FIT5187-S1_2018 LT03: Wireless Fundamentals

Based on

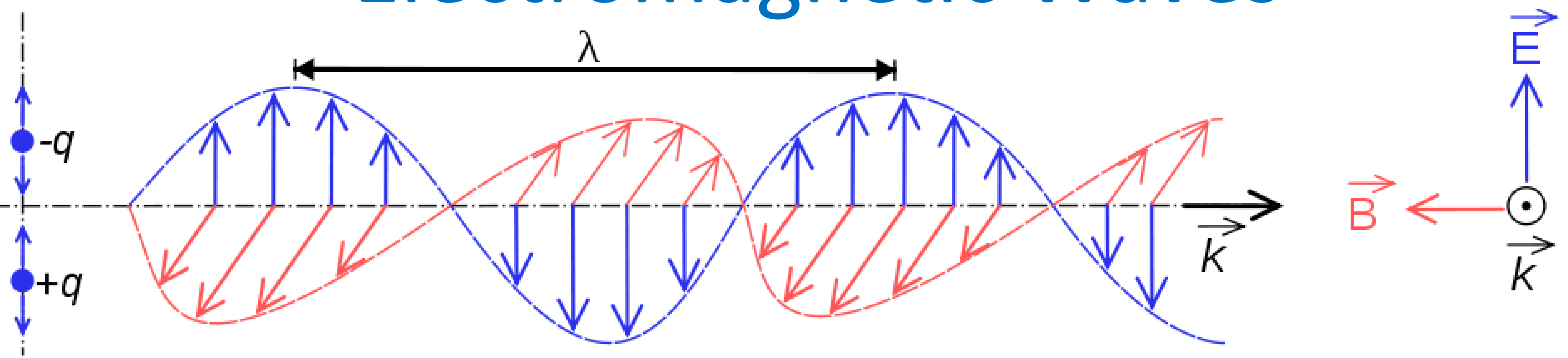
- Various sources
- Wikipedia
- C. Beard &W. Stallings: Wireless Communication Networks and Systems (2016), Chapters 5, 6 & 7

Learning outcomes

- Understand how EM wave propagates in space
- Understand how frequency spectrum is allocated
- Learn what radiation patterns and how the types of antenna can be used
- Analyse noise and interference and their cancellation techniques in wireless signal transmission and reception.
- Understand how signals can be modulated using digital modulation schemes

How EM wave propagates in space?

Electromagnetic Waves



EM radiation wiki EM radiation animation

Electromagnetic radiation comprises

- **electric and magnetic field** components,
- which oscillate in phase
- perpendicular to each other and
- perpendicular to the direction of energy propagation.

Electromagnetic radiation is classified into several types according to the **frequency** or **wavelength** of its **wave**.

Frequency and wavelength

Fundamental relationship between

- the frequency f,
- the wavelength λ, and
- the speed of light $c \approx$ 3e8 m/sec

$$\lambda = c / f$$

Good to remember that for

- f = 3GHz = 3e9 Hz
- the wavelength is $\lambda =$ 3e8/3e9 = 10cm
- The typical frequency range used in wireless networks is in the range of 1 to 10 GHz

Electromagnetic Waves/Radiation

- EM radiation is classified in order of increasing frequency and decreasing wavelength in:
  - radio waves, 3kHz – 300GHz (λ = 1 mm)
  - microwaves, 300MHz – 300GHz
  - infrared radiation, 1– 400THz (10^{12}), 300 – 0.75μm
  - visible light, 400 – 790THz, 750 – 390nm
  - ultraviolet radiation, 390 – 10nm
  - X-rays and gamma rays, 10 – 0.01nm, ...
  - ...

Visible Spectrum/light

- The **visible spectrum** is a small window of frequencies sensed by the eyes of various organisms:

  390 – 750 nm, 790 THz – 405 THz

- A very high frequency radiation is often better described in the quantum physics terms, rather than the classical Maxwell equations
- The **photon** is the quantum of the EM interaction and the basic "unit" of light and all other forms of electromagnetic radiation.
- The energy E associated with a photon is proportional to frequency f

$$E = h \cdot f$$

where $h = 6.6 \times 10^{-34}$ J·s is the Planck constant

How frequency spectrum is allocated?

Spectrum Allocation Chart

- Assignment of frequencies is done by the national authorities, e.g. Australian Communications and Media Authority based on recommendations of the Radio-communication sector of International Telecommunication Union, ITU-R
- Find a Chinese Authority (State Radio Office of China?) in charge of spectrum allocation.
- Spectrum allocation chart (local)

Things to know:

- Your favourite FM (Frequency Modulated) radio and TV stations are in the VHF band.
- For example, Melbourne Smooth 91.5 broadcasts in the 91.5 MHz frequency range and occupies the 38kHz band.
- Effective radiated power, ERP = 56kW,

More on Spectrum allocation

- Digital Television in Australia has adopted the DVB-T Digital Video Broadcasting — Terrestrial standard
- For example Channel 7, has the carrier frequency 182.25MHz and the 7MHz band.
- China has adopted the DTMB Digital Terrestrial Multimedia Broadcast standard.
- Mobile networks operates in the UHV and SHV frequency bands.
- For example, GSM networks operate (typically) in the 900MHz and 1.8GHz **licensed** bands
- WiFi networks operates predominantly in the 2.4GHz and 5GHz **unlicensed** frequency bands.
- Unlicensed frequency bands must operated with the limited radiated power (ERP)
- Unlicensed brands are typically called ISM – Industrial, Scientific and Medical applications.

Unlicensed Frequency bands for WLAN

- Wireless Local Area Networks (WLANs), also known as **WiFi** networks operate according to IEEE 802.11 standards.
- The 2.4 GHz band is divided into 13 5MHz channels with the central frequencies for each channel being:

$$f_s\,[MHz] = 2407 + 5 \times N$$

where N = 1..13 is the channel number

- The 5 GHz band is more complicated due to national regulations.
- See the channel allocation in Wikipedia
- Transmission **bandwidth** used in 802.11 networks is

20MHz, 40MHz and 80MHz, 160MHz in the latest versions of the WiFi standards.

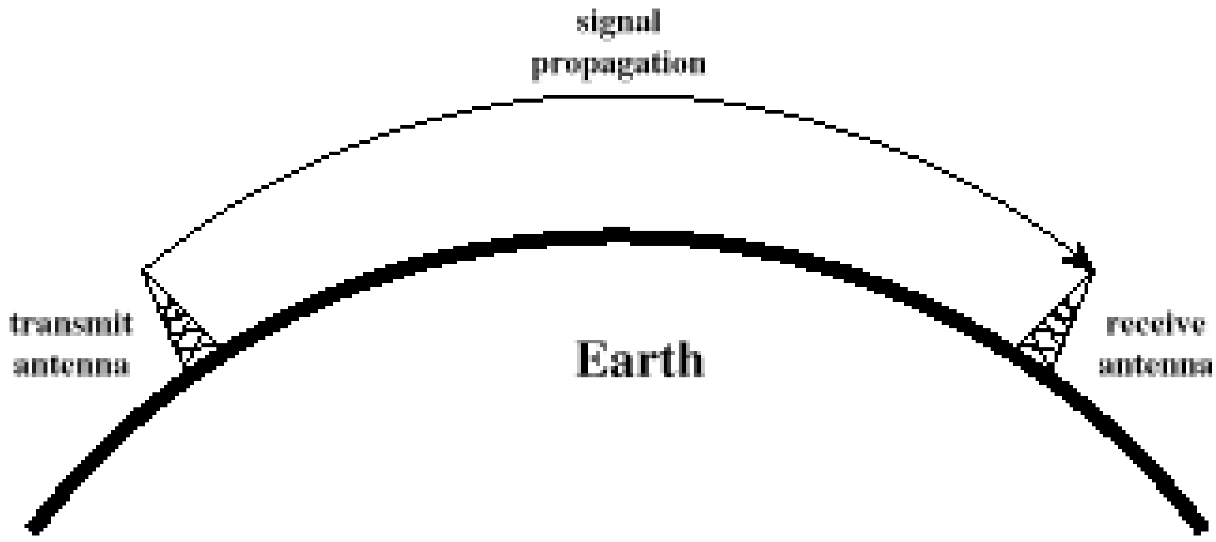
What radiation patterns and how the types of antenna can be used?

Radiation Patterns

Propagation of Radio Waves

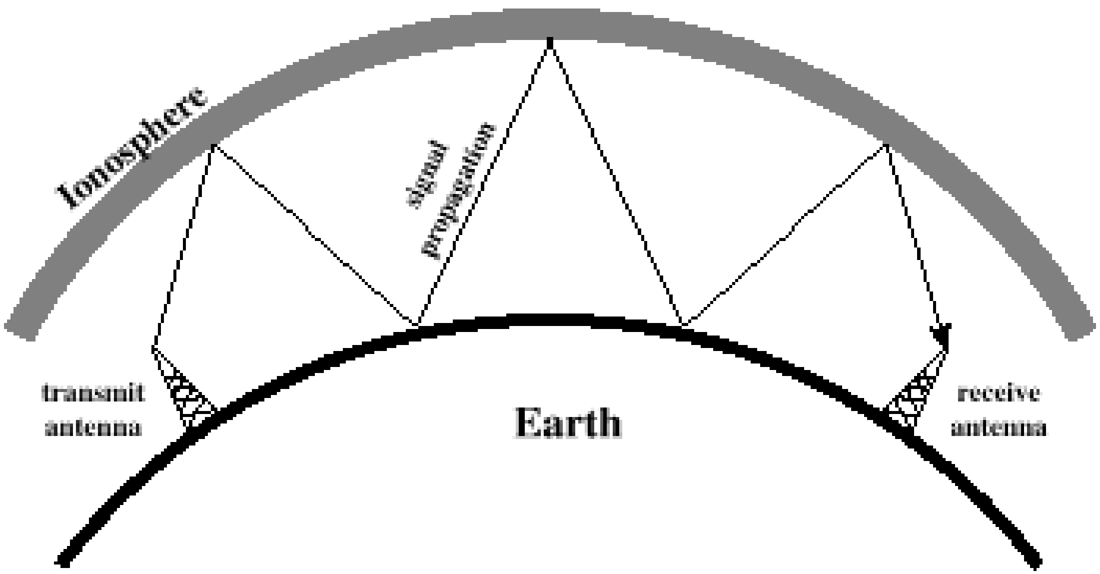
- Radio waves propagation is affected by the phenomena of
  - reflection,
  - refraction,
  - diffraction,
  - absorption,
  - polarization,
  - scattering
- Read about these phenomena in Wikipedia or similar source and attach a brief definition in your next **tutorial** submission.
- The primary modes of propagation of radio waves depends on their frequency.

Ground Wave Propagation



- Follows contour of the earth
- Can propagate over considerable distances
- Frequencies up to 2 MHz (λ = 150 m)
- Example: AM radio

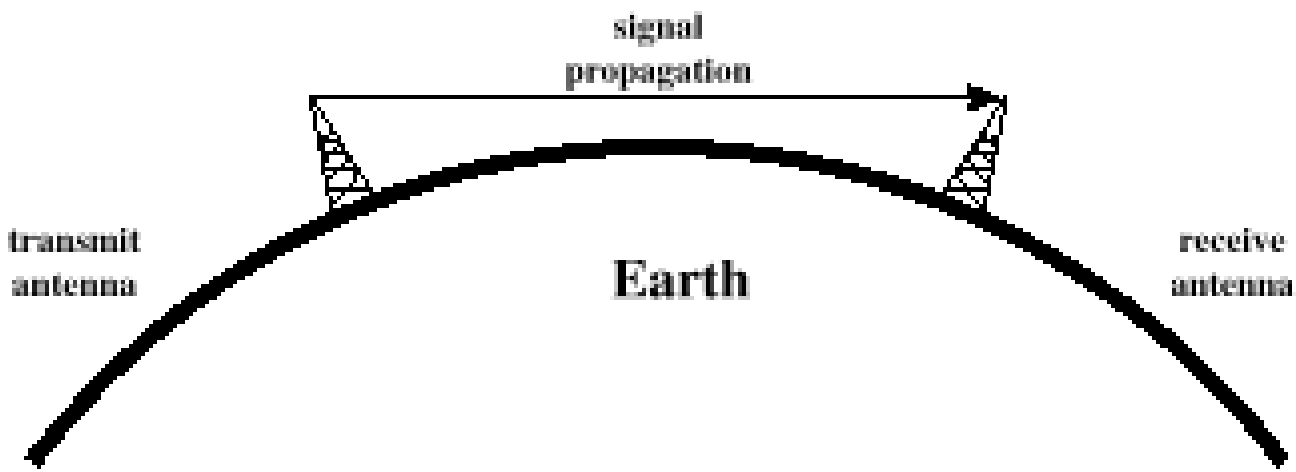
Sky Wave Propagation



Signal reflected from the ionized layer of the atmosphere back down to earth

- Signal can travel a number of hops, back and forth between the ionosphere and the earth's surface
- Reflection effect is caused by the refraction (bending of EM waves by the atmosphere/ionosphere)
- Examples: Amateur radio, short-wave radio, CB (citizen band) radio
- 3 to 30 MHz (100 to 10 m)

Line-of-Sight (LoS) Propagation



- Transmitting and receiving antennas must be within the line of sight
  - Satellite communication utilizes signals above 30 MHz which are not reflected by ionosphere
  - Ground communication – antennas within *effective* **line of sight** due to refraction

LoS Wireless Transmission Impairments

Wireless networks use the Line-of-Sight (LoS) transmission.

Most significant impairments of such transmission are:

- Attenuation and attenuation distortion
- Free space loss
- Noise
- Atmospheric absorption
- Multipath propagation
- Refraction
- Thermal noise

Free space loss

- Strength of EM signal is reduced with propagating distance
- Received power in the free space is reduced with the square of the distance from the transmitter.
- The free space loss L in ideal conditions can be expressed as

$$L = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi d f}{c}\right)^2$$

d – distance, f – frequency, λ – wavelength

c – speed of light

Free space loss Example

- Compare the ratio of free space loss for two distances:

$$d_1 = 10^{-1}\text{ m}, d_2 = 10\text{m}$$

- The **ratio of received powers** at the two distances:

$$\frac{L_1}{L_2} = \frac{d_1^2}{d_2^2} = \frac{10^{-2}}{10^2} = 10^{-4}$$

- In **logarithmic measure** (decibels, dB)

$$10 \log 10^{-4} = -40 \text{ dB}$$

- Note the significant loss of power over a relatively short distance.

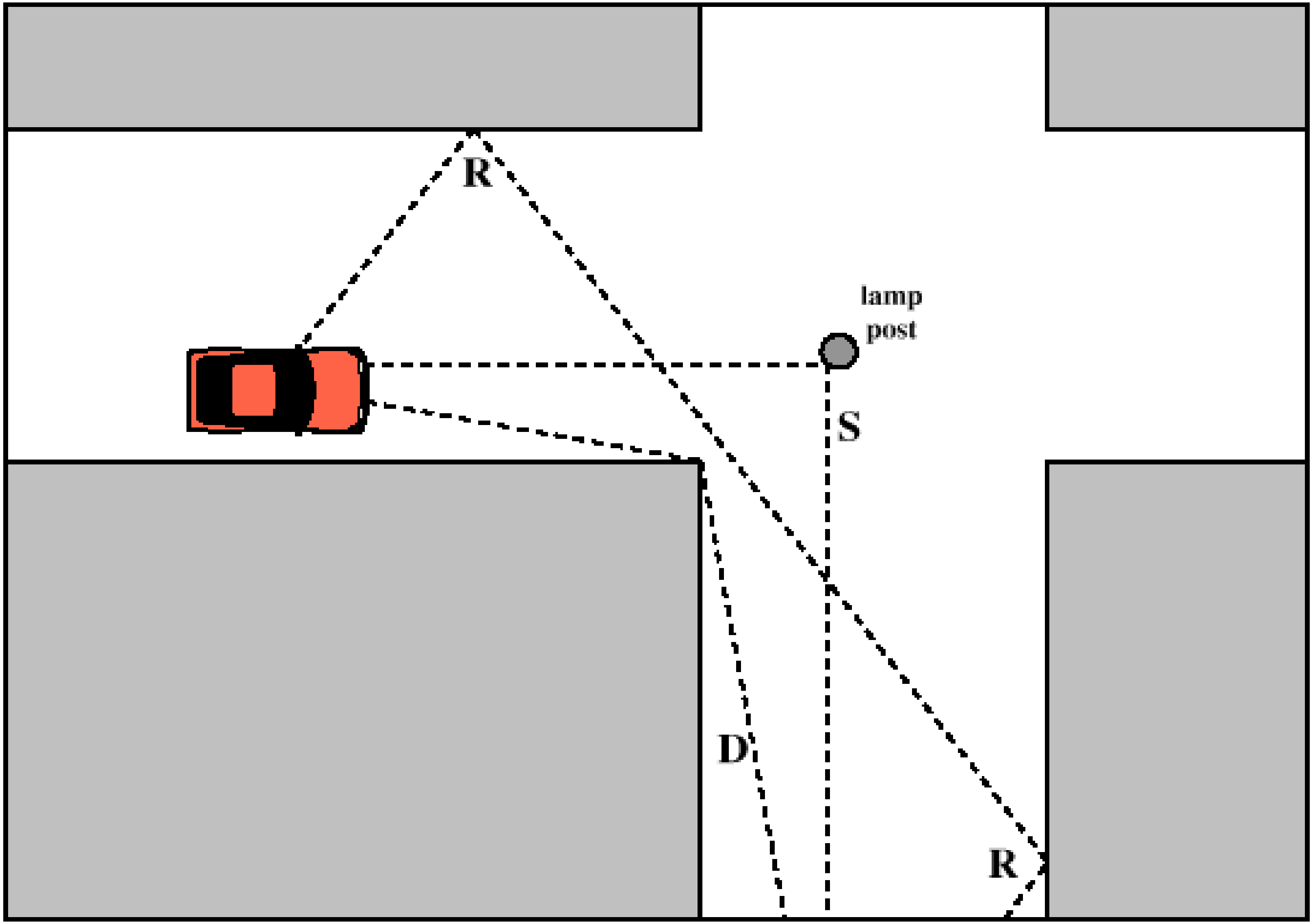


Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]

Reflection, Diffraction, Scattering

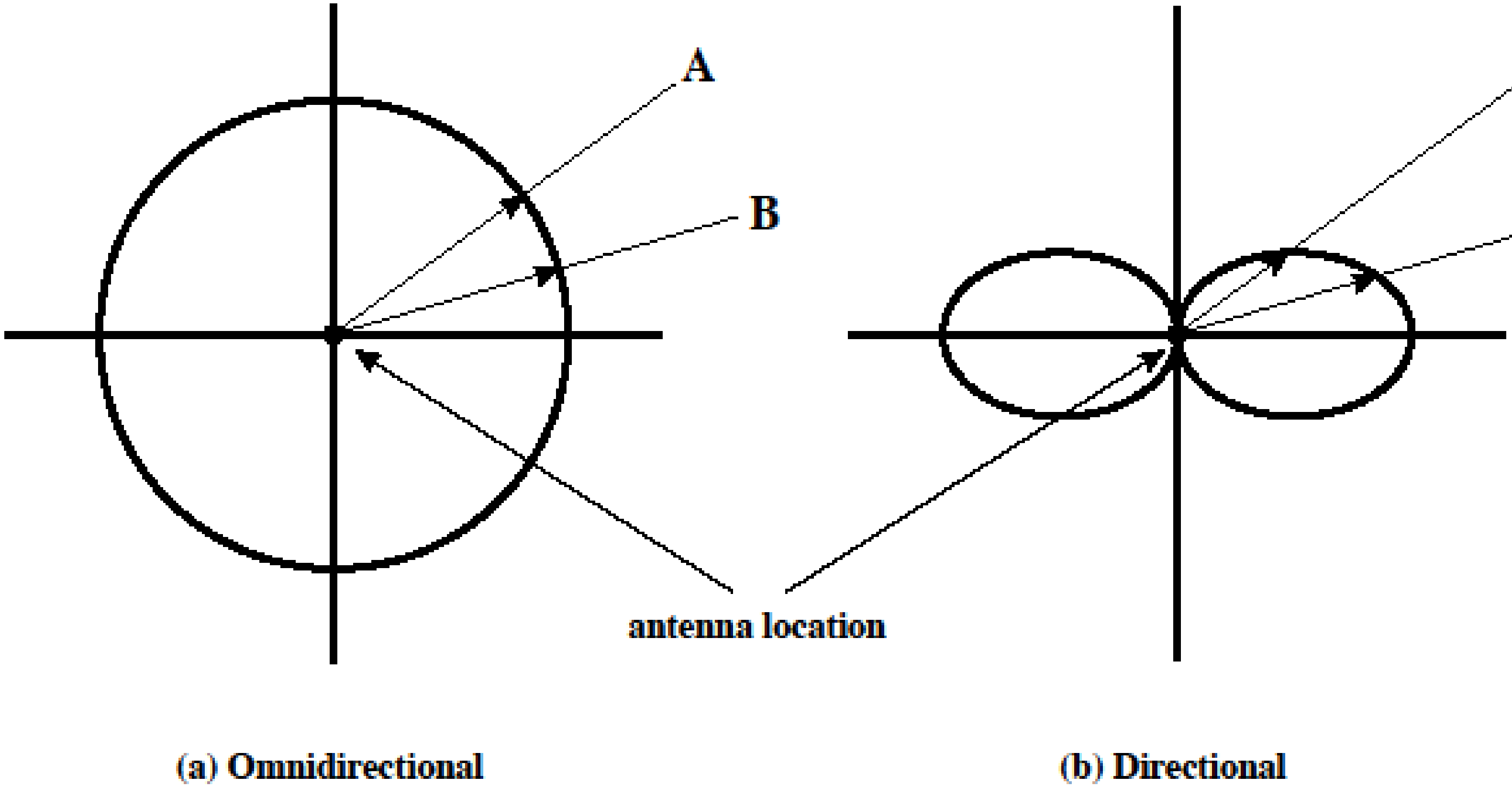
- Reflection – occurs when signal encounters a surface that is large relative to the wavelength of the signal
- Diffraction – occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave
- Scattering – occurs when incoming signal hits an object whose size in the order of the wavelength of the signal or less

Antenna types

Antennas

- An antenna is an electrical conductor, or system of conductors used for either:
  - Radiating electromagnetic energy as EM waves
  - Collecting EM energy from EM waves
- The same antenna can be used for transmission and reception
- An antenna is characterised by its radiation/ reception pattern representing the directivity of the antenna
- An idealised isotropic antenna, a point in space, has a spherical radiation/reception pattern

Radiation patterns

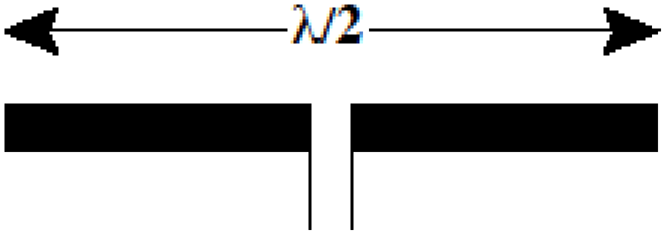


isotropic

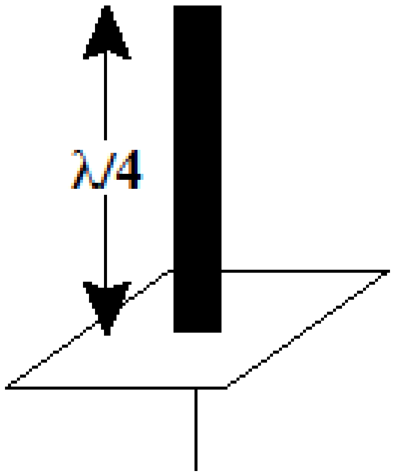
anisotropic

Antenna types

- Two most popular antennas:



(a) Half-wave dipole

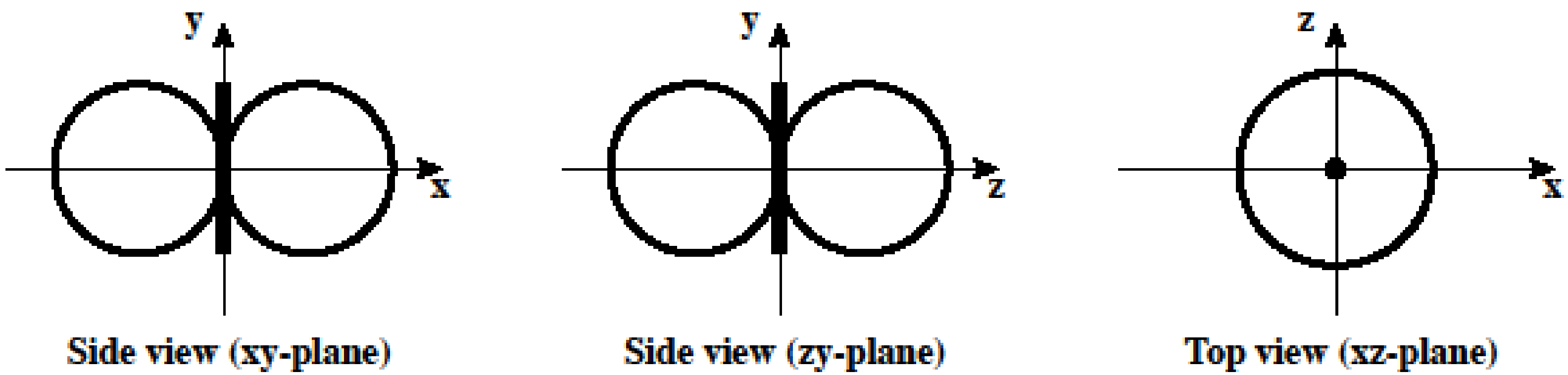


(b) Quarter-wave antenna

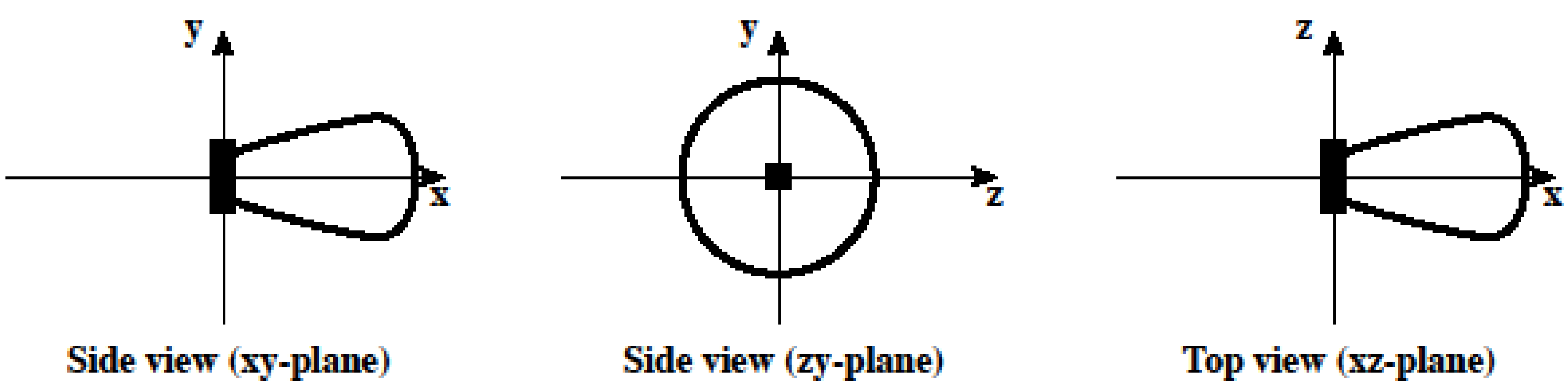
Vertical antenna
Monopole antenna

Radiation patterns (wikipedia)

Typical radiation patterns

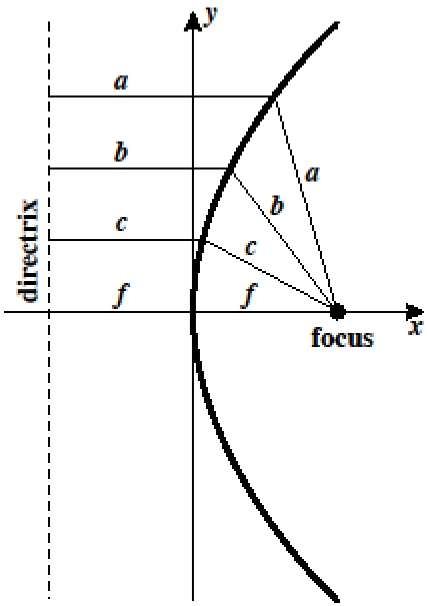


(a) Simple dipole

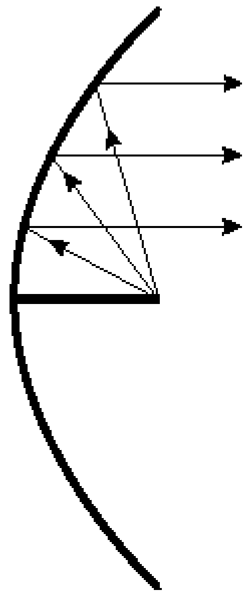


(b) Directional antenna

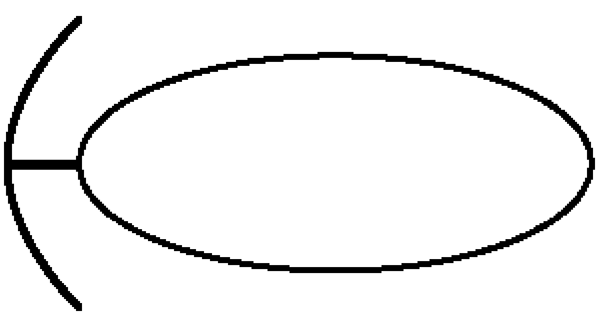
Parabolic Reflective Antenna



(a) Parabola



(b) Cross-section of parabolic antenna showing reflective property



(c) Cross-section of parabolic antenna showing radiation pattern

Used in

- terrestrial microwave and
- satellite applications

If the source of EM energy is placed at the **focus** of the antenna, then the waves will be reflected in a form of parallel lines/directions.

It means **no dispersion** of energy.

Noise and interference

Categories of Noise

- Thermal Noise
- Intermodulation noise
- Crosstalk
- Impulse Noise

Thermal Noise

- Thermal noise due to agitation of electrons
- Present in all electronic devices and transmission media
- Cannot be eliminated
- Function of temperature
- Particularly significant for satellite communication

Thermal Noise

- Amount of thermal noise to be found in a bandwidth of 1Hz in any device or conductor is:

$$N_0 = kT$$

  - N_0 – **noise power density** in watts per 1 Hz of bandwidth [W/Hz]
  - k – Boltzmann's constant = 1.3803×10^{-23} J/K
  - T – temperature, in Kelvins (absolute temperature)

Other Types of Noise

- **Inter-modulation noise** – occurs if signals with different frequencies share the same medium
  - Interfering signals are produced at frequencies that are the sum and/or difference of the original signal frequencies
- **Crosstalk** – unwanted coupling between signal paths
- **Impulse noise** – irregular pulses or noise spikes
  - Short duration and of the relatively high amplitude
  - Caused by external electromagnetic disturbances, or faults and flaws in the communications system

Expression E_b/N_0

- The ratio of **signal energy** S **per bit**: $E_b = S/R$
  to **noise power** density per Hertz, N_0
  $$\frac{E_b}{N_0} = \frac{S/R}{N_0} = \frac{S}{kTR}$$
  where R is the **bit rate** (bits per second)
- The **bit error rate** for transmitting digital data is measured by (is a function of) E_b/N_0
- Given a value for E_b/N_0 to achieve a desired bit rate, R, the signal energy S needs to be selected accordingly
- As bit rate R increases, transmitted signal power must increase to maintain required bit error rate measured by E_b/N_0

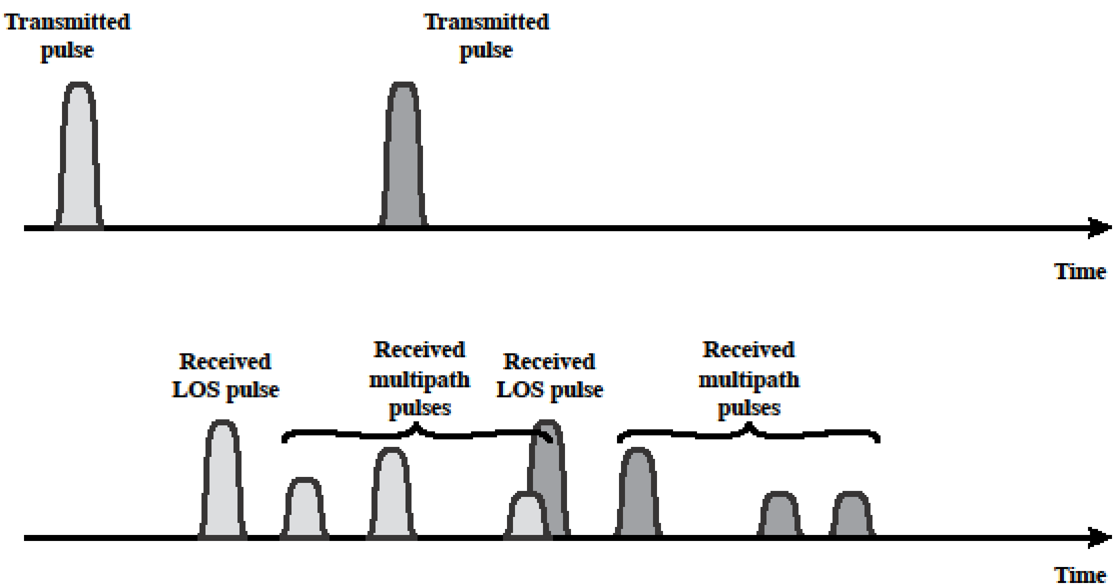
Noise interference effects and cancellation techniques

Other Impairments

- Atmospheric absorption – water vapor and oxygen contribute to additional attenuation of the transmitting signal
- Multipath transmission – obstacles reflect signals so that multiple copies with varying delays are received
- Refraction – bending of radio waves as they propagate through the atmosphere

The Effects of Multipath Propagation

- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult



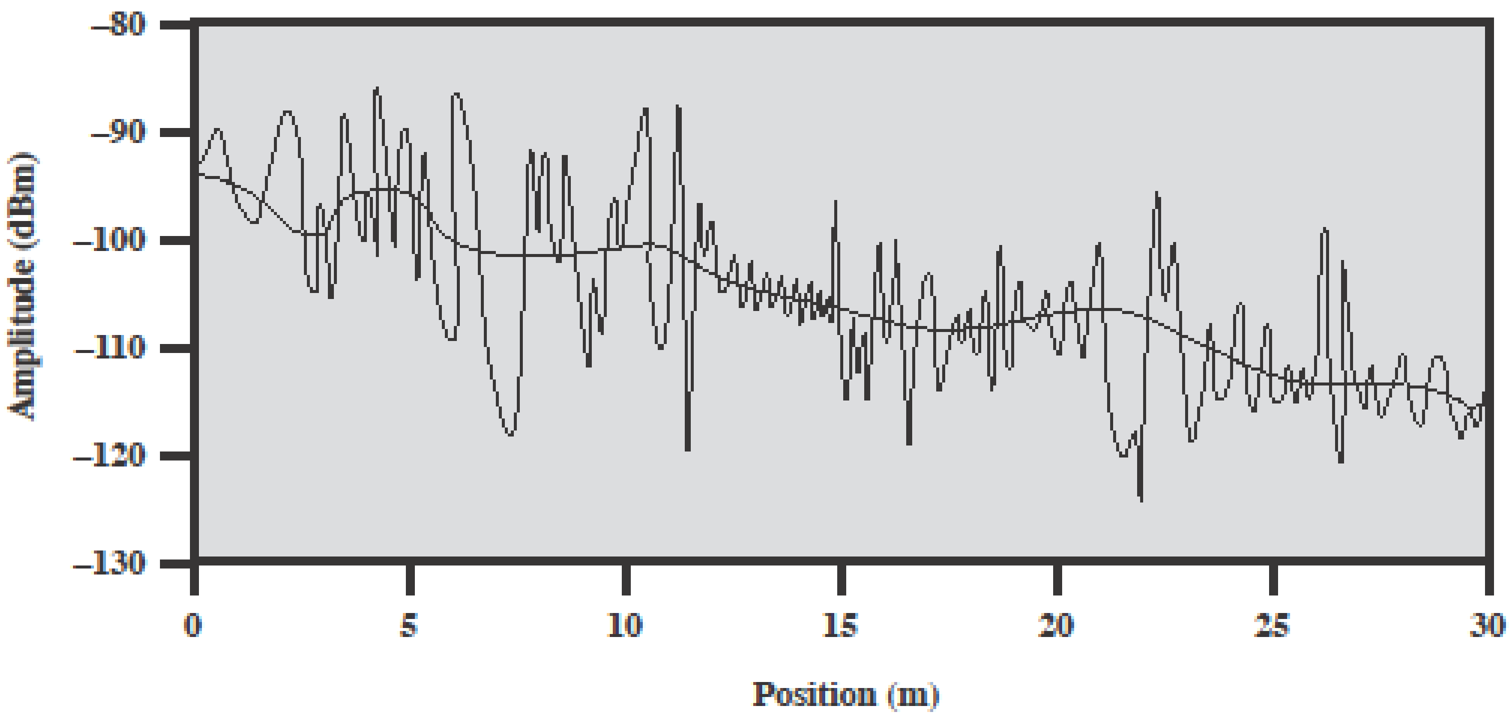
ISI

Inter symbol interference (ISI): One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

[Wikipedia: multipath propagation]

Fading

Fading is deviation of attenuation caused typically by the multipath propagation or by shadowing from obstacles.



The plot demonstrates fading when a mobile unit moves down the street and experiences rapid variation in signal strength over the distances of about half a wavelength.

Error Compensation Mechanisms for transmission impairments

To compensate for the multitude of possible errors caused by a significant number of possible transmission impairments the following groups of techniques are used:

- Error detection and retransmission (ARQ)
- Forward error correction algorithms
- Adaptive equalization
- Diversity techniques

Error Detection and Correction

- Error detection and correction techniques will be discussed in some detail in weeks 6 and 7

Error detection:

- Transmitter adds error-detecting code to data block
  - Code is a function of the data bits, e.g. checksum or CRC – Cyclic Redundancy Check
- Receiver calculates error-detecting code from incoming data bits
  - If calculated code matches incoming code, no error occurred
  - If error-detecting codes don’t match, the transmission is repeated

Forward Error correction:

- Redundancy is introduced in coding the bits
- The redundant code makes it possible to **correct error without retransmission.**

Adaptive Equalization

- Can be applied to transmissions that carry analog or digital information
  - Analog voice or video
  - Digital data, digitized voice or video
- Used to combat intersymbol interference
- Involves gathering dispersed symbol energy back into its original time interval
- Techniques
  - Lumped analog circuits
  - Sophisticated digital signal processing algorithms

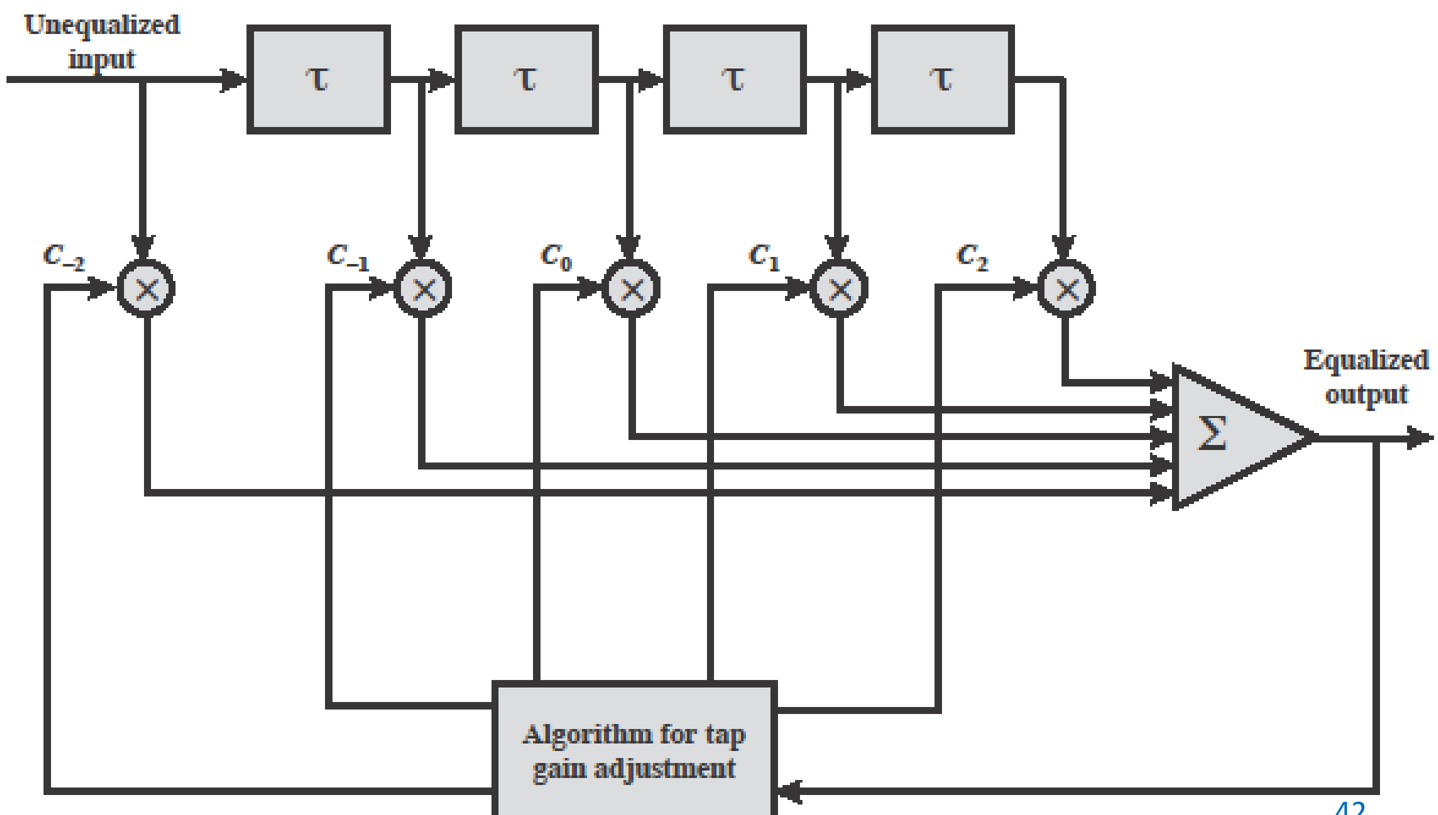
Adaptive equalization

The current corrected value of a signal sample, say, $y(t)$, is calculated as a linear combination of incoming samples of the signal, e.g.

$$y(t) = c_{-2}s(t) + c_{-1}s(t-1) + c_0 s(t-2) + c_1 s(t-3) + c_2 s(t-4)$$

The coefficients c_i are estimated from all the signal samples using a learning algorithm

Digital 4-th order adaptive equalizer



Diversity Techniques

- To reduce fading and other signal impairments during transmission over a single transmission channel, the signal is sent over a number of channels
- **Space diversity** – techniques involving creation of additional physical transmission path (Multi-Input Multi-Output (MIMO) techniques – multiple antennas
- **Frequency diversity** – techniques where the signal is spread out over a larger frequency bandwidth or carried on multiple frequency carriers (e.g. Spread Spectrum techniques).
  - Most common technique is OFDM – **O**rthogonal **F**requency **D**ivision **M**ultiplexing
- **Time diversity** – techniques aimed at spreading the data out over time (e.g. Time Division Multiplexing)

Multiple Antennas - MIMO systems

- Multiple antennas at both the transmitter and receiver can be used to improve communication performance.
- In wireless communications it offers significant increases in **data throughput** and **link range** without additional bandwidth or transmit power.
- It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading).
- Because of these properties, MIMO is an important part of modern wireless communication standards as IEEE 802.11 (WiFi), 3GPP Long Term Evolution (LTA), WiMAX and HSPA+ (High Speed Packet Access, 3.5G mobile technology).

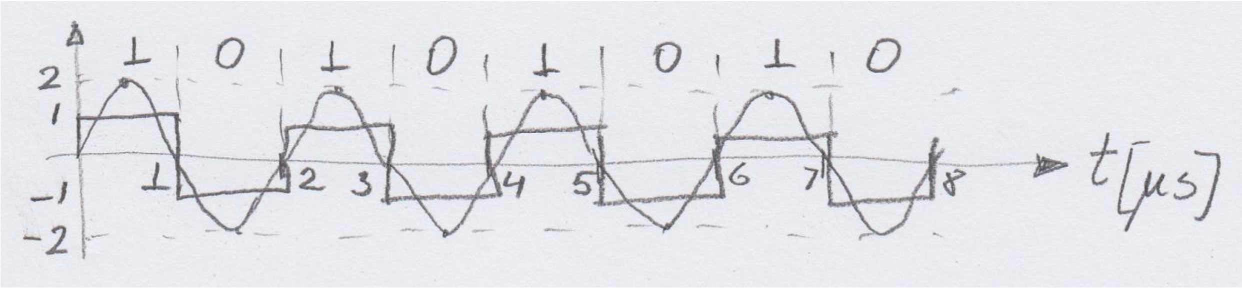
Functions of MIMO

Read about functions of MIMO in Wikipedia

How signals can be modulated using digital modulation schemes?

Introduction to digital modulation

- Consider a binary string of zeros and ones 010101..
- If we have a **bit rate** R bits/sec, then the duration of the bit is $t_b = \frac{1}{R}$ sec
- For example, if R = 1Mb/s (or Mbs), then t_b = 1μs
- If we associate the bit one with a high value, say +1, and the bit zero with a low value, say -1, than we can draw the following diagram:



- Note that the frequency of the related sinusoidal signal,

$$f = \frac{1}{2} R = 500\text{kHz}$$

Bits and symbols

- We have just demonstrated a basic relationship between a pair of **bits** (0, 1) and two **symbols**,
- In the example there is one bit per symbol: positive and negative part of a sinusoid,
- The bit rate, R, is twice the maximum symbol frequency, or bandwidth.
- Using $m = 2^n$ symbols we can increase the bit rate for the given frequency:

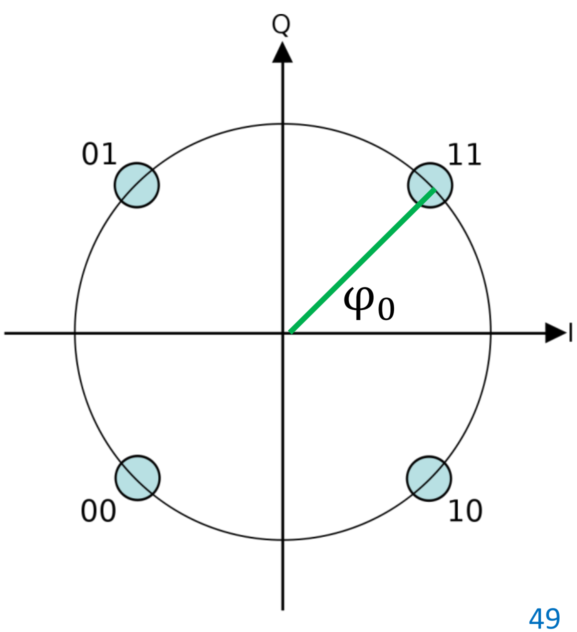
$$R = 2n\, f_s = 2 f_s \, \log_2 m$$

- The starting concept is given by the QPSK – Quadrature Phase-Shift Keying (modulation)

QPSK with 2 bits per symbol

- If we use $n = 2$ bits per symbol, we need to have $m = 2^n = 4$ symbols
- In Quadrature Phase-Shift Keying (modulation) we use the **phase** φ of a sinusoid to create different symbols
- Typically, we use: $\varphi_k = \frac{\pi}{4} + k\frac{\pi}{2}$, for $k = 0, 1, \ldots, m-1$

- It is convenient to present those four sinusoids as points on the complex plane (see prac 1).
- The resulting drawing is called the **constellation diagram**
- Note that we have 2 bits and four signals



More on QPSK

$\varphi_k = \frac{\pi}{4} + k\frac{\pi}{2}$ for $k = 0, 1, 2, 3$

QPSK signal(s) in the time domain:

$$s_k(t) = e^{j(\omega_c t + \varphi_k)}$$

The quadrature (imaginary) component:

$$Q_k(t) = \sin(\omega_c t + \varphi_k)$$

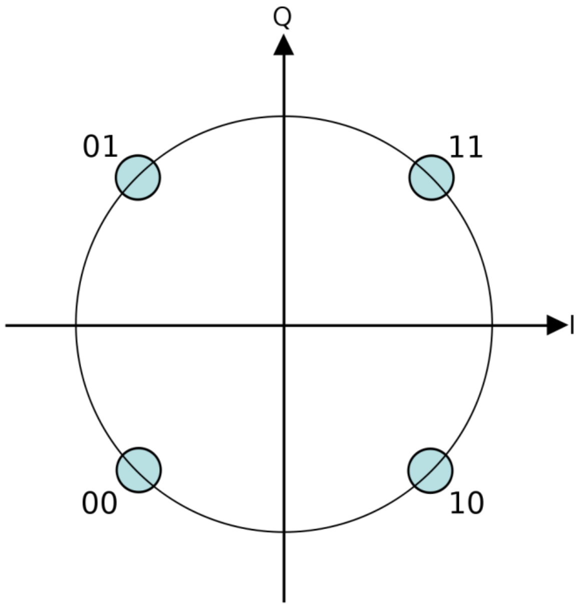
The in-phase (real) component:

$$I_k(t) = \cos(\omega_c t + \varphi_k)$$

where $\omega_c = 2\pi f_c$,

f_c – the carrier frequency

the constellation diagram

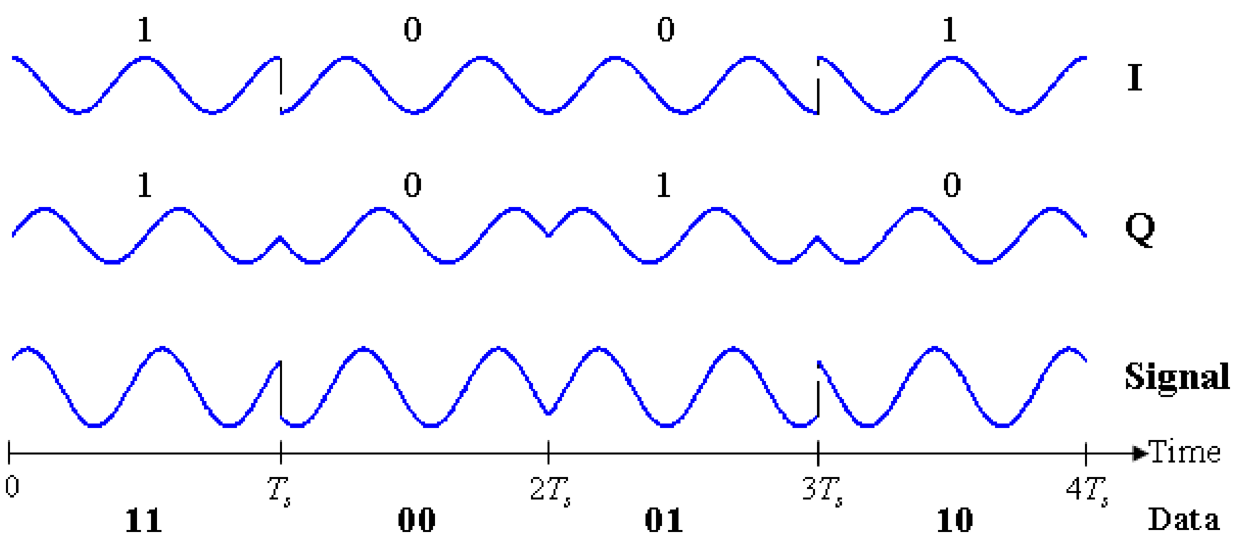


Note the Gray coding.
Adjacent symbols differ by one bit only

QPSK signal in time domain

- The modulated signal consists of two components:
- a cosine wave (I) and a sine wave (Q).
- The total signal (in the bottom) is the sum of the two components
- The data consists of the binary stream:

1 1 0 0 0 1 1 0



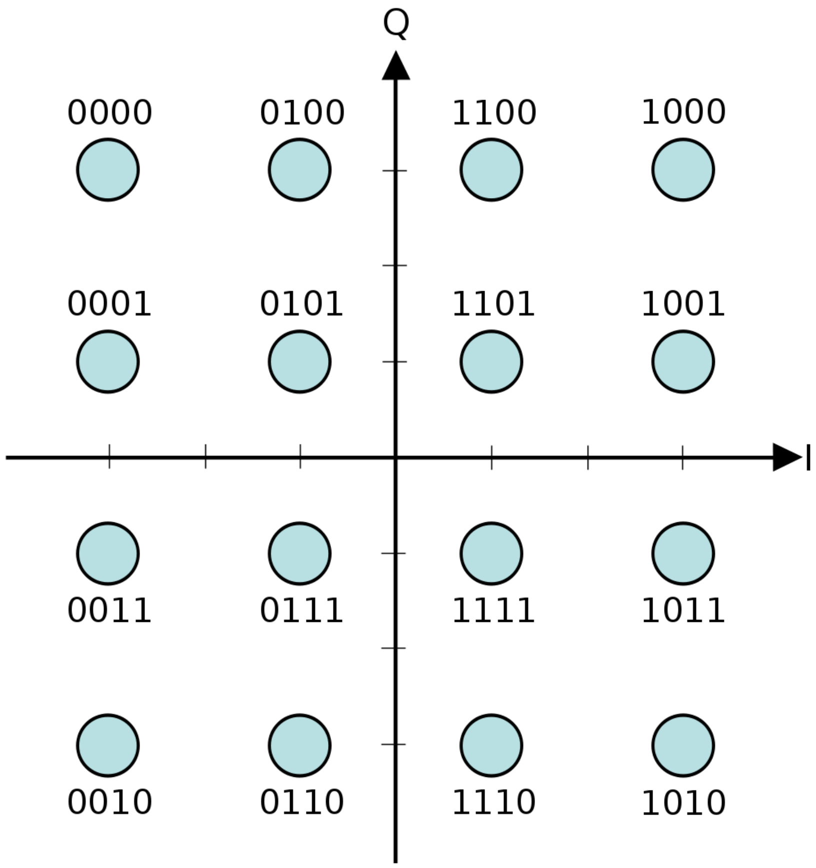
From QPSK to Quadrature Amplitude Modulation

- Note that in the QPSK the amplitude of the signals is constant.
- A natural extension to QPSK is the Quadrature Amplitude Modulation QAM.
- QPSK is identical to 4-QAM

The very popular are

- 16-QAM ($m = 2^4$) ,
- 64-QAM ($m = 2^6$)
- 256-QAM ($m = 2^8$)

Constellation Diagram of a 16-QAM:
16 symbols, each coding 4 bits



Summary

Reflect your achievement of the five learning outcomes.

For today's tutorial, work on Tutorial 3 and remember to submit tutorial 2 and 3 as a 3-members team report to Moodle submission page. Note that due to student number of 31, only one group has four members.

Next week lecture on S1_18L04 WLAN- WiFi part I – IEEE Standards.