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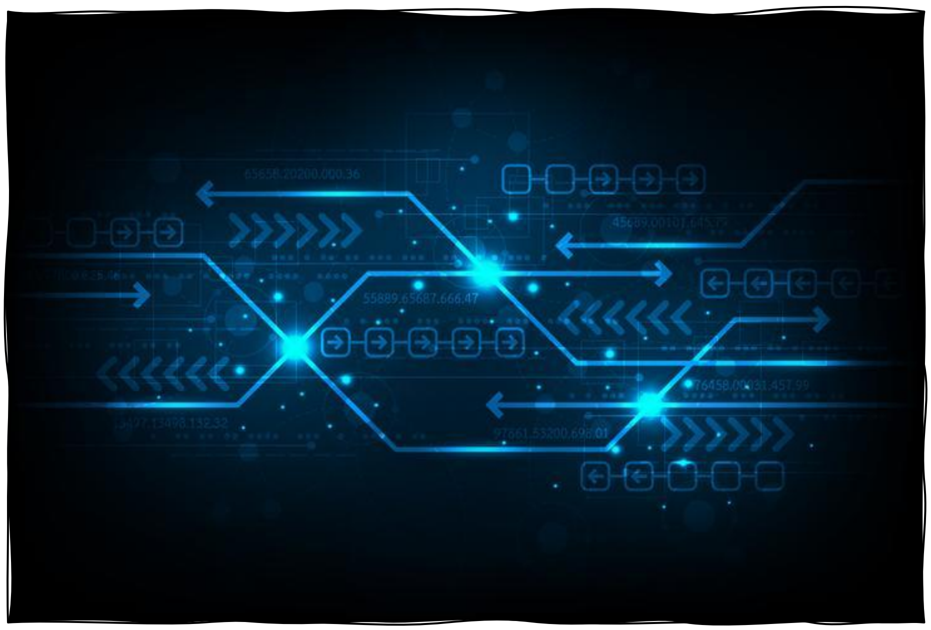
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & M.Sc. Huda Wasfi Hassoon
Lecture:10

Lecture 10

Part 2: Pulse Modulation



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Pulse modulation is a method of transmitting signals where information is conveyed through pulses. This technique is broadly classified into two categories: Analog Pulse Modulation and Digital 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 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.

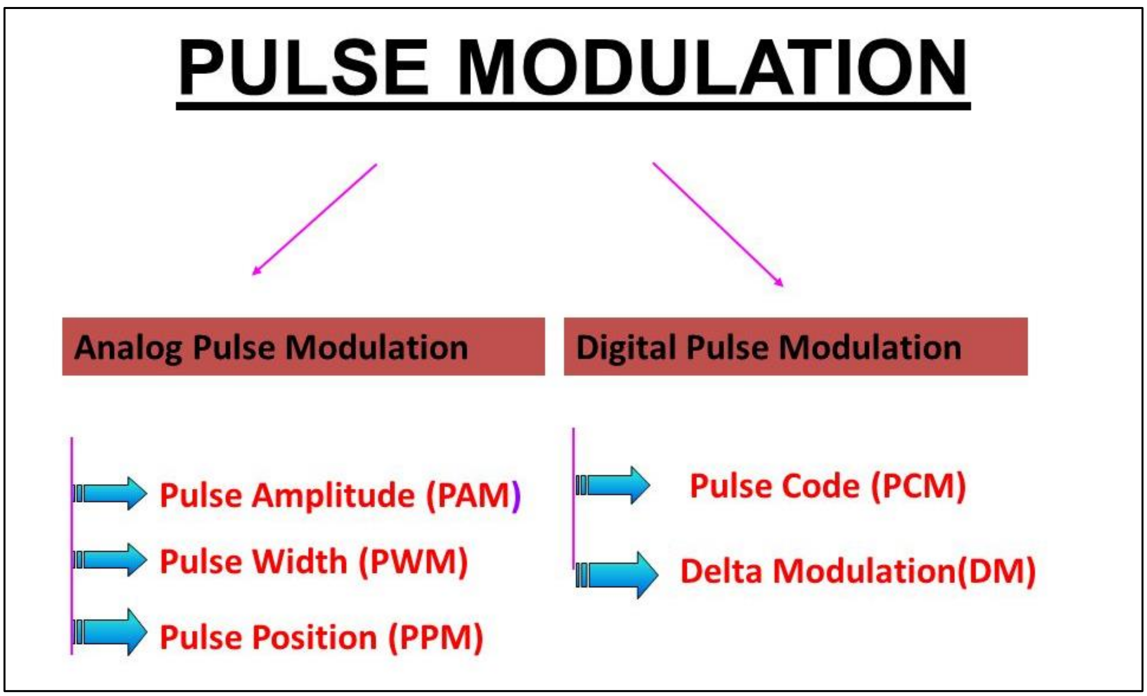

Figure 1: Types of Pulse Modulation.

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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.

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.

Generation of PWM Signal and Waveform Representation

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

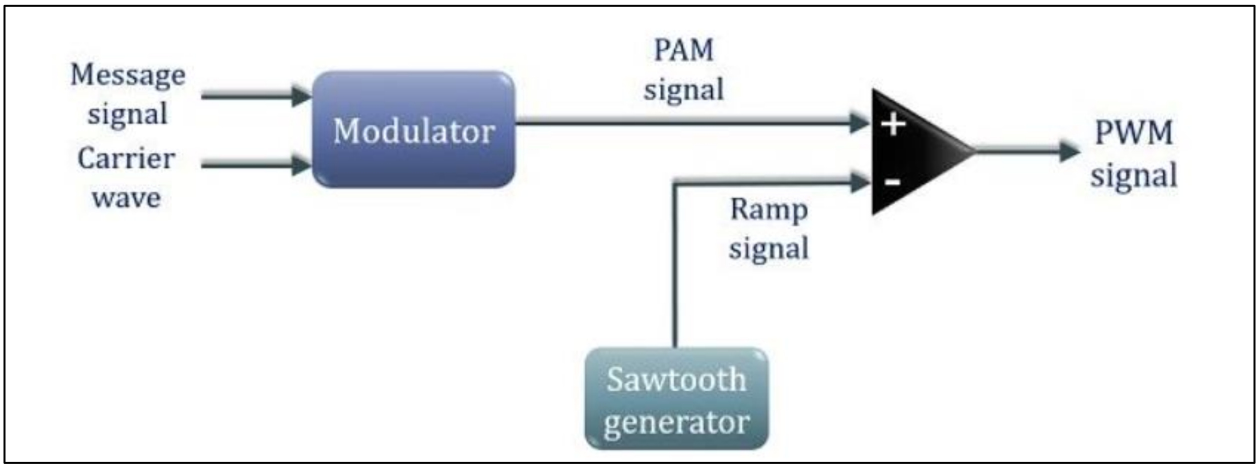

Figure 2: Generation of PWM.

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:**
   - A **message signal** (modulating signal) and a **carrier waveform** are fed into a modulator, which produces a **Pulse Amplitude Modulated (PAM) signal**.
   - This PAM signal is then applied to the **non-inverting terminal** of a **comparator circuit**.
2. **Ramp Signal from the Sawtooth Generator:**
   - 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:**
   - The **PAM signal and the ramp signal** are compared with a **reference voltage** set within the comparator circuit.
   - 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:**
   - The **PWM pulse starts** at the **leading edge** of the ramp signal.
   - The **width of the pulse** is defined by the **comparator circuit**, which determines where the ramp signal crosses the reference voltage.
5. **Proportional Pulse Width Control:**
   - The width of the PWM signal is directly proportional to the portion of the ramp signal that is **omitted** by the comparator level.

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- A higher input signal amplitude results in a wider pulse, while a lower amplitude results in a narrower pulse.

The figure below provides a clearer visualization of how a comparator circuit generates a PWM signal from an input waveform.

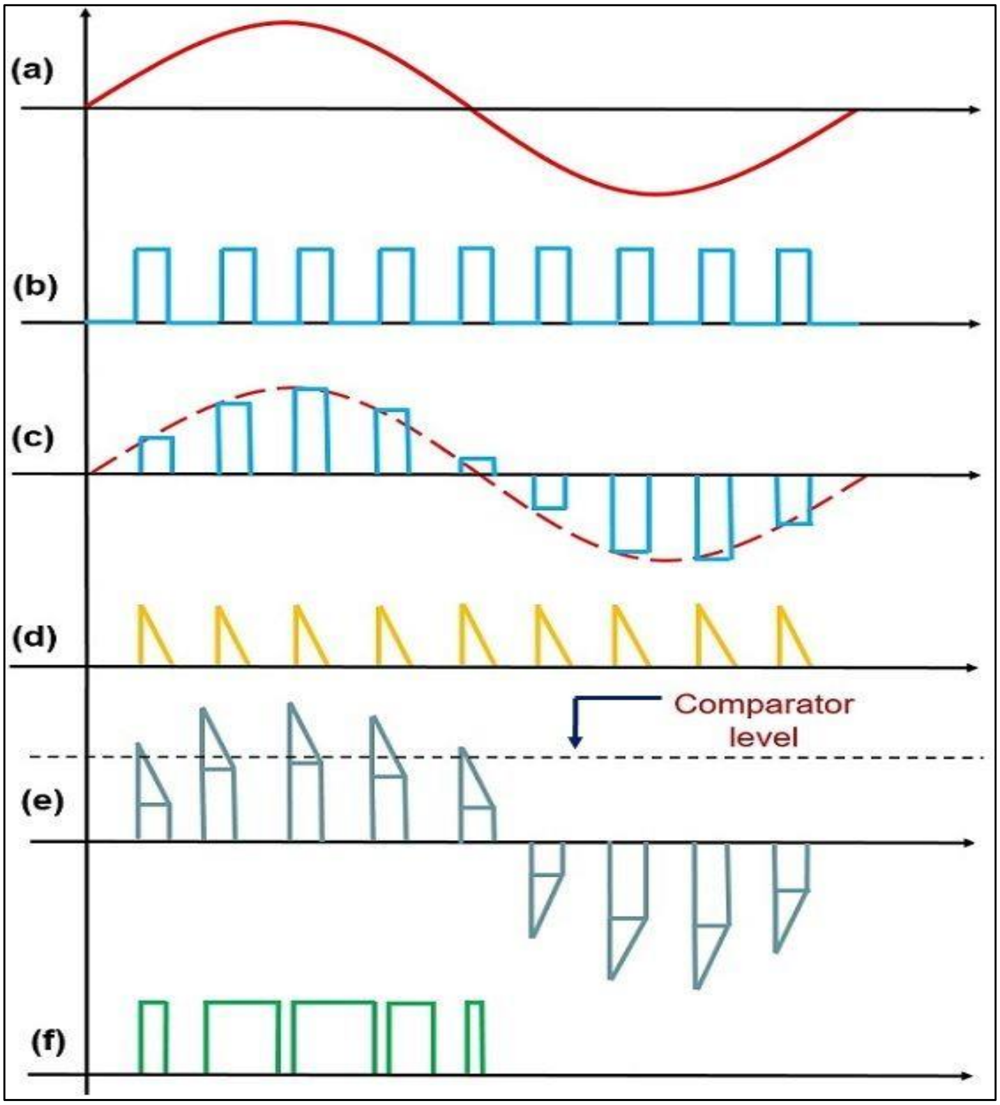

Figure 3: PWM waveform. (a) The sinusoidal modulating signal, (b) the pulsed carrier, (c) The PAM signal, (d) the ramp signal, (e) the reference voltage of the comparator, (f) the PWM signal.

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Detection of PWM Signal

The detection of a **Pulse Width Modulation (PWM)** signal involves extracting the original message signal from the modulated PWM waveform. The figure below illustrates the process of PWM signal detection.

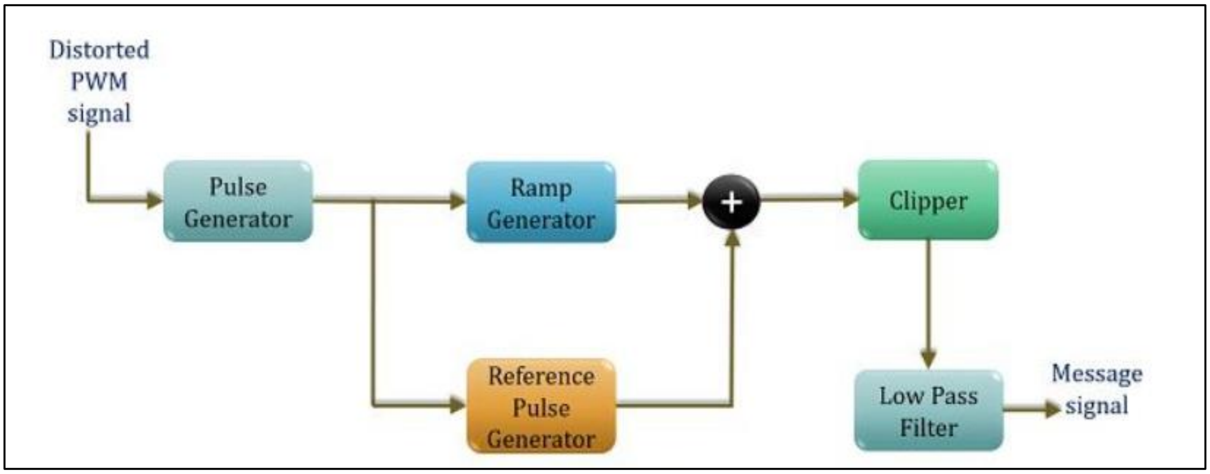

Figure 4: PWM Signal Detection.

Steps in PWM Signal Detection:

1. **Noise Removal and Signal Regeneration:**
    - During signal transmission, **noise** may interfere with the PWM signal.
    - To remove this noise, the received PWM signal is first passed through a **pulse generator**, which **regenerates** a clean PWM waveform.
2. **Reference Pulse Generation:**
    - The regenerated PWM signal is then sent to a **reference pulse generator**, which produces **pulses of constant amplitude and width**.
3. **Ramp Signal Generation:**

- The regenerated PWM pulses are also fed into a **ramp signal generator**.
- This generator creates a **ramp signal with a constant slope**, where the **duration of the ramp corresponds to the width of the PWM pulse**.
- As a result, the **height of the ramp signal becomes proportional to the width of the PWM pulse**.

4. **Summation and Signal Clipping:**
   - The **constant amplitude pulses** from the reference generator are then added to the **ramp signal** using a **summation unit**.
   - The **combined signal** is passed through a **clipper circuit**, which removes unwanted portions of the waveform by clipping it up to a threshold level.
   - This process results in a **Pulse Amplitude Modulated (PAM) signal**.
5. **Low-Pass Filtering to Retrieve the Original Signal:**
   - Finally, the PAM signal is passed through a **Low-Pass Filter (LPF)** to extract the **original message signal** from the modulated waveform.

This process ensures that the original information is accurately recovered from the transmitted PWM signal, even in the presence of noise.

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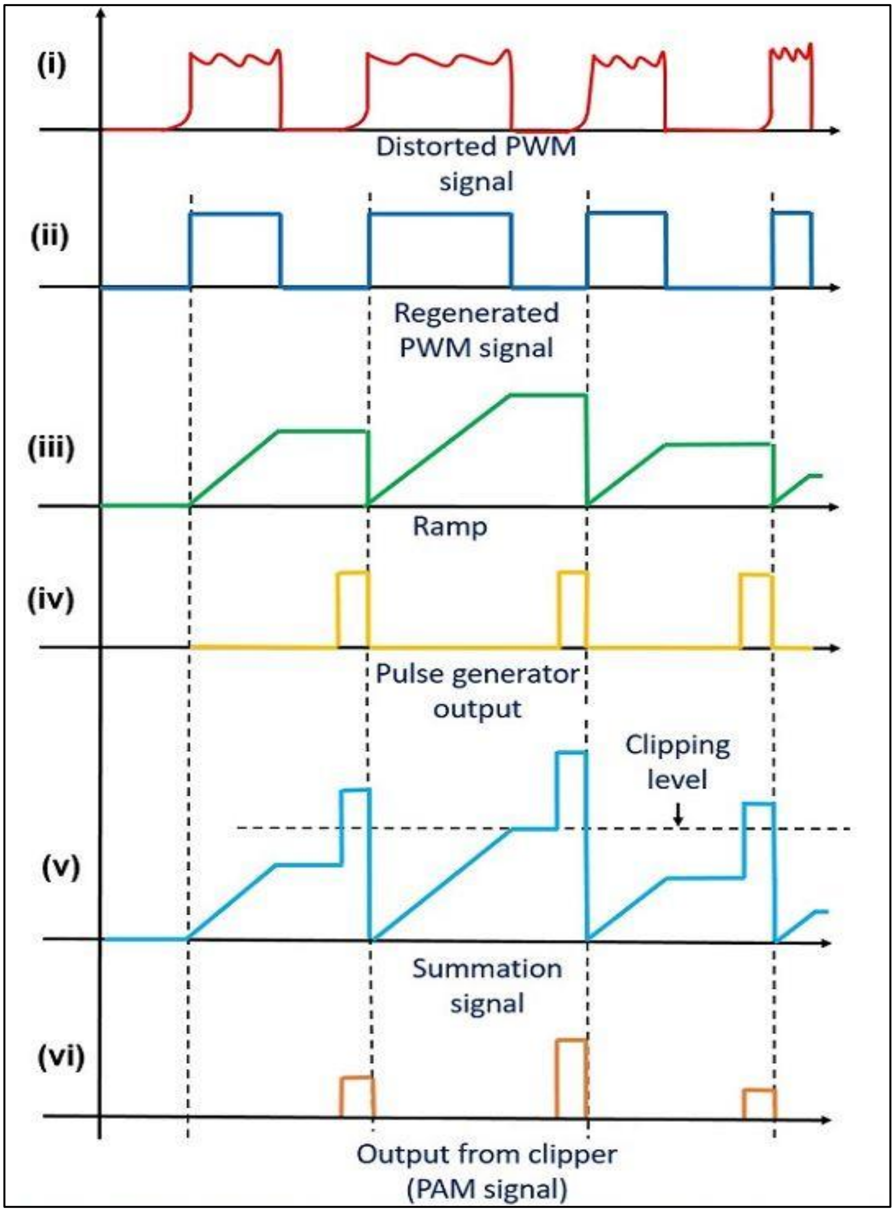

Figure 5: Waveform representation of the process of PWM detection.

(i) shows the distorted PWM wave, (ii) shows the regenerated PWM pulse, (iii) The operation of the ramp generator, (iv) shows the output of the reference pulse generator, (v)The summation operation and clipping off the signal, (vi) represents the PAM pulses from which the original message signal is recovered.

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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.

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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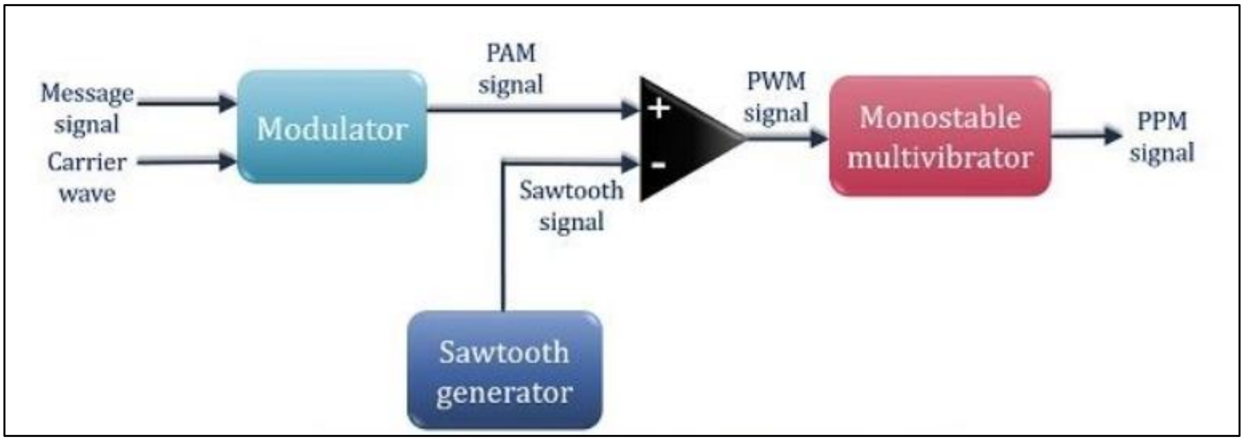

Figure 6: Block diagram for generation of PPM signal.

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

1. **Initial Signal Processing:**
   - The process begins with the generation of a **Pulse Amplitude Modulation (PAM) signal**.
   - This PAM signal is then processed using a **comparator circuit**, which converts it into a **PWM signal**.
2. **Using a Monostable Multivibrator:**
   - The output of the comparator (PWM signal) is then fed into a **monostable multivibrator**, which is **negative-edge triggered**.
   - This means that the **monostable multivibrator is activated when it detects the trailing edge of the PWM signal**.
   - As a result, when the trailing edge of the PWM pulse occurs, the output of the monostable circuit **goes high**, generating a PPM pulse.

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3. **Formation of PPM Pulses:**
    - 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.
    - 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.
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.

PPM signals are generated by detecting the trailing edge of PWM signals and using a monostable multivibrator to create pulses with a fixed width but varying position. The modulation information is carried by the shifts in pulse position, making PPM an efficient and noise-resistant communication method.

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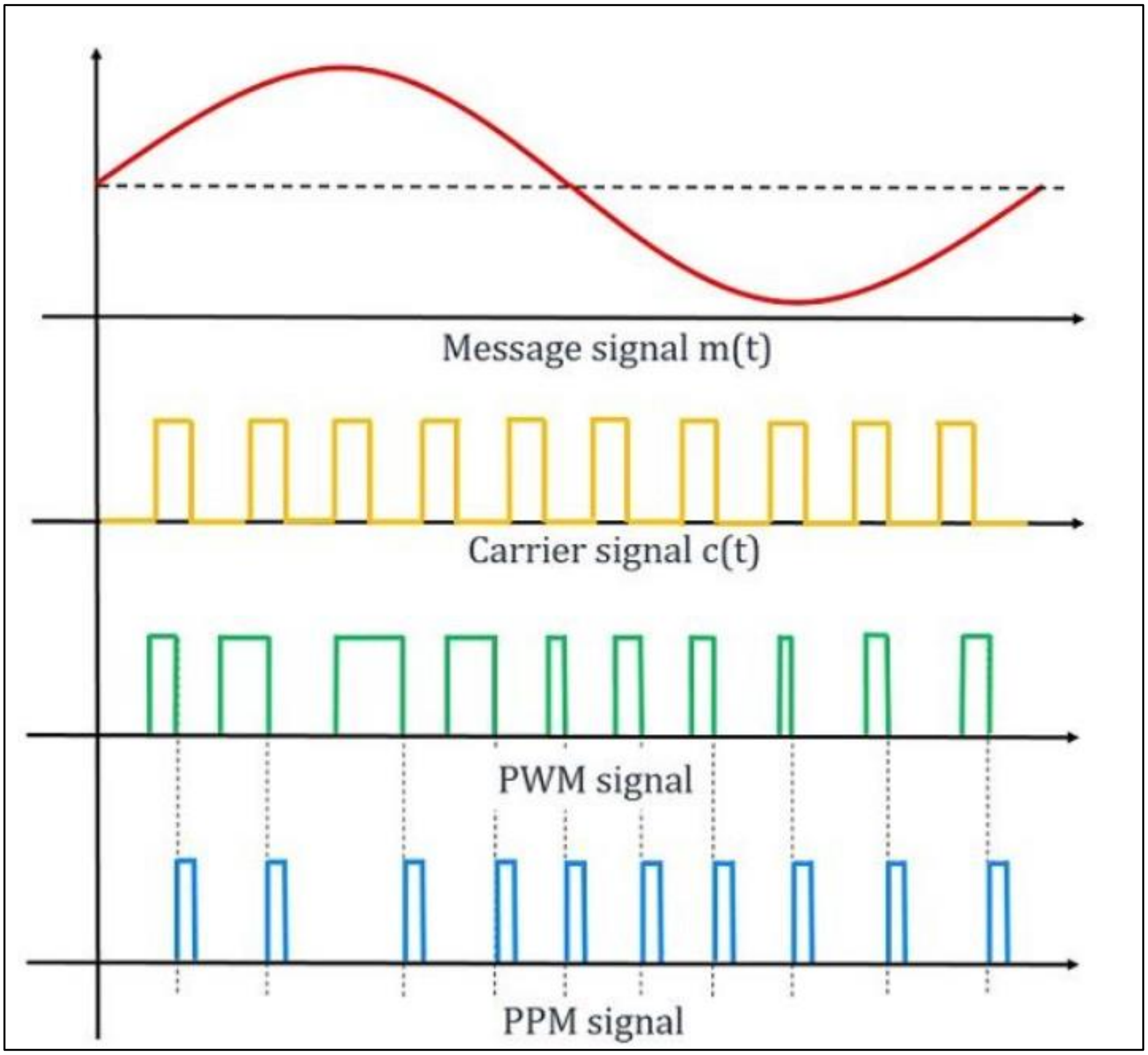

Figure 7: Waveform representation of the process of PPM generation.

The first image shows the modulating signal, and the second one shows a carrier signal. The next one shows a PWM signal which is considered as reference for the generation of the PPM signal shown in the last image.

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Detection of a PPM Signal

The process of detecting a PPM signal at the receiver involves extracting the original message signal from the modulated waveform. The figure below illustrates the block diagram of a typical PPM demodulation circuit, which consists of the following key components:

- **Pulse Generator**
- **SR Flip-Flop**
- **Reference Pulse Generator**
- **PWM Demodulator**

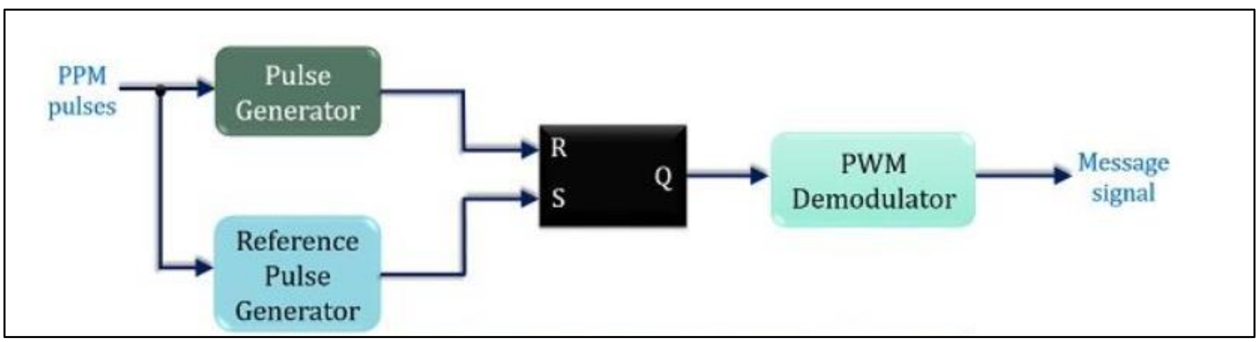

Figure 8: Block diagram of the PPM demodulation.

Step-by-Step Explanation of PPM Demodulation

1. **Receiving the Distorted PPM Signal:**
   - During transmission, the PPM signal may be affected by noise and interference, causing slight distortions in its waveform.
   - This distorted PPM signal is received by the **demodulation circuit**, which aims to reconstruct the original message signal.

2. **Pulse Generation and Flip-Flop Reset:**
   - A **pulse generator** is used to create a **fixed-duration pulse waveform**.
   - This generated pulse is then applied to the **reset (R) input** of an **SR flip-flop**, ensuring proper synchronization of the demodulation process.
3. **Reference Pulse Generation and Flip-Flop Set:**
   - A **reference pulse generator** is employed to produce a **reference pulse of a fixed period** whenever the transmitted **PPM signal** is applied to it.
   - This reference pulse is used to **set the SR flip-flop**, marking the beginning of the pulse timing.
4. **Generating a PWM Signal from PPM:**
   - With the **set and reset** signals from the reference pulse generator and the pulse generator, the **SR flip-flop produces a PWM (Pulse Width Modulation) signal** at its output.
   - The **width of this PWM signal corresponds to the original modulating signal**, making it an intermediate step in retrieving the message signal.
5. **Recovering the Original Message Signal:**
   - The **PWM signal** is then fed into a **PWM demodulator**, which extracts the original **message signal** by processing the variations in pulse width.
   - This final stage ensures that the transmitted information is accurately retrieved with minimal distortion.

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Digital Pulse Modulation

In modern digital communication systems, efficient signal transmission and data integrity are essential for high-quality communication. One of the key techniques used to achieve this is Pulse Digital Modulation, which involves converting analog signals into digital form for reliable transmission over digital networks. This method ensures improved resistance to noise, minimal signal degradation, and efficient bandwidth utilization, making it a fundamental aspect of modern telecommunications.

Pulse digital modulation techniques allow analog signals, such as voice, video, and sensor data, to be represented in a discrete digital format. Unlike traditional analog transmission, digital modulation enhances the quality and security of transmitted signals by encoding them into binary values (**0s and 1s**). This makes it possible to efficiently transmit information over fiber-optic networks, satellite communications, and wireless systems with minimal distortion.

There are several key types of pulse digital modulation, one of them:

Pulse Code Modulation (PCM) – Converts an analog signal into a digital sequence using sampling, quantization, and encoding.

Pulse Code Modulation (PCM)

In modern communication systems, the accurate transmission of signals is crucial for ensuring high-quality data transfer. One of the most widely used techniques for converting analog signals into digital form is **Pulse Code Modulation (PCM)**. This method plays a fundamental role in digital signal

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processing, allowing analog signals, such as voice, music, or sensor data, to be efficiently transmitted, stored, and processed in digital communication systems.

PCM works by representing continuous analog signals using discrete digital values. Unlike analog transmission, which is susceptible to noise, distortion, and signal degradation over long distances, PCM ensures a more reliable and interference-resistant communication process. It does this by converting the analog waveform into a series of binary numbers, consisting of only two states: **high (1) and low (0)**. This transformation enables data to be transmitted accurately over digital networks, such as fiber-optic cables, wireless communication systems, and computer networks.

The PCM process consists of three essential steps:

1. **Sampling** – The continuous analog signal is measured at fixed time intervals to capture key data points.
2. **Quantization** – Each sampled value is approximated to the closest available discrete level, reducing infinite possibilities into a finite set of values.
3. **Encoding** – The quantized values are converted into a binary format, making them suitable for digital storage and transmission.

Due to its ability to maintain signal integrity and resist noise interference, PCM is extensively used in various fields, including **telecommunications, audio recording, radar systems, and medical imaging**. From traditional telephone networks to modern digital audio formats like CDs and VoIP, PCM has been a cornerstone of digital communication technology, enabling efficient and high-fidelity signal transmission.

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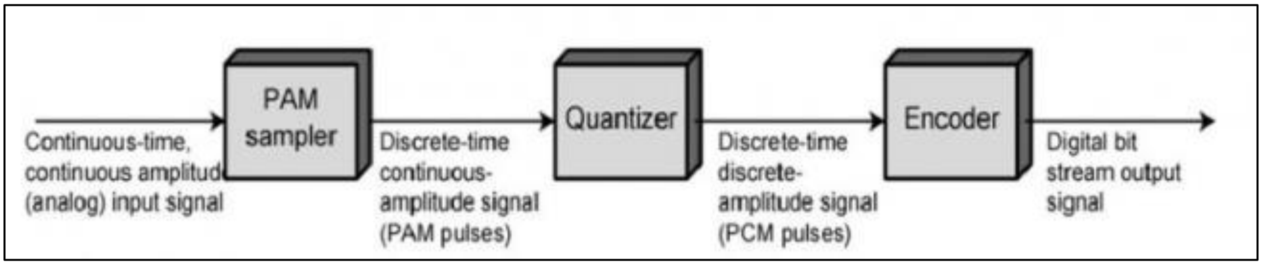

Figure 9: Block Diagram of Pulse Code Modulation.

The block diagram of the Pulse Code Modulation (PCM) process

The block diagram of the Pulse Code Modulation (PCM) process, which is used to convert analog signals into digital signals for efficient transmission over digital communication networks. The diagram consists of three main sections:

1. **Transmitter**
2. **Transmission Path**
3. **Receiver**

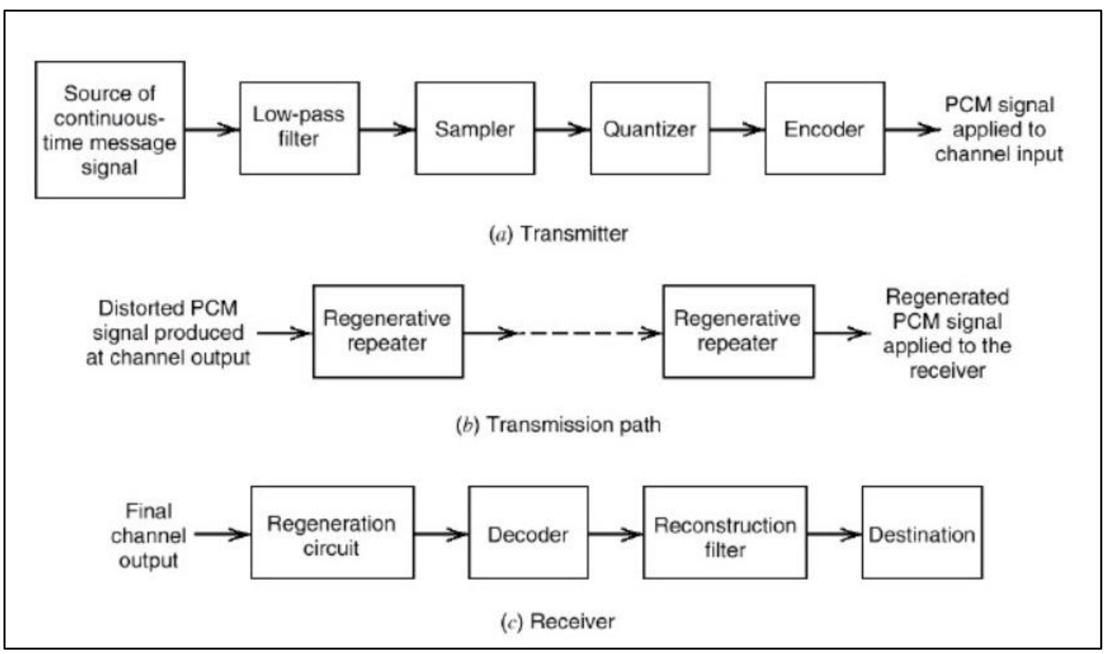

Figure 10: Basic Elements of Pulse Code Modulation System.

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A PCM GENERATION OR TRANSMITTER:

In a PCM generation show in figure 11, the signal x(t) is first passed through the low-pass filter of cutoff frequency f_m Hz. This low-pass filter blocks all the frequency components which are lying above f_m Hz.

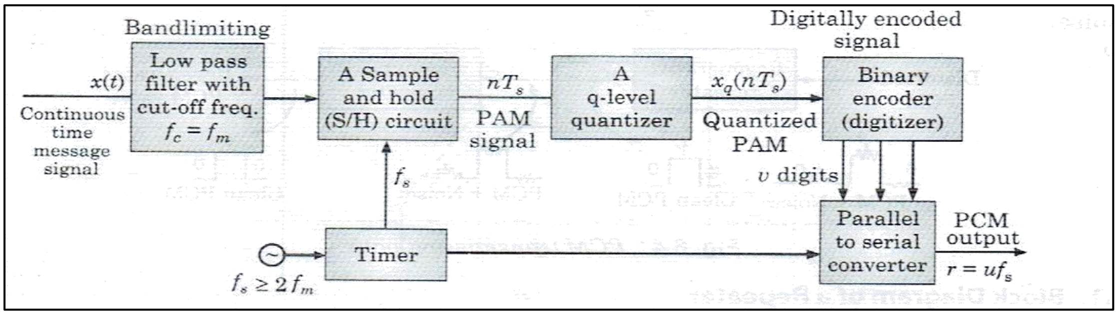

Figure 11: Practical PCM generation.

- Band-**limiting the Signal**
  - The original analog signal, represented as $x(t)$, is first **band-limited** to a maximum frequency f_m Hz.
  - This ensures that the signal does not contain frequency components higher than f_m , which is crucial for accurate sampling.
- Sampling **the Signal**
  - The **sample-and-hold circuit** takes periodic samples of the band-limited signal at a **sampling frequency** f_s.
  - To avoid aliasing (overlapping of frequency components), the sampling frequency must be **at least twice the highest frequency** in the signal, following Nyquist's theorem: $f_s \geq 2f_m$
  - The result is a series of discrete-time samples, denoted as $x(nT_s)$, where $T_s = 1/f_s$ is the sampling period.

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- Holding **the Sampled Value**
  - The sampled signal is held constant for a short duration before being processed further.
  - This ensures that each sample can be properly quantized and encoded without fluctuations.
- Quantization **Process**
  - The sampled values $x(nT_s)$ are **mapped to the nearest available digital level** from a predefined set of discrete levels.
  - Since an analog signal has infinite possible values, but a digital system can only represent a limited number of levels, the quantization process introduces a small difference between the actual sample value and the nearest digital level.
  - This difference is known as **quantization error** or **quantization noise**.
  - The output of the quantizer is denoted as $x_q(nT_s)$, which is now a **digitally represented signal**.
- Binary **Encoding**
  - The quantized values are $x_q(nT_s)$ then **converted into binary form** using a **binary encoder**.
  - Each quantized level is assigned a unique **binary word** consisting of ‘v’ bits.
  - This process ensures that the signal is now completely in digital form, suitable for transmission and storage.
  - The encoder used in this step is also known as a **digitizer**.
- Parallel**-to-Serial Conversion**

- The binary words generated for each sample contain multiple bits, but it is inefficient to transmit each bit separately.
- Instead, a **parallel-to-serial converter** is used to transform the multiple-bit parallel data into a **serial bit stream**.
- This is commonly done using a **shift register**, which sequentially outputs the binary bits as a continuous stream.

• Generation **of the PCM Signal**

- The final output of this process is a **PCM baseband signal**, consisting of a continuous stream of binary bits.
- This digital signal is now ready to be transmitted over a communication channel, such as a fiber-optic cable, radio link, or telephone network.

PCM transmission path:

The channel through which the PCM signal travels from the PCM transmitter to the PCM receiver is known as the **PCM transmission path**. This path facilitates the transfer of the digital signal and is illustrated in Figure 12.

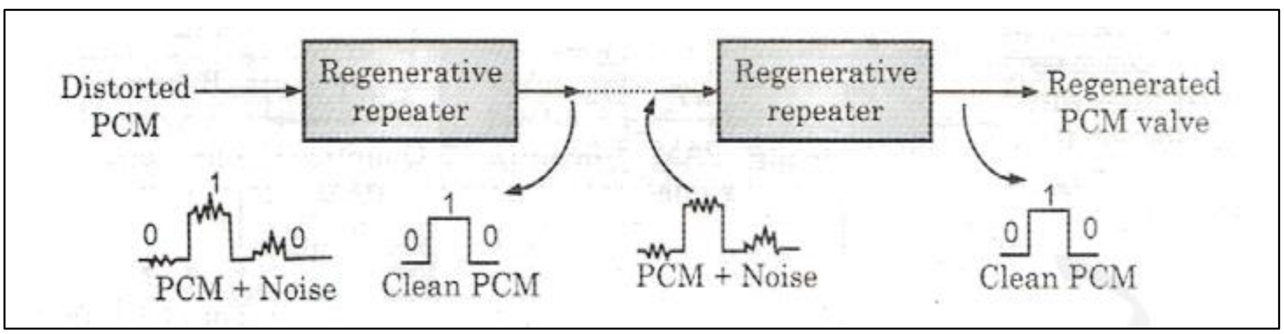

Figure 12: PCM transmission path.

Block diagram of a repeater:

- **Amplitude Equalization**
  - The **Amplitude Equalizer** is responsible for correcting any distortions in the received PCM signal.
  - It compensates for both **amplitude and phase distortions**, which may have occurred during transmission.
  - This ensures that the signal maintains its integrity before further processing.
- **Timing Circuit Generation**
  - A **timing circuit** extracts a **periodic pulse train** from the received PCM signal.
  - This pulse train is crucial as it helps in synchronizing the receiver with the incoming data.
  - The extracted timing pulses are then sent to the next stage for precise decision-making.
- **Decision-Making Device**
  - The **Decision-Making Device** utilizes the extracted pulse train to **sample** the equalized PCM pulses.
  - Sampling is performed at specific time instances where the **Signal-to-Noise Ratio (SNR)** is at its maximum.
  - This ensures that the signal is sampled at the most optimal moments, minimizing errors caused by noise or distortion.
- **Determining Digital Values (0 or 1)**
  - At the moment of sampling, the decision device must determine whether the received **equalized PCM signal** corresponds to a **binary 0 or 1**.

- This decision is made by comparing the received PCM signal against a **fixed reference level**, known as the **decision threshold**.
- If the signal amplitude is above the threshold, it is interpreted as **1**; otherwise, it is considered **0**.
- This threshold comparison ensures that the signal is accurately reconstructed.

• **Noise-Free PCM Output**

- After passing through the decision-making process, the output of the device is a **clean PCM signal**.
- At this stage, any noise or distortion present in the original received signal is effectively removed.
- The final output is a **restored and noise-free PCM waveform**, which is ready for further processing or decoding.

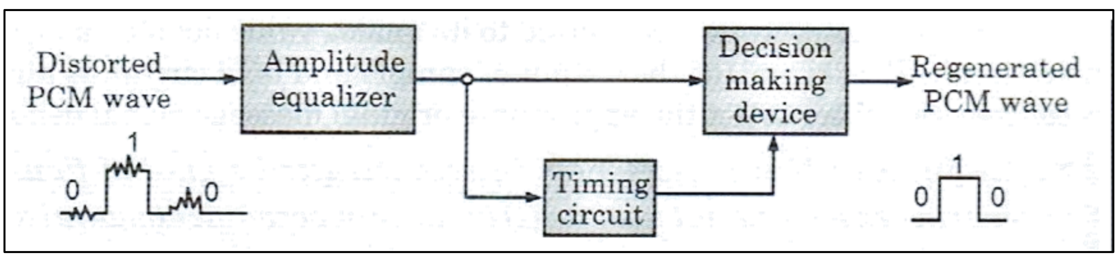

Figure 13: Block diagram of a repeater.

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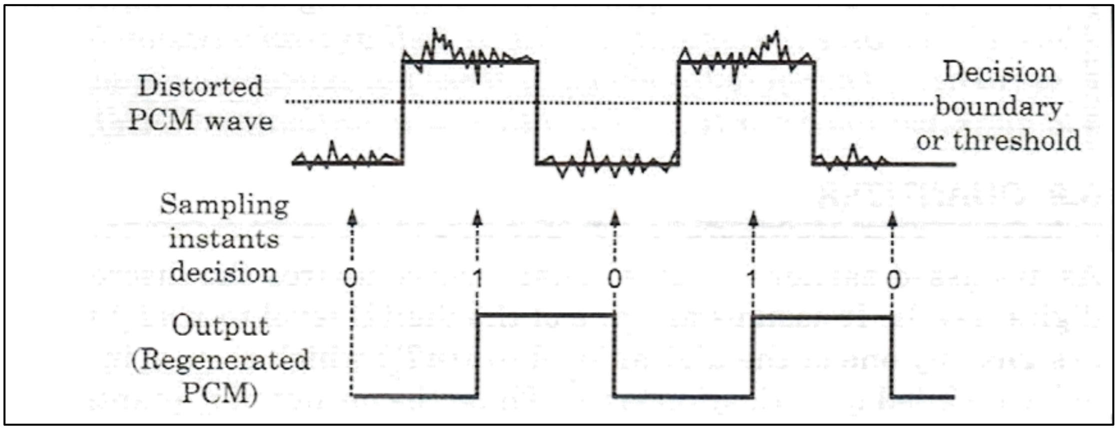

Figure 14: Waveform of Regenerated PCM.

PCM RECEIVER:

Figure 15(a) illustrates the block diagram of the PCM receiver, while Figure 15(b) shows the reconstructed signal. 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).

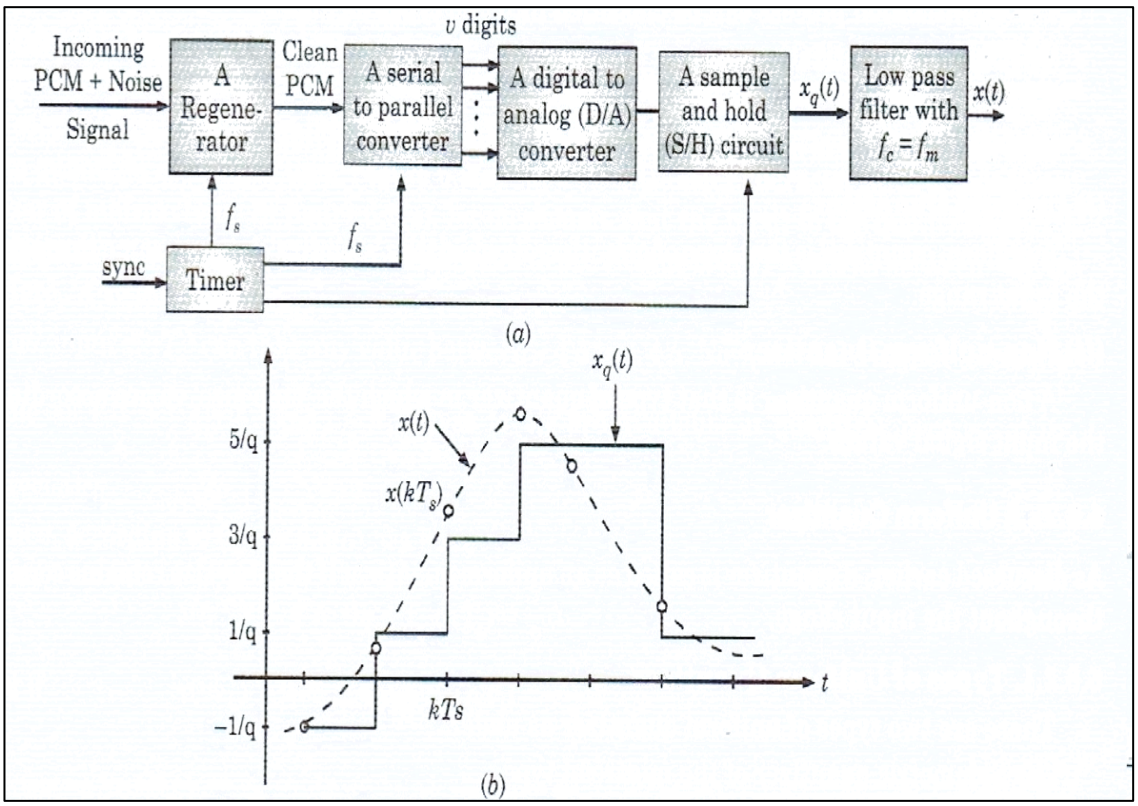

Figure 15: (a) PCM receiver, (b) the reconstructed signal.

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Quantizer

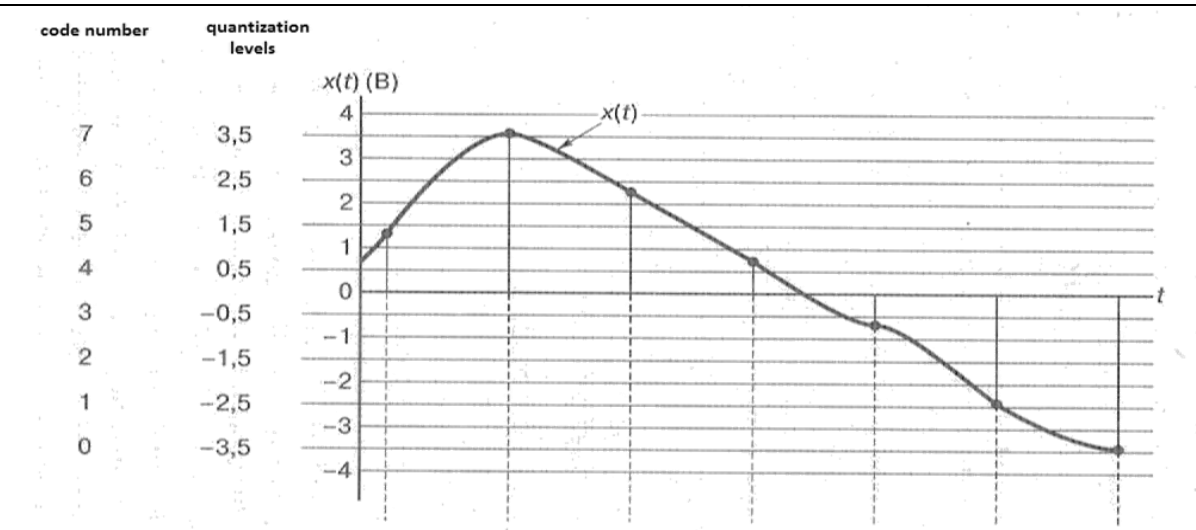
As mentioned earlier, a q-level quantizer compares the discrete-time input, $x(nT_s)$, with its predefined digital levels. It assigns the closest digital level to $x(nT_s)$, resulting in the least distortion or error. This distortion or error is referred to as **quantization error**. Therefore, the output of the quantizer is a digital level, denoted as, $x_q(nT_s)$.

Classification of the Quantization Process

The quantization process can be divided into two types:

a. **Uniform Quantization**

b. **Non-uniform Quantization**



values obtained with the natural sample	1,3	3,6	2,3	0,7	−0,7	−2,4	−3,4
values obtained whih the sample	1,5	3,5	2,5	0,5	−0,5	−2,5	−3,5
code number	5	7	6	4	3	1	0
PCM succession	101	111	110	100	011	001	000

natural sampling quantized samples and PCM

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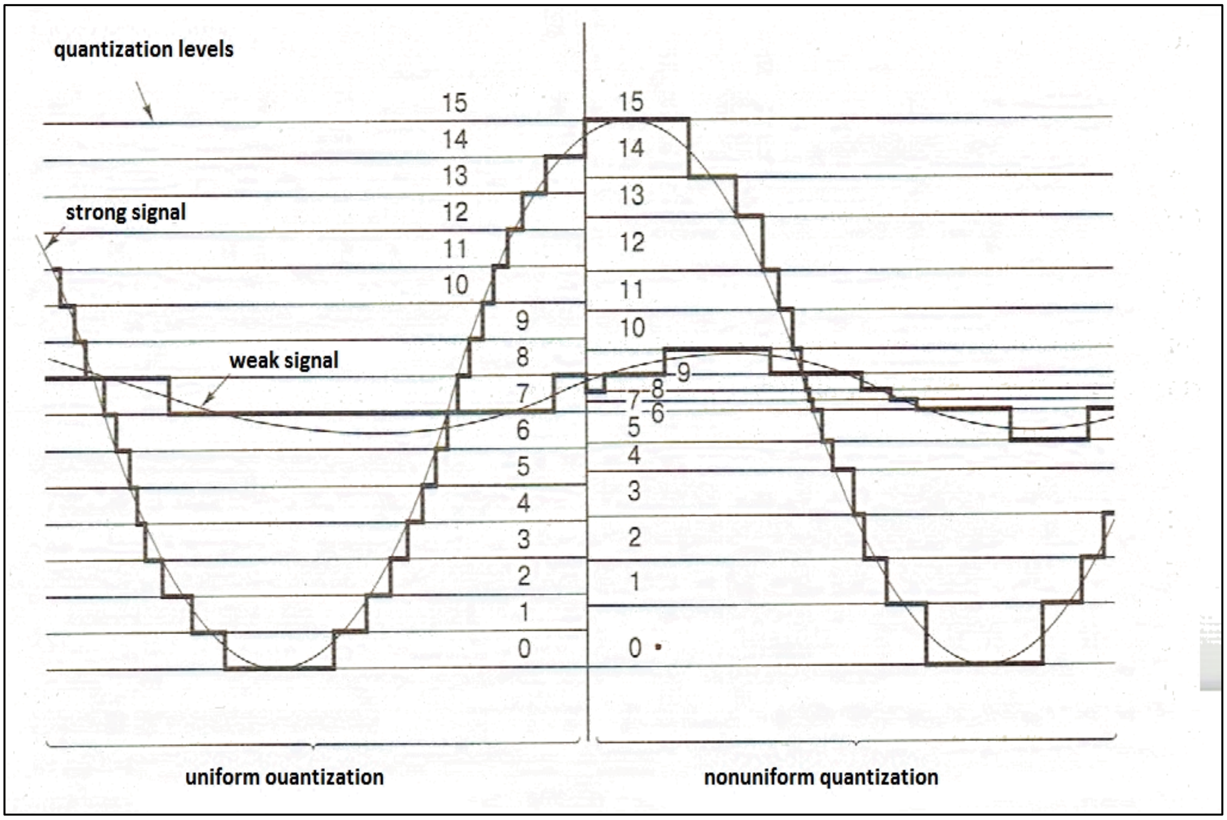

Figure 16: uniform and nonuniform quantization.