Analog & Digital Communication Systems

NAME OF FACULTY : MRS. ANSHU BHALLA **SEMESTER : 3rd**

Diploma in Electronics & Communication Engineering

Units covered: Analog Communication, AM, FM, Digital Communication, Digital Modulation Techniques

Syllabus Coverage revision tracker.

Unit	Syllabus topics covered	Where covered
Unit I	Need for modulation; frequency translation; demodulation; modern communication system	Sections 1.1 to 1.4 + Figures 1-2
Unit II	AM expression derivation; carrier and sidebands; modulation index; AM spectrum/BW; power distribution; DSB-SC, SSB-SC, ISB, VSB; comparison and applications	Sections 2.1 to 2.10 + Figures 3-5
Unit III	FM expression and spectrum; Bessel function idea; modulation index; deviation; deviation ratio; Carson's rule; noise, limiter, pre/de-emphasis, capture effect; AM vs FM	Sections 3.1 to 3.10 + Figures 6-9
Unit IV	Digital/data communication; comparison with analog; sampling theorem and uses; PAM, PPM, PWM; quantization; PCM/DPCM; delta/ADM; companding; FHSS	Sections 4.1 to 4.13 + Figures 10-16
Unit V	ASK with ICW and two-tone; FSK; PSK; QPSK; block diagrams, working principles and comparison	Sections 5.1 to 5.7 + Figures 17-19

UNIT I - Analog Communication

1.1 Meaning of Analog Communication

Analog communication transmits information using continuously varying electrical signals. Examples include voice radio, AM broadcasting and FM broadcasting. The message signal usually has low frequency, so it is placed on a high-frequency carrier before transmission.

1.2 Need for Modulation

Modulation is the process of changing one parameter of a high-frequency carrier wave according to the low-frequency message signal. The changed parameter may be amplitude, frequency or phase.

- **Practical antenna size:** For efficient radiation, antenna length is roughly one-quarter wavelength. A low-frequency audio signal has a very large wavelength, so its antenna becomes impractically long.
- **Long-distance transmission:** High-frequency carrier waves travel farther and radiate better than low-frequency message signals.
- **Avoids mixing:** Different transmitters can use different carrier frequencies, so their signals do not overlap.
- **Multiplexing:** Many signals can share the same medium by using different carrier frequencies.
- **Better quality:** Some modulation methods, especially FM and digital modulation, reduce noise effects.

Antenna-size formula

$\lambda = c/f$

Antenna length $L \approx \lambda/4$

Example: at 1 kHz, $\lambda = 300$ km, so $L \approx 75$ km (not practical).

1.3 Frequency Translation and Demodulation

Frequency translation means shifting the message signal from its original low-frequency range to a higher frequency range around a carrier. In AM, a message frequency f_m produces sidebands at $f_c - f_m$ and $f_c + f_m$.

Demodulation is the reverse process of modulation. The receiver removes the carrier effect and recovers the original message signal. For example, an AM radio receiver uses an envelope detector, while an FM receiver uses an FM detector or PLL.

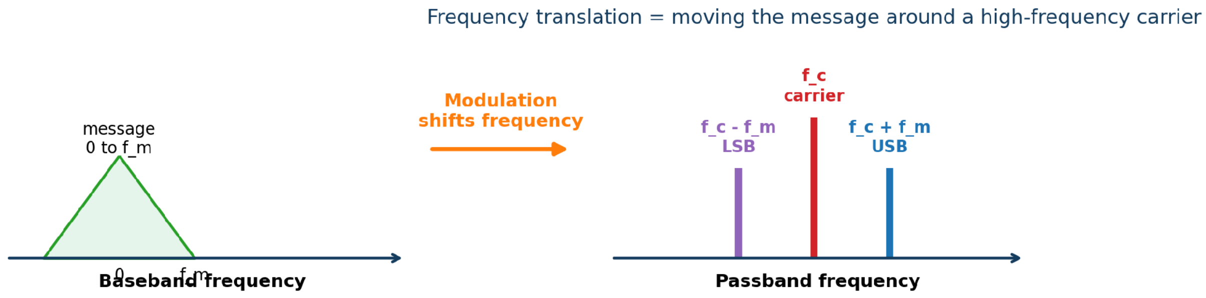

Figure 1: Frequency translation shifts the message to sidebands around the carrier.

1.4 Basic Scheme of a Modern Communication System

A communication system has a source, transmitter, channel, receiver and destination. The transmitter prepares the signal for the channel. The receiver extracts the original information from the received signal.

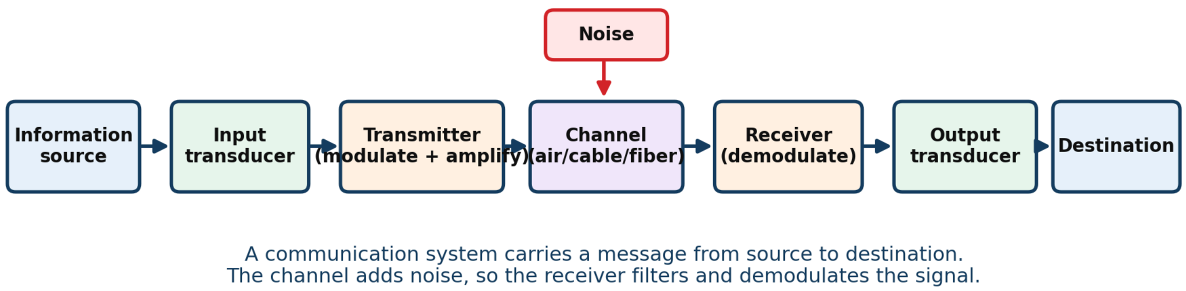

Figure 2: Basic block diagram of a modern communication system.

Block	Function	Example
Information source	Produces the message	Voice, video, sensor data
Input transducer	Converts physical information into an electrical signal	Microphone
Transmitter	Modulates, amplifies and filters the signal	Radio transmitter
Channel	Medium through which signal travels	Air, cable, optical fiber
Noise	Unwanted disturbance added to signal	Thermal or atmospheric noise
Receiver	Amplifies, filters and demodulates received signal	Radio receiver
Output transducer	Converts electrical signal into useful output	Speaker

UNIT II - Amplitude Modulation

2.1 Meaning of Amplitude Modulation

In amplitude modulation (AM), the amplitude of the carrier varies according to the message signal. The carrier frequency and carrier phase remain constant. The envelope of the AM wave follows the shape of the message signal.

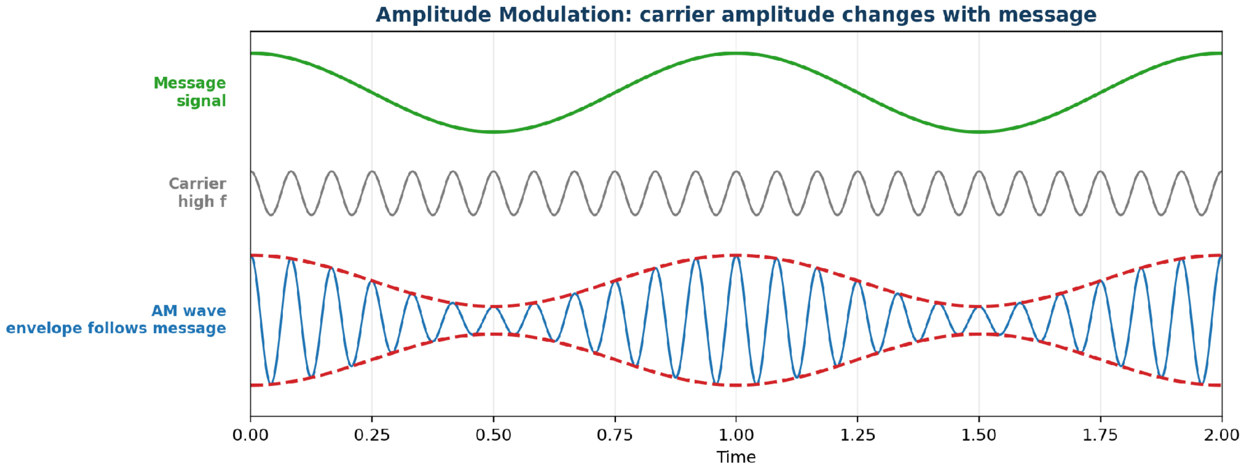

Figure 3: AM waveform. The red envelope follows the message signal.

2.2 Derivation of AM Wave Expression

Let the carrier signal be $c(t) = A_c \cos(\omega_c t)$, and the message signal be $m(t) = A_m \cos(\omega_m t)$. In AM, the carrier amplitude becomes $A_c[1 + \mu \cos(\omega_m t)]$.

AM expression

AM wave: $s(t) = A_c[1 + \mu \cos(\omega_m t)] \cos(\omega_c t)$

Using $\cos A \cos B = 1/2[\cos(A+B) + \cos(A-B)]$

$$s(t) = A_c \cos(\omega_c t) + (\mu A_c/2)\cos(\omega_c+\omega_m)t + (\mu A_c/2)\cos(\omega_c-\omega_m)t$$

This equation shows that an AM wave contains one carrier component and two sideband components.

2.3 Carrier and Sideband Components

Component	Frequency	Information carried?
Carrier	f_c	No useful message information; helps simple detection
Upper sideband (USB)	$f_c + f_m$	Yes
Lower sideband (LSB)	$f_c - f_m$	Yes

Both sidebands carry the same information. Therefore, standard AM wastes power in the carrier and duplicates information in two sidebands.

2.4 Modulation Index

The modulation index tells how strongly the carrier is varied by the message signal. It is denoted by μ.

AM modulation index

$\mu = A_m/A_c$

From waveform: $\mu = (V_{max} - V_{min})/(V_{max} + V_{min})$

For distortion-free AM: $\mu \leq 1$

Condition	Name	Result
$\mu < 1$	Under modulation	Less sideband power, but no distortion
$\mu = 1$	100% modulation	Best practical AM condition
$\mu > 1$	Over modulation	Envelope distortion occurs

2.5 Spectrum and Bandwidth of AM Wave

The AM spectrum has three main lines for single-tone modulation: lower sideband, carrier and upper sideband.

AM bandwidth

Highest frequency = $f_c + f_m$
Lowest frequency = $f_c - f_m$
Bandwidth BW = $(f_c + f_m) - (f_c - f_m) = 2f_m$

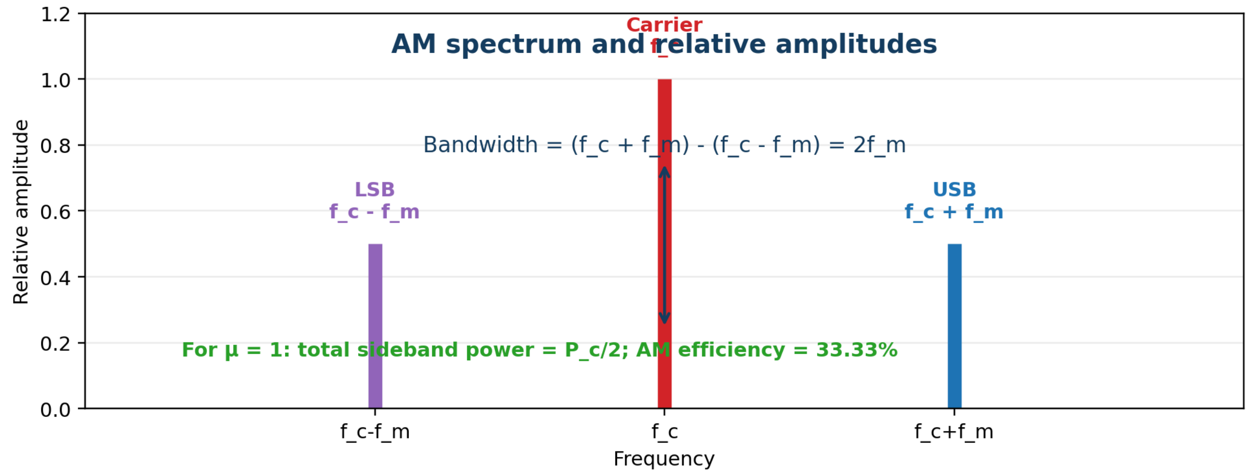

Figure 4: AM spectrum and bandwidth relation.

2.6 Relative Power Distribution in AM

Only the sidebands contain useful information. The carrier consumes most of the transmitted power but does not carry the message directly.

AM power formulas

Carrier power: $P_c = A_c^2/(2R)$
Power in each sideband: $P_{USB} = P_{LSB} = \mu^2 P_c/4$
Total sideband power: $P_{SB} = \mu^2 P_c/2$
Total AM power: $P_t = P_c(1 + \mu^2/2)$
Efficiency: $\eta = \mu^2/(2 + \mu^2)$. At $\mu = 1$, $\eta = 33.33\%$.

2.7 DSB-SC Modulation

DSB-SC means Double Sideband Suppressed Carrier. In this method, both sidebands are transmitted, but the carrier is suppressed. The bandwidth is still $2f_m$, but power efficiency is better than standard AM because carrier power is not transmitted.

- Advantages: saves carrier power; better efficiency than AM.
- Disadvantages: receiver is more complex; coherent detection is needed.
- Applications: telemetry, multiplexing systems and balanced modulator circuits.

2.8 SSB-SC Modulation

SSB-SC means Single Sideband Suppressed Carrier. Only one sideband, either USB or LSB, is transmitted and the carrier is suppressed. Its bandwidth is f_m, so it saves both power and bandwidth.

- Advantages: highest bandwidth saving; good for long-distance communication.
- Disadvantages: generation and detection are difficult; accurate carrier synchronization is required.
- Applications: HF radio, aircraft, marine and point-to-point voice communication.

2.9 ISB and VSB Modulation

ISB means Independent Sideband modulation. The upper and lower sidebands carry different information signals. This improves channel use but needs more complex filters and receivers.

VSB means Vestigial Sideband modulation. One complete sideband and a small part of the other sideband are transmitted. It is useful when pure SSB filtering is difficult, especially for television video transmission.

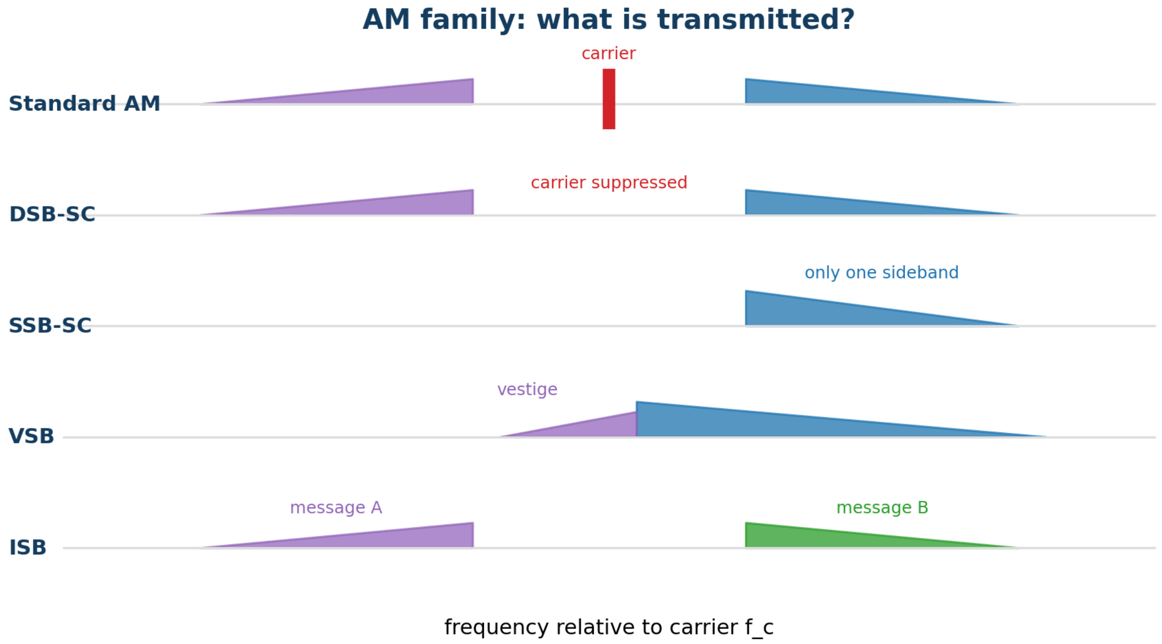

Figure 5: Comparison of AM, DSB-SC, SSB-SC, VSB and ISB spectra.

2.10 Comparison of AM Family

Type	Carrier	Sidebands sent	Bandwidth	Main use
AM	Sent	USB + LSB	2f_m	Broadcast radio
DSB-SC	Suppressed	USB + LSB	2f_m	Telemetry and multiplexing
SSB-SC	Suppressed	Only USB or LSB	f_m	Long-distance HF voice
ISB	Usually suppressed	USB and LSB carry different signals	Depends on channels	Multi-channel links
VSB	May be sent partly	One sideband + vestige	Between f_m and 2f_m	TV video

UNIT III - Frequency Modulation

3.1 Meaning of Frequency Modulation

In frequency modulation (FM), the instantaneous frequency of the carrier varies according to the message signal. The carrier amplitude remains constant. Because amplitude is constant, FM can reject amplitude noise using a limiter.

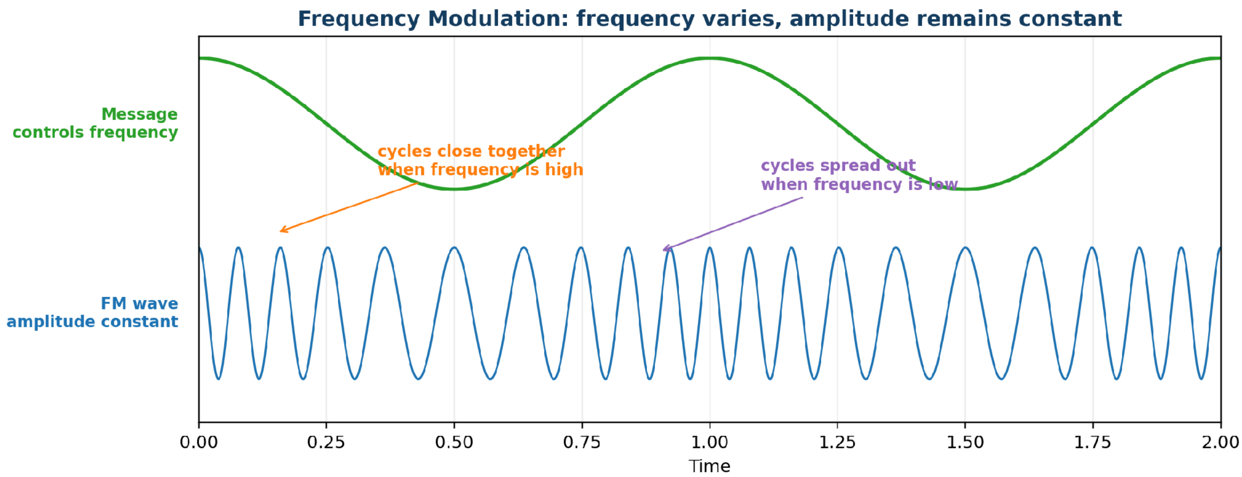

Figure 6: FM waveform. The cycles become closer or farther apart as frequency changes.

3.2 Expression for FM Wave

For a sinusoidal message signal, the FM wave can be written as follows.

FM wave expression

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

$\beta = \Delta f/f_m$

A_c remains constant; frequency changes around f_c.

3.3 Frequency Spectrum of FM and Bessel Function Idea

FM produces a carrier component and many sidebands at $f_c \pm f_m$, $f_c \pm 2f_m$, $f_c \pm 3f_m$ and so on. Theoretically, FM has infinite sidebands. Practically, only significant sidebands are transmitted.

The amplitude of each FM sideband is decided by Bessel functions $J_n(\beta)$. For diploma-level study, remember the idea: when β increases, the number of significant sidebands also increases.

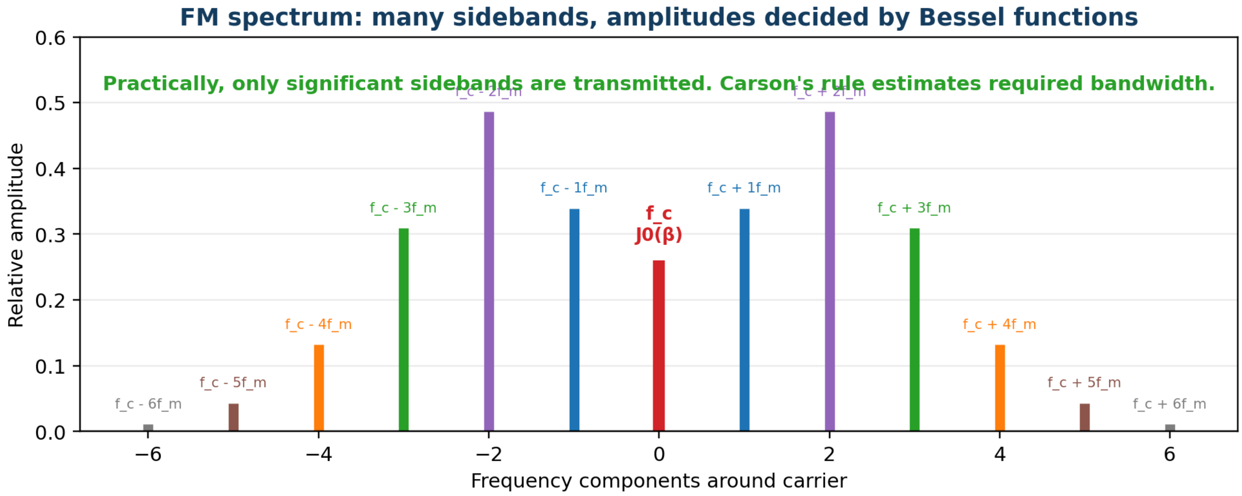

Figure 7: FM spectrum with multiple sidebands. Bessel coefficients decide their heights.

3.4 Modulation Index, Maximum Frequency Deviation and Deviation Ratio

FM important terms

FM modulation index: $\beta = \Delta f/f_m$

Maximum frequency deviation: Δf = maximum change of carrier frequency from f_c

Deviation ratio = $\Delta f_{max}/f_m(max)$

Example: If $f_c = 100$ MHz and the highest carrier frequency becomes 100.075 MHz, then $\Delta f = 75$ kHz.

3.5 Bandwidth of FM and Carson's Rule

Because FM has many sidebands, exact bandwidth calculation is difficult. Carson's rule gives a practical bandwidth estimate.

Carson's rule

$BW = 2(\Delta f + f_m)$

Using $\beta = \Delta f/f_m$: $BW = 2f_m(\beta + 1)$

Example: If $\Delta f = 75$ kHz and $f_m(max) = 15$ kHz, then $BW = 2(75 + 15) = 180$ kHz.

3.6 Effect of Noise on FM Carrier

Noise often produces unwanted amplitude variations. In FM, information is carried by frequency variation, so amplitude variations can be removed by a limiter. This is why FM has better noise immunity than AM.

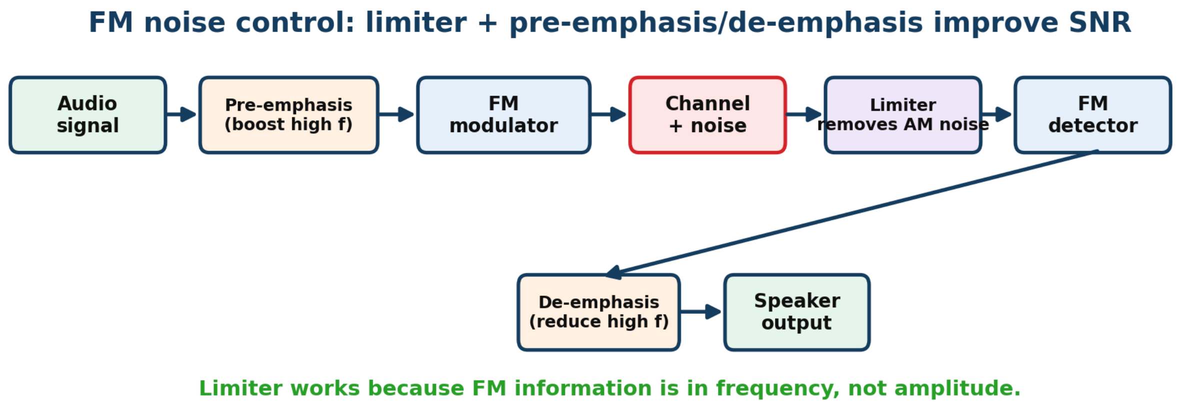

Figure 8: FM transmitter/receiver noise-control blocks.

3.7 Noise Triangle

At the output of an FM detector, noise voltage increases with modulating frequency. When noise level is plotted against frequency, it forms a triangular shape called the noise triangle. High-frequency audio components are affected more by noise.

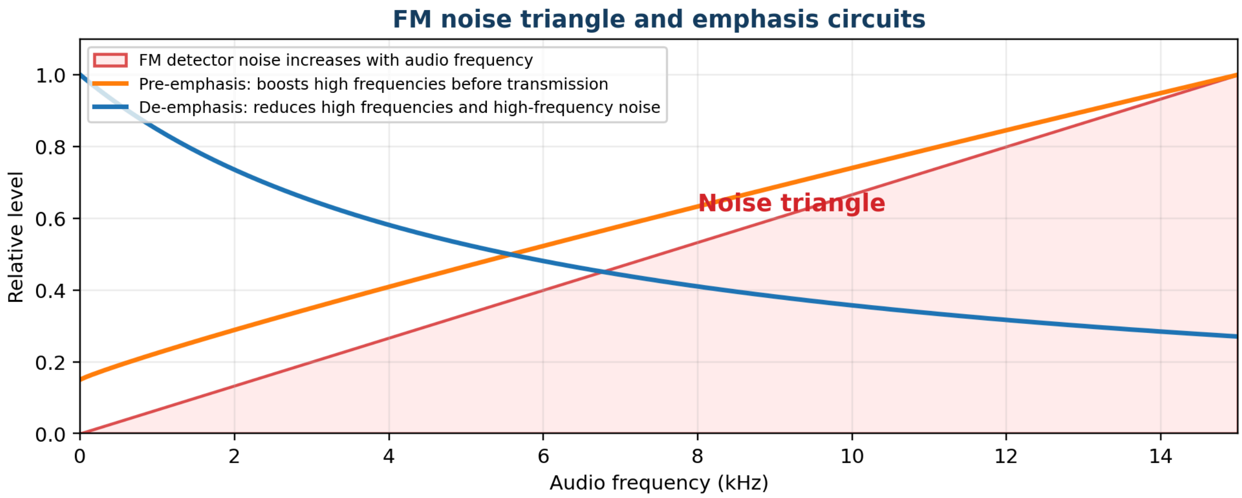

Figure 9: Noise triangle and the role of pre-emphasis/de-emphasis.

3.8 Role of Limiter

A limiter is placed before the FM detector. It removes amplitude variations and keeps the FM signal amplitude constant. Since FM information is in frequency changes, removing amplitude changes does not remove the message.

3.9 Need for Pre-emphasis, De-emphasis and Capture Effect

Pre-emphasis is used at the transmitter to boost high-frequency audio components before modulation. De-emphasis is used at the receiver to reduce those high-frequency components back to normal level. This also reduces high-frequency noise.

Capture effect means that if two FM signals of the same carrier frequency reach the receiver, the receiver tends to capture the stronger signal and reject the weaker signal. It reduces interference but can suppress a weaker station.

3.10 Comparison of AM and FM

Point	AM	FM

Quantity varied	Carrier amplitude	Carrier frequency
Amplitude	Varies	Constant
Noise immunity	Poor	Good
Bandwidth	Less	More
Power efficiency	Low	Better
Receiver	Simple	More complex
Limiter	Not useful	Used to remove amplitude noise
Applications	AM broadcasting	FM radio, TV sound, wireless systems

UNIT IV - Digital Communication

4.1 Basic Block Diagram of Digital Communication System

Digital communication sends information in the form of binary bits, 0 and 1. An analog message is first converted into digital form, protected from errors, modulated and then transmitted through the channel.

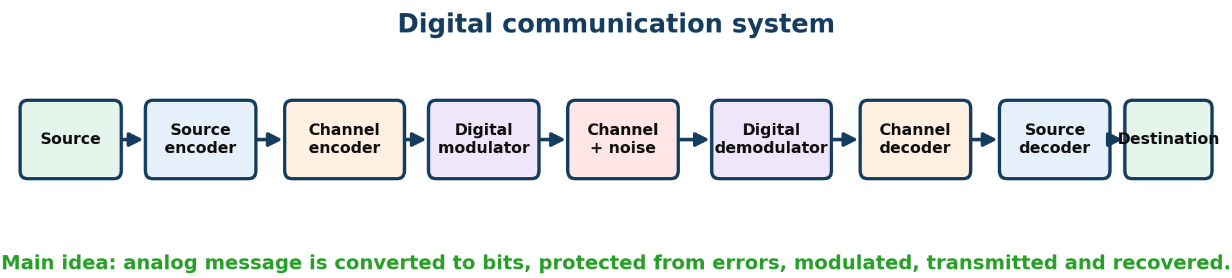

Figure 10: Basic digital communication system.

4.2 Data Communication System

Data communication means exchange of data between two devices. The five basic elements are message, sender, receiver, transmission medium and protocol.

Element	Meaning	Example
Message	Information to be sent	Text, file, image
Sender	Device that sends data	Computer or mobile
Receiver	Device that receives data	Server or printer
Medium	Path for transmission	Cable, fiber, wireless
Protocol	Rules of communication	TCP/IP, Wi-Fi, Bluetooth

4.3 Comparison of Digital and Analog Communication

Point	Analog communication	Digital communication
Signal	Continuous	Discrete bits
Noise effect	More affected	Less affected
Repeaters	Amplify signal and noise	Regenerate clean bits
Error control	Difficult	Easy using coding
Storage	Difficult	Easy
Security	Lower	Higher with encryption
Bandwidth	Usually less	Usually more

4.4 Sampling Theorem and Basic Concept

Sampling converts a continuous-time analog signal into a sequence of values taken at regular time intervals. The sampling theorem tells the minimum sampling frequency needed for perfect reconstruction.

Sampling theorem

If highest message frequency is f_m, then $f_s \geq 2f_m$

Nyquist rate = 2f_m
Nyquist interval = 1/(2f_m)

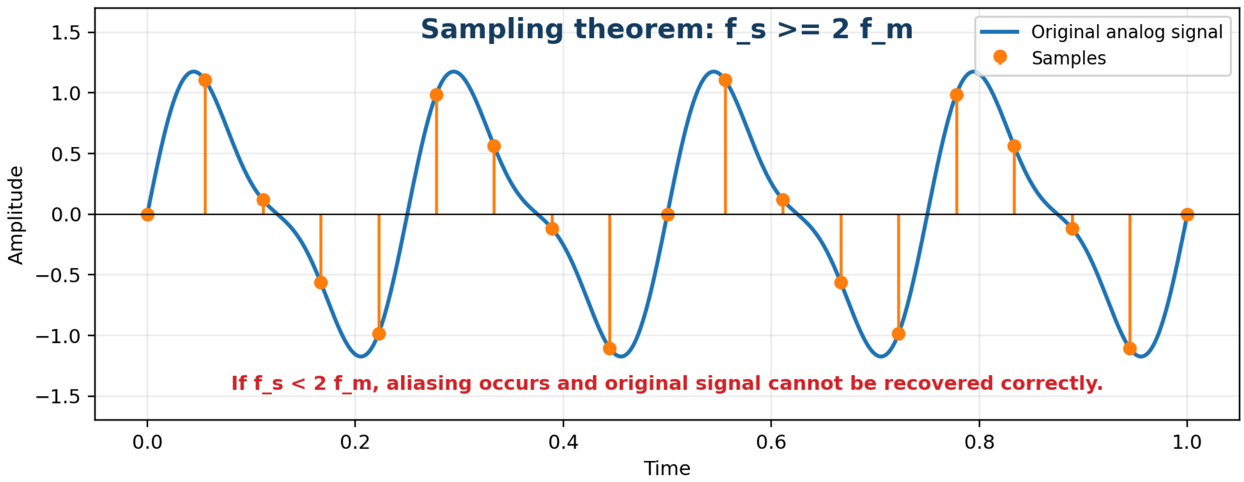

Figure 11: Sampling theorem and sample points.

If f_s is less than 2f_m, aliasing occurs. In aliasing, high-frequency components appear as wrong low-frequency components, so the original signal cannot be recovered correctly.

4.5 Uses of Sampling Theorem

- Analog-to-digital conversion
- PCM systems
- Digital telephone systems
- Digital audio recording
- Data acquisition
- Digital signal processing

4.6 PAM, PWM and PPM

Pulse modulation represents the message signal using a train of pulses. In PAM, pulse amplitude changes. In PWM, pulse width changes. In PPM, pulse position changes.

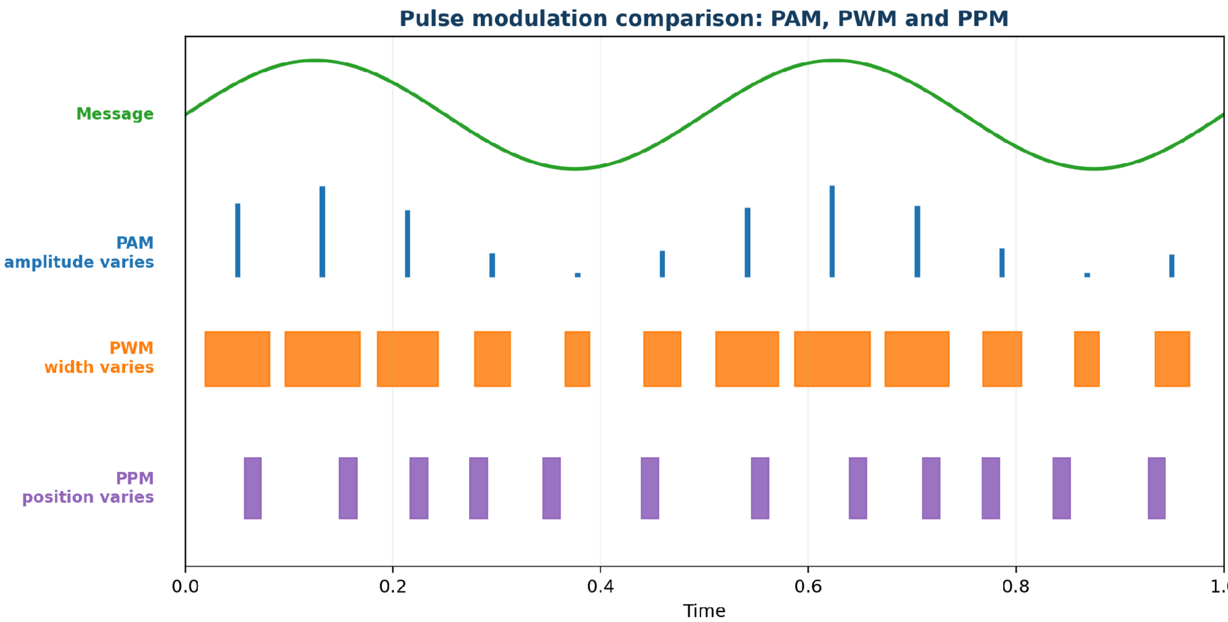

Figure 12: PAM, PWM and PPM compared using the same message signal.

Method	Quantity varied	Constant quantities	Noise performance

PAM	Pulse amplitude	Width and position	Poor, because amplitude noise affects information
PWM	Pulse width	Amplitude and position	Better than PAM
PPM	Pulse position	Amplitude and width	Best among the three, but needs synchronization

4.7 Quantization and Quantization Error

Quantization converts sampled amplitude values into a fixed number of allowed levels. The difference between the actual sample value and the selected quantization level is called quantization error.

Quantization formulas

Number of levels: $L = 2^n$

Step size: $\Delta = (V_{max} - V_{min})/L$

Maximum quantization error = $\pm\Delta/2$

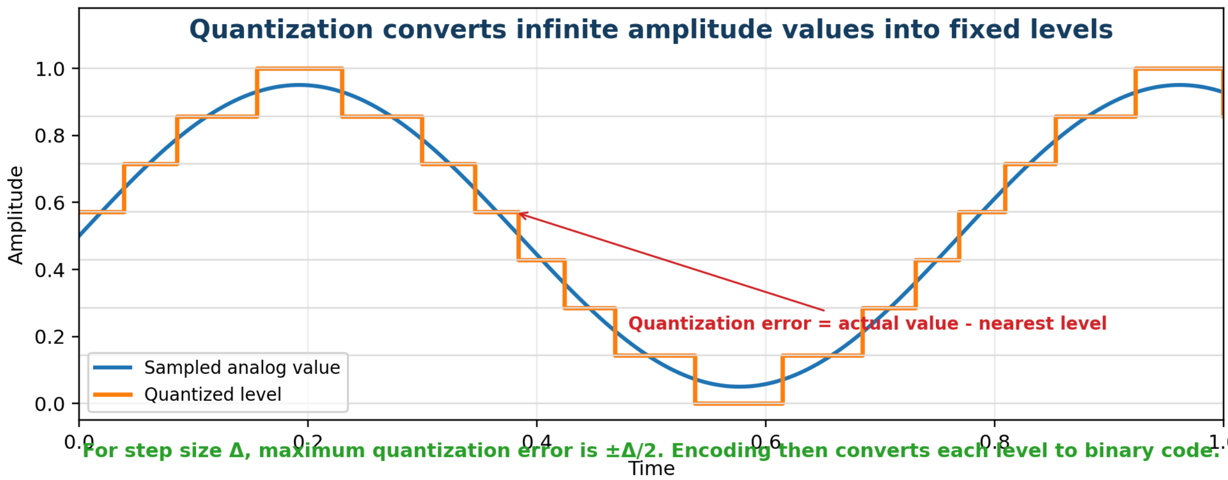

Figure 13: Quantization staircase and quantization error.

4.8 PCM - Pulse Code Modulation

PCM converts an analog signal into binary code. The three main steps are sampling, quantization and encoding.

PCM bit-rate formula

PCM bit rate: $R_b = n f_s$

n = bits per sample

f_s = sampling frequency

PCM step	Meaning
Sampling	Take samples of the analog signal
Quantization	Round each sample to nearest level
Encoding	Convert each level to binary code

- **Advantages:** good noise immunity, easy storage, error control possible, suitable for TDM.
- **Disadvantages:** requires more bandwidth, has quantization noise, system is more complex.

4.9 DPCM - Differential Pulse Code Modulation

In PCM, the actual sample value is transmitted. In DPCM, only the difference between the actual sample and the predicted sample is transmitted. Since this difference is usually smaller, fewer bits are needed.

DPCM idea

$d(n) = x(n) - \hat{x}(n)$

DPCM sends d(n), not the full sample x(n).

- **Advantages:** less bandwidth than PCM; reduces redundancy.
- **Disadvantages:** requires predictor; prediction error can reduce quality.

4.10 Delta Modulation and Adaptive Delta Modulation

Delta modulation is a simple one-bit form of DPCM. It sends whether the signal should step up or step down. Binary 1 may mean step up, and binary 0 may mean step down.

Two errors may occur in simple delta modulation: slope overload distortion when the input changes too fast, and granular noise when the input changes too slowly. Adaptive delta modulation solves this by changing the step size according to signal slope.

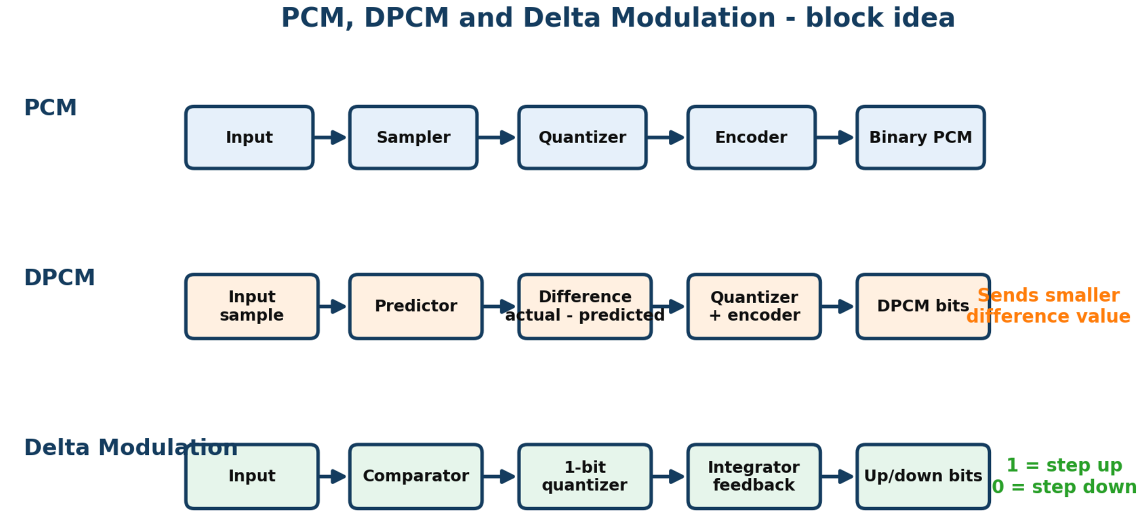

Figure 14: Block ideas of PCM, DPCM and Delta Modulation.

4.11 Companding

Companding means compression plus expansion. At the transmitter, a compressor reduces the dynamic range of the signal. At the receiver, an expander restores the original range. Companding improves the signal-to-quantization-noise ratio for weak signals.

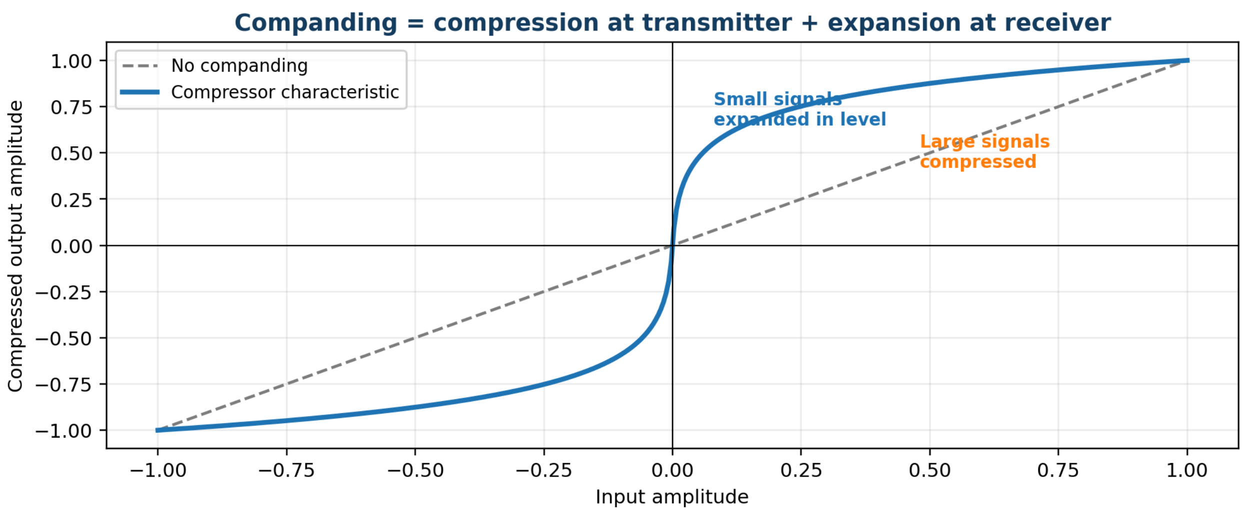

Figure 15: Companding characteristic. Small signals get better resolution.

4.12 Frequency Hopping Spread Spectrum Technique

Frequency Hopping Spread Spectrum (FHSS) changes the carrier frequency rapidly according to a pseudo-random code. The transmitter and receiver must use the same hopping sequence and timing.

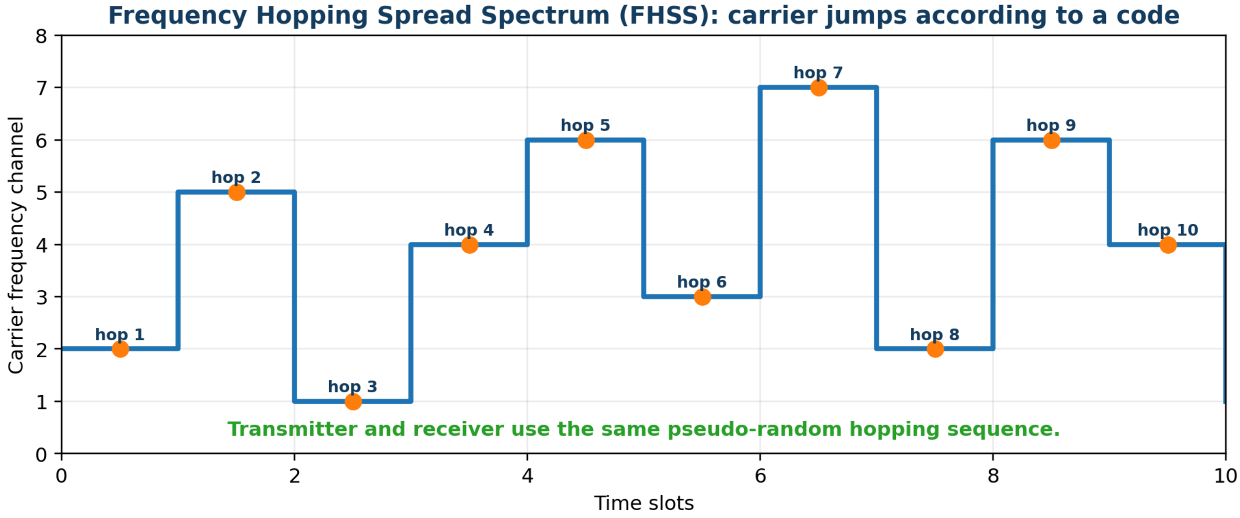

Figure 16: FHSS carrier jumps from one frequency channel to another.

- **Advantages:** resists jamming, reduces interference, improves security.
- **Disadvantages:** needs synchronization, complex frequency synthesizer, uses a wider band.
- **Applications:** military links, secure wireless systems and Bluetooth-type communication principles.

UNIT V - Digital Modulation Techniques

5.1 Basic Idea and Block Diagram

Digital modulation changes a carrier wave according to binary data. The carrier parameter may be amplitude, frequency or phase. ASK changes amplitude, FSK changes frequency, and PSK/QPSK change phase.

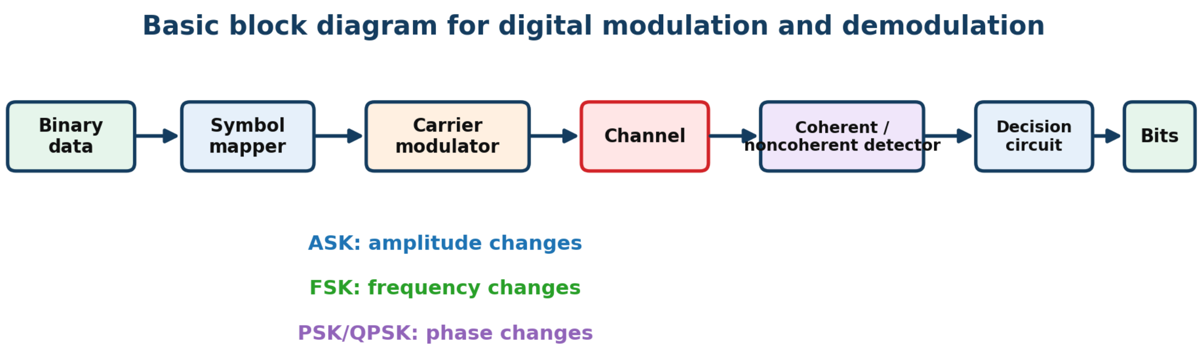

Figure 17: Basic block diagram for digital modulation and demodulation.

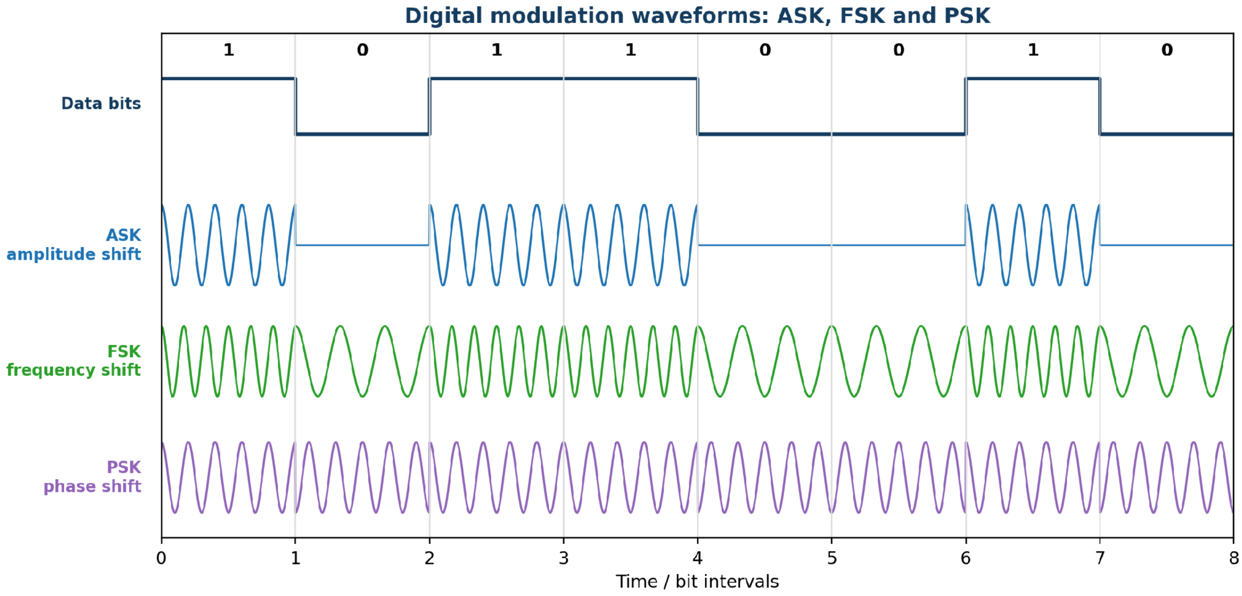

Figure 18: ASK, FSK and PSK waveforms for the same data bits.

5.2 ASK - Amplitude Shift Keying

In ASK, the amplitude of the carrier changes according to binary data. The simplest form is on-off keying. Carrier present means binary 1, and carrier absent means binary 0.

ASK / OOK signal

For bit 1: $s_1(t) = A_c \cos(2\pi f_c t)$

For bit 0: $s_0(t) = 0$

ICW, or Interrupted Continuous Wave, is a simple ASK method in which a continuous carrier is switched ON and OFF according to data.

- **Advantages:** simple circuit, low cost, easy detection.
- **Disadvantages:** poor noise immunity because amplitude noise causes errors.
- **Applications:** simple RF links, optical communication and low-cost remote controls.

5.3 Two-Tone Modulation

In two-tone modulation, two different tones are used for binary data. One tone represents binary 1 and another tone represents binary 0. This idea is closely related to audio FSK, where two audio frequencies carry data.

Bit	Tone/frequency	Meaning
1	High tone or mark frequency	Carrier/tone for binary 1
0	Low tone or space frequency	Carrier/tone for binary 0

5.4 FSK - Frequency Shift Keying

In FSK, the frequency of the carrier changes according to binary data. Amplitude remains constant, so FSK is less affected by amplitude noise than ASK.

FSK signal

For bit 1: $s_1(t) = A_c \cos(2\pi f_1 t)$

For bit 0: $s_0(t) = A_c \cos(2\pi f_2 t)$

f_1 **= mark frequency,** f_2 **= space frequency**

- **Transmitter idea:** binary data selects one of two frequencies or controls a VCO.
- **Receiver idea:** two band-pass filters or a PLL detect which frequency is present.
- **Applications:** modems, telemetry, caller-ID and low-speed wireless data.

5.5 PSK - Phase Shift Keying

In PSK, the phase of the carrier changes according to binary data. In binary PSK, bit 1 may be represented by 0° phase and bit 0 by 180° phase. Amplitude and frequency remain constant.

BPSK signal

For bit 1: $s_1(t) = A_c \cos(2\pi f_c t)$

For bit 0: $s_0(t) = -A_c \cos(2\pi f_c t)$

The minus sign means 180° phase reversal.

- **Advantages:** better noise immunity and bandwidth efficiency than ASK and FSK.
- **Disadvantages:** requires carrier synchronization and a more complex receiver.
- **Applications:** satellite links, modems and digital wireless communication.

5.6 QPSK - Quadrature Phase Shift Keying

QPSK uses four phase states and transmits two bits per symbol. Because two bits are sent at a time, QPSK uses bandwidth more efficiently than BPSK for the same bit rate.

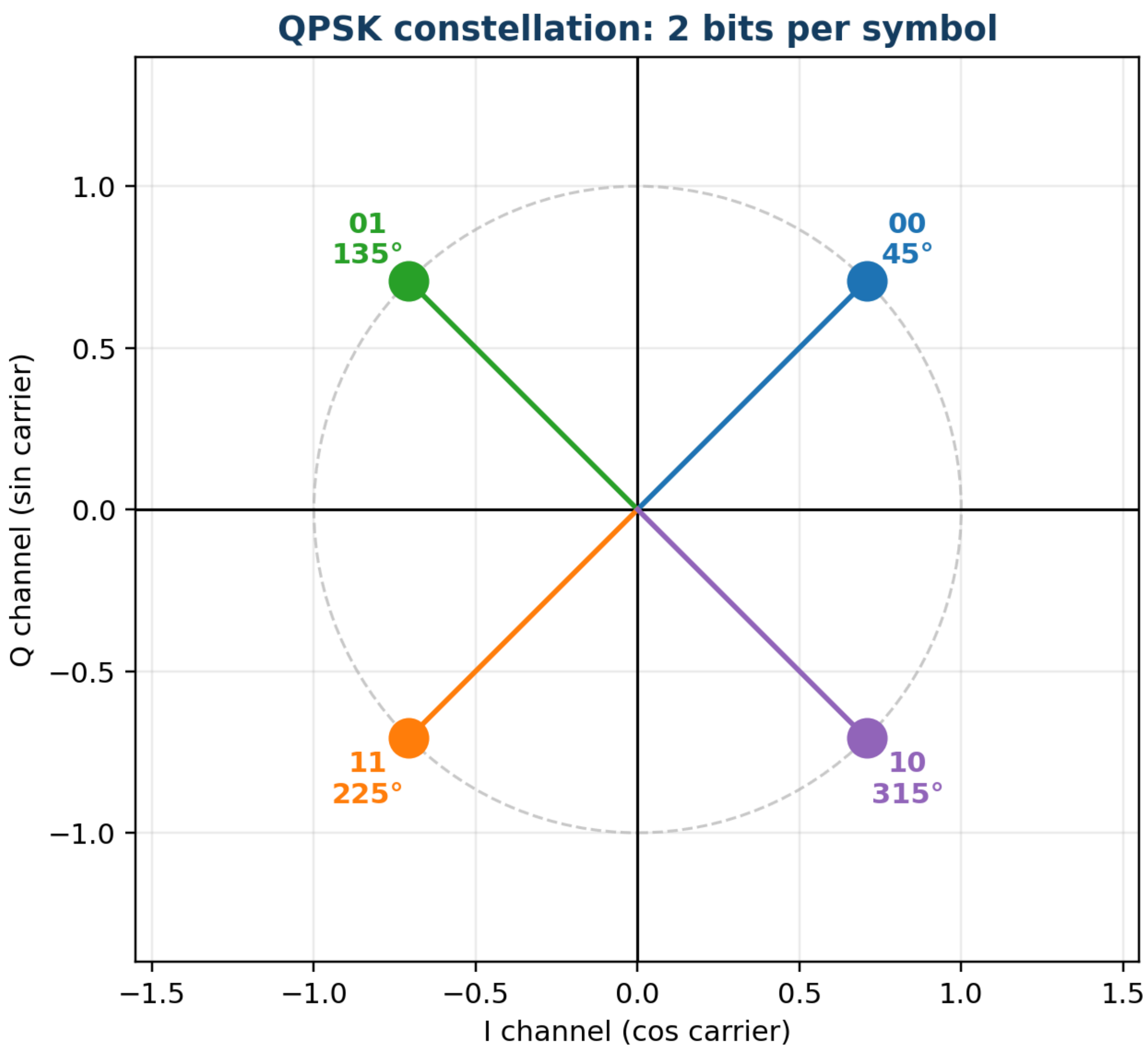

Figure 19: QPSK constellation showing four phase states and two bits per symbol.

Bit pair	Example phase
00	45°
01	135°
11	225°
10	315°

In a QPSK transmitter, serial data is divided into two streams: I-channel and Q-channel. The I-channel modulates a cosine carrier and the Q-channel modulates a sine carrier. The two outputs are added to form the QPSK signal.

5.7 Comparison of ASK, FSK, PSK and QPSK

Point	ASK	FSK	PSK	QPSK
Parameter changed	Amplitude	Frequency	Phase	Phase
Amplitude	Changes	Constant	Constant	Constant
Noise immunity	Poor	Medium	Good	Good
Bandwidth efficiency	Low	Low/medium	Good	Very good
Bits per symbol	1	1	1	2
Complexity	Simple	Medium	Complex	More complex
Typical use	Simple RF/optical links	Telemetry/modems	Digital radio	High-speed digital links

Quick Formula Sheet

Topic	Formula	Use
Wavelength	$\lambda = c/f$	Antenna and wave calculations
Antenna length	$L \approx \lambda/4$	Approximate quarter-wave antenna
AM modulation index	$\mu = A_m/A_c = (V_{max} - V_{min})/(V_{max} + V_{min})$	Depth of AM modulation
AM bandwidth	$BW = 2f_m$	Bandwidth for single-tone/message max frequency
AM total power	$P_t = P_c(1 + \mu^2/2)$	AM power calculation
AM efficiency	$\eta = \mu^2/(2 + \mu^2)$	Useful sideband power ratio
FM modulation index	$\beta = \Delta f/f_m$	Frequency deviation relative to message frequency
FM Carson rule	$BW = 2(\Delta f + f_m)$	Practical FM bandwidth
Sampling theorem	$f_s \geq 2f_m$	Minimum sampling frequency
Quantization levels	$L = 2^n$	Number of levels for n bits
Quantization step	$\Delta = (V_{max} - V_{min})/L$	Level spacing
PCM bit rate	$R_b = n f_s$	Bits per second in PCM

Very Short Exam Definitions

Term	Easy definition
Modulation	Changing amplitude, frequency or phase of a carrier according to the message signal.
Demodulation	Recovering the original message from the modulated signal.
Sideband	Frequency component produced above or below carrier after modulation.
AM	Carrier amplitude changes according to message signal.
FM	Carrier frequency changes according to message signal.
Sampling	Taking values of a continuous signal at regular intervals.
Quantization	Rounding sampled values to fixed amplitude levels.
PCM	Converting analog signal into binary code using sampling, quantization and encoding.
DPCM	Sending difference between actual and predicted samples.
Delta modulation	One-bit method that sends step-up or step-down information.
Companding	Compression at transmitter and expansion at receiver.
FHSS	Spread spectrum method where carrier frequency hops according to a code.
ASK	Digital modulation in which carrier amplitude changes.
FSK	Digital modulation in which carrier frequency changes.
PSK	Digital modulation in which carrier phase changes.
QPSK	Phase modulation method sending two bits per symbol using four phase states.

Suggested Diagram Practice List

- Modern communication system block diagram with noise source.
- Frequency translation showing f_c - f_m, f_c and f_c + f_m.
- AM waveform and AM spectrum.
- Comparison spectrum of AM, DSB-SC, SSB-SC, VSB and ISB.
- FM waveform, FM spectrum and noise triangle.
- Digital communication system block diagram.
- Sampling theorem diagram and quantization staircase.
- PAM, PWM and PPM waveforms.
- PCM, DPCM and delta modulation block diagrams.
- FHSS frequency hopping diagram.
- ASK, FSK, PSK waveforms and QPSK constellation.