6.1 Pulse Modulation : **MU : May 07**

University Questions

Q. 1 What are the various pulse modulation techniques ? Give one method for the generation of PAM. **(May 07, 10 Marks)**

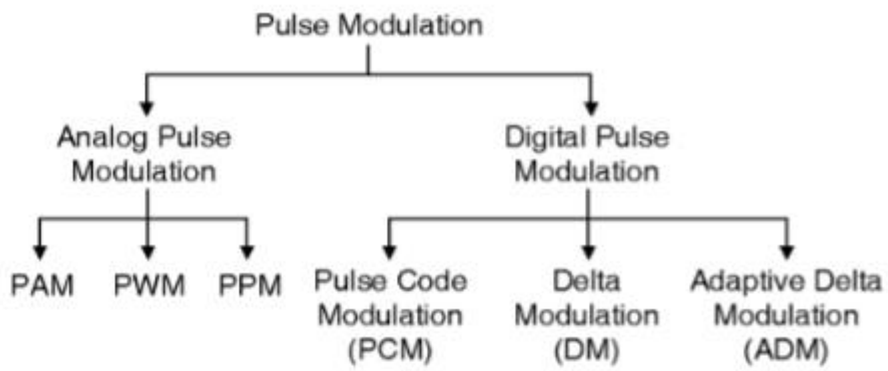
- In pulse modulation, the carrier is in the form of train of periodic rectangular pulses.
- Pulse modulation can be either analog or digital.

Analog Pulse Modulation :

- In the analog pulse modulation, the amplitude, width or position of the rectangular carrier pulses is varied in accordance with the modulating signal.
- This will result in PAM (Pulse Amplitude Modulation), PWM (Pulse Width Modulation) or PPM (Pulse Position Modulation) respectively.
- Thus PAM, PWM and PPM the examples of analog pulse modulation.

Digital Pulse Modulation :

- The pulse modulation can be digital as well. The well known examples of digital pulse modulation are Pulse Code Modulation (PCM), Delta Modulation (DM), Adaptive Delta Modulation (ADM), etc.
- The classification of the pulse modulation system is as follows :



(L-153)

1. Pulse Amplitude Modulation (PAM) :

- The amplitude of a constant width, constant position rectangular carrier is varied in proportion with the instantaneous magnitude of the modulating signal as shown in Fig. 6.1.1(c).

2. Pulse Width Modulation (PWM) :

- The width of carrier pulses is made to vary in proportion with the instantaneous magnitude of the modulating signal as shown in Fig. 6.1.1(d).

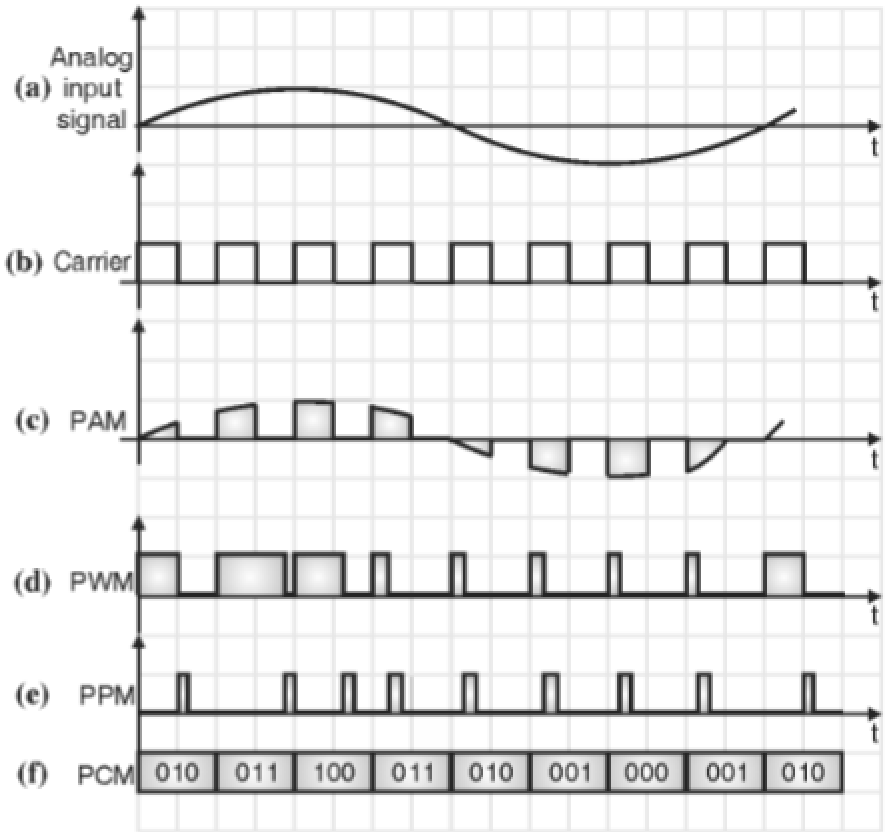
- PWM is also called as Pulse Duration Modulation (PDM) or Pulse Length Modulation (PLM).

3. Pulse Position Modulation (PPM) :

- In PPM the amplitude and width of the pulses is kept constant but the position of each pulse is varied in accordance with the amplitudes of the sampled values of the modulating signal.
- The position of the pulses is changed with respect to the position of reference pulses.
- The PPM pulses can be derived from the PWM pulses as shown in Fig. 6.1.1(e).
- Note that with increase in the modulating voltage the PPM pulses shift further with respect to reference.

4. Pulse Code Modulation (PCM) :

- The analog message signal is sampled and converted to a fixed length, serial binary number as shown in Fig. 6.1.1(f).
- In other words a binary code is transmitted. Hence the name pulse code modulation.



(L-154) **Fig. 6.1.1 : Pulse modulation**

- The PAM, PWM and PPM are called as the analog pulse communication systems whereas PCM, Delta Modulation (DM) are the examples of digital pulse communication systems.

6.4 Pulse Amplitude Modulation (PAM) :

MU : Dec. 03

University Questions

Q. 1 With proper waveforms explain principles of PWM, PAM, PPM systems of modulation. **(Dec. 03, 8 Marks)**

Principle :

- In the PAM system, the amplitude of the pulsed carrier is changed in proportion with the instantaneous amplitude of the modulating signal x(t).
- So the information is contained in the amplitude variation of PAM signal.
- The carrier is in the form of train of narrow pulses as shown in Fig. 6.4.1.
- If you compare the PAM system with the sampling process, you will find that these two processes are identical.
- The PAM signal is then sent by either wire or cable or it is used to modulate a carrier.

Types of PAM :

– There are two types of PAM :

1. Natural PAM 2. Flat top PAM

6.4.1 Generation of Natural PAM :

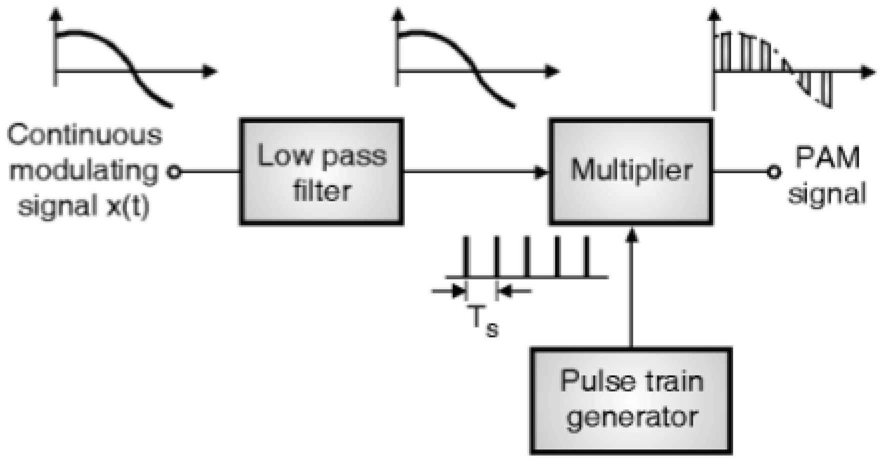
MU : May 07

University Questions

Q. 1 What are the various pulse modulation techniques ? Give one method for the generation of PAM. **(May 07, 10 Marks)**

Block diagram :

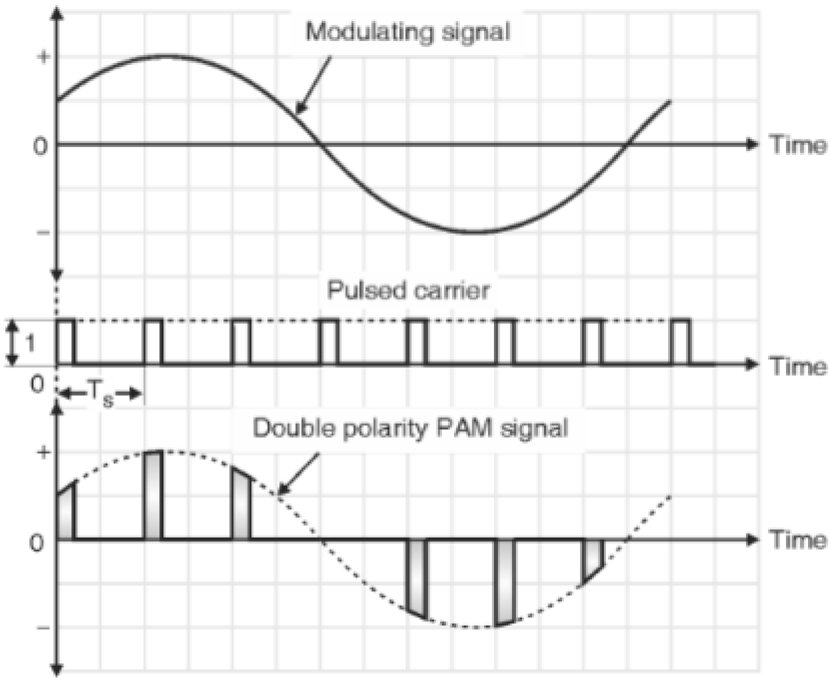
– Refer Fig. 6.4.1 to understand the generation of natural PAM.



(L-181) **Fig. 6.4.1 : Generation of PAM**

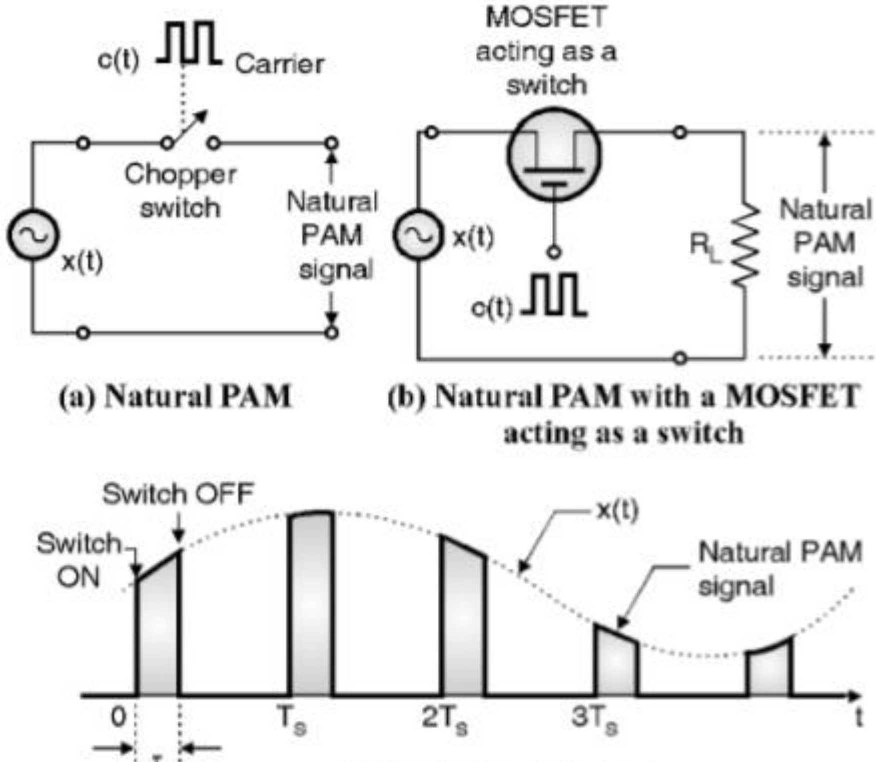
- The continuous modulating signal x(t), is passed through a low pass filter. The LPF will bandlimit this signal to f_m.
- That means all the frequency components higher than the frequency f_m are removed.
- Bandlimiting is necessary to avoid the "aliasing" effect in the sampling process.
- The pulse train generator generates a pulse train at a frequency f_s, such that $f_s \geq 2f_m$. Thus the Nyquist criteria is satisfied.
- The rectangular narrow carrier pulses generated by the pulse train generator would carry out the uniform "sampling" in the multiplier block, to generate the PAM signal as shown in Fig. 6.4.2.
- The samples are placed T_s seconds away from each other.
- The "information" in the modulating signal is contained in the "Amplitude variations" of the pulsed carrier.
- Therefore this system is similar to the AM system discussed earlier.

- Natural PAM is sometimes called as chopper sampled PAM because the waveform of the sampled signal appears to be chopped off from the continuous time signal x(t).
- The chopper arrangement is as shown in Fig. 6.4.3 where the chopper switch is being operated by the pulsed carrier "c (t)".



(L-182) Fig. 6.4.2 : Waveform of natural PAM

Circuit arrangement for natural PAM :



(a) Natural PAM (b) Natural PAM with a MOSFET acting as a switch

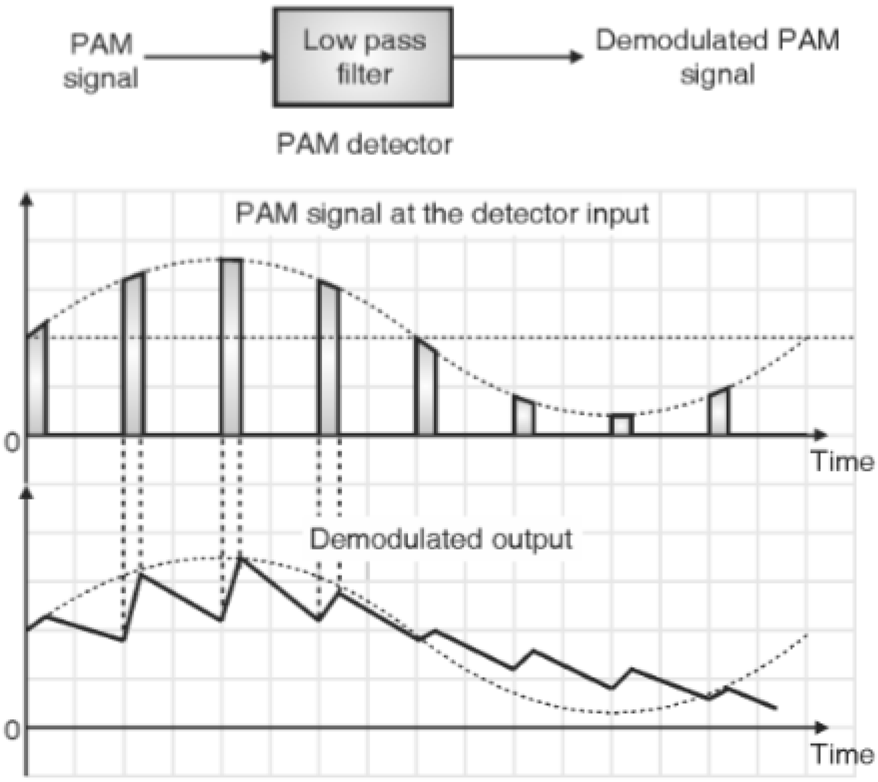
(c) Natural PAM signal

(L-183) Fig. 6.4.3

6.4.2 Detection of Natural PAM :

- The PAM signal can be detected (demodulated) by passing it through a low pass filter.
- The low pass filter cutoff frequency is adjusted to f_m so that all the high frequency ripple is removed and the original modulating signal is recovered back.

- The PAM detection and the corresponding waveforms are as shown in Fig. 6.4.4.
- From the waveforms, it is seen that the demodulated output signal is close to the original modulating signal x (t).



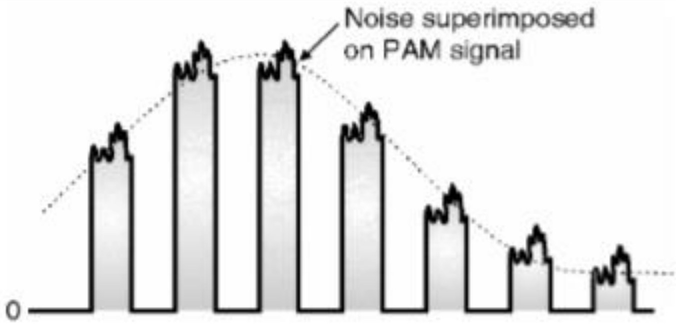
(L-185) Fig. 6.4.4 : Detection of PAM and waveforms

6.4.6 Advantages and Disadvantages of PAM :

- There are not many advantages of a PAM system except for the simplicity of generation and detection. But there are many disadvantages. They are as follows :
  1. The amplitude of PAM signal changes according to the amplitude of modulating signal. Therefore like AM, the effect of additive noise is maximum in PAM. The added noise cannot be removed easily.
  2. The transmission bandwidth required for a PAM signal is too large as compared to the maximum frequency content in x (t).
  3. Due to the changes in amplitudes of PAM pulses, the transmitted power is not constant.

6.4.7 Effect of Noise on PAM :

- The amplitude of the pulsed carrier is being changed in proportion with the amplitude of modulating signal in PAM.
- Hence all the "information" is contained in the amplitude variation of the PAM signal.
- When PAM signal travels over a communication channel, noise gets added to it as shown in Fig. 6.4.8.
- Note that the noise distorts the amplitude of PAM signal. Since the information is contained in the amplitude, the noise will contaminate the information.
- Therefore the noise performance of PAM system is very poor.



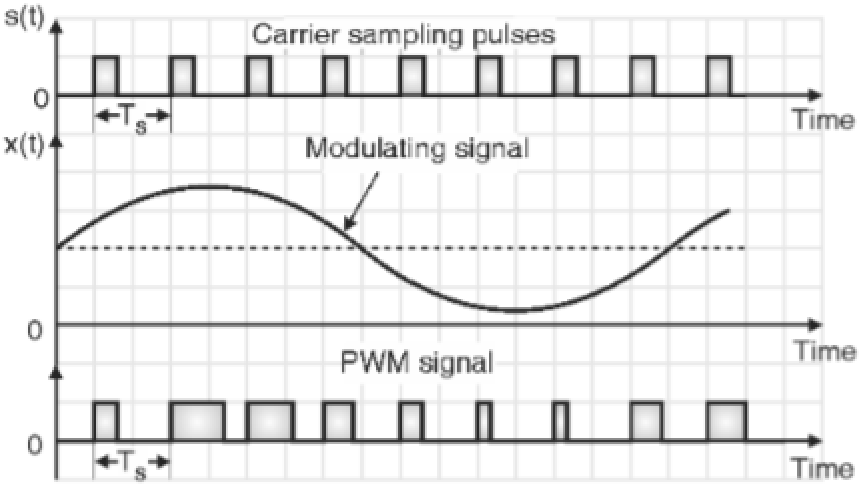
(L-190) Fig. 6.4.8 : Effect of noise on PAM signal

- The PWM and PPM systems have a better noise performance.

6.5 Pulse Width Modulation (PWM) or Pulse Duration Modulation (PDM) :

Principle :

- The other type of a pulse analog modulation is the Pulse Width Modulation (PWM).
- In PWM, the width of the carrier pulses varies in proportion with the amplitude of modulating signal.
- The waveforms of PWM are as shown in Fig. 6.5.1.



(D-454) Fig. 6.5.1 : PWM signal [Trail edge modulated signal]

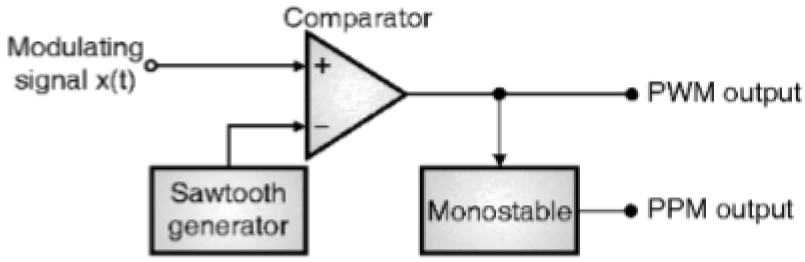
- As seen from the waveforms, the amplitude and the frequency of the PWM wave remains constant. Only the width changes.
- That is why the "information" is contained in the width variation. This is similar to FM.
- As the noise is normally "additive" noise, it changes the amplitude of the PWM signal.
- At the receiver, it is possible to remove these unwanted amplitude variations very easily by means of a limiter circuit.

- As the information is contained in the width variation, it is unaffected by the amplitude variations introduced by the noise.
- Thus the PWM system is more immune to noise than the PAM signal.

6.5.1 Generation of PWM Signal :

Block diagram :

- The block diagram of Fig. 6.5.2(a) can be used for the generation of PWM as well as PPM.



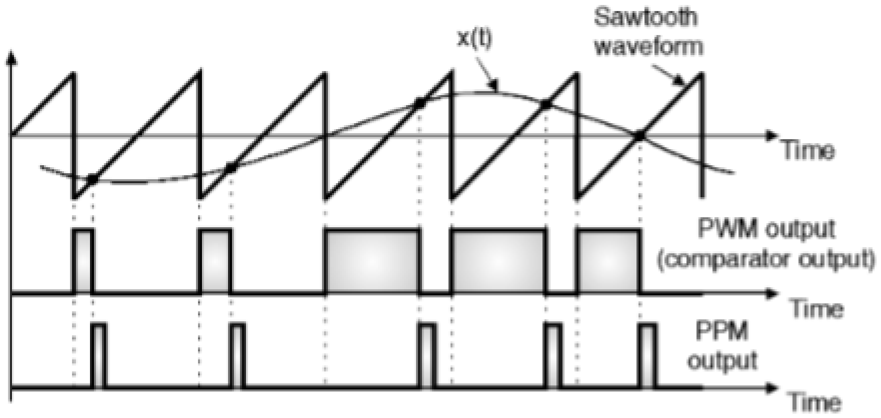
(D-455) **Fig. 6.5.2(a) : PWM and PPM generator**

Operation :

- A sawtooth generates a sawtooth signal of frequency f_s, therefore the sawtooth signal in this case is a sampling signal. It is applied to the inverting terminal of a comparator.
- The modulating signal x (t) is applied to the non-inverting terminal of the same comparator.
- The comparator output will remain high as long as the instantaneous amplitude of x (t) is higher than that of the ramp signal.
- This gives rise to a PWM signal at the comparator output as shown in Fig. 6.5.2(b).

Waveforms :

- The waveforms for the PWM generator are as shown in Fig. 6.5.2(b)



(D-456) **Fig. 6.5.2(b) : Waveforms**

- Note that the leading edges of the PWM waveform coincide with the falling edges of the ramp signal.
- Thus the leading edges of PWM signal are always generated at fixed time instants.
- However the occurrence of its trailing edges will be dependent on the instantaneous amplitude of x (t).
- Therefore this PWM signal is said to be trail edge modulated PWM.

6.5.2 Detection of PWM Signal :

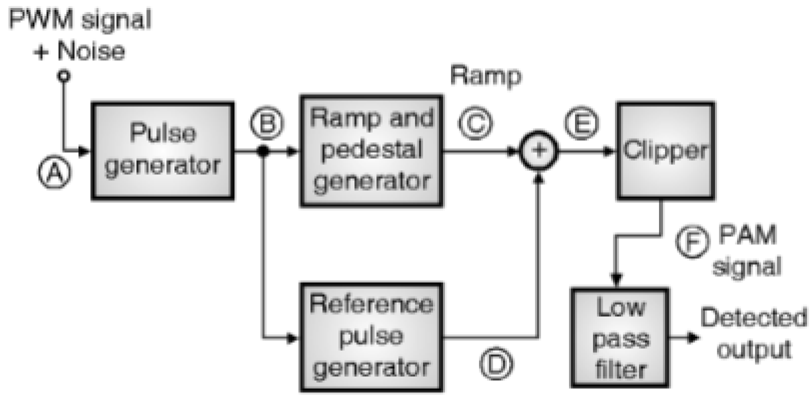
Block diagram :

– The block diagram of PWM detector is as shown in Fig. 6.5.3.

Operation :

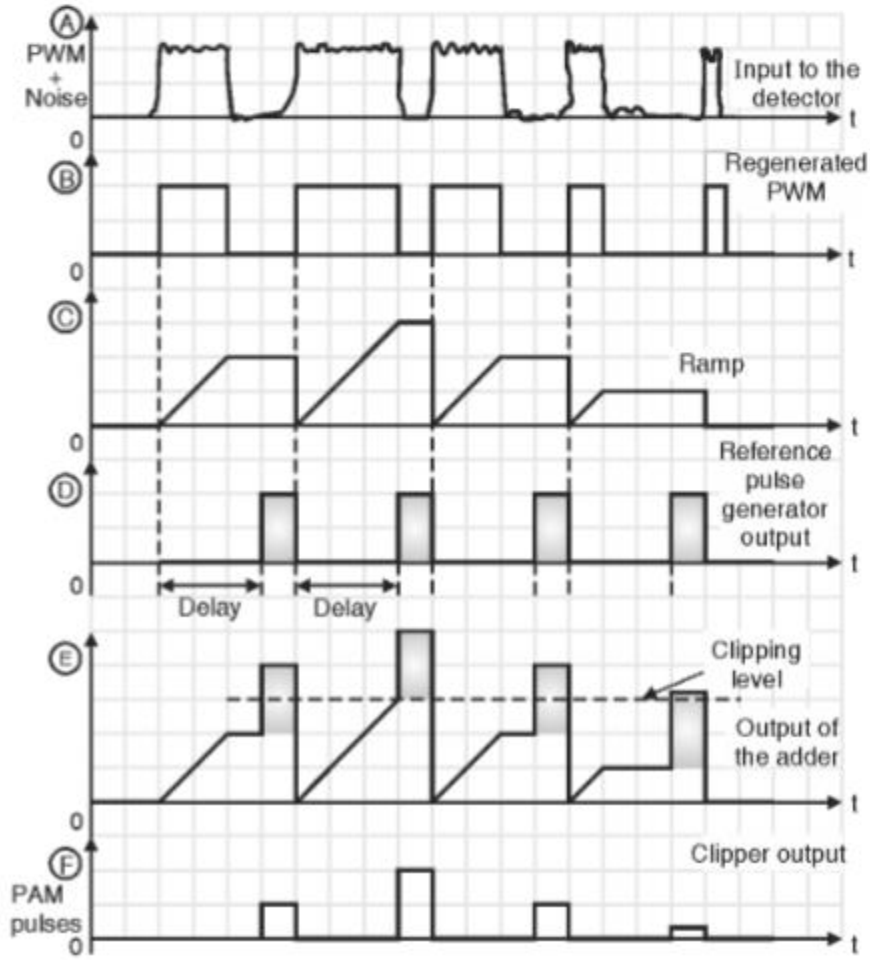
– The PWM signal received at the input of the detection circuit is contaminated with noise.

– This signal is applied to pulse generator circuit which regenerates the PWM signal.



(D-457) **Fig. 6.5.3 : PWM detection circuit**

- Thus some of the noise is removed and the pulses are squared up.
- The regenerated pulses are applied to a reference pulse generator. It produces a train of constant amplitude, constant width pulses.
- These pulses are synchronized to the leading edges of the regenerated PWM pulses but delayed by a fixed interval.
- The regenerated PWM pulses are also applied to a ramp generator.
- At the output of it we get a constant slope ramp for the duration of the pulse.
- The height of the ramp is thus proportional to the widths of the PWM pulses.
- At the end of the pulse a sample and hold amplifier retains the final ramp voltage until it is reset at the end of the pulse.
- The constant amplitude pulses at the output of reference pulse generator are then added to the ramp signal.
- The output of the adder is then clipped off at a threshold level to generate a PAM signal at the output of the clipper.
- A low pass filter is used to recover the original modulating signal back from the PAM signal.
- The waveforms for this circuit are as shown in Fig. 6.5.4.



(D-458) Fig. 6.5.4 : Waveforms for PWM detection circuit

6.5.3 Advantages of PWM : **MU : May 03**

University Questions

Q. 1 List the advantages and disadvantages of PWM and PPM. **(May 03, 4 Marks)**

1. Less effect of noise i.e. very good noise immunity.
2. Synchronization between the transmitter and receiver is not essential. (Which is essential in PPM).
3. It is possible to reconstruct the PWM signal from a noise contaminated PWM, as discussed in the detection circuit. Thus it is possible to separate out signal from noise (which is not possible in PAM).

6.5.4 Disadvantages of PWM : **MU : May 03**

University Questions

Q. 1 List the advantages and disadvantages of PWM and PPM. **(May 03, 4 Marks)**

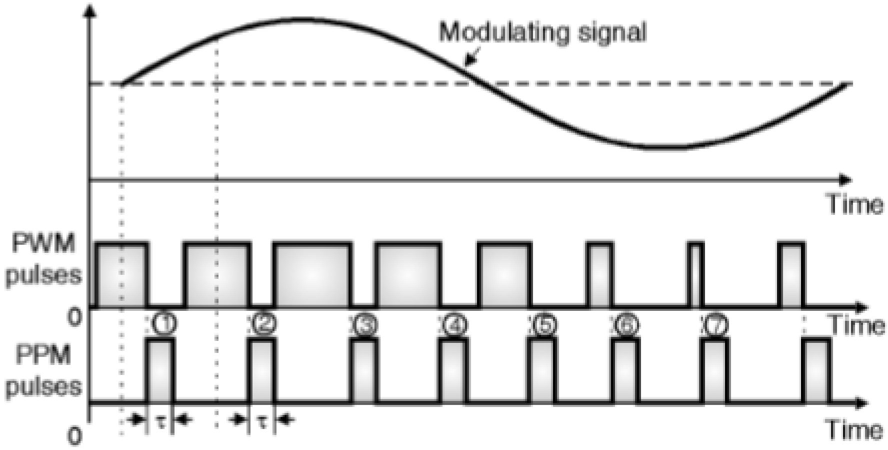
1. Due to the variable pulse width, the pulses have variable power contents. So the transmitter must be powerful enough to handle power corresponding to the maximum width pulse. The average power transmitted can be as low as 50% of this maximum power.
2. In order to avoid any waveform distortion, the bandwidth required for the PWM communication is large as compared to BW of PAM.

6.6 Pulse Position Modulation (PPM) :

Principle :

- In PPM the amplitude and width of the pulsed carrier remains constant but the position of each pulse is varied in proportion with the amplitudes of the sampled values of the modulating signal.
- The position of the pulses is changed with respect to the position of reference pulses.

- The PPM pulses can be derived from the PWM pulses as shown in Fig. 6.6.1. Note that with increase in the modulating voltage the PPM pulses shift further with respect to reference.



(D-460) Fig. 6.6.1 : PPM pulses generated from PWM signal

- The vertical dotted lines drawn in Fig. 6.6.1 are treated as reference lines to measure the shift in position of PPM pulses.
- The leading edge of each PPM pulse coincides with the trailing pulse of a PWM pulse.
- The PPM pulses marked 1, 2 and 3 etc. in Fig. 6.6.1 go away from their respective reference lines.
- This is corresponding to increase in the modulating signal amplitude. Then as the modulating voltage decreases the PPM pulses 4, 5, 6, 7 come progressively closer to their respective reference lines.

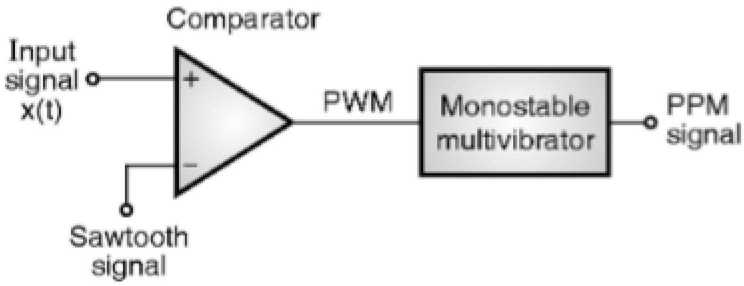
6.6.1 Generation of PPM Signal :

Block diagram :

- The PPM signal can be generated from PWM signal as shown in Fig. 6.5.2(a).
- The same block diagram has been repeated in Fig. 6.6.2 as shown.

Operation :

- The PWM pulses obtained at the comparator output are applied to a monostable multivibrator. The monostable is negative edge triggered.
- Hence corresponding to each trailing edge of PWM signal, the monostable output goes high.
- It remains high for a fixed time decided by its own RC components.
- Thus as the trailing edges of the PWM signal keep shifting in proportion with the modulating signal x(t), the PPM pulses also keep shifting as shown in Fig. 6.5.2(b).



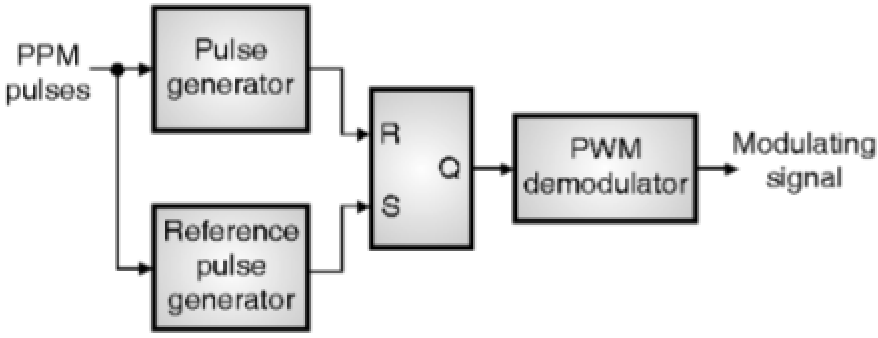
(D-461) Fig. 6.6.2 : Generation of PPM signal

> Note that all the PPM pulses have the same width and amplitude. The information is conveyed via changing position of the pulses.

6.6.2 Demodulation of PPM :

Block diagram :

– The PPM demodulator block diagram is as shown in Fig. 6.6.3.



(D-462) Fig. 6.6.3 : PPM demodulator circuit

Operation :

– The operation of the demodulator circuit is explained as follows :

– The noise corrupted PPM waveform is received by the PPM demodulator circuit.

– The pulse generator develops a pulsed waveform at its output of fixed duration and apply these pulses to the reset pin (R) of a SR flip-flop.

– A fixed period reference pulse is generated from the incoming PPM waveform and the SR flip-flop is set by the reference pulses.

– Due to the set and reset signals applied to the flip-flop, we get a PWM signal at its output.

– The PWM signal can be demodulated using the PWM demodulator.

– This is same as the one discussed in section 6.5.

6.6.3 Advantages of PPM : **MU : May 03**

University Questions

Q. 1 List the advantages and disadvantages of PWM and PPM. **(May 03, 4 Marks)**

1. Due to constant amplitude of PPM pulses, the information is not contained in the amplitude. Hence the noise added to PPM signal does not distort the information. Therefore it has good noise immunity. This is same as that explained for PWM in section 6.5.
2. It is possible to reconstruct PPM signal from the noise contaminated PPM signal. This is also possible in PWM but not possible in PAM.
3. Due to constant amplitude of pulses, the transmitted power always remains constant. It does not change as it used to, in PWM.

6.6.4 Disadvantages of PPM : **MU : May 03**

University Questions

Q. 1 List the advantages and disadvantages of PWM and PPM. **(May 03, 4 Marks)**

1. As the position of the PPM pulses is varied with respect to a reference pulse, a transmitter has to send synchronizing pulses to operate the timing circuits in the receiver. Without them the demodulation won't be possible to achieve.
2. Large bandwidth is required to ensure transmission

Sr. No.	Parameter	PAM	PWM	PPM
1.	Type of carrier	Train of pulses	Train of pulses	Train of pulses
2.	Variable characteristic of the pulsed carrier	Amplitude	Width	Position
3.	Bandwidth requirement	Low	High	High
4.	Noise immunity	Low	High	High
5.	Information is contained in	Amplitude variations	Width variation	Position variation
6.	Transmitted power	Varies with amplitude of pulses	Varies with variation in width	Remains constant
7.	Need to transmit synchronizing pulses	Not needed	Not needed	Necessary
8.	Complexity of generation and detection	Complex	Easy	Complex
9.	Similarity with other modulation systems	Similar to AM	Similar to FM	Similar to PM
10.	Output waveforms	 (D-463)		

7.2 Pulse Code Modulation (PCM) :

- PCM is a type of pulse modulation like PAM, PWM or PPM but there is an important difference between them.
- PAM, PWM or PPM are "analog" pulse modulation systems whereas PCM is a "digital" pulse modulation system.

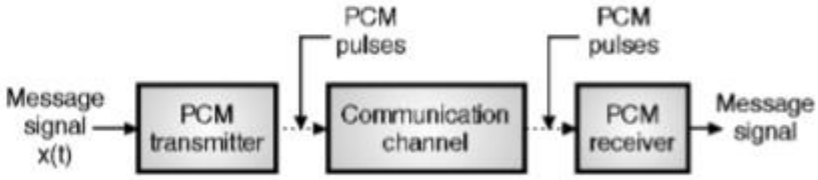
- That means the PCM output is in the coded digital form. It is in the form of digital pulses of constant amplitude, width and position.

Definition :

- Pulse Code Modulation (PCM) is a digital scheme for transmitting analog data.
- The information is transmitted in the form of "code words".
- A PCM system consists of a PCM encoder (transmitter) and a PCM decoder (receiver).
- The essential operations in the PCM transmitter are sampling, quantizing and encoding.
- All these operations are usually performed in the same circuit called as Analog-to-Digital (A to D) converter.
- It should be understood that the PCM is not modulation in the conventional sense.

A PCM System :

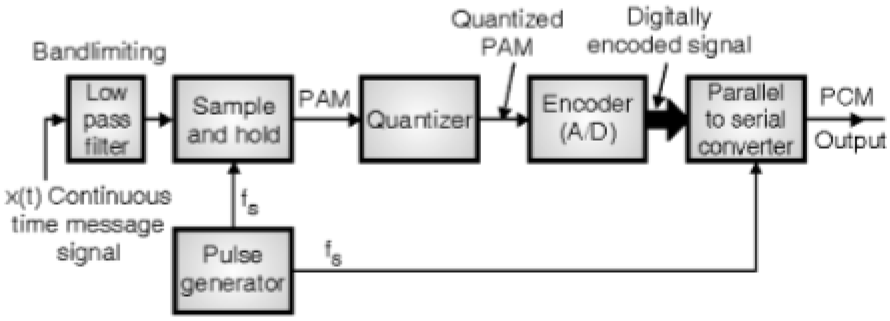
- Fig. 7.2.1 shows the simplified block diagram of a PCM system. It consists of a transmitter and receiver.
- The transmitter converts the message signal x (t) into a series of coded pulses and sends it over the communication channel.
- The transmitter is also called as an encoder.
- The receiver performs exactly in the reverse way as compared to the transmitter.
- It will convert the received encoded PCM pulses back into the message signal.



7.2.1 PCM Transmitter (Encoder) :

Block diagram :

- Block diagram of the PCM transmitter is as shown in Fig. 7.2.2.



(L-221) **Fig. 7.2.2 : PCM transmitter (Encoder)**

Operation of PCM transmitter :

Operation of the PCM transmitter is as follows :

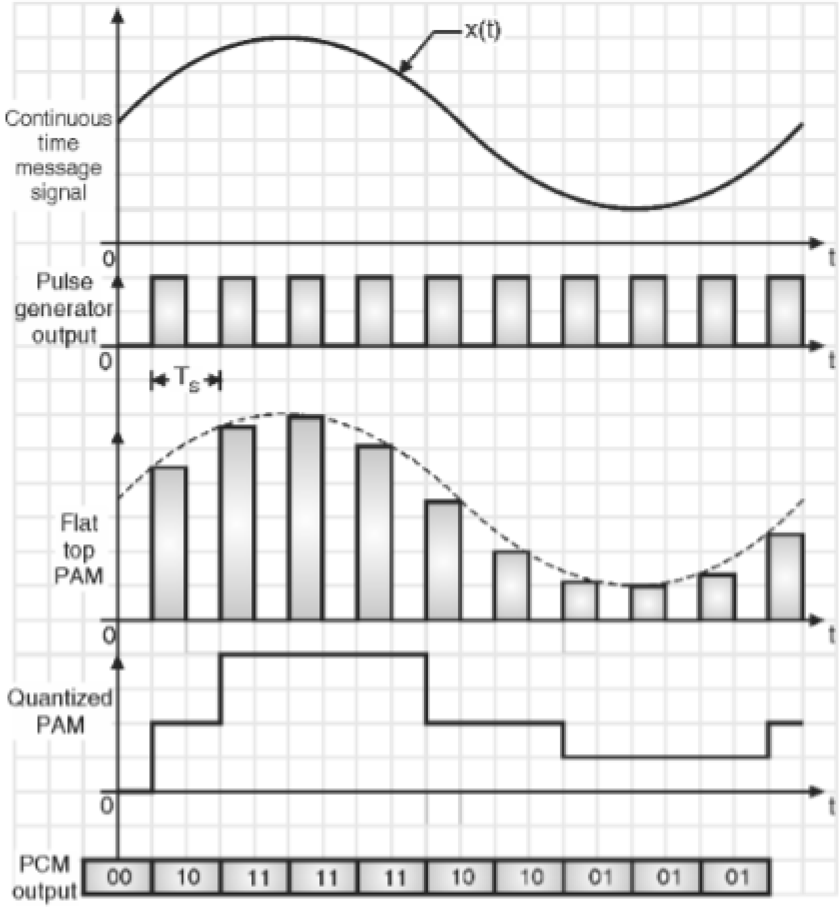
- The analog signal x (t) is passed through a bandlimiting low pass filter, which has a cut-off frequency f_c = W Hz.
- This will ensure that x (t) will not have any frequency component higher than "W". This will eliminate the possibility of aliasing.
- The band limited analog signal is then applied to a sample and hold circuit where it is sampled at adequately high sampling rate.
- Output of sample and hold block is a flat topped PAM signal.
- These samples are then subjected to the operation

- These samples are then subjected to the operation called "Quantization" in the "Quantizer".
- Quantization process is the process of approximation as will be explained later on.
- The quantization is used to reduce the effect of noise.
- The combined effect of sampling and quantization produces the quantized PAM at the quantizer output.

- The quantized PAM pulses are applied to an encoder which is basically an A to D converter.
- Each quantized level is converted into an N bit digital word by the A to D converter. The value of N can be 8, 16, 32, 64 etc.
- The encoder output is converted into a stream of pulses by the parallel to serial converter block.
- Thus at the PCM transmitter output we get a train of digital pulses.
- A pulse generator produces a train of rectangular pulses with each pulse of duration "τ" seconds.
- The frequency of this signal is "f_s" Hz. This signal acts as a sampling signal for the sample and hold block.
- The same signal acts as "clock" signal for the parallel to serial converter.
- The frequency "f_s" is adjusted to satisfy the Nyquist criteria.

Waveforms :

– The waveforms at various points in the PCM transmitter are as shown in Fig. 7.2.3.



(L-222) **Fig. 7.2.3 : Waveforms at different points in PCM transmitter**

7.2.2 Shape of the PCM Signal :

– Fig. 7.2.4 shows input to and output of a PCM system. It is important to understand that the output is in the form of binary codes.

– Each transmitted binary code represents a particular amplitude of the input signal.

– Hence the "information" is contained in the "code" which is being transmitted.

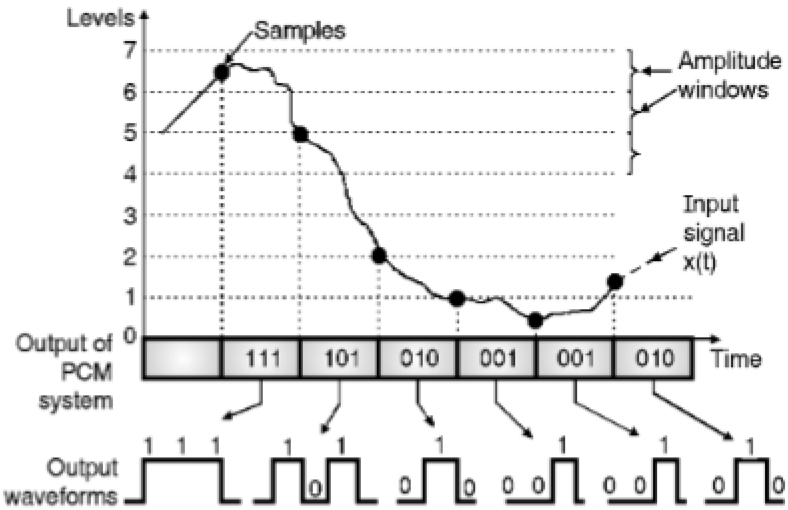
– The range of input signal magnitudes is divided into 8-equal levels.

– Each level is denoted by a three bit digital word between 000 and 111.

– Input signal x (t) is sampled. If the sample is in the 5th - window of amplitude then a digital word 101 is transmitted.

– If the sample is in the 2nd - window then the transmitted word is 010 and so on.

– In this example we have converted the amplitudes into 3 bit codes, but in practice the number of bits per word can be as high as 8, 9 or 10.

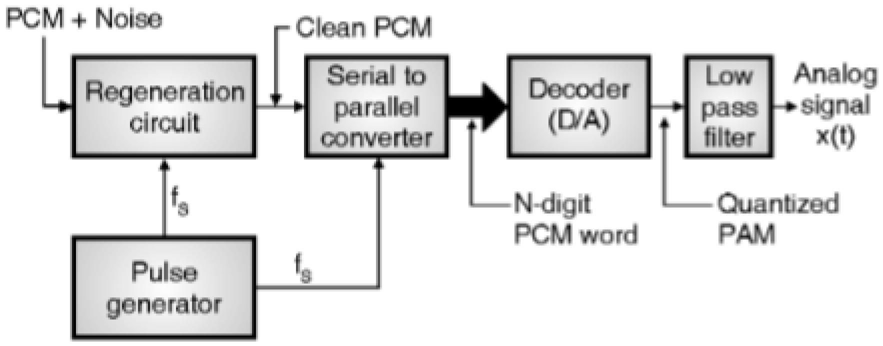


(L-223) Fig. 7.2.4 : Input and output waveforms of a PCM system

7.2.3 PCM Receiver (Decoder) :

Block diagram :

– Fig. 7.2.5 shows the block diagram of a PCM receiver.



(L-224) **Fig. 7.2.5 : PCM receiver (Decoder)**

Operation of PCM receiver :

– A PCM signal contaminated with noise is available at the receiver input.

– The regeneration circuit at the receiver will separate the PCM pulses from noise and will reconstruct the original PCM signal.

– The pulse generator has to operate in synchronization with that at the transmitter.

– Thus at the regeneration circuit output we get a "clean" PCM signal.

– The reconstruction of PCM signal is possible due to the digital nature of PCM signal.

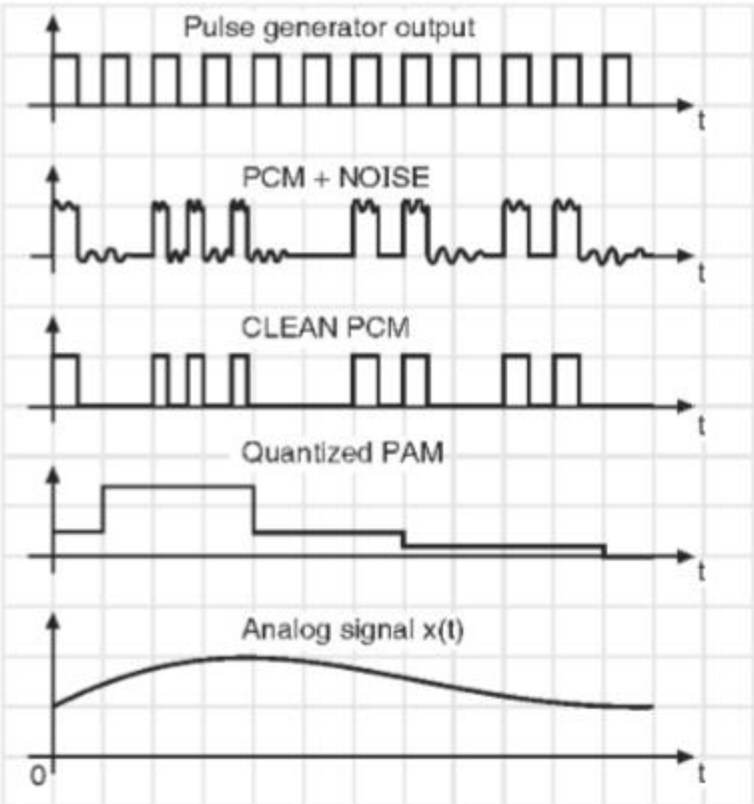
– The reconstructed PCM signal is then passed through a serial to parallel converter.

– Output of this block is then applied to a decoder.

- The decoder is a D to A converter which performs exactly the opposite operation of the encoder.
- The decoder output is the sequence of a quantized multilevel pulses.
- The quantized PAM signal is thus obtained, at the output of the decoder.
- This quantized PAM signal is passed through a low pass filter to recover the analog signal, x (t).
- The low pass filter is called as the reconstruction filter and its cut off frequency is equal to the message bandwidth W.

Waveforms :

- The waveforms at various points in the PCM receiver are as shown in Fig. 7.2.6.



(E-2003) Fig. 7.2.6 : Waveforms at various points in a PCM receiver

7.5.7 Advantages of PCM :

1. Very high noise immunity.
2. Due to digital nature of the signal, repeaters can be placed between the transmitter and the receivers. The repeaters actually regenerate the received PCM signal. This is not possible in analog systems. Repeaters further reduce the effect of noise.
3. It is possible to store the PCM signal due to its digital nature.
4. It is possible to use various coding techniques so that only the desired person can decode the received signal. This makes the communication secure.
5. The increased channel bandwidth requirement for PCM is balanced by the improved SNR.

7.5.8 Disadvantages of PCM :

1. The encoding, decoding and quantizing circuitry of PCM is complex.
2. PCM requires a large bandwidth as compared to the other systems.

Table 7.8.1 : Comparison of PCM, DM and ADM

Sr. No.	Parameter	PCM	DM	ADM
1.	Number of bits per sample	N can be 4, 8, 16, 32, 64 etc.	N = 1	N = 1
2.	Step size	Depends on the number of Q levels.	Step size is fixed	Step size is variable
3.	Distortions / errors	Quantization error	Slope overload and granular noise	Granular noise
4.	Signaling rate and bandwidth	Highest	Low, if the input is slow varying	Lowest
5.	System complexity	Complex	Simple	Simple
6.	Feedback from output	No feedback	Feedback is present	Feedback is present
7.	Noise immunity	Very good	Very good	Very good
8.	Use of repeaters	Possible	Possible	Possible