

# JCTVC-D048

## Low-Complexity 4-point Integer Discrete Sine Transform

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# Background

$$Y = C_m X R_m^T$$

$C_m, R_m \in \{M, K\}$

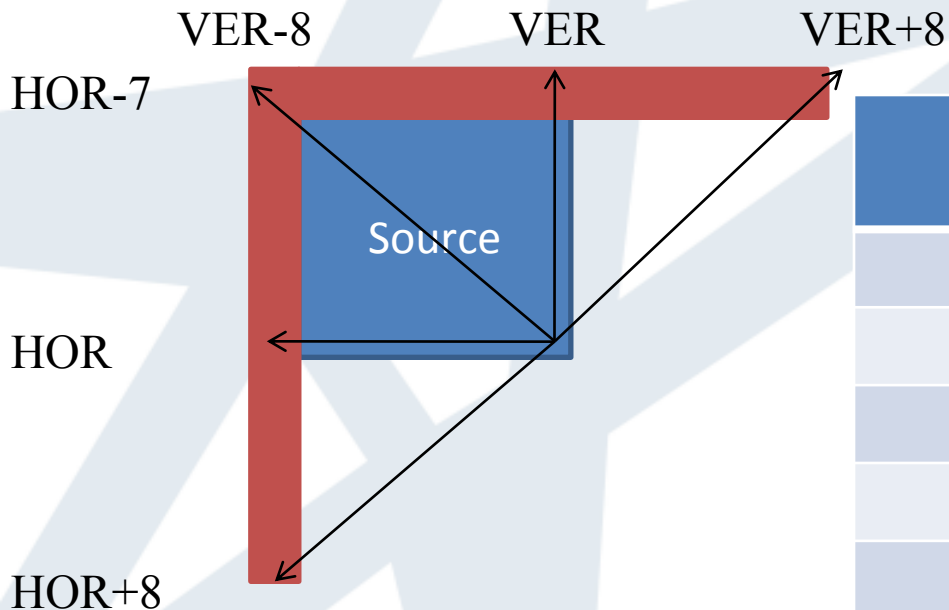
↗ Odd-Type DST-III  
 $K_{i,j} = \frac{2}{\sqrt{2N+1}} \sin\left(\frac{(2i-1)j\pi}{2N+1}\right)$

↘ DCT

Trained KLTs	Proposal
Requires training to compute KLT	<b>No training required</b>
Needs 18 transforms to be implemented	<b>Needs only 2 transforms</b>
16 muls, 12 adds per 4-pt tx	<b>8 muls, 10 adds per 4-pt tx (D046)</b>
All modes use KLT	<b>Combination of DCT/DST</b>

# Combination of DCT/DST

- Choice based on which reference pixels are used for prediction



Mode	Column Tx	Row Tx
DC	EDCT2	EDCT2
VER-8 to VER-1	ODST3	ODST3
VER to VER+8	ODST3	EDCT2
HOR-7 to HOR-1	ODST3	ODST3
HOR to HOR+8	EDCT2	ODST3

# Fast ODST-3 for N=4

## • Forward

$$\begin{pmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \end{pmatrix} = \begin{pmatrix} 29 & 55 & 74 & 84 \\ 74 & 74 & 0 & -74 \\ 84 & -29 & -74 & 55 \\ 55 & -84 & 74 & -29 \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{pmatrix}$$

$$c_0 = x_0 + x_3$$

$$c_1 = x_1 + x_3$$

$$c_2 = 74x_2$$

$$y_0 = 29c_0 + 55c_1 + c_2$$

$$y_1 = 74(x_0 + x_1 - x_3)$$

$$y_2 = 84c_0 - 29c_1 - c_2$$

$$y_3 = 55c_0 - 84c_1 + c_2$$

## Backward

$$\begin{pmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} 29 & 74 & 84 & 55 \\ 55 & 74 & -29 & -84 \\ 74 & 0 & -74 & 74 \\ 84 & -74 & 55 & -29 \end{pmatrix} \begin{pmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \end{pmatrix}$$

$$b_0 = y_0 + y_2$$

$$b_1 = 74y_1$$

$$b_2 = y_2 + y_3$$

$$x_0 = 29b_0 + b_1 + 55b_2$$

$$x_1 = 55b_0 + b_1 - 84b_2$$

$$x_2 = 74(y_0 - y_2 + y_3)$$

$$x_3 = 84b_0 - b_1 - 29b_2$$

- 8 multiplies, 10 adds

# Outstanding issues

- Fixed point arithmetic used to implement mode-dependent transforms
  - Implemented transform is not exactly orthogonal
  - Inherent distortion from forward and backward transform
- Requires separate transform/quantization architecture from typical transform

# Proposed Approach

- Exactly orthogonal integer transform

- $iK = \text{round}(K * 11.5) =$

3	5	7	8
7	7	0	-7
8	-3	-7	5
5	-8	7	-3

- $iK' * iK = \text{diag}([147 \ 147 \ 147 \ 147])$
- Multiplier-less implementation
  - 6 shifts, 15 adds
  - Similar to D286
- H.264 style quantization

# Multiplier-less implementation

- Forward transform example:

$$c_1 = x_1 + x_4$$

$$c_2 = x_2 + x_4$$

$$c_3 = (x_3 \ll 3) - x_3$$

$$c_4 = x_1 + x_2 - x_4$$

$$d_1 = (c_1 \ll 2)$$

$$d_2 = (c_2 \ll 2) + c_3$$

$$y_1 = d_1 - c_1 + d_2 + c_2$$

$$y_2 = (c_4 \ll 3) - c_4$$

$$y_3 = (c_1 \ll 3) - d_2 + c_2$$

$$y_4 = d_1 + c_1 - (c_2 \ll 3) + c_3$$

- Increase input dynamic range by about 5 bits (vs 8 bits before)
  - Avoids 64 bit arithmetic when computing transform

# Advantages

- Exactly orthogonal integer transform
- Implemented using only shifts and adds
- Smaller increase in dynamic range



# Experimental conditions

- Only difference from anchor is the use of proposed integer ODST3 for intra residual coding of 4x4 blocks and fixed point ODST3 for 8x8 blocks
  - HM DCT is used
  - Quantization scaling matrix is switched based on combination of transforms
- Following JCTVC-C500 and JCTVC-C507
  - Test Intra (high-efficiency and low-complexity) and Random Access (high-efficiency and low-complexity)

# Results (Proposed)

	Intra			Intra LoCo		
	U BD-rate			V BD-rate		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-2.2	-2.4	-2.4	-3.0	-1.6	-1.2
Class B	-0.9	-1.1	-1.1	-1.5	-1.2	-1.0
Class C	-1.2	-1.0	-1.1	-1.8	-1.2	-1.2
Class D	-1.3	-1.0	-1.0	-1.8	-1.1	-1.1
Class E	-1.5	-1.8	-1.7	-2.5	-0.7	-1.1
All	-1.3	-1.3	-1.3	-2.0	-1.1	-1.1
Enc Time[%]	102%			105%		
Dec Time[%]	101%			104%		

	Random access			Random access LoCo		
	U BD-rate			V BD-rate		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-0.9	-0.6	-0.3	-1.1	-0.2	-0.1
Class B	-0.5	-0.4	-0.5	-0.6	-0.3	-0.3
Class C	-0.7	-0.6	-0.6	-0.6	-0.5	-0.4
Class D	-0.6	-0.1	0.0	-0.5	-0.4	-0.2
Class E						
All	-0.6	-0.4	-0.4	-0.6	-0.4	-0.3
Enc Time[%]	101%			101%		
Dec Time[%]	100%			100%		

# Results (CE7: D046)

	Intra			Intra LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-2.2	-2.5	-2.6	-3.6	-1.5	-1.0
Class B	-0.9	-1.1	-1.1	-1.7	-1.1	-0.9
Class C	-1.2	-1.0	-1.0	-1.9	-1.1	-1.1
Class D	-1.3	-1.1	-1.0	-1.9	-1.0	-1.0
Class E	-1.5	-1.7	-1.5	-2.7	-0.4	-0.9
All	-1.3	-1.4	-1.3	-2.2	-1.0	-1.0
Enc Time[%]	101%			103%		
Dec Time[%]	101%			104%		

	Random access			Random access LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-0.9	-0.5	-0.2	-1.2	-0.2	0.1
Class B	-0.5	-0.3	-0.4	-0.6	-0.3	-0.3
Class C	-0.6	-0.3	-0.4	-0.6	-0.3	-0.3
Class D	-0.6	-0.3	-0.1	-0.5	-0.2	-0.2
Class E						
All	-0.6	-0.3	-0.3	-0.7	-0.2	-0.2
Enc Time[%]	100%			100%		
Dec Time[%]	100%			101%		

# Results (Trained KLTs)

	Intra			Intra LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-2.3	-2.4	-2.5	-3.5	-1.6	-1.2
Class B	-1.0	-1.2	-1.2	-1.9	-1.3	-1.1
Class C	-1.2	-1.1	-1.1	-2.0	-1.3	-1.3
Class D	-1.4	-1.2	-1.2	-2.0	-1.2	-1.2
Class E	-1.6	-1.7	-1.6	-2.9	-0.6	-1.1
All	-1.4	-1.4	-1.4	-2.3	-1.2	-1.1
Enc Time[%]	101%			105%		
Dec Time[%]	102%			106%		

	Random access			Random access LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-1.0	-0.4	-0.2	-1.3	-0.2	0.1
Class B	-0.6	-0.3	-0.3	-0.8	-0.3	-0.3
Class C	-0.7	-0.4	-0.5	-0.7	-0.4	-0.3
Class D	-0.7	-0.1	-0.2	-0.6	-0.3	-0.3
Class E						
All	-0.7	-0.3	-0.3	-0.8	-0.3	-0.2
Enc Time[%]	100%			100%		
Dec Time[%]	100%			101%		

# Complexity

- Operations count for DST
  - 4-point: 6 shifts, 15 adds
  - 8-point: 64 multiplies, 56 adds
- Requires one additional transform each for 4x4 and 8x8

# Training

- No training required to derive transform matrix

# Conclusions

- Proposed low-complexity and orthogonal integer approximation of ODST-3
  - No significant difference in coding performance from trained KLTs and 7-bit fractional fixed point ODST-3
  - One additional transform, no training required
- Recommend further study for adoption into HM