WIRELESS COMMUNICATION

UNIT I

SERVICES AND TECHNICAL CHALLENGES

- Types of Services, Requirements for the services, Multipath propagation, Spectrum Limitations, Noise and Interference limited systems, Principles of Cellular networks, Multiple Access Schemes.

Types of services

1. Broadcast
2. Paging
3. Cellular Telephony
4. Trunking Radio
5. Cordless Telephony
6. Wireless Local Area Networks
7. Personal Area Networks
8. Fixed Wireless Access
9. Ad hoc Networks and Sensor Networks
10. Satellite Cellular Communications

Broadcast

The properties of broadcast are

- The information is unidirectional.
- The transmitted information is the same for all users.
- The information is transmitted continuously.
- In many cases, multiple transmitters send the same information

Paging

Their properties are

- Paging systems are also unidirectional wireless communications systems
- The user can only receive information, but cannot transmit. Consequently, a "call" (message) can only be initiated by the call center, not by the user.
- The information is intended and received by a single user.
- The amount of transmitted information is very small.

Cellular Telephony

- The information is bidirectional
- The information is user specific
- Large number of users can be accommodated
- More amount of data can be transmitted
  - Key words- Cell, Handoff & Frequency reuse

Trunking Radio

- In trunking radio systems there is no connection between the wireless system and the PSTN.(e.g)Police Wireless, Call Taxi
- This facilitates closed user calls
- Multiple users can share the same channel
- The range of the network can be extended by using each Mobile Station as relay station

Cordless Telephony

- The cordless telephone can communicate with only a single base station
- Cordless is a local device, when a call is coming in from the PSTN, there is no need to find out the location of the device.
- No handoff is required between different BSs. Since it has only one base station
- A user has one BS so there is no need for frequency planning.
- It is free of cost except for the hardware.

Wireless Local Area Network

- A wireless local area network (WLAN) links two or more devices using some wireless distribution method
- It usually provides a connection through an access point to the wider internet

e.g. WiFi

Personal Area Networks

- When the coverage area of WLANs becomes smaller then it is called Personal Area Networks (PANs)

(e.g) Bluetooth

- Networks for even smaller distances are called Body Area Networks (BANs)

(e.g., pacemakers).

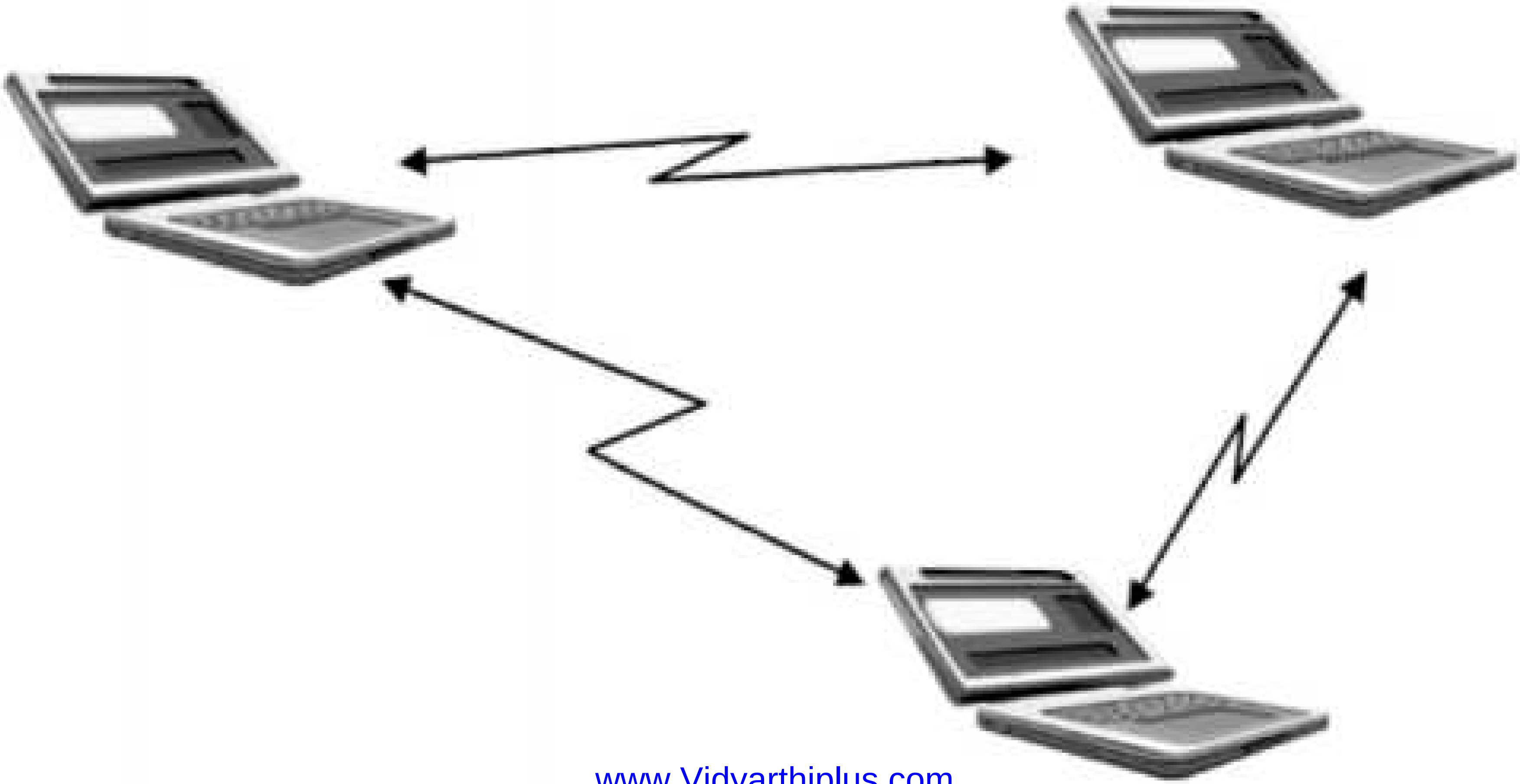
Fixed Wireless Access

- In fixed wireless there is no mobility of the user devices
- BS always serves multiple users
- It covers more area (between 100m and several tens of kilometers)

Ad hoc Networks and Sensor Networks

- This is an infrastructure less network (i.e) It does not have any central server
- Each node operates not only as a host but also as a router
- An ad hoc network has a multi-hop wireless connectivity and is without any definite network topology.

Ad hoc Networks and Sensor Networks



Satellite Cellular Communications

- In this the satellites will act as Base Station.
- The distance between the BS and the MS is much larger
- So the cell size will be more than 100km.
- It has good coverage but only less number of users can be accommodated.
- Also the installation cost is very high, so this service is used for emergency purposes.

Requirements

- Data Rate
- Range and Number of Users
- Mobility
- Energy Consumption
- Use of Spectrum
- Direction of Transmission
- Service Quality

Data Rate

- The data rates of the system will have a major role in the performance of the system.
- Not all the services require similar data rates.

Sensor networks -1 kbit/s.

Speech communications - 5 and 64 kbit/s

Personal Area Networks -100 Mbit/s

Range and Number of Users

- “Range” refers the distance between one transmitter and receiver.
- The coverage area of a system can be increased by combining more number of base station into one big network.
- For services like Cellular Telephones the number of users will be more. So our system has to be flexible enough to accommodate all.

Service	Range	Users
Body Area Networks	~1 m	1
Personal Area Networks	~10 m	1
WLANs	~100m	~10
Cellular systems	Microcells 500m	More
	Macrocells 10 -30 km	
Fixed wireless access	100m – several km	More
Satellite systems	Large (even the size of a country)	Limited

Mobility

- The ability to move around while communicating is one of the main features of wireless communication for the user.
- Not all the services require movement of the user.

Various types….

- Fixed wireless devices – these are planted once and they communicate with their BS, or with each other from the same location. The idea is to prevent physical cabling
- Nomadic devices - are placed at a certain location for a limited duration of time and then moved to a different location

(e.g) laptop

- Low mobility devices - devices are operated at pedestrian speeds.

  e.g cordless phones

- High mobility devices - Cellphones operated by people in moving vehicles (about 30 to 150km/h)
- Extremely high mobility - high-speed trains and planes (300 to 1000 km/h)

Energy Consumption

- Energy consumption is a critical aspect for wireless devices
- Most wireless devices use batteries.
- In order to increase the lifespan of the devices energy has to used efficiently.

Use of Spectrum

- The spectrum available for wireless communication is very limited.
- With this it is difficult to cover entire area
- The frequency reuse concept was a major breakthrough in solving this problem.
- Each base station is allocated a portion of the total number of channels available to the entire system.
- Neighboring base stations are assigned different groups of channels

Direction of Transmission

- Simplex -
- Semi-duplex-
- Full-duplex-
- Asymmetric duplex -data transmission in one direction is higher than in the other direction

Service Quality

- The main indicator for service quality is speech quality for speech services and file transfer speed for data services
- For voice communications, the delay(latency) between the time when one person speaks and the other hears the message must not be larger than about 100 ms.
- Latency is permissible for video streaming.
- But the sequence of data has to be maintained.
- For some applications even a small latency is not entertained - e.g., for industrial control applications, security and safety monitoring, etc.

GSM Bands

System	Band	Uplink (MHz	Downlink (MHz)	Channel Number
GSM-850	850	824.0–849.0	869.0–894.0	128–251
GSM-900	900	890.2–914.8	935.2–959.8	1–124
GSM-1800	1800	1710.2–1784.8	1805.2–1879.8	512–885
GSM-1900	1900	1850.0–1910.0	1930.0–1990.0	512–810

Cellular Networks

- GSM 900 has 25MHz for voice communication
- Width of each channel is 200KHz
- So GSM 900 has 124 channels.
- With that to cover the entire area we need antennas capable of transmitting for hundreds of miles.
- Such an antenna is nearly impossible.

Frequency Reuse

- Frequency Reuse is the technique used to cover the entire area with the limited spectrum.
- The total available channels will be divided into small groups(Clusters) and will be provided to the base stations.
- It is assigned such a way to prevent any interference.
- Adjacent base stations are assigned completely different channels than neighboring cells

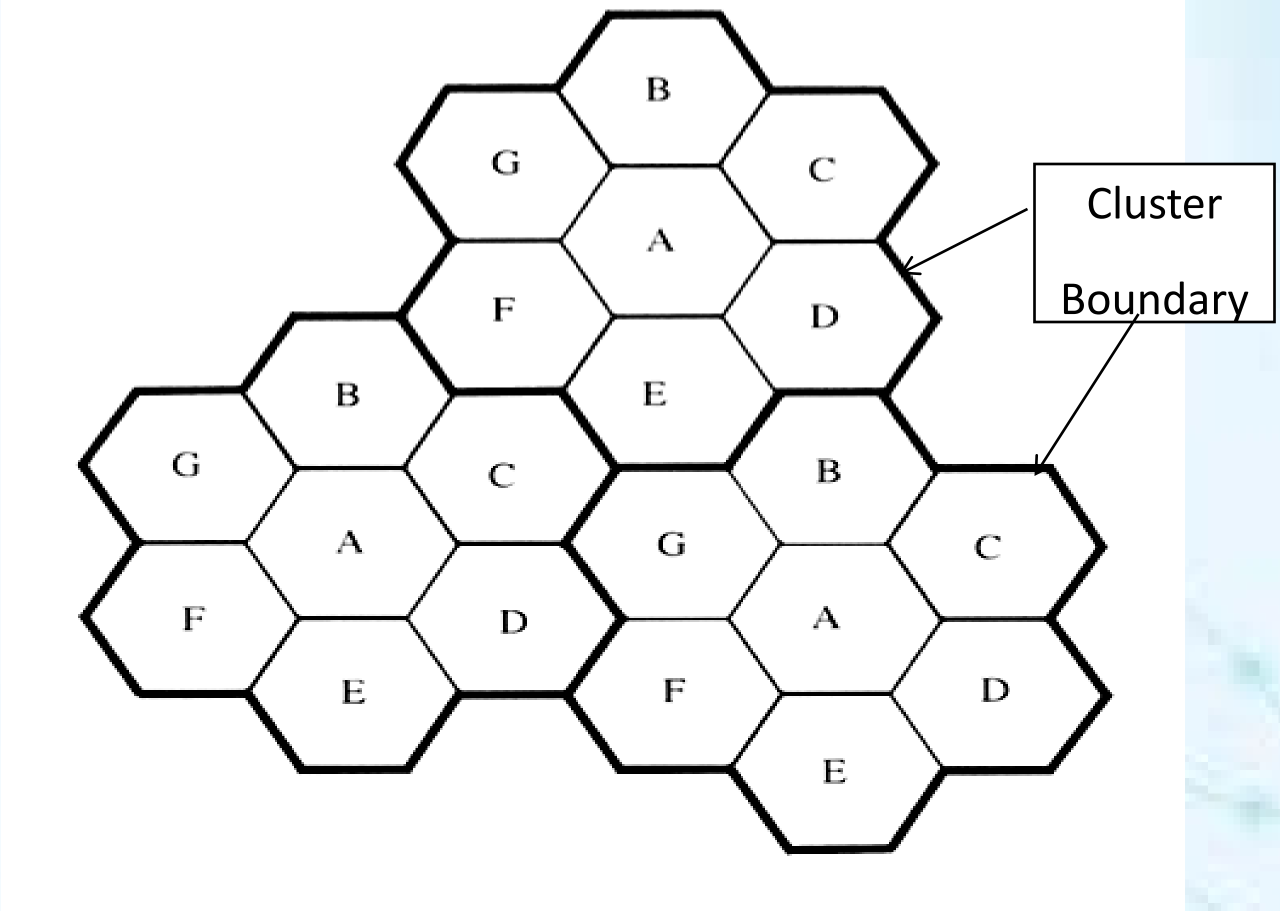
- The splitting up of channels is not random
- If “N” is the no of cells then it has to satisfy

$$N = i^2 + ij + j^2$$

i,j are non zero integers

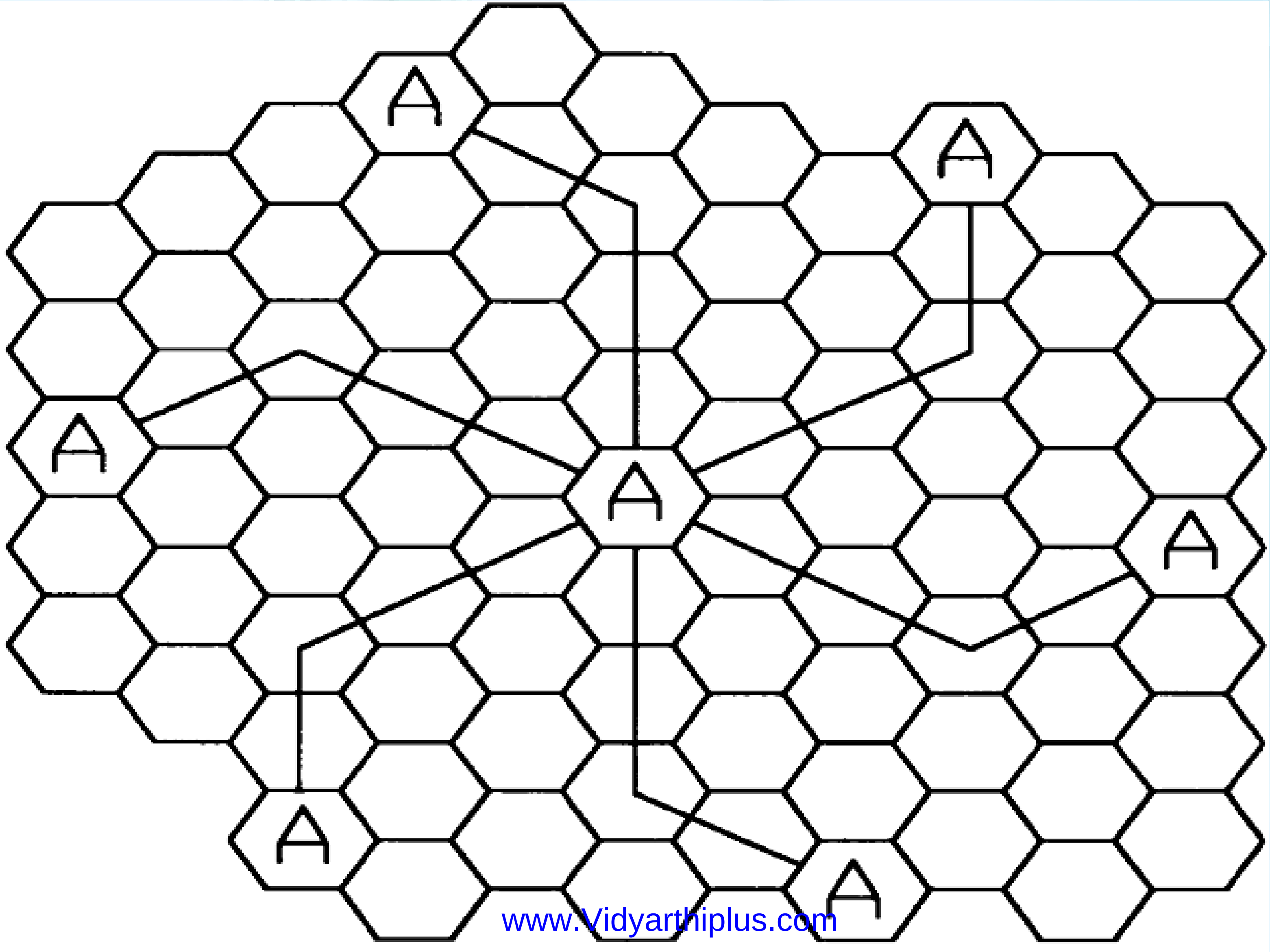
- Clusters are group of cells which share the entire spectrum

Illustration of 7-cell reuse concept



Cells with the same letter use the same set of frequencies

19- Cell Cluster



Handoff

- Process of transferring a moving active user from one base station to another without disrupting the call.

Handoff Strategies

1. Ist generation handoff
2. MAHO (Mobile Assisted HandOff)
3. Inter system handoff
4. Guard channel concept
5. Queuing
6. Umbrella approach
7. Soft and hard handoff
8. Cell dragging.

Ist generation handoff-

- In this almost all the work were carried out by MSC with the help of Base Station.
- Using the Locator Receiver the MSC will measure the signal strength of the moving mobile.
- If the level decreases it will perform handoff by its own.

MAHO (Mobile Assisted HandOff)

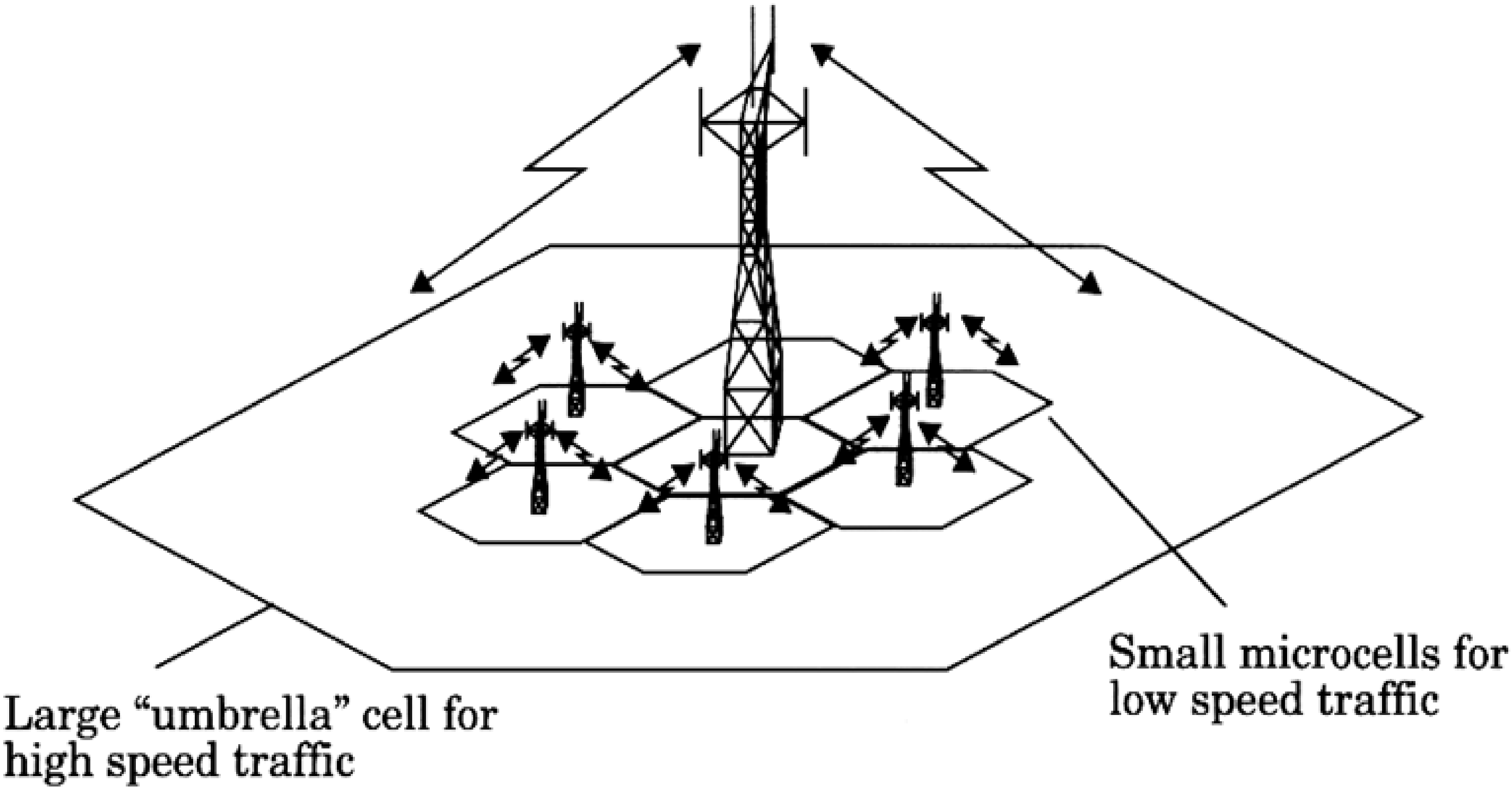
- In this every mobile station measures the received power from surrounding base stations and continually reports the results of these measurements to the serving base station.
- When the power received from the base station of a neighboring cell begins to exceed the power received from the current base station by a certain level or for a certain period of time a handoff is initiated.
- Since all the measurements were done by the mobile, the load of the MSC is reduced considerably

- <u>Inter system handoff</u> -occurs if a mobile moves from one cellular system to a different cellular system controlled by a different MSC (service provider) or while roaming
- <u>Guard channel concept</u> – In this some channels are reserved only for handoff.
- <u>Queuing</u> – If more number of users request handoff the they will be placed in queue before allotting channels

Umbrella approach

- Speed of the user is a main factor in deciding a successful handoff.
- In urban areas the cell size will be very small and high speed users will cross quickly.
- To perform handoff on these high speed users we use Micro and Macro cells concurrently.

Umbrella approach



Cell dragging

- Cell dragging occurs in an urban environment when there is a line-of-sight (LOS) radio path between the pedestrian subscriber and the base station.
- Even after the user has traveled well beyond the designed range of the cell, the received signal at the base station does not decay rapidly resulting in Cell Dragging

Soft and hard handoff

- Hard handoff- when the user moves to a new cell, he will be assigned with a new set of channels.
- Soft Handoff- when the user moves to a new cell, the channel itself will be switched to the new base station. CDMA uses soft Handoff.

Interference

- Co channel interference
- Adjacent channel interference

Co channel interference

- Cells that use the same set of frequencies. are called co-channel cells
- and the interference between signals from these cells is called co-channel inter-ference.
- To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

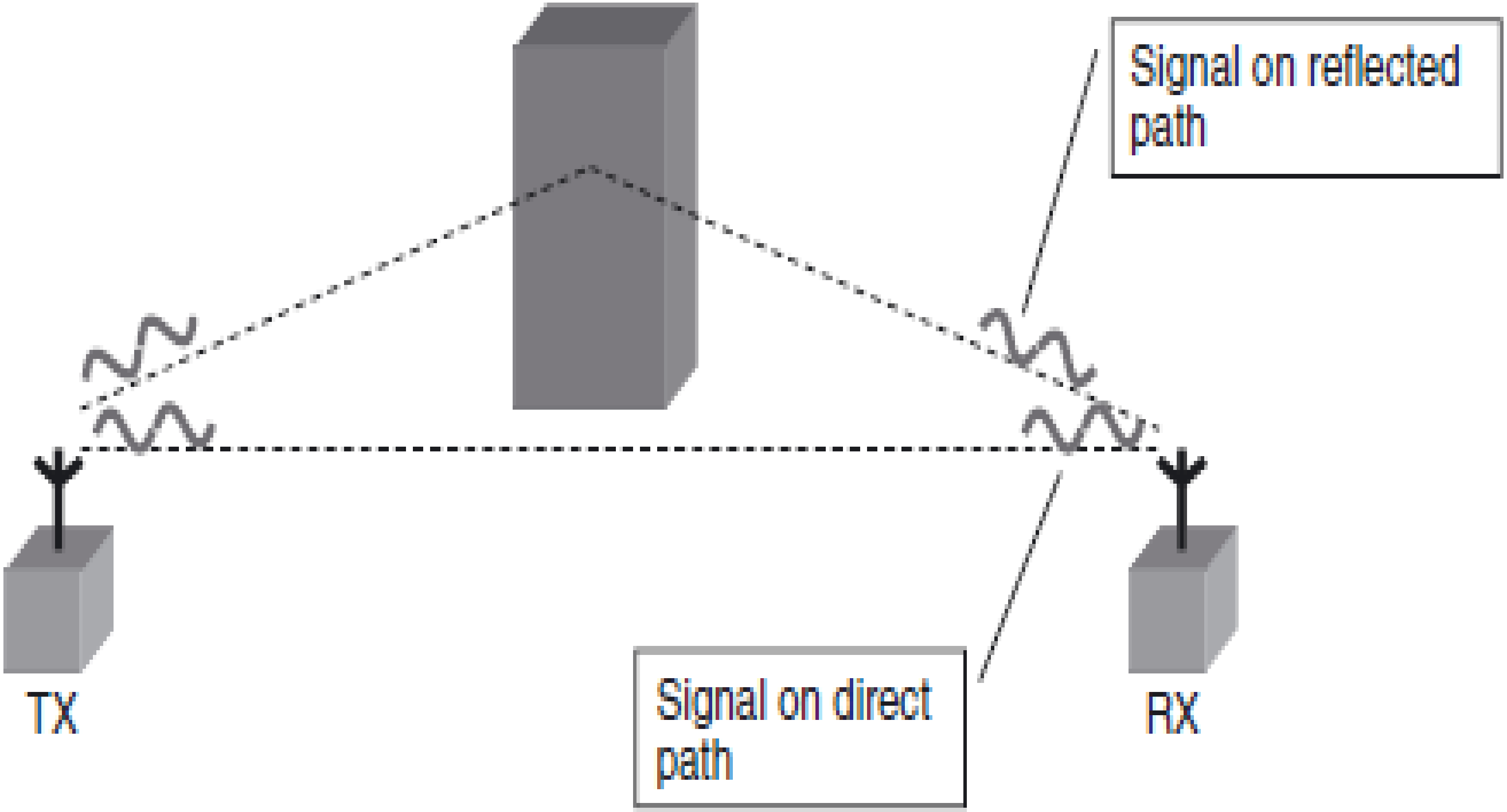
Adjacent channel interference

- Interference resulting from signals which are adjacent in frequency to the desired signal is called *adjacent channel interference.*
- Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the passband

- Adjacent channel interference can be minimized by keeping the frequency separation between each channel in a given cell as large as possible
- instead of assigning channels which form a contiguous band of frequencies to a particular cell, channels are allocated in a non sequential manner to have a sufficient separation .

Multipath Propagation

- Fading
- Intersymbol Interference


Signal on reflected path
Signal on direct path
TX
RX

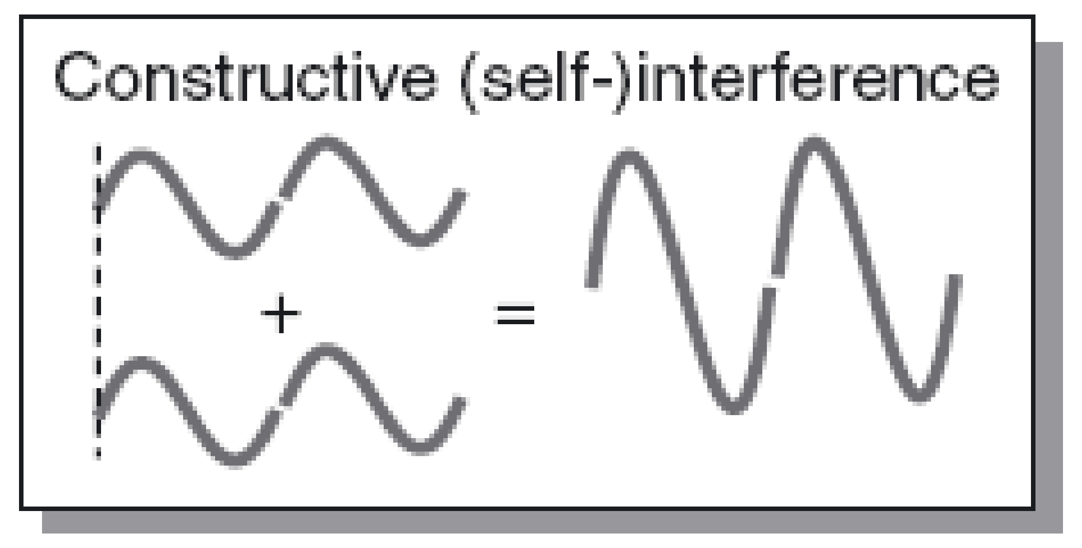
Fading

- Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times.
- These waves are called *multipath waves.*
- *They* combine at the receiver to give a resultant signal which can vary in amplitude and phase.

Types

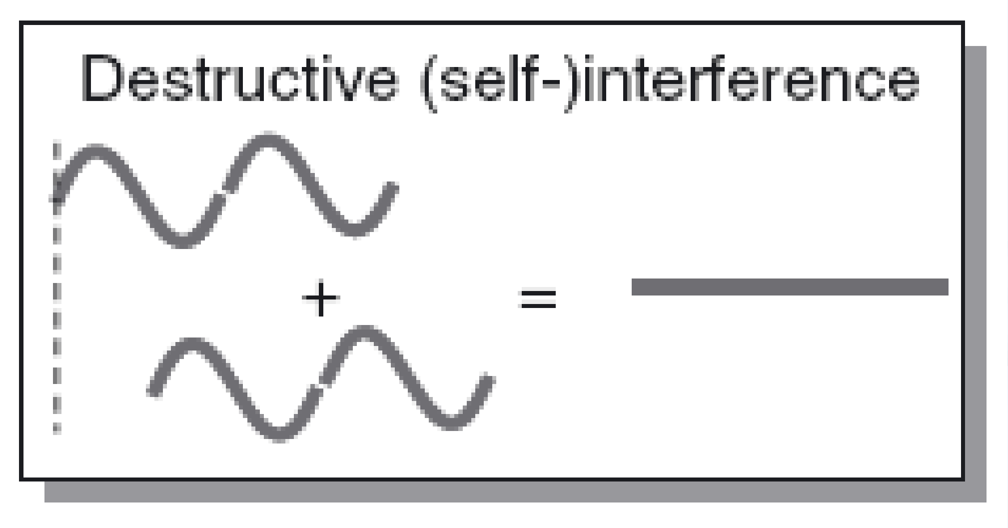
- Small scale fading - is the rapid fluctuation of the amplitude of a radio signal over a short period of time or distance.
- Large scale fading- is the fading associated with a larger coverage area for a long amount of time.

Constructive Interference



Amplitude gets boosted

Destructive Interference



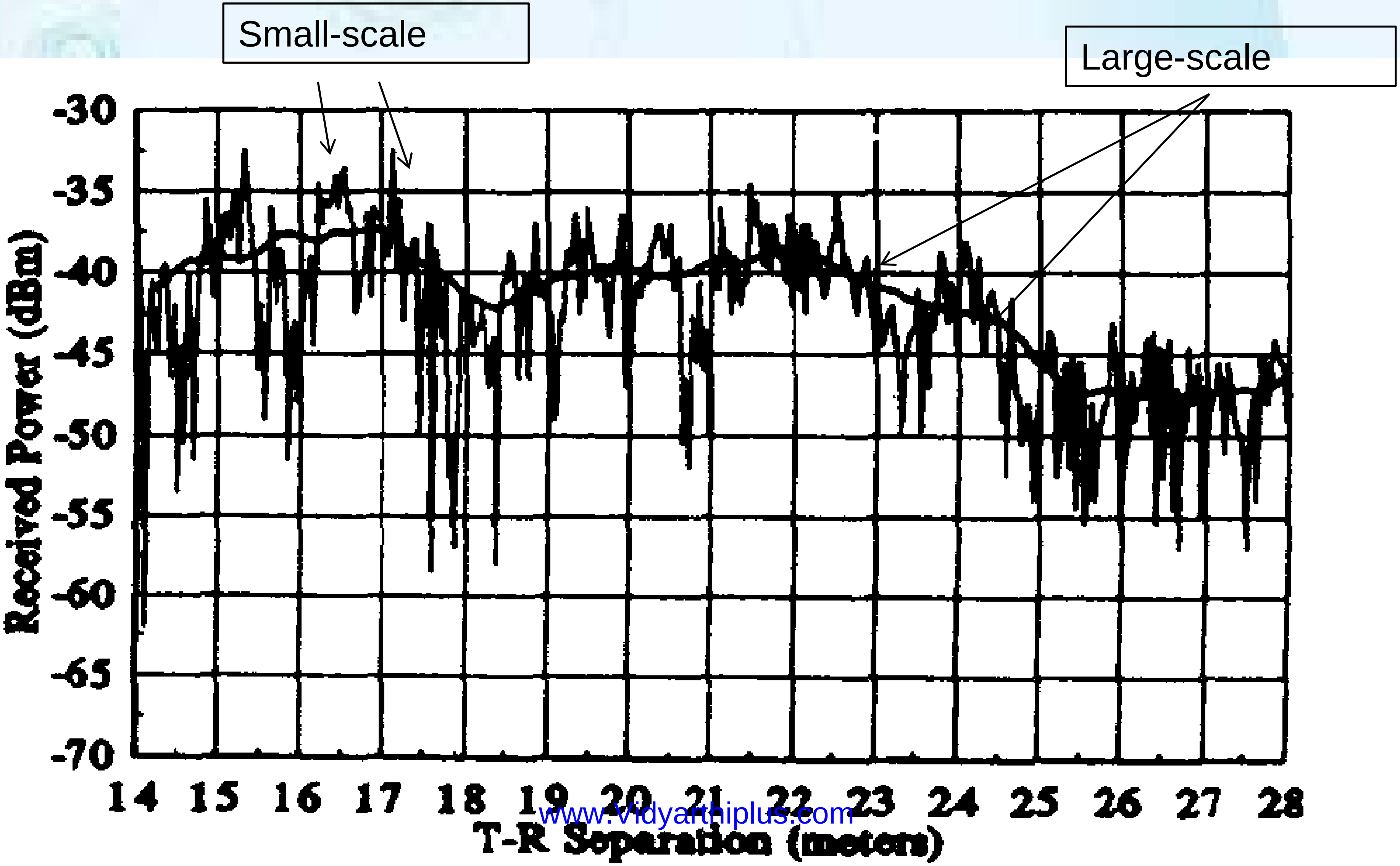
Amplitude reduces

Intersymbol Interference

- The signal dispersion leads to InterSymbol Interference
- Multipath waves play a major role in ISI

Noise Limited Systems

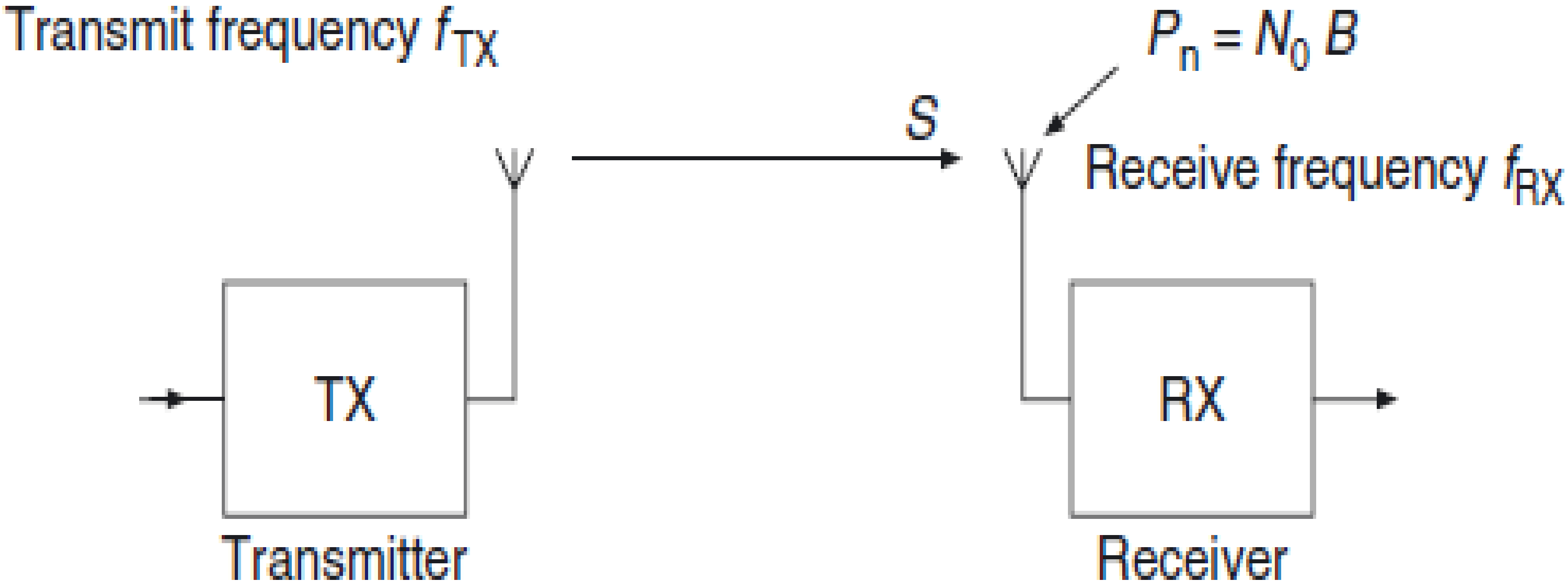
Small-scale & Large-scale fading



Small-scale

Large-scale

Typical system



Noise-limited systems.

- The power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance *d,* is given by the

Friis free space equation

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

where…

P_t → transmitted power,

$P_r(d)$ → received power from distance “d”

L → system loss factor

λ → wavelength in meters

G_t → transmitter antenna gain,

G_r → receiver antenna gain

Sources of noise

- **Thermal noise:** The noise generated by thermal agitation of electrons in a conductor.

Noise power $\boldsymbol{P_n = N_0 B}$

N_0 = Noise power spectral density

$\boldsymbol{N_0 = k_B \cdot Te}$

Boltzmann's constant $k_B = 1.38 \times 10^{-23}$ *J/K,*

Man-made noise

- Electrical appliances
- Car ignitions
- Other impulse sources emitting emi.
- Systems operating in unlicensed bands (2.45-ghz)

Receiver noise:

- This is associated with the receiver components.
- The amplifiers and mixers in the R_X are noisy
- For a digital system, the transmission quality is often described in terms of the *Bit Error Rate* (BER) probability

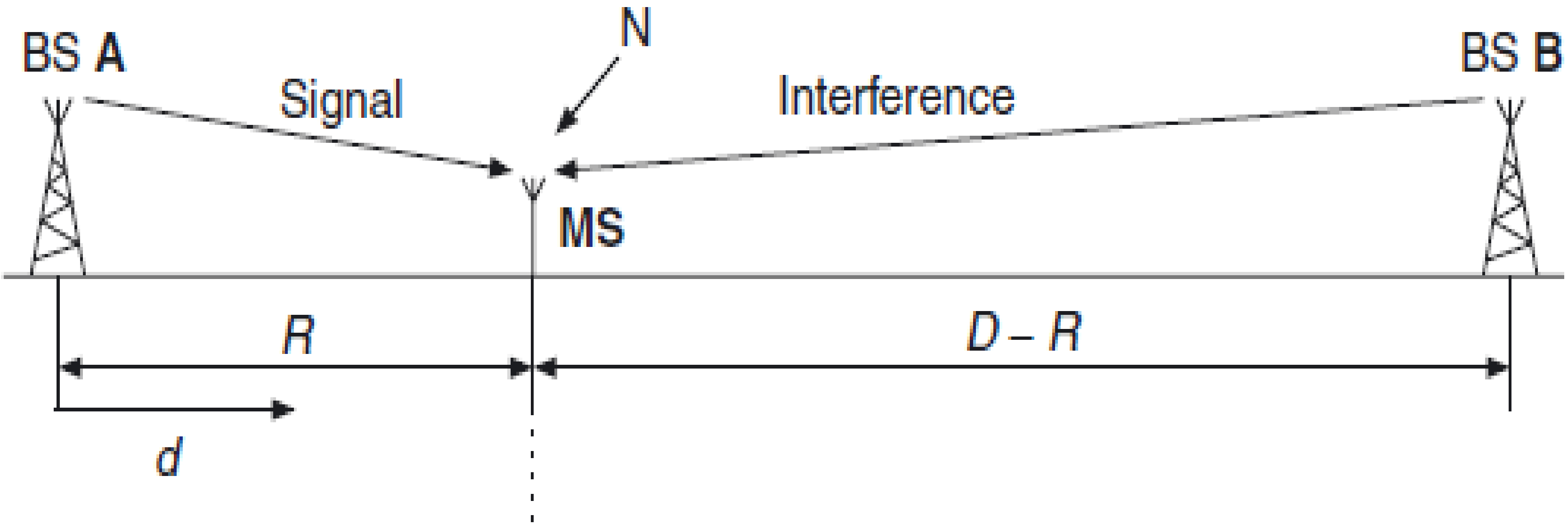
- The **bit error rate** or **bit error ratio** (**BER**) is the number of bit errors divided by the total number of transferred bits during a studied time interval.

- The **bit error probability** p_e is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability. This estimate is accurate for a long time interval and a high number of bit errors

Interference-Limited Systems

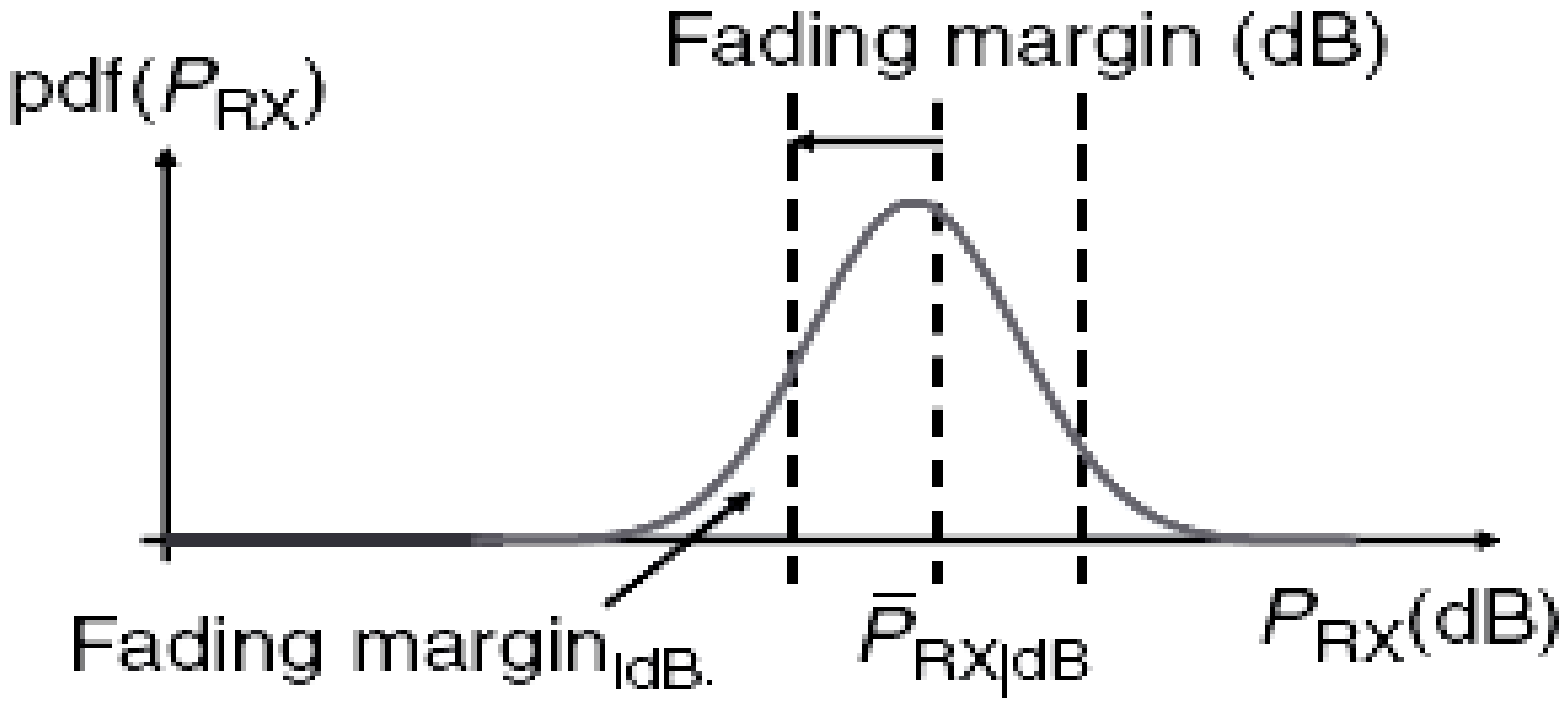
- Interference is a bigger issue than noise.
- Interference suffers from fading unlike noise.
- To have a good communication it is necessary to maintain good Signal-to-Interference ratio (SIR)

Interference-Limited Systems



- Interference happens when two cells having the same frequency are closer to each other
- And the MS is at the cell boundary.
- Interference is critical when the interfering signal is stronger than the desired signal

Fading Margin



Fading Margin

- The amount by which a received signal level may be reduced without causing system performance to fall below a specified threshold value.
- Normally it will be around 90% of the power.

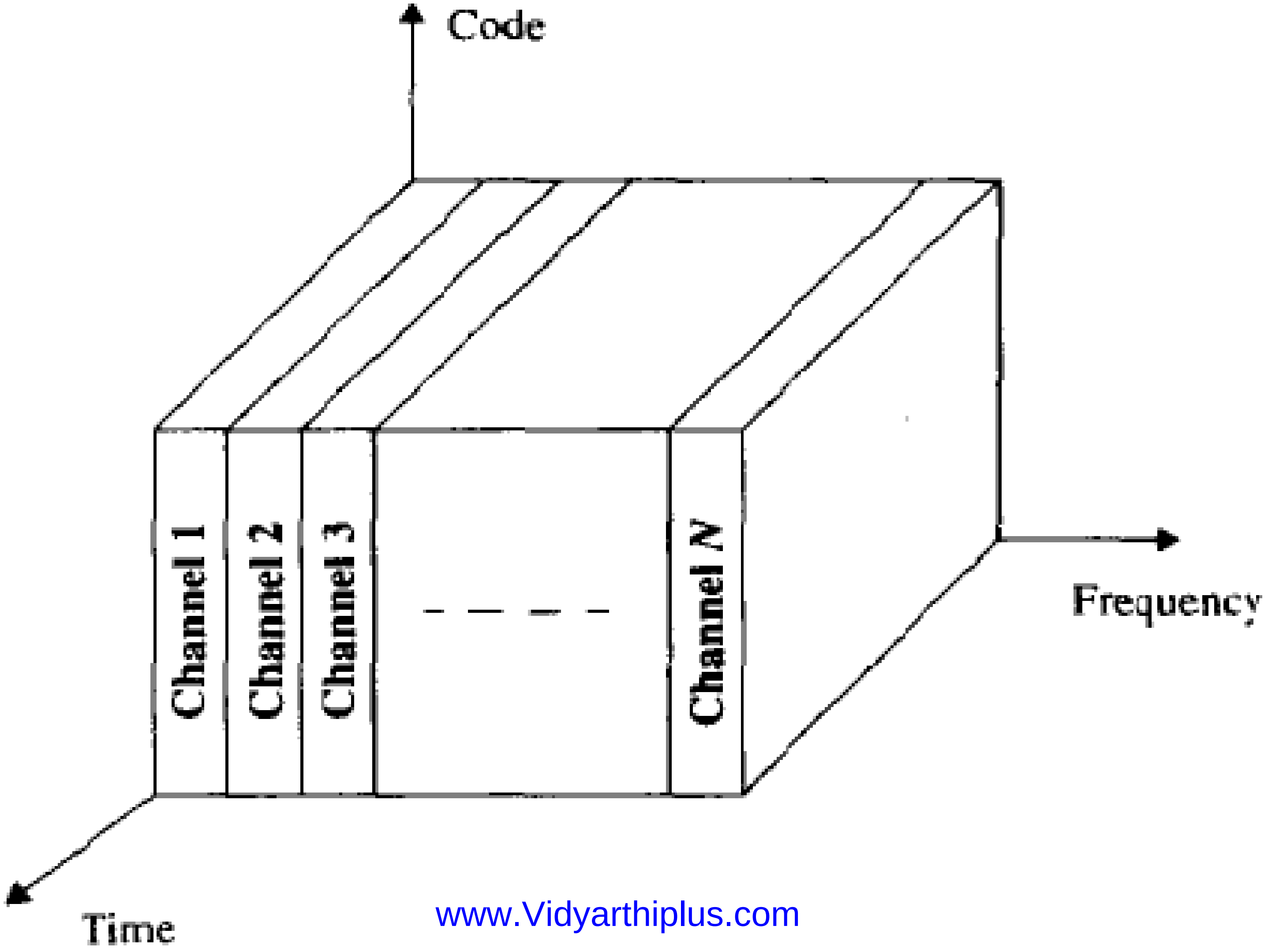
Multiple Access Techniques

- The available spectrum bandwidth for our wireless communication is limited.
- Multiple access techniques enable multiple signals to occupy a single communications channel.

Major Types

- Frequency division multiple access (FDMA)
- Time division multiple access (TDMA)
- Code division multiple access (CDMA)

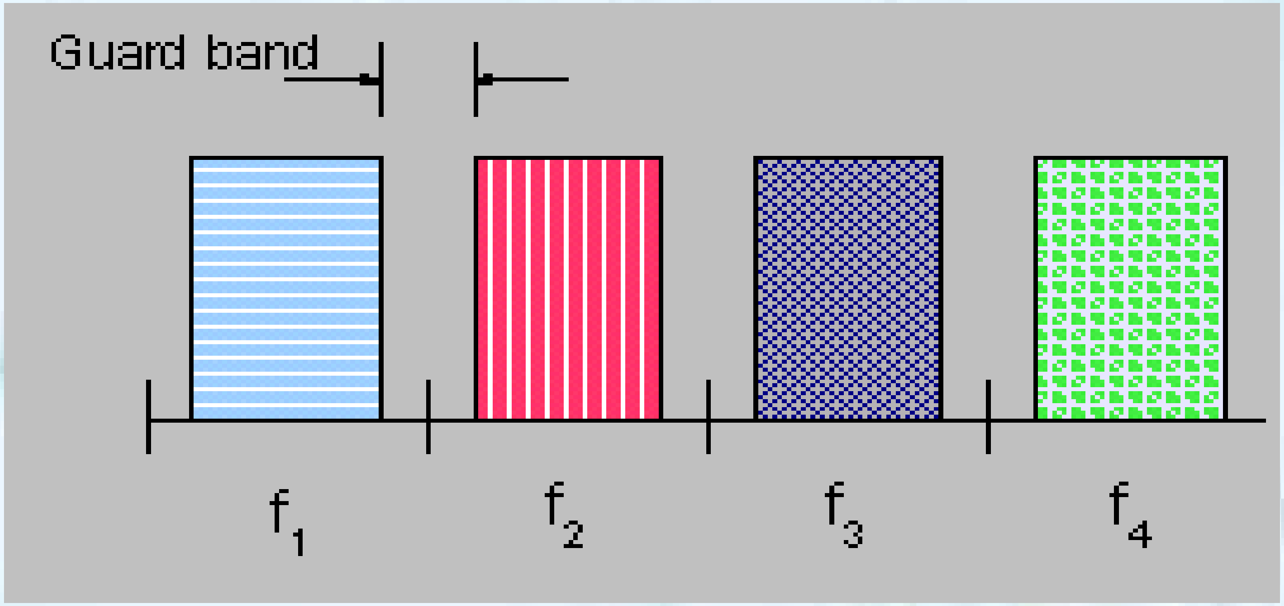
Frequency Division Multiple Access



Frequency Division Multiple Access

- It assigns individual frequency to individual users. (i.e) accommodates one user at a time.
- Each user is separated by Guard Bands.
- The complexity of FDMA mobile systems is lower when compared to TDMA systems

- A guardband is a narrow frequency band between adjacent frequency channels to avoid interference from the adjacent channels



- **The number of channels that can be simultaneously supported in a FDMA system is given by**

$$N = \frac{B_t - 2B_{guard}}{B_c}$$

- ***B_T* -> total spectrum allocation,**
- ***B_{GUARD}* -> the guard band**
- ***B_C* -> the channel bandwidth**

Key Features

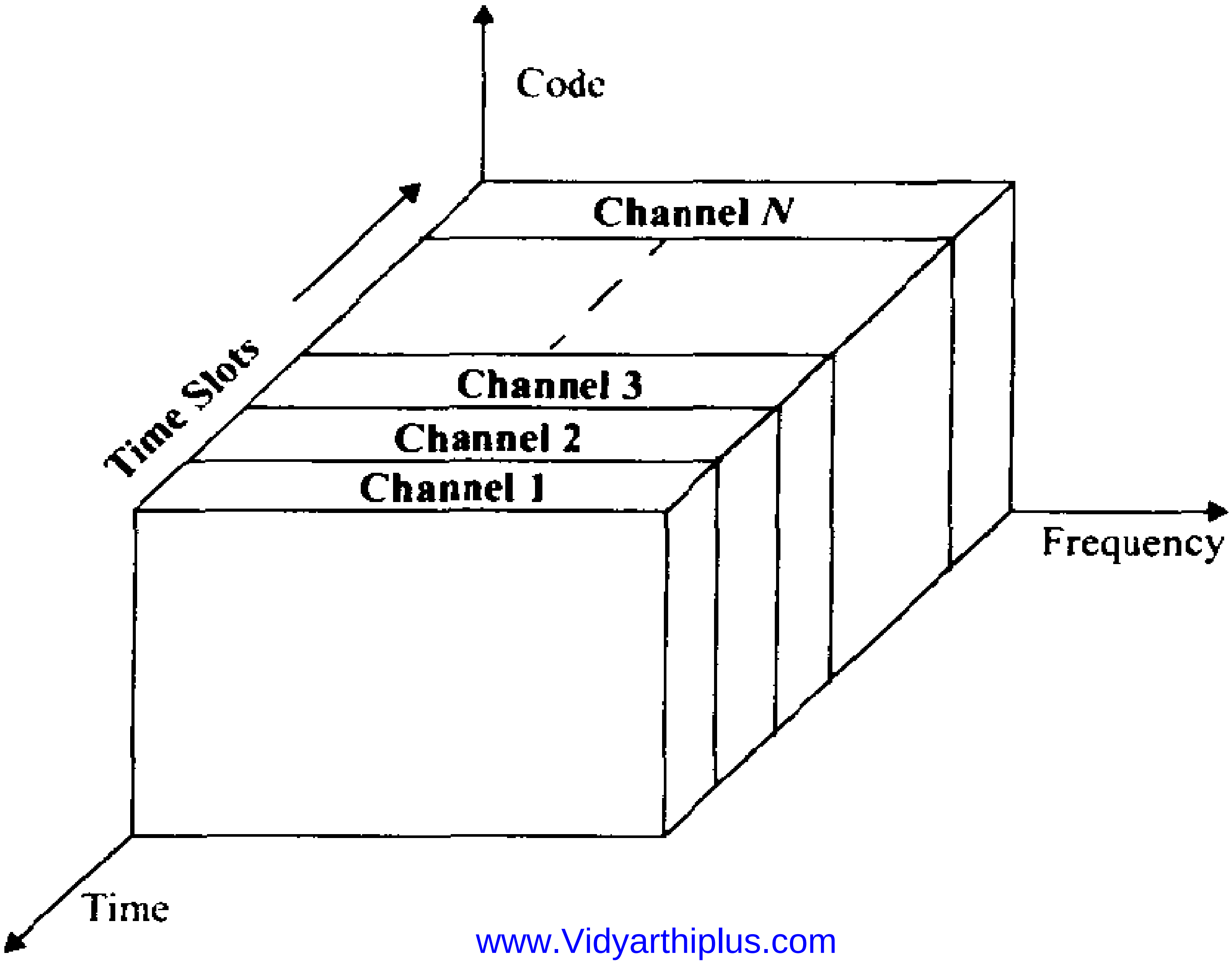
- If an FDMA channel is not in use, then it sits idle and cannot be used by other users
- The bandwidths of FDMA channels are narrow (30 kHz)
- Intersymbol interference is low
- It needs only a few synchronization bits

De Merits

- FDMA systems are costlier because of the single channel per carrier design,
- It need to use costly bandpass filters to eliminate spurious radiation at the base station.
- The FDMA mobile unit uses duplexers since both the transmitter and receiver operate at the same time. This results in an increase in the cost of FDMA subscriber units and base stations.
- FDMA requires tight RF filtering to minimize adjacent channel interference.

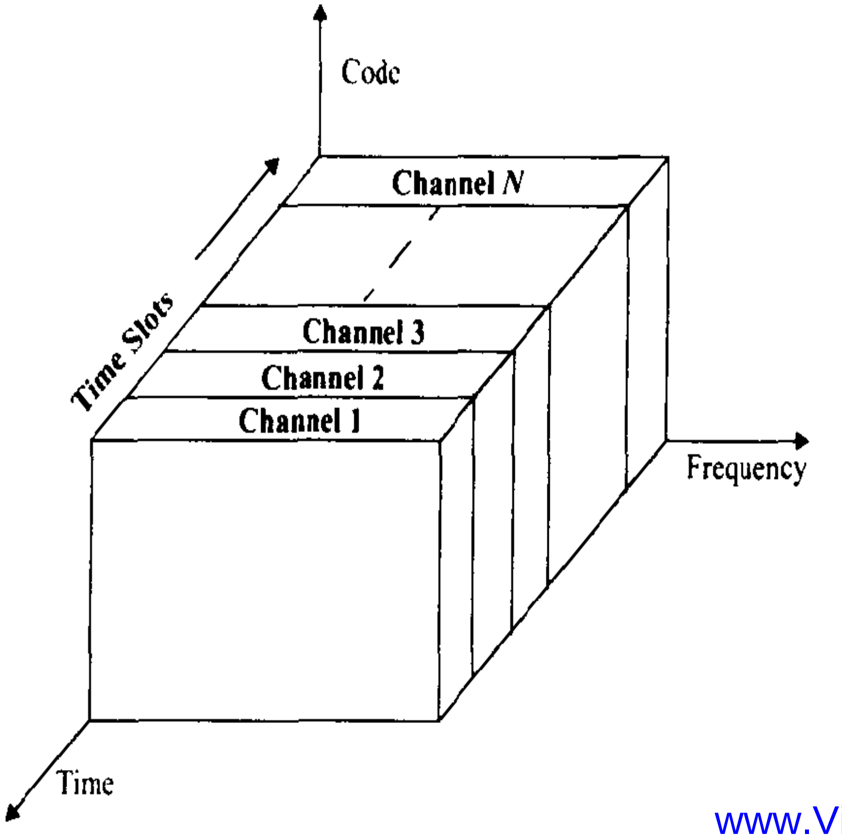
Time Division Multiple Access

Time division multiple access

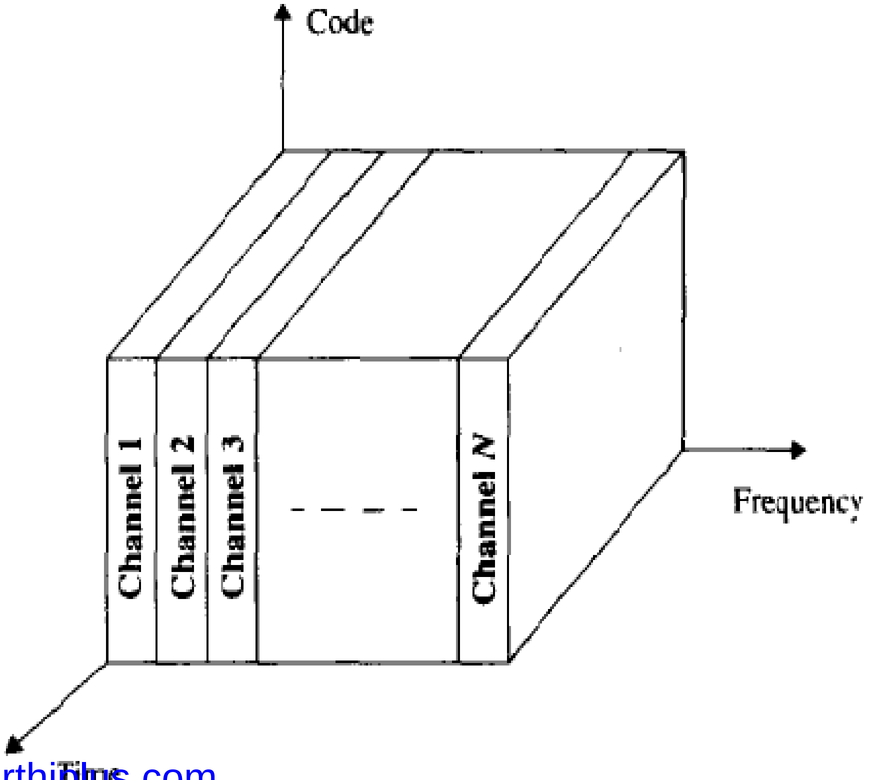


TDMA vs FDMA

TDMA



FDMA

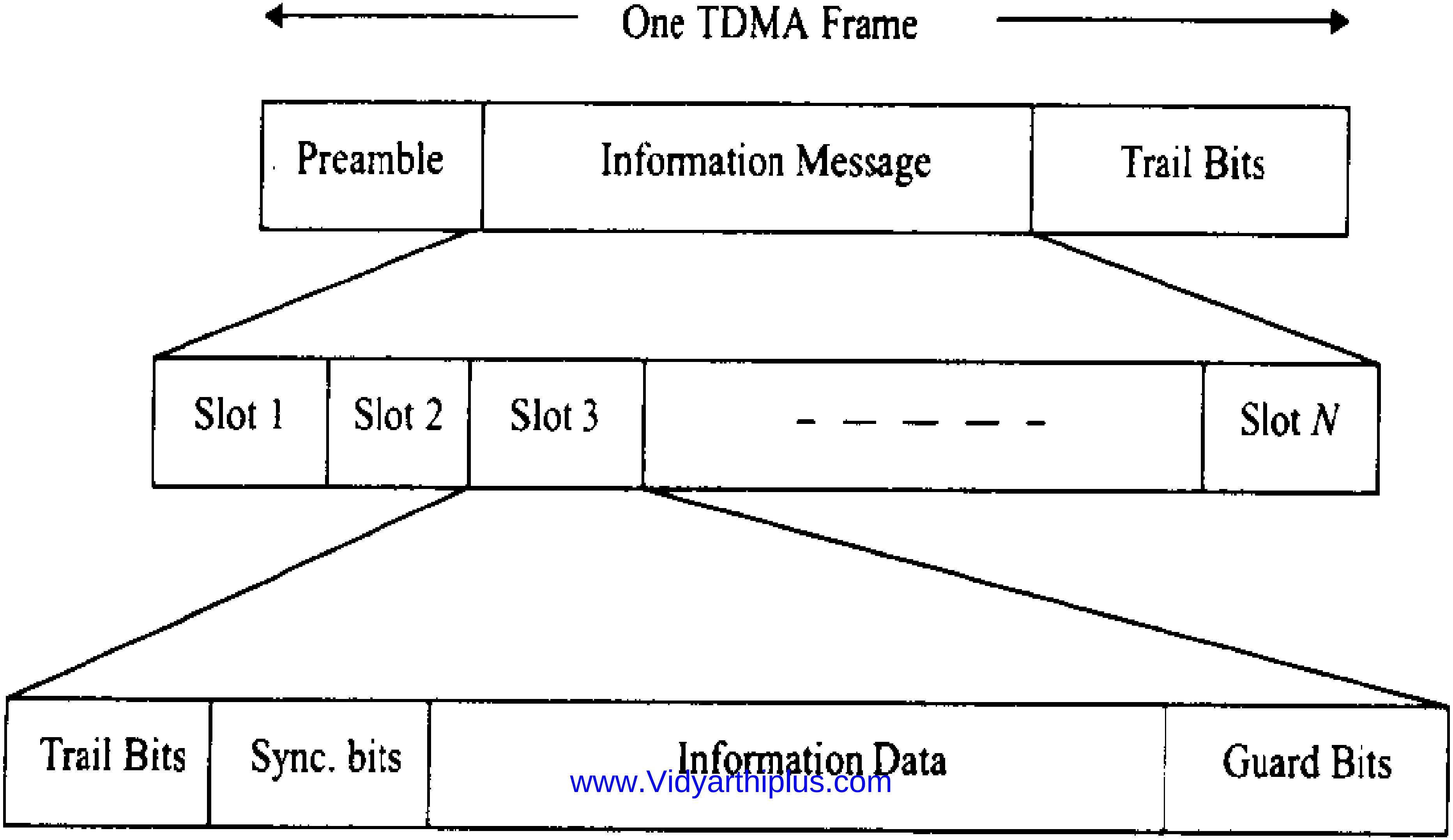


- Time division multiple access (TDMA) systems divide the radio spectrum into time slots
- Each user occupies a cyclically repeat-ing time slot
- A set of ‘N’ slots form a Frame.
- Each frame is made up of a preamble, an information message, and tail bits
- TDMA systems transmit data in a buffer-and-burst method

- TDMA shares a single carrier frequency with several users, where each user makes use of non-overlapping time slots
- TDMA uses different time slots for transmission and reception
- Adaptive equalization is usually necessary in TDMA systems, since the transmission rates are generally very high as compared to FDMA channels

- High synchronization overhead is required in TDMA systems because of burst transmissions
- Guard Bands are necessary to ensure that users at the edge of the band do not "bleed over" into an adjacent radio service.

Frame Structure



- The preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other.
- Trial bits specify the start of a data.
- Synchronization bits will intimate the receiver about the data transfer.
- Guard Bits are used for data isolation.

Efficiency of TDMA

- The efficiency of a TDMA system is a measure of the percentage of transmitted data that contains information as opposed to providing overhead for the access scheme

$$b_{0H} = N_r b_r + N_t b_p + N_t b_g + N_r b_g$$

where

b_{0H} – no over head bits per frame

b_r - no of overhead bits per

b_p - no overhead bits per preamble in each slot

b_g - no equivalent bits in each guard time interval

N_r - reference bursts per frame,

N_t- traffic bursts per frame

- The total number of bits per frame, b_T, is

$$b_T = T_f R$$

- T_f is the frame duration, and R is the channel bit rate
- Then the frame efficiency is

$$\eta_f = \left(1 - \frac{b_{OH}}{b_T}\right) \times 100\%$$

- And the no of frames

$$N = \frac{m\left(B_{tot} - 2B_{guard}\right)}{B_c}$$

m - maximum number of TDMA users supported on each radio channel

Spread spectrum multiple access (SSMA)

- *Frequency Hopped Multiple Access* (FHMA)
- *Direct Sequence Multiple Access* (DSMA)

Direct sequence multiple access is also called code division multiple access (CDMA).

Frequency Hopped Multiple Access

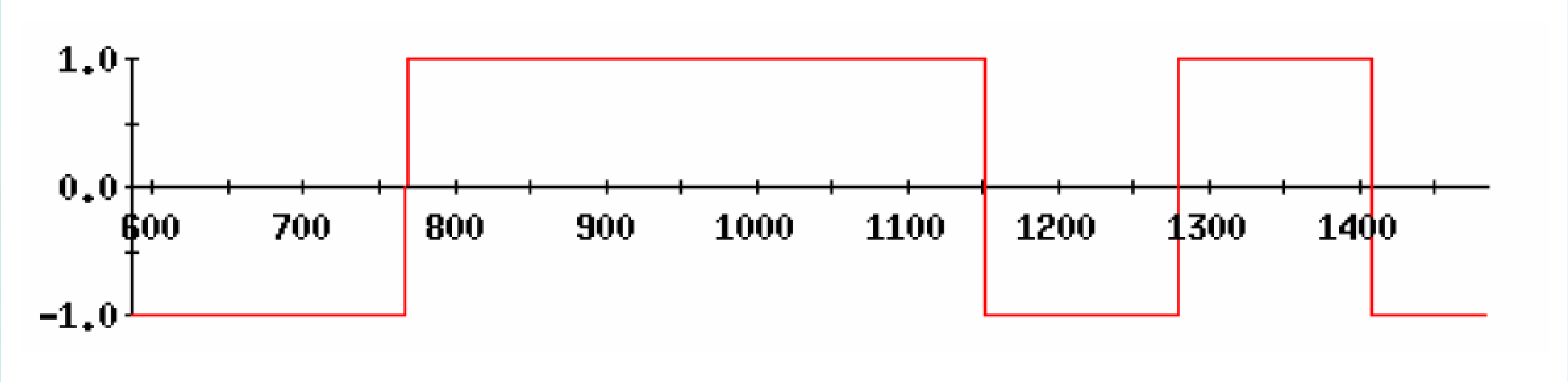
- The carrier frequencies of the individual users are varied in a pseudorandom fashion within a wideband channel
- The digital data is broken into uniform sized bursts which are transmitted on different carrier frequencies

- <u>Fast Frequency Hopping System </u>-> the rate of change of the carrier frequency is greater than the symbol rate
- <u>Slow Frequency Hopping -></u> the channel changes at a rate less than or equal to the symbol rate

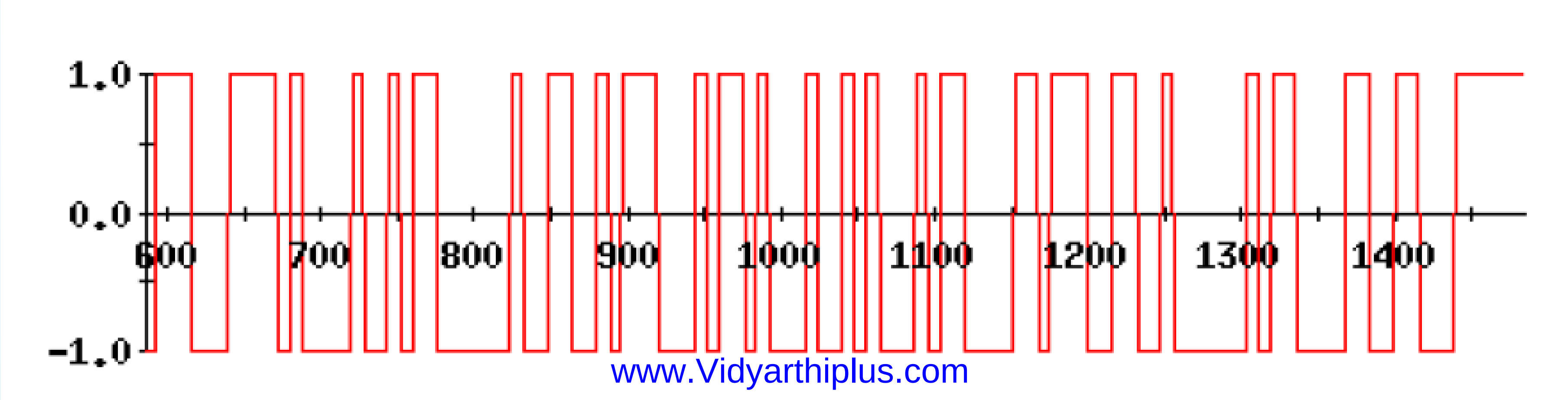
Code Division Multiple Access (CDMA)

- The narrowband message signal is multiplied by a very large bandwidth signal called the spreading signal (pseudo-noise code)
- The chip rate of the pseudo-noise code is much more than message signal.
- Each user has its own pseudorandom codeword.

Message



PN sequence



- CDMA uses CO-Channel Cells
- All the users use the same carrier frequency and may transmit simultaneously without any knowledge of others.
- The receiver performs a time correlation operation to detect only the specific desired codeword.
- All other code words appear as noise

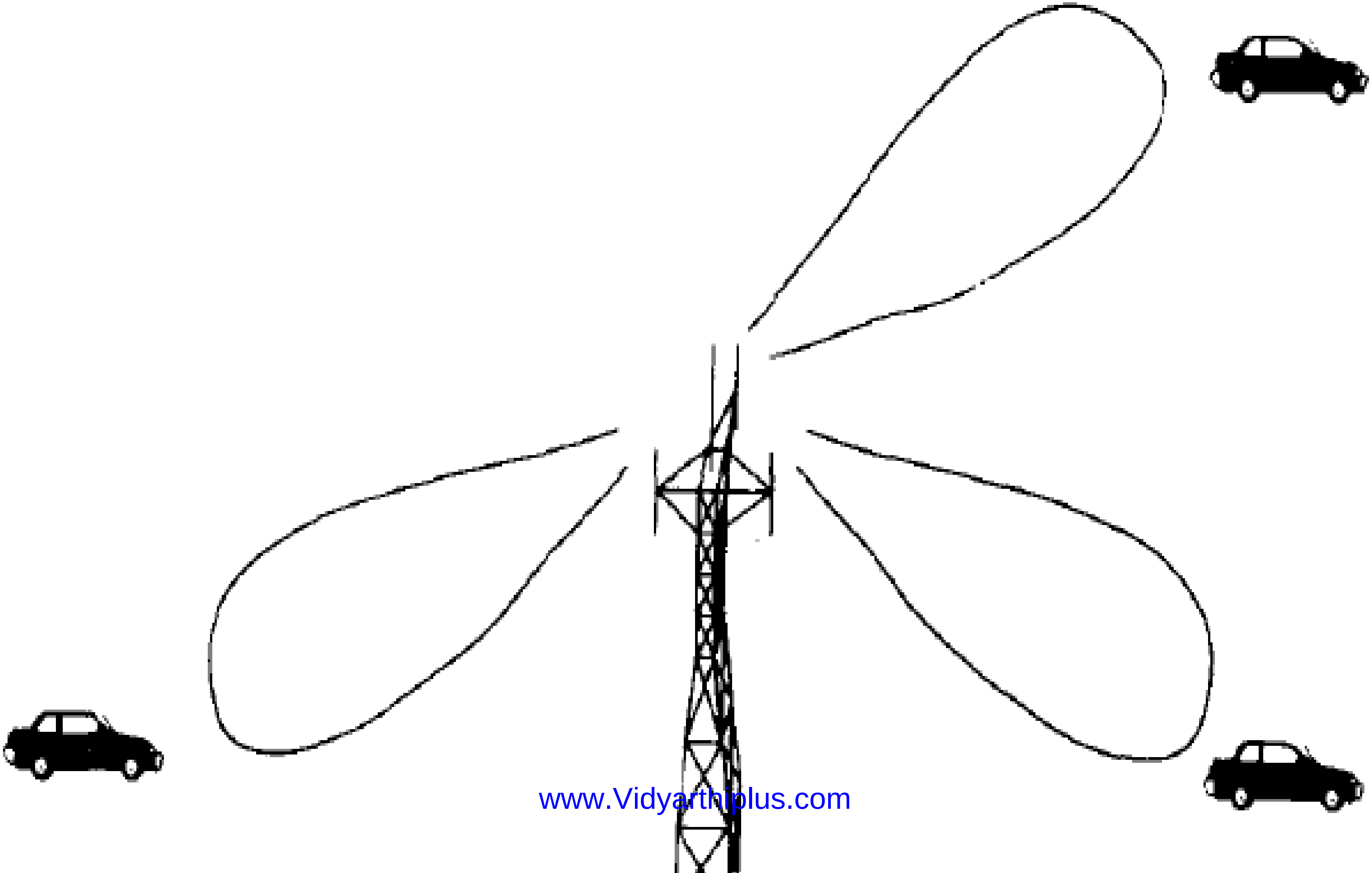
- Multipath fading may be substantially reduced because the signal is spread over a large spectrum
- Channel data rates are very high in CDMA systems
- CDMA supports Soft handoff MSC can simultaneously monitor a particular user from two or more base stations. The MSC may chose the best version of the signal at any time without switching frequencies.

- In CDMA, the power of multiple users at a receiver determines the noise floor.
- In CDMA, stronger received signal levels raise the noise floor at the base station demodulators for the weaker signals, thereby decreasing the probability that weaker signals will be received. This is called Near- Far problem.
- To combat the Near- Far problem, power control is used in most CDMA

Space division multiple access (SDMA)

- It controls the radiated energy for each user in space.
- Traditional single omnidirectional antennas are replaced by many small directional antennas for specific users.
- It is done by Phased Array Antennas.
- This will track users by their location

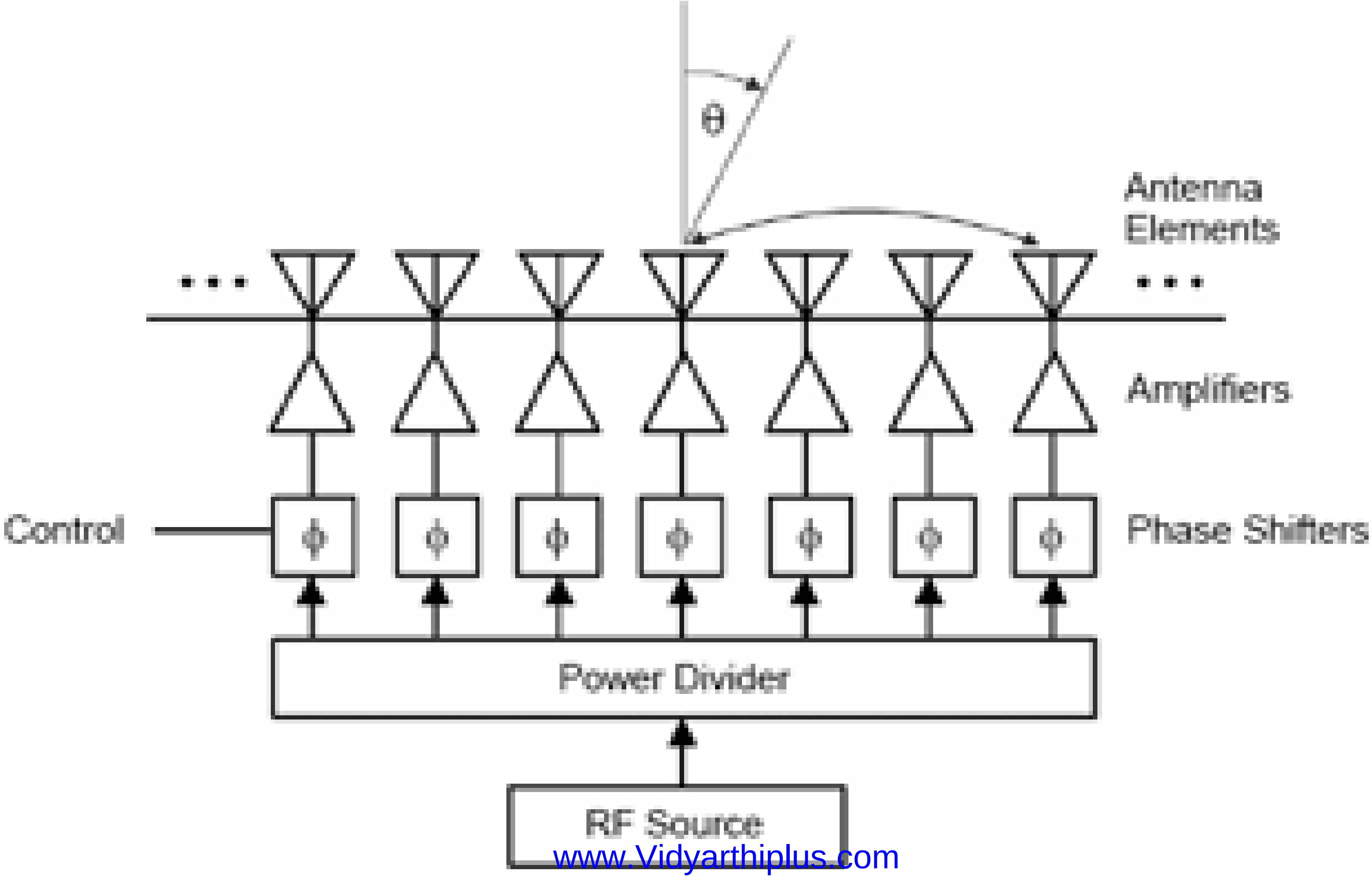
Space division multiple access (SDMA)



Phased array

- Phased array is a group of antennas in which the relative phases of the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions

Phased array



WIRELESS COMMUNICATION

UNIT II

WIRELESS PROPAGATION CHANNELS

Propagation Mechanisms (Qualitative treatment), Propagation effects with mobile radio, Channel Classification, Link calculations, Narrowband and Wideband models

PROPAGATION MECHANISMS

- The radio path between the user and base station is not free from obstacles.
- We won’t get Line of sight with BS very often.
- So the signal propagation in a coverage area is always random.
- Hence to study the propagation pattern we need some prediction tools.
- In this section we will study some prediction models, which will give an estimate of the signal strength

Propagation models predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance

Classification

1. Large-scale propagation models
2. Small-scale propagation models

Large-scale propagation models

- Large scale propagation models predict the mean signal strength over large Transmitter(T_x)-Receiver(R_x) separation distances (several hundreds or thousands of meters)

Small-scale propagation models

- Small-scale propagation models deals with the rapid fluctuations of the received signal strength over very short travel distances (a few wavelengths) or short time durations (on the order of seconds)

Free Space propagation model

- The free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear line-of-sight path between them.

Free Space propagation model

- An isotropic radiator is an ideal antenna which radiates power with unit gain uniformly in all directions, and is often used to reference antenna gains in wireless systems. The effective isotropic radiated power (EIRP) is defined as

$$EIRP = P_t G_t$$

- But in practice, effective radiated power (ERP) is used instead of EIRP

- The free space power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance *d,* is given by the Friis free space equation…

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

where…

P_t → transmitted power,

$P_r(d)$ → received power from distance “d”

L → system loss factor

λ → wavelength in meters

G_t → transmitter antenna gain,

G_r → receiver antenna gain

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

A_e → effective aperture.

- The validity of Friis’ law is restricted to the far field of the antenna or *Fraunhofer region*

far-field distance d_f *is*

$$d_f = \frac{2D^2}{\lambda}$$

D- largest physical linear dimension of the antenna

the far field requires $d > \lambda$ *and* $d >> D$

- The *path loss* is defined as the difference (in dB) between the effective transmitted power and the received power.

$$PL\,(dB) = 10 \log P_t - 10 \log P_r$$

$$PL\,(\mathrm{dB}) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right]$$

If the antennas are assumed to have unity gain

$$PL\,(\mathrm{dB}) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right]$$

- *Considering* $\boldsymbol{d_0}$ as a known received power reference point, the received power, $P_r(d)$, at any distance **d>** $\boldsymbol{d_0}$ *is*

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^2$$

- The reference distance d_0 for practical systems is typically chosen to be ***1 m*** in indoor environments and ***100 m or 1 km*** in outdoor environments

- The P_r from the above expression will be a large value so for our convenience it can be represented in dBm(measured power referenced to one milliwatt (mW) …

$$P_r(d)\ \mathrm{dBm} = 10\log\left[\frac{P_r(d_0)}{0.001\ \mathrm{W}}\right] + 20\log\left(\frac{d_0}{d}\right)$$

Large scale Propagation

- In practice the path for radio propagation is not so smooth.
- When a radio wave propagating in one medium impinges upon another medium having different electrical properties, the wave is partially reflected and partially transmitted.

Factors Influencing Propagation

- Reflection
- Diffraction
- Scattering

Reflection

- Reflection occurs when a propagating electromagnetic wave impinges upon an object which has very large dimensions when compared to the wavelength of the propagating wave. Reflections occur from the surface of the earth and from buildings.

Diffraction

- Bending of waves around the edges of an obstacle is called diffraction.
- It occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp edges.

Scattering

- Scattering is caused by objects with small dimensions compared to the wavelength.
- Street lamps, Vehicles and other small objects will cause scattering

Reflection

- If the second medium is a **perfect conductor**, then all incident energy is reflected back into the first medium without loss of energy.
- When a radio wave propagating impinges on a **perfect dielectric**, part of the energy is transmitted into the second medium and part of the energy is reflected back into the first medium, and there is no loss of energy in absorption.

- The electric field intensity of the reflected and transmitted waves may be related to the incident wave in the medium of origin through the *Fresnel reflection coefficient* (Γ).
- The reflection coefficient is a function of the material properties, and generally depends on the wave polarization, angle of incidence, and the frequency of the propagating wave.

Reflection Co-Efficient (Γ)

$E_r = \Gamma \, . \, E_i$

$$\Gamma_{\parallel} = \frac{-\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}}{\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}}$$

(E-field in plane of incidence)

$$\Gamma_{\perp} = \frac{\sin\theta_i - \sqrt{\varepsilon_r - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}}$$

(E-field not in plane of incidence)

- When a wave passes through an interface between two materials at an oblique angle, and the materials have different indices of refraction, both reflected and refracted waves are produced.
- For a lossless medium angle of incidence is equal to angle of reflection

$$\theta_i = \theta_r$$

$$\varepsilon = \varepsilon_0 \varepsilon_r$$

- For a lossy dielectric medium

$$\varepsilon = \varepsilon_0 \varepsilon_r - j\varepsilon'$$

$$\varepsilon' = \frac{\sigma}{2\pi f}$$

Brewster Angle

- The Brewster angle is the angle at which no reflection occurs in the medium of origin. It occurs when the incident angle ϑ_B is such that the reflection coefficient ($\Gamma_{||}$) is equal to zero.

$$\sin(\theta_B) = \sqrt{\frac{\varepsilon_1}{\varepsilon_1 + \varepsilon_2}}$$

………..

- When the first medium is free space and the second medium has a relative permittivity ε_r

$$\sin(\theta_B) = \frac{\sqrt{\varepsilon_r - 1}}{\sqrt{\varepsilon_r^2 - 1}}$$

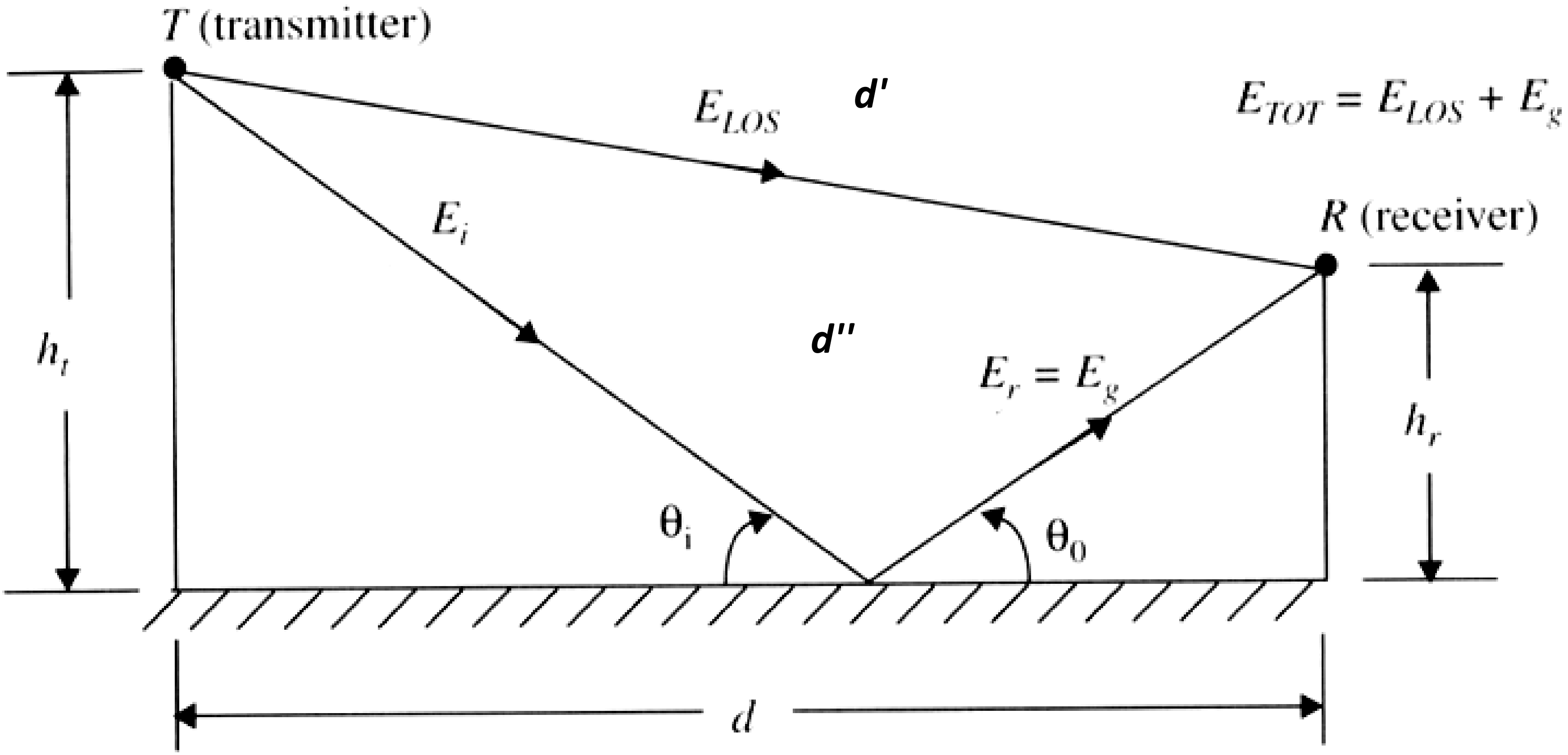
Snell’s Law

- According to Snell’s law, for a perfect conductor angle of incidence is equal to angle of reflection

$$\theta_i = \theta_r$$

GROUND REFLECTION (2-RAY) MODEL

Ground Reflection (2-ray) Model



- This model considers both the direct path and a ground reflected propagation path between transmitter and receiver.
- This model is used for predicting the large-scale signal strength over distances of several kilometers for mobile radio systems

$$E_{TOT} = E_{LOS} + E_g$$

- *Let* E_0 is the free space E-field (V/m) at a reference distance d_0 from the transmitter, then for $d > d_0$

$$E(d,t) = \frac{E_0 d_0}{d}\cos\left(\omega_c\left(t - \frac{d}{c}\right)\right) \qquad (d > d_0)$$

$$|E(d,t)| = \frac{E_0 d_0}{d}$$

Two waves arrive at the receiver:

1. The direct wave that travels a distance *d*'
2. The reflected wave that travels a distance *d*".

then ,

The E-field due to Line of Sight component

$$E_{LOS}(d',t) = \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right)$$

The E-field due to Ground reflected component

$$E_g(d'',t) = \Gamma \frac{E_0 d_0}{d''} \cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

where Γ = reflection coefficient for ground

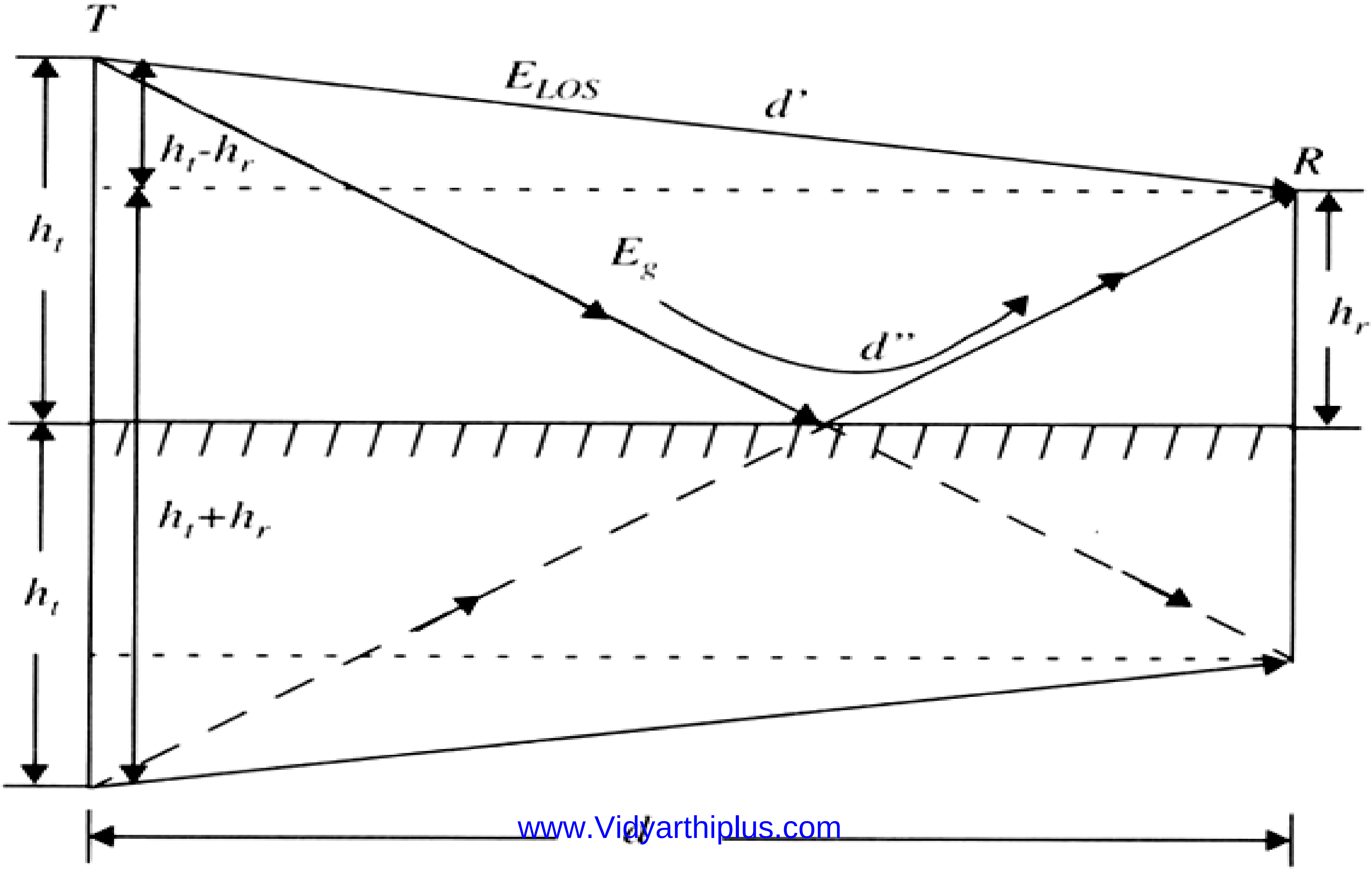
For a perfect reflected wave Γ= -1

(i.e) reflected wave is equal in magnitude and 180° out of phase with the incident wave

$$|\boldsymbol{E_{TOT}}| = |\boldsymbol{E_{LOS} + E_g}|$$

$$E_{TOT}(d,t) = \frac{E_0 d_0}{d'}\cos\left(\omega_c\left(t-\frac{d'}{c}\right)\right) + (-1)\frac{E_0 d_0}{d''}\cos\left(\omega_c\left(t-\frac{d''}{c}\right)\right)$$

Method of Images to find Δ = d“- d‘



$$\Delta = d'' - d' = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$$

when the T-R separation distance *d* is very large compared to $h_t + h_r$, Using Taylor’s approximation

$$\Delta = d'' - d' \approx \frac{2h_t h_r}{d}$$

the phase difference $\vartheta_\Delta = \frac{2\pi\Delta}{\lambda} = \frac{\Delta\omega_c}{c}$

the time delay $T_d = \frac{\Delta}{c} = \frac{\theta_\Delta}{2\pi f_c}$

- *When d* becomes large, the difference between the dis-tances *d’* and *d"* becomes very small, and the amplitudes of E_{LOS} and E_g are virtually identical and differ only in phase.

$$\left|\frac{E_0 d_0}{d}\right| \approx \left|\frac{E_0 d_0}{d'}\right| \approx \left|\frac{E_0 d_0}{d''}\right|$$

Taylor Series

$$P_k(x) = f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \cdots + \frac{f^{(k)}(a)}{k!}(x-a)^k$$

- Final expression

$$E_{TOT}(d) \approx \frac{2E_0 d_0}{d} \frac{2\pi h_t h_r}{\lambda d} \approx \frac{k}{d^2} \text{ V/m}$$

where k is a constant related to Antenna Height

- Now the received power is

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

- $PL(\text{dB}) = 40\log d - (10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r)$

Diffraction
&
Knife-edge Diffraction Model

Diffraction

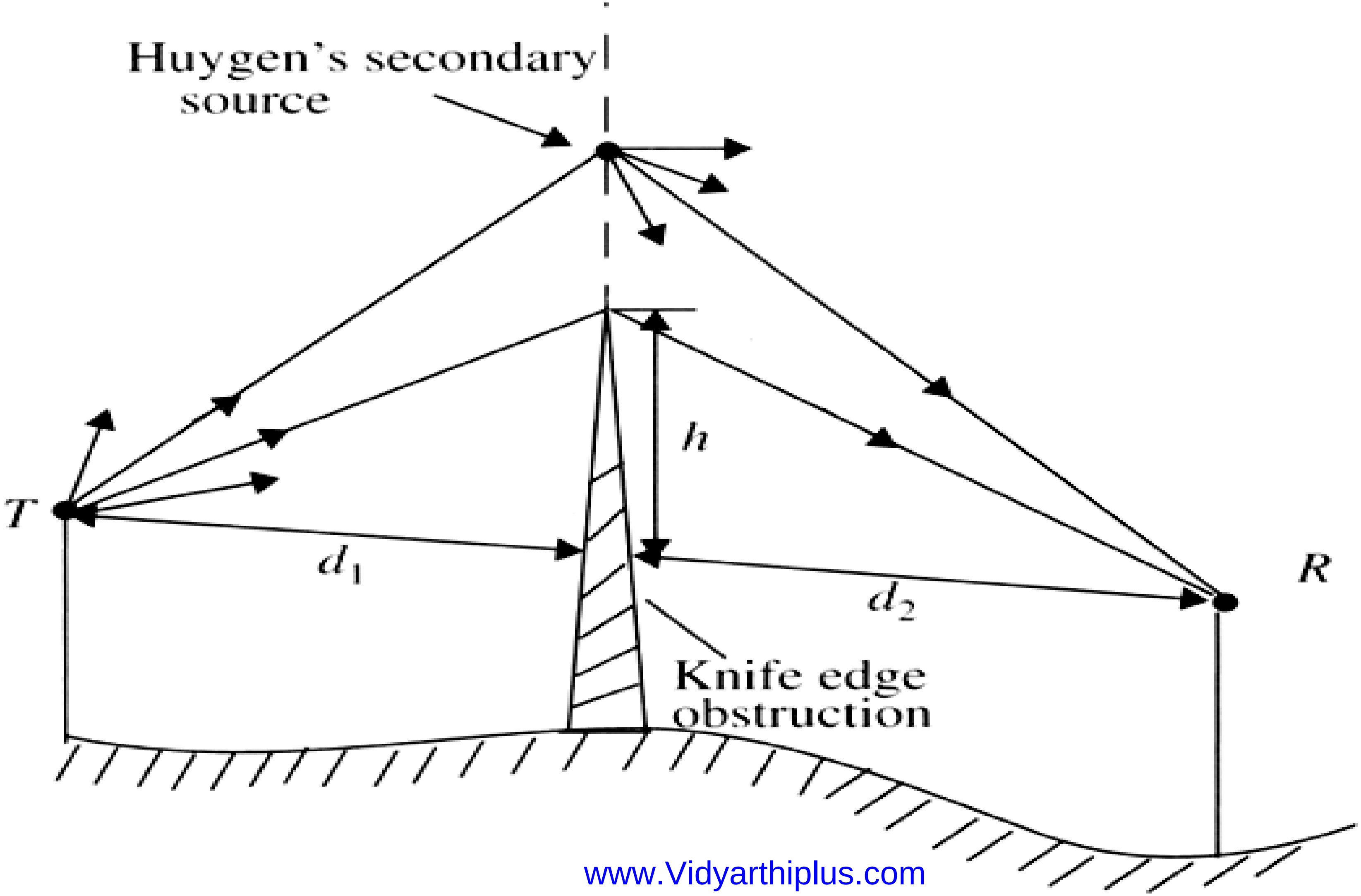
- Bending of waves around the edges of an obstacle is called diffraction.
- Diffraction allows radio signals to propagate around the curved surface and to propagate behind obstructions.
- The received field strength decreases rapidly as a receiver moves deeper into the shadowed region.
- Diffraction can be explained by Huygens principle & Fresnel’s Geometry.

Huygens principle

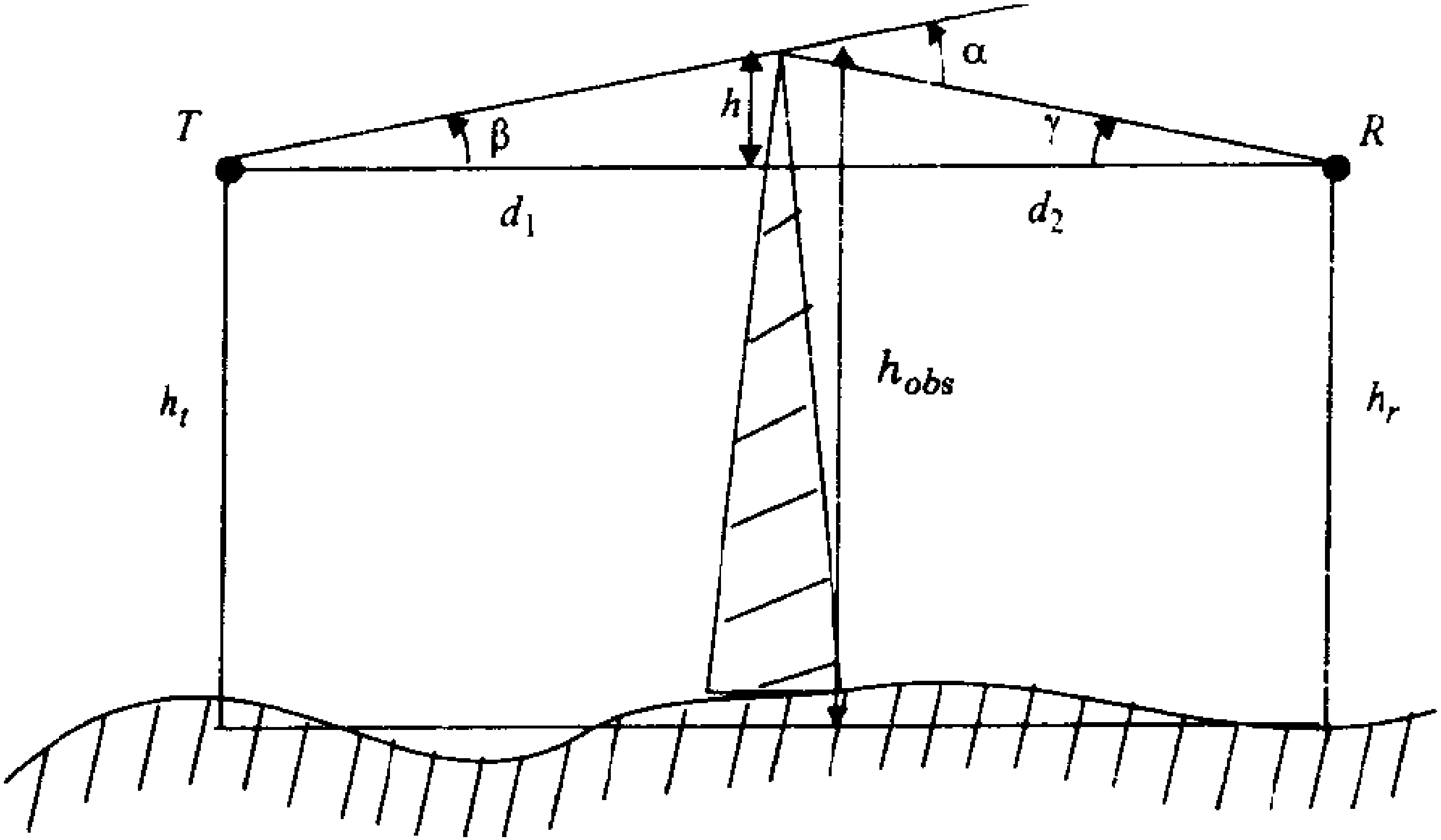
“All points on a wavefront can be considered as point sources for the production of secondary wavelets, and that these wavelets combine to produce a new wavefront in the direction of propagation.”

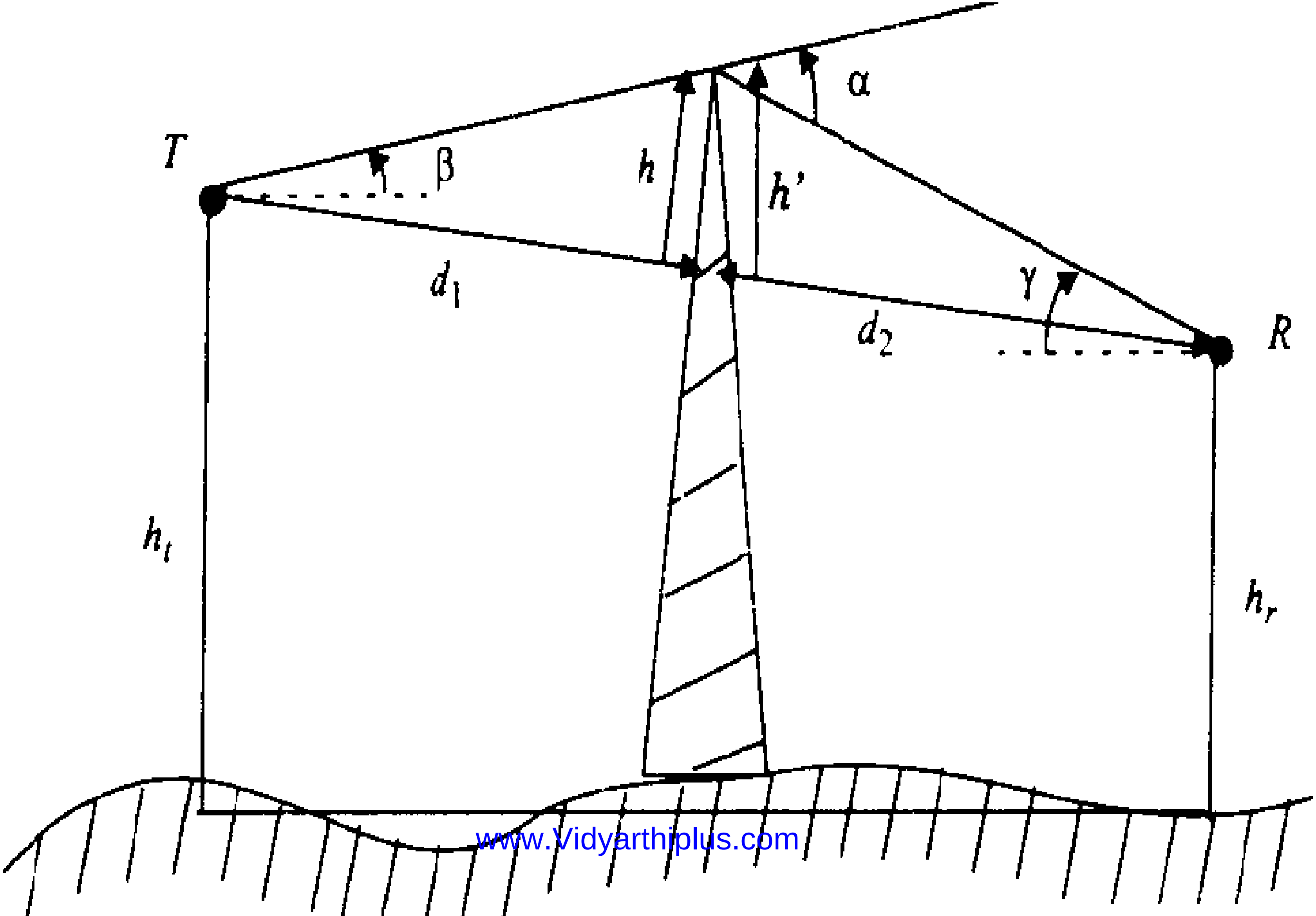
Diffraction is caused by the propagation of secondary wavelets into a shadowed region

Huygens principle



Fresnel Geometry




α
T
β
h
h'
d1
γ
d2
R
ht
hr

- *Excess path length (Δ)*

$$\Delta \approx \frac{h^2}{2}\frac{(d_1 + d_2)}{d_1 d_2}$$

- Phase Difference Φ =

$$\frac{2\pi\Delta}{\lambda} \approx \frac{2\pi}{\lambda}\frac{h^2}{2}\frac{(d_1 + d_2)}{d_1 d_2}$$

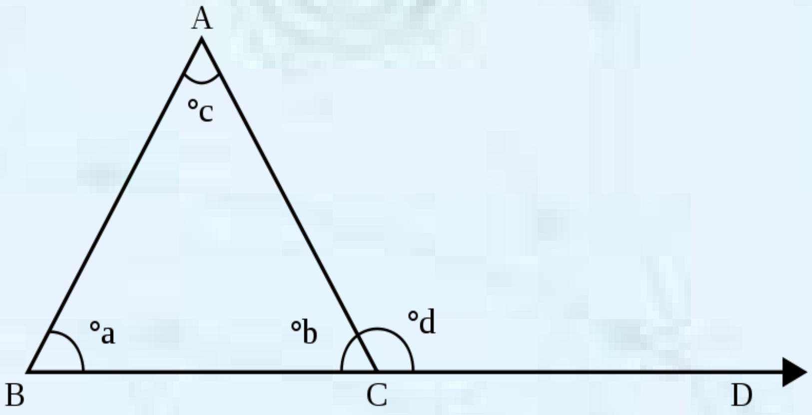
$$\approx \frac{\pi h^2}{\lambda}\frac{(d_1 + d_2)}{d_1 d_2}$$

- By Exterior angle theorem $\alpha = \beta + \gamma$
- For acute angles $\tan x = x$

$$\alpha = h\left(\frac{d_1 + d_2}{d_1 d_2}\right)$$

$$h = \alpha \left(\frac{d_1\, d_2}{d_1 + d_2}\right)$$

Exterior angle theorem

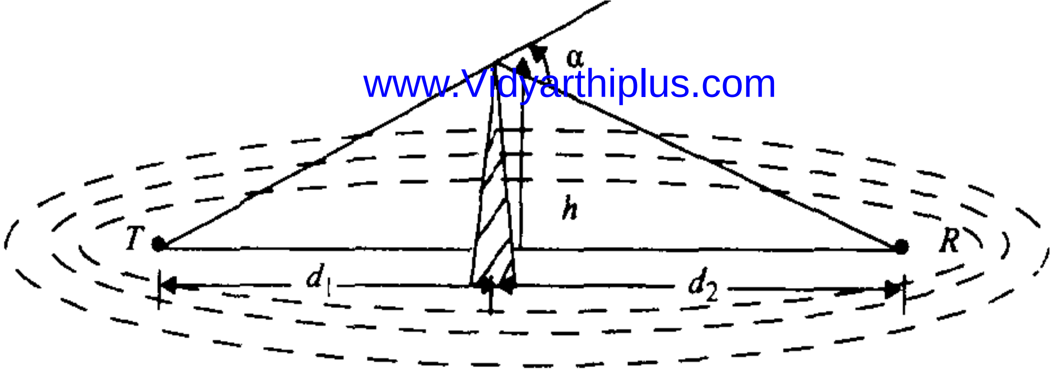


- The exterior angle of a triangle is equal to the sum of the two remote interior angles
- $d^o = a^o + c^o$

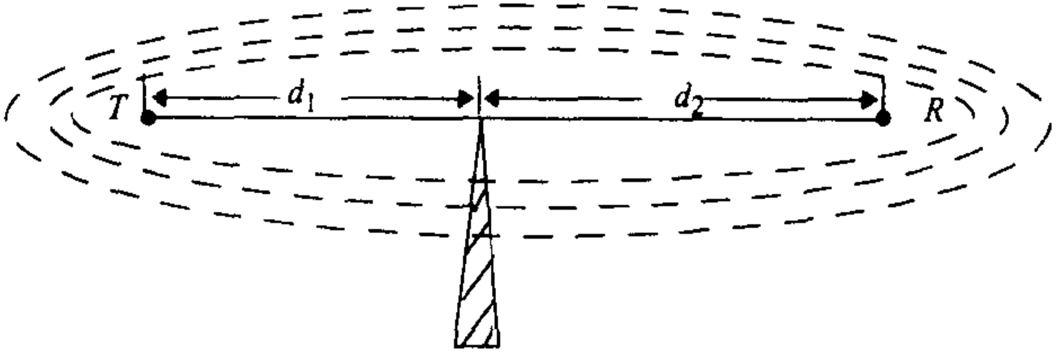
- *Fresnel-Kirchoff* diffraction parameter (*v)*

$$v = h\sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}} = \alpha\sqrt{\frac{2d_1 d_2}{\lambda(d_1 + d_2)}}$$

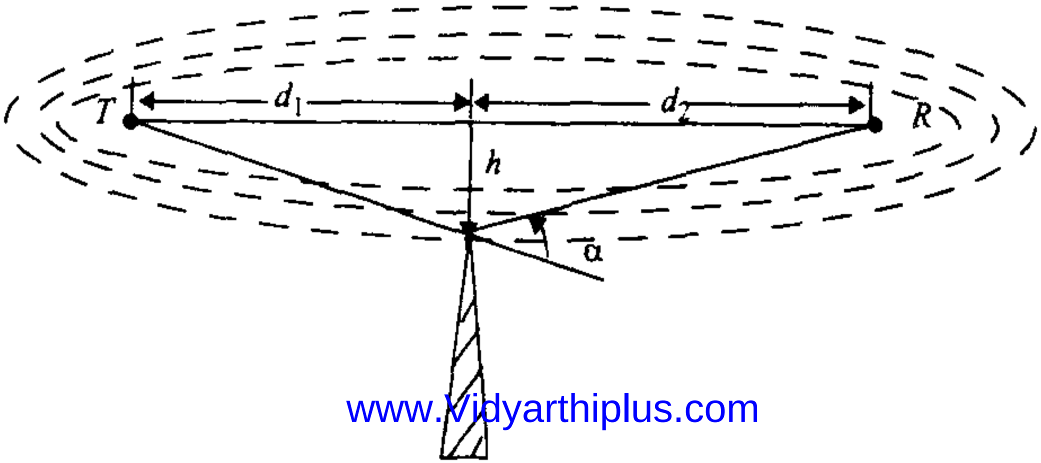
- $\Phi = \pi . v^2 / 2$



(a) α and ν are positive, since *h* is positive

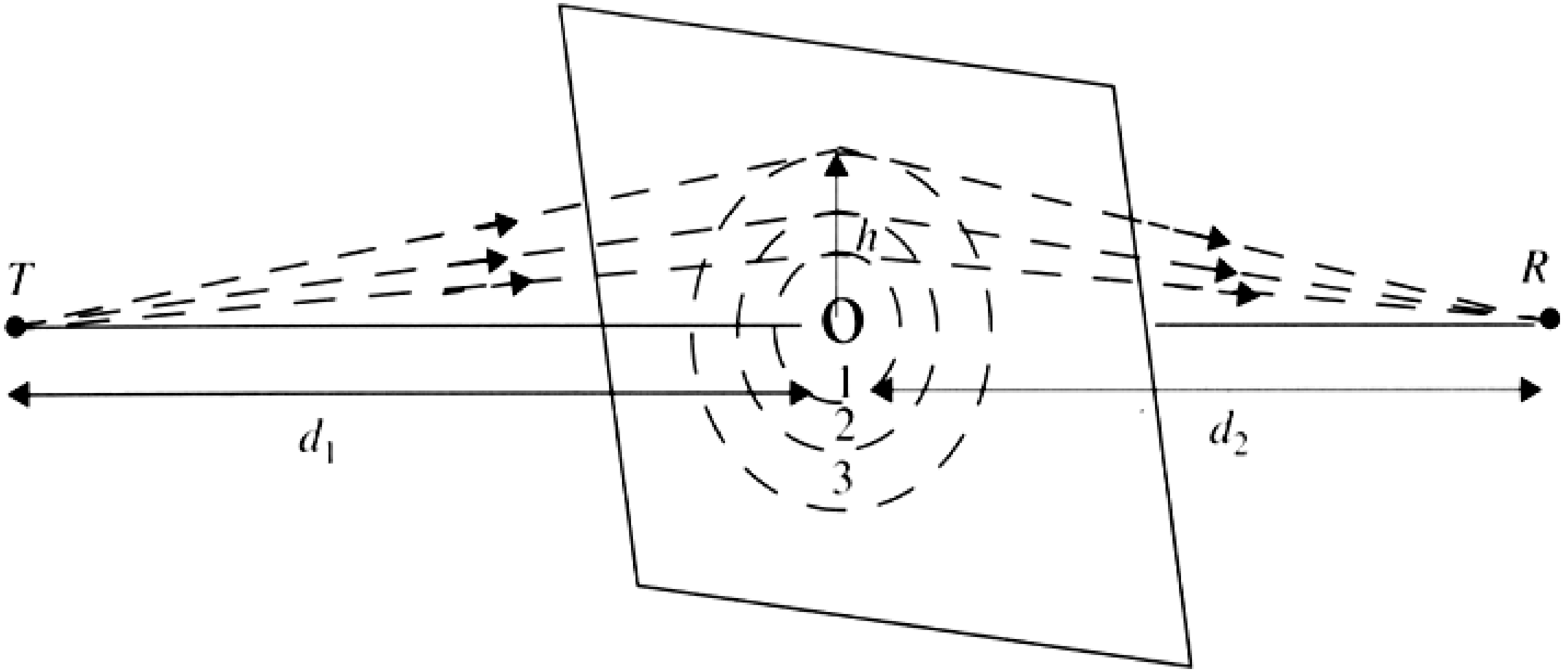


(b) α and ν are equal to zero, since *h* is equal to zero



(c) α and ν are negative, since *h* is negative

Fresnel Zones



Concentric circles which define the boundaries of successive Fresnel zones.

- Fresnel zones represent successive regions where secondary waves originates.
- The path length for successive regions increase by a factor of **nλ/2** from path length of line-of-sight path wave.
- The concentric circles on the plane represent the loci of the origins of secondary wavelets which propagate to the receiver.
- These circles are called Fresnel zones

- The radius of the *n* th Fresnel zone circle is

$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

- The electric field strength E_d is….

$$E_d = F(v).\, E_0$$

where *F(v) is a complex Fresnel Integral*

$$F(v) = \frac{(1+j)}{2}\int_{v}^{\infty} \exp\left((-j\pi t^2)/2\right) dt$$

The diffraction gain is

$$G_d\,(\mathrm{dB}) = 20\log|F(v)|$$

- Some practical values

$$G_d(dB) = 0 \qquad \upsilon \le -1$$

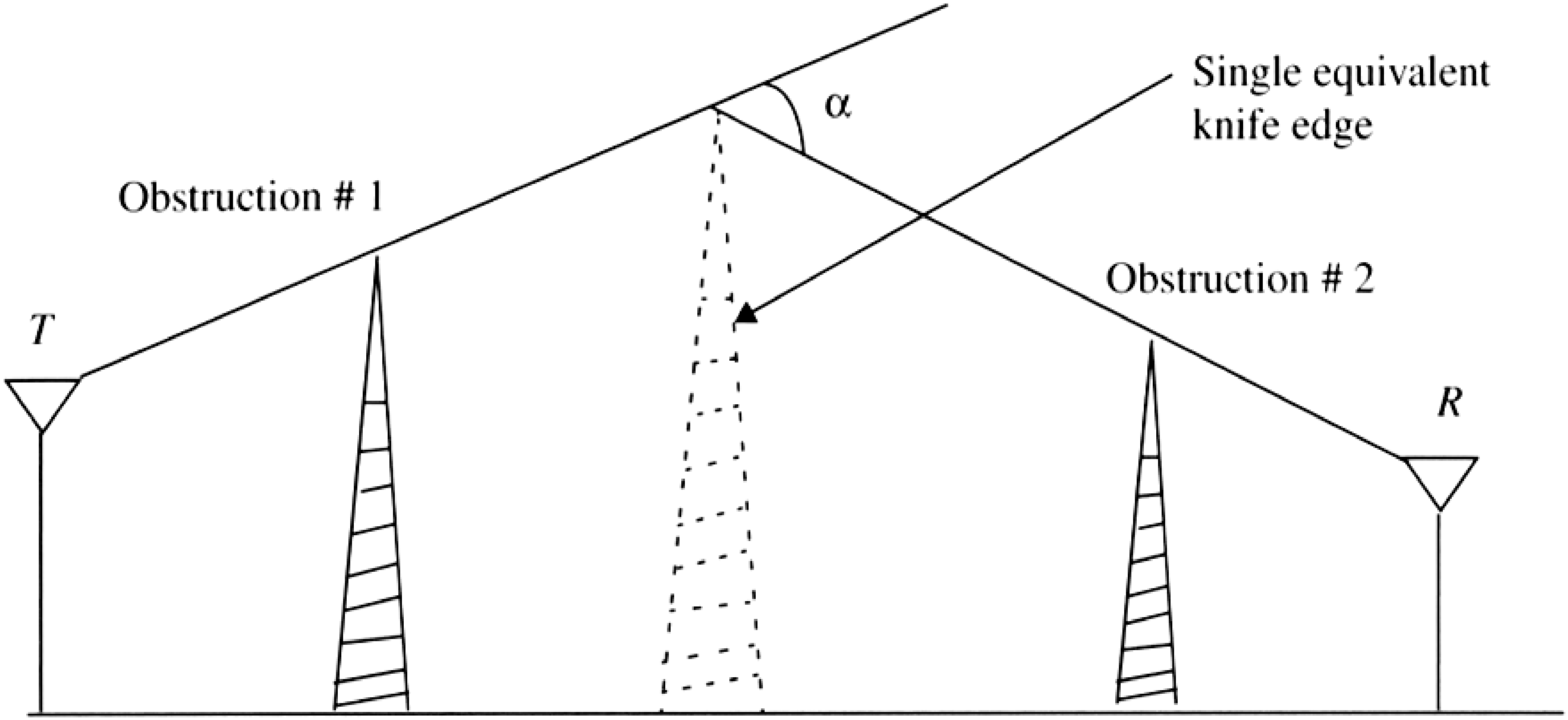
$$G_d(\mathrm{dB}) = 20\log(0.5 - 0.62\upsilon) \qquad -1 \le \upsilon \le 0$$

$$G_d(\mathrm{dB}) = 20\log(0.5\exp(-0.95\upsilon)) \qquad 0 \le \upsilon \le 1$$

$$G_d(\mathrm{dB}) = 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1\upsilon)^2}\right) \qquad 1 \le \upsilon \le 2.4$$

$$G_d(\mathrm{dB}) = 20\log\left(\frac{0.225}{\upsilon}\right) \qquad \upsilon > 2.4$$

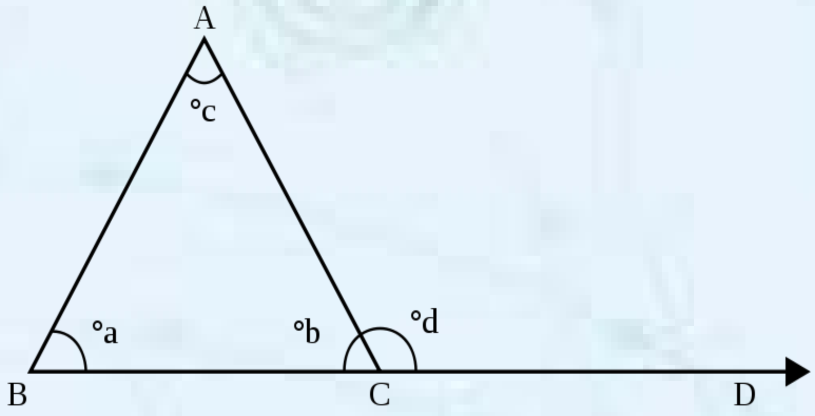
Multiple Knife-edge Diffraction



Bullington's construction of an equivalent knife edge

- Predicting diffraction loss due to multiple knife edge obstacles is not easy.
- So **Bullington** suggested that the series of obstacles be replaced by a single equivalent obstacle.
- **Millington** gave a wave-theory solution for the two knife edges in series
- Calculations beyond two knife edges becomes a formidable mathematical problem

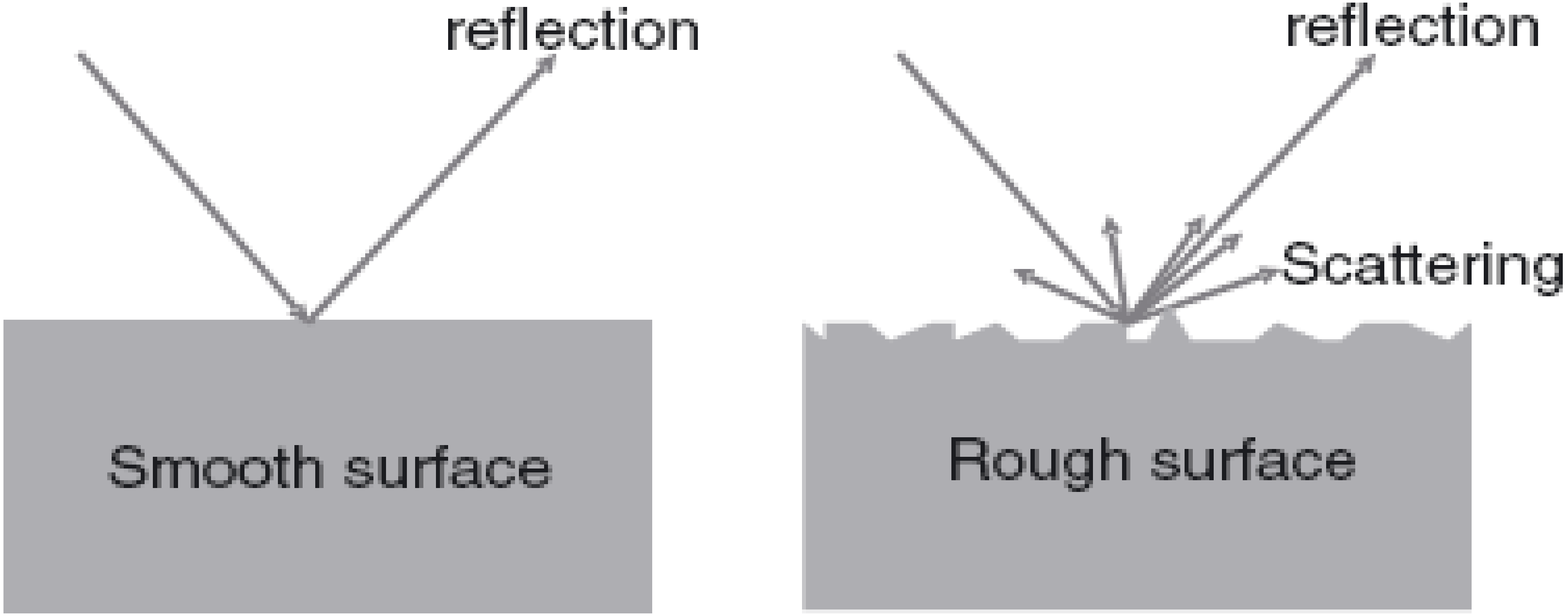
Exterior angle theorem



- The exterior angle of a triangle is equal to the sum of the two remote interior angles
- $d^o = a^o + c^o$

SCATTERING

Reflection Vs Scattering



- *Scattering is caused by rough surfaces, small objects, or by other irregularities in the channel*
- *The roughness of flat surfaces also induces Scattering.*
- *Rayleigh criterion defines a critical height (h_c) of surface protuberances of flat surfaces*

$$h_c = \frac{\lambda}{8\sin\theta_i}$$

- *A surface is considered smooth if its maximum protuberance h is less than h_c and vice-versa*

- *For rough surfaces, the flat surface reflection coefficient needs to be multiplied by a scattering loss factor(ρ_s)*

$$\Gamma_{rough} = \rho_S \Gamma$$

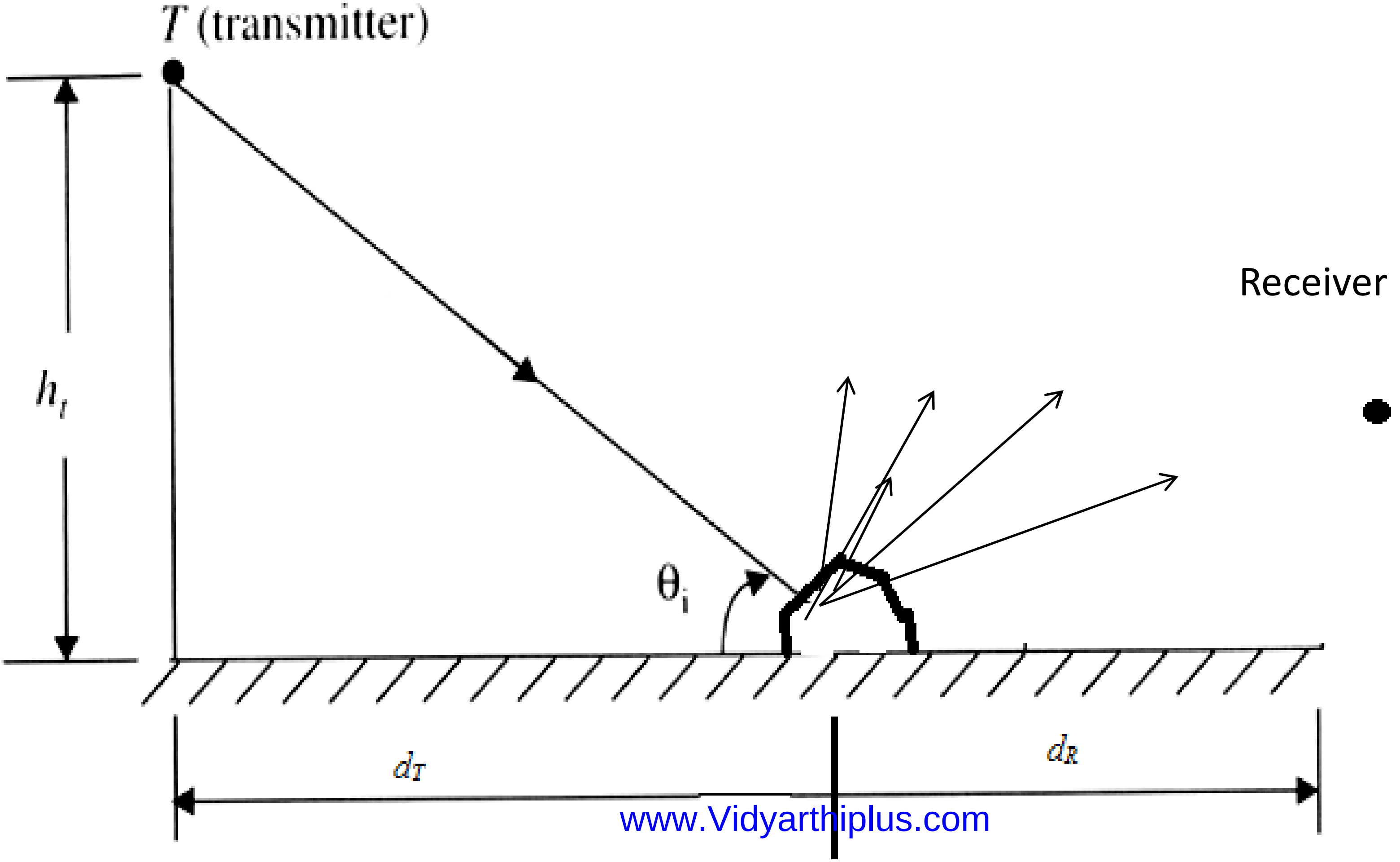
Where

$$\rho_S = \exp\left[-8\left(\frac{\pi\sigma_h \sin\theta_i}{\lambda}\right)^2\right] I_0\left[8\left(\frac{\pi\sigma_h \sin\theta_i}{\lambda}\right)^2\right]$$

σ_h = standard deviation of surface height.

I_0 = *Bessel's function*

Radar Cross Section Model



- *The radar cross section (RCS) of a scattering object is defined as the ratio of the power density of the signal scattered in the direction of the receiver to the power density of the radio wave incident upon the scattering object.*
- *The bistatic radar equation is used to compute the received power*

$$P_R(\text{dBm}) = P_T(\text{dBm}) + G_T(\text{dBi}) + 20\log(\lambda) + RCS[\text{dB m}^2] - 30\log(4\pi) - 20\log d_T - 20\log d_R$$

Wave Guiding

- Wave Guiding explains the propagation in street canyons, corridors, and tunnels, which resembles like a wave guide.
- The materials are lossy (dielectric).
- The surfaces are rough.
- The waveguides is filled with metallic (cars,….) and dielectric materials

Wideband Channel Characterization

- Multipath propagation for narrowband signals and wideband signals vary.

- Effects of Multipath propagation in wideband systems

(i) The transfer function of the channel varies over the bandwidth (frequency selectivity of the channel)

(ii) The arriving signal has a longer duration than the transmitted signal (delay dispersion)

Wideband channels properties

1. It undergo InterSymbol Interference (ISI)
2. Even if some part of the transmit spectrum is strongly attenuated, there are other frequencies that do not suffer from attenuation
3. The properties of the channel can vary depending on the frequency and the location

Delay Dispersion

The Two-Path Model

- Let The transmitted signal gets to the receiver via two different propagation paths with different runtimes
- $\tau_1 = d_1/c_0$
- $\tau_2 = d_2/c_0$

- Impulse response when the Tx and Rx is stationary

$$h(\tau) = a_1\delta(\tau - \tau_1) + a_2\delta(\tau - \tau_2)$$

$$\text{where } a = |a| \exp(j\phi)$$

Fourier transformation of the impulse response gives the transfer function *H(f)*

$$H(f) = \int_{-\infty}^{\infty} h(\tau)\exp[-j2\pi f\tau]\,d\tau = a_1\exp[-j2\pi f\tau_1] + a_2\exp[-j2\pi f\tau_2]$$

- Dispersion will be

$$\tau_2 - \tau_1$$

Magnitude of transfer function will be

$$|H(f)| = \sqrt{|a_1|^2 + |a_2|^2 + 2|a_1||a_2|\cos(2\pi f \cdot \Delta\tau - \Delta\varphi)}$$

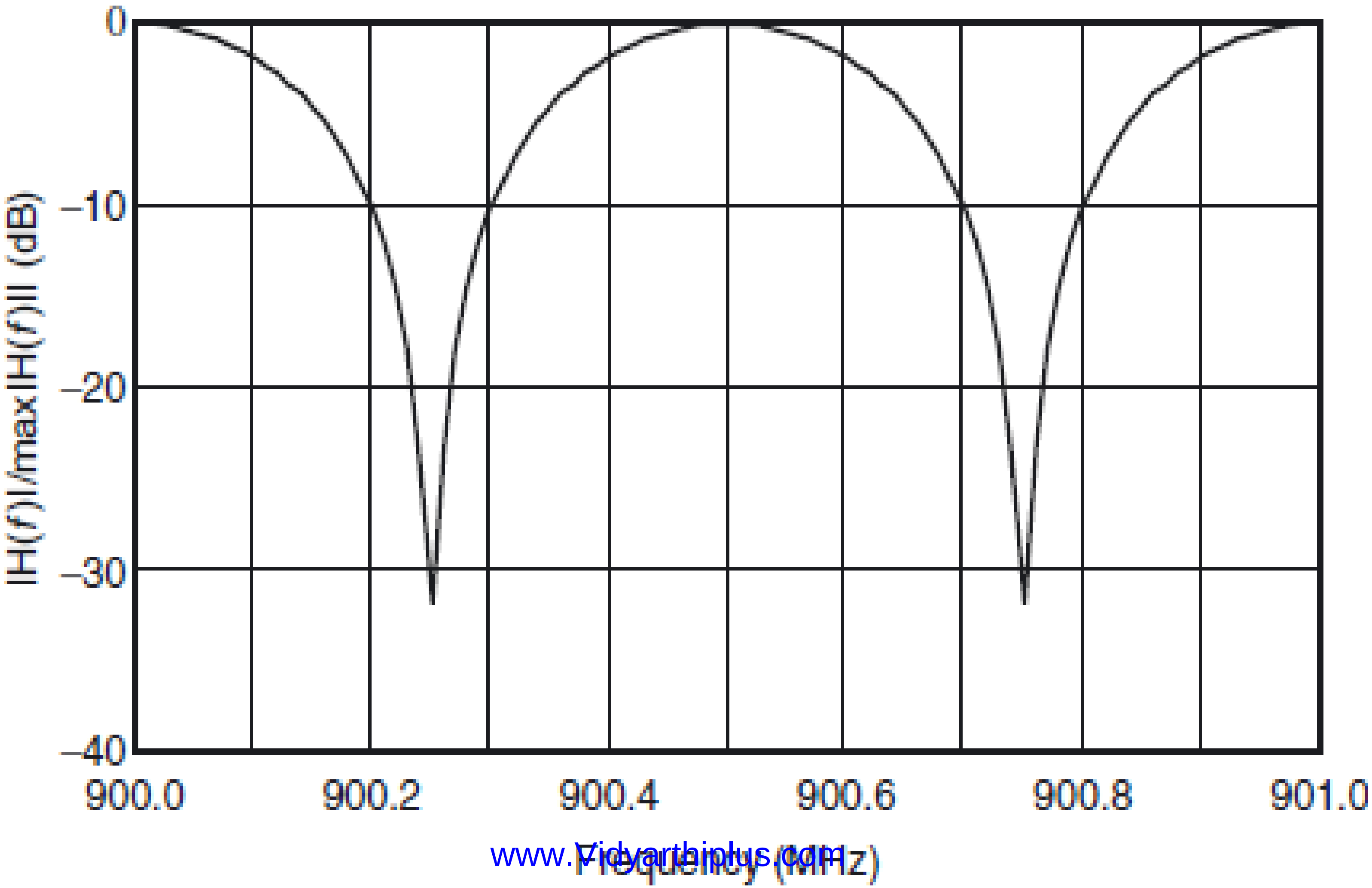
$$\text{with } \Delta\tau = \tau_2 - \tau_1 \text{ and } \Delta\varphi = \varphi_2 - \varphi_1$$

- The transfer function depends on the frequency, so that we have frequency-selective fading

- There are dips (notches) in the transfer function The notch frequencies are those frequencies where the phase difference of the two arriving waves becomes 180°. The frequency difference between two adjacent notch frequencies is

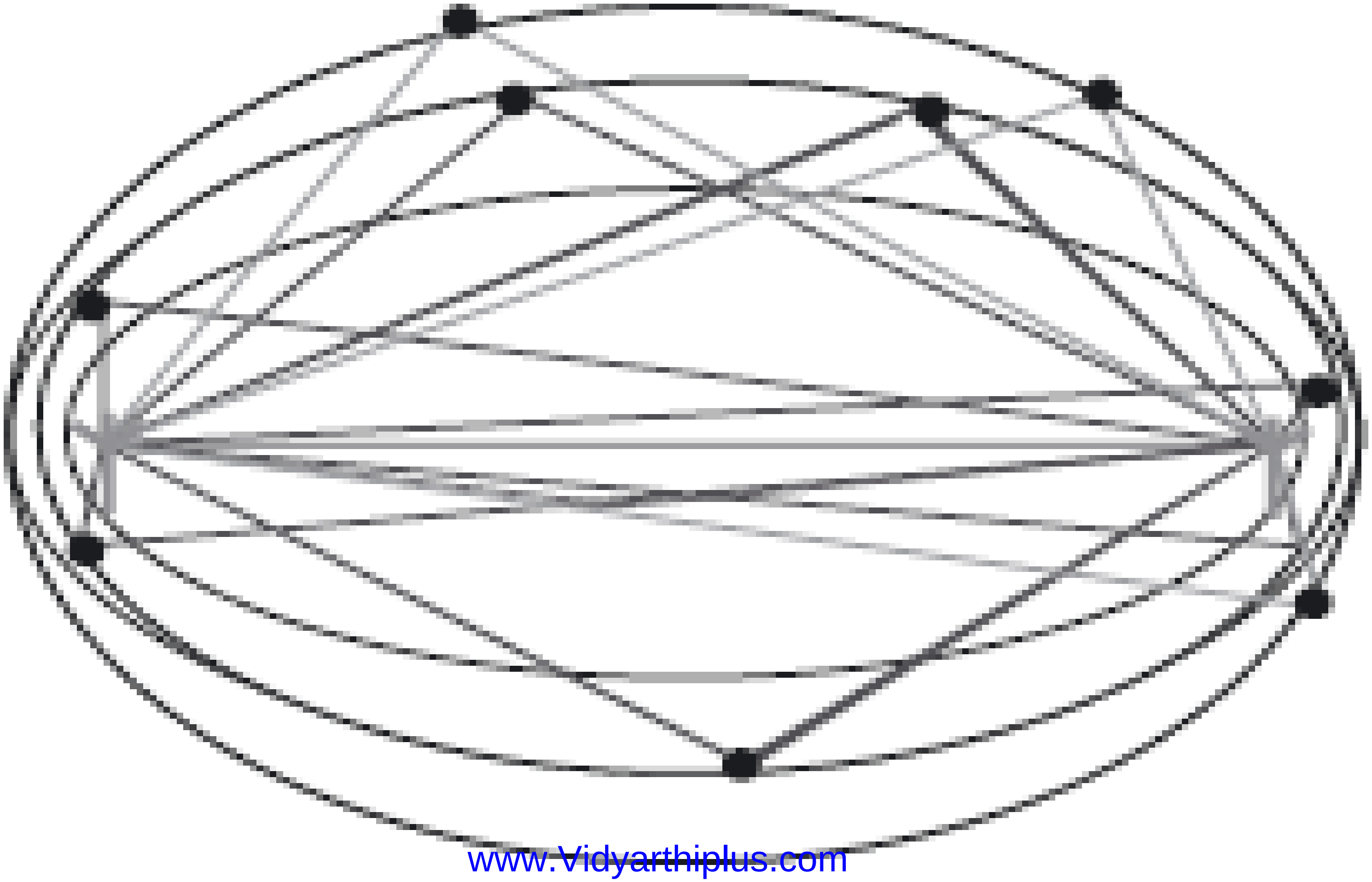
$$\Delta f_{\text{Notch}} = \frac{1}{\Delta\tau}$$

- $\Delta\tau = \tau_2 - \tau_1$


0
−10
−20
−30
−40
IH(f)I/maxIH(f)II (dB)
900.0
900.2
900.4
900.6
900.8
901.0
Frequency (MHz)

- The destructive interference between the two waves is stronger if the amplitudes of the two waves are closer to each other
- Channels with fading dips distort not only the amplitude but also the phase of the signal .

Multiple propagations



- The ellipses are drawn with TX and RX at the focal points.
- Rays that undergo a single interaction with an object on a specific ellipse arrive at the RX at the same time.
- The channels are **delay-dispersive** if the interacting Objects in the environment are not located on a single ellipse

Difficulties

- In a realistic environment the multipath waves never lie exactly on a single ellipse.
- An RX with bandwidth *W cannot distinguish between echoes arriving at* τ *and* $\tau + \Delta\tau$, ***if*** $\boldsymbol{\Delta\tau = 1/W}$

- A time-discrete approximation to the impulse response of a wideband channel can thus be obtained by dividing the impulse response into groups of width τ and then computing the sum of echoes within each group.
- The maximum excess delay τ_{max} is then defined as the difference between minimum and maximum delay

Frequency selective fading

- If the bandwidth of the channel is smaller than the bandwidth of the transmitted signal, the received signal will undergo Frequency selective fading.
- The received signal has multiple versions of the transmitted waveform which are faded and delayed in time.

- Due to the mobility of transmitter and/or receiver the principal characteristics of the wireless channel change in time
- The channel spectral response is not flat.
- It has dips or fades in the response due to cancellation of certain frequencies at the receiver.
- This results in deep nulls in the received signal power due to destructive interference.

Small-Scale Fading and Multipath Propagation

Effects of small-scale fading

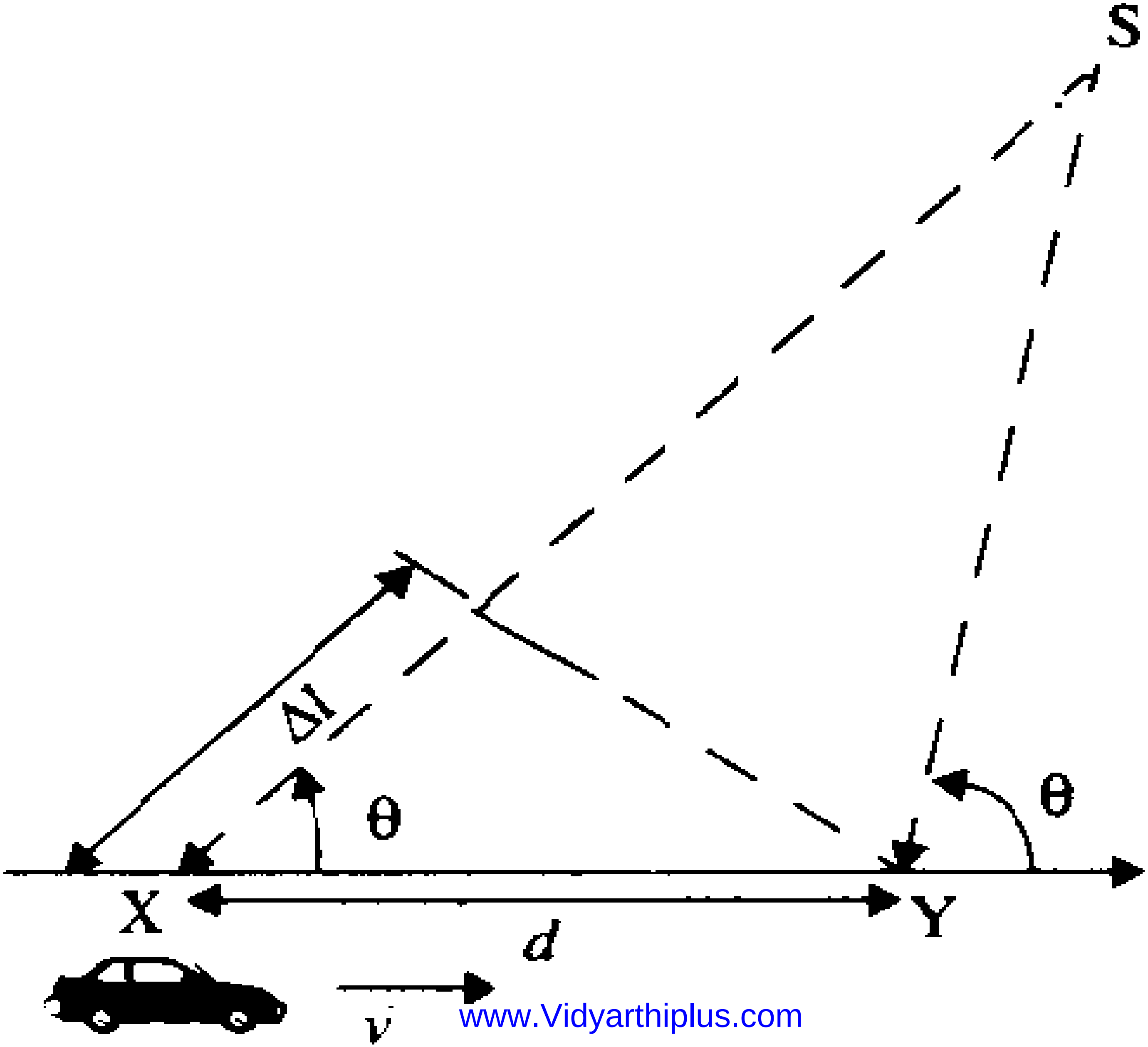
1. Rapid changes in signal strength over a small travel distance or time interval
2. Random frequency modulation due to varying Doppler shifts on different multipath signals
3. Time dispersion (echoes) caused by multipath propagation delays

Factors Influencing Small-Scale Fading

1. Multipath propagation
2. Speed of the mobile or Doppler shift
3. Speed of surrounding objects
4. The transmission bandwidth of the signal

Doppler shift

- Due to the relative motion between the mobile and the base station, each multipath wave experiences an shift in frequency. The shift in received signal frequency due to motion is called the Doppler shift.
- It is directly proportional to the velocity and direction of motion of the mobile with respect to the direction of arrival of the received multipath wave.


S
Δl
θ
θ
X
Y
d
v

Let

v = Velocity

Δl = path difference

Source "S" is assumed to be far away…. So both angles are approximately equal

$$\Delta l = d \cos\vartheta$$

Distance = Velocity x Time

$$d = v \,.\, \Delta t$$

$\Delta l = v \,.\, \Delta t \,.\, \mathit{Cos}\vartheta$

The phase change

$$\Delta\phi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\theta$$

Doppler shift is given by f_d

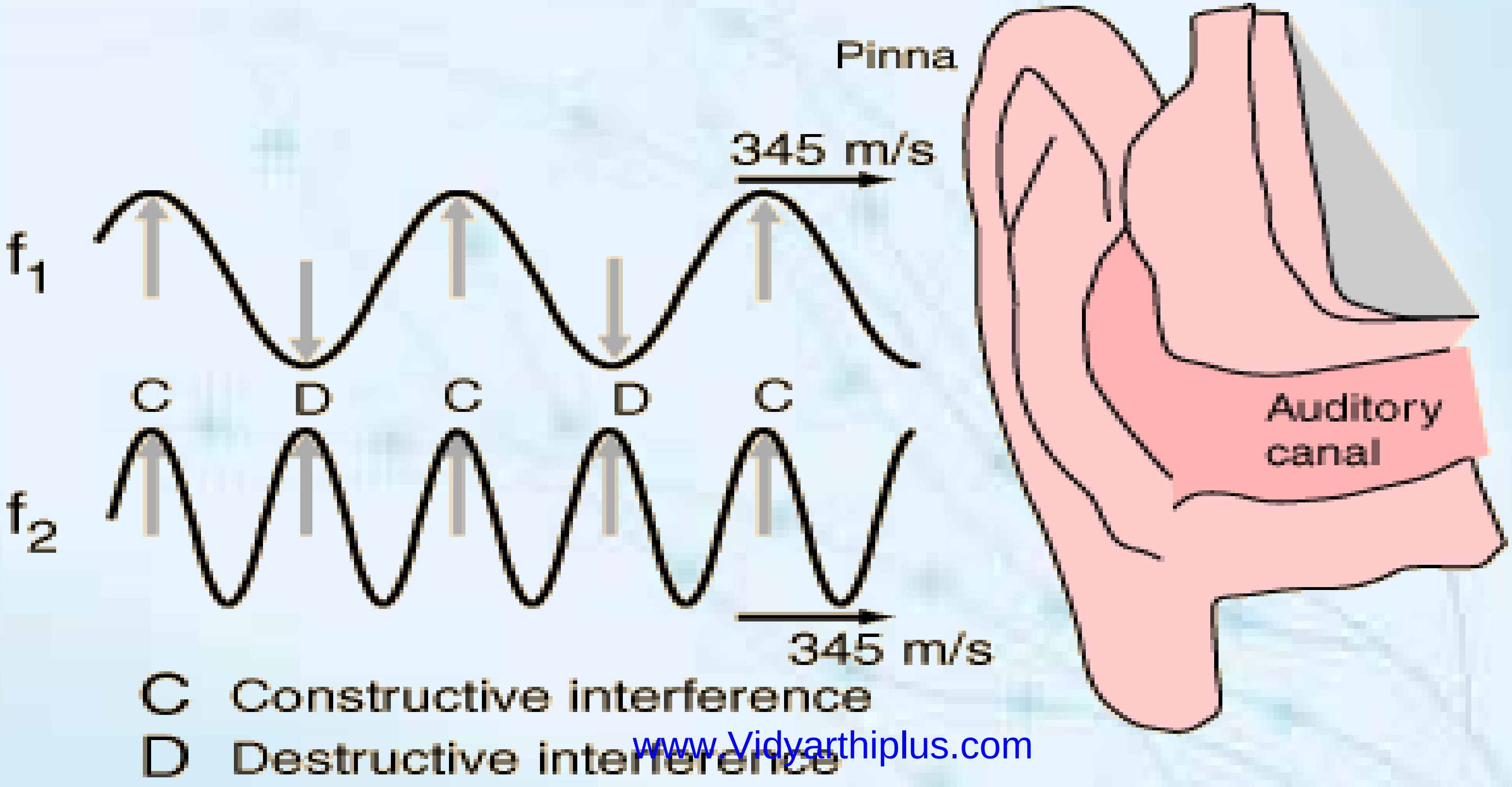
$$f_d = \frac{1}{2\pi}\cdot\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cdot\cos\theta$$

The maximum Doppler shift *is between 1Hz and 1 kHz*

- Individual Doppler shifts are so small and negligible.
- But superposition of several Doppler-shifted waves creates the sequence of fading dips.

- As the receiver moves, it receives two waves that are Doppler shifted by different amounts.
- This will cause beating of two oscillations with slightly different frequencies at the receiver

When two sound waves of different frequency approach your ear, the alternating constructive and destructive interference causes the sound to be alternatively soft and loud - a phenomenon which is called "beating" or producing beats



Parameters of Mobile Multipath Channels

Time Dispersion Parameters

1. Mean excess delay($\bar{\tau}$)
2. RMS delay spread (σ_τ)
3. Excess delay spread

Mean excess delay

- The mean excess delay (τ) is the first moment of the power delay profile

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

Rms delay spread (σ_τ)

- The RMS delay spread is the square root of the second central moment of the power delay profile

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

where

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\,\tau_k^2}{\sum_k P(\tau_k)}$$

Excess delay spread or maximum *excess delay* (X dB)

- *The maximum excess delay (X dB) of the power delay profile is defined to be the time delay during which multipath energy falls to X dB below the maximum.*
- *(i.e) The maximum excess delay is defined as T_x- T_0 , where T_0 is the first arriving signal and T_x is the maximum delay at which a multipath component is within X dB of the strongest arriving multipath signal*

Coherence Bandwidth (B_c)

- Coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered "flat“.
- “Flat” refers to a channel which passes all spectral components with approximately equal gain and linear phase
- In other words, coherence bandwidth is the range of frequencies over which two frequency components have a strong amplitude correlation.

- Mathematically coherence bandwidth is inversely proportional to RMS delay spread.

$$B_c \ \alpha \ 1/\sigma_\tau$$

Doppler spectrum

- When a pure sinusoidal tone of frequency f_c is transmitted, the received signal spectrum will have components in the range f_c - f_d to f_c + *fd.* This called the *Doppler spectrum.*

  where f_d is the Doppler shift.

  f_d is a function of the relative velocity of the mobile, and the angle between the direction of motion of the mobile and direction of arrival of the scattered waves

Coherence Time (T_c)

- Coherence Time is the time duration over which two received signals have a strong potential for amplitude correlation.
- Mathematically coherence Time is inversely proportional to Doppler spread.

CHANNEL MODELS

Applications for channel models

1. For the design, testing, and type approval of wireless systems (i.e) to compute the parameters that affect the channel performance.
2. To simulate the real time characteristics of the channel before physical implementation of base station.

Methods

1. Stored channel impulse responses
2. Deterministic channel models
3. Stochastic channel models

Stored channel impulse responses

- In this the channel is first analyzed, real time data is collected and impulse responses h(t, τ) are stored.
- Then the simulations are done with the available stored data.
- The stored data can be used for future reference.

Disadvantage

- The large effort is necessary in acquiring and storing the data
- The data will be specific for only a certain area.
- So the prediction may not be accurate all the time.

Deterministic channel models

- The deterministic channel model can provide deep insight into the structure and property of channels.
- This is similar to stored channel model, but this require a lot more computation.
- But we will not use any real time measurements.

Stochastic channel models

- These methods do not predict the impulse response in one specific location, but rather it will predict the PDF over a large area.

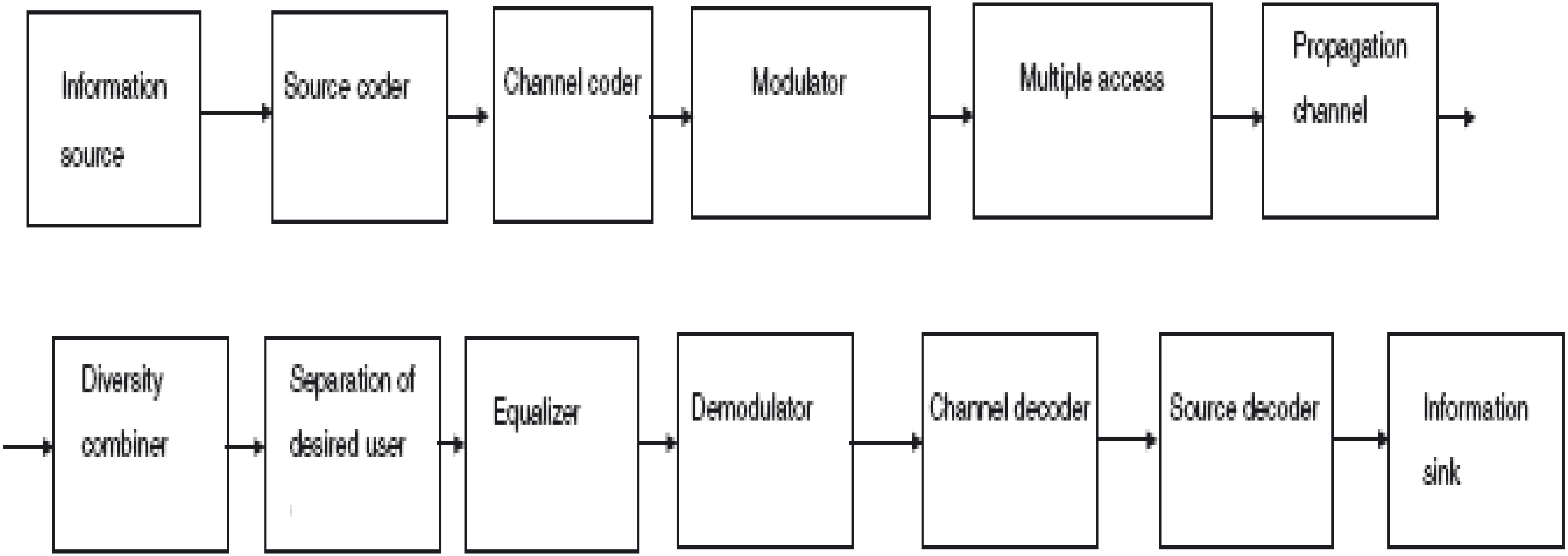
  E.g. Rayleigh-fading model

- Stochastic models are used more for the comparison of systems, while site-specific models are preferable for network planning and system deployment
- Deterministic and stochastic approaches can be combined to enhance the efficiency of a model

WIRELESS COMMUNICATION

UNIT III
WIRELESS TRANSCEIVERS

Structure of a wireless communication link



- *Information source*
  - The information source provides an analog source signal and feeds it into the source ADC, where the signal is converted into a stream of digital data at a certain sampling rate and resolution.
- *Source coder*
  - This reduces the amount of source data to be transmitted.
  - Datas are encrypted in order to prevent unauthorized listening
  - GSM speech coder reduces the source data rate from 64 kbit/s to 13 kbit/s

- ***Channel coder***
  - Channel coder adds redundancy in order to protect data against transmission errors
  - GSM channel coding increases the data rate from 13 to 22.8 kbit/s
- ***Baseband modulator***
  - The baseband modulator converts the raw data bits to complex transmit symbols in the baseband.

- ***Multiple access***
  - In this a suitable multiple access scheme is chosen
  - In GSM, multiple access increases the data rate from 22.8 to 182.4 kbit/s (8 · 22*.8) for* the standard case of eight users.
- ***Propagation channel***
  - This will be mostly our air-interface.

- ***Diversity combiner***
  - For negating the multipath propagation we use diversity techniques for reception.
  - It receives the time delayed signals and combine them to form an effective output
- ***Separation***
  - In this we separate the multiple accessed signals.
  - For GSM each of the 8 user’s data will be separated.

- ***Equalizer***
  - Equalization compensates for intersymbol interference (ISI)
- ***Channel decoder***
  - This is used to detect or correct the errors introduced by the channel.
  - All the redundant bits added during channel encoding will be removed.

- ***Source Decoder***
  - The source decoder reconstructs the source signal from the rules of source coding
  - The data are transferred to the DAC, which converts the transmitted information into an analog signal and hands it over to the information sink.

BINARY FREQUENCY SHIFT KEYING

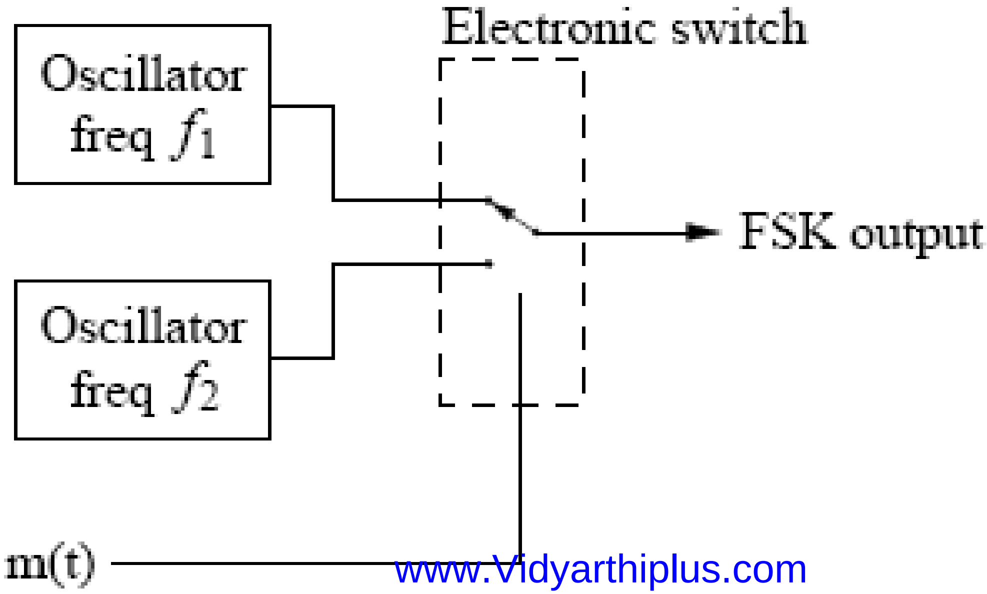
Binary Frequency Shift Keying

- BFSK uses a pair of discrete frequencies to transmit binary data.
- The frequency of a constant amplitude carrier signal is switched between two values corresponding to a binary 1 or 0

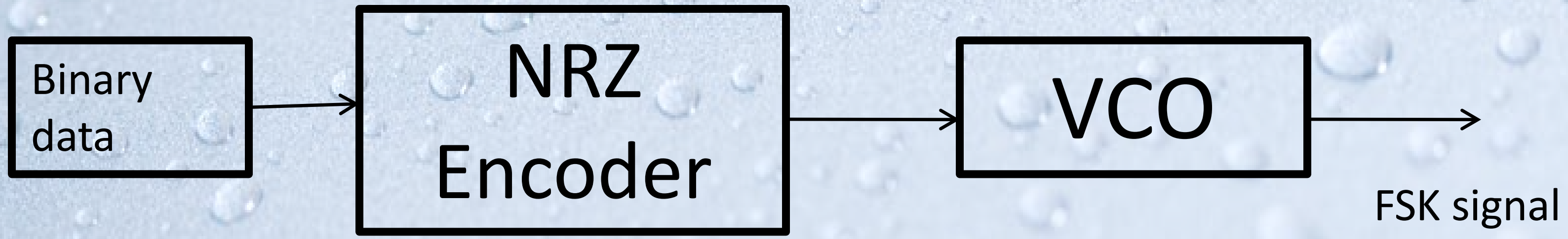
Method 1

$$s_{\text{FSK}}(t) = v_H(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_H t + \theta_1) \quad 0 \le t \le T_b \text{ (binary 1)}$$

$$s_{\text{FSK}}(t) = v_L(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_L t + \theta_2) \quad 0 \le t \le T_b \text{ (binary 0)}$$

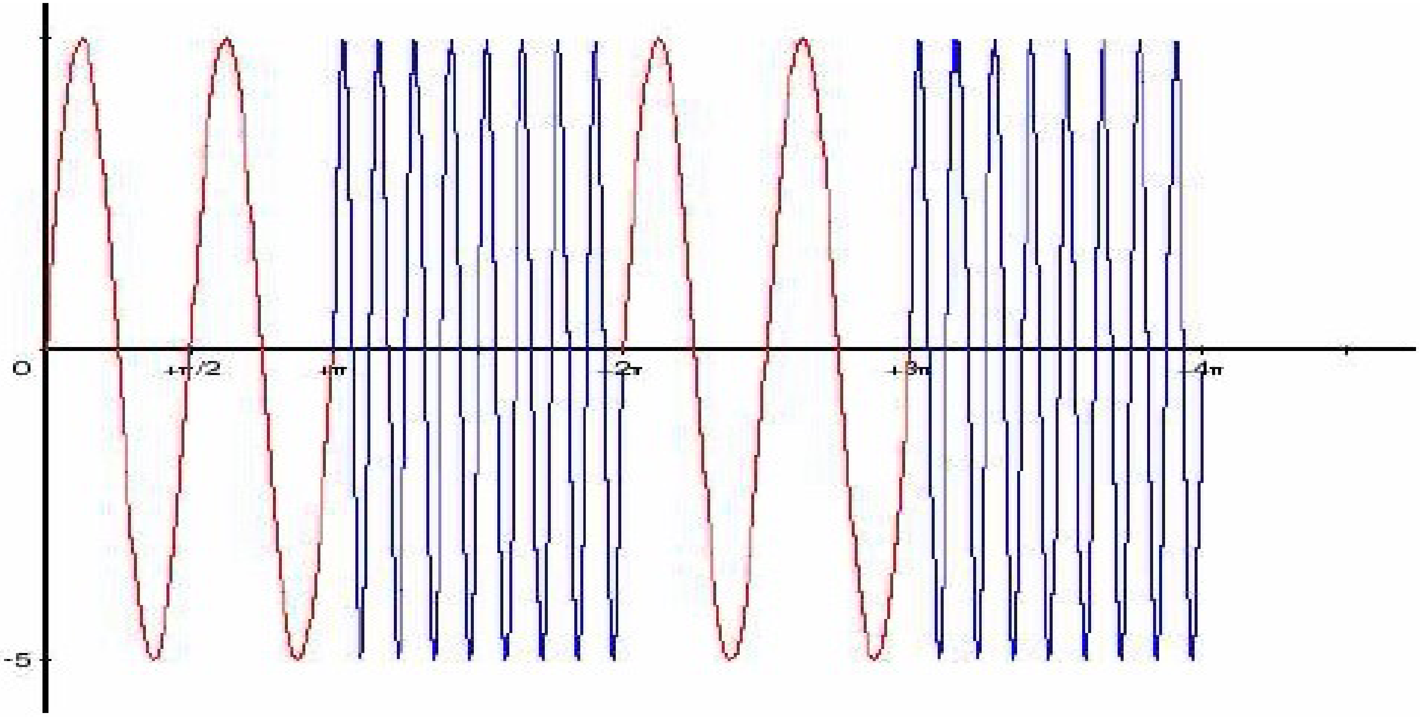


Method 2



$$s_{\mathrm{FSK}}(t) = v_H(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c + 2\pi\Delta f)t \quad 0 \le t \le T_b \ \text{(binary 1)}$$

$$s_{\mathrm{FSK}}(t) = v_L(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c - 2\pi\Delta f)t \quad 0 \le t \le T_b \ \text{(binary 0)}$$



0 1 0 1

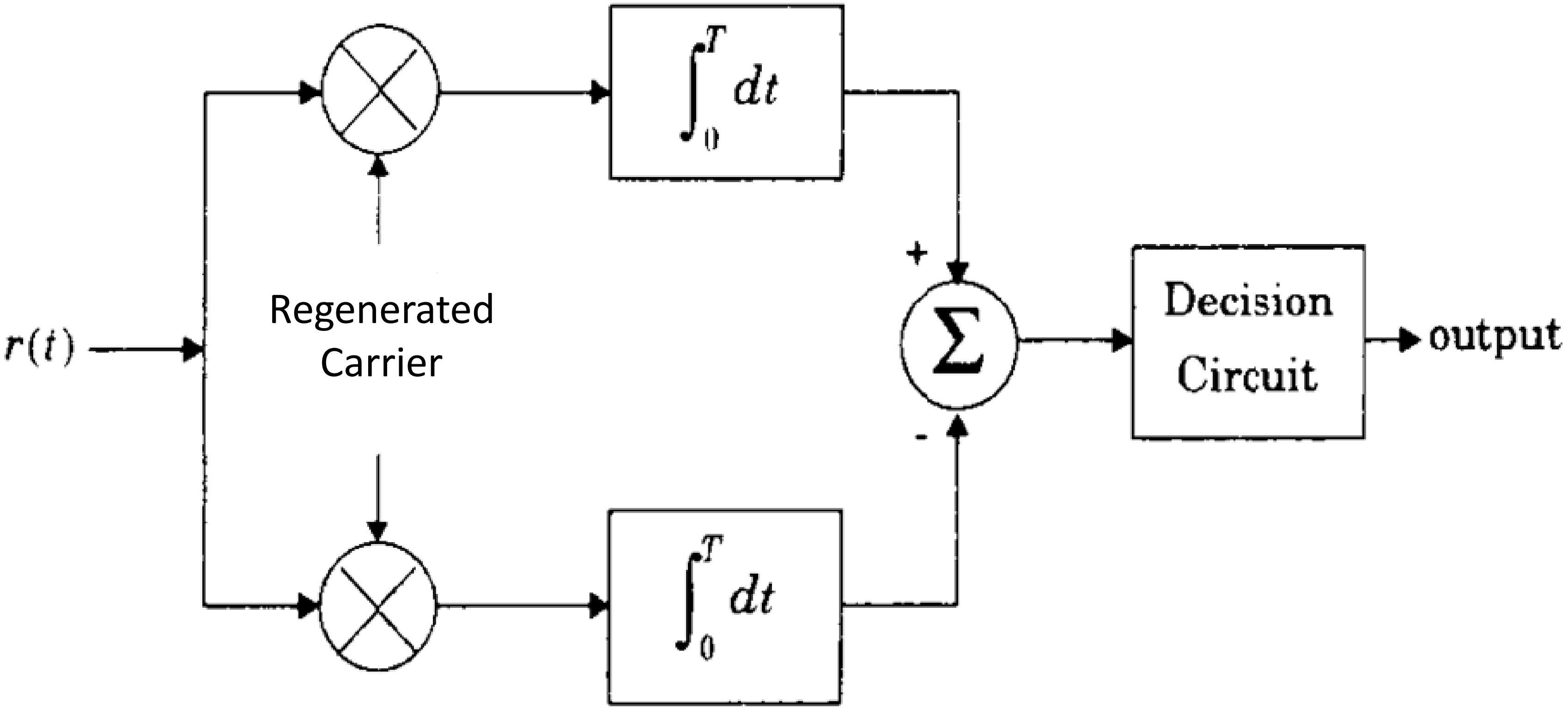
Spectrum and Bandwidth

- FSK signal consists of discrete frequency components at $f_c, f_c + n \pi f, f_c - n \pi f$

- $B_{FSK} = 2\Delta f + 2B$

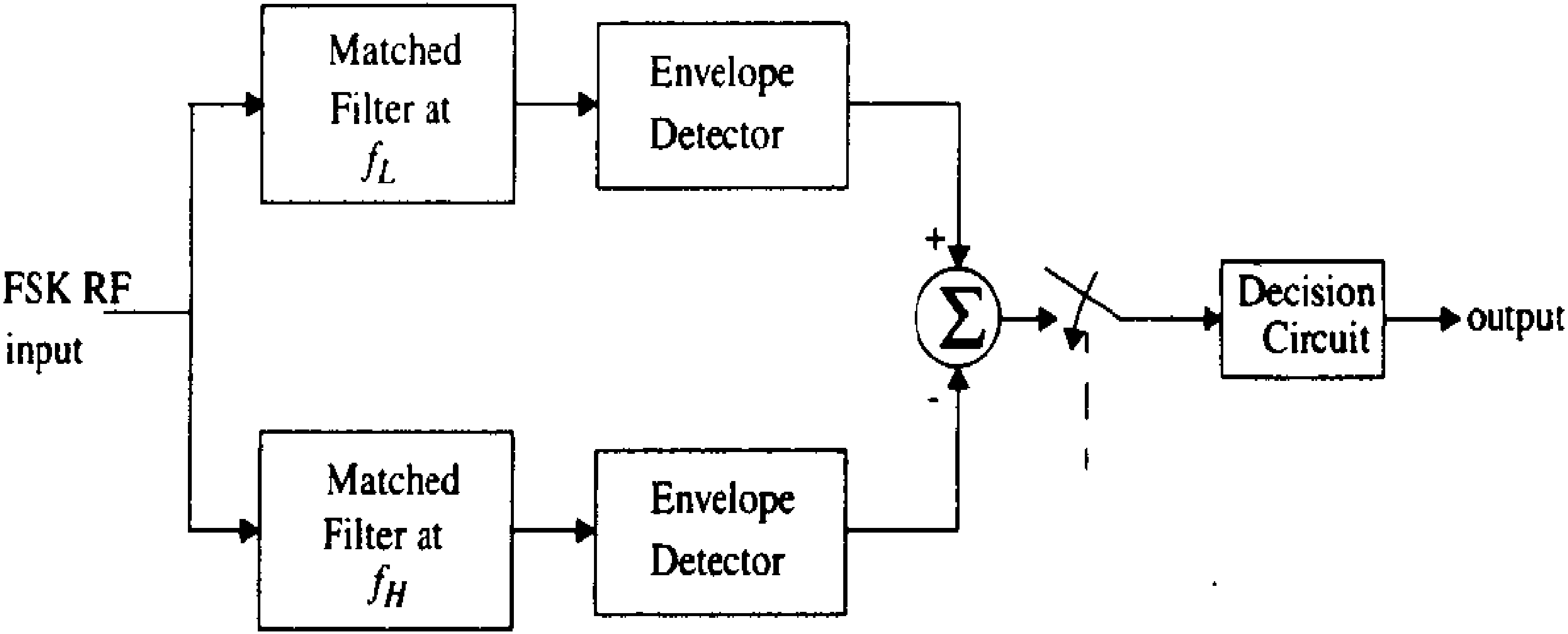
  - B is the bandwidth of the digital baseband signal.

Coherent Receiver



- The carrier used in the transmitter was regenerated by the Carrier Recovery circuit.
- Then they are multiplied with the incoming FSK signal.
- Then the high frequency components are filtered out and only the low frequency message is passed though.
- Threshold comparator will decide whether the received signal is logic 1 or a 0

Non-Coherent Receiver



- Extracting the same Carrier from the FSK signal will not be accurate , and it take lot of effort to do that.
- To avoid this we use Non Coherent detection, where we don’t need any information about the original carrier.
- The receiver consists of a pair of matched filters, upper filter is matched to the FSK signal of frequency f_H and the lower filter is matched to the frequency f_L

- Depending on the magnitude of the envelope detector output, the comparator decides whether the data bit was a 1 or 0.

QUDRATURE PHASE SHIFT KEYING

QPSK

- 2 bits are combined in a single symbol.
- It is represented by carriers with 4 different phases.
- QPSK has twice the bandwidth efficiency of BPSK.

$$S_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \sin\left[2\pi f_c t + (i-1)\frac{\pi}{2}\right] \quad 0 \le t \le T_s \quad i = 1, 2, 3, 4.$$

E_s – Amplitude of digital symbol

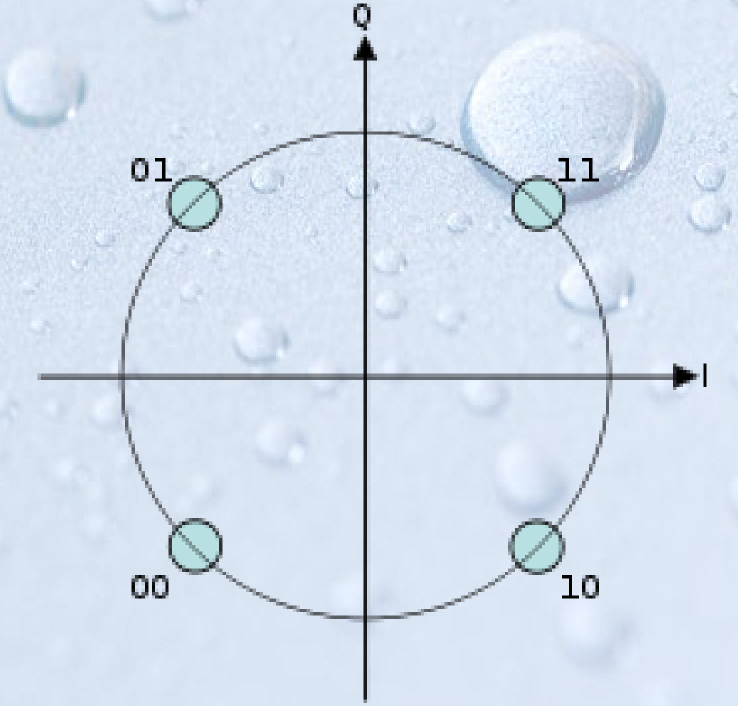
T_s - duration of symbol

T_b- duration of a single bit

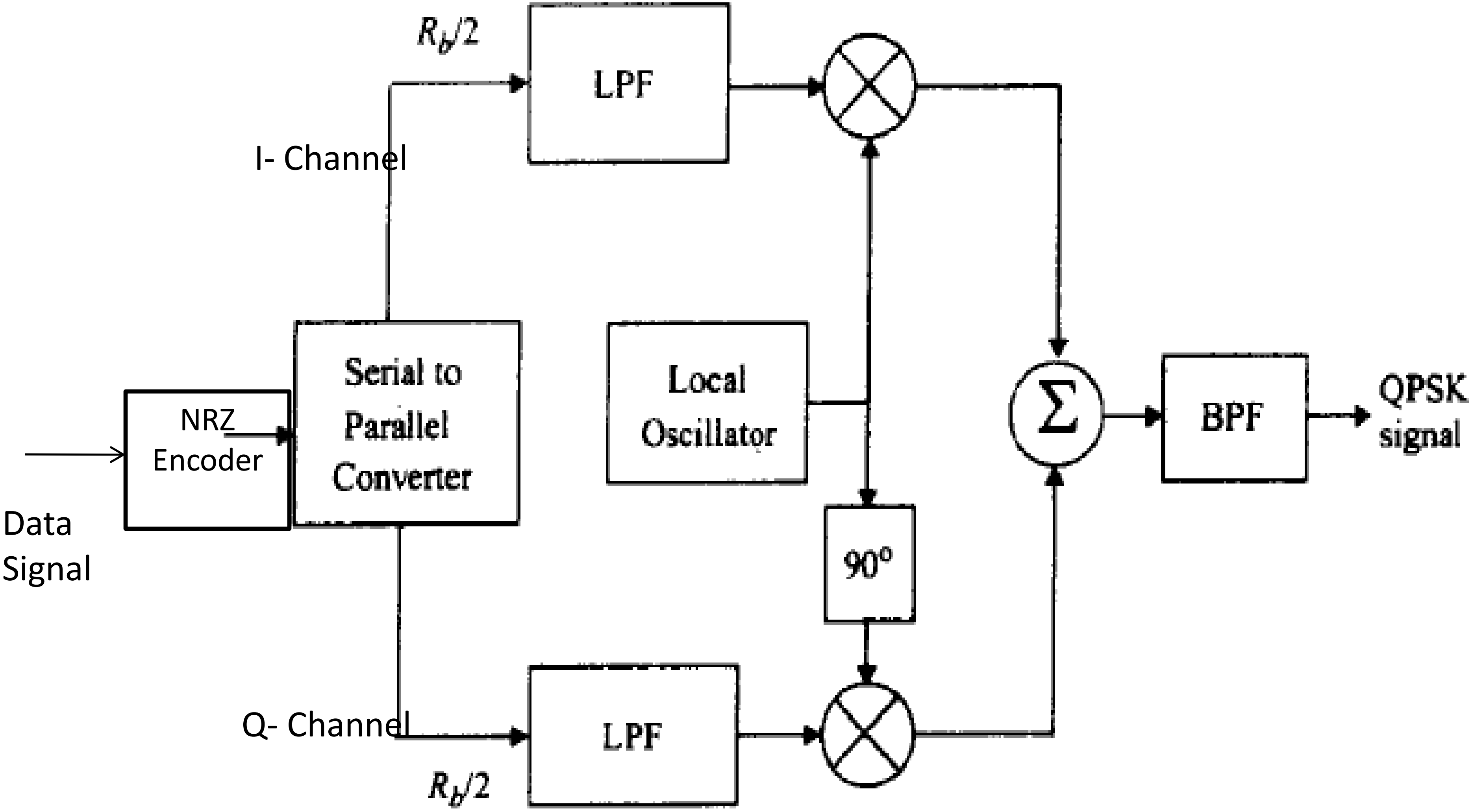
- *For QPSK* $T_s = 2\,T_b$

Phasor diagram

00	-135(225)
01	+135
10	-45 (315)
11	+45



QPSK Transmitter Block



I- Channel

NRZ Encoder

Data Signal

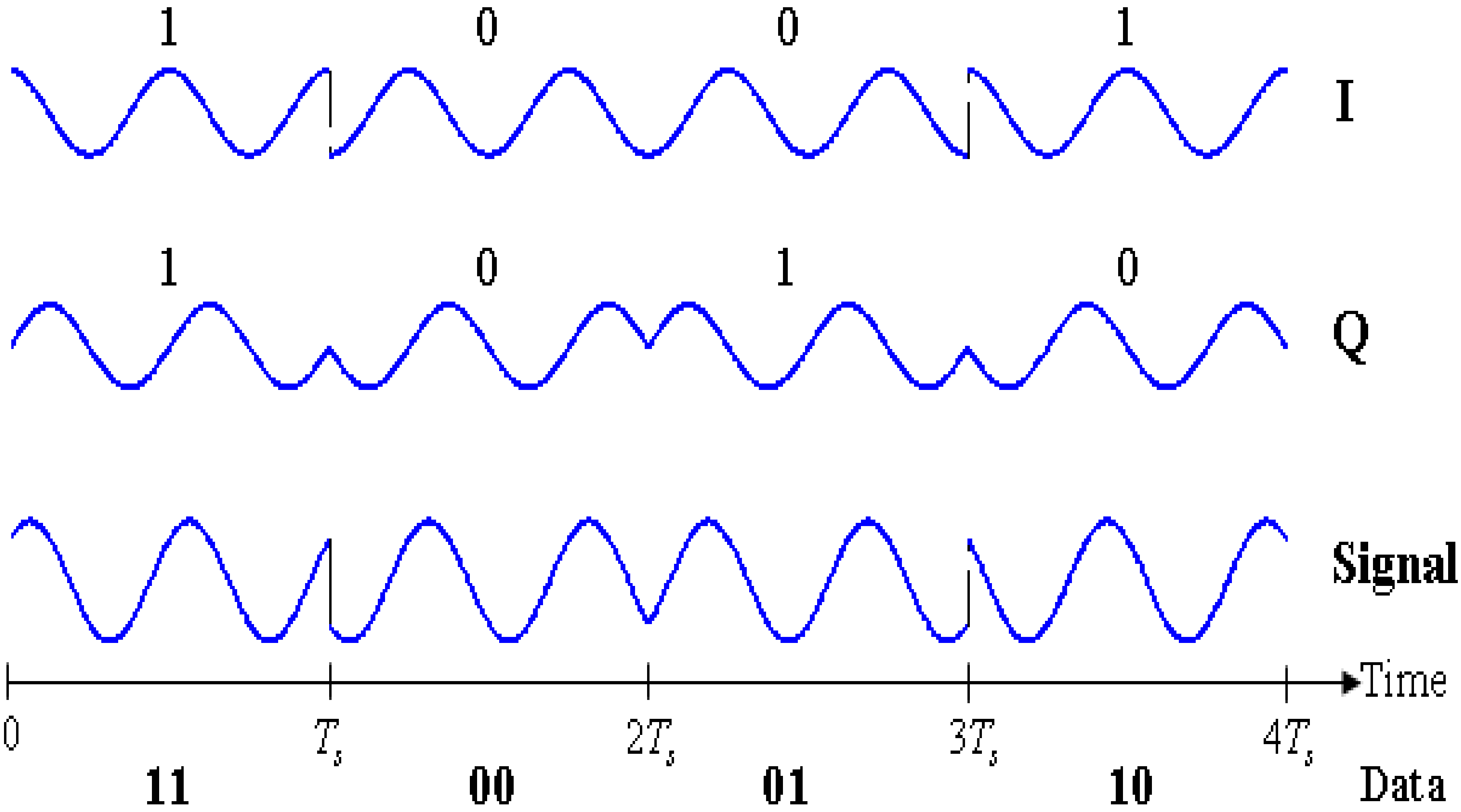
Q- Channel

- The input to the system is a binary message stream has bit rate R_b
- The NRZ Encoder will convert the unipolar message to bipolar bit sequence.
- The serial to parallel convertor will split the stream of bits into two separate data streams.
- They are provided to the I-channel and Q-Channel.

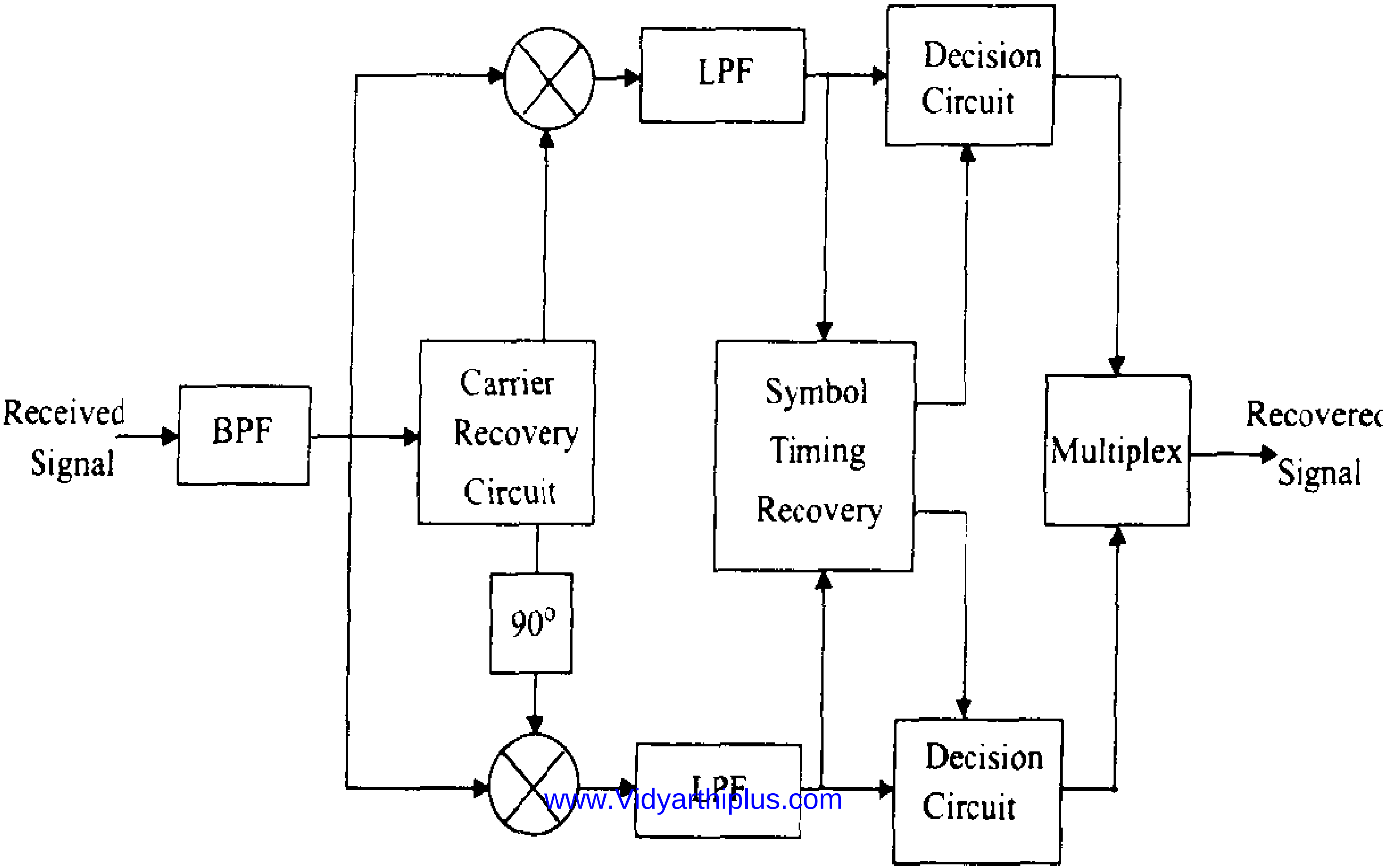
- The bit stream $m_I(t)$ is called the "even" stream and m_Q (t) is called the "odd" stream
- The oscillator produces a high frequency carrier.
- The 90^o phase shifter will produce an exactly out of phase signal to that of the carrier.
- The two binary sequences are separately modulated by two carriers

- The two modulated signals are summed to produce a QPSK signal.
- The filter at the output of the modulator confines the power spectrum of the QPSK signal within the allocated band.
- This prevents spill-over of signal energy into adjacent channels and also removes out-of-band spurious signals generated during the modulation process

QPSK- Waveforms



Receiver


Received Signal
BPF
Carrier Recovery Circuit
90⁰
LPF
LPF
Decision Circuit
Decision Circuit
Symbol Timing Recovery
Multiplex
Recoverec
Signal

- A carrier recovery is used to estimate the frequency and phase of a received signal's carrier.
- The incoming signal is split into two parts, and each part is coherently demodulated using the in-phase and quadrature carriers.
- The decision making device is used to regenerate digital signals. It uses a threshold level to distinguish between “0” & “1”

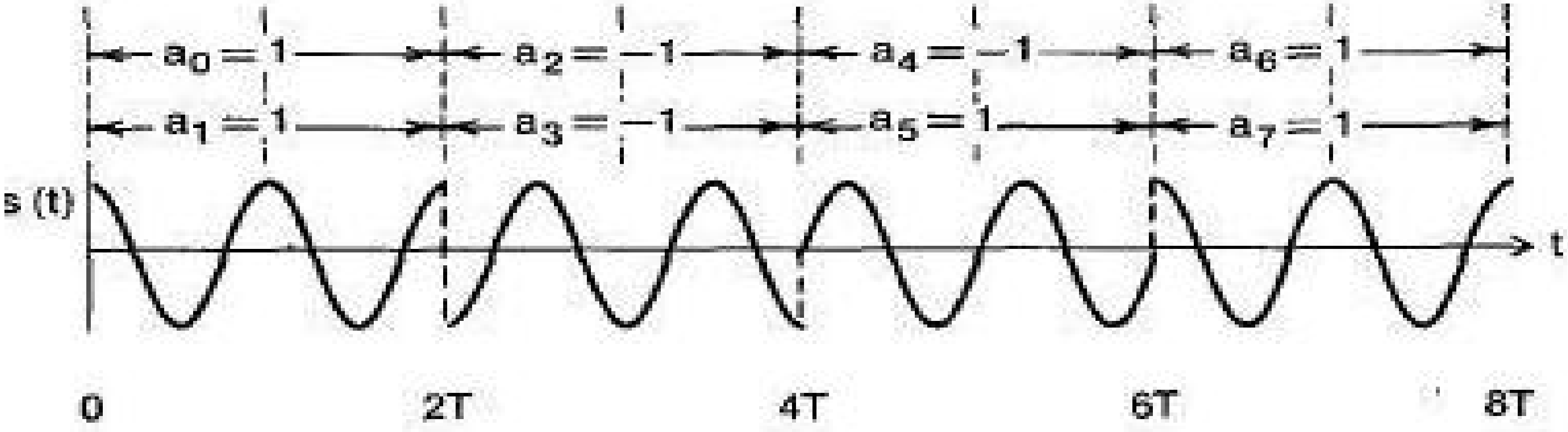
OFFSET QPSK

Offset QPSK

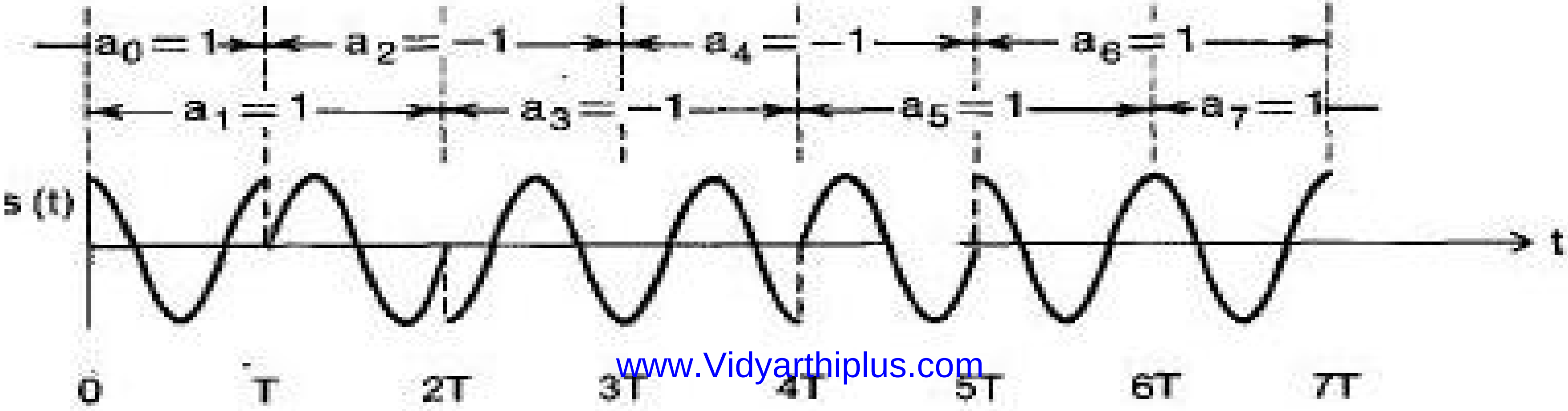
- In QPSK phase shift of π radians will cause the amplitude to fluctuations.
- This will lead to generation of side lobes and spectral widening.
- To reduce this 180° phase shift we use O-QPSK
- In this we have only 90° shifts.
- This is achieved by delaying one channel by T_b sec

- In QPSK the even and odd bit streams occur at the same time instants.
- But in OQPSK signaling, the even and odd bit streams, $m_I(t)$ and $m_Q(t)$ are offset in their relative alignment by one bit period (half-symbol period).
- Because of this at any given time only one of the two bit streams can change values.
- So the maximum phase shift of the transmitted signal at any given time is limited to ±90°

QPSK


$a_0 = 1$
$a_2 = -1$
$a_4 = -1$
$a_6 = 1$
$a_1 = 1$
$a_3 = -1$
$a_5 = 1$
$a_7 = 1$
s (t)
t
0
2T
4T
6T
8T

O-QPSK

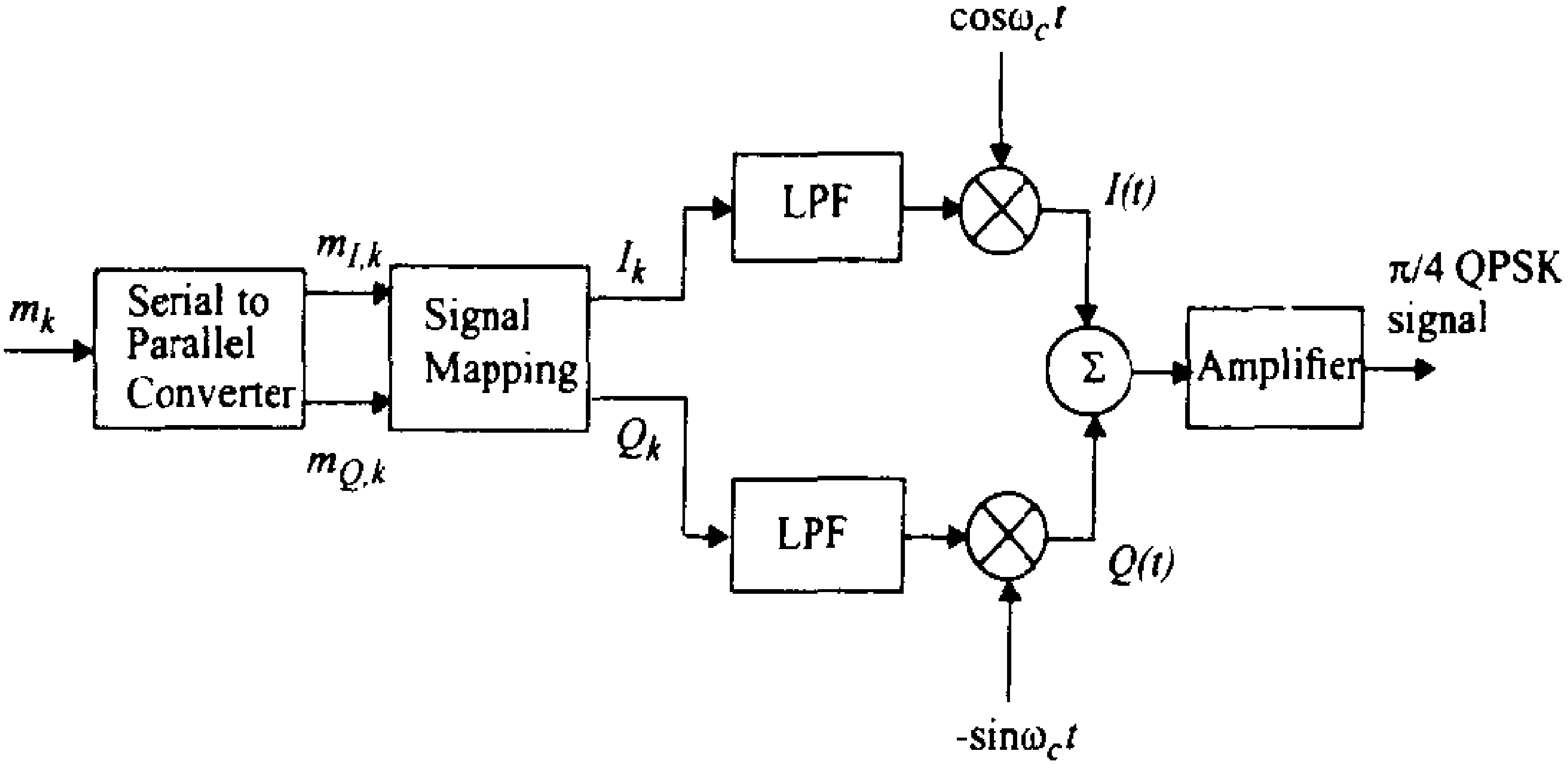

$a_0 = 1$
$a_2 = -1$
$a_4 = -1$
$a_6 = 1$
$a_1 = 1$
$a_3 = -1$
$a_5 = 1$
$a_7 = 1$
s (t)
t
0
T
2T
3T
4T
5T
6T
7T

π/4 QPSK

π/4 QPSK

- In π/4 QPSK the maximum phase change is limited to ±135°.
- So it has less amplitude fluctuations than QPSK.
- It can be detected non coherently .
- The phase shift between successive symbols is an integer multiple of $\pi/4$ radians

π/4 QPSK Generator



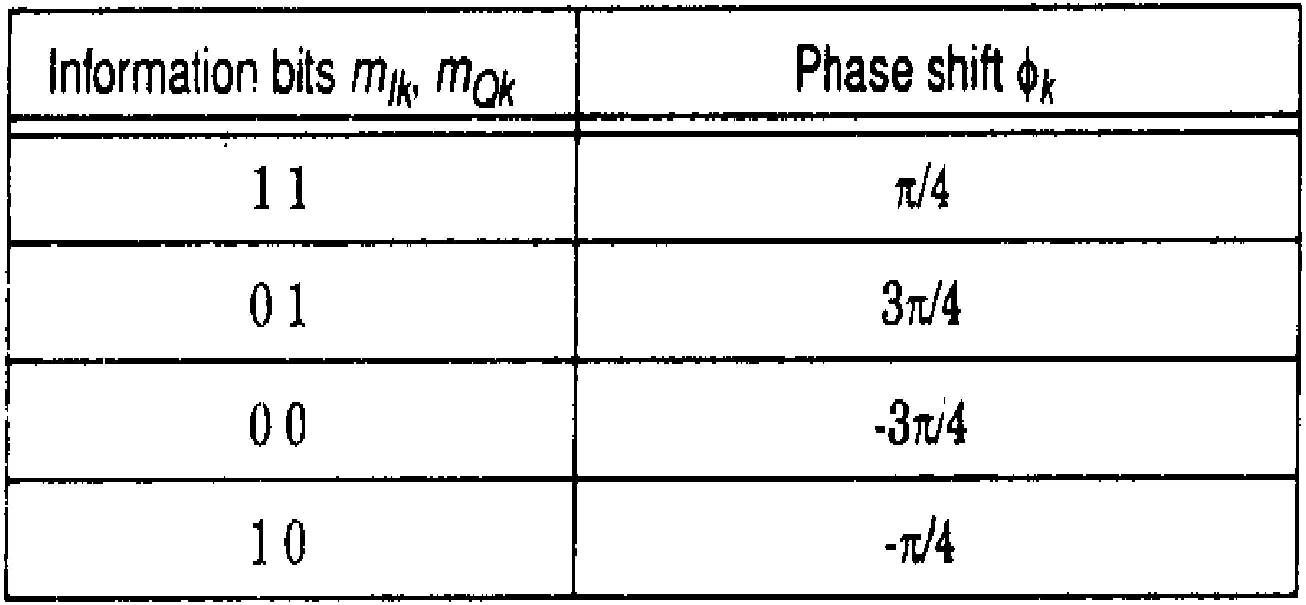
$$s_{\pi/4\,\mathrm{QPSK}}(t) = I(t)\cos\omega_c t - Q(t)\sin\omega_c t$$

where

$$I(t) = \sum_{k=0}^{N-1} I_k p(t - kT_s - T_s/2) = \sum_{k=0}^{N-1} \cos\theta_k p(t - kT_s - T_s/2)$$

$$Q(t) = \sum_{k=0}^{N-1} Q_k p(t - kT_s - T_s/2) = \sum_{k=0}^{N-1} \sin\theta_k p(t - kT_s - T_s/2)$$

$p(t-kT_s-T_s/2)$ *represents pulse shape*



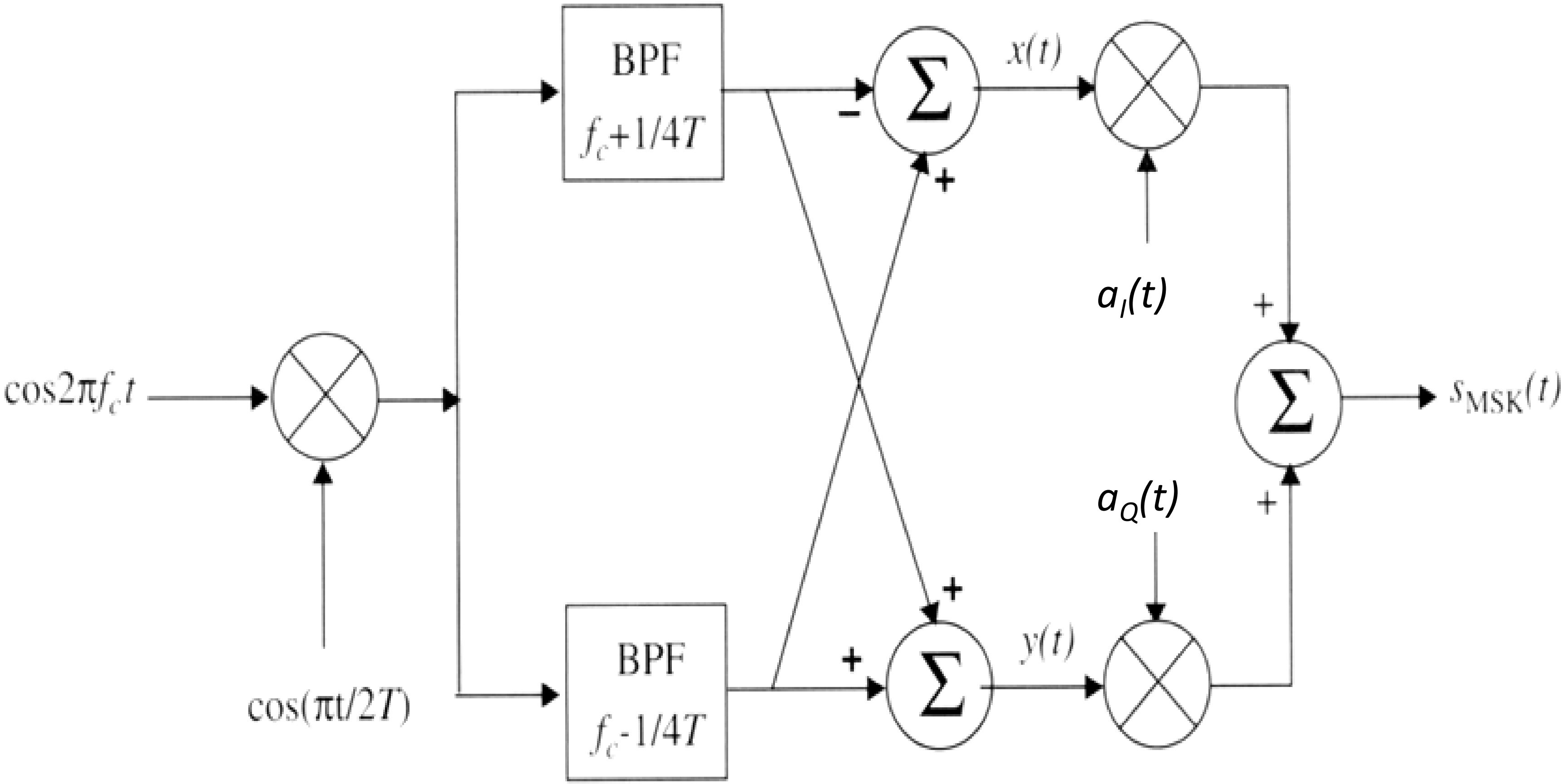
Information bits m_{Ik}, m_{Qk}	Phase shift ϕ_k
1 1	$\pi/4$
0 1	$3\pi/4$
0 0	$-3\pi/4$
1 0	$-\pi/4$

MINIMUM SHIFT KEYING

Intro….

- QPSK results in larger side lobes due to the phase change of 90^0 or $180^{0.}$.
- So to reduce this we use MSK, where the peak deviation is ¼ of bit rate.
- MSK is closely related to OQPSK, where we replace rectangular pulses by sinusoidal pulses.
- Modulation index of MSK is 0.5

MSK Transmitter



Block diagram of an MSK transmitter.

- MSK uses two frequencies which are separated by 1/4T.
- The carrier frequency is choose to be the multiple of 1/4T

  $f_c - 1/4T$ & $f_c + 1/4T$.
- The filtered signal is then multiplied with the odd and even data sequences to form MSK signal.

- $S_{MSK}(t) = a_I(t)\cos(\pi/2T)t.\ \cos 2\pi f_c t + a_Q(t)\sin(\ \pi/2T)t\ .\ \sin 2\pi f_c t$

$a_I(t)$ = In-phase bit sequence (Even)

$a_Q(t)$ = Qudrature sequence (odd)

let $b_k(t) = a_I(t)\ .\ a_Q(t)$

after simplification

$S_{MSK}(t) = \cos[2\ \pi f_c t + b_k(t)\ \pi t/2T + \phi_k\ ]$

$a_I(t)$ & $a_Q(t) = +1$ for Binary "1" & $\Phi_k = 0$

$a_I(t)$ & $a_Q(t) = -1$ for Binary "0" & $\Phi_k = \pi$

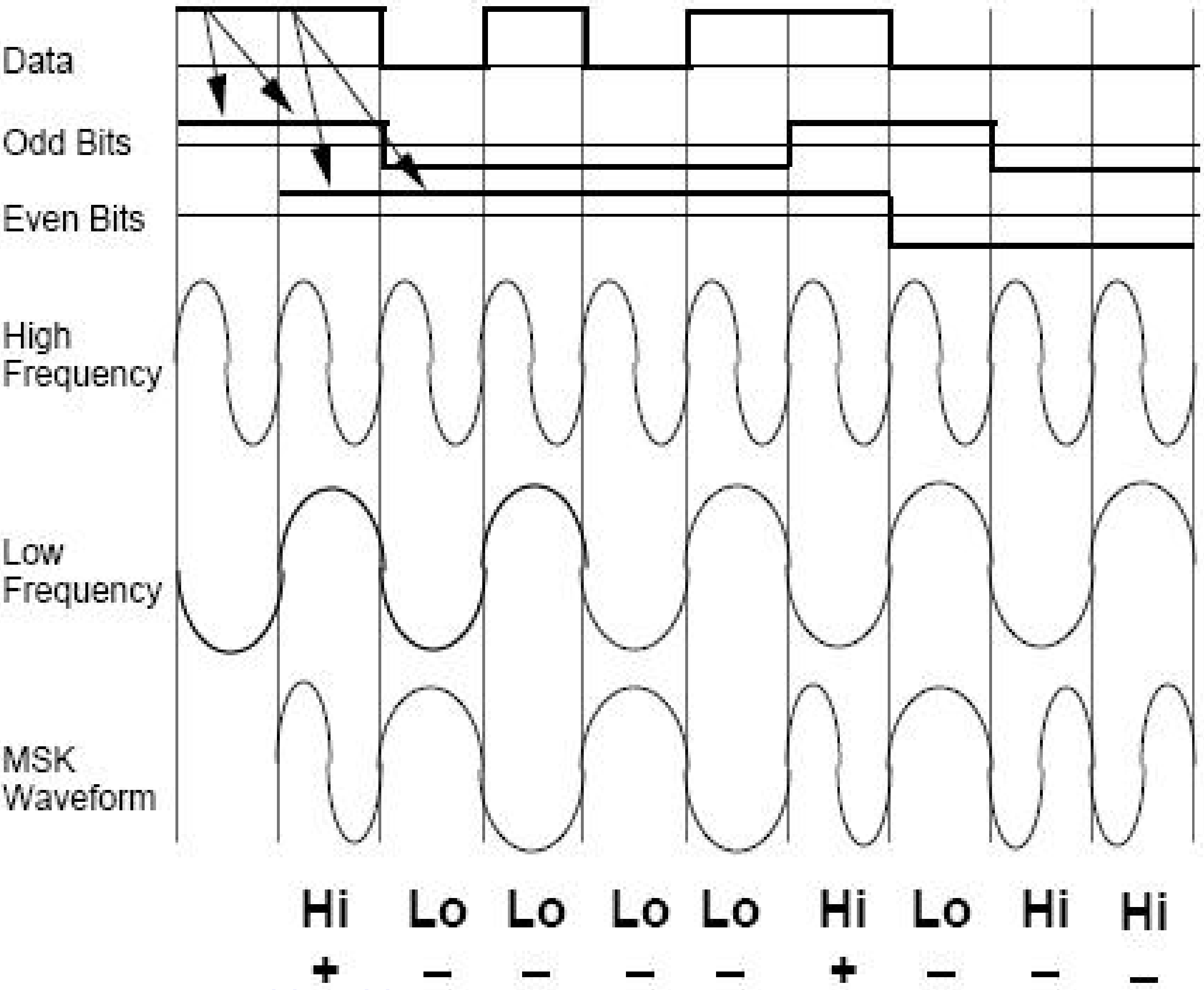
Also $b_k(t) = 0$ if $a_I(t)$ & $a_Q(t)$ are opposite

$b_k(t) = 1$ if $a_I(t)$ & $a_Q(t)$ are same

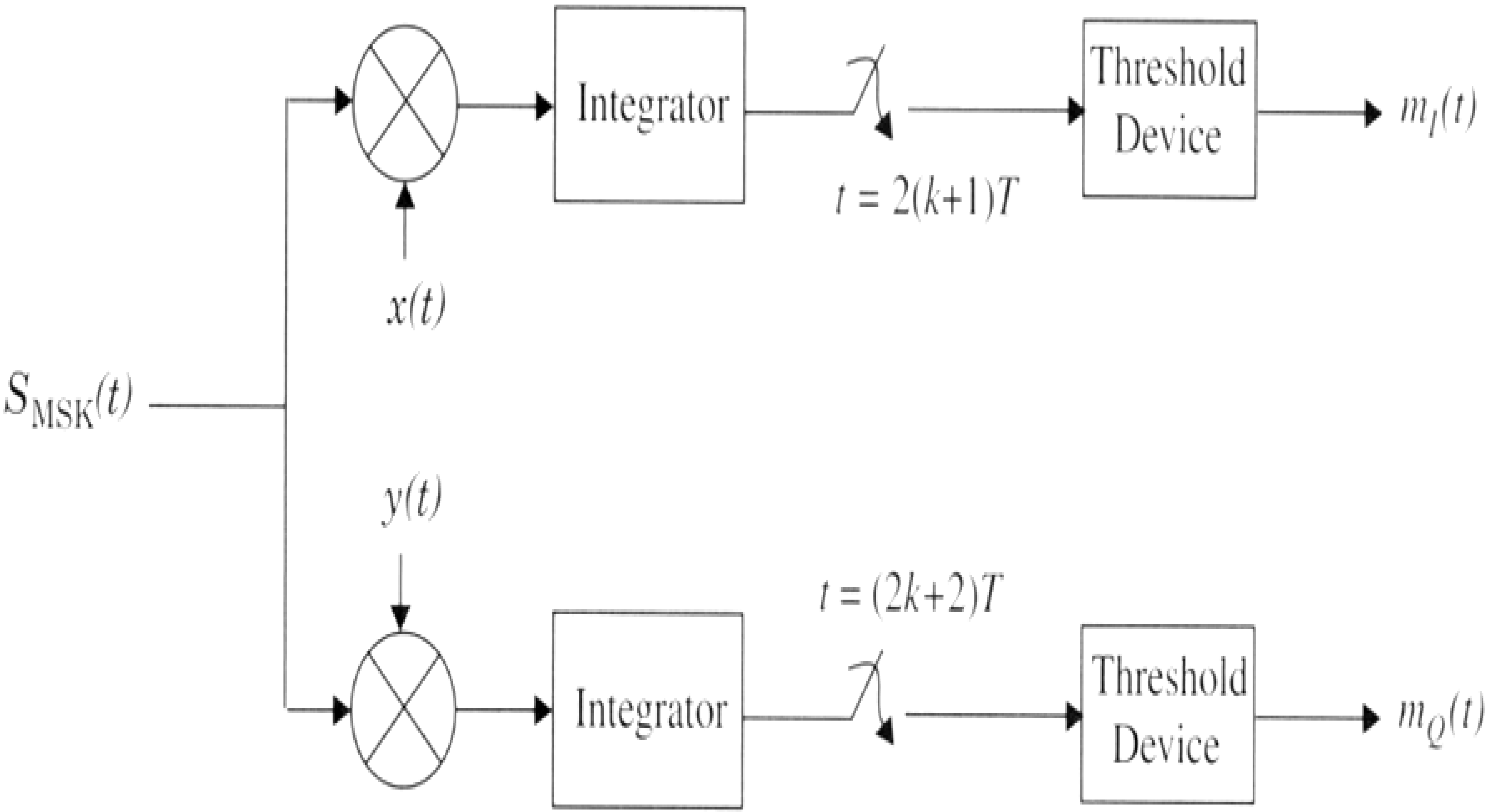
Generating Minimum Shift Keying

Odd, Even Bits stretched to 2 bit times

Bit Value		MSK Output	
Odd	Even	Freq	Sense
1	1	Hi	+
-1	1	Lo	–
1	-1	Lo	+
-1	-1	Hi	–

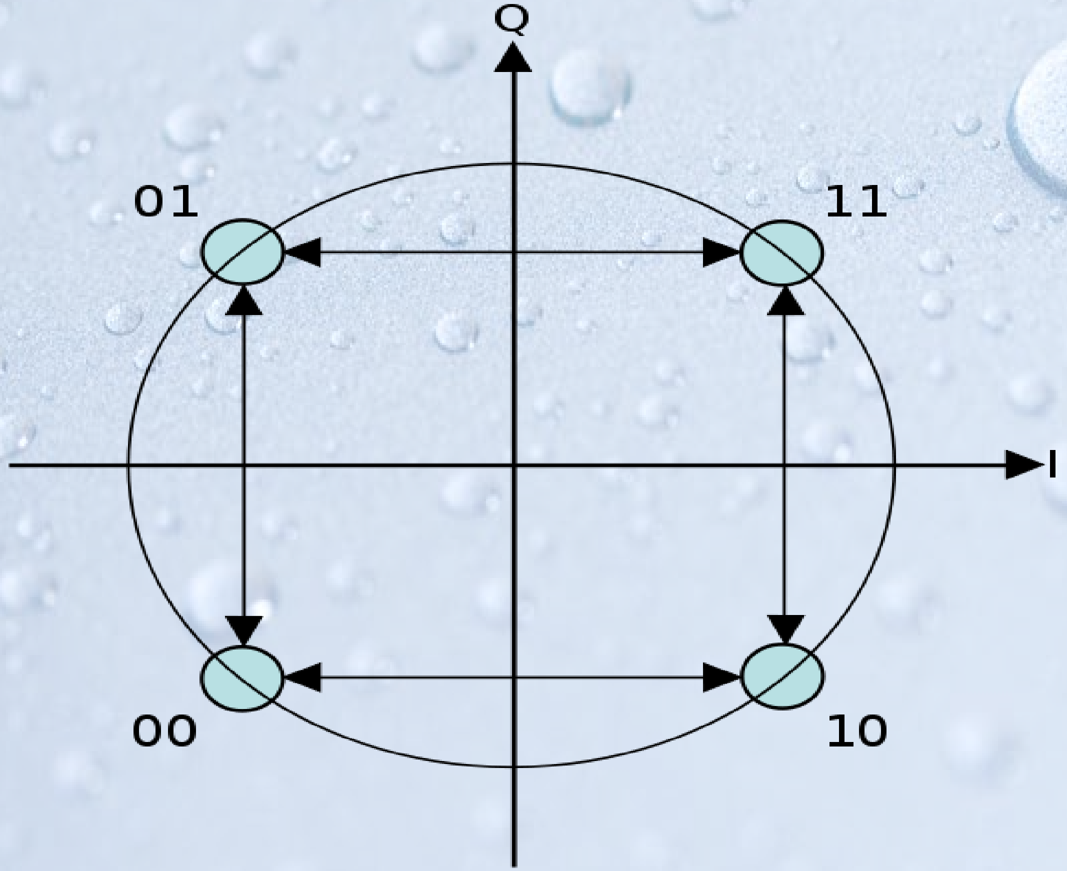


MSK Receiver



Block diagram of an MSK receiver.

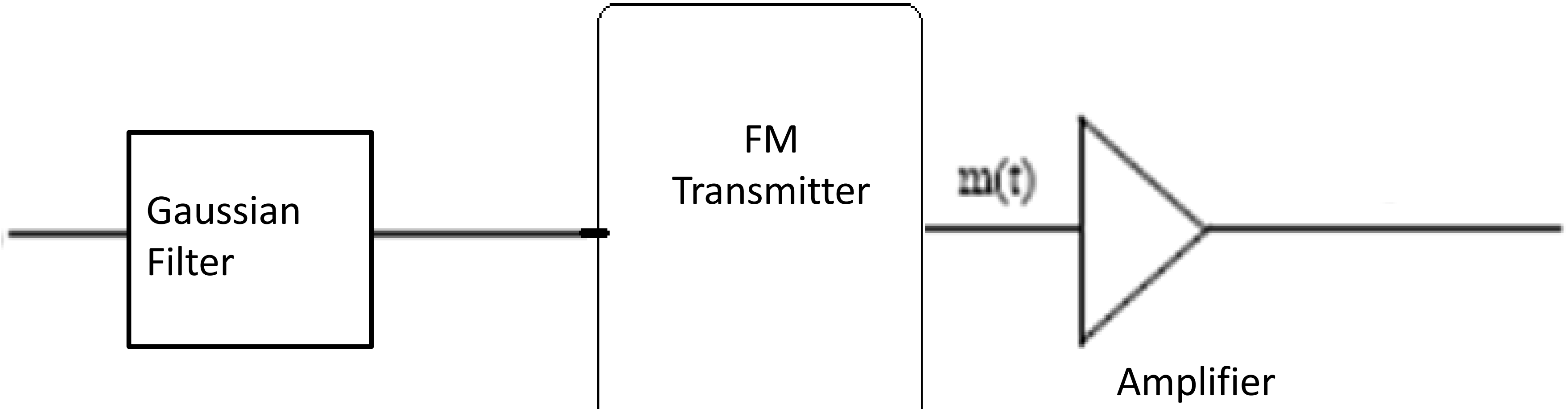
Phasor Diagram



GAUSSIAN MINIMUM SHIFT KEYING

- In GMSK the side lobe levels of the spectrum are further reduced.
- GMSK will minimize bandwidth, improve spectral performance, and easy for detection.
- GMSK has excellent power efficiency , so it is used for GSM applications.
- But GMSK is affected by ISI.

GMSK Transmitter



Gaussian Filter

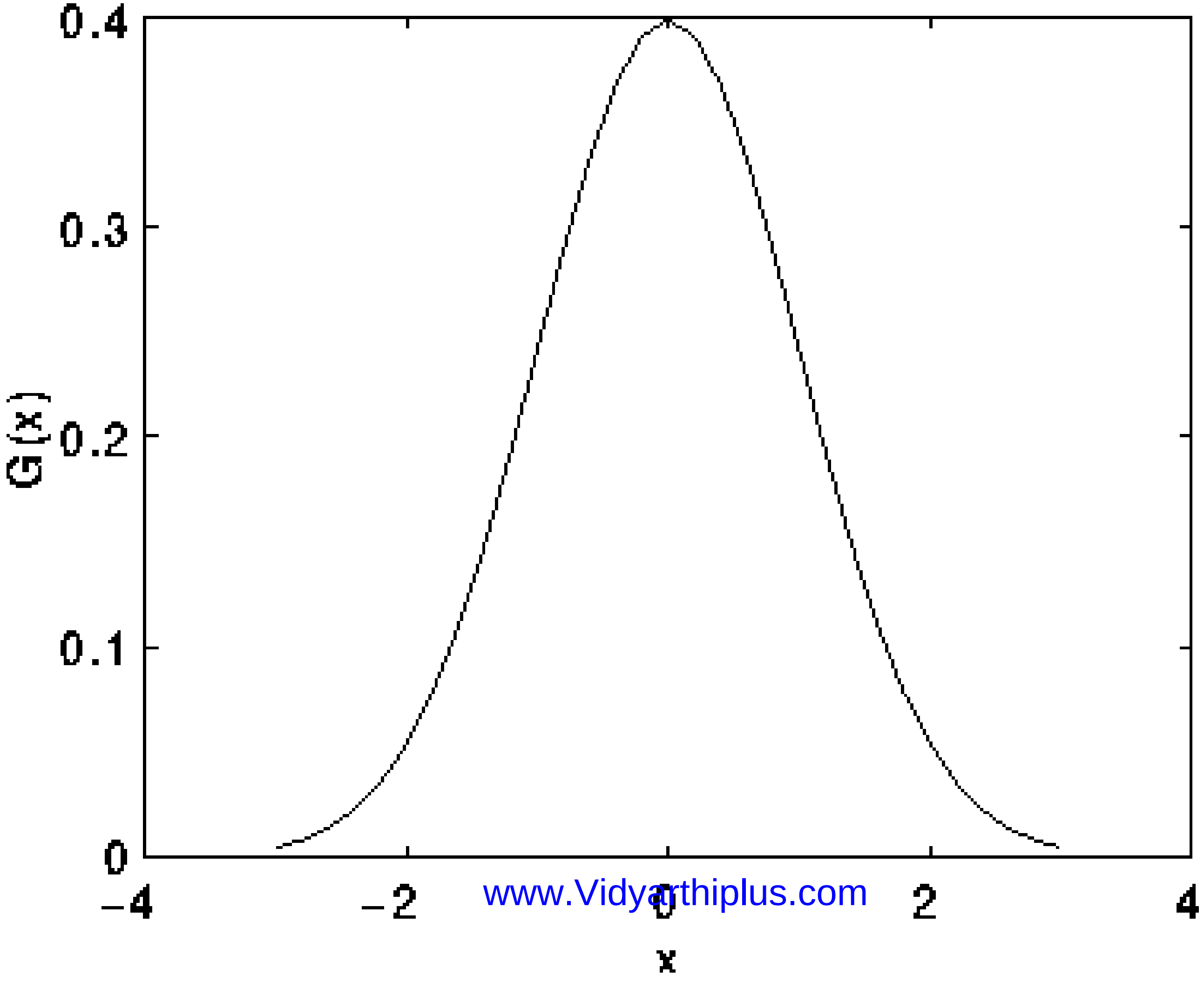
FM Transmitter

m(t)

Amplifier

- An unfiltered binary data stream will produce an RF spectrum of considerable bandwidth.
- A Gaussian pulse-shaping filter smoothes the phase trajectory of input NRZ code.

Gaussian Filter response



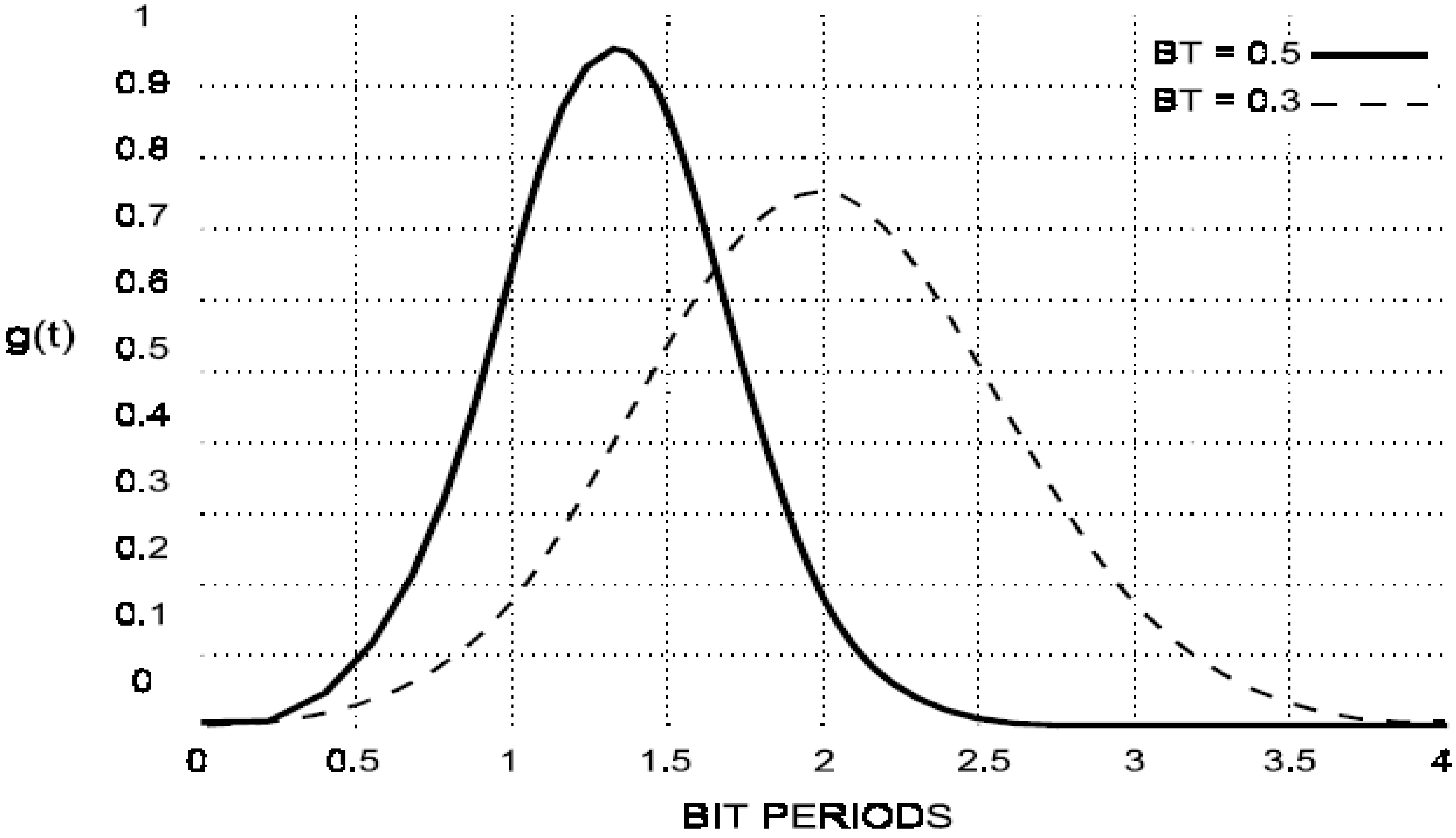
- The impulse response of the filter is

$$h_G(t) = \frac{\sqrt{\pi}}{\alpha}\exp\left(-\frac{\pi^2}{\alpha^2}t^2\right)$$

BT- bandwidth-bit duration product is

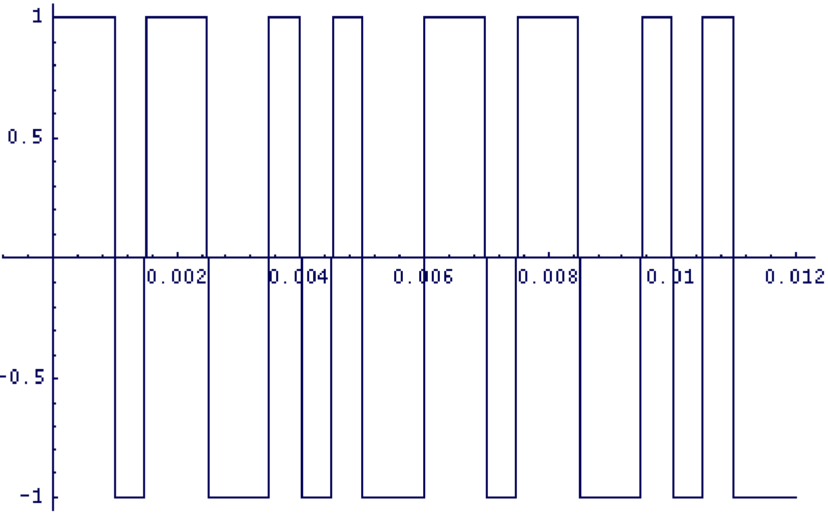
$$BT = \frac{f_{-3dB}}{BitRate}$$

As the BT value decreases the GMSK spectrum becomes more compact and the ISI increases .

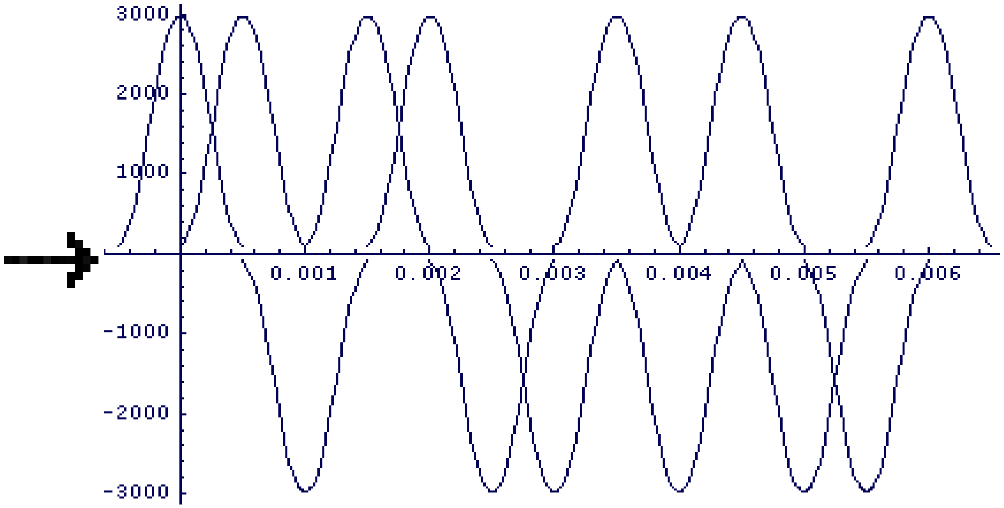


- For BT=0.3 the adjacent symbols will interfere with each other more than for BT=0.5

Pulse Shaping



Input NRZ



Output from filter

- Input: Binary NRZ Signal
- Each binary pulse goes through a Gaussian LPF
- The filter smoothes the phase trajectory of the binary pulses and stabilizes the instantaneous frequency variations.
- The power spectrum of MSK & GMSK are equivalent.

Bit Error Rate

- The bit error probability is a function of *BT.*

$$P_e = \sqrt{\frac{2\gamma E_b}{N_0}}$$

- Where γ is a constant related to *BT*

$$\gamma = \begin{cases} 0.68 \text{ for GMSK with } BT = 0.25 \\ 0.85 \text{ for simple MSK BT} = \infty \end{cases}$$

- E_b/N_0 is the energy per bit to noise power spectral density ratio.
- It is a normalized signal-to-noise ratio (SNR) measure, also known as the "SNR per bit“
- N_0 = Noise Spectral Density

$$\frac{E_b}{N_0} = \frac{S}{RN_0} = \frac{S}{N}\left(\frac{B_n}{R}\right)$$

where,

S = signal power

R = data rate in bits per second

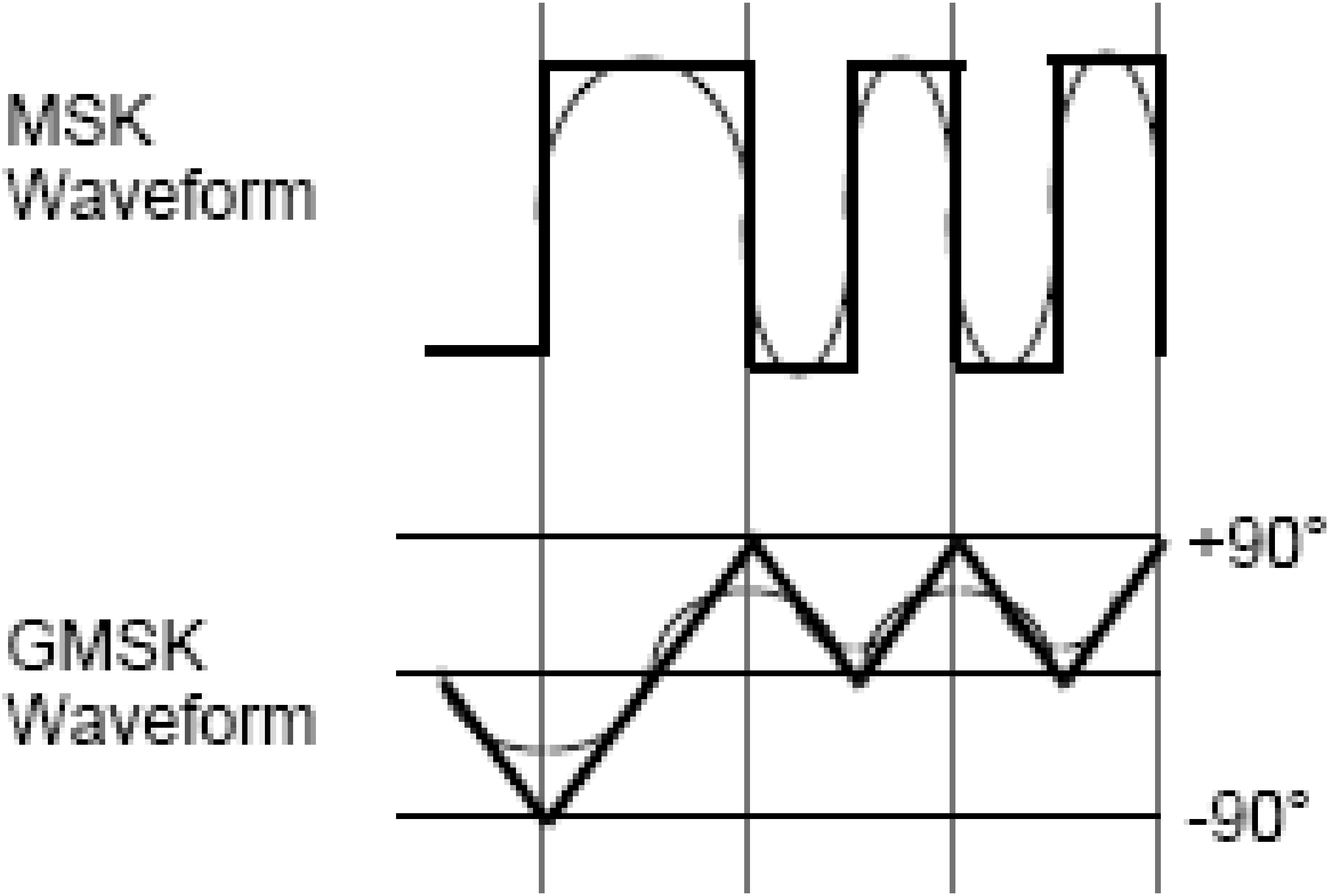
N_0 = noise power spectral density (watts/Hz)

E_b = energy per bit

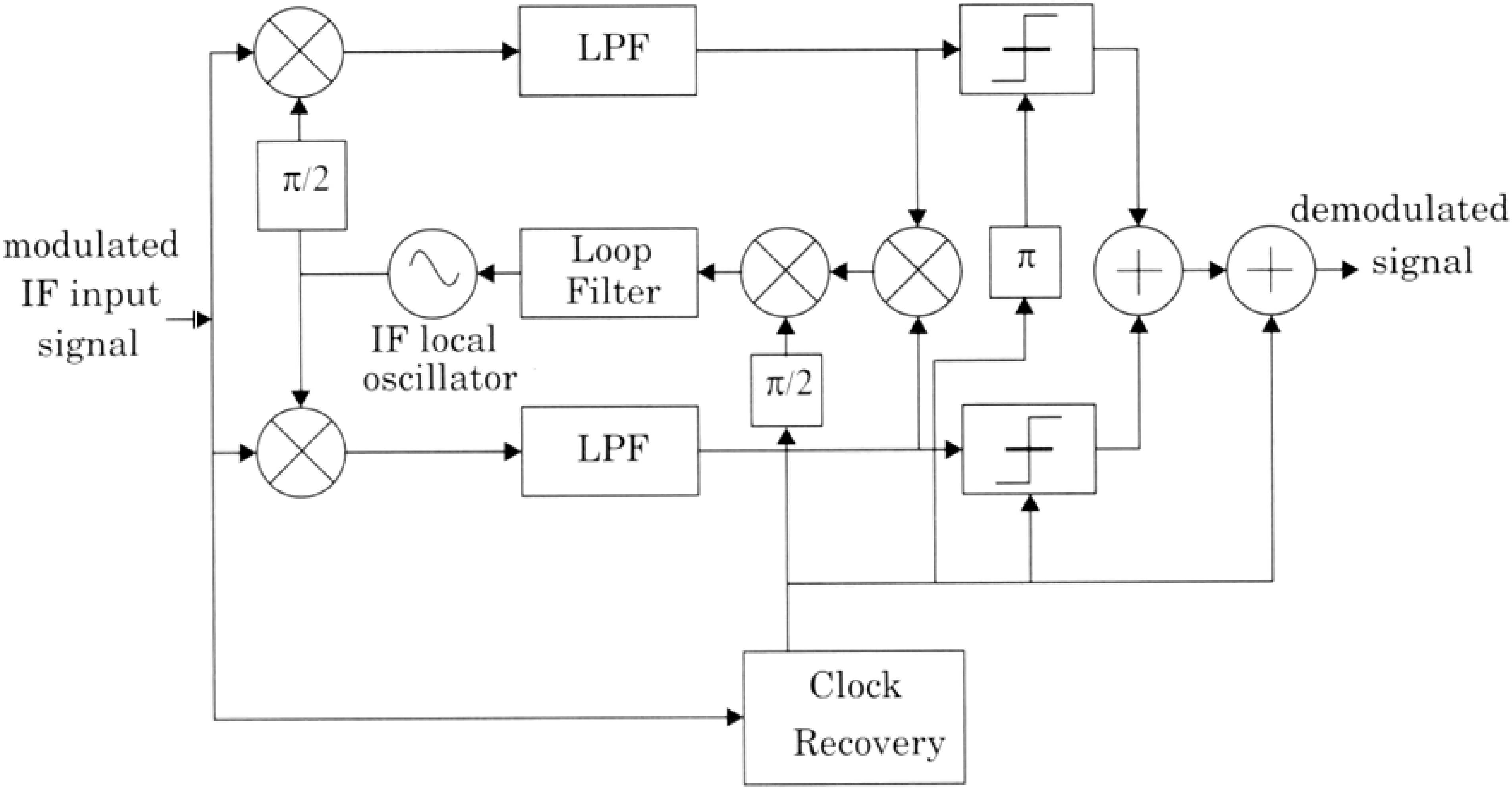
$B_n \times N_0 = N$ = noise power

B_n = noise BW of IF filter

MSK Vs GMSK



Receiver



Block diagram of a GMSK receiver.

WIRELESS COMMUNICATION

IV. SIGNAL PROCESSING IN WIRELESS SYSTEMS

Principle of Diversity, Macro diversity , Micro diversity, Signal Combining Techniques, Transmit diversity, Equalizers- Linear and Decision Feedback equalizers, Review of Channel coding and Speech coding techniques

Diversity Techniques

- **Diversity** is a method for improving the reliability of a message signal by using two or more communication channels with different characteristics.
- It is based on the fact that individual channels experience different levels of fading and interference.
- The main concept of diversity is that if one radio path undergoes a deep fade, another independent path may have a strong signal.

- *Diversity* is usually implemented by using two or more receiving antennas.
- Multiple versions of the same signal may be received and combined in the receiver
- Diversity plays an important role in combating fading, co-channel interference and avoiding error bursts.

Types

1. Micro Diversity
2. Macro Diversity

Micro Diversity Techniques

Types

A. Space or Antenna diversity

B. Polarization diversity

C. Frequency diversity

D. Time diversity

Space or Antenna Diversity

A. Space or Antenna diversity

- It uses two or more antennas to improve the quality .
- Antenna diversity is effective at negating the multipath loss.
- Each antenna will experience a different level of interference. Thus, if one antenna is experiencing a deep fade, another antenna will have sufficient signal.
- Collectively such a system can provide a efficient signal

Space diversity reception methods

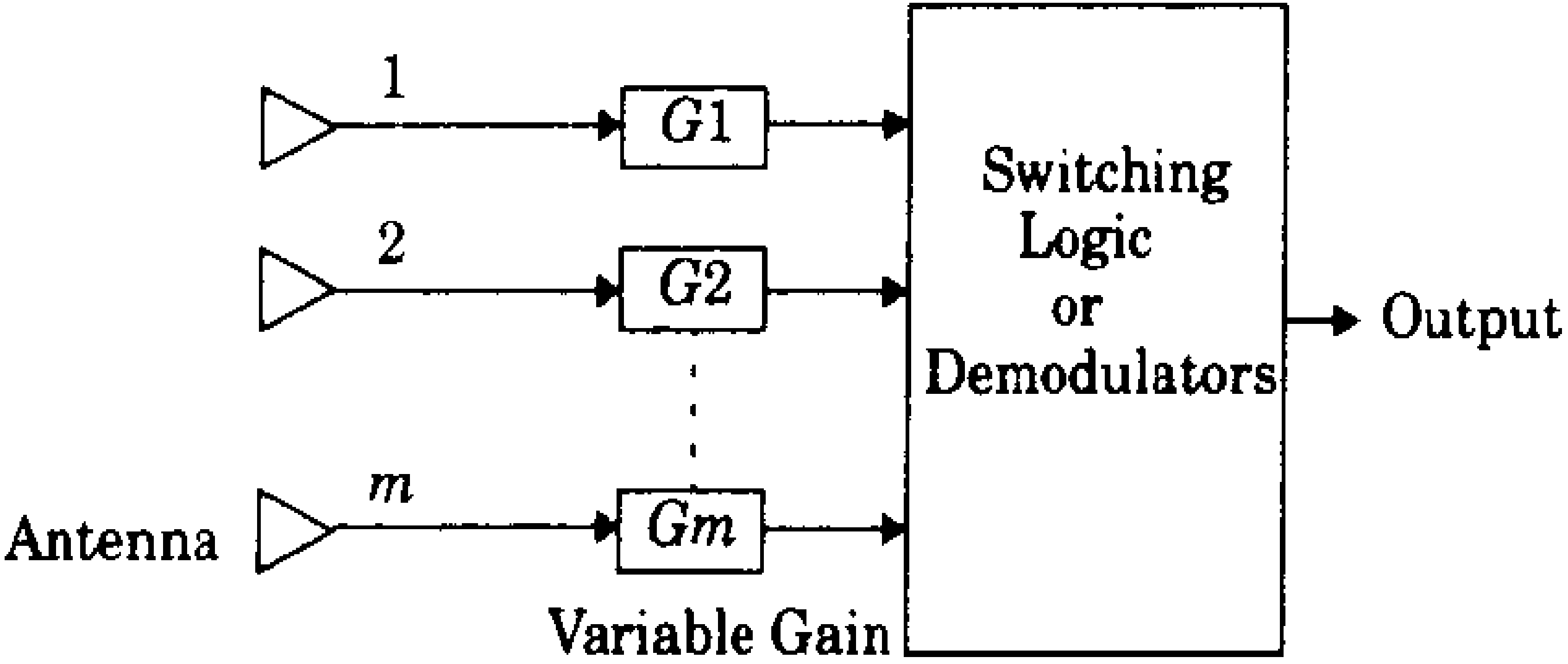
a. Selection diversity

b. Feedback or Scanning Diversity

c. Maximal ratio combining

d. Equal gain diversity

a. Selection diversity

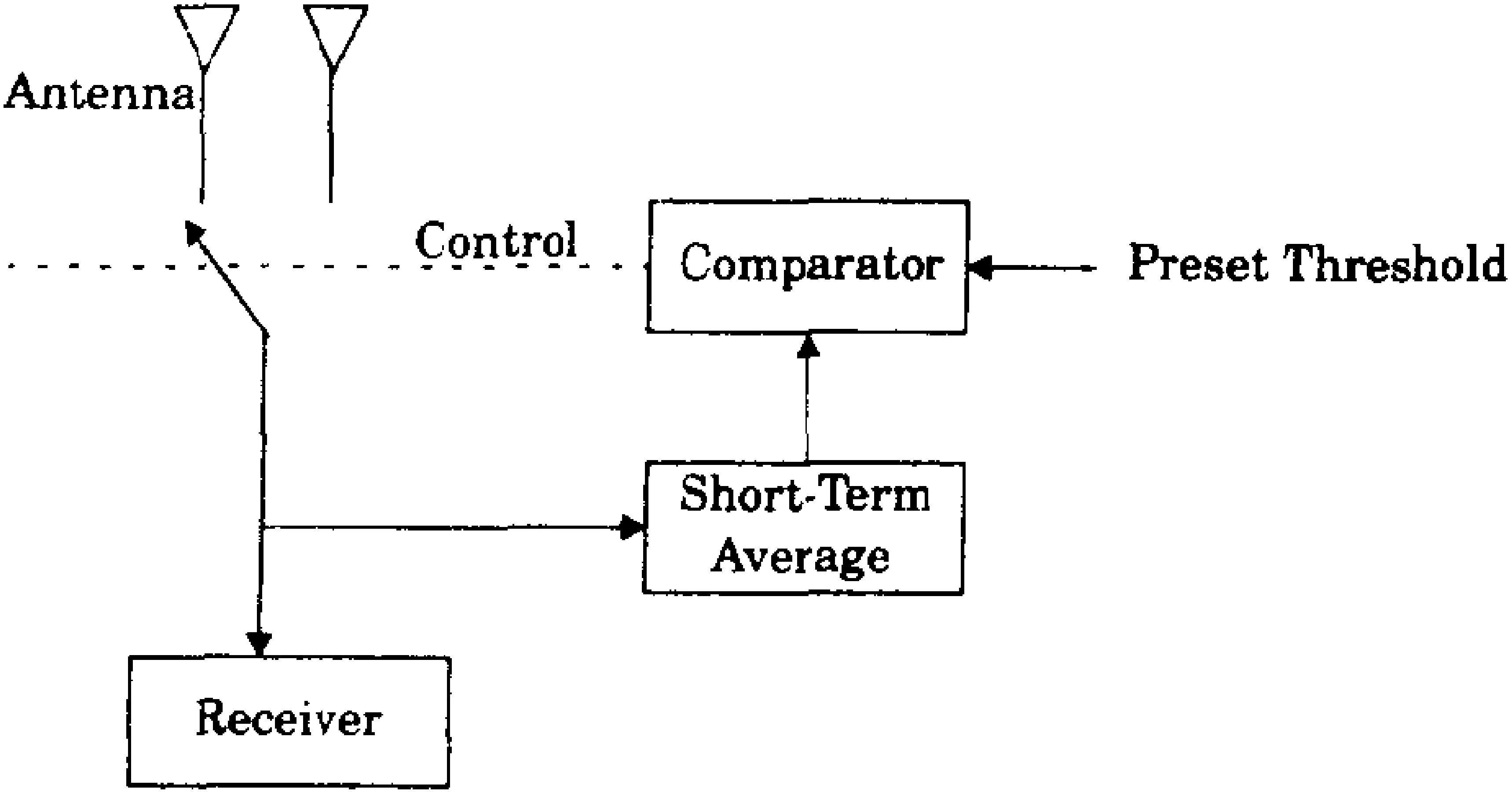


- Here *m* antennas are used to provide “*m*” diversity branches.
- At any particular instant the receiver branch having the highest instantaneous SNR is connected to the demodulator.

Disadvantage:

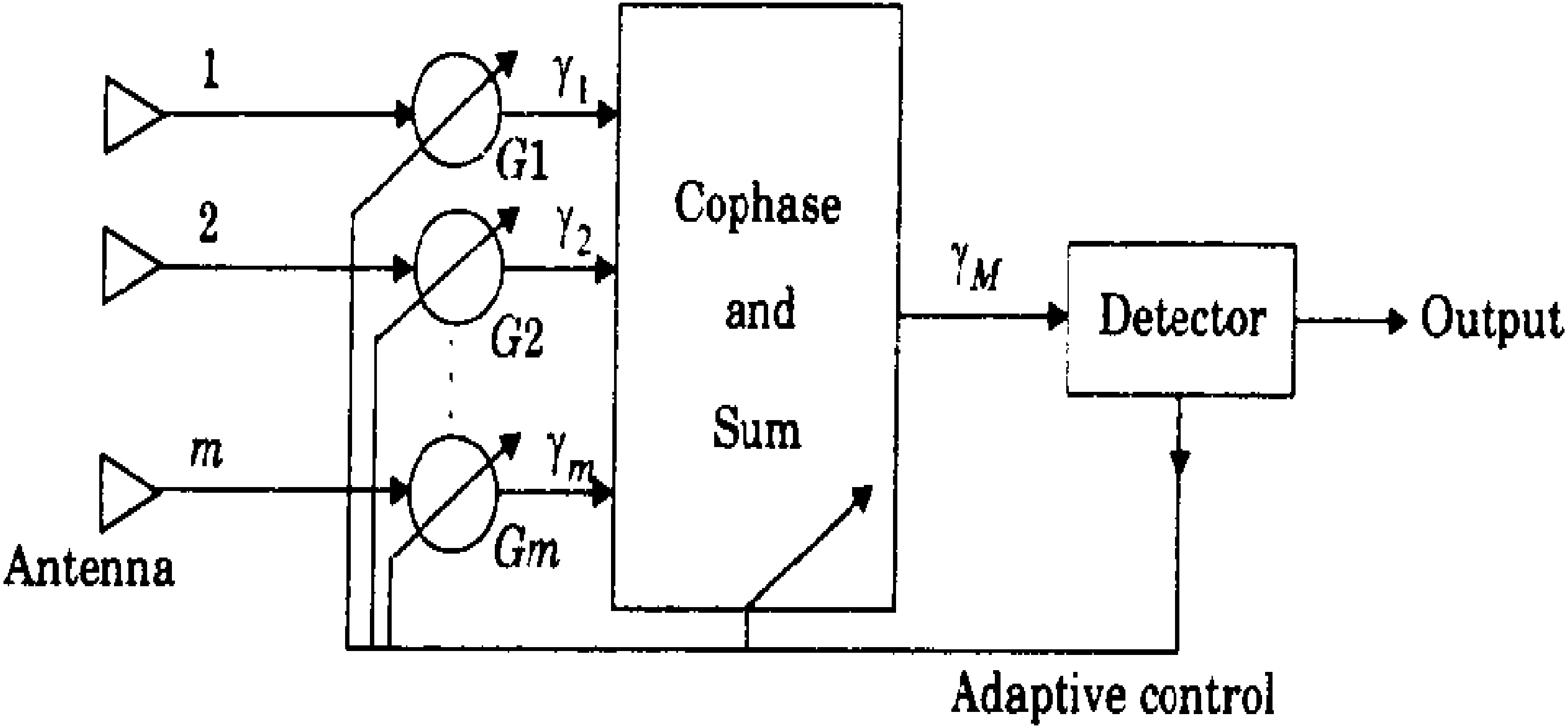
- It is hard to switch between antennas in real time.

b. Feedback or Scanning Diversity



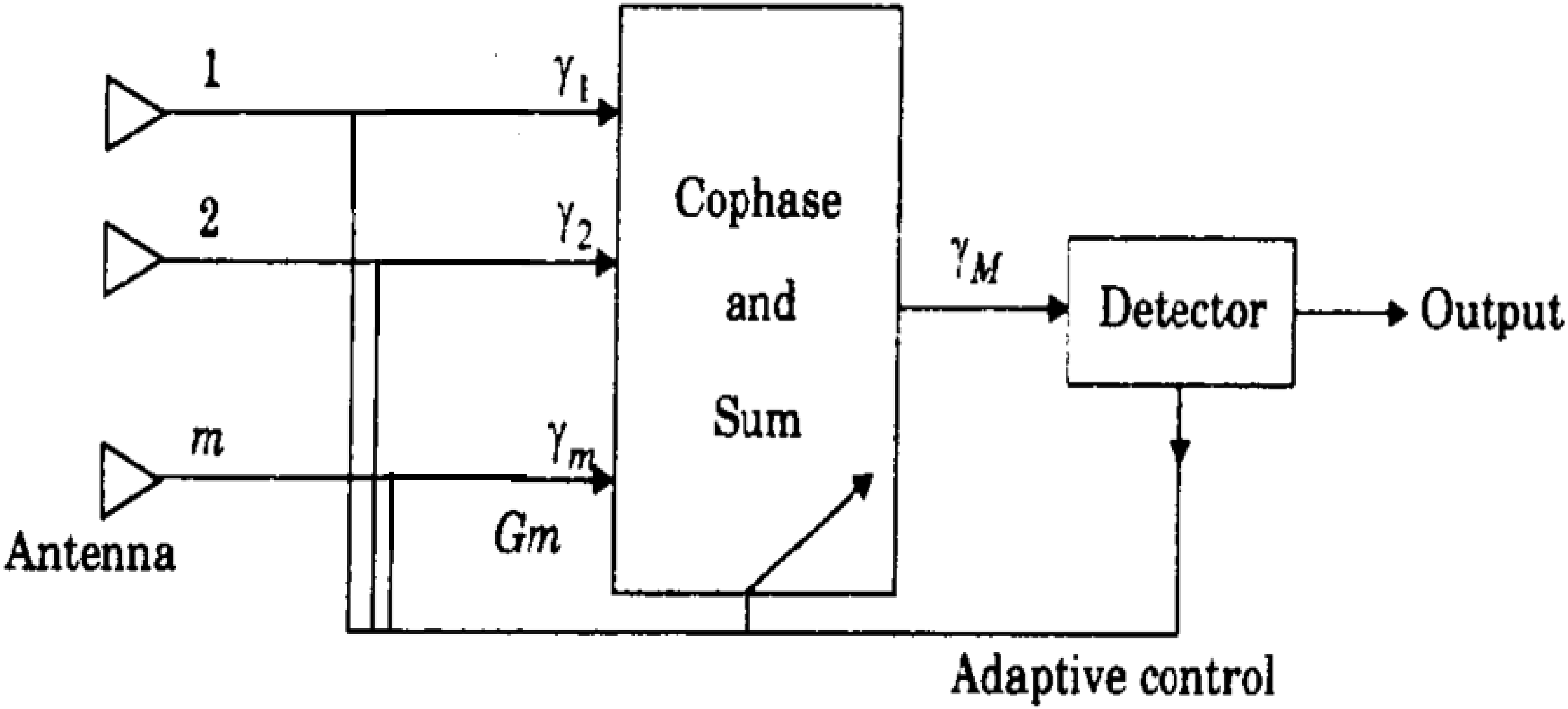
- In this instead of always using the best of “*m*” signals, the “*m*” signals are scanned and one signal is found to be above a predetermined threshold.
- This signal is then locked to the receiver until it falls below threshold .
- And after this a new scanning process is initiated.

c. Maximal ratio combining



- In this the all the co phased signals of the *“m”* branches are weighted according to their individual signal voltage to noise power ratios and then summed.
- Maximal ratio combining produces an output SNR equal to the sum of the individual SNRs

d. Equal gain diversity



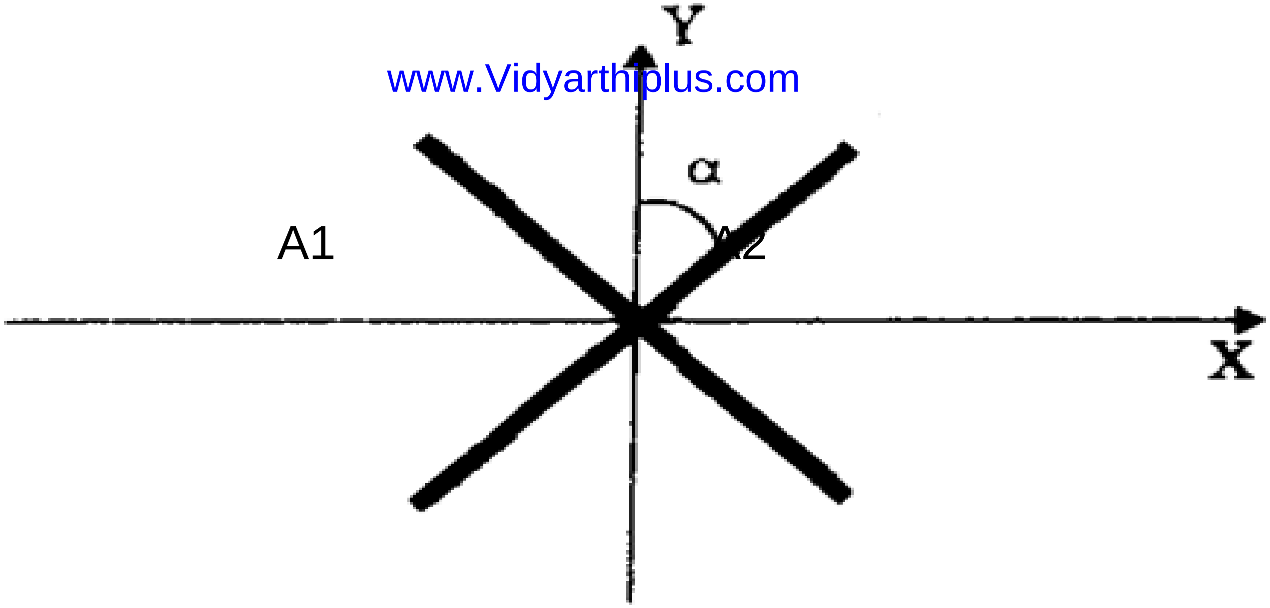
- In certain cases, it is not convenient to provide for the variable weighting capability as used in ***Maximal ratio combining.***
- For such cases the branch weights are all set to unity.

Polarization Diversity

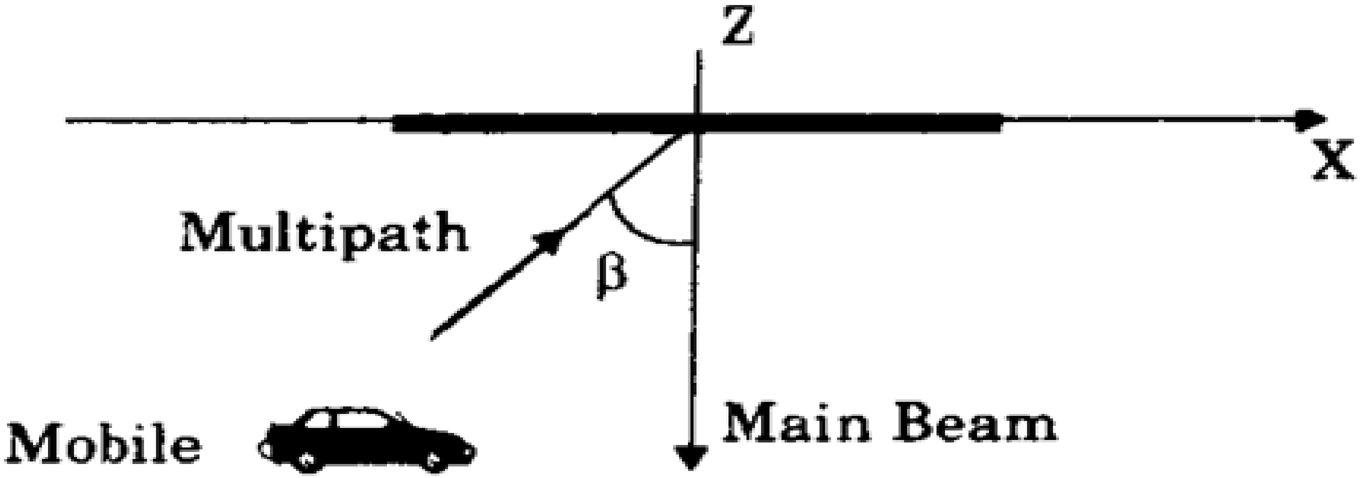
B.Polarization diversity

- Space diversity is less practical since large antenna spacing was required to have enough angle of incident.
- Polarization diversity allows us to have the antenna elements to be co-located.
- This provides diversity by orthogonal (*horizontal and vertical*) polarization

- Circular and linear polarized antennas are used to characterize multipath inside buildings .
- Polarization diversity was found to reduce the multi path delay spread without decreasing the received power
- Vertical and horizontal Polarization paths has little correlation. This De-correlation is mainly because of multiple reflections.



(a) *x-y* plane



(b) *x-z* plane

- It is assumed that the signal is transmitted from a mobile with vertical (or horizontal) polarization.
- The base station polarization diversity antenna has 2 branches A_1 and A_2

α = polarization angle

β = offset angle of mobile

Frequency Diversity

- Frequency diversity transmits information on more than one carrier frequency.
- Frequency diversity is implemented using frequency division multiplex mode (FDM).
- Normally 1 frequency will be held as a backup for performing diversity.
- When diversity is needed, the appropriate traffic is simply switched to the backup frequency

Disadvantage

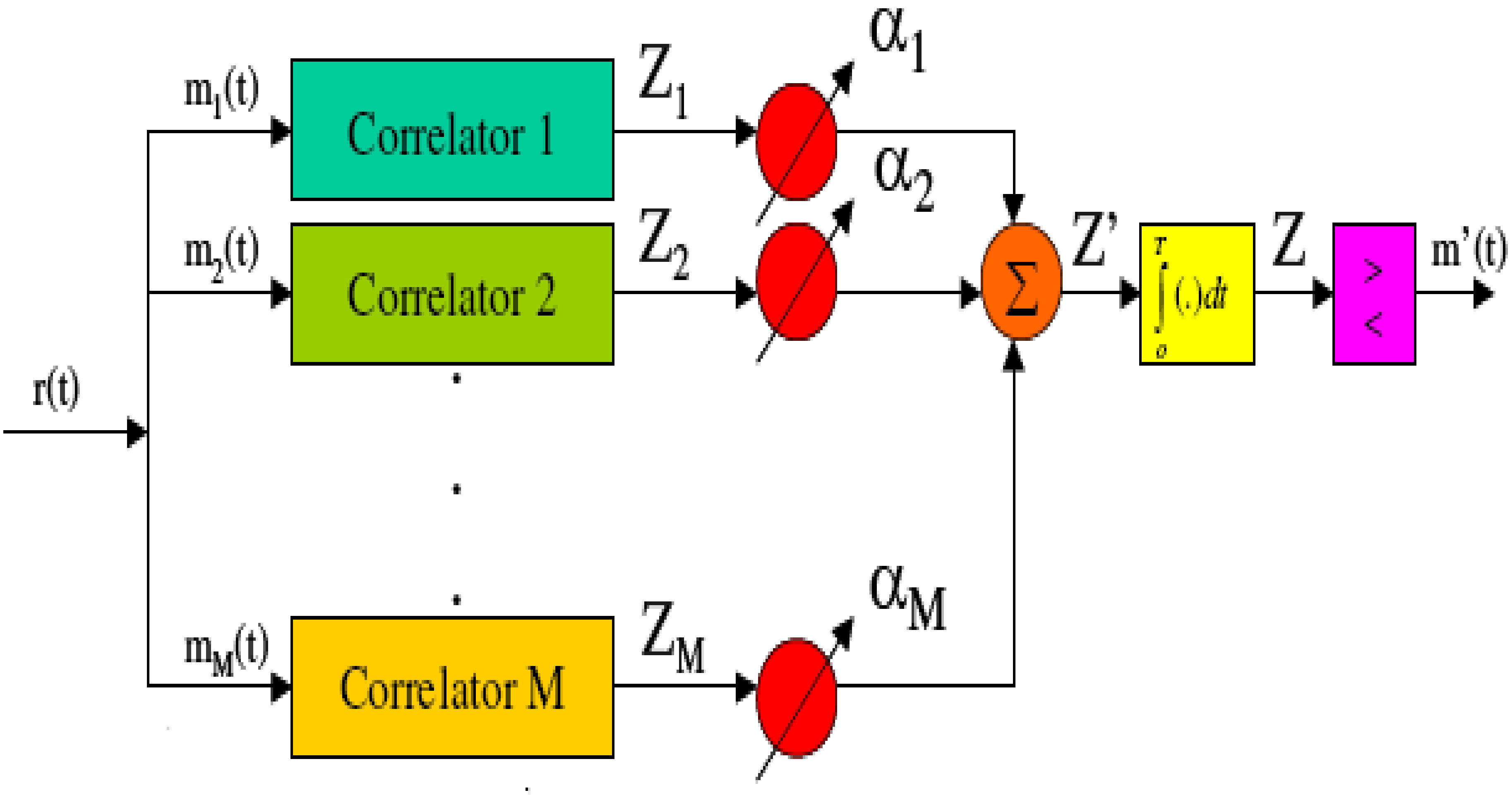
- It requires additional bandwidth
- Many receivers are necessary to record Frequency diversity

Time Diversity

- Time diversity repeatedly transmits information at time spacing
- E.g RAKE RECEIVER

RAKE RECEIVER

- Rake receiver is designed to counter the effects of multipath fading.
- If multipath components are delayed in time by more than one chip duration ($1/R_c$), they appear like uncorrelated noise
- It is mainly used in reception of CDMA signals where conventional equalization wont work.
- Multipath results in multiple versions of the transmitted signal at the receiver.
- Each component has some information in it.


r(t)
$m_1(t)$
$m_2(t)$
$m_M(t)$
Correlator 1
Correlator 2
Correlator M
Z_1
Z_2
Z_M
α_1
α_2
α_M
Σ
Z'
$\int_0^T (.)dt$
Z
>
<
m'(t)

- The RAKE receiver uses a multipath time diversity principle.
- It uses several "sub-receivers" called fingers, that is, several correlators each assigned to a different multipath component.
- Each multipath component is extracted by using a single correlator. In all we use several correlators which independently decodes a single multipath component.

- The outputs of each correlator are weighted to provide better estimate of the transmitted signal than is provided by a single component.
- The Integrator is used to provide the average for a specific time period.
- The decision maker is used to regenerate digital signals from the incoming weak signals.

- Outputs of the M correlators are denoted as Z_1, Z_2,…, and Z_M
- The weighting coefficients are based on the power or the SNR from each correlator output
- If the power or SNR is small out of a particular correlator, it will be assigned a small weighting factor, .

the total output Z’ is given by

$$Z' = \sum_{m=1}^{M} \alpha_m Z_m$$

$$\alpha_m = \frac{Z_m^2}{\sum_{m=1}^{M} Z_m^2}$$

- RAKE receiver has to know
  - Multipath delays -> time delay synchronization
  - Phases of the multipath components -> carrier phase synchronization
  - Amplitudes of the multipath components -> amplitude tracking
  - Number of multipath components
- The main challenges is receiver synchronization.

Channel Encoding

Introduction

- According to Shannon it is possible to transmit information without much errors by providing suitable coding mechanisms.
- His idea was the base for all the further developments in coding techniques.

Channel coding

- Channel coding protects digital data from errors by selectively introducing redundancies in the transmitted data.
- A channel coder operates on digital message by encoding the source information into a code sequence for transmission through the channel.

Types

1. Error detection codes. - Channel codes that are used to detect errors
2. Error Correction Codes - Codes that can detect and correct errors

Shannon’s Formula for Information capacity

$$C = B\log_2\left(1 + \frac{P}{N_0 B}\right)$$

- C - channel capacity (bits per second)
- *B* - transmission band-width (Hz),
- *P* - received signal power (watts)
- N_0 -single-sided noise power density (watts/Hz).

Types of error correction and detection codes

1. Block codes
2. Convolutional codes.

Block Codes

- Block codes are also called as forward error correction (FEC) codes
- In block codes the redundant bits are added to data blocks.
- The key idea of FEC is to transmit enough redundant data to allow receiver to recover from errors all by itself, without retransmission.

Key words

- Block coding - source data are grouped into blocks of K symbols.
  - Each of these uncoded data blocks is then converted to a codeword of length N symbols
- *Code rate:* The ratio K/N is called the code rate Rc

- The **Hamming distance** $d_H(x, y)$ *between two codewords is the number of* different bits.

$$d_{\mathrm{H}}(\mathbf{x}, \mathbf{y}) = \sum_{n} |x_n - y_n|$$

- **Weight of a Code** — The weight of a codeword is given by the number of nonzero elements in the codeword

Block Codes

- *Linear codes* - the sum of any two code words gives another valid codeword.
- *Systematic codes* - is one in which the parity bits are appended to the end of the information bits.
- *Cyclic codes* - any cyclic shift of a codeword results in another valid codeword

Encoding

Encoding

- Information is divided into blocks of length k
- “r” parity bits or check bits are added to each block (total length n = k + r),.
- Code rate R = k/n
- So normally a code is represented as (n,k)

Encoding -Steps

- For transforming k bits of data into a “n” bit code word use a k×n **Generator matrix [G].**

http://en.wikipedia.org/wiki/Generator_matrix

- The number of rows of the generator matrix are the number of message bits and the number of columns are equal to the total number of bits

  i.e parity bits + message bits

- P is of dimension *k*×*r*.

$$G = [P \mid I] = \begin{bmatrix} p_1 & 1\,0\cdots 0 \\ p_2 & 0\,1\cdots 0 \\ \cdots & \cdots\cdots\cdots\cdots \\ p_k & 0\,0\cdots 1 \end{bmatrix},$$

- ***C = m G*** *or* ***C(x) = m(x) g(x)***
  - *m is the information codeword block length*
  - *G is the generator matrix*
  - *g(x) is the generator polynomial*
- **G = [p | I]**
  - p_i = Remainder of $[x^{n-k+i-1}/g(x)]$
  - ***I*** is unit matrix or Identity matrix

Example

- Find linear block code , if code generator polynomial *$g(x)=1+x+x^3$ for a (7, 4) code.*

Given

- Number of parity bits $r = n - k = 7 - 4 = 3$
- $g(x)=1+x+x^3$
- p_i = Remainder of $[x^{n-k+i-1}/g(x)]$

- Let $m = [1,0,0,1]$

$$p_1 = \mathrm{Re}\left[\frac{x^3}{1+x+x^3}\right] =$$

$$p_2 = \mathrm{Re}\left[\frac{x^4}{1+x+x^3}\right] =$$

$$p_3 = \mathrm{Re}\left[\frac{x^5}{1+x+x^3}\right] =$$

$$p_4 = \mathrm{Re}\left[\frac{x^6}{1+x+x^3}\right] =$$

$$p_1 = \mathrm{Re}\left[\frac{x^3}{1+x+x^3}\right] = 1+x$$ = [0 1 1]

$$p_2 = \mathrm{Re}\left[\frac{x^4}{1+x+x^3}\right] = x+x^2$$ = [1 1 0]

$$p_3 = \mathrm{Re}\left[\frac{x^5}{1+x+x^3}\right] = 1+x+x^2$$ = [1 1 1]

$$p_4 = \mathrm{Re}\left[\frac{x^6}{1+x+x^3}\right] = 1+x^2$$ = [1 0 1]

Generator Matrix

- G = $\begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix}$

- Code word ***C = m G***

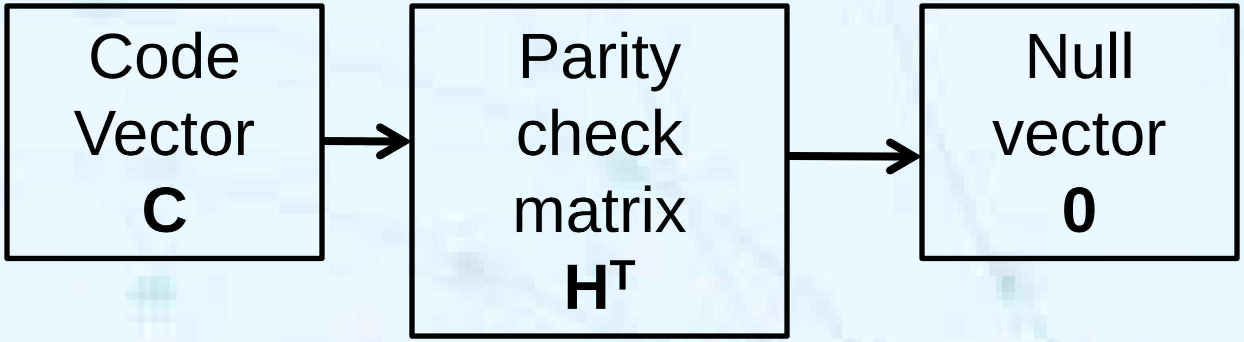
$$C = [1001] \begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix}$$

C = [1 1 0 1 0 0 1]

Decoding

- The coded data is checked for errors.
- If the error checking is successful only the message block is processed further and the parity bits will be discarded.
- Else suitable error correction methods will be applied.

Steps



Code Vector **C**

Parity check matrix $\mathbf{H}^T$

Null vector **0**

- The parity check matrix H is used to detect errors in the received code by using the fact that

$$C * H^T = \mathbf{0}$$

- The parity check matrix for a given code can be derived from its generator matrix

$$H = [P^T \mid I_{rxr}]$$

where p^T *is the transpose of the matrix P.*

Note : $GH^T = 0.$

- The received code word is multiplied with the Transpose of Parity Check Matrix (*H*)
- If the product is a “0” vector the code word is free of errors.

….example

- Received code word;

  C = [0 1 1 1 0 0 1]

$$P = \begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 0 & 1 \end{pmatrix}$$

Note: The parity bits in the code word undergo a bit reversal during transmission

- $H = [P^T \mid I_{r \times r}]$
- $P^T = \begin{pmatrix} 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \end{pmatrix}$
- $H = \begin{pmatrix} 1 & 0 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 \end{pmatrix}$

- $H^T \quad = \quad \begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$

$C \, . \, H^T \;= [\,0\;0\;0\,]$

- *Hence no error in the received code*

SPEECH CODING

Vocoders

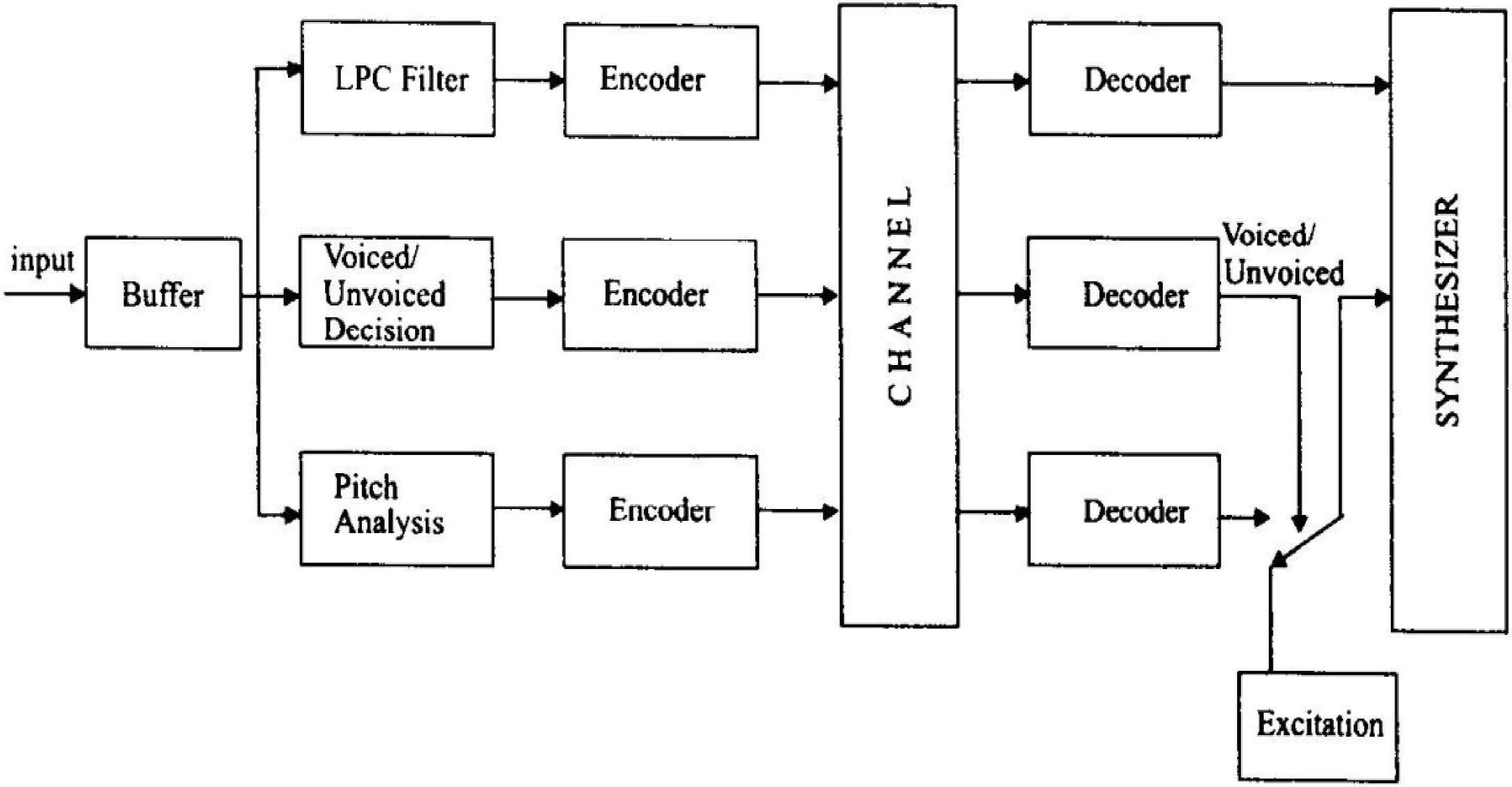
- Vocoders (voice encoders) are speech coding systems that analyze the voice signal at the transmitter, transmit only the parameters derived from the analysis, and then synthesize the voice at the receiver using those parameters.

Eg. *Channel Vocoder, Cepstrum Vocoder ,Voice Excited Vocoder. Linear Predictive Coder (LPC),*

Linear Predictive Coder (LPC)

- Instead of transmitting the analog voice signals we analyze, extract and transmit only the significant features(formants) of speech signal
- It is a digital method for encoding an analog signal in which the present value is predicted by a linear function of the past values of the signal.
- These formats are used to re-create the original speech signal in the receiver.

- Key formats
    - Gain factor
    - Pitch information
    - Voiced/ Unvoiced decision information


input
Buffer
LPC Filter
Voiced/
Unvoiced
Decision
Pitch
Analysis
Encoder
Encoder
Encoder
CHANNEL
Decoder
Decoder
Decoder
Voiced/
Unvoiced
SYNTHESIZER
Excitation

- Pitch is the auditory attribute of sound according to which sounds.
- It is determined by how quickly the sound wave is making the air vibrate.
- “High" pitch means very rapid oscillation, and "low" pitch corresponds to slower oscillation
- Pitch is closely related to frequency, but the two are not equivalent.

- Women have higher pitched voices than men as a result of a faster rate of vibration during the production of voiced sounds
- The categorization of sounds as voiced or unvoiced is an important consideration in the analysis and synthesis process
- Unvoiced sounds are usually consonants and generally have less energy and higher frequencies than voiced sounds.

- The input signal is sampled at a rate of 8000 samples per second.
- This input signal is then broken up into segments or blocks which are each analyzed and transmitted to the receiver
- Each segment represents app 20ms

- The linear predictive coder uses a weighted sum of p past samples to estimate the present sample.
- Mathematically

$$s_n = \sum_{k=1}^{p} a_k s_{n-k} + e_n$$

- where, e_n is the prediction error
- This estimate is then compared with the original signal and an error signal(difference signal) is found.

- The average error energy

$$E = \sum_{n=1}^{N} e_n^2 = \sum_{n=1}^{N} \left(\sum_{k=0}^{p} a_k s_{n-k} \right)^2$$

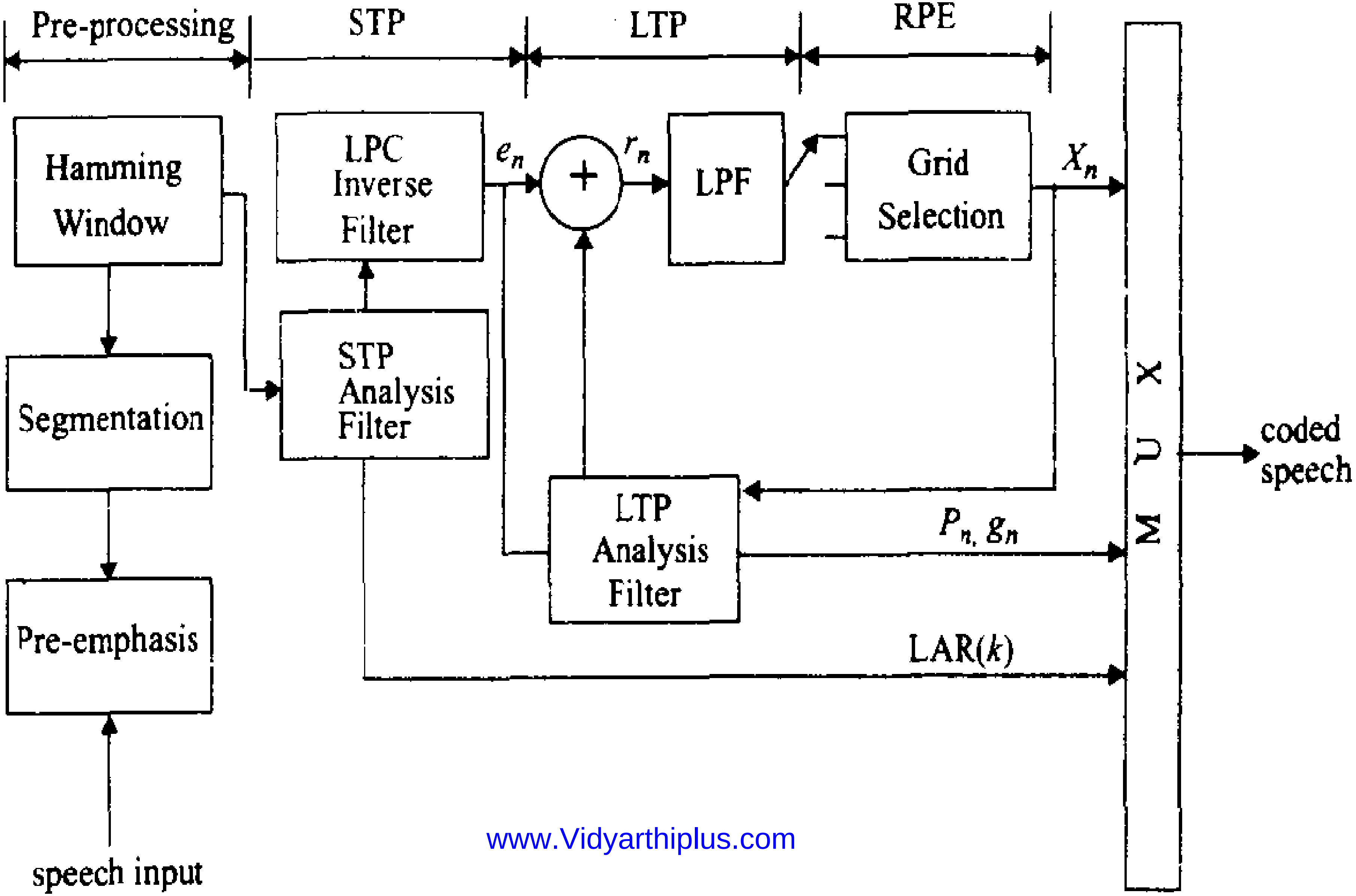
- Instead of transmitting the voice signals, only the estimated error signal will be transmitted.
- With the help of other formants the original voice is synthesized in the synthesizer.

GSM Codec

Intro….

- GSM Codec is also known *as Regular Pulse Excited Long Term Prediction* (RPE-LTP) codec
- This has a net bit rate of 13 kbps.
- The GSM codec is complex

BLOCK DIAGRAM



PROCESSING BLOCKS

- It has four major processing blocks

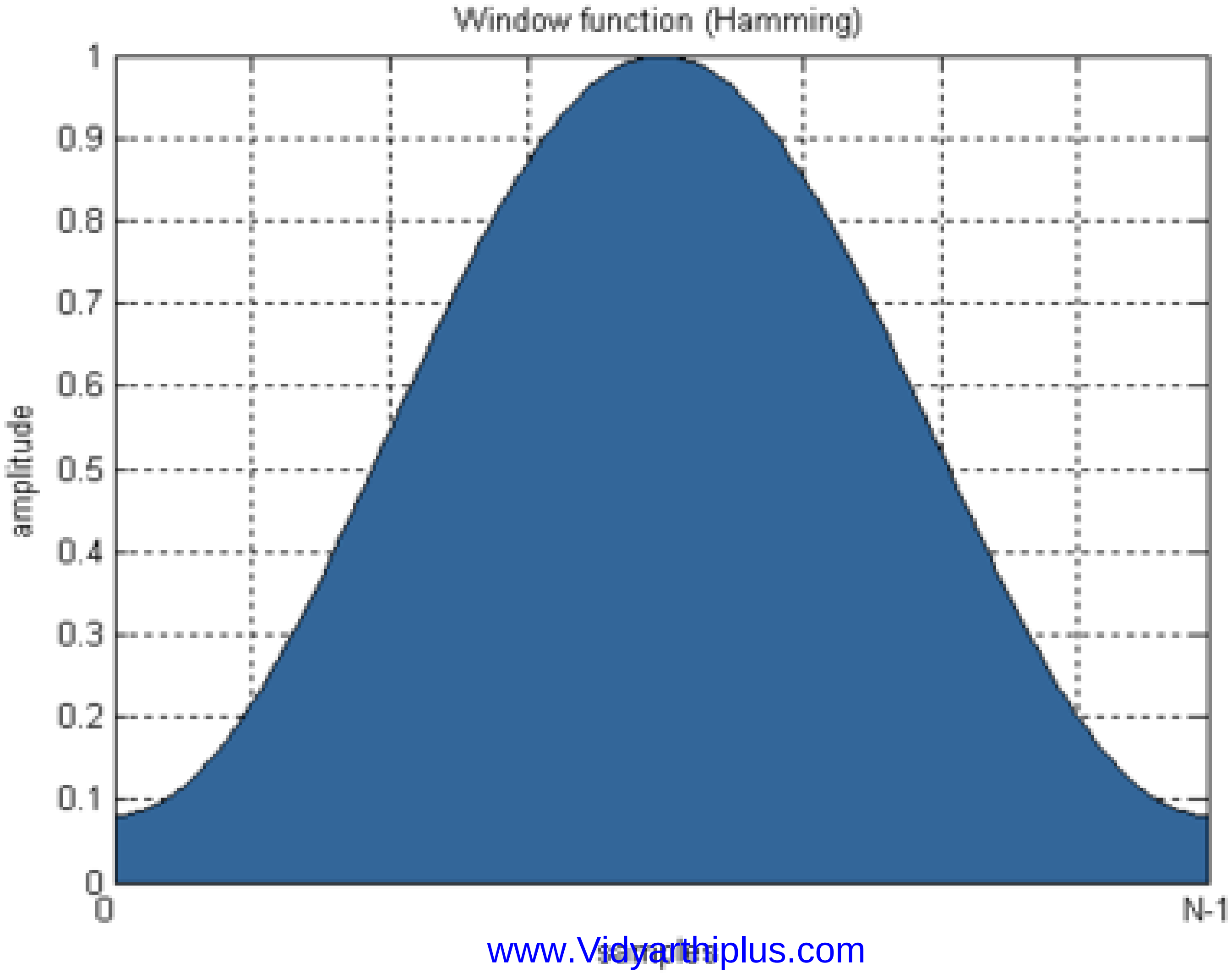
1. Pre processing block
2. Short Term Prediction (STP) block
3. Long Term Prediction (LTP) block
4. Regular pulse excited block.

Pre processing

- The speech signal is pre-emphasized i.e it was amplified to a specific level in order to improve the overall signal-to-noise ratio .
- Then it is divided into segments of 20 ms duration.
- Next it is Hamming Windowed using the Hamming Window Function

$$w(n) = 0.54 - 0.46\ \cos\left(\frac{2\pi n}{N-1}\right)$$

Hamming Window Function is used to smoothen out the unwanted side lobes of the signal



Short Term Prediction

- In STP filtering analysis the Logarithmic Area Ratios (LAR's) of the coefficients [$r_n(k)$] are computed.

  Let r_k be the k^{th} coefficient of a filter, the k^{th} LAR is given by

$$A_k = \log \frac{1 + r_k}{1 - r_k}$$

- The LAR parameters are decoded by the LPC inverse filter so as to minimize the error e_n

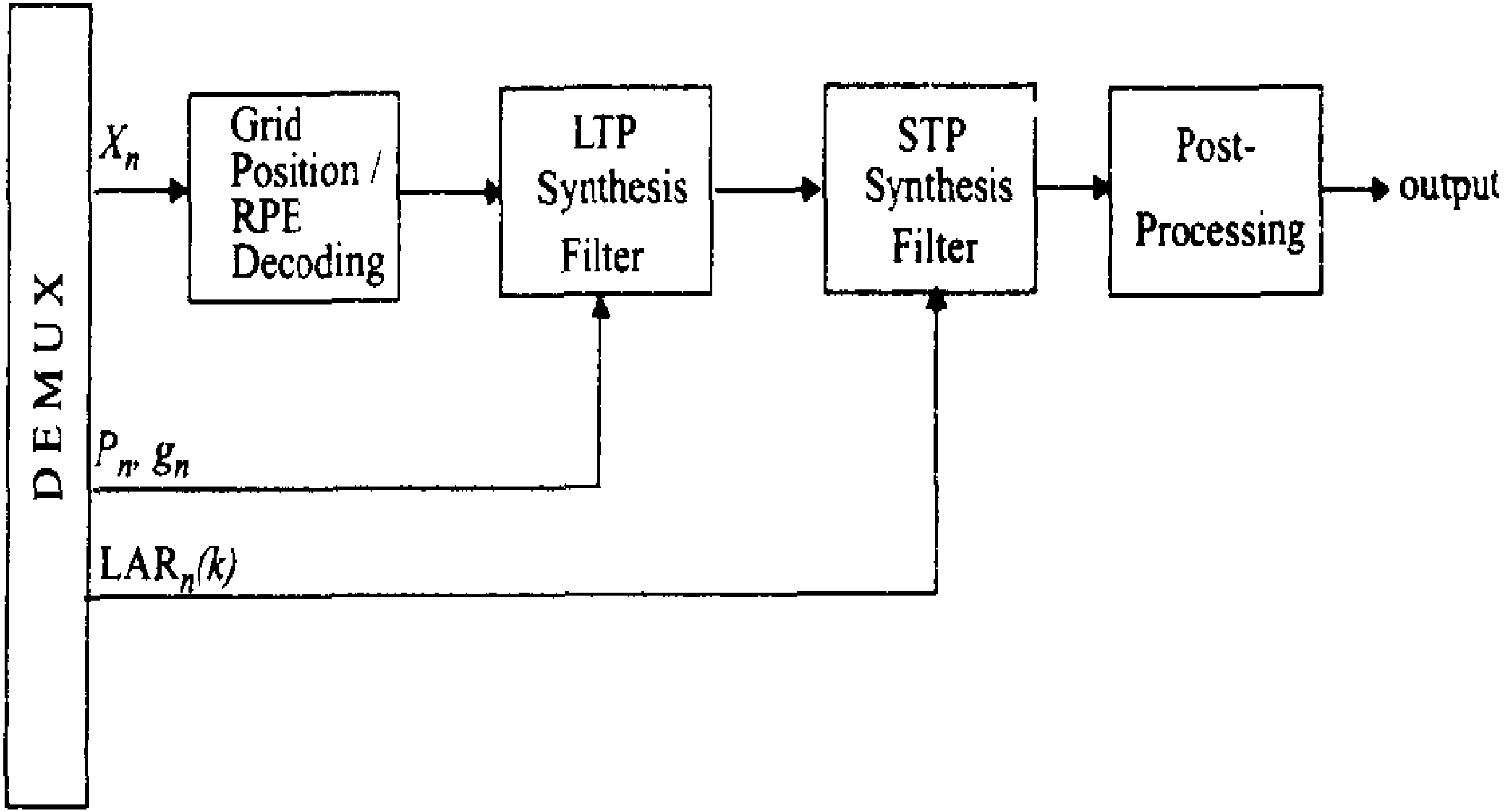
Long Term Prediction

- LTP analysis is to find the pitch period p_n and gain factor g_n
- The extracted pitch p_n and gain g_n are transmitted and encoded at a rate of 3.6 kbps
- It also minimize the LTP residue r_n
- Pitch extraction is done using the cross-correlation between the current STP error sample, e_n and a previous error sample e_{n-D}

Regular pulse excited block.

- r_n is weighted and splited into three excitation sequences. The one with the highest energy is selected to represent the LTP residue(r_n).
- The pulses in the excitation sequence are normalized quantized, and transmitted at a rate of 9.6 kbps.
- The signal formants *LTP residue*(r_n)*, LARs, pitch period* p_n *and gain factor* g_n are multiplexed and transmitted through the channel

GSM Decoder


DEMUX
X_n
Grid Position / RPE Decoding
LTP Synthesis Filter
STP Synthesis Filter
Post-Processing
output
P_n, g_n
$LAR_n(k)$

Self Study topics

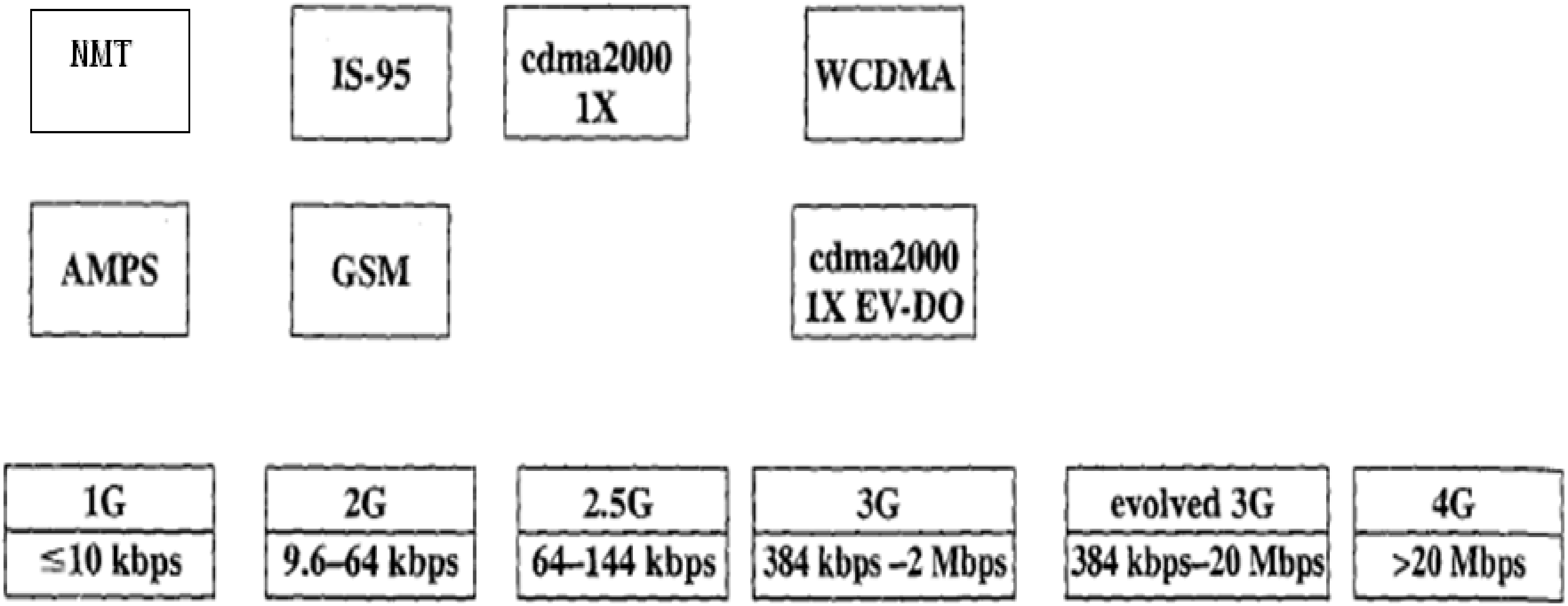
- Linear Equalizers
- Decision Feedback equalizers

WIRELESS COMMUNICATION

V. ADVANCED TRANSCEIVER SCHEMES

Spread Spectrum Systems- Cellular Code Division Multiple Access Systems- Principle, Power control, Effects of multipath propagation on Code Division Multiple Access, Orthogonal Frequency Division Multiplexing – Principle, Cyclic Prefix, Transceiver implementation, Second Generation(GSM, IS–95) and Third Generation Wireless Networks and Standards

1G	• Voice Signals Only • Analogue Cellular Phones • NMT, AMPS
2G	• Voice & Data Signals • Digital Fidelity Cellular Phones • GSM, CDMA, TDMA
2.5G	• Enhance 2G • Higher Data Rates • GPRS, EDGE
3G	• Voice, Data & Video Signals • Video Telephony / Internet Surfing • 3G, W-CDMA, UMTS
4G	• Enhanced 3G / Interoperability Protocol • High Speed & IP-based • 4G, Mobile IP



NMT	IS-95	cdma2000 1X	WCDMA		
AMPS	GSM		cdma2000 1X EV-DO		
1G	2G	2.5G	3G	evolved 3G	4G
≤10 kbps	9.6–64 kbps	64–144 kbps	384 kbps –2 Mbps	384 kbps–20 Mbps	>20 Mbps

Evolution of Cellular Wireless Systems

GSM

GSM Intro

- Global System for Mobile (GSM) is a 2G cellular standard.
- It is the most popular standard.
- GSM was first introduced into the European market in 1991

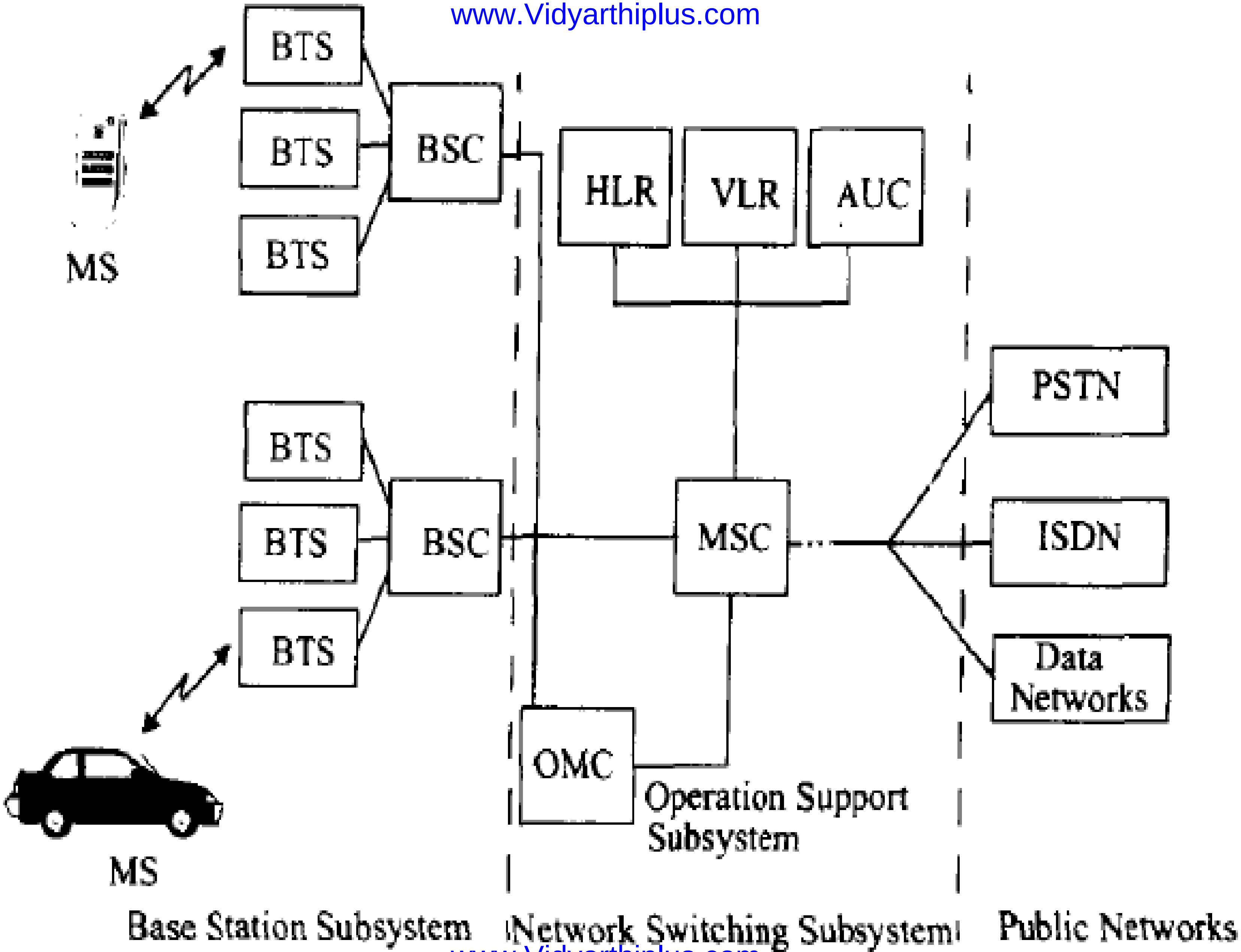
GSM Services

- The has 3 main services
  1. Telephone services – this refers to the normal telephone services, in addition to that we have video calls and teleconferencing calls.
  2. Bearer services or data services- GPRS & EDGE
  3. Supplementary ISDN services- SMS, call diversion, closed user groups and caller identification

Key features

1. *Subscriber Identity Module* (SIM) - a memory device that stores all the user information
2. On air privacy- The privacy is made possible by encrypting the digital bit stream sent by a GSM transmitter. Each user is provided with a unique secret cryptographic key, that is known only to the cellular carrier. This key changes with time for each user

GSM SYSTEM ARCHITECTURE


BTS
BTS
BTS
BSC
MS
HLR
VLR
AUC
PSTN
BTS
BTS
BTS
BSC
MSC
ISDN
Data Networks
MS
OMC
Operation Support Subsystem
Base Station Subsystem
Network Switching Subsystem
Public Networks

GSM System Architecture

- It has 3 sub system

1. *Base Station Subsystem* (BSS),
2. *Network and Switching Subsystem* (NSS),
3. *Operation Support Subsystem* (OSS)

Base Station Subsystem (BSS)

- The Mobile Station (MS) is usually considered to be part of the BSS.
- The BSS is also known as the ***Radio Subsystem***
- BSS facilitates communication between the mobile stations and the Mobile Switching Center (MSC).
- The Mobile Stations (MS) communicate with the Base Station Subsystem (BSS) using radio air interface

- Each BSS consists of many Base Station Controllers (BSCs) which connect the MS to the Network and Switching Subsystem (NSS) via the MSCs
- Each BSC typically controls up to several hundred *Base Transceiver Stations* (BTSs).
- BTSs are connected to the BSC by microwave link or dedicated leased lines
- Handoffs between two BTSs (under same BSC)can be handled by the BSC instead of the MSC. This greatly reduces the switching burden of the MSC.

Network and Switching Subsystem (NSS)

- The NSS manages the switching functions of the system and allows the MSCs to communicate with other networks such as the PSTN and ISDN.
- The MSC is the central unit in the NSS and controls the traffic among all of the BSCs.
- Communication between the MSC and the BSS is carried out by using SS7 protocol.
- The NSS handles the switching of calls between external networks and the BSCs

- NSS maintains are three databases for switching operations.

1. *Home Location Register* (HLR)
2. *Visitor Location Register* (VLR)
3. *Authentication Center* (AUC)

- The HLR contains subscriber information and location information for each user under a single MSC.
- Each subscriber is assigned a unique *International Mobile Subscriber Identity* (IMSI), and this number is used to track each user.

Visitor Location Register (VLR)

- This will oversee the operations of a ROAMING mobile.
- It temporarily stores the IMSI and customer information of the roamer.
- Once a roaming mobile is logged in the VLR, the MSC sends the necessary information to the roamer’s HLR so that calls to the roaming mobile can be appropriately routed over the PSTN by the *roaming* user's HLR

Authentication Center

- Authentication Center is a strongly protected database which handles the authentication and encryption keys for every user in the HLR and VLR.
- The Authentication Center contains a register called the *Equipment Identity Register* (EIR) which identifies stolen or fraudulently altered phones

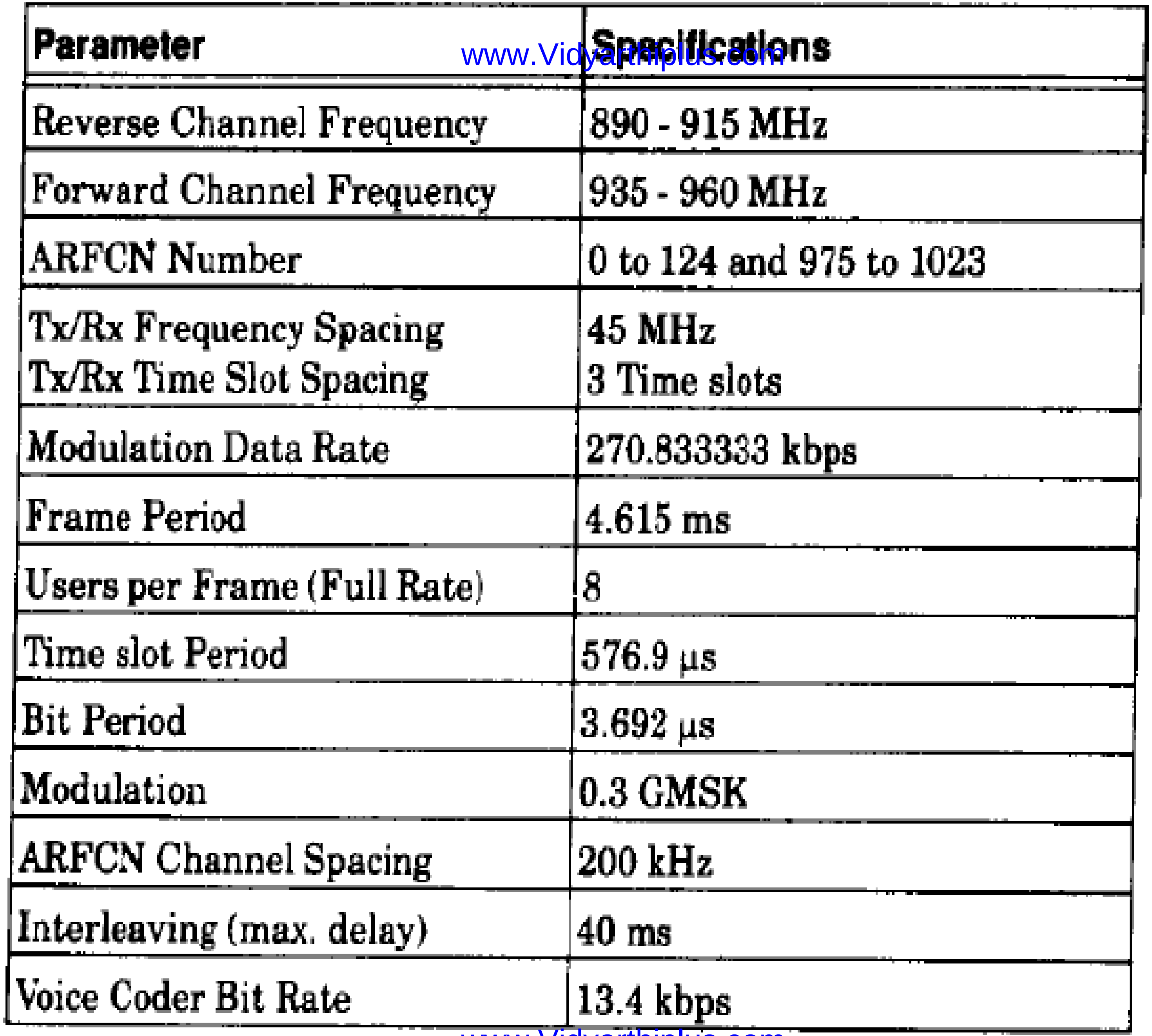
Operation Support Subsystem (OSS)

- The OSS has one or more *Operation Maintenance Centers* (OMC) ,which will

1. Maintain all telecommunications hardware and network operations within a particular market
2. Manage all charging and billing procedures
3. Manage all mobile equipment in the system.

GSM Radio Subsystem

- GSM utilizes two bands of 25 MHz (forward and reverse)
- The available forward and reverse frequency bands are divided into 200 kHz wide channels called ARFCNs (Absolute Radio Frequency Channel Numbers).
- ARFCN denotes a forward and reverse channel pair
- Eight subscribers can use the same ARFCN in different time slots.



Parameter	Specifications
Reverse Channel Frequency	890 - 915 MHz
Forward Channel Frequency	935 - 960 MHz
ARFCN Number	0 to 124 and 975 to 1023
Tx/Rx Frequency Spacing Tx/Rx Time Slot Spacing	45 MHz 3 Time slots
Modulation Data Rate	270.833333 kbps
Frame Period	4.615 ms
Users per Frame (Full Rate)	8
Time slot Period	576.9 µs
Bit Period	3.692 µs
Modulation	0.3 GMSK
ARFCN Channel Spacing	200 kHz
Interleaving (max. delay)	40 ms
Voice Coder Bit Rate	13.4 kbps

GSM CHANNELS

GSM Channels

1. Traffic channels (TCH) - carry digitally encoded user speech or user data
2. Control channels (CCH) - carry signaling and synchronizing commands between the base station and the mobile station

GSM Traffic Channels (TCH)

- GSM traffic channels may be either

1. Full-rate – input raw data is processed at a rate of 13 kbps
2. Half-rate - input raw data is processed at a rate of 6.5 kbps

Full-Rate TCH

1. Full-Rate Speech Channel (TCH/FS) — The full-rate speech channel carries user speech at the rate of 13 kbps. After GSM channel coding the data rate will be increased to 22.8 kbps.
2. Full-Rate Data Channel for 9600 bps (TCH/F9.6) — This channel carries raw user data at 9600 bps. After GSM channel coding the data rate will be increased to 22.8 kbps.

3. Full-Rate Data Channel for 4800 bps (TCH/F4.8)

   — This channel carries raw user data at the rate 4800 bps. Additional forward error correction coding is applied by the GSM standard, and the 4800 bps user data is sent at 22.8 kbps.

4. Full-Rate Data Channel for 2400 bps (TCH/F2.4)

   — This channel carries raw user data at 2400 bps. After GSM channel coding the data rate will be increased to 22.8 kbps.

Half-Rate TCH

1. Half-Rate Speech Channel (TCH/HS)

   The half-rate speech channel has been designed to carry digitized speech which is sampled at a rate half that of the full-rate channel at 6.5 kbps. After GSM channel coding the data rate will be increased to 11.4 kbps.

2. Half-Rate Data Channel for 4800 bps (TCH/H4.8)

   Raw user data rate - 4800 bps.

   After GSM channel coding- 11.4 kbps.

3. Half-Rate Data Channel for 2400 bps (TCH/H2.4)

   Raw user data rate - 2400 bps

   After GSM channel coding- 11.4 kbps.

GSM Control Channels (CCH)

Types

1. The Broadcast Channel (BCH)
2. The Common Control Channel (CCCH)
3. The Dedicated Control Channel (DCCH)

1.The Broadcast Channel (BCH)

- BCHs only use the forward link and transmits data only in the first time slot (TS 0) of certain GSM frames.
- The BCH provides synchronization for all mobiles within the cell
- BCH has 3 types
  - a) *Broadcast Control Channel (BCCH)*
  - b) *Frequency Correction Channel (FCCH)*
  - c) *Synchronization Channel (SCH)*

a) Broadcast Control Channel (BCCH)

- The BCCH is a forward control channel that is used to broadcast information such as cell and network identity, and operating characteristics of the cell (current control channel structure, channel availability, and congestion).
- The BCCH also broadcasts a list of channels that are currently in use within the cell

b) Frequency Correction Channel (FCCH)

- The FCCH allows each user to synchronize its internal frequency (local oscillator) to the exact frequency of the base station.
- The FCCH occupies TS 0 for the very first GSM frame (frame 0) and is repeated every ten frames within a control channel multiframe .

c) Synchronization Channel (SCH)

- SCH is broadcast in TS 0 of the frame immediately following the FCCH frame and is used to identify the serving base station while allowing each mobile to frame synchronize with the base station.
- Since a mobile may be as far as 30 km away from a serving base station, it is often necessary to adjust the timing of a particular mobile user such that the received signal at the base station is synchronized with the base station clock.
- The SCH is transmitted once every ten frames within the control channel multiframe

2.The Common Control Channel (CCCH)

a) *Paging Channel (PCH)-* notifies a mobile of an incoming call originated from the PSTN through paging message.

b) *Random Access Channel (RACH)- is a* reverse link channel used by a subscriber to acknowledge a paging message from the PCH, and also used by mobiles to originate a call

c) *Access Grant Channel (AGCH)-* is used by the base station to provide forward link to the mobile, and carries data which instructs the mobile to operate in a particular physical channel.

3.The Dedicated Control Channel (DCCH)

a) *Stand-alone Dedicated Control Channels (SDCCH) .*

b) *Slow Associated Control Channel (SACCH)*

c) *Fast Associated Control Channels (FACCH)*

a) Stand-alone Dedicated Control Channels (SDCCH)

- The SDCCH ensures that the mobile station and the base station remain connected while the base station and MSC verify the subscriber unit and allocate resources for the mobile.
- The SDCCH can be thought of as an intermediate and temporary channel which accepts a newly completed call from the BCH and holds the traffic while waiting for the base station to allocate a TCH channel

b) Slow Associated Control Channel (SACCH)

- On the forward link, the SACCH sends slow but regularly changing control information to the mobile, such as transmit power level instructions and specific timing advance instructions.
- The reverse SACCH carries information about the received signal strength and quality of the TCH, as well as BCH measurement results from neighboring cells

c) Fast Associated Control Channels (FACCH)

- FACCH carries urgent messages such as a handoff request.
- The FACCH gains access to a time slot by "stealing" frames from the traffic channel

CDMA

Intro

- CDMA is officially termed as Interim Standard 95 (IS-95), it is the first CDMA-based digital cellular standard by Qualcomm.
- The brand name for IS-95 is cdmaOne.
- CDMA-3G is CDMA2000

Frequency and Channel Specifications

- Reverse Link → 824 - 849 MHz & 1850–1910MHz
- Forward Link →869 - 894 MHz & 1930–1990MHz
- A forward and reverse channel pair is separated by 45 MHz
- IS-95 specifies two possible speech rates 13.3 or 8.6 kbit/s.
- Channel Chip Rate of 1.2288 Mchip/s

- IS-95 allows each user within a cell to use the same radio channel, and users in adjacent cells also use the same radio channel, since this is a direct sequence spread spectrum CDMA system.
- CDMA completely eliminates the need for frequency reuse.

- Each IS-95 channel occupies 1.25 MHz of spectrum on each one-way link.
- IS-95 uses a different modulation and spreading technique for the forward and reverse links.
- On the forward link, the base station simultaneously transmits the user data for all mobiles in the cell by using a different spreading sequence for each mobile.
- A pilot code is transmitted simultaneously and at a higher power level, to all mobiles to synchronize with the carrier frequency.

- On the reverse link, all mobiles respond in an asynchronous fashion and have ideally a constant signal level due to power control applied by the base station.
- Received power is controlled at the base station to avoid Near-Far Problem.

Speech Coder

- The speech coder used in the IS-95 system is the Qualcomm 9600 bps Code Excited Linear Predictive (QCELP) coder
- Intermediate user data rates of 2400 and 4800bps are also used for special purposes
- QCELP13 uses 13.4 kbps of speech data .

Spreading and Modulation

IS-95 uses three types of spreading codes:

1. Walsh codes.
2. Short spreading codes,
3. Long spreading codes,

Walsh codes

- Walsh codes will convert messages of length n to codewords of length 2^n
- This is used for forward communication
- Walsh codes are strictly orthogonal codes that can be constructed systematically using

Walsh–Hadamard matrix

$$\mathbf{H}_{\text{had}}^{(n+1)} = \begin{pmatrix} \mathbf{H}_{\text{had}}^{(n)} & \mathbf{H}_{\text{had}}^{(n)} \\ \mathbf{H}_{\text{had}}^{(n)} & -\mathbf{H}_{\text{had}}^{(n)} \end{pmatrix}$$

- **Short spreading codes**

→are PN-sequences, generated with a shift register of length 15

$$G_{\mathrm{i}}(x) = x^{15} + x^{13} + x^{9} + x^{8} + x^{7} + x^{5} + 1$$

$$G_{\mathrm{q}}(x) = x^{15} + x^{12} + x^{11} + x^{10} + x^{6} + x^{5} + x^{4} + x^{3} + 1$$

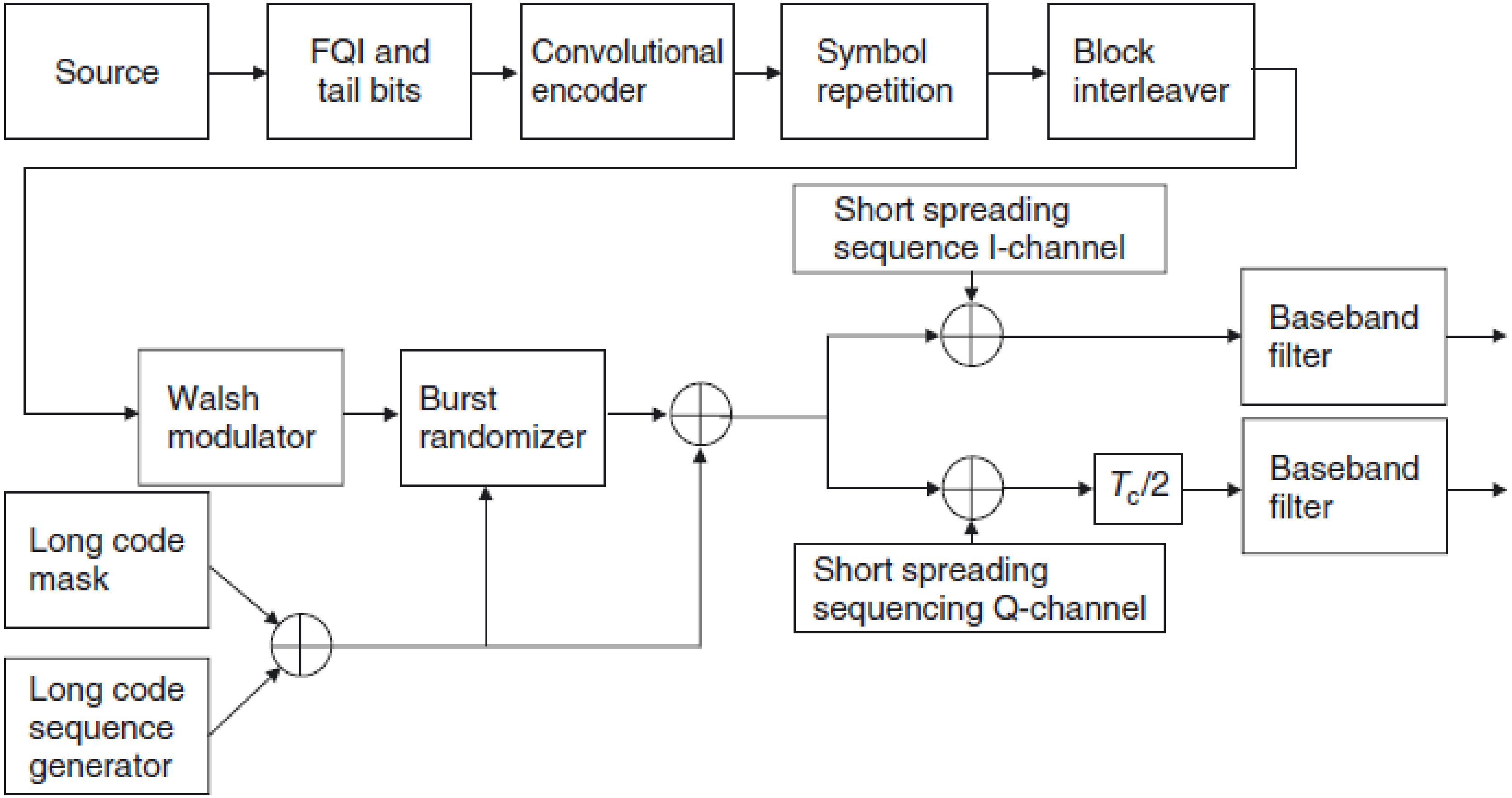
Long Spreading Codes

→PN-sequences generated using shift registers having length 42

The generator polynomial is

$$G_1 = x^{42} + x^{35} + x^{33} + x^{31} + x^{27} + x^{26} + x^{25} + x^{22} + x^{21} + x^{19}$$
$$+ x^{18} + x^{17} + x^{16} + x^{10} + x^{7} + x^{6} + x^{5} + x^{3} + x^{2} + x^{1} + 1$$

Transmitter



Block diagram of an IS-95 mobile station transmitter.

Spreading and Modulation

- The source data rate of 8.6 kbit/s or 13.3 kbit/s to a chip rate of 1.2288 Mchip/s
- Encoding is usually done with standard convolutional encoders.
- Spreading is done with “M-ary orthogonal keying” or multiplication by spreading sequences

Channels

1. Pilot Channel
2. Power Control Subchannel
3. Synchronization Channel
4. Paging Channel
5. *Traffic Channels*
6. *Access Channel*

Pilot Signal

- Each BS sends out a pilot signal that the MS can use for timing acquisition, channel estimation, and to help with the handover process.
- It is not power controlled
- It uses Walsh code 0 for transmission: this code is the all-zero code.
- It has higher transmit power than traffic channels

Power Control Subchannel

- IS-95 strives to force each user to provide the same power level at the base station receiver to avoid near-far problem
- Mobiles use peak power of 200mW
- Since both the signal and interference are continually varying, power control updates are sent by the base station every 1.25 ms.

- Power control commands are sent to each subscriber unit on the forward control subchannel which instruct the mobile to raise or lower its transmitted power in 1 dB steps.
- If the received signal is low, a ‘0' is transmitted over the power control subchannel, thereby instructing the mobile station to increase its mean output power level.
- If the mobile's power is high, a ‘1’ is transmitted to indicate that the mobile station should decrease its power level

Synchronization Channel

- The synchronization channel transmits information about system details that are required for the MS to synchronize itself to the network.
- The synchronization channel transmits data at 1.2 kbit/s.
- Synch message includes system ID (SID), network ID (NID), the offset of the PN short code, the state of the PN-long code, and the paging channel data rate (4.8/9.6 Kbps)

Paging Channel

- The paging channel transmits system and call information from the BS to the MS like…
  - Message to indicate incoming call
  - System information and instructions
  - Handoff thresholds
  - Maximum number of unsuccessful access attempts
  - Channel assignment messages.
  - Acknowledgments to access requests.

Access Channel

- The access channel is a channel in the uplink that is used for signaling by MSs
- Access channel messages include security messages (authentication challenge response page response, origination, and registration)
- A call initiated by the MS starts with a message on the access channel

Traffic Channels

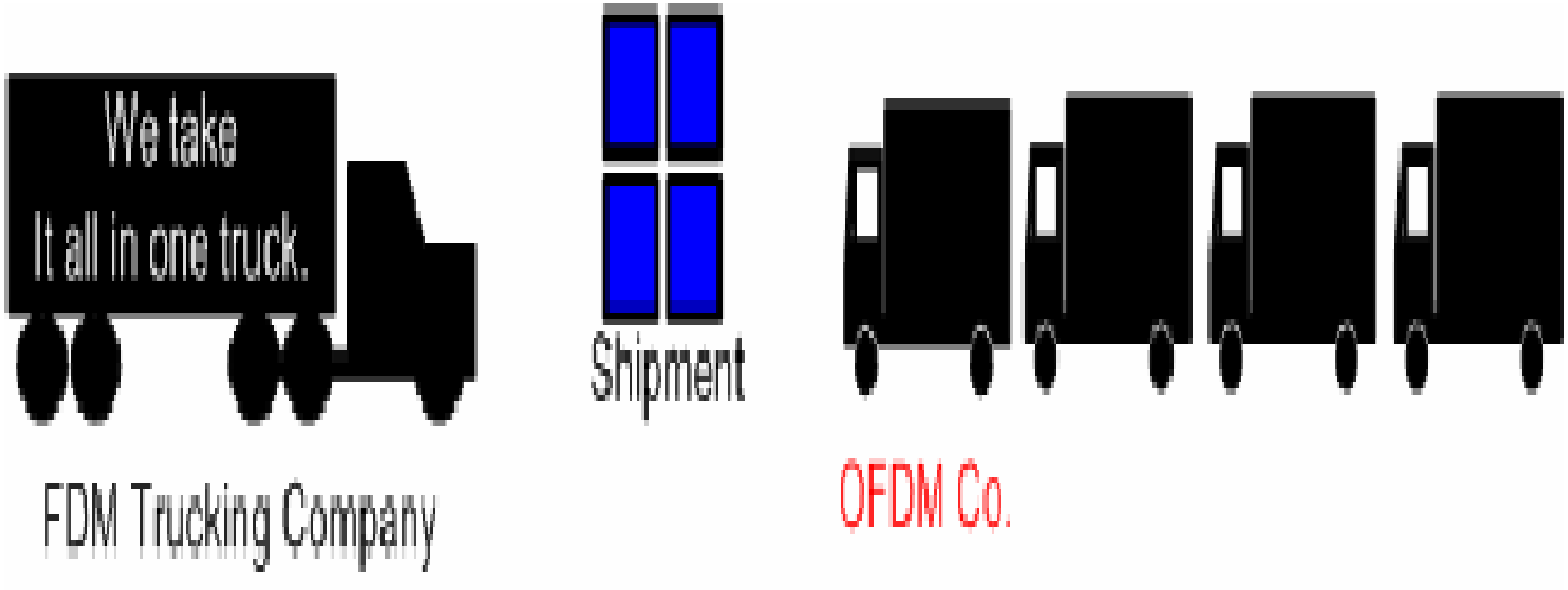
- Traffic channels are the channels on which the voice data for each user are transmitted
- A number of control messages are also transmitted on traffic channels

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

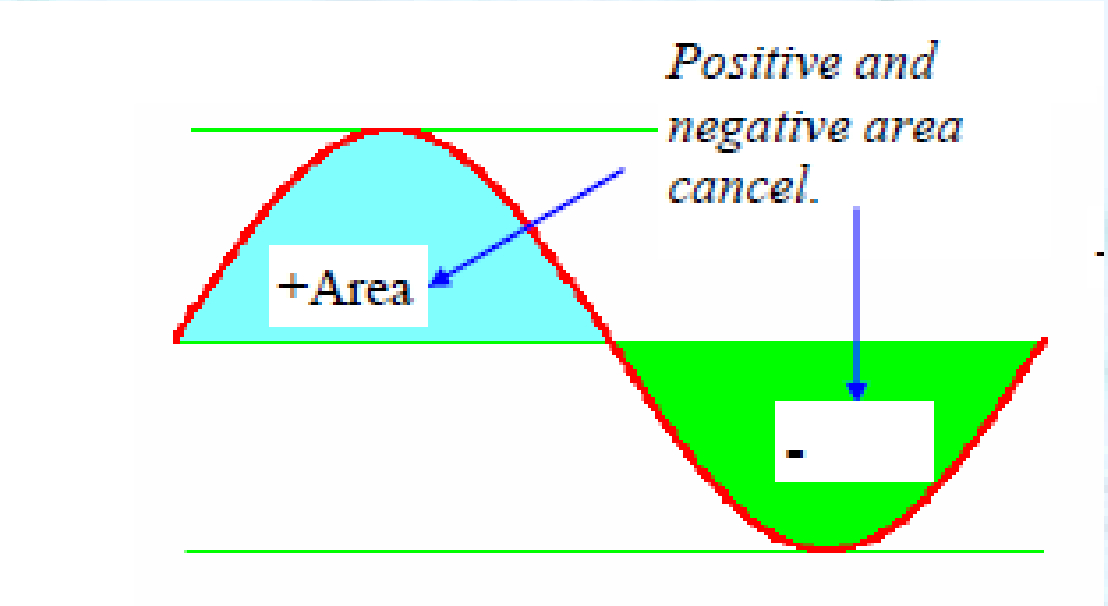
- Orthogonal Frequency Division Multiplexing (OFDM) is a modulation scheme suited for high-data-rate transmission in delay-dispersive environments
- It converts a high-rate data stream into a number of low-rate streams that are transmitted over parallel, narrowband channels.
- OFDM is a combination of modulation and multiplexing.

- Multiplexing generally refers to independent signals.
- In OFDM the multiplexing is applied to independent signals but these independent signals are a sub-set of the one main signal.
- In OFDM the signal itself is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM carrier

FDM Vs OFDM


We take
It all in one truck.
FDM Trucking Company
Shipment
OFDM Co.

- The main concept in OFDM is orthogonality of the sub-carriers.
- Since the carriers are all sine/cosine wave, we know that area under one period of a sine or a cosine wave is zero



Conditon for othogonality

f(x) . f(y) = 0

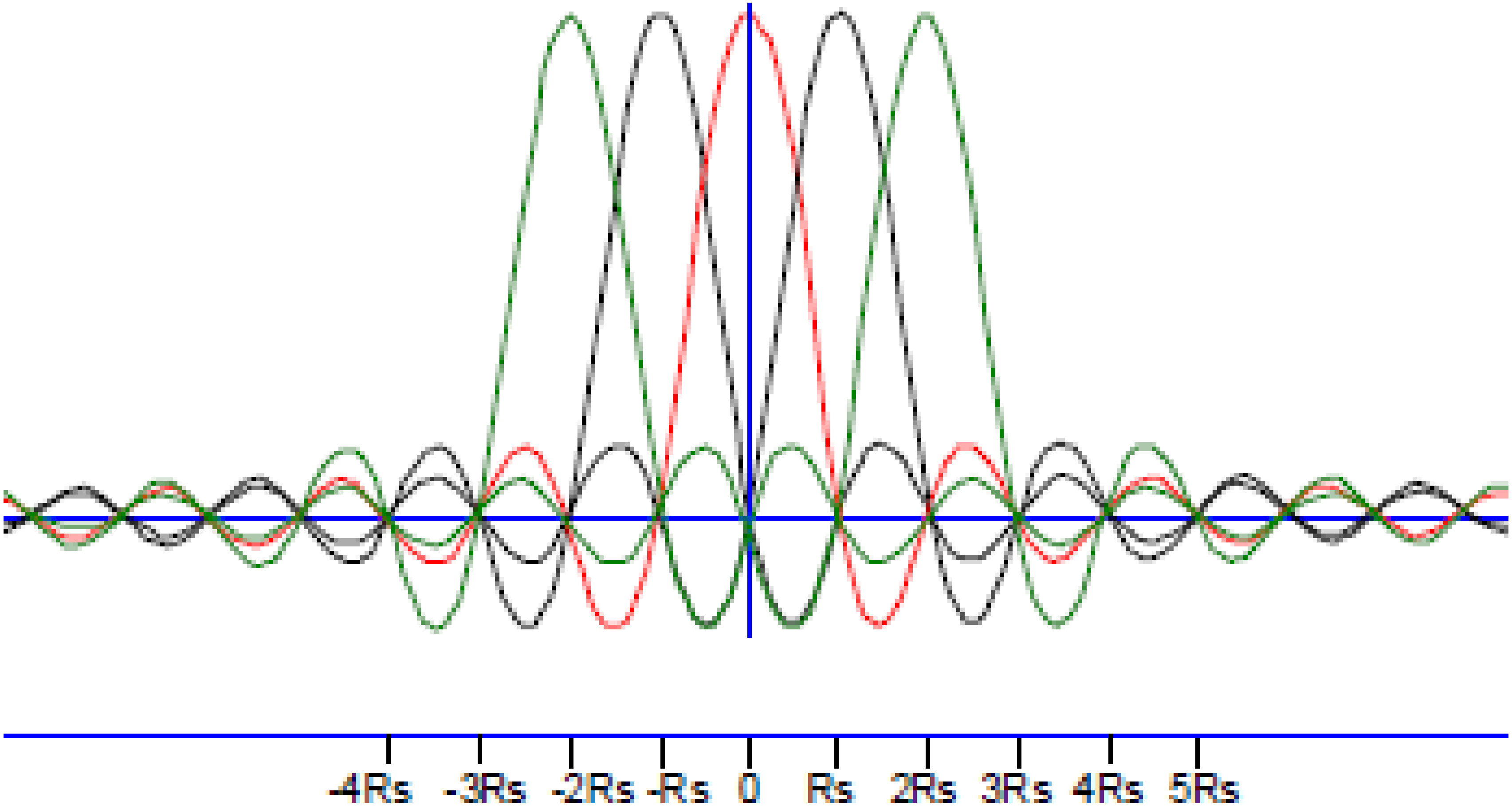
Multiplying 2 sine waves

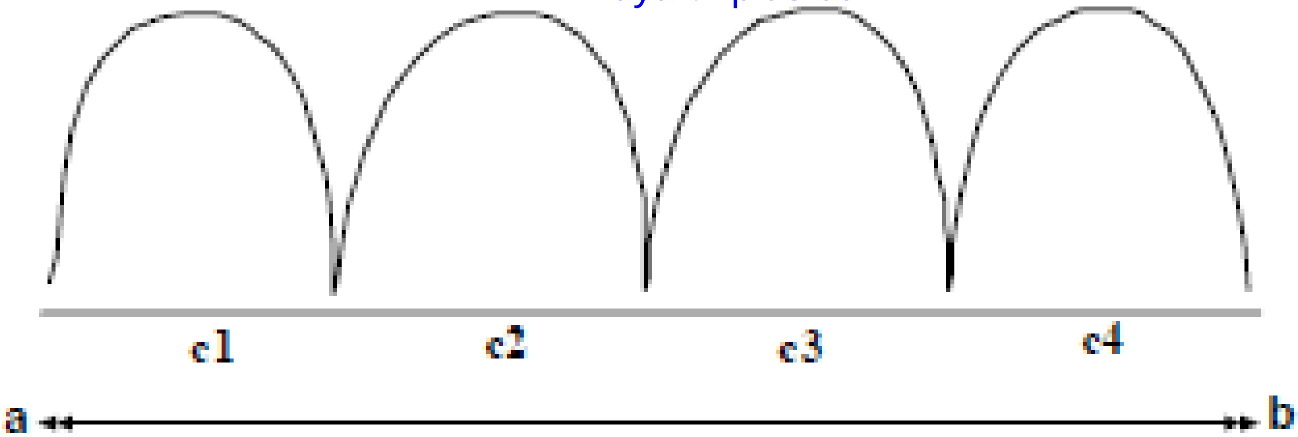
f (t) = sinmwt   sin nwt

$$= \int_0^{2\pi} \frac{1}{2} \cos(m-n)\omega t - \int_0^{2\pi} \frac{1}{2} \cos(m+n)\omega t$$

$$= 0 - 0$$

- Hence we conclude that when we multiply a sinusoid of frequency *n by a sinusoid of frequency m/n, the* area under the product is zero.
- In general for all integers *n and m,* sin*mx, cosmx, cos nx, sin nx* are all orthogonal to each other. These frequencies are called harmonics.
- A harmonic of a wave is a component frequency of the signal that is an integer multiple of the fundamental frequency
- The orthogonality allows simultaneous transmission on a lot of sub-carriers in a tight frequency space without interference from each other


-4Rs
-3Rs
-2Rs
-Rs
0
Rs
2Rs
3Rs
4Rs
5Rs



$$c_n = n \times c_1$$

So that

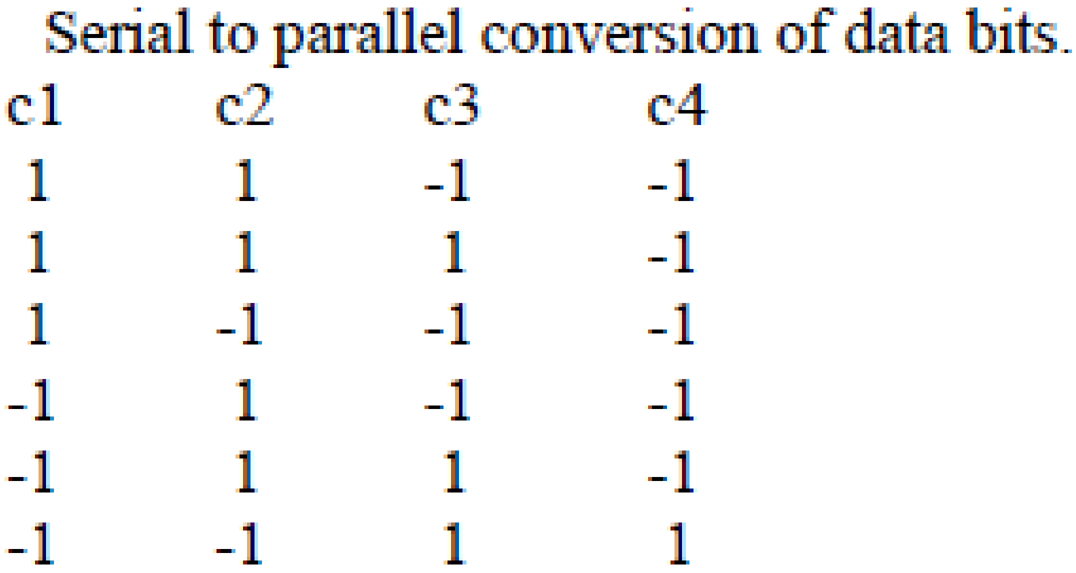
$$c_2 = 2c_1$$
$$c_3 = 3c_1$$
$$c_4 = 4c_1$$

All three of these frequencies are harmonic to c1

- These carriers are orthogonal to each other, when added together, they do not interfere with each other

Let the first few bits are

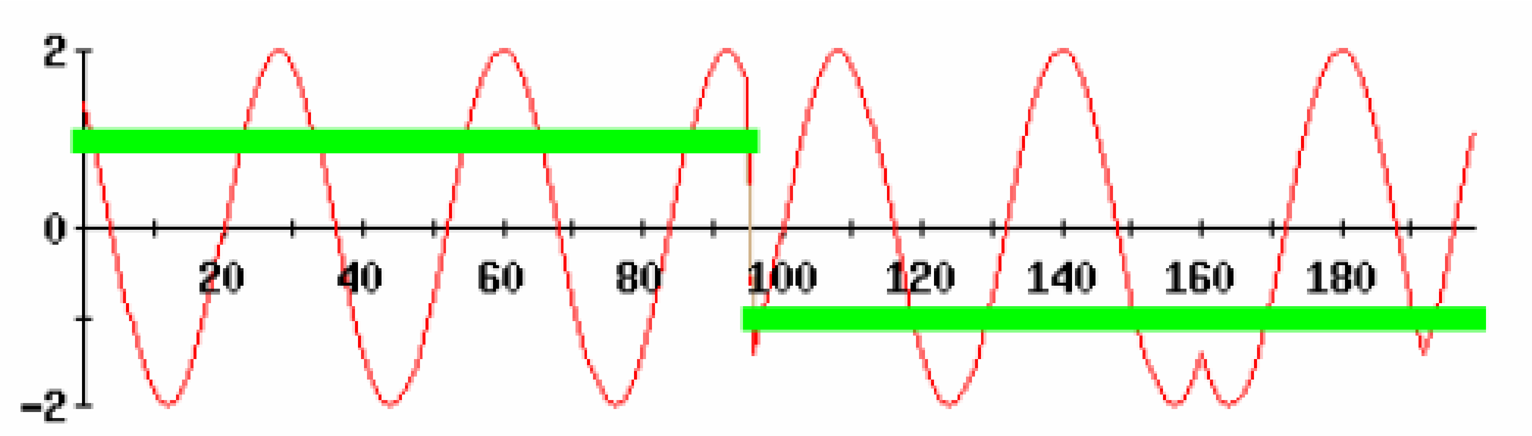
B(t)= 1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, -1, -1, 1, -1, -1, -1, 1 . . . . . .



Serial to parallel conversion of data bits.

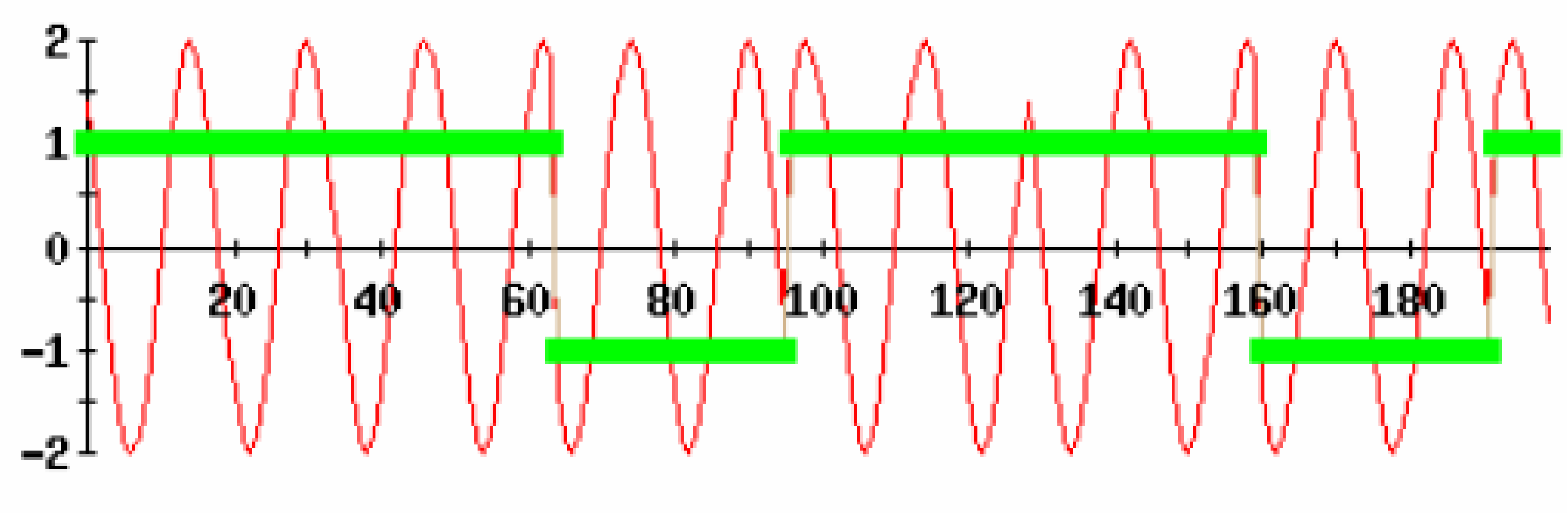
c1	c2	c3	c4
1	1	-1	-1
1	1	1	-1
1	-1	-1	-1
-1	1	-1	-1
-1	1	1	-1
-1	-1	1	1

c1



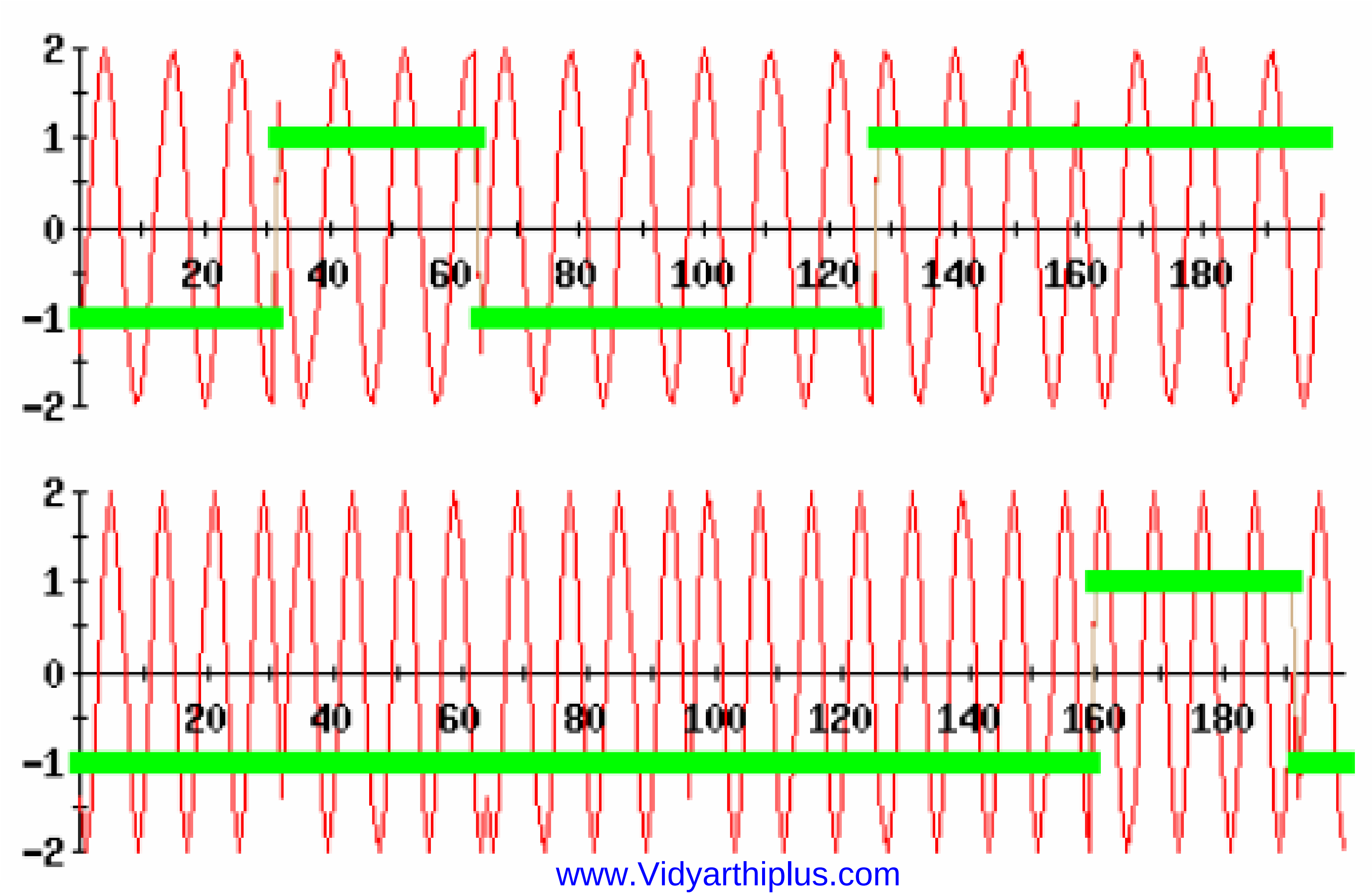
Carrier 1 - We need to transmit 1, 1, 1 -1,-1,-1 , with a BPSK carrier of frequency 1 Hz. First three bits are 1 and last three -1

c2



Carrier 2 - The next carrier is of frequency 2 Hz. It is the next orthogonal/harmonic to frequency of the first carrier of 1 Hz. Now take the bits in the second column, marked c2, 1, 1, -1, 1, 1, -1

c3 & c4


2
1
0
-1
-2
20
40
60
80
100
120
140
160
180
2
1
0
-1
-2
20
40
60
80
100
120
140
160
180