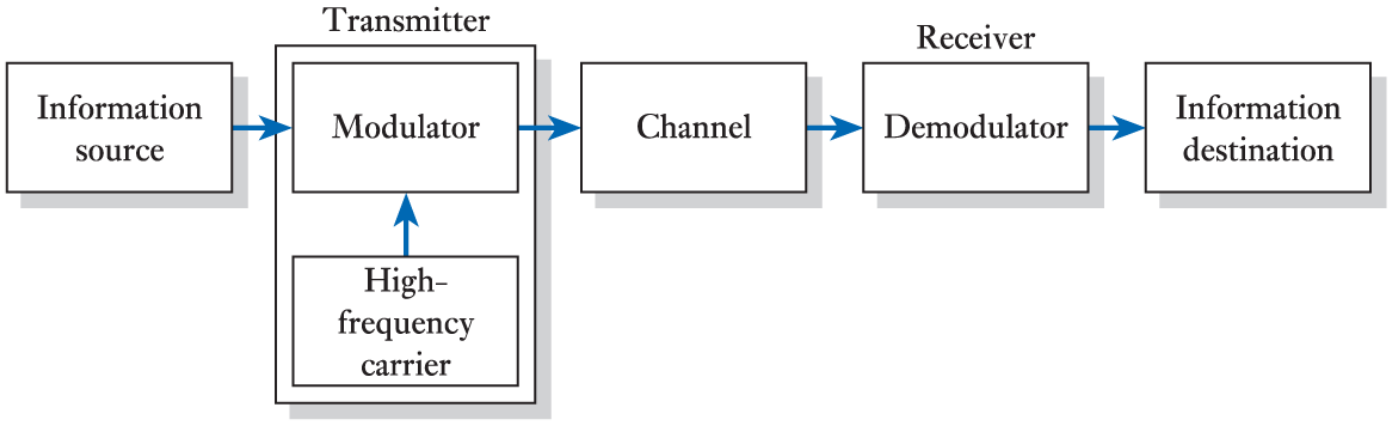

+ Phase 2
London-Johannesburg
Sat path RTTs: 81ms, 82ms
Great Circle Fibre RTT: 90ms
Current Internet RTT: 190ms
Starlink
10x realtime


HIGH-SPEED, LOW LATENCY BROADBAND INTERNET.
Starlink is now delivering initial beta service both domestically and internationally, and will continue expansion to near global coverage of the populated world in 2021.
During beta, users can expect to see data speeds vary from 50Mb/s to 150Mb/s and latency from 20ms to 40ms in most locations over the next several months as we enhance the Starlink system. There will also be brief periods of no connectivity at all.
As we launch more satellites, install more ground stations and improve our networking software, data speed, latency and uptime will improve dramatically.


SPEEDTEST by OOKLA
@Speedtest
2/28/2022
8:33 PM GMT
DOWNLOAD Mbps
136.76
UPLOAD Mbps
23.93
Ping 77ms
Jitter 4.0ms
Loss 0.5%
SpaceX Starlink
iPhone SE
Kiev
< 50 mi

Modulation (1/2)

- **Modulation performs two basic functions.**
  - **It allows a signal to be "moved" to a different part of the frequency spectrum**
  - **It allows a number of different signals to be sent simultaneously over the same channel**
- **At the receiver, the original signal is recovered through a process of demodulation**



Modulation (2/2)

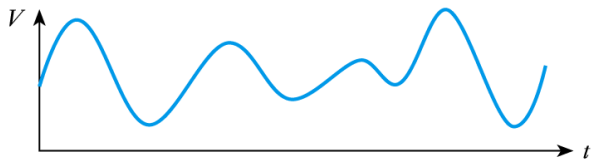
- **Analog modulation**
  - **Includes amplitude modulation (AM) and frequency modulation (FM)**
- **Digital modulation**
  - **Includes amplitude-shift keying (ASK), frequency-shift keying (FSK) and phase-shift keying (PSK)**
- **Pulse modulation**
  - **Includes pulse-amplitude modulation (PAM), pulse-width modulation (PWM), and pulse-code modulation (PCM)**

Analog Modulation

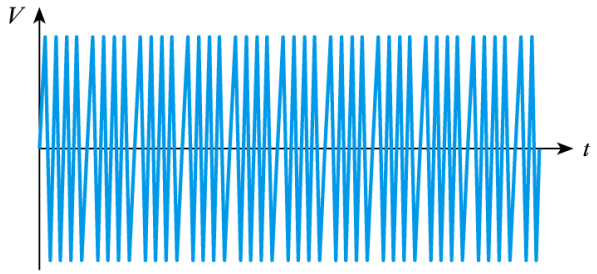
- Analog modulation involves using a low-frequency *baseband* signal to control some aspect of a high-frequency *carrier* signal
  - This can be used to change the frequency range of a signal
- Common forms include:
  - Amplitude modulation (AM)
  - Frequency modulation (FM)
  - Both forms are used in radio broadcasting

Amplitude Modulation

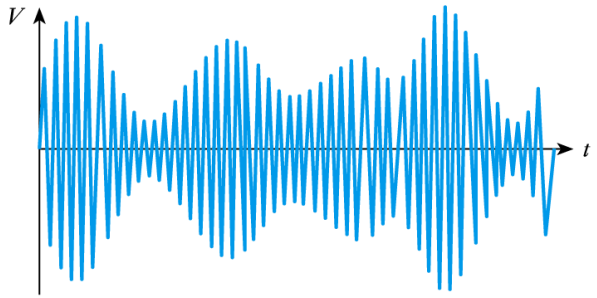
- The amplitude of a carrier wave is varied (or *modulated*) to represent the magnitude of the input signal
- This slide shows the full amplitude modulation (as used in medium wave transmission)
- Here the *envelope* of the waveform represents the input signal



(a) The input signal



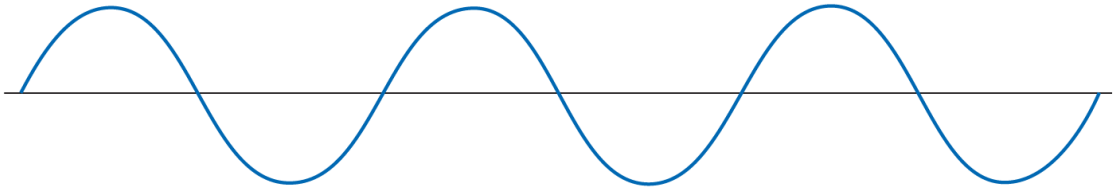
(b) The carrier signal



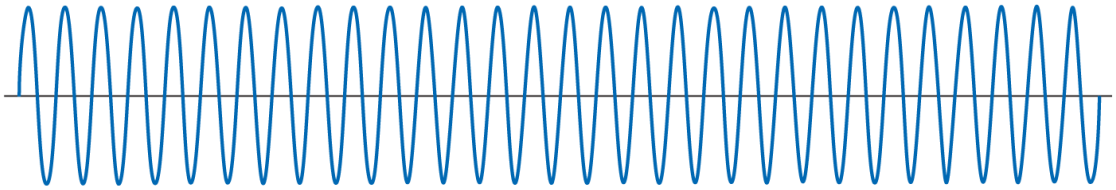
(c) An amplitude-modulated signal

Frequency Modulation

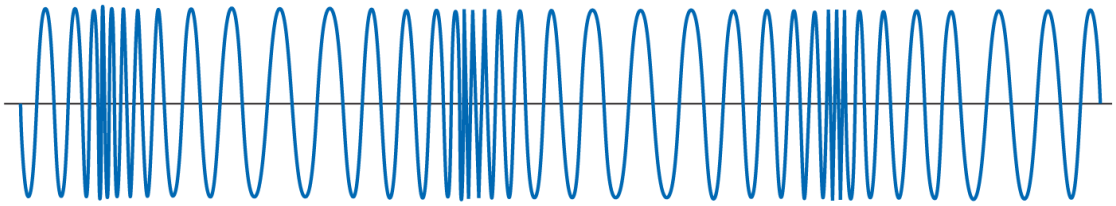
- **In this slide, the amplitude of the carrier is constant, but the frequency is varied to represent the input signal**



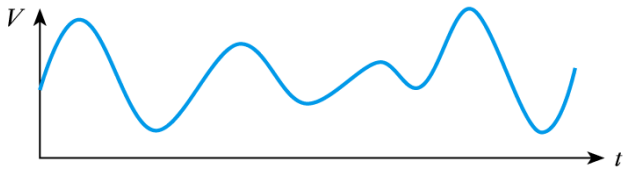
(a) Baseband signal



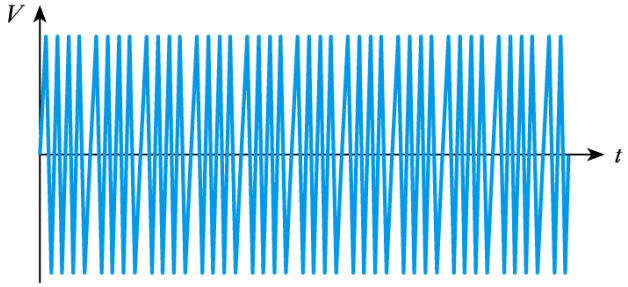
(b) Carrier signal



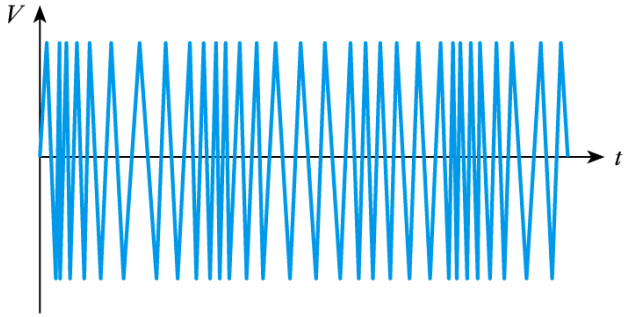
(c) Frequency modulated signal



(a) The input signal



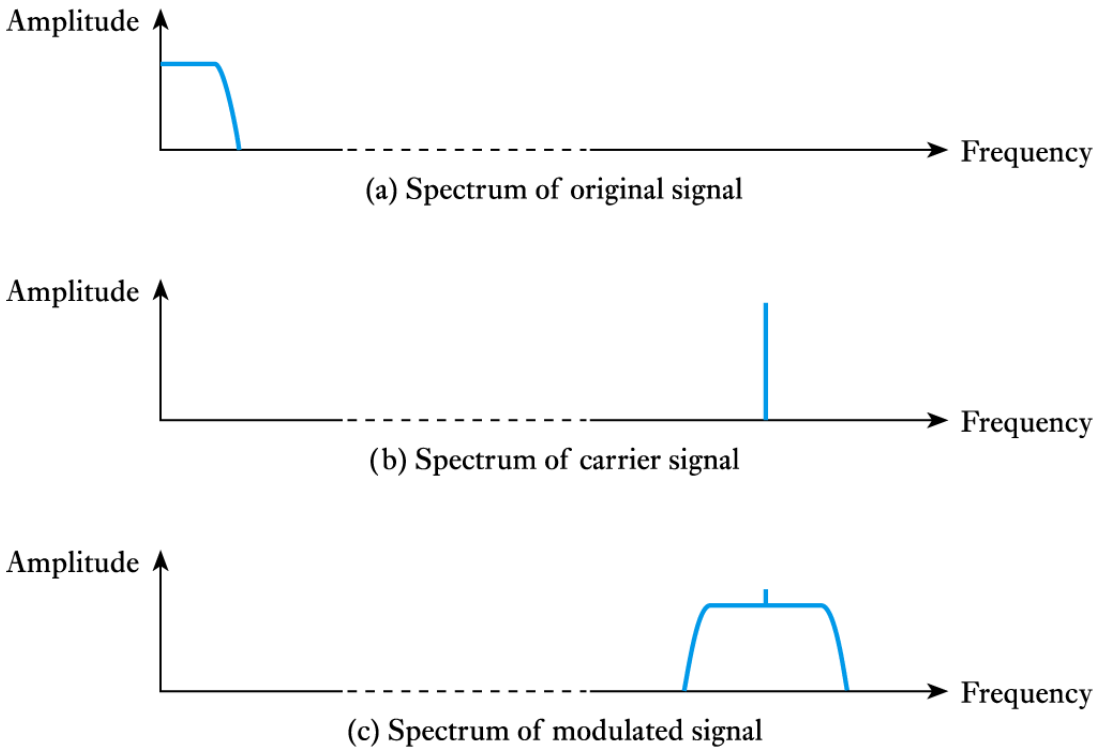
(b) The carrier signal



(d) A frequency-modulated signal

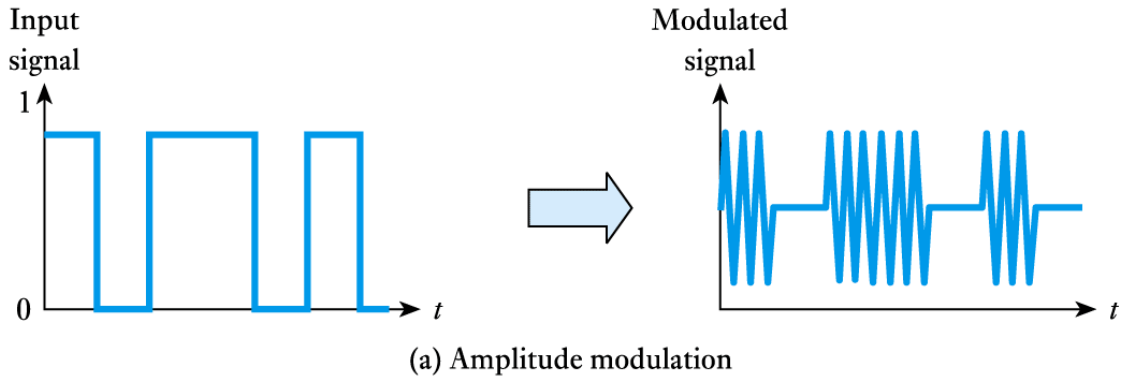
Modulation Spectra

- **Both AM and FM change the frequency range and frequency spectrum of the signal**

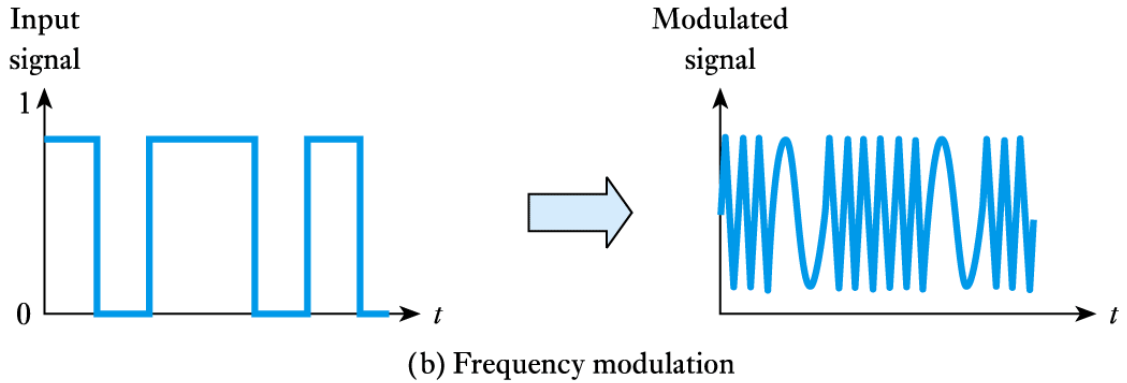


Digital Modulation

- **Amplitude and frequency modulation can also be applied to digital signal**
  - **Used in computer modems**

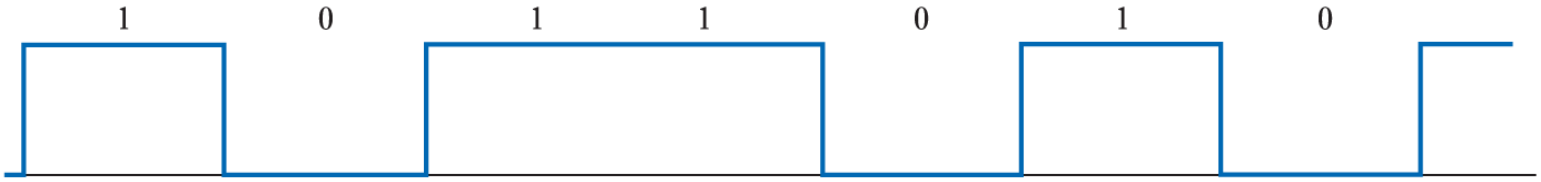


(a) Amplitude modulation

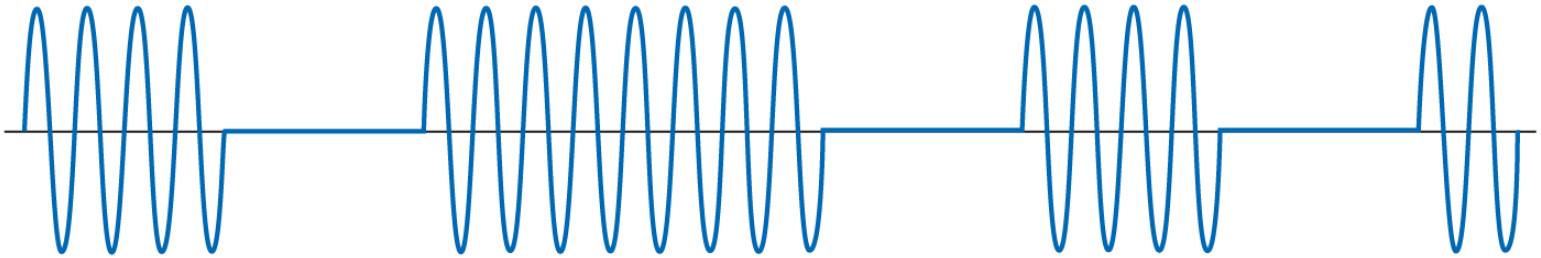


(b) Frequency modulation

Amplitude Shift Keying (ASK)

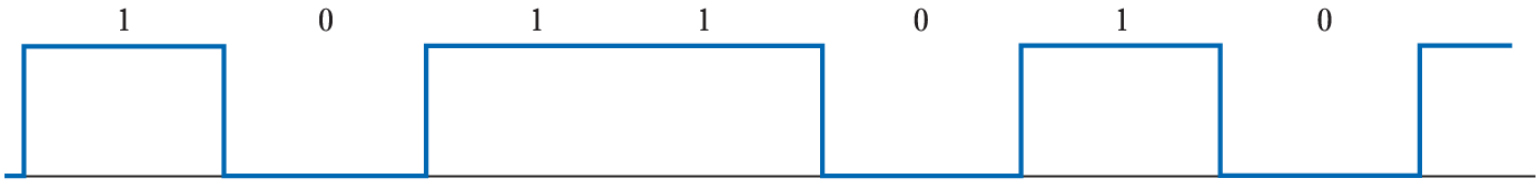


(a) Baseband signal

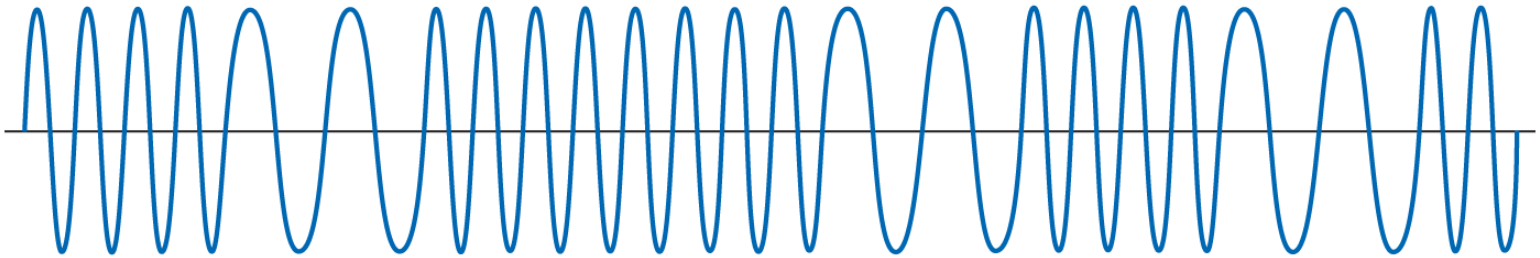


(b) ASK signal

Frequency Shift Keying (FSK)

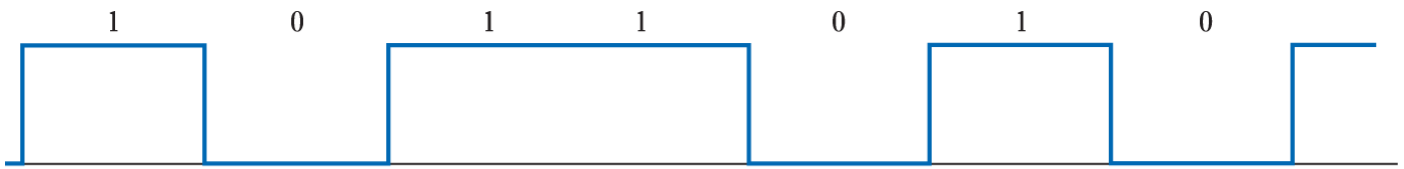


(a) Baseband signal

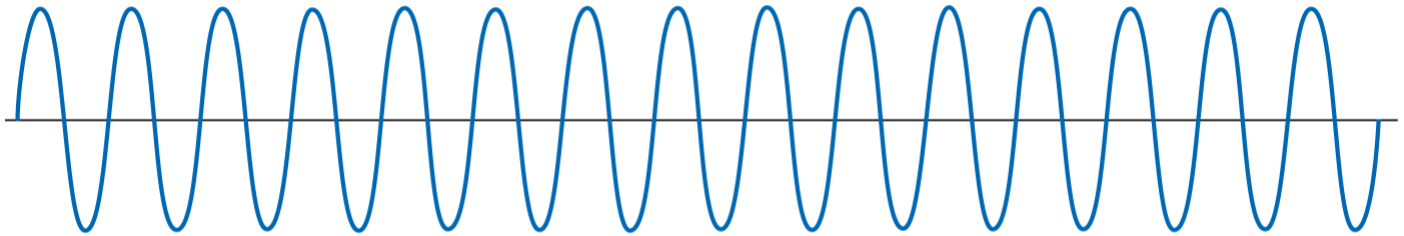


(b) FSK signal

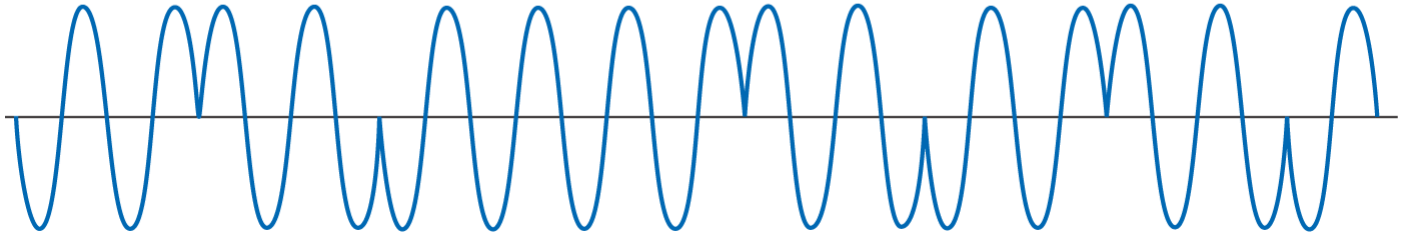
Phase Shift Keying (PSK)



(a) Baseband signal



(b) Carrier signal

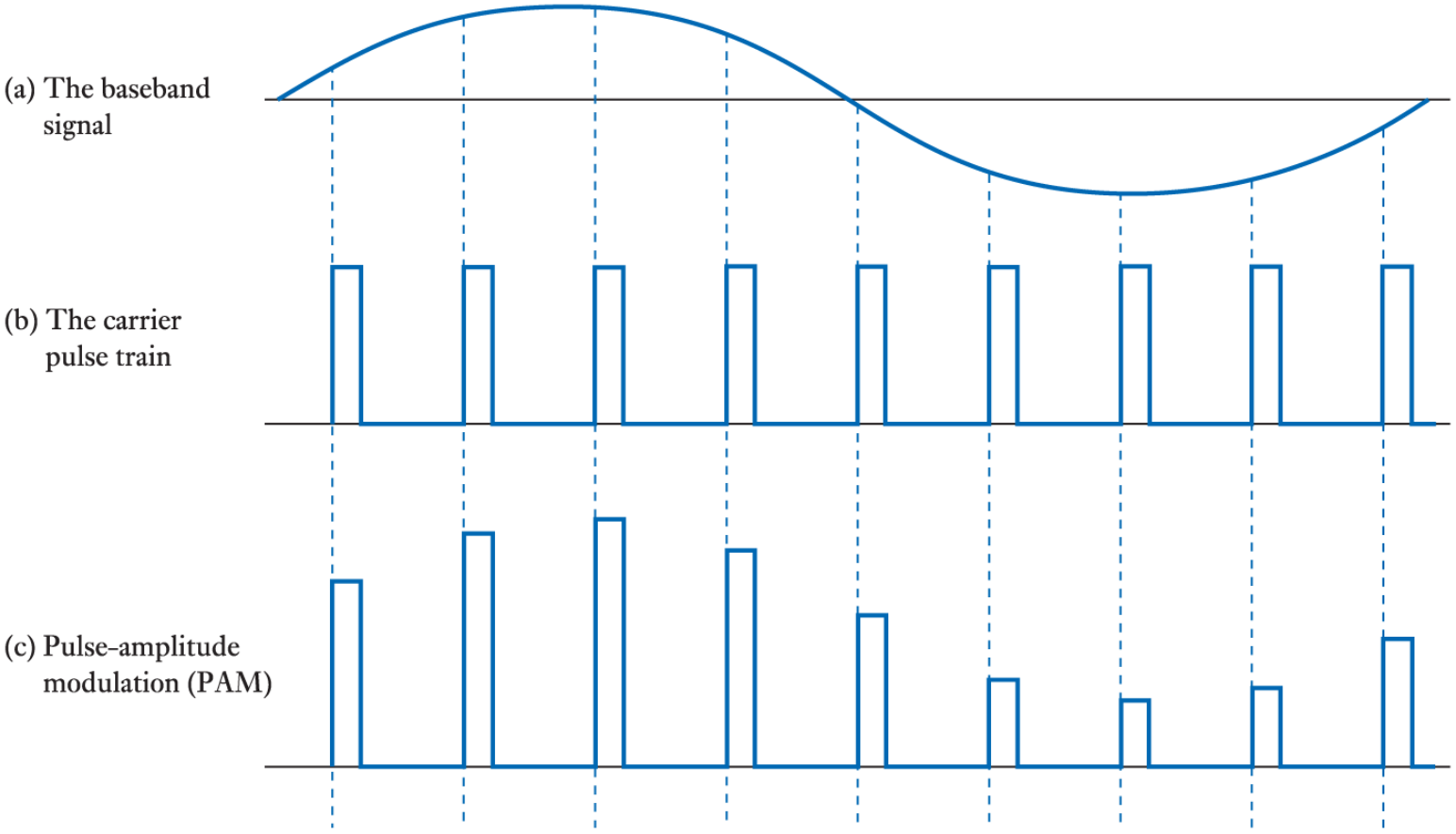


(c) PSK signal

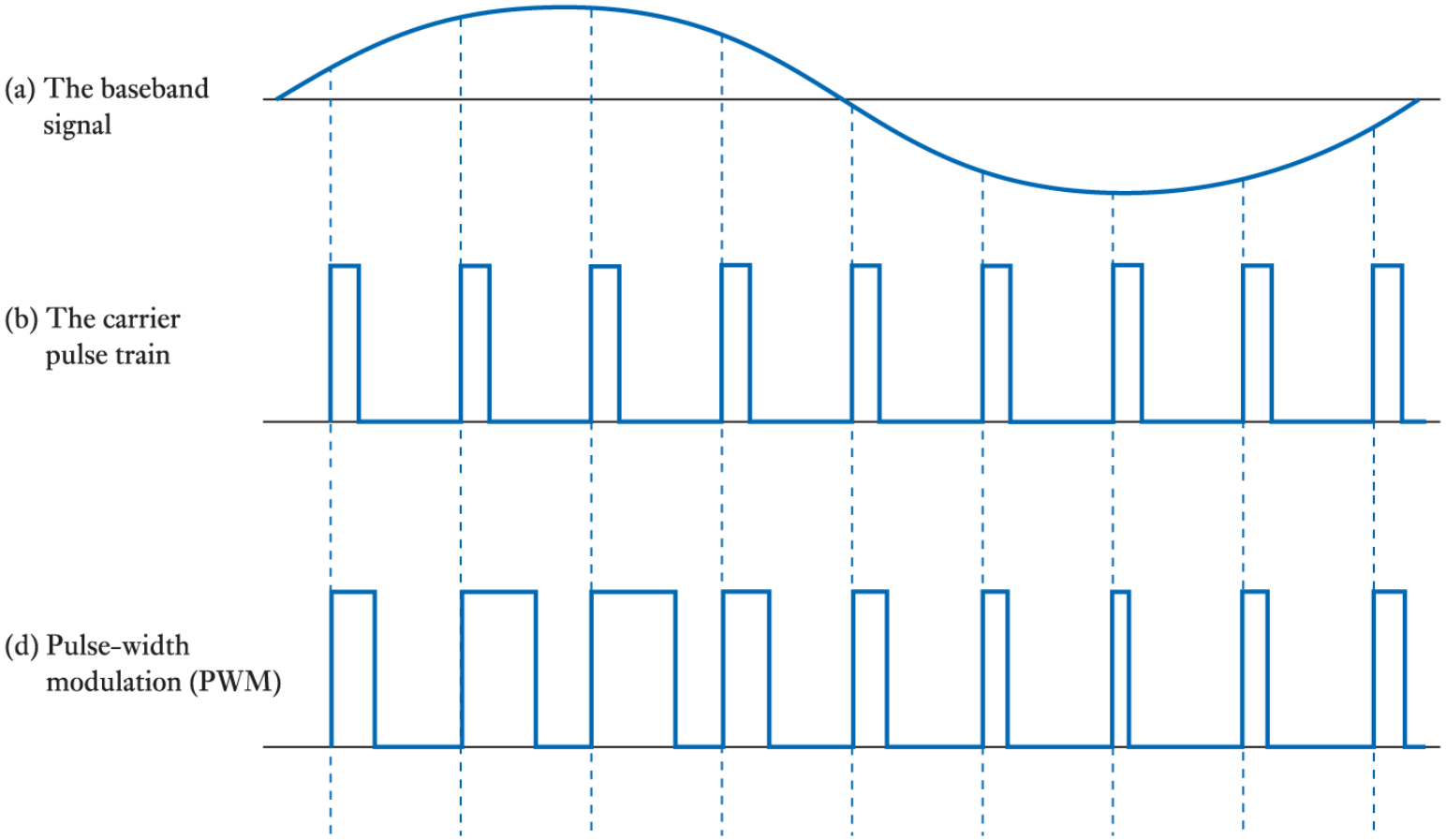
Pulse Modulation

- Pulse modulation is a form of signal modulation to encode analog information in a series of signal pulses
- Commonly forms include:
  - Pulse amplitude modulation (PAM)
  - Pulse width modulation (PWM)
  - Pulse code modulation (PCM)

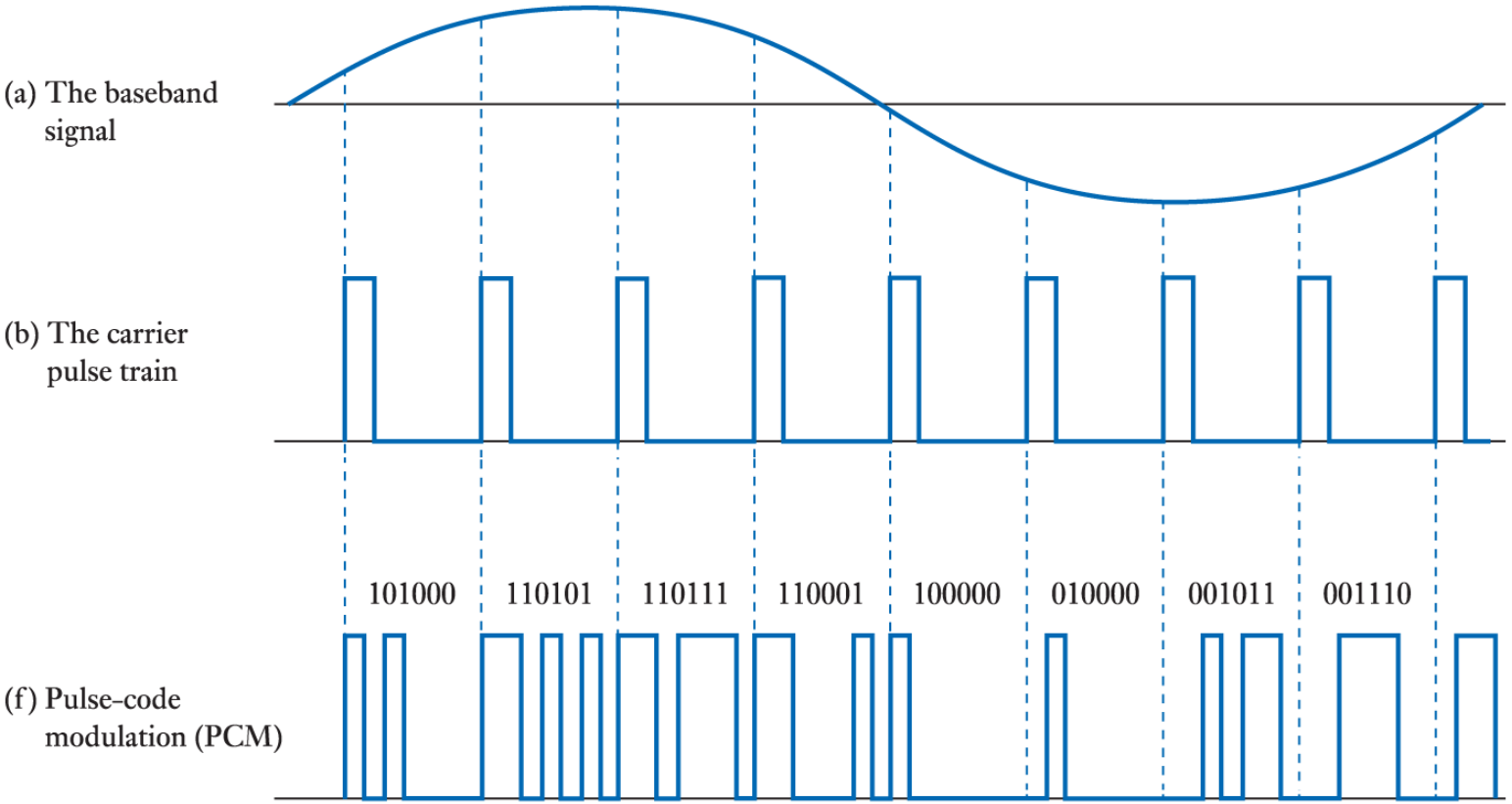
Pulse Amplitude Modulation (PAM)



Pulse Width Modulation (PWM)

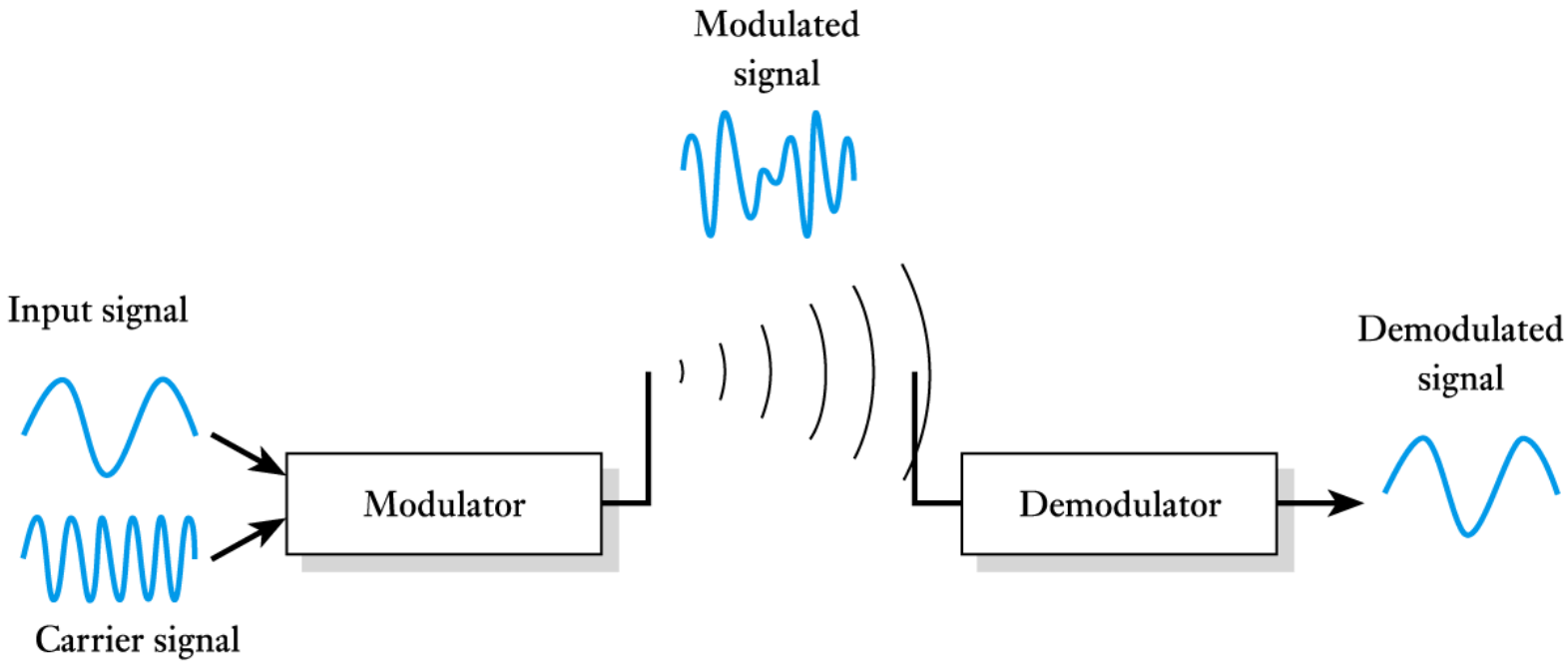


Pulse Code Modulation (PCM)



Demodulation

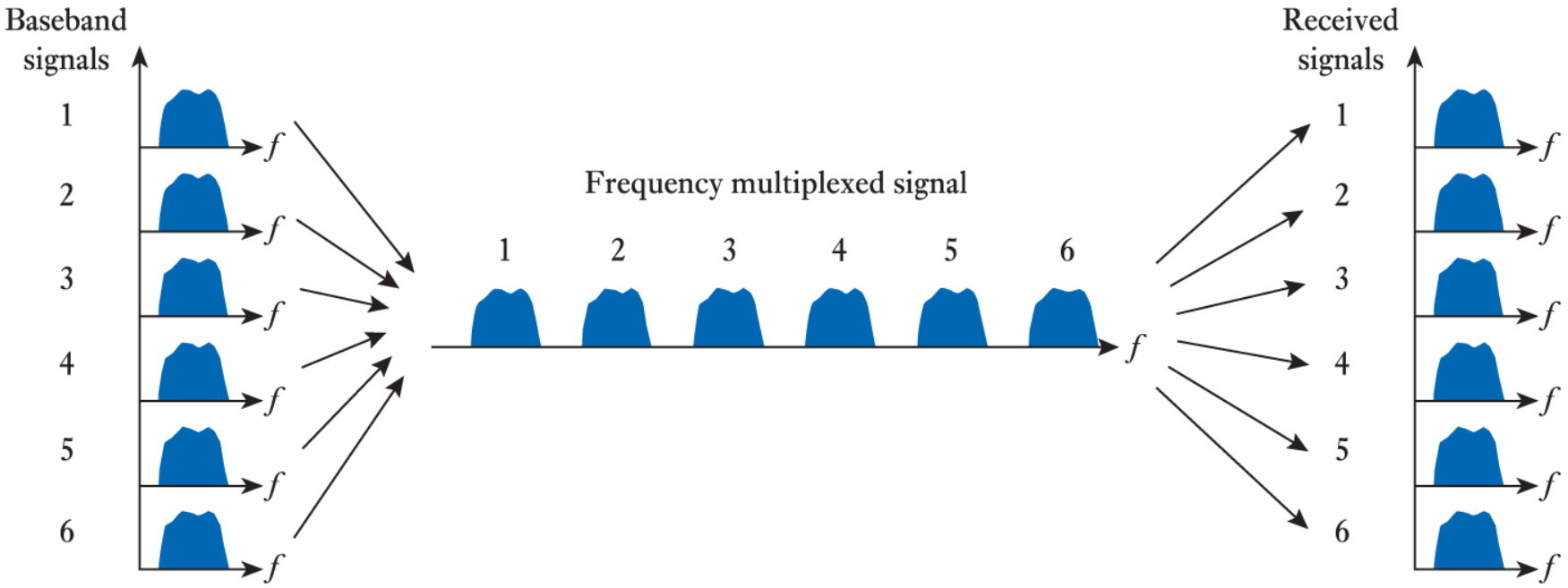
- The inverse process of recovering the original signal is called **demodulation**



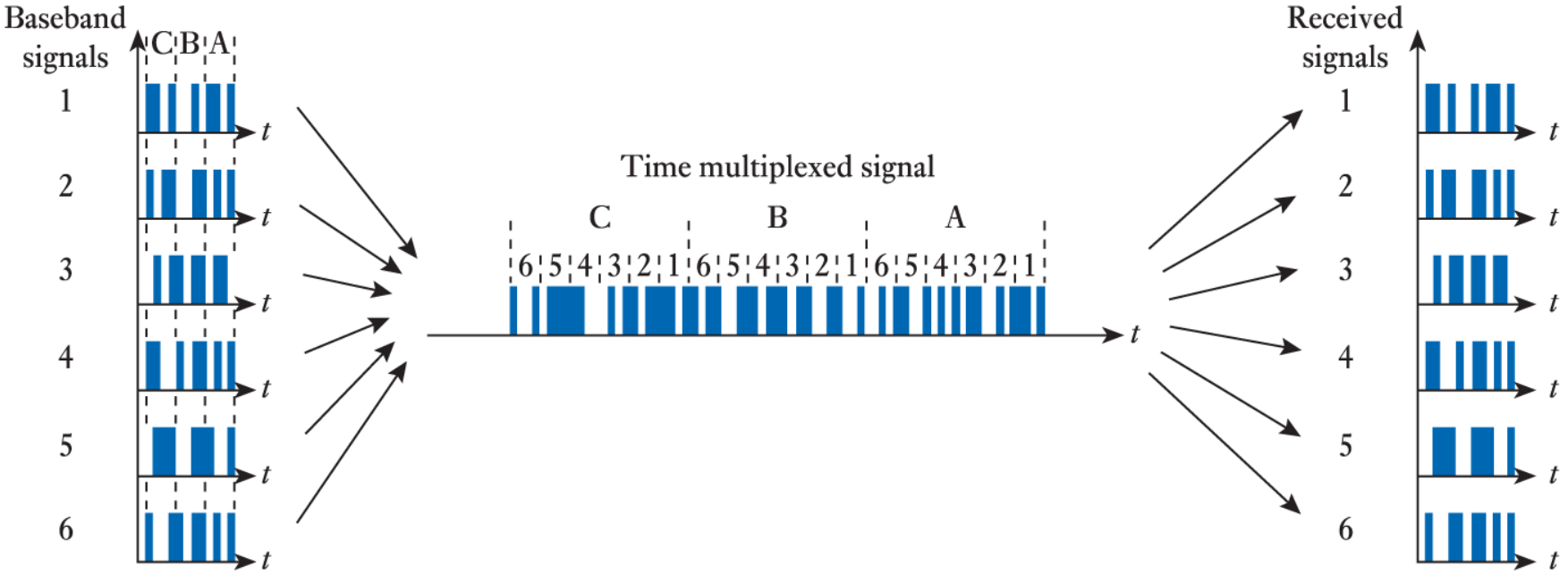
Multiplexing

- **Multiplexing enables a number of signals to be transmitted simultaneously over a single channel**
  - **The ability to shift the frequency range of a signal using modulation allows us to make more effective use of the bandwidth of communication channels**
- **Many forms of multiplexing are used including:**
  - **Frequency-division multiplexing**
  - **Time-division multiplexing**
- **After transmission the process is reversed using demultiplexing to recover the original signals**

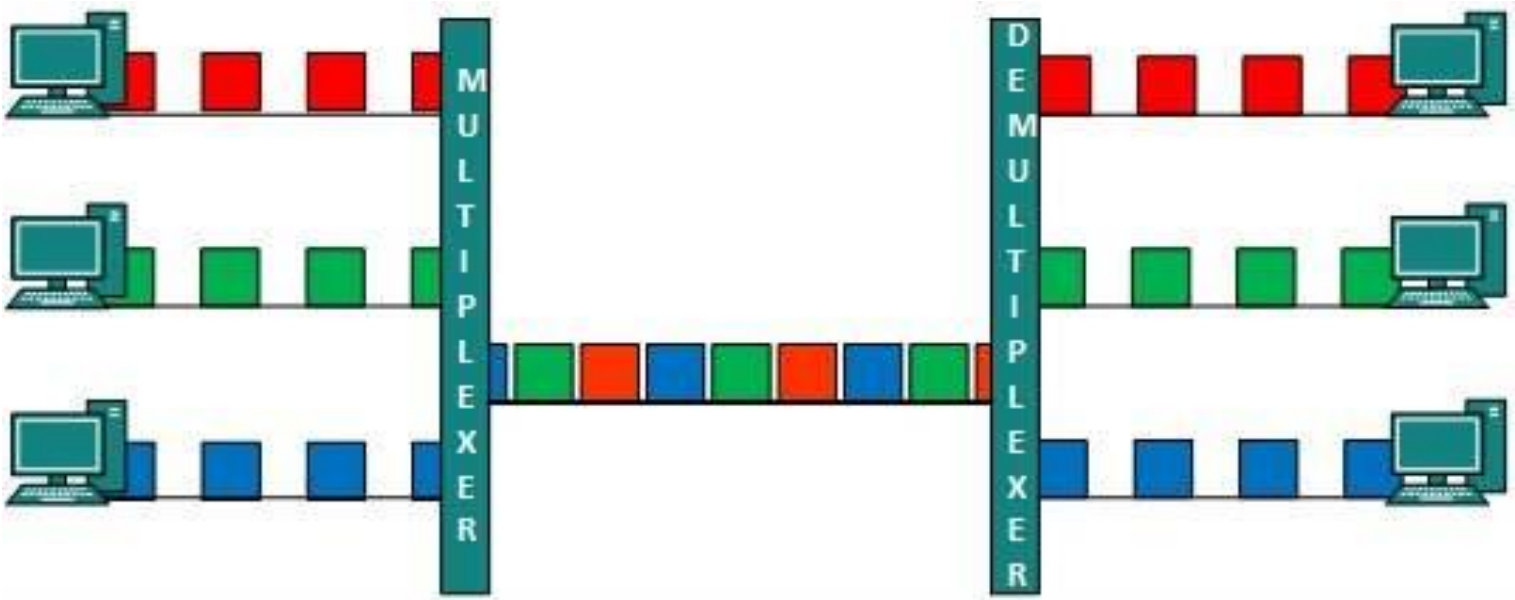
Frequency Division Multiplexing



Time Division Multiplexing (1/1)

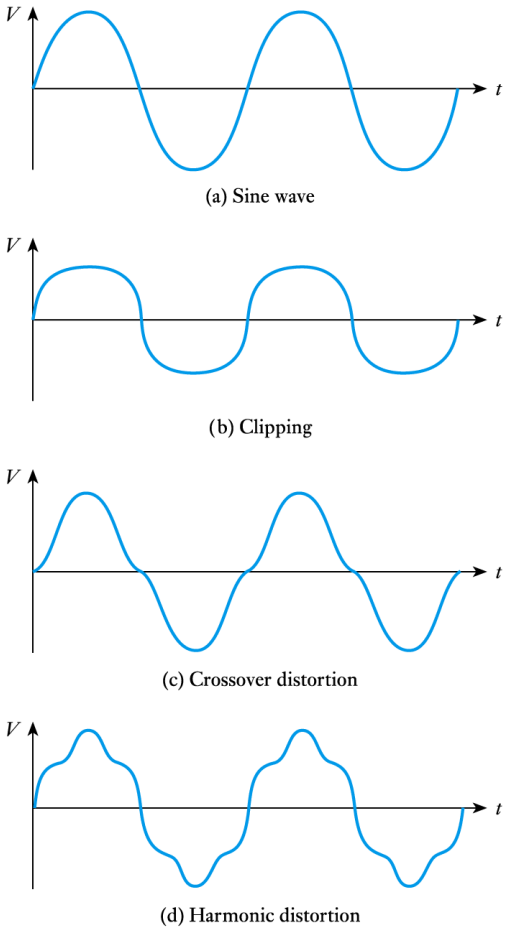


Time Division Multiplexing (2/2)



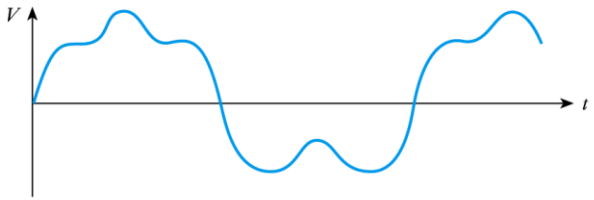
Distortion

- All systems distort electrical signal to some extent
  - Examples include clipping, crossover distortion, and harmonic distortion
- Distortion is systematic and is repeatable

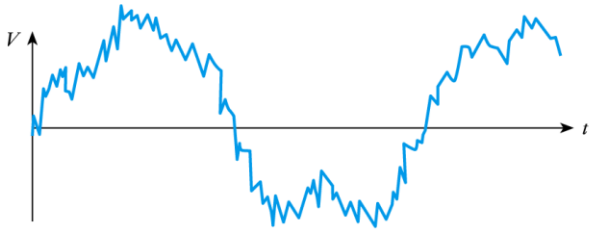


Noise

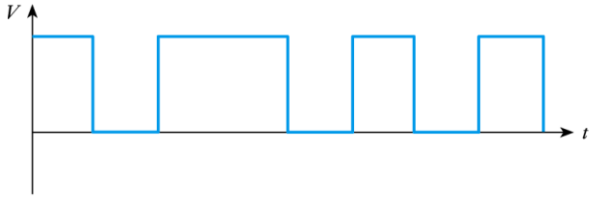
- All systems also add noise to the signals that pass through them
- Unlike distortion, noise is **random** and not repeatable
- Noise can often be removed from digital signals but this is often impossible with analog signals



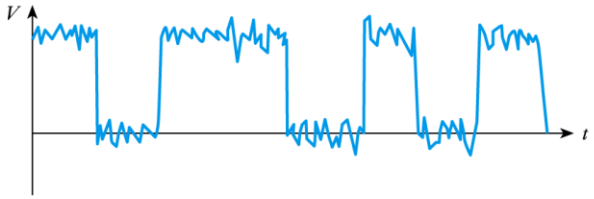
(a) Original analogue signal



(b) Analogue signal with noise



(c) Original digital signal



(d) Digital signal with noise

Key Points

- Electrical signals can take many forms and can be analog or digital
- A simple analog form is where a voltage is proportional to the amplitude of a quantity
- A simple digital form is where the voltage takes one of two values to represent the two states of a quantity
- Communication relates to the transfer of information from one place to another via channels
- Modulation is often used to change the frequency range
- Multiplexing can be used to combine signals
- All electrical circuits add distortion and noise to signals