DL applications and concepts in communications

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- Basic Concepts in Communication
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  - Modes of Communication

- Different Types of Signals
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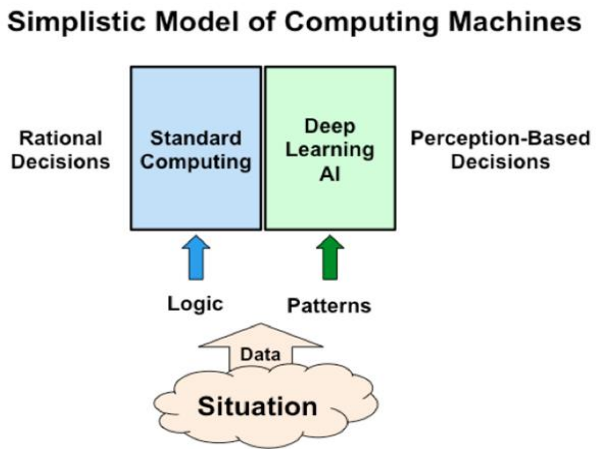
Introduction

- **What is Deep Learning?**

Deep learning is a branch of machine learning that uses data, loads and loads of data, to teach computers how to do things only humans were capable of before.

For example, how do machines solve the problems of perception?



Applications:

- The deep learning played a crucial role in **channel estimation, signal detection, and modulation recognition etc.**

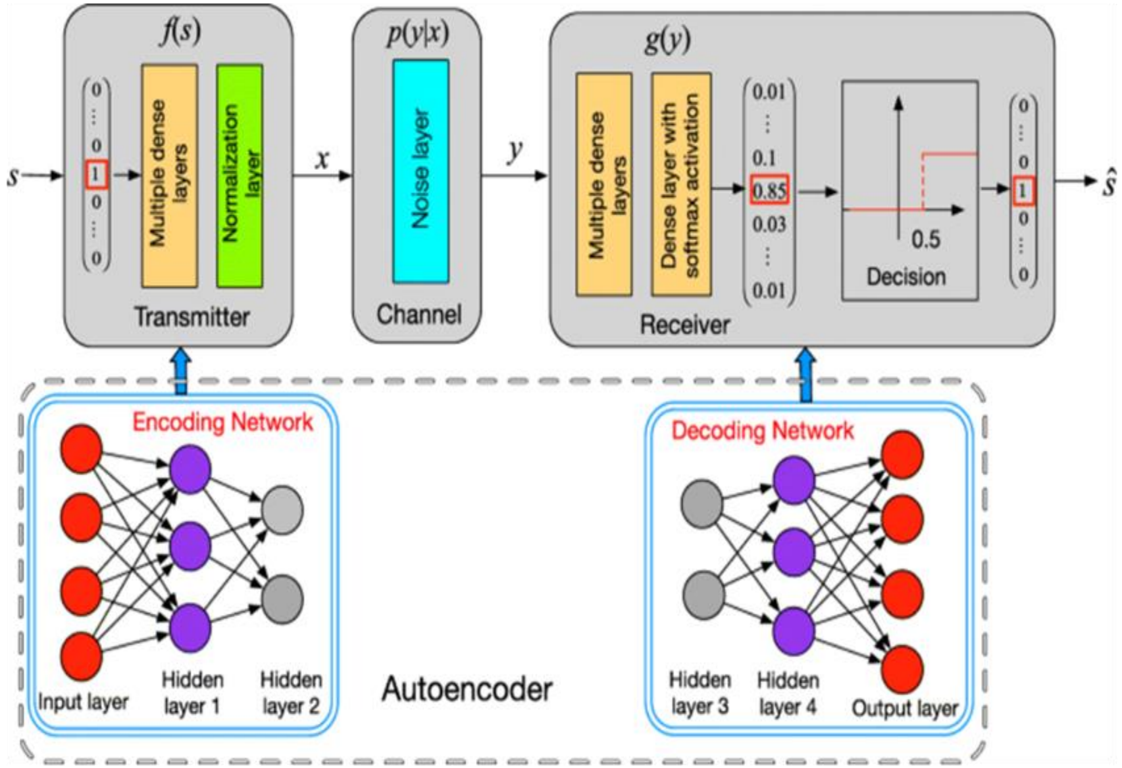
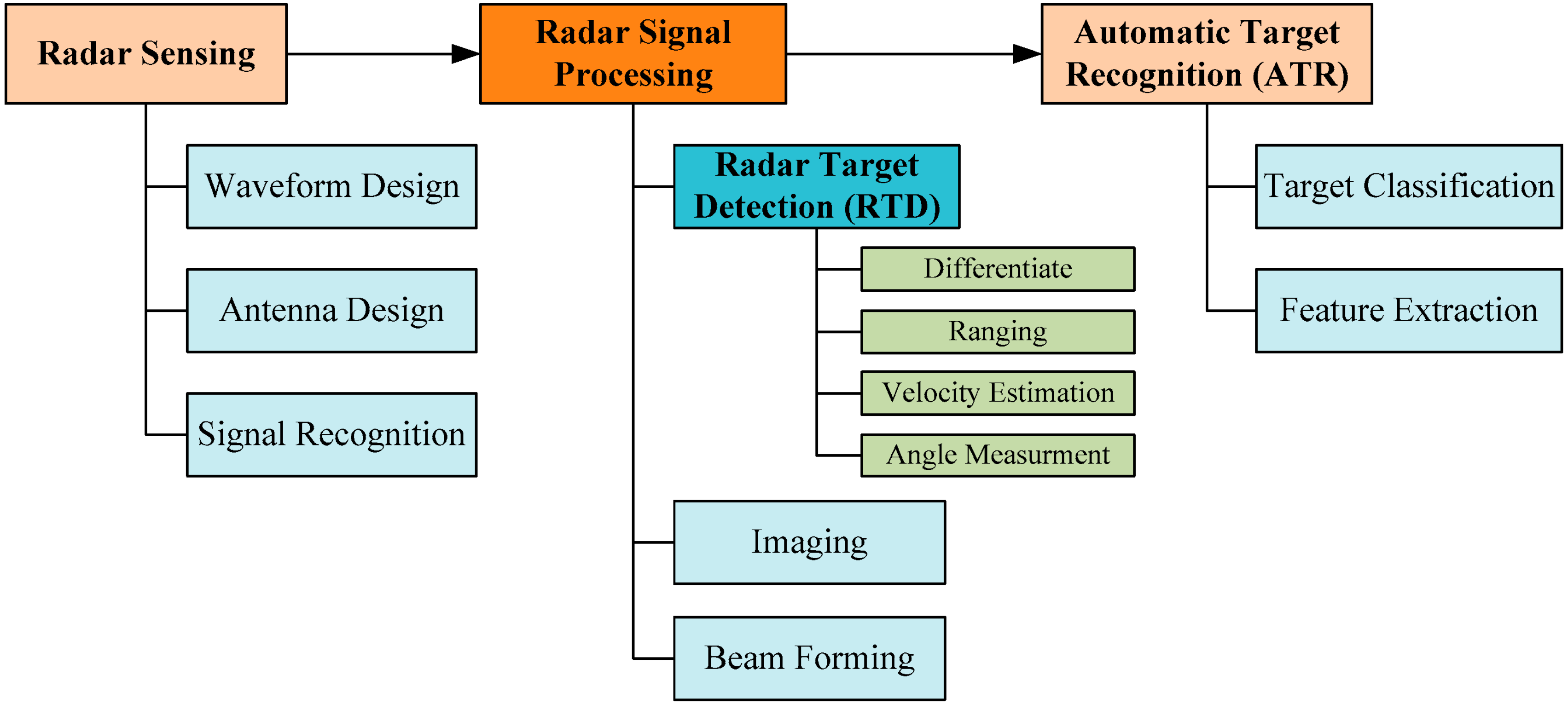


Fig: Deep learning-driven wireless communication for edge-cloud computing

In Radar Communication:

Radar application problems that can be solved by deep learning-based methods:
radar sensing, radar signal processing, and radar automatic target recognition (ATR)



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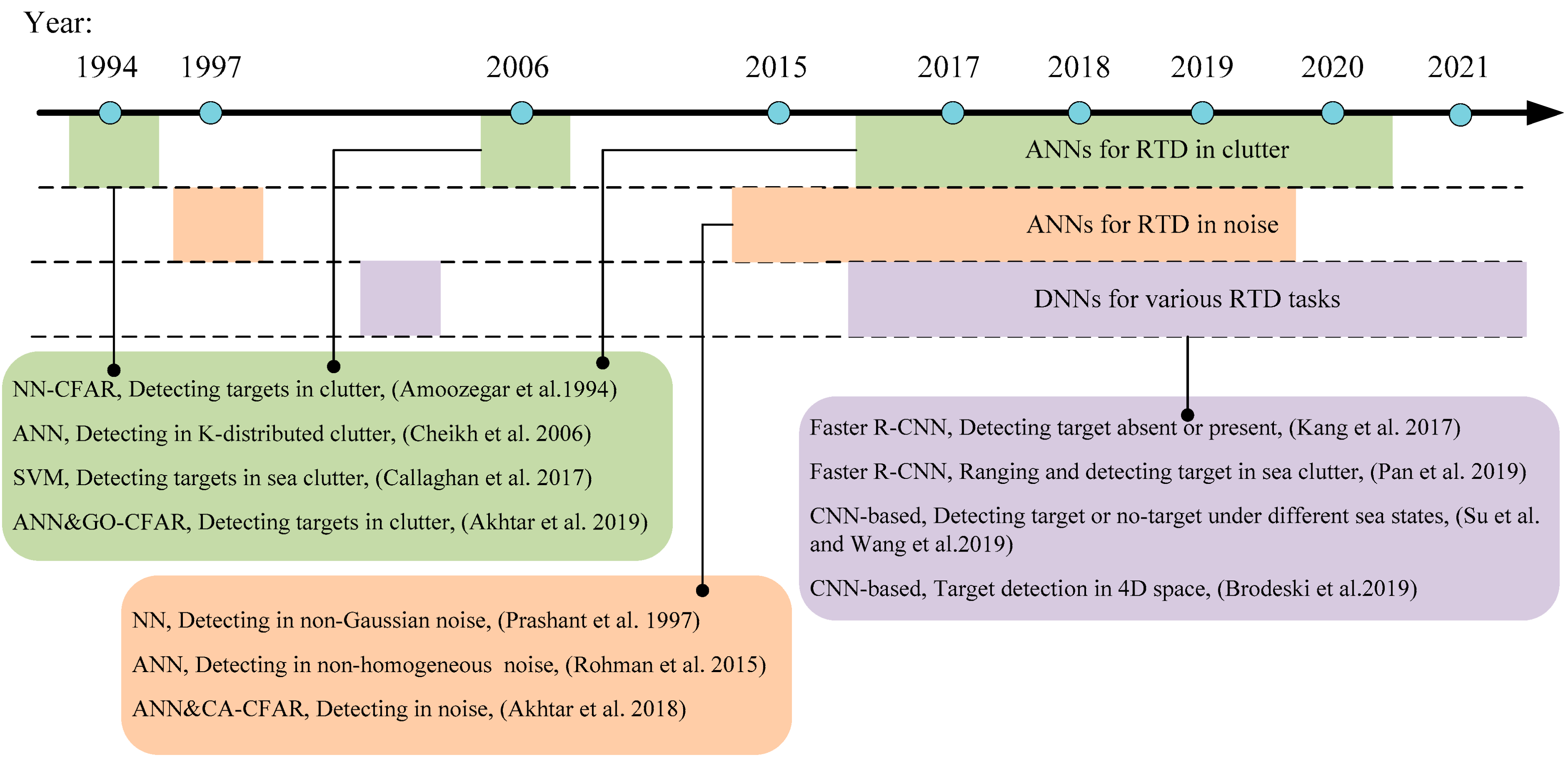
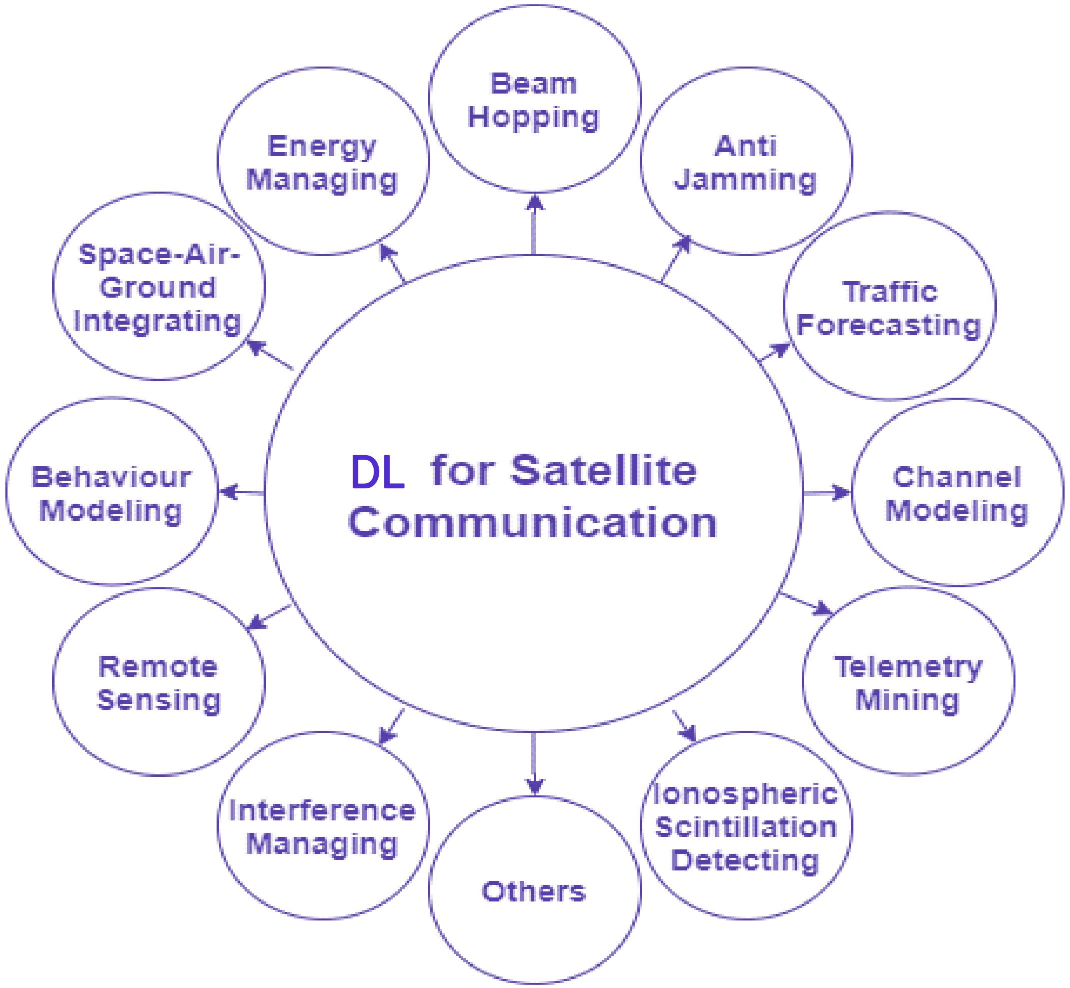
Below figure illustrates the major developments and application of deep learning in RTD



DL in Satellite Comm:



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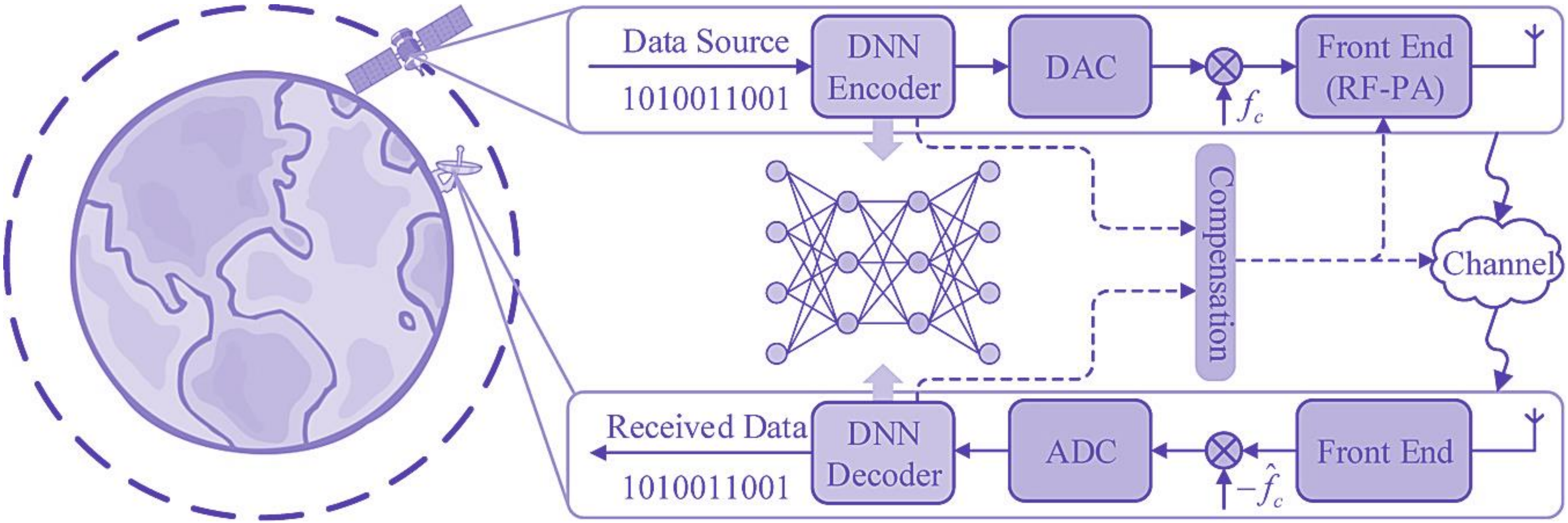
DL in Satellite Comm:



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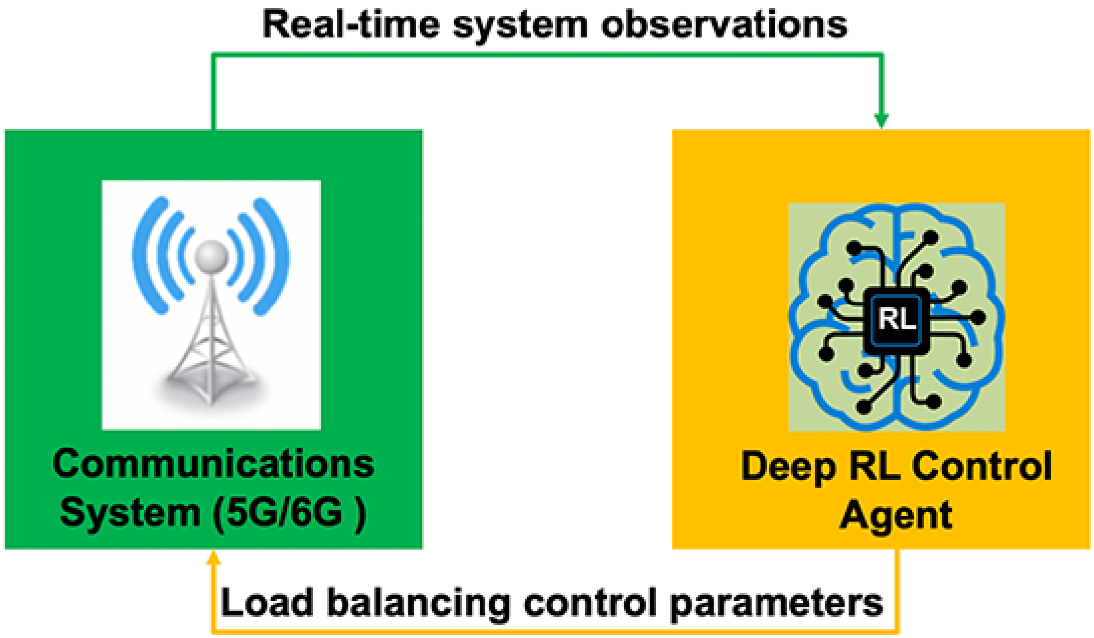
DRL in telecommunications

- RL is a machine learning paradigm that aims to learn an optimal control policy via interacting with the system. Below figure shows the concept of the RL paradigm. In RL, an agent will take control **actions** based on the current observations of environment **states** and receive the corresponding **rewards** from the environment.

- Deep RL has achieved impressive success on Go games, board games, and many other real-world applications, e.g., data center cooling and recommender systems.

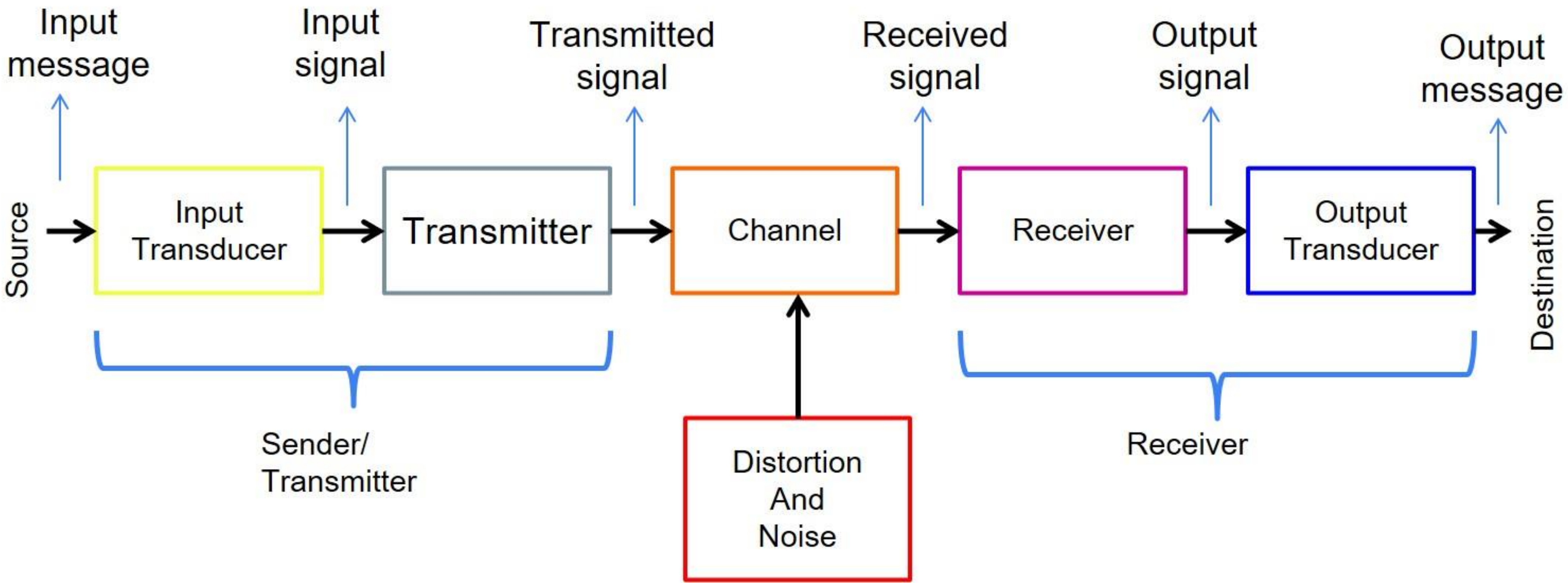


Concepts in Communications

Communications System Model

- Communication system is a system which describes the exchange of information or data between two stations, i.e. between transmitter and receiver.

- To transmit signal in communication system, it must be first processed by several stages.



Elements of communication system:

- **Source:** Produces an input message (voice, picture, computer data etc).

Input messages are of two types discrete (Digital) and continuous (Analog)

- Input Transducer: If the input message is nonelectrical (e.g. voice), it must be converted by an input transducer to an electrical signal
  - A *transducer*: is a device that converts one form of energy into another.

- **Transmitter:** The **transmitter** converts the electrical signal into a form that is suitable for transmission through the transmission medium or channel by a process called ***modulation***.

- **Channel:** medium used to transfer signal from transmitter to receiver (wired or wireless).

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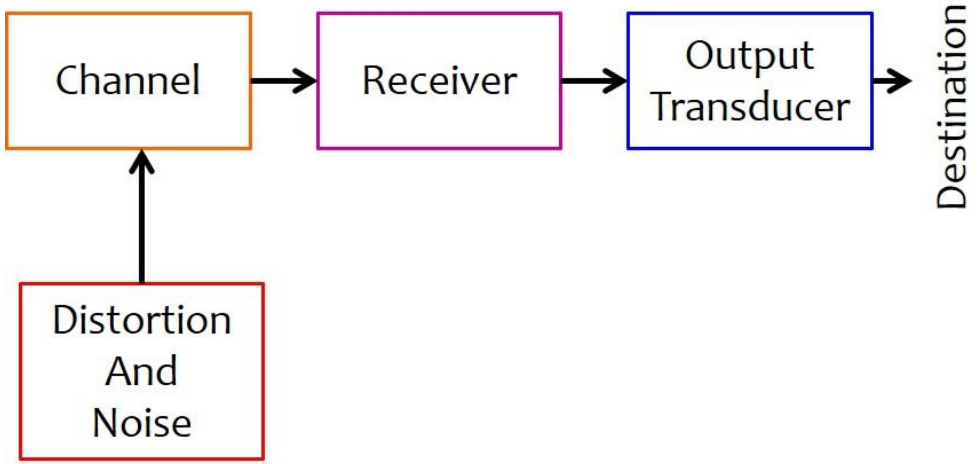
- **Noise:** The signal is not only distorted by a channel, but it is also contaminated along the path by undesirable signals lumped under the broad term **noise**

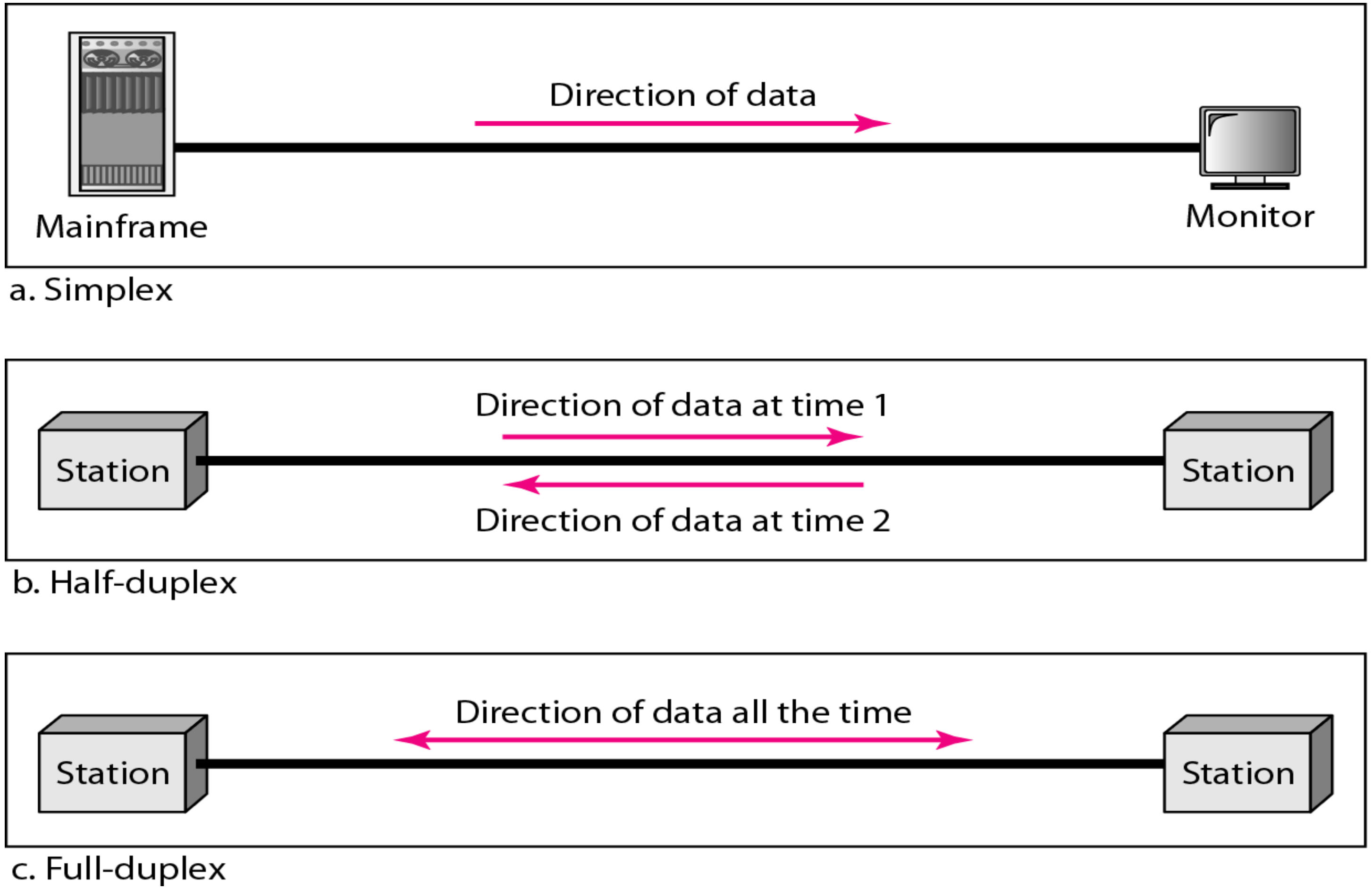
- **Receiver:** The function of the receiver is to recover the message signal contained in the signal received from the channel. (receiver reconstruct a recognizable form of the original message signal)

- **Output Transducer:** The receiver output is fed to the *output transducer*, which convert the electrical signals that are received into a form that is suitable for the final destination (e.g., speaker, monitor, etc).



Modes of Communication:

Simplex, Half-Duplex and Full-Duplex



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- **Simplex (SX) –** one direction only, e.g. TV

- **Half Duplex (HDX) –** both directions but not at the same time, e.g. CB radio

- **Full Duplex (FDX) –** transmit and receive simultaneously between two stations, e.g. standard telephone system.

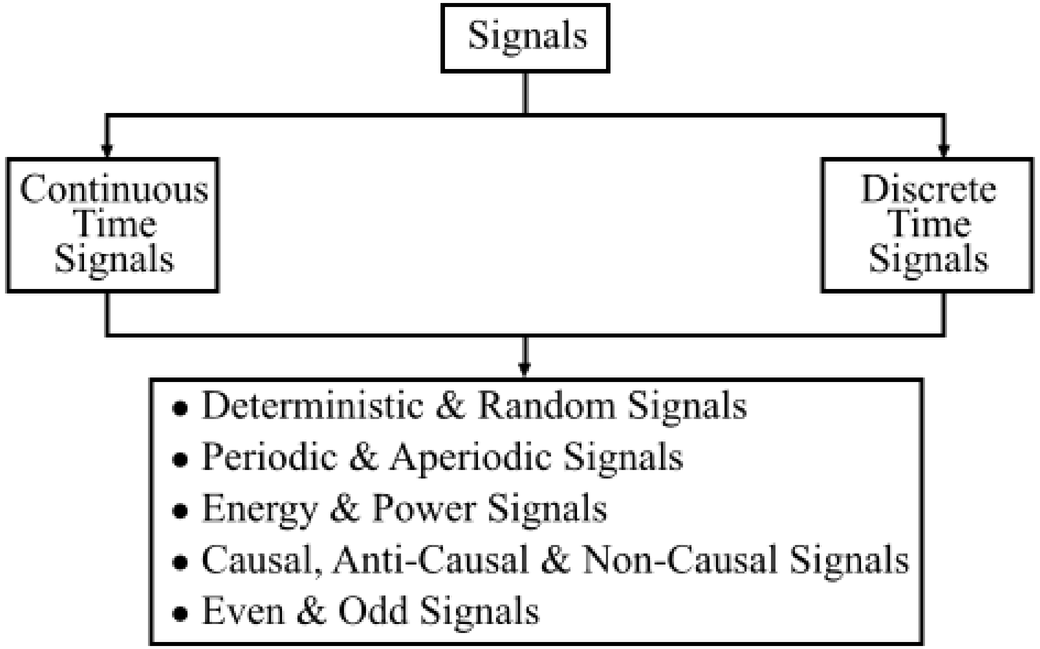
- **Full/Full Duplex (F/FDX) -** transmit and receive simultaneously but not necessarily just between two stations,

  e.g. data communications circuits

Different Types of Signals

- **A Signal** is the function of one or more independent variables that carries some information to represent a physical phenomenon. e.g. ECG, EEG

- A signal may be represented in time domain or frequency domain. Some common examples of a signal are human speech, electric current, electric voltage, etc



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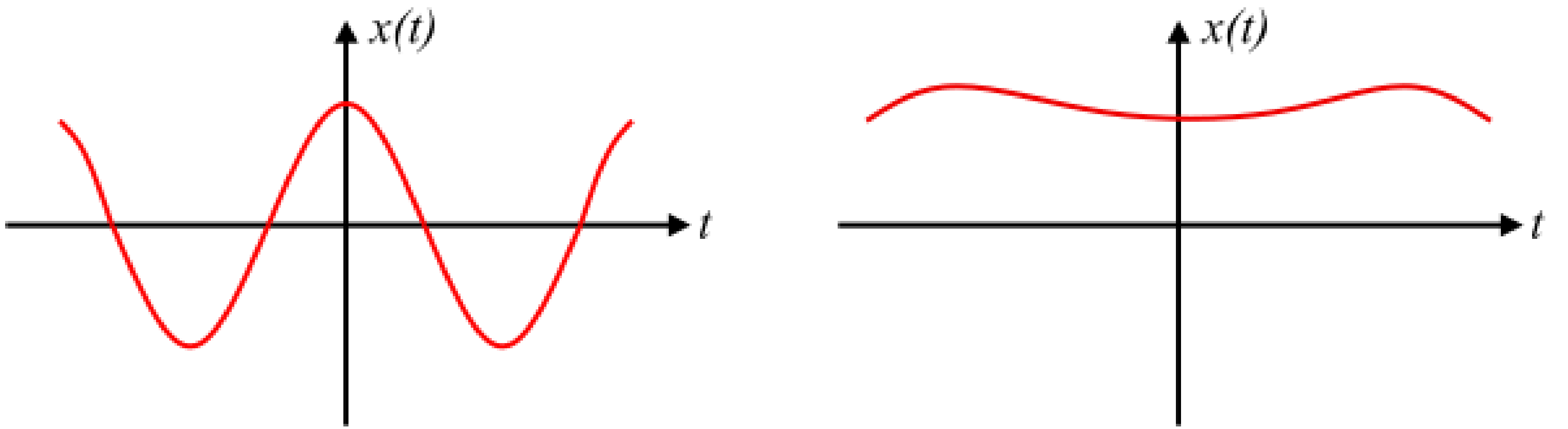
- **Continuous-time signal:** The signals which are defined for every instant of time are called as continuous time signals. The continuous-time signals are also called as analog signals. In case of continuous time signals, the independent variable is time.



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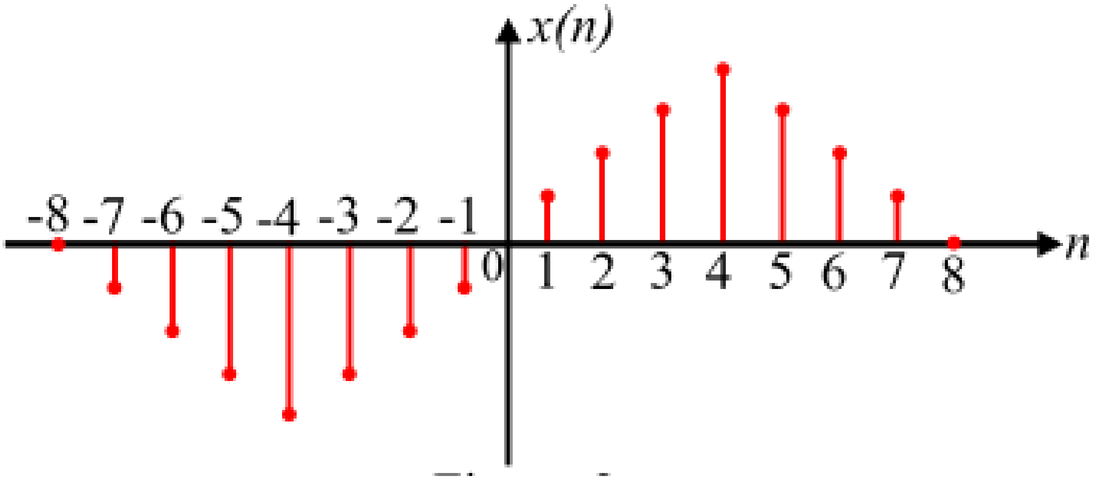
Discrete Time Signals

- Those signals which are defined only at discrete instants of time are called as discrete time signals. The amplitude of discrete time signals is continuous but these signals are discrete in time. The amplitude of a discrete time signal between two time instants is just not defined.

- For the discrete time signals, the independent variable is time, denoted by n. As these signals are defined only at discrete time instants, therefore, they are given by a sequence x(n) or x(nT) where, n is an integer.



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Both discrete-time and continuous-time signals may be further classified as follows

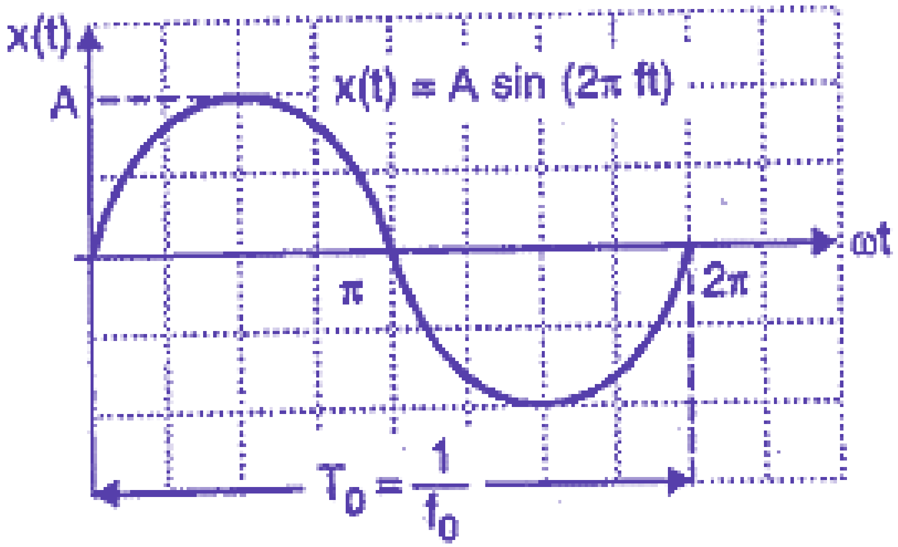
- Deterministic & Non-Deterministic or Random signals
- Periodic & Aperiodic Signals
- Energy & Power Signals
- Causal, Anti-Causal & Non-Causal Signals
- Even & Odd Signals

Deterministic & Non Deterministic Signals

Deterministic signals:

- Deterministic signals can be described by a mathematical expression, lookup table or some well-defined rule.

  Examples: Sine wave, cosine wave, square wave, etc.



A sine wave can be represented mathematically as,

$$\mathbf{x(t) = A\ sin\ (2\pi ft)}$$

where

•A is the amplitude of a signal
•f = frequency of a signal

Note: The deterministic signals such as sine wave, cosine wave, etc. are periodic in nature. Besides this, some deterministic signals may not be periodic. The exponential signal is an example of a non-periodic signal.

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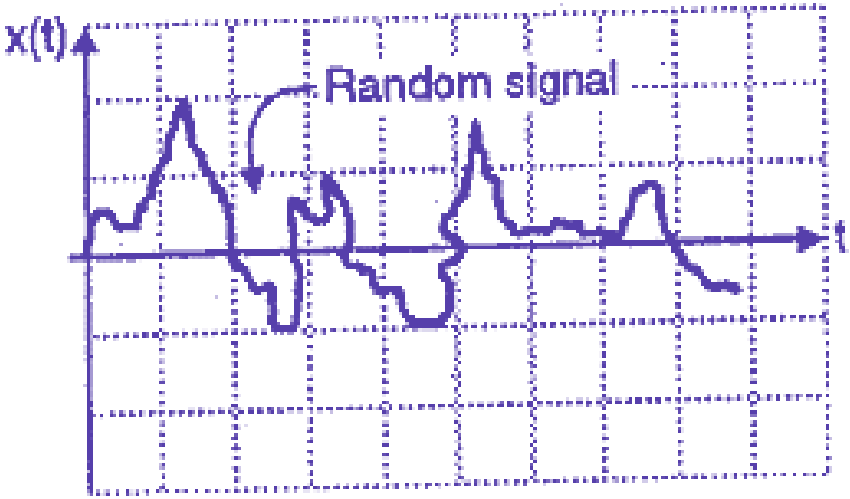
Non Deterministic or Random signals:

- A signal which cannot be described by any mathematical expression is called as a random signal. Therefore, it is not possible to predict the amplitude of such signals at a given instant of time.

- Example: A good example of a random signal is noise in the communication signal. Below figure shows one of the random signals.



Periodic and Aperiodic Signals:

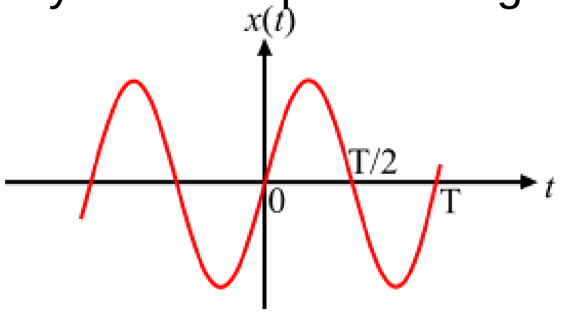
- A signal is said to be **periodic signal** if it has a definite pattern and repeats itself at a regular interval of time. Whereas, the signal which does not at the regular interval of time is known as an **aperiodic signal** or **non-periodic signal**.

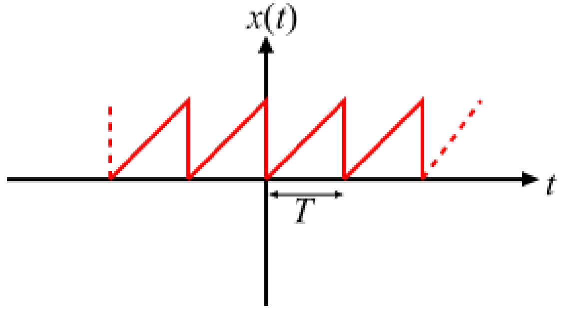
- **Continuous Time Periodic Signal:**

A continuous time signal x(t) is said to be periodic if and only if

$$x(t + mT) = x(t) \text{ for } -\infty < t < \infty$$

Where, m is an integer. This means if the definition is satisfied for $T = T_0$, then it is also satisfied for $T = 2T_0$, $T = 3T_0$ … and so on with T_0 as the fundamental time period. Therefore, the fundamental time period defines the duration of one complete cycle of the periodic signal x(t).





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- **Discrete Time Periodic Signal:**

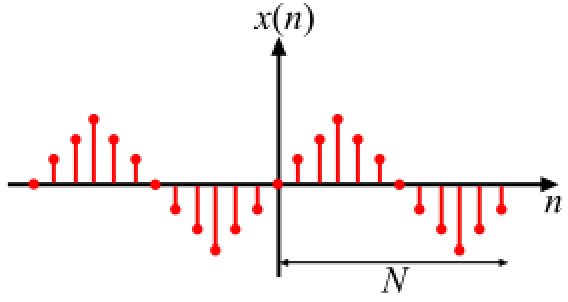
A discrete-time signal x(n) is said to be periodic if it satisfies the following condition

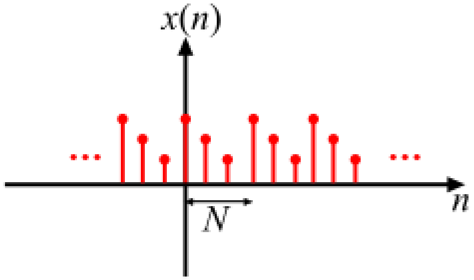
$$x(n) = x(n + N); \quad \text{for all integers } n$$

Here, N is the time period of the periodic signal and a positive integer. The smallest value of the time period (N) which satisfies the above condition is known as fundament time period of the signal. The fundamental time period (N) may be defined as the minimum number of samples taken by signal to repeat itself.

The angular frequency of the discrete time periodic sequences is given by, $\omega = \frac{2\Pi}{N}$

The time period of the sequence is, $N = \frac{2\Pi}{\omega}$





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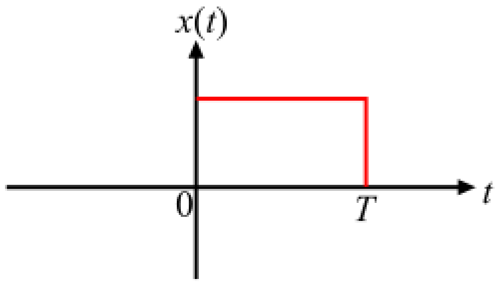
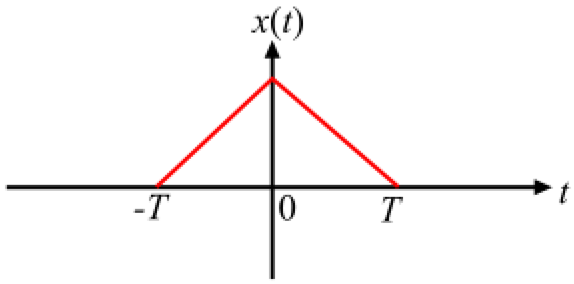
- **Continuous Time Aperiodic Signal**

If a continuous time signal does not have a definite pattern and does not repeat at regular intervals of time is known as continuous time **aperiodic signal** or **nonperiodic signal**.

In other words, a signal x(t) for which no value of time t satisfies the condition of periodicity, is known as **aperiodic** or **non-periodic signal**.





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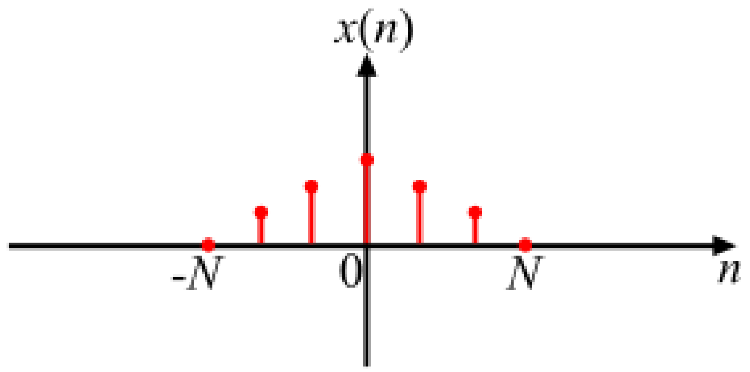
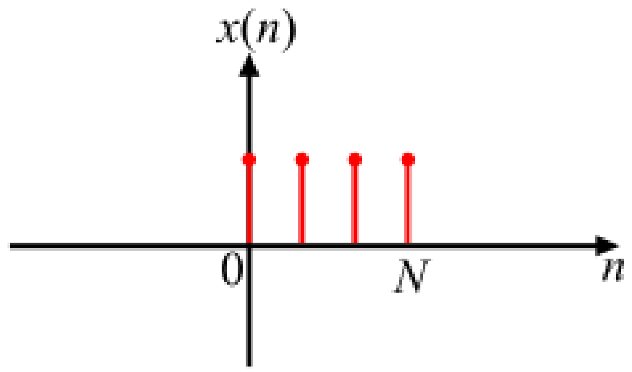
- **Discrete Time Aperiodic Signal**

If the condition of periodicity is not satisfied even for one value of n for a discrete time signal x(n), then the discrete time signal is aperiodic or nonperiodic.





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Examples:

- Examine whether the following signals are periodic or not? If periodic then determine the fundamental period of the signal. 1) $x(t) = \sin 10\pi t$ 2) $x(t) = \sin \pi t \, u(t)$

Solution

1) Given signal is,

$$x(t) = \sin 10\pi t$$

Since the signal x(t) is a sinusoidal signal, hence, it is a periodic signal.
Now, comparing x(t) with standard signal, i.e., sin ωt, we get,

$$\omega = 10\pi$$

$$\therefore \text{ Fundamental Period, T} = \frac{2\Pi}{\omega} = \frac{2\Pi}{10\Pi} = \frac{1}{5} \text{ sec}$$

2) Given signal is,

$$\bullet x(t) = \sin \pi t \, u(t)$$

Here, x(t) is the product of sinusoidal signal (sin πt) and unit step signal ($u(t)$). As we know, the signal sin πt is periodic with time period $T = 2\pi/\omega$ while the signal $u(t)$ exists only for $0 < t < \infty$. Thus, $u(t)$ is not a periodic signal.
Therefore, the signal x(t) is an aperiodic or non-periodic signal.

Energy and Power Signals

- **Energy Signal**

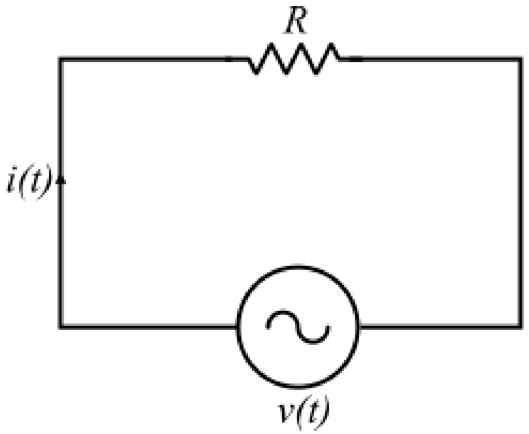
A signal is said to be an energy signal if and only if its total energy E is finite, i.e., $0 < E < \infty$. For an energy signal, the average power P = 0. The nonperiodic signals are the examples of energy signals.

- **Power Signal**

A signal is said to be a power signal if its average power P is finite, i.e., $0 < P < \infty$. For a power signal, the total energy E = ∞. The periodic signals are the examples of power signals.

- **Continuous Time Case:**

In electric circuits, the signals may represent current or voltage. Consider a voltage v(t) applied across a resistance R and i(t) is the current flowing through it as shown in the figure.



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The instantaneous power in the resistance R is given by,

$$p(t) = v(t) \cdot i(t) \ldots$$

By Ohm's law,

$$p(t) = v(t)\frac{v(t)}{R} = \frac{v^2(t)}{R}$$

Or,

$$p(t) = i(t)R \cdot i(t) = i^2(t)R$$

When the values of the resistance R = 1Ω, then the power dissipated in it is known as normalised power. Hence,

- Normalised power, $p(t) = v^2(t) = i^2(t)$

If v(t) or i(t) is denoted by a continuous-time signal x(t), then the instantaneous power is equal to the square of the amplitude of the signal, i.e.,

$$p(t) = |x(t)|^2$$

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Therefore, the average power or normalised power of a continuous time signal x(t) is given by,

$$P = \lim_{T \to \infty} \frac{1}{T} \int_{-(T/2)}^{(T/2)} |x(t)|^2 \, dt \quad \text{Watts}$$

The total energy or normalised energy of a continuous time signal is defined as,

$$E = \lim_{T \to \infty} \int_{-(T/2)}^{(T/2)} |x(t)|^2 \, dt \quad \text{Joules}$$

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- **Discrete Time Case**

For the discrete time signal x(n), the integrals are replaced by summations. Hence, the total energy of the discrete time signal x(n) is defined as

$$E = \sum_{n=-\infty}^{\infty} |x(t)|^2$$

The average power of a discrete time signal x(t) is defined as

$$P = \lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=-N}^{N} |x(t)|^2$$

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- Numerical Example

Determine the power and energy of the signal $x(t) = A\sin(\omega_0 t + \varphi)$.
Solution:

Average Power of the Signal

$$P = \lim_{T\to\infty} \frac{1}{T}\int_{-(T/2)}^{(T/2)} |x(t)|^2\, dt$$

$$\Rightarrow P = \lim_{T\to\infty} \frac{1}{T}\int_{-(T/2)}^{(T/2)} |A\sin(\omega_0 t + \varphi)|^2\, dt$$

$$\Rightarrow P = \lim_{T\to\infty} \frac{A^2}{T}\int_{-(T/2)}^{(T/2)} \left|\frac{1-\cos(2\omega_0 t + 2\varphi)}{2}\right| dt$$

$$\Rightarrow P = \lim_{T\to\infty} \frac{A^2}{2T}\int_{-(T/2)}^{(T/2)} dt - \frac{A^2}{2T}\int_{-(T/2)}^{(T/2)} \cos(2\omega_0 t + 2\varphi)\, dt$$

$$\Rightarrow P = \lim_{T\to\infty} \frac{A^2}{2T}\int_{-(T/2)}^{(T/2)} dt - 0 = \lim_{T\to\infty} \frac{A^2}{2T}\left[\frac{T}{2} + \frac{T}{2}\right] = \frac{A^2}{2}$$

Normalised Energy of the Signal

$$E = \int_{-\infty}^{\infty} |x(t)|^2\, dt = \int_{-\infty}^{\infty} |A\sin(\omega_0 t + \varphi)|^2\, dt$$

$$\Rightarrow E = A^2 \int_{-\infty}^{\infty} \left[\frac{1-\cos(2\omega_0 t + 2\varphi)}{2}\right] dt$$

$$\Rightarrow E = \frac{A^2}{2}\int_{-\infty}^{\infty} dt - \frac{A^2}{2}\int_{-\infty}^{\infty} \cos(2\omega_0 t + 2\varphi)\, dt$$

$$\Rightarrow E = \frac{A^2}{2}[t]_{-\infty}^{\infty} - 0 = \infty$$

Causal, Non-Causal, and Anti-Causal Signals

- **Causal Signal:**
  - A continuous time signal $x(t)$ is called causal signal if the signal $x(t) = 0$ for $t < 0$. Therefore, a causal signal does not exist for negative time.

The unit step signal u(t) is an example of causal signal as shown in Figure

Similarly, a discrete time sequence x(n) is called the causal sequence if the sequence x(n) = 0 for n < 0.

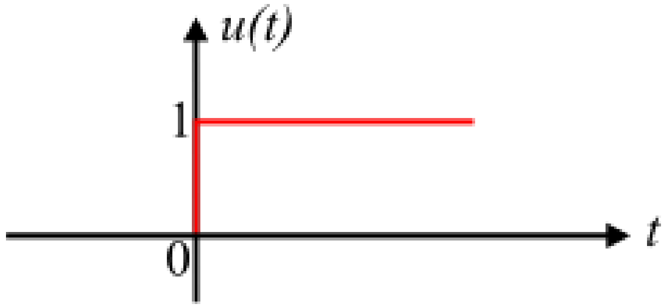

Figure-1

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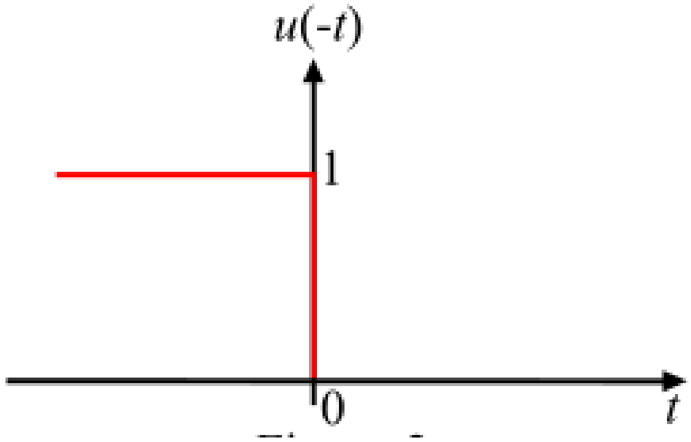
- **Anti-Causal Signal**

A continuous-time signal x(t) is called the anti-causal signal if x(t) = 0 for t > 0. Hence, an anti-causal signal does not exist for positive time. The time reversed unit step signal u(-t) is an example of anti-causal signal.

Similarly, a discrete time sequence x(n) is said to be anti-causal sequence if the sequence x(n) = 0 for t > 0.



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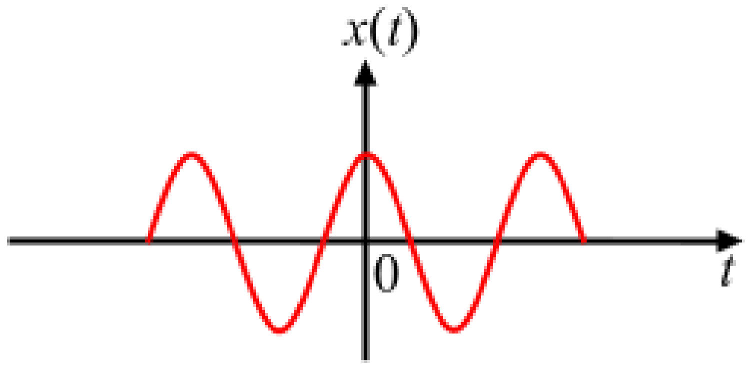
- **Non-Causal Signal:**

A signal which is not causal is called the non-causal signal. Hence, by the definition, a signal that exists for positive as well as negative time is neither causal nor anti-causal, it is non-causal signal. The sine and cosine signals are examples of non-causal signal.



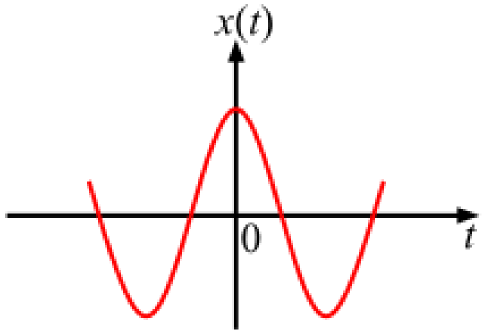
Even & Odd Signal

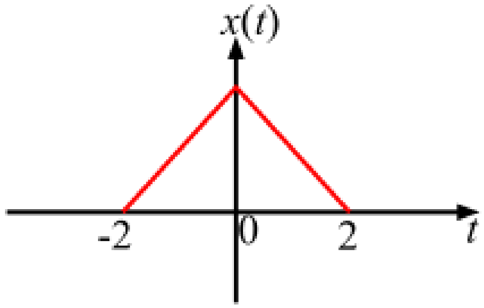
A signal which is symmetrical about the vertical axis or time origin is known as **even signal** or **even function**. Therefore, the even signals are also called the **symmetrical signals**. Cosine wave is an example of even signal.

- ## Continuous-time Even Signal:

A continuous-time signal x(t) is called the even signal or symmetrical signal if it satisfies the following condition,

$$x(t) = x(-t);\ \text{for} -\infty < t < \infty$$





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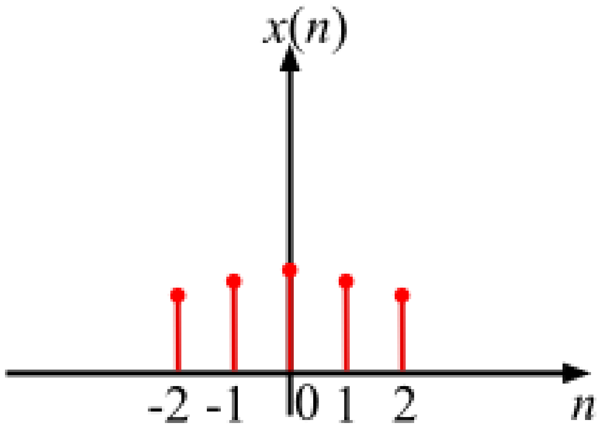
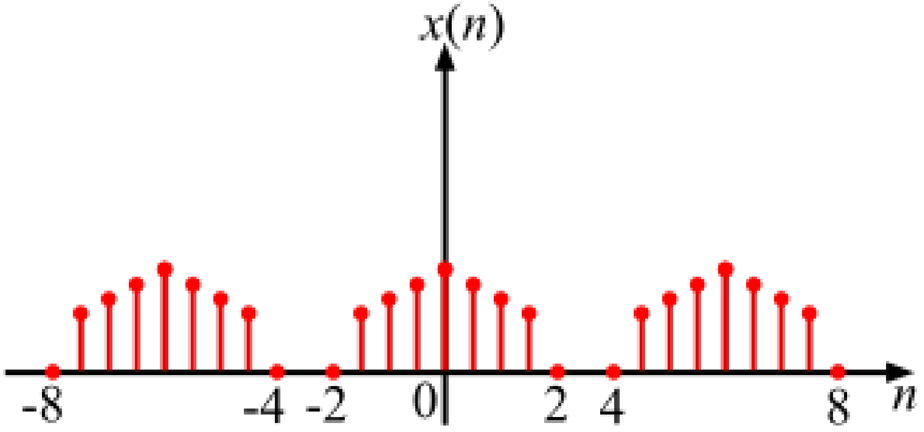
- **Discrete-time Even Signal:**

A discrete-time signal x(n) is said to be even signal or symmetrical signal if it satisfies the condition,

$$x(n) = x(-n);\ \text{for} -\infty < n < \infty$$





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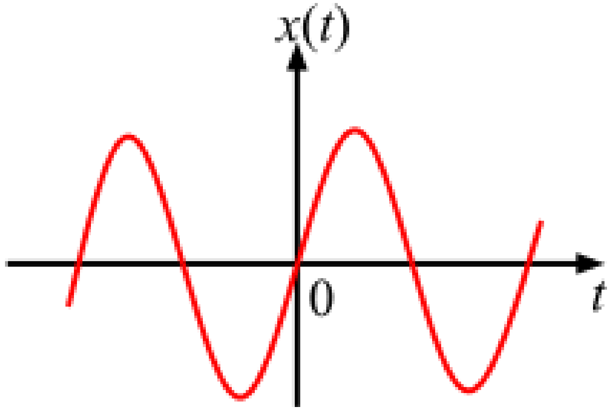
- ## Odd Signal

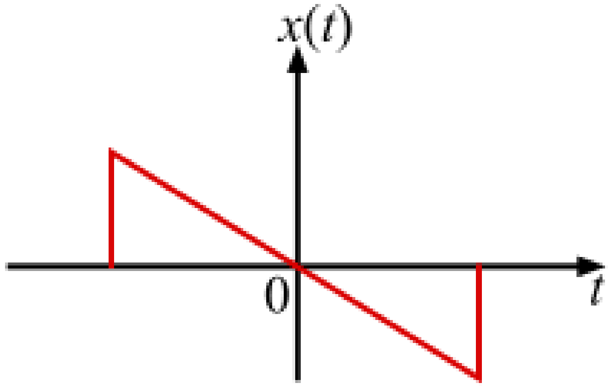
A signal that is anti-symmetrical about the vertical axis is known as odd signal or **odd function**. Therefore, the odd signals are also called the **antisymmetric signals**. Sine wave is an example of odd signal.

  - ### Continuous-time Odd Signal:

A continuous time signal x(t) is called an odd signal or antisymmetric signal if it satisfies the following condition,

$$x(-t) = -x(t);\ \text{for} -\infty < t < \infty$$





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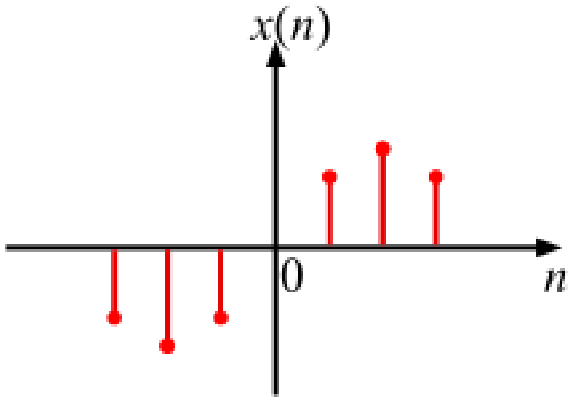
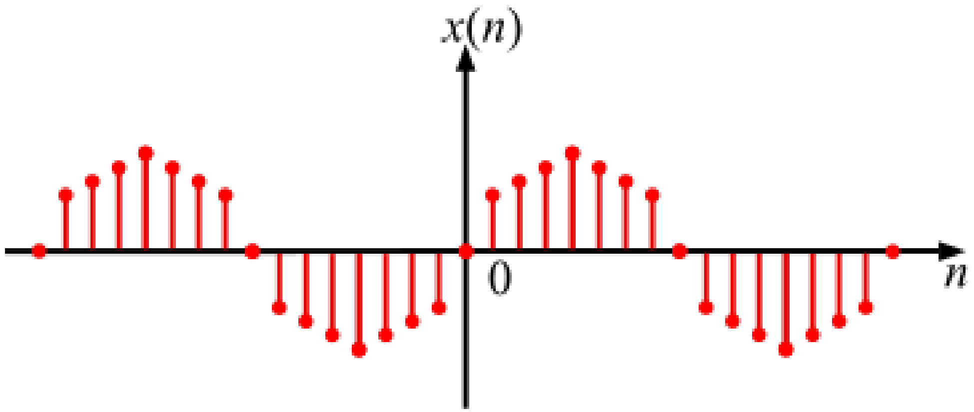
- **Discrete-time Odd Signal:**

A discrete time signal x(n) is said to be an odd signal or antisymmetric signal, if it satisfies the following condition,

$$x(-n) = -x(n);\ \text{for} - \infty < n < \infty$$





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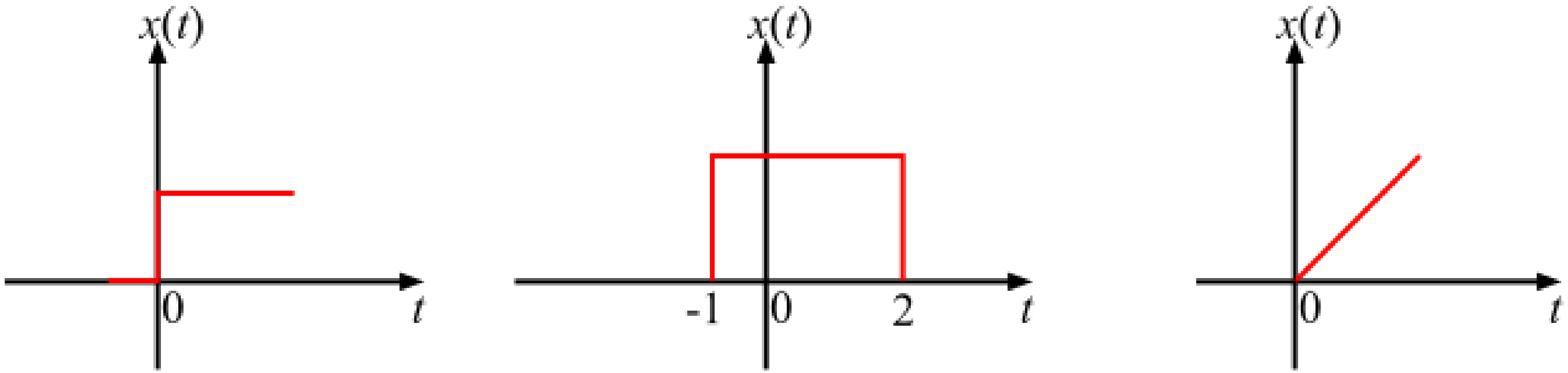
- **Neither even nor odd signal:**

Note – A continuous-time signal is said to be **neither even nor odd** if it does not satisfy the condition of the even signal and that of the odd signal.



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Example:

Find whether the signals are even or odd.

1) $x(t) = e^{-5t}$ 2) $x(t) = \sin 2t$ 3) $x(t) = \cos 5t$

Solution

1) Given signal is,

- $x(t) = e^{-5t}$
- $x(-t) = e^{5t}$
- $-x(t) = -e^{-5t}$

It is clear that $x(t) \neq x(-t)$ and $x(-t) \neq -x(t)$, thus the given signal is neither even signal nor odd signal.

2) The given signal is,

- $x(t) = \sin 2t$
- $x(-t) = -\sin 2t$
- $-x(t) = -\sin 2t$

Hence, $x(t) \neq x(-t)$; but $x(-t) = -x(t)$, thus the given signal is an odd signal.

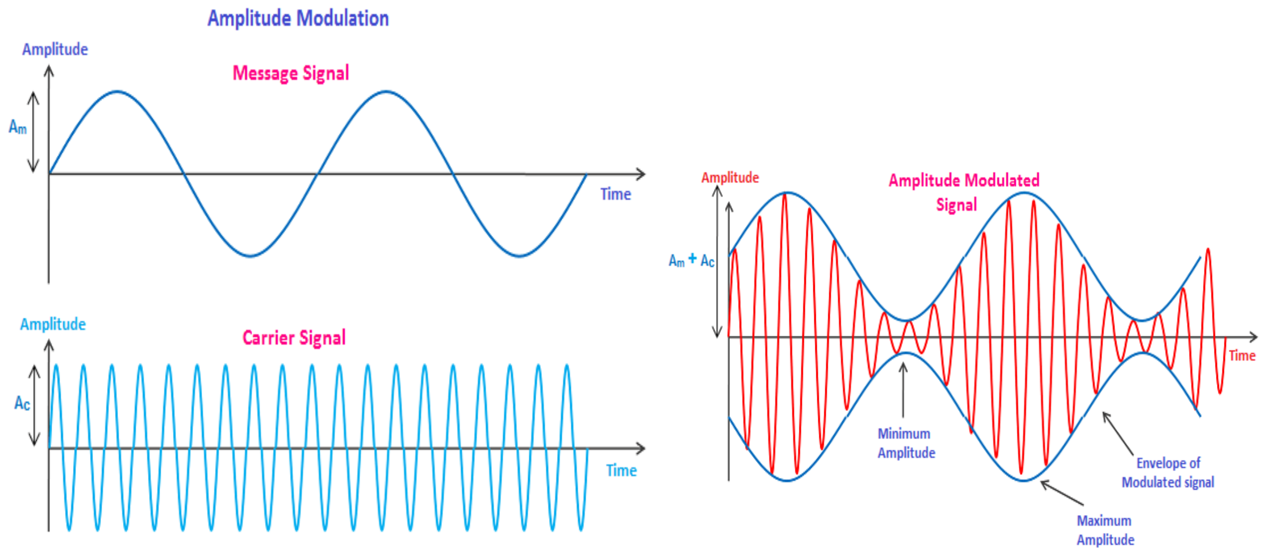
3) Given signal is,

- $x(t) = \cos 5t$
- $x(-t) = \cos 5t$
- $-x(t) = -\cos 5t$

Therefore, $x(t) = x(-t)$ and $x(-t) \neq -x(t)$, thus the given signal is an even signal.

Amplitude modulation

- A continuous-wave goes on continuously without any intervals and it is the baseband message signal, which contains the information. This wave has to be modulated.
- "The amplitude of the carrier signal varies in accordance with the instantaneous amplitude of the modulating signal." Which means, the amplitude of the carrier signal containing no information varies as per the amplitude of the signal containing information, at each instant.



- Let the modulating signal be,

$$m(t) = A_m \cos(2\pi f_m t)$$

and the carrier signal be,

$$c(t) = A_c \cos(2\pi f_c t)$$

Am and Ac are the amplitude of the modulating signal and the carrier signal respectively.

fm and fc are the frequency of the modulating signal and the carrier signal respectively.

- The Amplitude Modulated wave will be:

$$s(t) = [A_c + A_m \cos(2\pi f_m t)] \cos(2\pi f_c t)$$

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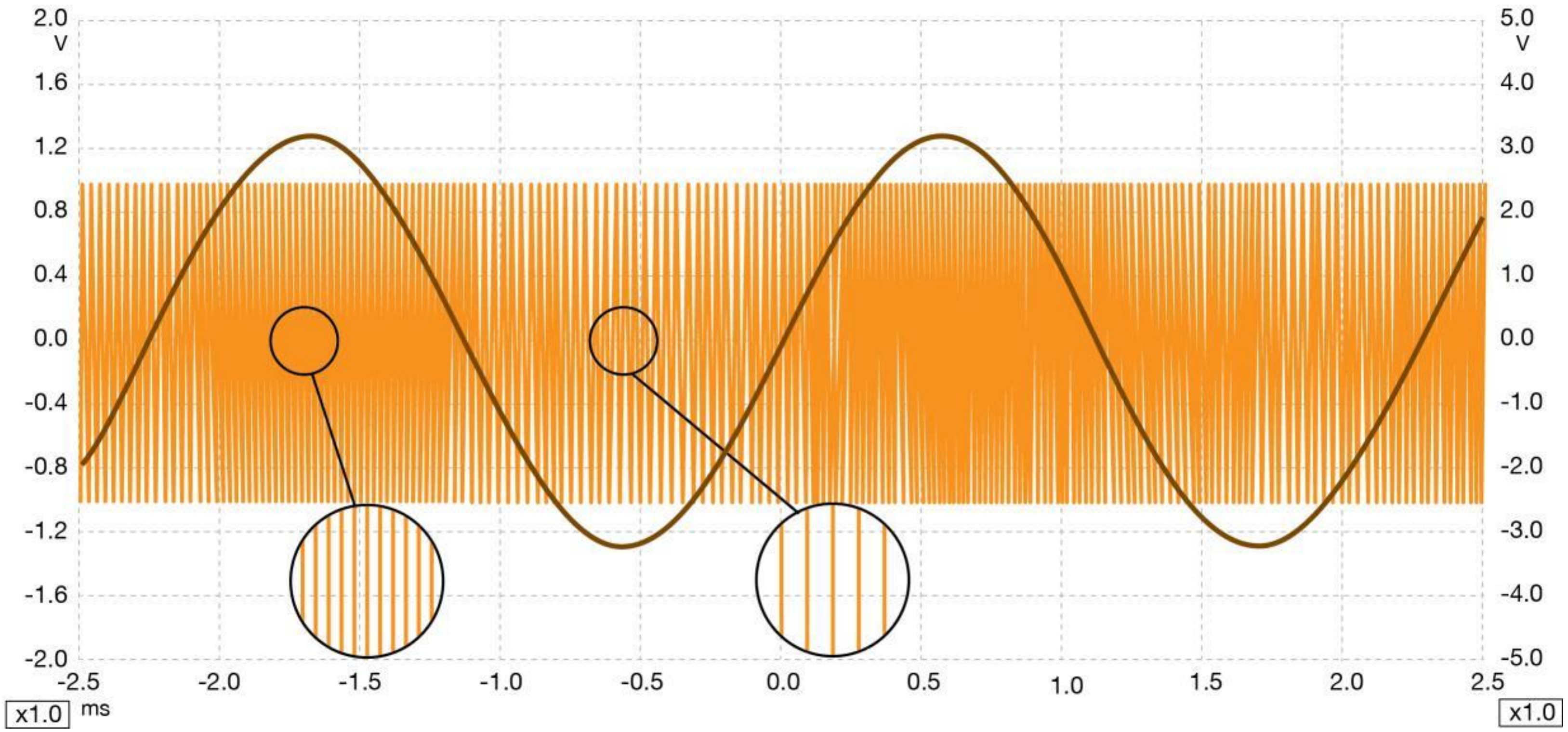
Frequency modulation



Modulating the frequency of a carrier wave

AM Vs FM

Amplitude Modulation (AM)	Frequency Modulation (FM)
Frequency and phase remain the same	Amplitude and phase remain the same
Can be transmitted over a long distance but has poor sound quality.	Better sound quality with higher bandwidth.
The frequency range varies between 535 to 1705 kHz	For FM it is from88 to 108 MHz mainly in the higher spectrum
Signal distortion can occur in AM	Less instances of signal distortion
Consists of two sidebands	An infinite number of sidebands
Circuit design is simple and less expensive	Circuit design is intricate and more expensive
Easily susceptible to noise	Less susceptible to noise

Thank you