

Electronics Engineering

Communication Systems

Comprehensive Theory

with Solved Examples and Practice Questions



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Publications



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Communication Systems

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First Edition: 2015

Second Edition: 2016

Third Edition: 2017

Fourth Edition: 2018

Fifth Edition: 2019

Sixth Edition: 2020

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Introduction to Communication Systems

1.1 Historical Sketch

The development of communication technology has proceeded in step with the development of electronic technology as a whole. For example, the demonstration of telegraphy by Joseph Henry in 1832 and by Samuel F.B. Morse in 1838 followed hard on the discovery of electromagnetism by Oersted and Ampere early in 1820's. Similarly, Hertz's verification late in the 1880's of Maxwell's postulation (1873) predicting the wireless propagation of electromagnetic energy led within 10 years of the radio-telegraph experiments of Marconi and Popov. The invention of diode by Flaming in 1904 and of triode by deforest in 1906 made possible the rapid development of long distance telephony, both by radio and wireless.

1.2 Why Study Communication

The rapidly changing face of technology necessitates learning of new technology. Today the question is no longer in the field of invention but of innovation. The question today in the twenty first century is not how to transmit data from point A to point B but how efficiently can we do it. To be able to answer this question, first we should be able to diagnose the problem. This can be done only by studying communication from the beginning to its modern form.

1.3 What is Communication

In the most fundamental sense, communication involves implicitly the transmission of information from one point to another through a succession of processes, as described here:

1. The generation of a message signal: voice, music, picture, or computer data.
2. The description of that message signal with a certain measure of precisions, by a set of symbols: electrical, audio, or visual.
3. The encoding of these symbols in a form that is suitable for transmission over a physical medium of interest.
4. The transmission of the encoded symbols to the desired destination.
5. The decoding of the reproduction of the original symbols.
6. The re-creation of the original message signal, with a definable degradation in quality; the degradation is caused by imperfections in the system.

There are, of course, many other forms of communication that do not directly involve the human mind in real time. For example, in computer communications involving communication between two or more computers, human decisions may enter only in setting up the programs or commands for the computer, or in monitoring the results.

1.4 Communication Model

The study of communication becomes easier, if we break the whole subject of communication in parts and then study it part by part. The whole idea of presenting the model of communication is to analyse the key concepts used in communication in isolated parts and then combining them to form the complete picture.

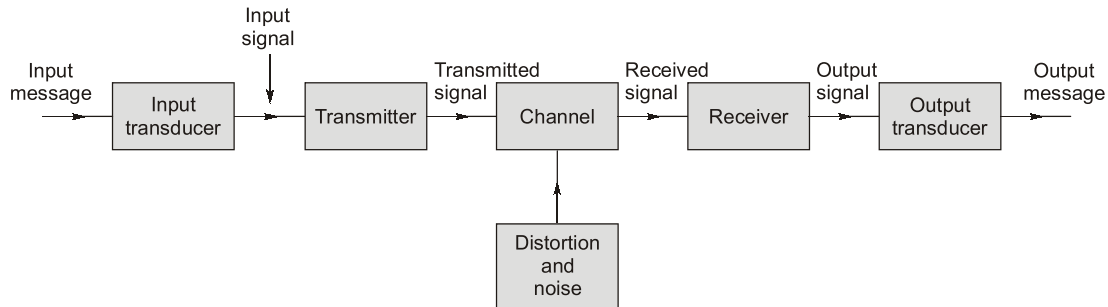


Figure-1.1: Model of communication system

Source

The source originates a message, such as a human voice, a television picture, an e-mail message, or data. If the data is non-electric (e.g., human voice, e-mail text, television video), it must be converted by an **input transducer** into an electric waveform referred to as the **baseband signal** or **message signal** through physical devices such as a microphone, a computer keyboard or a CCD camera.

Transmitter

The transmitter modifies the baseband signal for efficient transmission. The transmitter may consist of one or more subsystems: an A/D converter, an encoder and a modulator. Similarly, the receiver may consist of a demodulator, a decoder and a D/A converter.

Channel

The channel is a medium of choice that can carry the electric signals at the transmitter output over a distance. A typical channel can be a pair of twisted copper wires (telephone and DSL), coaxial cable (television and internet), an optical fibre or a radio link. Channel may be of two types.

1. **Physical channel:** When there is a physical connection between the transmitter and receiver through wires. eg. coaxial cable.
2. **Wireless channel:** When no physical channel is present and transmission is through air. eg. mobile communication.

It is inevitable that the signal will deteriorate during the process of transmission and reception as a result of some distortion in the system, or because of the introduction of noise, which is unwanted energy, usually of random character, present in a transmission system, due to a variety of causes. Since noise will be received together with the signal, it places a limitation on the transmission system as a whole. When noise is severe, it may mask a given signal so much that the signal becomes undetectable and therefore useless. Noise may interfere with signal at any point in a communications system, but it will have its greatest effect when the signal is weakest. This means that noise in the channel or at the input to the receiver is the most noticeable.

Receiver

The receiver reprocesses the signal received from the channel by reversing the signal modifications made at the transmitter and removing the distortions made by the channel. The receiver output is fed to the output transducer, which converts the electric signal to its original form i.e. the message signal.

Destination

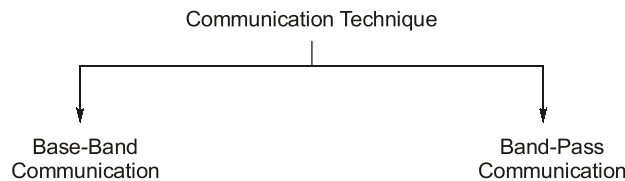
The destination is the unit to which the message is communicated.

1.5 Modes of Communication

There are two basic modes of communication:

1. **Broadcasting**, which involves the use of a single powerful transmitter and numerous receivers that are relatively inexpensive to build. Here information-bearing signals flow only in one direction.
2. **Point-to-point communication**, in which the communication process takes place over a link between a single transmitter and a receiver. In this case, there is usually a bidirectional flow of information-bearing signals, which requires the use of a transmitter and receiver at each end of the link.

1.5.1 Communication Technique



1. Base Band Communication:

It is generally used for short distance communication. In this type of communication message is directly sent to the receiver without altering its frequency.

2. Band Pass Communication:

It is used for long distance communication. In this type of communication, the message signal is mixed with another signal called as the carrier signal for the process of transmission. This process of adding a carrier to a signal is called as modulation.

1.5.2 Need of Modulation

1. To avoid the mixing of signals

All messages lies within the range of 20 Hz - 20 kHz for speech and music, few MHz for video, so that all signals from the different sources would be inseparable and mixed up. In order to avoid mixing of various signals, it is necessary to translate them all to different portions of the electromagnetic spectrum.

2. To decrease the length of transmitting and receiving antenna

For a message at 10 kHz, the antenna length 'l' for practical purposes is equal to $\lambda/4$ (from antenna theory) i.e.,

$$\lambda = \frac{3 \times 10^8}{10 \times 10^3} = 3 \times 10^4 \text{ m}$$

and
$$l = \frac{\lambda}{4} = \frac{3 \times 10^4}{4} = 7500 \text{ m}$$

An antenna of this size is impractical and for a message signal at 1 MHz

$$\lambda = \frac{3 \times 10^8}{10^6} = 300 \text{ m}$$

and
$$l = \frac{\lambda}{4} = 75 \text{ m (practicable)}$$

3. To allow the multiplexing of signals

By translating all signals from different sources to different carrier frequency, we can multiplex the signals and able to send all signals through a single channel.

4. To remove the interference
5. To improve the quality of reception i.e. increasing the value of S/N ratio
6. To increase the range of communication

1.6 Types of Modulation

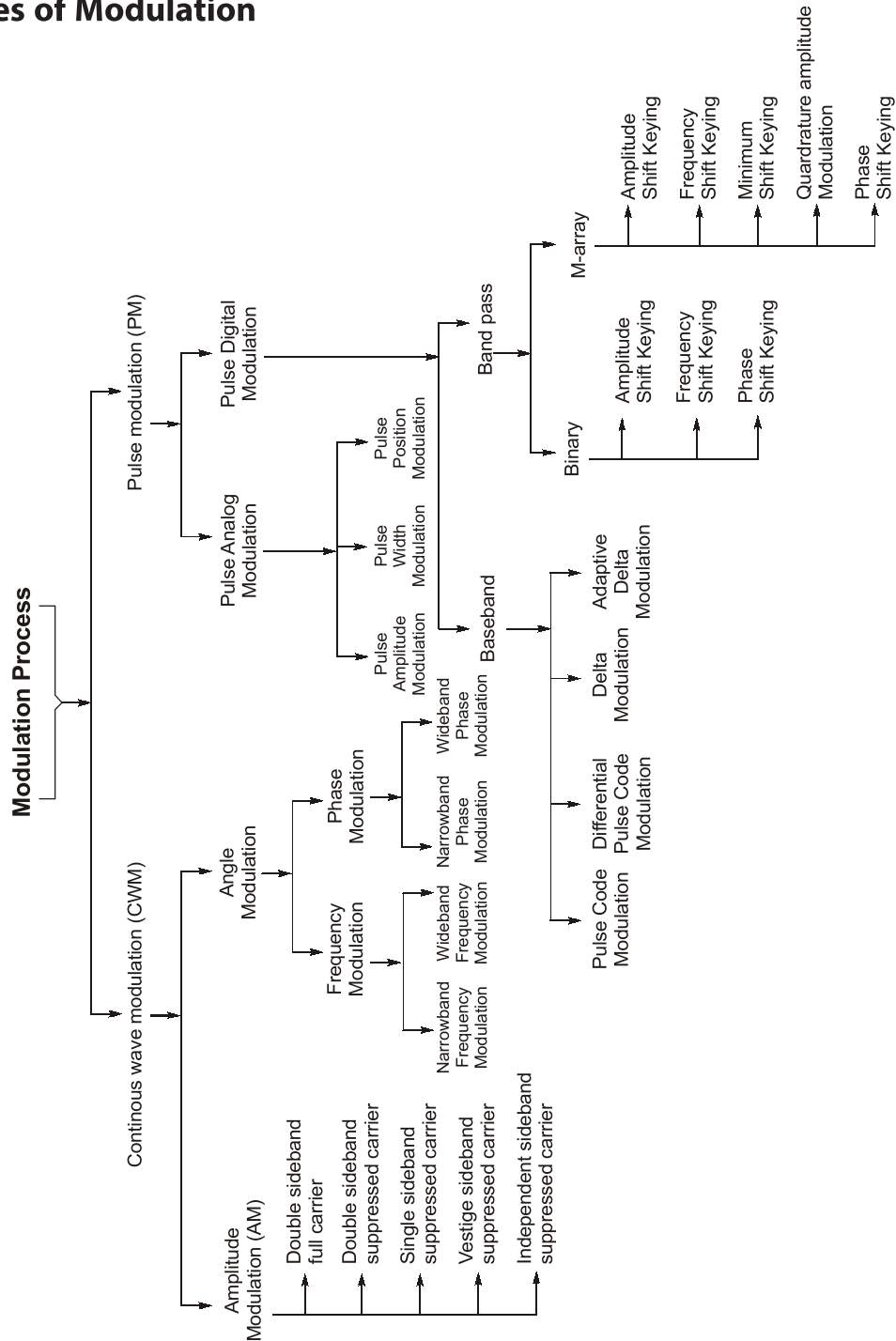


Figure-1.2

1.7 An Exam Oriented Approach

Communication is a modern technology is undergoing many changes. The main focus of a student should be to single out on optimum path in which he develops a theoretically strong background of the subject while keeping in mind that he should be able to solve questions asked in various exams using the theory they have studied. Focusing on one aspect leads to failure in written exam or in the interview. Thus this book and communication both have the same approach and that is “optimization” and being a communication engineer one should have this approach too.

Frequency (f) range	Wavelength (λ) range	EM Spectrum Nomenclature	Typical Application
30 – 300 Hz	$10^7 - 10^6$ m	Extremely low frequency (ELF)	Power line communication
0.3 – 3 kHz	$10^6 - 10^5$ m	Voice frequency (VF)	Face to face speech, communication intercom
3 – 30 kHz	$10^5 - 10^4$ m	Very low frequency (VLF)	Submarine communication
30 – 300 kHz	$10^4 - 10^3$ m	Low frequency (LF)	Marine communication
0.3 – 3 MHz	$10^3 - 10^2$ m	Medium frequency (MF)	AM broadcasting
3 – 30 MHz	$10^2 - 10^1$ m	High frequency (HF)	Landline telephony
30 – 300 MHz	$10^1 - 10^0$ m	Very high frequency (VHF)	FM broadcasting, TV
0.3 – 3 GHz	$10^0 - 10^{-1}$ m	Ultra high frequency (UHF)	TV, Cellular telephony
3 – 30 GHz	$10^{-1} - 10^{-2}$ m	Super high frequency (SHF)	Microwave oven, radar
30 – 300 GHz	$10^{-2} - 10^{-3}$ m	Extremely high frequency (EHF)	Satellite communication, radar
0.3 – 3 THz	0.1 – 1 mm	Experimental	For all new explorations
3 – 430 THz	100 – 0.7 μm	Infrared	LED, Laser, TV remote
430 – 750 THz	0.7 – 0.4 μm	Visible light	Optical communication
750 – 3000 THz	0.4 – 0.1 μm	Ultraviolet	Medical application
> 3000 THz	< 0.1 μm	X-rays, gamma rays, cosmic rays	Medical application

Table-1.1: EM Spectrum



Basics of Signal and System

Introduction

Just as a carpenter requires proper set of tools before he can sit down to make a piece of furniture, in a similar manner a communication engineer needs to know about signals before he can start the process of learning communication.

2.1 Signal and System

The communication technology can be conveniently broken down into three interacting parts.

- Signal processing operations performed.
- The device that performs these operations.
- The underlining physics.

Thus to study the basic form of modulation and signal processing used in the communication it will be fruitful to have a quick review of the concepts of signal and system.

2.1.1 Some Basic Signals

It will be very helpful to study some signals before hand, so that the analysis of the communication system becomes easier. Some important and frequently used signals and their properties are mentioned in this section.

The Impulse Signal

Impulse function is not a function in its strict sense. It is a distributed or generalized function. A generalized function is defined in terms of its effect on other function. The unit impulse function is generalised as any function that follow the following condition:

1. Impulse signal (Dirac delta function):

$$\delta(t) = \begin{cases} \infty; & t = 0 \\ 0; & t \neq 0 \end{cases}$$

and
$$\int_{-\infty}^{\infty} \delta(t) dt = 1$$

2. Unit impulse signal:

$$\delta[n] = \begin{cases} 1; & n = 0 \\ 0; & n \neq 0 \end{cases}$$

Properties of Impulse Function

1. Product property

$$x(t) \delta(t) = x(0) \delta(t)$$

Similarly, $x(t) \delta(t - \alpha) = x(\alpha) \delta(t - \alpha)$

2. Shifting property

$$\int_{-\infty}^{\infty} x(t) \delta(t) dt = x(0)$$

Similarly,

$$\int_{-\infty}^{\infty} x(t) \delta(t - \alpha) dt = x(\alpha)$$

$$\int_{-\infty}^{\infty} \delta(t) dt = 1$$

3. Scaling property

$$\delta(\alpha t) = \frac{1}{|\alpha|} \delta(t)$$

Example 2.1

Find the impulse function form if $x(t) = 4t^2 \delta(2t - 4)$, where $x(t)$ is an arbitrary

signal.

Solution:

$$\begin{aligned} x(t) &= 4t^2 \delta(2t - 4) \\ &= 4t^2 \delta\{2(t - 2)\} \\ &= 4t^2 \cdot \frac{1}{2} \delta(t - 2) && \dots \text{from scaling property} \\ &= 2t^2 \delta(t - 2) \end{aligned}$$

Now, from product property we have,

$$x(t) \delta(t - \alpha) = x(\alpha) \delta(t - \alpha)$$

So,

$$x(t) = 2t^2 \Big|_{t=2} \cdot \delta(t - 2) = 8 \delta(t - 2)$$

Example 2.2

Let $\delta(t)$ denote the delta function. The value of the integral

$$\int_{-\infty}^{\infty} \delta(t) \cos\left(\frac{3t}{2}\right) dt \text{ is}$$

(a) 1

(b) -1

(c) 0

(d) $\pi/2$

Solution: (a)

We know,

$$\int_{-\infty}^{\infty} \delta(t) x(t) dt = x(0)$$

So here,

$$\int_{-\infty}^{\infty} \delta(t) \cos\left(\frac{3t}{2}\right) dt = \cos 0 = 1$$

Do you know? Impulse signals do not occur naturally but they are important functions providing a mathematical frame work for the representation of various processes and signals. These come under a special class of functions known as generalized functions.

Gate Function/Rectangular Pulse

Let us consider a rectangular pulse as shown in figure below:

$$x(t) = A \operatorname{rect}(t) = \begin{cases} A, & \text{for } -\frac{1}{2} < t < \frac{1}{2} \\ 0 & \text{otherwise} \end{cases}$$

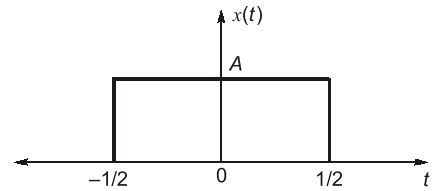


Figure-2.1

$$x(t) = A \operatorname{rect}\left(\frac{t}{\tau}\right) = \begin{cases} A, & \text{for } -\frac{\tau}{2} < t < \frac{\tau}{2} \\ 0 & \text{otherwise} \end{cases}$$

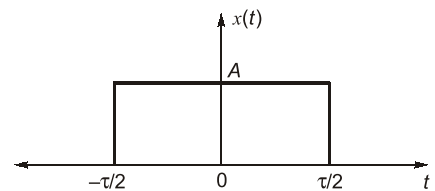


Figure-2.2

Step Signal

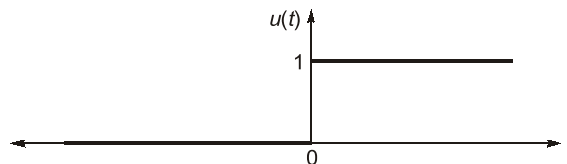


Figure-2.3: Continuous-time version of the unit-step function of unit amplitude

The continuous-time version of the unit-step function is defined by

$$u(t) = \begin{cases} 1; & t > 0 \\ 0; & t < 0 \end{cases}$$

NOTE



- Figure depicts the unit-step function $u(t)$. It is said to exhibit discontinuity at $t = 0$, since the value of $u(t)$ changes instantaneously from 0 to 1 when $t = 0$. It is for this reason that we have left out the equal sign in equation; that is $u(0)$ is undefined.
- Unit step function denote sudden change in real time and a frequency or phase selectivity in frequency domain.

There is one more definition of unit step function.

$$u(t) = \begin{cases} 0 & ;t < 0 \\ 1/2 & ;t = 0 \\ 1 & ;t > 0 \end{cases}$$

Properties of Unit-Step Function

1. $u(t - t_0) = [u(t - t_0)]^2 = u[u(t - t_0)]^k$, with k being any positive integer.
2. $u(at - t_0) = u\left(t - \frac{t_0}{a}\right)$; $a > 0$

3. $\delta(t) = \frac{d}{dt} u(t)$

4. $u(t) = \int_{-\infty}^t \delta(\tau) d\tau = \begin{cases} 1, & t > 0 \\ 0, & t < 0 \end{cases}$

Do you know? The unit-step function $u(t)$ may also be used to construct other discontinuous waveforms. The value at $t = 0$ gives rise to Gibb's phenomenon when unit step function is constructed by sinusoidal signals.

Sampling/Interpolating/Sinc Function

The function $\frac{\sin \pi x}{\pi x}$ is the "sine over argument" function and it is denoted by "sinc (x)". It is also known as "filtering function".

Mathematically,

$$\begin{aligned} \text{sinc}(x) &= \frac{\sin \pi x}{\pi x} \\ &= \text{Sa}(\pi x) \end{aligned}$$

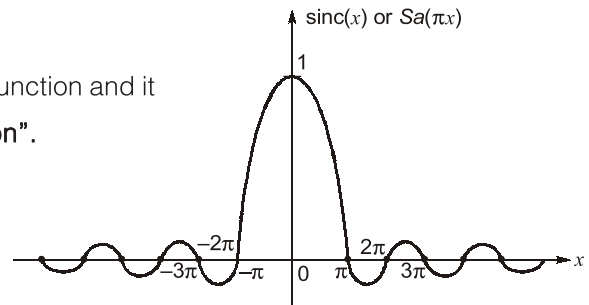


Figure-2.4 : Sinc Function

Do you know? Just like impulse function $\delta(x)$ is also a conceptual function since it can not be realized.

The Unit-Ramp Function

The ramp function $r(t)$ is a linearly growing function for positive values of independent variable t . The ramp function shown in figure is defined by

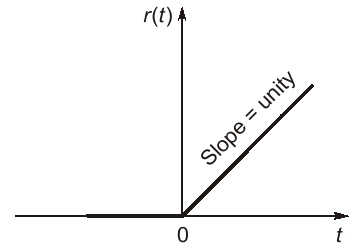
$$r(t) = \begin{cases} t, & t \geq 0 \\ 0, & t < 0 \end{cases}$$

or

$$r(t) = tu(t)$$

The ramp function is obtained by integrating the unit step function

$$\int_{-\infty}^t u(\tau) d\tau = r(t)$$



The relationship between the impulse, step and ramp signals are represented below:

Remember: Relationship between impulse, step and ramp signals

$$\begin{aligned} \delta(t) &\xrightarrow{\text{Integrate}} u(t) \xrightarrow{\text{Integrate}} r(t) \\ r(t) &\xrightarrow{\text{Differentiate}} u(t) \xrightarrow{\text{Differentiate}} \delta(t) \end{aligned}$$

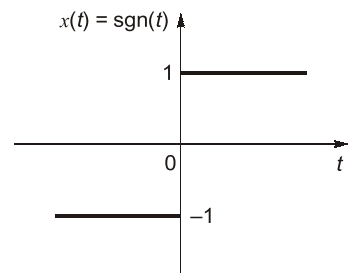
Unit Signum Function

The unit signum function shown in figure is defined as follows

$$\text{sgn}(t) = \begin{cases} 1 & t > 0 \\ 0 & t = 0 \\ -1 & t < 0 \end{cases}$$

This function can be expressed in terms of unit step function as

$$\text{sgn}(t) = -1 + 2u(t)$$



Unit Signum Function