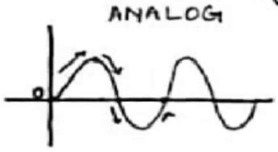
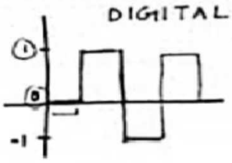
Data must be transformed into signals, for transmission.

SIGNALS → Analog → continuous values → infinite no. of values
SIGNALS → Digital → discrete values → limited no. of values.

ANALOG



DIGITAL



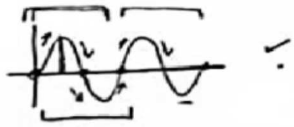
Frequency : Rate of change of a signal.

No change → 0 frequency.

SIGNALS → Periodic : follows a pattern within a time frame → period
SIGNALS → Non-Periodic → Do not follow any pattern.

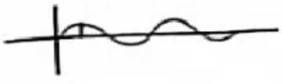
cycle

sine

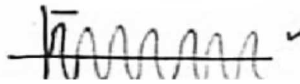


Peak Amplitude : Value of a signal at its highest intensity. UNIT : Volts

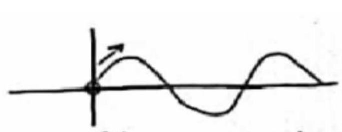
Period : Amount of time reqd. by a signal to complete 1 cycle. UNIT : seconds



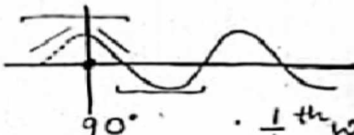
Frequency : No. of periods in 1 sec. UNIT : Hertz



Phase : Describes the position of a wave relative to time 0.
UNIT : Radians / Degrees



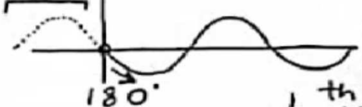
Wavelength : Combines frequency with the speed of propagation in a medium.



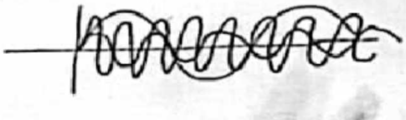
* Distance travelled by a signal in 1 cycle. (λ)

FORMULA : λ = Speed of propagation × Period

UNIT : Micrometers (μm).



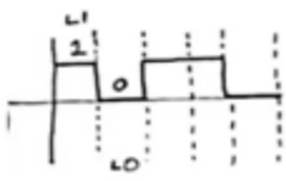
Composite Signal : Combination of single analog waves
↳ Multiple frequencyies.

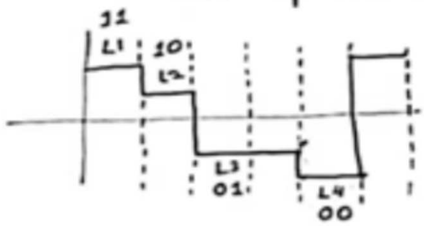


Bandwidth : Range of frequencies present in a composite signal.

FORMULA : Highest frequency - lowest frequency.

Information can be transmitted using digital signals also. (N.Per.)
Example : Represent 1 → positive voltage   Represent 0 → zero voltage
Digital signal consists of LEVEL
↳ represents information (bits)





If a signal has L levels it requires $\log_2 L$ bits
$\log_2 2 = 1$ $\log_2 4 = 2$

BIT RATE : Number of bits sent per second.
UNIT : bits per second (bps)

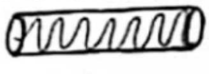
5 pages
1 page → 20 lines
Each line → 15 chars
1 char → 8 bits
$5 \times 20 \times 15 \times 8$ bps.
12000 bps.

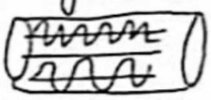
BIT LENGTH : Distance occupied by one bit on a transmission medium.

FORMULA : propagation speed × bit duration.

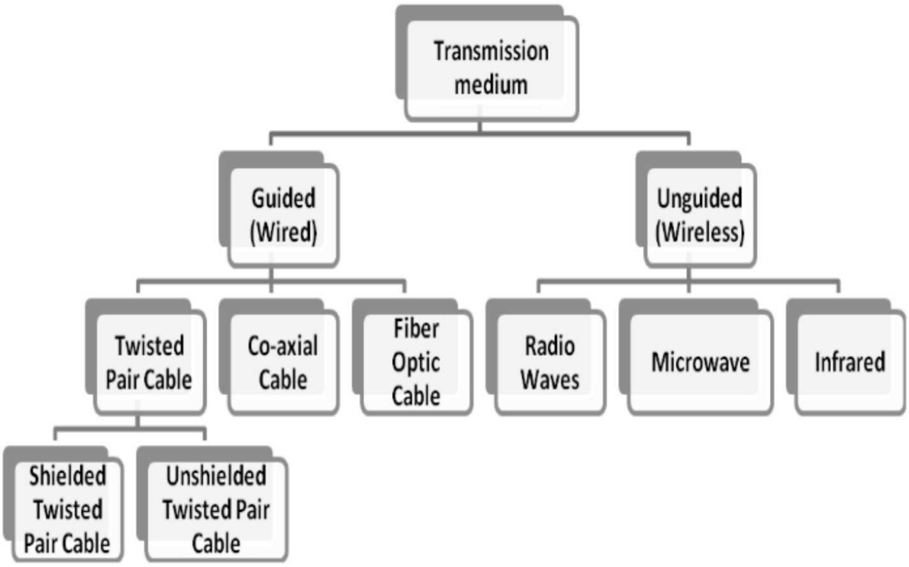
Digital Signal Transmission

Digitally signal can be transmitted by
→ Baseband Transmission
→ Broadband Transmission

① Baseband Transmission
* Transmits digital signal without changing it to analog signal
* Requires a channel having a bandwidth that starts at 0.
* Requires a dedicated medium → 
* Example : wired LANs   Bandwidth ∝ Bit Rate

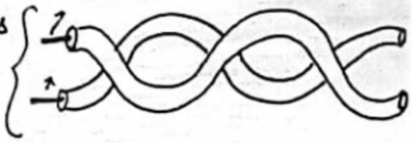
② Broadband Transmission
* Changes digital signal into analog signal for transmission
* Uses a channel with bandwidth not starting at 0
* Does not require a dedicated medium 
* Example : Sending computer data through digital cellular telephone.

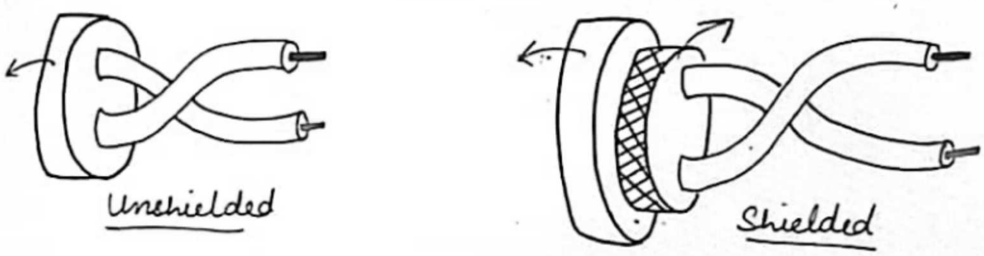
Categories of transmission media

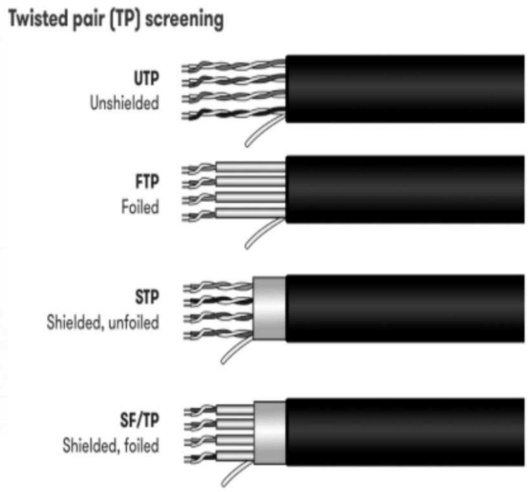


Guided Transmission Media

1. TWISTED PAIR CABLE
- Consists of 2 insulated copper wires (each about 1mm thick) + plastic
- Wires are twisted along so as to cancel out interference.
- Can run several kms w/o amplification
- Useful for both analog and digital signals
- Bandwidth depends on wire thickness
- Adequate performance + low cost
- Example: telephone wires connecting company offices
- Types of Twisted Pair → Unshielded Twisted Pair
  → Shielded Twisted Pair



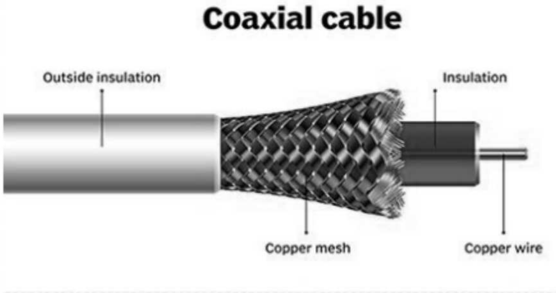


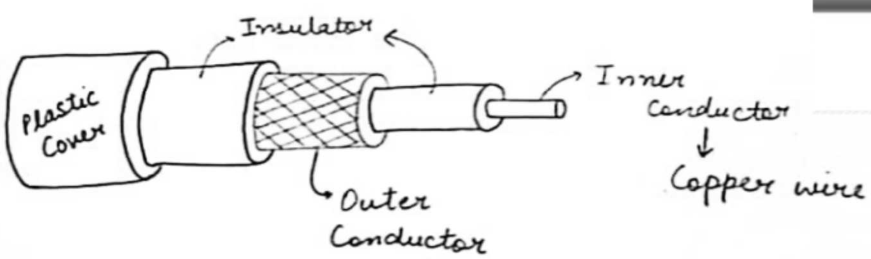


- **Applications**: Telephone networks, Ethernet cables.

Co-Axial Cables

- Consists of copper wire at its core + Insulating material + Cylindrical conductor in the form of a braided mesh + protective plastic cover
- Better shielding than twisted pair → travel longer distances at higher speed
- Useful for both digital + analog transmission
- High bandwidth + Noise Immunity
- Example: Metropolitan Area Network

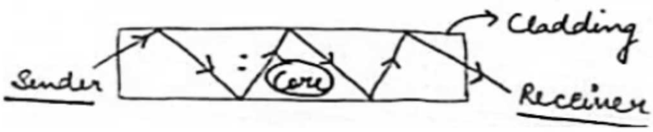


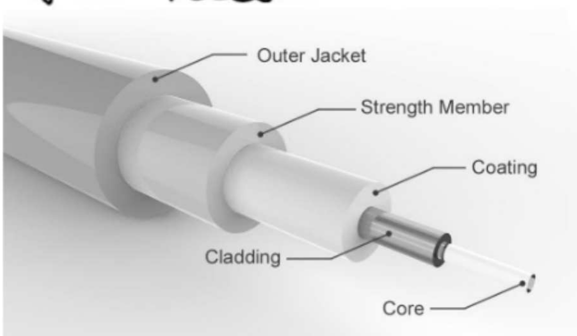


- **Applications**: Cable TV, broadband internet.

Fiber Optic Cable

- Center is glass core through which light travels.
- Core surrounded by glass cladding w/ refractive index Lower than the core → keeps all the light inside the core
- A thin plastic jacket to protect the cladding
- Grouped in bundles, protected by an outer sheath.
- Has higher bandwidth than Copper. +
- Low attenuation ✓ +
- Not affected by corrosive chemicals, power surges, magnetic pulses +
- Thin and lightweight +
- Gets damaged easily if bent too much (−)
- Requires trained engineers
- Optical transmission is unidirectional

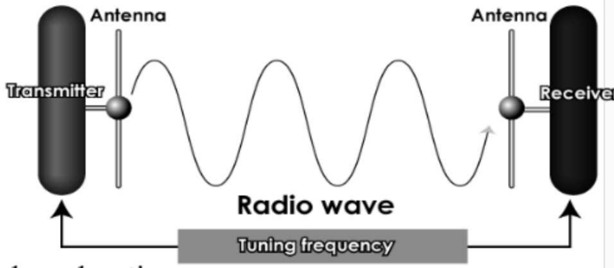




- **Applications**: Long-distance communication, high-speed internet.

UNGUIDED (WIRELESS) TRANSMISSION MEDIUM

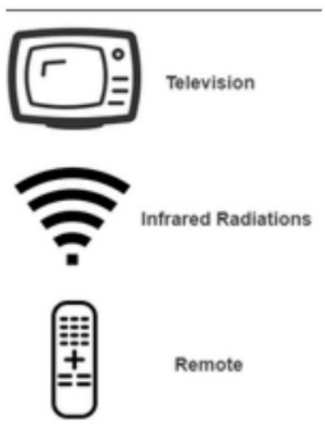
- Unguided media transport data without using a physical conductor. This type of communication is often referred to as wireless communication. It uses wireless electromagnetic signals to send data.
- There are three types of Unguided Media :



- 1- **Radio waves :**
- **Frequency Range:** 30 Hz to 300 GHz.
- **Characteristics:** Can travel long distances, penetrate walls, suitable for broadcasting.
- **Applications:** AM/FM radio, TV, mobile communication.
- **2-Microwaves:**
- **Frequency Range:** 1 GHz to 300 GHz.
- **Characteristics**: Line-of-sight communication, affected by obstacles.
- **Applications:** Satellite communication, Wi-Fi, Bluetooth.

UNGUIDED (WIRELESS) TRANSMISSION MEDIUM

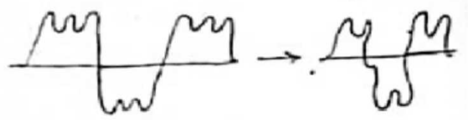
- **3- Infrared Waves:**
- **Frequency Range:** 300 GHz to 400 THz.
- **Characteristics:** Short-range, cannot penetrate walls.
- **Applications:** Remote controls, short-distance device communication.



Signal Impairment

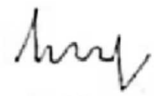
① **Attenuation** : Loss of energy of a signal during transmission
- * Use of amplifiers to strengthen the signal again
- * Unit of signal strength : Decibel (dB)

② **Distortion** :



- * Change in the shape or form of a signal.
- * Composite signal → Multiple frequencies → Different Propagation Speed → Delay in Arrival at receiver → Change in Phase of signal → Distortion of signal

③ **Noise** :
- Thermal Noise : Random motion of electrons in a wire (medium)
- Induced Noise : External sources like motors & appliances
- Crosstalk : Effect of one wire on another
- Impulse Noise : Spike in signal



4 Signal To Noise Ratio : $\dfrac{\text{Avg. signal power}}{\text{Avg. noise power}}$ $\quad SNR_{dB} = 10 \log_{10} SNR$

Data Rate Limits

Data Rate : How fast we can send data (bps) → Bandwidth, → Levels, → Noise

Noiseless Channel : Nyquist Bit Rate

$$\text{Bit Rate} = 2 \times \text{bandwidth} \times \log_2 L$$

L = no. of levels present in a signal

Increasing the no. of levels increases the bit rate
↳ decreases the reliability of a channel.

Noisy Channel : Shannon Capacity

$$\text{Capacity} = \text{bandwidth} \times \log_2 (1 + SNR)$$

SNR ↳ No units

✓ Independant of the no. of levels in a signal

Noiseless

Bit Rate : 265 kbps

Bandwidth : 20 kHz

Levels = $2^{6.625} = 987$

$$\left[\begin{array}{l} 265000 = 2 \times 20{,}000 \times \log_2 L \\ \log_2 L = 6.625 \end{array}\right]$$

Noisy

Bandwidth = 3000 Hz

SNR = 3162

Capacity = $3000 \times (\log_2 3163)$
$= 3000 \times 11.62$
$= 34{,}860$ bps

Digital Transmission

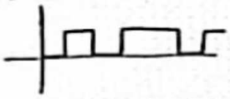
Digital to Digital Conversion : In this section, we see how we can represent digital data by using digital signals. The conversion involves three techniques: line coding, block coding, and scrambling. Line coding is always needed; block coding and scrambling may or may not be needed.

(19)

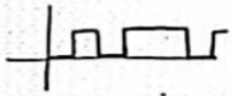
Line Coding : Converts a $\underbrace{\text{sequence of bits}}_{\text{digital data}}$ to a digital signal.

Sender Side

01011101



Medium →



Receiver Side

01011101

Digital data → Digital Signal

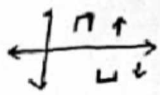
Digital signal → Digital data

Types of Line Coding

- → UNIPOLAR → NRZ (Non Return To Zero)
- → POLAR → NRZ, RZ, Biphase
  - NRZ → NRZ-L, NRZ-I
  - Biphase → Manchester, Differential Manchester
- → BIPOLAR → AMI, Pseudoternary
- → MULTI-LEVEL → 2B1Q, 8B6T, 4D-PAM5
- → MULTI-TRANSITION → MLT-3

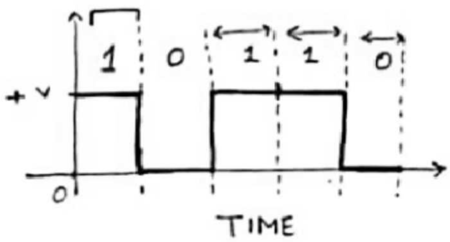
UNIPOLAR Line Encoding

↳ All signal levels are present on one side of time axis, above or below.



① **Non-Return-to-Zero (NRZ)**

- 1 → Positive Voltage   0 → Zero voltage
- Signal does not return to 0 in the middle of bit.



1 0 1 1 0 → +V 0 +V +V 0

Drawback : very costly as compared to polar counterparts

↳ Not used these days.

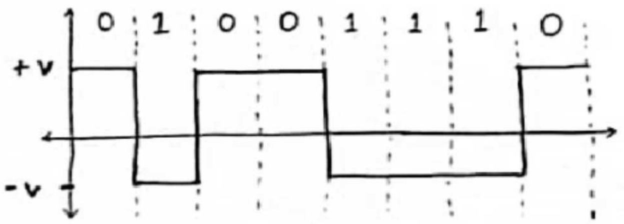
POLAR Line Encoding

↳ Voltages are present on both sides of time axis

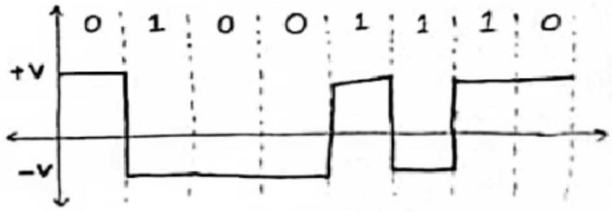
① Polar Non-Return-to-Zero (Polar NRZ)

* Uses ② voltage levels → +V, -V
* Two types → NRZ-Level : Level of voltage determines value of bit.
  ↳ NRZ-Invert : Change or lack of change in the level of voltage determines the value of bit.
  ⇓
  No change in voltage = 0
  Change in voltage = 1

NRZ-L

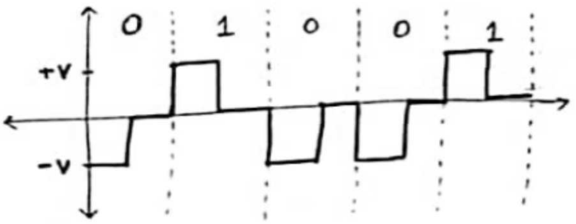


NRZ-I



② POLAR Return-to-Zero

* Uses ③ voltage levels : positive, negative, zero voltage
* Signal changes during the bit, not between the bits
  ↳ goes to 0 in the middle of each bit and remains at 0 untill the beginning of next bit.



ʃ 0
˥ 1

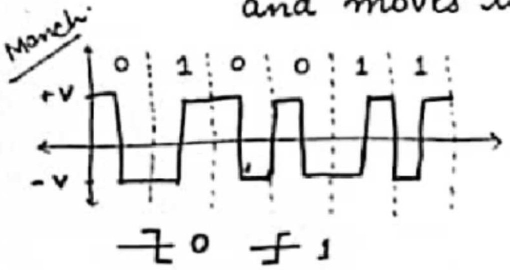
Drawbacks

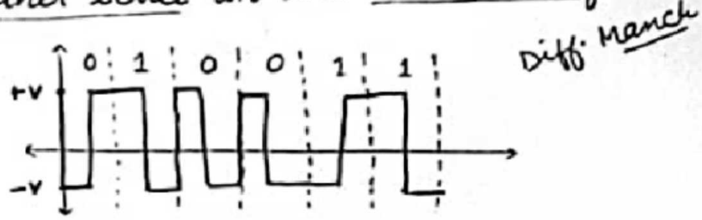
① each bit requires 2 changes in signal level.
② high complexity

3) BIPHASE Line Encoding Scheme

3.1. Manchester Scheme

* Combination of NRZ-L and RZ line encoding schemes.
* Duration of a bit is divided into 2 halves.
    - ↳ Voltage remains at one level during first half and moves to the other level in the second half.





3.2. Differential Manchester Scheme : NRZ-I and RZ combination

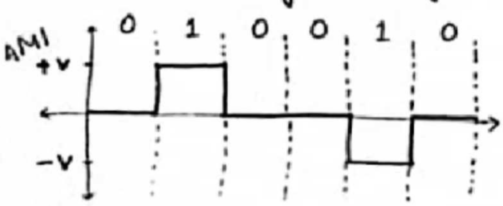
* Signal changes in the middle of the bit.
* Bit value is determined at the beginning of the bit
* 0 → transition 1 → no transition

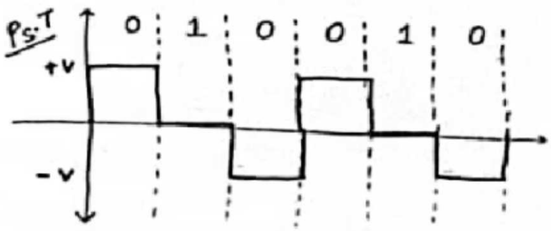
BIPOLAR Line Encoding

(22)

* 3 voltage levels : zero, positive, negative voltage
* One bit is represented by zero voltage
  other bit is represented by alternating positive & negative voltage

1. Alternate Mark Inversion (AMI)
    - Mark → 1 ⇒ Alternating voltages for 1, zero voltage for 0
2. Pseudoternary
    - Variation of AMI scheme
    - Alternating voltages for bit 0, zero voltage for bit 1





✓ AMI has been used for long-distance communication

Multi-Level Line Coding

(23)

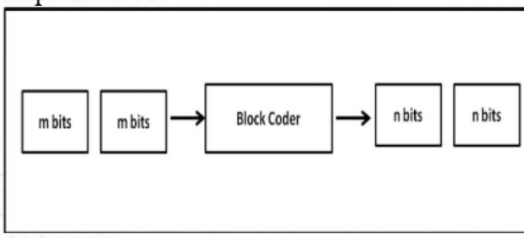
- **2B1Q** : 2 Binary 1 Quaternary
  - 2 Binary → Data patterns of 2 bits
  - 1 Quaternary → One signal has 4 different levels
- **8B6T** : 8 Binary 6 Ternary
  - 8 Binary → 8 bits
  - 6 Ternary → 6 signal elements, each having 3 different levels
- **4D-PAM5** : Four Dimensional Five-Level Pulse Amplitude Modulation
  - Data is sent over four wires (channels) simultaneously

Multi-Transition Line Coding

MLT-3 : Multiline transition using 3 levels

- ✓ If next bit is 0 → No transition
- ✓ Next bit = 1, current level ≠ 0 , next level = 0
- ✓ Next bit = 1, current level = 0 , next level is the opposite of last nonzero level.

Block coding : adds redundancy to line coding so that error detection can be implemented.



Block Coding

Redundancy of bits is required during transmission
- ↳ synchronisation
- ↳ error detection

Block Coding improves Line Coding by incorporating Redundancy.

↳ mB/nB coding : Changes a block of (m) bits to a block of (n) bits where $n > m$
  ↳ bits

Steps of Block Coding

1. Division → divide a sequence of bits into groups of m-bits each
2. Substitution → replace m-bit group with an n-bit group
3. Combination → n-bit groups are combined to form a stream (more bits than original)

0110 0101 1011 1000 1110 → $\boxed{\text{mB/nB Coding}}$ → 00110 01110 11001 00001 11111

Types of Block Coding

(25)

0000 → 11110
0001 → 01001
0010 → 10100
00000 :
11111 :
00100

① 4B/5B

- Divide the original bit sequence intogroups of 4 bits
- Substitute each 4-bit group with 5-bit group
- Combine all the 5-bit groups into a single data stream.

00
01
10
11

$2^4 = 16$ combinations $2^5 = 32$ combinations

UNUSED COMBINATIONS (16) → control purposes
→ error detection
→ synchronisation

② 8B/10B

- 8-bit groups substituted by 10-bit groups.
- Better error detection capability than 4B/5B scheme.

8-bit group → 5B/6B (→ 5 Most Signif. bits) and → 3B/4B (→ 3 Least Sign. bits) → 10-bit group

Split to simplify Mapping Table

$2^{10} - 2^8 = 768$ redundant groups.

3 Scrambling

- Scrambling is a technique used in data transmission to modify the digital signal before sending it, without changing the actual data bits.
- **In simple words:** When you send digital data (like 1s and 0s), sometimes you get long sequences like:0000000000000000 or 1111111111111111 Those are bad for transmission, because: There are no transitions (no change from 0 → 1 or 1 → 0), The receiver's clock can lose synchronization (it doesn't know when bits start or end), It's harder to recover the signal.
- **Digital data** = 1s and 0s When we send digital data, it looks like this:1011010100110 Each bit (1 or 0) is sent as an electrical signal — **for example:**1 = high voltage 0 = low voltage **2. The problem:** long sequences of the same bit Sometimes, the data might look like this:0000000000000000 or 1111111111111111 That means the signal stays constant (doesn't change) for a long time**.**
- **3. Why that's bad When the signal doesn't change (no transition between 0 and 1): a) No transitions No movement in the signal → it looks flat. So instead of a wave like this:101010 → ↑↓↑↓↑↓ (changes often ☑)you get this:000000 → ________ (no change ✖.**
- **b) The receiver loses timing (synchronization)** The receiver needs to know when each bit starts and ends. It uses the signal transitions (changes) to keep its clock in sync. If the signal never changes, the receiver's clock drifts —it can't tell:"Is this still the same 0? Or a new one?"So it starts reading bits incorrectly. ✖ **c) Harder to recover data** Without transitions, the receiver can't tell where to "cut" the signal into bits. This causes errors in the received data.
- Example Without scrambling: Data: 0000000000000000 Signal: no transitions ✖ → sync lost
- With scrambling: Data: 0000000000000000 Scrambled signal: 1011001010010110 ☑ → more transitions **At the receiver:** Unscrambler → restores original 0000000000000000
- Scrambling is used with Line coding (e.g., NRZ, Manchester) Telecom systems like SONET/SDH, DSL,

Digital Transmission

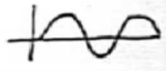
Digital to Analog Conversion

Digital To Analog Conversion (29)

↳ Process of modifying one of the characteristics of an analog signal based on the digital data that has to be transmitted.

CHARACTERISTICS : Amplitude, Frequency, Phase

Amplitude Shift Keying   Frequency Shift Keying   Phase shift Keying



Data element : Smallest piece of information to be exchanged → bit

Signal element : Smallest unit of a signal that is constant.

RELATIONSHIP : $S = N \times \frac{1}{r}$

S: Signal Rate (baud) ← unit

N: Data Rate (bps)

r: No. of data elements carried in one signal element.

↳ $r = \log_2 L$

Bit Rate : No. of bits per second

Baud Rate : No. of signal elements per second

↳ Signal Rate

CARRIER SIGNAL :

The high-frequency signal produced by a sending device, on which digital information is represented.

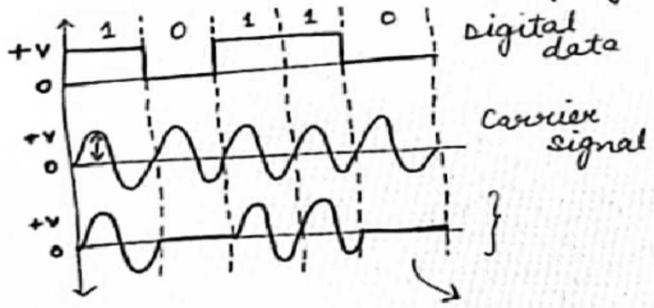
AMPLITUDE SHIFT KEYING (ASK)

- Amplitude of a carrier signal is changed to represent data
- Both phase and frequency remain constant

1) Binary Amplitude Shift Keying (BASK)

* Implemented using 2 levels only
- ↳ bit 0 → amplitude 0 voltag
- ↳ bit 1 → positive voltage

* Also known as On-Off keying



Non Periodic Composite Signal

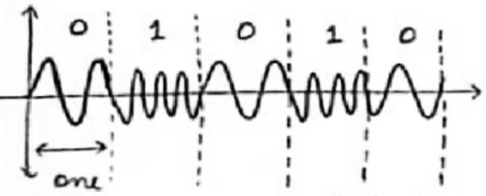
2) Multilevel ASK
- More than 2 different amplitude levels
- Never implemented as ASK purely.
- 2, 3, 4 bits ⟶ 4, 8, 16 Amplitudes

Frequency Shift Keying (FSK)

- Variation in the frequency of the carrier signal
- Each data element is represented by a unique frequency
- Peak Amplitude and Phase will remain constant.

1) Binary FSK

- 2 carrier frequency → first carrier frequency → bit 0; → second carrier frequency → bit 1



signal element

Non-Periodic Composite Signal with multiple frequencies

2 bits → $2^2 = 4$

Voltage Controlled Oscillator (VCO)
→ 0 voltage → original
→ +ve voltage → increased

2) Multilevel FSK

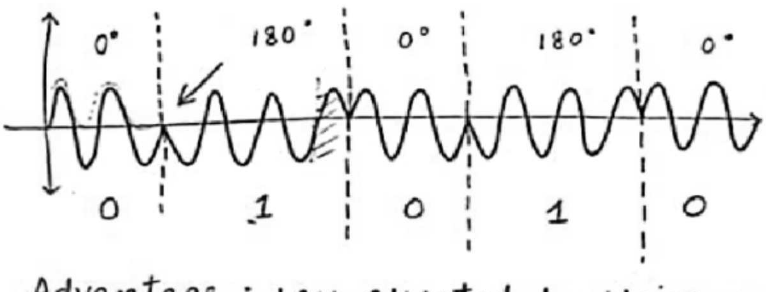
- More than 2 frequencies
- 2 bits → 4 combⁿ → $f_1\ f_2\ f_3\ f_4$
- 3 bits → 8 combⁿ → $f_1 \ldots f_8$

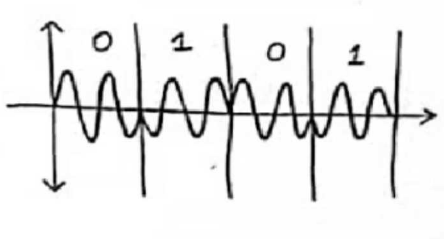
Phase Shift Keying

- Phase of the carrier is varied to represent different signal els.
- Both peak amplitude and frequency remain constant

1) Binary Phase Shift Keying

- Only 2 signal elements → one in-phase (0°); → other out-phase (180°)





Advantage : Less affected by Noise → PSK is better than ASK

- Requires a single carrier frequency.
→ PSK better than FSK.

Quadrature Amplitude Modulation

(32)

- Alter more than 1 characteristic of a sine wave at a time
- Combination of Amplitude Shift Keying + Phase Shift Keying
- Uses 2 carrier waves
- Each carrier contains different

Analog Transmission

Analog to Analog Conversion

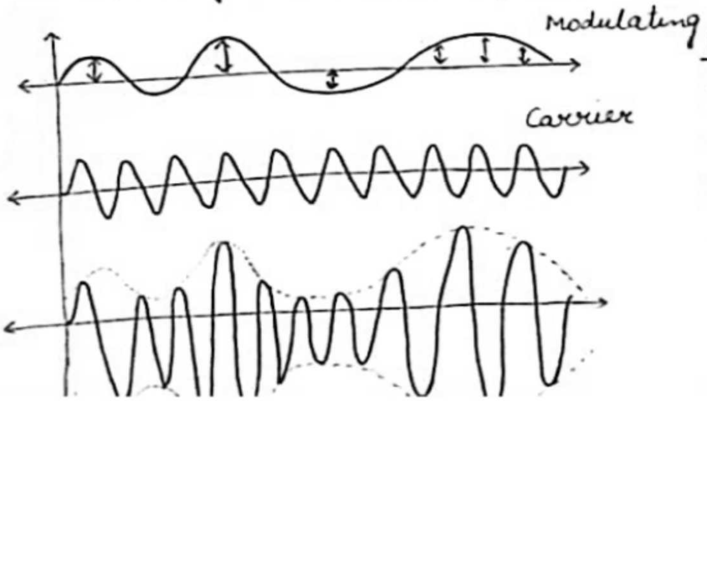
(33)

Analog-to-Analog Conversion

↳ Representing analog information by an analog signal

1. Amplitude Modulation

- Amplitude of carrier signal is changed based on the amplitude of modulating signal. original analog data
- Frequency and phase of carrier remain constant.

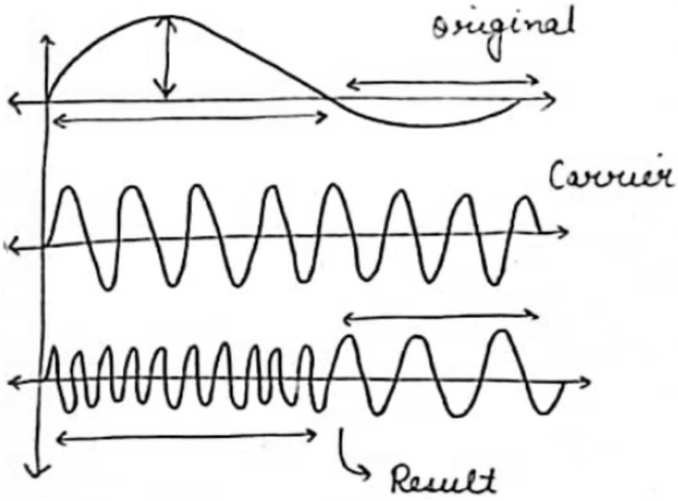


Example

In case of radios, a narrow bandwidth is assigned by the govt. Signals produced by various stations lie in the same range. To listen to different stations, these signals need to be shifted to different ranges.

Frequency Modulation

- Frequency of the carrier signal is changed based on the amplitude of the modulating signal.
- Peak amplitude and phase of carrier remains constant



Implemented using Voltage-Controlled Oscillator (VCO)

↓

The frequency of the oscillator changes on the basis of the amplitude of the original signal

Phase Modulation

* Phase of the carrier is changed based on the amplitude of the modulating wave.
* Peak Amplitude and frequency of the carrier remain fixed.
* Phase Modulation is similar to Frequency Modulation, except that in FM, change in carrier frequency is proportional to the amplitude of the modulating signal. In Phase Modulation, the change in frequency is proportional to the derivative of the amplitude of the modulating signal.

FM → freq of carrier

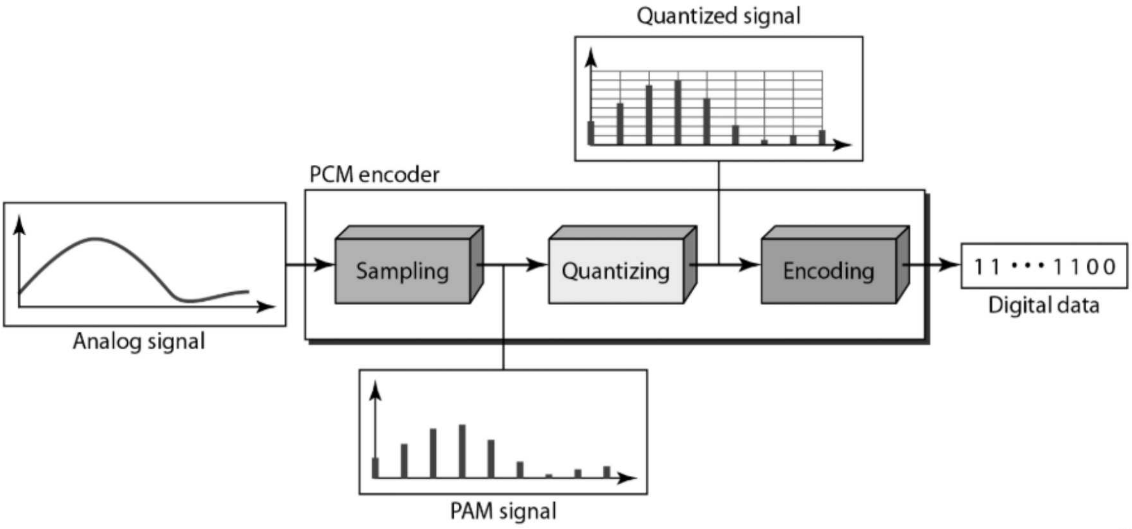
PM → phase of carrier →

Analog Transmission

Analog to Digital Conversion

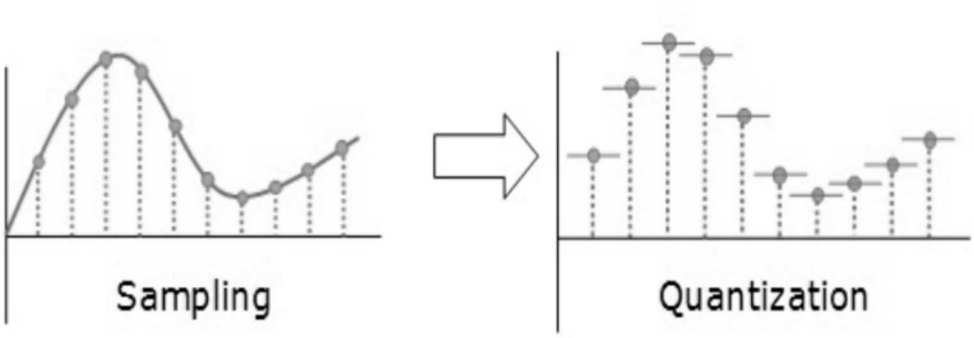
- **PCM (Pulse Code Modulation):** To convert analog wave into digital data, we use Pulse Code Modulation (PCM). With PCM all forms of analog data like video, voice, music and telemetry can be transferred.
- PCM is one of the most commonly used method to convert analog data into digital form. It involves three steps:

- Sampling
- Quantization
- Encoding.
- **Components of PCM encoder**



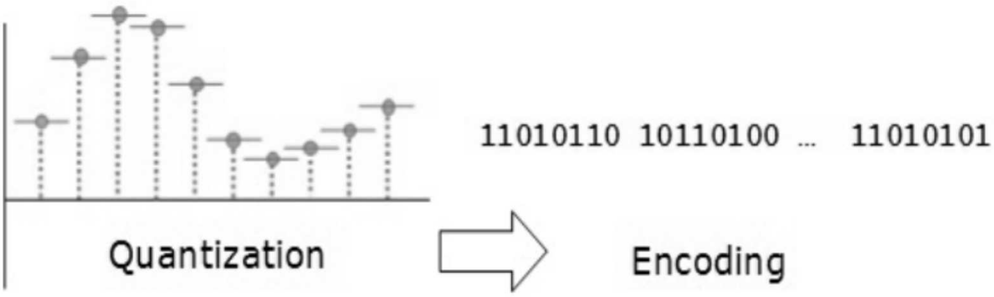
- **Quantization**

- Sampling yields discrete form of continuous analog signal. Every discrete pattern shows the amplitude of the analog signal at that instance. The quantization is done between the maximum amplitude value and the minimum amplitude value. Quantization is approximation of the instantaneous analog value.



- **Encoding**

- In encoding, each approximated value is then converted into binary format.



When the physical link connecting 2 devices has a higher bandwidth than the bandwidth required by those devices, link can be shared.

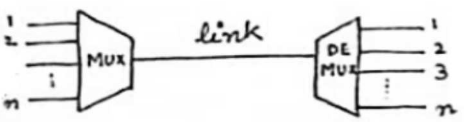
MULTIPLEXING

↳ The set of techniques that allow simultaneous transmission of multiple signals through a single physical link.

Advantages

1. Efficient use of available bandwidth of the link
2. Avoids any wastage of available bandwidth.

Multiplexer
De-Multiplexer



- n lines share the bandwidth of 1 link
- MUX combines multiple signals into a single composite signal at sender side
- DE-MUX separates the composite signal into its components at receiver side

Types of Multiplexing

1. Frequency –
2. Wavelength –
3. Time –

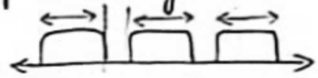
} Division Multiplexing

- Link → physical medium
- Channel → portion of a link that is used for transmission

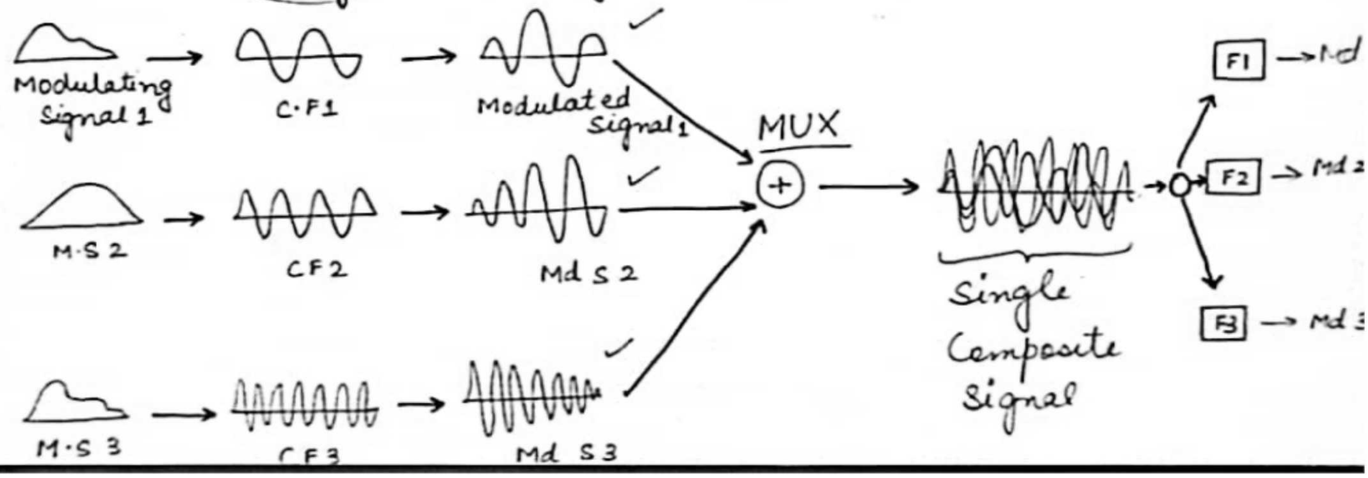
Frequency Division Multiplexing

* Multiple Carrier frequencies are used for modulating signals generated by different senders
* Modulated signals are combined into a single composite signal

GUARD BANDS → Unused portions of the bandwidth of links → to prevent signal overlapping



* FDM is an analog multiplexing technique.



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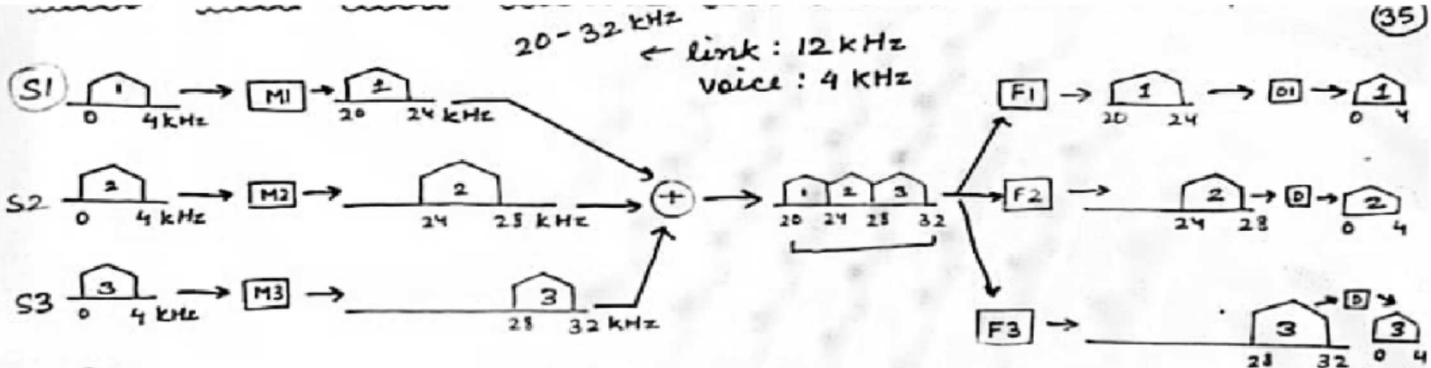
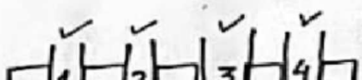


Q Five channels, each of 100 KHz bandwidth have to be multiplexed. What should be the minimum bandwidth of the link if a guard band is also needed (10 KHz) between the channels ?

Each channel's bandwidth : 100 KHz → 5×100 = 500 kHz

Guard Band bandwidth : 10 KHz

4×10 = 40



Min. Bandwidth = 500 + 40 = 540 KHz

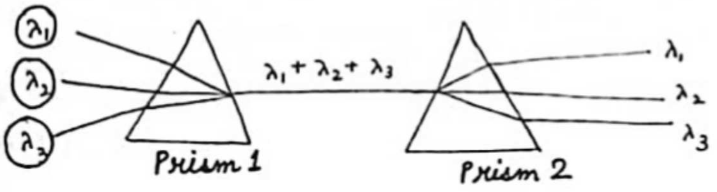
Use of FDM :

↳ AM and FM radios .

Wavelength Division Multiplexing

* Aims to use the high data rate available in fiber optic cables,
  bandwidth of fiber optic > bandwidth of metallic cables.
* WDM is similar to FDM, except that optical signals are multiplexed and demultiplexed using fiber optic channels.

Analog Multiplexing Techniques



MUX : Combines multiple light sources into one

DE-MUX : separates the composite signal (light)

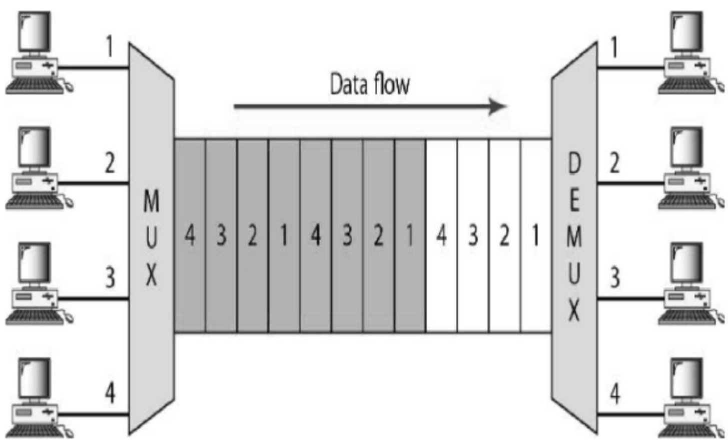
Application : Synchronous Optical Networking (SONET)

Dense WDM (DWDM) : Multiplexes a large no. of channels by spacing them very close to each-other.

Time Division Multiplexing (TDM)

Is a technique that allows multiple signals to use the **same transmission medium** by sharing it based on **time**.

•Each user is assigned a **time slot** during which they can transmit their data.
•The users' data is sent **sequentially**, one after the other in their designated time slot.
•Once all users have transmitted their data, the cycle repeats.



Types of TDM

1️⃣ **Synchronous TDM**

- Each user is given **a fixed time** slot even if they have no data to send.
- If a user has no data, their time slot remains empty.
- Used in: Telephone networks (e.g., E1, T1).

2️⃣ **Asynchronous TDM**

•Time slots are **dynamically allocated** based on need.
•If a user has no data to send, their slot is given to another user.
•Used in: Modern packet-switched networks (e.g., Ethernet).