10.4 PULSE CODE MODULATION (PCM)*

1. Defimition

Pulse-code modulation is known as a **digital pulse modulation technique**. In fact, the pulse-code modulation (PCM) is quite complex compared to the analog pulse modulation techniques (*i.e.*, PAM, PWM and PPM) in the sense that the message signal is subjected to a great number of operations.

2. Elements of a PCM system

Figure 10.2 shows the basic elements of a PCM system. It consists of three main parts *i.e.*, transmitter, transmission path and receiver. The essential operations in the transmitter of a PCM system are sampling, quantizing and encoding as shown in figure 10.2. As discussed earlier, sampling is the operation in which an analog (*i.e.*, continuous-time) signal is sampled according to the sampling theorem resulting in a discrete-time signal. The quantizing and encoding operations are usually performed in the same circuit which is known as an **analog-to-digital converter (ADC).** Also, the essential operations in the receiver are regeneration of impaired signals, decoding and demodulation of the train of quantized samples. These operations are usually performed in the same cirucit which is known as a digital-to-analog converter (DAC).

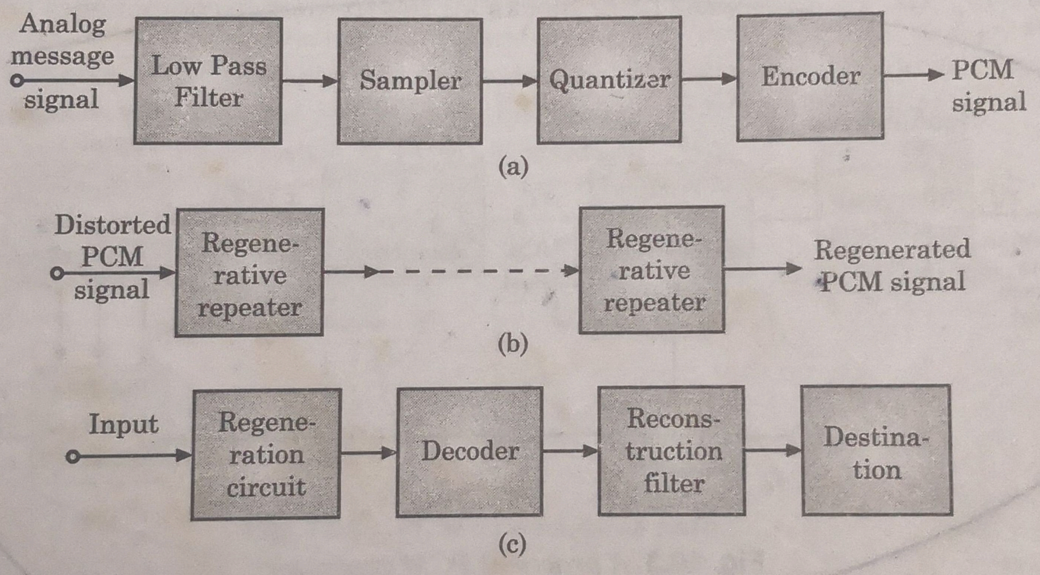

Fig. 10.2 *The basic elements of a PCM system (a) Transmitter (b) Transmission path (c) Receiver.*

* Pulse code modulation (PCM) is the name given to the class of baseband signals obtained form the quantized PAM signals by encoding each quantized sample into a digital word.

receiver, regenerative repeaters are used to reconstruct (*i.e.*, regenerate) the transmitted sequence of coded pulses in order to combat the accumulated effects of signal distortion and noise. As discussed in article 10.3, the quantization refers to the use of a finite set of amplitude levels and the selection of a level nearest to a particular sample value of the message signal as the representation for it. In fact, this operation combined with sampling, permits the use of coded pulses for representing the message signal. *Thus, it is the combined use of quantizing and coding that distinguishes pulse code modulation from analog modulation techniques.*

3. Few Important Points

Now, let us summarize PCM in the form of few points as under:

(*i*) 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.

(*ii*) This means that the PCM output is in the coded digital form. It is in the form of digital pulses of constant amplitude, width and position.

(*iii*) The information is transmitted in the form of *code words*. A PCM system consists of a PCM encoder (transmitter) and a PCM decoder (receiver).

(*iv*) The essential operations in the PCM transmitter are sampling, quantizing and encoding.

(*v*) All the operations are usually performed in the same circuit called as **analog-to-digital converter.**

(*vi*) It should be understood that the PCM is not modulation in the conventional sense.

(*vii*) Because in modulation, one of the characteristics of the carrier is varied in proportion with the amplitude of the modulating signal. Nothing of that sort happen in PCM.

10.5 A PCM GENERATOR OR TRANSMITTER

In the last article, we had an overview of the elements of a PCM system (*i.e.*, transmitter, transmission-path and receiver). In this section, we shall discuss the PCM generator (*i.e.*, transmitter) from a practical point of view. Figure 10.3 shows a practical block diagram of a PCM generator.

In PCM generator of figure 10.3, 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.*

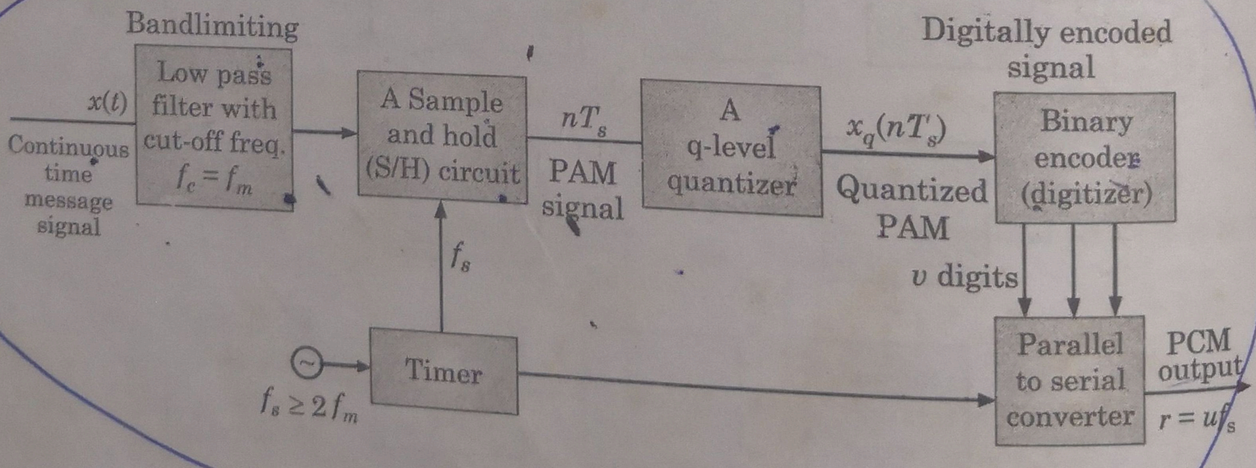

Fig. 10.3 *A practical PCM generator*

This means that now the signal $x(t)$ is bandlimited to f_m Hz. The sample and hold circuit then

*Recall that this filter is used to avoid aliasing.

samples this signal at the rate of f_s. Sampling frequency f_s is selected sufficiently above nyquist rate to aviod aliasing *i.e.*,

$$f_s \geq 2f_m$$

In figure 10.3, the output of sample and hold circuit is denoted by $x(nT_s)$. This signal $x(nT_s)$ is discrete in time and continuous in amplitude. A q-level quantizer compares input $x(nT_s)$ with its fixed digital levels. It assigns any one of the digital level to $x(nT_s)$ with its fixed digital levels. It then assigns any one of the digital level to $x(nT_s)$ which results in minimum distortion or error. This error is called **quantization error.** Thus, output of quantizer is a digital level called $x_q(nT_s)$. Now, the quantized signal level $x_q(nT_s)$ is given to binary encoder. This encoder converts input signal to 'v' digits binary word. Thus $x_q(nT_s)$ is converted to 'v' binary bits. This encoder is also known as digitizer.

Important Point: *It may be noted that it is not possible to transmit each bit of the binary word separately on transmission line. Therefore 'v' binary digits are converted to serial bit stream to generate single baseband signal. In a parallel to serial converter, usually a shift register does this job. The output of PCM generator is thus a single baseband signal of binary bits.*

Also, an oscillator generates the clocks for sample and hold circuit and parallel to serial converter. In the pulse code modulation generator discussed above, sample and hold, quantizer and encoder combinely form an analog to digital converter (ADC).

10.6 PCM TRANSMISSION PATH

The path between the PCM transmitter and PCM receiver over which the PCM signal travel, is called as **PCM transmission path** and it is as shown in figure 10.4. The most important feature of PCM system lies in its ability to control the effects of distortion and noise when the PCM wave travels on the channel. PCM accomplishes this capacity by means of using a chain of regenerative repeaters as shown in figure 10.4. Such repeaters are spaced close enough to each other on the transmission path. The regenerative performs three basic operations namely equalization, timing and decision making. Hence, each repeater actually reproduces the clean noise free PCM signal from the PCM signal distorted by the channel noise. This improves the performance of PCM in presence of noise.

DO YOU KNOW?

PCM requires that the amplitude of each sample of a signal be converted to a binary number. The more bits used for the number, the greater the accuracy, but the greater the bit rate required.

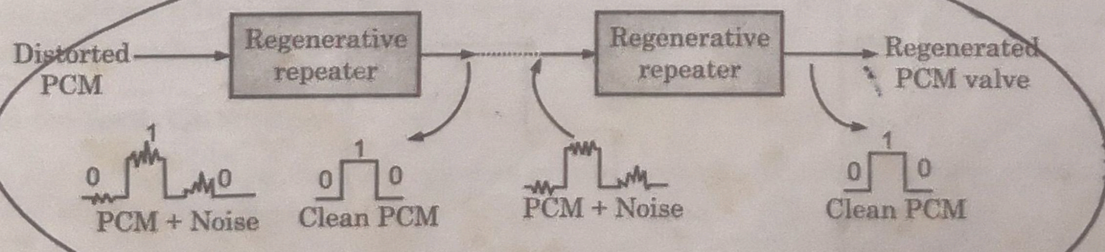

Fig. 10.4 *PCM transmission path.*

10.6.1. Block Diagram of a Repeater

Figure 10.5 shows the block diagram of a regenerative repeater.

The amplitude equalizer shapes the distorted PCM wave so as to compensate for the effects of amplitude and phase distortions. The timing circuit produces a periodic pulse train which is derived from the input PCM pulses. This pulse train is then applied to the decision making device. The decision making device uses this pulse train for sampling the equalized PCM pulses. The sampling is carried out at the instants where the signal to noise ratio is maximum. The decision device makes a decision about whether the equalized PCM wave at its input has a 0 value or 1 value at the instant of sampling.

Such a decision is made by comparing equalized PCM with a reference level called **decision threshold** as illustrated in figure 10.6. At the output of the decision device, we get a clean PCM signal without any trace of noise.*

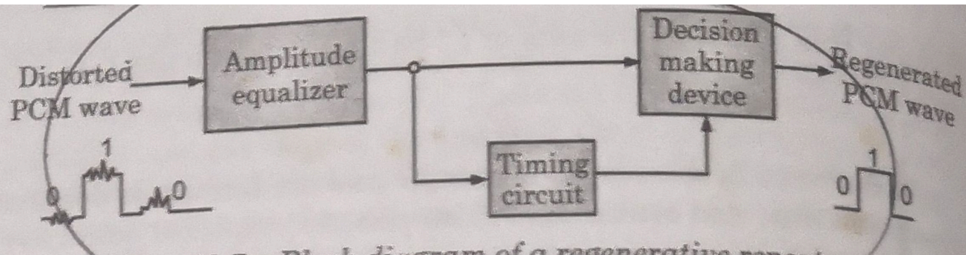

Fig. 10.5 *Block diagram of a regenerative repeater.*

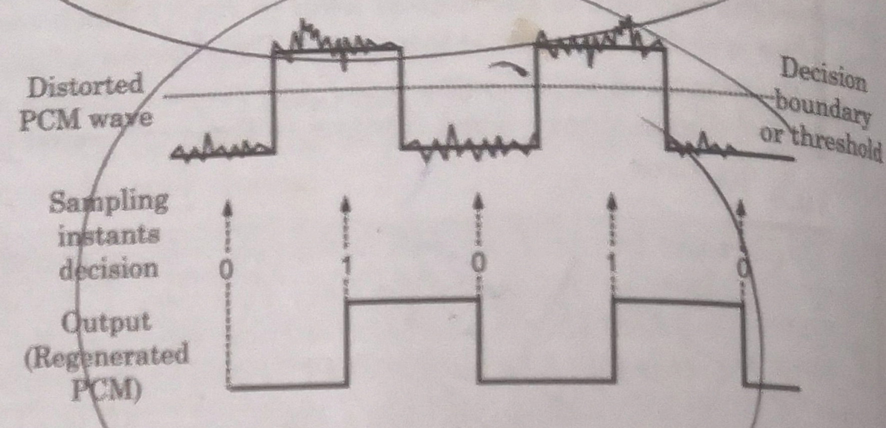

Fig. 10.6 *Waveforms of a regenerative repeater.*

10.7 PCM RECEIVER

In this section, we shall discuss a PCM receiver from practical point of view. Figure 10.7(*a*) shows the block diagram of PCM receiver and figure 10.7 (*b*) shows the reconstructed signal. The regenerator at the start of PCM receiver reshapes the pulse and removes the noise. This signal is then converted to parallel digital words for each sample.

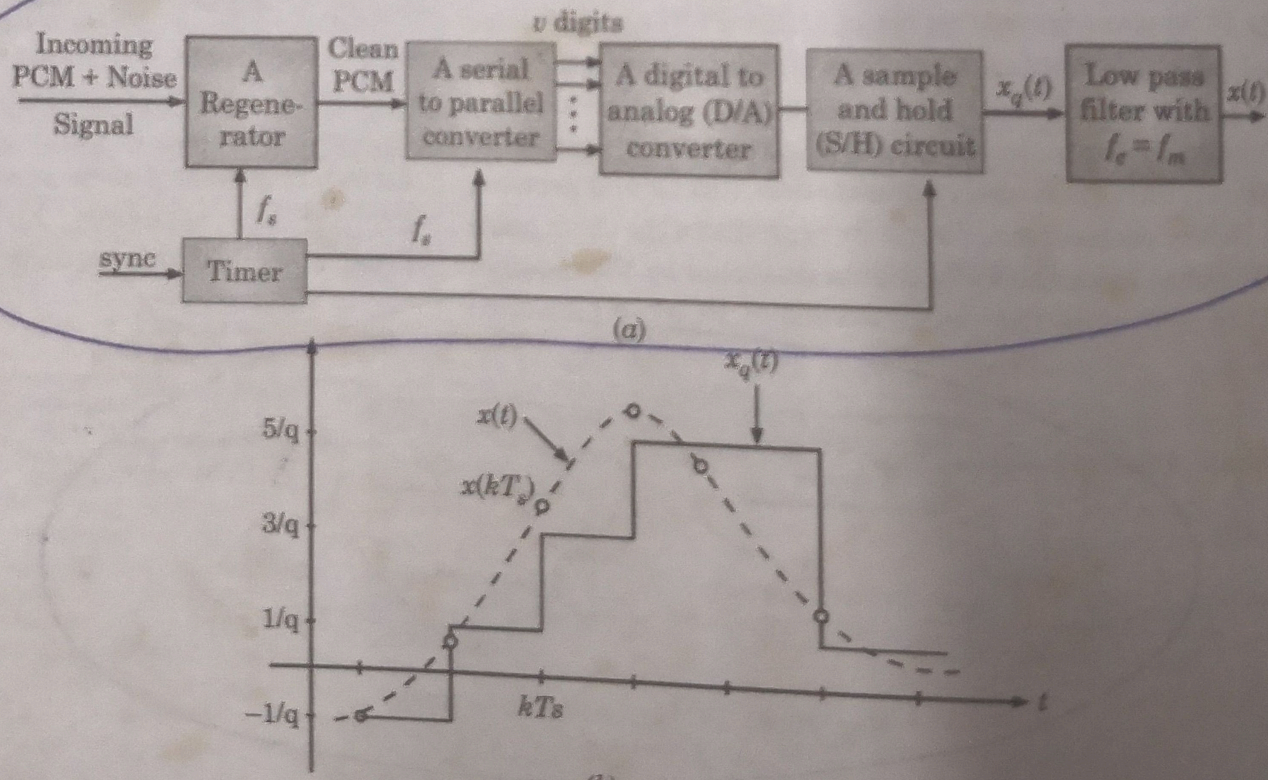

Fig. 10.7 *(a) PCM receiver (b) Reconstructed waveform.*

*Actually, the use of digital techniques with analog signals is one of the fastest growing areas in communications, for several good reasons.

Now, the digital word is converted to its analog value denoted as $x_q(t)$ with the help of a sample and hold circuit. This signal, at the output of sample and hold circuit, is allowed to pass through a lowpass reconstruction filter to get the appropriate original message signal denoted as $y(t)$.

Important Note : *As shown in reconstructed signal of figure 10.7 (b), it is impossible to reconstruct exact original signal x(t) because of permanent quantization error introduced during quantization at the transmitter. In fact, this quantization error can be reduced by increasing the binary levels. This is equivalent to increasing binary digits (bits) per sample. But increasing bits 'v' increases the signalling rate as well as transmission bandwidth as we have observed in last article. Therefore the choice of these parameters is made, in such a manner that noise due to quantization error (i.e., also called as quantization noise) is in tolerable limits.*