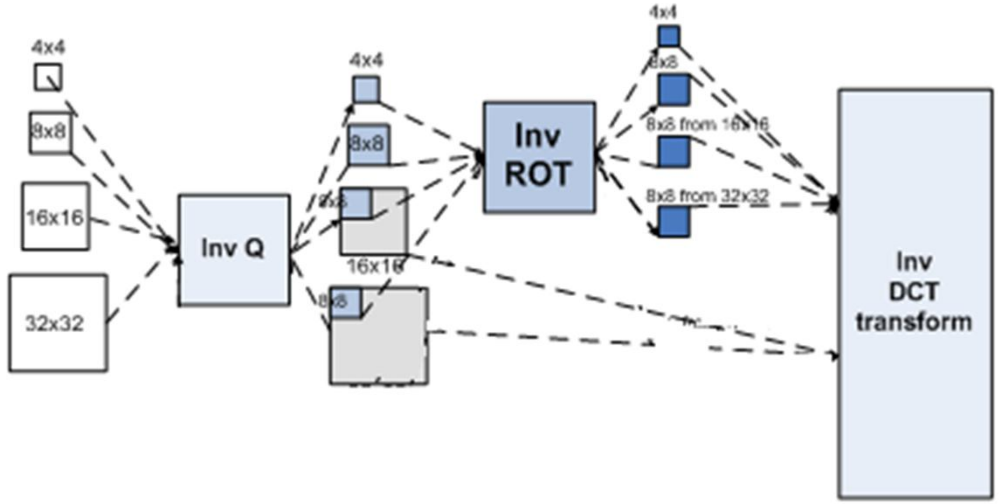
JCTVC-380: CE7: Experimental results of ROT by Samsung

E. Alshina, A. Alshin , F. Fernandes, A. Saxena , V. Seregin, Z. Ma ,W.-J. Han (Samsung)

ROT application scheme



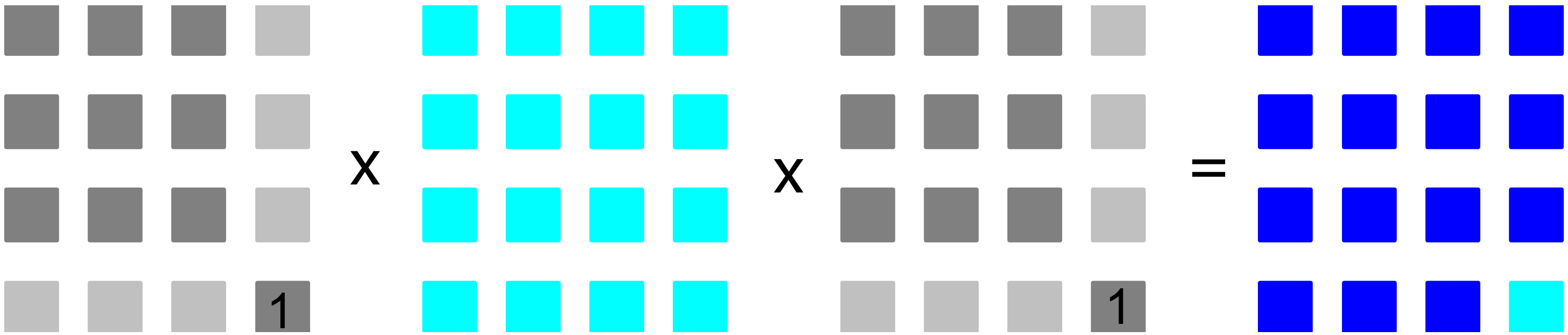
✓Implemented as secondary transform
→ <u>no change to existing HM transform core</u>

✓ROT doesn't require change of HM quantization
→ <u>no additional Q/Q^{-1} matrices</u>

✓Only low-frequency part of transform coefficients matrix is involved in ROT
→ Implemented for 4x4 and 8x8 only, but applied for all TU sizes

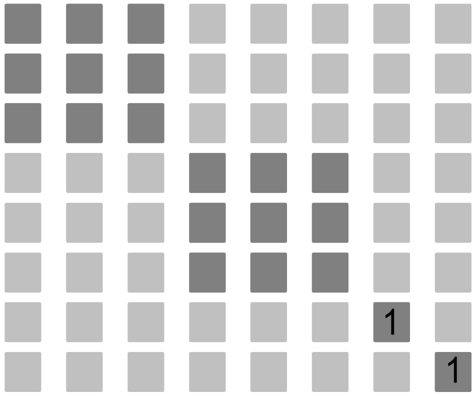
Sparse structure of ROT matrices

ROT4 process



$R_{Horizontal}$ × input × $R_{Vertical}$ = rotated output

ROT8 matrix



Number of operations

	Core HM transform				Additional operations for ROT				Total			
TU size	“*”	“+”	“>>”	all	“*”	“+”	“>>”	all	“*”	“+”	“>>”	all
4x4	0	5	2	**7**	3.6	3.2	1.6	10.4	3.6	8.2	3.6	**17.4**
8x8	0	10	5.5	**15.5**	3.6	3.2	1.6	10.4	3.6	13.2	7.1	**25.9**
16x16	5.5	10.3	6.3	**22.1**	0.9	0.8	0.4	2.6	5.9	11.1	6.7	**24.7**
32x32	7.3	13.1	7.1	**27.5**	0.2	0.2	0.1	0.6	7.5	13.3	7.2	**28.1**
Avg	18				6				24			

- Because ROT matrices are very sparse, number introduced by ROT is small compare to core transform:
  - for 4x4 block: is comparable to 4x4 core transform
  - for 8x8 block: is ~ ½ compared to 8x8 core transform.
  - for larger TU sizes: ROT operations count becomes negligible compared to core transform.

Partial energy exchange

$$R_{vertical}\left(\alpha_1,\alpha_2,\alpha_3\right)=$$

$$=\begin{pmatrix} \cos\alpha_1\cos\alpha_3 - \sin\alpha_1\cos\alpha_2\sin\alpha_3 & -\sin\alpha_1\cos\alpha_3 - \cos\alpha_1\cos\alpha_2\sin\alpha_3 & \sin\alpha_2\sin\alpha_3 & 0 \\ \cos\alpha_1\sin\alpha_3 + \sin\alpha_1\cos\alpha_2\cos\alpha_3 & -\sin\alpha_1\sin\alpha_3 + \cos\alpha_1\cos\alpha_2\cos\alpha_3 & -\sin\alpha_2\cos\alpha_3 & 0 \\ \sin\alpha_1\sin\alpha_2 & \cos\alpha_1\sin\alpha_2 & \cos\alpha_2 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$R_{horizontall}\left(\alpha_4,\alpha_5,\alpha_6\right)=$$

$$=\begin{pmatrix} \cos\alpha_4\cos\alpha_6 - \sin\alpha_4\cos\alpha_5\sin\alpha_6 & -\sin\alpha_4\cos\alpha_6 - \cos\alpha_4\cos\alpha_5\sin\alpha_6 & \sin\alpha_5\sin\alpha_6 & 0 \\ \cos\alpha_4\sin\alpha_6 + \sin\alpha_4\cos\alpha_5\cos\alpha_6 & -\sin\alpha_4\sin\alpha_6 + \cos\alpha_4\cos\alpha_5\cos\alpha_6 & -\sin\alpha_5\cos\alpha_6 & 0 \\ \sin\alpha_4\sin\alpha_5 & \cos\alpha_4\sin\alpha_5 & \cos\alpha_5 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$\alpha_1=\alpha_2=\alpha_3=0$ → no change

$\alpha_1=\pi$, $\alpha_2=\alpha_3=0$ → 1st and 2nd column switching with sign change for 2nd column

$\alpha_1=\pi/2$, $\alpha_2=\alpha_3=0$ → sign change for 1st and 2nd row

$\{\alpha_k\}$: $|\alpha_k|<\varepsilon$, $|\alpha_k$-□$|<\varepsilon$ → small change of main transform coefficients with possible sign change

Additional memory usage 144 bytes

```
const Int g_INV_ROT_MATRIX_4[4][18]=
  {
   { 248,  -55,  -28,  -60, -244,  -52,  -16,   57, -249,  250,  -49,  -26,  -54, -240,  -71,  -11,   75, -245,},
   { 255,   22,   -8,  -22,  254,  -17,    6,   17,  255,  241,  -84,  -18,   69,  221, -110,   52,   98,  231,},
   { 237,  -96,   -9,   90,  229,  -73,   35,   64,  245,  243,  -80,   -6,   70,  222, -107,   38,  100,  233,},
   { 250,  -18,  -54,  -13,  220, -131,   55,  130,  213,  212, -143,    9,  134,  192, -103,   51,   90,  234,},
};
const Int g_INV_ROT_MATRIX_8[4][18]=
{
   { 251,  -36,  -31,   23,  237,  -94,   42,   90,  236,   236, -100,    3,  100,  234,  -25,    7,   24,  255,  },
   { 243,  -61,  -50,  -75, -230,  -83,  -25,   94, -237,   254,  -27,  -18,   22,  249,  -56,   24,   54,  249,  },
   { 243,  -81,   12,   81,  232,  -70,   11,   71,  246,  252,  -41,   -9,  -42, -251,  -28,   -4,   29, -254,},
   { 174, -186,   23,  181,  158,  -87,   49,   75,  240,  236,  -99,  -10,  -99, -235,  -25,    1,   27, -255,},
};
```

- These matrices are enough for realization of 4 alternative transforms for any TU sizes

- In total, 144 integers with absolute values less than 256 should be stored.

- For comparison, consider Q/Q^{-1} matrices in HM:
  - for 4×4 transform core: 192 elements,
  - for 8x8 transform core: 768 elements.

Test 1: ROT with matrix multiplications

	Intra			Intra LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-1.7	0.1	0.1	-2.7	1.2	1.1
Class B	-1.7	1.1	1.0	-2.3	1.8	1.7
Class C	-1.7	1.6	1.5	-2.3	1.8	1.8
Class D	-1.8	1.6	1.7	-2.5	1.9	1.9
Class E	-1.5	0.3	0.3	-2.2	1.1	1.1
All	-1.7	1.0	0.9	-2.4	1.6	1.5
Enc Time[%]	147%			184%		
Dec Time[%]	105%			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	-0.7	0.2	0.0	-1.3	1.3	1.2
Class B	-1.0	0.8	1.0	-1.5	1.0	1.1
Class C	-1.2	0.9	0.7	-1.4	1.0	0.9
Class D	-1.1	0.7	0.7	-1.3	0.9	0.7
Class E						
All	-1.0	0.7	0.6	-1.4	1.0	1.0
Enc Time[%]	104%			104%		
Dec Time[%]	103%			100%		

Test 2: ROT with lifting

	Intra			Intra LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-1.6	0.1	0.2	-2.5	1.1	1.0
Class B	-1.6	1.1	0.9	-2.2	1.7	1.6
Class C	-1.6	1.4	1.5	-2.2	1.7	1.7
Class D	-1.7	1.6	1.6	-2.3	1.8	1.8
Class E	-1.4	0.3	0.3	-2.1	1.0	1.1
All	-1.6	0.9	0.9	-2.3	1.5	1.5
Enc Time[%]	163%			204%		
Dec Time[%]	106%			110%		

	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	-0.7	-0.1	0.1	-1.1	1.4	1.4
Class B	-0.9	0.7	0.7	-1.4	1.1	1.1
Class C	-1.1	0.8	0.8	-1.4	0.8	1.0
Class D	-0.9	0.5	0.5	-1.2	0.9	0.7
Class E						
All	-0.9	0.5	0.6	-1.3	1.1	1.0
Enc Time[%]	109%			106%		
Dec Time[%]	101%			101%		

Test 3: ROT + DCT/DST (Best Coding Gain)

	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	-1.0	-0.8	-3.8	0.7	0.7
Class B	-1.7	0.4	0.2	-2.6	1.0	0.9
Class C	-1.8	0.7	0.7	-2.8	1.0	1.0
Class D	-2.0	0.9	0.9	-3.0	1.2	1.2
Class E	-1.6	-0.8	-0.6	-2.9	0.3	0.3
All	**-1.9**	0.1	0.1	**-3.0**	0.9	0.9
Enc Time[%]	157%			198%		
Dec Time[%]	105%			110%		

	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	-0.8	-0.5	-0.4	-1.5	1.1	1.1
Class B	-0.9	0.4	0.6	-1.4	0.9	0.8
Class C	-1.3	0.5	0.5	-1.6	0.6	0.8
Class D	-1.1	0.3	0.4	-1.4	0.7	0.5
Class E						
All	**-1.0**	0.2	0.3	**-1.5**	0.8	0.8
Enc Time[%]	108%			106%		
Dec Time[%]	101%			101%		

Test 4: ROT for MPM + DCT/DST

	Intra			Intra LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-1.7	-1.3	-1.1	-2.9	0.0	0,1
Class B	-1.3	-0.4	-0.4	-2.0	-0.2	-0,1
Class C	-1.3	-0.3	-0.3	-2.1	-0.4	-0,4
Class D	-1.4	-0.2	-0.2	-2.1	-0.3	-0,3
Class E	-1.3	-1.4	-1.2	-2.5	-0.3	-0,5
All	-1.4	-0.7	-0.6	-2.3	-0.2	-0,2
Enc Time[%]	123%			130%		
Dec Time[%]	103%			105%		

	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	-0.7	-0.3	-0.3	-1.1	0.6	0,6
Class B	-0.6	0.2	0.3	-1.0	0.3	-0,2
Class C	-0.9	-0.1	-0.1	-1.2	-0.1	0,2
Class D	-0.7	-0.1	0.1	-1.0	-0.1	-0,1
Class E						0,1
All	-0.7	0.0	0.0	-1.0	0.2	0,6
Enc Time[%]	104%			102%		
Dec Time[%]	100%			100%		

Test 5: ROT + DCT/DST + 2nd Step MDT (JCTVC-E074)

	Intra			Intra LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-1,8	-1,5	-1,3	-3,0	-0,2	-0,1
Class B	-1,5	-0,4	-0,5	-2,2	-0,3	-0,3
Class C	-1,5	-0,3	-0,3	-2,3	-0,4	-0,4
Class D	-1,5	-0,2	-0,2	-2,2	-0,3	-0,3
Class E	-1,7	-1,8	-1,6	-2,8	-0,7	-0,9
All	**-1,6**	**-0,8**	**-0,7**	**-2,5**	**-0,4**	**-0,4**
Enc Time[%]		125%			134%	
Dec Time[%]		104%			107%	

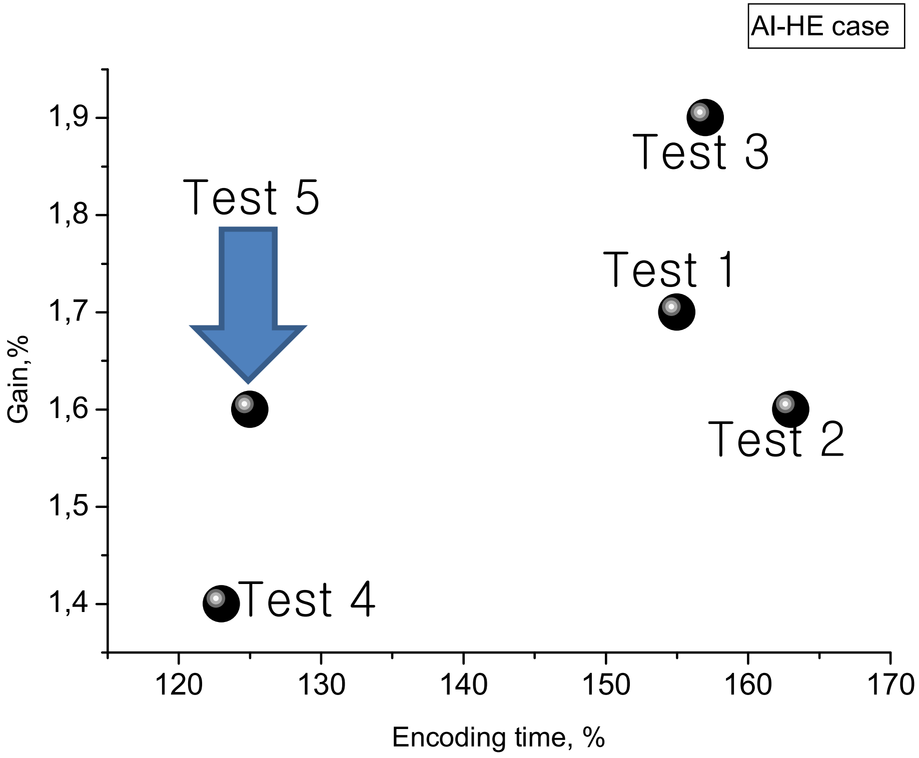
	Random access			Random access LoCo		
	Y BD-rate	U BD-rate	V BD-rate	Y BD-rate	U BD-rate	V BD-rate
Class A	-0.8	-0.7	-0.8	-1,2	0,3	0,3
Class B	-0.8	0.1	0.1	-1,2	0,1	0,0
Class C	-1,0	-0,1	-0,1	-1,3	-0,2	0,0
Class D	-0,8	-0,1	0,0	-1,0	0,1	-0,1
All	**-0.8**	**-0.2**	**-0.2**	**-1,2**	**0,1**	**0,0**
Enc Time[%]		106%			104%	
Dec Time[%]		101%			101%	

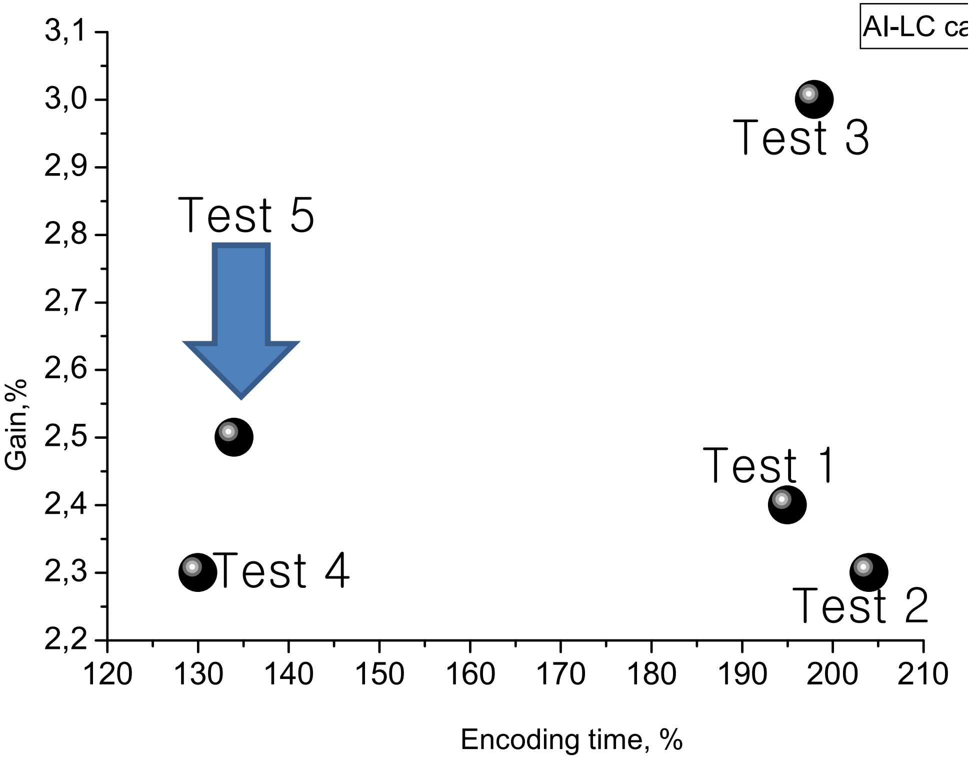
Recommended alternative transform design

	indexROT = 0 || UDI mode != MPM	indexROT > 0 && UDI mode == MPM
4x4	DCT/DST	HM core transform + ROT
8x8	DCT/DST	HM core transform + ROT
16x16	HM core transform + 2nd step MDT	HM core transform + ROT
32x32	HM core transform + 2nd step MDT	HM core transform + ROT

Average operations per pixel	
Core Transform	6
Proposed	7

Tests 1…5 Summary
(Test 5 is the best trade-off)





Conclusion

Based on these test results

- 2% (in average for All Intra test) and
- 1% (in average for Random access test) performance improvement

we recommend HM adoption of following alternative transform design:

- DCT/DST for 4x4 and 8x8
- 2nd step mode dependent transform for 16x16 and 32x32
- ROT for all block sizes restricted for MPM and no mode dependent transforms.

Only one alternative transform tool is applied for each Intra TU in this design.

No quantization part change is needed.