Subject Name Solutions

1333201 – Winter 2023

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Define: (A) Amplitude Modulation, (B) Frequency Modulation, and (C) Phase Modulation

Solution

Table 1: Types of Modulation Techniques

Modulation Type	Definition
Amplitude Modulation (AM)	Process where amplitude of carrier signal is varied according to the instantaneous value of modulating signal while frequency remains constant
Frequency Modulation (FM)	Process where frequency of carrier signal is varied according to the instantaneous value of modulating signal while amplitude remains constant
Phase Modulation (PM)	Process where phase of carrier signal is varied according to the instantaneous value of modulating signal while amplitude remains constant

Mnemonic

"A-F-P: Amplitude changes, Frequency shifts, Phase adjusts"

Question 1(b) [4 marks]

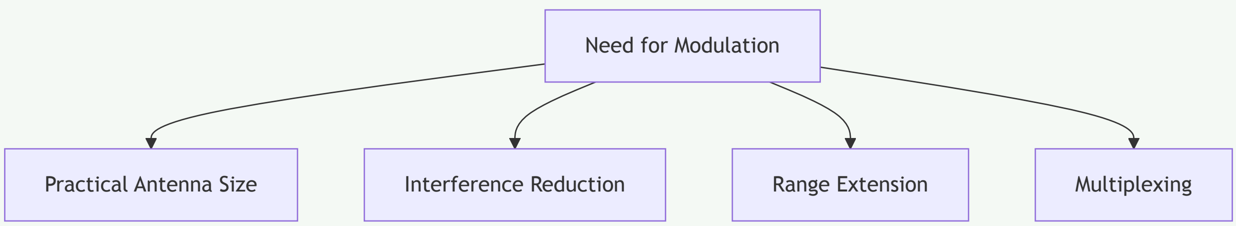
Explain the need for modulation.

Solution

Table 2: Need for Modulation

Need	Explanation
Practical Antenna Size	Reduces antenna size by increasing frequency (Antenna length = /4)
Interference Reduction	Allows multiple signals to be transmitted simultaneously on different frequencies
Range Extension	Higher frequency signals travel farther in atmosphere
Multiplexing	Enables multiple signals to share communication medium

Diagram:



Mnemonic

"PIRM: Practical antennas, Interference reduction, Range extension, Multiplexing"

Question 1(c) [7 marks]

A modulating signal has amplitude of 3 V and frequency of 1 KHz is amplitude modulated by a carrier of amplitude 10 V and frequency 30KHz. Find modulation index, frequencies of sideband components and their amplitudes. Also draw the spectrum of AM wave.

Solution

Table 3: Given Information

Parameter	Modulating Signal	Carrier Signal
Amplitude	3 V	10 V
Frequency	1 kHz	30 kHz

Calculations:
- **Modulation Index (m)** = Am/Ac = 3/10 = 0.3
- **Sideband Frequencies** = fc $\pm fm = 30 \pm 1 = 29kHzand31kHz$
- **Sideband Amplitudes** = m $\times Ac/2 = 0.3 \times 10/2 = 1.5V$

Diagram: AM Spectrum

```


                          10V






       1.5V                                      1.5V


f
         29kHz                     30kHz                     31kHz
      (fc - fm)                     fc                    (fc + fm)
```

Mnemonic

"LSB-C-USB: Lower sideband, Carrier, Upper sideband at 29-30-31"

Question 1(c) OR [7 marks]

Derive mathematical relation between carrier powers, and modulated signal power for AM.

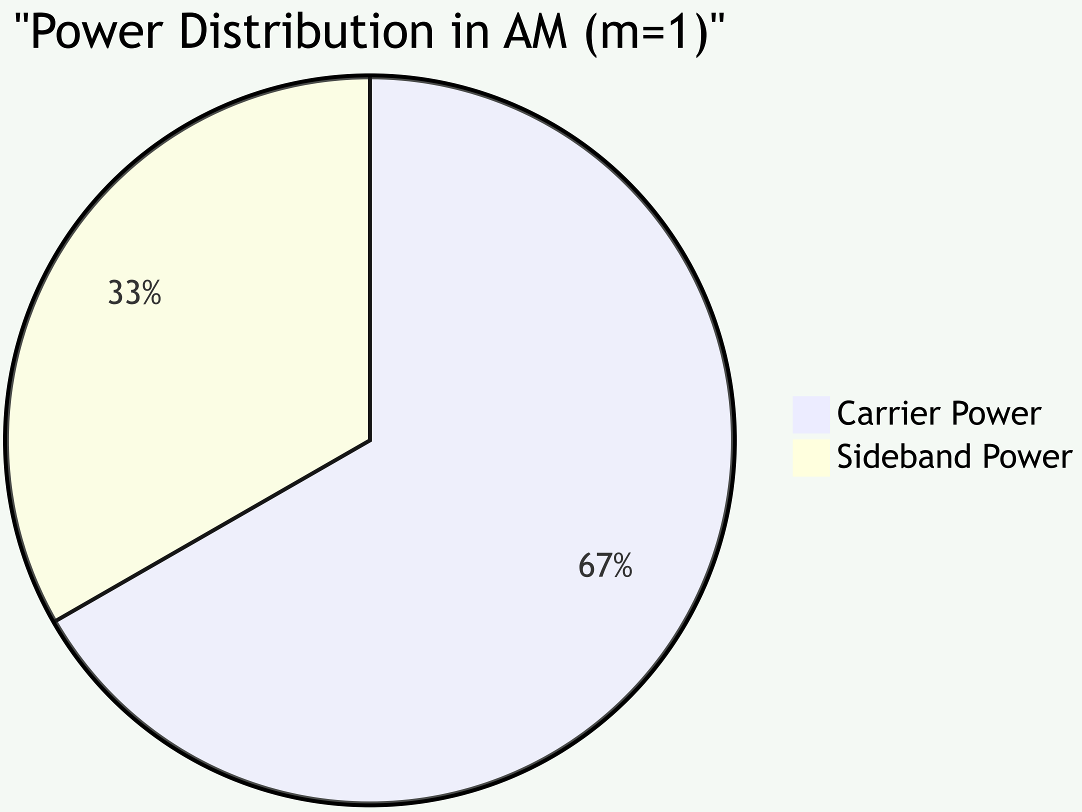
Solution

Mathematical Relation:
- Carrier signal: c(t) = Ac cos(2 fc · t)
- Modulating signal: m(t) = Am cos(2 fm · t)
- AM signal: s(t) = Ac[1 + m · cos(2 fm · t)] · cos(2 fc · t)

Table 4: Power Distribution in AM

Component	Expression	In Terms of Pc
Carrier Power (Pc)	$Ac^2/2$	Pc
Total Sideband Power (Ps)	$m^2Ac^2/4$	$m^2Pc/2$
Total AM Power (Pt)	$Pc(1 + m^2/2)$	$Pc(1 + m^2/2)$

Diagram: Power Distribution



- **Modulation Efficiency** = Ps/Pt = $(\mathrm{m}^2/2)/(1+m^2/2)\times 100\%$

Mnemonic

"Total Power = Carrier Power $\times(1+m^2/2)''$

Question 2(a) [3 marks]

Compare AM and FM.

Solution

Table 5: Comparison between AM and FM

Parameter	AM	FM
Modulation Parameter	Amplitude varies	Frequency varies
Bandwidth	2 $\times fm$	2 $\times(f+fm)$
Noise Immunity	Poor	Excellent
Power Efficiency	Low	High
Circuit Complexity	Simple	Complex

Mnemonic

"ABNPC: Amplitude/Bandwidth/Noise/Power/Complexity differences"

Question 2(b) [4 marks]

Explain envelope detector with the help of circuit diagram.

Solution

Diagram: Envelope Detector Circuit

```
                D
                   |
AM                        Demodulated
Inpt                         Output
                            R
                          L

                        C


```

Table 6: Envelope Detector Components

Component	Function
Diode (D)	Rectifies AM signal to extract positive half cycles
Capacitor (C)	Charges to peak of input, holds charge between peaks
Resistor (RL)	Discharges capacitor at rate suitable for envelope extraction

Time Constant Selection:

- 1/fm « RC « 1/fc (for proper envelope detection)

Mnemonic

"DCR: Diode rectifies, Capacitor charges, Resistor discharges"

Question 2(c) [7 marks]

Draw and explain the block diagram of Superheterodyne receiver.

Solution

Diagram: Superheterodyne Receiver

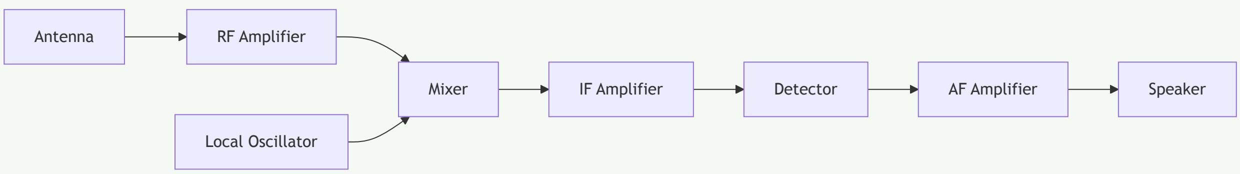


Table 7: Functions of Superheterodyne Receiver Blocks

Block	Function
RF Amplifier	Amplifies weak RF signal, provides selectivity, rejects image frequency
Local Oscillator	Generates frequency fo = fRF + fIF for mixing
Mixer	Combines RF signal with local oscillator to produce IF (Intermediate Frequency)
IF Amplifier	Provides most of the receiver gain and selectivity at fixed frequency
Detector	Extracts the modulating signal from the IF signal
AF Amplifier	Amplifies recovered audio to drive speaker

Mnemonic

"RLMIDS: RF, Local oscillator, Mixer, IF, Detector, Speaker"

Question 2(a) OR [3 marks]

Define the followings terms: (A) Sensitivity, and (B) Selectivity

Solution

Table 8: Receiver Characteristics

Term	Definition
Sensitivity	Ability of receiver to detect and amplify weak signals; measured as minimum input signal strength (μV) needed for standard output
Selectivity	Ability of receiver to separate desired signal from adjacent channels; measured as ratio of response at resonant frequency to off-resonant frequency

Diagram: Selectivity Curve

```

       Response










       f1   fc    f2    Frequency
```

Mnemonic

"SS: Signal Strength for Sensitivity, Signal Separation for Selectivity"

Question 2(b) OR [4 marks]

Describe the block diagram of general communication system.

Solution

Diagram: General Communication System

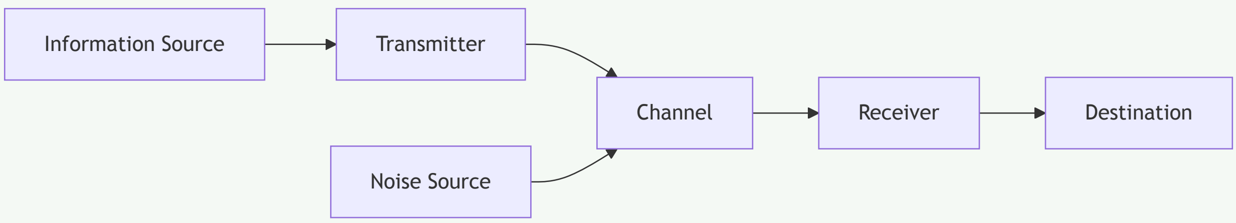


Table 9: Components of Communication System

Component	Function
Information Source	Generates message to be communicated (voice, data, video)
Transmitter	Converts message into signals suitable for transmission
Channel	Medium through which signals travel (wire, fiber, air)
Receiver	Extracts original message from received signals
Destination	Entity for which message is intended
Noise Source	Unwanted signals that interfere with the message

Mnemonic

"I-T-C-R-D: Information Travels Carefully, Reaches Destination"

Question 2(c) OR [7 marks]

Draw and explain the block diagram of Superheterodyne FM receiver.

Solution

Diagram: Superheterodyne FM Receiver

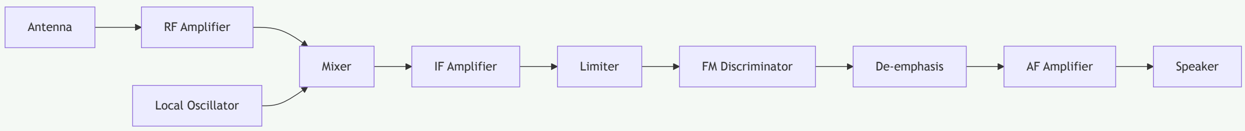


Table 10: Additional Components in FM Receiver

Component	Function
Limiter	Removes amplitude variations, provides constant amplitude signal
FM Discriminator	Converts frequency variations to amplitude variations (demodulation)
De-emphasis	Attenuates higher frequencies boosted at transmitter

Unique Aspects of FM Receiver:

- Uses wider bandwidth IF amplifier (200 kHz vs 10 kHz for AM)
- Requires limiter stage for noise reduction
- Employs specialized discriminator for FM demodulation

Mnemonic

"MILD: Mixer, IF, Limiter, Discriminator - key components in FM reception"

Question 3(a) [3 marks]

Draw the waveform of (A) Impulse (B) Pulse in time and frequency domain

Solution

Table 11: Impulse and Pulse Characteristics

Signal	Time Domain	Frequency Domain
Impulse	Infinitely narrow spike with infinite amplitude	Flat spectrum with all frequencies equally present
Pulse	Rectangular shape with finite width and height	Sinc function (sin(x)/x) shape

Diagram: Impulse and Pulse

```
Time Domain                      Frequency Domain

Impulse                          Impulse



      ↑



      t_{0}                                f

Pulse                            Pulse





       t_{0}  t_{0}+T                          f_{0}  2f_{0}  3f_{0}
```

Mnemonic

"I-P: Impulse is a Pinpoint spike, Pulse has Persistent width"

Question 3(b) [4 marks]

Describe under sampling and critical sampling

Solution

Table 12: Types of Sampling

Type of Sampling	Description	Effect
Under Sampling	Sampling frequency fs < 2fm (less than Nyquist rate)	Aliasing occurs; signal cannot be recovered
Critical Sampling	Sampling frequency fs = 2fm (exactly Nyquist rate)	Theoretically perfect reconstruction possible
Over Sampling	Sampling frequency fs > 2fm (exceeds Nyquist rate)	Better reconstruction, easier filtering

Diagram: Under Sampling vs Critical Sampling

```
Under Sampling (fs < 2fm)




    ↑     ↑     ↑     ↑     ↑
    Aliasing occurs - samples too far apart

Critical Sampling (fs = 2fm)




    ↑   ↑   ↑   ↑   ↑   ↑   ↑   ↑
    Just enough samples to reconstruct
```

Mnemonic

"UCO: Under (fs<2fm), Critical (fs=2fm), Over (fs>2fm)"

Question 3(c) [7 marks]

State the PAM, PWM and PPM signals with waveform.

Solution

Table 13: Pulse Modulation Techniques

Technique	Description	Signal Parameter Varied
PAM (Pulse Amplitude Modulation)	Amplitude of pulses varies according to modulating signal	Amplitude
PWM (Pulse Width Modulation)	Width/duration of pulses varies according to modulating signal	Pulse width
PPM (Pulse Position Modulation)	Position/timing of pulses varies according to modulating signal	Pulse position

Diagram: PAM, PWM, PPM Waveforms

```
Modulating Signal

        /     \
       /       \
      /         \        /\
     /           \      /  \
                  \    /    \
                   \  /      \
                    \/

PAM






PWM






PPM





```

Mnemonic

"APP: Amplitude, Position, Pulse-width change respectively"

Question 3(a) OR [3 marks]

State and explain sampling theorem.

Solution

Sampling Theorem Statement: "A band-limited continuous-time signal can be completely represented by and reconstructed from its samples, if the sampling frequency is at least twice the highest frequency component in the signal."

Table 14: Key Elements of Sampling Theorem

Term	Description
Nyquist Rate	Minimum sampling frequency (fs) required = 2fm
Nyquist Interval	Maximum time between samples = 1/(2fm)
Band-limited Signal	Signal with finite highest frequency component

Diagram: Proper Sampling

```
Original Signal

       /     \
      /       \
     /         \
                \
                 \


Sampled at fs \geq 2fm
        *   *
       /|\  |\
      / | \ | \
     /  |  \|  \
        |   *   *
        |       |
            **
```

Mnemonic

"2F: Frequency must be sampled at least Twice its highest Frequency"

Question 3(b) OR [4 marks]

Explain Concept of Quantization.

Solution

Table 15: Quantization Concepts

Term	Description
Quantization	Process of converting continuous amplitude values into discrete levels
Quantization Levels	Total number of discrete values used (usually 2^n)
Quantization Step Size	Voltage difference between adjacent levels (Q = Vmax/2^n)
Quantization Error	Difference between actual signal value and quantized value

Diagram: Quantization Process

```
Continuous Signal          Quantized Signal

      /\
     /  \
    /    \
   /      \
           \
            \

                             Quantization
                                Levels
```

Mnemonic

"LSED: Levels, Step size, Error, Discrete values"

Question 3(c) OR [7 marks]

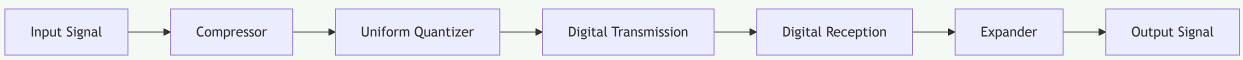
Explain the Companding in detail.

Solution

Table 16: Companding Concepts

Term	Description
Companding	COMpressing + exPANDING; non-linear quantization technique
Compression	Reduces amplitude range of signal before transmission
Expansion	Restores original amplitude range at receiver
Purpose	Improves SNR for weak signals while maintaining dynamic range
Types	-law (North America, Japan), A-law (Europe)

Diagram: Companding Process



Companding Laws:

- **-law**: y = sgn(x) $\times ln(1+|x|)/ln(1+)where = 255inUSA$
- **A-law**: y = sgn(x) $\times A|x|/(1+ln(A))for|x| < 1/Ay = sgn(x) \times (1+ln(A|x|))/(1+ln(A))for 1/A \leq |x| \leq 1$

Mnemonic

"CEQS: Compress, Encode, Quantize, Send; then Decode, Expand, Recover"

Question 4(a) [3 marks]

Explain delta modulation

Solution

Table 17: Delta Modulation Concepts

Concept	Description
Delta Modulation	Simplest form of DPCM where only 1-bit quantization is used
Step Size	Fixed increment/decrement in approximating signal
Output	Binary stream (1 for increase, 0 for decrease)
Advantages	Simple implementation, low bandwidth

Diagram: Delta Modulation

```
Original Signal    Delta Modulated
                   Approximation

      /\
     /  \
    /    \
          \
           \
            \


Binary Output: 1 1 1 1 0 0 0 0 0 0
```

Mnemonic

"1B1S: 1-Bit, 1-Step tracking"

Question 4(b) [4 marks]

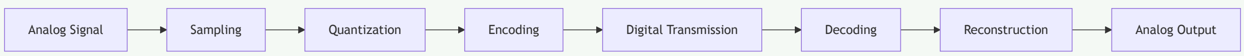
List out of advantage and disadvantage of PCM.

Solution

Table 18: Advantages and Disadvantages of PCM

Advantages	Disadvantages
High noise immunity	**Requires higher bandwidth**
Better signal quality	**Complex system implementation**
Compatible with digital systems	**Quantization noise present**
Secure transmission possible	**Synchronization required**
Multiplexing capability	**Higher power requirement**

Diagram: PCM System Overview



Mnemonic

"NCSMP: Noise immunity, Compatible with digital, Secure, Multiplexing, Processing benefits"

Question 4(c) [7 marks]

Draw and explain block diagram of PCM-TDM system.

Solution

Diagram: PCM-TDM System

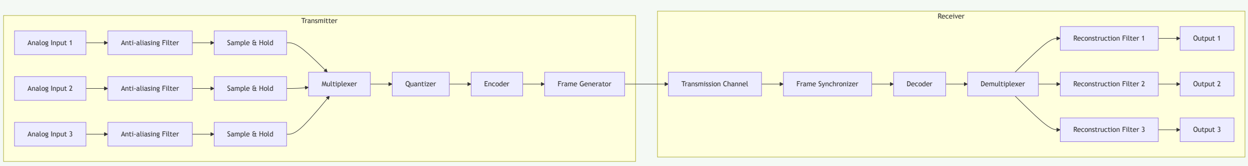


Table 19: PCM-TDM System Components

Component	Function
Anti-aliasing Filter	Limits signal bandwidth to avoid aliasing

Sample & Hold	Captures analog value and holds it for processing
Multiplexer	Combines multiple input channels into single time division multiplexed stream
Quantizer	Converts continuous samples to discrete values
Encoder	Converts quantized values to binary code
Frame Generator	Adds synchronization and control bits
Demultiplexer	Separates combined signal back into individual channels
Reconstruction Filter	Smooths the decoded signal to recover analog waveform

Mnemonic

"SAMPLER: Sample, Amplify, Multiplex, Process, Limit, Encode, Reconstruct"

Question 4(a) OR [3 marks]

Describe slop overload error.

Solution

Table 20: Slope Overload Error

Concept	Description
Slope Overload Error	Error occurring when input signal changes faster than DM step size can track
Cause	Fixed step size in Delta Modulation too small for steep input slopes
Effect	Distortion in reconstructed signal, particularly at high frequencies
Solution	Adaptive Delta Modulation (variable step size)

Diagram: Slope Overload Error

```
Original Signal vs DM Approximation

                      Slope Overload

         /\              /\
        /  \            /  \
       /    \    vs    /    \
      /      \          /   \
     /        \       /      \
               \     /         \
                \   /           \
                    \/
          Original     DM Approximation
```

Mnemonic

"SOS: Signal Outpaces Steps when slope is steep"

Question 4(b) OR [4 marks]

Explain transmitter of Differential PCM

Solution

Diagram: DPCM Transmitter

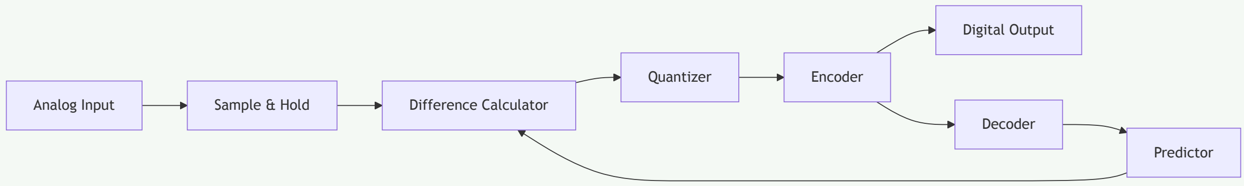


Table 21: DPCM Transmitter Components

Component	Function
Sample & Hold	Captures analog signal at regular intervals
Difference Calculator	Computes error between current sample and predicted value
Quantizer	Converts error signal to discrete levels
Encoder	Converts quantized values to binary code
Predictor	Estimates next sample based on previous values
Decoder	Same as in receiver, used in feedback loop

Key Advantage:

- Transmits only the difference between successive samples
- Reduces bit rate compared to standard PCM

Mnemonic

"SDQEP: Sample, Difference, Quantize, Encode, Predict"

Question 4(c) OR [7 marks]

Explain in detail PCM transmitter

Solution

Diagram: PCM Transmitter

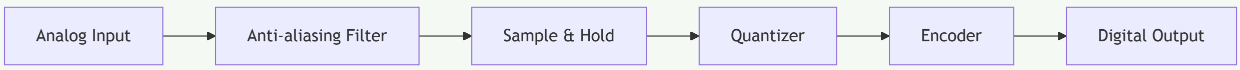


Table 22: PCM Transmitter Components in Detail

Component	Function	Design Considerations
Anti-aliasing Filter	Limits input bandwidth to fs/2	Cutoff frequency < fs/2, sharp roll-off
Sample & Hold	Captures instantaneous signal value	Sampling rate $\geq 2fm, aperturetime << samplingperiod$
Quantizer	Approximates sample amplitudes to discrete levels	Levels = $2^n where$ n = bit depth, typically 8-16 bits
Encoder	Converts quantized values to digital codes	Uses coding schemes like NRZ, RZ, Manchester
Line Coder	Prepares binary sequence for transmission	May use regenerative repeaters for long distance

Signal Processing Details:

- **Time Domain**: Sampling at intervals Ts = 1/fs
- **Amplitude Domain**: Quantizing continuous amplitudes into $2^n discretelevels$
- **Code Domain**: Converting levels to n-bit binary code

Mnemonic

"SAFE-Q: Sample And Filter, then Encode after Quantizing"

Question 5(a) [3 marks]

Compare PCM and DM

Solution

Table 23: Comparison of PCM and DM

Parameter	PCM	DM
Bit Rate	Higher (multiple bits per sample)	Lower (1 bit per sample)
Circuit Complexity	More complex	Simpler
Signal Quality	Better	Lower, suffers from slope overload & granular noise
Bandwidth	Wider	Narrower
Sampling Rate	At least 2fm	Much higher than 2fm

Mnemonic

"BCSBS: Bit rate, Complexity, Signal quality, Bandwidth, Sampling"

Question 5(b) [4 marks]

Define: (A) Antenna (B) Radiation pattern (C) Directivity and (D) Polarization

Solution

Table 24: Antenna Terminology

Term	Definition
Antenna	Device that converts electrical signals into electromagnetic waves and vice versa
Radiation Pattern	Graphical representation of radiation properties of antenna as function of space coordinates
Directivity	Ratio of radiation intensity in a given direction to average radiation intensity
Polarization	Orientation of electric field vector of electromagnetic wave radiated by antenna

Diagram: Radiation Pattern

Mnemonic

"ARDP: Antennas Radiate with Directivity and Polarization"

Question 5(c) [7 marks]

Write brief note on (A) smart antenna (B) parabolic reflector antenna

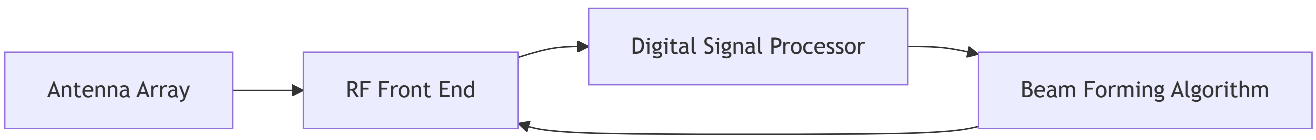
Solution

0.0.1 (A) Smart Antenna

Table 25: Smart Antenna Characteristics

Feature	Description
Definition	Antenna array with signal processing capability to adapt to changing conditions
Types	Switched beam, Adaptive array
Benefits	Increased range/coverage, interference reduction, capacity improvement
Applications	Mobile communications, 5G networks, WiMAX, military systems

Diagram: Smart Antenna System



0.0.2 (B) Parabolic Reflector Antenna

Table 26: Parabolic Reflector Characteristics

Feature	Description
Structure	Feed antenna at focal point with parabolic reflecting surface
Operation	Focuses parallel incoming waves to focal point or radiates from focal point into parallel beams
Gain	Very high directivity and gain
Applications	Satellite communication, radio astronomy, radar systems

Diagram: Parabolic Reflector

```










                  X



                Receiver
             (at focal point)
```

Mnemonic

"PFHS: Parabolic Focus gives High Signal strength"

Question 5(a) OR [3 marks]

Write a short note on Microstrip antenna

Solution

Table 27: Microstrip Antenna Characteristics

Feature	Description
Structure	Conductive patch on dielectric substrate with ground plane
Shape	Rectangular, circular, elliptical, triangular patches
Size	Typically /2 in length, very thin (h «)
Advantages	Low profile, lightweight, low cost, easy fabrication, compatible with PCB technology
Disadvantages	Low efficiency, narrow bandwidth, low power handling

Diagram: Microstrip Patch Antenna

```
                  \ leftarrow Patch (Copper)




                  \ leftarrow Dielectric Substrate
                              (FR4, PTFE, etc.)

                  \ leftarrow Ground Plane (Copper)

```

Mnemonic

"PDGF: Patch on Dielectric with Ground plane gives Flat profile"

Question 5(b) OR [4 marks]

Explain EM wave spectrum, its Frequency ranges and its applications.

Solution

Table 28: EM Wave Spectrum and Applications

Band	Frequency Range	Wavelength	Applications
ELF	3 Hz - 30 Hz	10,000 - 100,000 km	Submarine communication
VLF	3 kHz - 30 kHz	10 - 100 km	Navigation, time signals
LF	30 kHz - 300 kHz	1 - 10 km	AM radio, maritime radio
MF	300 kHz - 3 MHz	100 m - 1 km	AM broadcasting
HF	3 MHz - 30 MHz	10 - 100 m	Shortwave radio, amateur radio
VHF	30 MHz - 300 MHz	1 - 10 m	FM radio, TV broadcasting
UHF	300 MHz - 3 GHz	10 cm - 1 m	TV, mobile phones, WiFi
SHF	3 GHz - 30 GHz	1 - 10 cm	Satellite, radar, 5G
EHF	30 GHz - 300 GHz	1 mm - 1 cm	Radio astronomy, security scanning
IR	300 GHz - 400 THz	750 nm - 1 mm	Thermal imaging, remote control
Visible	400 THz - 800 THz	380 - 750 nm	Optical communications

Diagram: EM Wave Spectrum

Mnemonic

"RVMIXG: Radio, Visible, Microwave, Infrared, X-ray, Gamma"

Question 5(c) OR [7 marks]

Write brief note on (A) Space Wave Propagation (B) Ground Wave Propagation.

Solution

0.0.3 (A) Space Wave Propagation

Table 29: Space Wave Propagation Characteristics

Feature	Description
Definition	Direct wave propagation through space, including line-of-sight and reflected waves
Frequency Range	VHF and above (>30 MHz)
Distance	Limited by horizon, typically 50-80 km
Types	Direct wave, Ground reflected wave, Tropospheric scatter, Duct propagation
Applications	TV broadcasting, microwave links, satellite communication

Diagram: Space Wave Propagation

```
                  /\/\/\/\/\/\/\/\  \leftarrow Troposphere
                 /                \
                /                  \
               /                    \
    Transmitter *                     * Receiver
                |                     |
                |                     |
     ___________|_____________________|__________
                     Ground Surface
```

0.0.4 (B) Ground Wave Propagation

Table 30: Ground Wave Characteristics

Feature	Description
Definition	Wave propagation along Earth's surface, follows curvature of Earth
Frequency Range	LF, MF (up to 2 MHz)
Distance	Up to 1000 km depending on frequency and power
Mechanism	Vertically polarized wave attaches to conductive Earth surface
Applications	AM radio broadcasting, maritime communication

Diagram: Ground Wave Propagation

```
    Transmitter                           Receiver
         *                                    *
         |                                    |
         |       Ground Wave                  |
     ____|____________________________________|____
         \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
                           Earth
```

Mnemonic

"SHGM: Space waves go High, Ground waves hug Medium surface"