Design and simulation of a low power and high speed Fast Fourier Transform for medical image compression

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OBJECTIVE:

➢To design and concentrate on the development of high-performance FFT algorithm (based on Decimation-In- Time (DIT) domain) to apply in the real time medical diagnosis.

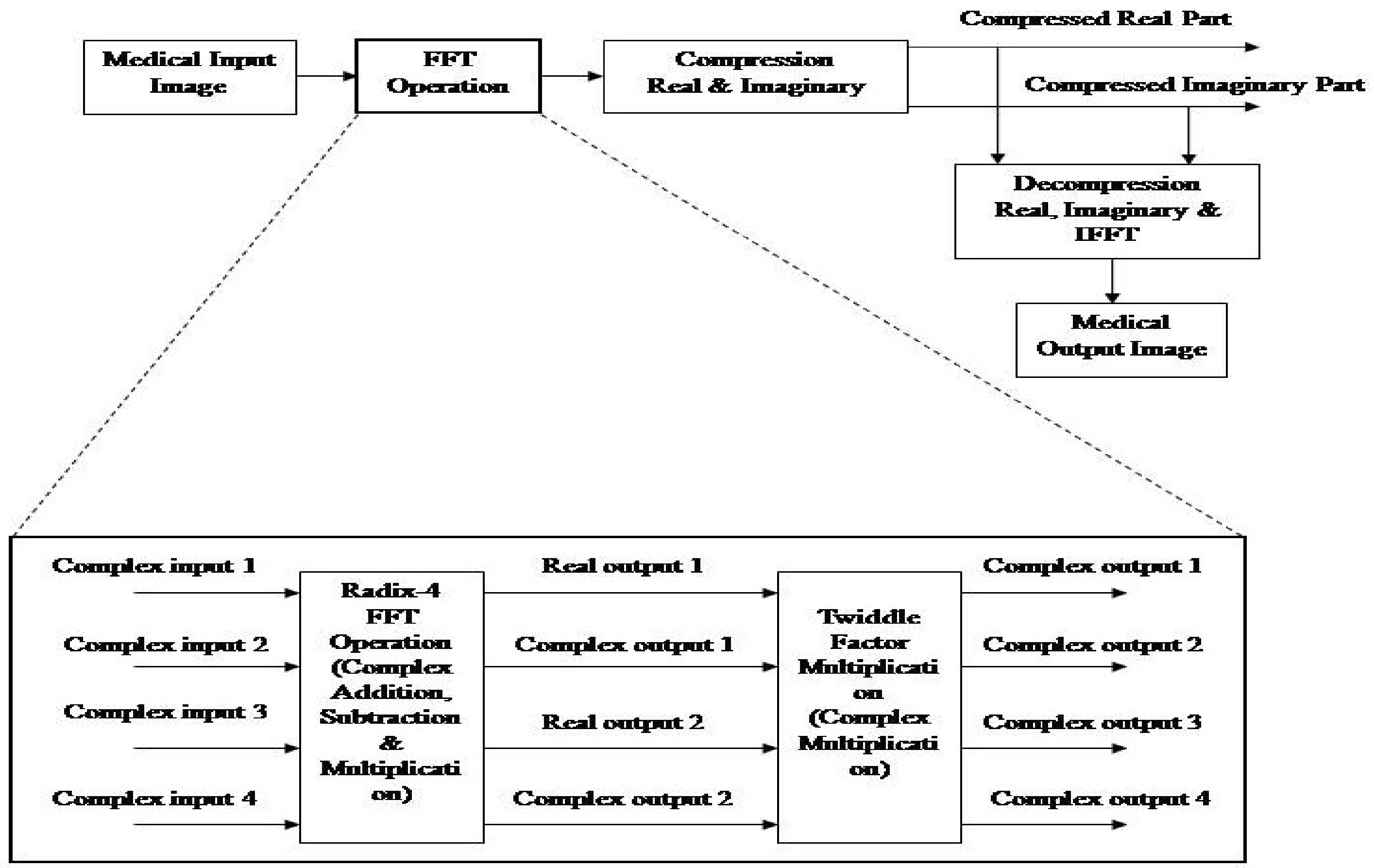


Fig: Block representation of medical image compression using proposed FFT

INTRO…..

- ➢Medical applications use FFT for image reconstruction and frequency domain analysis.
- ➢Medical imaging method/technology - CT, MRI, Ultrasound and Optical Imaging provides images of the human body for clinical diagnosis.
- ➢Images consists of patient's most vital information in the form of pixels
- ➢As hospitals are progressing into digitization, filmless imaging and telemedicine, the medical imagery becomes significantly important in the health sector.
- ➢Led to the major difficulty of developing compression algorithms that prevent diagnostic errors and have a high compression ratio for lower bandwidth and storages.

EXISTING SYSTEM:

- Deemed from paper titled "Design and Simulation of 32-Point FFT Using Radix-2 Algorithm for FPGA Implementation"
- Implementation can be done depending on 2^M
- Follows DOA algorithm

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-j\left(\frac{2\pi}{N}\right)kn},\ 0 \le k \le N-1$$

$$x(n) = 1/N \sum_{k=0}^{N-1} X(K) e^{j\left(\frac{2\pi}{N}\right)kn};0 \le n \le N-1$$

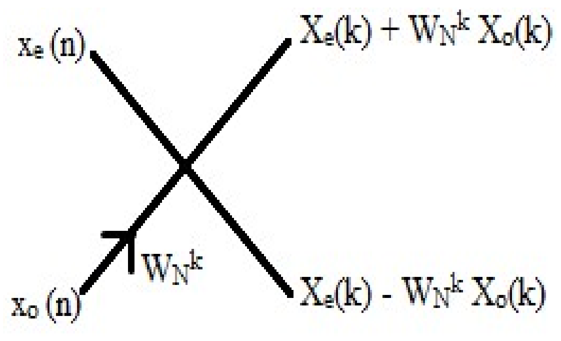


Fig: Radix-2 butterfly

- $W_N^k = e^{-j2\pi k/N}$ - represents twiddle factor
- Decimation in time FFT:
  - Number of stages = $\log_2 N$
  - Number of blocks/stage = $N/2^{stage}$
  - Number of butterflies/block = $2^{stage-1}$
  - Number of multiplications = $N/2 \log_2 N$
  - Number of addition = $N\log_2 N$

FLOW CHART:

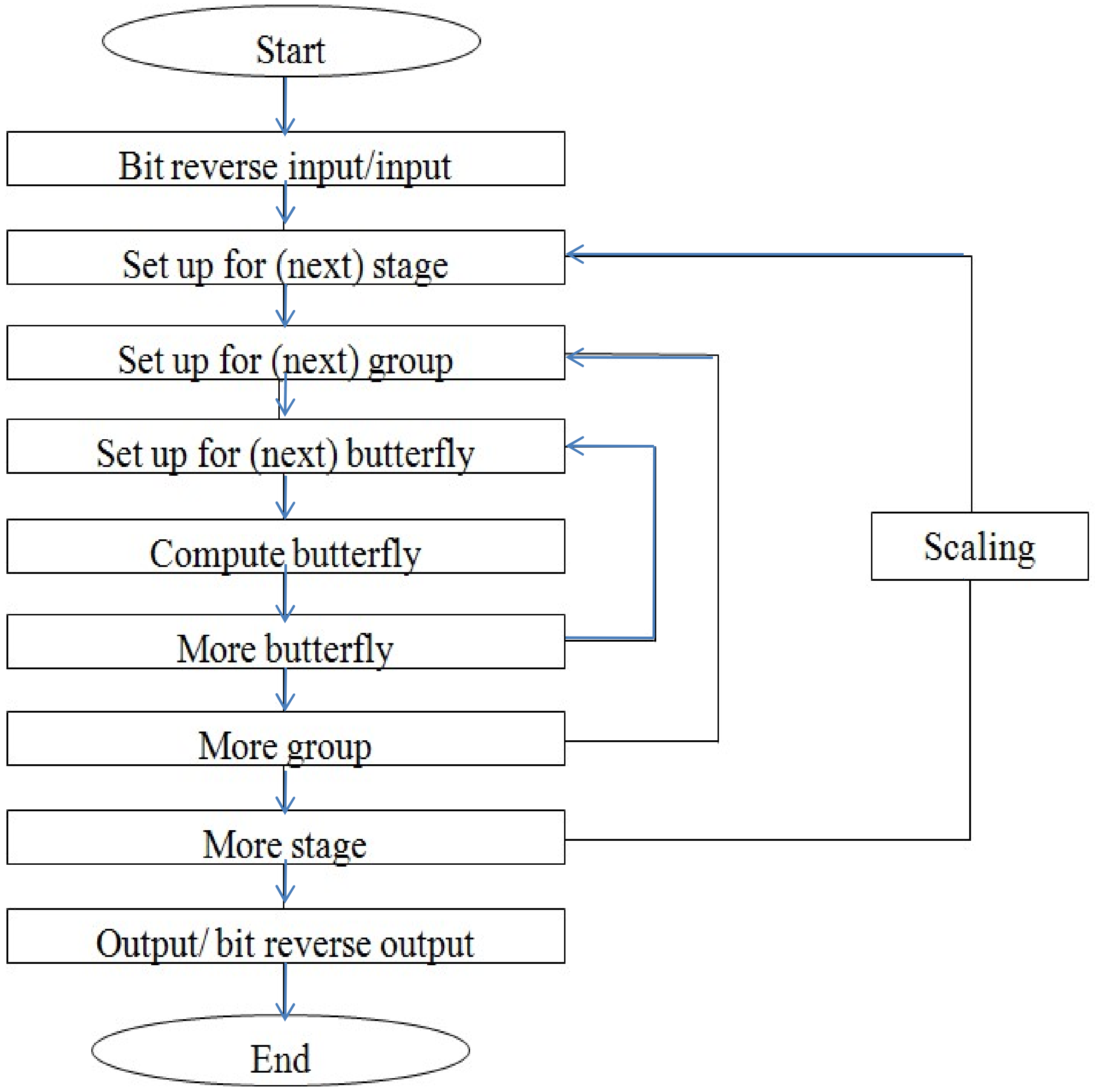


Fig: Flow chart for DIT- FFT Algorithm

STRUCTURE OF 32-POINT RADIX-2 FFT:

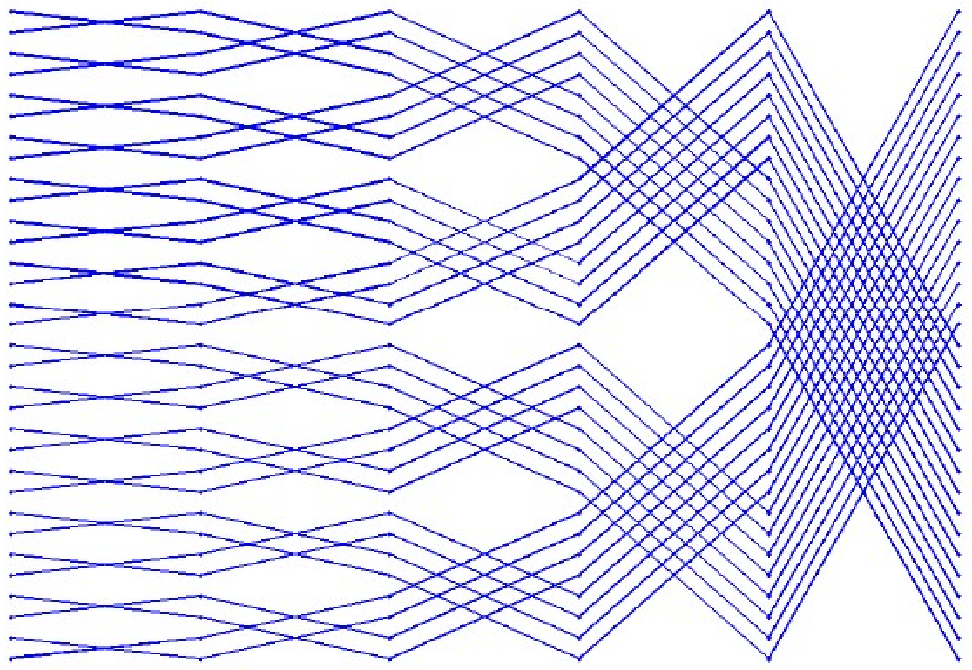


Fig: 32-point radix-2 fft algorithm

LIMITATIONS OF EXISTING SYSTEM:

- ➢Large computational requirements implies less speed
- ➢Maximum amount of resources
- ➢ Number of input and output pins also very low

PROPOSED SYSTEM:

- *Radix-4 algorithm*
- Butterfly of a radix 4 algorithm consists of four inputs and four outputs.
- FFT length is 4^M .
- Samples lies in subsequent locations

BASIC R4 BUTTERFLY:

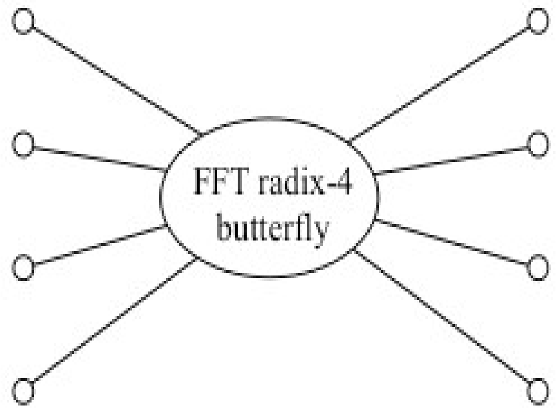


Fig: Basic Radix 4 butterfly diagram

- R-4 DIT-FFT gains its speed by reusing the results of smaller, intermediate stages
- It rearranges the DFT equation into 4 parts as

  n = [0, 4, 8, ... N - 4], n = [1, 5, 9, ... N - 3],

  n = [2, 6, 10, ... N - 2] and

  n = [3, 7, 11, ... N - 1]
- Twiddle factors

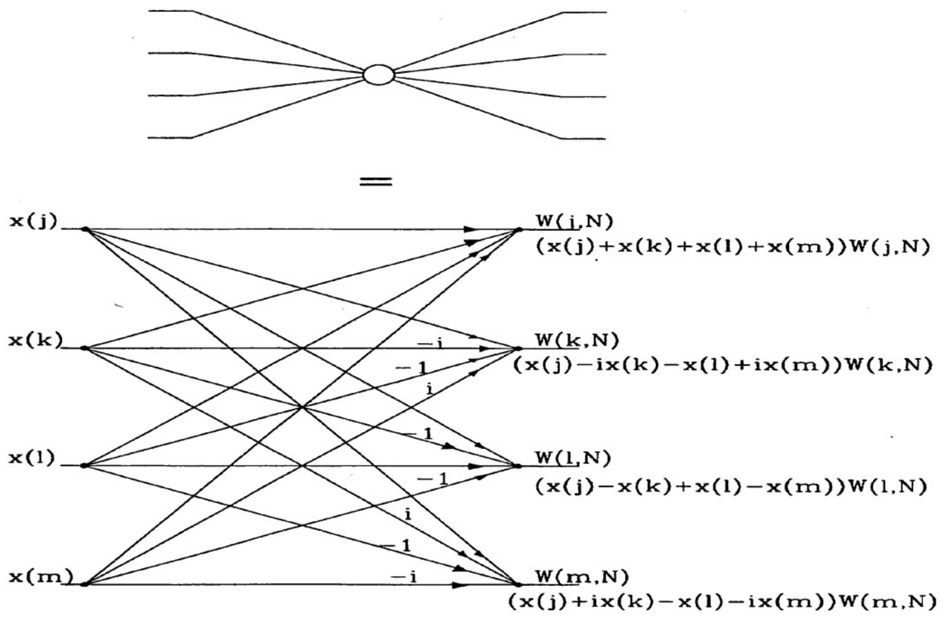

=
x(j)
x(k)
x(l)
x(m)
W(j,N)
(x(j)+x(k)+x(l)+x(m))W(j,N)
W(k,N)
(x(j)−ix(k)−x(l)+ix(m))W(k,N)
W(l,N)
(x(j)−x(k)+x(l)−x(m))W(l,N)
W(m,N)
(x(j)+ix(k)−x(l)−ix(m))W(m,N)
−i
−1
i
−1
−1
i
−1
−i

Fig: Operation of R4 DIT FFT

- If the input sequence is [1,0,1,1] then the output sequence is [3,j,1,-j]

64 POINT R4 BUTTERFLY SCHEMATIC DIAGRAM:

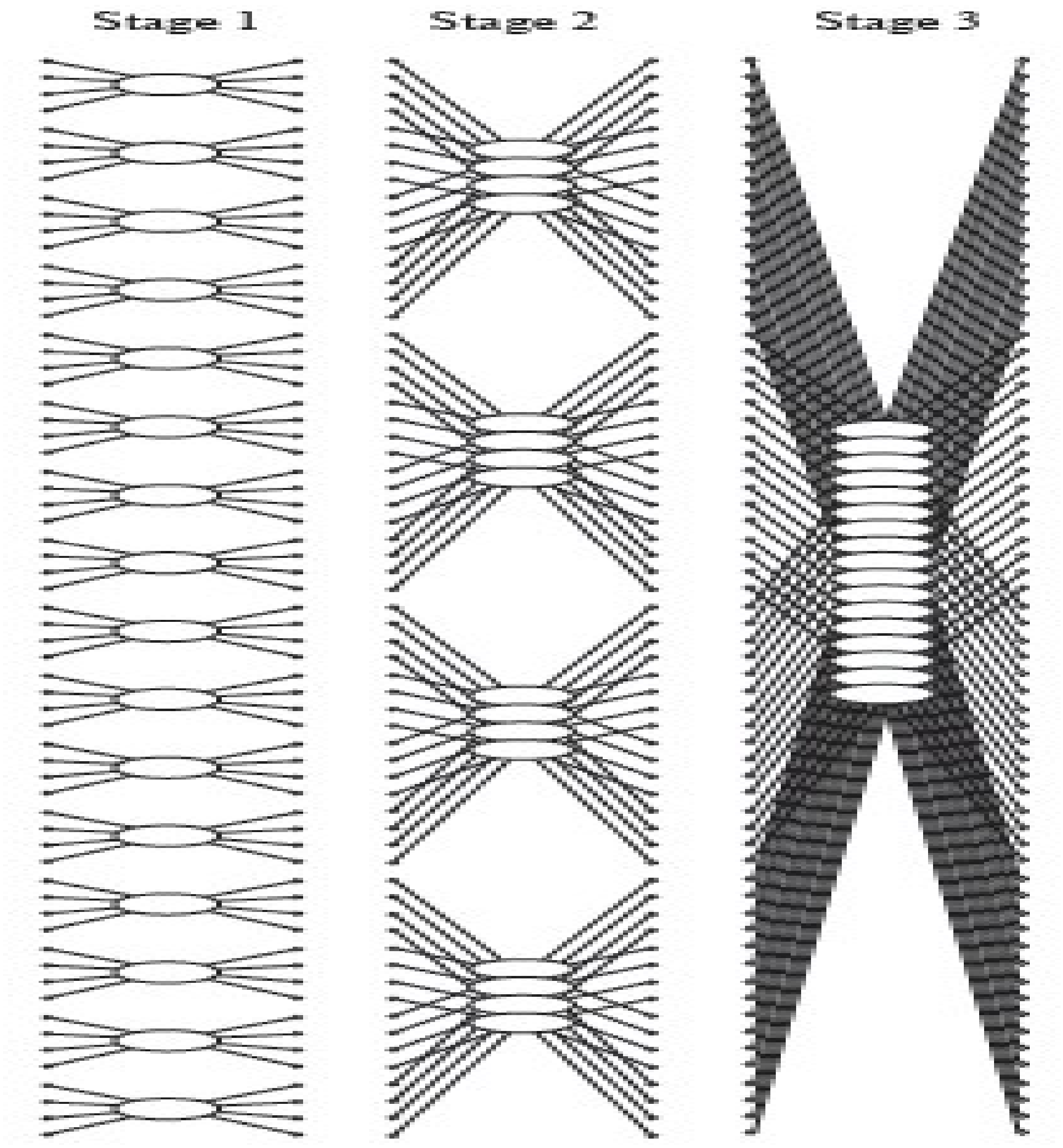


Fig: Radix-4 butterfly diagram

256-bit 64-point R-4 butterfly contains the following:

- Data split of 256 bits and 64 bits
- Even and odd
- DFT four
- Butterfly 4, 8, 16
- Comutator
- Top butter

ALGORITHM:

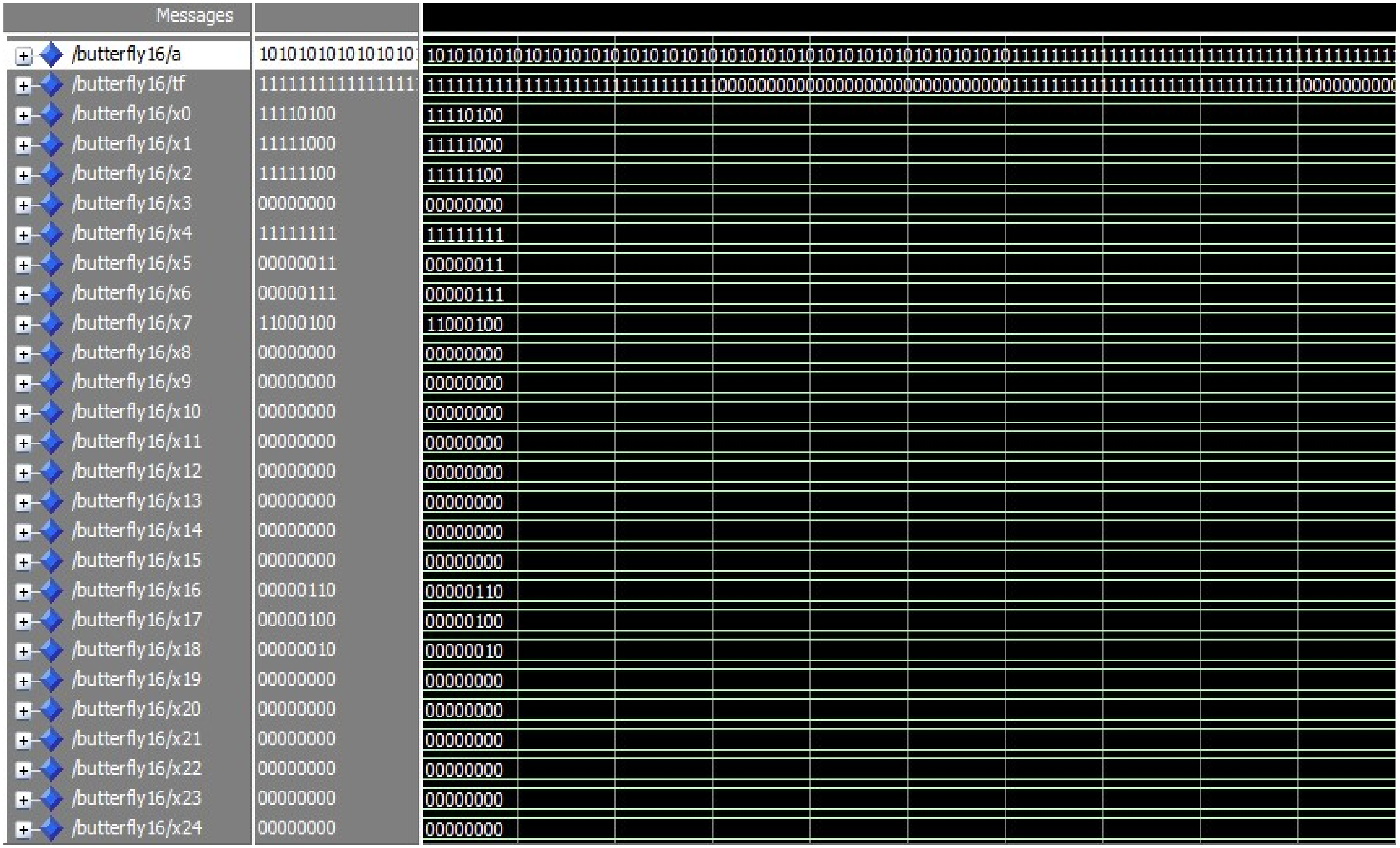
- Declare the input (256 bits), output (64 points each of 8 bits) and other signals (twiddle factors of 256 bits).
- Call the data split and top butter and declare the signals as

```
COMPONENT datasplit256 is
    Port(A: in signed (0 to 255);
        B,C,D,E:OUT SIGNED (0 TO 63));
    End COMPONENT;
    COMPONENT Topbutter is
    port(A: in signed (0 to 63);
        Tf1 ......... Tf16:in signed(0 to 3);
        od11 ......... od88:out signed(0 to 7);
        ev11 ......... ev88:out signed(0 to 7));
    End COMPONENT;
    SIGNAL B,C,D,E:SIGNED (0 TO 63);
```

```
BEGIN
        M1:datasplit
        port
map(A=>A,B=>B,C=>C,D=>D,E=>E);
        M2:Topbutter
        PORT MAP(A=>B,Tf1=>Tf (0 TO
3)......... Tf16=>Tf (60 TO 63),
        od11=>x0,......... od88=>x7,
        ev11=>x8,......... ev88=>x15);
        M3:Topbutter A=>C
        M4:Topbutter A=>D
        M5:Topbutter A=>E
```

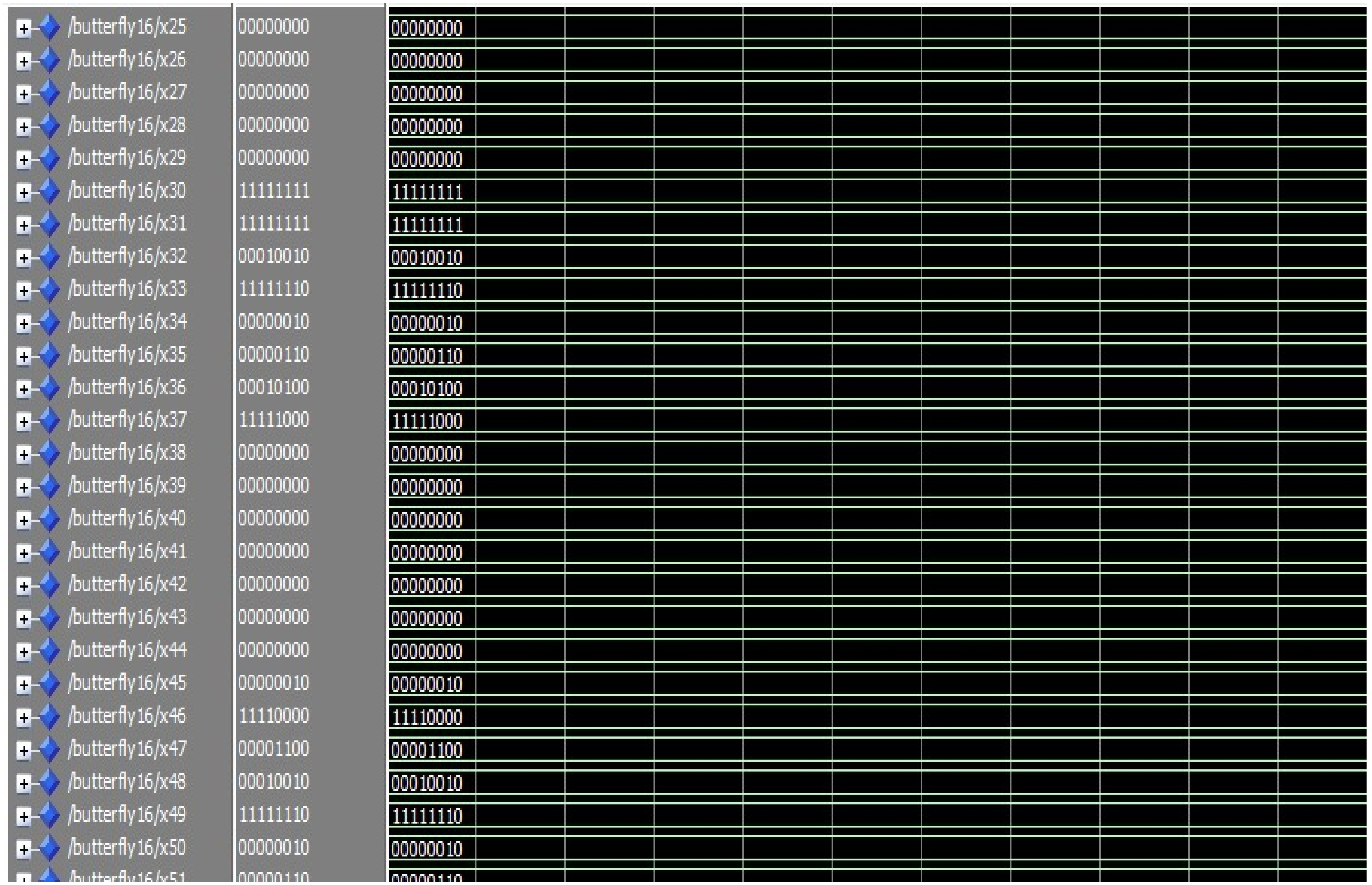
SIMULATION RESULTS:

Simulation results are:



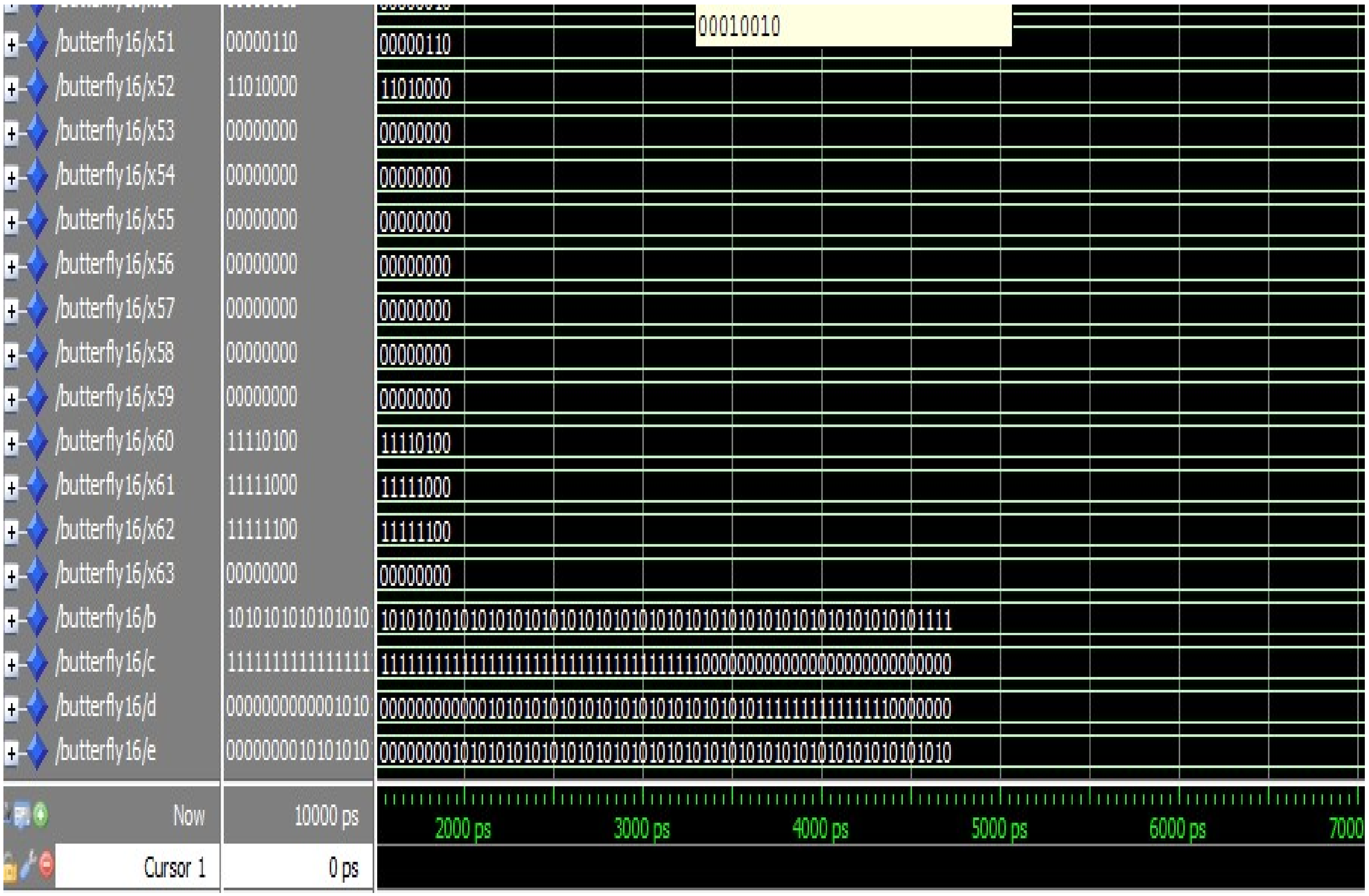
```
Messages
/butterfly16/a     1010101010101010   10101010101010101010101010101010101010101010101010101010101011111111111111111111111111111111111111
/butterfly16/tf    1111111111111111   11111111111111111111111111111000000000000000000000000000000111111111111111111111111111111000000000
/butterfly16/x0    11110100           11110100
/butterfly16/x1    11111000           11111000
/butterfly16/x2    11111100           11111100
/butterfly16/x3    00000000           00000000
/butterfly16/x4    11111111           11111111
/butterfly16/x5    00000011           00000011
/butterfly16/x6    00000111           00000111
/butterfly16/x7    11000100           11000100
/butterfly16/x8    00000000           00000000
/butterfly16/x9    00000000           00000000
/butterfly16/x10   00000000           00000000
/butterfly16/x11   00000000           00000000
/butterfly16/x12   00000000           00000000
/butterfly16/x13   00000000           00000000
/butterfly16/x14   00000000           00000000
/butterfly16/x15   00000000           00000000
/butterfly16/x16   00000110           00000110
/butterfly16/x17   00000100           00000100
/butterfly16/x18   00000010           00000010
/butterfly16/x19   00000000           00000000
/butterfly16/x20   00000000           00000000
/butterfly16/x21   00000000           00000000
/butterfly16/x22   00000000           00000000
/butterfly16/x23   00000000           00000000
/butterfly16/x24   00000000           00000000
```

Cont …..



```
/butterfly16/x25   00000000   00000000
/butterfly16/x26   00000000   00000000
/butterfly16/x27   00000000   00000000
/butterfly16/x28   00000000   00000000
/butterfly16/x29   00000000   00000000
/butterfly16/x30   11111111   11111111
/butterfly16/x31   11111111   11111111
/butterfly16/x32   00010010   00010010
/butterfly16/x33   11111110   11111110
/butterfly16/x34   00000010   00000010
/butterfly16/x35   00000110   00000110
/butterfly16/x36   00010100   00010100
/butterfly16/x37   11111000   11111000
/butterfly16/x38   00000000   00000000
/butterfly16/x39   00000000   00000000
/butterfly16/x40   00000000   00000000
/butterfly16/x41   00000000   00000000
/butterfly16/x42   00000000   00000000
/butterfly16/x43   00000000   00000000
/butterfly16/x44   00000000   00000000
/butterfly16/x45   00000010   00000010
/butterfly16/x46   11110000   11110000
/butterfly16/x47   00001100   00001100
/butterfly16/x48   00010010   00010010
/butterfly16/x49   11111110   11111110
/butterfly16/x50   00000010   00000010
/butterfly16/x51   00000110   00000110
```

Cont …..



```
/butterfly16/x51   00000110            00000110
/butterfly16/x52   11010000            11010000
/butterfly16/x53   00000000            00000000
/butterfly16/x54   00000000            00000000
/butterfly16/x55   00000000            00000000
/butterfly16/x56   00000000            00000000
/butterfly16/x57   00000000            00000000
/butterfly16/x58   00000000            00000000
/butterfly16/x59   00000000            00000000
/butterfly16/x60   11110100            11110100
/butterfly16/x61   11111000            11111000
/butterfly16/x62   11111100            11111100
/butterfly16/x63   00000000            00000000
/butterfly16/b     1010101010101010    1010101010101010101010101010101010101010101010101010101010101111
/butterfly16/c     1111111111111111    1111111111111111111111111111111111111000000000000000000000000000
/butterfly16/d     0000000000001010    0000000000001010101010101010101010101010101111111111111110000000
/butterfly16/e     0000000010101010    0000000010101010101010101010101010101010101010101010101010101010
Now                10000 ps
Cursor 1           0 ps
```

00010010

CHRONALOGICAL VIEW OF PROPOSED ALGORITHM:

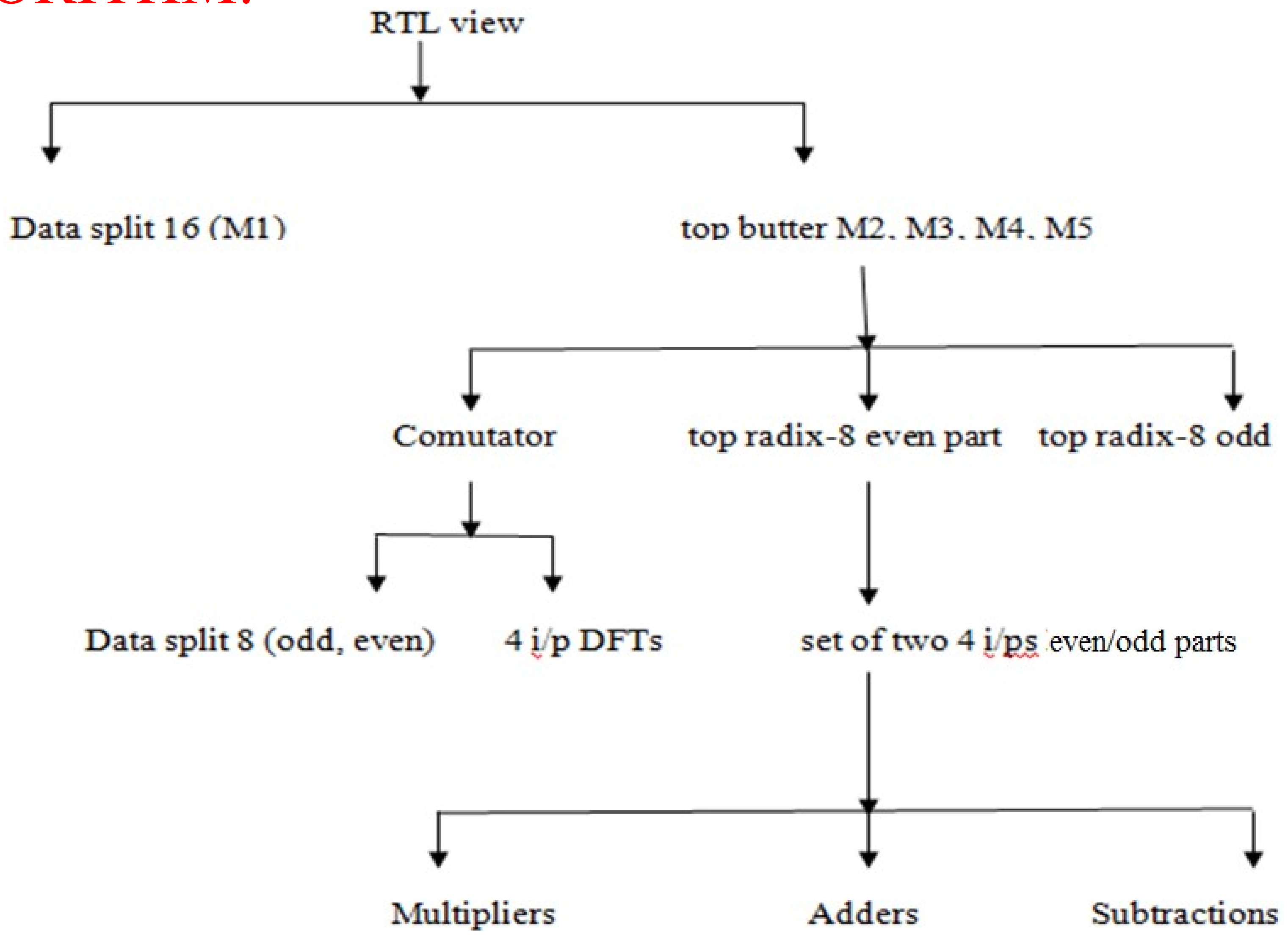


Fig: Tree diagram of functioning of proposed system

RTL VIEW OF R4 ALGORITHM:

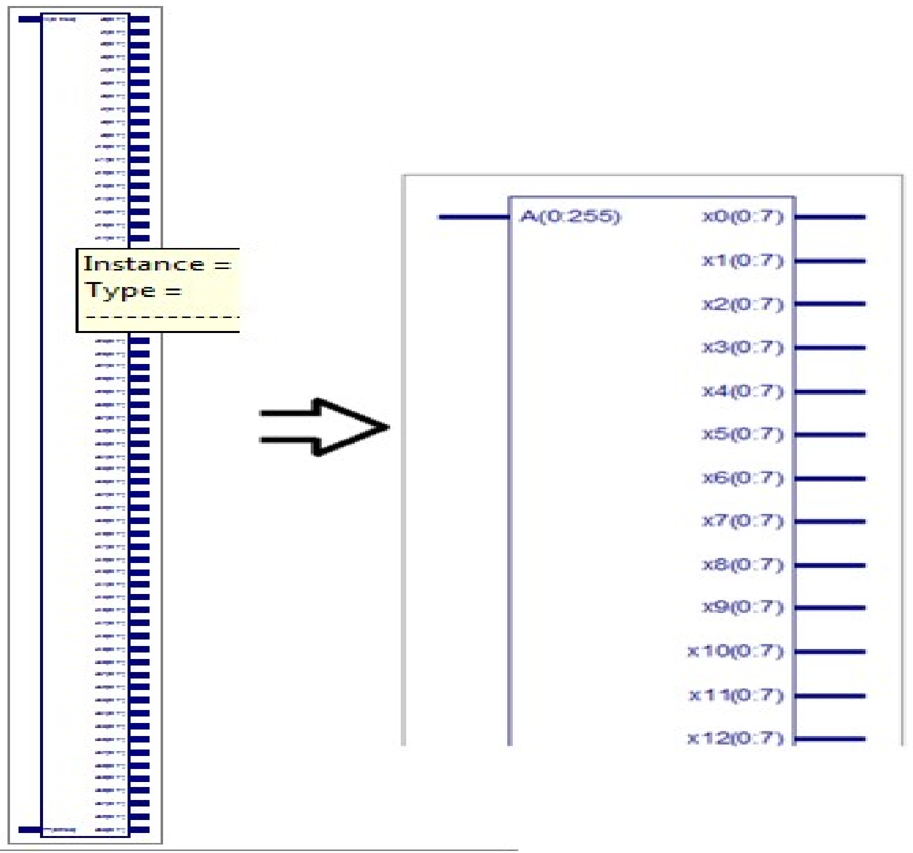


Fig: RTL view of radix-4 algorithm

DATA SPLIT OF 64-POINT:

➢A is an input sequence of 256-bits (0 to 255), divide into 4 equal parts of each 16-point, 64-bit (0 to 63, 64 to 127, 128 to 191, 192 t0 255).

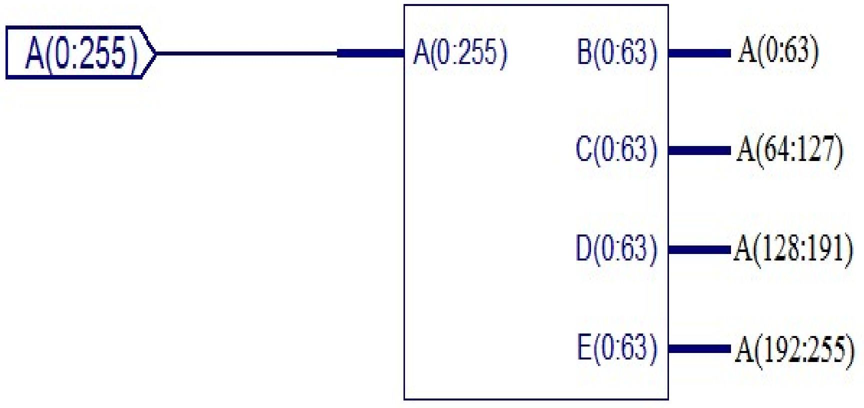


Fig. : RTL view of data split of 64-points

RTL INTERNAL VIEW:

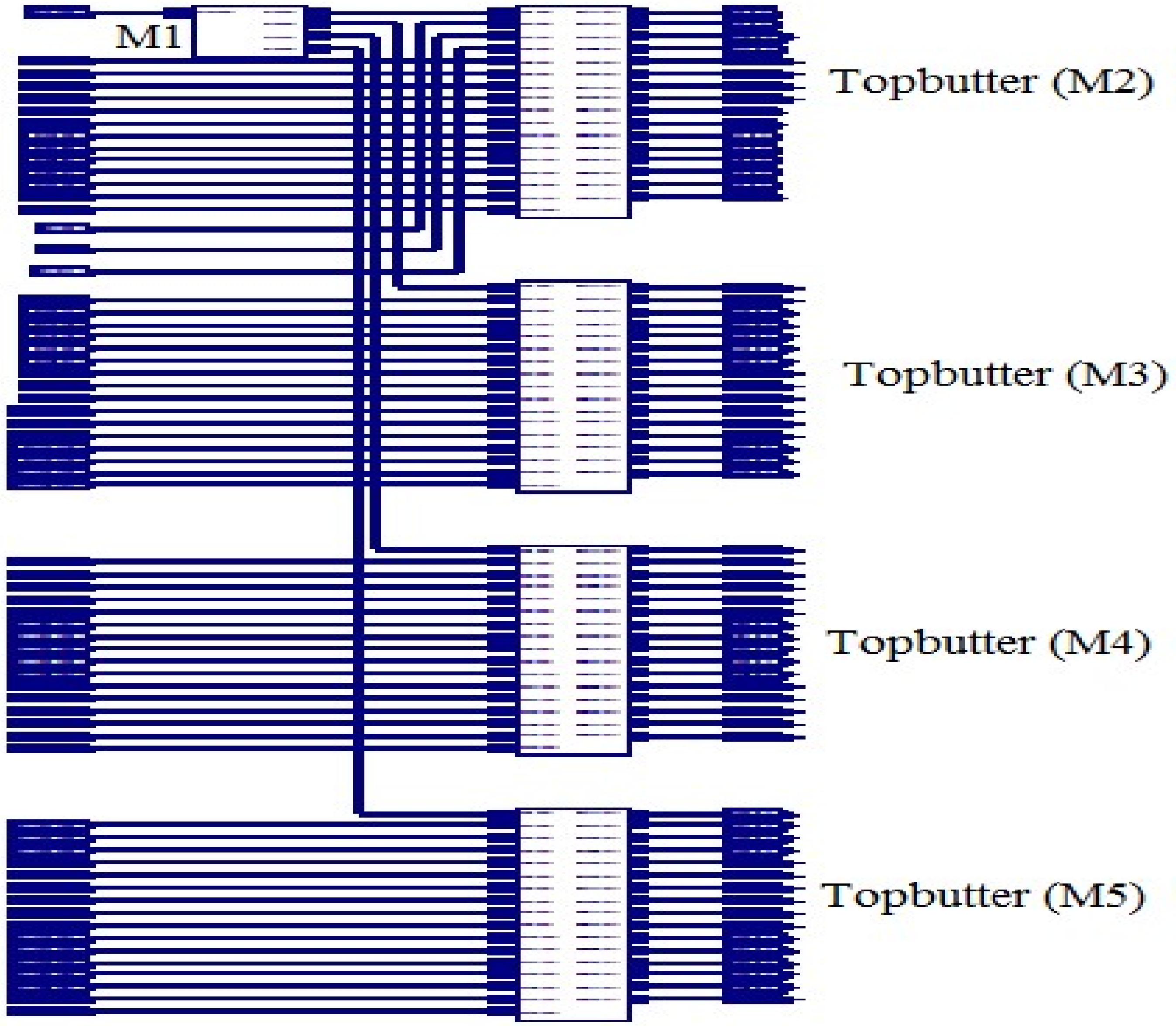


Fig: RTL internal view

OVERVIEW OF TOP BUTTER (M2):

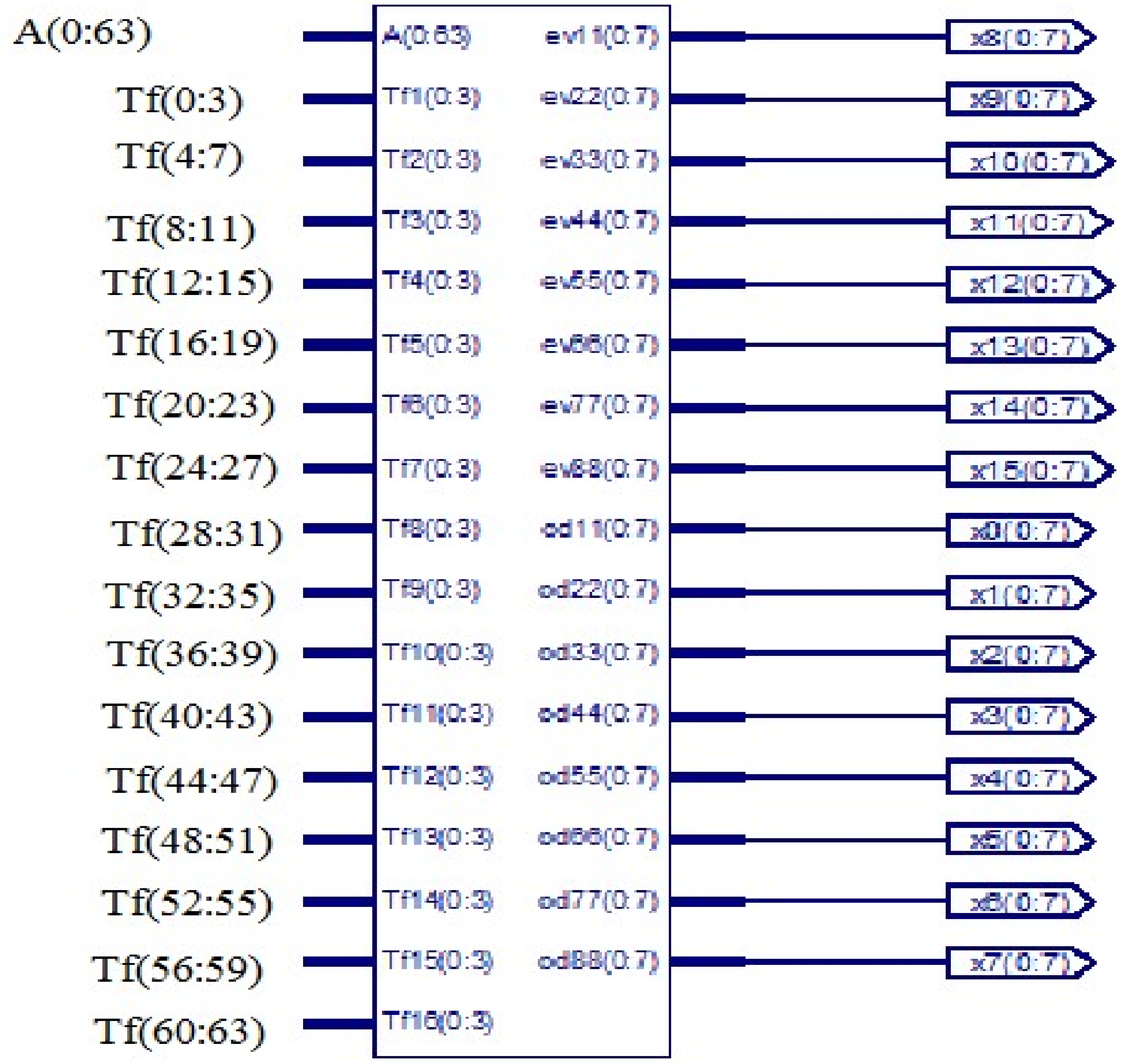


Fig: Overview of Top butter (M2).

TOP BUTTER:

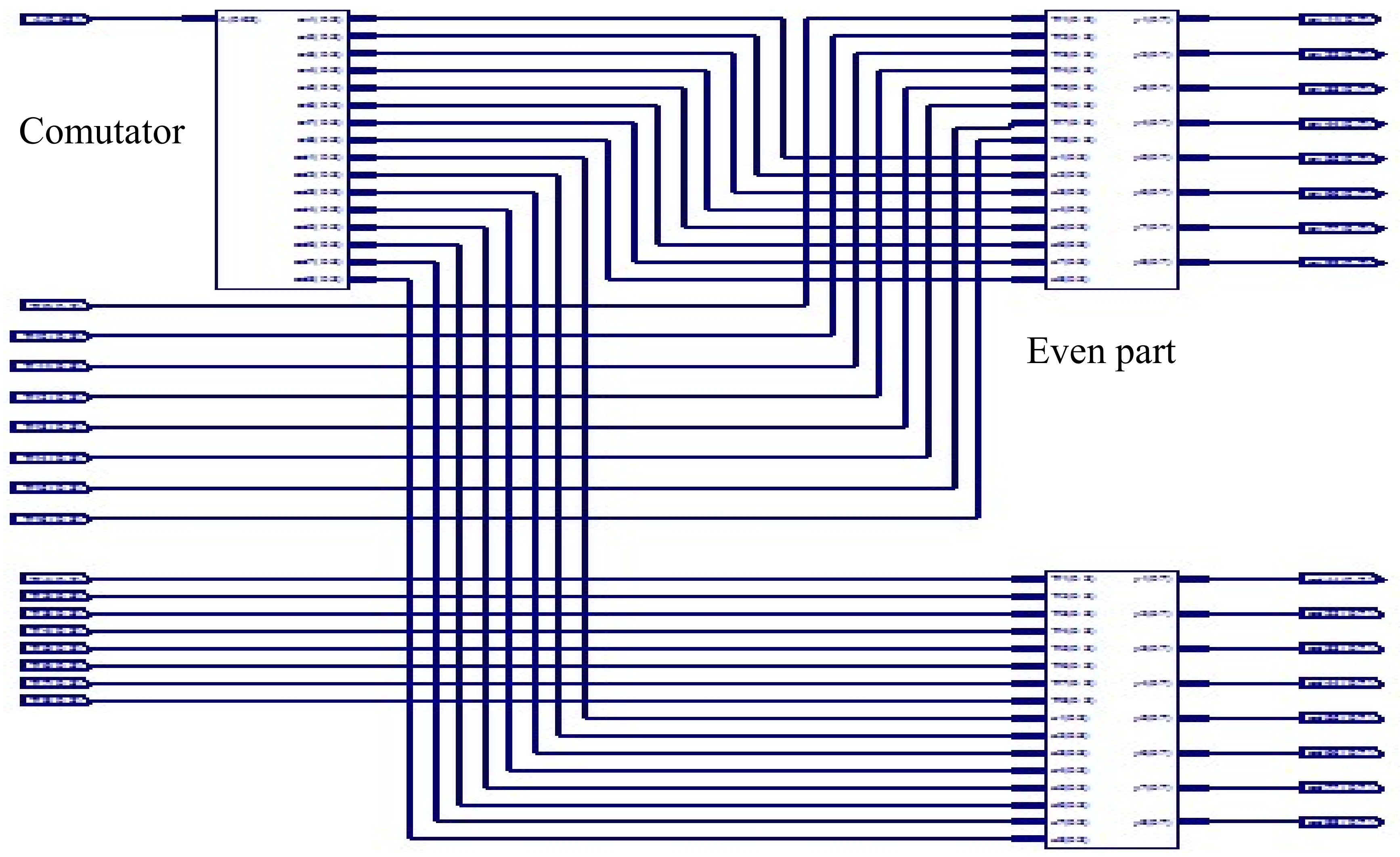


Fig: Internal view of Top butter (M2)

COMUTATOR:

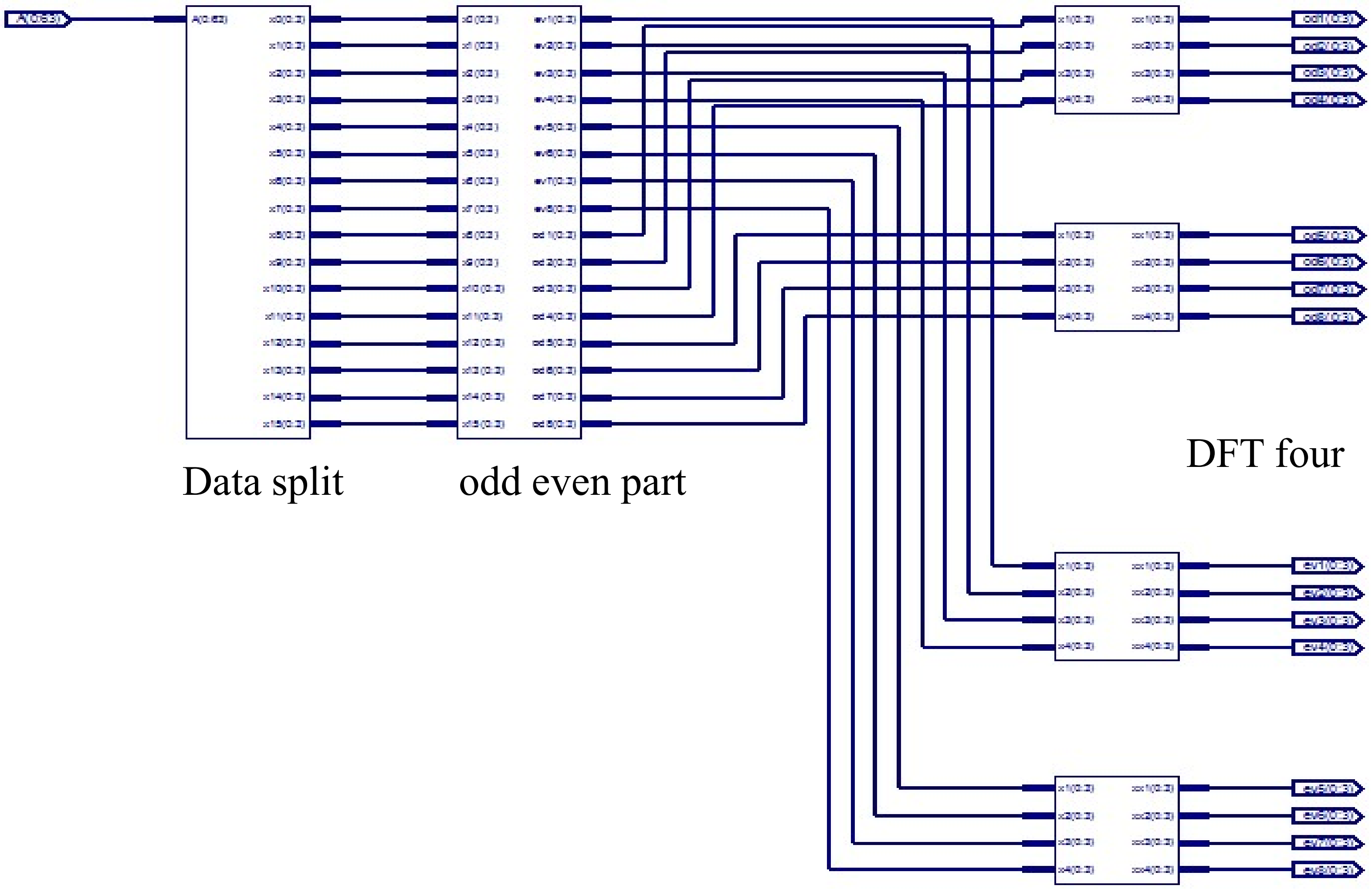


Fig: Comutator internal view

DFT FOUR:

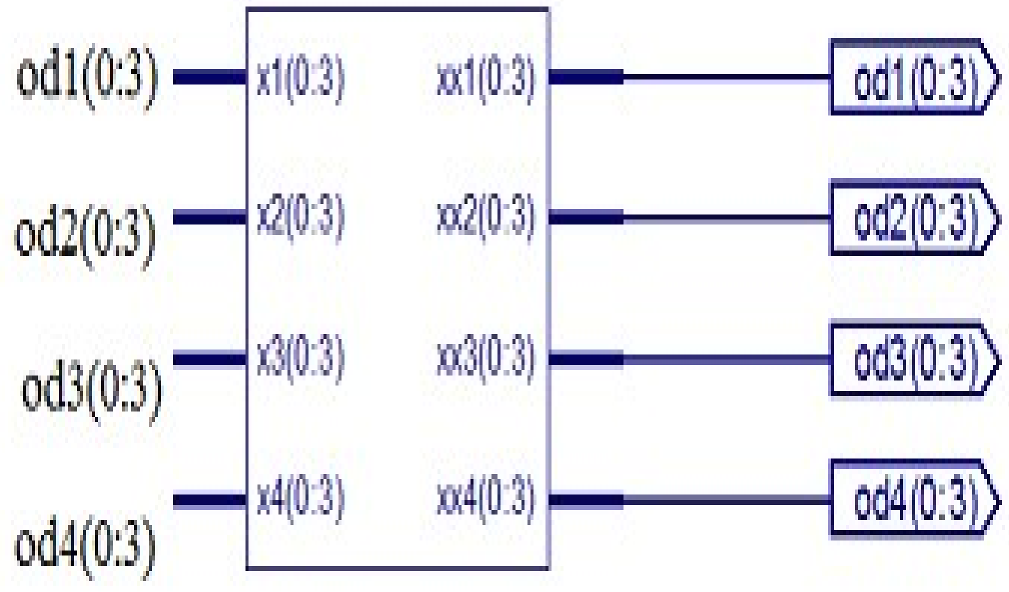


Fig: The arrangement of even and odd parts

- ➢DFT four is the basic unit in radix-4 structure.
- ➢Four inputs and four outputs

BUTTER R8:

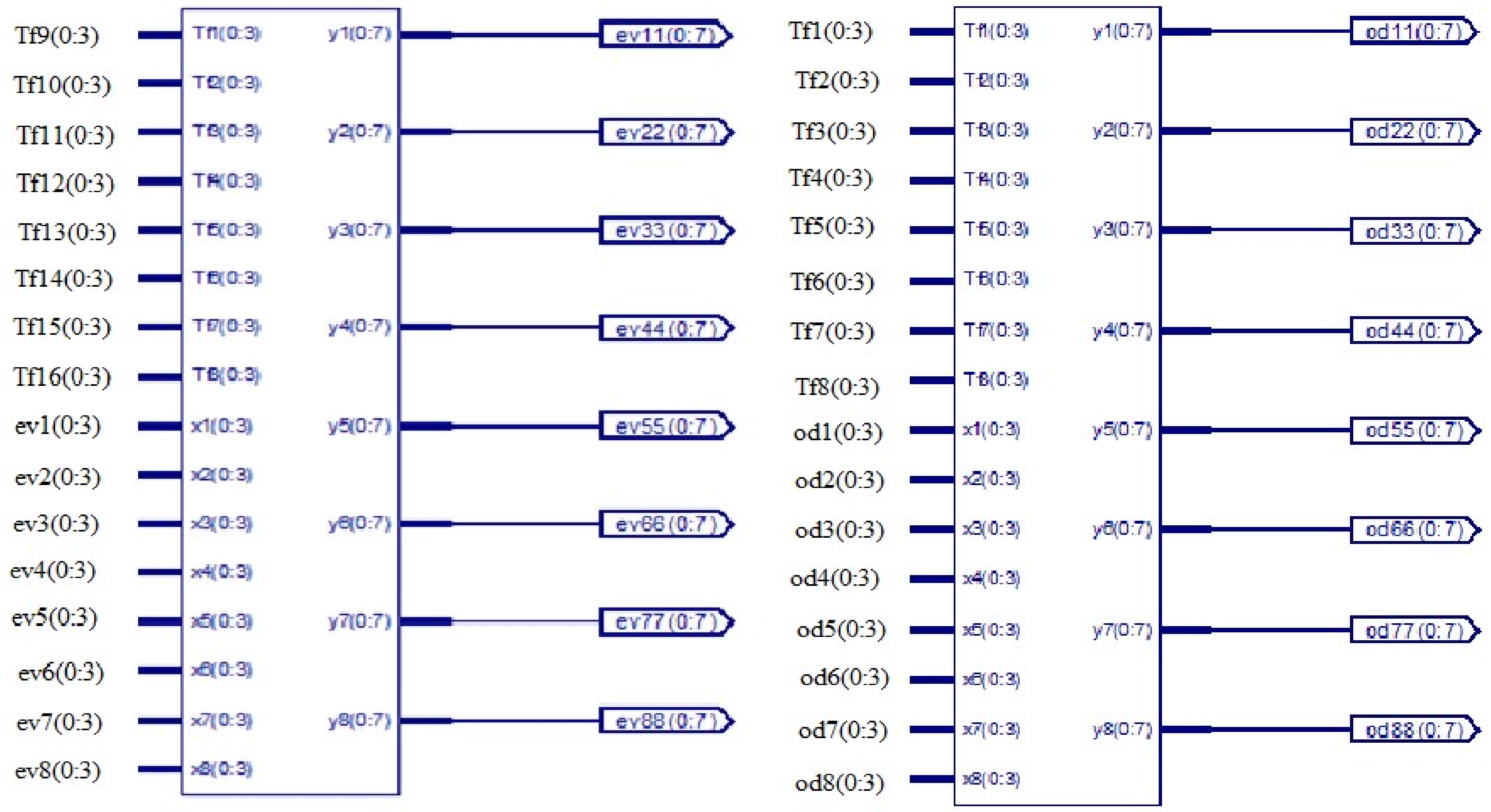


Fig: Over view of butter R8

BUTTER R4:

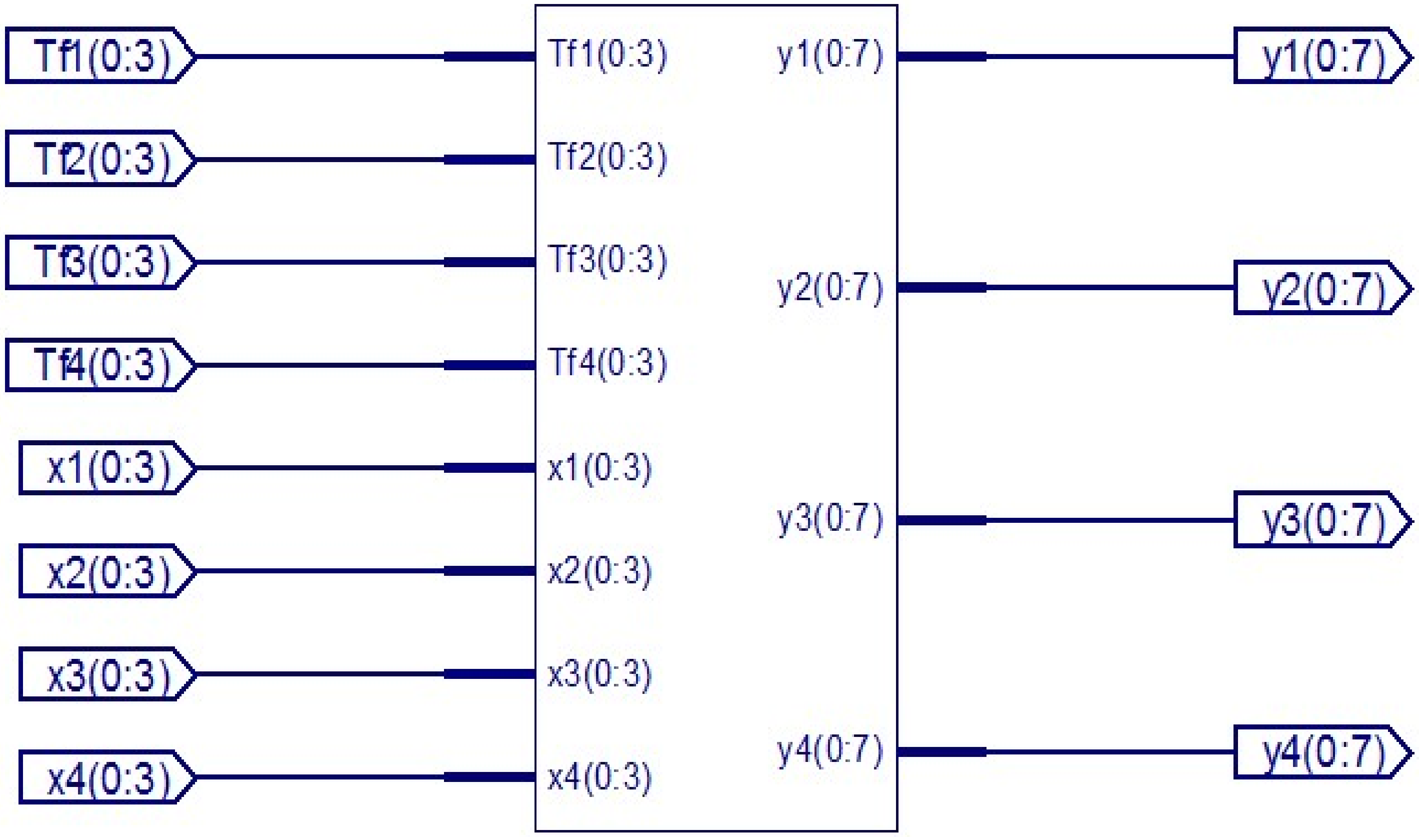


Fig: Over view of butter R4

EVEN AND ODD PARTS:

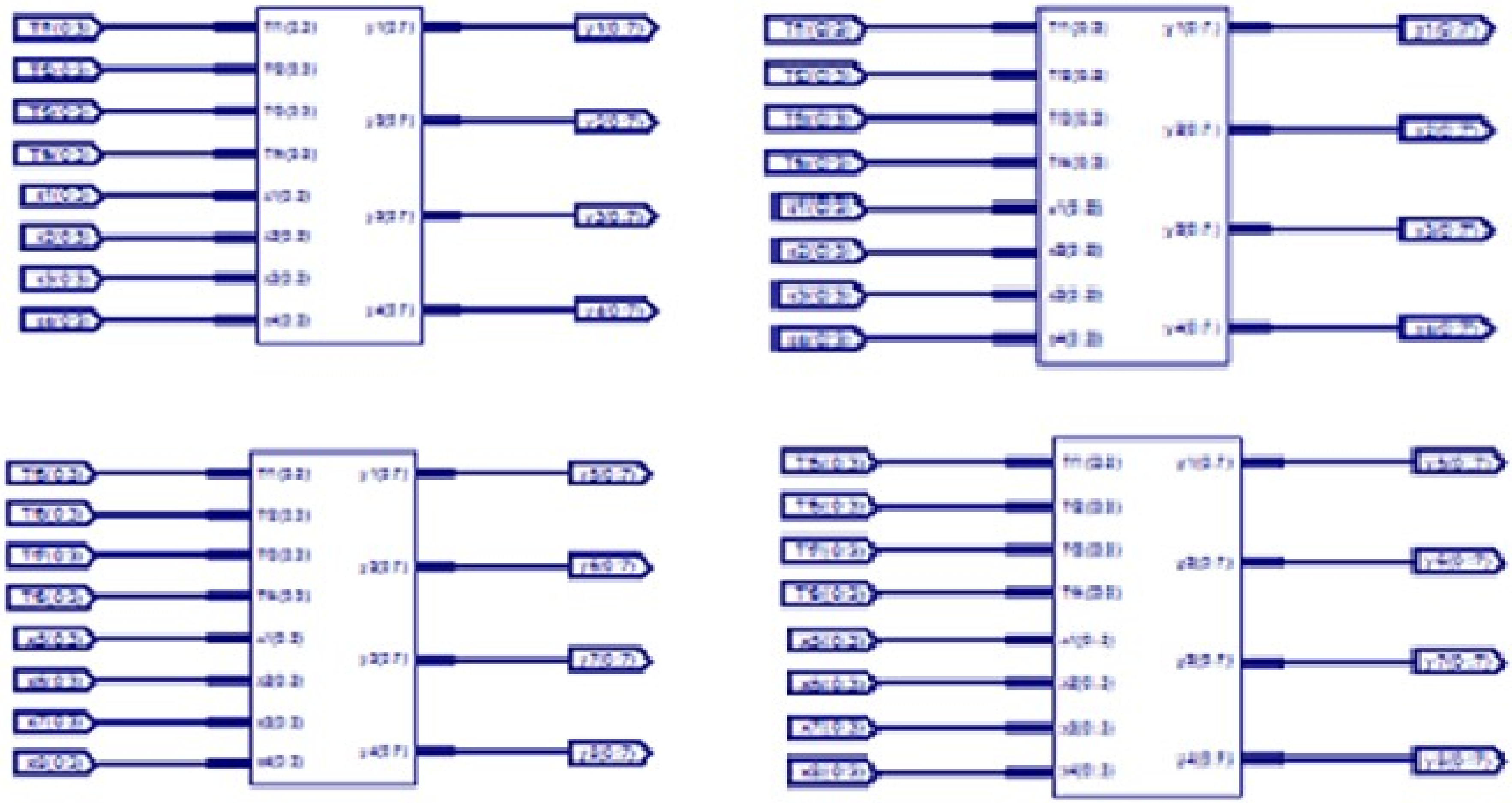
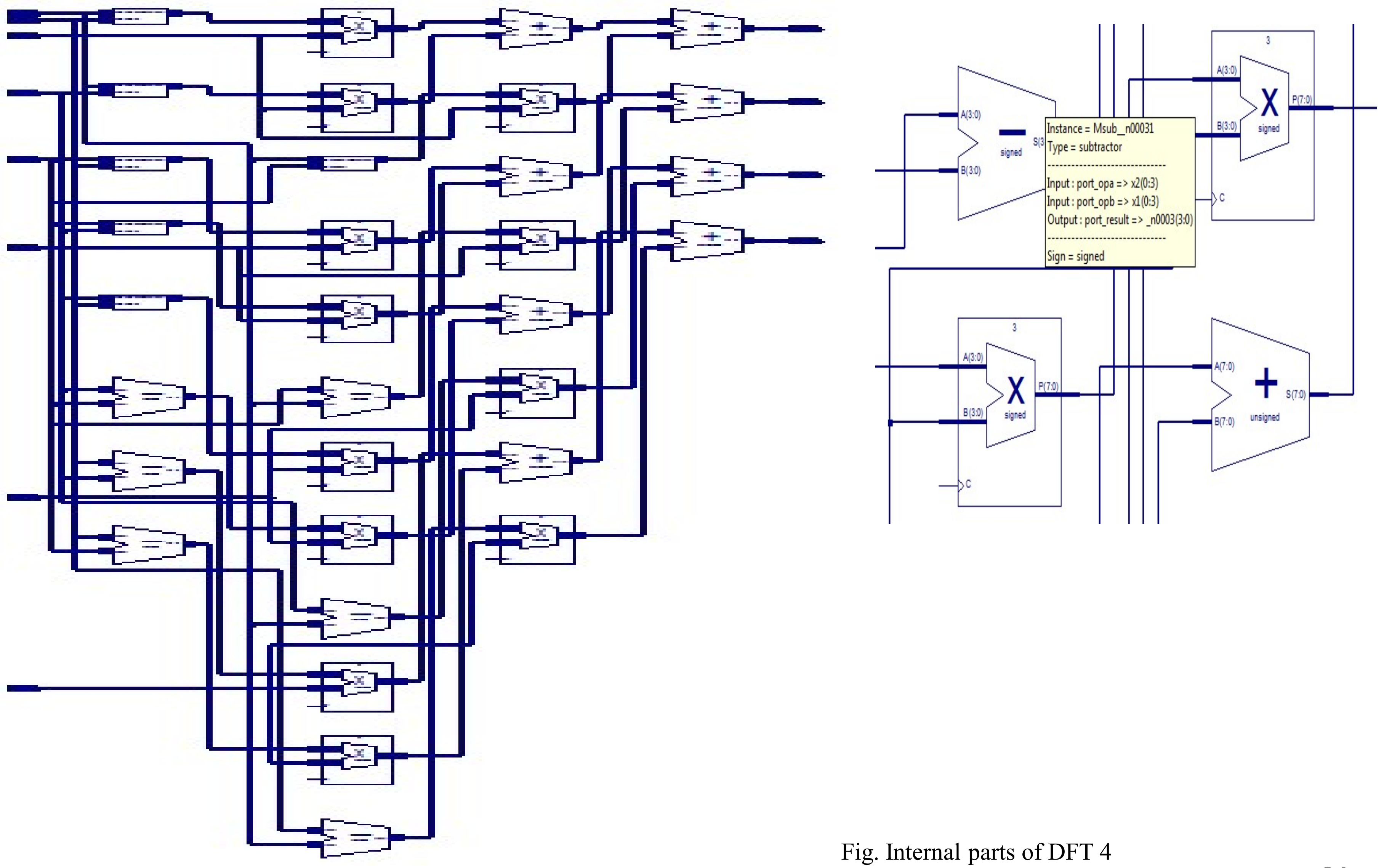


Fig: The even and odd parts

Cont ……



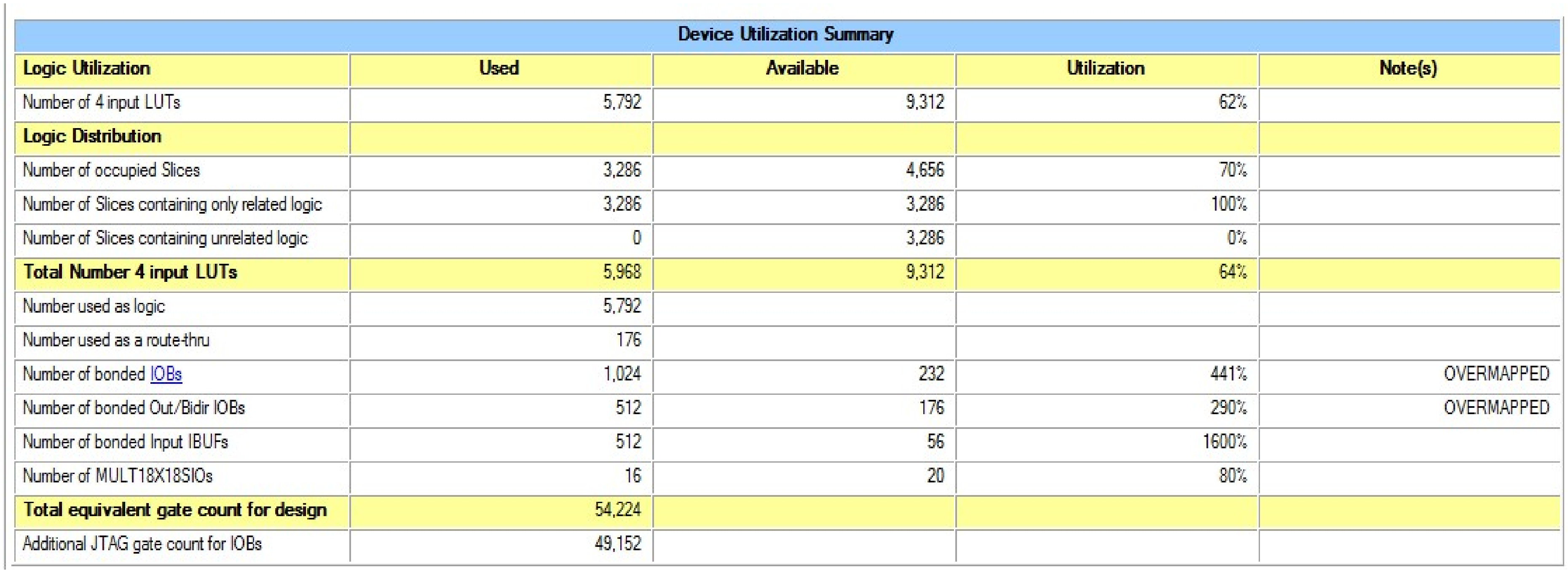
Instance = Msub_n00031
Type = subtractor

Input : port_opa => x2(0:3)
Input : port_opb => x1(0:3)
Output : port_result => _n0003(3:0)

Sign = signed

Fig. Internal parts of DFT 4

DESIGN SUMMARY:



Device Utilization Summary				
Logic Utilization	**Used**	**Available**	**Utilization**	**Note(s)**
Number of 4 input LUTs	5,792	9,312	62%	
Logic Distribution				
Number of occupied Slices	3,286	4,656	70%	
Number of Slices containing only related logic	3,286	3,286	100%	
Number of Slices containing unrelated logic	0	3,286	0%	
Total Number 4 input LUTs	5,968	9,312	64%	
Number used as logic	5,792			
Number used as a route-thru	176			
Number of bonded IOBs	1,024	232	441%	OVERMAPPED
Number of bonded Out/Bidir IOBs	512	176	290%	OVERMAPPED
Number of bonded Input IBUFs	512	56	1600%	
Number of MULT18X18SIOs	16	20	80%	
Total equivalent gate count for design	54,224			
Additional JTAG gate count for IOBs	49,152			

COMPARISON TABLE:

Table: comparison of radix-4 and radix-2 algorithm

DEVICE UTILIZATION	RADIX-2				RADIX-4			
	USED	AVAILABLE	UTILIZATION	RESULTS	USED	AVAILABLE	UTILIZATION	RESULTS
Number of Slices	2388	4656	51%		3332	4656	71%	
Number of 4 input LUTs	4282	9312	45%		5936	9312	63%	
Number of bonded IOBs	135	232	58%		1024	232	441%	Overused
Number of MULT18X18SIOs	----	----------	-------------	----------	16	20	80%	
Number of slices FFs	235	9312	2%		---	---------	------------	--------
Number of GCLKs	3	24	12%		-----	----------	-----------	--------
Minimum delay	**75.050ns** **(44.212ns logic, 30.838ns route)(58.9% logic, 41.1% route)**				**18.963ns** **(11.549ns logic, 7.414ns route) (60.9% logic, 39.1% route)**			
Total memory usage	**206720 kilobytes**				**228928 kilobytes**			

ADVANTAGES OF RADIX-4 ALGORITHM:

- In radix-2 implementation, $64=2^6$, FFT index is changed as, there are *6 Σ computations*. This corresponds to *six stages* architecture.
- If in case of radix-4 implementation, $64=4^3$, FFT index is changed as, there are *3 Σ computations*. This corresponds to *three stages* architecture.
- Complex multiplications are 75% of R2 and additions are same
- High speed and throughput

Performance Comparison

Parameter	This work	[2]	[8]	[10]	[14]
FFT Size	64-4	32-8	64-4	16-4	16-4
Delay (ns)	18.96	419	8.10	2.2	2.67
Power(mW)	12.68	739.5	33.5	3.5	4

APPLICATIONS:

- Communications
- Convolution
- Signal filtering
- Image/Data compression
- The proposed algorithm for image compression is simulated using target device xc3s500e-5fg320.
- The considered medical image has compressed using different tolerance values like 0.0007625, 0.003246, 0.013075 and 0.03924 and it also returns the drop values calculated using the formula **Drop ratio = (Total number of nonzero Fourier coefficients dropped/Total number of initially nonzero Fourier coefficients)** given as 0.10, 0.31, 0.61 and 0.83 respectively

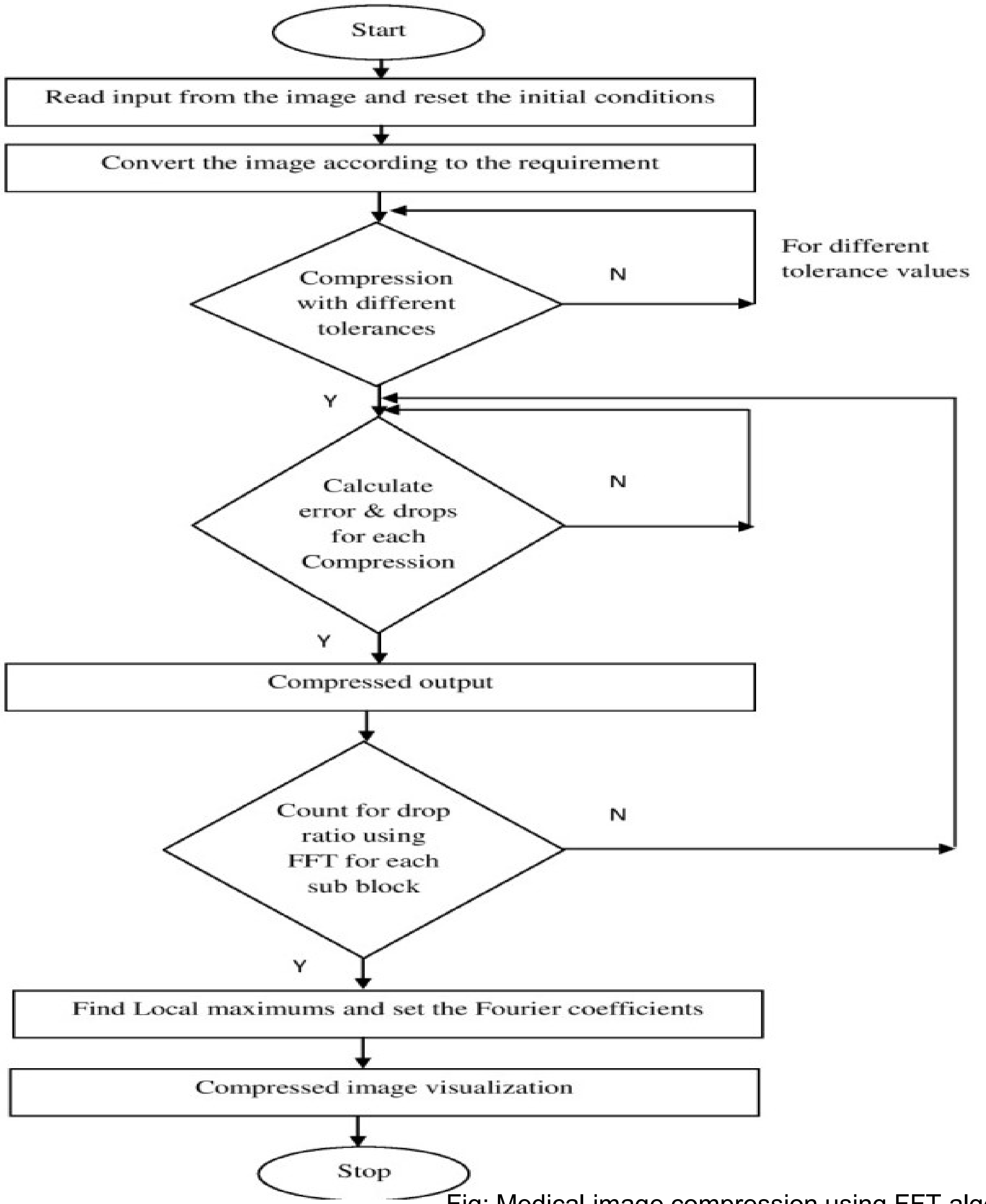

Start
Read input from the image and reset the initial conditions
Convert the image according to the requirement
Compression with different tolerances
N
For different tolerance values
Y
Calculate error & drops for each Compression
N
Y
Compressed output
Count for drop ratio using FFT for each sub block
N
Y
Find Local maximums and set the Fourier coefficients
Compressed image visualization
Stop

Fig: Medical image compression using FFT algorithm flowchart

COMPRESSION IMAGES

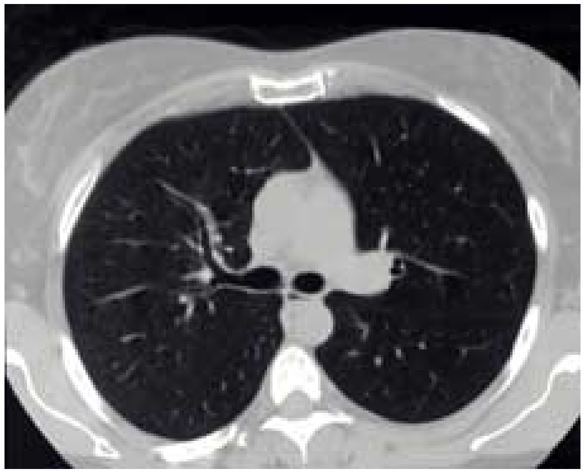


Fig: Original image

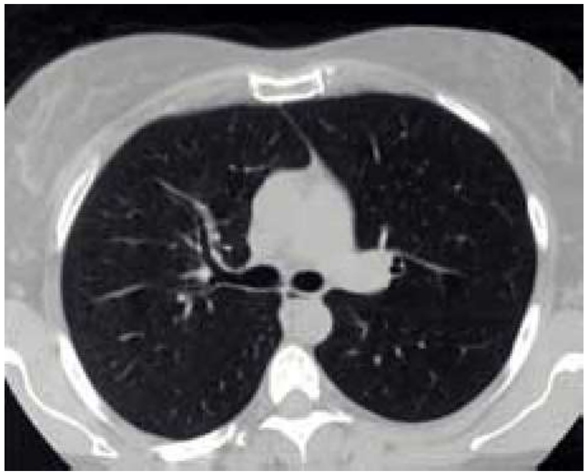


Fig: Compressed image with tolerenece=0.0007625 resulting drop ratio of 0.10

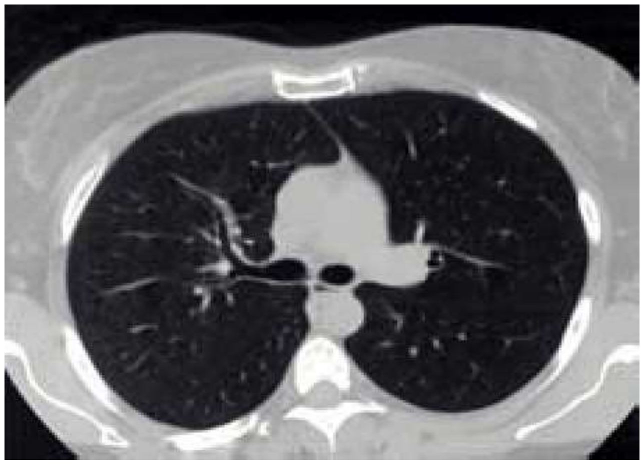


Fig: Compressed image with tolerenece=0.003246 resulting drop ratio of 0.31

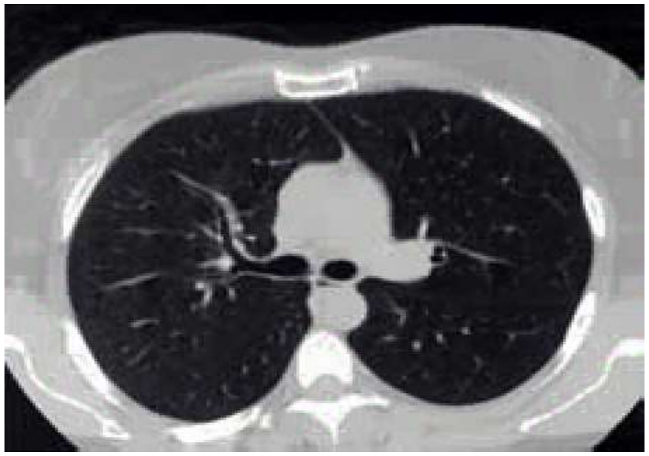
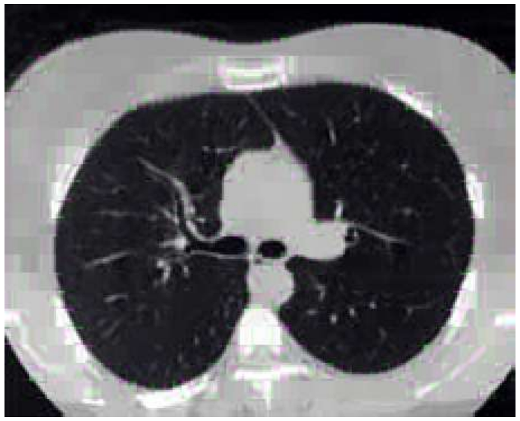


Fig: Compressed image with tolerenece=0.013075 resulting drop ratio of 0.61

Compressed image with tol = 0.03924 resulting a drop ratio of 0.83



CONCLUSION:

- Radix-4 having less delay in processing input when compared with radix-2. Regarding time delay, approximately 75% of time is saved in radix-4 algorithm. Delay time is reduced, then the fastness of the system is increased.
- The level of compression and tolerance values for medical images can be chosen based on the drop ratio and application.

LIMITATIONS AND FUTURE SCOPE

- An improvement is possible further, by minimizing the twiddle factors which in turn reduces the area, size and cost of the implementation.
- The proposed work will suitable only to the values of N in terms of power 4, it makes the limitation of the proposed work which further can be solved by using composite radix methods.

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