Communication Engineering (1333201) - Winter 2023 Solution

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Question 1(a) [3 marks]

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

Solution

Answer:

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

Answer:

Table 2. Need for Modulation

Need	Explanation
Practical Antenna Size	Reduces antenna size by increasing frequency (Antenna length = $\lambda/4$)
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

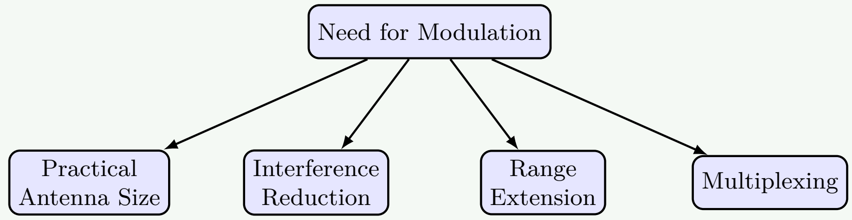

Figure 1. Need for Modulation

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

Answer:

Given Information:

- Modulating Signal: $A_m = 3$ V, $f_m = 1$ kHz
- Carrier Signal: $A_c = 10$ V, $f_c = 30$ kHz

Calculations:

1. **Modulation Index (m)**:

$$m = \frac{A_m}{A_c} = \frac{3}{10} = 0.3$$

2. **Sideband Frequencies**:

$$f_{LSB} = f_c - f_m = 30 - 1 = 29 \text{ kHz}$$

$$f_{USB} = f_c + f_m = 30 + 1 = 31 \text{ kHz}$$

3. **Sideband Amplitudes**:

$$A_{SB} = \frac{m \cdot A_c}{2} = \frac{0.3 \cdot 10}{2} = 1.5 \text{ V}$$

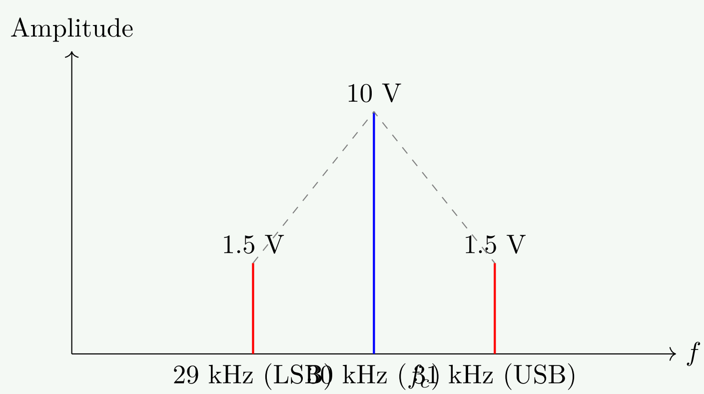

Figure 2. AM Spectrum

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

Answer:
Mathematical Relation:
Only the carrier signal is: $c(t) = A_c \cos(2\pi f_c t)$ The modulating signal is: $m(t) = A_m \cos(2\pi f_m t)$ The AM signal equation is:

$$s(t) = A_c[1 + m\cos(2\pi f_m t)]\cos(2\pi f_c t)$$

Expanding this:

$$s(t) = A_c \cos(2\pi f_c t) + \frac{mA_c}{2}\cos[2\pi(f_c - f_m)t] + \frac{mA_c}{2}\cos[2\pi(f_c + f_m)t]$$

Power Calculations: Power is proportional to square of amplitude ($P = V^2/R$, assuming R=1Ω).
1. **Carrier Power** (P_c):

$$P_c = \frac{(A_c/\sqrt{2})^2}{R} = \frac{A_c^2}{2}$$

2. **Total Sideband Power** (P_s):

$$P_{LSB} = \frac{(mA_c/2\sqrt{2})^2}{R} = \frac{m^2A_c^2}{8}$$

$$P_{USB} = \frac{(mA_c/2\sqrt{2})^2}{R} = \frac{m^2A_c^2}{8}$$

$$P_s = P_{LSB} + P_{USB} = \frac{m^2A_c^2}{4} = P_c \cdot \frac{m^2}{2}$$

3. **Total AM Power** (P_t):

$$P_t = P_c + P_s = P_c + P_c\frac{m^2}{2}$$

$$P_t = P_c\left(1 + \frac{m^2}{2}\right)$$

Table 3. Power Distribution in AM

Component	Expression	In Terms of P_c
Carrier Power (P_c)	$A_c^2/2$	P_c
Total Sideband Power (P_s)	$m^2A_c^2/4$	$m^2P_c/2$
Total AM Power (P_t)	$P_c(1 + m^2/2)$	$P_c(1 + m^2/2)$

Modulation Efficiency (η): ratio of sideband power to total power.

$$\eta = \frac{P_s}{P_t} = \frac{m^2/2}{1 + m^2/2} \times 100\%$$

For 100% modulation ($m = 1$), $\eta = 33.3\%$.

Mnemonic

"Total Power = Carrier Power × (1 + m²/2)"

Question 2(a) [3 marks]

Compare AM and FM.

Solution

Answer:

Table 4. Comparison between AM and FM

Parameter	**AM**	**FM**
Modulation Parameter	Amplitude varies	Frequency varies
Bandwidth	$2 \times f_m$	$2 \times (\Delta f + f_m)$
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

Answer:

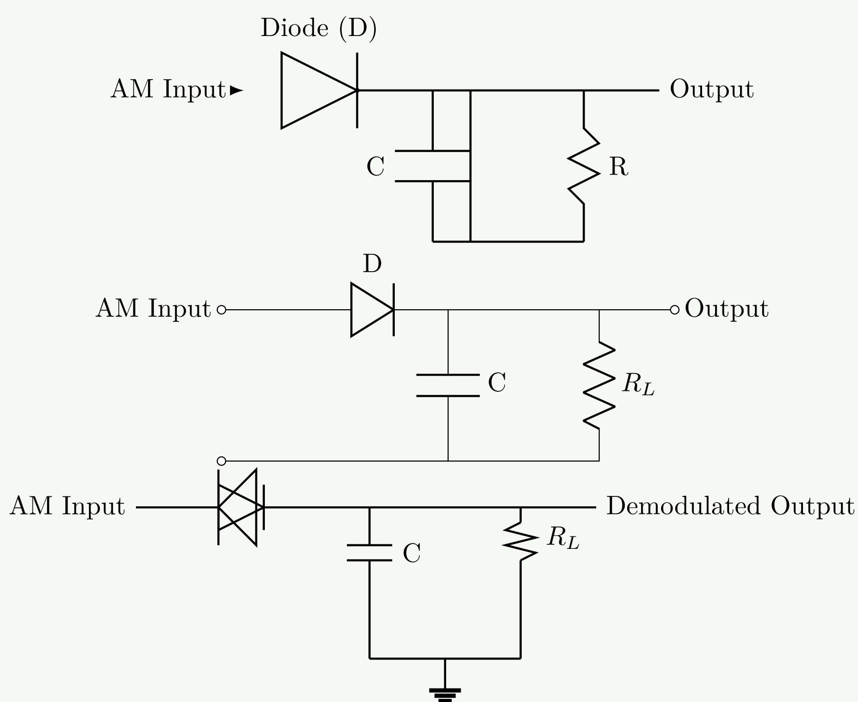

Figure 3. Envelope Detector Circuit

Envelope Detector Components:

Table 5. Component Functions

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

Time Constant Selection:

$$\frac{1}{f_c} \ll RC \ll \frac{1}{f_m}$$

(Correct standard condition 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

Answer:

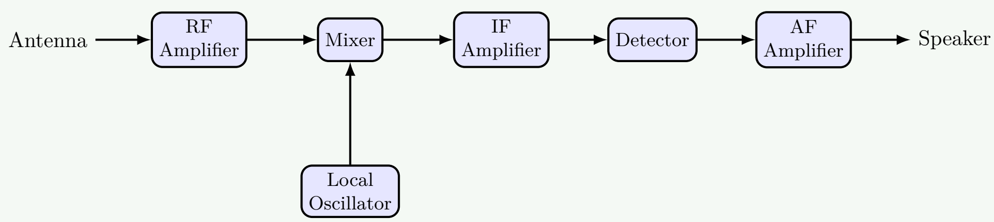

Figure 4. Superheterodyne Receiver

Functions of Blocks:

Table 6. Receiver Blocks

Block	Function
RF Amplifier	Amplifies weak RF signal, provides selectivity, rejects image frequency
Local Oscillator	Generates frequency $f_o = f_{RF} + f_{IF}$ 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

Answer:

Table 7. 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

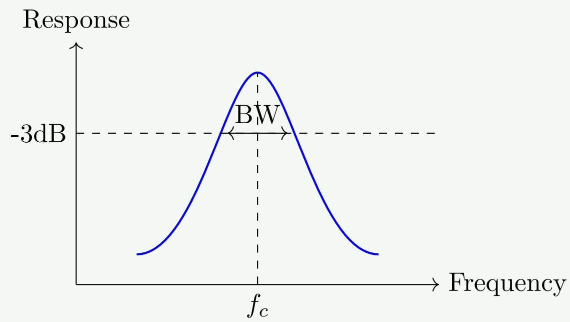

Figure 5. Selectivity Curve

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

Answer:

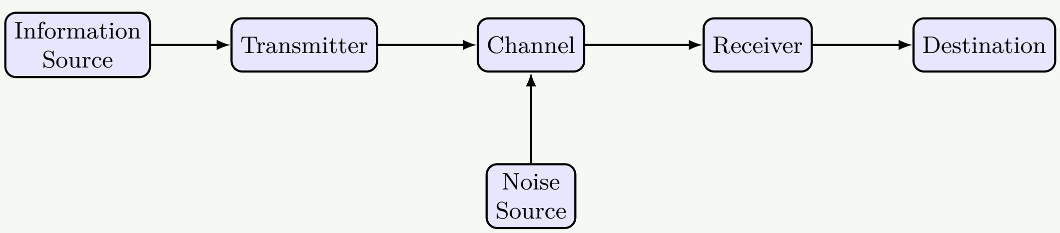

Figure 6. General Communication System

Table 8. 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

Answer:

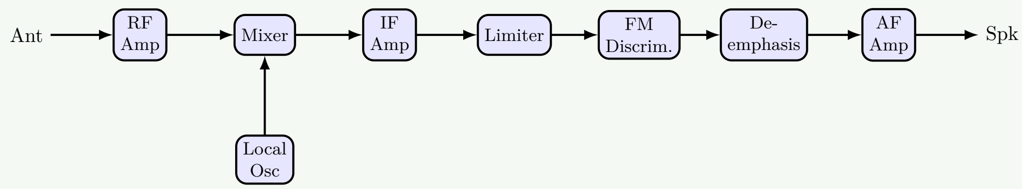

Figure 7. Superheterodyne FM Receiver

Additional Components in FM Receiver:

Table 9. FM Specific Components

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]

What is PAM?

Solution

Answer:
Pulse Amplitude Modulation (PAM): PAM is a modulation technique where the amplitude of regularly spaced rectangular pulses allows variation according to the instantaneous value of the modulating signal.
- **Process**: Analog signal is sampled at regular intervals.
- **Result**: A train of pulses where pulse height $\propto$ signal amplitude.
- **Types**: Natural sampling, Flat-top sampling.

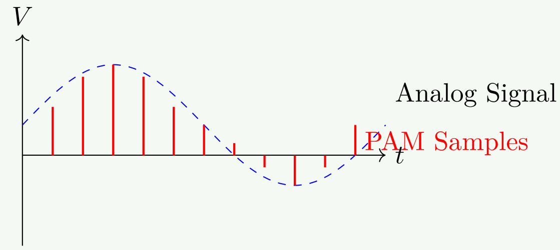

Figure 8. PAM Waveform

Mnemonic

"PAM: Pulse Amplitude Matches signal"

Question 3(b) [4 marks]

State and prove sampling theorem.

Solution

Answer:
Statement: A continuous-time signal $x(t)$ with maximum frequency f_m can be completely reconstructed from its samples if the sampling frequency f_s satisfies:

$$f_s \geq 2f_m$$

Where $2f_m$ is called the Nyquist rate.
Proof (Conceptual): Consider a signal $x(t)$ with spectrum $X(f)$ band-limited to f_m.
1. **Sampling Process**: Sampling is equivalent to multiplying $x(t)$ by a pulse train $\delta(t)$. 2. **Frequency Domain**: Multiplication in time is convolution in frequency.

$$X_s(f) = f_s \sum_{n=-\infty}^{\infty} X(f - nf_s)$$

3. **Spectrum Replication**: The spectrum of sampled signal consists of replicas of $X(f)$ spaced at intervals of f_s.
4. **Recovery Condition**: To recover original spectrum without overlap (aliasing):

$$f_s - f_m \geq f_m \implies f_s \geq 2f_m$$

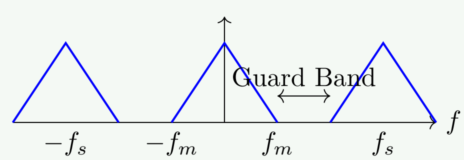

Figure 9. Sampled Signal Spectrum ($f_s > 2f_m$)

Mnemonic

"Nyquist: Sample twice the max frequency to avoid aliasing"

Question 3(c) [7 marks]

Draw and Explain block diagram of digital communication system.

Solution

Answer:

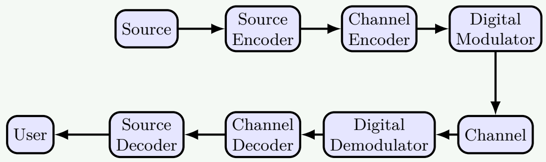

Figure 10. Digital Communication System

Table 10. Functions of Blocks

Block	Function
Source Encoder	Removes redundancy to compress data / converts analog to digital (ADC)
Channel Encoder	Adds redundancy bits for error detection and correction
Digital Modulator	Converts digital bits into analog waveform (ASK, FSK, PSK) suitable for channel
Channel	Transmission medium, adds noise and interference
Digital Demodulator	Estimates Transmitted bits from received noisy waveform
Channel Decoder	Uses redundancy to detect/correct errors
Source Decoder	Reconstructs original information from bits

Mnemonic

"S-C-M-C-D-C-S: Source, Channel, Modulate, Channel, Demodulate, Decode, Sink"

Question 3(a) OR [3 marks]

What is PWM?

Solution

Answer:
Pulse Width Modulation (PWM): PWM (also known as Pulse Duration Modulation - PDM) is a technique where the width (duration) of the pulse is varied proportional to the instantaneous amplitude of the modulating signal.

- **Constant**: Amplitude and position of start/center of pulses.
- **Variable**: Width of pulses.
- **Use**: Motor control, efficient power delivery.

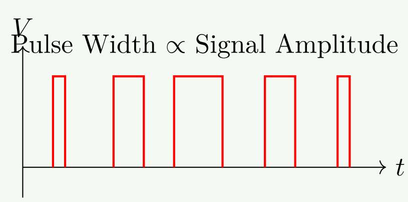

Figure 11. PWM Waveform

Mnemonic

"PWM: Width varies, Amplitude constant"

Question 3(b) OR [4 marks]

What is PPM?

Solution

Answer:
Pulse Position Modulation (PPM): PPM is a modulation technique where the position of a constant-width pulse within a prescribed time slot is varied according to the amplitude of the sampled signal.

- **Constant**: Amplitude and width of pulses.
- **Variable**: Relative position of the pulse.
- **Advantage**: Requires less power than PWM (only short pulses sent).
- **Disadvantage**: Requires complex synchronization between Tx and Rx.

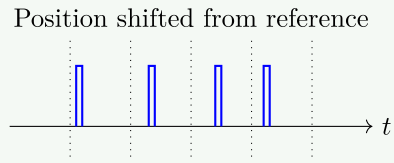

Figure 12. PPM Waveform

Mnemonic

"PPM: Position Shifts, Width Fixed"

Question 3(c) OR [7 marks]

Describe PCM with block diagram.

Solution

Answer:

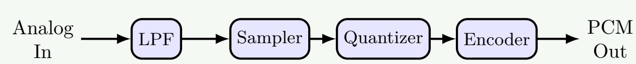

Figure 13. PCM Transmitter

Pulse Code Modulation (PCM): A digital modulation technique that converts analog signals into binary form.
Key Steps:

Table 11. PCM Process

Step	Description
1. Filtering (LPF)	Limits signal frequency to f_m to prevent aliasing
2. Sampling	Discretizes signal in time ($f_s \geq 2f_m$). Output is PAM
3. Quantization	Discretizes signal in amplitude. Rounds values to nearest levels. Introduces quantization noise
4. Encoding	Converts quantized levels into binary code (0s and 1s)

Advantages:

- Noise immunity (digital)
- Possibility of storage
- Efficient multiplexing

Mnemonic

"FSQE: Filter, Sample, Quantize, Encode - The path to Digital"

Question 4(a) [3 marks]

Explain Quantization and Quantization noise.

Solution

Answer:
Quantization: The process of approximating a continuous range of values (infinite possibilities) by a relatively small set of discrete values (finite levels).

- It is a non-reversible process (lossy).
- Input: Sampled Signal (PAM).
- Output: Quantized Signal (Discrete Amplitude).

Quantization Noise (Error): The difference between the actual input value and the quantized output value.

$$\epsilon = x(t) - x_q(t)$$

- Maximum error is $\pm\Delta/2$, where Δ is the step size.
- Random in nature, acts like additive noise.

Mnemonic

"Quantization: Rounding off values; Noise: The rounding error"

Question 4(b) [4 marks]

Explain Amplitude shift keying with waveforms.

Solution

Answer:
Amplitude Shift Keying (ASK): A digital modulation technique where the amplitude of the carrier signal is switched between two levels according to the binary data.

- **Logic 1**: High amplitude carrier (or simply Carrier present).
- **Logic 0**: Low amplitude carrier (or No carrier - OOK).

Expression:

$$s(t) = \begin{cases} A_c \cos(2\pi f_c t) & \text{for Logic 1} \\ 0 & \text{for Logic 0} \end{cases}$$

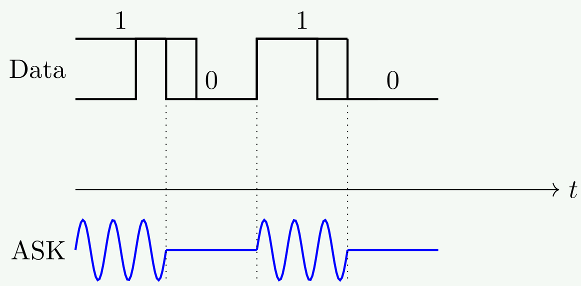

Figure 14. ASK Waveforms

Mnemonic

"ASK: Amplitude Switched Keying - Carrier On/Off"

Question 4(c) [7 marks]

Compare ASK, FSK and PSK techniques.

Solution

Answer:

Table 12. Comparison of Digital Modulation Techniques

Parameter	ASK	FSK	PSK
Definition	Amplitude varies with data	Frequency varies with data	Phase varies with data
Bandwidth	Approx $2 \times R_b$	Large, $> 2 \times R_b$	Approx $2 \times R_b$
Noise Immunity	Low (Affected by amplitude noise)	High (Envelope constant)	High (Envelope constant)
Bit Error Rate	High	Medium	Low (Performance best)
Complexity	Simple	Medium	Complex
Applications	Optical fiber, low speed data	Modems, Radio	WiFi, Satellite, Bluetooth

Mnemonic

"Comparison: FSK/PSK beat ASK in noise; PSK best performance"

Question 4(a) OR [3 marks]

Explain Frequency shift keying with waveforms.

Solution

Answer:

Frequency Shift Keying (FSK): A digital modulation technique where frequency of the carrier is shifted between two values.

- **Logic 1**: High Frequency Carrier (f_1).
- **Logic 0**: Low Frequency Carrier (f_2).
- **Amplitude**: Remains constant.

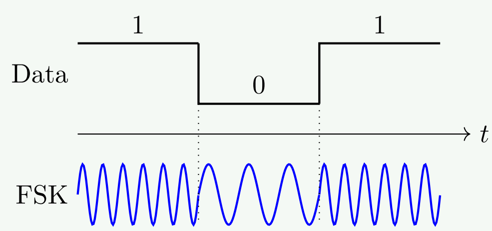

Figure 15. FSK Waveforms

Mnemonic

"FSK: Frequency Switched Keying - High/Low tones"

Question 4(b) OR [4 marks]

Explain Phase shift keying with waveforms.

Solution

Answer:
Phase Shift Keying (PSK): A digital modulation technique where phase of the carrier is shifted (usually by 180 degrees) according to binary data.

- **Logic 1**: Carrier with 0° phase.
- **Logic 0**: Carrier with 180° phase.
- **Amplitude & Frequency**: Constant.

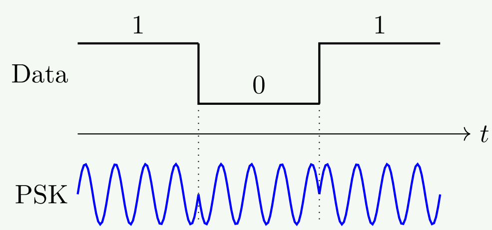

Figure 16. PSK Waveforms

Mnemonic

"PSK: Phase Switched - 0 to 180 flip"

Question 4(c) OR [7 marks]

Explain DPCM with suitable block diagram.

Solution

Answer:
Differential Pulse Code Modulation (DPCM): A technique where, instead of transmitting the absolute sample value, the *difference* between consecutive samples (or predicted and actual sample) is quantized and transmitted.

- **Goal**: Takes advantage of correlation between adjacent samples to reduce bandwidth.
- **Process**: $e[n] = x[n] - \hat{x}[n]$, then $e[n]$ is quantized and encoded.

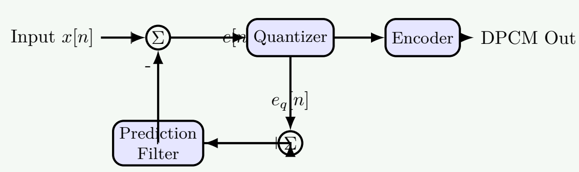

Figure 17. DPCM Transmitter Block Diagram

Advantages:

- Reduced bandwidth requirement compared to PCM.
- Better SNR for same bit rate.

Mnemonic

"DPCM: Difference Encoded - Send only the change"

Question 5(a) [3 marks]

Compare PCM and DM

Solution

Answer:

Table 13. Comparison of PCM and DM

Parameter	PCM	DM (Delta Modulation)
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 $2f_m$	Much higher than $2f_m$

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

Answer:

Table 14. 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

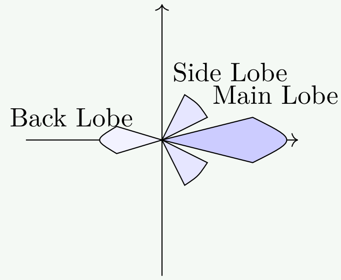

Figure 18. Radiation Pattern

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

Answer:

(A) Smart Antenna

Table 15. 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

Block Diagram:

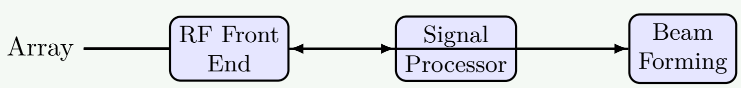

Figure 19. Smart Antenna System

(B) Parabolic Reflector Antenna

Table 16. 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

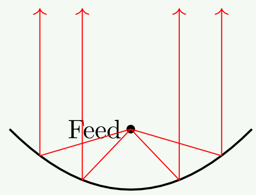

Figure 20. Parabolic Reflector

Mnemonic

"PFHS: Parabolic Focus gives High Signal strength"

Question 5(a) OR [3 marks]

Write a short note on Microstrip antenna

Solution

Answer:

Table 17. Microstrip Antenna Characteristics

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

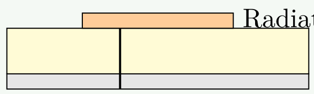

Figure 21. Microstrip Patch Antenna (Side View)

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

Answer:

Table 18. EM Wave Spectrum and Applications

Band	Frequency Range	Wavelength	Applications
ELF	3 Hz - 30 Hz	100 Mm	Submarine comm.
VLF	3 kHz - 30 kHz	10-100 km	Navigation
LF	30-300 kHz	1-10 km	AM radio
MF	300 kHz - 3 MHz	100m - 1 km	AM broadcast
HF	3-30 MHz	10-100 m	Shortwave
VHF	30-300 MHz	1-10 m	FM, TV
UHF	300 MHz - 3 GHz	10cm - 1m	Mobile, WiFi
SHF	3-30 GHz	1-10 cm	Satellite, Radar
EHF	30-300 GHz	1-10 mm	Radio astronomy
Visible	400-800 THz	380-750 nm	Optical comm.

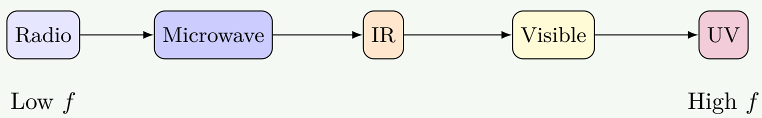

Figure 22. EM Spectrum Increasing Frequency

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

Answer:

(A) Space Wave Propagation

Table 19. Space Wave Propagation Characteristics

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

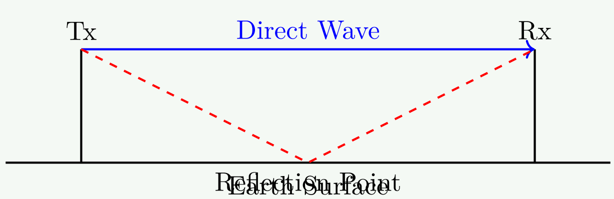

Figure 23. Space Wave Propagation

(B) Ground Wave Propagation

Table 20. 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 induces current in conductive Earth surface
Applications	AM radio broadcasting, maritime communication

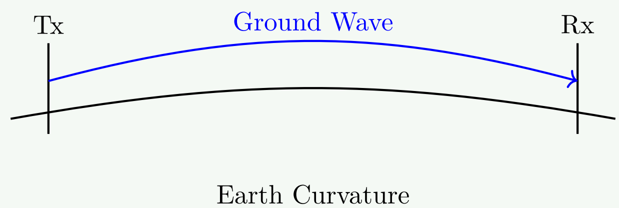

Figure 24. Ground Wave Propagation

Mnemonic

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