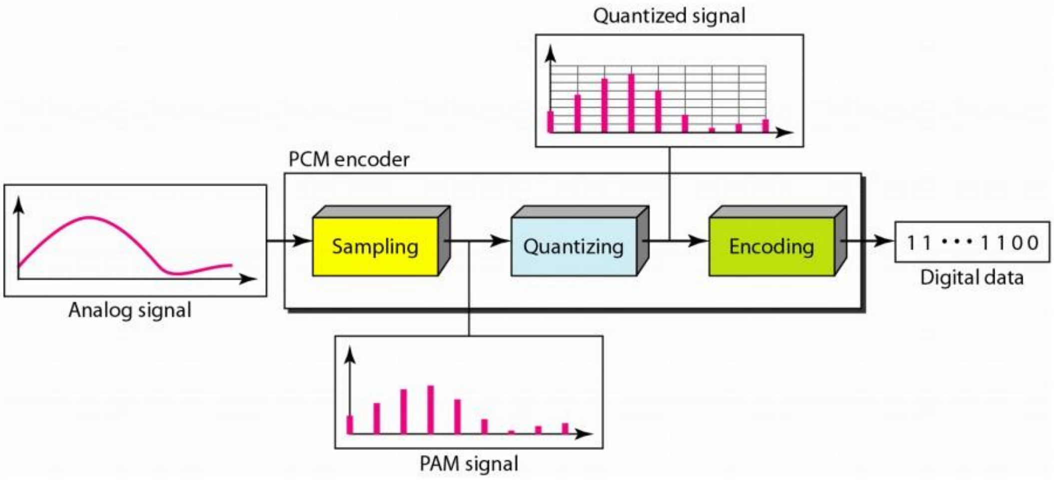
Pulse code modulation (PCM)

Pulse code modulation (PCM) is the name given to the class of baseband signals obtained from the quantized PAM signals by encoding each quantized sample into a digital word. Figure below shows the steps required in PCM communication.



The source of information is sampled and quantized to one of **L**-levels, then each quantized sample is digitally encoded into a **k**-bits code word.

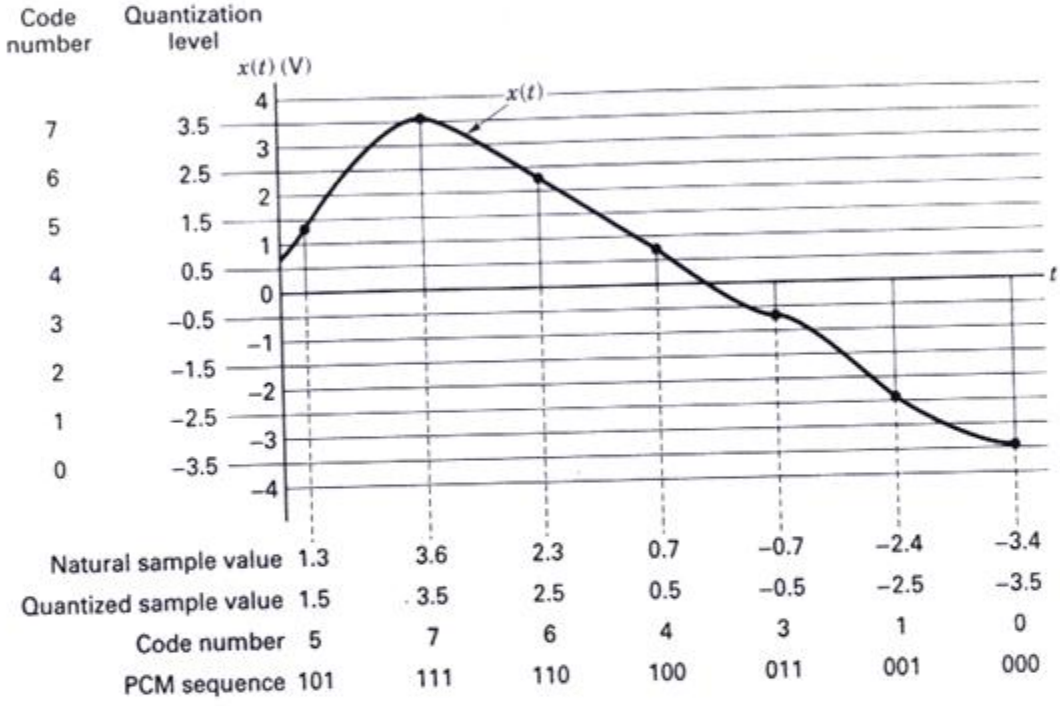
Where $k = \log_2 L$

$$L = 2^k$$

The essential features of binary PCM are shown in figure below. Assume that an analog signal, x(t), is limited in its excursions to the range (-4V to +4V). The step size between quantization levels has been set at 1V. Thus eight quantization level are employed, these located at -3.5V, -2.5V, ………., +3.5V.

The code number 0 may be assigned to the level at -3.5V; the code number 1 may be assigned to the level at -2.5V, and so on until the level at 3.5V, which is assigned the code number 7.

Each code number has its representation in binary arithmetic, ranging from 000 for code number 0 to 111 for code number 7.



Natural sample value	1.3	3.6	2.3	0.7	−0.7	−2.4	−3.4
Quantized sample value	1.5	3.5	2.5	0.5	−0.5	−2.5	−3.5
Code number	5	7	6	4	3	1	0
PCM sequence	101	111	110	100	011	001	000

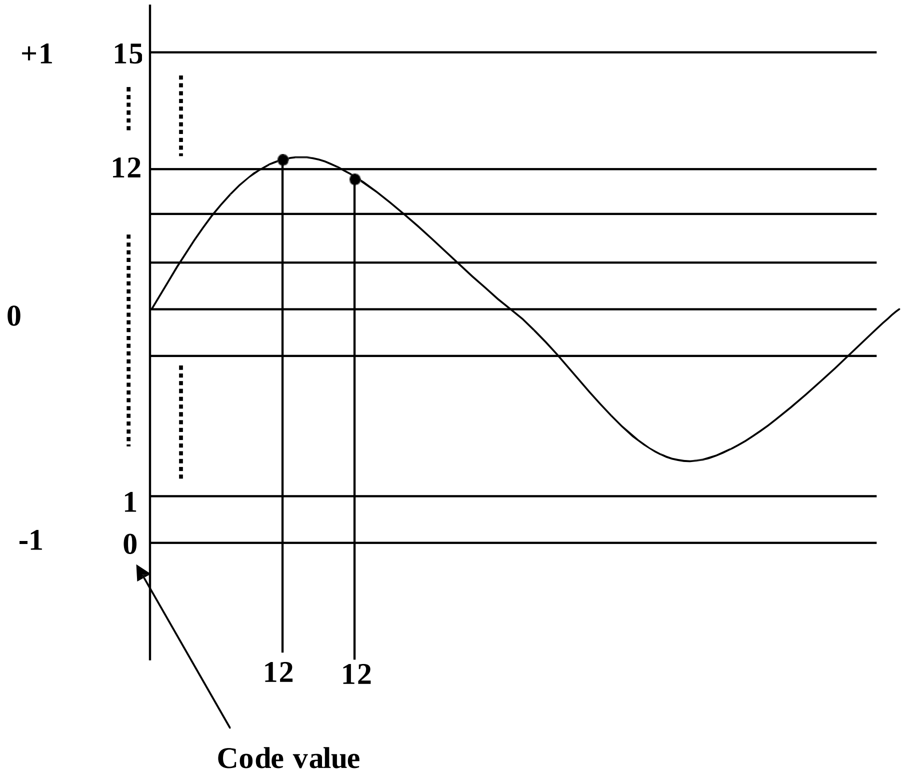
From the above figure each sample of analog signal is assigned to the quantization level closest to the value of the sample. Beneath the analog waveform, x(t), are seen four representations of x(t) as follows:- the natural sample value, the quantized sample value, the code numbers, and the PCM sequence.

➢ ***Quantization***

The objective of the quantization step in PCM process is to represent each sample by a fixed number of bits.

For example, if the amplitude of PAM resulting from sampling process ranges between (-1V and +1V), there can be infinite values of voltage between (-1 and +1). For instance, one value can be -0.27689V. To assign a different binary sequence to each voltage value, we would have to construct a code of infinite length. Therefore, we can take a limit number of voltage values between (-1V and +1V) to represent the original signal and these values must be discrete.

Assume that the quantization steps were in 0.1V increment, and the voltage measurement for one sample is 0.58V. That would have to be rounded off to 0.6V, the nearest discrete value. Note that there is a 0.02V error, the difference between 0.58V and 0.6V. See figure below. Take step 12 in the curve, for example, the curve is passing through a maximum and is given tow values of 12. For the first value, the actual curve is above 12 and for second value below 12. That error from the true value to the quantum value is called ***quantization distortion***. This distortion is the major source of imperfection in PCM system.



The more quantization level, the better quality the system will deliver. However, increasing the number of quantization level has two major costs:-

1) The cost of designing a system with large binary code size needed.
2) The time it takes to process this large number of quantizing steps by the coder.

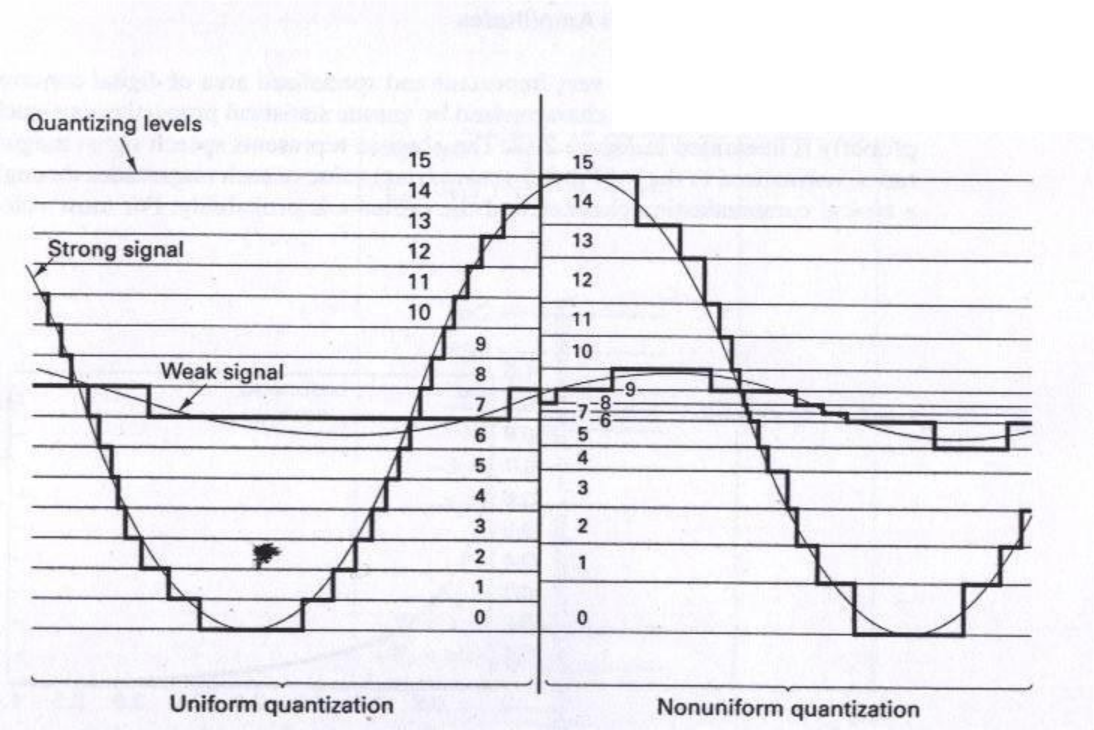
Therefore, a very large number of quantizing levels may induce unwanted delays in the system.

Uniform and Nonuniform Quantization

Form the above discussion it cam be seen that the quantization noise depends on the step size. When the steps have uniform size the quantization called as ***uniform quantization***.

For uniform quantization, the quantization noise is the same for all signal magnitudes. Therefore, with uniform quantization the signal to noise ratio (SNR) is worse for low level signals than for high level signals.

Nonuniform quantization can provide fine quantization of the weak signal and coarse quantization of the strong signal. Thus in the case of nonuniform quantization, quantization noise can be made proportional to signal size. The effect is to improve the overall SNR by reducing the noise for the predominant weak signals, at the expense of an increase in noise for the rarely occurring strong signals. Figure below compares the quantization of strong signal versus a weak signal for uniform and nonuniform quantization.



➢ Noise consideration in PCM system

The performance of a PCM system is influenced by two major sources of noise.

1) ***Channel noise***, which is introduced anywhere between the transmitter output and the receiver input, channel noise is always present, once the equipment is switched on.
2) ***Quantization noise***, which is introduced in the transmitter and is carried all the way along to the receiver output.

Quantization Noise

The peak signal to r.m.s noise power ratio is given by

$$\frac{S_0}{N_0} = 3L^2$$

$$\left.\frac{S_0}{N_0}\right)_{dB} = 4.8 + 20\log_{10} L$$

where L=number of quantizer level.

S_0= peak signal power.

N_0= r.m.s noise power.

Increasing L increases the number of code pulses and hence the bandwidth. We can thus relate SNR to bandwidth. This is easily done by noting that

$$L = n^m$$

where m=the number pulses in code group.

n=the number of code levels.

$$\therefore \frac{S_0}{N_0} = 3n^{2m}$$

and $$\left.\frac{S_0}{\Lambda_0}\right)_{dB} = 4.8 + 20m\log_{10} n$$

In particular, for binary code n=2.

$$\left.\frac{S_0}{\Lambda_0}\right)_{dB} = 4.8 + 6m$$

Since the bandwidth is proportional to m, the output SNR increases exponentially with bandwidth.

Example

Ten voice channels each of bandwidth (B.W) =3.2 KHz are sequentially sampled at 8 KHz and TDM'ed.

(a) What is the system bandwidth (B.W).

(b) If TDM'ed signal is PCM'ed using 8-level quantization, find bit rate (R_b)

Solution:-

(a) Without guard band

$$T_s = \frac{1}{f_s} = \frac{1}{8KHz} = 125\mu\,\text{sec}.$$

□ 10 voice channels, $\therefore$ 10 samples

$$\therefore \text{ Necessary B.W} = \frac{10}{125 * 10^{-6}} = 80KHz$$

(b) $$k = \log_2 L = \log_2 8 = 3\frac{bit}{sample}$$

$$\therefore R_b = 80 * 10^3 \frac{sample}{\text{sec}.} * 3\frac{bit}{sample} = 240\frac{bit}{\text{sec}.}$$