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:12

Lecture 12

Digital Modulation

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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.

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

Advantages of Digital Modulation

Digital modulation offers several key benefits over analog modulation, making it the preferred choice in modern communication systems. Its advantages include higher information capacity, improved data security, superior communication quality, and greater system reliability. Some of the most notable benefits are:

- **Higher Data Transmission Capacity** – Digital modulation allows for the transmission of significantly larger amounts of data compared to analog systems.
- **Exceptional Bandwidth Efficiency** – It enables the accommodation of vast amounts of data within a limited bandwidth, optimizing spectrum usage.
- **Flexible Signal Multiplexing** – Various types of data, including digital information, video, and voice, can be multiplexed and transmitted efficiently.
- **Greater Resistance to Interference** – Digital modulation is less susceptible to crosstalk, waveform distortion, non-linearities, and noise, ensuring reliable communication.
- **Stronger Signal Integrity** – Enhanced signal strength helps prevent unwanted interference and communication disruptions.
- **Cost-Effective Integration** – Digital modulation is the most economical option when interfacing with digital switching systems.

- **Enhanced Data Security** – The ease of encrypting and decrypting digital signals provides high security, making it ideal for sensitive and secure communications.

These advantages make digital modulation a **superior** and **efficient** choice for modern communication technologies, ensuring **faster, more secure, and more reliable** data transmission.

Amplitude shift Key (ASK)

Amplitude Shift Keying (ASK) is a digital modulation technique used to transmit digital information by **modulating the amplitude** of a carrier signal. In ASK, a **high-amplitude** carrier signal represents a binary **'1'**, while a **low-amplitude** carrier signal represents a binary **'0'**.

This modulation method involves the **superimposition** of a digital message signal onto a high-frequency carrier signal, typically a sinusoidal waveform. The **binary message signal**, composed of **'1's and '0's**, directly controls the amplitude of the carrier wave. As a result, the **modulated signal**, formed by combining the carrier and message signal, is then transmitted over the communication channel.

ASK is widely used in various communication systems due to its **simplicity and efficiency**, particularly in applications such as optical fiber transmission and infrared remote controls.

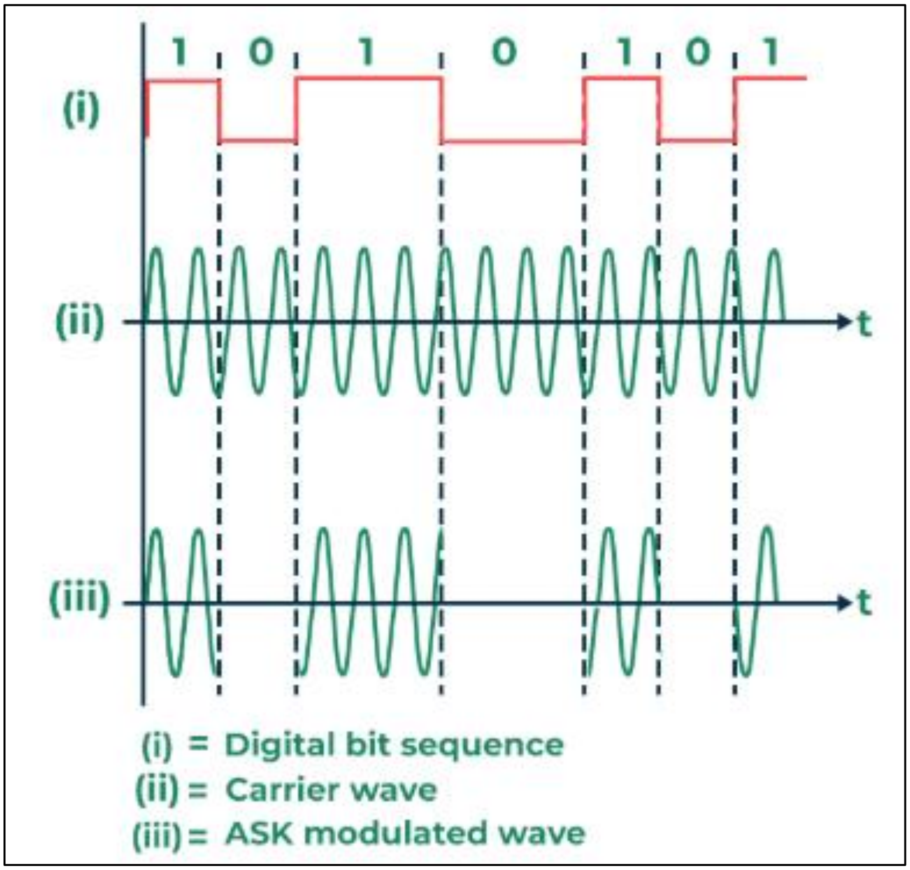

Figure 1: The ASK waveform.

ASK Modulator

The provided diagram illustrates the **Amplitude Shift Keying (ASK)** modulation process, which is a method of digital modulation where the **amplitude** of a sinusoidal carrier signal is varied according to a **unipolar binary sequence** (message signal). Let's break down each block in the diagram:

1. Sinusoidal Carrier:

- The process begins with a high-frequency sinusoidal carrier signal.
- This carrier signal serves as the base waveform that will be modulated to carry digital information.

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2. Modulator (Mixing the Message and Carrier Signal):

- The **unipolar binary sequence (message signal)**, consisting of **binary 1s and 0s**, is applied to the modulator.
- The modulator adjusts the **amplitude** of the carrier signal based on the input binary sequence:
  - **Binary '1'** → The carrier signal is transmitted at full amplitude.
  - **Binary '0'** → The carrier signal is either completely suppressed or reduced in amplitude.
- This results in an **ASK-modulated signal**, where the carrier appears only when the message signal is **'1'** and disappears (or has a lower amplitude) when the message signal is **'0'**.

3. Band-Limiting Filter (ASK Output):

- After modulation, the signal passes through a band-limiting filter to remove unwanted high-frequency components.
- The output is a clean ASK-modulated waveform, ready for transmission over a communication channel.

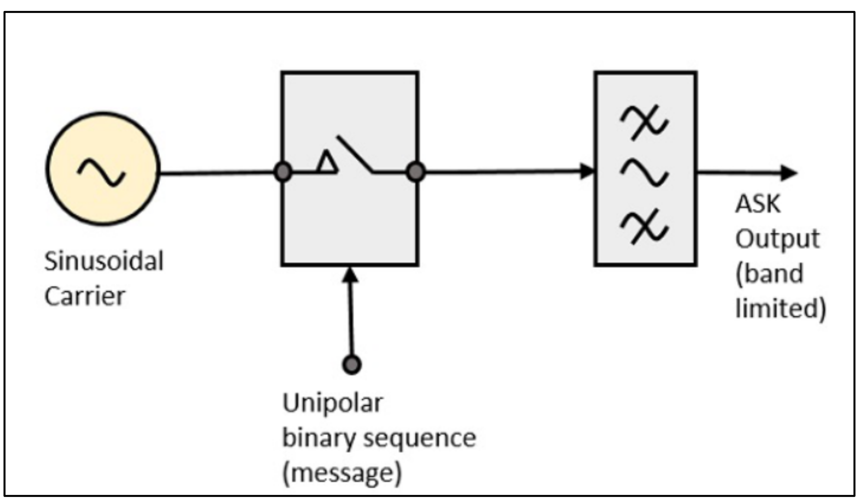

Figure 2: ASK Modulator.

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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:

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.

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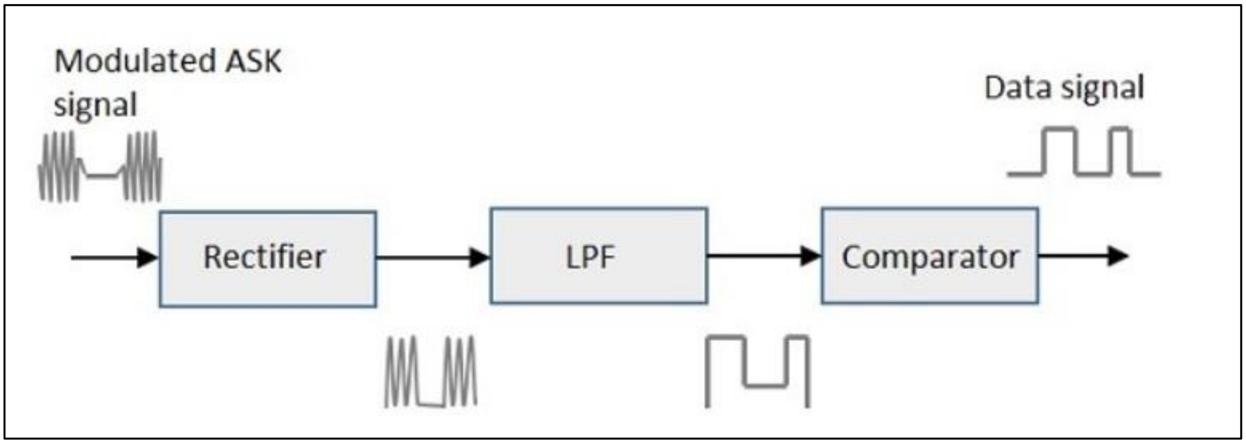

Figure 3: Asynchronous Demodulation for ASK.

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. The steps are:

1. **Reception**: The received signal is mixed with a locally generated carrier signal, synchronized in phase and frequency with the original carrier.
2. **Filtering**: The mixed signal is filtered to isolate the data component.
3. **Thresholding**: An amplitude threshold is set to distinguish between '1' and '0'.
4. **Decision**: The signal's amplitude is compared to the threshold to identify the transmitted data.
5. **Message Recovery**: The original message is reconstructed by decoding the bits.

This process ensures accurate data recovery by phase synchronization and amplitude comparison.

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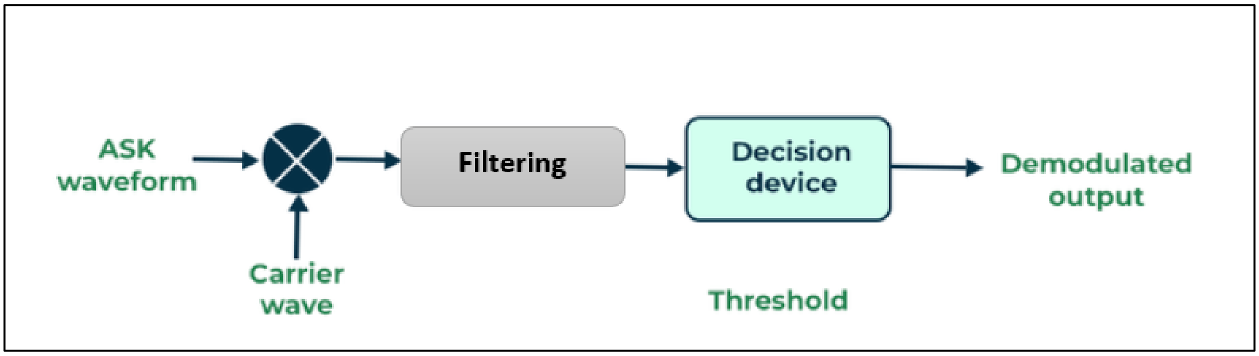

Figure 4: Coherent Detection Method.

Frequency Shift Key (FSK)

Frequency Shift Keying (FSK) is a digital modulation technique in which the frequency of the carrier signal changes in response to variations in the digital input signal. This modulation scheme falls under the category of frequency modulation (FM), where information is transmitted by altering the frequency of the carrier wave rather than its amplitude or phase.

In FSK modulation, the output waveform exhibits a higher frequency when the input signal represents a binary "1" and a lower frequency when the input corresponds to a binary "0." These distinct frequencies used to represent binary states are referred to as the **Mark frequency** (for binary 1) and the **Space frequency** (for binary 0).

The following diagram visually illustrates an FSK-modulated waveform, depicting how the input digital signal governs changes in the carrier signal's frequency.

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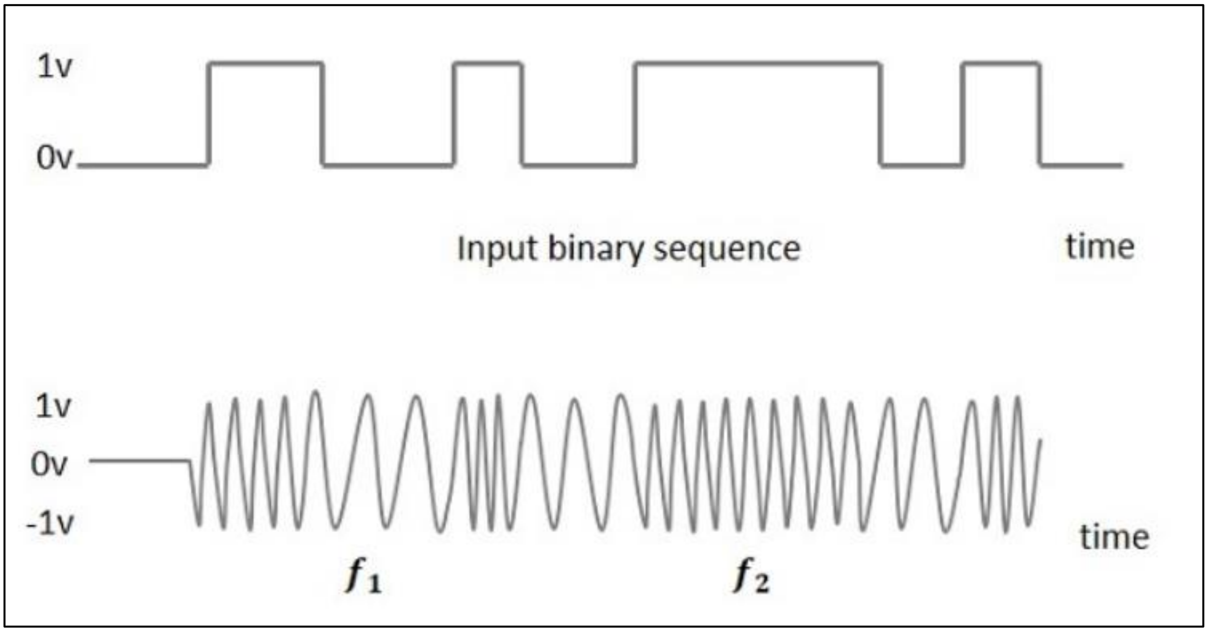

Figure 5: The FSK waveform.

FSK Modulator

The block diagram of an FSK modulator consists of two oscillators, a clock, and an input binary sequence. The following diagram illustrates its structure.

The two oscillators are responsible for generating signals at distinct frequencies—one at a higher frequency and the other at a lower frequency. These oscillators are connected to a switch that selects between them based on the input signal. An internal clock is applied to both oscillators to ensure synchronization and maintain phase continuity, preventing abrupt phase discontinuities in the output waveform during message transmission.

The binary input sequence is fed into the transmitter, which determines the selection of the appropriate frequency. When the input is binary "1," the modulator switches to the higher frequency, and when the input is binary "0," it switches to the lower frequency. This process ensures that the output waveform accurately represents the digital input signal.

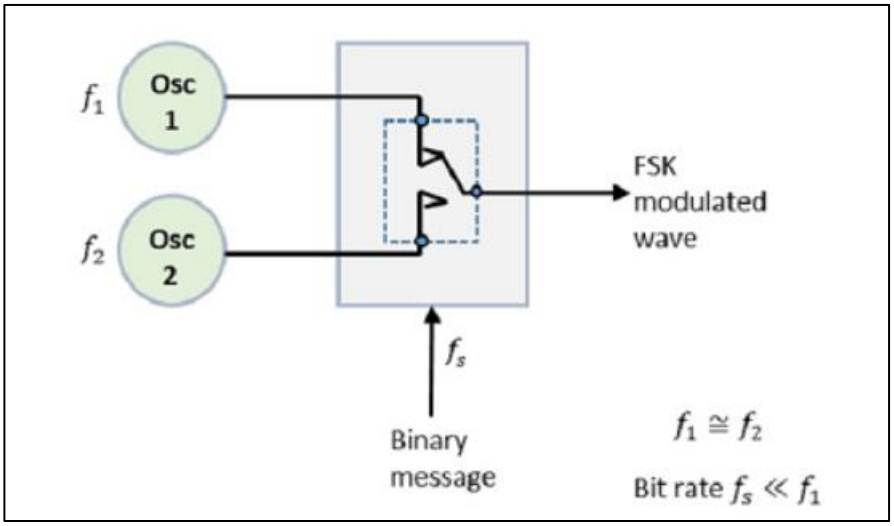

Figure 6: The block diagram of an FSK modulator.

FSK Demodulator

There are various techniques for demodulating an FSK signal. The two primary methods are **synchronous detection** and **asynchronous detection**. The **synchronous detector** is a **coherent** approach that requires a reference signal, whereas the **asynchronous detector** is a **non-coherent** method that operates without the need for synchronization.

1- Asynchronous FSK Detector

The Asynchronous FSK Detector is a non-coherent method used to demodulate Frequency Shift Keying (FSK) signals. Unlike synchronous detection, this method does not require a reference signal synchronized with the received signal.

The block diagram of an asynchronous FSK detector consists of the following components:

1. **Band-Pass Filters (BPFs):**
   - The incoming FSK signal is passed through two Band-Pass Filters (BPF 1 and BPF 2).
   - Each BPF is tuned to one of the two frequencies used in FSK modulation:
     - **BPF 1** is tuned to the **Mark frequency** (representing binary "1").
     - **BPF 2** is tuned to the **Space frequency** (representing binary "0").
   - These filters allow only the respective frequency components to pass through, effectively separating the two frequency components of the incoming FSK signal.
2. **Envelope Detectors:**
   - The outputs from both BPFs resemble Amplitude Shift Keying (ASK) signals.
   - These signals are fed into envelope detectors, which extract the amplitude variations and convert them into baseband signals.
3. **Decision Circuit:**
   - The decision circuit receives the outputs from both envelope detectors and determines which frequency is currently present in the signal.
   - It selects the stronger signal and maps it to the corresponding binary value (either "0" or "1").
   - Finally, it reshapes the waveform into a clean rectangular digital signal, ready for further processing.

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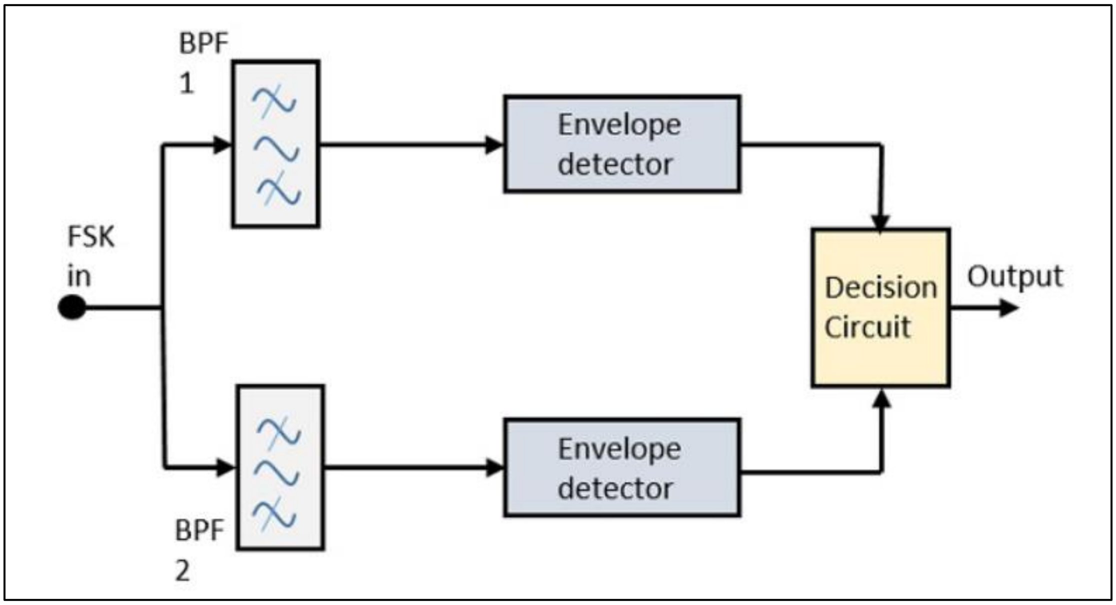

Figure 7: Asynchronous FSK Detector**.**

2- Synchronous FSK Detector

The Synchronous FSK Detector is a coherent demodulation method that relies on a reference signal to extract the transmitted data accurately.

The block diagram of a Synchronous FSK Detector consists of the following components:

1. **Mixers with Local Oscillators:**
   - The incoming FSK signal is fed into two mixers, each paired with a local oscillator circuit.
   - These local oscillators generate reference signals that correspond to the two FSK frequencies.
   - The mixers help shift the input frequencies to an intermediate frequency (IF) or directly to baseband for further processing.

2. **Band-Pass Filters (BPFs):**
   - The outputs from the mixers pass through two Band-Pass Filters (BPFs), each tuned to a specific frequency.
   - These filters help isolate the respective frequency components, effectively acting as demodulators.
3. **Decision Circuit:**
   - The decision circuit analyzes the outputs from both demodulators and determines which signal is more dominant at a given moment.
   - It selects the appropriate frequency and maps it to the corresponding binary value ("0" or "1").

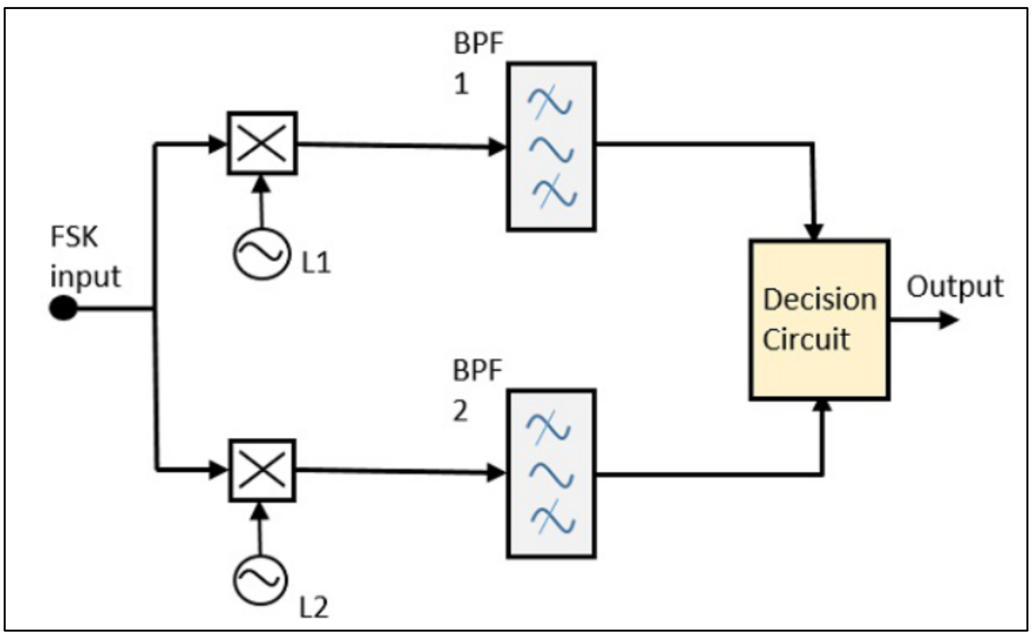

Figure 8: Synchronous FSK Detector.

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Comparison Between ASK and FSK:

Feature	ASK (Amplitude Shift Keying)	FSK (Frequency Shift Keying)
Definition	Modulates the **amplitude** of the carrier wave to represent digital data.	Modulates the **frequency** of the carrier wave to represent digital data.
Noise Resistance	Highly **susceptible to noise**, as amplitude variations can be easily affected by interference.	More **resistant to noise**, since frequency changes are less affected by interference.
Bandwidth Requirement	Requires **less bandwidth**.	Requires **more bandwidth**.
Power Efficiency	More **power-efficient**, but less reliable in noisy environments.	Requires **more power**, but provides better reliability.
Complexity	**Simpler** to implement with basic circuitry.	**More complex** due to frequency synchronization requirements.
Data Transmission Rate	Generally **slower** than FSK in practical applications.	Can achieve **higher data rates** with better noise resistance.
Error Probability	Higher **error rate** due to amplitude distortions.	Lower **error rate**, making it more suitable for long-distance communication.
Application Areas	Used in RFID, optical fiber communication, and low-cost wireless systems**.**	Used in radio transmission, modems, Bluetooth, and high-frequency data transmission**.**
Performance in Noisy Environments	**Poor performance** in noisy environments.	**Better performance** in noisy and wireless environments.

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