❖ *Analog vs. Digital*

The difference between analog and digital is similar to the difference between continuous-time and discrete-time. However, in this case the difference involves the values of the function. Analog corresponds to a continuous set of possible function values, while digital corresponds to a discrete set of possible function values.

Analog signals are a type of continuous signals which are time-varying. Most of the environmental sensors such as, temperature, light, pressure, and sound sensors communicate with microcontrollers using analog signals. These analog sensors output values in a specific range based on what the sensors are sensing. Analog signals normally take the form of sine waves and they can be defined by amplitude, frequency, and phase.

Digital signals are a type of discrete signals which are time-varying. The data is carried in the form of binary in a digital signal. This means it can either carry a "0" or a "1". If you think about a switch, it sends out digital signals when pressing it to turn on while transmitting as a "1" and when pressed again to turn off while transmitting as a "0". Digital signals also have an amplitude, frequency, and a phase just like analog signals. Digital Signals are normally defined by bit interval and bit-rate where, bit-interval is the required time to transmit one bit, and bit-rate is the frequency of the bit interval. Accordingly, a common example of a digital signal is a binary sequence, where the values of the function can only be one or zero.

The analog signal defines by the amplitude, frequency, and a phase. While, the digital signal can be defined by the bit interval and bit-rate. In term of signal nature, the analog signals correspond to the CTS, while the digital signals corresponding the DTS. In term of waveform, Mostly, the analog signals represented by sine wave while, the digital signal represented by square wave. Moreover, for the analog signals, there is no fixed range for it. On the other hand, the digital signal has a finite range (0,1). The transmission data step is done in the form of wave for the analog signals, whereas in the digital signals, the transmission data step through 0s and 1s.

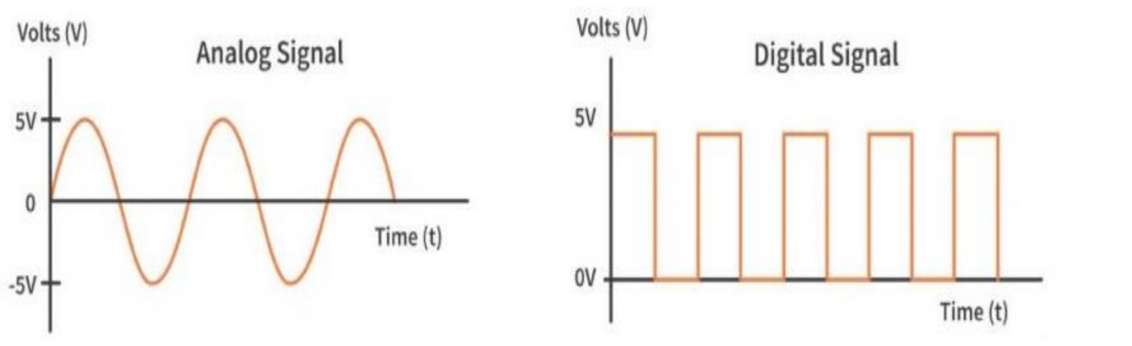
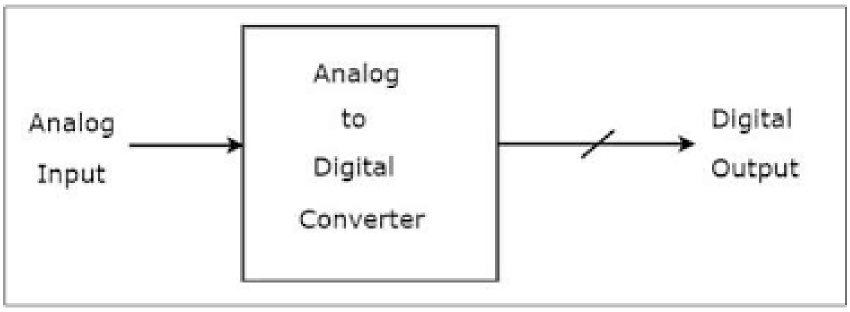


Figure 1: The analog and digital signals

The advantages of the analog signal are, natural representation, smooth signal, easy to interpret and modify. The main shortcomings of analog signal are, the noise, interference, and signal degradation. The pros of the digital signals are, noise resistance, long-distance transmission, and it can be duplicated and transmitted excellently, making them ideal for high-accuracy and precision applications. The advantages of the digital signals are, it need the sampling and quantization steps which might result in some information and accuracy loss. Moreover, it mostly requires sophisticated algorithms and processing techniques.

Usually, the microcontroller uses and process the digital signals. When you need to use analog sensors and communicate with a microcontroller, it is not possible for the microcontroller to directly understand these analog signals because microcontrollers only understand digital signals which are formed by 1's and 0's. Therefore, this kind of system needs an intermediate device that could convert the analog signals from these sensors to digital signals in order for the microcontroller to understand these signals. An ADC (Analog to Digital Converter) is an electronic integrated circuit which is able to convert these analog signals to digital signals. Most signals are analog signals in nature, while the most widely used systems are digital systems.



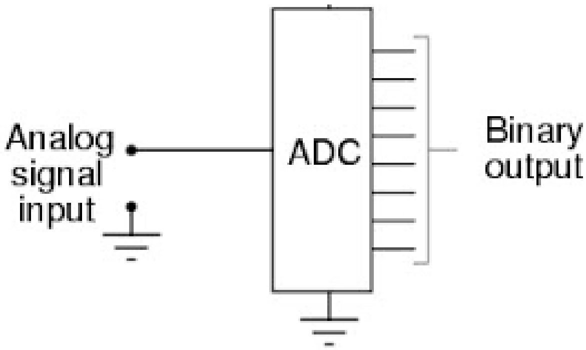


Figure 2: signal converter

In the same context, the type of systems based on the type of signal before processing (main signal type). When the main input signal is analog then, the system is called as analog system. On the other hand, if the main signal of a system is digital, then, the system is known as digital system.

- ***Periodic vs. Aperiodic (non-periodic)***

Periodic signals repeat with some period T, while aperiodic, or non-periodic, signals do not. We can define a periodic function through the following mathematical expression:

$f(t)= f (t + T)$

where (t) can be any number and T is a positive constant.

In other words, the signal is said to be periodic signal if it has a definite pattern and repeats itself at a regular interval of time such as, sin and cosine signals. Whereas, the signal which does not at the regular interval of time is known as an aperiodic signal (or non-periodic signal).

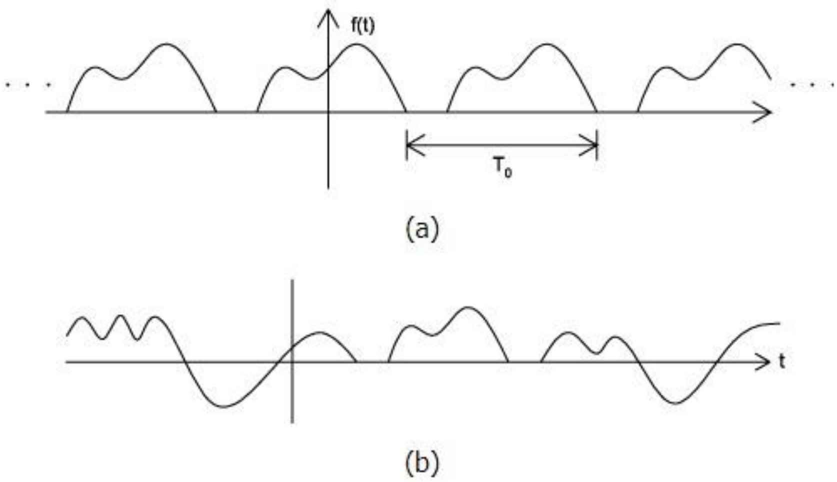


Figure 3: (a) A periodic signal with period T_0 (b) An aperiodic signal

❖ *Causal vs. Anticausal vs. Noncausal*

Causal signals are signals that are zero for all negative time, while anticausal are signals that are zero for all positive time. Noncausal signals are signals that have nonzero values in both positive and negative time.

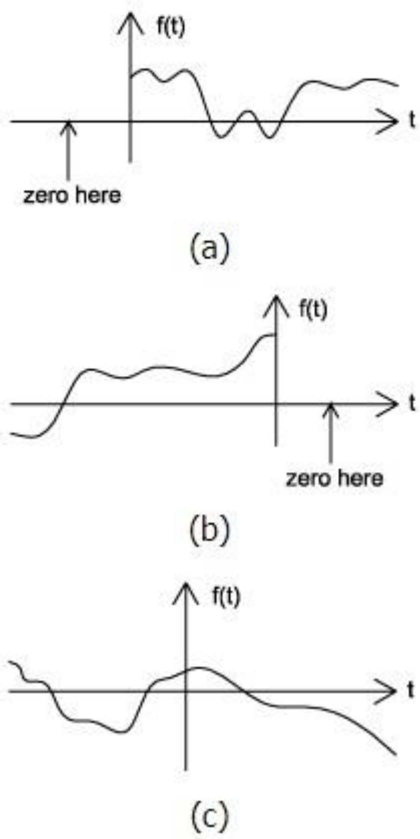


Figure 4: a) Causal signal (b) Anticausal signal (c) Noncausal signal

❖ *Finite vs. Infinite Length*

Another way of classifying a signal is in terms of its length along its time axis. Is the signal defined for all possible values of time, or for only certain values of time? Mathematically speaking, f(t) is a finite-length signal if it is defined only over a finite interval.

In practice, these are not all classifications of signals. In addition to what was mentioned above, signals can be classified into: deterministic vs. random, even vs. odd, energy vs. power, real vs. imaginary, and others.

Furthermore, the signals can be classified into different categorized based on other criteria such as:

- ***The number of signal sources***

- ✓ One-channel signals: signal generated by a single source or sensor are called one-channel signals. For example, the record of temperature with respect to time is an example of one-channel signal.
- ✓ Multichannel signals: signals that are generated by multiple sources or sensors are called multichannel signals. The record of ECG (Electro Cardio Graph) at eight different places in a human body is an example of eight-channel signal.

- ***The number of independent variables***

- ✓ One-dimensional signals: a signal which is a function of single independent variable is called one-dimensional signal.
- ✓ Multidimensional signals: a signal which is a function of two or more independent variables is called multidimensional signal.

$$X\ (p, q) = 0.6p+0.5q + 1.1\ q^2$$

- ***The independent variable is continuous or discrete.***

- ✓ Analog or continuous signals: when a signal is defined continuously for any value of independent variable, it is called analog or continuous signal. Most of the signals encountered in science and engineering are analog in nature.
- ✓ Discrete signals: when a signal is defined for discrete intervals of independent variable, it is called discrete signal.

Continuous Time Signal

If the signal is defined continuously for any value of the independent variable time “t”, then the signal is called Continuous Time Signal (CTS). The continuous time signal is denoted as “$X_{(t)}$”.

CTS is defined for every instant of the independent variable time and so the magnitude (or the value) of continuous time signal is continuous in the specified range of time. Hence both the magnitude of the signal and the independent variable are continuous. For historical reasons, CTS are often called Analog Signals.

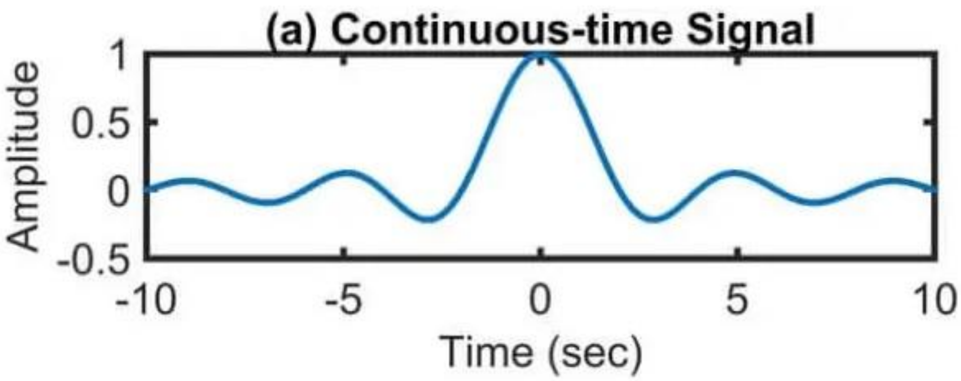


Figure 5: CTS

In this signal type, the independent variable need not be time, it could be distance, for example. But for simplicity we will always consider it to be time.

Discrete Time Signal

In contrast, Discrete Time Signal (DTS) is the signal that define only for discrete instants of the independent variable time. In other words, DTS are sequences of values that are defined at discrete, evenly spaced intervals of time as explained in Figure 9.

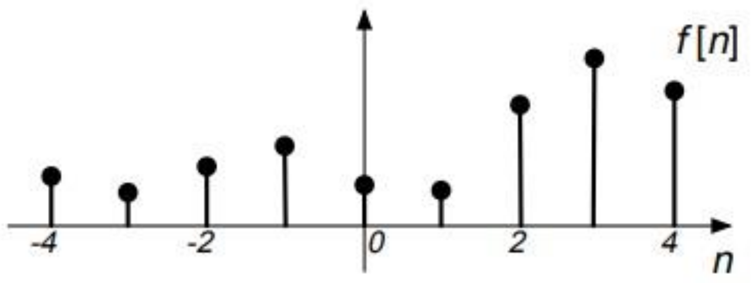


Figure 6: DTS

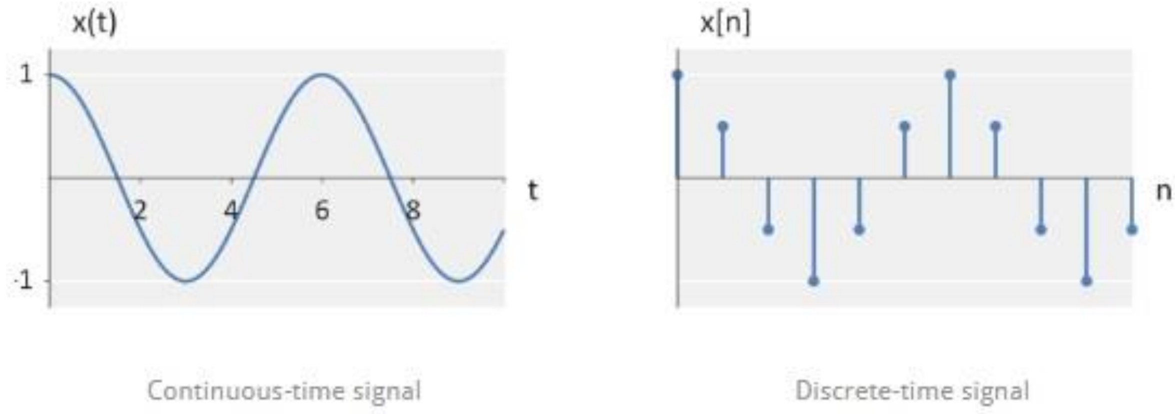


Figure 7: The difference between the CTS and DTS

Accordingly, the causal and anticausal signals are as follows:

A continuous-time signal x(t) is said to be causal when:

$x_{(t)} = 0$ for $t < 0$

A continuous-time signal x(t) is said to be anticausal when:

$x_{(t)} = 0$ for $t \geq 0$

A discrete-time signal x[n] is said to be causal when:

$x_{[n]} = 0$ for $n < 0$

A discrete-time signal x[n] is said to be anticausal if:

$x_{[n]} = 0$ for $n \geq 0$

Basic Operation on Signals

An issue of major importance is the use of systems to process or manipulate signals. This issue involves a combination of some basic operations.

However, two classes of these operations can be identified that are:

① Operation of dependent variables

A. Amplitude scaling (Amplitude shifting, Amplification): The scaled signal $ax_{(t)}$ is $x_{(t)}$ multiplied by the factor a where a is a constant real number, such as, the physical device that performs amplitude scaling is an electronic amplifier.

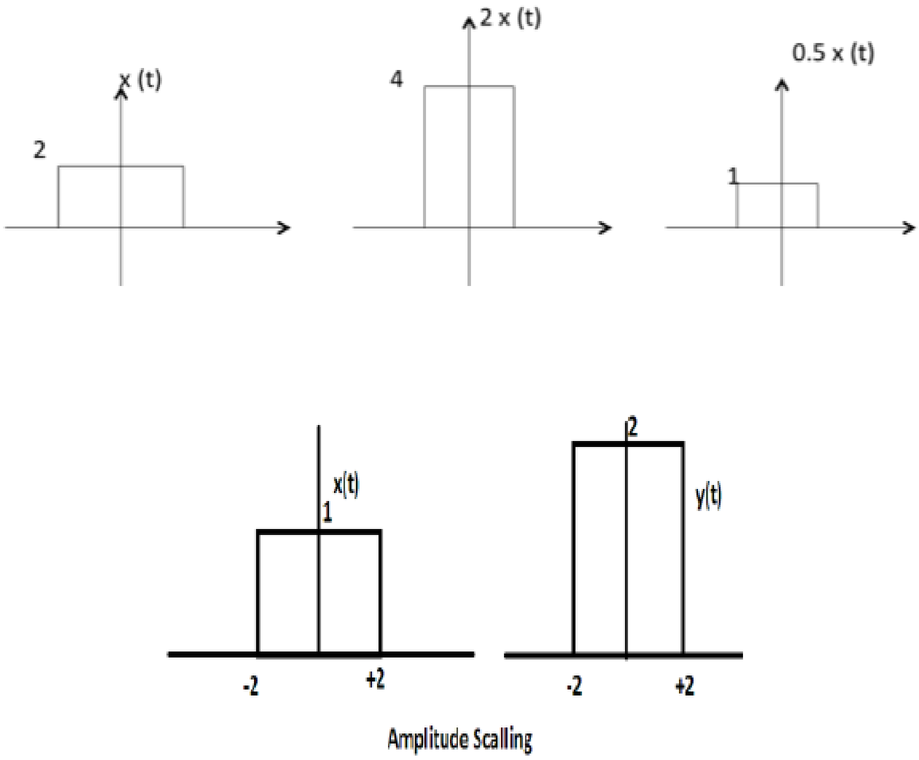


Figure 8: The amplitude scaling operation

In this case, only the values of y axis is changed since the amplitude is associated with this axis while, the values of x axis is constant.

B. Addition: If $x_1(t)$ and $x_2(t)$ denote a pair of CTSs. The signal z(t) obtained by the addition of $x_1(t)$ and $x_2(t)$ is defined by:

$z(t) = x_1(t) + x_2(t)$

In the case of DTS, it written as:

$z[n] = x_1[n] + x_2[n]$

It can be noted that the addition of two signals is nothing but addition of their corresponding amplitudes. This can be best explained by using the following example:

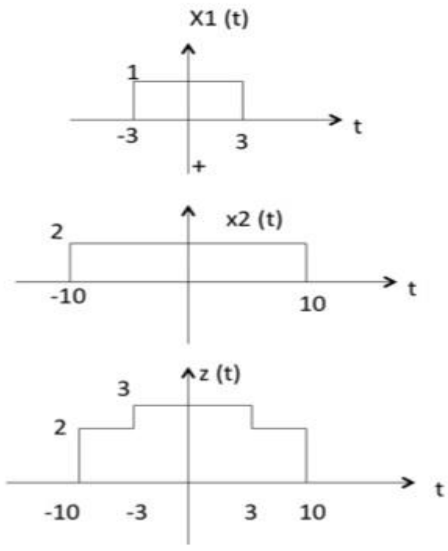


Figure 9: The addition operation

C. Subtraction: If $x_1(t)$ and $x_2(t)$ refer to a pair of CTSs. Then, the signal z(t) obtained by the subtracting of $x_1(t)$ from $x_2(t)$ is defined by:

$z(t) = x_1(t) - x_2(t)$

In the case of DTS, it written as:

$z[n] = x_1[n] - x_2[n]$

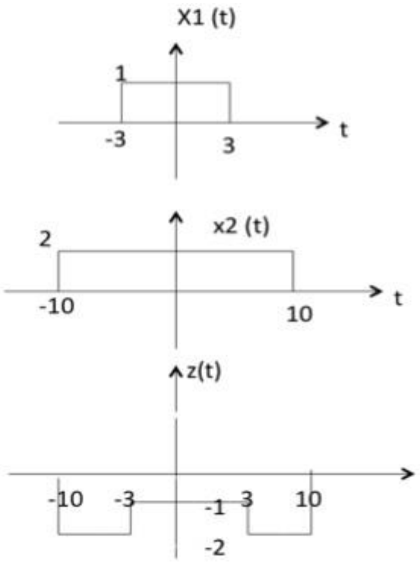


Figure 10: The subtraction operation

D. Multiplication: let $x_1(t)$ and $x_2(t)$ denote a pair of CTSs. The signal z(t) resulting from the multiplication of $x_1(t)$ and $x_2(t)$ is defined by the following equation:

$z(t) = x_1(t) * x_2(t)$

That is, for each prescribed time (t) the value of z(t) is given by the product of the corresponding values of $x_1(t)$ and $x_2(t)$.

For discrete-time signals we write:

$z[n] = x_1[n]\, x_2[n]$

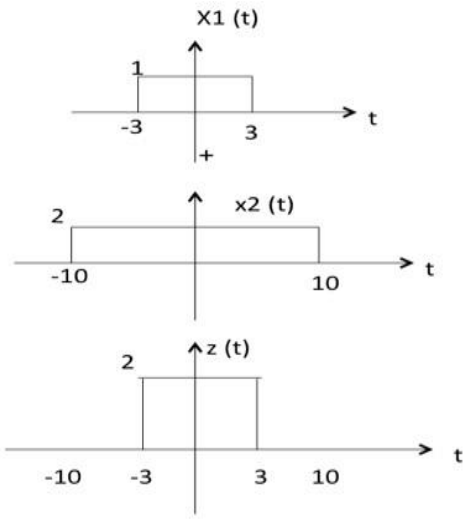


Figure 11: The Multiplication operation

② Operation of independent variables

A. Time shifting: Suppose that we have a signal x(t) and we define a new signal by adding/subtracting a finite time value to/from it. We now have a new signal, z(t). Graphically, this kind of signal operation results in a positive or negative "shift" of the signal along its time axis. However, note that while doing so, none of its characteristics are altered. This means that the time-shifting operation results in the change of just the positioning of the signal without affecting its amplitude.

If CTS is x(t), then $z(t)=x(t-T)$ is the signal x(t) shifted to the right by T units.

If CTS is x(t), then $z(t)=x(t+T)$ is the signal x(t) shifted to the left by T units.

When DTS is x[n], then $z[n]=x[n-N]$ is the signal x[n] shifted to the right by N samples.

When DTS is x[n], then $z[n]=x[n+N]$ is the signal x[n] shifted to the left by N samples.

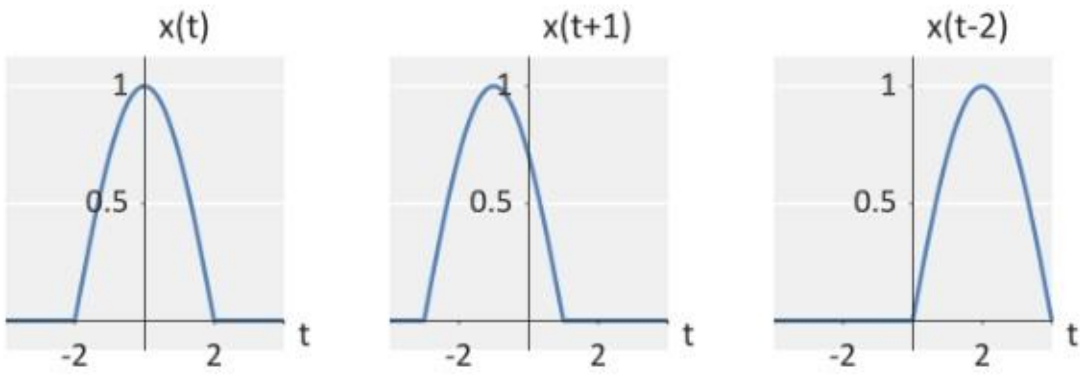


Figure 12: The time shifting operation

B. Time scaling: is a compression or expansion of a signal in time let x(t) denote a CTS, the signal z(t) obtained by scaling the independent variable, time (t), by a factor "a" is defined by two cases which are:

- If $a > 1$, the signal z(t) is a compressed version of x(t). In this case:

  $z(t) = x(at)$

- If $a < 1$, the signal z(t) is an expanded (stretched) version of x(t). Thus, the resulted signal z(t) is computed as:

  $z(t) = x(t/a)$

  Note: the factor "a" must not be equal to 0.

This mean that the signal x(t) is scaled in time by multiplying the time variable by a positive constant (a), to produce z(t).

All these cases are described in the below figure.

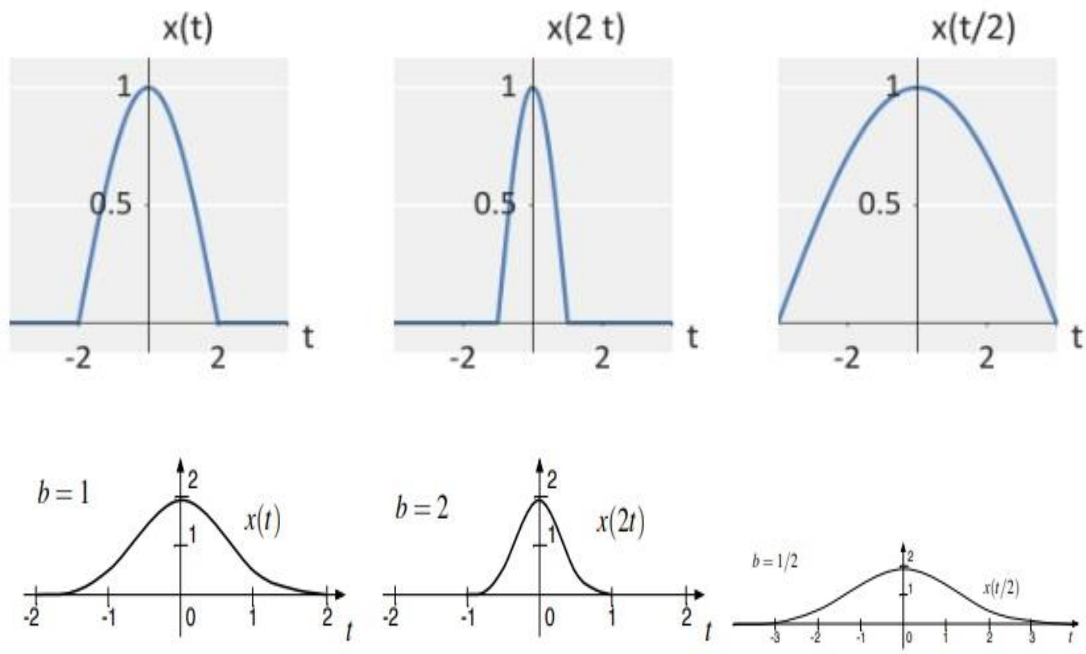


Figure 13: The time scaling operation

C. Time reversal (time inversion, reflection): The signal z(t) represents a reflected version of x(t) about the amplitude axis. Let x(t) denotes a CTS signal and z(t) denotes the signal obtained by replacing time (t) with (–t), as shown in the next two cases:

- The CTS is represented as:

$y(t)=x(-t)$

- While the DTS is as follows:

$y[n]=x[-n]$

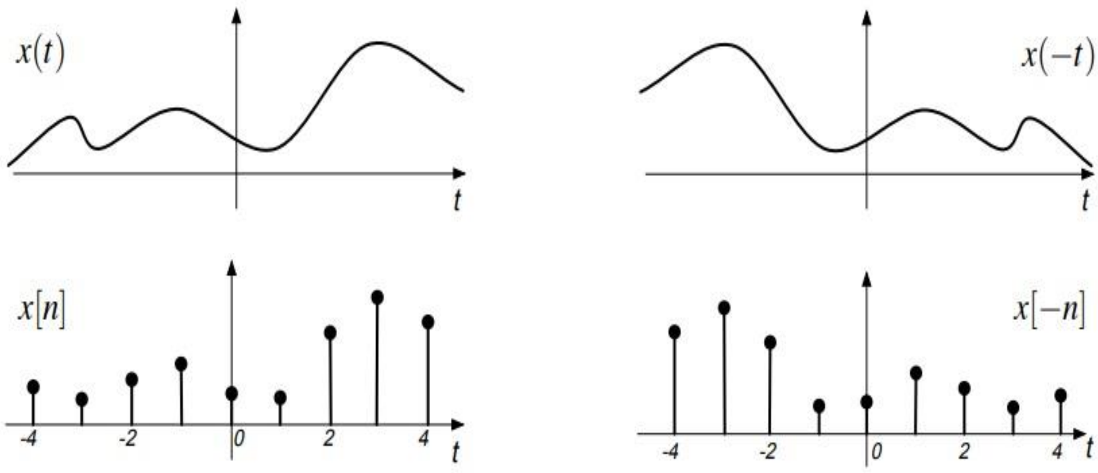


Figure 14: The time reversal operation