June : 2016 (CBCS)

Note : **Max. marks : 60**

(i) Attempt any five questions out of seven questions.

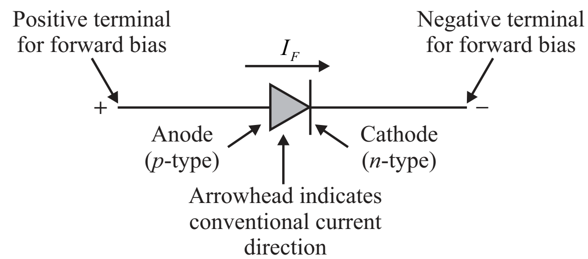
(ii) All questions carry equal marks.

(iii) Draw the neat diagram, whenever necessary.

(iv) Assume data, wherever necessary.

Q.1 (a) Define diode. Describe theory of diode operation. What is the application of it?

Ans. **Diode :** A *p-n* junction forms a popular semiconductor device called *p-n* junction diode. It has two terminals called electrodes, one electrode each from *p*-region and *n*-region hence called diode (Di + electrode).

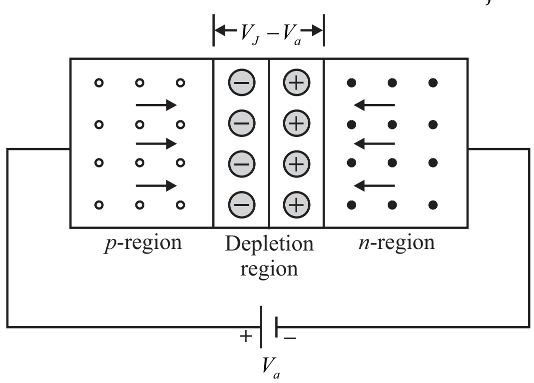


In the symbol of a diode, an arrowhead indicates the conventional current direction when it is forward biased. A diode allows current to flow in only one direction.

Operation :

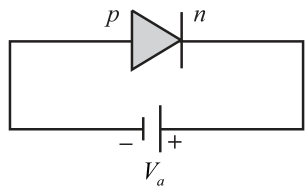
Forward bias :

1. A *p-n* junction is forward bias when a voltage is applied positive to the *p*-side and negative to the *n*-side.
2. When a diode is connected in a forward bias, the negative terminal of the battery pushes the free electrons in *n*-region towards the junction. Similarly the holes from *p*-region are repelled by the positive terminal of the battery and move towards the junction.
3. A forward biased junction has a narrow depletion region.
4. The forward bias applied voltage V_a , reduces the barrier potential across the junction from its original value V_J to $(V_J - V_a)$.
5. The electric field reduces.
6. The immobile ions in depletion region reduces.
7. A majority charge carrier current flows across a forward bias junction.

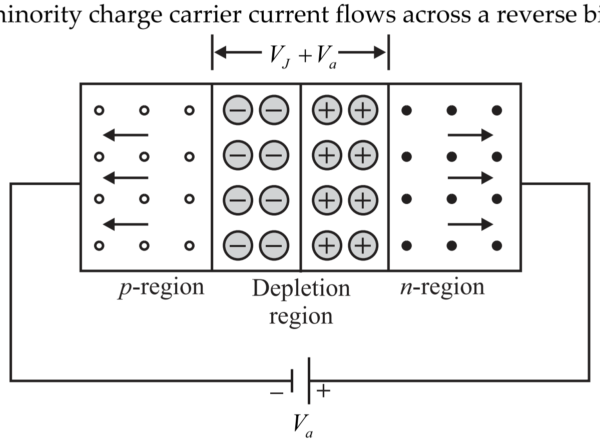


Reverse bias :

1. A *p-n* junction is reverse bias when a voltage is applied positive to the *n*-side and negative to the *p*-side.



2. When a diode is connected in a reverse bias, the negative terminal of the battery attracts the holes in *p*-region away from the junction. Similarly the electrons from *n*-region are attracted by the positive terminal of the battery and move away from the junction.
3. A reverse biased junction has a wide depletion region.
4. The reverse bias applied voltage V_a , increases the barrier potential across the junction from its original value V_J to $(V_J + V_a)$.
5. The electric field increases.
6. The immobile ions in depletion region increases.
7. A very small minority charge carrier current flows across a reverse bias junction.

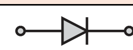
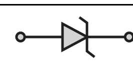
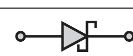


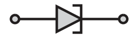
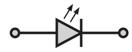
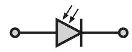
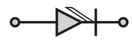
Application :

1. Rectifiers which are further classified as half wave, full wave and bridge rectifiers.
2. Clipper circuits to remove unwanted portions of waveform.
3. Clamper circuits to add DC level to waveform.
4. Voltage multipliers such as voltage doubler, voltage tripler etc.
5. Various electronic and operational amplifier circuits such as voltage to current converters, log and antilog amplifiers, precision rectifiers, protection circuits etc.

Q.1 (b) What are the types of diode? List them and draw their symbol.

Ans. Types of diode and their symbol :

Name	Symbol
General purpose diode	
Zener diode	
Schottky diode	
Varactor/varicap diode	

Tunnel diode	
Light emitting diode (LED)	
Photodiode	
Pin diode	

Q.2 **(a)** Determine the decimal numbers represented by following binary numbers :

(i) 110101 (ii) 101101

(iii) 11111111 (iv) 00000000

Ans. (i) 110101

$(110101)_2 = (\ )_{10}$

$$N = 1\times 2^5 + 1\times 2^4 + 0\times 2^3 + 1\times 2^2 + 0\times 2^1 + 1\times 2^0$$
$$N = 32 + 16 + 0 + 4 + 0 + 1$$
$$N = 53$$

$\therefore \quad (110101)_2 = (53)_{10}$ **Ans.**

(ii) 101101

$(101101)_2 = (\ )_{10}$

$$N = 1\times 2^5 + 0\times 2^4 + 1\times 2^3 + 1\times 2^2 + 0\times 2^1 + 1\times 2^0$$
$$N = 32 + 0 + 8 + 4 + 0 + 1$$
$$N = 45$$

$\therefore \quad (101101)_2 = (45)_{10}$ **Ans.**

(iii) 11111111

$(11111111)_2 = (\ )_{10}$

$$N = 1\times 2^7 + 1\times 2^6 + 1\times 2^5 + 1\times 2^4 + 1\times 2^3 + 1\times 2^2 + 1\times 2^1 + 1\times 2^0$$
$$N = 255$$

$\therefore \quad (11111111)_2 = (255)_{10}$ **Ans.**

(iv) 00000000

$(00000000)_2 = (\ )_{10}$

$$N = 0\times 2^7 + 0\times 2^6 + 0\times 2^5 + 0\times 2^4 + 0\times 2^3 + 0\times 2^2 + 0\times 2^1 + 0\times 2^0$$
$$N = 0$$

$\therefore \quad (00000000)_2 = (0)_{10}$ **Ans.**

Q.2 **(b)** Perform the following :

(i) Addition (?) $= 1011 + 1101$

(ii) Subtraction (?) $= 1011 - 0110$

Ans. (i) Addition (?) $= 1011 + 1101$

$1011 + 1101$

$$\begin{array}{r} 1011 \\ +1101 \\ \hline 11000 \end{array}$$

$\therefore \quad 1011 + 1101 = 11000$ **Ans.**

(ii) Subtraction (?) $= 1011 - 0110$

$1011 - 0110$

$$\begin{array}{r} 1011 \\ -\ 0110 \\ \hline 0101 \end{array}$$

$\therefore \quad 1011 - 0110 = 0101$ **Ans.**

Q.3 (a) Describe the OR, AND, NAND gate with the help of truth table.

Ans. **AND gate :** A logic circuit whose output is HIGH only when all inputs are HIGH.

Symbol of AND gate :

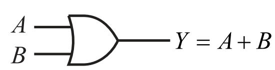
Truth table of AND gate :

Inputs		Output
A	B	$Y = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

Output is 1 when all inputs are 1

OR gate : A logic circuit whose output is HIGH when atleast one input is HIGH.

Symbol of OR gate :



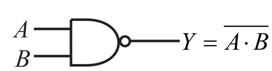
Truth table of OR gate :

Inputs		Output
A	B	$Y = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

Output is 0 when all inputs are 0

NAND gate : A logic circuit whose output is LOW when all inputs are HIGH.

Symbol of 2 input NAND gate :



Truth table :

Inputs		Output
A	B	$Y = \overline{A \cdot B}$
0	0	1
0	1	1
1	0	1
1	1	0

Output is 0 when all inputs are 1

Q.3 (b) Given the logical equation $Y = (A + BC)(B + \bar{C}A)$. Design a circuit using gates to realize this function.

Ans. Given Boolean function is,

$$Y = (A + BC)(B + \bar{C}A)$$

$$Y = AB + \bar{C}A \cdot A + B \cdot BC + BC \cdot \bar{C}A$$

$$Y = AB + A\bar{C} + BC \qquad [\text{AND law : } X \cdot X = X \text{ and } X \cdot X = 0]$$

$$Y = B + \bar{C}A + AB$$

$$Y = CB(A + \bar{A}) + \bar{C}A(B + \bar{B}) + AB(C + \bar{C}) \qquad [\text{OR law : } X + \bar{X} = 1]$$

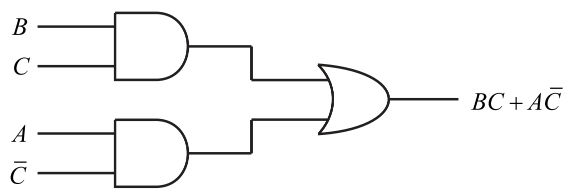
$$Y = ABC + \bar{A}BC + AB\bar{C} + A\bar{B}\bar{C} + ABC + AB\bar{C}$$

$$Y = ABC + \bar{A}BC + AB\bar{C} + A\bar{B}\bar{C}$$

$$Y = BC(A + \bar{A}) + A\bar{C}(B + \bar{B}) \qquad [\text{OR law : } X + \bar{X} = 1]$$

$$Y = BC + A\bar{C}$$

Logic diagram :



Q.4 (a) Define analog and digital communications. Draw the basic block diagram of transmitter and receivers.

Ans. **Analog communication :** Analog communication is that types of communication in which the transmitted message or information signal is analog in nature. This means that in analog communication the modulating signal i.e. base-band signal is an analog signal. This analog message signal may be obtained from sources such as speech, video shooting etc.

Digital communication : In digital communication, the message signal to be transmitted is digital in nature. This means that digital communication involves the transmission of information in digital form. The immunity to channel noise and external interference is better than analog communication.

Block diagram of transmitter and receiver :

1. **Radio transmitter :** A radio transmitter consists of several elements that work together to generate radio waves that contain useful information such as audio, video, or digital data.
   - (i) **Power supply :** It provides the necessary electrical power to operate the transmitter.
   - (ii) **Oscillator :** It creates alternating current at the frequency on which the transmitter will transmit. The oscillator usually generates a sine wave, which is referred to as a carrier wave.
   - (iii) **Modulator :** It adds useful information to the carrier wave. There are two main ways to add this information. The first, called amplitude modulation or AM, makes slight increases or decreases to the amplitude of the carrier wave. The second, called frequency modulation or FM, makes slight increases or decreases the frequency of the carrier wave.
   - (iv) **Amplifier :** It amplifies the modulated carrier wave to increase its power. The more powerful the amplifier, the more powerful the broadcast.
   - (v) **Antenna :** It converts the amplified signal to radio waves.

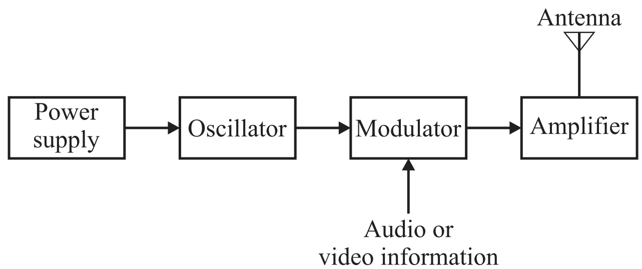


Fig.1 Block diagram of transmitter

2. **Radio receiver :** A radio receiver is the opposite of a radio transmitter. It uses an antenna to capture radio waves, processes those waves to extract only those waves that are vibrating at the desired frequency, extracts the audio signals that were added to those waves, amplifies the signals.
   (i) **Antenna :** It captures the radio waves. Typically, the antenna is simply a length of wire. When this wire is exposed to radio waves, the waves induce a very small alternating current in the antenna.
   (ii) **RF amplifier :** A sensitive amplifier that amplifies the very weak radio frequency (RF) signal from the antenna so that the signal can be processed by the tuner.
   (iii) **Tuner :** A circuit that can extract signals of a particular frequency from a mix of signals of different frequencies. On its own, the antenna captures radio waves of all frequencies and sends them to the RF amplifier, which dutifully amplifies them all.
   (iv) **Detector :** It is responsible for separating the audio information from the carrier wave. For AM signals, this can be done with a diode that just rectifies the alternating current signal.
   (v) **Audio amplifier :** This component's task is to amplify the weak signal that comes from the detector so that it can be heard. This can be done using a simple transistor amplifier circuit.

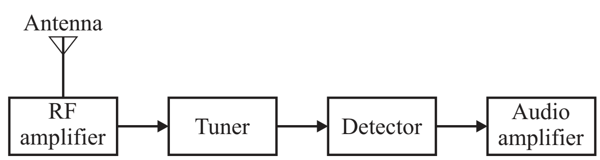


Fig.2 Block diagram of receiver

Q.4	**(b)**	Draw the various RF bands of IEEE spectrum and write their applications.

Ans. In wireless communication, electromagnetic waves are used as a media for transfer of information. Thus in such a communication, the information signal is converted into the electromagnetic signal before transmission. The electromagnetic (EM) waves consist of both electric and magnetic fields and they can travel a long distance through space. The range of all possible frequencies of EM waves is called the electromagnetic spectrum, shown in the figure below. It extends from the frequencies used for modern radio (at the long wavelength end) to gamma radiation (at the short wavelength end). In the mid-range includes most commonly used radio frequencies for two way communications, television and other applications.

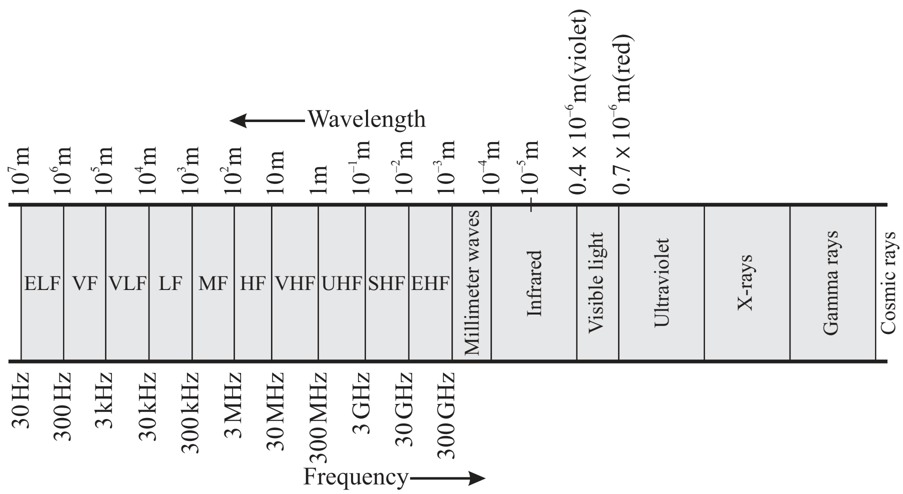


Fig. Electromagnetic spectrum

The table below shows the radio frequency spectrum and its application according to various frequency bands.

Frequency band	Frequency	Wavelength	Applications
Extremely low frequency (ELF)	30-300 Hz	10^4 km-10^3 km	Communication with submarines
Voice frequency (VF)	300-3000 Hz	10^3 km-100 km	Audio application
Very low frequency (VLF)	3-30 kHz	100 km-10 km	Submarine communication, avalanche beacons, wireless heart rate monitors, geophysics
Low frequency (LF)	30-300 kHz	10 km-1 km	Navigation, time signals, AM long-wave broadcasting
Medium frequency (MF)	300-3000 kHz	1 km-100 m	AM (Medium wave) broadcasts
High frequency (HF)	3-30 MHz	100 m-10 m	Shortwave broadcasts, amateur radio and over the horizon aviation communications
Very high frequency (VHF)	30-300 MHz	10 m-1 m	FM, television broadcasts and line of sight ground to aircraft and aircraft to aircraft communications
Ultra high frequency (UHF)	300-3000 MHz	1 m-100 mm	Television broadcasts, mobile phones, wireless LAN, bluetooth and two way radio such as FRS and GMRS radios
Super high frequency (SHF)	3-30 GHz	100 mm-10 mm	Microwave device, wireless LAN, most modern radars
Extremely high frequency (EHF)	30-300 GHz	10 mm-1 mm	Radio astronomy, high speed microwave radio relay

Q.5 (a) How 'NOT' operation can be performed using transistor? Describe.

Ans. When input $X = 0$, the base of the transistor is low (0) and therefore transistor operates in cut-off region $I_C = 0$. Hence no voltage drop across R_C and output Y is V_{CC} (HIGH).

When input $X = 1$, the base of the transistor is high (1) and therefore transistor operates in saturation region. In the saturation region $V_{CE} \approx 0.2$ V. Hence output voltage 0.2 V, i.e. logic 0 (Low).

Thus for the circuit shown in figure output is complement of input and we can say that it represents NOT gate.

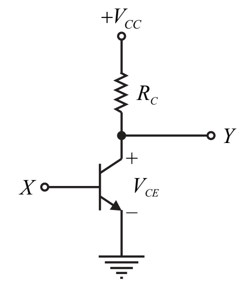


Fig. NOT gate using transistor

Q.5 (b) Describe various Boolean identities. Draw the 'AND' circuit using diode logics.

Ans. Laws of Boolean algebra are used for simplifying a complex Boolean expression. The different Boolean laws are discussed as follows :

1. OR law : The following theorems implement the OR law :

(i) Out of two variables to be ORed, if any one variable is low (0), then the output value is the other variable i.e.

$$A + 0 = A$$

(ii) Out of two variables to be ORed, if any one variable is high (1), then the output value is high i.e.

$$A + 1 = 1$$

(iii) If both variables to be ORed have the same value, then the output value is of one input variable i.e.

$$A + A = A$$

(iv) Out of two variables to be ORed, if any one variable is the complement of the other, then the output value is high i.e.

$$A + \overline{A} = 1$$

2. AND law : The following theorems implement the AND law :

(i) Out of two variables to be ANDded, if any one variable is low (0), then the output value is zero i.e.

$$A \cdot 0 = 0$$

(ii) Out of two variables to be ANDed, if any one variable is high (1), then the output value is other variable i.e.

$$A \cdot 1 = A$$

(iii) If both variables to be ANDed have the same value, then the output value is also the same of one of the variable i.e.

$$A \cdot A = A$$

(iv) Out of two variables to be ANDed, if any one variable is the complement of the other, then the output value is zero i.e.

$$A \cdot \overline{A} = 0$$

3. Commutative law : It states that changing the sequence of the variables to perform logic operation does not change the output, which means that change of variable sequence is allowed i.e.

$$A + B = B + A$$

$$A \cdot B = B \cdot A$$

4. **Associative law :** It states that changing the order of logic operations does not change the output, which means that changing the order of logic operations is allowed i.e.

$$A+(B+C)=(A+B)+C$$

$$A\cdot(B\cdot C)=(A\cdot B)\cdot C$$

5. **Distributive law :** It states that ANDing the result of several ORed variables with a single variable is the same as ANDing result with a individual variable with each of the multiple variables, and its product is an ORed variable i.e.

$$A\cdot(B+C)=A\cdot B+A\cdot C$$

$$A+(B\cdot C)=(A+B)\cdot(A+C)$$

$$A+(\overline{A}\cdot B)=(A+\overline{A})\cdot(A+B)=1\cdot(A+B)=A+B$$

$$\therefore \quad A+(\overline{A}\cdot B)=A+B$$

6. **Complementation law :** It states that the complement of 0 is 1, of 1 is 0, and of A is $\overline{A}$ i.e.

$$\overline{0}=1$$

$$\overline{1}=0$$

$$\overline{A}=A$$

$$A\cdot\overline{A}=0$$

$$A+\overline{A}=1$$

7. **Absorption law :** It states the following properties :

$$A+AB=A$$

$$A(A+B)=A$$

8. **Idempotency law :** It states the following properties :

$$A+A=A$$

$$A\cdot A=A$$

9. **Inversion law :** It states that if a variable is subjected to a double inversion than it will result in the original variable itself i.e.

$$\overline{\overline{A}}=A$$

AND gate circuit using diode :

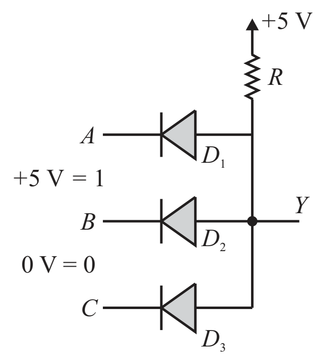


Fig.1 Diode AND gate circuit using positive logic

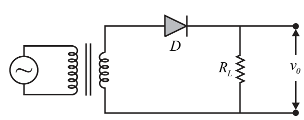
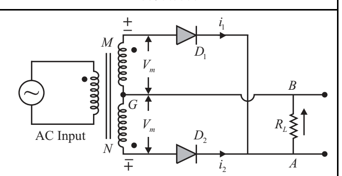
In Fig.1 for positive logic, if any of the three inputs is at 0 V (logic - 0), the corresponding diode becomes forward biased or conducting showing zero resistance and hence the voltage at Y becomes zero. If all the inputs A, B and C are at +5 V (logic-1), the diodes are in reversed bias, hence no diode conducts and the voltage at Y will be +V (logic-1) This is described with the help of the truth table shown in Fig.2.

A	B	C	Y
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Fig.2 Truth table for AND gate

Q.6 (a) Compare half wave rectifier with full wave rectifier with neat sketch.

Ans.

S. No.	Particulars	HWR	FWR
1.	Number of diodes	1	2
2.	DC current	I_m / π	$2I_m / \pi$
3.	DC voltage	V_m / π	$2V_m / \pi$
4.	RMS current	$I_m / 2$	$I_m / \sqrt{2}$
5.	Ripple factor	1.21	0.48
6.	Maximum efficiency	40.6%	81.2%
7.	TUF	0.287	0.693
8.	PIV	V_m	$2V_m$
9.	Output frequency	f	2f
10.	Form factor	1.57	1.11
11.	Peak factor	2	1.414
12.	Figure		

Q.6 (b) What is signal? Define. Amplitude is important variable parameters of signal. What kind of operations can be performed with amplitude? Describe.

Ans. **Signal** is a function which conveys some information. A signal is defined as a physical quantity that varies with time, space or any other independent variable.

Example :

(i) Electric voltage or current, such as radio signal, TV signal, telephone signal, computer signal etc.

(i) Pressure signal, sound signal etc. are non-electric signals.

Mathematically, a signal is represented as a function of an independent variable t. Usually, t represent time. Thus, a signal is denoted by $x(t)$.

Classification of signals :

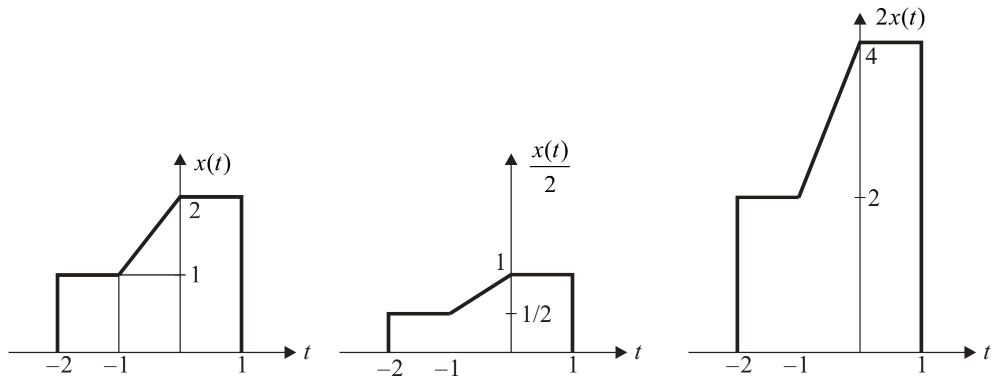
1. Continuous and discrete time signals
2. Analog and digital signals
3. Deterministic and random signals
4. Even and odd signals
5. Periodic and non-periodic signals
6. Energy and power signals

Amplitude scaling :

Consider a signal $x(t)$ is provided and we have to scale or multiply it by factor A, where A can be any value.

$0 < A < 1$, the amplitude compress by a factor A.

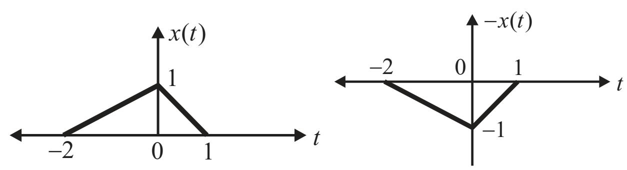
$A > 1$, then the amplitude is stretched by factor A.



Amplitude inversion : $x(t) \rightarrow -x(t)$

Example : Consider a signal $x(t)$.

For $x(t)$	
Time	**Amplitude**
$t = -2$	$x(t) = 0$
$t = 0$	$x(t) = 1$
$t = 1$	$x(t) = 0$



For $-x(t)$, multiply amplitude with -1.

Q.7 (a) Describe different analog and digital signal in detail.

Ans. Analog signal :

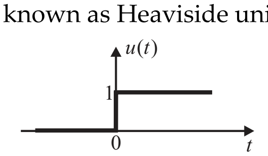
(i) Unit step signal :

Unit step signal is defined as, $u(t) = \begin{cases} 1 & \text{for} \quad t > 0 \\ 0.5 & \text{for} \quad t = 0 \\ 0 & \text{for} \quad t < 0 \end{cases}$

The unit step signal is discontinuous at $t = 0$ and at $t = 0$ its value is undefined. So,

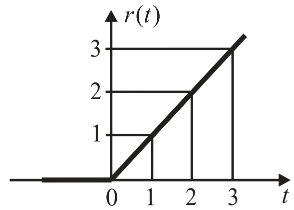
$$u(0) = \frac{u(0^+) + u(0^-)}{2} = \frac{1+0}{2}$$

The unit step function is also known as Heaviside unit function.



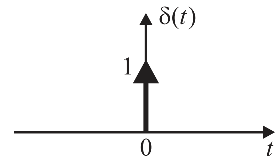
(ii) Unit ramp signal :

Unit ramp signal is defined as, $r(t) = \begin{cases} t & \text{for} \quad t \geq 0 \\ 0 & \text{for} \quad t < 0 \end{cases}$



(iii) Unit impulse signal :

The impulse signal is a signal with infinite magnitude and zero duration, but with unit area. The unit impulse function is also known as the Dirac delta function.



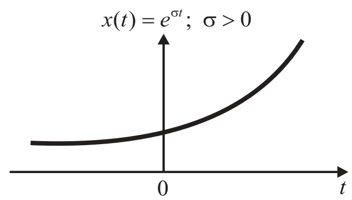
Mathematically, $\delta(t) = \begin{cases} \infty & \text{at} \quad t = 0 \\ 0 & \text{at} \quad t \neq 0 \end{cases}$ and $\int_{-\infty}^{\infty} \delta(t) dt = 1$

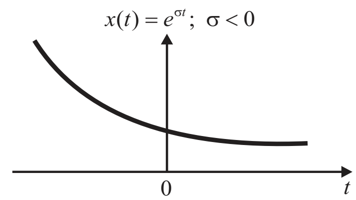
(iv) Exponential signal :

Exponential signals are of two types :

(a) Real exponential signal : $x(t) = e^{\sigma t}$

If $\sigma > 0$, then $x(t)$ is a growing exponential, and if $\sigma < 0$, then $x(t)$ is a decaying exponential.





(b) Complex exponential signal : $x(t) = e^{j\omega t} = \cos \omega t + j \sin \omega t$

The signal $x(t)$ is known as complex exponential signal whose real part is $\cos \omega t$ and imaginary part is $\sin \omega t$. It is periodic with time period $T = 2\pi / \omega$.

The general complex exponential signal is,

$$x(t) = Ae^{st} = Ae^{(\sigma + j\omega)t} = Ae^{\sigma t} (\cos \omega t + j \sin \omega t)$$

where real part $= Ae^{\sigma t} \cos \omega t$ and imaginary part $= Ae^{\sigma t} \sin \omega t$

The real part of complex frequency variable is called attenuation or growth constant. It denotes by how much amount amplitude of the signal is increased or decreased.

The imaginary part of a complex frequency variable is called angular frequency with a usual meaning.

With $\omega = 0$ and $\sigma = 0, x(t) = A$ i.e. constant amplitude signal.

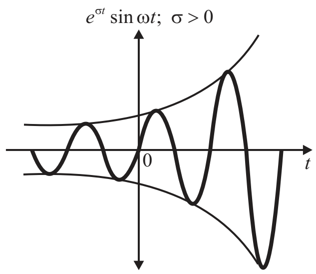
With $\omega = 0$ and $s = \sigma$ and $\sigma > 0,\ x(t) = Ae^{\sigma t}$ i.e. exponentially growing signal.

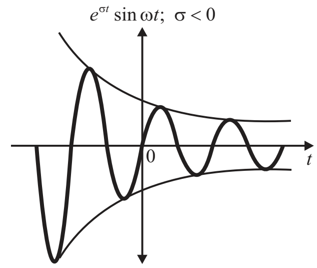
With $\omega = 0$ and $s = \sigma$ and $\sigma < 0,\ x(t) = Ae^{\sigma t}$ i.e. exponentially decaying signal.

With $s = +j\omega, x(t) = Ae^{j\omega t}$, i.e. purely sinusoidal signal with sustained oscillations.

With $s = \sigma \pm j\omega$ and $\sigma < 0$, we get sinusoidal signal with decaying oscillations.

With $s = \sigma \pm j\omega$ and $\sigma > 0$, we get sinusoidal signal with growing oscillations.





Digital signal :

(i) Unit step sequence :

Unit step sequence is mathematically defined as,

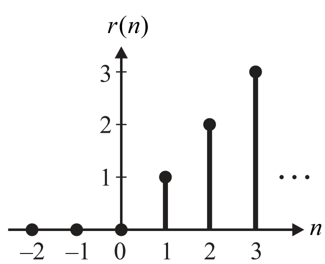
$$u(n) = \begin{cases} 1 & \text{for} \quad n \geq 0 \\ 0 & \text{for} \quad n < 0 \end{cases}$$

The value of $u(n)$ at $n = 0$ is defined and equals unity.

(ii) Unit ramp sequence :

Unit ramp sequence is defined as,

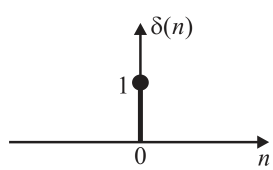
$$r(n) = \begin{cases} n & \text{for} \quad n \geq 0 \\ 0 & \text{for} \quad n < 0 \end{cases}$$



(iii) Unit sample sequence :

Unit sample sequence is defined as,

$$\delta(n) = \begin{cases} 1 & \text{at} \quad n = 0 \\ 0 & \text{at} \quad n \neq 0 \end{cases}$$



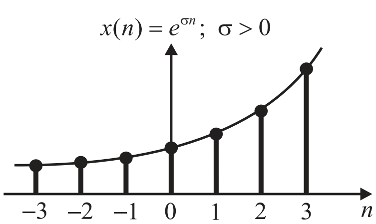
(iv) Exponential sequence :

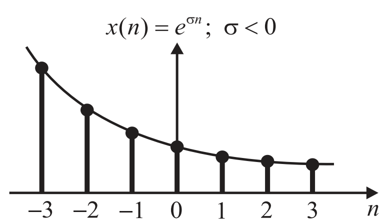
Exponential sequences are of two types :

(a) Real exponential sequence : $x(n) = e^{\sigma n}$

If $\sigma > 0$, then $x(n)$ is a growing exponential.

If $\sigma < 0$, then $x(n)$ is a decaying exponential.





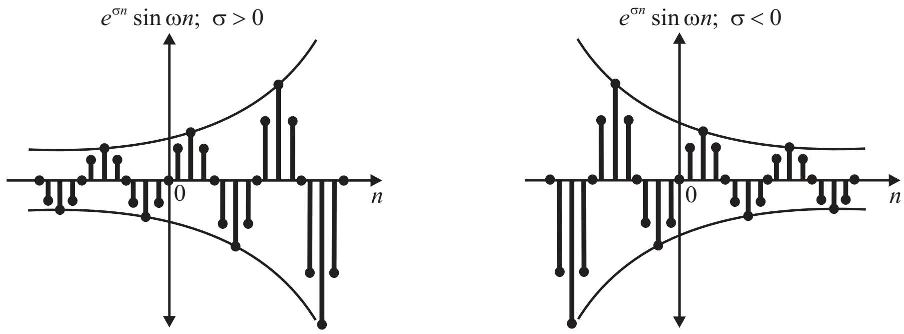
(b) Complex exponential sequence : $x(n) = e^{j\omega n} = \cos\omega n + j\sin\omega n$

The signal $x(n)$ is known as complex exponential signal whose real part is $\cos\omega n$ and imaginary part is $\sin\omega n$.

The general complex exponential signal is,

$$x(n) = e^{sn} = e^{(\sigma + j\omega)n} = e^{\sigma n}(\cos\omega n + j\sin\omega n)$$

whose real part $e^{\sigma n}\cos\omega n$ and imaginary part $e^{\sigma n}\sin\omega n$ are exponentially increasing if $\sigma > 0$ and exponentially decreasing if $\sigma < 0$.

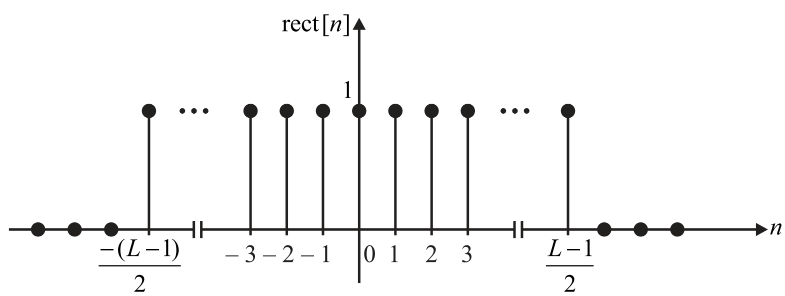


(v) Rectangular pulse sequence :

Let L be a positive odd integer. An important example of a discrete time signal is the discrete time rectangular pulse function $\text{rect}[n]$ of length L defined by,

$$\text{rect}[n] = \begin{cases} 1, & n = -(L-1)/2, \ldots\ldots, -1, 0, 1, \ldots\ldots (L-1)/2 \\ 0, & \text{all other } n \end{cases}$$

The discrete time rectangular pulse is shown in figure.



Q.8	**(b)**	How analog signal can be converted into a digital one? Describe.

Ans. Analog signal can be converted into digital signal by following procedure as shown in figure below.

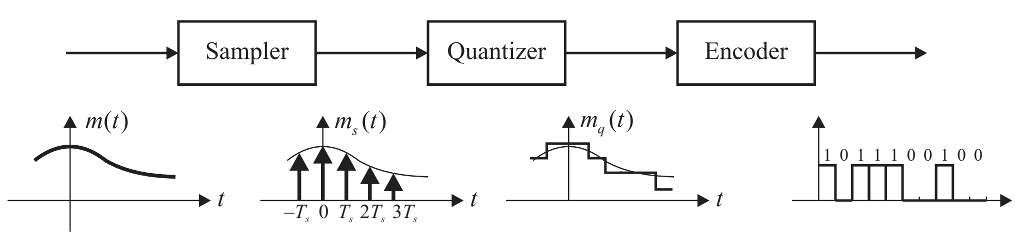


Fig. Block diagram of analog to digital converter

Sampler : It converts continuous amplitude continuous time signal into continuous amplitude discrete time signal.

Quantizer : It converts continuous amplitude discrete time signal into discrete amplitude discrete time signal. It approximates each sample into its nearest standard voltage level called quantization level. It is a process of rounding-off the signal.

Encoder : An encoder converts each quantized sample into distinct code word. Thus at the output of the encoder we get digital code words.

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