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LEARNING OBJECTIVES

By the end of this lecture, students will be able to:

1. **Classify communication systems** based on their direction of data transmission: simplex, half-duplex, and full-duplex.



2. **Describe the advantages and disadvantages** of each communication mode.
3. **Explain line coding techniques** (Unipolar, Polar, Bi-polar) and their practical applications.
4. **Understand and interpret constellation diagrams** to represent modulated signals in the I-Q plane.
5. **Explain Amplitude Shift Keying (ASK)**, including on-off keying (OOK), and calculate the energy and bandwidth of ASK signals.
6. **Differentiate between asynchronous and synchronous demodulation methods** for ASK.
7. **Compute bandwidth requirements** for digital signals and understand the impact of roll-off factors and transmission modes (half/full-duplex).

1 INTRODUCTION

Communication systems are designed to **transfer information** from one point to another. Depending on the **direction of information flow**, communication systems can be classified as:

1. **Simplex (SX)** – One-way communication (e.g., radio, TV channels, satellite receivers).
2. **Half-duplex (HDX)** – Two-way communication, but only one direction at a time (e.g., walkie-talkies).
3. **Full-duplex (FDX)** – Two-way simultaneous communication (e.g., mobile phones, computer networks).



Digital communication involves **converting binary data (0s and 1s) into digital signals** for transmission over a channel. This is achieved using **line coding techniques** such as **unipolar, polar, and bi-polar schemes**, which help minimize errors and interference.

Modulation techniques like **Amplitude Shift Keying (ASK)**, along with their **demodulation methods** and **bandwidth requirements**, are fundamental for transmitting digital data over analog channels. Tools like **constellation diagrams** are used to visualize the amplitude and phase of signals and to diagnose transmission impairments.

2 TRANSMISSION TYPES OF COMMUNICATION SYSTEM

There are three types of Communication systems according to the direction of transmission:

2.1 SIMPLEX (SX) COMMUNICATION SYSTEM:

The simplex (SX) communication system is capable of transmit information in one-way, for example of this system (Radio channel, TV channel, satellite receiver). Figure 1 below shows the block diagram of this system.

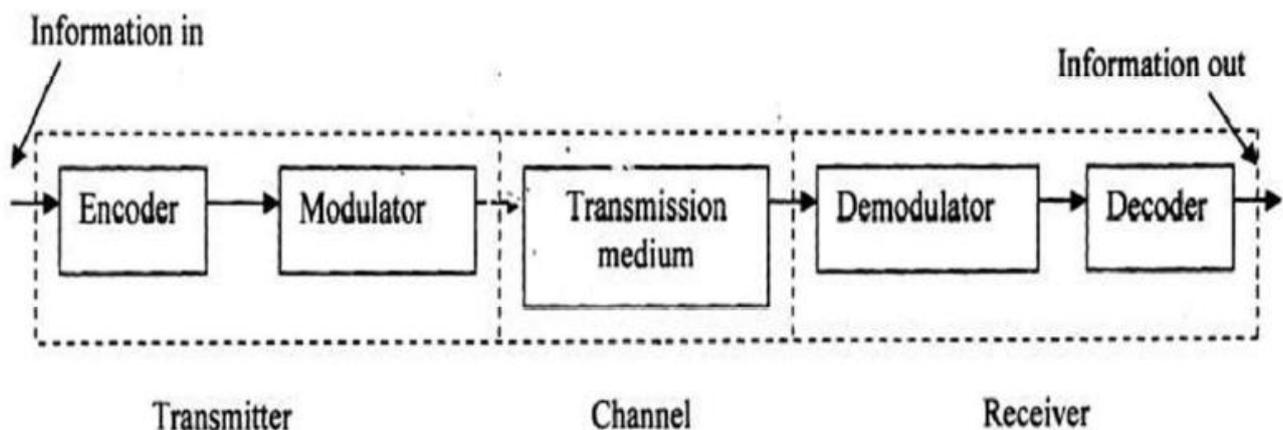


Figure 1: Block diagram of Simplex communication system.



2.1.1 ADVANTAGES OF SIMPLEX MODE

1. **Simplicity:** Simplex mode is simple to implement because data travels in only one direction. This reduces the difficulty of the communication system.
2. **Cost-Effective:** Since communication is single directional, the hardware required (e.g., cables, connectors) can be less costly compared to more complex modes like half-duplex or full-duplex.
3. **No Collision:** As data travels in only one direction, there's no risk of data collision, making the communication secure and consistent.
4. **Efficient Use for Specific Applications:** Ideal for applications where only one-way communication is necessary, such as broadcasting, keyboard input to a computer, or sending data to a printer.

2.1.2 DISADVANTAGES OF SIMPLEX MODE

1. **Lack of Bidirectional Communication:** The most significant disadvantage is the incapacity to send data back in the opposite way. This limitation makes it unsuitable for interactive communication.
2. **Inefficiency for Complex Tasks:** Simplex mode is not suitable for tasks requiring response or acknowledgment, such as error-checking or data authentication, which are crucial in many communication systems.
3. **Limited Flexibility:** Simplex systems lack flexibility because they cannot be easily adjusted to situations where bidirectional communication might become necessary.
4. **Not Ideal for Modern Networks:** Most advanced communication systems require bidirectional data flow, making simplex mode largely antiquated in networking scenarios.

2.2 HALF-DUPLEX (HDX) COMMUNICATION SYSTEM.

The half-duplex (HDX) communication system is capable of transmit information in two-way alternately. Although communication flows in both directions in half-duplex transmission, the flow of information is only one-way at any given time. In many cases it is desirable to maintain two-way communication, or at least to be able to send a message back to its origin for possible verification, comparison, or control. Figure 2 shows the block diagram of this system. For example, of this system (walky-talky of the police men).

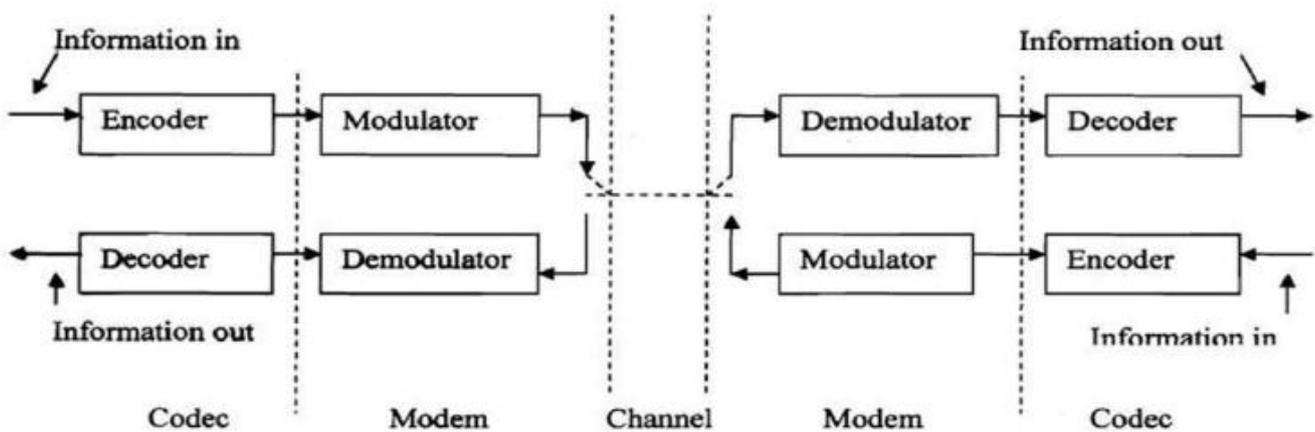


Figure 2: block diagram of half-duplex (HDX) communication system.

2.2.1 ADVANTAGES OF HALF-DUPLEX MODE

- 1. Efficient Use of Channel:** Half-duplex allows for bidirectional communication over a single channel, making it effective for scenarios where parallel transmission isn't required.
- 2. Cost-Effective:** It requires less complicated and less costly hardware than full-duplex systems, as only one device conveys at a time.
- 3. Simplified Collision Handling:** Since only one device can transmit at a time, crashes are reduced, reducing the need for complicated collision detection and management protocols.



4. Suitable for Periodic Communication: Optimal for situations where communication doesn't need to happen concurrently in both directions, such as walkie-talkies or specific network protocols.

2.2.2 DISADVANTAGES OF HALF-DUPLEX MODE

1. Slower Data Transmission: Since data can only run in one direction at a time, communication is naturally delayed compared to full-duplex systems where data can be delivered and received simultaneously.

2. Increased Latency: The need to exchange between sending and receiving modes introduces delay, which can affect performance in congestion applications.

3. Not Ideal for High-Traffic Networks: In networks with congestion or applications requiring constant communication, half-duplex mode can become a restriction.

4. Inefficient for Complex Communications: For tasks that require frequent two-way communication, half-duplex can be less effective as it forces devices to wait their turn, which can lead to pauses.

2.3 FULL-DUPLEX (FDX) COMMUNICATION SYSTEM

In full-duplex transmission, simultaneous communication is accomplished in both directions. Figure 3 below shows the block diagram of this system. For example, of this system (computer networks, mobile phones).

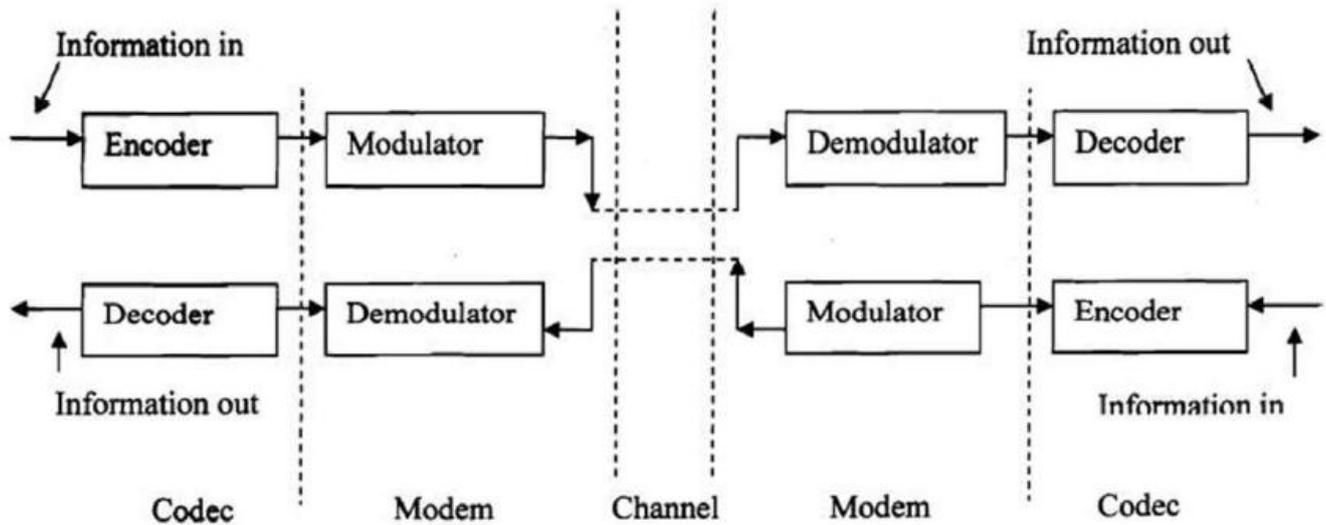


Figure 3: block diagram of Full -duplex (FDX) communication system.

2.3.1 ADVANTAGES OF FULL-DUPLEX MODE

- 1- **High-Speed Communication:** Data transfer is quicker because there is no delaying for the channel to clear before sending or receiving data.
- 2- **Reduced Latency:** Since communication is parallel, time lag is minimized, which is critical for real-time applications like web conferencing.
- 3- **Better Utilization of Bandwidth:** The available transmission capacity is used more efficient because both directions of communication can occur at once

2.3.2 DISADVANTAGES OF FULL-DUPLEX MODE

- 1- **Complexity and Cost:** Executing full-duplex systems requires more complicated hardware and can be more costly than simplex or half-duplex systems.
- 2- **Requires Quality Infrastructure:** Full-duplex communication demands an advanced quality of architecture, such as better cabling and more refined networking equipment, to avoid interference and assure smooth data flow.



3 LINE CODE

A **line code** is the code used for data transmission of a digital signal over a transmission line. This process of coding is chosen so as to avoid overlap and distortion of signal such as inter-symbol interference. It is the process of converting binary data (1s and 0s) into digital signals (voltage/current waveforms) for baseband transmission, ensuring low bandwidth, power efficiency, and self-synchronization. Common techniques include Unipolar, Polar (NRZ/RZ), Bipolar (AMI), and Manchester, chosen to avoid dc components and minimize errors.

3.1 UNIPOLAR

Unipolar signaling is also called as **On-Off Keying** or simply **OOK**. The presence of pulse represents a **1** and the absence of pulse represents a **0**.

3.1.1 UNIPOLAR NON-RETURN TO ZERO (NRZ)

In this type of unipolar signaling, a High in data is represented by a positive pulse called as **Mark**, which has a duration T_0 equal to the symbol bit duration. A Low in data input has no pulse. The following figure clearly depicts this.

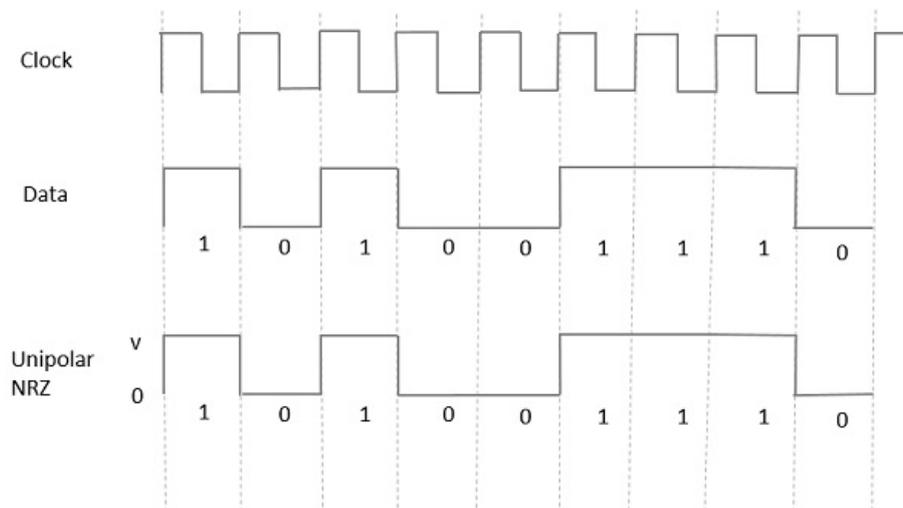


Figure 4: Unipolar Non-Return to Zero Waveform.



3.1.2 UNIPOLAR RETURN TO ZERO (RZ)

In this type of unipolar signaling, a High in data, though represented by a **Mark pulse**, its duration T_0 is less than the symbol bit duration. Half of the bit duration remains high but it immediately returns to zero and shows the absence of pulse during the remaining half of the bit duration. It is clearly understood with the help of the following figure.

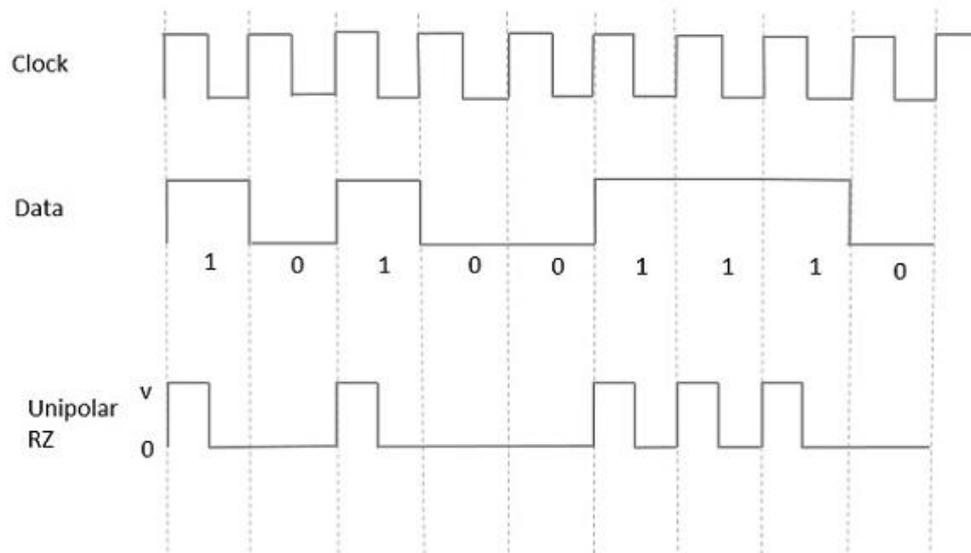


Figure 5: Unipolar Return to Zero Waveform.

3.2 POLAR

Polar line coding represents digital data (0s and 1s) using two opposite voltage levels—positive (+V) and negative (-V)—situated on both sides of the 0V time axis, unlike unipolar schemes. This method provides higher noise immunity and reduced DC components.

3.2.1 POLAR NRZ

In this type of Polar signaling, a High in data is represented by a positive pulse, while a Low in data is represented by a negative pulse. The following figure depicts this well.

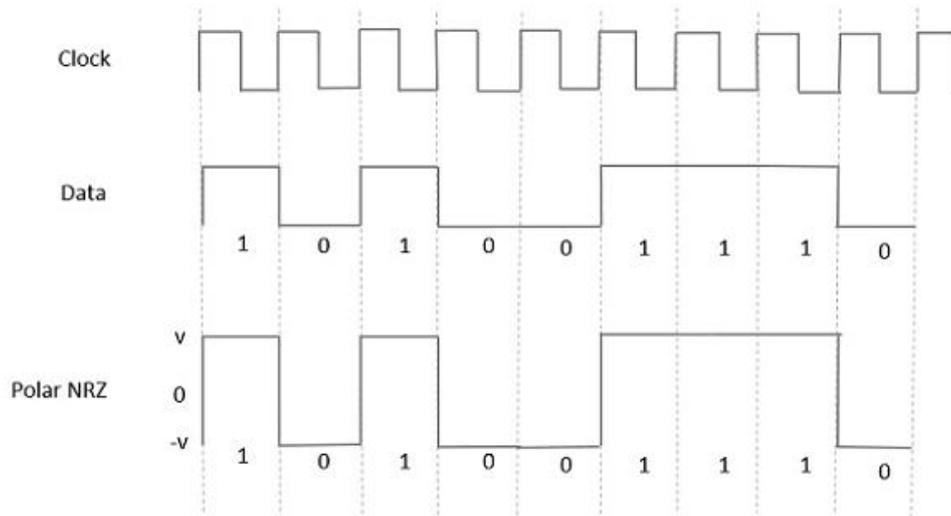


Figure 6: Polar NRZ Waveform.

3.2.2 POLAR RZ

In this type of Polar signaling, a High in data, though represented by a **Mark pulse**, its duration T_0 is less than the symbol bit duration. Half of the bit duration remains high but it immediately returns to zero and shows the absence of pulse during the remaining half of the bit duration.

However, for a Low input, a negative pulse represents the data, and the zero level remains same for the other half of the bit duration. The following figure depicts this clearly.

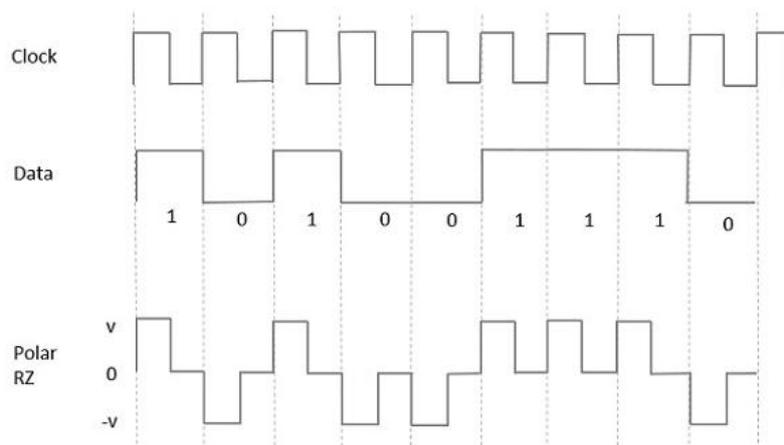


Figure 7: Polar RZ Waveform.

3.3 BI-POLAR

This is an encoding technique which has three voltage levels namely **+**, **-** and **0**. Such a signal is called as **duo-binary signal**.

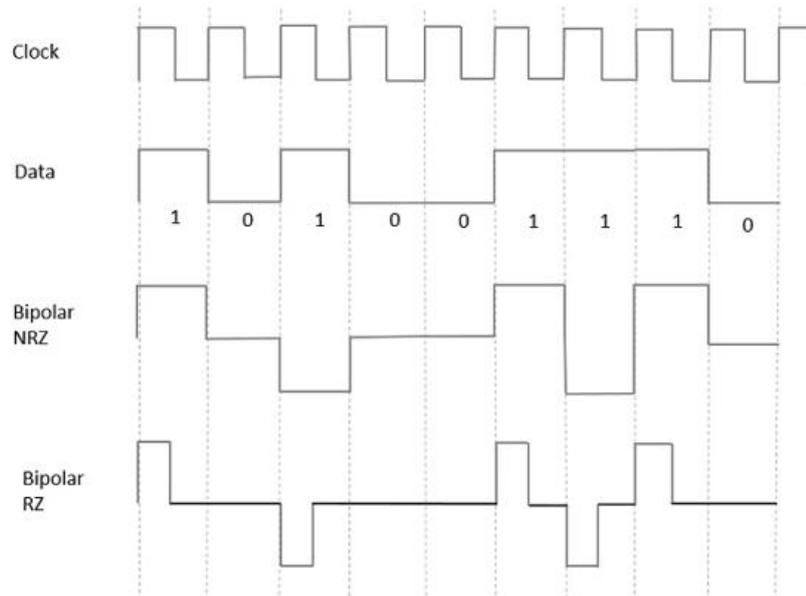


Figure 8: BI-polar Waveform.

An example of this type is **Alternate Mark Inversion (AMI)**. For a **1**, the voltage level gets a transition from **+** to or from **-** to **+**; having alternate **1s** to be of equal polarity. A **0** will have a zero-voltage level.

From the models so far discussed, we have learnt the difference between NRZ and RZ. It just goes in the same way here too. The following figure clearly depicts this.

4 CONSTELLATION DIAGRAM

A constellation diagram is a 2D graphical representation of a modulated radio signal in the complex plane, used in digital communications to display amplitude and phase. It plots in-phase (I) and quadrature (Q) components as points, illustrating modulation schemes (e.g., QAM, PSK) and diagnosing impairments like noise, interference, and distortion

A real-valued modulated RF or bandpass signal $s(t)$ is mathematically represented by combining these two components with a cosine and a sine carrier of the same frequency:

$$s(t) = I(t)\cos (2\pi f_c t) - Q(t)\sin (2\pi f_c t) \quad (1)$$

In this equation:

$I(t)$: The in-phase component, which modulates the cosine carrier.

$Q(t)$: The quadrature component, which modulates the sine carrier.

In signal processing and communications, a bandpass signal can be decomposed into two orthogonal components: the in-phase (I) component and the quadrature (Q) component. These components represent the two-dimensional amplitude and phase information of a signal relative to a reference carrier frequency (f_c).

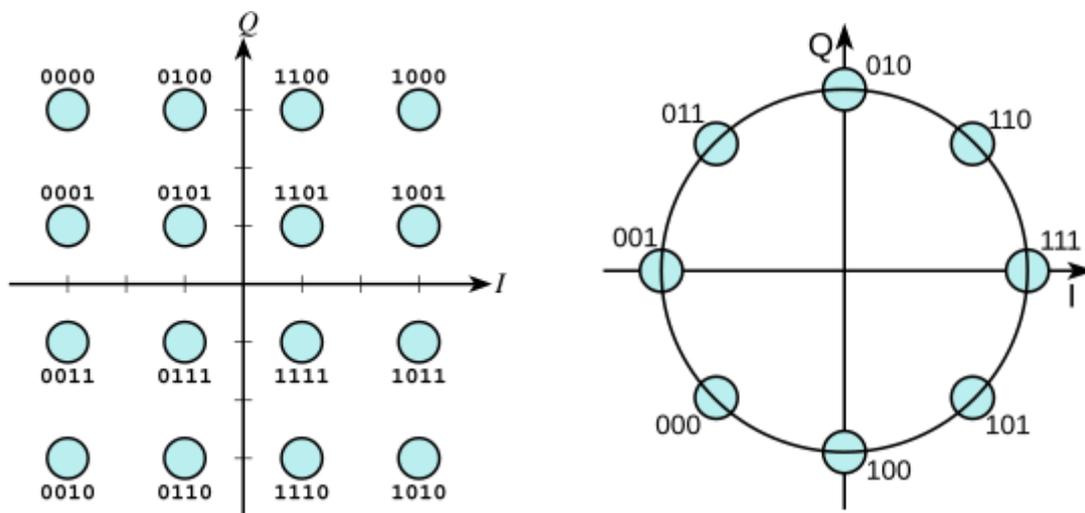


Figure 9: Example of Constellation diagram.

5 AMPLITUDE - SHIFT KEYING (ASK)

In amplitude -shift keying, the amplitude of a high -frequency carrier signal is switched two or more values in response to the PCM code. For the binary case, the usual choice is on-off keying (sometimes abbreviated as OOK). The resultant amplitude-

modulation waveform consists of RF pulses, called marks, representing binary (1), and spaces representing binary (0).

ASK waveform for one bit can be written as: -

$$\phi(t) = \begin{cases} A \sin \omega_c t & 0 \leq t \leq T \\ 0 & \text{elsewhere} \end{cases} \quad (2)$$

The energy E for that symbol is calculated by integrating the squared signal over the bit duration:

$$E = \int_0^T A^2 \sin^2 \omega_c t dt = A^2 T / 2 \quad (3)$$

On-Off Keying (OOK): This is the most common form of ASK.

Bit 1: Represented by a carrier with amplitude. Energy = $A^2 T / 2$

Bit 0: Represented by zero amplitude. Energy = 0

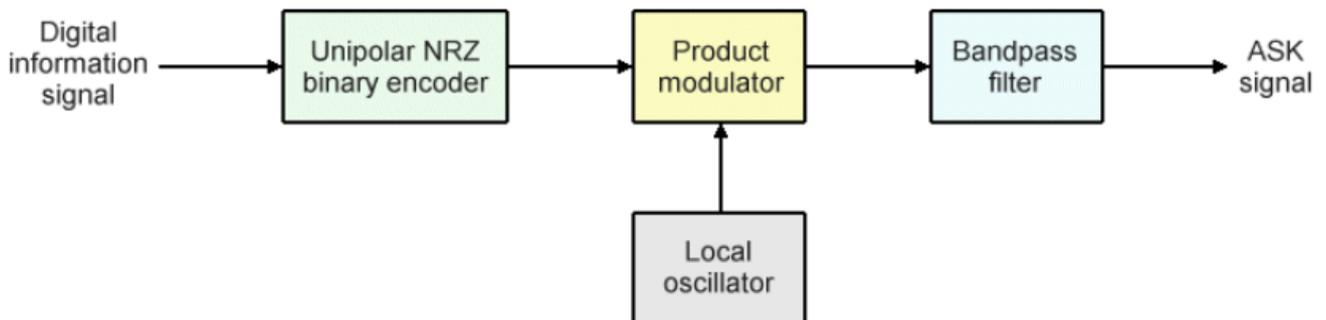


Figure 10: Ask Modulation Block Diagram.

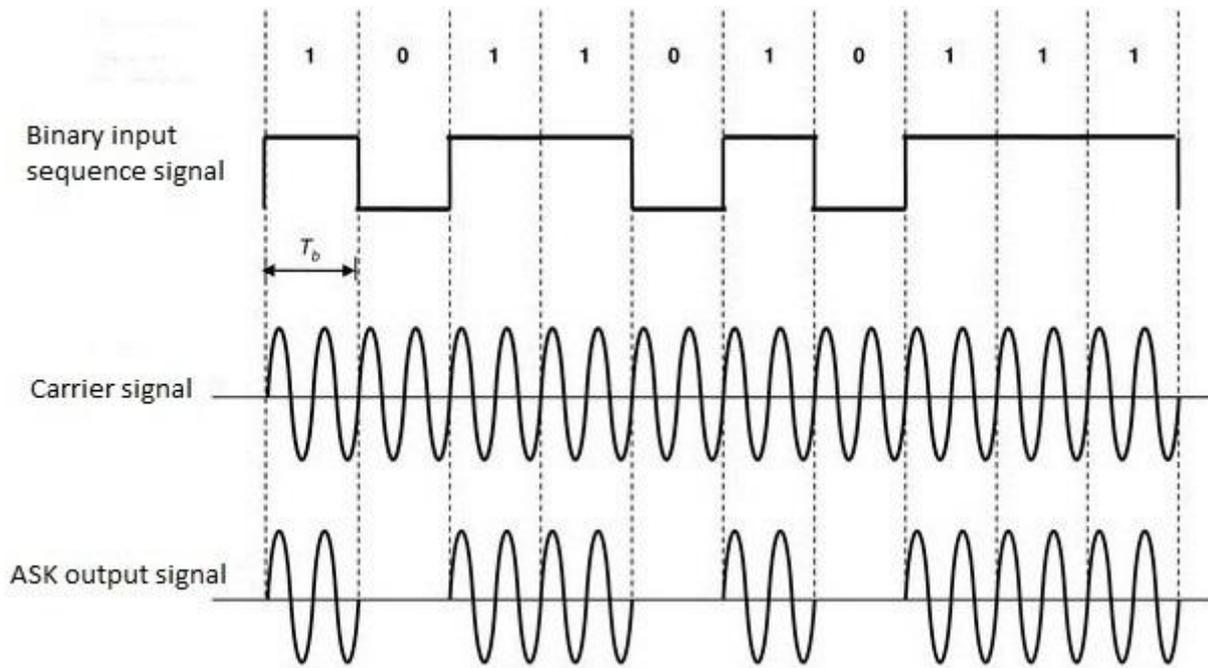


Figure 11: Ask Waveform.

5.1 ASK DEMODULATION

Amplitude Shift Keying (ASK) demodulation is the process of extracting the original digital data from a received ASK-modulated signal. There are two main methods for demodulating ASK signals:

5.1.1 ASYNCHRONOUS DEMODULATION (ENVELOPE DETECTOR METHOD)

This method does not require a reference signal synchronized with the transmitter's carrier signal. Instead, it detects the **variations in the amplitude** of the received signal to recover the original digital data.

Working Principle:

1. **The received ASK-modulated signal** is captured by the receiver, containing a sinusoidal carrier with varying amplitude.
2. **The signal passes through an envelope detector circuit:**

- A **diode rectifier** is used to convert the signal into a unidirectional waveform (removing negative cycles).
- The signal is then passed through a **low-pass filter**, which smooths out the variations and extracts the envelope of the modulated signal.

3. The extracted signal is sent to a comparator circuit:

- The signal is compared against a threshold voltage to determine whether the received bit is '1' or '0'.

4. The original digital data is reconstructed, forming the transmitted binary sequence.

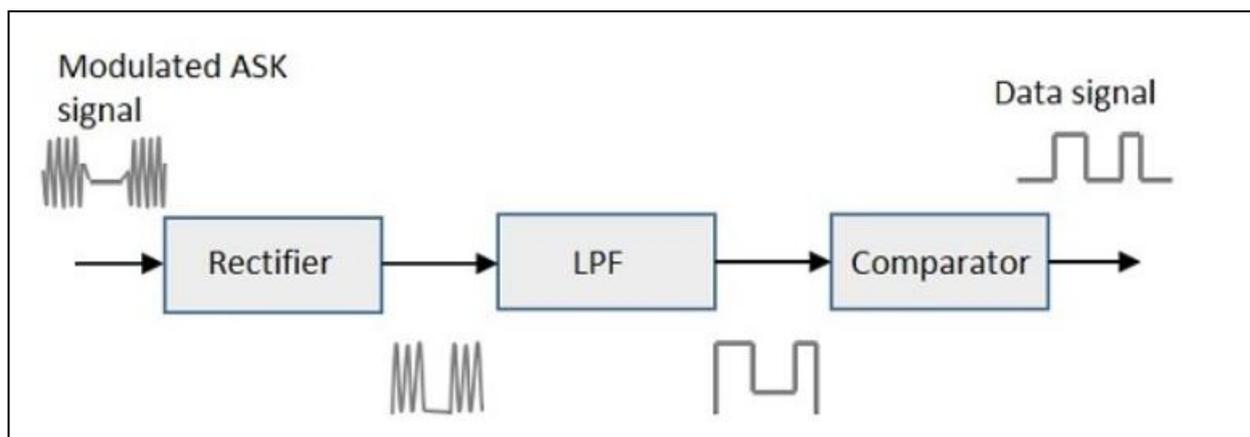


Figure 12: Asynchronous Demodulation for ASK.

5.1.2 SYNCHRONOUS DEMODULATION (COHERENT DETECTION METHOD)

Coherent detection is a method used to demodulate an ASK signal by synchronizing the phase with the carrier wave. Coherent detection requires the receiver to have exact knowledge of the carrier's **phase and frequency**. This is typically achieved using a **Phase-Locked Loop (PLL)** to synchronize a local oscillator with the incoming carrier. Generally, there are two methods of coherent detection: **The Matched Filter and The Correlator**.



The matched filter is a linear filter whose impulse response is the **time-reversed** and shifted version of the transmitted pulse shape. It maximizes the peak signal power relative to the mean noise power at a specific sampling instant.

For a rectangular pulse in ASK, the matched filter acts as an **integrator** that resets after each bit period. The output at the sampling time T is proportional to the **energy** of the received signal bit.

The impulse response of the matched filter for optimum detection of this ASK waveform in the presence of white noise is, within an arbitrary constant,

$$h(t) = \phi(T - t) \quad (4)$$

The matched-filter output for the (noiseless) input $\phi(t)$ is:

$$\begin{aligned} y(t) &= \phi(t) \otimes h(t) \\ &= \int_{-\infty}^{\infty} \phi(\tau) \phi(T - t + \tau) d\tau \\ &= r_{\phi}(T - t), \end{aligned} \quad (5)$$

Where $r_{\phi}(t)$ is the time-autocorrelation function for the finite-energy signal $\phi(t)$ The optimum decision time is for $t = T$; thus,

$$y(T) = r_{\phi}(0) = E \quad (6)$$

The receiver must make a decision at $t = T$ based on the two possibilities $y(T) = n_0(T)$ and $y(T) = E + n_0(T)$. For equal source probabilities of ones and zeros and noise which has a symmetrical probability density function, the optimum decision threshold is set at $E/2$. Thus, the net probability-of-error computation reduces to that of the on-off baseband system. For gaussian-distributed noise, we have found that this gives:

$$P_e = Q \left(\sqrt{\frac{E}{2\eta}} \right) \quad (7)$$



Where, η (the Greek letter eta) represents the one-sided Power Spectral Density (PSD) of the noise. For purposes of comparison with other systems, we express the probability of error in terms of the average signal energy per bit, $E_{\text{avg}} = ST$ so that:

$$P_e = Q \left(\sqrt{\frac{E_{\text{avg}}}{\eta}} \right) \quad (8)$$

The average signal power is $S = (1/2)(A^2/2)$ as before, $N = \eta B$ and if we assume Nyquist sampling, $B = 1/(2T)$ so that we can rewrite Eq. (8) in terms of the average signal-to-noise ratio:

$$P_e = Q \left(\sqrt{\frac{S}{2N}} \right) \quad (9)$$

The correlator is a mathematically equivalent structure to the matched filter but is implemented differently.

- **Operation:** It multiplies the incoming signal by a locally generated **reference carrier** (template) and integrates the product over the bit duration T .
- **Equivalence:** At the exact sampling instant $t = T$, the output of a correlator is **identical** to that of a matched filter.
- **Choice:** Historically, correlators were easier to build with analog components, while matched filters are now easily implemented via **digital signal processing** algorithms.

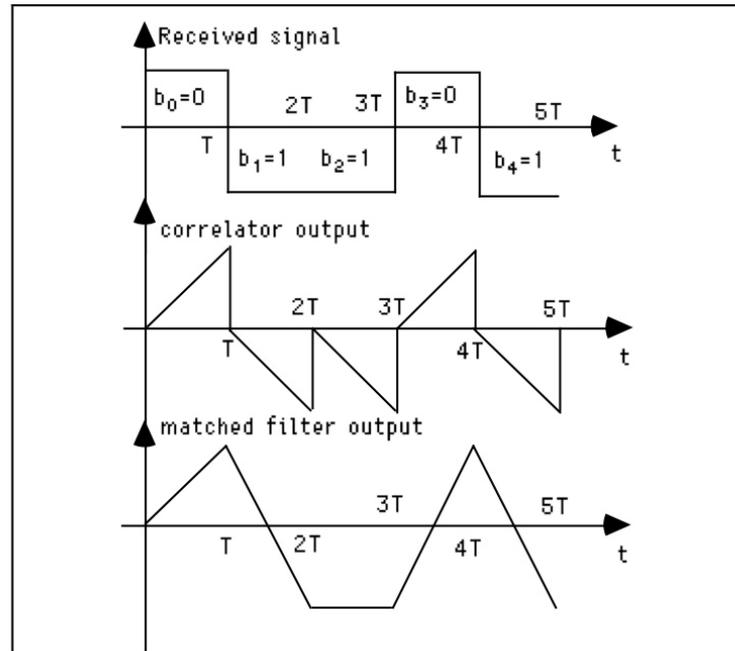


Figure 13: Example of the operation of Matched filter and correlator.

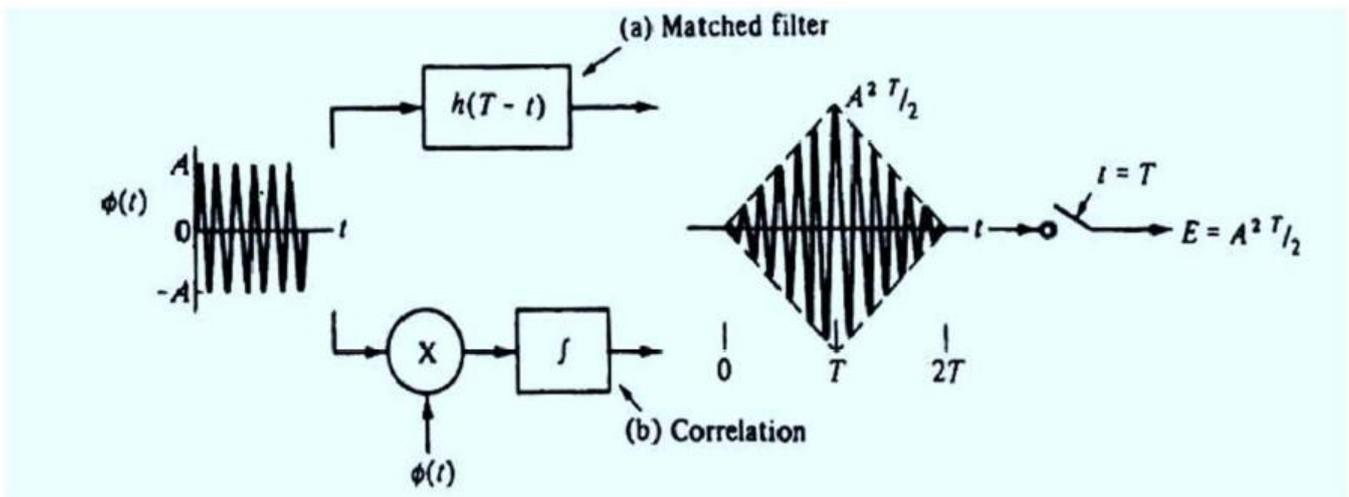


Figure 14: Matched filter of ASK.

5.2 BAND WIDTH OF ASK

The bandwidth of a signal is the total range of frequencies occupied by that signal. When we decompose an ASK-modulated signal, we get a spectrum of many simple

frequencies. However, the most significant ones are those between. The **bandwidth formula** for digital signals is:

$$BW = (1 + d) \cdot N_d \tag{10}$$

Where,

BW = Required bandwidth of the digital signal (Hz).

d = Roll-off factor (or excess bandwidth factor, $0 \leq d \leq 1$).

N_d = Data rate (in symbols per second, i.e., baud rate).

The formula comes from Nyquist bandwidth theory for pulse-shaped digital signals. If you transmit N_d symbols per second and apply a filter with roll-off d , the occupied bandwidth increases by a factor of $(1 + d)$.

EXAMPLE 1 : If Data rate $N_d = 1000$ symbols /sec, Roll-off factor $d = 0.2$ calculate BW?

Solution

$$BW = (1 + 0.2) \cdot 1000 = 1200 \text{ Hz}$$

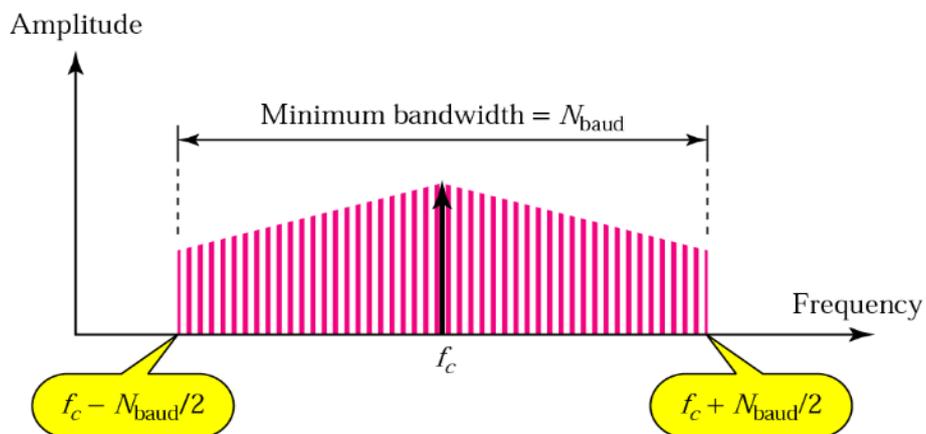


Figure 15: ASK bandwidth.



EXAMPLE 2 : Find the minimum bandwidth for an ASK signal transmitting at 2000 bps. The transmission mode is half-duplex.

Solution

In ASK the baud rate and bit rate are the same. The baud rate is therefore 2000.
An ASK signal requires a minimum bandwidth equal to its baud rate. Therefore, the minimum bandwidth is 2000 Hz

EXAMPLE 3 : Given a bandwidth of 10,000 Hz (1000 to 11,000 Hz), if draw the full-duplex ASK diagram of the system. We can find the carriers and the bandwidths in each direction. Assume there is no gap between the bands in the two directions.

Solution

For full-duplex ASK, the bandwidth for each direction is

$$BW = 10000/2 = 5000 \text{ Hz}$$

The carrier frequencies can be chosen at the middle of each band

$$f_c(\text{ forward }) = 1000 + 5000/2 = 3500 \text{ Hz}$$

$$f_c(\text{ backward }) = 11000 - 5000/2 = 8500 \text{ Hz}$$

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