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=> Linear convolution :-

$x_1(n) = [1, 1, \underset{\uparrow}{0}, 1, 1]$ — No. of +ve side = 2, No. of -ve side = 2

$x_2(n) = [1, -2, -3, \underset{\uparrow}{4}]$ — No. of +ve side = 0, No. of -ve side = 3

$x_1(n) * x_2(n)$ — Total no. of +ve side = 2+0 = 2, " " -ve side = 2+3 = 5

Sol)

$x_1(n)$	1	1	0	1	1
1	1	1	0	1	1
-2	-2	-2	0	-2	-2
-3	-3	-3	0	-3	-3
4	4	4	0	4	4

$x_1(n) * x_2(n) = \{1, -1, -5, 2, 3, -5, 1, 4\}$

-ve side, Answer, +ve side

Q Compute linear convolution of sequence $x(n) = \{7, 6, 4, 5, 2, 4, 5, 2, 3\}$ and $h(n) = \{1, 2, 3\}$ using overlap save method.

Sol) Step 1:- L, M, N

L → Padded zeroes → $L = M - 1$, $L = 2$

M → elements in h(n) → 3

N → Total samples → $N = L + M - 1$, $= 2 + 3 - 1$, $= 4$

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Add other zeroes to make $h(n)$ equal to N

Step 2:- $h(n) = \{1, 2, 3, 0\}$

$x_1(n) =$ | 0 | 0 | 7 | 6 |

$x_2(n) =$ | 7 | 6 | 4 | 5 |

$x_3(n) =$ | 4 | 5 | 2 | 4 |

$x_4(n) =$ | 2 | 4 | 5 | 2 |

$x_5(n) =$ | 5 | 2 | 3 | 0 |

$x_6(n) =$ | 3 | 0 | 0 | 0 |

(No of zeroes is written equal to $L(2)$)

$$y_1(n) = \begin{bmatrix} 1 & 0 & 3 & 2 \\ 2 & 1 & 0 & 3 \\ 3 & 2 & 1 & 0 \\ 0 & 3 & 2 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 7 \\ 6 \end{bmatrix} = \begin{bmatrix} 33 \\ 18 \\ 7 \\ 20 \end{bmatrix}$$

$$y_2(n) = \begin{bmatrix} 1 & 0 & 3 & 2 \\ 2 & 1 & 0 & 3 \\ 3 & 2 & 1 & 0 \\ 0 & 3 & 2 & 1 \end{bmatrix} \begin{bmatrix} 7 \\ 6 \\ 4 \\ 5 \end{bmatrix} = \begin{bmatrix} 29 \\ 35 \\ 30 \\ 31 \end{bmatrix}$$

$$y_3(n) = \begin{bmatrix} 18 \\ 25 \\ 24 \\ 23 \end{bmatrix}$$

$$y_4(n) = \begin{bmatrix} 21 \\ 14 \\ 19 \\ 24 \end{bmatrix}$$

$$y_5(n) = \begin{bmatrix} 14 \\ 12 \\ 22 \\ 12 \end{bmatrix}$$

$$y_6(n) = \begin{bmatrix} 3 \\ 6 \\ 9 \\ 0 \end{bmatrix}$$

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Step 3:-

$y_1(n)$	33	18	7	20										
$y_2(n)$			29	35	37	31								
$y_3(n)$					18	25	24	23						
$y_4(n)$							21	14	19	24				
$y_5(n)$									14	12	22	12		
$y_6(n)$											3	6	9	0

write no. of only overlap numbers :-

$$y(k) = \{7, 20, 37, 31, 24, 23, 19, 24, 22, 12, 9, 0\}$$

Answers.

Q. Compute linear convolution of sequence $x(n) = \{1, 2, 3, 4, 5, 6, 7, 8\}$, $h(n) = \{1, 1, 1\}$ using overlap add method.

Sol-> Step 1 :- L M N

$L = M-1 = 2$, $M = 3$, $N = L+M-1 = 4$

Step 2 :- $x_1(n) = \{1, 2, 0, 0\}$

Last mein 0 lagana hain jitne L hain phir uss se digit likhna hai

$x_2(n) = \{3, 4, 0, 0\}$

$x_3(n) = \{5, 6, 0, 0\}$

$x_4(n) = \{7, 8, 0, 0\}$

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Step 3 :- $y_1(n) = h(n) * x_1(n)$

$$\begin{bmatrix} 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 3 \\ 3 \\ 2 \end{bmatrix}$$

~~Same for all~~

$$y_2(n) = \begin{bmatrix} 3 \\ 7 \\ 7 \\ 4 \end{bmatrix}$$

$$y_3(n) = \begin{bmatrix} 5 \\ 11 \\ 11 \\ 6 \end{bmatrix}$$

$$y_4(n) = \begin{bmatrix} 7 \\ 15 \\ 15 \\ 8 \end{bmatrix}$$

Step 4 :-

1	3	3	2	
	3	7	7	4
		5	11	11	6
			7	15	15	8

Answer = $y(k) = \{1, 3, 6, 9, 12, 15, 18, 21, 15, 8\}$

Adding 3+3 and 7+7

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=> Circular convolution :-

Q. Perform circular convolution $x_1(n) = \{1, -1, 2, -4\}$
$x_2(n) = \{1, 2\}$

$x_1(n) * x_2(n)$

Sol:-

$$\begin{bmatrix} 1 & -4 & 2 & -1 \\ -1 & 1 & -4 & 2 \\ 2 & -1 & 1 & -4 \\ -4 & 2 & -1 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 7 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

Ans = $\{7, 1, 0, 0\}$

Q Circular convolution using DFT :-

For DFT :-

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix}$$

For IDFT :-

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}$$

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Q. $x_1(n) = [5, 6, 2, 1]$
$x_2(n) = [3, 2, 1, 4]$

Solve circular convolution using DFT

Sol) Step 1:- DFT of signal 1

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} 5 \\ 6 \\ 2 \\ 1 \end{bmatrix} = \begin{bmatrix} 14 \\ 3-5j \\ 0 \\ 3+5j \end{bmatrix}$$

Step 2: DFT of signal 2

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix} \begin{bmatrix} 3 \\ 2 \\ 1 \\ 4 \end{bmatrix} = \begin{bmatrix} 10 \\ 2+2j \\ -2 \\ 2-2j \end{bmatrix}$$

Step 3: Multiply both DFT (normal multiply)

$$\begin{bmatrix} 14 \\ 3-5j \\ 0 \\ 3+5j \end{bmatrix} \begin{bmatrix} 10 \\ 2+2j \\ -2 \\ 2-2j \end{bmatrix} = \begin{bmatrix} 140 \\ 16-4j \\ 0 \\ 16+4j \end{bmatrix}$$

$j^2 = -1$

$6j - 10j = -6j^2$
$= 4j$

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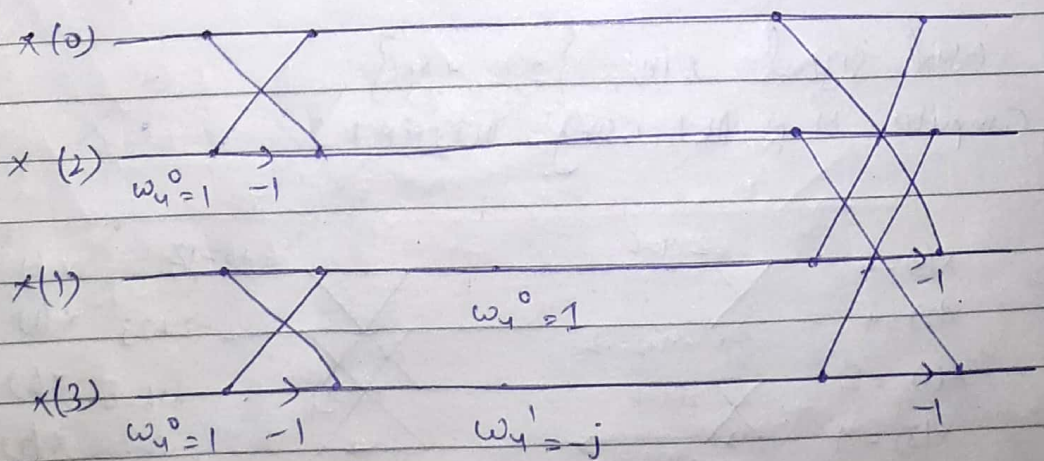
Step 4: Finding IDFT

$$\frac{1}{N}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}\begin{bmatrix} 140 \\ 16-4j \\ 0 \\ 16+4j \end{bmatrix}$$

$$\frac{1}{4}\begin{bmatrix} 172 \\ 148 \\ 108 \\ 132 \end{bmatrix} = \begin{bmatrix} 43 \\ 37 \\ 27 \\ 33 \end{bmatrix}$$

=> DIT-FFT using Butterfly method
Radix 4 pt.



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Twiddle factor = W_4^0, W_4^1

$W_N = e^{-j\frac{2\pi}{N}}$ where N is radix

Here N = 4

$W_4^r = e^{-j\frac{\pi}{2}}$

$W_4^0 = e^0 = 1$

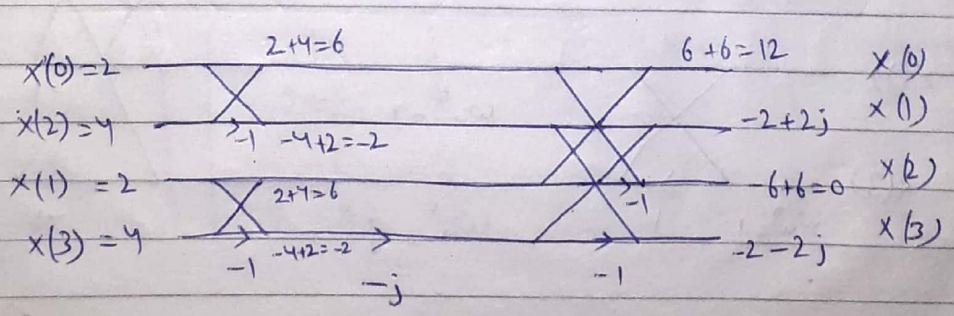
$W_4^1 = e^{-j\frac{\pi}{2}*1}$

$= \cos\left(\frac{\pi}{2}\right) - j\sin\left(\frac{\pi}{2}\right)$

$= 0 - j(1) = -j$

Q For casual signal $x(n) = \{2, 2, 4, 4\}$
Compute 4 pt DFT using DIT FFT

Sol:>



$X(K) = \{12, -2+2j, 0, -2-2j\}$

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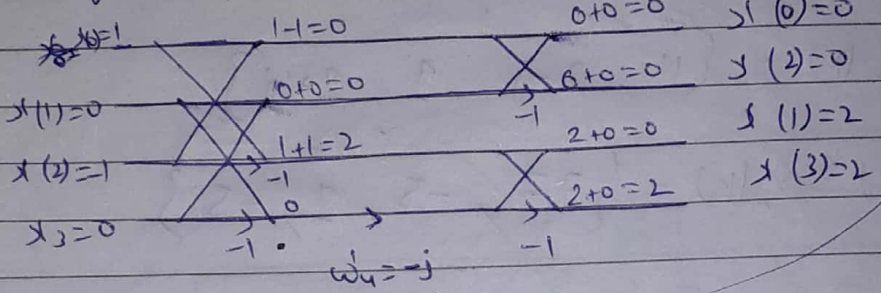
→ Inverse of DFT (IDFT)

=> Con DIF-FFT using Butterfly method
Radix 4 pt.

IFFT nem sirf jaha tj gayga, baaki same

Q. Compute 4pt DFT of $x(n) = \cos \frac{n\pi}{2}$



Sol-> $x(0) = \cos 0 = 1$

$x(1) = \cos \pi/2 = 0$

$x(2) = \cos \pi = -1$

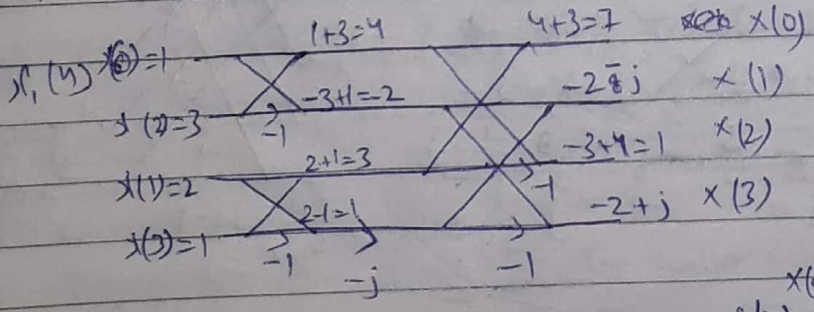
$x(3) = \cos \frac{3\pi}{2} = 0$

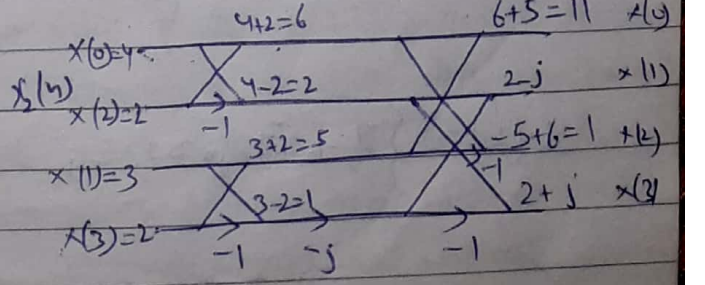
$X(k) = \{0, 2, 0, 2\}$

Q. Determine circular convolution of 2 sequence using DIT FFT

$x_1(n) = \{1, 2, 3, 1\}$

$x_2(n) = \{4, 3, 2, 2\}$





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Now, $x_1(n) * x_2(n)$

$x_1(k) = \{7, -2-j, 1, -2+j\}$

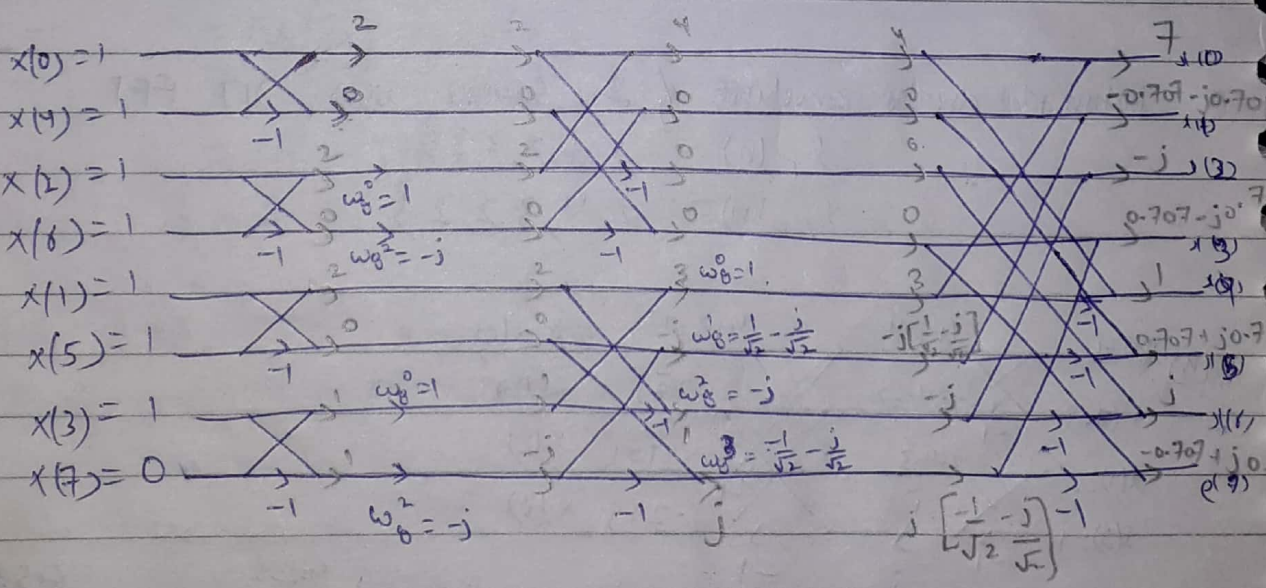
$x_2(k) = \{11, 2-j, 1, 2+j\}$

$x_1(k) * x_2(k) = \{77, -5, 1, -5\}$ $\quad [j^2 = -1]$

Q DIT FFT [8 point DFT]

Calc. 8 point DFT of $x(n) = \{1, 1, 1, 1, 1, 1, 1, 0\}$ using radix 2. DIT FFT algorithm.

Sol->



$X(k) = \{7, -0.707 - j0.707, -j, \ldots\}$

[Pencil written is the calculation else have to learned]

IFFT ke liye same bataya bas points ke sign change honge.

$\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}$ $\quad j$ $\quad 1$

j $\quad 1$

$-\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}$ $\quad j$

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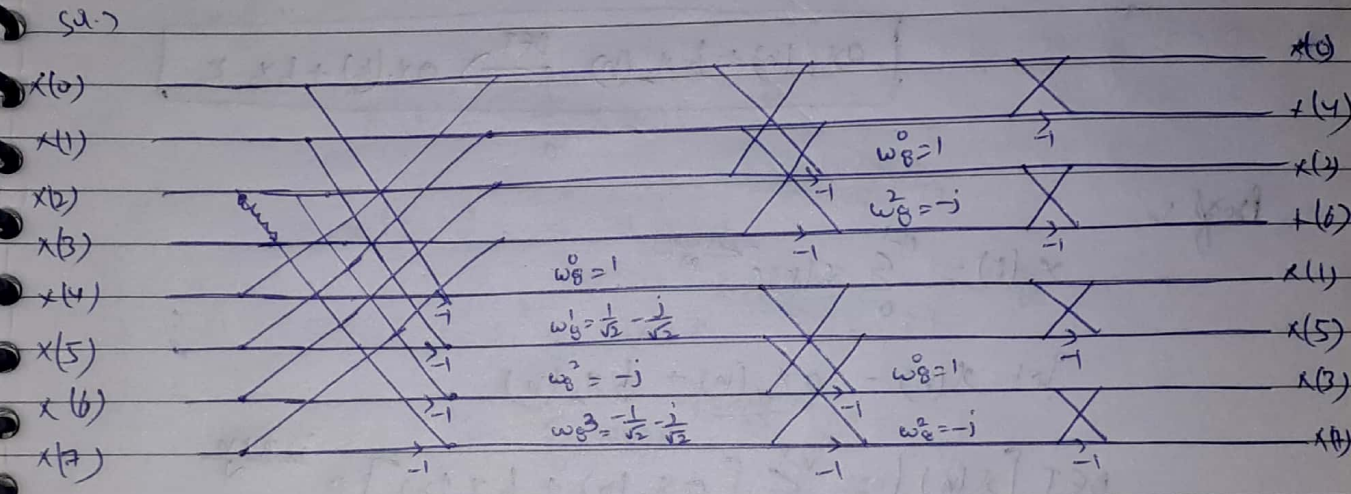
Q DIF-FFT

Calc. DFT for sequence {1, 2, 3, 4, 4, 3, 2, 1} using radix 2, DIF-FFT algorithm.

Sol.)



→ Calc. of multiplication of DFT & FFT algorithm with N sequence.

Sol.) $\frac{N}{2} \log_2 N$

→ Calc addition of DFT & FFT algorithm in N sequence

Sol.) $N \log_2 N$

→ warping & prewarping :- Relation b/w analog & digital freq. in bilinear transformation is given by $\Omega = \frac{2}{T} \tan \frac{\omega}{2}$. For smaller value of ω, relationship b/w ω and Ω is linear but for large value of ω, relationship is non-linear. This non-linear introduces distortion in frequency axis which is known as warping effect. This effect is compensated by using desired magnitude response and introducing a suitable prescaling or prewarping the critical frequency. $\Omega^* = \frac{2}{T} \tan \frac{\Omega T}{2}$

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Q. Determine Linear convolution using circular convolution.

$x_1(n) = \{1, 2, 3\}$ & $x_2(n) = \{1, 1\}$

Sol-> $x_1(n) = \{1, 2, 3\} \rightarrow M = 3$

$x_2(n) = \{1, 1\} \rightarrow N = 2$

$L = M + N - 1$

$= 3 + 2 - 1 = 4$

So adding extra zeros in $x_2(n)$ and $x_1(n)$

$x_1(n) = \{1, 2, 3, 0\}$

$x_2(n) = \{1, 1, 0, 0\}$

$$\begin{bmatrix} 1 & 0 & 3 & 2 \\ 2 & 1 & 0 & 3 \\ 3 & 2 & 1 & 0 \\ 0 & 3 & 2 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1+0+0+0 \\ 2+1+0+0 \\ 3+2+0+0 \\ 0+3+0+0 \end{bmatrix}$$

Ans = $\{1, 3, 5, 3\}$