Communication System

Communication is the process of establishing connection or link between two points for information exchange. OR Communication is simply the basic process of exchanging information. The electronics equipment which used for communication purpose, are called communication equipment. Different communication equipment when assembled together form a communication system. Typical example of communication system are line telephony and line telegraphy, radio telephony and radio telegraphy, radio broadcasting, point-to-point communication and mobile communication, computer communication, radar communication, television broadcasting, radio telemetry, radio aids to navigation, radio aids to aircraft landing etc.

Block Diagram of Communication System

Fig.1 shows the block diagram of a general communication system, in which the different functional elements are represented by blocks.

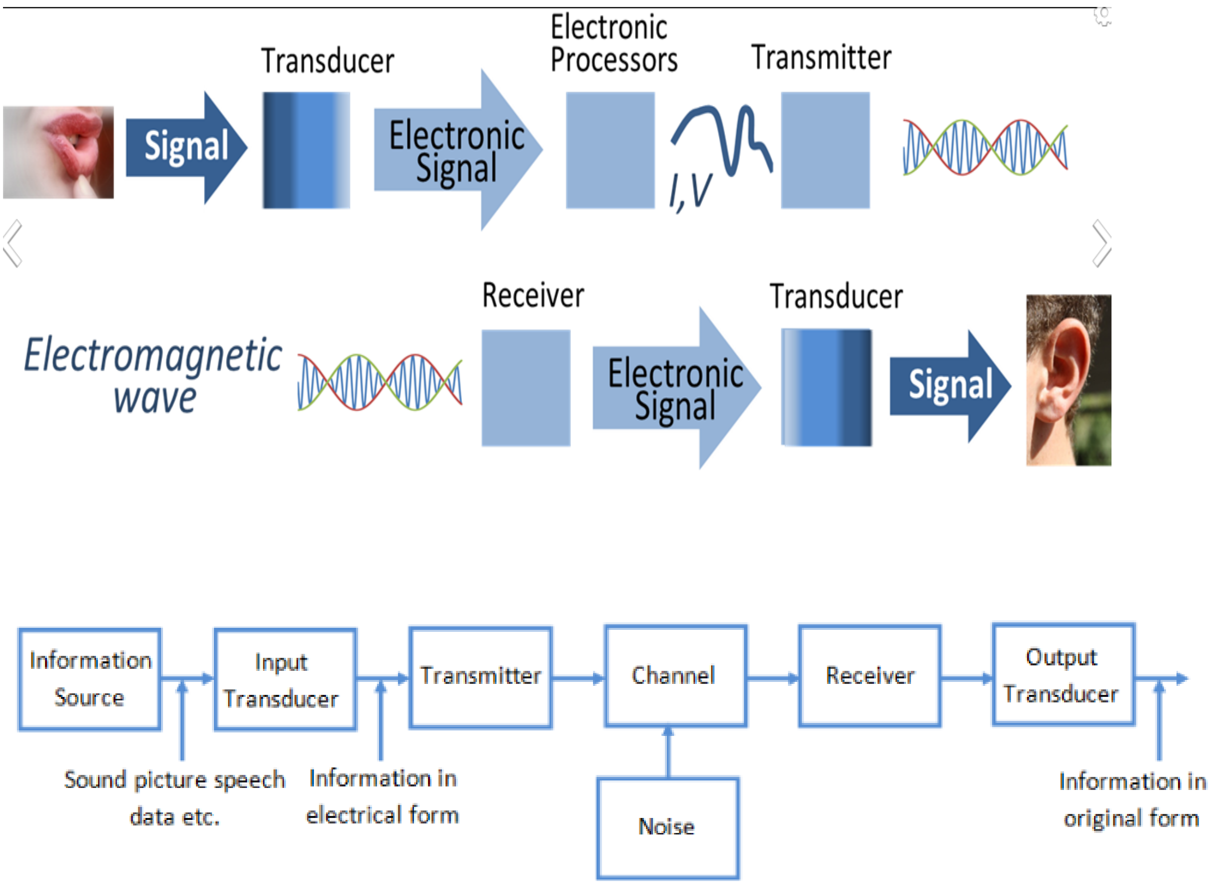


Fig 1

The essential components of a communication system are information source, input transducer, transmitter, communication channel, receiver and destination.

(i) Information Source

As we know, a communication system serves to communicate a message or information. This information originates in the information source. In general, there can be various messages in the form of words, group of words, code, symbols, sound signal etc. However, out of these messages, only the desired message is selected and communicated. Therefore, we can say that the function of information source is to produce required message which has to be transmitted.

(ii) Input Transducer

A transducer is a device which converts one form of energy into another form. The message from the information source may or may not be electrical in nature. In a case when the message produced by the information source is not electrical in nature, an input transducer is used to convert it into a time-varying electrical signal. For example, in case of radio-broadcasting, a microphone converts the information or massage which is in the form of sound waves into corresponding electrical signal.

(iii) Transmitter

The function of the transmitter is to process the electrical signal from different aspects. For example, in radio broadcasting the electrical signal obtained from sound signal, is processed to restrict its range of audio frequencies (up to 5 kHz in amplitude modulation radio broadcast) and is often amplified.

In wire telephony, no real processing is needed. However, in long-distance radio communication, signal amplification is necessary before modulation. Modulation is the main function of the transmitter. In modulation, the message signal is superimposed upon the high-frequency carrier signal. In short, we can say that inside the transmitter, signal processing such as restriction of range of audio frequencies, amplification and modulation of are achieved. All these processing of the message signal are done just to ease the transmission of the signal through the channel.

(iv) The Channel and The Noise

The term channel means the medium through which the message travels from the transmitter to the receiver. In other words, we can say that the function of the channel is to provide a physical connection between the transmitter and the receiver. There are two types of channels, namely point-to-point channels and broadcast channels. Example of point-to-point channels are wire lines, microwave links and optical fibers. Wire-lines operate by guided electromagnetic waves and they are used for local telephone transmission. In case of microwave links, the transmitted signal is radiated as an electromagnetic wave in free space. Microwave links are used in long distance telephone transmission. An optical fiber is a low-loss, well-controlled, guided optical medium. Optical fibers are used in optical communications. Although these three channels operate differently, they all provide a physical medium for the transmission of signals from one point to another point. Therefore, for these channels, the term point-to-point is used. On the other hand, the broadcast channel provides a capability where several receiving stations can be reached simultaneously from a single transmitter. An example of a broadcast channel is a satellite in geostationary orbit, which covers about one third of the earth's surface. During the process of transmission and reception the signal gets distorted due to noise introduced in the system. Noise is an unwanted signal which tend to interfere with the required signal. Noise signal is always random in character. Noise may interfere with signal at any point in a communication system. However, the noise has its greatest effect on the signal in the channel.

(v) Receiver

The main function of the receiver is to reproduce the message signal in electrical form from the distorted received signal. This reproduction of the original signal is accomplished by a process known as the demodulation or detection. Demodulation is the reverse process of modulation carried out in transmitter.

(vi) Destination

Destination is the final stage which is used to convert an electrical message signal into its original form. For example, in radio broadcasting, the destination is a loudspeaker which works as a transducer i.e. converts the electrical signal in the form of original sound signal.

Signals and their properties

Definition of Signal:

Any time varying physical phenomenon that can convey information is called signal. Some examples of signals are human voice, electrocardiogram, sign language, videos etc. There are several classifications of signals such as Continuous time signal, discrete time signal and digital signal, random signals and non-random signals.

Continuous-time Signal: A continuous-time signal is a signal that can be defined at every instant of time. A continuous-time signal contains values for all real numbers along the X-axis. It is denoted by *x(t)*. Figure 2(a) shows continuous-time signal.

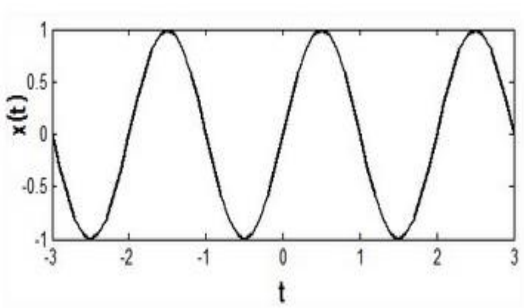


Figure 2(a) Continuous-time signal

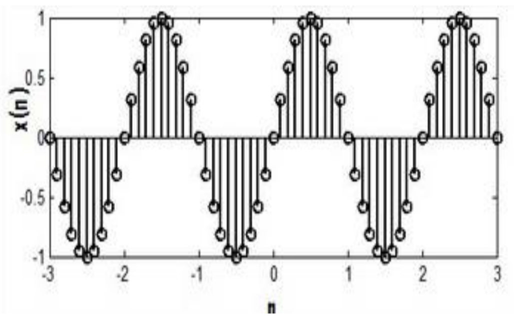


Figure 2(b) Discrete-time signal.

Discrete-time Signal: Signals that can be defined at discrete instant of time is called discrete time signal. Basically discrete time signals can be obtained by sampling a continuous-time signal. It is denoted as *x(n)*. Figure 2(b) shows discrete-time signal.

Digital Signal: The signals that are discrete in time and quantized in amplitude are called digital signal. The term "digital signal" applies to the transmission of a sequence of values of a discrete-time signal in the form of some digits in the encoded form.

Periodic and Aperiodic Signal: A signal is said to be periodic if it repeats itself after some amount of time $x(t+T) = x(t)$, for some value of T. The period of the signal is the minimum value of time for which it exactly repeats itself. Signal which does not repeat itself after a certain period of time is called aperiodic signal. The periodic and aperiodic signals are shown in Figure 3(a) and 3(b) respectively.

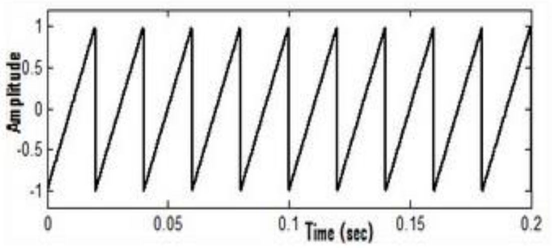


Figure 3(a) Periodic Signals

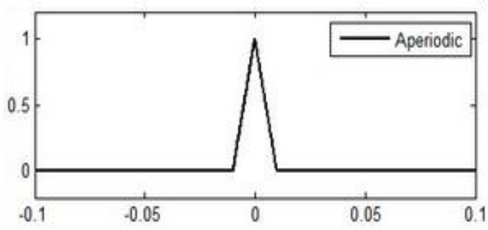


Figure 3(a) Aperiodic Signals

Ex) calculate the fundamental freq. & time for a signal x(t)=10 cos200πt*sin 1000 πt if the signal is periodic. If cos(A)sin(B) $=\frac{1}{2}$ [sin(A+B) – sin(A-B)]

Sol. x(t)=10 cos200πt*sin 1000 πt=5 [sin (1200 πt) - sin sin (800 πt)]

$$T1=\frac{2\pi}{1200\pi}=\frac{1}{600}, \qquad T2=\frac{2\pi}{800\pi}=\frac{1}{400}$$

$$T=\frac{LCM(1/1)}{HCF(600/400)}=\frac{1}{200}\text{ sec.} \qquad f=200\text{Hz}$$

Random and Deterministic Signal: A random signal cannot be described by any mathematical function, where as a deterministic signal is one that can be described mathematically. A common example of random signal is noise. Random signal and deterministic signal are shown in the Figure 4(a) and 4(b) respectively.

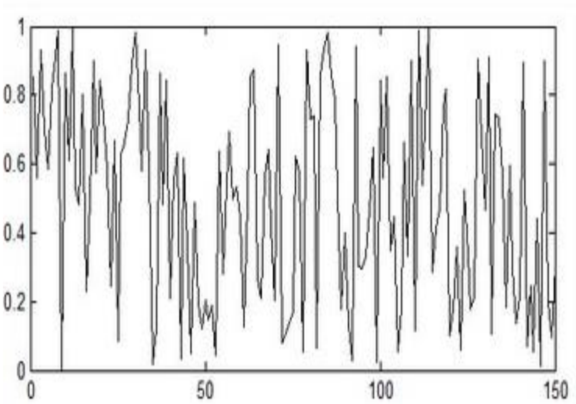


Figure 4(a) Random Signal

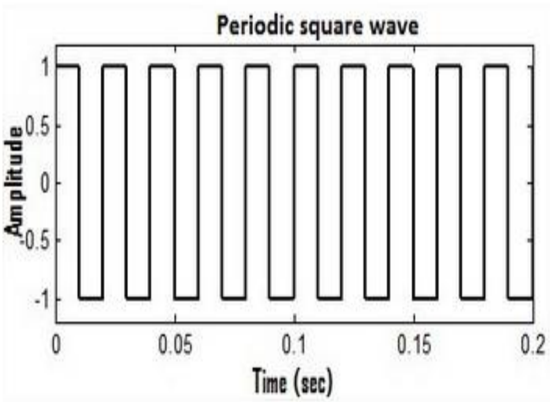


Figure 4(b) Deterministic Signal

Causal, Non-Causal and Anti-Causal Signal: Signal that are zero for all negative time, that type of signals are called causal signals, while the signals that are zero for all positive value of time are called anti-causal signal. A non-causal signal is one that has non zero values in both positive and negative time. Causal, non-causal and anti-causal signals are shown below in the Figure 5(a), 5(b) and 5(c) respectively.

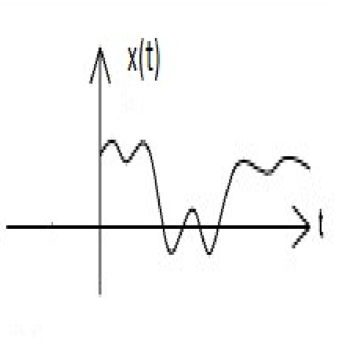


Fig.5(a) Causal signal

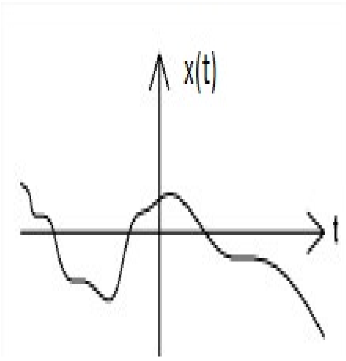


Fig.5(b) Non-Causal signal

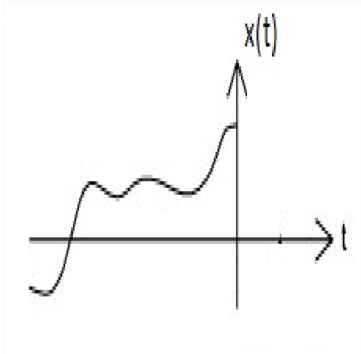


Fig.5(c)Anti-Causal signal

Even and Odd Signal: An even signal is any signal *'x'* such that $x(t) = x(-t)$. On the other hand, an odd signal is a signal *'x'* for which $x(t) = -x(-t)$. Even signals are symmetric around the vertical axis, so that they can easily spotted. An even signal is one that is invariant under the time scaling $t \rightarrow -t$ and an odd signal is one that is invariant under the amplitude and time scaling $x(t) \rightarrow -x(-t)$. For even signals, the part of $x(t)$ for $t > 0$ and the part of $x(t)$ for $t < 0$ are mirror images of each other. In case of an odd signal, the same two parts of the signals are negative mirror images of each other. Some signals are odd, some signals are even and some signals are neither odd nor even. Figure 6(a) and 6(b) shows the odd signal and even signal respectively.

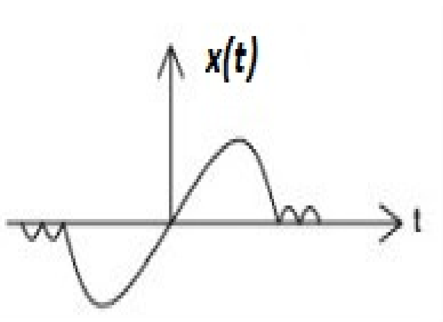


Figure 6(a) Odd Signal

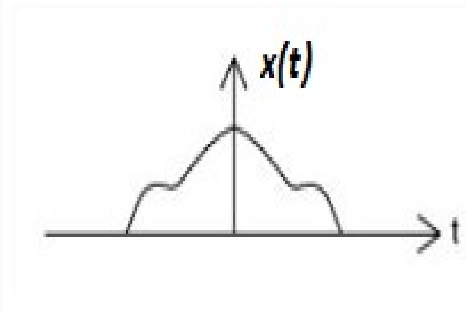


Figure 6(b) Even Signal

Amplitude-Scaling of Signal: There are some important properties of signal such as amplitude-scaling, time-scaling and time-shifting. Among these properties now we are discussing about amplitude scaling. Consider a signal $x(t)$ which is multiplying by a constant *'A'* and this can be indicated by a notation $x(t) \rightarrow Ax(t)$. For any arbitrary *'t'* this multiplies the signal value $x(t)$ by a constant *'A'*. Thus, $x(t) \rightarrow Ax(t)$ multiplies $x(t)$ at every value of *'t'* by a constant *'A'*. This is called amplitude-scaling. If the amplitude-scaling factor is negative, then it flips the signal with the *t*-axis as the rotation axis of the flip. If the scaling factor is -1 then only the signal will be flip. This is shown in the Figure 7(a), 7(b), 7(c) which is given below.

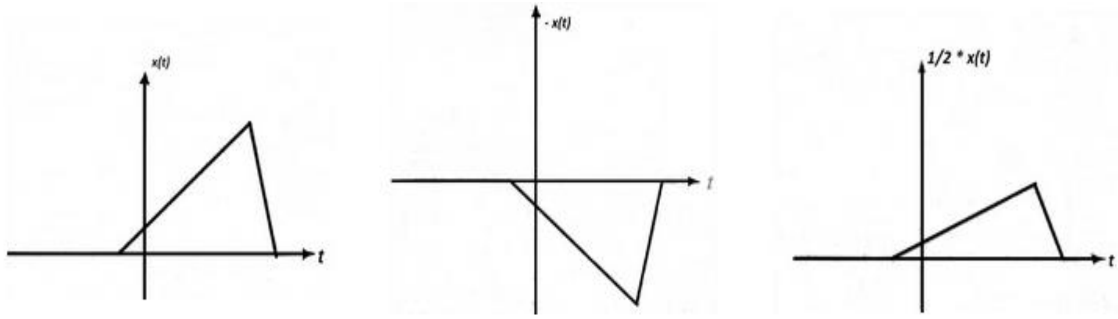


Fig.7(a) A signal x (t) Fig.7(b) x(t) scaled by *-1* Fig.7(c) x(t) scaled by *1/2*

Time-Scaling of Signal: Time scaling compresses or dilates a signal by multiplying the time variable by some quantity. If that quantity is greater than one, the signal becomes narrower and the operation is called compression. If that quantity is less than one, the signal becomes wider and the operation is called dilation. Figure 8(a), 8(b), 8(c) shows the signal x(t), compression of signal and dilation of signal respectively.

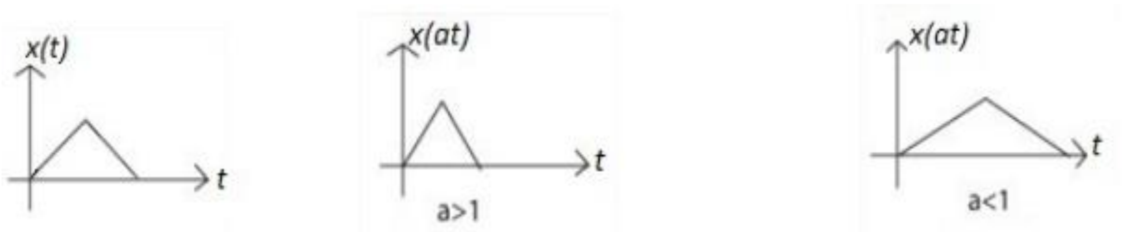


Fig.8(a) Signal x(t) Fig.8(b) Compression of signal Fig.8(c) Dilation of signal

Time-Shifting of Signal: In signals and system amplitude scaling, time shifting and time scaling are some important properties. If a continuous time signal is defined as $x(t) = s(t - t1)$. Then we can say that $x(t)$ is the time shifted version of $s(t)$. Consider a simple signal Now shifting the function by time $t1 = 2$ sec.

$$x(t) = s(t-2) = t-2 \qquad for \quad 0 < (t-2) < 1$$

$$= t-2 \qquad for \quad 2 < (t-2) < 3$$

Which is simply signal $s(t)$ with its origin delayed by 2 sec. Now if we shift the signal by $t1 = -1$ sec.

$$\text{then } x(t) = s(t+1) = t+1 \qquad for \quad 0 < (t+1)$$

$$= t+1 \qquad for \quad -1 < t < 0$$

Which is simply $s(t)$ with its origin shifted to the left or advance in time by 1 seconds. This time-shifting property of signal is shown in the Figure 9(a), 9(b) and 9(c) given above.

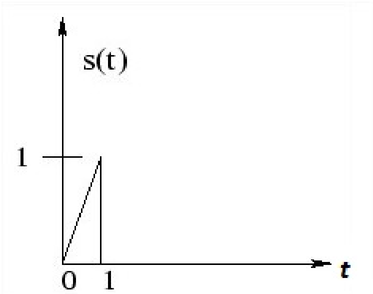


Fig.9(a) Signal (*0< t < 1)*

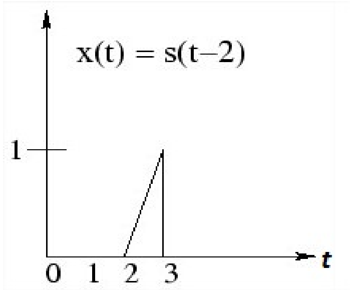


Fig.9(b) Shifted by 2

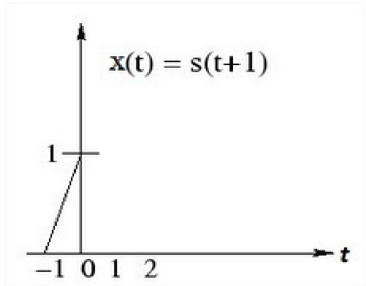


Fig.9(c)Shifted by -1

Continuous-Time Fourier Transform (CTFT):

Due to the large number of continuous-time signals that are present, the Fourier series provided us the first glimpse of how many we may represent some of these signals in a general manner: as a superposition of a number of sinusoids. Now, we can look at a way to represent continuous-time non-periodic signals using the same idea of superposition. Below we will present the Continuous-Time Fourier Transform (CTFT), also referred to as just the Fourier Transform (FT). Because the CTFT now deals with non-periodic signals, we must now find a way to include all frequencies in the general equations.

Continuous-Time Fourier Transform

$$F(\Omega) = \int_{-\infty}^{\infty} f(t)\, e^{-(j\Omega t)} dt$$

Inverse CTFT

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\Omega)\, e^{j\Omega t} d\Omega$$

The above equations for the CTFT and its inverse come directly from the Fourier series and our understanding of its coefficients. For the CTFT we simply utilize integration rather than summation to be able to express the aperiodic signals. This should make sense since for the CTFT we are simply extending the ideas of the Fourier series to include non-periodic signals, and thus the entire frequency spectrum. Look at the Derivation of the Fourier Transform for a more in depth look at this.

Exercise 1: Find the Fourier Transform (CTFT) of the function: -

$$f(t) = \begin{cases} e^{-(\alpha t)} \text{ if } t \geq 0 \\ 0 \text{ otherwise} \end{cases}$$

Solution: In order to calculate the Fourier transform, all we need to use is Equation of complex exponentials, and basic calculus: -

$$\begin{aligned} F(\Omega) &= \int_{-\infty}^{\infty} f(t)\, e^{-(j\Omega t)} dt \\ &= \int_{0}^{\infty} e^{-(\alpha t)} e^{-(j\Omega t)} dt \\ &= \int_{0}^{\infty} e^{(-t)(\alpha + j\Omega)} dt \\ &= 0 - \frac{-1}{\alpha + j\Omega} \end{aligned}$$

$$F(\Omega) = \frac{1}{\alpha + j\Omega}$$

Signal Energy and Power

The terms signal energy and signal power are used to characterize a signal. They are not actually measures of energy and power. The definition of signal energy and power refers to any signal x(t), including signals that take on complex values.

The signal energy in the signal x(t) is:

$$E = \int_{-\infty}^{\infty} |x(t)|^2 \, dt .$$

The signal power in the signal x(t) is:

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

If $0 < E < \infty$, then the signal $x(t)$ is called an energy signal. However, there are signals where this condition is not satisfied. For such signals we consider the power. If $0 < P < \infty$, then the signal is called a power signal. Note that the power for an energy signal is zero $(P = 0)$ and that the energy for a power signal is infinite $(E = \infty)$. Some signals are neither energy nor power signals.

Let us consider a periodic signal x (t) with period To. The signal energy in one period is

$$E_1 = \int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} |\, x(t)|^2 \, \mathrm{d}t$$

and energy in n periods is

$$E_n = nE_1 = n \int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} |\, x(t)|^2 \, \mathrm{d}t \, .$$

The power of this signal over all periods is given by

$$P = \lim_{n\to\infty} \frac{nE_1}{nT_0} = \frac{1}{T_0} E_1 = \frac{1}{T_0} \int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} |\, x(t)|^2 \, \mathrm{d}t \, .$$

If the signal energy over one period is larger than zero but finite, then the total energy is infinite and the signal power is finite. Therefore, the signal is a power signal. If the signal energy in one period is infinite, then both the power and the total energy are infinite. Consequently, the signal is neither an energy signal nor a power signal. Consider a current signal i(t) flowing through a transmission line represented by resistance R. The energy loss in the line is

$$E_R = \int_{-\infty}^{\infty} R(i(t))^2 \, \mathrm{d}t = RE_i$$

where E_i is the signal energy in the signal $i(t)$. If the current $i(t)$ is periodic with period T_0, the average power loss in the line is given by

$$P_{av} = \frac{1}{T_0} \int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} R(i(t))^2 \, \mathrm{d}t = RP_i$$

where P_i is the power of the periodic current signal $i(t)$.

Example 1: -

Let us consider a signal

$$x(t) = e^{-t}u(t).$$

The energy of this signal is

$$E = \int_{-\infty}^{\infty} \left| e^{-t}u(t) \right|^2 dt = \int_{0}^{\infty} e^{-2t} dt = -\frac{1}{2}e^{-2t}\Big|_0^{\infty} = \frac{1}{2}.$$

The signal $x(t)$ is an energy signal. Since E is finite the signal power $P = 0$.

Example 2: -

Let us consider a complex signal

$$x(t) = Ae^{j\omega_0 t}.$$

Signal $x(t)$ is periodic with period $T_0 = \dfrac{2\pi}{\omega_0}$; hence, it cannot be an energy signal.

To compute the signal power we use (12.3)

$$P = \frac{1}{T_0}\int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} \left| Ae^{j\omega_0 t} \right|^2 dt = \frac{1}{T_0}\int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} A^2 dt = A^2.$$

Since P is finite, $x(t)$ is a power signal and its energy is infinite.

Parseval's Theorem

If a function has a Fourier series given by

$$f(x) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n \cos(n x) + \sum_{n=1}^{\infty} b_n \sin(n x),$$

then Bessel's inequality becomes an equality known as Parseval's theorem. From above equation:

$$[f(x)]^2 = \frac{1}{4}a_0^2 + a_0 \sum_{n=1}^{\infty} [a_n \cos(n x) + b_n \sin(n x)] + \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} [a_n a_m \cos(n x)\cos(m x) + a_n b_m \cos(n x)\sin(m x) + a_m b_n \sin(n x)\cos(m x) + b_n b_m \sin(n x)\sin(m x)].$$

Integrating

$$\int_{-\pi}^{\pi}[f(x)]^2\,dx = \frac{1}{4}a_0^2\int_{-\pi}^{\pi}dx + a_0\int_{-\pi}^{\pi}\sum_{n=1}^{\infty}[a_n\cos(n\,x)+b_n\sin(n\,x)]\,dx +$$

$$\int_{-\pi}^{\pi}\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}[a_n\,a_m\cos(n\,x)\cos(m\,x)+a_n\,b_m\cos(n\,x)\sin(m\,x)+$$

$$a_m\,b_n\sin(n\,x)\cos(m\,x)+b_n\,b_m\sin(n\,x)\sin(m\,x)]\,dx$$

$$= \frac{1}{4}a_0^2(2\pi)+0+\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}[a_n\,a_m\,\pi\delta_{n\,m}+0+0+b_n\,b_m\,\pi\delta_{n\,m}],$$

so

$$\frac{1}{\pi}\int_{-\pi}^{\pi}[f(x)]^2\,dx = \frac{1}{2}a_0^2+\sum_{n=1}^{\infty}\left(a_n^2+b_n^2\right).$$

For a generalized Fourier series of a complete orthogonal system , an analogous relationship holds. For a complex Fourier series,

$$P_{av} = \sum_{-\infty}^{\infty}|Cn|^2 \quad \text{Watt}$$

Spectrum Representation

Extending the investigation of Chapter 1, we now consider signals/waveforms that are composed of multiple sinusoids having different amplitudes, frequencies, and phases:

$$\begin{aligned} x(t) &= A_0 + \sum_{k=1}^{N} A_k\cos(2\pi f_k t+\phi_k) \\ &= X_0 + \mathrm{Re}\left\{\sum_{k=1}^{N} X_k e^{j2\pi f_k t}\right\} \end{aligned}$$

where here $X_0 = A_0$ is real, $X_k = A_k e^{j\phi_k}$ is complex, and f_k is the frequency in Hz

We desire a graphical representation of the parameters versus frequency.

The Spectrum of a Sum of Sinusoids

An alternative form of equation above, which involves the use of the inverse Euler formula's, is to expand each real cosine into two complex exponentials:

$$x(t) = X_0 + \sum_{k=1}^{N} \left\{ \frac{X_k}{2} e^{j2\pi f_k t} + \frac{X_k^*}{2} e^{-j2\pi f_k t} \right\}$$

Note that we now have each real sinusoid expressed as a sum of positive and negative frequency complex sinusoids Two-Sided Sinusoidal Signal Spectrum: Express as in equation above and then the spectrum is the set of frequency/amplitude pairs:

$$\begin{gathered} \{(0, X_0), (f_1, X_1/2), (-f_1, X_1^*/2), \ldots \\ \ldots (f_k, X_k/2), (-f_k, X_k^*/2), \ldots \\ (f_N, X_N/2), (-f_N, X_N^*/2)\} \end{gathered}$$

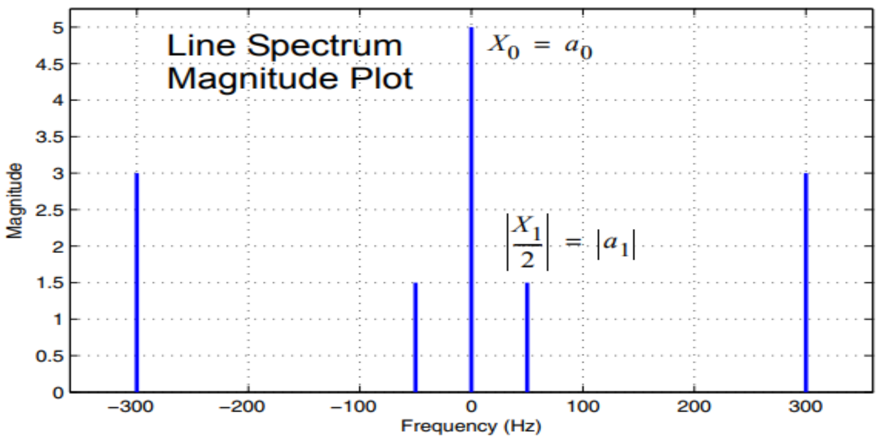
The spectrum can be plotted as vertical lines along a frequency axis, with height being the magnitude of each X_K or the angle (phase), thus creating either a two-sided magnitude or phase spectral plot, respectively.

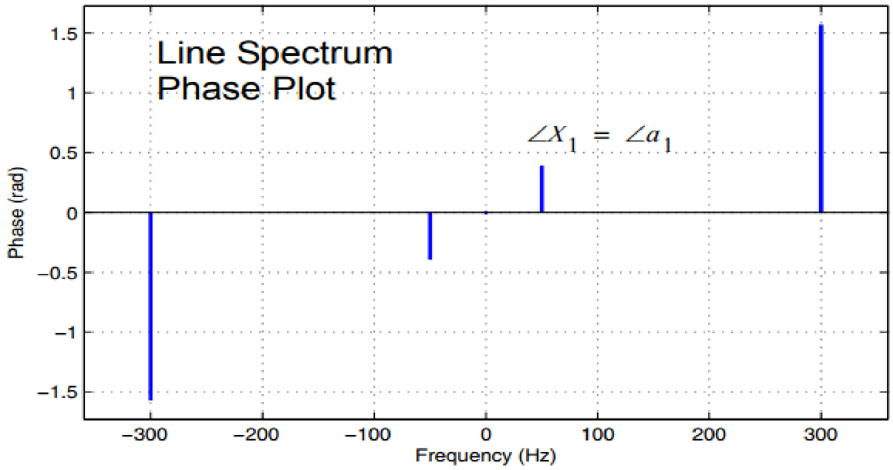
Example: Constant + Two Real Sinusoids

$$\begin{aligned} x(t) &= 5 + 3\cos(2\pi \cdot 50 \cdot t + \pi/8) \\ &\quad + 6\cos(2\pi \cdot 300 \cdot t + \pi/2) \end{aligned}$$

- **We expand $x(t)$ into complex sinusoid pairs**

$$\begin{aligned} x(t) &= 5 + \frac{3}{2} e^{j\left(2\pi 50t + \frac{\pi}{8}\right)} + \frac{3}{2} e^{-j\left(2\pi 50t + \frac{\pi}{8}\right)} \\ &\quad + \frac{6}{2} e^{j\left(2\pi 300t + \frac{\pi}{2}\right)} + \frac{6}{2} e^{-j\left(2\pi 300t + \frac{\pi}{2}\right)} \end{aligned}$$





Spectrum of Periodic Signal

The spectrum of any periodic Signal can be obtained by plotting $|Cn|$ and Θ_n versus nf_o where

$$C_n = \frac{1}{T}\int_0^T f(t)e^{-j\omega ot}\,dt = \frac{a_n}{2} - j\,\frac{b_n}{2}$$

$$|C_n| = \sqrt{\left(\frac{a_n}{2}\right)^2 + \left(\frac{b_n}{2}\right)^2} \qquad \& \quad \Theta_n = \tan^{-1}\left(\frac{b_n}{a_n}\right)$$

Ex-1 Plot the amplitude and phase spectrum of the signal $f(t)=e^{-t}$ & T=0.5sec

Ex-2 Plot the amplitude and phase spectrum of rectangular pulse signal with τ=1sec,

T_o= 5, 10, 20 sec

Ex-3 For a rectangular pulse signal if $\frac{\tau}{T_o}$ = 0.25, find : -

a- The total average power.
b- The ratio of average power in the first three harmonics to total average power.