Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:13

# Lecture 13

# Part2: Digital Modulation

Lecturer: Prof. Dr. Bayan Mahdi Sabbar

M.Sc. Huda Wasfi Hassoon

Email: huda.wasfi@uomus.edu.iq

Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:13

**Digital modulation** is the process of encoding a digital information signal by modifying specific characteristics of a transmitted signal, such as its **amplitude, phase, or frequency**. This encoding process directly impacts both the **bandwidth** of the transmitted signal and its **resistance to channel impairments** such as noise and interference.

In contrast, analog modulation involves transmitting a low-frequency digital baseband signal—such as a digital bitstream from a computer—over a higher-frequency carrier signal, typically within a radio frequency band. While digital modulation shares some similarities with analog modulation, the key distinction lies in the nature of the baseband signal. In digital modulation, the baseband signal consists of discrete amplitude levels, as opposed to the continuous variations found in analog signals.

For a **binary signal**, the amplitude takes on only two distinct levels:

- A **high level**, representing **logic 1**
- A **low level**, representing **logic 0**

Digital modulation techniques are broadly classified into three main types:

1. **Amplitude Shift Keying (ASK)** – The amplitude of the carrier signal is varied in response to the digital data.
2. **Frequency Shift Keying (FSK)** – The frequency of the carrier signal is altered based on the binary data.
3. **Phase Shift Keying (PSK)** – The phase of the carrier signal is modified to represent digital information.

Email: huda.wasfi@uomus.edu.iq

Each of these modulation schemes has its advantages and is selected based on factors such as data transmission requirements, bandwidth availability, and resistance to signal degradation.

## Phase Shift Keying (PSK)

The term **Phase Shift Keying (PSK)** is widely used in radio communication systems and is particularly well-suited for data transmission. This modulation technique enables information to be transmitted more efficiently over a radio signal compared to other modulation methods. As data communication continues to evolve, transitioning from analog to digital formats, various modulation techniques are employed to enhance transmission efficiency. PSK comes in multiple forms, each with its own advantages and limitations. Selecting the optimal PSK format for a given radio communication system requires a thorough understanding of its principles and functionality.

### What is Phase Shift Keying (PSK)?

**Phase Shift Keying (PSK)** is a type of digital modulation technique used to transmit data by altering the phase of a carrier signal, which serves as a reference. In digital modulation, data is represented using a limited number of distinct signal variations. PSK specifically employs a finite number of phase shifts, where each phase is assigned a unique binary value. Typically, each phase encodes a fixed number of bits, and each bit pattern forms a symbol that corresponds to a specific phase.

A constellation diagram is commonly used to represent PSK. In this graphical representation, constellation points are uniformly spaced around a circle to maximize phase separation between adjacent points. This arrangement enhances resistance to signal corruption while ensuring that all symbols are transmitted with equal energy, optimizing communication efficiency.

## Types of PSK

The PSK can be classified into two types which include the following.

- BPSK – Binary Phase-Shift Keying
- QPSK – Quadrature Phase-Shift Keying

### Binary Phase-Shift Keying (BPSK)

**Binary Phase-Shift Keying (BPSK)**, also known as **Phase Reversal Keying (PRK)** or **2-PSK**, is a type of phase-shift keying that employs two distinct phase states, separated by 180 degrees. This phase difference is why it is referred to as 2-PSK.

In BPSK, the exact placement of constellation points is not crucial, as the modulation scheme is highly resistant to noise and signal distortion. Among all PSK variants, BPSK is the most robust, as it can tolerate the highest levels of noise and interference before the demodulator makes an incorrect decision. However, its major limitation is that it can only encode **1 bit per symbol**, making it unsuitable for high-data-rate applications.

In a **simple BPSK (Binary Phase-Shift Keying) system**, the phase of the carrier signal changes based on whether the data bit is **1 or 0**. If the bit is **1**, the phase remains at **0°**, but if the bit is **0**, the phase shifts by **180°**.

Think of it like flipping a switch—when the data is **1**, the signal stays the same, and when the data is **0**, the signal flips to the opposite phase. This switching process helps transmit information in a way that can resist noise and interference better than some other modulation techniques.

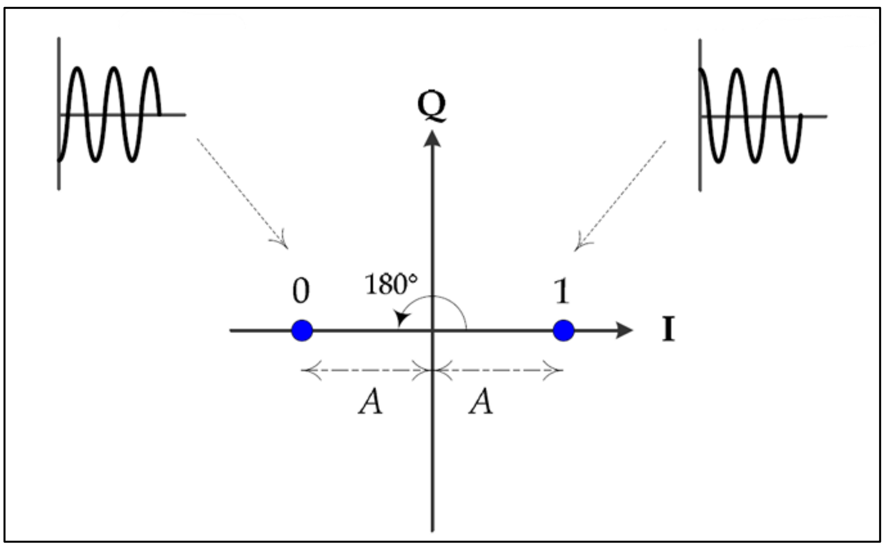


Figure 1: Constellation Diagram of BPSK.

## Principle of BPSK:

Binary Phase Shift Keying (BPSK) is the simplest form of Phase Shift Keying (PSK). In this modulation scheme, each signaling element represents a single data bit. The carrier signal undergoes two possible phase reversals: **0°** and **180°**.

In BPSK, the digital bit sequence is first converted into a Non-Return-to-Zero (NRZ) bipolar signal, which then directly modulates the carrier wave.

## Mathematical Representation of BPSK:

Consider a carrier wave expressed as:

$$s(t) = A\cos(2\pi f_c t)$$

where **A** represents the peak amplitude of the carrier wave. Assuming a standard load resistance of **1 ohm**, the power dissipated in the system is given by:

$$P = \frac{A^2}{2}$$

When the bit sequence changes, the phase of the carrier shifts by **180°** accordingly.

For **binary 1**, the carrier signal can be written as:

$$s_1(t) = A\cos(2\pi f_c t)$$

For **binary 0**, the carrier undergoes a phase shift of **π (180°)**, resulting in:

$$s_2(t) = A\cos(2\pi f_c t + \pi)$$

Using the trigonometric identity:

$$\cos(\emptyset + \pi) = -cos\emptyset$$

we can rewrite $s_2(t)$ as:

$$s_2(t) = -A\cos(2\pi f_c t)$$

Thus, the general expression for a **BPSK signal** can be written as:

$$s(t) = A\, b(t)\cos(2\pi f_c t)$$

where:

- $b(t) = +1$ when transmitting **binary 1**
- $b(t) = -1$ when transmitting **binary 0**

This modulation scheme ensures that each bit is represented by a phase shift of **0° or 180°**, making BPSK robust against noise and simple to implement.

Email: huda.wasfi@uomus.edu.iq

Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:13

## BPSK modulation:

The given block diagram represents a **Binary Phase Shift Keying (BPSK) modulator**, which consists of **three main components**:

1. Bipolar NRZ Level Encoder
2. Balanced Modulator
3. Carrier Generator

Each component plays a crucial role in converting binary data into a BPSK signal. Let's go through the working process step by step.

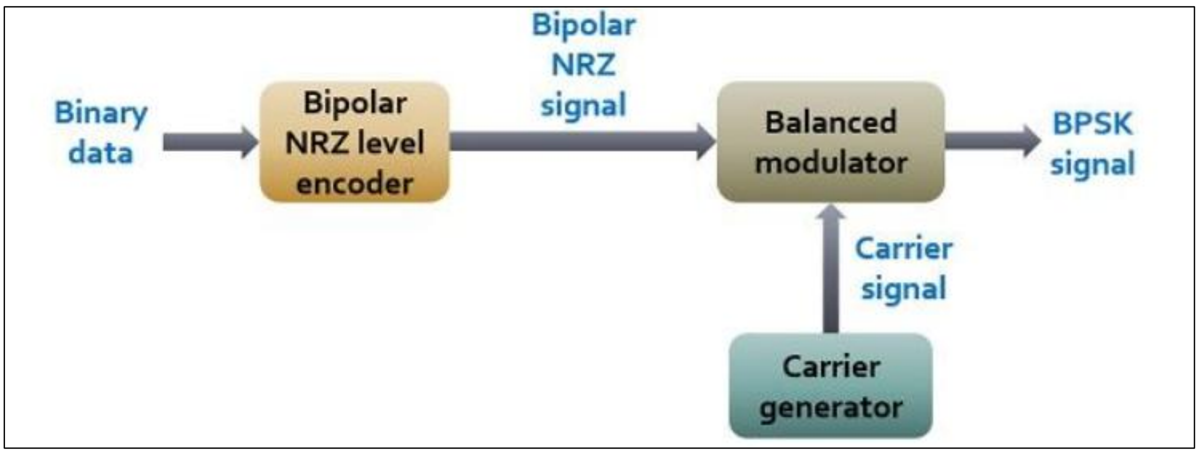


Figure 2: Generation of BPSK.

### 1. Binary Data Input → Bipolar NRZ Level Encoder

- The **binary data** (a sequence of 0s and 1s) is first fed into a **Bipolar NRZ (Non-Return-to-Zero) level encoder**.
- This encoder converts the binary data into an equivalent bipolar NRZ signal m(t), where:
  - **Binary 1** is represented as +A (high voltage).
  - **Binary 0** is represented as −A (low voltage).

Email: huda.wasfi@uomus.edu.iq

Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:13

- The **bipolar NRZ signal** is essential because BPSK requires a phase shift of 0° for binary 1 and 180° for binary 0.

**2. Bipolar NRZ Signal → Balanced Modulator**

- The bipolar NRZ signal $m(t)$ is then fed into a **Balanced Modulator**.
- At the same time, a **Carrier Generator** provides a continuous sinusoidal carrier signal $c(t)$.
- The **Balanced Modulator** acts as a **multiplication circuit** that combines the carrier signal $c(t)$ with the bipolar NRZ signal $m(t)$.

**3. Carrier Generator → Balanced Modulator → BPSK Output**

- The balanced modulator multiplies the bipolar NRZ signal $m(t)$ with the carrier wave $c(t)$, which results in the BPSK signal:

$$s(t) = m(t). A\cos(2\pi f_c t)$$

- Since $m(t)$ takes values of **+1 (for binary 1) and -1 (for binary 0)**, this multiplication causes a **180° phase shift** when transmitting binary 0:
  - When **m(t) = +1** (binary 1):

$$s(t) = A\cos(2\pi f_c t)$$

  - When **m(t) = -1** (binary 0):

$$s_2(t) = A\cos(2\pi f_c t + \pi)$$

- This means that the output BPSK signal has the same frequency as the carrier but undergoes phase shifts of 0° or 180° depending on the input data.

Let us have a look at the figure below which shows the generated waveform with the binary bit sequence and carrier wave.

Email: huda.wasfi@uomus.edu.iq

Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:13

 **Binary Data Sequence**

- The first waveform represents the **binary data sequence** that is to be transmitted.
- The data consists of a series of **ones (1s) and zeros (0s)**, which are used as input for modulation.
- The waveform is shown as a rectangular digital signal, where:
  - **High level (1)** represents a binary "1".
  - **Low level (0)** represents a binary "0".
- The example sequence in the image is **1 1 0 0 0 1 0 1 0 1 0 0 1 0**.

 **Bipolar Non-Return-to-Zero (NRZ) Sequence**

- The second waveform represents the **bipolar NRZ** signal, which is an intermediate representation of the binary sequence.
- In this encoding method:
  - A **binary "1"** is represented by **+1 (positive voltage)**.
  - A **binary "0"** is represented by **-1 (negative voltage)**.
- This signal is essential in BPSK modulation because it helps in determining the phase shifts in the modulated signal.

 **Carrier Wave**

- The third waveform is a **carrier signal**, which is a continuous sine wave of a fixed frequency and amplitude.
- This wave serves as the base signal for modulation.
- Before modulation, this signal oscillates at a constant frequency without any phase shifts.

 **BPSK Modulated Waveform**

Email: huda.wasfi@uomus.edu.iq

- The fourth waveform shows the **BPSK (Binary Phase Shift Keying) modulated signal**.
- In BPSK modulation:
  - A **binary "1"** keeps the carrier wave in its original phase.
  - A **binary "0"** causes a **180-degree phase shift** in the carrier wave.
- The result is that the waveform inverts (flips upside down) whenever there is a transition from **1 to 0** or **0 to 1** in the original binary data sequence.

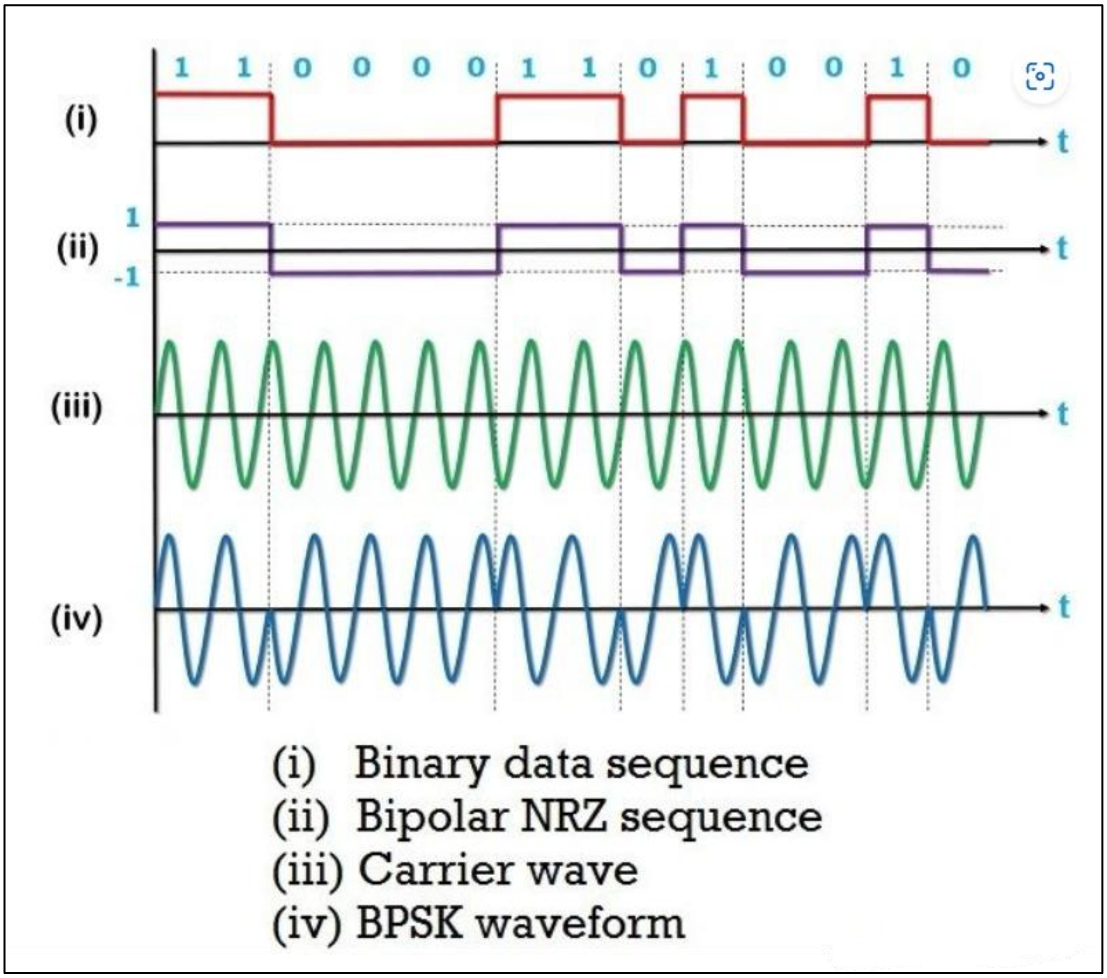


Figure 3: BPSK waveform.

Email: huda.wasfi@uomus.edu.iq

## BPSK Demodulation:

The given circuit diagram represents a **coherent demodulation** technique for Binary Phase Shift Keying (BPSK). This method extracts the original digital data from the received **B**PSK-modulated signal by synchronizing with the carrier wave. Below is a detailed step-by-step explanation of the demodulation process:

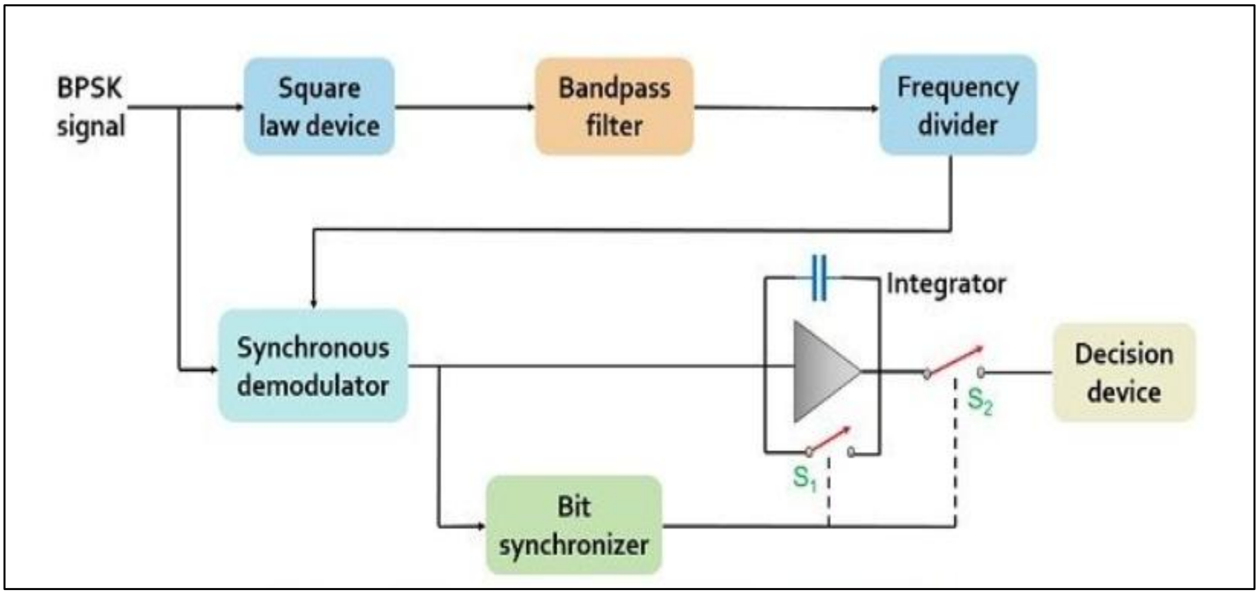


Figure 4: The block diagram of BPSK demodulation.

### Step 1: Receiving the BPSK Signal

- The incoming **BPSK signal** is received at the input of the demodulator.
- This signal contains **phase-shifted versions** of a carrier wave, where:
  - **Phase 0° represents binary "1".**
  - **Phase 180° represents binary "0".**
- The goal of demodulation is to recover the original binary sequence by analyzing these phase shifts.

Email: huda.wasfi@uomus.edu.iq

Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:13

**Step 2: Extracting the Carrier Frequency (Upper Path – Carrier Recovery)**

To demodulate the signal properly, the system needs to extract a reference **carrier signal** from the received BPSK waveform. This is done in the following steps:

1. **Square Law Device:**
    - This component **squares the incoming signal** to generate frequency components at **twice the carrier frequency**.
    - This helps in recovering the carrier wave from the phase-modulated signal.
2. **Bandpass Filter (BPF):**
    - The **BPF removes unwanted frequency components** and allows only the required frequency band to pass through.
    - This helps in isolating the carrier signal needed for coherent demodulation.
3. **Frequency Divider:**
    - Since the squared signal contains a frequency that is **twice the original carrier frequency**, the frequency divider **reduces it back to the correct carrier frequency**.
    - The output is a synchronized **reference carrier wave**, which will be used for demodulation in the next stage.

**Step 3: Synchronous Demodulation (Lower Path – Data Extraction)**

Now that the system has recovered the carrier signal, it can use it to **demodulate** the received BPSK waveform.

Email: huda.wasfi@uomus.edu.iq

Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:13

1. **Synchronous Demodulator:**
   - This block **multiplies the received BPSK signal with the recovered carrier**.
   - Since the BPSK signal has either a **0° or 180° phase shift**, this multiplication helps to remove the carrier frequency component while preserving the original data information.
   - The output is a baseband signal containing **positive and negative voltage levels** corresponding to binary "1" and "0".
2. **Bit Synchronizer:**
   - Ensures that the extracted data is aligned correctly with the bit timing of the original transmitted sequence.
   - This improves detection accuracy by ensuring that each bit is sampled at the correct moment.

**Step 4: Signal Integration and Decision Making**

At this stage, the system processes the demodulated signal to make a final decision on whether each received bit corresponds to **"1" or "0"**.

1. **Integrator:**
   - The integrator accumulates the signal over each bit period.
   - This helps to smooth out noise and ensures a more reliable bit decision.
2. **Decision Device:**
   - The final stage of the demodulation process.
   - The integrator's output is compared to a threshold (reference signals $\mathbf{S_1}$ and $\mathbf{S_2}$):
     - If the value is **positive**, the system decides the bit is "1".

- If the value is **negative**, the system decides the bit is "0".

- This restores the original binary data sequence.

## Advantages of BPSK:

1. It allows more efficient transmission of radio frequency signal.
2. Better noise immunity is noticed in the case of BPSK technique.
3. Less bandwidth is utilized by the BPSK signal in comparison to BFSK.

## Disadvantages of BPSK:

1. Detection of a BPSK signal is quite complex.
2. Phase discontinuity sometimes leads to variation in amplitude of the signal.

## Applications of BPSK:

BPSK is a widely used modulation technique due to its **simplicity, robustness, and efficiency** in various communication systems. From **wireless networks and Bluetooth** to **satellite telemetry, biometric security, and IoT**, it plays a crucial role in **modern digital communication technologies**.