Subject Name Solutions

4331104 – Winter 2022

Semester 1 Study Material

Detailed Solutions and Explanations

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 (amplitude, frequency, or phase) of a high-frequency carrier signal with a modulating signal containing information.

Need for modulation:

- **Antenna size reduction**: Makes practical antenna size possible (= c/f)
- **Multiplexing**: Allows multiple signals to share the medium
- **Noise reduction**: Improves SNR by shifting to higher frequency bands
- **Range extension**: Increases transmission distance

Mnemonic

"AMEN" - Antenna size, Multiplexing, Eliminate noise, New range

Question 1(b) [4 marks]

Derive voltage equation for Amplitude modulation.

Solution

For AM, the carrier signal is modulated by the message signal.

Mathematical derivation:

- **Carrier signal**: $e_c(t) = A_c \cos(2\pi f_c t)$
- **Message signal**: $e_m(t) = A_m \cos(2\pi f_m t)$
- **Instantaneous amplitude**: $A_i = A_c + e_m(t)$
- **AM signal**: $e_{AM}(t) = A_i \cos(2\pi f_c t)$
- **Substituting**: $e_{AM}(t) = [A_c + A_m \cos(2\pi f_m t)] \cos(2\pi f_c t)$
- **Expanding**: $e_{AM}(t) = A_c \cos(2\pi f_c t) + A_m \cos(2\pi f_m t) \cos(2\pi f_c t)$
- **Final equation**: $e_{AM}(t) = A_c \cos(2\pi f_c t) + \frac{A_m}{2} \cos(2\pi (f_c + f_m)t) + \frac{A_m}{2} \cos(2\pi (f_c - f_m)t)$

Mnemonic

"CAT" - Carrier, Addition, Three components (carrier + 2 sidebands)

Question 1(c) [7 marks]

Classify Noise signal and explain flicker noise, shot noise and thermal noise.

Solution

Noise classification:

Type	Sources	Characteristics
External Noise	Atmospheric, Space, Industrial, Man-made	Originates outside communication system
Internal Noise	Thermal, Shot, Transit-time, Flicker	Originates inside components

Types of Internal Noise:

- **Flicker Noise**:
  - Occurs at low frequencies (below 1 kHz)
  - Inversely proportional to frequency (1/f noise)
  - Common in semiconductor devices and carbon resistors
- **Shot Noise**:
  - Caused by random fluctuations of current carriers
  - White noise with constant power density
  - Occurs in active devices like diodes and transistors
- **Thermal Noise**:
  - Due to random motion of electrons in a conductor
  - Directly proportional to temperature and bandwidth
  - Present in all passive components
  - Also called Johnson noise or white noise

Mnemonic

"FAST" - Flicker (low frequency), Active (shot), Semiconductor (flicker), Temperature (thermal)

Question 1(c) OR [7 marks]

Write application of different band of EM wave spectrum.

Solution

EM Spectrum Applications:

Frequency Band	Frequency Range	Applications
ELF (Extremely Low Frequency)	3Hz - 30Hz	Submarine communication
VLF (Very Low Frequency)	3kHz - 30kHz	Navigation, time signals
LF (Low Frequency)	30kHz - 300kHz	AM radio, navigation
MF (Medium Frequency)	300kHz - 3MHz	AM broadcasting, maritime
HF (High Frequency)	3MHz - 30MHz	Shortwave radio, amateur radio
VHF (Very High Frequency)	30MHz - 300MHz	FM radio, TV broadcasting, air traffic control
UHF (Ultra High Frequency)	300MHz - 3GHz	TV broadcasting, mobile phones, WiFi, Bluetooth
SHF (Super High Frequency)	3GHz - 30GHz	Satellite communication, radar, WiFi
EHF (Extremely High Frequency)	30GHz - 300GHz	Radio astronomy, 5G, millimeter-wave radar
Infrared	300GHz - 400THz	Remote controls, thermal imaging, fiber optics
Visible Light	400THz - 800THz	Fiber optics, LiFi, photography
Ultraviolet	800THz - 30PHz	Sterilization, fluorescence, security
X-rays	30PHz - 30EHz	Medical imaging, security screening
Gamma rays	>30EHz	Medical treatments, nuclear detection

Mnemonic

"Every Very Lovely Monkey Has Visited Uncle Sam's House Easily In Visible Upper Xtra Gamma" (first letter of each band)

Question 2(a) [3 marks]

State advantages of SSB over DSB.

Solution

Advantages of SSB over DSB:

Advantage	Description
Bandwidth Efficiency	Uses half the bandwidth (only one sideband)
Power Efficiency	Requires less transmitter power (83.33% power saving)
Reduced Fading	Less susceptible to selective fading
Less Distortion	Reduced intermodulation distortion
Simplified Receiver	Simpler circuit design possible

Mnemonic

"BPFDS" - Bandwidth, Power, Fading, Distortion, Simple

Question 2(b) [4 marks]

Explain generation of FM using Phase lock loop technique.

Solution

FM Generation using PLL:
A Phase-Locked Loop (PLL) generates FM signals by applying the modulating signal to the VCO control input.
PLL FM Modulator:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Modulating Signal] {-{-}{} B[Summing Circuit]}
    E[Reference Oscillator] {-{-}{} F[Phase Detector]}
    F {-{-}{} G[Low Pass Filter]}
    G {-{-}{} B}
    B {-{-}{} H[VCO]}
    H {-{-}{} I[FM Output]}
    H {-{-}{} J[Feedback]}
    J {-{-}{} F}
{Highlighting}
{Shaded}
```

Operation:

- **Reference Oscillator**: Provides stable reference frequency
- **Phase Detector**: Compares reference and feedback signals
- **Low Pass Filter**: Removes high-frequency components
- **VCO**: Generates output frequency that varies with control voltage
- **Modulating Signal**: Added to control voltage to produce FM output

Mnemonic

"PROVE" - Phase detector, Reference oscillator, Output VCO, Voltage controlled

Question 2(c) [7 marks]

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

Solution

Power in AM:
The AM wave equation: $e_{AM}(t) = A_c[1 + m\cos(2\pi f_m t)]\cos(2\pi f_c t)$

Power derivation:

- **Total power**: $P_T = P_c\left(1 + \frac{m^2}{2}\right)$
- Where $P_c = \frac{A_c^2}{2R}$ (carrier power) and m is modulation index

Power distribution:

- **Carrier power**: $P_c = \frac{A_c^2}{2R}$
- **Total sideband power**: $P_{SB} = \frac{m^2 P_c}{2}$
- **Each sideband**: $P_{LSB} = P_{USB} = \frac{m^2 P_c}{4}$

Power savings:

- **In DSB-SC**: No carrier power, so savings $= \frac{P_c}{P_T} \times 100\% = \frac{1}{1+\frac{m^2}{2}} \times 100\%$
  - For m=1, savings = 66.67%
- **In SSB**: No carrier and one sideband, so savings $= \frac{P_c + P_{SB}/2}{P_T} \times 100\%$
  - For m=1, savings = 83.33%

Mnemonic

"CEPTS" - Carrier Eliminated Provides Tremendous Savings

Question 2(a) OR [3 marks]

Draw and explain Time domain and Frequency domain display of AM wave.

Solution

Time and Frequency Domain of AM:
Diagram:

```
Time Domain:

     +          +           +           +
     |          |           |           |
     |    ++    |     ++    |    ++     |
     |   /  {   |    /     |   /      |}
     |  /    {  |   /      |  /       |}
     | /      { |  /       | /        |}
     |/        {|/        |/        | |}
{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-
     |{        /|        /|        /| |}
     | {      / |       / |       /  |}
     |  {    /  |      /  |      /   |}
     |   {\_\_/   |   \_\_/   |   \_\_/    |}
     |          |           |           |
     +          +           +           +

Frequency Domain:

     |
     |
     |     +           +           +
     |     |           |           |
     |     |           |           |
     |     |           |           |
     |     |           |           |
{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-
     |   f\_c{-f\_m     f\_c    f\_c+f\_m}
```

Time Domain:

- Shows amplitude variation of carrier with time
- Envelope follows modulating signal

- Upper and lower envelopes = carrier peak $\times(1)$

Frequency Domain:

- Shows frequency components and their amplitudes
- Carrier at frequency fc with amplitude Ac
- Two sidebands at fcwith amplitude mAc/2
- Bandwidth = 2fm (twice the modulating frequency)

Mnemonic

"EBS" - Envelope in time, Bandwidth in frequency, Sidebands symmetric

Question 2(b) OR [4 marks]

Explain pre-emphasis & de-emphasis circuit.

Solution

Pre-emphasis and De-emphasis:
Circuit Diagrams:

```
Pre{-emphasis:                    De{-}emphasis:}

+{-{-}+     +{-}{-}+                 +{-}{-}+     +{-}{-}+}
|  |     |  |                 |  |     |  |
+{-{-}+     R  |                 +{-}{-}+     R  |}
Input    |  +{-{-}+{-}{-}+  Output   Input    |  +{-}{-}+{-}{-}+  Output}
o{-{-}{-}{-}{-}{-}{-}{-}+  |  |  o{-}{-}{-}{-}{-}{-}{-}{-}   o{-}{-}{-}{-}{-}{-}{-}{-}+  |  |  o{-}{-}{
            C  |                          C  |
            |  |                          |  |
            +{-{-}+                          +{-}{-}+}
              |                          |
            {-{-}{-}{-}{-}                    {-}{-}{-}{-}{-}}
             {-{-}{-}                      {-}{-}{-}}
              {-                         {-}}
```

Purpose:

- **Pre-emphasis**: Boosts high-frequency components at transmitter
- **De-emphasis**: Attenuates high-frequency components at receiver

Operation:

- **Pre-emphasis**: High-pass RC circuit (R series, C parallel)
- **De-emphasis**: Low-pass RC circuit (R parallel, C series)
- Time constants are identical:
  = RC = 75 s (standard)

Benefits:

- Improves SNR for higher frequencies in FM
- Compensates for higher noise power at high frequencies
- Restores original frequency response at receiver

Mnemonic

"BETH" - Boost (pre-emphasis), Emphasizes Treble, Helps SNR

Question 2(c) OR [7 marks]

Compare AM, FM and PM.

Solution

Comparison of AM, FM and PM:

Parameter	AM	FM	PM
Definition	Amplitude varies with message signal	Frequency varies with message signal	Phase varies with message signal
Mathematical expression	$A_c[1 + m\cos(_m t)]\cos(_c t)$	$A_c\cos[_c t + mf\sin(_m t)]$	$A_c\cos[_c t + mp\cos(_m t)]$
Bandwidth	2fm (narrow)	2(Δf+fm) (wide)	2(mp+1)fm (wide)
Power efficiency	Low (carrier contains no info)	High (constant amplitude)	High (constant amplitude)
Noise immunity	Poor	Excellent	Excellent
Circuit complexity	Simple	Complex	Complex
Applications	AM broadcasting, aircraft communication	FM broadcasting, TV sound, mobile radio	Satellite communication, telemetry
Modulation index	m = Am/Ac (0 to 1)	mf = Δf/fm (no limit)	mp = Δ /fm (no limit)

Mnemonic

"BANCP-MAP" - Bandwidth, Amplitude, Noise, Complexity, Power, Modulation, Applications, Parameters

Question 3(a) [3 marks]

Define any FOUR characteristics of radio receiver.

Solution

Radio Receiver Characteristics:

Characteristic	Definition
Sensitivity	Minimum signal strength required for acceptable output
Selectivity	Ability to separate desired signal from adjacent signals
Fidelity	Accuracy in reproducing the original signal without distortion
Image rejection	Ability to reject image frequency interference
Signal-to-noise ratio	Ratio of desired signal to unwanted noise
Stability	Ability to maintain tuned frequency without drift

Mnemonic

"SFIS-SS" - Sensitivity, Fidelity, Image rejection, Selectivity, SNR, Stability

Question 3(b) [4 marks]

Draw the block diagram of FM receiver. What is the use of Limiter in FM receiver.

Solution

FM Receiver Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Antenna] {-{-}{} B[RF Amplifier]}
    B {-{-}{} C[Mixer]}
    D[Local Oscillator] {-{-}{} C}
```

```
    C {-{-}{} E[IF Amplifier]}
    E {-{-}{} F[Limiter]}
    F {-{-}{} G[FM Detector]}
    G {-{-}{} H[Audio Amplifier]}
    H {-{-}{} I[Speaker]}
{Highlighting}
{Shaded}
```

Use of Limiter in FM Receiver:

- **Primary function**: Removes amplitude variations/noise
- **Operation**: Clips the signal to provide constant amplitude
- **Benefits**:
  - Eliminates AM interference
  - Improves SNR
  - Ensures proper FM detection
  - Prevents false frequency demodulation
- **Location**: Placed between IF amplifier and FM detector

Mnemonic

"CARE" - Clips Amplitude, Removes noise, Ensures constant signal

Question 3(c) [7 marks]

Draw and explain block diagram of super heterodyne receiver.

Solution

Super Heterodyne Receiver:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Antenna] {-{-}{} B[RF Amplifier]}
    B {-{-}{} C[Mixer]}
    D[Local Oscillator] {-{-}{} C}
    C {-{-}{} E[IF Amplifier]}
    E {-{-}{} F[Detector]}
    F {-{-}{} G[Audio Amplifier]}
    G {-{-}{} H[Speaker]}
    F {-{-}{} I[AGC]}
    I {-{-}{} B}
    I {-{-}{} E}
{Highlighting}
{Shaded}
```

Function of each block:

- **Antenna**: Captures RF signals from electromagnetic waves
- **RF Amplifier**: Amplifies weak signals, provides selectivity
- **Local Oscillator**: Generates signal to mix with incoming RF
- **Mixer**: Produces IF by heterodyning RF with local oscillator
- **IF Amplifier**: Main amplification and selectivity at fixed frequency
- **Detector**: Extracts audio from modulated IF signal
- **Audio Amplifier**: Amplifies audio signal to drive speaker
- **AGC (Automatic Gain Control)**: Maintains constant output level
- **Speaker**: Converts electrical signal to sound

Super Heterodyne Principle:

- Converts high-frequency RF to fixed IF for better amplification
- IF = |RF $\pm LO|(typically 455 kHz for AM, 10.7 MHz for FM)$

Mnemonic

"ARLMIDAS" - Antenna Receives, Local Mixes, IF Delivers, Audio Sounds

Question 3(a) OR [3 marks]

Draw and explain block diagram for envelope detector.

Solution

Envelope Detector:
Circuit Diagram:

```
          D
    +{-{-}{-}|{-}{-}{-}+{-}{-}{-}+}
    |         |   |
AM  |         |   |     Audio
Input o       C   R    Output
    |         |   |      o
    |         |   |      |
    +{-{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+{-}{-}{-}{-}{-}{-}+}
              |
            {-{-}{-}}
             {-}
```

Component Functions:

- **Diode (D)**: Rectifies AM signal (allows only positive half-cycles)
- **Capacitor (C)**: Charges to peak of input, filters carrier frequency
- **Resistor (R)**: Discharges capacitor, follows modulating signal envelope

Operation:

1. Diode conducts during positive half-cycles
2. Capacitor charges to peak voltage
3. During negative half-cycles, diode blocks
4. Capacitor discharges through resistor
5. RC time constant follows envelope variations

RC Selection Criteria: $\frac{1}{f_c} << RC << \frac{1}{f_m}$

Mnemonic

"DRIVER" - Diode Rectifies, RC Values Extract Envelope, Restores audio

Question 3(b) OR [4 marks]

What is IF? Explain its importance in brief.

Solution

Intermediate Frequency (IF):
Definition: IF is a fixed frequency to which incoming RF signals are converted in superheterodyne receivers.
Importance of IF:

Aspect	Importance
Fixed Frequency	Allows optimized amplification at one frequency
Improved Selectivity	Fixed-tuned filters provide better adjacent channel rejection
Stable Gain	Consistent amplification across entire tuning range
Image Rejection	Helps reject image frequency interference
Simplified Tuning	Only local oscillator needs to be tuned for different stations
Better AGC	More effective gain control at fixed frequency

Typical IF Values:

- AM receivers: 455 kHz
- FM receivers: 10.7 MHz
- Television: 45 MHz

Mnemonic

"FIGS-ST" - Fixed frequency, Improved selectivity, Gain stability, Simplified tuning

Question 3(c) OR [7 marks]

Explain phase discriminator circuit for FM detection.

Solution

Phase Discriminator for FM Detection:
Circuit Diagram:

```
                +{-{-}{-}{-}+}
                |    |
     +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}|  T1|{-}{-}{-}{-}{-}{-}{-}+}
     |          |    |       |
     |          +{-{-}{-}{-}+       |}
     |                       |
     |                       |
     |                       |
     |   D1                  |   D2
FM   o{-{-}|{-}{-}{-}+           +{-}{-}{-}|{-}{-}+}
Input|        |          |       |
     |        |  +{-{-}{-}{-}+   |       |}
     |        +{-{-}|    |{-}{-}{-}+       |}
     |          |  T2|           |
     +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}| CT |{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}|}
                |    |           |
                +{-{-}{-}{-}+           |}
                   |             |
                   |     C1      |     C2
                   o{-{-}{-}{-}||{-}{-}{-}{-}{-}{-}{-}o{-}{-}{-}{-}{-}||{-}{-}{-}{-}o Audio }
                   |             |          Output
                 {-{-}{-}           {-}{-}{-}}
                  {-             {-}}
```

Operation:

1. **Center-tapped transformer (T2)** creates $180^\circ phasedifference$
1. **Primary transformer (T1)** sets reference phase
2. **Diode D1 and D2** form phase comparators
3. **When carrier at center frequency:**
   - Equal currents through both diodes
   - Equal voltages across C1 and C2
   - Net output is zero
4. **When frequency deviates:**
   - Phase changes
   - Unequal diode currents
   - Output voltage proportional to frequency deviation

Advantages:

- Good linearity
- Reduced distortion
- Better noise performance than slope detector

Mnemonic

"PERFECT" - Phase Ensures Rectification For Extracting Carrier Transitions

Question 4(a) [3 marks]

Explain quantization process and its necessity.

Solution

Quantization Process:
Definition: Quantization is the process of mapping continuous analog values to discrete digital levels.
Process:

1. Sampling converts continuous-time signal to discrete-time
2. Range of amplitudes divided into finite number of levels
3. Each sample assigned to nearest quantization level
4. Difference between original and quantized value is quantization error

Necessity of Quantization:

Necessity	Explanation
Digital Processing	Enables digital storage and manipulation
Error Control	Allows error detection and correction
Noise Immunity	Digital signals more resistant to noise
Storage Efficiency	More efficient than storing analog values
Transmission	Digital signals can be regenerated without error

Mnemonic

"DENSE" - Digital conversion, Error control, Noise immunity, Storage, Efficient transmission

Question 4(b) [4 marks]

Give difference between DM and ADM.

Solution

Difference between DM and ADM:

Parameter	Delta Modulation (DM)	Adaptive Delta Modulation (ADM)
Step Size	Fixed	Variable (adapts to signal)
Slope Overload	Common at steep signals	Reduced with adaptive step
Granular Noise	High for small signals	Reduced with smaller steps
Signal Tracking	Slow for rapidly changing signals	Better tracking of signal variations
Complexity	Simple	Moderate
Bit Rate	Higher for good quality	Lower for same quality
Error Performance	More sensitive	More robust

Diagram:

```
DM:                              ADM:

   \^{                                  \^{}}
   |                                |
   |    Original                    |    Original
   |      /{                        |      /}
   |     /  {                       |     /  }
   |    /    {                      |    /    }
   |   /      {                     |   /      }
   |  /  \_\_\_\_  {                    |  /        }
   | /\_\_|    |\_\_{\_\_\_                 | /\_         \_\_\_}
   |/  |    |  |   {                |/         /    }
{-{-}{-}+{-}{-}{-}+{-}{-}{-}{-}+{-}{-}+{-}{-}{-}{-}+{-}{-}           {-}+{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{
   |   |    |  |    |               |     |     |      |

Slope Overload              Better Signal Tracking
```

Mnemonic

"SAVAGES" - Step size, Adaptable, Variable tracking, Avoids overload, Granular noise reduction, Error performance, Signal fidelity

Question 4(c) [7 marks]

Draw & explain block diagram of PCM system.

Solution

PCM System Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    subgraph "PCM Transmitter"
    A[Input Signal] {-{-}{} B[Anti{-}aliasing Filter]}
    B {-{-}{} C[Sample \& Hold]}
    C {-{-}{} D[Quantizer]}
    D {-{-}{} E[Encoder]}
    E {-{-}{} F[Parallel to Serial]}
    end

    F {-{-}{} G[Transmission Channel]}

    subgraph "PCM Receiver"
    G {-{-}{} H[Serial to Parallel]}
    H {-{-}{} I[Decoder]}
    I {-{-}{} J[Reconstruction Filter]}
    J {-{-}{} K[Output Signal]}
    end
{Highlighting}
{Shaded}
```

PCM Transmitter:

- **Anti-aliasing Filter**: Limits input signal bandwidth to satisfy Nyquist criterion
- **Sample & Hold**: Converts continuous signal to discrete-time samples
- **Quantizer**: Approximates sample amplitudes to nearest discrete levels
- **Encoder**: Converts quantized levels to binary code
- **Parallel-to-Serial**: Converts parallel bits to serial for transmission

PCM Receiver:

- **Serial-to-Parallel**: Converts serial data back to parallel form
- **Decoder**: Converts binary code back to amplitude levels
- **Reconstruction Filter**: Smooths stepped output to recover analog signal

PCM Parameters:

- **Sampling rate**: fs > 2fm (Nyquist rate)
- **Quantization levels**: L = 2^n (n = number of bits)
- **Resolution**: Smallest distinguishable change = Vmax/L
- **Bit rate**: R = n $\times fs bits/second$

Mnemonic

"SAFE-PETS" - Sample, Amplify, Filter, Encode, Pulse train, Extract, Transform, Smooth

Question 4(a) OR [3 marks]

Define quantization. Explain non uniform quantization in brief.

Solution

Quantization Definition: Quantization is the process of converting continuous amplitude values to a finite set of discrete levels in analog-to-digital conversion.

Non-uniform Quantization:

Diagram:

```
     \^{}
     |                     {-{-}{-}{-}}
     |                 {-{-}{-}{-}}
     |             {-{-}{-}{-}}
Lvls |         {-{-}{-}{-}}
     |     {-{-}{-}{-}}
     |  {-{-}{-}}
     | {-}
     +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
                Input Signal
```

Characteristics:

- Unequal step sizes throughout the amplitude range
- Smaller steps for low amplitudes, larger for high amplitudes
- Better matches human perception (logarithmic response)
- Improves SNR for small signals without increasing bit rate

Implementation Methods:

- **Companding**: Compressing at transmitter, expanding at receiver
- **Logarithmic coding**: -law (North America) and A-law (Europe)
- **Adaptive quantization**: Adjusts levels based on signal statistics

Mnemonic

"CLASP" - Compressed Levels, Adaptive Steps, Small steps for small signals, Perceptual matching

Question 4(b) OR [4 marks]

Explain Adaptive delta modulation with its application.

Solution

Adaptive Delta Modulation (ADM):

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
```

```
{Highlighting}[]
graph LR
    A[Input Signal] {-{-}{} B[Comparator]}
    B {-{-}{} C[1{-}bit Quantizer]}
    C {-{-}{} D[Transmission Channel]}
    D {-{-}{} E[Step Size Control]}
    E {-{-}{} F[Integrator]}
    F {-{-}Feedback{-}{-}{} B}
    F {-{-}{} G[Output Signal]}
    C {-{-}Controls{-}{-}{} E}
{Highlighting}
{Shaded}
```

Operation:

- Adapts step size based on input signal slope
- Increases step size for rapid changes (prevents slope overload)
- Decreases step size for slow changes (reduces granular noise)
- Uses previous bits pattern to determine slope changes

Advantages:

- Better signal tracking than DM
- Lower bit rate for same quality
- Reduced slope overload and granular noise
- Wider dynamic range

Applications:

- Speech and audio compression
- Voice-grade communication channels
- Digital telephony systems
- Video signal encoding
- Telemetry systems

Mnemonic

"ADAPT" - Automatically Decides Appropriate Pulse Transitions

Question 4(c) OR [7 marks]

What is sampling? Explain types of sampling in brief.

Solution

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

Types of Sampling:

Type	Description	Diagram
Ideal Sampling	Instantaneous samples of infinitesimal duration	Impulses at sampling instants
Natural Sampling	Samples have finite width, amplitude follows input	Original signal visible during sampling duration
Flat-top Sampling	Samples have constant amplitude during sampling interval	Step-like appearance, used in sample-and-hold

Diagrams:

```
Ideal Sampling:           Natural Sampling:         Flat{-top Sampling:}

   \^{                         \^{}                        \^{}}
   |                         |                        |
   | |   |   |   |           |   \_   \_   \_            |  \_\_\_   \_\_\_   \_\_\_
   | |   |   |   |           |  / { /  /            | |   | |   | |   |}
   | |   |   |   |           | /   |   |   {          | |   | |   | |   |}
{-{-}{-}+{-}{-}{-}+{-}{-}{-}+{-}{-}{-}+{-}{-}{-}{-}     {-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}+{-}{-}{-}{-}{-
   |                         |                         |
```

Sampling Parameters:

- **Sampling period (Ts)**: Time between consecutive samples
- **Sampling frequency (fs)**: Number of samples per second (fs = 1/Ts)
- **Nyquist rate**: Minimum sampling rate (fs > 2fm) to avoid aliasing

Mnemonic

"INFS" - Ideal (impulses), Natural (follows signal), Flat-top (constant), Sufficient rate

Question 5(a) [3 marks]

Define bit rate and baud rate.

Solution

Bit Rate and Baud Rate:

Parameter	Definition	Formula	Unit
Bit Rate	Number of binary digits (bits) transmitted per second	R = fs $\times n$	bits per second (bps)
Baud Rate	Number of signal elements or symbols transmitted per second	B = fs	symbols per second (baud)

Relationship:

- For binary signaling: Bit Rate = Baud Rate
- For M-ary signaling: Bit Rate = Baud Rate $\times log_2 M$
  - Where M = number of different signal elements

Example:

- 4-QAM (M=4): Each symbol carries $\log_2 4 = 2bits$
- If Baud Rate = 1000 symbols/s, then Bit Rate = 2000 bits/s

Mnemonic

"BBSM" - Bits per second, Baud for Symbols, Modulation determines relationship

Question 5(b) [4 marks]

Explain working of DPCM.

Solution

Differential Pulse Code Modulation (DPCM):
Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
```

```
    subgraph "Transmitter"
    direction LR
    A[Input] {-{-}{} B[Difference]}
    B {-{-}{} C[Quantizer]}
    C {-{-}{} D[Encoder]}
    D {-{-}{} E[Output]}
    F[Predictor] {-{-}{} B}
    C {-{-}{} F}
    end

    subgraph "Receiver"
    direction LR
    G[Input] {-{-}{} H[Decoder]}
    H {-{-}{} I[Output]}
    H {-{-}{} J[Predictor]}
    J {-{-}{} I}
    end
{Highlighting}
{Shaded}
```

Working Principle:

- Encodes difference between current sample and predicted sample
- Prediction based on previous samples (correlation)
- Smaller dynamic range of differences allows fewer bits per sample

Advantages:

- Higher compression ratio than PCM
- Reduced bit rate for same quality
- Exploits signal correlation
- Improved SNR performance

Mnemonic

"DEEP" - Difference Encoded, Efficient Prediction, Exploits correlation, Preserves quality

Question 5(c) [7 marks]

The binary data 1011001 is to be transmitted using following line coding techniques: (i) Unipolar RZ and NRZ (ii) Polar RZ and NRZ (iii) AMI (iv) Manchester. Draw all the waveforms.

Solution

Line Coding Waveforms for 1011001:

```
Data:      1    0    1    1    0    0    1
           |    |    |    |    |    |    |
           v    v    v    v    v    v    v

Unipolar
NRZ:     \_\_\_\_|  |\_\_\_\_|  |  |\_\_\_\_|\_\_\_\_|  |\_\_\_\_

Unipolar
RZ:      \_\_\_\_| |\_\_|\_\_\_\_| |\_\_| |\_\_|\_\_\_\_|\_\_\_\_| |\_\_|\_\_\_\_

Polar
NRZ:     \_\_\_\_|  |\_\_\_\_|  |  |\_\_\_\_|\_\_\_\_|  |\_\_\_\_

Polar
RZ:      \_\_\_\_| |\_\_|\_\_\_\_| |\_\_| |\_\_|\_\_\_\_|\_\_\_\_| |\_\_|\_\_\_\_
            |\_|  |\_| |\_| |\_|  |\_|  |\_| |\_|
AMI:     \_\_\_\_\_| |\_\_|\_\_\_\_|\_\_\_| |\_\_|\_\_\_\_|\_\_\_\_| |\_\_|\_\_\_\_\_
            |\_|  |\_|  |\_|  |\_|  |\_|  |\_|  |\_|
```

```
Manchester:
          \_\_\_\_| |\_\_|\_|  |\_\_\_\_| |\_\_| |\_\_|\_\_\_\_|\_\_\_\_| |\_\_|\_\_\_\_
            |\_|   |\_|   |\_|  |\_|   |\_|   |\_|  |\_|  |\_|
```

Description of Line Coding Techniques:

Technique	Logic 1	Logic 0	Characteristics
Unipolar NRZ	High level	Zero level	No return to zero between bits
Unipolar RZ	Pulse for half bit	Zero level	Returns to zero for half bit
Polar NRZ	Positive	Negative	No return to zero between bits
Polar RZ	Positive pulse	Negative pulse	Returns to zero for half bit
AMI	Alternating +/-	Zero level	Alternates polarity for consecutive 1s
Manchester	High	Low	Transition in middle of bit

Mnemonic

"UPAM" - Unipolar, Polar, AMI, Manchester encoding options

Question 5(a) OR [3 marks]

Compare RZ and NRZ coding with example.

Solution

Comparison of RZ and NRZ Coding:

Parameter	Return-to-Zero (RZ)	Non-Return-to-Zero (NRZ)
Signal levels	Returns to zero in each bit	Maintains level for full bit period
Bandwidth	Higher ($\approx 2 \times NRZ$)	Lower
Self-clocking	Better (transitions in every bit)	Poorer (may have long runs without transitions)
Power requirement	Higher	Lower
Bit synchronization	Easier	More difficult
Implementation	More complex	Simpler
DC component	Less	More

Example for binary data 101:

```
Data:        1     0     1
             |     |     |
             v     v     v

NRZ:      \_\_\_|   |\_\_\_\_\_|   |\_\_\_\_

RZ:       \_\_\_| |\_\_\_|\_\_\_\_\_| |\_\_\_|\_\_\_\_
```

Mnemonic

"BPSIDC" - Bandwidth, Power, Synchronization, Implementation, DC component

Question 5(b) OR [4 marks]

Explain delta modulation in brief.

Solution

Delta Modulation (DM):
Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input Signal] {-{-}{} B[(Comparator)]}
    B {-{-}{} C[1{-}bit Quantizer]}
    C {-{-}{} D[Transmission]}
    C {-{-}{} E[Integrator]}
    E {-{-}Feedback{-}{-}{} B}
    D {-{-}{} F[Integrator]}
    F {-{-}{} G[Output Signal]}
{Highlighting}
{Shaded}
```

Working Principle:

- Encodes only the difference between samples using 1 bit
- Comparator checks if input is higher/lower than predicted value
- Integrator accumulates the bits to approximate original signal
- Output is series of 1s and 0s representing up/down steps

Limitations:

- **Slope Overload**: Cannot track rapidly changing signals
- **Granular Noise**: Small variations around steady signal

Advantages:

- Simplest form of differential encoding
- Low bit rate (1 bit per sample)
- Simple implementation
- Hardware efficiency

Mnemonic

"SIDE" - Single-bit, Integrates Differences, Encodes changes

Question 5(c) OR [7 marks]

Explain PCM-TDM system.

Solution

PCM-TDM System:
Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph "Transmitter"
    A1[Channel 1] {-{-}{} B1[LPF]}
    A2[Channel 2] {-{-}{} B2[LPF]}
    A3[Channel 3] {-{-}{} B3[LPF]}
    A4[Channel n] {-{-}{} B4[LPF]}
    B1 {-{-}{} C[Multiplexer]}
    B2 {-{-}{} C}
    B3 {-{-}{} C}
    B4 {-{-}{} C}
    C {-{-}{} D[Sample \& Hold]}
    D {-{-}{} E[Quantizer]}
```

```
    E {-{-}{} F[Encoder]}
    F {-{-}{} G[Frame Generator]}
    G {-{-}{} H[Line Coder]}
    H {-{-}{} I[Transmission Medium]}
    end

    subgraph "Receiver"
    I {-{-}{} J[Line Decoder]}
    J {-{-}{} K[Frame Sync]}
    K {-{-}{} L[Decoder]}
    L {-{-}{} M[Demultiplexer]}
    M {-{-}{} N1[LPF]}
    M {-{-}{} N2[LPF]}
    M {-{-}{} N3[LPF]}
    M {-{-}{} N4[LPF]}
    N1 {-{-}{} O1[Channel 1]}
    N2 {-{-}{} O2[Channel 2]}
    N3 {-{-}{} O3[Channel 3]}
    N4 {-{-}{} O4[Channel n]}
    end
{Highlighting}
{Shaded}
```

PCM-TDM Operation:

Stage	Process
Filtering	Band-limits each channel to prevent aliasing
Multiplexing	Samples each channel sequentially
Conversion	Quantizes samples and converts to binary code
Framing	Adds sync bits and channel identification
Transmission	Sends frame over communication medium
Demultiplexing	Separates channels from received frame
Reconstruction	Converts digital samples back to analog signals

System Parameters:

- **Channel Capacity**: N channels
- **Sampling Rate**: fs per channel
- **Quantization**: n bits per sample
- **Frame Structure**: 1 sample from each channel + sync
- **Total Bit Rate**: N $\times n \times fs + overhead$

Mnemonic

"MOST-FDR" - Multiplex, Quantize, Sample, Transmit, Frame, Demultiplex, Reconstruct