Unit 1

Wireless Transmission

Frequencies for radio transmission, Regulations, Signals, Antennas

Signal propagation-Path loss of radio signals, Additional signal propagation effects, Multipath propagation.

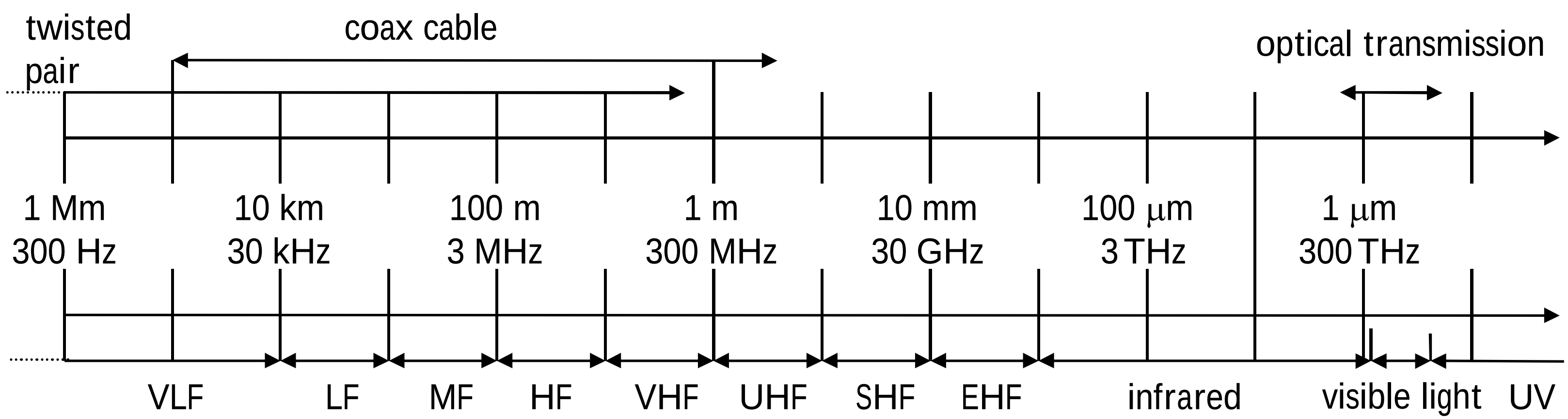
Multiplexing-Space, Frequency, Time, Code division multiplexing. Modulation- Amplitude, Frequency, Phase Shift Keying,

Advanced frequency and phase shift keying,

Spread spectrum- DSSS, FHSS.

Cellular System

Frequencies for Radio Transmission



VLF = Very Low Frequency

LF = Low Frequency

MF = Medium Frequency

HF = High Frequency

VHF = Very High Frequency

UHF = Ultra High Frequency

SHF = Super High Frequency

EHF = Extra High Frequency

UV = Ultraviolet Light

Frequency and wave length:

$\lambda = c/f$ wave length λ, speed of light $c \cong 3\times10^8$ m/s, frequency f

Frequencies for Radio Transmission

Wave	Description
VLF	Long waves
LF	Used in submarines
MF & HF	Radio transmission (AM, SW, FM)
VHF & UHF	Analog TV transmission, digital audio broadcast
SHF	Microwave links and fixed satellite services
EHF	Extensive use of SHF applications
IR	Directed link transmission
Visible Light	Not very reliable due to interference

Regulations

	Europe	USA	Japan
Cellular Phones	**GSM** 450-457, 479-486/460-467,489-496, 890-915/935-960, 1710-1785/1805-1880 **UMTS** (FDD) 1920-1980, 2110-2190 **UMTS** (TDD) 1900-1920, 2020-2025	**AMPS**, **TDMA**, **CDMA** 824-849, 869-894 **TDMA**, **CDMA**, **GSM** 1850-1910, 1930-1990	**PDC** 810-826, 940-956, 1429-1465, 1477-1513
Cordless Phones	**CT1+** 885-887, 930-932 **CT2** 864-868 **DECT** 1880-1900	**PACS** 1850-1910, 1930-1990 **PACS-UB** 1910-1930	**PHS** 1895-1918 **JCT** 254-380
Wireless LANs	**IEEE 802.11** 2400-2483 **HIPERLAN 2** 5150-5350, 5470-5725	902-928 **IEEE 802.11** 2400-2483 5150-5350, 5725-5825	**IEEE 802.11** 2471-2497 5150-5250
Others	**RF-Control** 27, 128, 418, 433, 868	**RF-Control** 315, 915	**RF-Control** 426, 868

Signals

- Signal
- Periodic Signal
- Sine waves
- Amplitude
- Frequency
- Phase shift
- Wavelength

Signals

- General Sine wave function

  $s(t) = A_t \sin(2\pi f_t t + \varphi_t)$

- It is possible to construct every periodic signal g by using only sine and cosine functions by fundamental equation of **Fourier**

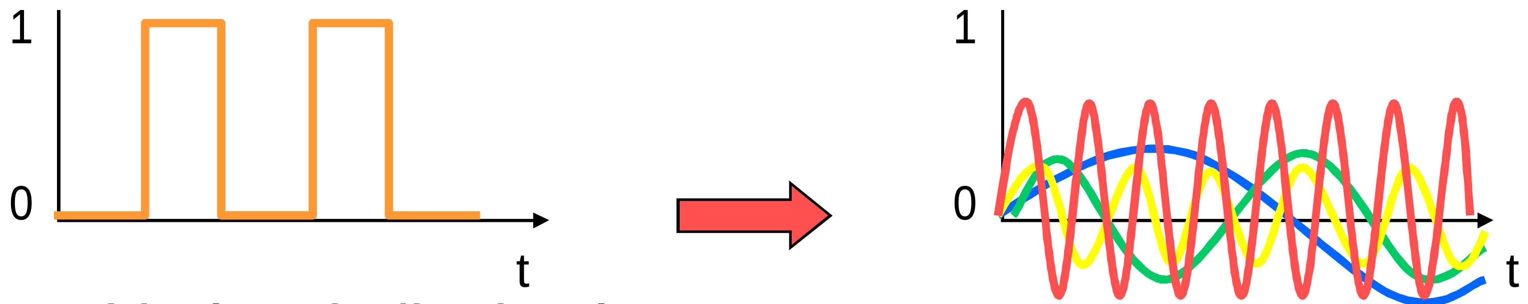
$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

C – Direct Current

a_n and b_n – amplitudes of nth sine and cosine functions

Frequencies of these functions are called **Harmonics**

Signals



ideal periodic signal

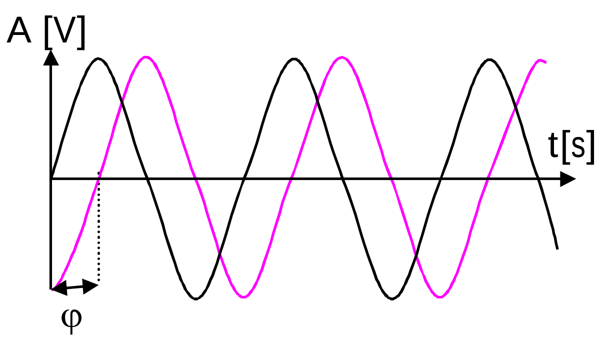
real composition (based on harmonics)

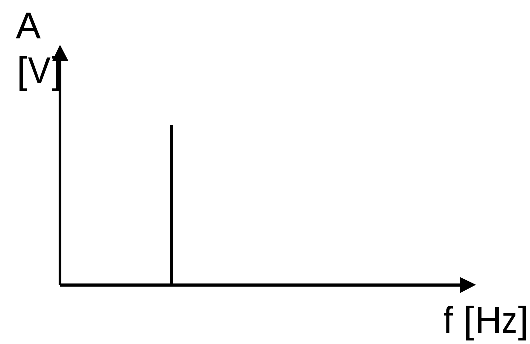
Representation of signals

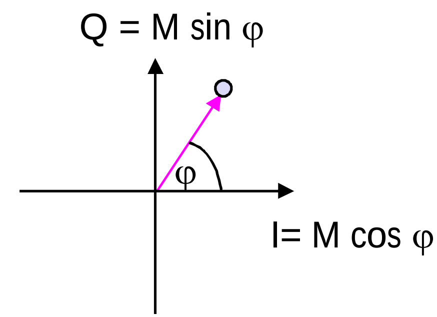
1. Time domain
2. Frequency domain
3. Phase domain

Signals

Time Domain | Frequency Domain | Phase Domain







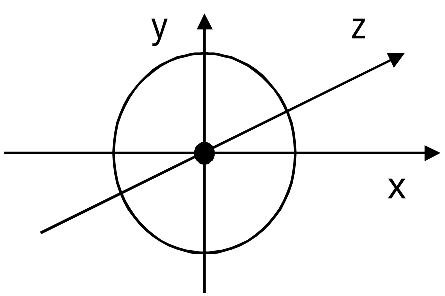
- If a signal consists of multiple frequency waves then frequency domain representation is better.
- Phase domain representation is also called state diagram or phase state. (0 – In Phase, 90 – Quadrature)

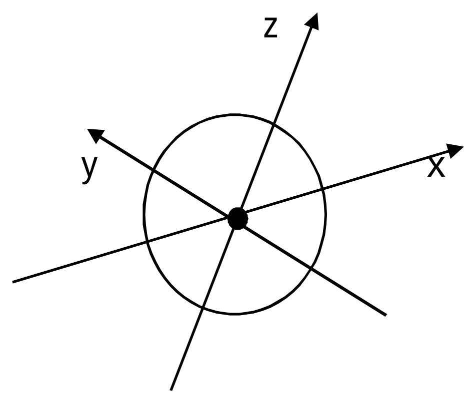
Antennas: Isotropic Radiators

- Main function:

  Radiation and Reception of electromagnetic waves.
- Isotropic Radiator:

  equal radiation in all directions.
- A theoretical reference antenna is isotropic radiator.



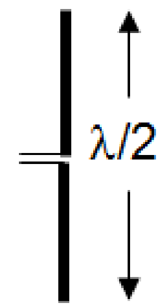


ideal
isotropic
radiator

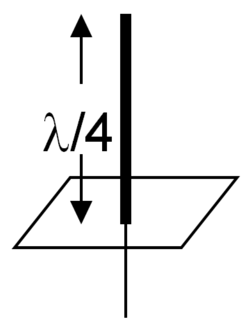
Antennas: Simple dipole

- <u>Real antennas</u> are **not** <u>isotropic radiators</u>, they exhibit directive effects.
- It is thin center fed dipole – Hertzian Dipole.
- Two collinear conductors of equal length separated by small feeding gap.
- For efficient radiation of energy,

  length of the antenna = $\lambda/2$



- If mounted on roof of the car, $\lambda/4$ is sufficient (Marconi Antenna).



Antennas: Simple dipole

- Simple dipole antenna:

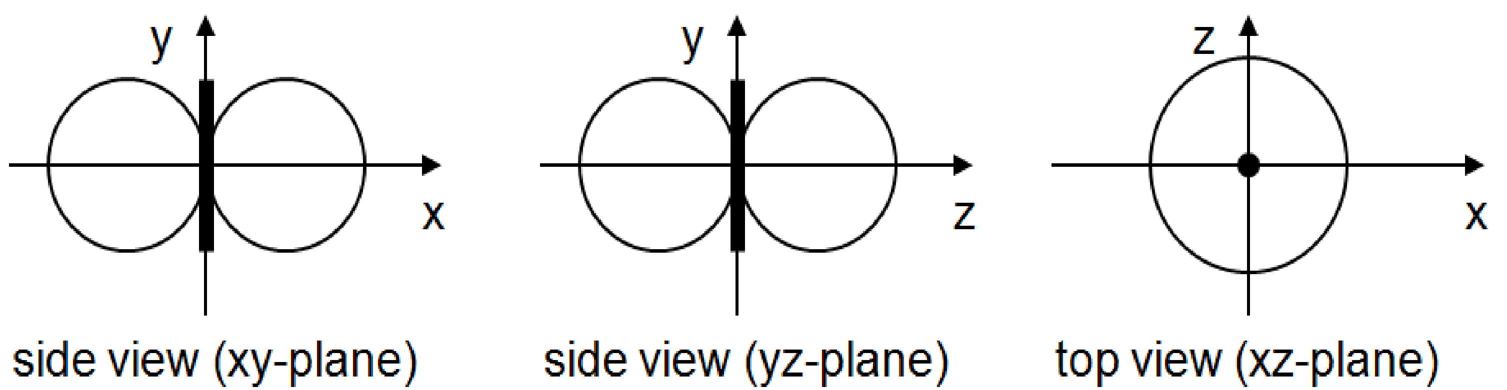
- Marconi Antenna:

Antenna: Simple dipole

- Radiation Pattern:

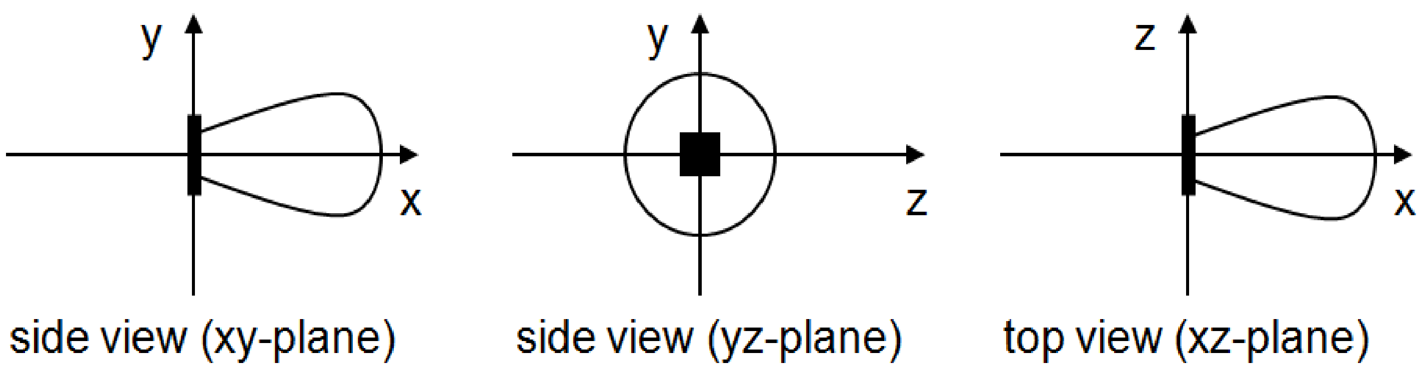
  $\lambda/2$ dipole antenna has uniform or Omni-directional pattern in only one plane.

  It is used in today's mobile phones.



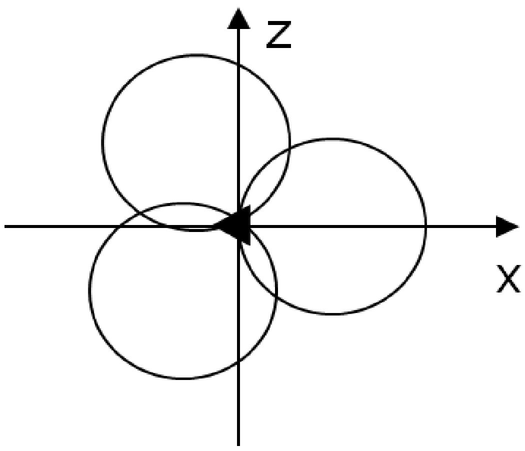
Antennas: Directional Antenna

- If simple dipole antenna placed in valley or between buildings – No use of Omni-directional pattern.
- Directional antennas with certain preferred direction is used in such cases.

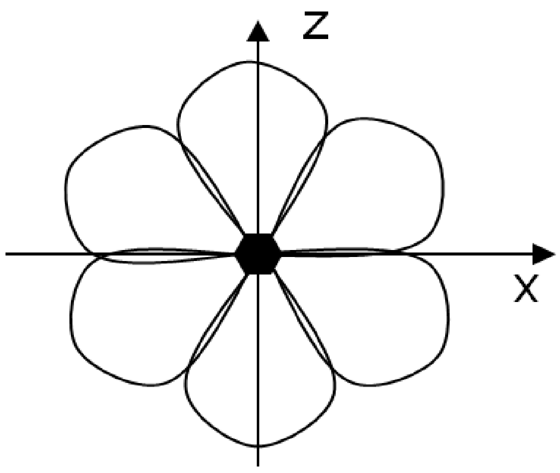


Antennas: Sectorized

- Several directional antennas can be combined on single pole to construct a sectorized antenna.



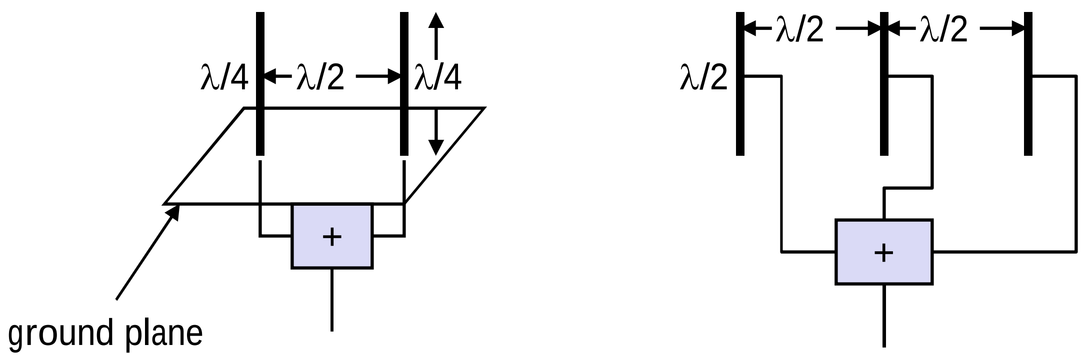
top view, 3 sector



top view, 6 sector

Antenna: Diversity Antenna Systems

- Multi-element antenna array
- It is used to combine power of all antennas to produce gain.
- Receiver always selects antenna element with largest power.



Antenna: Smart Antenna

- Antenna Array
- Used to optimize radiation patterns
- These antennas adapt change in

  - reception power

  - transmission condition

  - many signal propagation effects.

Signal Propagation

Transmission range

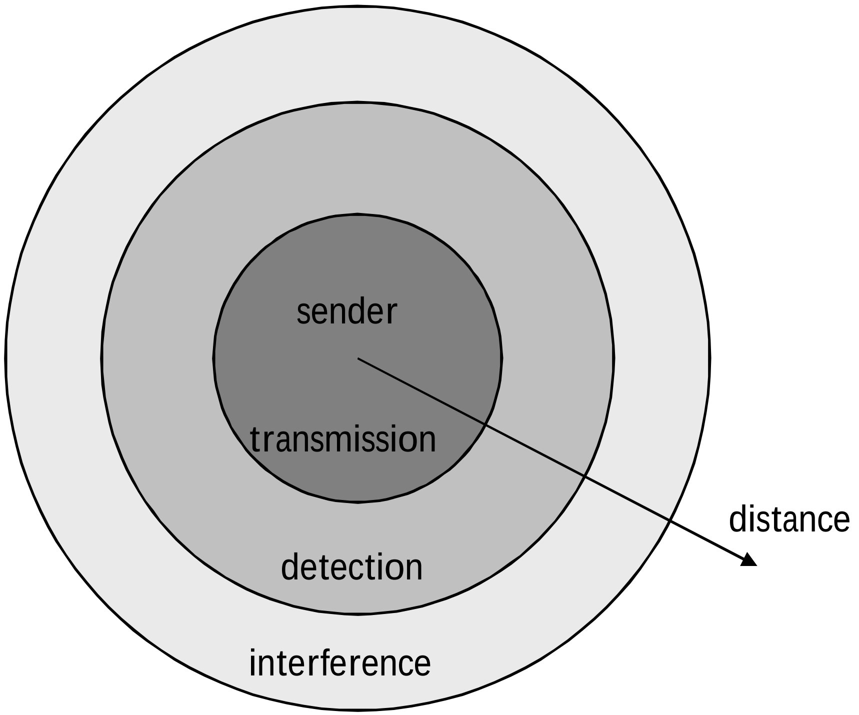
- communication possible
- low error rate

Detection range

- detection of the signal possible
- no communication possible

Interference range

- signal may not be detected
- signal adds to the background noise



Path Loss of Radio Signals

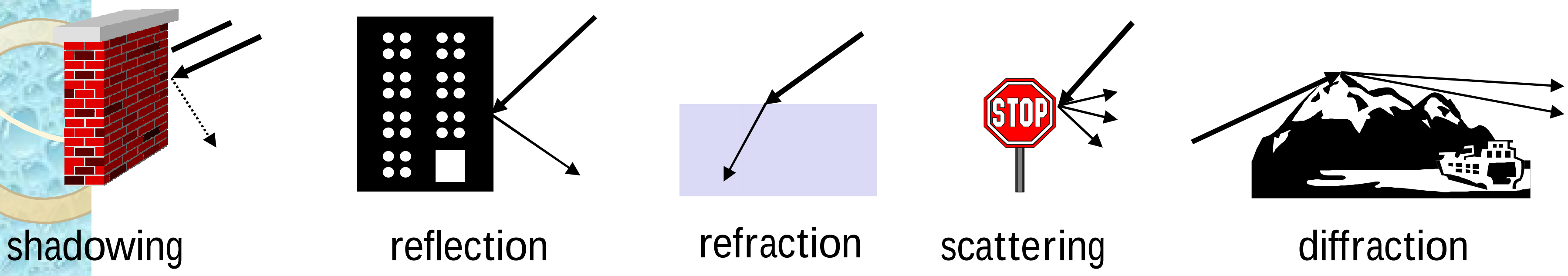
- In free space radio signals propagates as light does (straight line).
- If a straight line exists between sender and receiver then it is called as line-of-sight (LOS).
- Inverse square law:

  Receiving power proportional to $1/d^2$
  (d = distance between sender and receiver)
- Path loss or attenuation does not cause too much trouble at short distance.

Path Loss of Radio Signals

Wave	Frequency	Description
Ground Wave	< 2MHz	Used is submarines or AM radio due to low frequency
Sky Wave	2 – 30 MHz	Used for broadcast & radio due to it's reflection at ionosphere
Line-of-Sight	> 30 MHz	Mobile phones, Satellites, Cordless phones

Additional Signal Propagation Effects

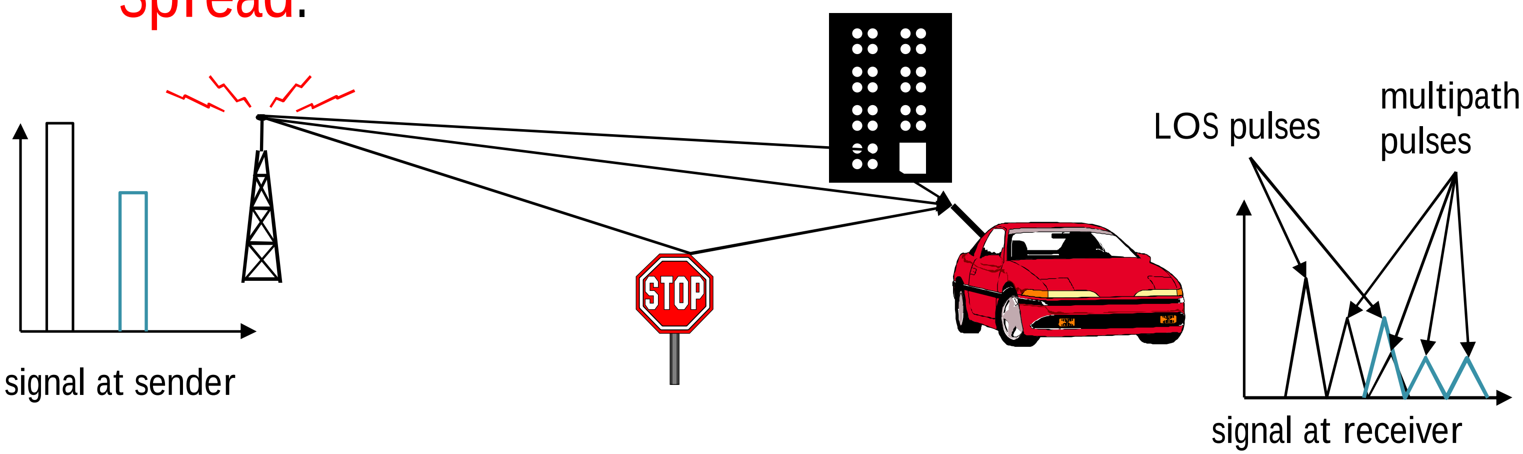


- Shadowing – Blocking due to large obstacle cause attenuation
- Reflection – causes due to object is larger than wavelength of signal.
- Refraction – Velocity of waves depends on velocity of medium. When waves travels through denser medium, it bends.
- Scattering – Size of obstacle <= Wavelength
- Diffraction – Radio waves reflected at edge & propagates in different directions

Multipath Propagation

- Multipath Propagation - Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction
- Signal travelling along different paths with different lengths arrive at receiver at different times.

This effect of multipath propagation is called Delay Spread.

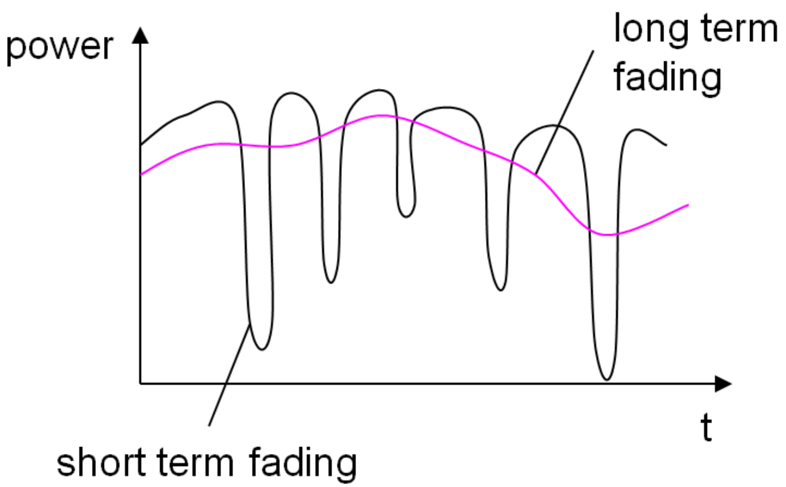


Multipath Propagation

- Effects of Delay Spread

Short Term Fading –

Sudden change in power of received signal



Long Term Fading –

Average power over time due to change in distance to sender or obstacle.

Multiplexing

- In communication-

  Multiplexing: how several users share same medium

- Dimensions –

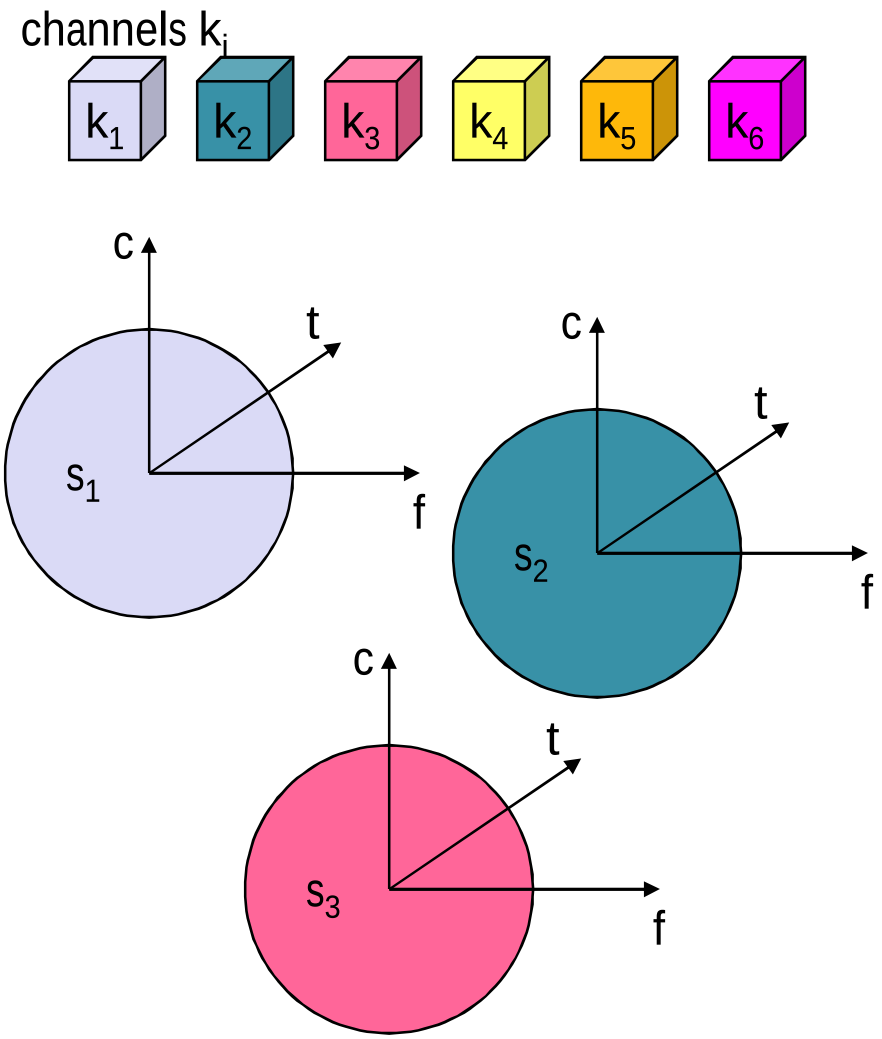
  1. Space 2. Time 3. Frequency 4. Code

- To perform multiplexing assign these dimensions for channels to multiple users, keeping one variable and others constant.
- Types –

1. Space Division Multiplexing (SDM)
2. Frequency Division Multiplexing (FDM)
3. Time Division Multiplexing (TDM)
4. Code Division Multiplexing (CDM)

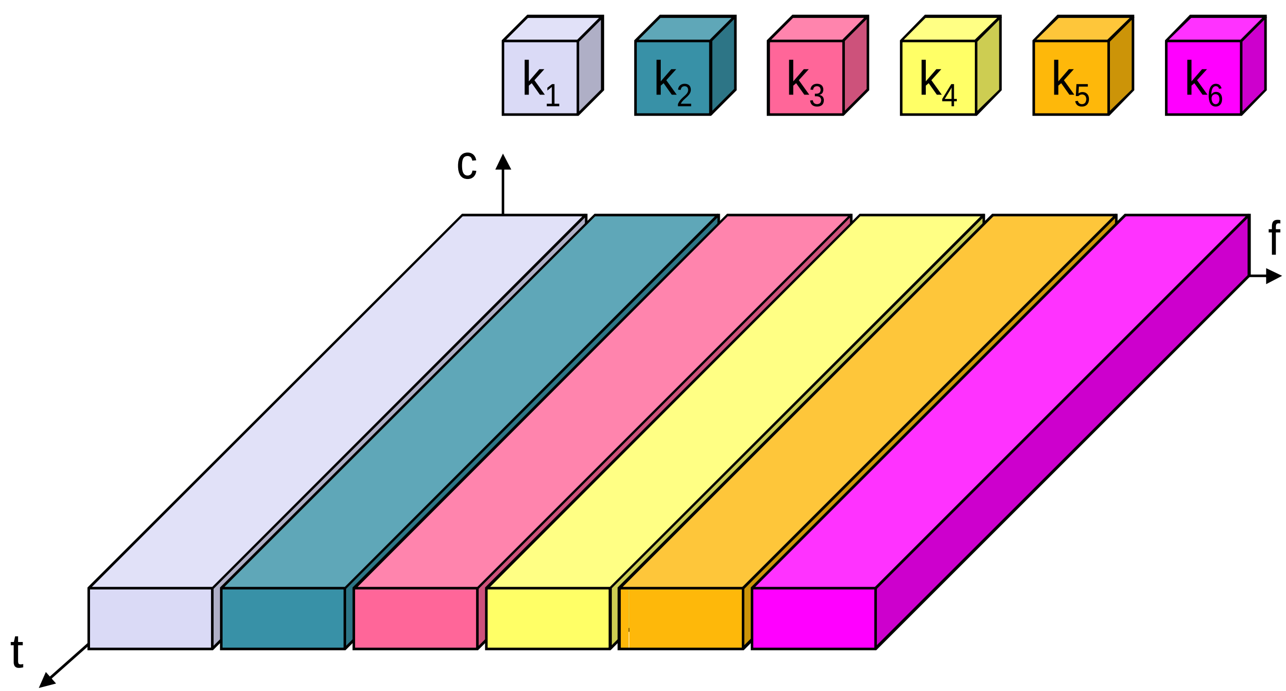
Space Division Multiplexing (SDM)

- 3D spaces S1, S2,S3
- 3 radio stations k1, k2, k3
- K1 to k3 mapped on S1 to S3 respectively
- Circle represents interference range in space
- Spaces between interference ranges = Guard Space
- Disadvantage – waste of Space
- Use – Analog phones, FM radio



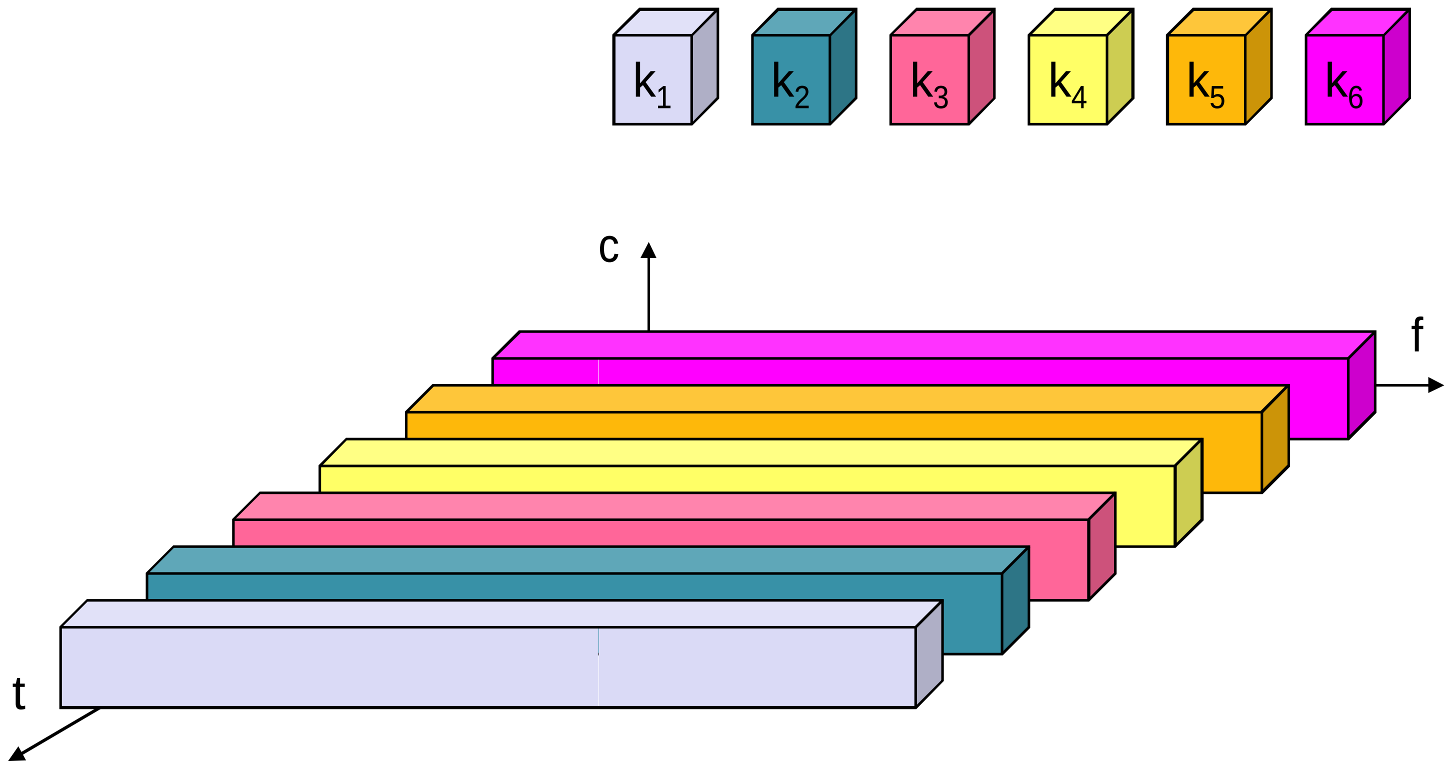
Frequency Division Multiplexing (FDM)

- Way to divide frequency dimension into non-overlapping bands.
- Guard spaces used to avoid frequency band overlapping called Adjacent Channel Interference.
- Dynamic co-ordination between sender & receiver not required
- Wastage of bandwidth & limits number of users.



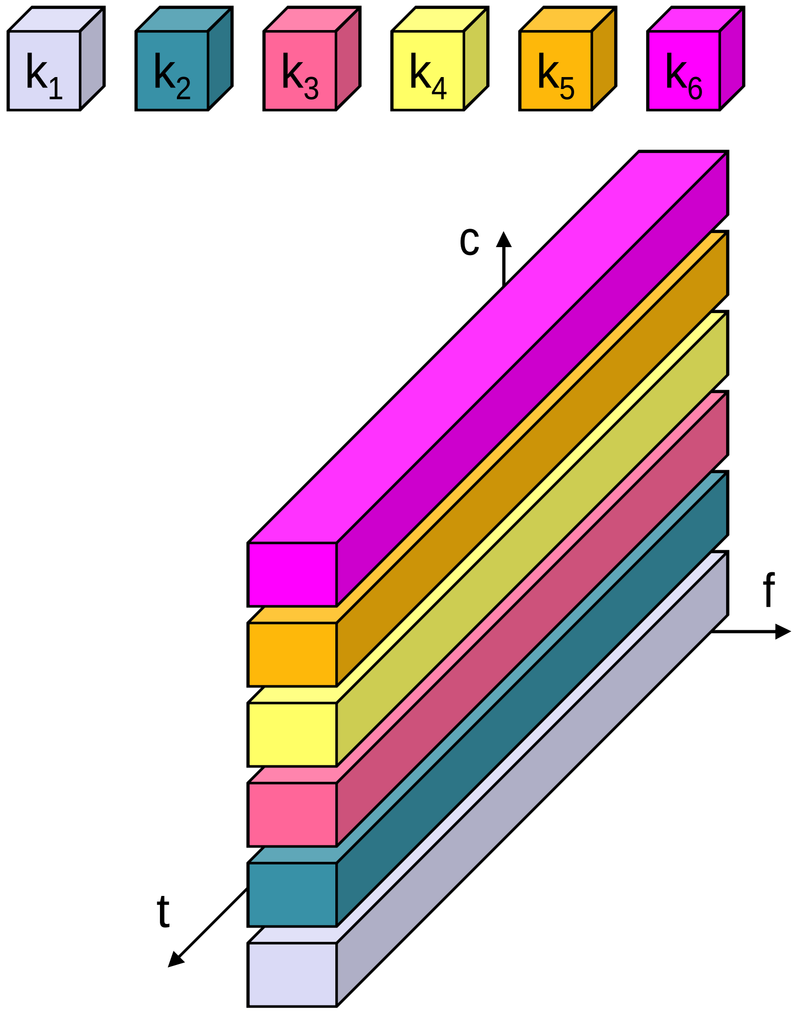
Time Division Multiplexing (TDM)

- Guard spaces are required for time gaps.
- If two transmission overlaps in time called co-channel interference.
- Synchronization between sender and receiver is necessary
- Only one user can use medium at a time.



Code Division Multiplexing (CDM)

- Each user has unique code.
- Guard spaces are used in the form of code that separates two user codes – Orthogonal Codes
- By using secrete code, secure communication can be established.
- Utilization of bandwidth is efficient.
- No synchronization between sender & receiver required.



Modulation – Basic Terms

- Frequency band – specific range of frequencies
- Broadband – multiple frequencies are available on wide band to transmit information (256 kbps)
- Narrowband – wide enough to carry voice (64kbps)
- Baseband – original non-modulated or low pass signal
- Radio wave – electromagnetic waves within the range of 3kHz to 300 GHz.
- Carrier wave – It is a waveform which is modulated (modified) with an input signal to transfer information.

Modulation

- Modulation is process of changing the properties of original signal by using carrier, to transmit the information.
- Types

1. Digital Modulation:

   Digital signal (0 &1) translated into **analog baseband signal.**

   It is used when digital data has to be transmitted over medium that allows only analog transmission.

2. Analog Modulation

   Used to transfer analog baseband signal over media.

   It shifts center of the frequency of analog baseband signal up to the frequency of radio carrier wave.

Digital Modulation

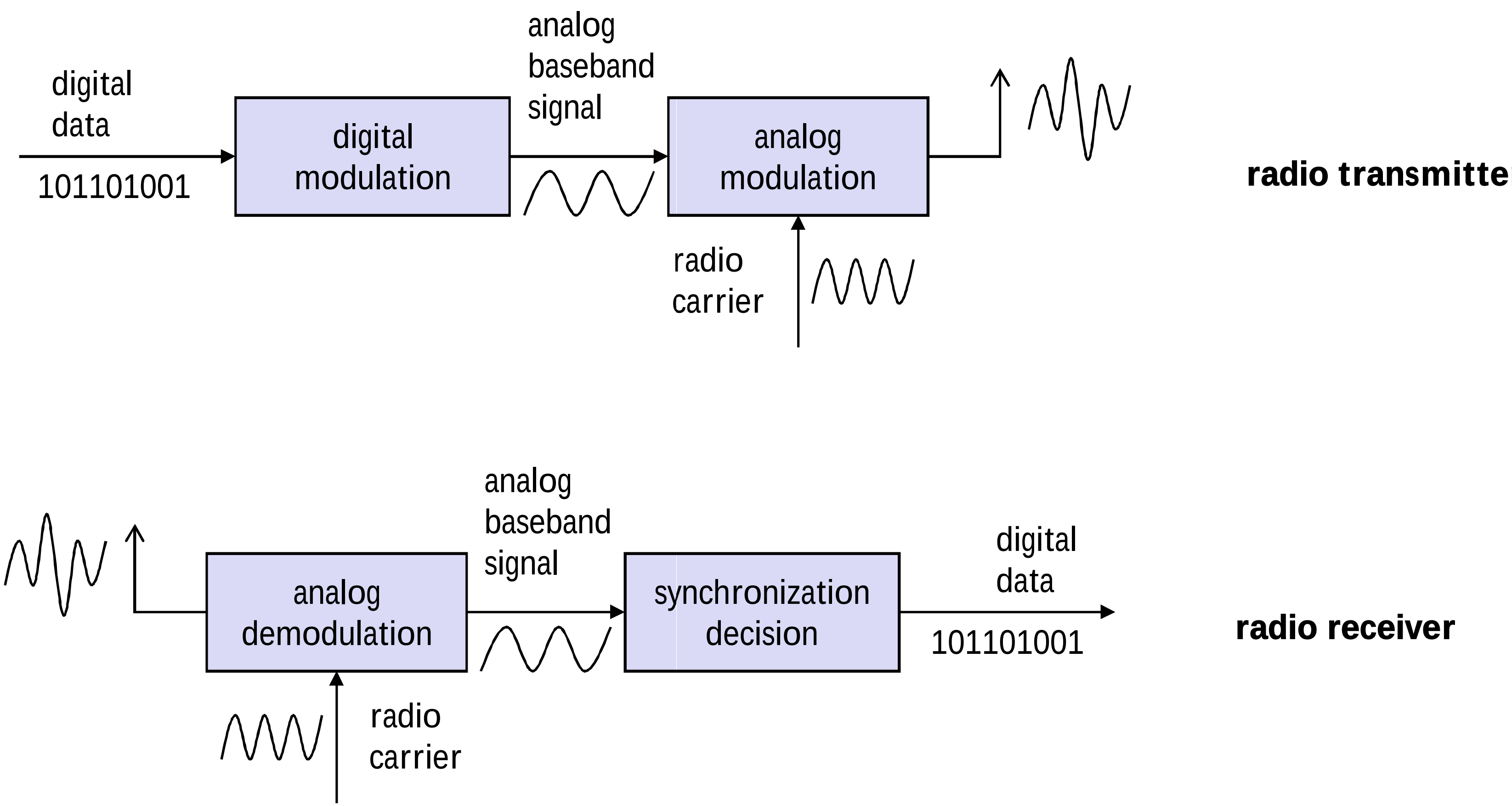
- Digital Modulation : Basic Schemes

1. Amplitude Shift Keying (ASK)
2. Frequency Shift keying (FSK)
3. Phase Shift Keying (PSK)

- Advanced Techniques

1. Advanced Frequency Shift Keying
2. Advanced Phase Shift Keying

Digital Modulation



Digital Modulation

- Why analog baseband signal can not be directly transmitted in wireless system ?

1. Antennas

   To transmit 1 GHz signal – Antenna length in cm.

2. Frequency Division Multiplexing

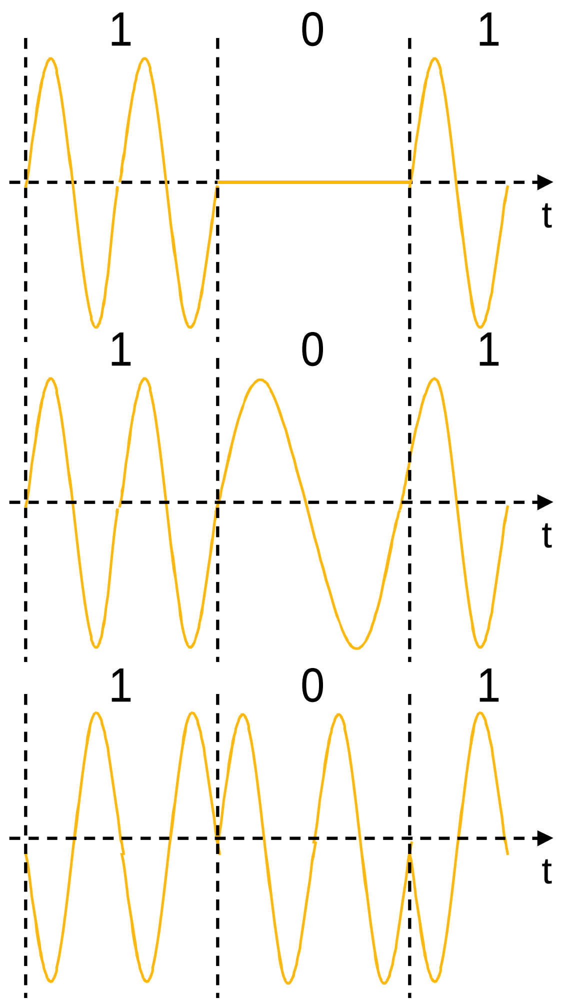
   FDM can not be applied analog modulation as it shifts baseband signal to different carrier.

3. Medium Characteristics

   Path-loss, reflection, refraction, scattering and other

Digital Modulation

- **Amplitude Shift Keying (ASK):**
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- **Frequency Shift Keying (FSK):**
  - needs larger bandwidth
  - Continuous Phase Modulation (CPM)
- **Phase Shift Keying (PSK):**
  - more complex
  - robust against interference
  - BPSK
  - Phase Lock Loop (PLL) for synchronization.



Advanced Frequency Shift Keying

- Minimum Shift Keying (MSK)
- Adding Gaussian Low Pass filter to MSK called GMSK.
- Data bits are separated into even bits and odd bits
- Duration of each bit is doubled
- Two frequencies used: f1 (low),   f2 (high), f2=2f1
- Rules:

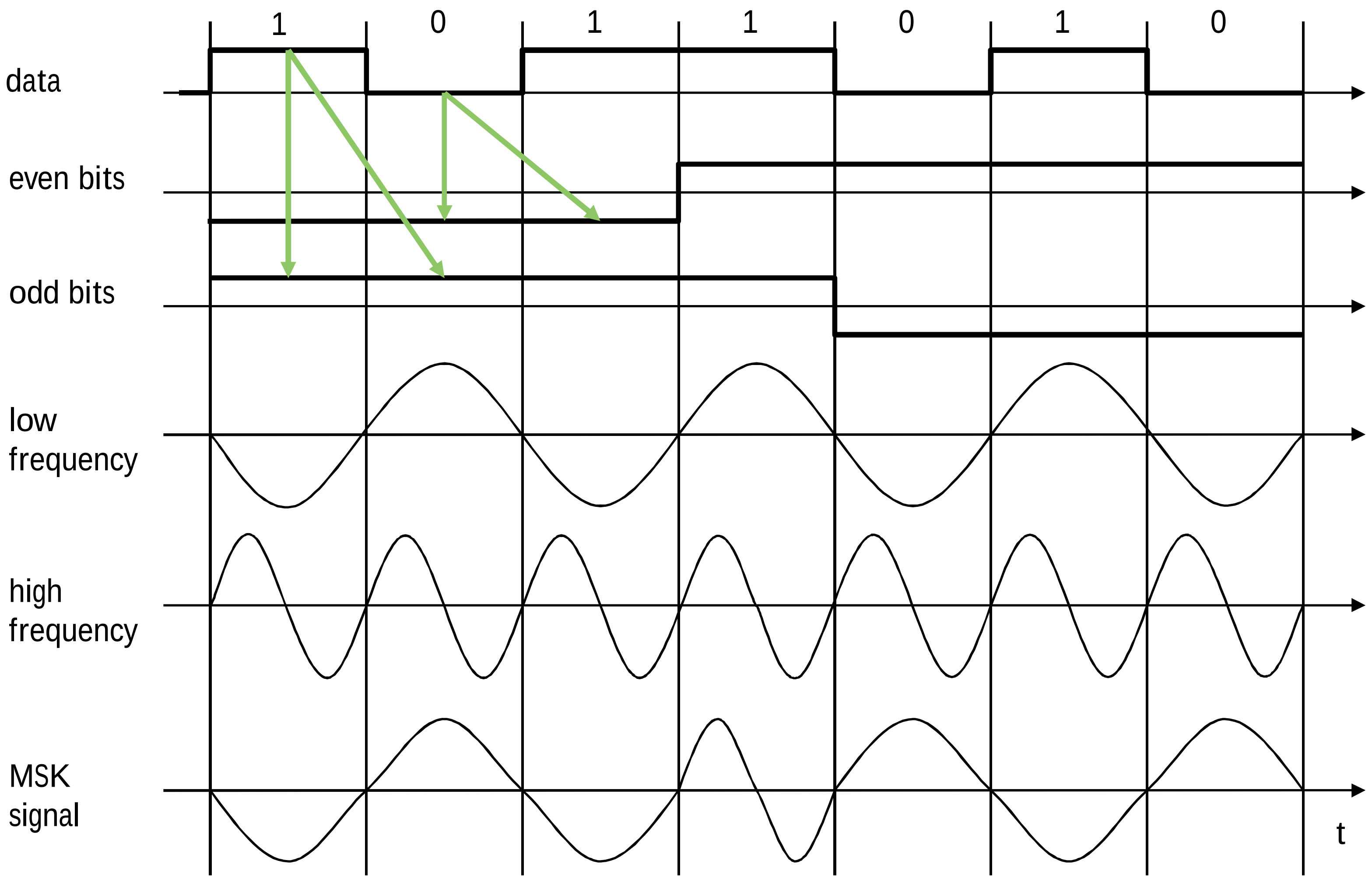
Even Bit	Odd Bit	Result
0	0	F2 inverted
1	0	F1 inverted
0	1	F1 original
1	1	F2 original

Advanced Frequency Shift Keying

- Steps:

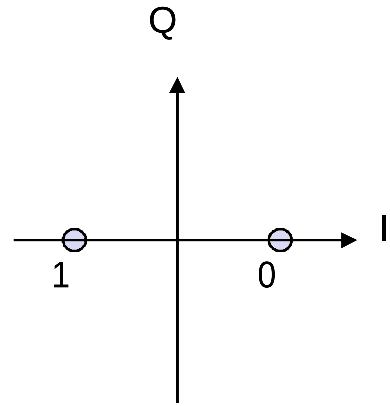
1. Let the data bits are 1011010
2. Determine 1^{st} Even bit count and Odd bit count in signal for 1s.
3. Initially keep even bit count 0 and shift to 1 after count for 1s is 2
4. Initially keep odd bit count 1 and shift to 0 after count for 1s is 3.
5. Consider respective low frequency (f1) and high frequency (f2) waves.
6. Apply rules and determine MSK signal.

Advanced Frequency Shift Keying (MSK)

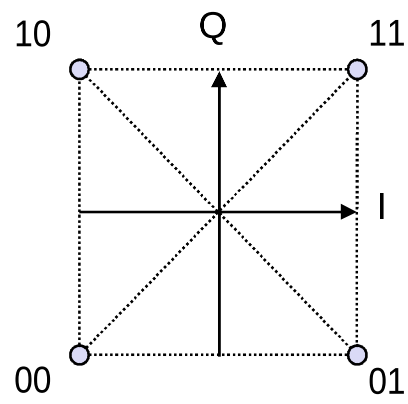


Advanced Phase Shift Keying

- The basic BPSK uses only one possible phase shift of 180^0



- Quaternary PSK (QPSK) is used to achieve higher bit rates by coding two bits into one phase shift.



Advanced Phase Shift Keying

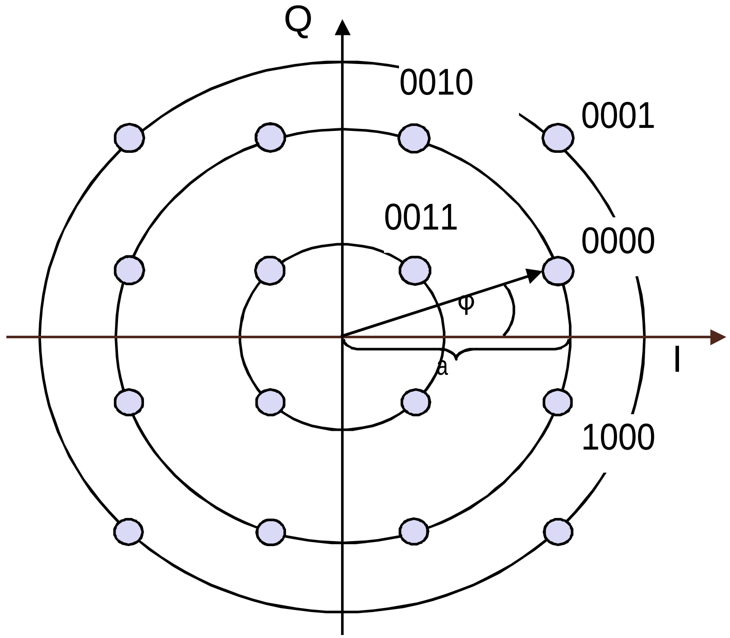
- Problem: synchronization between sender and receiver is essential to determine shift.
- To avoid this problem Differential QPSK (DQPSK) is used.
- In this scheme, phase shift is not relative to the reference signal, but to the phase of previous two bits.

e.g.

Quadrature Amplitude Modulation (QAM) that combines ASK and PSK together.

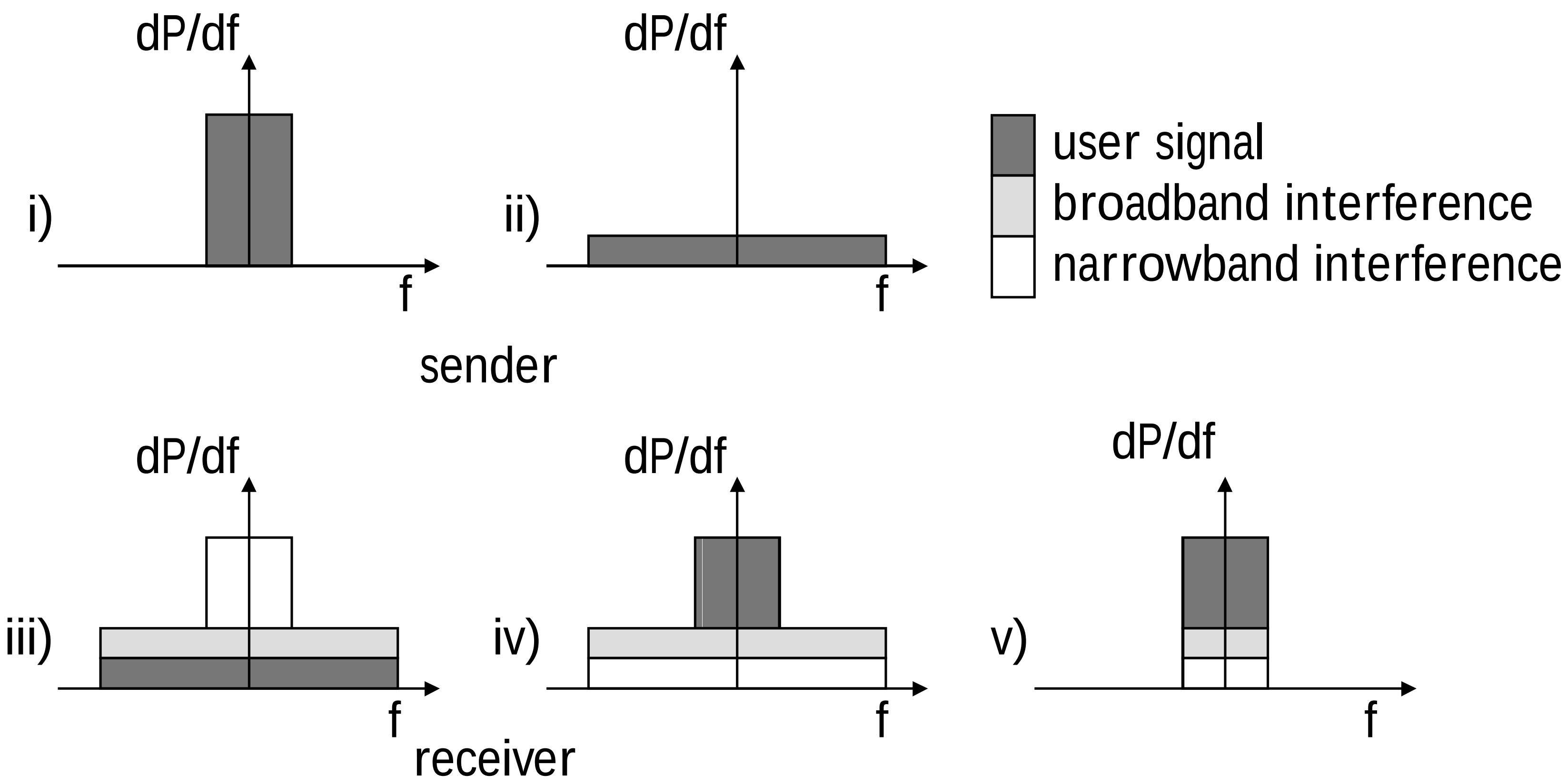
Advanced Frequency Phase Keying

- Example: 16-QAM (4 bits = 1 symbol)
- Symbols 0011 and 0001 have the same phase φ, but different amplitude a.
- 0000 and 1000 have different phase, but same amplitude.
- used in standard 9600 bit/s modems

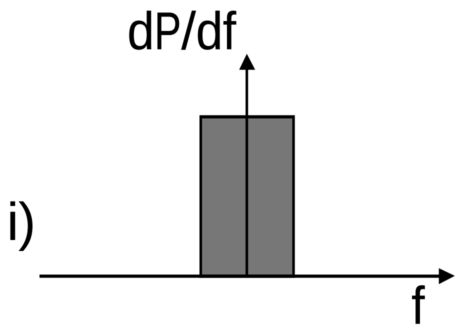


Spread Spectrum

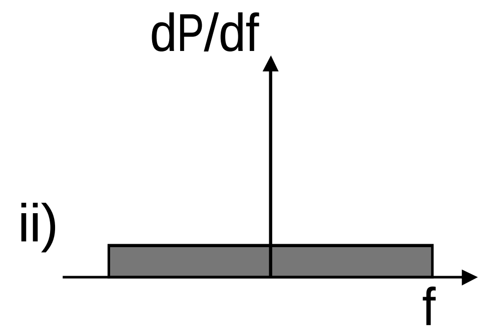
- Spread Spectrum is a technique that involves spreading the bandwidth needed to transmit data.
- Advantage: Resistance to narrowband interference.



Spread Spectrum: Spreading by Sender

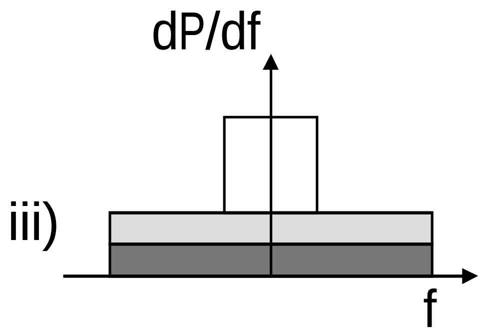


Idealized narrowband Signal of user data from Sender.



Energy needed to transmit the signal is same but now it is distributed over large Frequency range.

Spread Spectrum: Dispreading by Receiver

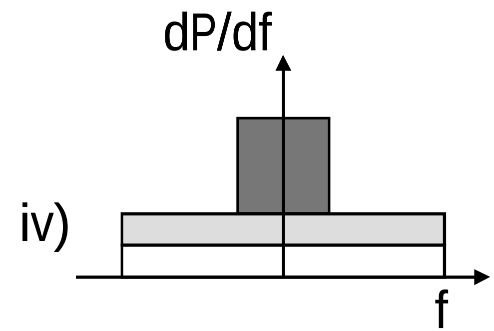


During transmission,

Narrowband Interference &

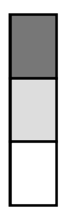
Broadband Interference

Added to the user signal.



Receiver converts broadband user signal to narrowband user signal &

Narrowband interference to broadband.



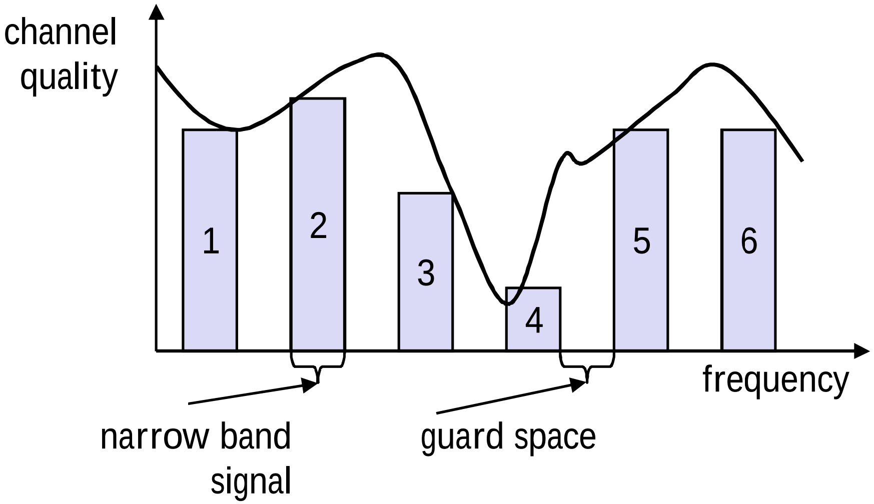
user signal
broadband interference
narrowband interference

Spread Spectrum: Dispreading by Receiver

- Receiver applied band-pass filter to cut off frequencies to the left and right side of narrowband signal.
- Finally receiver constructs original signal as power level of user signal is still high enough .

Spread Spectrum

- Narrowband interference without spread spectrum

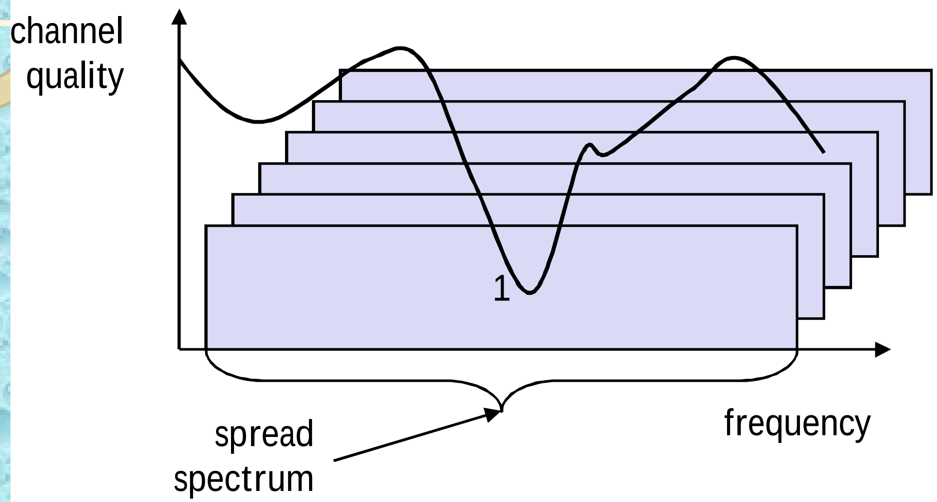


narrowband channels

- ✓ 6 different channels (user) use FDM
- ✓ Each one has it's own narrow frequency band for transmission.
- ✓ Depending on receiver characteristics, only 1, 2, 5, 6 could be received.
- ✓ Channel quality of 3, 4 is too bad to transmit data.
- ✓ Thus, communication is difficult using narrowband signals.

Spread Spectrum

- Spread Spectrum channels



spread spectrum channels

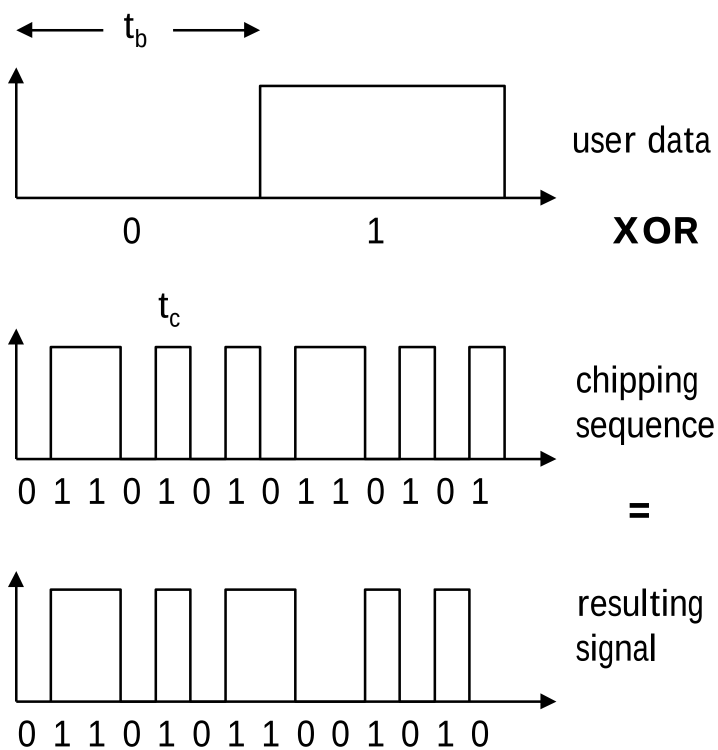
- ✓ All narrowband signals are spread with broadband signals using same frequency range.
- ✓ To separate channels CDM is used instead of FDM.

Direct Sequence Spread Spectrum (DSSS)

- DSSS system takes user bit stream and perform XOR with chipping sequence (spreading pattern).
- t_b: bit period
- t_c: chip period
- If chipping sequence generated properly, it appears as random noise, Sometimes it is called as pseudo noise.
- Spreading factor

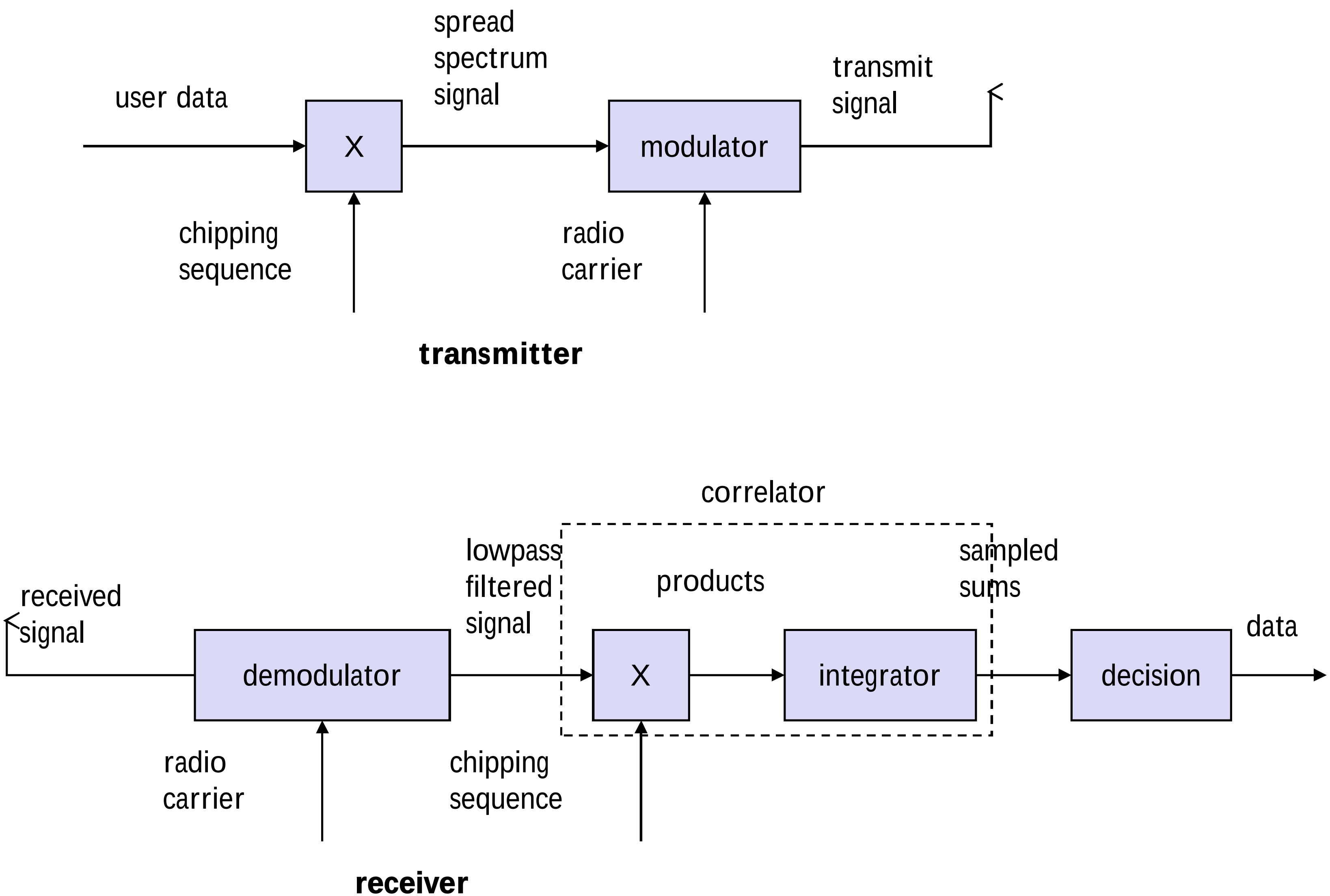
$$s = t_b / t_c$$

- IEEE 802.11 Wireless LAN uses **10110111000** (Barker code) as chipping sequence to DSSS.



t_b: bit period
t_c: chip period

Direct Sequence Spread Spectrum (DSSS)



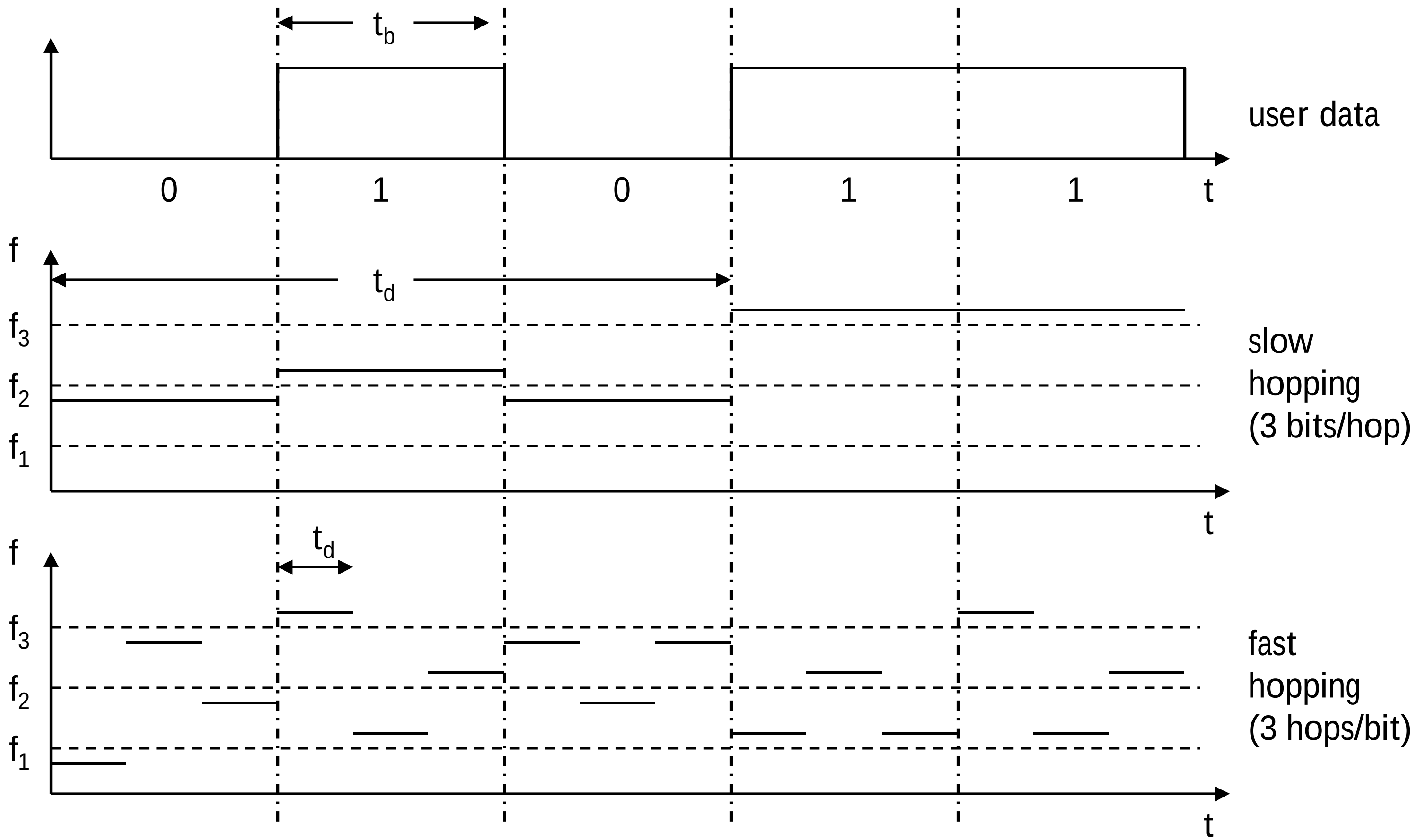
Direct Sequence Spread Spectrum (DSSS)

- Synchronization between sender and receiver is essential.
- Due to multipath propagation, delay spread may exist.
- Solution to this problem is RAKE receiver.
- It uses ‘n’ corelators for ‘n’ strongest paths.
- Output of corelators combined and fed into decision unit.

Frequency Hoping Spread Spectrum (FHSS)

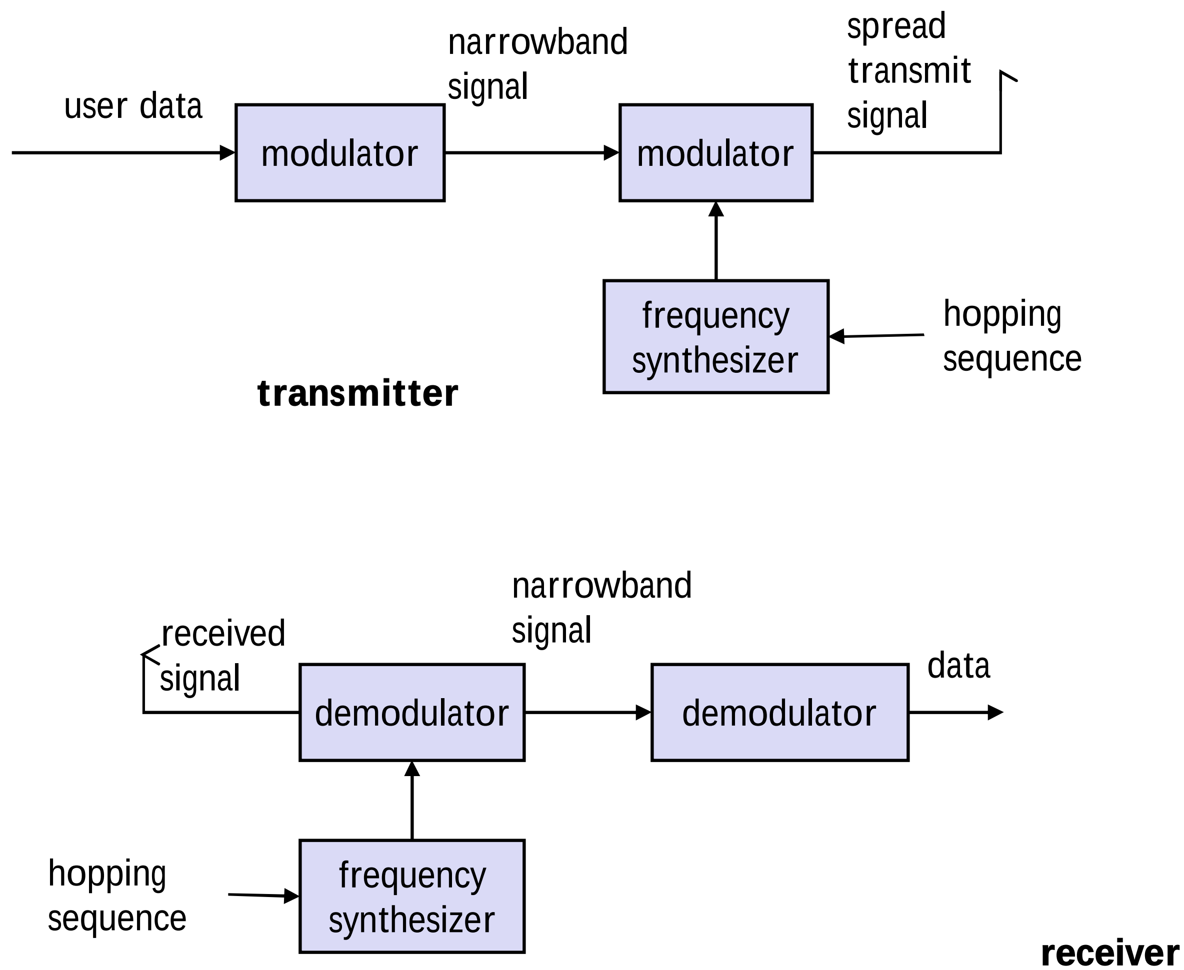
- In FHSS, total bandwidth is divided into many channels of small bandwidths.
- *Signal passes through channel for certain time then it hops to another channel*.
- It uses FDM & TDM both.
- The pattern of one by one channel usage is called Hopping Sequence.
- Time spend on channel by signal with certain frequency is called dwell time.

Frequency Hoping Spread Spectrum (FHSS)



t_b: bit period $\quad$ t_d: dwell time

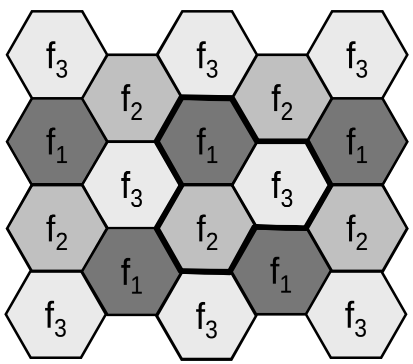
Frequency Hopping Spread Spectrum (FHSS)



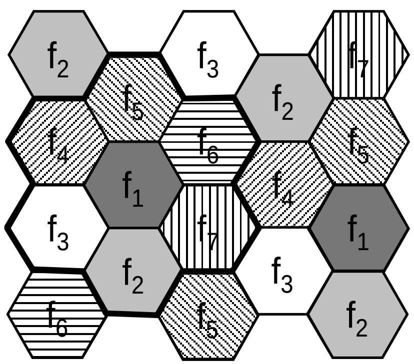
- Bluetooth performs 1600 hops/second.

Cellular System

- Cellular systems for mobile communication implements **SDM**.
- Each transmitter is called as 'Base Station'.
- Each base station covers certain physical area, called as **Cells**.
- Shape of the cells are never perfect circles or hexagon shape, it depends on *environment, weather conditions and system load*.



3 cell cluster



7 cell cluster

Cellular System

- Advantages of cellular system with small cells

1. Higher capacity – SDM allows frequency reuse.
2. Less transmission power – Short distanced
3. Local interference only – Interference due to neighbors
4. Robustness – against failures

- Small cells also have some disadvantages

1. Infrastructure is needed - Complex
2. Handover is needed – changing from one cell to other
3. Frequency planning – to avoid interference

Channel Allocation schemes in Cellular Systems

- Fixed Channel Allocation (FCA)

✓ Fixed assignments of frequencies to cells & clusters.

✓ Not very efficient if traffic load varies.

- Borrowing Channel Allocation (BCA)

✓ In case of heavy load in one cell and light weight in neighboring cell then one could borrow the frequency.

- Dynamic Channel Allocation (DCA)

✓ Frequencies can be borrowed & it is possible to freely assign frequencies within the cell.

Cellular System

- Cell Breathing

✓ cell size depends on current load

✓ Additional traffic appears as noise to other users

✓ If the noise level is too high users drop out of cells