20CYS301
Digital Communications
L01-L03 Aug 18, 2023

Administration Matters
History
Introduction to Communication Systems

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I. History

History of Communications [1/6]

1864
James Clerk Maxwell

*Postulated **EM theory of light,** predicted existence of **radio waves** & gave the eponyomous **EM equations***

1884
Henrich Herz

*Demonstrated the existence of **radio waves** empirically*

1894-1900
Jagadish Chandra Bose

*Invented **WiFi technology** through work on detecting, generating & transmitting radio waves*

1901
Guglielmo Marconi

*Transceived the 1st **transatlantic radio signal** from Cornwall, England, to Newfoundland, Canada across c3,400 km*

1906
Reginald Fessenden

*1st radio broadcast that voice & music using what came to be known as **amplitude modulation (AM)***

1924
Harry Nyquist

*What is the **max signalling rate achievable over a fixed bandwidth channel for a given pulse shape** with 0 intersymbol interference*

History of Communications [2/6]

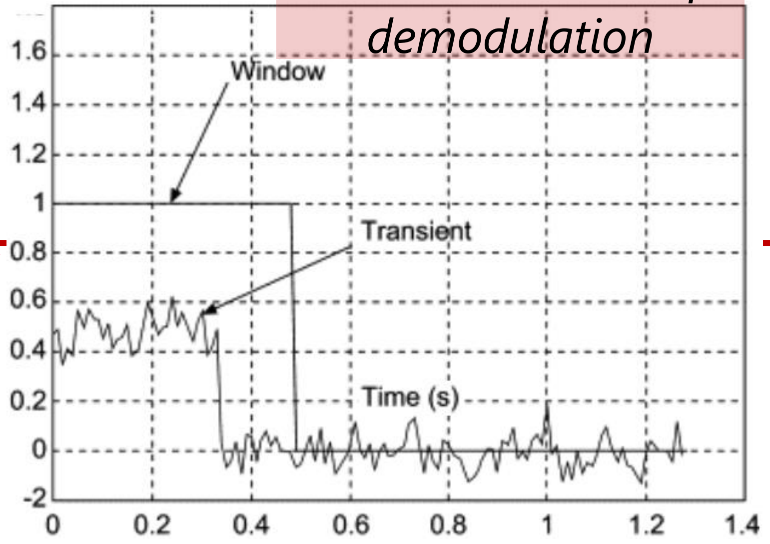
1928
Ralph Hartley

*What is the **max data rate** under Nyquist conditions **when using multiple bits/symbol** under amplitude accuracy of A_δ?*

1939
Kolmogorov

*Limits to **inferring the waveform** from a received signal in the presence of additive nose **[optimum Kolmogorov-Wiener linear filter]***

arises in context of demodulation



1948
Claude Shannon

*Defined **channel capacity** to capture extractable info content given received power & max bandwidth constraint & additive noise power*

1949
Marcel Golay

*Designed first nontrivial **error correction codes** for lossy channels*

History of Communications [3/6]

1950
Richard Hamming

*Hamming codes - a family of **linear error-correcting codes***

1954
Narinder Singh Kampani

***Father of fibre optics** – invented fibre optics cables to transmit optical images along a flexible axis*

1962
Robert Gallager

*Invented **Low Density Parity Check (LDPC) codes** which allow noise to approach max Shannon-allowable levels without information loss*

1971
US Defense Research

***ARPANET** – the precursor to the internet.*

1985
-

*ARPANET renamed as **'Internet'***

1988
Europe: Civilian Bureaucracy

Global System for Mobile (GSM) standard for digital cellular communications

History of Communications [4/6]

1990
Berners Lee

*Proposed a **software interface to the internet***

1993
Glavieux Berrou & Thitimjshima

***Turbo Codes** have near-optimum EC coding & decoding performance in AWGN. E.g. used in 4G*

1994
Corporations

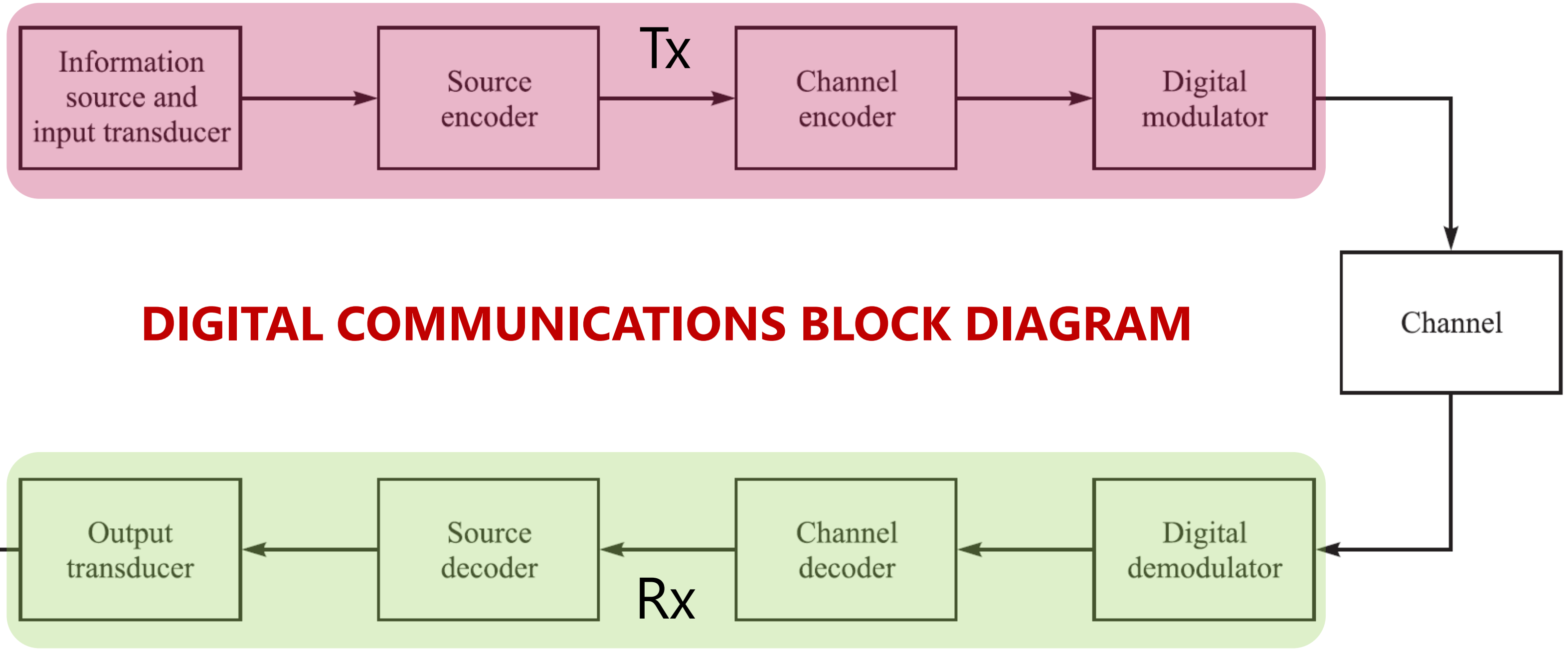
*Within 2 years of when it was proposed, the **World Wide Web** went from non-existent to global popularity*

II. Overview

Overview [1/17]

Source encoder: compresses the input data to reduce its redundancy. Source codework is the output symbol sequence.

Channel encoder: adds controlled redundancy to the source codework so that the Rx can autocorrect the data despite channel noise or interference.



Channel codework is the output symbol sequence upon channel encoding. Some of the channel codes are *LDPC codes*, *Turbo codes*, *Convolution codes*, and *Reed-Solomon codes*.

The channel codework is dispatched to **Channel modulator.** The modulator converts each symbol in the channel codeword to one of the finite elements in a digitized version of an analog value set. The output sequence of channel modulator is called waveform. Some of the modulation techniques are *m-ary PSK, FSK, ASK & QAM.*

The processes are reversed at the receiver.

Overview [2/17]

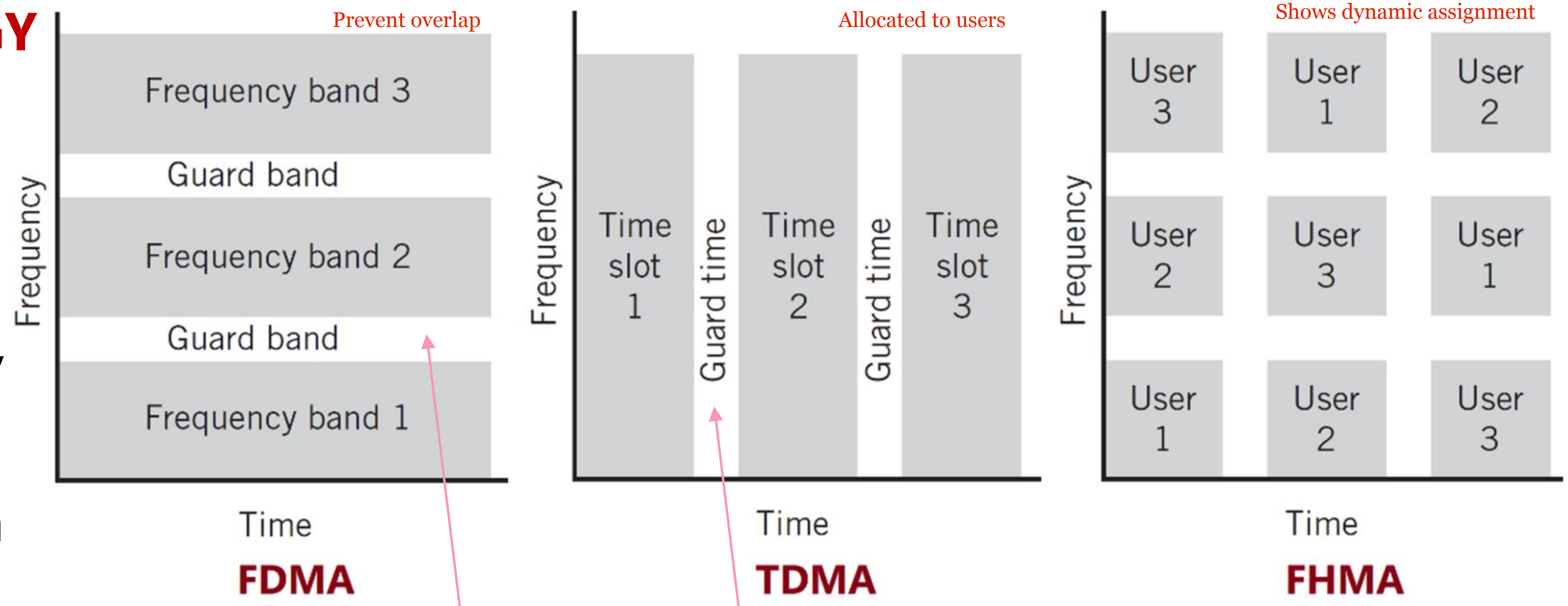
COMMUNICATION TOPOLOGY

1. Point-to-point (email)

2. Broadcast (TV)

Multiple access is the sharing of a channel by users in highly dispersed locations (satellite).

Multiplexing sharing of a channel by local site users.



In multiplexing, we have a greater need for dynamic channel allocation than in multiple access (*not true if the channel itself is unstable e.g. ionospheric bounce*).

Guard Band is a part of the *spectrum kept unused* to minimize interference with other adjacent channel transmissions, or comprises *unused time* to account for synchronization issues.

FHMA aka CDMA is more secure than FDMA or TDMA. **SDMA** exploits spatial separation between users or uses a multi-beam antenna.

Overview [3/17]

CIRCUIT SWITCHING

1. A phone call request must propagate all the way to the destination and acknowledged before a transmission can begin.
2. Circuit switching refers to a communications process in which a dedicated path with allocated bandwidth is set up on an on-demand or a pre-set basis before the actual communication can take place.
3. It is performed by a centralized or a distributed hierarchical unit.

Is circuit switching suitable for WhatsApp messages? If yes, then, why? If no, then, why not?

PACKET SWITCHING

1. It divides data into segments, each of which is wrapped in an envelope to form a packet.
2. The packet additionally comprises fields such as addressing, sequencing, and error control.

Why WhatsApp Uses Packet Switching:
Low Latency: No setup delay; packets transmit immediately.
Resource Sharing: Supports millions of users concurrently.
Adaptability: Handles variable message sizes (text, images, videos).

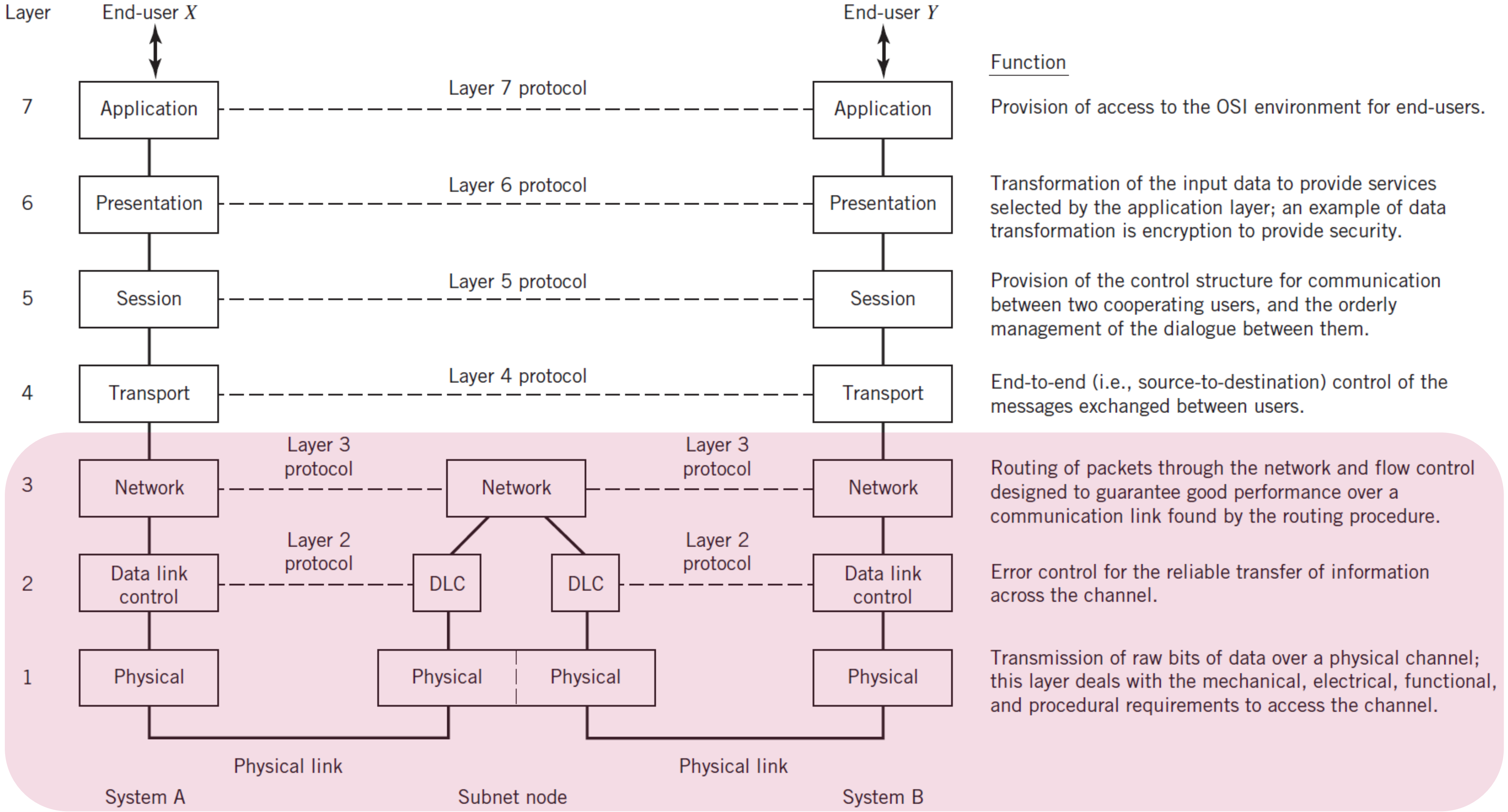
No, circuit switching is not suitable for WA coz,
Bursty Traffic: WhatsApp messages are irregular; reserving a dedicated path wastes bandwidth.
Delay Sensitivity: Call setup time is impractical for instant messaging.
Scalability Issues: Millions of simultaneous users would exhaust circuit resources.

Overview [4/17]

Not there

CONCEPTUAL MODEL FOR COMMUNICATIONS BETWEEN COMPUTING DEVICES

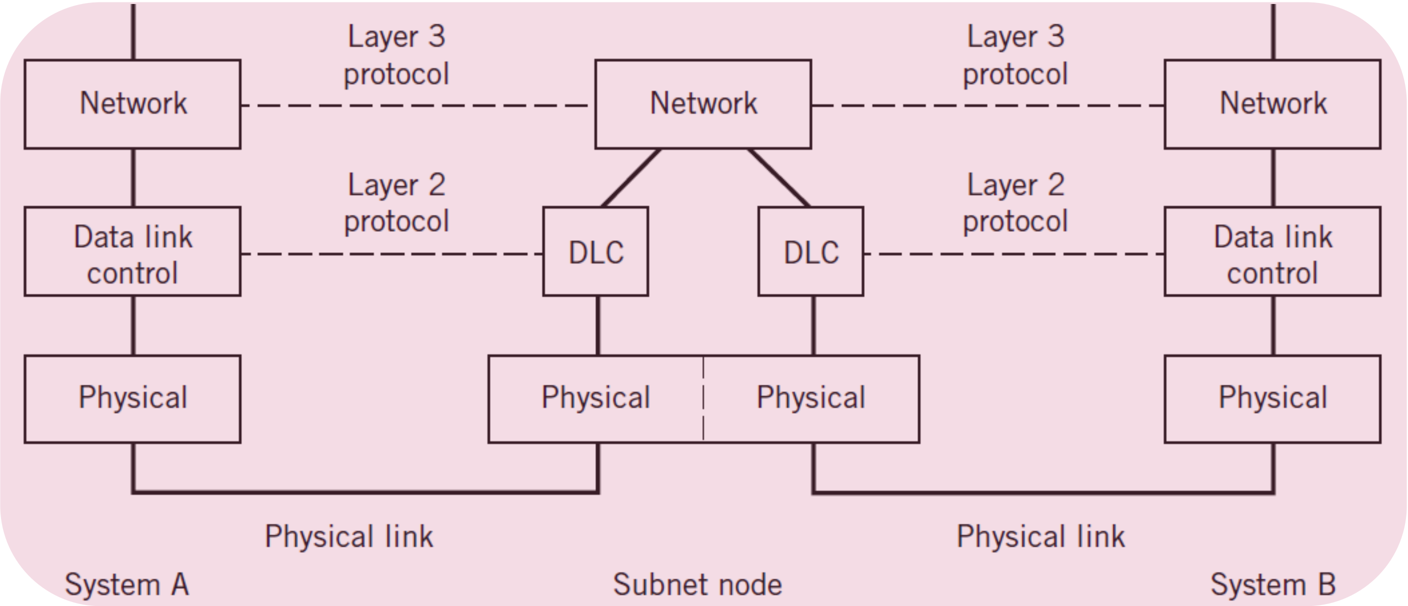
1. Open Systems Interconnection (OSI) is a conceptual model that "*provides a common basis for the coordination of standards development for the purpose of systems interconnection*".
2. It has a 7-layer architecture.



A layer comprises processes or devices inside the system that perform specific functions.

Overview [5/17]

PARTS OF OSI MODEL THAT IS FOCUS OF THE BOOK



1. **Physical layer.** It embodies the physical mechanism in transmitting bits between any pair of network nodes. Communications is accomplished by modulation at the Tx, use of transmission channel and demodulation at the Rx. Modem performs modulation & demodulation.
2. **Data-link layer.** This layer is for **a)** error control: error detection, error correction, **b)** allowing multiple users share the channel; in fact, a portion of this layer is called Medium Access control (MAC) sublayer. In some sense, the two functions are related: ill-managed channel accesses are one of the main sources for errors.
3. **Network layer.** This layer is responsible for **a)** handling routing, **b)** transferring variable-length network packets from a source to a destination, **c)** flow control to ensure the network does not become congested.

ques like why we need amplifiers here, is led transmitter or receiver?

photo diodes convert light signals to electric signal which is later converted into our message.

Overview [6/17]

light has very high freq - therefore, we consider LED light
Modulation requires high freq bandwidth.

TRANSMISSION MEDIUM I

1. **Twisted-pair wire:** A guided electromagnetic channel that provides a modest bandwidth (*e.g. those used in industrial control systems*).

2. **Co-axial cable:** A guided electromagnetic channel that provides bandwidth of several MHz (*e.g. those used by cable TV firms*).

3. **Fibre optic cable:** A guided communication that has several orders of magnitude of that fof a coaxial cable (*e.g. those used by cable TV firms*).

   light is the source,
   electromagnetic wave at 800 megaHz
   messages has to be communicated in LED light freq itself - above threshold = 1

   The Tx or modulator is either a light-emitting diode (LED) or a laser. transmittor is LED.

   Information is transmitted by varying (modulating) the intensity of the light source with the message signal.

   light → electric signals → waves → ?

   At the Rx, the light intensity is detected by a photodiode, whose output is an electrical signal that $\propto$ power of the light impinging on the photodiode.

   1. what is Amplifier
   2. is LED is used as transmitter or reciever?
   3. What is the carrier here?
   4. Diode is used for what?

   Noise sources in fiber-optic channels are photodiodes and electronic amplifiers.

Overview [7/17]

at least (lowerbound)
$\frac{6cm}{10} = 0.6\ cm$

6cm for 10Hz

TRANSMISSION MEDIUM II

1. **Wireless electromagnetic channels:** In wireless communication systems, electromagnetic energy is coupled to the propagation medium by an antenna which serves as the radiator.

   The physical size and configuration of the antenna depends mainly on the wave frequency.

   coupling : sending signals as 0/1 wave, there are only 2 states

   ~~Fission~~ Field Coupling

   For efficient coupling of generated to transmitted EM energy, antenna must be $> \frac{1}{10}\lambda$.

   signal can't penerate into water

   lamda is the length

   Very efficient. ; very expensive

   E.g. ULF (ultra low frequency) used in submarine communication due to its high penetrative depth for seawater has an upper bound of 3 KHz has a λ of nearly 100 km $[\lambda = {}^{c}/_{f} = {}^{3\times10^5}/_{3\times10^3}]$. Thus, antenna must be at least 10 km long!

   regulator → normal bandwidth
   less cyber security

   On the other hand, 500 Hz sound can also travel far in sea water. It's λ is 306 cm in sea water. Thus, an antenna must be at least a 1 ft long.

   getting speed is very tough ⇒ very small deviations are taken b/w 0 to 1.

   why antenna length went down ?

   sound is faster in water.
   high eff coupling

   high coupling of electromagnetic is very poor.

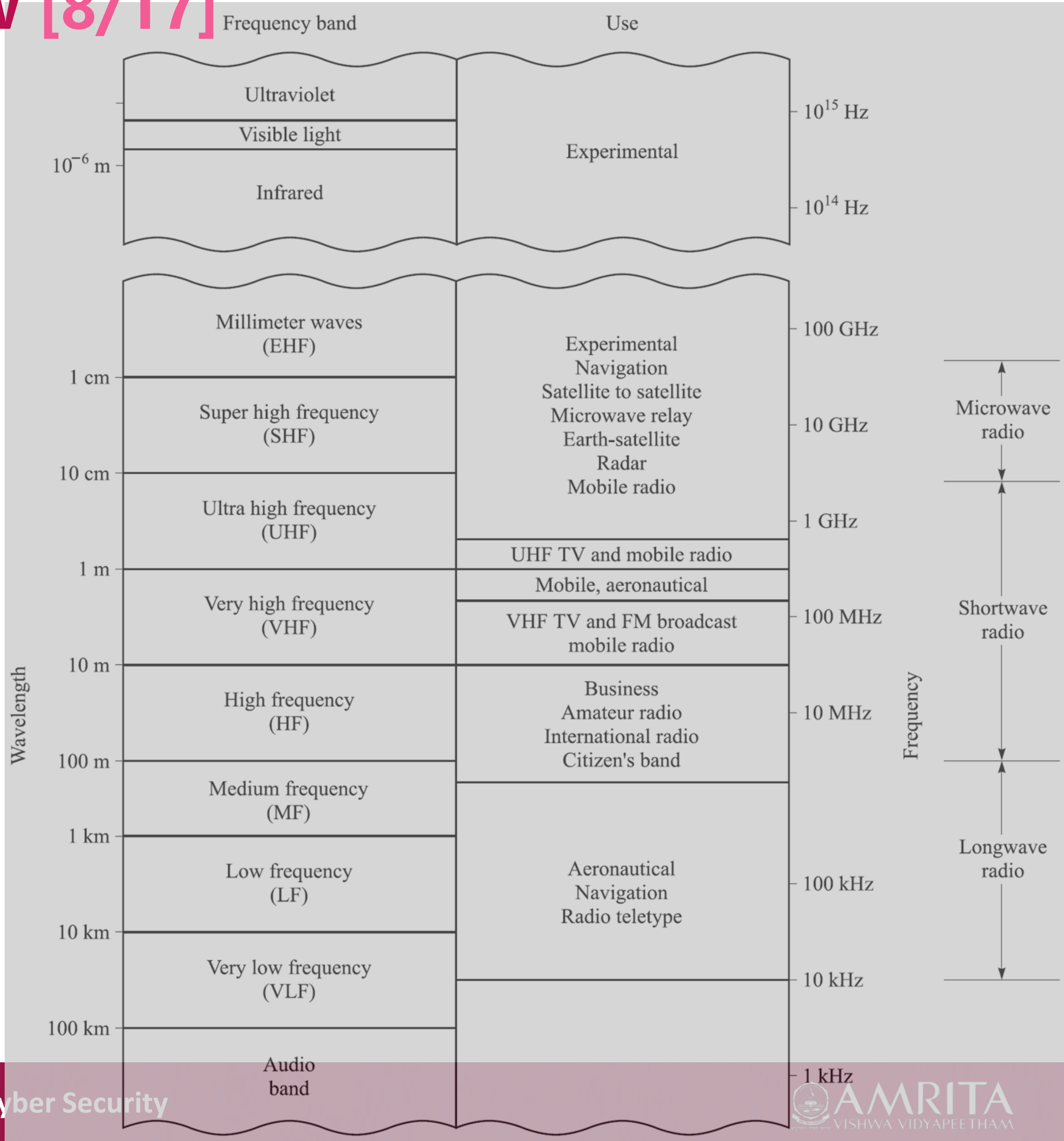
   signal → sunalpoi → satellite
   ↳ submarine

   loudest sound → piston shrimp
   wave sound

Overview [8/17]

TRANSMISSION MEDIUM III

no questions on this slide.

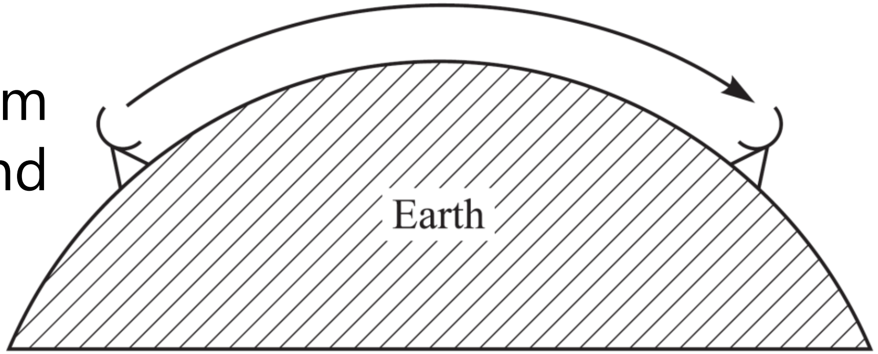


why is it not used for video frequency? because video needs more MHz for transmission... It requires more bandwidth

Overview [9/17]

EM PROPAGATION MODES I

atmosphere thickness changes as per time of the day



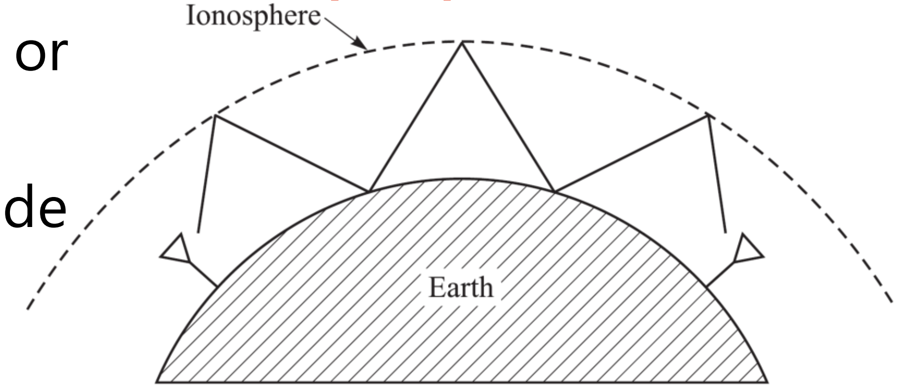
1. **Groundwave:** Dominant mode of propagation for medium frequency (MF) band, 0.3-3 MHz. It is used for AM and maritime radio broadcasting.

   severe distortion happens and it becomes unusable

   Max range: even with powerful transmitters, is 150 km

   Noise: mainly, atmospheric noise and thermal noise

for some waves, ionosphere acts as a wave... possible question



2. **Skywave:** Results from transmitted signals being reflected or refracted from the ionosphere.

   The ionosphere comprises charged particles in at an altitude of 80-400 km ASL (above sea level).

   Lower layers are formed due to heating by sun in daytime.

   The lower layers absorb frequencies < 2 MHz, thus severely limiting sky-wave propagation.

   ∴ AM reception is clearer during nighttime as, instead of bouncing off the lower, D-layer, signal bounces off the higher, F-layer.

   upper layer is more smoother than lower layer.

Why are powerful transmitters needed for tropospheric than ionospheric?
The higher the frequency we generate, we need more energy. Another reason is the change in distance

Overview [10/17]

above this frequency, it will penetrate through the ionosphere

↑ too much of energy ∴ it'll penerate through

EM PROPAGATION MODES II

2. **Skywave:** … *continued* skywave propagation ceases above 30 MHz which is where HF spectrum ends.

very important.

Noise: multipath is the major concern. It results in intersymbol interference. Also, the it results in constructive/destructive interfere resulting in the fading phenomenon which one may have experienced while listening to a distant radio station at night.

any wave has.

this happens in phones

Additive noise is a combo of atmospheric (typically, 10-20 MHz) and thermal noise.

cuz channel is very unreliable in case of ionosphere.

Max usable bandwidth of a single channel is just about 100 Hz (there are ways to increase it!).

max

Tropospheric scattering still works in the 40-300 MHz range. However, like MF, propagation losses are large and therefore, powerful transmitters/large antenna are needed.

because this is a very unreliable channel in the case of ionospheric bounces. it is a very very small portion of 30 MHz.

3. **LOS (line-of-sight):** Satellite downlink is typically in the 2.0-4.0 GHz.

Galactic noise is significant below 2.0 GHz (*typically, it ranges from 15 MHz to 160 GHz and, is particularly severe for antennae pointed at the Sun*).

O_2 absorption begins to get significant above 4 GHz.

will the satellite downlink freq be higher or uplink freq be higher?
Downlink is with a lower freq cuz satellite needs to conserve its energy so its hard to send high freq from there to earth... Instead we uplink it with higher freq cuz we have a proper power source here, so more energy from here can be sent to space

1) Which has higher frequency upperlink or downlink? and why?
more freq means more energy, very expensive to transmit → satellite, no power cables that's y upper → ↑er freq; → ↑er energy
down → ↓er freq → ↑er energy

EM PROPAGATION MODES III

3. **LOS (line-of-sight):** … *continued* coverage of VHF and UHF propagation is limited by curvature of the Earth.

d is in km and h is in m's

If the transmitter is at a height h above the surface of Earth then, in the absence of physical obstructions, transmission radius is $\mathrm{d} = \sqrt{15h}$ km. E.g. if $h = 300m$ then $\mathrm{d} = 67$ km.

even if the object is at LOS, how far can it actually transmit.

$\log_{10}(\text{Power}^2) = \text{dB}$.

Noise: In VHF/UHF mainly thermal noise and cosmic noise.

Power transmitted

In super high frequency (SHF), above 10 GHz, atmospheric conditions play an important role.

The attenuation ranges from c0.003 dB/km in light rain to c0.3 dB/km in heavy rain. At 100 GHz, it is c0.1 dB/km in light rain to c6 dB/km in heavy rain.

At extremely high frequency (EHF), we have IR and visible light that provides LOS optical communication. EHF has been used in satellite-to-satellite experimental communications.

Overview [12/17]

UNDERWATER ACOUSTIC CHANNEL EM wave attenuation in seawater varies with penetration depth. Skin depth is distance over which a signal is attenuated by ($\frac{1}{e}$, i.e., by 36.8%).

It is $\delta = 250/\sqrt{f}$ where f is in Hz & δ is in meters. E.g., for 3 KHz, i.e., the upper limit of ULF, skin depth is $\delta = 250/\sqrt{3000}$ which is < 15 ft!

they go very far. they go very far and dont require super long antennas

Acoustic transmissions at low frequencies can, on the other hand, travel several hundred km.

∴ these are preferred for inter-submarine communications.

Noise: mainly, multipath concerns due to:

- *reflection from sea surface, sea bottom and large ocean vessels*
- *varying sea depth due to waves*
- *varying sound speed due to differences in temperature and ocean depths*)

Ambient ocean acoustic noise is caused by shrimp, fishes and whales.

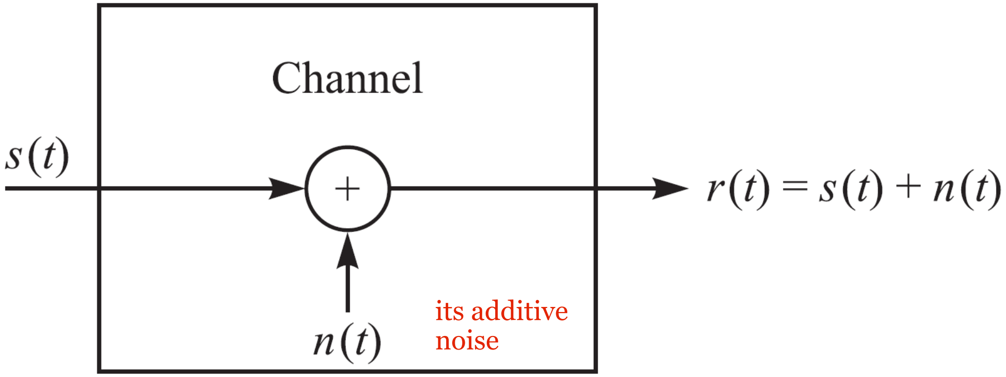
Manmade noise near harbors …

SOME MATH I

In this course, we focus on math for the physical, data link and network layers of the OSI model.

The models reflect the most important characteristics of the transmission medium, channel encoder, modulator and error detection and correction codes.

Noise introduced by electronic components may be characterized as thermal noise. The process underlying thermal noise is Gaussian. The noise is additive. Thus, the term additive gaussian noise.



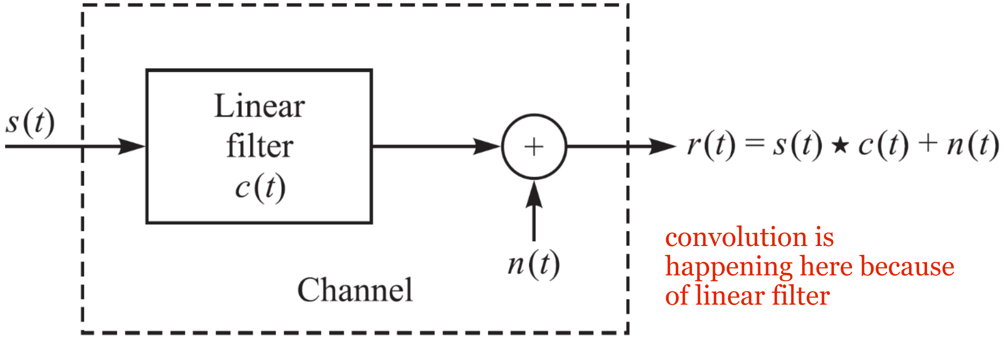
what happens if there are 2 signals?
s1c1+n1+s2c2+n2

Additive Gaussian Noise

Let $c(t)$ be the instantaneous channel condition.

Then, signal $s(t)$ in presence of additive gaussian noise, $\eta(t)$, is received as $r(t) = s(t) * c(t) + \eta(t)$.

This in turn is simply $r(t) = \int_{-\infty}^{\infty} s(t-\tau) * c(\tau) d\tau + \eta(t)$



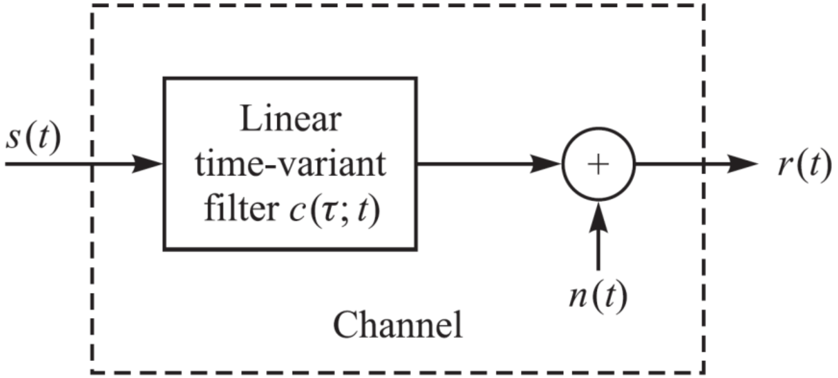
convolution is happening here because of linear filter

SOME MATH II

Linear Time-variant Filter Channel

Band-limit filters are used to ensure that transmitted signals do not exceed a certain bandwidth. This bandwidth itself could be dynamic depending on channel conditions or instantaneous pricing. The output on such channels are characterized as an outcome of the linear process given above.

if both (s, c) are time variant, what do we get?
If there are 2 noises, what happens? its additive



If the channel conditions are time-variant, i.e., instead of having a LTI system we have a LTV system then, $r(t) = \int_{-\infty}^{\infty} s(t-\tau) * c(\tau, t) d\tau + \eta(t)$ **(i)**

A good model for multipath signal propagation via ionosphere bounce (frequencies < 30 MHz) and mobile cellular radio channels, is a special case of the equation above:

$c(\tau, t) = \sum_{k=1}^{L} a_k(t)\delta(t-\tau_k)$ **(ii)** where $a_k(t)$ is the time-variant attenuation for L propagation paths and τ_k is corresponding time delays. Substituting this in (i) we get:

$r(t) = \int_{-\infty}^{\infty} s(t-\tau) * \sum_{k=1}^{L} a_k(t)\delta(t-\tau_k)\, d\tau + \eta(t)$, i.e., $r(t) = \sum_{k=1}^{L} a_k(t) s(t-\tau_k) + \eta(t)$ ... **(iii)**

Overview [15/17]

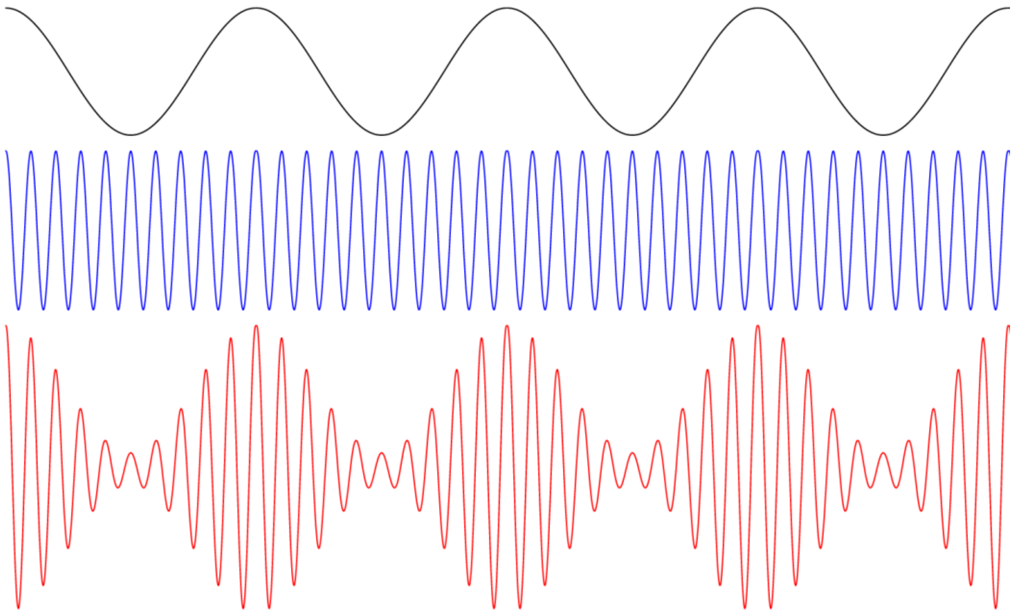
signal frequency is much smaller than carrier frequency

MODULATION

signal or data waveform

What is modulation? It is the process of introducing small changes to a waveform (carrier) based changes in another waveform (signal/data).

carrier waveform



Why modulate? Without modulation:

modulated waveform

1. The signals will simply collide. They can still collide even if you modulate but collision management is simpler for modulated signals.

frequency is not changing in the final, so it is amplitude is only changing. The rate of zero crossing of an amplitude modulated signal is the same as the carriers frequency

2. Antenna length will be huge. E.g., a phone call at 64 kbps without modulation will need an antenna c470 meter long! For a 4G carrier, it requires an antenna only c1.3 cm long. These are theoretical values, nevertheless, illustrative.

phone calls are worse than whatsapp calls because whatsapp can utilise more kbps

3. Long-distance transmission infrastructure is expensive. It is far, far more efficient to bundle different types of transmitting devices on to a single infrastructure.
4. Improves quality of reception (AM *cannot do this*).

A zero crossing is a point where a wave's value is exactly zero as it crosses the horizontal axis. The rate at which these crossings occur is directly proportional to the wave's frequency. A faster-moving wave (higher frequency) will cross the zero line more often in a given amount of time than a slower one.

Overview [16/17]

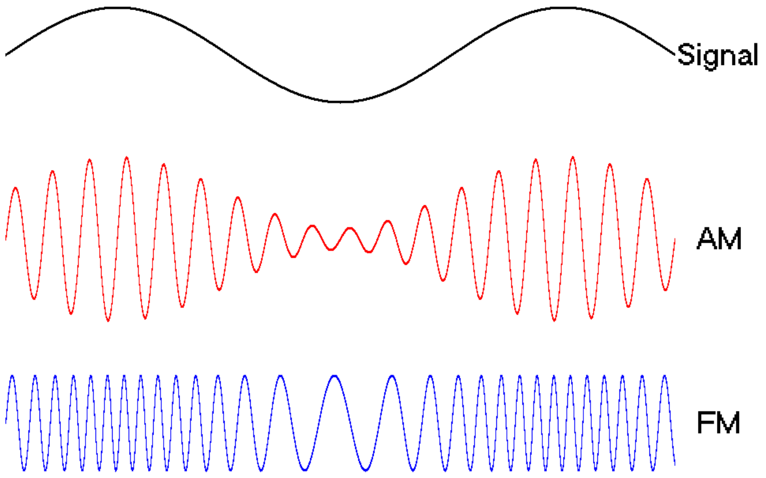
Sampling the analog data (A) at regular intervals.

Quantizing the sampled values to a discrete level.

Encoding the quantized levels into a digital bitstream.

EXAMPLES OF MODULATION

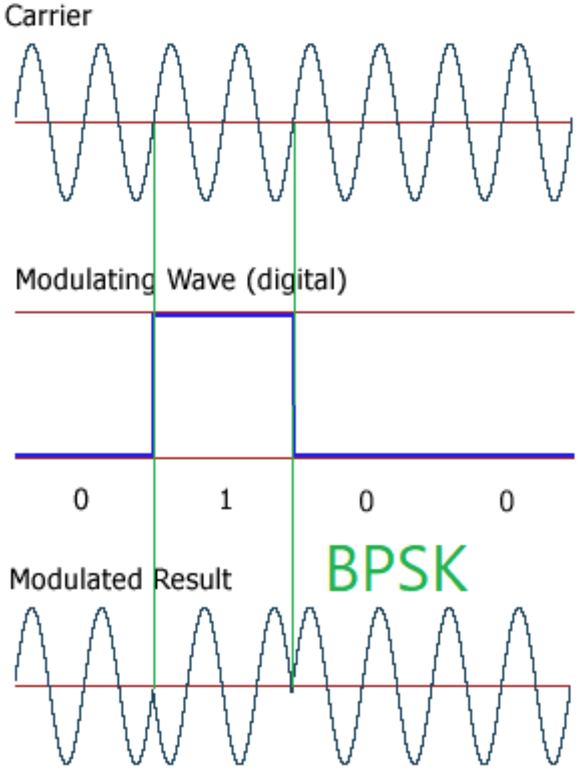
Analog data over analog channel



AM - The amplitude of the carrier wave is varied to match the analog signal.

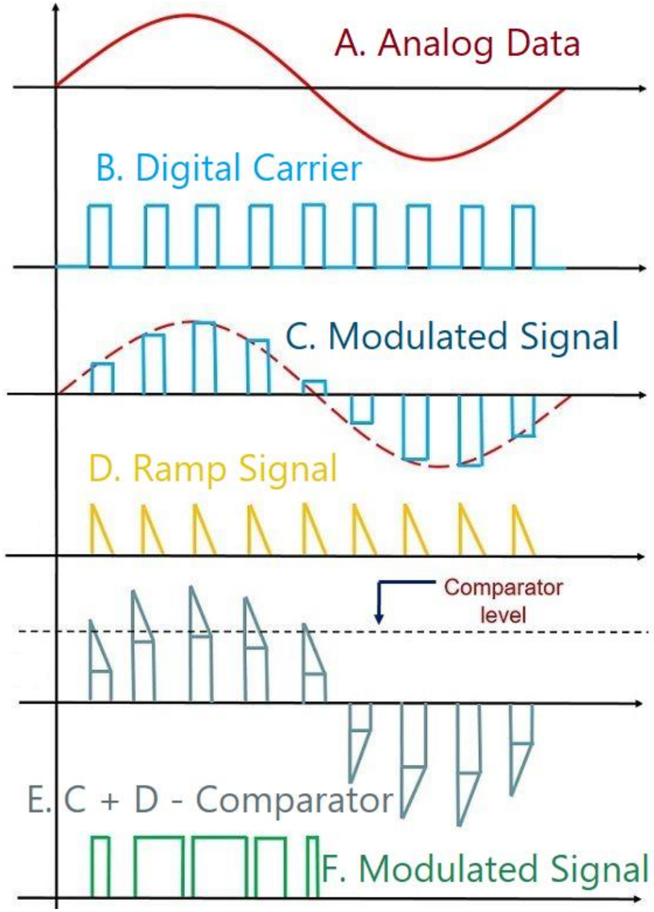
FM - The Freq of the carrier wave is varied to match the analog signal.

Digital data over analog channel



changes the phase of the wave flips by 180 deg

Analog data over digital channel



Digital data over digital channel

… … left to imagination!

Overview [17/17]

Digital data over analog channel

ASK (Amplitude Shift Keying) → varies carrier amplitude

FSK (Frequency Shift Keying) → varies carrier frequency

PSK (Phase Shift Keying) → varies carrier phase

QAM (Quadrature Amplitude Modulation) → varies amplitude & phase

MODULATION MODES

Analog data over analog channel

Digital data over analog channel

Analog data over digital channel

Digital data over digital channel

Analog data over digital channel

PAM (Pulse Amplitude Modulation) → varies pulse amplitude

PWM (Pulse Width Modulation) → varies pulse width

PPM (Pulse Position Modulation) → varies pulse position

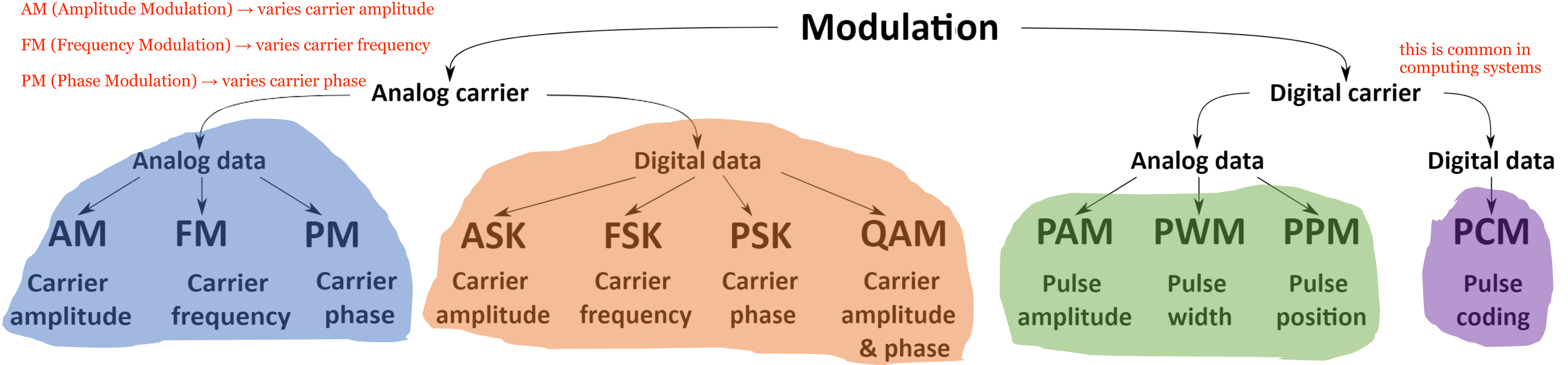
Digital data over digital channel

PCM (Pulse Code Modulation) → digital coding of analog signal (common in computing systems)

AM (Amplitude Modulation) → varies carrier amplitude

FM (Frequency Modulation) → varies carrier frequency

PM (Phase Modulation) → varies carrier phase



this is common in computing systems