Subject Name Solutions

4331104 – Winter 2024

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 according to the instantaneous value of a lower frequency message signal.

Need for modulation:

- **Antenna size reduction**: Allows practical antenna size (/4)
- **Multiplexing**: Enables multiple signals to share same medium
- **Interference reduction**: Shifts signal to suitable frequency band
- **Range extension**: Increases transmission distance

Mnemonic

"AMIR" - Antenna, Multiplexing, Interference, Range

Question 1(b) [4 marks]

Derive the expression for DSBFC of AM wave.

Solution

DSBFC (Double Sideband Full Carrier) AM wave derivation:

Mathematical derivation:

- Carrier signal: c(t) = Ac cos(ct)
- Message signal: m(t) = Am cos(mt)
- AM signal: s(t) = Ac[1 + m(t)]cos(ct)
- Where
   = modulation index = Am/Ac

Substituting message signal: s(t) = Ac[1 +   cos(mt)]cos(ct) s(t) = Ac cos(ct) + Ac cos(mt)cos(ct)

Using trigonometric identity: cos(A)cos(B) = 1/2[cos(A+B) + cos(A-B)]

Final expression: s(t) = Ac cos(ct) + (Ac/2)[cos((c+ m)t) + cos((c- m)t)]

Diagram:

```
    \^{}
    |    Carrier
Ac  |    /|{}
    |   / | {}
    |  /  |  {}
    | /   |   {}
    |/    |    {}
    +{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-} f}
         fc

    \^{}
    |               LSB   Carrier   USB
    |                |      |        |
Pam |                |      |        |
    |                |      |        |
    |                |      |        |
    |               /|{    /|      /|}
    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+{-}+{-}{-}{-}{
               fc{-fm     fc    fc+fm}
```

Question 1(c) [7 marks]

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

Solution

Noise Classification:

Type	Source	Characteristics
External Noise	Environmental sources	Outside communication system
Internal Noise	Components	Generated within system

Types of internal noise:

1. **Flicker Noise:**
   - **Source**: Occurs in active devices
   - **Characteristics**: Inversely proportional to frequency (1/f)
   - **Effect**: Dominant at low frequencies
2. **Shot Noise:**
   - **Source**: Random electron flow across junctions
   - **Characteristics**: Independent of frequency (white noise)
   - **Effect**: Random current fluctuations in diodes/transistors
3. **Thermal Noise:**
   - **Source**: Random motion of electrons due to temperature
   - **Characteristics**: Present in all conductors, resistors
   - **Formula**: Pn = kTB (k=Boltzmann constant, T=temperature, B=bandwidth)
   - **Effect**: Sets noise floor in receivers

Mnemonic

"FST" - Flicker decreases with Frequency, Shot is from electron flow, Thermal depends on Temperature

Question 1(c) OR [7 marks]

Describe EM wave also write at least one application of different band of spectrum.

Solution

EM Wave: Electromagnetic waves are energy propagating through space as time-varying electric and magnetic fields, traveling at speed of light ($3\times10^8 m/s$).

Characteristics:

- Transverse waves with E and H fields perpendicular to each other
- No medium required for propagation
- Described by wavelength ( ) and frequency (f)
- Relation: c = f ×

EM Spectrum and Applications:

Frequency Band	Frequency Range	Application
ELF	3Hz-30Hz	Submarine communication
VLF	3kHz-30kHz	Navigation systems
LF	30kHz-300kHz	AM broadcasting
MF	300kHz-3MHz	AM radio broadcasting
HF	3MHz-30MHz	Shortwave radio
VHF	30MHz-300MHz	FM radio, TV broadcasting
UHF	300MHz-3GHz	TV, mobile phones, WiFi
SHF	3GHz-30GHz	Satellite communication, radar
EHF	30GHz-300GHz	Millimeter wave communication
Infrared	300GHz-400THz	Remote controls, thermal imaging
Visible	400THz-800THz	Fiber optic communication
Ultraviolet	800THz-30PHz	Sterilization, authentication
X-Rays	30PHz-30EHz	Medical imaging
Gamma Rays	>30EHz	Cancer treatment

Diagram:

```
      +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}
      |                 |                 |                 |                 |
Radio   Microwave    Infrared       Visible         Ultraviolet     X{-ray    Gamma}
      |                 |                 |                 |                 |
      +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}
  Increasing Frequency
  Decreasing Wavelength
```

Mnemonic

"RMIUXG" - Radio, Microwave, Infrared, Ultraviolet, X-ray, Gamma

Question 2(a) [3 marks]

State advantages of SSB over DSB.

Solution

Advantages of SSB over DSB:

Parameter	SSB Advantage
Bandwidth	50% less bandwidth requirement
Power	Power saving of 83.33%
Transmitter	Less power amplification needed
Receiver	Simpler design without phase distortion
SNR	Better signal-to-noise ratio
Fading	Less susceptible to selective fading

Mnemonic

"BP TRFS" - Bandwidth, Power, Transmitter, Receiver, Fading, SNR

Question 2(b) [4 marks]

Explain generation of FM wave using FET reactance modulator.

Solution

FET Reactance Modulator:
Working principle:

- Uses FET as voltage-controlled reactance
- Changes effective capacitance based on modulating signal
- Connected across LC tank circuit of oscillator

Circuit operation:

1. Modulating signal applied to gate of FET
2. FET drain-source resistance varies with gate voltage
3. Capacitive reactance changes with modulating signal
4. Oscillator frequency deviates with input signal

Diagram:

```
      +{-{-}{-}{-}{-}||{-}{-}{-}{-}{-}+}
      |             |
      |             C
      |             |
    V\_in          +{-{-}{-}+}
      |           |FET|
      +{-{-}{-}{-}{-}R{-}{-}{-}{-}{-}|   |}
                 +{-{-}{-}+}
```

```
                    |
                   LC
                 Circuit
```

Key features:

- **Simple design**: Fewer components than other modulators
- **Linearity**: Good for wide-band FM generation
- **Stability**: Temperature stable compared to varactor diodes

Mnemonic

"LOVE FM" - LC Oscillator with Voltage-controlled Element for FM

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 signal:
For AM signal s(t) = Ac[1 + cos(mt)]cos(ct)
Total power calculation:

1. Power in carrier: Pc = Ac^2/2
1. Power in sidebands: Ps = $^2 Ac^2/4(totalforbothsidebands)$
1. Total power: Pt = Pc + Ps = Ac^2/2 $\times$ $(1 + ^2/2)$

For 100% modulation (=1):

- Pt = Pc $\times(1 + 1/2) = 1.5 \times Pc$
- Carrier power = 66.67% of total
- Sideband power = 33.33% of total

Power savings:

1. **In DSB-SC:**
   - Carrier is suppressed
   - Power saved = 66.67%
2. **In SSB:**
   - Carrier + one sideband suppressed
   - Power saved = 66.67% + 16.67% = 83.33%

Comparative Table:

Modulation	Carrier Power	Sideband Power	Total Power	Power Saving
AM (=1)	100%	50%	150%	0%
DSB-SC	0%	50%	50%	66.67%
SSB	0%	25%	25%	83.33%

Mnemonic

"CST" - Carrier power, Sideband power, Total power

Question 2(a) OR [3 marks]

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

Solution

Time Domain and Frequency Domain Display of AM Wave:
Time Domain:

- Shows amplitude variations over time
- Envelope follows modulating signal
- Maximum amplitude: A$_1$ $= Ac(1 +)$
- Minimum amplitude: A$_2$ $= Ac(1 -)$
- Modulation index: $= (\mathrm{A}_1 - A_2)/(A_1 + A_2)$

Frequency Domain:

- Shows power distribution across frequencies
- Carrier at center frequency fc
- Upper sideband at fc+fm
- Lower sideband at fc-fm
- Bandwidth = 2fm

Diagram:

```
Time Domain:                                 Frequency Domain:
    \^{                                             \^{}}
    |                                            |
A_{1  |    /      /                              |          Carrier}
    |   /  {    /                               |            |}
Ac  |{-{-}/{-}{-}{-}{-}{-}{-}/{-}{-}{-}{-}{-}{-}                      |             |}
    |  {    /      /                            |   LSB       |       USB}
A_{2  |     /      /                             |    |        |        |}
    |    {/      /                              |    |        |        |}
    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}        +{-}{-}{-
        t                                          fc{-fm      fc      fc+fm}
```

Mnemonic

"TEF" - Time domain shows Envelope, Frequency domain shows spectral components

Question 2(b) OR [4 marks]

Explain pre-emphasis & de-emphasis circuit.

Solution

Pre-emphasis and De-emphasis Circuits:

Purpose:

- Improve SNR for high-frequency components
- Compensate for higher noise in high frequencies
- Used primarily in FM systems

Pre-emphasis:

- Applied at transmitter
- Boosts high-frequency components
- Typically +6dB/octave above 2.1kHz
- Circuit: High-pass RC network (resistor in series, capacitor in parallel)

De-emphasis:

- Applied at receiver
- Attenuates high-frequency components
- Restores original signal balance
- Circuit: Low-pass RC network (resistor in parallel, capacitor in series)

Diagrams:

```
Pre{-emphasis:                   De{-}emphasis:}
    R                                C
+{-{-}{-}www{-}{-}{-}+{-}{-}{-}+              +{-}{-}{-}||{-}{-}{-}+{-}{-}{-}+}
|         |   |                 |        |   |
Vin       C   Vout              Vin      R   Vout
|         |   |                 |        |   |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}   |                +{-}{-}{-}{-}{-}{-}{-}{-}{-}   |}
             {-{-}{-}                         {-}{-}{-}}
              {-                           {-}}
```

Frequency response:

```
    \^{}
    |        Pre{-emphasis}
Gain|          /
```

```
    |         /
    |        /
0dB |{-{-}{-}{-}{-}{-}{-}/}
    |      /       De{-emphasis}
    |     /          {}
    |    /            {}
    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
       2.1kHz          f
```

Mnemonic

"HIGH-LOW" - HIGHer frequencies boosted at transmitter, LOWered at receiver

Question 2(c) OR [7 marks]

Compare narrowband FM and wideband FM.

Solution

Comparison of Narrowband FM and Wideband FM:

Parameter	Narrowband FM	Wideband FM
Modulation Index ( )	« 1 (typically <0.5)	» 1 (typically >5)
Bandwidth	2fm (twice message bandwidth)	2fm(+1) (Carson's rule)
Significant Sidebands	Only first pair of sidebands	Multiple sidebands
Applications	Mobile communication, two-way radio	FM broadcasting, high-fidelity audio
Signal Quality	Lower fidelity, less noise immunity	Higher fidelity, better noise immunity
Power Efficiency	Higher	Lower
Spectrum Utilization	Efficient	Less efficient
Circuit Complexity	Simpler	More complex

Bandwidth calculation:

- Narrowband FM: BW = 2fm
- Wideband FM: BW = 2fm(+1) (Carson's rule)

Spectrum diagram:

```
Narrowband FM:                    Wideband FM:
    \^{                                 \^{}}
    |                                |
    |            |                   |
    |        |   |   |               |   | | | | | | | | | | |
    |    |   |   |   |   |           | | | | | | | | | | | | | |
    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}          +{-}{-}{-}{-}{-}{-}{-}
       fc{-fm  fc  fc+fm                 fc{-}5fm    fc    fc+5fm}
```

Mnemonic

"BASPCB" - Bandwidth, Applications, Sidebands, Power, Complexity, Beta

Question 3(a) [3 marks]

Define any FOUR characteristics of radio receiver.

Solution

Characteristics of Radio Receiver:

1. **Sensitivity:**
    - Ability to amplify weak signals

- Measured in microvolts (V)
- Typically 1-10 V for good receivers

2. **Selectivity:**
   - Ability to separate desired signal from adjacent channels
   - Determined by bandwidth of IF amplifier
   - Measured in dB at specific frequency offsets
3. **Fidelity:**
   - Accuracy in reproducing original signal
   - Depends on bandwidth and distortion
   - Measured as frequency response flatness
4. **Image Frequency Rejection:**
   - Ability to reject signals at image frequency (fi = fs $\pm 2fIF$)
   - Measured in dB
   - Higher values indicate better performance

Additional characteristics:

- Signal-to-noise ratio (SNR)
- Automatic gain control (AGC) range
- Dynamic range

Mnemonic

"SFID" - Sensitivity, Fidelity, Image rejection, selectivity Determines quality

Question 3(b) [4 marks]

Explain Diode Detector circuit.

Solution

Diode Detector Circuit:

Purpose:

- Extracts original message signal from AM wave
- Also called envelope detector

Circuit components:

- Diode: Rectifies AM signal
- RC network: Filters carrier frequency
- R & C values: RC » 1/fc and RC « 1/fm

Operation:

1. Diode conducts during positive half-cycles
2. Capacitor charges to peak value
3. Capacitor discharges through resistor
4. RC time constant critical for proper demodulation

Diagram:

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

Waveforms:

```
Input:                  After Diode:            Output:
    /{      /              /      /              \_\_\_\_\_}
   /  {    /              /      /              /     }
  /    {  /             /      /             /       }
 /      {/              /      /      }
```

Limitations:

- Distortion for high modulation index
- Poor performance at low signal levels

Mnemonic

"DRCO" - Diode Rectifies, Capacitor holds peaks, Output follows envelope

Question 3(c) [7 marks]

Draw and explain block diagram of super heterodyne receiver.

Solution

Super Heterodyne Receiver:
Block Diagram:

```
+{-{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}+    +{
| Antenna|{-{-}{-}| RF    |{-}{-}{-}| Mixer|{-}{-}{-}| IF  |{-}{-}{-}|Detector|{-}{-}{-}| Audio  |{-}{-
|        |     | Amp   |     |       |     | Amp |     |         |     | Amp    |     |         |
+{-{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}+    +{
                              \^{}
                              |
                        +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
                        | Local      |
                        | Oscillator |
                        +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Function of each block:

1. **RF Amplifier:**
   - Amplifies weak RF signals
   - Provides selectivity
   - Improves signal-to-noise ratio
2. **Local Oscillator:**
   - Generates stable frequency fLO
   - fLO = fRF + fIF (for high-side injection)
   - Tuned with RF amplifier
3. **Mixer:**
   - Combines RF signal with local oscillator
   - Produces sum and difference frequencies
   - Difference frequency = IF (intermediate frequency)
4. **IF Amplifier:**
   - Fixed frequency amplification (typically 455kHz for AM)
   - Provides most of receiver gain and selectivity
   - Multiple stages for better performance
5. **Detector:**
   - Demodulates IF signal
   - Extracts original message signal
   - Diode detector for AM, discriminator for FM
6. **Audio Amplifier:**
   - Amplifies demodulated signal
   - Drives speaker or headphones

Working principle:

- Converts any RF frequency to fixed IF for efficient amplification
- IF frequency = |fRF - fLO|

Advantages:

- Better selectivity and sensitivity
- Stable gain at all frequencies
- Reduced tracking problems

Mnemonic

"RLMIDS" - RF amp, Local oscillator, Mixer, IF amp, Detector, Speaker

Question 3(a) OR [3 marks]

Describe AGC principle and its application in Radio receiver.

Solution

AGC (Automatic Gain Control) Principle:
Definition:

- Circuit that automatically adjusts receiver gain based on signal strength
- Maintains constant output level despite varying input signals

Working principle:

1. Detects received signal strength
2. Generates control voltage proportional to signal
3. Applies negative feedback to reduce gain for strong signals
4. Increases gain for weak signals

Application in Radio Receiver:

- **Prevents overloading:** Protects against strong signal distortion
- **Compensates fading:** Maintains constant volume during signal fading
- **Controls IF amplifier:** Primarily applied to IF stages
- **Improves dynamic range:** Handles wide range of signal strengths

Types:

- **Simple AGC:** Direct feedback from detector
- **Delayed AGC:** Only activates above threshold level
- **Amplified AGC:** Uses additional amplifier for better control

Diagram:

```
+{-{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}+}
| RF    |{-{-}{-}| Mixer|{-}{-}{-}| IF  |{-}{-}{-}|Detector|{-}{-}{-} Audio}
| Amp   |    |      |    | Amp |    |        |
+{-{-}{-}|{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}+    +{-}|{-}{-}{-}+    +{-}{-}{-}{-}|{-}{-}{-}+}
    |                    |            |
    |                    |        +{-{-}{-}{-}{-}{-}{-}{-}+}
    |                    |{-{-}{-}{-}{-}{-}{-}{-}{-}|  AGC   |}
    |                              | Circuit|
    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{
                                  +{-{-}{-}{-}{-}{-}{-}{-}+}
```

Mnemonic

"FADS" - Fading compensation, Automatic adjustment, Dynamic range, Signal consistency

Question 3(b) OR [4 marks]

Write short-note on intermediate frequency

Solution

Intermediate Frequency (IF):
Definition:

- Fixed frequency to which incoming RF signal is converted in superheterodyne receivers
- Result of mixing (heterodyning) RF signal with local oscillator

Standard IF values:

- **AM radio:** 455 kHz
- **FM radio:** 10.7 MHz
- **TV receivers:** 38-41 MHz

Importance:

- **Consistent gain:** Amplifiers operate at fixed frequency

- **Better selectivity:** Narrowband filters at fixed frequency
- **Simplified design:** Easier to design efficient fixed-frequency stages

Selection criteria:

- High enough to provide good image rejection
- Low enough for practical filter Q and gain
- Should avoid harmonics of common signals

Image frequency calculation:

- High-side injection: fimage = fRF + 2fIF
- Low-side injection: fimage = fRF - 2fIF

Diagram:

```
   Original      IF Stage      Audio
   Spectrum        Fixed       Output
     |  |           |  |          |
     V  V           V  V          V
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}+}
|  Mixer   |{-{-}{-}|    IF    |{-}{-}{-}| Det |}
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}+}
      \^{}
      |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
|  Local     |
| Oscillator |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Mnemonic

"CIGS" - Conversion, Improved selectivity, Gain stability, Simplified design

Question 3(c) OR [7 marks]

Explain phase discriminator circuit for FM detection.

Solution

Phase Discriminator for FM Detection:

Purpose:

- Converts frequency variations in FM signal to amplitude variations
- Demodulates FM signal to recover original message

Circuit components:

- Center-tapped transformer
- Two diodes (D1 and D2)
- RC filter network
- Phase-shifting network (L-C circuit)

Working principle:

1. Input FM signal splits into two paths
2. Reference path goes directly to center tap
3. Phase-shifted path passes through LC network
4. Phase shift varies with frequency deviation
5. Two diodes produce voltages proportional to phase difference
6. Output voltage varies with input frequency

Circuit diagram:

```
                      D1
              +{-{-}{-}{-}{-}||{-}{-}{-}{-}{-}+}
              |               |
              |               R1
              |               |
              |               |
 FM Input     |               +{-{-}{-}+}
 +{-{-}{-}{-}{-}+     |                  |}
 |      |{-{-}{-}{-}+                  +{-}{-}{-} Output}
```

```
+{-{-}{-}{-}{-}{-}+     |                   |}
             |              +{-{-}{-}+}
             |              |
             |              R2
             |              |
             +{-{-}{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}+}
                    D2
```

Characteristics:

- **Linear response** over moderate frequency range
- **Balanced design** reduces amplitude variations
- **High sensitivity** to frequency changes
- **Limitations** at extreme frequency deviations

S-curve response:

```
   \^{}
   |              /
   |             /
   |            /
 0V +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
   |          /
   |         /
   |        /
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
      fc{-Δf  fc   fc+Δf}
```

Mnemonic

"PSDO" - Phase shift Demodulates, Signal frequency determines Output

Question 4(a) [3 marks]

Compare analog and digital communication techniques

Solution

Comparison of Analog vs. Digital Communication:

Parameter	Analog Communication	Digital Communication
Signal	Continuous waveform	Discrete binary values
Bandwidth	Less bandwidth required	More bandwidth required
Noise Immunity	Poor, noise accumulates	Excellent, error correction possible
Power Efficiency	Less efficient	More efficient
Quality	Degrades with distance	Maintains quality until SNR threshold
Multiplexing	FDM primarily used	TDM primarily used
System Complexity	Simpler	More complex
Cost	Lower	Higher but decreasing
Examples	AM/FM radio, analog TV	Mobile networks, digital TV, internet

Mnemonic

"BNPQ MCE" - Bandwidth, Noise immunity, Power, Quality, Multiplexing, Complexity, Efficiency

Question 4(b) [4 marks]

Explain Adaptive delta modulation with its application.

Solution

Adaptive Delta Modulation (ADM):
Definition:

- Improved version of Delta Modulation (DM)
- Uses variable step size adjusted to signal slope

Working principle:

1. Compares input signal with predicted value
2. Outputs binary 1 or 0 based on comparison
3. Adjusts step size based on consecutive bits
4. Increases step size for rapid changes
5. Decreases step size for slow changes

Advantages over Delta Modulation:

- Reduces slope overload distortion
- Minimizes granular noise
- Better dynamic range
- Lower bit rate for same quality

Diagram:

```
                        +{-{-}{-}{-}{-}{-}{-}+}
                        |       |
                        | Step  |{{-}{-}+}
Input                   | Size  |   |
  +{-{-}{-}+    +{-}{-}{-}+         | Logic |    |}
  |   |{-{-}{-}|+/{-}|{-}{-}{-}{-}{-}{-}{-}|         |    |}
  +{-{-}{-}+    +{-}{-}{-}+         +{-}{-}{-}{-}{-}{-}{-}+   |}
    \^{         |              |       |}
    |         |              V       |
    |      +{-{-}{-}+         +{-}{-}{-}+      |}
    +{-{-}{-}{-}{-}{-}|   |{-}{-}{-}{-}{-}{-}{-}{-}| Δ |{-}{-}{-}{-}{-}{-}+}
           +{-{-}{-}+         +{-}{-}{-}+}
           Integrator
```

Applications:

- **Speech transmission:** Voice over digital networks
- **Audio compression:** Music storage and transmission
- **Telemetry systems:** Remote data collection
- **Military communications:** Secure transmission

Mnemonic

"VSOG" - Variable Step size Overcomes Granular noise & slope overload

Question 4(c) [7 marks]

Draw & explain block diagram of PCM system.

Solution

Pulse Code Modulation (PCM) System:
Block Diagram:

```
                  +{-{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{
                  |       |    |          |    |          |    |         |
Input signal {-{-}{-}{-}|Sample |{-}{-}{-}|Quantizer |{-}{-}{-}|Encoder  |{-}{-}{-}|Channel |}
                  |\& Hold |    |          |    |          |    |         |
                  +{-{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{
                                                 |
                                                 V
                  +{-{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{
                  |        |    |         |    |          |    |         |
Output signal {{-}{-}{-}|Low Pass|{-}{-}{-}| DAC     |{-}{-}{-}|Decoder  |{-}{-}{-}| Buffer |}
                  |Filter  |    |         |    |          |    |         |
```

+{-{-}{-}{-}{-}{-}{-}{-}+ +{-}{-}{-}{-}{-}{-}{-}{-}+ +{-}{-}{-}{-}{-}{-}{

Transmitter components:

1. **Sample & Hold:**
   - Samples analog signal at regular intervals
   - Nyquist rate (fs $\geq 2fmax$)
   - Holds value until next sample
2. **Quantizer:**
   - Divides amplitude range into discrete levels
   - Maps each sample to nearest level
   - Introduces quantization error
3. **Encoder:**
   - Converts quantized levels to binary code
   - n-bit encoder gives 2^n quantization levels
   - Common formats: 8-bit, 16-bit

Receiver components:

1. **Decoder:**
   - Converts binary to quantized levels
   - Reverses encoder operation
2. **Digital-to-Analog Converter (DAC):**
   - Converts discrete levels to analog values
   - Produces staircase approximation of signal
3. **Low-Pass Filter:**
   - Smooths staircase output
   - Removes high-frequency components
   - Reconstructs original waveform

Key characteristics:

- Sampling rate: Typically 8 kHz (voice), 44.1 kHz (CD audio)
- Resolution: 8-bit (256 levels) to 24-bit (16.8M levels)
- Bit rate = Sampling rate $\times bitspersample$

Mnemonic

"SQEC-DFL" - Sample, Quantize, Encode, Channel - Decode, Filter, Listen

Question 4(a) OR [3 marks]

Explain quantization process and its necessity.

Solution

Quantization Process and its Necessity:

Definition:

- Process of mapping continuous amplitude values to discrete levels
- Second step in analog-to-digital conversion after sampling

Process:

1. Divide amplitude range into finite number of levels
2. Assign each sample to nearest quantization level
3. Represent each level with binary code
4. Quantization levels = 2^n (n = number of bits)

Types:

- **Uniform quantization:** Equal step size throughout range
- **Non-uniform quantization:** Variable step size (smaller for lower amplitudes)
- **Mid-tread quantization:** Zero is a valid level
- **Mid-rise quantization:** Zero falls between levels

Necessity:

- **Digital representation:** Enables conversion to binary format
- **Storage efficiency:** Allows finite storage of analog signals
- **Processing capability:** Enables digital signal processing
- **Transmission benefits:** Facilitates error correction and encryption

Quantization error:

- Difference between actual and quantized value
- Maximum error = /2 (where
  Q = step size)
- Signal-to-quantization-noise ratio: SQNR = 6.02n + 1.76 dB

Diagram:

```
\^{}
|                    Quantized
|   Original         Output
|    Signal          /|
|      /{           / |}
|     /  {         /  |}
|    /    {       /   |}
|   /      {     /    |}
|  /        {   /     |}
| /          { /      |}
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
              Time
```

Mnemonic

"DEBS" - Digitization Enables Binary Storage

Question 4(b) OR [4 marks]

Explain PCM receiver.

Solution

PCM Receiver:

Block Diagram:

```
                +{-{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{
                |        |    |         |    |         |    |        |
Digital PCM  {-{-}{-}{-}| Buffer |{-}{-}{-}| Decoder |{-}{-}{-}|   DAC   |{-}{-}{-}|Low Pass|{-}{-}{-}
  Input         |        |    |         |    |         |    | Filter |
                +{-{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{
```

Components and their functions:

1. **Buffer:**
   - Temporarily stores received PCM data
   - Compensates for timing variations
   - Provides protection against jitter
2. **Decoder:**
   - Converts binary code to quantized amplitude levels
   - Detects and corrects transmission errors (if error coding used)
   - Outputs discrete amplitude values
3. **Digital-to-Analog Converter (DAC):**
   - Converts digital values to analog voltage levels
   - Creates staircase approximation of original signal
   - Resolution determined by bit depth (2^n levels)
4. **Low-Pass Filter:**
   - Smooths the staircase waveform
   - Removes high-frequency components
   - Reconstructs continuous analog signal

Waveforms in PCM Receiver:

```
Digital Input      Decoded Values      DAC Output         Final Output
 1001              {-{-}{-}{-}                \_                    /}
 0110              {-  {-}              \_| |\_               /  }
 1010             {-{-} {-}            \_|   |\_            /    }
 0101              {- {-} {-}            \_|     |\_          /      }
```

Performance factors:

- **SNR:** Determined by quantization bits (6.02n + 1.76 dB)
- **Bandwidth:** Depends on sampling rate and filter characteristics
- **Distortion:** Related to quantization error

Mnemonic

"BDFL" - Buffer stores, Decoder converts, Filter smooths, Listen to output

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 into a discrete-time signal by taking measurements (samples) at regular time intervals.
Mathematical expression: x[n] = x(nTs), where n = 0, 1, 2...

- x[n] is discrete-time sample
- x(t) is continuous-time signal
- Ts is sampling period (1/fs)

Nyquist Theorem:

- Sampling frequency (fs) must be at least twice the highest frequency component (fmax) in the signal
- fs $\geq 2fmax$
- Prevents aliasing (distortion due to overlap of spectrum)

Types of Sampling:

Type	Description	Characteristics
Ideal Sampling	Instantaneous samples at regular intervals	- Theoretical concept- Represented by impulse train- Infinite bandwidth required
Natural Sampling	Signal multiplied by pulse train with finite width	- Samples have same shape as signal- Width determined by sampling pulse- Used in analog systems
Flat-Top Sampling	Sample-and-hold technique	- Holds sampled value until next sample- Creates staircase approximation- Common in practical systems

Sampling Rates:

- **Under-sampling:** fs < 2fmax (causes aliasing)
- **Critical sampling:** fs = 2fmax (minimum required rate)
- **Over-sampling:** fs > 2fmax (improves reconstruction quality)

Diagram:

```
Original Signal:    /{///////}

Ideal Sampling:     |  |  |  |  |  |

Natural Sampling:

Flat{-top Sampling:               }
```

Mnemonic

"INF" - Ideal (impulses), Natural (pulse-shaped), Flat-top (staircase)

Question 5(a) [3 marks]

List the need of Multiplexing.

Solution

Need for Multiplexing:

Need	Description
Bandwidth Utilization	Efficiently uses available transmission bandwidth
Cost Reduction	Shares expensive transmission medium among multiple users
Infrastructure Optimization	Reduces physical connections and hardware requirements
Spectrum Efficiency	Maximizes use of limited frequency spectrum
Network Capacity	Increases number of channels/users on single medium
Flexibility	Allows dynamic allocation of resources based on demand

Mnemonic

"BCSINF" - Bandwidth, Cost, Spectrum, Infrastructure, Network capacity, Flexibility

Question 5(b) [4 marks]

Explain working of DPCM.

Solution

Differential Pulse Code Modulation (DPCM):
Definition:
- Enhanced version of PCM that encodes difference between current and predicted sample
- Exploits correlation between adjacent samples to reduce bit rate

Block Diagram:

```
                 +{-{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}
                 |      |     |          |    |         |
Input signal {-{-}{-}{-}| ADC  |{-}{-}+{-}|Quantizer |{-}{-}{-}|Encoder  |{-}{-}{-} DPCM Output}
                 |      |  |  |          |    |         |
                 +{-{-}{-}{-}{-}{-}+  |  +{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}{-}
                           |        \^{}
                           |        |
                           v        |
                       +{-{-}{-}{-}{-}{-}{-}{-}{-}+  |}
                       |Predictor|{-{-}+}
                       +{-{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Working principle:
1. Current sample is predicted based on previous sample(s)
2. Only the difference (error) between actual and predicted value is encoded
3. Smaller difference requires fewer bits than full amplitude
4. Predictor uses previous reconstructed values for prediction

Advantages:
- **Reduced bit rate:** Typically 25-50% lower than PCM
- **Better SNR:** For same bit rate as PCM
- **Correlation utilization:** Exploits signal redundancy

Limitations:
- **Error propagation:** Errors affect subsequent samples
- **Complexity:** More complex than simple PCM
- **Signal dependency:** Performance varies with signal characteristics

Mnemonic

"PDQE" - Predict sample, Difference calculated, Quantize error, Encode result

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 of Binary Data: 1011001
Waveforms:

```
Binary Data:   1   0   1   1   0   0   1
              \_   \_   \_   \_   \_   \_   \_

1. Unipolar NRZ:

              \_\_\_   \_\_\_\_\_\_\_

2. Unipolar RZ:
               \_   \_    \_ \_ \_  \_
              \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_

3. Polar NRZ:

              \_\_\_   \_\_\_\_\_\_\_

4. Polar RZ:
               \_ \_ \_    \_ \_ \_   \_
              \_  \_ \_ \_ \_    \_ \_ \_

5. AMI:
               \_     \_ \_ \_  \_
              \_ \_  \_ \_ \_ \_ \_ \_ \_ \_

6. Manchester:

              \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_
```

Characteristics of Each Coding:

Coding Technique	Description	Advantages	Disadvantages
Unipolar NRZ	1 = high voltage0 = zero voltageNo return to zero	Simple implementation	DC component, no clock recovery
Unipolar RZ	1 = high for half bit0 = zero voltageReturns to zero	Self-clocking	Requires more bandwidth
Polar NRZ	1 = positive voltage0 = negative voltageNo return to zero	No DC component	Poor clock recovery
Polar RZ	1 = positive for half bit0 = negative for half bitReturns to zero	Self-clocking, no DC component	Requires more bandwidth
AMI	1 = alternating +/- voltage0 = zero voltage	No DC component, error detection	Long strings of zeros problematic
Manchester	1 = transition low to high0 = transition high to low	Self-clocking, no DC component	Requires double bandwidth

Mnemonic

"UPRMA" - Unipolar, Polar, Return-to-zero, Manchester, AMI line coding techniques

Question 5(a) OR [3 marks]

Explain polar RZ and NRZ format

Solution

Polar RZ and NRZ Line Coding:
Polar NRZ (Non-Return to Zero):

- Binary 1: Positive voltage (+V) for entire bit duration
- Binary 0: Negative voltage (-V) for entire bit duration
- Signal remains at level during entire bit period
- No transition to zero between consecutive similar bits

Characteristics of Polar NRZ:

- **Bandwidth efficiency:** Requires minimum bandwidth
- **DC component:** Zero average for equal 1s and 0s
- **Clock recovery:** Poor for long sequences of same bit
- **Error detection:** No inherent capability

Polar RZ (Return to Zero):

- Binary 1: Positive voltage (+V) for half bit, zero for remainder
- Binary 0: Negative voltage (-V) for half bit, zero for remainder
- Signal returns to zero during each bit period

Characteristics of Polar RZ:

- **Bandwidth:** Requires twice the bandwidth of NRZ
- **Self-clocking:** Better clock recovery
- **Power requirement:** Higher than NRZ
- **Error detection:** No inherent capability

Waveform Comparison:

```
Binary Data:   1   0   1   1   0   0   1
              \_   \_   \_   \_   \_   \_   \_

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

Polar RZ:       \_ \_ \_     \_ \_ \_   \_
              \_   \_ \_ \_ \_     \_ \_ \_
```

Mnemonic

"HZRT" - Half bit active + Zero Return in RZ, full Time in NRZ

Question 5(b) OR [4 marks]

Explain delta modulation in brief.

Solution

Delta Modulation (DM):
Definition:

- Simplest form of differential encoding
- Encodes only the sign of difference between current and previous sample
- Single bit per sample for transmission (1 or 0)

Block Diagram:

```
                    +{-{-}{-}{-}{-}+       Encoded}
 Input      +{-{-}{-}+   |     |      Bitstream}
 Signal {-{-}{-}|+/{-}|{-}{-}{-}  C  |{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
            +{-{-}{-}+   |     |}
              \^{     +{-}{-}{-}{-}{-}+}
              |        |
              |        v
            +{-{-}{-}+    +{-}{-}{-}+}
            |   |{{-}{-}{-}{-}|+/{-}|}
```

```
           +{-{-}{-}+    +{-}{-}{-}+}
         Integrator   Step Size
```

Working principle:

1. Compare input signal with predicted value (from integrator)
2. If input > predicted: Output = 1, increase predicted value
3. If input < predicted: Output = 0, decrease predicted value
4. Step size determines how much predicted value changes

Advantages:

- **Simple implementation:** Minimal hardware
- **Low bit rate:** 1 bit per sample
- **Robust:** Relatively immune to channel noise

Limitations:

- **Slope overload:** Cannot track rapid signal changes
- **Granular noise:** Oscillations around steady signals
- **Limited resolution:** Quality depends on step size and sampling rate

Waveforms:

```
Original:      /{///}

Reconstructed: /{///}
               (Staircase approximation)

Binary output: 1101001011
```

Mnemonic

"1BSG" - 1 Bit per Sample, Slope overload and Granular noise limitations

Question 5(c) OR [7 marks]

Explain PCM-TDM system.

Solution

PCM-TDM System:

Definition:

- Combined system using Pulse Code Modulation (PCM) with Time Division Multiplexing (TDM)
- Multiple analog channels converted to digital PCM, then multiplexed in time

Block Diagram:

```
                +{-{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}{-
 Channel 1 {-{-}{-}{-}{-}| PCM 1 |{-}{-}{-}{-}|        |     |         |}
                +{-{-}{-}{-}{-}{-}+     |        |     |         |}
                +{-{-}{-}{-}{-}{-}+     |        |     |         |     Multiplexed}
 Channel 2 {-{-}{-}{-}{-}| PCM 2 |{-}{-}{-}{-}|  Time  |{-}{-}{-}{-}|  Frame  |{-}{-}{-} PCM{-}TDM}
                +{-{-}{-}{-}{-}{-}+     |        |     | Format  |     Output}
                              |  MUX   |     |         |
                +{-{-}{-}{-}{-}{-}+     |        |     |         |}
 Channel N {-{-}{-}{-}{-}| PCM N |{-}{-}{-}{-}|        |     |         |}
                +{-{-}{-}{-}{-}{-}+    +{-}{-}{-}{-}{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}{-
```

PCM Process for Each Channel:

1. **Sampling:** Each channel sampled at fs $\geq 2fmax$
1. **Quantization:** Samples assigned to discrete levels
2. **Encoding:** Quantized values converted to binary code

TDM Frame Structure:

- Frame consists of one sample from each channel
- Frame includes synchronization bits/word
- Frame rate equals sampling rate (fs)
- Bit rate = fs $\times N \times n(N = channels,$

n = bits/sample)

Typical Parameters:

- **Voice channels:** 8 kHz sampling, 8 bits/sample
- **T1 system:** 24 channels, 1.544 Mbps
- **E1 system:** 30 channels, 2.048 Mbps

Advantages:

- **Efficient transmission:** Single high-speed link
- **Digital benefits:** Noise immunity, regeneration
- **Flexibility:** Easy to add/drop channels

Applications:

- **Telephone networks:** Digital transmission systems
- **Digital audio:** Broadcasting and recording
- **Satellite communications:** Multiple channel transmission

Diagram of TDM Frame:

```
|{{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} One TDM Frame {-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+       +{-}{-}{-}{-}
| Sync| Ch1 | Ch2 | Ch3 | Ch4 | ..... | ChN |
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}+       +{-}{-}{-}{-}
```

Mnemonic

"MSQT" - Multiplex, Sample, Quantize, Transmit