Communication Engineering (1333201) - Winter 2024 Solution

Milav Dabgar

May 19, 2024

Question 1(a) [3 marks]

What is modulation? What is the need of it?

Solution

Modulation is the process of varying one or more properties of a high-frequency carrier signal with a modulating signal containing information.

Table 1. Need for Modulation

Reason	Explanation
Antenna Size	Reduces antenna size requirements ($\lambda = c/f$)
Multiplexing	Allows multiple signals to share the spectrum
Range	Increases transmission distance
Interference	Reduces noise interference

- **Practical transmission**: Makes low-frequency information signals suitable for wireless transmission
- **Signal separation**: Enables different signals to be transmitted simultaneously

Mnemonic

"RARE Messages: Range, Antenna, Reduce interference, Enable multiplexing"

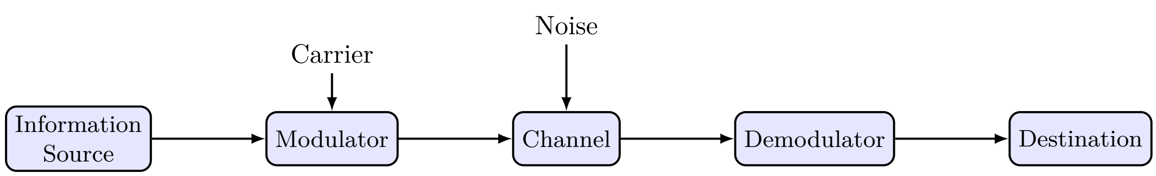

Figure 1. Communication System Block Diagram

Question 1(b) [4 marks]

Compare AM and FM.

Solution

Table 2. Comparison between AM and FM

Parameter	AM (Amplitude Modulation)	FM (Frequency Modulation)
Parameter varied	Amplitude of carrier	Frequency of carrier
Bandwidth	Narrow $(2 \times f_m)$	Wide $(2 \times (m_f + 1)f_m)$
Noise immunity	Poor	Excellent
Power efficiency	Less efficient	More efficient
Circuit complexity	Simple	Complex
Quality	Moderate	High
Applications	Medium wave broadcasting	High-fidelity broadcasting

Mnemonic

"BANC-QA: Bandwidth, Amplitude/frequency, Noise, Complexity, Quality, Applications"

Question 1(c) [7 marks]

Explain Amplitude modulation with waveform and derive voltage equation for modulated signal also Sketch the frequency spectrum of the DSBFC AM.

Solution

Amplitude Modulation (AM) is a technique where the amplitude of a carrier wave is varied in proportion to the instantaneous amplitude of the modulating signal.

Voltage Equation:

- Carrier signal: $v_1(t) = A_1 \sin(\omega_c t)$
- Modulating signal: $v_2(t) = A_2 \sin(\omega_m t)$
- Modulated signal: $v(t) = A_1[1 + m \sin(\omega_m t)] \sin(\omega_c t)$
- Where $m = A_2/A_1$ (modulation index)

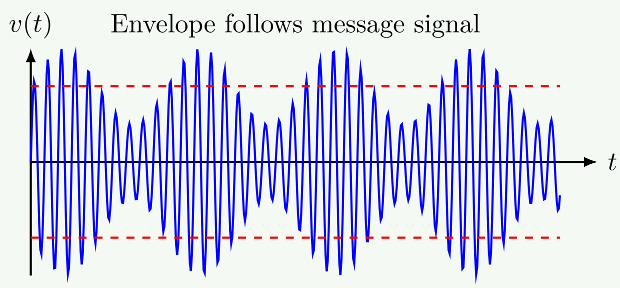

Figure 2. AM Waveform

Frequency Spectrum of DSBFC AM

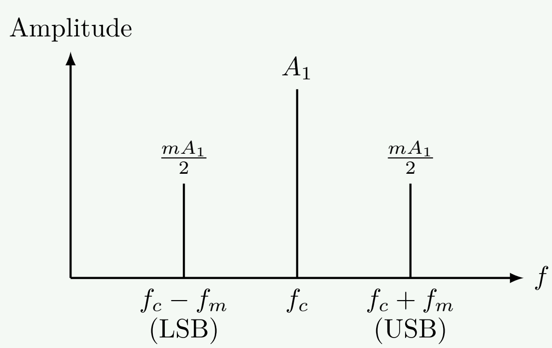

Figure 3. AM Frequency Spectrum

- **Bandwidth**: The bandwidth of AM signal is $2 \times f_m$
- **Sidebands**: Upper sideband (USB) at $f_c + f_m$ and Lower sideband (LSB) at $f_c - f_m$
- **Power distribution**: In carrier and two sidebands

Mnemonic

"CAM-SIP: Carrier Amplitude Modified, Sidebands In Pair"

Question 1(c OR) [7 marks]

Derive the equation for total power in AM, calculate percentage of power savings in DSB and SSB.

Solution

Derivation of Total Power in AM:

- AM signal: $v(t) = A_1[1 + m\sin(\omega_m t)]\sin(\omega_c t)$
- Total power: $P = P_{\text{carrier}} + P_{\text{sidebands}}$
- $P_{\text{carrier}} = A_1^2/2$
- $P_{\text{sidebands}} = A_1^2 m^2/4$

Table 3. Power Distribution in AM

Component	Power Expression	% of Total Power (m=1)
Carrier	$P_c = A_1^2/2$	66.67%
Sidebands	$P_s = A_1^2 m^2/4$	33.33%
Total	$P_t = A_1^2(1 + m^2/2)/2$	100%

Power Savings:

- **DSB-SC**: 100% carrier power saved (66.67% of total power)
  - Only sidebands are transmitted
  - Percentage savings = $(P_c/P_t) \times 100 = 66.67\%$
- **SSB**: 50% of sideband power + 100% carrier power saved
  - One sideband + carrier removed
  - Percentage savings = $(P_c + P_s/2)/P_t \times 100 = 83.33\%$

Mnemonic

"CAST-83: Carrier And Sideband Transmission, 83% saved in SSB"

Question 2(a) [3 marks]

Define (1) Modulation index for AM (2) Modulation index For FM.

Solution

Table 4. Modulation Index Definitions

Parameter	AM Modulation Index	FM Modulation Index
Definition	Ratio of peak amplitude of modulating signal to peak amplitude of carrier	Ratio of frequency deviation to modulating frequency
Formula	$m = A_m/A_c$	$m_f = \Delta f/f_m$
Range	$0 \leq m \leq 1$ for no distortion	No specific upper limit
Effect	Determines % modulation	Determines bandwidth

- **AM Modulation Index**: Controls the amplitude variation and power distribution
- **FM Modulation Index**: Determines bandwidth and signal quality

Mnemonic

"ARM-FDM: Amplitude Ratio for Modulation, Frequency Deviation for Modulation"

Question 2(b) [4 marks]

Draw and explain block diagram for envelope detector.

Solution

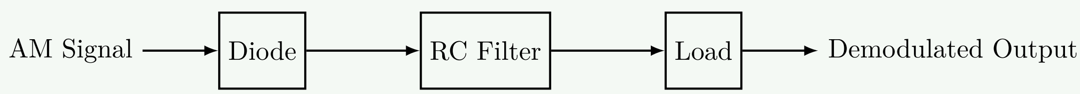

Figure 4. Envelope Detector Block Diagram

Table 5. Components and Their Functions

Component	Function
Diode	Rectifies the AM signal (removes negative half-cycles)
RC Filter	Smooths the rectified signal to recover the envelope
Load	Provides output circuit and impedance matching

- **Working principle**: The diode conducts only during positive half-cycles
- **Time constant**: RC must be large enough to prevent ripple but small enough to follow modulation
- **Condition**: $RC \gg 1/f_c$ but $RC \ll 1/f_m$

Mnemonic

"DEER: Diode Extracts Envelope Representation"

Question 2(c) [7 marks]

Draw block diagram of FM radio receiver and explain working of each block.

Solution

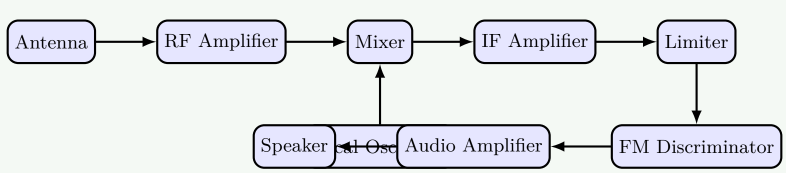

Figure 5. FM Radio Receiver

Table 6. Functions of Each Block

Block	Function
Antenna	Receives electromagnetic waves
RF Amplifier	Amplifies weak RF signals (88-108 MHz)
Mixer	Converts RF to IF frequency (10.7 MHz)
Local Oscillator	Generates frequency for mixing (RF+10.7 MHz)
IF Amplifier	Amplifies IF signal with fixed gain
Limiter	Removes amplitude variations
FM Discriminator	Converts frequency variations to voltage
Audio Amplifier	Amplifies recovered audio
Speaker	Converts electrical to sound waves

- **Superheterodyne principle**: Uses frequency conversion to process signals at fixed IF
- **Distinctive FM feature**: Limiter removes noise in amplitude before demodulation

Mnemonic

"RAMLIDASS: RF, Amplifier, Mixer, Local oscillator, IF, Discriminator, Audio, Speaker System"

Question 2(a OR) [3 marks]

Draw only Waveform For frequency modulation and Phase modulation.

Solution

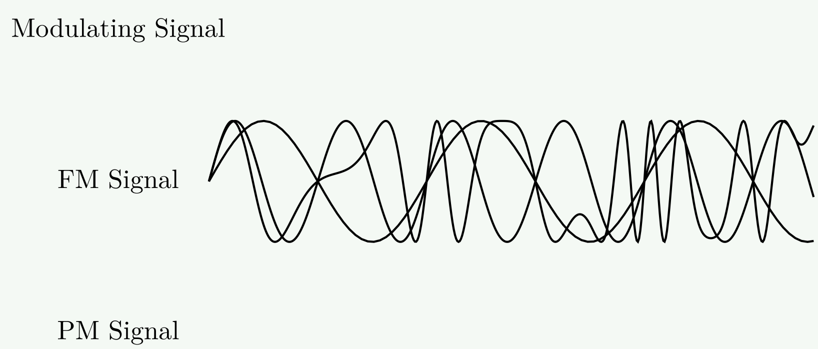

Figure 6. FM and PM Waveforms

Key Characteristics:

- **FM**: Frequency increases when modulating signal is positive
- **PM**: Phase shifts immediately with amplitude changes

Mnemonic

"FIP-PAF: Frequency Increases with Positive signal, Phase Advances with Faster changes"

Question 2(b OR) [4 marks]

Define any FOUR characteristics of radio receiver.

Solution

Table 7. Characteristics of Radio Receiver

Characteristic	Definition
Sensitivity	Ability to receive weak signals (measured in μV or dBm)
Selectivity	Ability to separate desired signal from adjacent channels
Fidelity	Accuracy of reproducing the original modulating signal
Image Rejection	Ability to reject image frequency interference

Additional characteristics:

- **Signal-to-Noise Ratio**: Ratio of signal power to noise power
- **Bandwidth**: Range of frequencies that can be received
- **Stability**: Ability to maintain tuned frequency

Mnemonic

"SFIS-BSS: Sensitivity, Fidelity, Image rejection, Selectivity - Better Signal Stability"

Question 2(c OR) [7 marks]

Draw block diagram of AM radio receiver and explain working of each block.

Solution

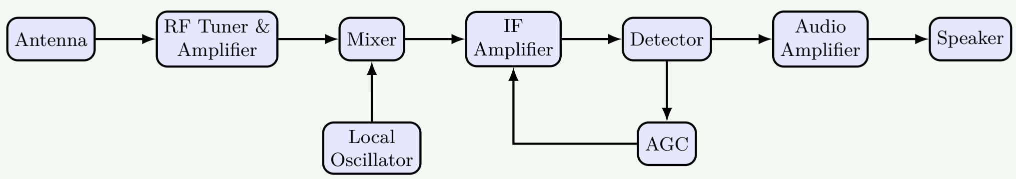

Figure 7. AM Radio Receiver

Table 8. Functions of Each Block

Block	Function
Antenna	Captures AM radio waves
RF Tuner & Amplifier	Selects and amplifies desired frequency
Mixer	Converts RF signal to IF (455 kHz)
Local Oscillator	Generates frequency for mixing (RF+455 kHz)
IF Amplifier	Amplifies IF signal with fixed selectivity
Detector	Recovers audio from AM envelope
AGC	Provides automatic gain control
Audio Amplifier	Amplifies audio signal
Speaker	Converts electrical to sound waves

- **Superheterodyne principle**: Uses frequency conversion for better selectivity
- **AGC feedback loop**: Maintains constant output despite signal strength variations

Mnemonic

"ARMLESS: Antenna, RF, Mixer, Local oscillator, Envelope detector, Sound System"

Question 3(a) [3 marks]

Define quantization. Explain non uniform quantization in brief.

Solution

Quantization is the process of converting continuous amplitude values into discrete levels for digital representation.

Table 9. Non-uniform Quantization

Aspect	Description
Definition	Assigning different step sizes for different amplitude ranges
Advantage	Reduces quantization noise for small amplitude signals
Implementation	Using companding (compression-expansion) techniques
Example	μ-law and A-law companding used in telephony

- **Working principle**: Smaller step sizes for lower amplitudes, larger steps for higher amplitudes
- **Effect**: Improves SNR for weak signals at the expense of strong signals

Mnemonic

"QUEST-CS: QUantization with Enhanced Steps - Compressing Small signals"

Question 3(b) [4 marks]

Explain Sample and hold Circuit with Waveform.

Solution

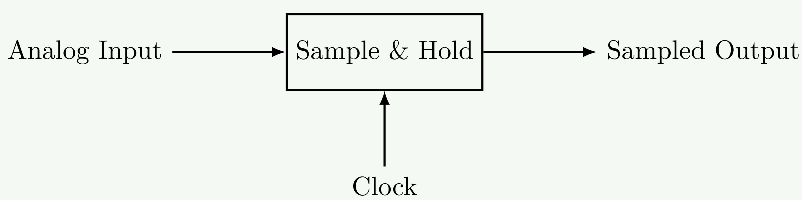

Figure 8. Sample and Hold Circuit

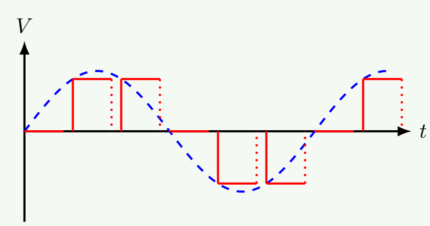

Figure 9. Sample and Hold Waveform

- **Sampling mode**: Switch closes, capacitor charges to input voltage
- **Hold mode**: Switch opens, capacitor maintains voltage

Mnemonic

"CHASED: Capacitor Holds Amplitude Samples for Extended Duration"

Question 3(c) [7 marks]

What is sampling? Explain types of sampling in brief.

Solution

Sampling is the process of converting a continuous-time signal into a discrete-time signal by taking measurements at regular intervals.

Table 10. Types of Sampling

Type	Description	Characteristics
Natural Sampling	Signal is multiplied with rectangular pulses	Retains original signal shape during pulse
Flat-top Sampling	Sample value is held constant during sampling interval	Creates a staircase-like output
Ideal Sampling	Instantaneous samples represented as impulses	Theoretical concept with zero width pulses
Uniform Sampling	Samples taken at equal time intervals	Most common in practice
Non-uniform Sampling	Samples taken at varying intervals	Used for specialized applications

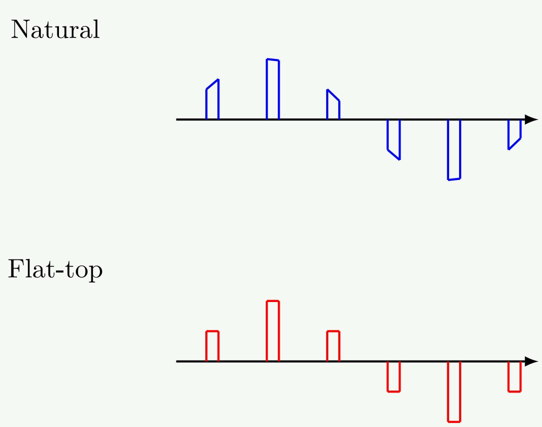

Figure 10. Natural vs Flat-top Sampling

- **Nyquist criterion**: Sampling frequency must be at least twice the highest frequency in the signal

Mnemonic

"INFUN: Ideal, Natural, Flat-top, Uniform, Non-uniform"

Question 3(a OR) [3 marks]

Explain quantization process and its necessity.

Solution

Quantization Process maps continuous amplitude values to finite discrete levels for digital representation.

Table 11. Quantization Process and Necessity

Aspect	Description
Process	Dividing amplitude range into discrete levels
Necessity	Required for analog-to-digital conversion
Effect	Introduces quantization error/noise
Parameters	Step size, number of levels (2^n for n-bit)

- **Step size calculation**: Step size = $(V_{\max} - V_{\min})/2^n$
- **Quantization error**: Maximum error is $\pm Q/2$ where Q is step size

Mnemonic

"SEND: Step-size Establishes Noise in Digitization"

Question 3(b OR) [4 marks]

State and explain Nyquist Criteria for sampling of signal.

Solution

Nyquist Sampling Theorem states that to perfectly reconstruct a bandlimited signal, the sampling frequency must be at least twice the highest frequency component in the signal.

Table 12. Nyquist Criteria

Parameter	Description
Criterion	$f_s \geq 2f_{\max}$
Nyquist Rate	$2f_{\max}$ (minimum sampling frequency)
Nyquist Interval	$1/(2f_{\max})$ (maximum sampling period)
Aliasing	Occurs when $f_s < 2f_{\max}$

- **Consequences of undersampling**: Aliasing (frequency folding)
- **Practical application**: Anti-aliasing filters used before sampling

Mnemonic

"TRAP-A: Twice Rate Avoids Problematic Aliasing"

Question 3(c OR) [7 marks]

Explain PAM, PWM and PPM with waveform.

Solution

Table 13. Pulse Modulation Techniques

Technique	Description	Parameter Varied	Application
PAM	Pulse Amplitude Modulation	Amplitude of pulses	Simple ADC systems
PWM	Pulse Width Modulation	Width/duration of pulses	Motor control, power regulation
PPM	Pulse Position Modulation	Position/timing of pulses	High noise immunity systems

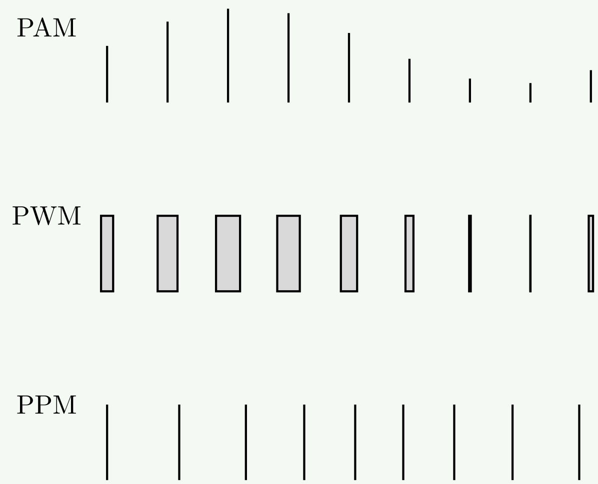

Figure 11. Pulse Modulation Waveforms

- **PAM**: Simplest form, most susceptible to noise
- **PWM**: Better noise immunity, easy generation
- **PPM**: Best noise immunity, requires precise timing

Mnemonic

"AWP-PAW: Amplitude, Width, Position - Pulse Alteration Ways"

Question 4(a) [3 marks]

What is slope overload noise and granular noise in DM?

Solution

Table 14. Noise Types in Delta Modulation

Noise Type	Definition	Cause	Solution
Slope Overload Noise	Error when signal slope exceeds step size capability	Step size too small for rapidly changing signals	Increase step size or sampling frequency
Granular Noise	Error due to continuous hunting around slowly varying signals	Step size too large for slowly changing signals	Decrease step size

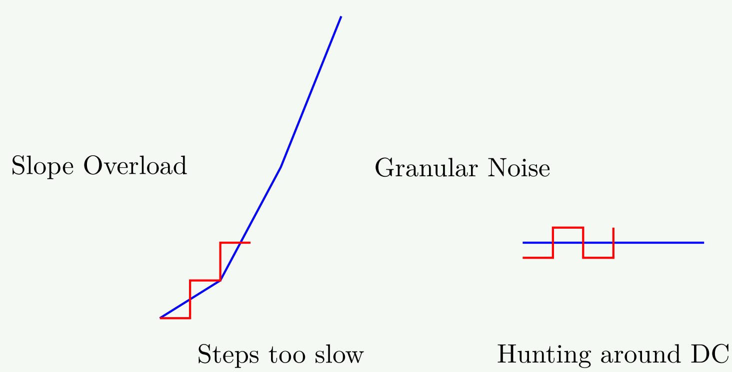

Figure 12. DM Noise Types

Mnemonic

"FAST-SLOW: Fast signals cause Slope overload, SLOW signals cause Granular noise"

Question 4(b) [4 marks]

Draw and explain TDM frame.

Solution

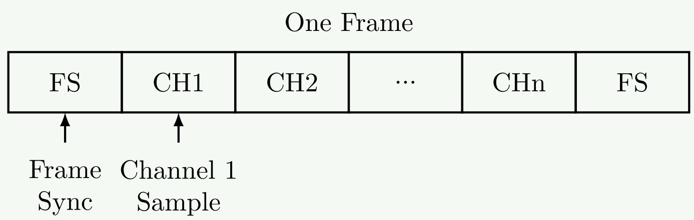

Figure 13. TDM Frame Structure

Table 15. TDM Frame Components

Component	Description
Frame Sync (FS)	Pattern that marks the start of frame
Time Slot	Portion allocated to one channel
Channel Sample	Data from a specific channel
Frame Length	Total duration (FS + all channels)

- **Working principle**: Allocates different time slots to different channels
- **Synchronization**: Essential for proper demultiplexing

Mnemonic

"FAST-Ch: Frame And Slots for Transmitting Channels"

Question 4(c) [7 marks]

Describe the function of each block of PCM transmitter and Receiver. Give application, advantage and disadvantage of PCM system.

Solution

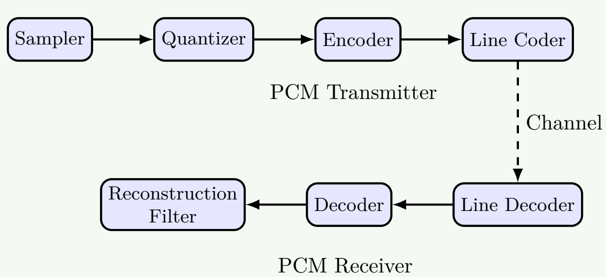

Figure 14. PCM System

Table 16. PCM Block Functions

Block	Function
Sampler	Converts analog signal to PAM signal
Quantizer	Assigns discrete levels to samples
Encoder	Converts quantized levels to binary code
Line Coder	Converts binary to transmission format
Line Decoder	Recovers binary from received signal
Decoder	Converts binary back to quantized levels
Reconstruction Filter	Smooths decoded output into analog signal

Applications, Advantages and Disadvantages:

Table 17. PCM System Characteristics

Category	Description
Applications	Telephone systems, CD audio, Digital TV, Mobile communications
Advantages	Immune to noise, Signal regeneration possible, Compatible with digital systems
Disadvantages	Requires higher bandwidth, Higher complexity, Quantization noise

Mnemonic

"SEQUEL-DR: Sample, Quantize, Encode - Line code, Decode, Reconstruct"

Question 4(a OR) [3 marks]

Give difference between DM and ADM modulation.

Solution

Table 18. Comparison between DM and ADM

Parameter	Delta Modulation (DM)	Adaptive Delta Modulation (ADM)
Step Size	Fixed	Variable (adapts to signal slope)
Tracking Ability	Limited	Better signal tracking
Noise Performance	Suffers from slope overload and granular noise	Reduced noise problems
Complexity	Simpler	More complex

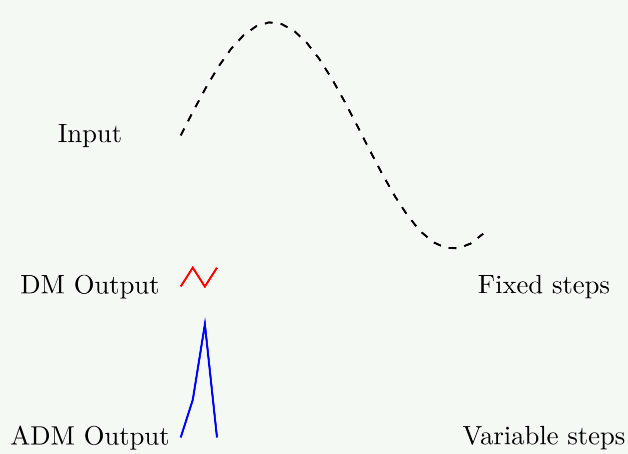

Figure 15. DM vs ADM Tracking

Mnemonic

"FAST-VAR: Fixed And Simple Tracking vs Variable Adaptive Response"

Question 4(b OR) [4 marks]

Explain Block diagram of basic PCM-TDM system.

Solution

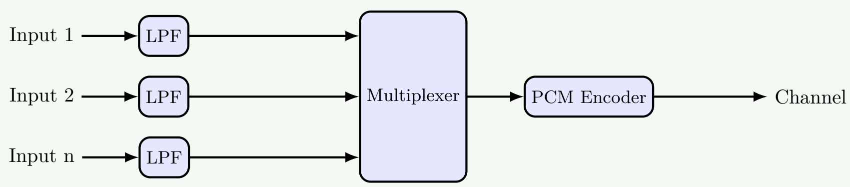

Figure 16. PCM-TDM System

Table 19. PCM-TDM System Components

Component	Function
Low-pass Filters	Limit bandwidth of input signals
Multiplexer	Combines multiple signals into time slots
PCM Encoder	Converts to digital (sample, quantize, encode)
Transmission Channel	Carries digitized, multiplexed signal
PCM Decoder	Reconstructs quantized samples
Demultiplexer	Separates channels from time slots

- **Working principle**: Combines time division multiplexing with pulse code modulation

Mnemonic

"FLIMPED: Filter, Limit, Multiplex, PCM Encode, Decode"

Question 4(c OR) [7 marks]

Explain DPCM modulator with equation and waveform.

Solution

Differential Pulse Code Modulation (DPCM) encodes the difference between the current sample and a predicted value based on previous samples.

Equation:

- Error signal: $e(n) = x(n) - \hat{x}(n)$
- Where $x(n)$ is current sample, $\hat{x}(n)$ is predicted sample
- Prediction: $\hat{x}(n) = \Sigma(a_i \times x(n-i))$
- Transmitted signal: DPCM output $= Q[e(n)]$

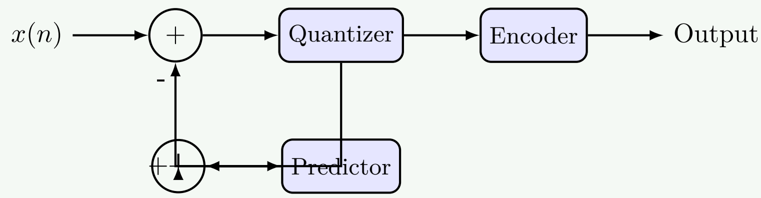

Figure 17. DPCM Modulator

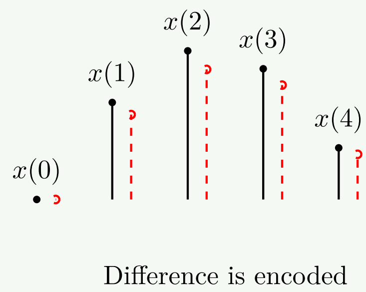

Figure 18. DPCM Waveform

Table 20. DPCM Characteristics

Feature	Description
Advantage	Reduced bit rate (30-50% compared to PCM)
Prediction	Uses previous sample(s) for current prediction
Complexity	Higher than PCM but lower than ADPCM
Application	Speech coding, image compression

Mnemonic

"PQED: Predict, Quantize Error, Encode Difference"

Question 5(a) [3 marks]

Define Antenna and radiation pattern and polarization.

Solution

Table 21. Antenna Definitions

Term	Definition
Antenna	A device that converts electrical energy into electromagnetic waves and vice versa
Radiation Pattern	Graphical representation of radiation properties of an antenna as a function of space coordinates
Polarization	Orientation of the electric field vector of the electromagnetic wave radiated by the antenna

Types of Polarization:
- **Linear**: Electric field oscillates in one direction (vertical, horizontal)
- **Circular**: Electric field rotates with constant amplitude (RHCP, LHCP)
- **Elliptical**: Electric field rotates with varying amplitude

Mnemonic

"WAVE-PRO: Wireless Antenna Validates Electromagnetic Propagation, Radiation, Orientation"

Question 5(b) [4 marks]

Explain Microstrip Antenna with sketch.

Solution

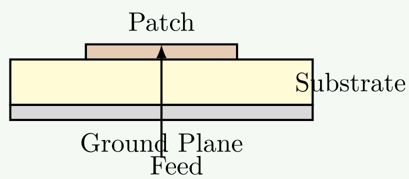

Figure 19. Microstrip Patch Antenna

Table 22. Microstrip Antenna Components

Component	Function
Patch	Radiating element (usually copper)
Substrate	Dielectric material between patch and ground
Ground Plane	Metal layer at bottom
Feed Point	Connection point for signal

- **Working principle**: Fringing fields at edges cause radiation
- **Advantages**: Low profile, lightweight, easy fabrication, compatible with PCB

Mnemonic

"SPGF: Substrate, Patch, Ground, Feed"

Question 5(c) [7 marks]

Explain delta modulation with necessary sketch and waveform.

Solution

Delta Modulation (DM) is the simplest form of differential pulse code modulation where the difference between successive samples is encoded into a single bit.

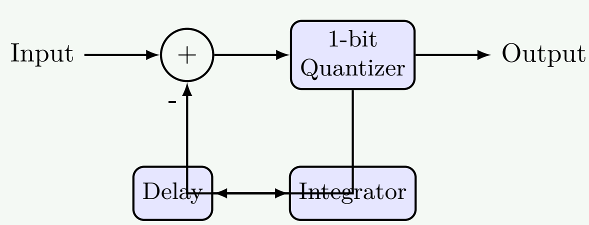

Figure 20. Delta Modulator

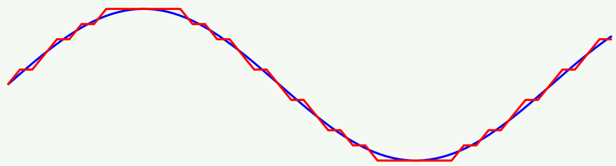

Figure 21. Delta Modulation Waveform

Table 23. Delta Modulation Characteristics

Characteristic	Description
Bit Rate	1 bit per sample
Step Size	Fixed (major limitation)
Slope Overload	Occurs when signal changes faster than step size can track
Granular Noise	Occurs in slowly changing signals (continuous hunting)
Advantages	Simplicity, low bit rate
Disadvantages	Limited dynamic range, noise problems

Mnemonic

"SIGN-UP: SInGle bit, Next step Up or down, Predict"

Question 5(a OR) [3 marks]

What is smart antenna? list application of it.

Solution

A **Smart Antenna** is an adaptive array system that uses digital signal processing algorithms to dynamically adjust its radiation pattern to enhance communication performance.

Table 24. Smart Antenna Applications

Application	Benefit
Cellular Base Stations	Increased capacity and coverage
Wireless LAN	Improved throughput and reduced interference
Satellite Communications	Better signal quality and power efficiency
Military Communications	Enhanced security and jam resistance
IoT Networks	Extended battery life, improved connectivity

- **Working principle**: Uses beamforming to focus signal energy toward desired users
- **Types**: Switched beam systems and adaptive array systems

Mnemonic

"SWIM-CM: Smart Wireless In Mobile-Cellular-Military"

Question 5(b OR) [4 marks]

Explain parabolic reflector antenna With Sketch.

Solution

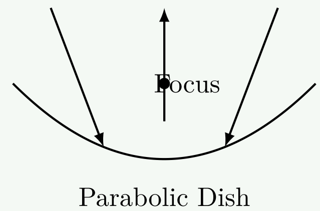

Figure 22. Parabolic Reflector Antenna

Table 25. Parabolic Reflector Components

Component	**Function**
Parabolic Dish	Reflects and focuses signals
Feed Horn	Radiates/receives signals at focal point
Supporting Structure	Maintains geometry and stability
Waveguide	Connects feed horn to transmitter/receiver

- **Working principle**: Incoming parallel rays are reflected to focus at focal point
- **Characteristics**: High gain, directivity, narrow beamwidth
- **Applications**: Satellite communication, radio astronomy, radar, microwave links

Mnemonic

"PFGH: Parabolic Focus Gives High-gain"

Question 5(c OR) [7 marks]

Explain Adaptive Delta modulation with necessary sketch and waveform.

Solution

Adaptive Delta Modulation (ADM) improves on standard DM by dynamically adjusting the step size according to the input signal characteristics.

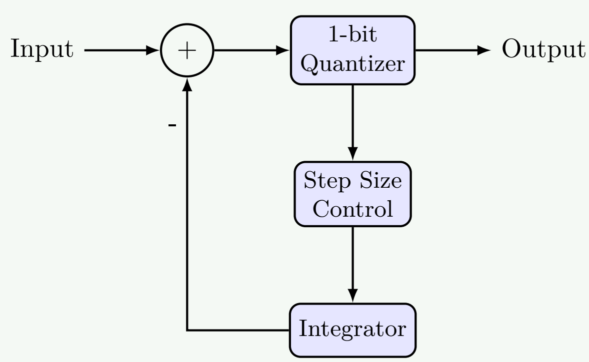

Figure 23. Adaptive Delta Modulator

Variable Step Size

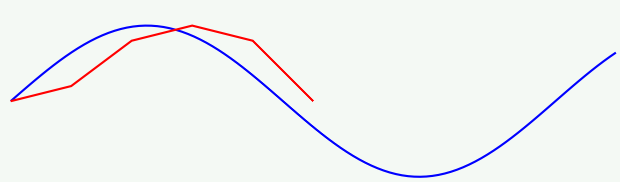

Figure 24. ADM Waveform

Table 26. ADM Characteristics

Aspect	**Description**
Step Size	Variable (adapts to signal slope)
Control Logic	Increases step size for consecutive same bits
Advantages	Reduced slope overload and granular noise
Disadvantages	More complex than DM

- **Step size adaptation**: $\mu(n) = \mu(n-1) \times K$ if consecutive bits are same
- **Step size adaptation**: $\mu(n) = \mu(n-1)/K$ if consecutive bits change

Mnemonic

"ADVISED: ADaptive Variable Increment Step for Enhanced Delta modulation"