Vaibhav Singh
58, D9A

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Tutorial 1

Signals & Systems

Q. ①.

i. $x(t) = \cos\left(\left(\frac{\pi}{3}\right)t\right) + \sin\left(\frac{\pi t}{4}\right)$

Soln. $x_1(t) = \cos\left(\frac{\pi}{3}t\right)$, $2\pi f_0 = \frac{\pi}{3}$, $f_{0_1} = \frac{1}{6}$ $T_1 = 6$

$x_2(t) = \sin\left(\frac{\pi t}{4}\right)$, $2\pi f_0 = \frac{\pi}{4}$, $f_{0_2} = \frac{1}{8}$, $T_2 = 8$

$\frac{T_1}{T_2} = \frac{6}{8} = \frac{3}{4}$ rational number.

as $x_1(t)$ and $x_2(t)$ are periodic
$\Rightarrow$ $x(t)$ is periodic

$T = \text{LCM}(6, 8) = 24$ $\therefore$ $\boxed{T = 24 \text{ samples}}$

ii ② $x[n] = \cos^2\left[\frac{\pi n}{8}\right]$

Method.1 $x[n] = \frac{1}{2} + \cos\left[\frac{\pi n}{4}\right]/2$ — ($\because \cos^2\theta = \frac{1+\cos 2\theta}{2}$)

Standard form $x[n] = B + A\cos 2\pi f_0 n$

$2\pi f_0 = \frac{\pi}{4}$ $f_0 = \frac{1}{8}$

$\boxed{T = 8 \text{ samples}}$ As $x[n]$ is a cosinosoidal signal
$\therefore$ $x[n]$ is periodic.

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Method 2 $x[n] = \cos^2\left(\frac{\pi n}{8}\right)$

$x[n] = 1 + \cos\left[\frac{\pi n}{4}\right] / 2$ —— $\left(\because \cos^2\theta = \frac{1+\cos 2\theta}{2}\right)$

Let M and N be integers.

$$x[n+N] = \frac{1 + \cos\left[\frac{\pi}{4}(n+N)\right]}{2}$$

$$= \frac{1 + \cos\left(\frac{n\pi}{4} + \frac{N\pi}{4}\right)}{2}$$

Since, $\cos(\theta + 2\pi M) = \cos\theta$

$\therefore$ for periodicity $\frac{N\pi}{4} = 2\pi M$, integral multiple of 2π.

$\therefore N = 8M$

Let $M = 1$; $N = 8$

$$x[n+N] = 1 + \cos\left[\frac{n\pi}{4} + 2\pi M\right] / 2$$

$$= 1 + \cos\left[\frac{n\pi}{4}\right] / 2$$

$$\therefore x[n+N] = \cos^2\left[\frac{n\pi}{8}\right]$$

As $x[n] = x[n+N]$ $\longrightarrow$ $x[n]$ is periodic

$\boxed{N = T = 8 \text{ samples}}$ $\rightarrow$ Fundamental Period.

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3. $x[n] = \sin\left[\left(\frac{6\pi}{7}\right)n + 1\right]$

Method.1 $\because \sin(A+B) = \sin A \cdot \cos B + \cos A \sin B$

$x[n] = \sin\left[\left(\frac{6\pi}{7}\right)n\right] \cdot \cos(1) + \cos\left[\left(\frac{6\pi}{7}\right)n\right] \cdot \sin(1)$

$x[n] = \sin\left[\left(\frac{6\pi}{7}\right)n\right]$

$x[n]$ is sinusoidal

$\therefore$ it is periodic.

comparing with standard form,

$x[n] = A\sin[2\pi f_0 n]$

$2\pi f_0 = \frac{6\pi}{7}$, $f_0 = \frac{3}{7}$ cycles per samples

$f_0 = \frac{M}{N}$, M is an integer.

N = fundamental period $\therefore$ $\boxed{N = 7 \text{ samples}}$

Method 2 $x[n+N] = \sin\left[\frac{6\pi}{7}[n+N] + 1\right]$

$= \sin\left[\frac{6\pi n}{7} + 1 + \frac{6\pi N}{7}\right]$

$\because \sin(\theta + 2\pi M) = \sin\theta$

$\therefore$ for periodicity $\frac{6\pi N}{7}$ = integral multiple of 2π

$\therefore \frac{6\pi N}{7} = 2\pi M$, M, N are integers.

Here N → integer, if $M = 3, 6, 9, 12 \ldots$

let $M = 3$, $\therefore N = 7$.
where $N = 7$ samples,

$$\therefore x[n+N] = \sin\left[\frac{6\pi n}{7} + 1 + \frac{6\pi}{7} \times 7\right]$$

$$= \sin\left[\frac{6\pi n}{7} + 1 + 3(2\pi)\right]$$

$$x[n+N] = \sin\left[\frac{6\pi n}{7} + 1\right] = x[n] \quad \text{——} \because \sin(\theta + 2\pi M) = \sin\theta$$

As $x[n+N] = x[n]$

It is periodic with $\boxed{N = 7 \text{ samples}}$ as fundamental period.

4. $x(t) = \sin\left(\frac{2\pi t}{6}\right) - \cos(\pi t)$

let $x_1(t) = \sin\left(\frac{2\pi t}{6}\right)$, $x_2 = \cos(\pi t)$

Standard form: $A\sin(2\pi f_0 t)$
comparing with $x_1(t)$, we get

$$2\pi f_{0_1} = \pi/3$$

$$f_{0_1} = \frac{1}{6}, \quad T = \frac{1}{f_0} = 6.$$

Standard form: $A\cos(2\pi f_0 t)$, comparing with $x_2(t)$

$$2\pi f_{0_2} = \pi, \quad f_{0_2} = \frac{1}{2}, \quad T = 2$$

$\therefore T_1/T_2 = 6/2 = 3.$ Since $x_1(t)$ and $x_2(t)$ are both periodic and ratio is rational

$\Rightarrow x(t)$ is periodic

$LCM(6, 2) = \boxed{6 \text{ samples} = T} \rightarrow$ fundamental period.

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Q.②

1. $x(t) = 0.9e^{-3t} . u(t)$

it is an exponential aperiodic signal

$\therefore$ Energy signal.

$x(t) = 0.9e^{-3t} . u(t)$; for all t

$x(t) = 0.9e^{-3t}$; for $t \geq 0$

$$\therefore \int_{-T}^{T} |x(t)|^2 . dt = \int_{0}^{T} |0.9e^{-3t}|^2 . dt$$

$$= (0.9)^2 \int_0^T e^{-6t} . dt$$

$$= 0.81 \left[\frac{e^{-6t}}{-6}\right]_0^T$$

$$= \frac{0.81}{6} [e^{-6T} - 1]$$

$$E = \text{Energy} = \lim_{T\to\infty} \int_{-T}^{T} |x(t)|^2 . dt = \lim_{T\to\infty} \frac{0.81}{6} [e^{-6T} - 1]$$

$$= \frac{0.81}{6} [e^{-\infty} - 1] = \frac{0.81}{6} (-1)$$

$\boxed{E = 0.135 \text{ J}}$ $\rightarrow$ Energy is constant

$\therefore$ power = 0

$$P = \text{Power} = \lim_{T\to\infty} \int_{-T}^{T} |x(t)|^2 . dt = \lim_{T\to\infty} \frac{1}{2T} \times \frac{0.81}{-6} [e^{-6T} - 1]$$

$$= \frac{1}{2\infty} \times \frac{0.81}{6} \times [e^{-\infty} - 1] = \boxed{0 = P}$$

$\therefore$ $x(t)$ is an energy signal

As $x(t)$ is aperiodic signal with constant energy of 0.135J.

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2. $x[n] = u[n]$

$x[n]$ is a discrete signal.

$u[n]$ = unit step signal $= 1 ;\ n \geq 0$

$= 0 ;\ n < 0$

$\therefore$ range $= 0$ to ∞

$$\text{Energy} = E = \sum_{n=-\infty}^{n=\infty} |x[n]|^2 = \sum_{n=0}^{n=\infty} u[n] = 1+1+1+1+1 \ldots \infty$$

$$\boxed{E = \infty} \rightarrow \text{infinite energy}$$

$$\text{Power} = P = \underset{N\to\infty}{Lt} \frac{1}{2N+1} \sum_{n=-N}^{N} |x[n]|^2$$

$$= \underset{N\to\infty}{Lt} \left[\frac{1}{2N+1} \sum_{n=0}^{\infty} u[n] \right.$$

$$= \underset{N\to\infty}{Lt} \frac{1}{2N+1} \left[\underbrace{1+ +1+1+ \ldots +1}_{N+1 \text{ terms}} \right]$$

$$= \underset{N\to\infty}{Lt} \frac{1}{2N+1} (N+1)$$

$$= \underset{N\to\infty}{Lt} \frac{N\left(1+\frac{1}{N}\right)}{N\left(2+\frac{1}{N}\right)} = \frac{1+\frac{1}{\infty}}{2+\frac{1}{\infty}} = \frac{1+0}{2+0}$$

$$\boxed{P = \frac{1}{2} \text{ Watts}} \rightarrow \text{Finite power}$$

$\because$ E is infinte and P is finite

$x[n]$ is a power signal.

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3. $x[n] = \left(\frac{1}{6}\right)^n u[n]$

$x[n]$ is a discrete signal
$u[n]$ is a unit step signal

$$x[n] = \left(\frac{1}{6}\right)^n u[n] = (0.166)^n u[n] \text{ ; for all } n$$
$$= (0.166)^n \text{ ; for } n \geq 0$$

Range = 0 to ∞

$$\text{Energy} = E = \sum_{n=-\infty}^{\infty} |x[n]|^2 = \sum_{n=0}^{\infty} (0.166)^{2n}$$
$$= \sum_{n=0}^{\infty} (0.0275)^n \quad \text{———} \left(\because \sum_{n=0}^{\infty} (A^n) = \frac{1}{1-A}\right)$$
$$= \frac{1}{1-0.0275}$$
$$\boxed{E = 1.0282 \text{ J}} \rightarrow \text{Finite Energy}$$

$$\text{Power} = P = \lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=-N}^{N} |x[n]|^2 = \lim_{N\to\infty} \cancel{\frac{1}{2N+1}}$$
$$= \lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=0}^{N} (0.166^{2n})$$
$$= \lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=0}^{\infty} (0.0275)^n$$
$$= \frac{1}{2\infty+1} \qquad \boxed{P = 0 \text{ Watts}} \rightarrow \text{zero Power}$$

Since E is finite and P is zero,
$\therefore$ $x[n]$ is an Energy signal.

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4. $x(t) = 3\cos(5\Omega_0 t)$

$x(t)$ is continuous signal.

$x(t) = 3\cos(5\Omega_0 t)$ $\quad \Omega_0 = 2\pi f_0$

Also cosinusoidal signal

⇒ periodic and power signal

Energy $= \infty$

$$\therefore \int_{-T}^{T} |x(t)|^2 dt = \int_{-T}^{T} |3\cos(5\Omega_0 t)|^2 dt$$

$$= 9\int_{-T}^{T} \cos^2(5\Omega_0 t).dt$$

$$= 9\int_{-T}^{T} \frac{1+\cos(10\Omega_0 t)}{2} dt$$

$$= 9\left[\int_{-T}^{T} \frac{1}{2} dt + \frac{1}{2}\cancel{\int_{-T}^{T} \cos 10\Omega_0 t . dt}^{\,0}\right]$$

$$= 9 \left.\frac{t}{2}\right]_{-T}^{T} = \frac{9}{2} \times 2T = \boxed{9T}.$$

$$\text{Energy} = E = \lim_{T\to\infty} \int_{-T}^{T} |x(t)|^2 . dt = \lim_{T\to\infty} 9T = \infty$$

$\boxed{E = 0}$

$$\text{Power} = P = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} |x(t)|^2 . dt = \lim_{T\to\infty} \frac{1}{2T} \times 9T = \lim_{T\to\infty} \frac{9}{2}$$

$\boxed{P = 4.5 \text{ Watts}}$

∵ E is infinite and P is constant

$x(t)$ is periodic and power signal.

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Q. 3.

(1). $x(t) = t^3 + 3t$

$x(-t) = -t^3 - 3t$

Even part : $x_e(t) = \frac{1}{2}[x(t) + x(-t)] = \frac{1}{2}[t^3 + 3t - t^3 - 3t]$

$\boxed{x_e(t) = 0}$

Odd part : $x_o(t) = \frac{1}{2}[x(t) - x(-t)] = \frac{1}{2}[t^3 + 3t + t^3 + 3t]$

$\boxed{x_o(t) = t^3 + 3t}$

$\therefore$ x(t) is an odd signal.

(2). $x[n] = \cos(n) + \sin(n) + \cos(n)\sin(n)$

$x[-n] = \cos(n) - \sin(n) - \sin(n).\cos(n)$

Folded Signal

Even part : $x_e[n] = \frac{1}{2}(x[n] + x[-n])$

$x_e[n] = \frac{1}{2}[2\cos(n)] = \boxed{\cos(n). = x_e[n]}$

Odd part : $x_o[n] = \frac{1}{2}(x[n] - x[-n])$

$\boxed{x_o[n] = \sin(n) + \cos(n).\sin(n)}$

3. $x(t) = \cos^2\left(\frac{\pi t}{2}\right)$

$x(t) = \frac{1}{2} + \frac{\cos(\pi t)}{2}$, ——— $\because \cos^2\theta = \frac{1+\cos 2\theta}{2}$

$x(-t) = \frac{1}{2} + \frac{\cos(-\pi t)}{2}$ ——— $\because \cos(-\theta) = \cos\theta$

$= \frac{1}{2} + \frac{\cos(\pi t)}{2}$

Even part: $\frac{1}{2}[x(t) + x(-t)]$

$$\boxed{x_e(t) = \frac{1}{2}[1 + \cos(\pi t)]}$$

Odd part: $\frac{1}{2}[x(t) - x(-t)] = \frac{1}{2}\left[\frac{1+\cos(\pi t)}{2} - \frac{1+\cos(\pi t)}{2}\right]$

$$\boxed{x_o(t) = 0}$$

4. $x[n] = u[n] - u[n-4]$

$u[n]$ = unit step signal $= 1 ; n \geq 0$
$\qquad 0 ; n < 0$

$u[n-4]$ = Delayed unit step $= 1 ; n \geq 4$
$\qquad 0 ; n < 4$

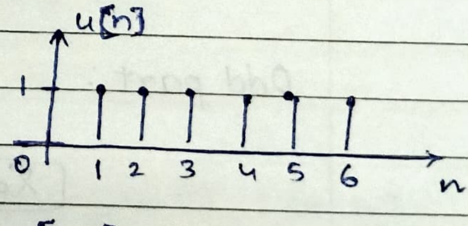
$x[n] = u[n] - u[n-4]$

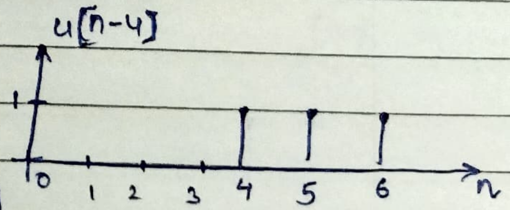
when $n=0$, $x[0] = 1 - 0 = 1$

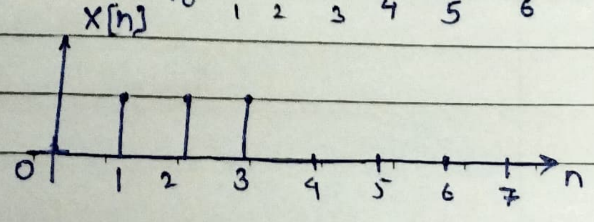
$n=1$, $x[1] = 1 - 0 = 1$

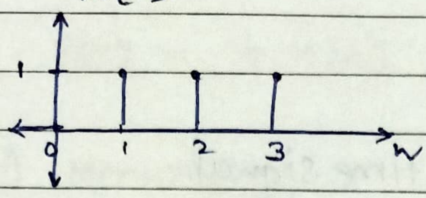
$n=2$, $x[2] = 1 - 0 = 1$

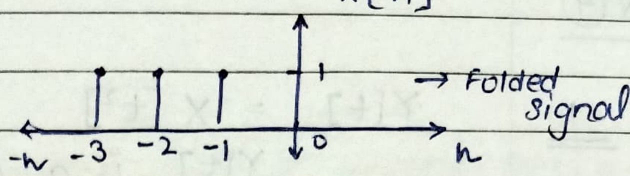
$n=5$ $x[5] = 1 - 1 = 0$ …… n









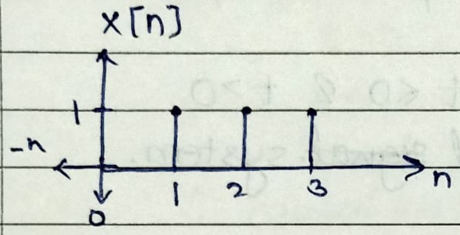


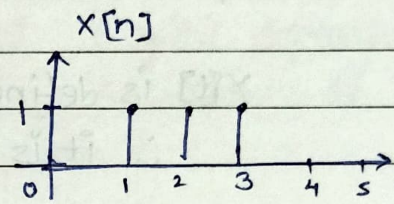
Even part $X_e[n]$

$= \frac{1}{2}\left[x[n] + x[-n]\right]$

Odd part $X_o[n]$

$= \frac{1}{2}\left[x[n] - x[-n]\right]$





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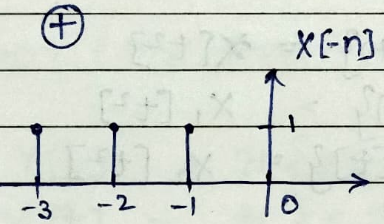

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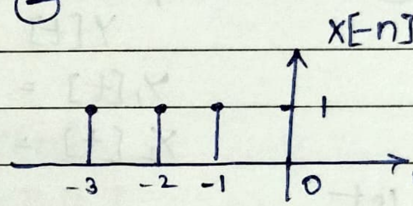
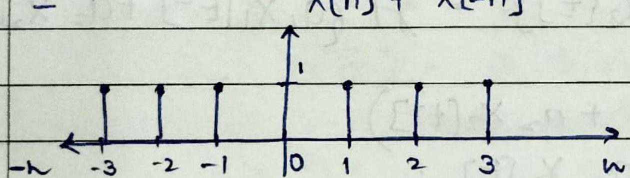
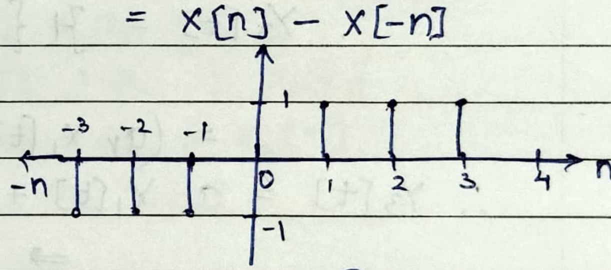


$= x[n] + x[-n]$



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



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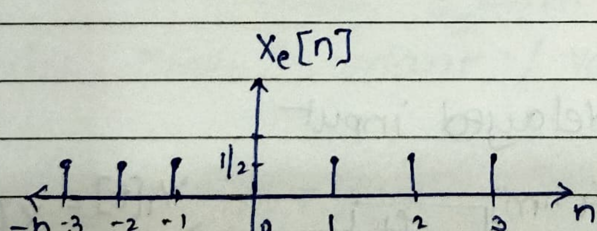
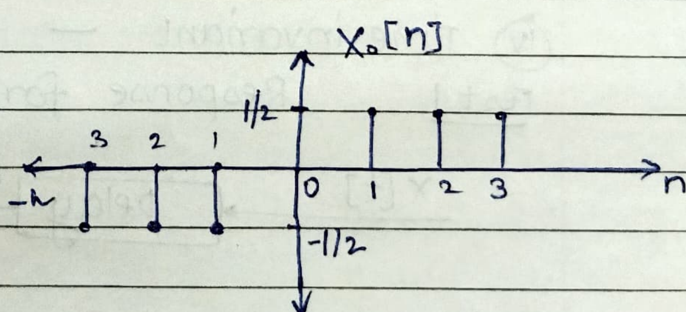


Even Part.



Odd Part.

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Q (4).

1. $Y[t] = x[t^2]$

$Y[t]$ is a continuous time signal.

(i) Memory less – ∵ $Y(t)$ depends on future values of input it is not memory less. system.

(ii). causal / non-causal – $Y[t]$ depends on future values of input.

$Y[t]$ is defined for both $t \leq 0$ & $t > 0$

∴ it is a non-causal ~~signal~~ system.

(iii). linear / Non-linear –

$$Y[t] = \mathcal{H}\{x(t)\} = x[t^2]$$
$$Y_1[t] = \mathcal{H}\{x_1[t]\} = x_1[t^2]$$
$$Y_2[t] = \mathcal{H}\{x_2[t]\} = x_2[t^2]$$

let

$$X_3[t] = a_1 X_1[t] + a_2 X_2[t]$$
$$\therefore Y_3[t] = \mathcal{H}\{x_3\{t]\} = \mathcal{H}\{a_1 x_1[t^2] + a_2 x_2[t^2]\}$$
$$= (a_1 x_1[t^2] + a_2 x_2[t^2])$$
$$\therefore Y_3[t] = a_1 Y_1[t] + a_2 Y_2[t].$$

⇒ $Y[t]$ is a linear system.

(iv) Time invariant –

Test 1 Response for delayed input

$$x[t] \rightarrow \boxed{\text{Delay}} \xrightarrow{x[t-m]} \boxed{\mathcal{H}} \rightarrow Y_1[t] = x(t^2 - m]^2$$

Test 2 Delayed Response

$$x(t) \rightarrow \boxed{\mathcal{H}} \xrightarrow{Y(t) = x[t^2]} \boxed{\text{Delay}} \rightarrow Y_2[t] = x[[t-m]^2]$$

Time invariant.

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2. $Y[t] = t\, x[t]$

(i) Memoryless — Since the system output depends only on the present values of input, it is a memoryless system.

(ii) Causal / Non-causal —

$t=0,\ y(0) = 0\, x[0]$
$t=1,\ Y[1) = x[1]$ $\Big\}$ $y[t]$ depends on present values of input

$\therefore$ causal system.

(iii). Linear / Non-linear —

$Y[t] = \mathcal{H}\{X[t]\} = t\, x[t]$
$Y_1[t] = \mathcal{H}\{x_1[t]\} = t x_1[t]$
$Y_2[t] = \mathcal{H}\{x_2[t]\} = t\, x_2[t]$
Let $\cancel{X_3}[t] = a_1 x_1[t] + a_2 x_2[t]$
$Y_3[t] = a_1 . t\, x_1[t] + a_2 .\ t\, x_2[t]$
$= a_1 . t\, x_1[t] + a_2 . t\, x_2[t]$
$Y_3[t] = a_1 Y_1[t] + a_2 Y_2[t]$

$\therefore$ linear system.

(iv). Time-invariant / Variant —
$Y[t] = t\, X[t]$

Test 1 Response for delayed input

$x[t] \rightarrow$ Delay $\xrightarrow{x[t-m]}$ $\mathcal{H}$ $\rightarrow$ $Y_1[t] = t\, X[t-m]$

Test 2 Delayed Response

$X[t] \rightarrow$ $\mathcal{H}$ $\xrightarrow{Y[t] = t X[t]}$ Delay $\rightarrow$ $Y_2[t] = 2(t-m)\, x[t-m]$

$\because Y_1[t] \neq Y_2[t]$ $\therefore$ Time Variant system

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3. $y(n) = a^n x(n)$

(i) Memoryless – $n=0,\ y(0) = a^0 x(0)$; $n=1,\ y(1) = a^1 x(1)$ } y(t) depends of present values of input

$\therefore$ it is memoryless.

(ii) causal / Non-causal –

$n=0,\ y(0) = a^0 x(0)$; $n=1,\ y(1) = a^1 x(1)$ } Depends on present values of input

$\therefore$ causal system.

(iii). Linear / Non-linear –

$y(n) = H\{x(n)\} = a^n . x(n)$

$y_1(n) = H\{x_1(n)\} = a^n x_1(n)$,

$y_2(n) = H\{x_2(n)\} = a^n x_2(n)$

let $x_3(n) = a_1 x_1(n) + a_2 x_2(n)$

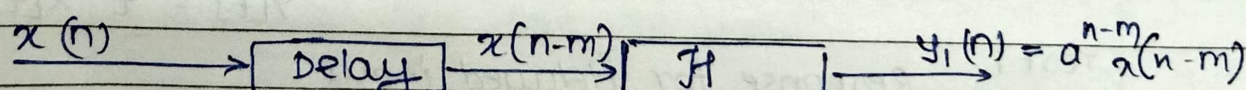
$y_3(n) = H\{a_1 x_1(n) + a_2 x_2(n)\}$

$= a_1 a^n x_1(n) + a_2 a^n x_2(n)$

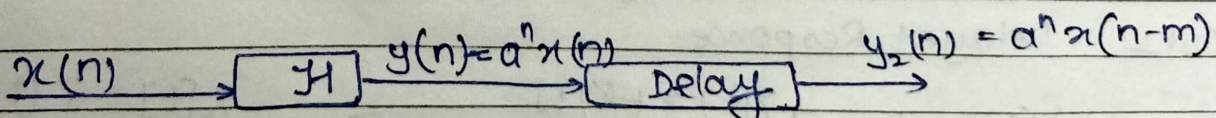
$y_3(n) = a_1 y_1(n) + a_2 y_2(n)$ $\therefore$ Linear System.

(IV) Time-invariant / Variant –

Test 1 Response for delayed input



Test 2 Delayed Response



$\because y_1(t) \neq y_2(t)$ $\therefore$ Time variant

4. $y(n) = x(-n)$

(i) Memoryless –

$n=1, \quad y(1) = x(-1)$
$n=2, \quad y(2) = x(-2)$
} depends on past values of input

$\therefore$ Not a memoryless system.

(ii) Causal / Non-causal – exists for $n \leq 0$ & $n > 0$

$n=-2, \quad y(-2) = x(2)$
$n=-1, \quad y(-1) = x(1) \rightarrow$ Future input
$n=0, \quad y(0) = x(0) \rightarrow$ Present input
$n=1, \quad y(1) = x(-1) \rightarrow$ past input

for $n<0$ response depends on future input
$\therefore$ Non-causal.

(iii) Linear / Non-linear.

$y(n) = H\{x(n)\} = x(-n)$
$y_1(n) = H\{x_1(n)\} = x_1(-n)$
$y_2(n) = H\{x_2(n)\} = x_2(-n)$

Let,

$x_3(n) = a_1 x_1(n) + a_2 x_2(n)$
$y_3(n) = H\{x_3(n)\} = H\{a_1 x_1(n) + a_2 x_2(n)\}$
$= a_1 x_1(-n) + a_2 x_2(-n)$
$y_3(n) = a_1 y_1(n) + a_2 y_2(n)$ $\quad \therefore$ Linear system.

(iv) Time invariant / variant –

Test 1

Response for delayed input

$x(n) \longrightarrow \boxed{\text{Delay}}_{z^{-m}} \xrightarrow{x(n-m)} \boxed{H} \longrightarrow y_1(n) = x(-(n-m))$
$= x(-n+m)$

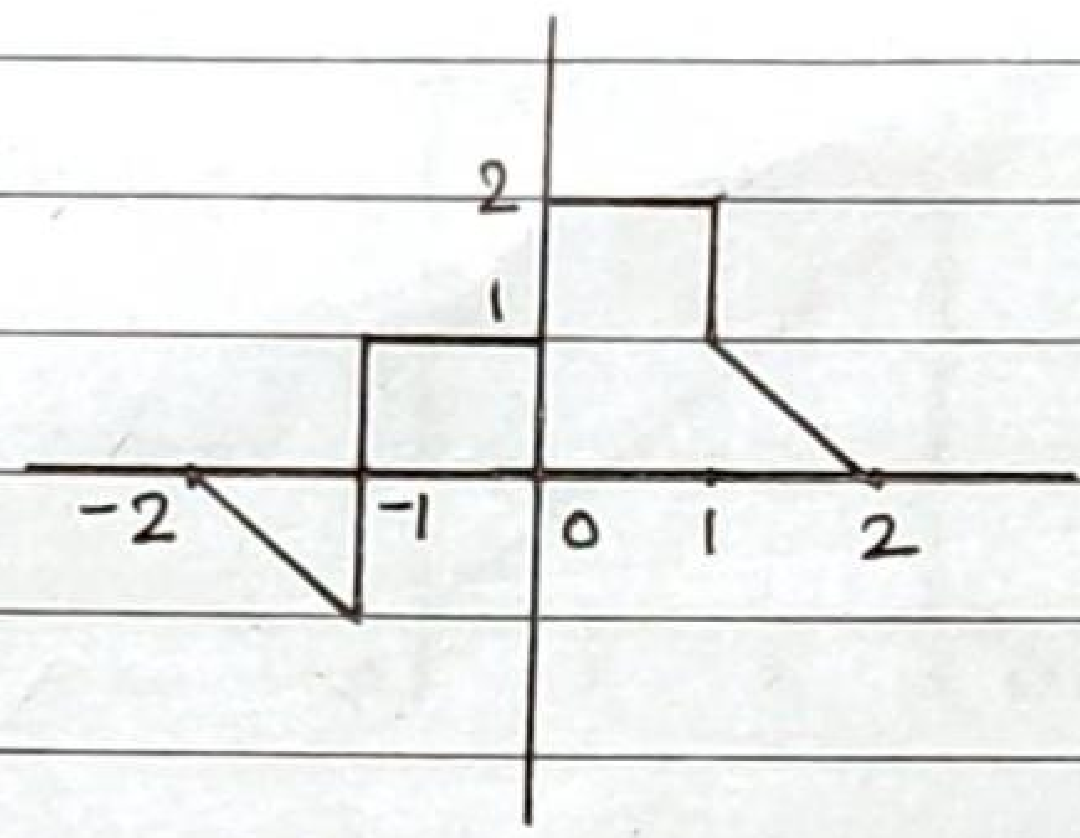
Test 2 Delayed Response

$$x(n) \longrightarrow \boxed{H} \xrightarrow{y(n) = x(-n)} \underset{z^{-m}}{\boxed{\text{Delay}}} \xrightarrow{y_2(n)} = x(-n-m)$$

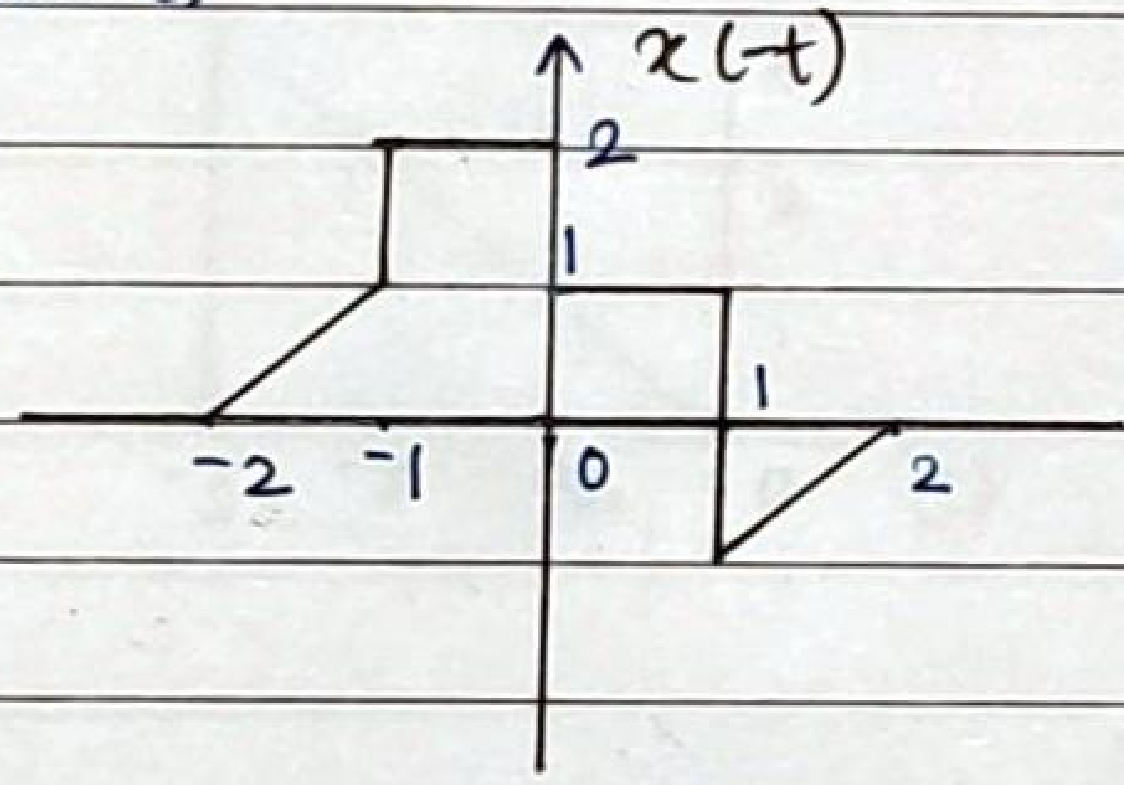
$y_1(t) \neq y_2(t)$

Time variant

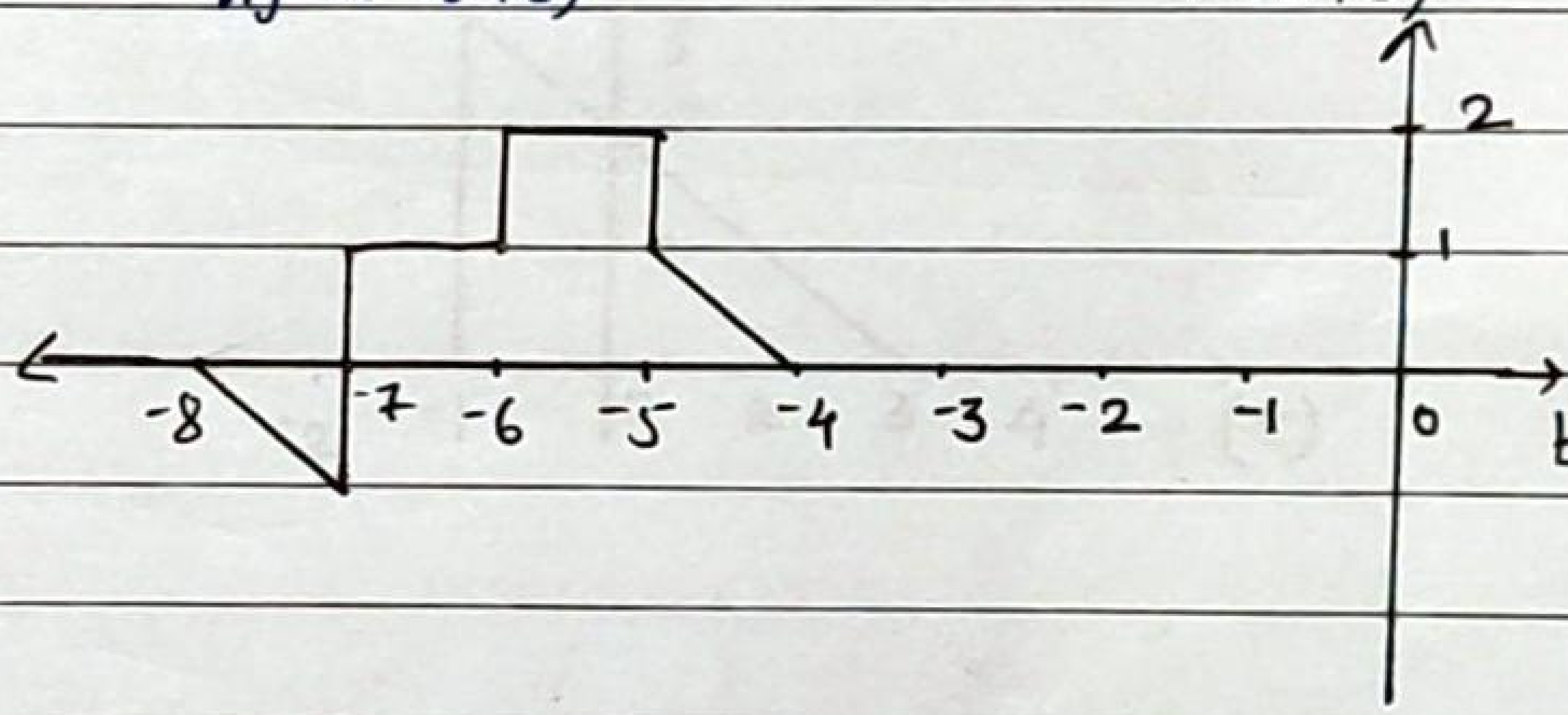
Q.5 For signal $x(t)$ sketch i) $x(-t)$ ii) $x(t+6)$ iii) $x(3t)$ iv) $x\left(\frac{t}{2}\right)$



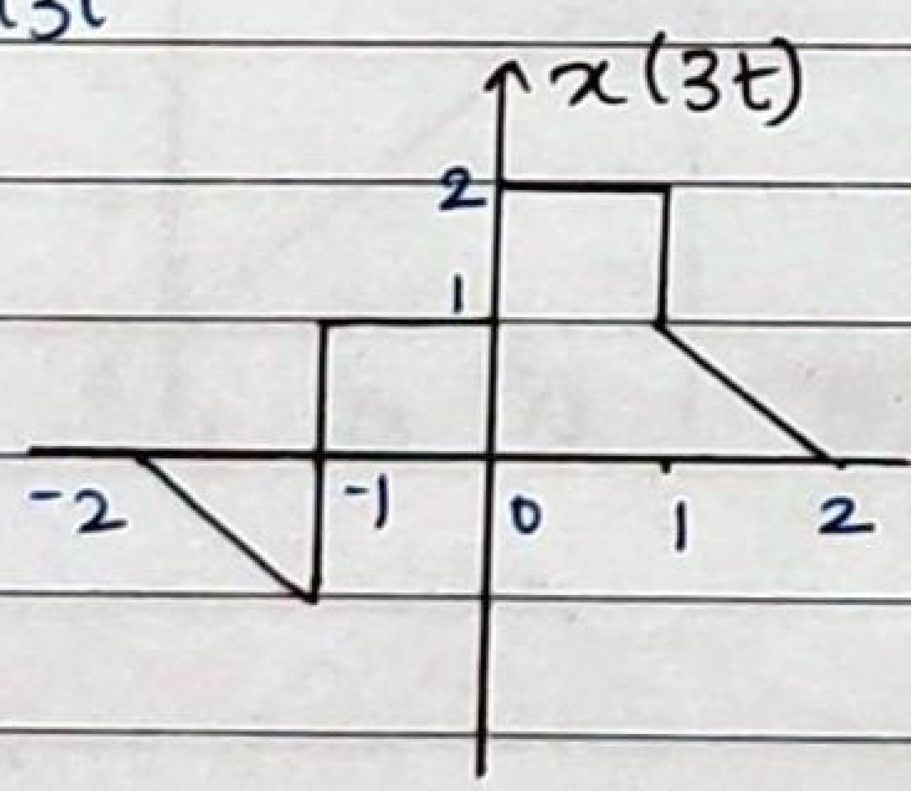
i) $x(-t)$



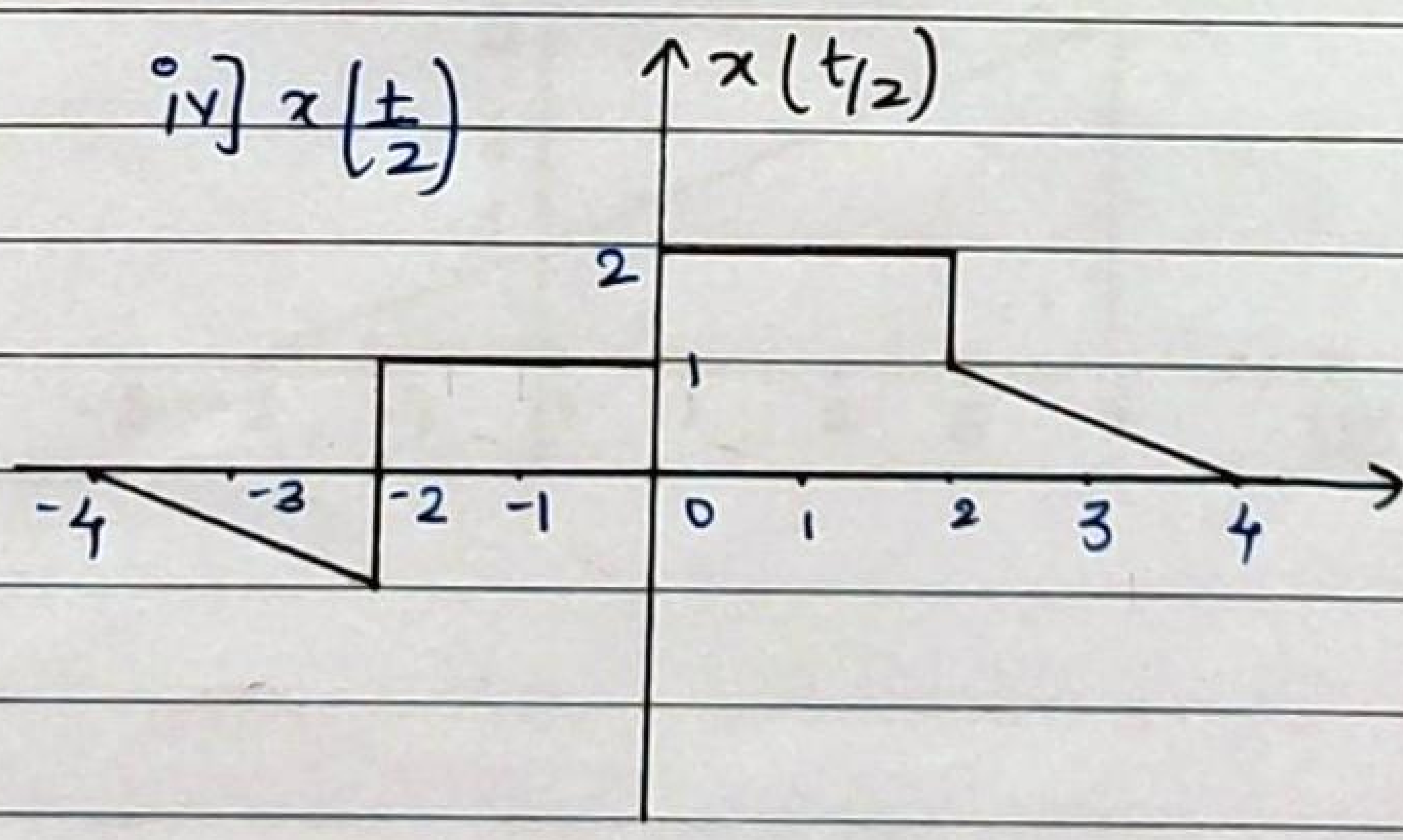
ii) $x(t+6)$



iii) $x(3t$



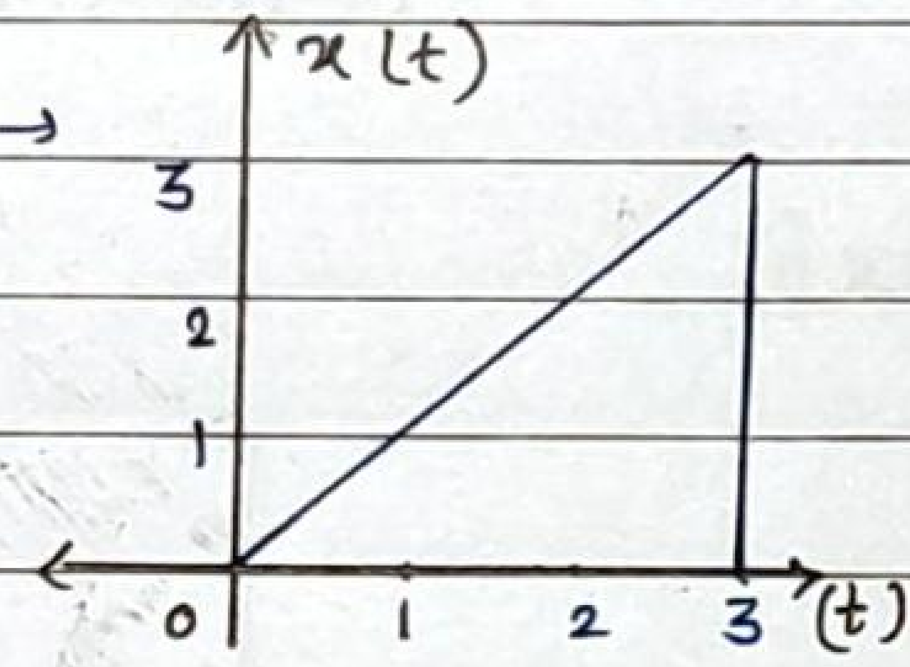
iv) $x\left(\frac{t}{2}\right)$



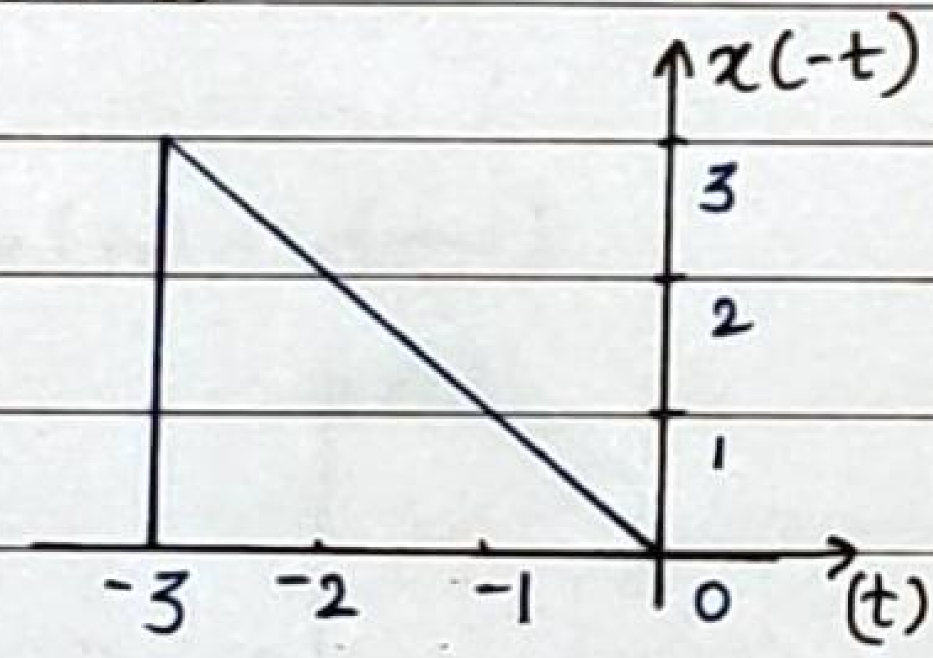
Q.6 A continuous signal $x(t) = t$; ~~0≤3~~ $0 \le t \le 3$ Sketch, i) $x(-t)$ ii) $x(2-t)$

$x(t) = 0$; $t > 0$ iii] $x(3t)$ iv) $x(0.5t+1)$

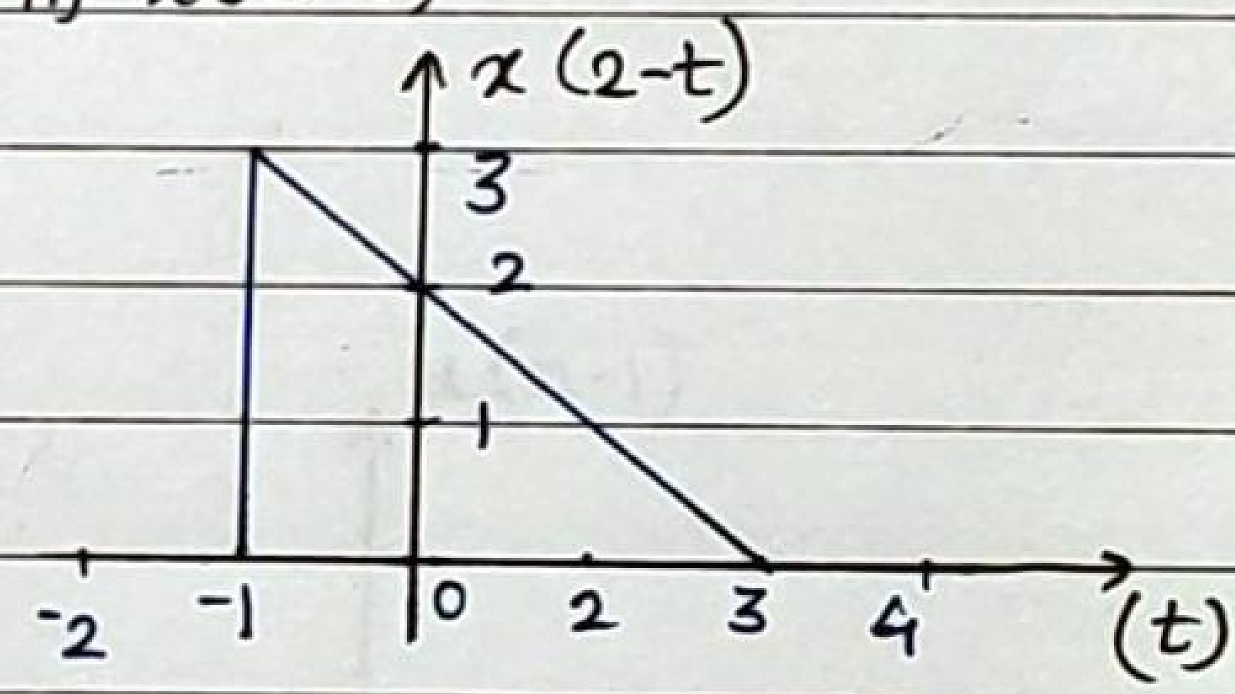
∴ $x(t)$ signal is →



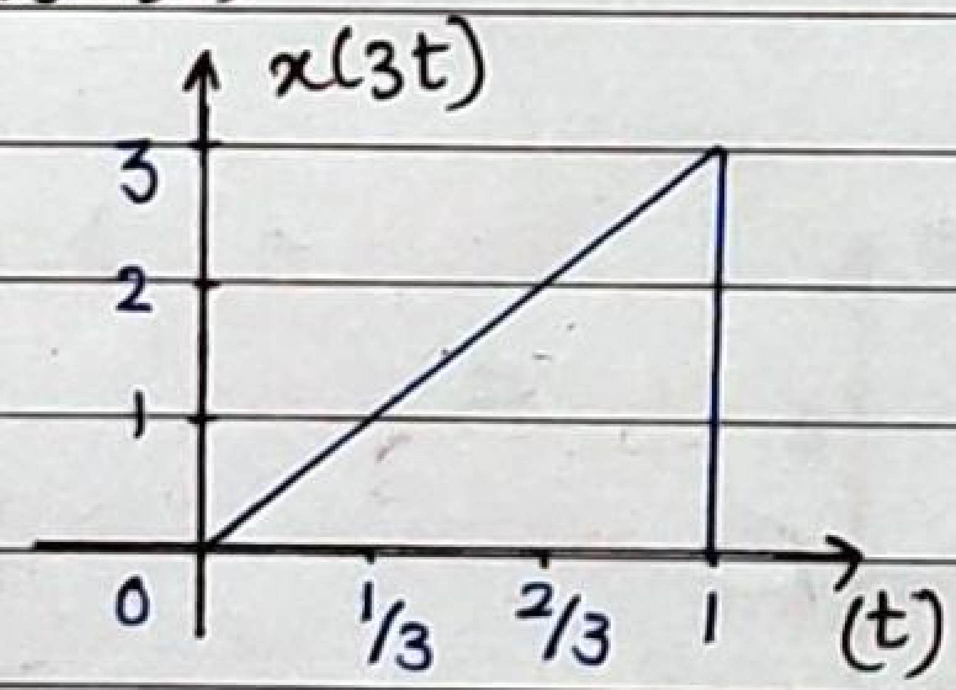
i) $x(-t)$



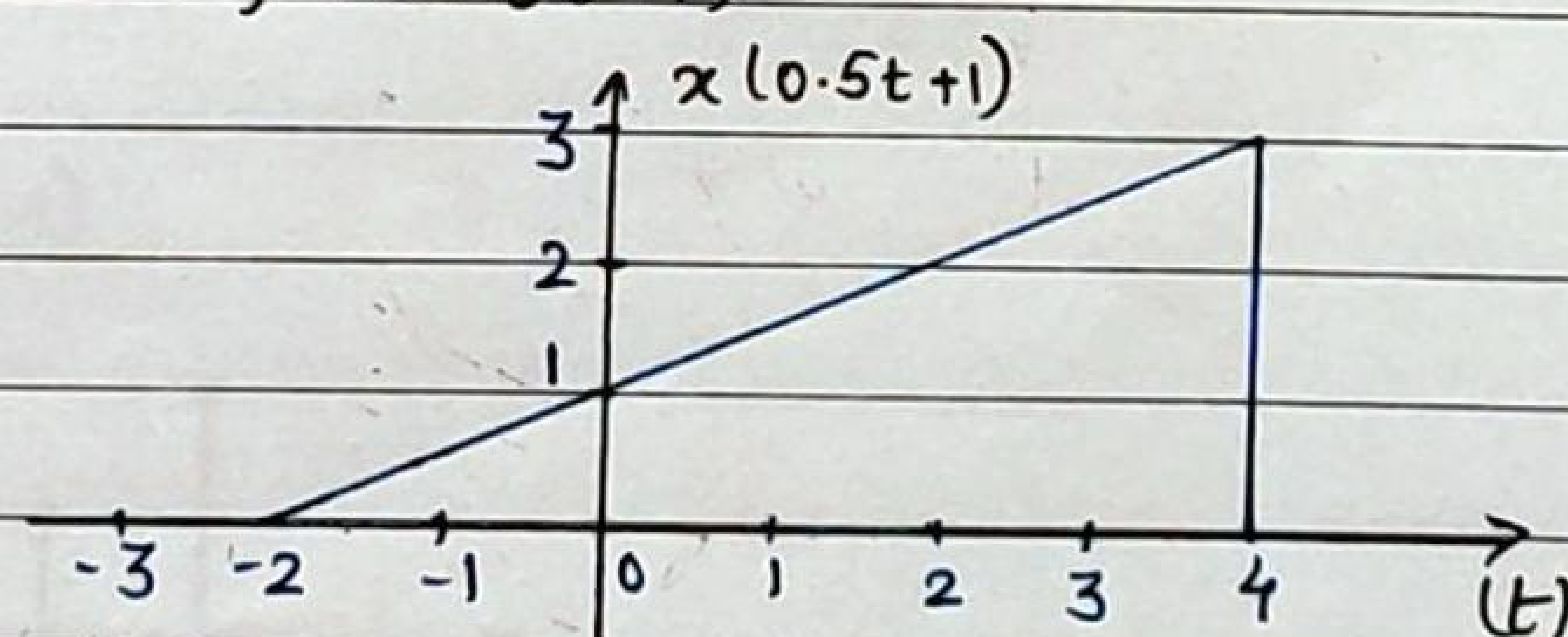
ii) $x(2-t)$



iii) $x(3t)$



iv) $x(0.5t+1)$

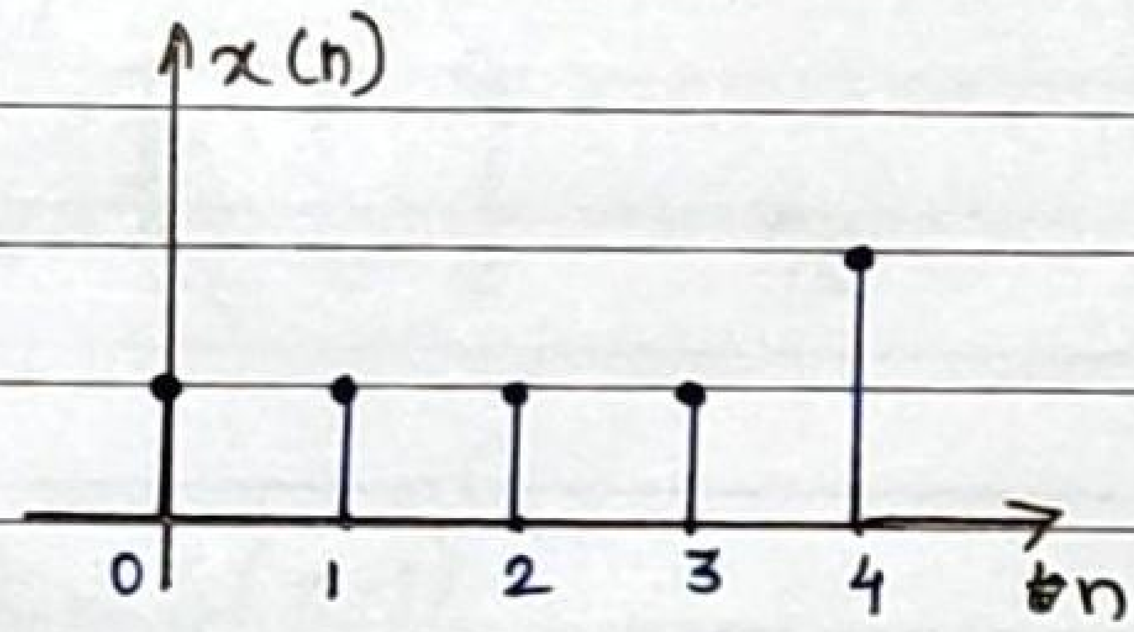


Q.7 A discrete time signal is given by $x(n) = \{\underset{\uparrow}{1}, 1, 1, 1, 2\}$. Sketch

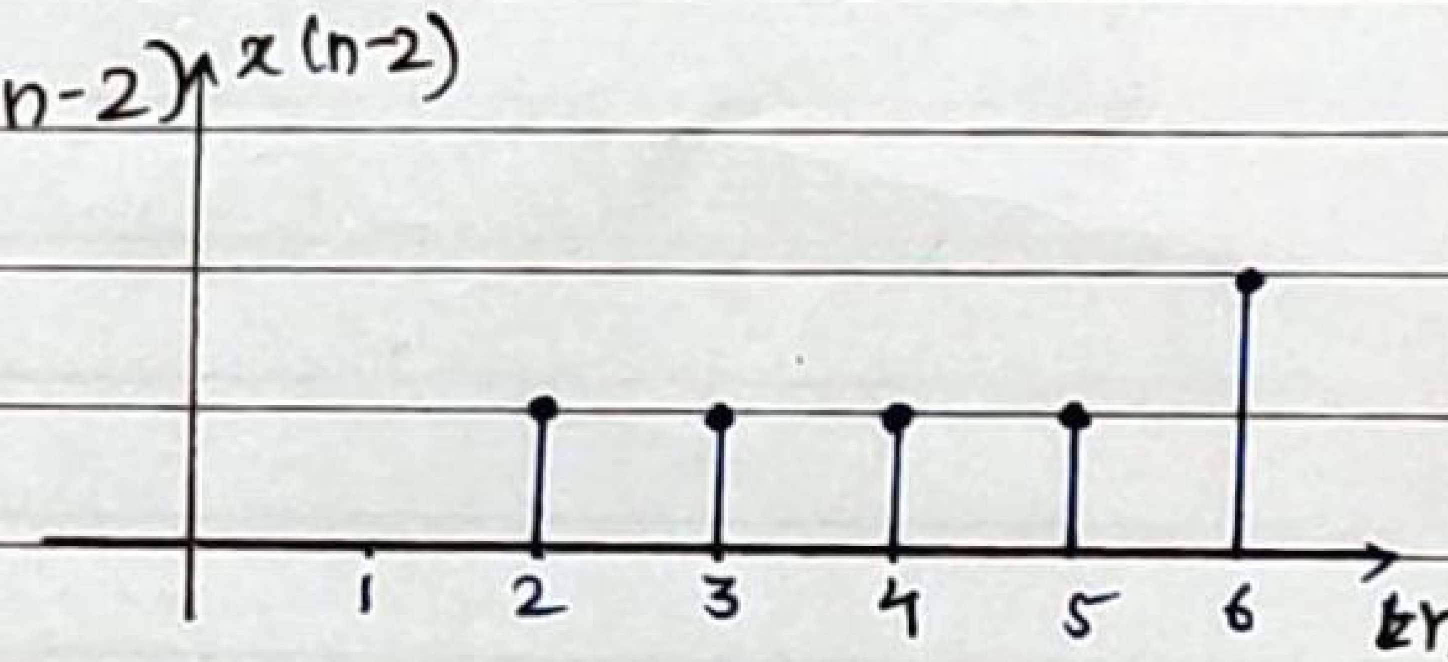
i) $x(n)$ ii) $x(n-2)$ iii) $x(n).u(n-1)$

iv) $x(3-n)$ v] $x(n-1)\cdot\delta(n-1)$

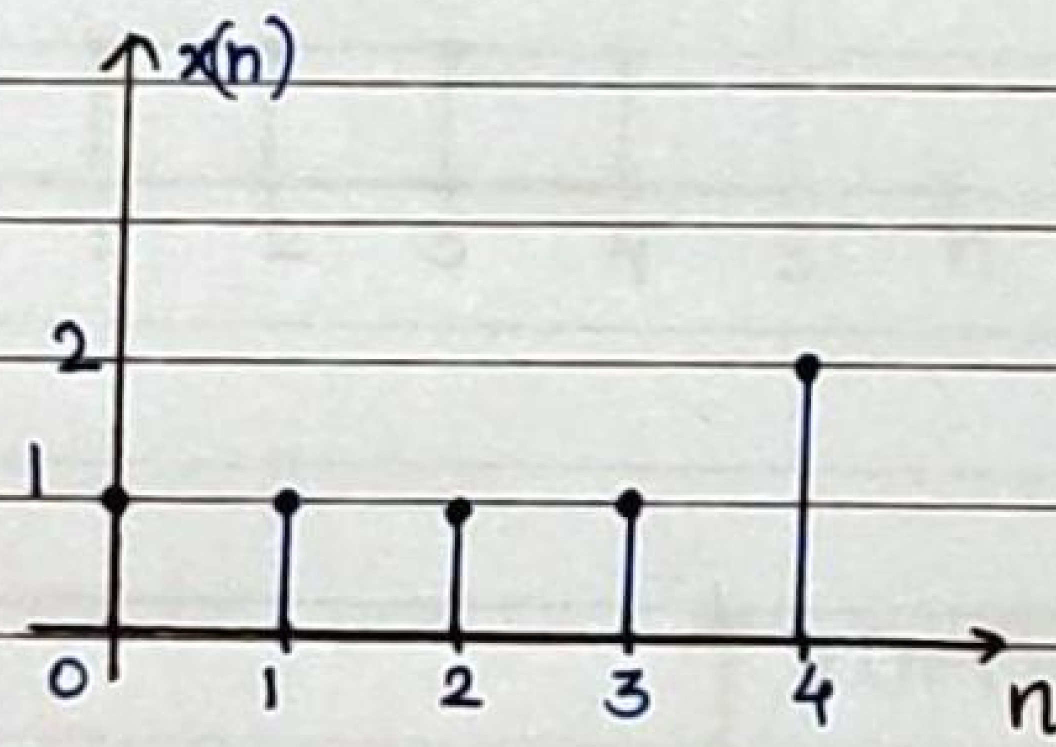
i] $x(n) =$



ii] $x(n-2)$



iii] $x(n) \cdot u(n-1)$



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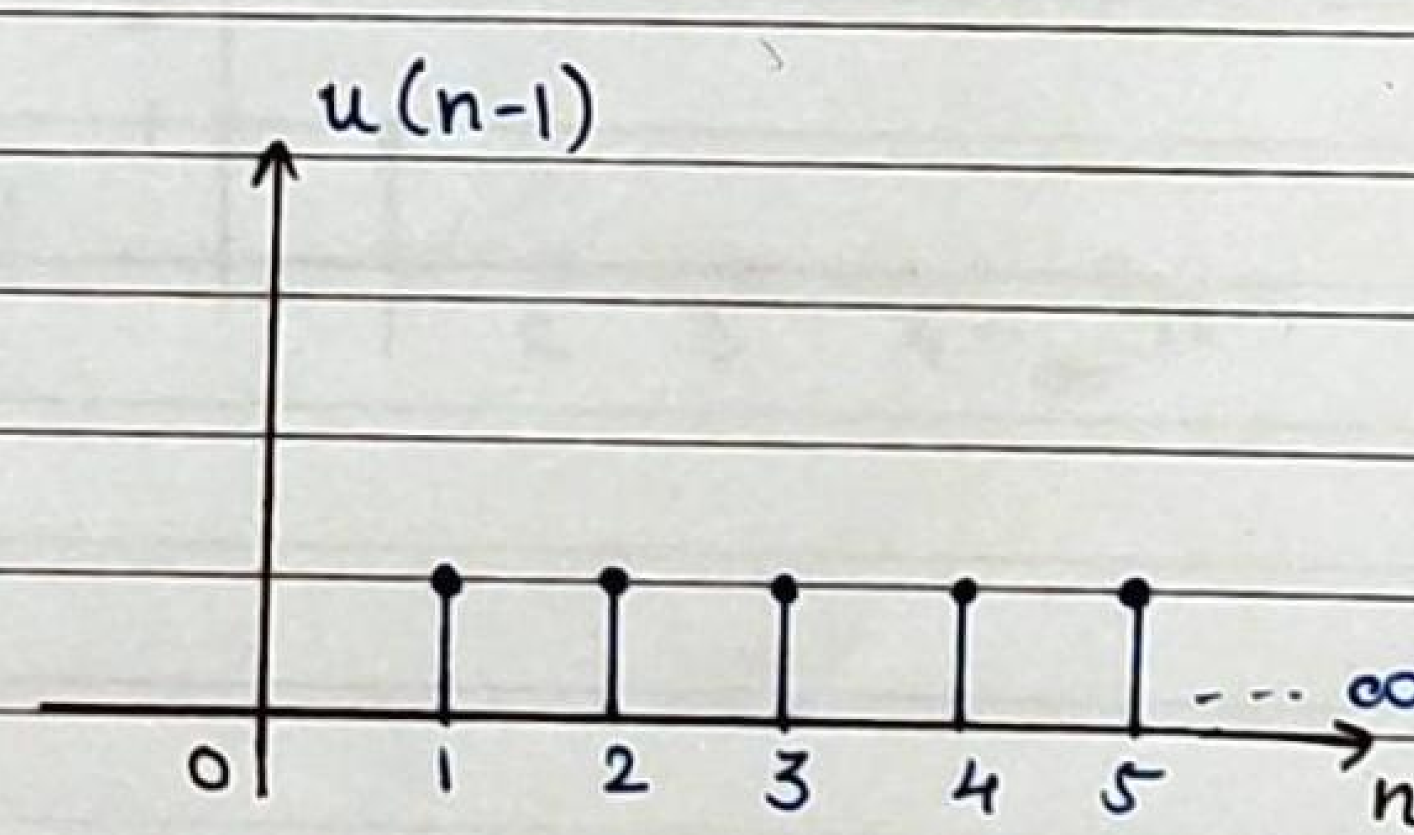

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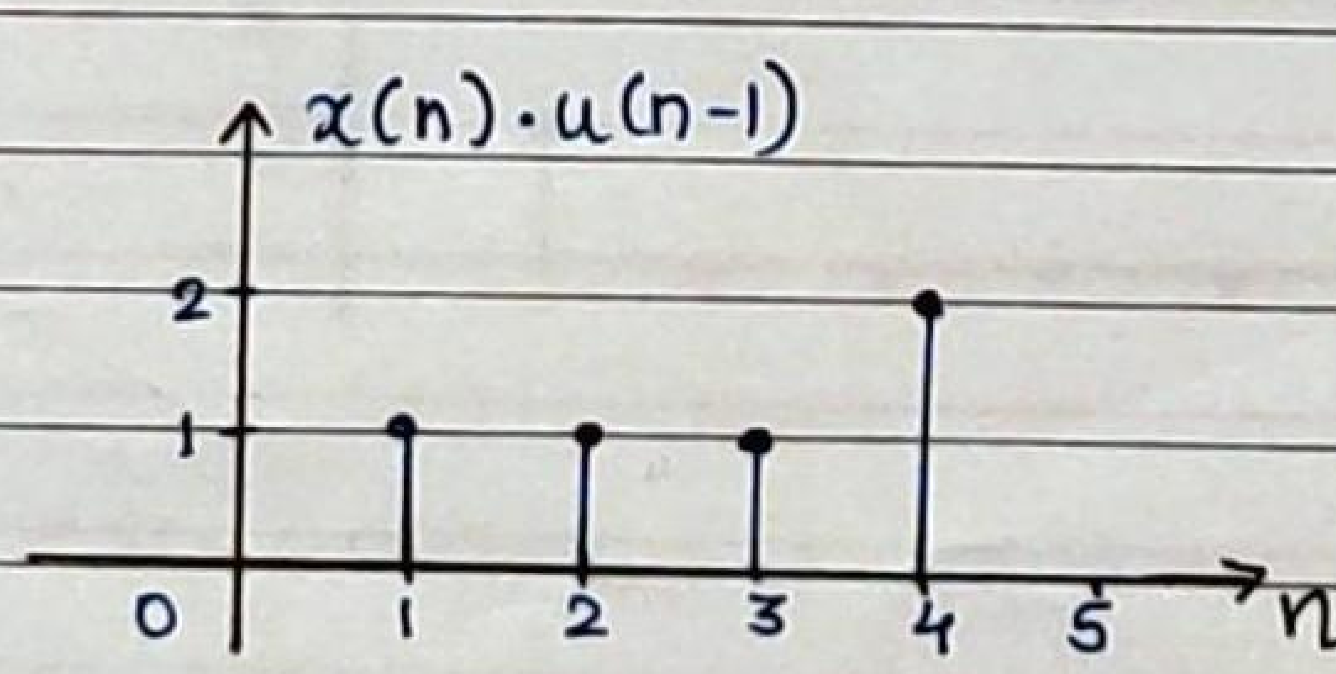
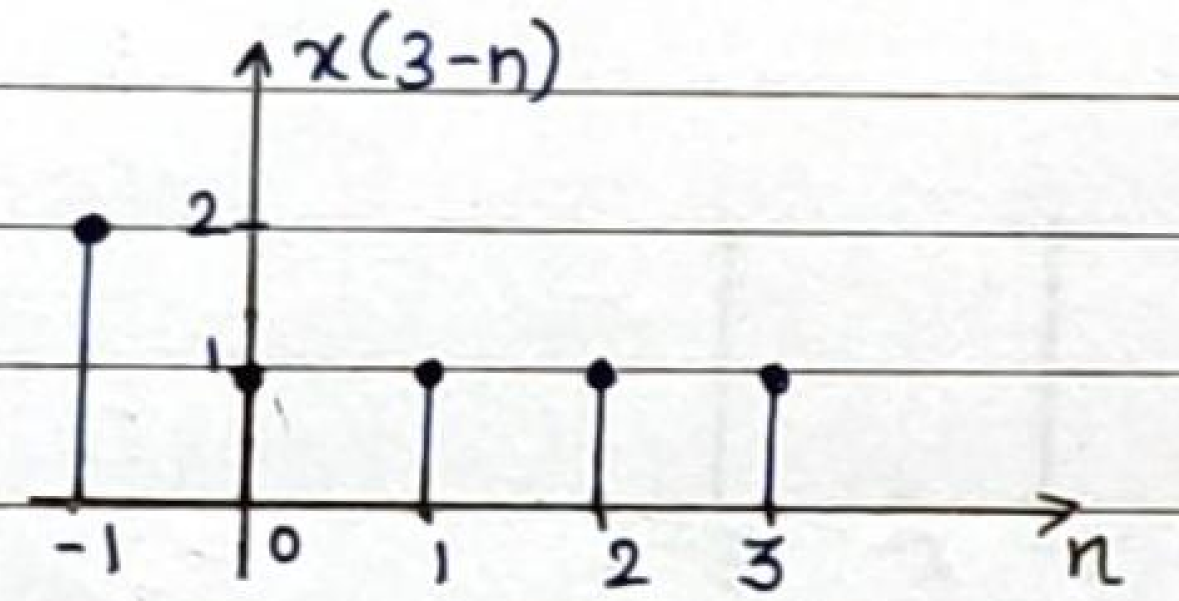
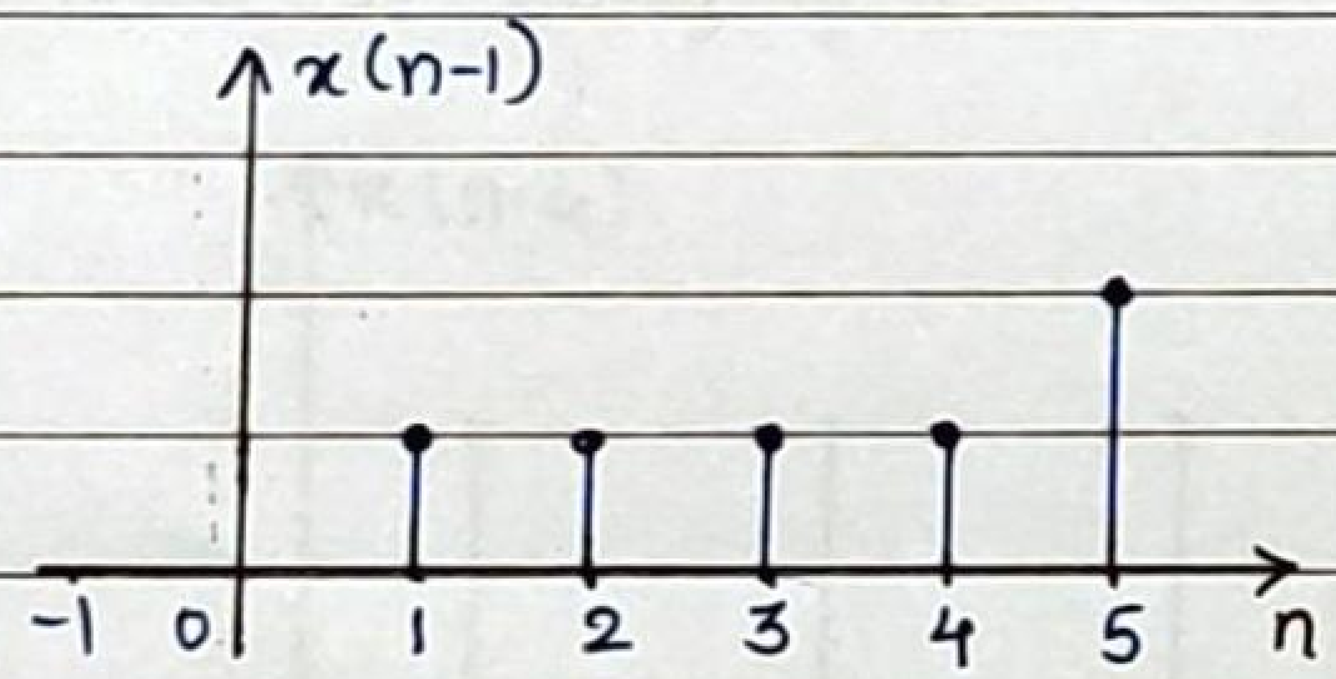


iv] $x(3-n)$

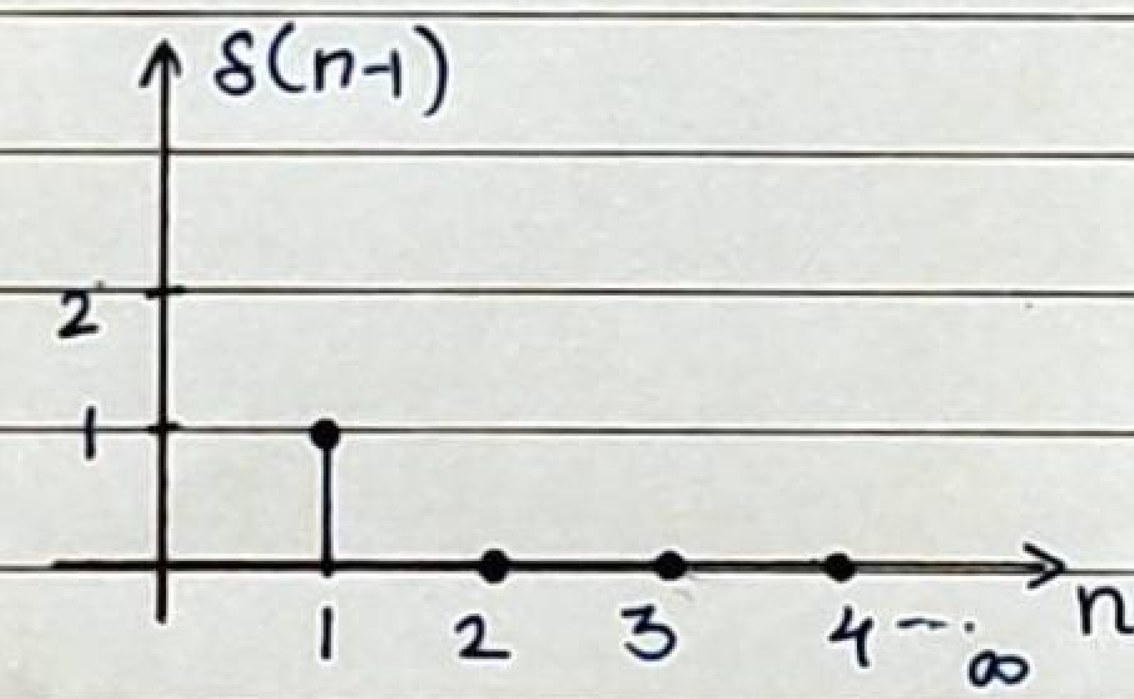
$x(-n)$ then delayed by 3



v] $x(n-1) \cdot \delta(n-1)$



(x) Multiply



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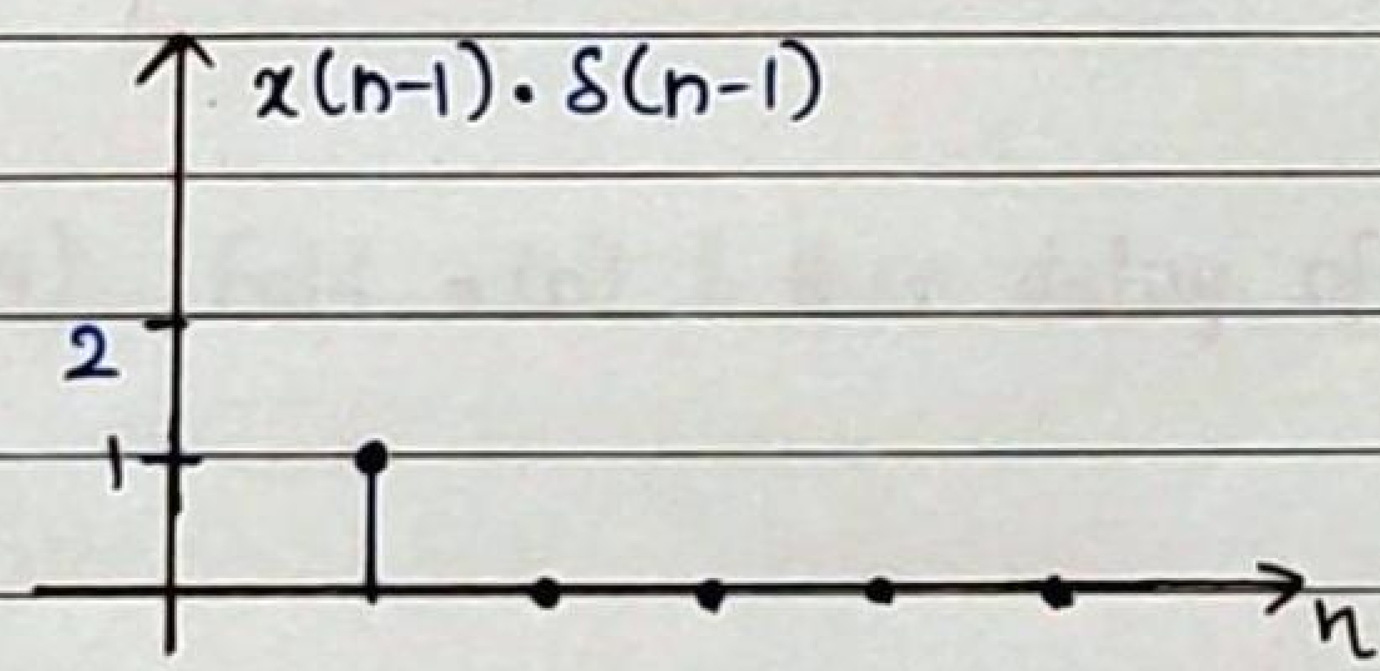
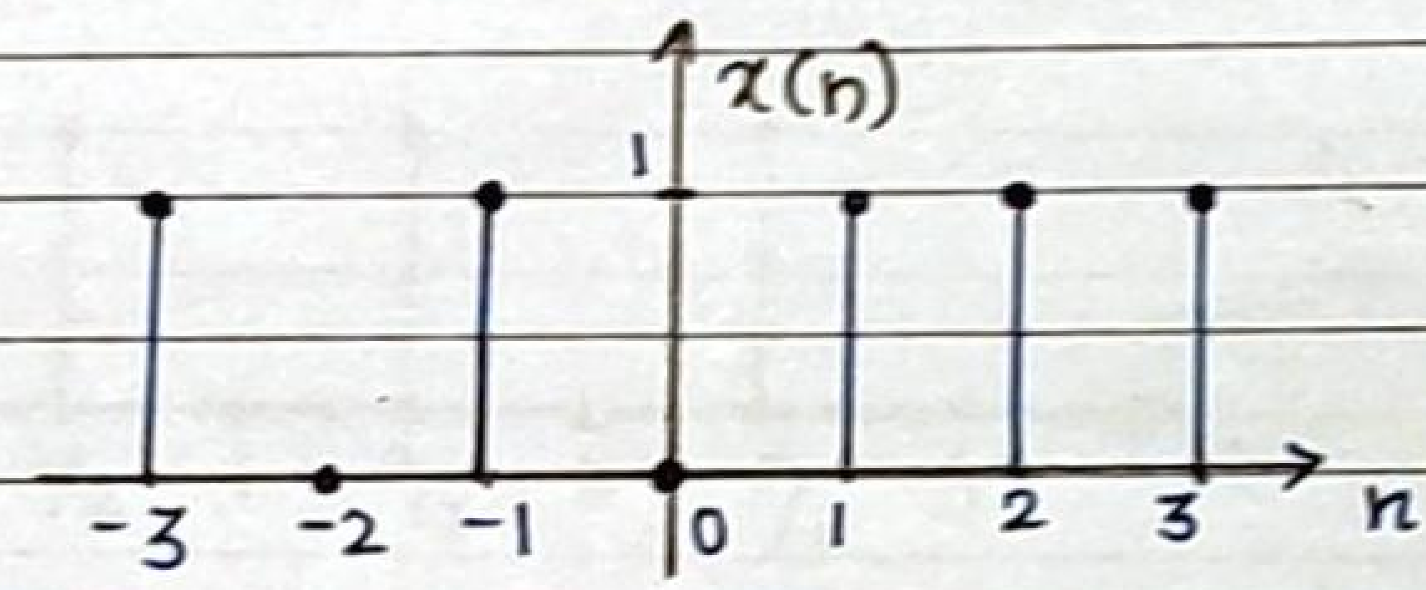
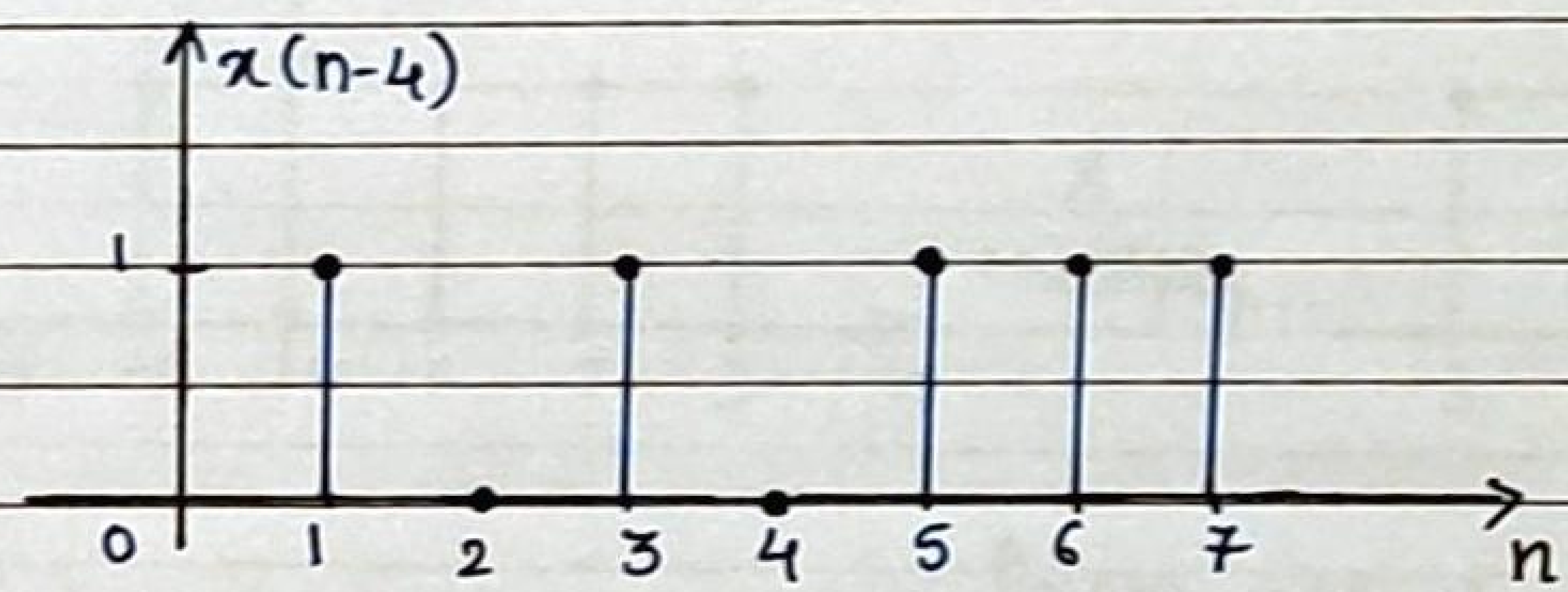


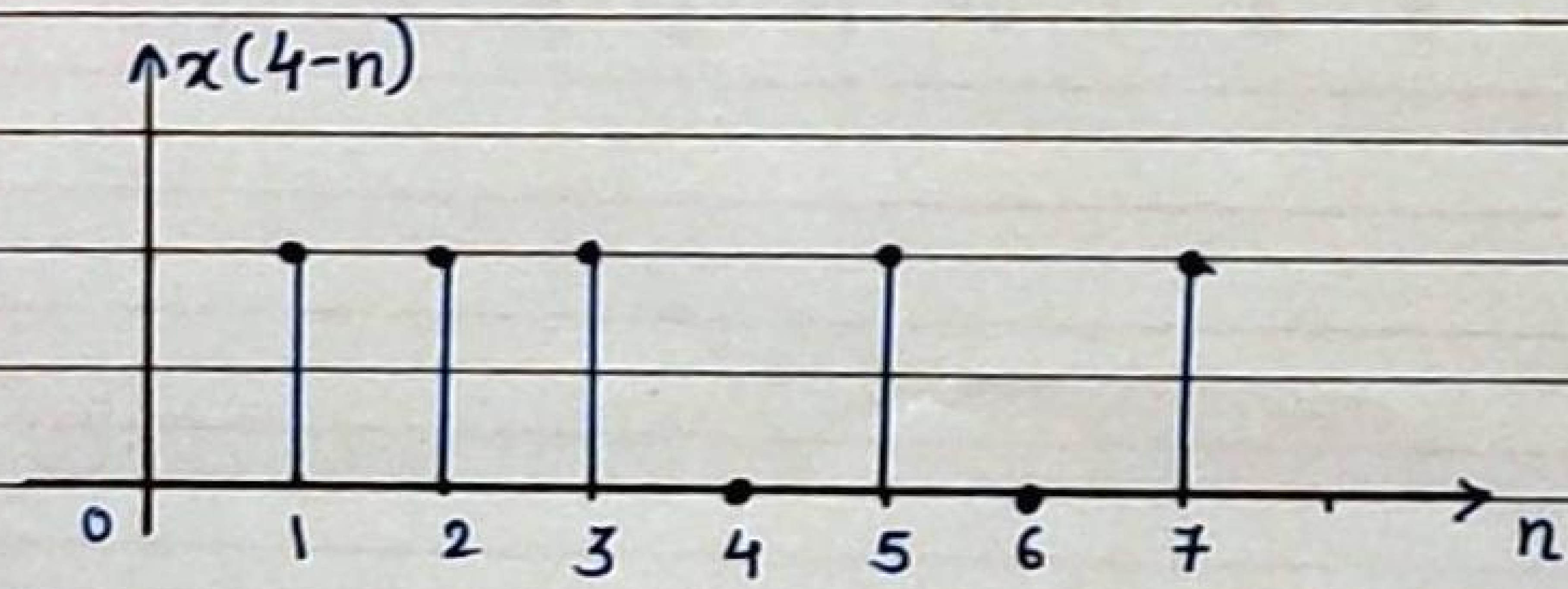
Q.8 A DT signal has been shown. sketch, i) $x(n-4)$ ii) $x(4-n)$
iii) $x(-2n+2)$ iv) $x(n).u(3-n)$.



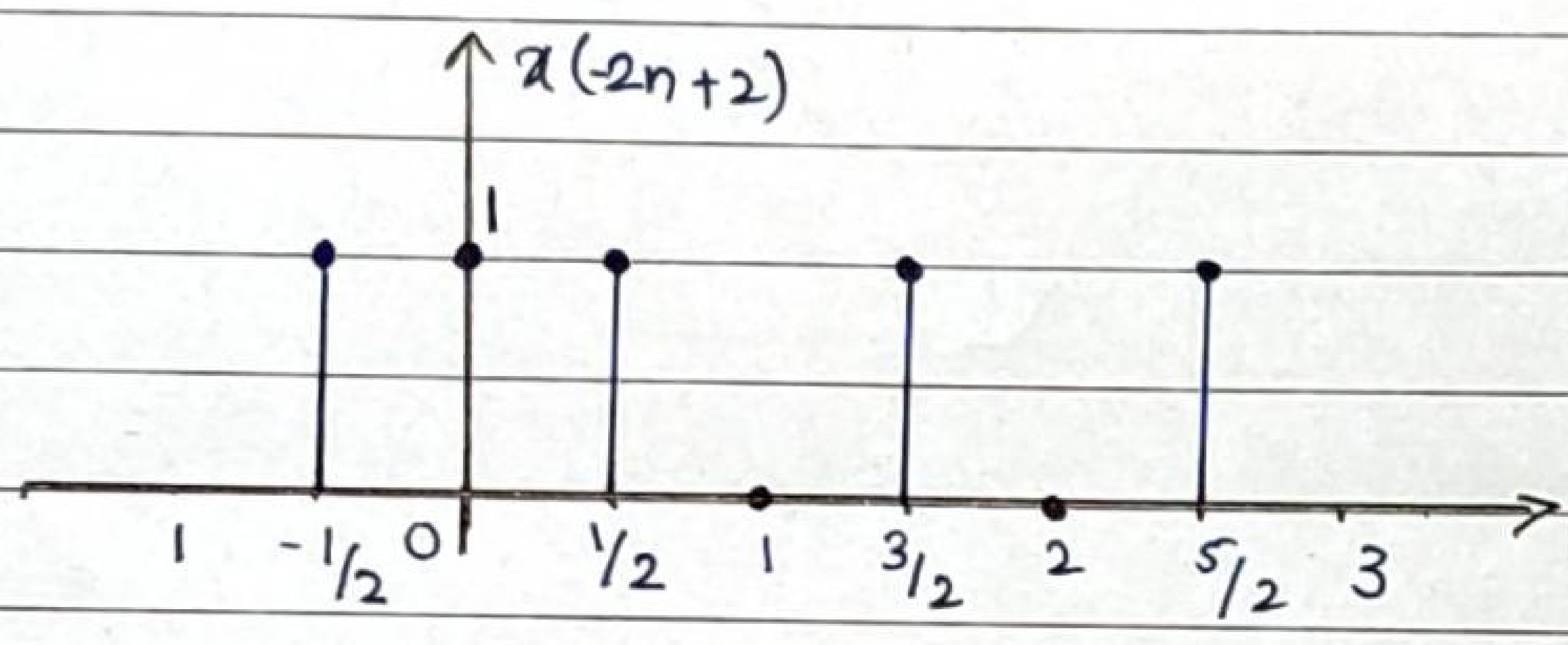
i] $x(n-4)$ delay by 4



ii] $x(4-n) = x(-n+4)$ Fold $x(n)$ & then delay of 4

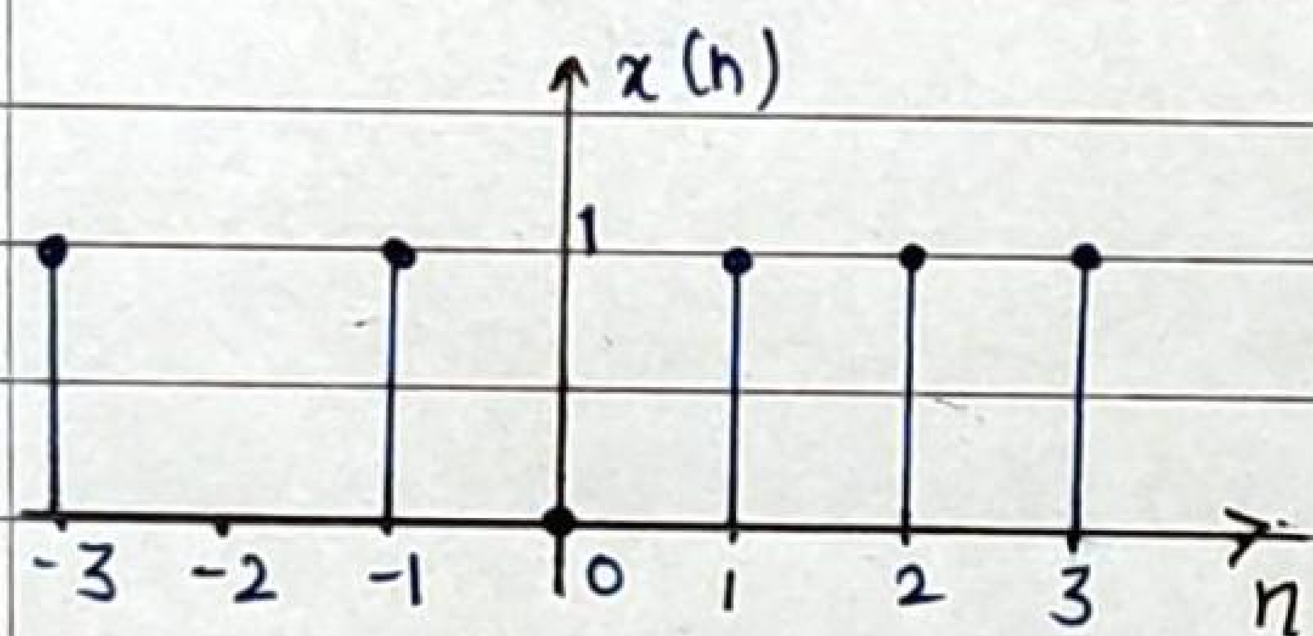


iii) $x(-2n+2)$ Fold $x(n)$ & delay by 2 and then compress by 2



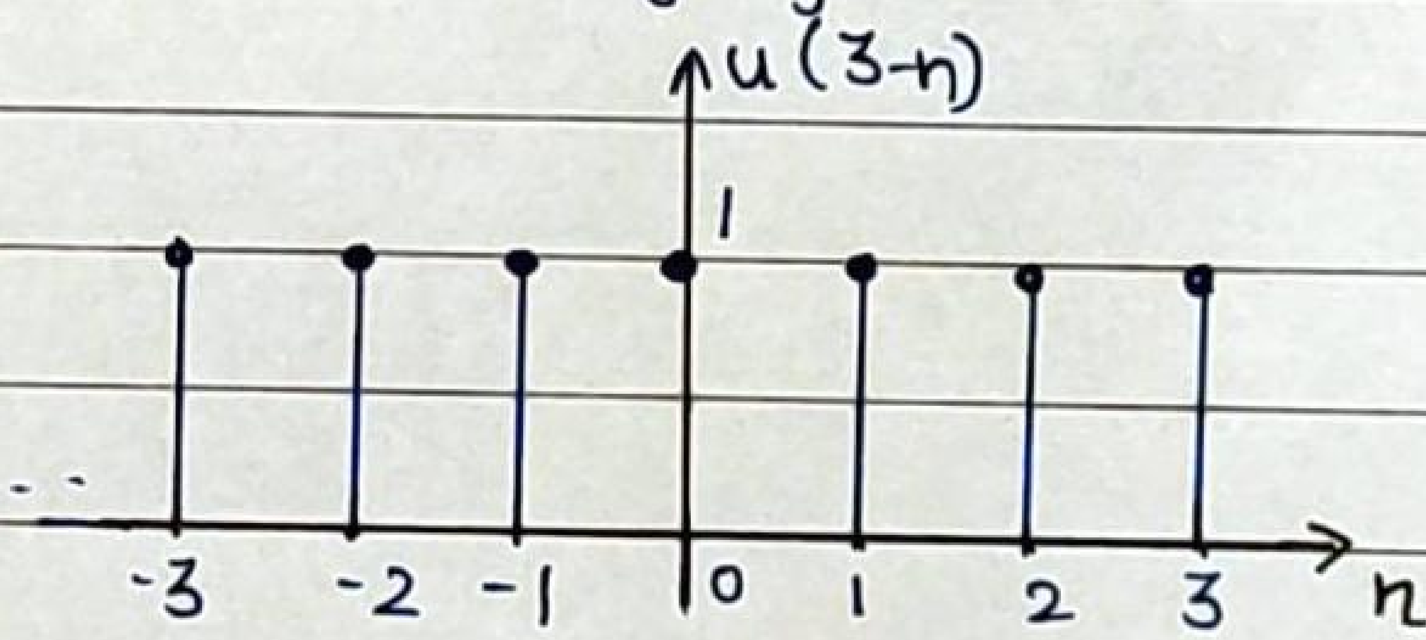
iv) $x(n) \cdot u(3-n)$.

$u(-n) \rightarrow$ delay by 3



X

Multiply....



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