Al-Mustaqbal University
Department (Medical Instrumentation Techniques Engineering)
Class (3rd)
Subject (Medical Communication systems)
Lecturer (Dr. Osamah Jaber Ghayyib)
6th Semester – Lect. (PAM, PWM, PPM and PCM)

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CONTENTS

LEARNING OBJECTIVES

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

1- Explain the concept of pulse modulation and its importance in medical communication systems.

2- State and apply the Sampling Theorem in signal transmission.

3- Differentiate between analog pulse modulation and digital pulse modulation.

4- Describe the working principles of:

- Pulse Amplitude Modulation (PAM)

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- Pulse Width Modulation (PWM)

- Pulse Position Modulation (PPM)

- Pulse Code Modulation (PCM)

5- Compare Natural PAM and Flat-Top PAM.

6- Explain the generation methods of PWM and PPM signals.

7- Define quantization and quantization noise in PCM systems.

8- Calculate quantization levels and relate them to the number of bits used.

9- Describe different PCM encoding techniques:

10- Analyze the advantages of PCM over analog pulse modulation in terms of noise immunity and signal quality.

1 INTRODUCTION

In modern medical instrumentation systems, reliable transmission of physiological signals such as ECG, EEG, EMG, blood pressure, and respiratory signals is essential. These signals are typically analog in nature and must be transmitted, processed, and stored efficiently with high accuracy and minimal noise distortion.

Pulse modulation techniques provide an effective method for converting continuous-time analog signals into pulse-based representations suitable for communication systems. In pulse modulation, the message signal is sampled at regular intervals, and specific characteristics of pulses—such as amplitude, width, position, or digital code—are varied according to the instantaneous value of the signal.

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Analog pulse modulation techniques modify a pulse parameter directly according to the signal amplitude, while digital pulse modulation converts the sampled signal into discrete binary codes, offering better noise immunity and reliability.

In medical communication systems, these techniques play a critical role in patient monitoring devices, telemetry systems, digital medical recorders, and remote healthcare applications. Understanding these modulation methods is fundamental for designing efficient biomedical communication systems.

2   PULSE MODULATION

Pulse modulation is a type of modulation in which the signal is transmitted in the form of pulses. It can be used to transmit analogue information. In pulse modulation, continuous signals are sampled at regular intervals.
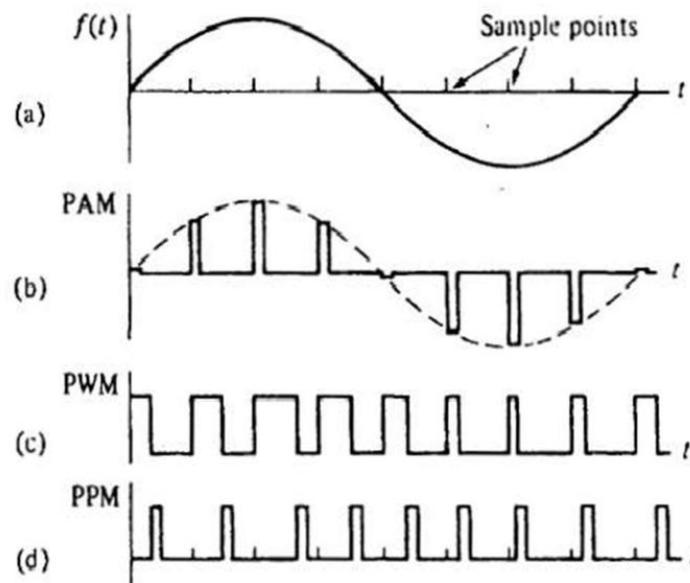

Figure 1: Pulse Modulation.

In Analog Pulse Modulation, analog information is transmitted by varying certain characteristics of the pulses, such as their amplitude, duration, or position. On the other hand, Digital Pulse Modulation involves transmitting information by encoding it into

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discrete digital pulses. Pulse modulation, as a whole, serves as an effective means of transmitting both analog and digital information, depending on the specific type employed.

2.1 PULSE AMPLITUDE MODULATION (PAM)

Pulse Amplitude Modulation (PAM) is a modulation technique where the amplitude of each pulse is determined by the instantaneous amplitude of the modulating signal. In this method, the original signal is sampled at regular intervals, and each sample's amplitude corresponds directly to the amplitude of the signal at the specific sampling instant.

This technique is commonly used to encode information in the form of amplitude variations of the pulses. Pulse amplitude modulation is further categorized into two types based on the polarity of the message signal:

- **Single-Polarity-PAM:**
  In this type of PAM, all pulse amplitudes are kept positive by adding a fixed DC bias to the modulating signal. This ensures that the signal does not cross the zero level, maintaining a unipolar characteristic.

- **Double-Polarity-PAM:**
  In double polarity PAM, the pulses can have both positive and negative amplitudes. The modulating signal is allowed to take its natural form, enabling the pulses to reflect the original signal's polarity, resulting in a bipolar characteristic.

This classification enables PAM to represent a variety of signal types depending on the requirements of the communication system, as shown in the diagram, which illustrates the modulating signal, pulse carrier, and the resulting PAM signals for both double-polarity and single-polarity cases. **Pulse Amplitude Modulation (PAM)** is categorized into two types:

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1. **Natural PAM**

2. **Flat-Top PAM**

2.1.1 NATURAL PAM

- In this method, the top of each pulse follows the natural shape of the modulating signal during the sampling interval.
- The amplitude of the pulses varies smoothly, maintaining continuity with the modulating signal.
- Natural PAM provides a more accurate representation of the original signal but can be more prone to distortion due to the overlap of adjacent pulses in certain systems.
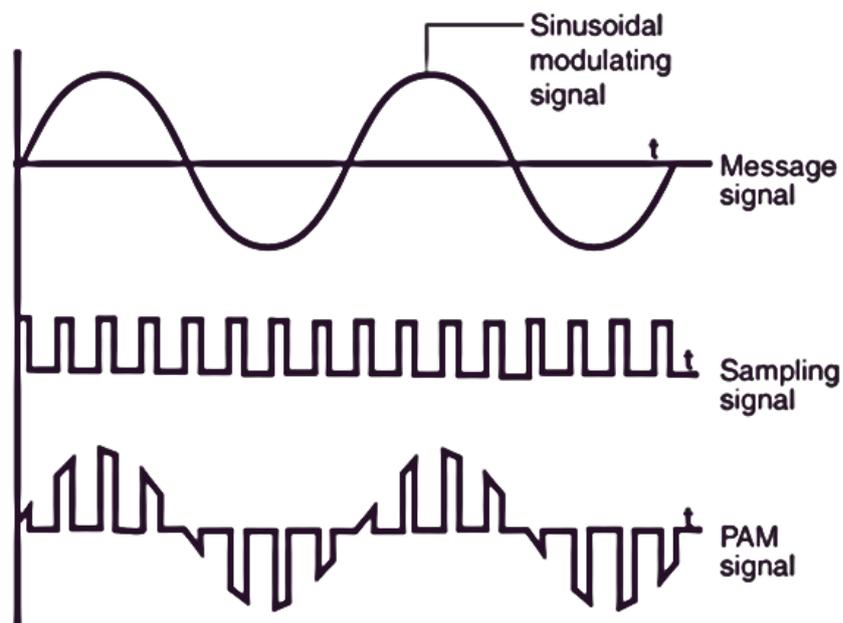

Figure 2: Natural PAM.

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2.1.2 FLAT-TOP PAM

- In this method, the top of each pulse is flattened and held constant for the entire duration of the pulse.

- The amplitude of the pulse is determined at the sampling instant and remains constant until the next pulse.

- Flat-top PAM is less sensitive to distortion caused by overlapping pulses, making it more suitable for digital communication systems. However, it introduces a small error known as aperture distortion because of the flat-top approximation.
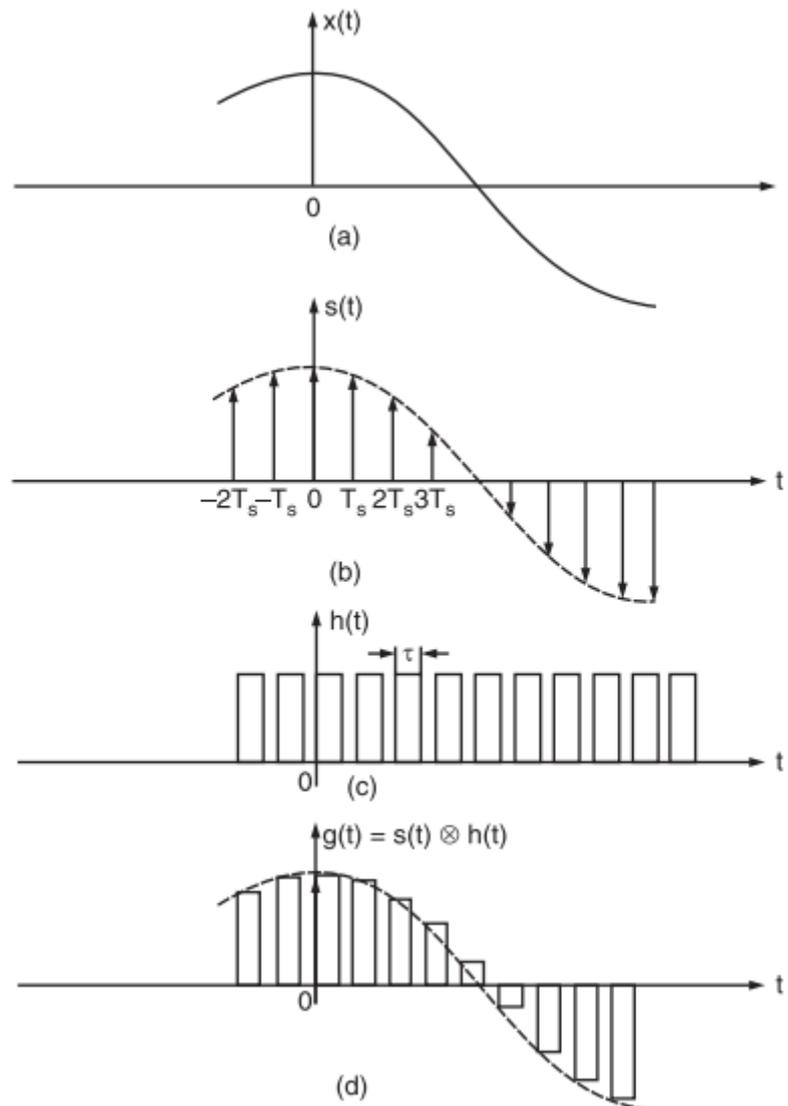

Figure 3: Flat-top PAM.

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Both types are used depending on the application, with flat-top PAM being more common in modern communication systems due to its robustness and ease of implementation.
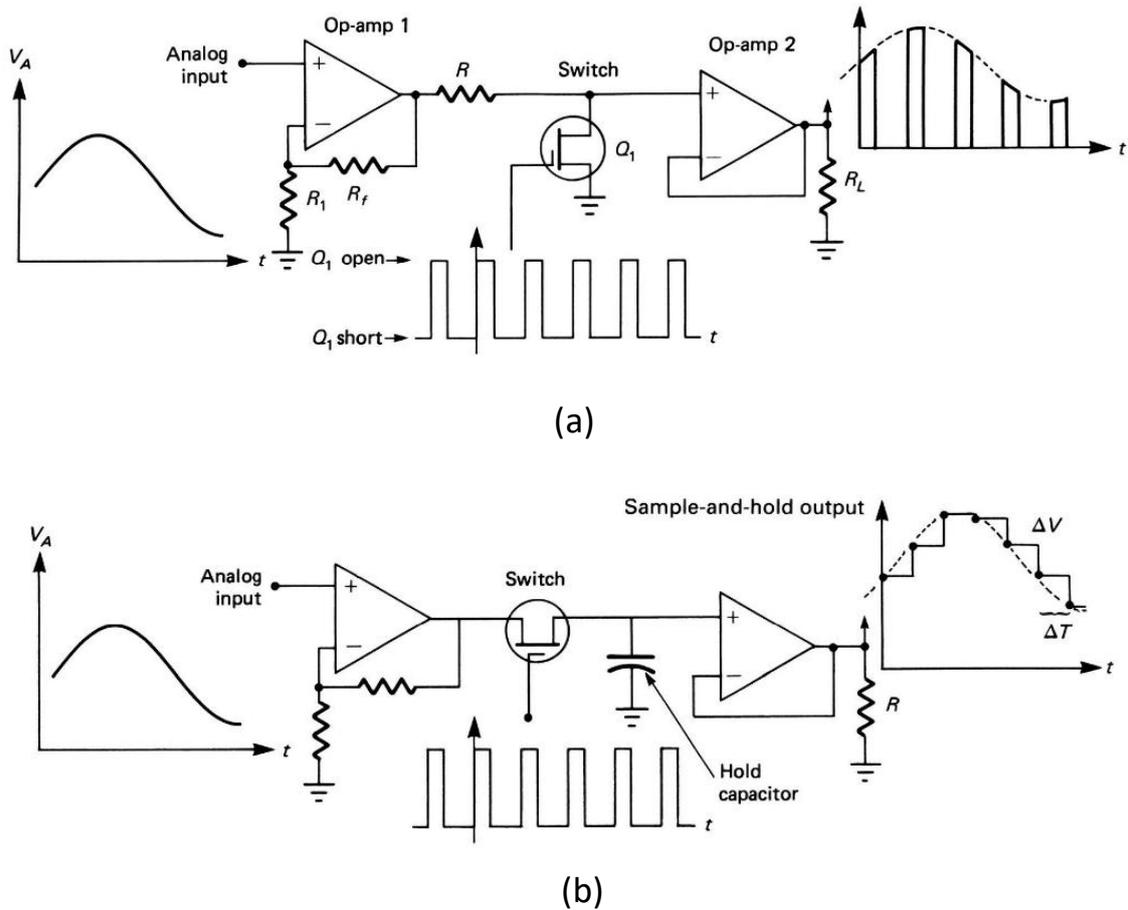

(a)

(b)

Figure 4: PAM Generation circuit.

2.2 PULSE WIDTH MODULATION (PWM)

Pulse Width Modulation (PWM) is a technique used in communication systems to encode information into a pulsing signal by varying the width (duration) of the pulses while keeping the frequency constant. This method is particularly useful in digital and analog communication for transmitting signals efficiently with minimal distortion.

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In analog communication, PWM is used as a modulation scheme to convert analog signals into a series of pulses. The width of each pulse corresponds to the amplitude of the original analog signal at a specific time. This allows for effective transmission of audio and video signals while maintaining a degree of resistance to noise. Compared to traditional Amplitude Modulation (AM) and Frequency Modulation (FM), PWM is less affected by amplitude variations caused by channel noise, making it a reliable method for signal transmission.

In digital communication, PWM is commonly employed in data encoding and optical transmission systems. For instance, in infrared (IR) remote controls, digital information is represented by pulses of varying width, allowing devices to interpret binary data efficiently. Similarly, in fiber optic communication, PWM can be used to modulate laser signals, ensuring accurate data transmission over long distances.

Key Characteristics of PWM:

1. **Duty Cycle Variation:** The percentage of time the pulse remains in the "ON" state within one cycle determines the encoded information.

2. **Constant Frequency:** Unlike other modulation techniques, PWM maintains a fixed carrier frequency, ensuring stable transmission.

3. **Noise Immunity:** As information is embedded in pulse width rather than amplitude, PWM signals are less affected by interference and amplitude distortion.

4. **Power Efficiency:** Since the signal switches between "ON" and "OFF" states, PWM allows for efficient power utilization, making it ideal for wireless communication.

2.2.1 GENERATION OF PWM SIGNAL

The generation of a **Pulse Width Modulation (PWM)** signal involves modulating the width of a pulse based on an input signal while maintaining a constant frequency. This

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technique is widely used in communication and control systems for efficient signal transmission and power management.
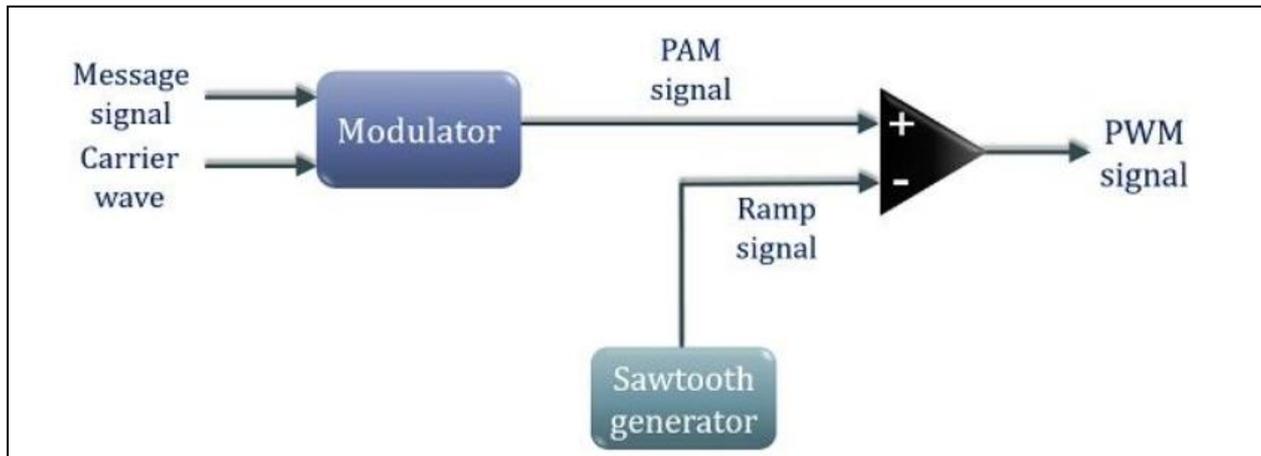

Figure 5: Generation of PWM.

The figure above illustrates the process of PWM signal generation, which is commonly known as an **indirect method** of PWM generation.

1. **Input Signals to the Modulator:**

   o A **message signal** (modulating signal) and a **carrier waveform** are fed into a modulator, which produces a **Pulse Amplitude Modulated (PAM) signal**.

   o This PAM signal is then applied to the **non-inverting terminal** of a **comparator circuit**.

2. **Ramp Signal from the Sawtooth Generator:**

   o A **sawtooth wave (ramp signal)** is generated using a **sawtooth generator** and is applied to the **inverting terminal** of the comparator.

3. **Comparison and Pulse Formation:**

   o The **PAM signal and the ramp signal** are compared with a **reference voltage** set within the comparator circuit.

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o The comparator's threshold level is adjusted so that the **intersection** of the reference voltage with the ramp waveform determines the pulse width.

4. **PWM Pulse Generation:**

   o The **PWM pulse starts** at the **leading edge** of the ramp signal.

   o The **width of the pulse** is defined by the **comparator circuit**, which determines where the ramp signal crosses the reference voltage.

2.3 PULSE POSITION MODULATION (PPM)

Pulse Position Modulation (PPM) is a **pulse modulation technique** commonly used in communication systems to transmit information by varying the **position** of each pulse based on the amplitude of the modulating signal. Unlike other pulse modulation techniques such as **PAM** or **PWM,** PPM keeps both the **amplitude and width of the pulses constant**, modifying only their timing (position). This method belongs to the Pulse Time Modulation (PTM) category, where information is encoded in the timing of the pulses rather than their amplitude or width.

This technique is particularly useful in applications where high noise immunity, power efficiency, and signal clarity are essential. By encoding information in the timing of the pulses rather than their amplitude or width, PPM reduces the impact of noise and interference that typically affect analog and amplitude-based signals. As a result, it is widely used in optical communication systems, infrared (IR) communication, deep-space telemetry, and wireless data transmission.

2.3.1 GENERATION OF A PPM SIGNAL

A Pulse Position Modulation (PPM) signal can be easily generated using a **PWM signal** as an intermediate step. In this process, we assume that a PWM signal has already been generated at the output of a comparator, and the next step is to derive a **PPM signal** from it.
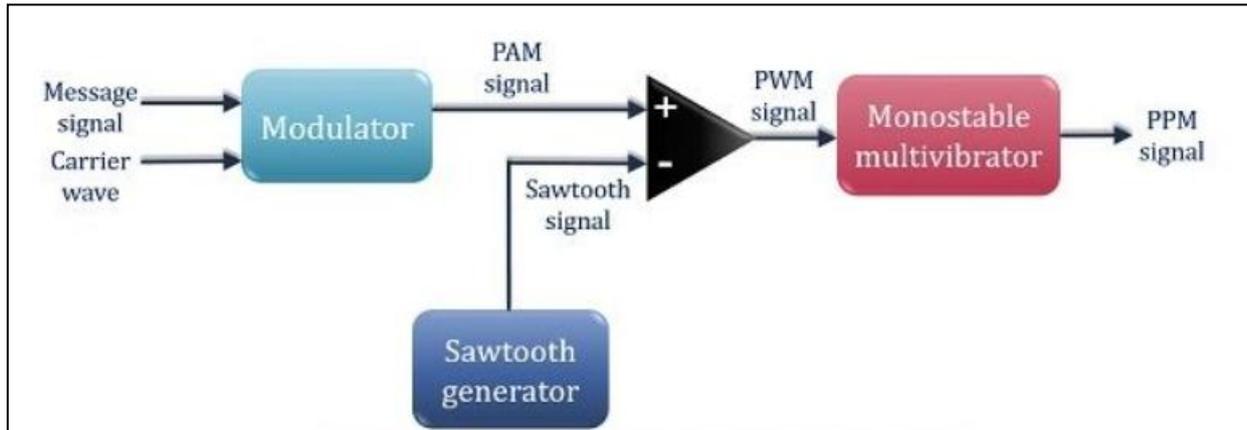
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Figure 6: Block diagram for generation of PPM signal.

To explain this in detail, let's break it down step by step:

1. **Initial Signal Processing:**

   o The process begins with the generation of a **Pulse Amplitude Modulation (PAM) signal**.

   o This PAM signal is then processed using a **comparator circuit**, which converts it into a **PWM signal**.

2. **Using a Monostable Multivibrator:**

   o The output of the comparator (PWM signal) is then fed into a **monostable multivibrator**, which is **negative-edge triggered**.

   o This means that the **monostable multivibrator is activated when it detects the trailing edge of the PWM signal**.

   o As a result, when the trailing edge of the PWM pulse occurs, the output of the monostable circuit **goes high**, generating a PPM pulse.

3. **Formation of PPM Pulses:**

   o Since the PPM pulse is triggered by the **trailing edge of the PWM pulse**, each PPM pulse begins at the point where the PWM pulse ends.

   o The **width of each PPM pulse remains constant** because the duration of the output high state is determined by the **RC components** of the monostable multivibrator.

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4. **Effect of the Modulating Signal:**

   - The position of each PPM pulse depends on the **modulating signal**.
   - Since the **PWM pulse width varies** with the modulating signal, its **trailing edge shifts accordingly**.

This shift in the trailing edge causes a corresponding **shift in the position of the PPM pulses**, encoding the information in the timing of the pulses rather than their width or amplitude.

2.3.2 GENERATION OF PWM AND PPM

Generation of pulse-timing modulation commonly employs various combinations of a sample-and-hold circuit, a precision ramp voltage generator, and a comparator. The block diagram of a typical circuit for generating PWM and PPM is shown Figure 7.
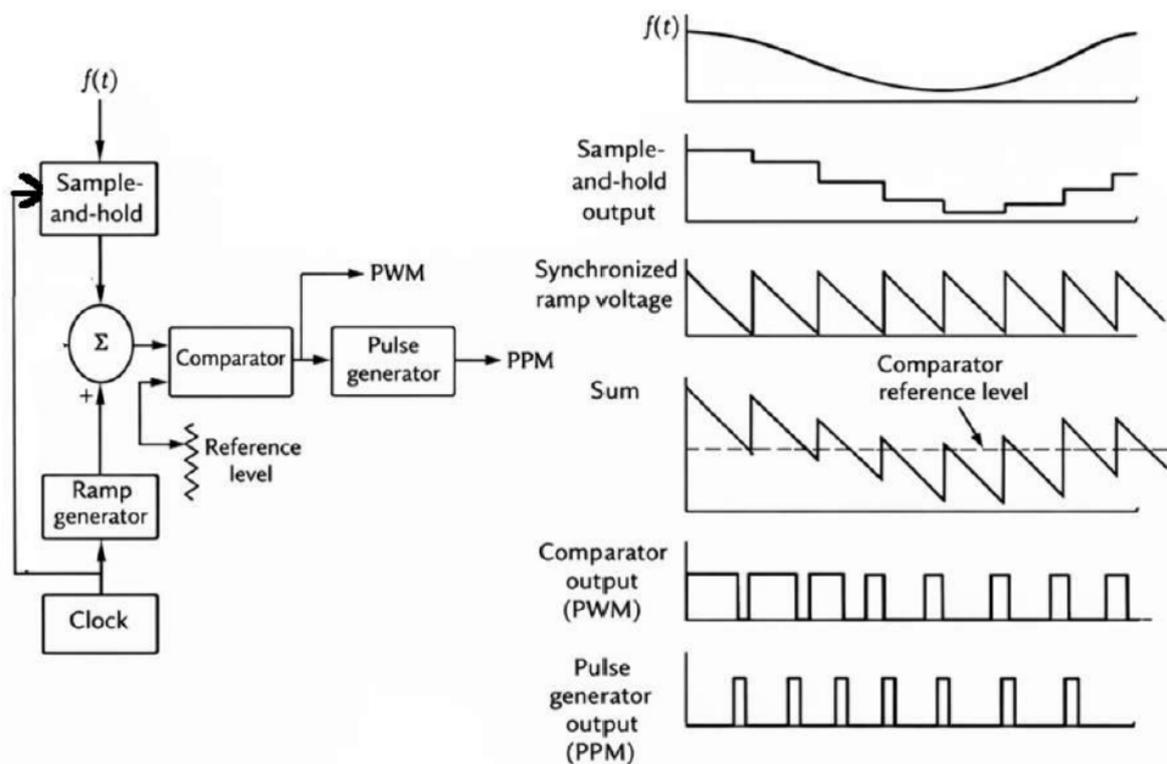

Figure 7: PWM & PPM.

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The ramp generator produces a precision ramp voltage that has a peak-to-peak amplitude slightly larger than the maximum amplitude range of the input signals. This ramp voltage is the basis for the amplitude-to-timing conversion and therefore must be accurately known. It is resettable by the clock command. The comparator is a high-gain amplifier intended for two-state operation. If the input signal is higher than a preset reference level, the output is held in one state (i.e., a given volt-age level). Whenever the input signal level is less than the reference level, the output.

2.4 PULSE CODE MODULATION (PCM)

The major form of digital pulse modulation (DPM) is pulse code modulation (PCM). its primary advantage is much better noise and interference immunity.
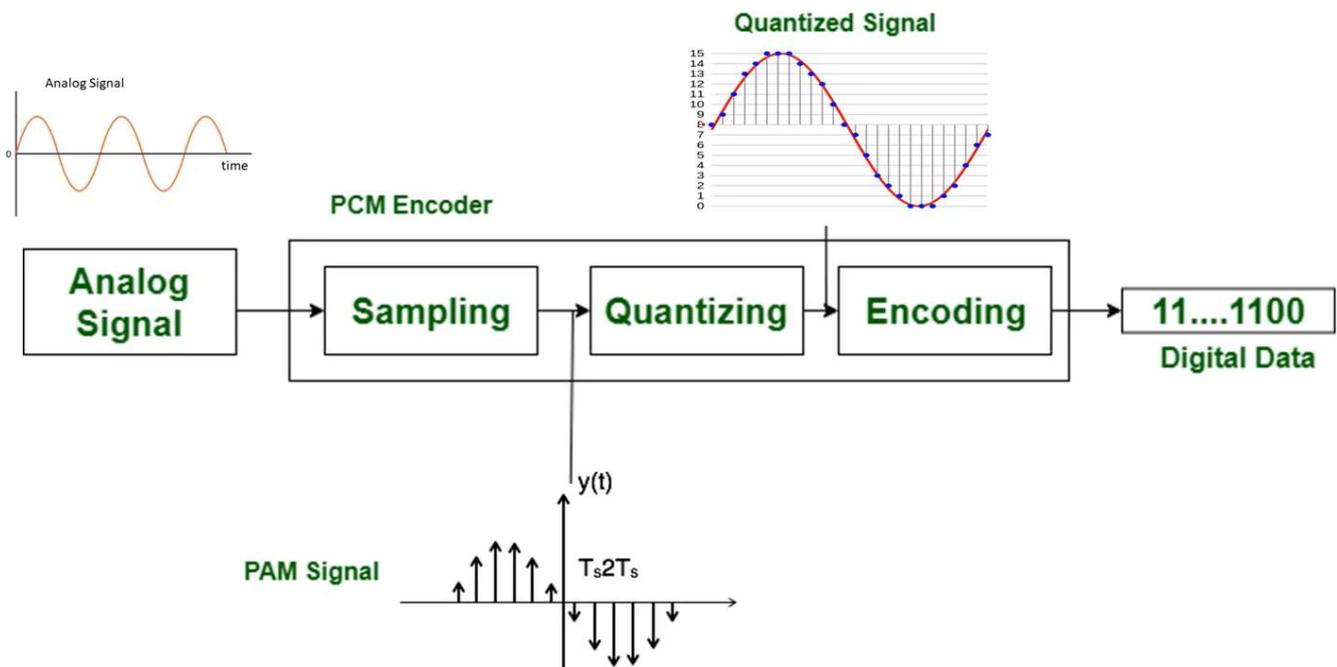

Figure 8: Block Diagram of PCM.

The preceding types of pulse modulation made use of the discrete time samples of analog signals. In these cases, the transmission is composed of analog information sent at discrete times. The variation of pulse amplitude or pulse timing is allowed to vary

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continuously over all values. A further refinement is to quantize the sampled analog signal into a number of discrete levels. This is sometimes done in PAM systems and is referred to as "M-ary PAM," where M designates the number of levels used. We now not only quantize the sampled analog signal into a number of discrete levels but also use a code to designate each level at each sample time. This type of modulation is called pulse-code modulation (PCM).

2.4.1 QUANTIZATION

In PCM the modulating signal is sampled, the sampled amplitude converted into a binary and the binary code is transmitted a group as a train of pulses. A major difference is that PCM the sampled amplitude must be transmitted as a specific binary number out of a limited range of binary numbers to accomplish this, each sample must be: first converted to the nearest standard amplitude, called quantum. This process of sample conversion is called quantizing the signal.

$$\text{Quantization level} = \mathbf{2^n} \qquad\qquad (1)$$

Where, n of bit

If $n = 3 \longrightarrow$ Quantization level $= 2^3 = 8$

If $n = 7 \longrightarrow$ Quantization level $= 2^7 = 128$

2.4.1.1 Quantization noise

It is the difference between sampling point amplitude and quantum level. Quantization noise can be reducing by increasing the number of Quantization level, however a disadvantage of increasing the number of levels is an increased transmission bandwidth requirement. Suppose, for example, that we wish to quantize one-half a cycle of a $1 - V$ (peak) sinusoid using eight discrete levels. At each sample time we must decide which of these eight levels is the best approximation to the sinusoid. We choose the closest value

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(some other criterion can be chosen as well, depending on the particular circuit), and use this value until the next sample time, etc. Obviously, this process of quantization introduces some fluctuations about the true value; these fluctuations can be regarded as noise. An increase in the number of quantizing levels assigned will tend to decrease this quantization noise. The quantization may be linear or it may be nonlinear (i.e., nonuniform level spacings).
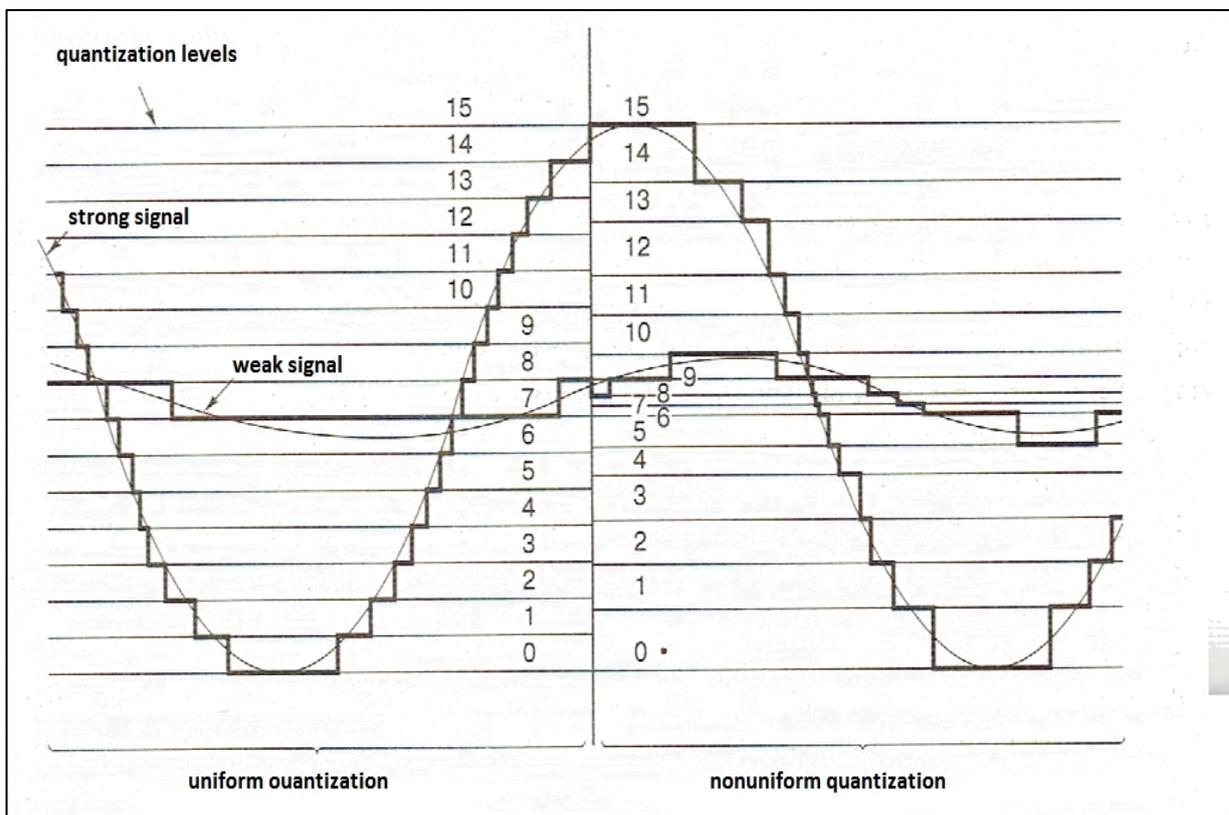

Figure 9: Uniform Vs Nonuniform Quantization.

2.4.2 GENERATION OF PCM

2.4.2.1 Ramp Encoder

In Pulse Code Modulation (PCM), a ramp **encoder** (also known as a **level-at-a-time coder**) is a specific type of analog-to-digital converter (ADC) that converts a sampled analog level into a binary code by comparing it to a linear voltage ramp.
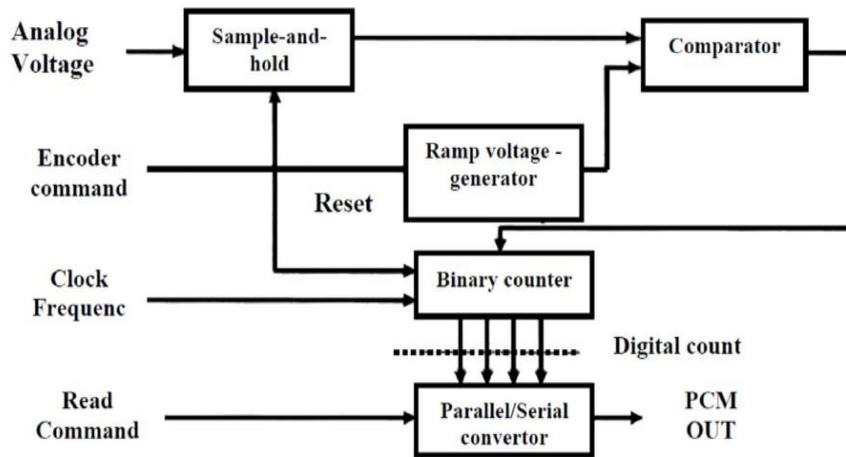
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Figure 10: Ramp Encoder.

The ramp-type PCM encoder typically includes the following functional blocks:

- **Sample-and-Hold (S&H) Circuit**: Captures and holds the instantaneous voltage of the analog input signal at specific intervals.

- **Ramp Generator**: Produces a linear voltage ramp (often a **sawtooth wave**) that starts at zero and increases at a constant rate.

- **Comparator**: Compares the held analog sample to the increasing ramp voltage. It outputs a "high" signal as long as the ramp is lower than the sample.

- **Clock & Binary Counter**: A high-frequency clock drives a binary counter that begins counting the moment the ramp starts.

- **Control Logic/Gate**: When the ramp voltage exceeds the sample voltage, the comparator switches, signaling the logic to stop the counter or latch its current value.

- **Output Register**: The final value in the counter represents the digital PCM codeword for that specific sample.

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2.4.2.2 Feedback Encoder

The accuracy of the feedback encoder is dependent on the accuracy of the trial voltages; speed is limited by the speed with which the voltage-divider switches can be operated. The feedback encoder requires more precision components than the ramp encoder, but it also allows a more accurate encoding.
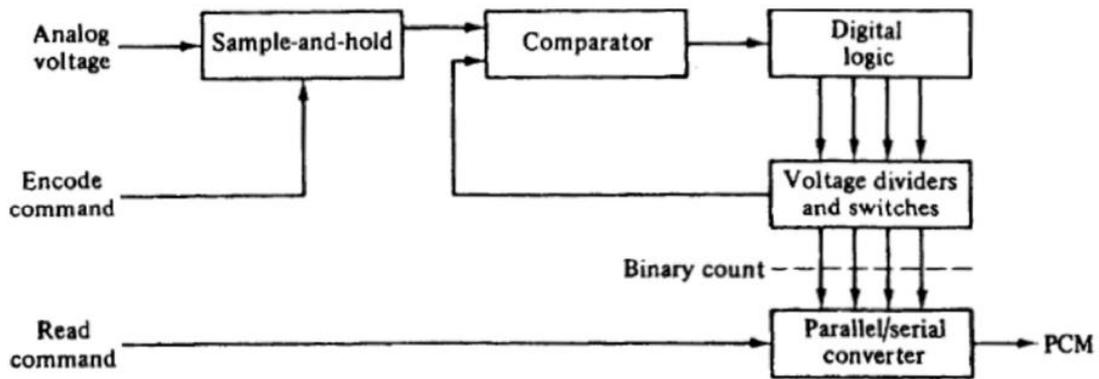

Figure 11: Feedback Encoder.

2.4.2.3 Parallel of Flash Encoder

Resistive dividers are operated by switches that are controlled by the binary code. By weighting the resulting voltage levels in the same proportions as the weights of the code pulses, we produce a composite voltage, which reproduces the original quantized voltage. This receiver design is simple and widely used in instrumentation systems. It is generally not used on long-distance communication systems, which attempt to maintain as low an error rate as possible.
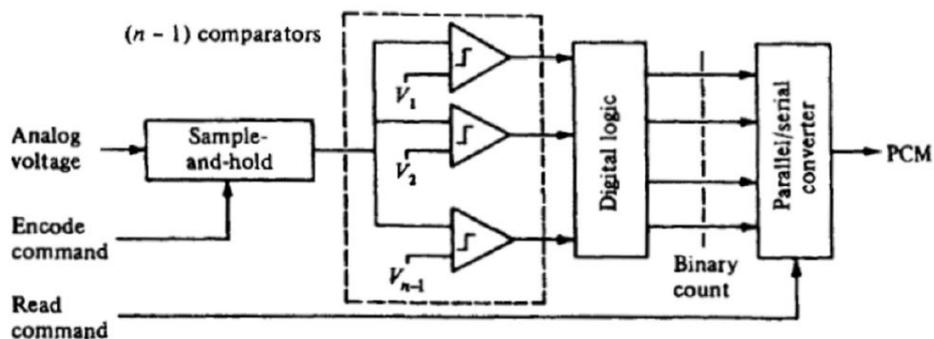

Figure 12: Parallel of Flash Encoder.

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2.4.3 RECEIVER OF PCM

Figure 13 illustrates the block diagram of the PCM receiver. In the PCM receiver, the process begins with a regenerator.

- This **regenerator's role** is to reshape the received pulse signal, correcting any distortion and removing noise that may have been introduced during transmission. This ensures that the signal is as accurate as possible before further processing.

- Once the pulse is regenerated, the signal is then converted into parallel digital words, where each digital word corresponds to a sample of the original signal. These digital words represent the quantized values of the continuous-time signal at specific intervals, which were taken during the sampling process.

- Afterward, each of these digital words is converted back to its corresponding analog value, denoted as $x_q t$. This conversion is carried out using a sample-and-hold circuit, which takes each digital word and holds its value for a short period to allow for smooth reconstruction.

- The output from the sample-and-hold circuit is still not a perfect analog signal, so it is passed through a low-pass reconstruction filter. This filter is essential for smoothing out the signal and removing any high-frequency components that might have been introduced during the quantization and sampling process. The output of this filter is the reconstructed signal, which closely matches the original message signal, denoted as y(t).
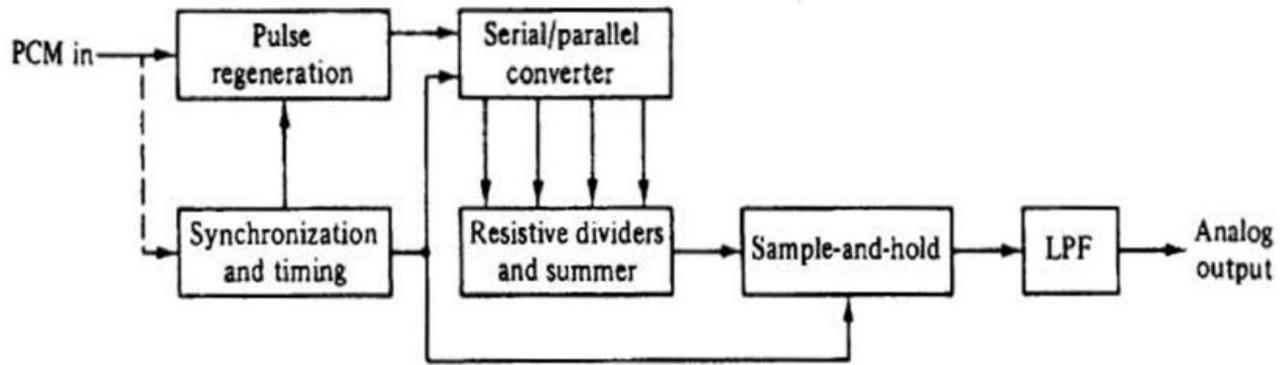
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Figure 13: PCM Receiver.

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