



# DCT

## 2-D Forward Discrete Cosine Transform Megafunction

The DCT megafunction implements the 2D Forward Cosine Transform. Most of the image/video compression standards (JPEG, MPEGx, H.261, H.263, DV etc) are based on the Discrete Cosine Transform (DCT). The DCT megafunction, able to operate over 8x8 and 16x16 blocks of samples, covers the needs of hardware image/video compression systems in the most efficient manner. Possibly the fastest megafunction in the market, it is able to provide processing rates up to 190 MSamples/sec in FPGA technologies and over 250 MSamples/sec in ASIC technologies. Furthermore, the megafunction allows the designers to perform area/quality trade-offs by adjusting the cosine coefficients and data-path precision. Finally the 2-4-8 DCT transform, as this is specified in the DVC (or DV) standard, can be optionally supported by the DCT megafunction.

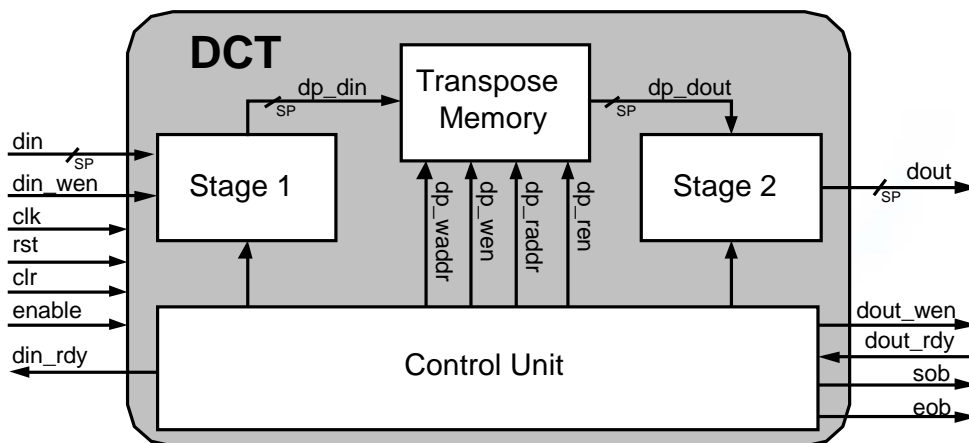
Comprehensive documentation and a complete verification environment - including a bit-accurate model - help designers integrate and verify the megafunction. The DCT is designed for reuse in ASIC and FPGA implementations. The design is fully synchronous with positive edge clocking and no internal tri-state buffers.

### Applications

The DCT megafunction can be utilized for a variety of multimedia applications including:

- Office automation equipment (Multifunction printers, digital copiers etc)
- Digital cameras & camcorders
- Video production, video conference
- Surveillance systems

### Block Diagram



### Features

#### Ease of Integration & Performance

- High clock speed (>250 MHz in 0.18um ASIC technologies)
- Low gate count
- Single clock cycle per sample operation
- Low latency (87 cycles)

#### Design Quality

- Fully compliant with the JPEG standard
- Registered input and outputs
- Strictly positive edge triggered fully synchronous design
- Robust verification environment
- No internal latches or tri-states, scan-ready design

#### Optional add-on Features

- Operation over 16x16 blocks of samples
- Programmable mode of operation (8-8 or 2-4-8)

## Functional Description

The forward DCT (DCT) is a transform that converts a signal into its constituent frequency components as represented by a set of coefficients. The inverse DCT (IDCT) reconstructs the original signal from its constituent DCT coefficients. A 2-dimensional array of coefficients results by applying the DCT to 2-dimensional signals, such as images. The megafunction receives image samples and outputs DCT coefficients on a block by block basis, where each block has a size of either 8x8 or 16x16. The megafunction implements the DCT over the input blocks by performing two 1-dimensional transforms, using row-column decomposition, as defined by the following formula:

DCT:

$$Y_{uv} = \frac{2}{N} C_u C_v \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} X_{ij} \cos \frac{(2i+1)u\pi}{2N} \cos \frac{(2j+1)v\pi}{2N} = \sqrt{\frac{2}{N}} C_u \sum_{i=0}^{N-1} \left[ \sqrt{\frac{2}{N}} C_v \sum_{j=0}^{N-1} X_{ij} \cos \frac{(2i+1)v\pi}{2N} \right] \cos \frac{(2j+1)u\pi}{2N}$$

where  $C_u = C_v = \frac{1}{\sqrt{2}}$  for  $u, v = 0$  and  $C_u = C_v = 1$  otherwise,  $X_{ij}$  are the image samples,  $Y_{uv}$  are the DCT coefficients.

The intermediate results being produced from the first 1-dimensional transform are stored in the "Transpose Memory". The Transpose Memory is a dual ported RAM capable of storing an entire 8x8 or 16x16 block resulting from applying the first stage of row decomposition. While the Transpose Memory is written in row-major order, the second stage of processing reads data from the Transpose Memory in a column-major order, effectively performing a transposition of the intermediate results.

The number of bits used for each intermediate result stored in the Transpose Memory, as well as the number of bits used to represent each of the cosine coefficients, is configurable at synthesis time. This allows the designers to perform their own accuracy versus megafunction area tradeoffs. Furthermore, the bit-width of both input image samples and output DCT coefficients is also configurable at synthesis time. It is noted that the default settings for these synthesis parameters, result to a DCT implementation that satisfy the accuracy criteria of the JPEG standard.

The first DCT coefficient of an output block will appear at the output 87 clock cycles after the first image sample of an input block has been fed to the megafunction.

## Implementation Results

Reference designs have been evaluated in a variety of technologies. The following are sample Altera results obtained after area optimization during synthesis and place and route, while assuming that all megafunction I/Os are routed off-chip.

Altera Device	Logic	Frequency	Special Features
Apex 20KE EP20K100E-1	3,210 LEs	73 MHz	3 ESB
Apex-II EP2A15-C7	3,211 LEs	109 MHz	3 ESB
Cyclone EP1C6-C6	3,005 LEs	102 MHz	1 M4K
Stratix EP1S10-C5	1,345 LEs	137 MHz	1 M4K 16 DSP blocks 9 bit
Cyclone-II EP2C5-C6	1,240 LEs	151 MHz	1 M4K 16 DSP blocks 9 bit
Stratix-II EP2S15-C3	1,410 ALUTs	198 MHz	1 M4K 16 DSP blocks 9 bit

## Support

The megafunction as delivered is warranted against defects for ninety days from purchase. Thirty days of phone and email technical support are included, starting with the first interaction. Additional maintenance and support options are available.

## Verification

The megafunction has been verified through extensive simulation and rigorous code coverage measurements. Being embedded in numerous of products, the megafunction is silicon proven in both FPGA and ASIC technologies.

## Deliverables

The megafunction is available in ASIC (synthesizable HDL) and FPGA (netlist) forms, and includes everything required for successful implementation. The Altera version includes:

- Post-synthesis EDIF netlist
- A bit-accurate model (BAM) of the megafunction including support of custom test vector generation
- Sophisticated self-checking Testbench (Verilog versions use Verilog 2001) supporting test vectors, expected results, and verification
- RTL and gate level (FPGAs) simulation scripts
- Place and route script
- Comprehensive user documentation, including detailed specifications and a system integration guide