since less cosine functions are sufficient to approximate a particular signal.

B. 1D-Dimensional DCT

The most common DCT definition of a 1-D sequence of length N is

$$X_K = C_K \sum_{n=0}^{N-1} x_n \cos\left[\frac{\pi}{N}\left(n + \frac{1}{2}\right)K\right]$$

$$K = 0, 1 \ldots, N-1$$

$$C_k = 1 \quad for\ k = 0,$$

$$C_k = \frac{\sqrt{2}}{\sqrt{N}}\ for\ k \neq 0$$

This above equation X_k represents a linear combination of basis vectors. The case of K=0, X(0) is the first transform coefficient is average value of the sequence. The first term is referred as DC coefficient and other transform coefficients are referred as AC coefficients.1-D IDCT is given by

$$x(n) = \sqrt{\frac{2}{N}}\alpha(k) \sum_{n=0}^{N-1} \alpha(k) y(k) \cos\left[\frac{(2n+1)k\pi}{2N}\right]$$

Where x is an N×1 vector of input pixels and v is an N×1 vector of 1-D DCT coefficients.

C. 2D-Dimensional DCT

The 2-D DCT is a direct extension of the 1-D case and is given by

$$X(u,v) = C_u C_v \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} \cos\left[\frac{\pi}{N}\left(x + \frac{1}{2}\right)v\right] \cos\left[\frac{\pi}{N}\left(y + \frac{1}{2}\right)u\right] f(x,y)$$

$$u, v = 0, 1 \ldots, N-1$$

Fig.1.shows that the coefficient matrix can be partitioned into areas of DC, horizontal frequencies, vertical frequencies and combinations of horizontal and vertical.

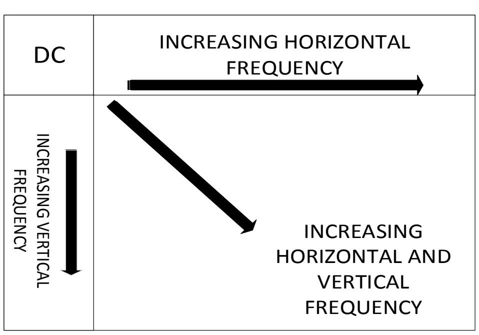


Fig.1.Partition of DCT coefficient matrix

The DC component of the input signal appears in the upper left corner of the coefficient matrix. Moving from left to right along the top row of the matrix is increasing horizontal frequency. Moving from top to bottom in the left column of the matrix is increasing vertical frequency. Moving from the top left of the matrix toward the lower right is increasing horizontal and vertical frequency. When viewed in the frequency domain, intra-frame redundancy means that the coefficients of the high-frequency components tend to have lower magnitude than the low-frequency components.

D. Seperability

The multi-dimensional DCT can be computed by successive 1-D transforms. For a 2-D DCT we can compute 2D DCT coefficients in two steps by computing 1D DCT on rows and columns.Consider for example an 8-point 1-D DCT,

$$C_k = \sqrt{\frac{2}{N}} \cos\left[\frac{k\pi}{N}\right] = 0.5 \cos\left[\frac{k\pi}{16}\right]$$

Using this notation, the second point in the DCT, y(1) can be written as

$$y(1) = \begin{bmatrix} c1 & c3 & c5 & c7 & c9 & c11 & c13 & c15 \end{bmatrix} \begin{bmatrix} x(0) \\ x(1) \\ x(2) \\ x(3) \\ x(4) \\ x(5) \\ x(6) \\ x(7) \end{bmatrix}$$

To calculate all the points of the 1-D DCT, a matrix of cosine coefficients, 1-D DCT, a matrix of cosine coefficients, is defined so that the 1-D DCT can be written as

$$\mathbf{y} = \Gamma\, \mathbf{x}$$

Where

$$\Gamma = \begin{bmatrix} C4 & C4 & C4 & C4 & C4 & C4 & C4 & C4 \\ C1 & C3 & C5 & C7 & C9 & C11 & C13 & C15 \\ C2 & C6 & C10 & C14 & C18 & C22 & C26 & C30 \\ C3 & C9 & C15 & C21 & C27 & C33 & C39 & C45 \\ C4 & C12 & C20 & C28 & C36 & C44 & C52 & C60 \\ C5 & C15 & C25 & C35 & C45 & C55 & C65 & C75 \\ C6 & C18 & C30 & C42 & C54 & C66 & C78 & C90 \\ C7 & C21 & C35 & C19 & C63 & C77 & C91 & C105 \end{bmatrix}$$

And $\Gamma_{k,n}$ the element in the k^{th} row and n^{th} column of Γ, is given by

$$\Gamma_{k,n} = \begin{cases} \sqrt{\frac{1}{N}}, & k = 0, 0 \leq n \leq N-1 \\ C_{(2n+1)k}, & 1 \leq k \leq N-1, 0 \leq n \leq N-1 \end{cases}$$

Taking advantage of the identities

$$\cos(x + 2\pi) = \cos(x)$$

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

Γ can also be simplified so that an 8-point 1-D DCT can be written in matrix form as

$$\begin{bmatrix} y(0)\\ y(1)\\ y(2)\\ y(3)\\ y(4)\\ y(5)\\ y(6)\\ y(7) \end{bmatrix} = \begin{bmatrix} C4 & C4 & C4 & C4 & C4 & C4 & C4 & C4\\ C1 & C3 & C5 & C7 & -C7 & -C5 & -C3 & -C1\\ C2 & C6 & -C6 & -C2 & -C2 & -C6 & C6 & C2\\ C3 & -C7 & -C1 & -C5 & C5 & C1 & C1 & -C3\\ C4 & -C4 & -C4 & C4 & C4 & -C4 & -C4 & C4\\ C5 & -C1 & C7 & C3 & -C3 & -C7 & C1 & -C5\\ C6 & -C2 & C2 & -C6 & -C6 & C2 & -C2 & C6\\ C7 & -C5 & C3 & -C1 & C1 & -C3 & C5 & -C7 \end{bmatrix} \begin{bmatrix} x(0)\\ x(1)\\ x(2)\\ x(3)\\ x(4)\\ x(5)\\ x(6)\\ x(7) \end{bmatrix}$$

And an 8-point 1-D IDCT can be written as

$$x = \Gamma^T y$$

(Or)

$$\begin{bmatrix} x(0)\\ x(1)\\ x(2)\\ x(3)\\ x(4)\\ x(5)\\ x(6)\\ x(7) \end{bmatrix} = \begin{bmatrix} C4 & C1 & C2 & C3 & C4 & C5 & C6 & C7\\ C4 & C3 & C6 & -C7 & -C4 & -C1 & -C2 & -C5\\ C4 & C5 & -C6 & -C1 & -C4 & C7 & C2 & C3\\ C4 & C7 & -C2 & -C5 & C4 & C3 & -C6 & -C1\\ C4 & -C7 & -C2 & C5 & C4 & -C3 & -C6 & C1\\ C4 & -C5 & -C6 & C1 & -C4 & -C7 & C2 & -C3\\ C4 & -C3 & C6 & C7 & -C4 & C1 & -C2 & C5\\ C4 & -C1 & C2 & -C3 & C4 & -C5 & C6 & -C7 \end{bmatrix} \begin{bmatrix} y(0)\\ y(1)\\ y(2)\\ y(3)\\ y(4)\\ y(5)\\ y(6)\\ y(7) \end{bmatrix}$$

To get the DCT matrix we use the following equations

$$\begin{Bmatrix} \frac{1}{\sqrt{N}} if i = 0 \\ \sqrt{\frac{2}{N}} \cos\left[\frac{(2j+1)i\pi}{2N}\right] if i > 0 \end{Bmatrix}$$

E. Bin DCT and Loeffler factorization

Fast bi-orthogonal block transforms come under the category of binDCT that can only be implemented using add and shift operations. In this procedure the coefficients are obtained by a procedure of lifting operations which result in a fast and efficient computation of the transform coefficients.The BinDCTprocess [8] used here is based on the Loeffler's factorization technique asit is recognized as the most computationally efficient algorithm, because it requires the theoretically least number ofcomputational operations.

TABLE I. NUMBER OF OPERATIONS FOR A 8 POINT DCT

	Chen	Wan g	Lee	Vetterli	Hou	Loeffle r
Multiplic ation	16	13	12	12	12`	11
Additions	26	29	29	29	29	29

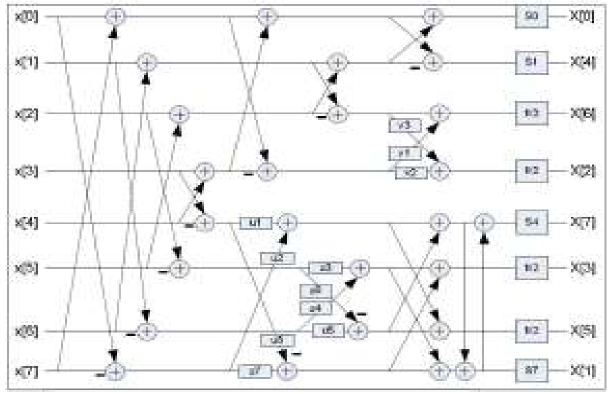


Fig .2. BinDCT architecture for 1D-DCT

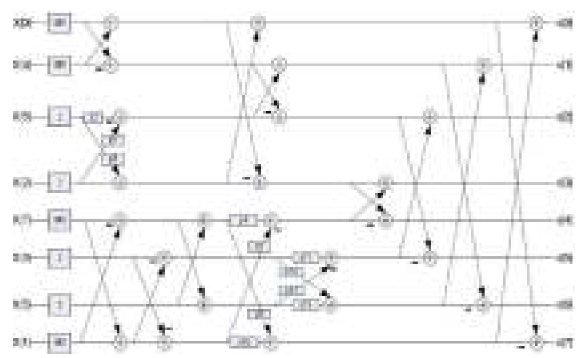


Fig.3. BinIDCT architecture for 1D-DCT

TABLE II. APPROPRIATE LIFTING FACTORS

Lifting Factors	Approximati on	Lifting Factor	Approximati on
u1,u7	25/32	u8,p5,p9	9/16
u2	35/64	v1,p2	13/32
u3,u5	63/64	v2,p1	59/64
u4,p12	3/16	v3,s0,s1	23/64
u6,p14	13/64	s4,s7	23/64
m0	181/64	p3	49/128
p11,p13	63/64	p10	53/64

F. 2D DCT Architecture Flow

In this 2D architecture we have to transpose the row transformed DCT coefficients and feed them into another 1D DCT block. We can use transposition matrices with skew registers for transposing row to column.

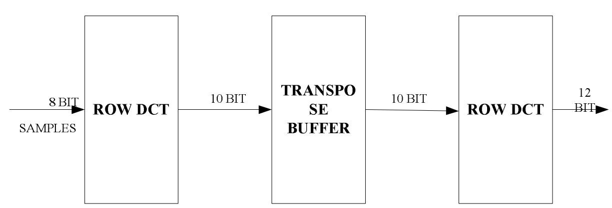


Fig.4.2D-DCT Architecture

The 1D DCT units accepts input vectors in parallel and produces the N DCT coefficients in parallel. The N outputs from the row transform are fed into an array of skewed shift registers as shown in fig.6 above to enable the reading of only one coefficient from the same output vector at any one time. This achieves the appropriate reordering of the data into the second array of skewed registers.

III. SIMULATION RESULTS

1D-DCT has been designed using above architecture and implemented on ALTERA IDE environment and we found the following results.

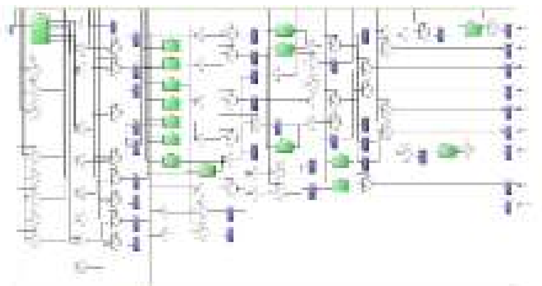


Fig.5.Synthesized RTL view of 1D-DCT.

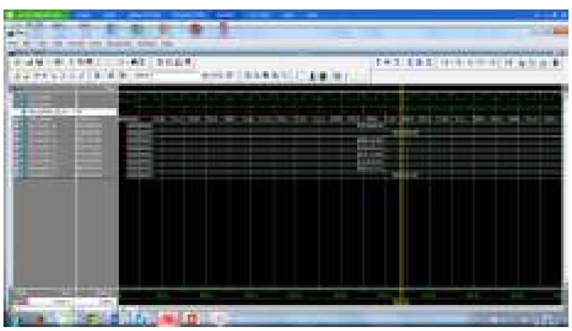
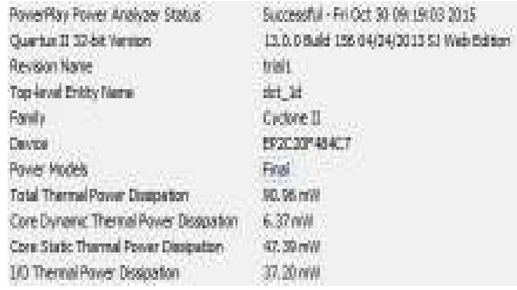


Fig.6.Simulated Waveform for 1D-DCT

TABLE III. RESOURCE UTILIZATION FOR 1D-DCT

Logic utilization	Used	Available	Utilization
Number of Logic Elements	2839	18752	15%
Number of Registers	461	18752	2%
Number of IOBs	83	315	26%
Number of DSP48	0	0	0%

Latency for 1D-DCT block is 12clocks while for Loeffler architecture latency is 13clocks.We have improved the architecture by using BinDCT.



PowerPlay Power Analyzer Status	Successful - Fri Oct 30 09:19:03 2015
Quartus II 32-bit Version	13.0.0 Build 156 04/24/2013 SJ Web Edition
Revision Name	trial1
Top-level Entity Name	dct_1d
Family	Cyclone II
Device	EP2C20F484C7
Power Models	Final
Total Thermal Power Dissipation	90.96 mW
Core Dynamic Thermal Power Dissipation	6.37 mW
Core Static Thermal Power Dissipation	47.39 mW
I/O Thermal Power Dissipation	37.20 mW

Fig.7.Power Analysis of 1D-DCT

TABLE IV. TIMING ANALYSIS OF 1D-DCT

Timing Parameter	Values
Fmax	15.08MHz
Setup Slack	3.690ns
Hold Slack	0.445ns

IV. CONCLUISON

We have designed and implemented the 1D-DCT block using BinDCT architecture, various analysis are extracted, we found power dissipation of 90.96mw, with a maximum operating frequency of 15.08 MHz. Utilization of resources were optimum with 15% of logic elements and 26% of pins.

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