Pulse Code Modulation

Pulse-code modulation or PCM is known as a digital pulse modulation technique . In fact, the pulse-code modulation is quite complex as 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 . In PCM an anlog signal or information is converted into a binary sequence, i.e.,' **1's** and '**0's**. The output of a PCM resembles a binary sequence. The following figure 5.7.1 shows an example of PCM output with respect to instantaneous values of a given sine wave.

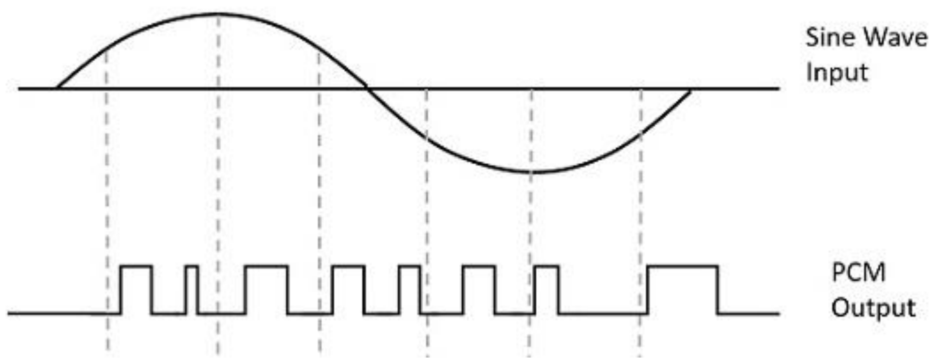


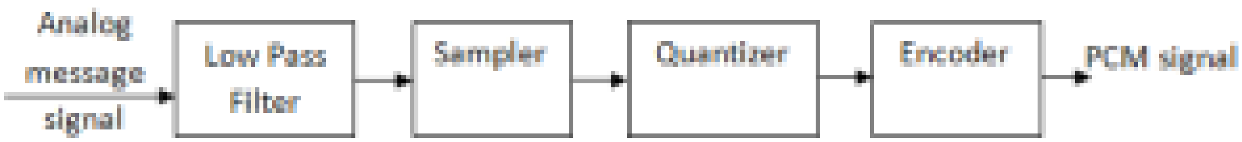
Figure 5.7.1 PCM Output

Diagram Source Brain Kart

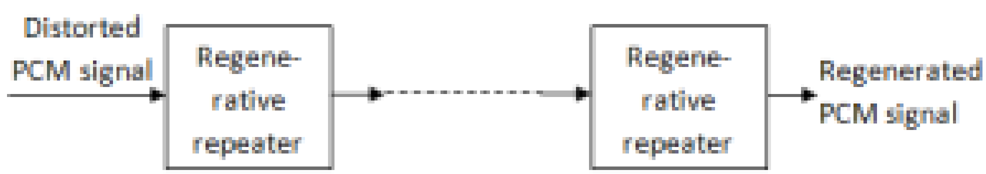
PCM produces a series of numbers or digits instead of a pulse train,. Each one of these digits, in binary code, represent the approximate amplitude of the signal sample at that instant. In Pulse Code Modulation, the message signal is represented by a sequence of coded pulses. This message signal is achieved by representing the signal in discrete form in both time and amplitude.

Elements of a PCM System

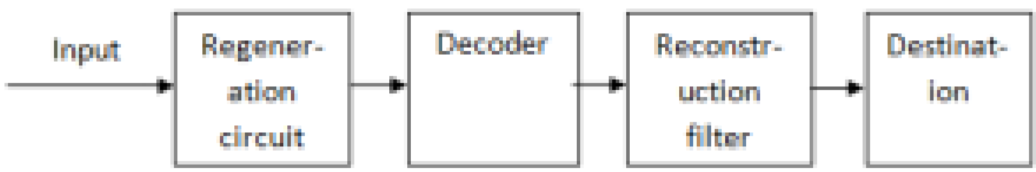
Fig.5.7.2 shows the basic elements of a PCM system .



(a): PCM Transmitter



(b) : Transmitter Path



(c) : Receiver

Figure.5.7.2 : The basic elements of a PCM System

Diagram Source Brain Kart

It consists of three main parts i.e. ,

1. Transmitter
2. Transmission path
3. Receiver

The essential operation in the transmitter of a PCM system are :

1. Sampling
2. Quantizing
3. Encoding

As discussed earlier, sampling is the operation in which an analog (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) .

The essential operations in the receiver of a PCM system are :

1. Regeneration of impaired signals
2. Decoding and demodulation of the train of quantized samples

These operations are usually performed in the same circuit which is known as a digital-to-analog converter (DAC) .

Further, at intermediate points, along the transmission route from the transmitter to the 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 before, 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 .

Few Important Points :

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

1. PCM is a type of pulse modulation like PAM, PWM or PPM but there is an important difference between them i.e. PAM, PWM or PPM are analog pulse modulation systems whereas PCM is a digital pulse modulation system .
2. 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 .

3. The information is transmitted in the form of code words . A PCM system consists of a PCM encoder (transmitter) and a PCM decoder (receiver) .
4. The essential operations in the PCM transmitter are sampling, quantizing and encoding .
5. All the operations are usually performed in the same circuit called as analog-to digital converter .
6. It should be understood that the PCM is not modulation in the conventional sense . 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 .

1. PCM Transmitter

Fig.5.7.3 shows a practical block diagram of a PCM generator or transmitter.

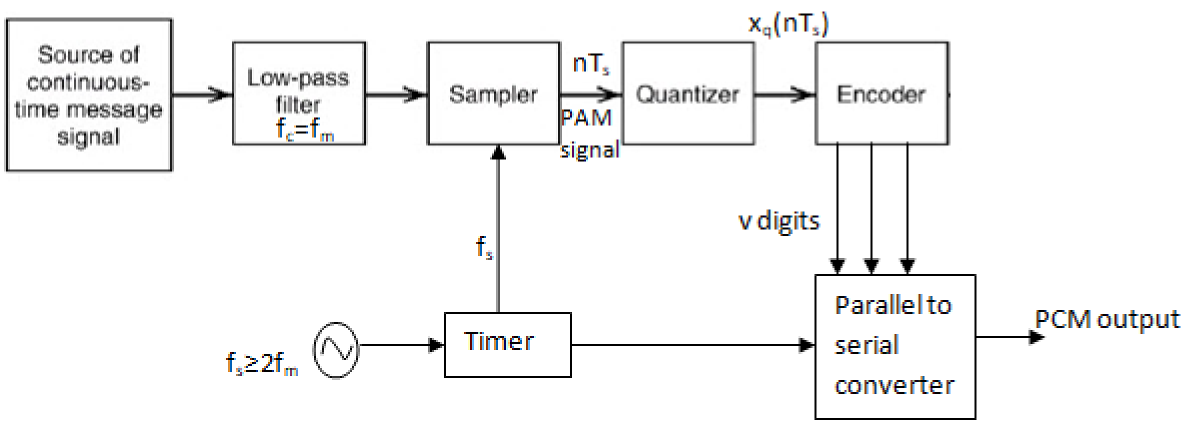


Figure 5.7.3 : PCM Transmitter

Diagram Source Brain Kart

In PCM transmitter , the signal x(t) is first passed through the low-pass filter of cut-off frequency f_m Hz . This low-pass filter blocks all the frequency components above f_m Hz.This means that now the signal x(t) is bandlimited to f_m Hz .

The sample and hold circuit then samples this signal at the rate of f_s. Sampling frequency f_s is selected sufficiently above nyquist rate to avoid aliasing i.e.,

$$f_s \geq 2f_m$$

The output sample and hold circutit 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 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.This encoder is also known as digitizer. In addition to these, there is an oscillator which generates the clocks for sample and hold circuit and parallel to serial converter.

In PCM, sample and hold, quantizer and encoder combinely form an analog to digital converter (ADC).

2. PCM Transmission Path

The path between the PCM transmitter and receiver over which the PCM signal travel, is known as PCM transmission path and it is shown in Fig.5.7.4

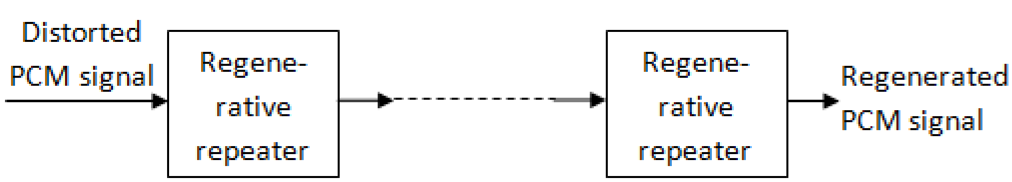


Figure 5.7.4: PCM Transmission path

Diagram Source Brain Kart

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. This is accomplished by means of using a chain of regenerative repeaters as shown in Such repeaters are spaced close enough to each other on the transmission path.

The repeaters perform three basic operations such as : quantization, timing and decision making. Hence, each repeaters actually reproduces the clean and noise free PCM signal. This improves the performance of PCM in presence of noise.

Repeater

Fig.5.7.5 shows the block diagram of a repeater.

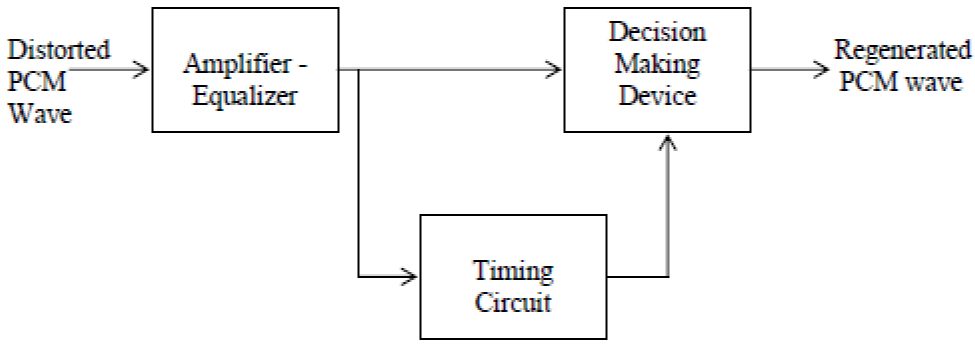


Figure 5.7.5: Block Diagram Of Regenerative Repeater

Diagram Source Brain Kart

The amplitude quantizer 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 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 thershold . At the output of the decision device, we get a clean PCM signal without any noise.

PCM Receiver

Fig. 5.7.6 shows the block diagram of a PCM receiver .

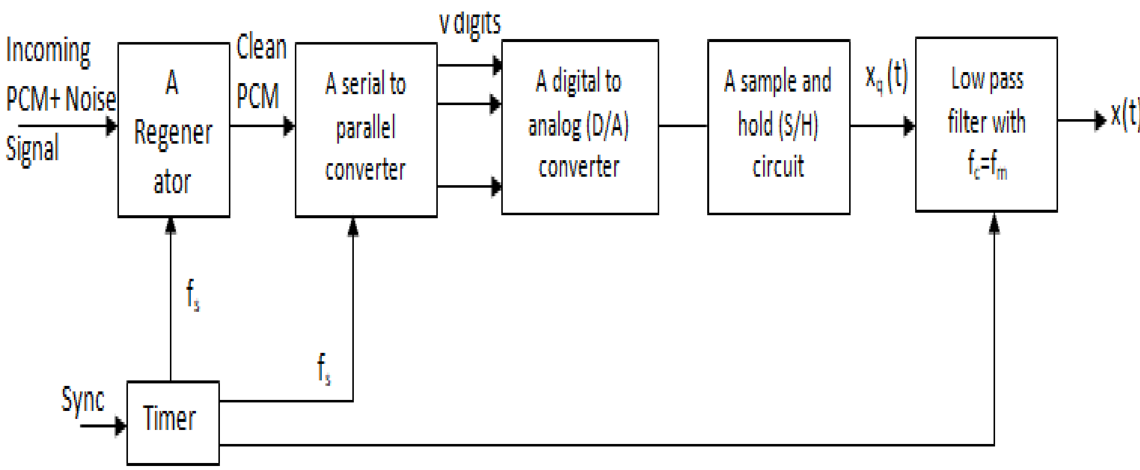


Figure 5.7.6 PCM Receiver

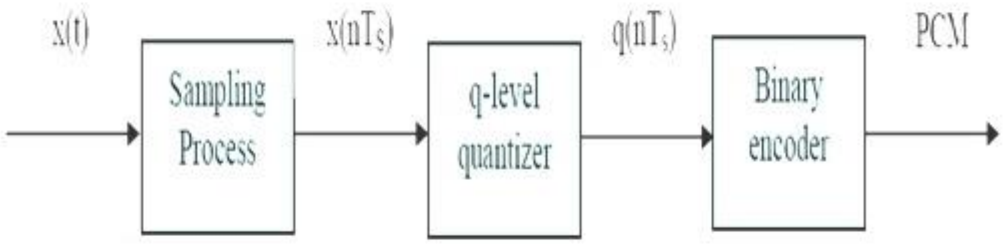
Diagram Source Brain Kart

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. 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 low-pass reconstruction filter to get the original message signal x(t) .

Pulse code Modulation:

The pulse code modulator technique samples the input signalx(t) at a sampling frequency. This sampled variable amplitude pulse is then digitalized by the analog to digital converter. Figure 5.7.7 shows the PCM generator.

The signal is first passed through sampler which is sampled at a rate of (fs) where:The output of the sampler x(nTs) which is discrete in time is fed to a „q" level quantizer. The quantizer compares the input x(nTs) with it's fixed levels. It assigns any one of the digital level to x(nTs) that results in minimum distortion or error. The error is called quantization error, thus the output of the quantizer is a digital level called q(nTs). The quantized



$$f_s \geq 2f_m$$

Figure .5.7.7 Analog To Digital Conversion

Diagram Source Brain Kart

signal level q(nTs) is binary encode. The encoder converts the input signal to ***v*** digits binary word.The receiver starts by reshaping the received pulses, removes the noise and then converts the binary bits to analog shown in the figure 5.7.8. The received samples are then filtered by a low pass filter; the cut off frequency is at fc.

fc= fm.

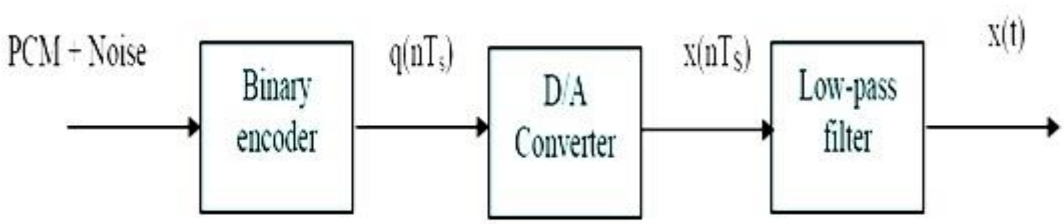


Figure.5.7.8 Digital To Analog Converter

Diagram Source Brain Kart

It is impossible to reconstruct the original signal x(t) because of the permanent quantization error introduced during quantization at the transmitter. The quantization error can be reduced by the increasing quantization levels. This corresponds to the increase of bits persample(more information). But increasing bits ***(v***) increases the signaling rate and requires a large transmission bandwidth. The choice of the parameter for the number of quantization levels must be acceptable with the quantization noise (quantization error).

Signaling Rate in PCM

Let the quantizer use 'v' number of binary digits to represent each level. Then the number of levels that can be represented by ***v*** digits will be : q=2*v*

The number of bits per second is given by : (Number of bits per second)=(Number of bits per samples)x(number of samples per second) = ***v*** (bits per sample) x fs (samples per second). The number of bits per second is also called signaling rate of PCM and is Signaling rate= ***v***fs

Quantization Noise in PCM System

Errors are introduced in the signal because of the quantization process. This error is called "quantization error".

$$\varepsilon = xq\ (nTs) - x(nTs)$$

Let an input signal x(nTs) have an amplitude in the range of *x*max to - *x*max The total amplitude range is : Total amplitude

$$x\text{max} - (-\,x\text{max}) = 2\,x\text{max}$$

If the amplitude range is divided into 'q' levels of quantizer, then the step size 'Δ'. Δ= q/2 X max If the minimum and maximum values are equal to 1,

*x*max,=1, - *x*max=-1, Δ= q/2.

Signal to Quantization Noise ratio in PCM

The signal to quantization noise ratio is given as

$$\boxed{\frac{S}{N_q} = \frac{\text{Normalized signal power}}{\text{Normalized noise power}}}$$

$$= \frac{\text{Normalized signal power}}{\frac{\Delta^2}{12}}$$

The number of quantization value is equal to: $q=2\boldsymbol{v}$

$$\Delta = \frac{2X_{max}}{2^{\nu}}$$

$$\frac{S}{N_q} = \frac{\text{Normalized signal power}}{\left[\frac{2X_{max}}{2^{\nu}}\right]^2 * \frac{1}{12}}$$

Let the normalized signal power is equal to P then the signal to quantization noise will be given by:

$$\boxed{\frac{S}{N_q} = \frac{3P * 2^{2\nu}}{X_{max}^2}}$$

Advantages of PCM

1. Effect of noise is reduced.
2. PCM permits the use of pulse regeneration.
3. Multiplexing of various PCM signals is possible.