

JCTVC-G628

Comparison of core transform proposals

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Two structures

- Partial factorization with 8-bit matrix coefficients (PF8) (JCTVC-G495, HM4.0)
- Full factorization with 14-bit matrix coefficients (FF14) (JCTVC-G737)

Core transform properties

- Fundamental properties
- Properties relevant for hardware implementations
- Properties relevant for software implementations

Two core transform proposals

Feature	G495 (HM4.0)	G737
Matrix multiplication	Yes	Yes
Partial factorization	Yes	Yes
Full factorization	No	Yes
Matrix coefficients	8 bit	14 bit

8x8 transform matrices

PF8

{64, 64, 64, 64, 64, 64, 64, 64}
{89, 75, 50, 18, -18, -50, -75, -89}
{83, 36, -36, -83, -83, -36, 36, 83}
{75, -18, -89, -50, 50, 89, 18, -75}
{64, -64, -64, 64, 64, -64, -64, 64}
{50, -89, 18, 75, -75, -18, 89, -50}
{36, -83, 83, -36, -36, 83, -83, 36}
{18, -50, 75, -89, 89, -75, 50, -18}

FF14

{ 4096, 4096, 4096, 4096, 4096, 4096, 4096, 4096}
{ 5696, 4800, 3264, 1088, -1088, -3264, -4800, -5696}
{ 5312, 2304, -2304, -5312, -5312, -2304, 2304, 5312}
{ 4770, -1080, -5670, -3240, 3240, 5670, 1080, -4770}
{ 4096, -4096, -4096, 4096, 4096, -4096, -4096, 4096}
{ 3240, -5670, 1080, 4770, -4770, -1080, 5670, -3240}
{ 2304, -5312, 5312, -2304, -2304, 5312, -5312, 2304}
{ 1088, -3264, 4800, -5696, 5696, -4800, 3264, -1088}

Some fundamental properties

Feature	PF8	FF14
Matrix coefficient bit depth	8 bit	14 bit
Intermediate buffer bit depth	16 bit	16 bit
Size of dequantizer matrix	6 bytes	6 bytes
Embedded structure	Yes	Yes
Multipliers in software	16-bit	16-bit & 32-bit

Additional properties

- Hardware -related
 - “Odd-half” sub-matrices
 - Number of multiplications for partial transforms
- Software-related
 - Number of unique matrix coefficients
 - Bit depth of accumulator

"Odd-half" sub-matrices

8x8 DCT matrix

0.354	0.354	0.354	0.354	0.354	0.354	0.354	0.354
0.490	0.416	0.278	0.098	-0.098	-0.278	-0.416	-0.490
0.462	0.191	-0.191	-0.462	-0.462	-0.191	0.191	0.462
0.416	-0.098	-0.490	-0.278	0.278	0.490	0.098	-0.416
0.354	-0.354	-0.354	0.354	0.354	-0.354	-0.354	0.354
0.278	-0.490	0.098	0.416	-0.416	-0.098	0.490	-0.278
0.191	-0.462	0.462	-0.191	-0.191	0.462	-0.462	0.191
0.098	-0.278	0.416	-0.490	0.490	-0.416	0.278	-0.098

Symmetric "odd-half" 4x4 matrix

0.490	0.416	0.278	0.098
0.416	-0.098	-0.490	-0.278
0.278	-0.490	0.098	0.416
0.098	-0.278	0.416	-0.490

"Odd-half" sub-matrices

PF8

{64, 64, 64, 64, 64, 64, 64, 64}
{89, 75, 50, 18, -18, -50, -75, -89}
{83, 36, -36, -83, -83, -36, 36, 83}
{75, -18, -89, -50, 50, 89, 18, -75}
{64, -64, -64, 64, 64, -64, -64, 64}
{50, -89, 18, 75, -75, -18, 89, -50}
{36, -83, 83, -36, -36, 83, -83, 36}
{18, -50, 75, -89, 89, -75, 50, -18}

FF14

{ 4096, 4096, 4096, 4096, 4096, 4096, 4096, 4096}
{ 5696, 4800, 3264, 1088, -1088, -3264, -4800, -5696}
{ 5312, 2304, -2304, -5312, -5312, -2304, 2304, 5312}
{ 4770, -1080, -5670, -3240, 3240, 5670, 1080, -4770}
{ 4096, -4096, -4096, 4096, 4096, -4096, -4096, 4096}
{ 3240, -5670, 1080, 4770, -4770, -1080, 5670, -3240}
{ 2304, -5312, 5312, -2304, -2304, 5312, -5312, 2304}
{ 1088, -3264, 4800, -5696, 5696, -4800, 3264, -1088}

"Odd-half" sub-matrices of 8x8

PF8

{89, 75, 50, 18}
{75,-18,-89,-50}
{50,-89, 18, 75}
{18,-50, 75,-89}

FF14

{5696, 4800, 3264, 1088}
{4770,-1080,-5670,-3240}
{3240,-5670, 1080, 4770}
{ 1088,-3264, 4800,-5696}

Symmetric around main diagonal

Non-symmetric around main diagonal

- Symmetry allows for joint optimization of forward and inverse transforms in hardware.
- JCTVC-G132: 40% - 45% reduction in hw area for PF8

Number of unique matrix coefficients

- NxN real-valued DCT matrix:
N-1 unique coefficients (excluding sign)
- Integer approximations:
more unique coefficients, or
less unique coefficients

Unique coefficients in the 8x8 DCT

0.354	0.354	0.354	0.354	0.354	0.354	0.354	0.354
0.490	0.416	0.278	0.098	-0.098	-0.278	-0.416	-0.490
0.462	0.191	-0.191	-0.462	-0.462	-0.191	0.191	0.462
0.416	-0.098	-0.490	-0.278	0.278	0.490	0.098	-0.416
0.354	-0.354	-0.354	0.354	0.354	-0.354	-0.354	0.354
0.278	-0.490	0.098	0.416	-0.416	-0.098	0.490	-0.278
0.191	-0.462	0.462	-0.191	-0.191	0.462	-0.462	0.191
0.098	-0.278	0.416	-0.490	0.490	-0.416	0.278	-0.098

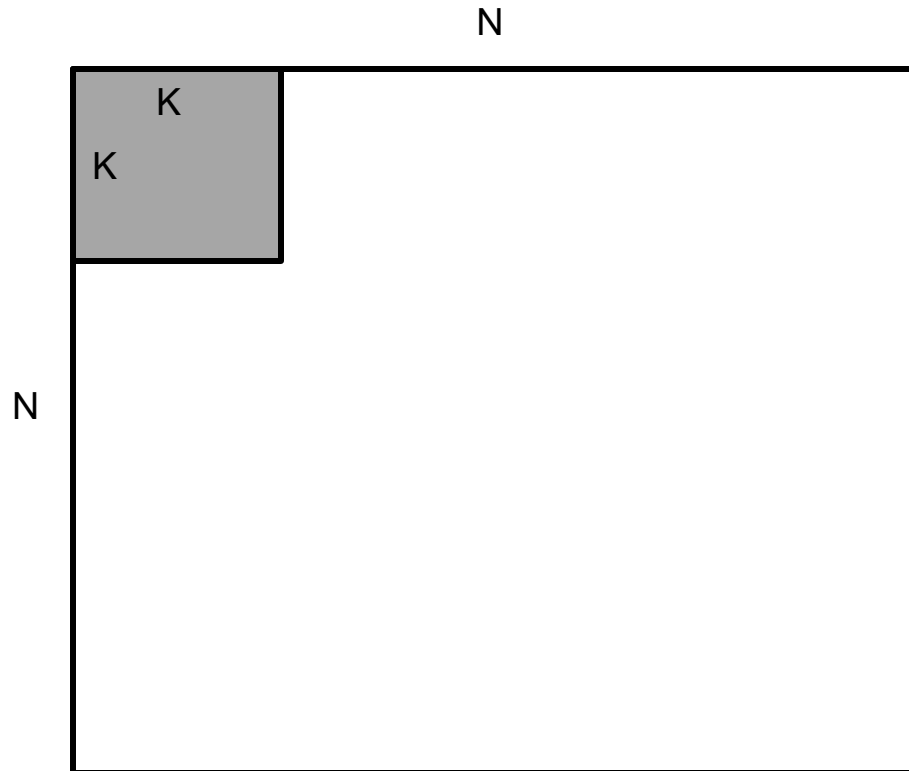
Number of unique coefficients

N	DCT	PF8	FF14
4	3	3	3
8	7	7	11
16	15	15	43
32	31	29	171

- JCTVC-G265: ~25% reduction in hw area for PF8

Partial transforms

- $N \times N$ transform matrix
- $K \times K$ low frequency coefficients are non-zero

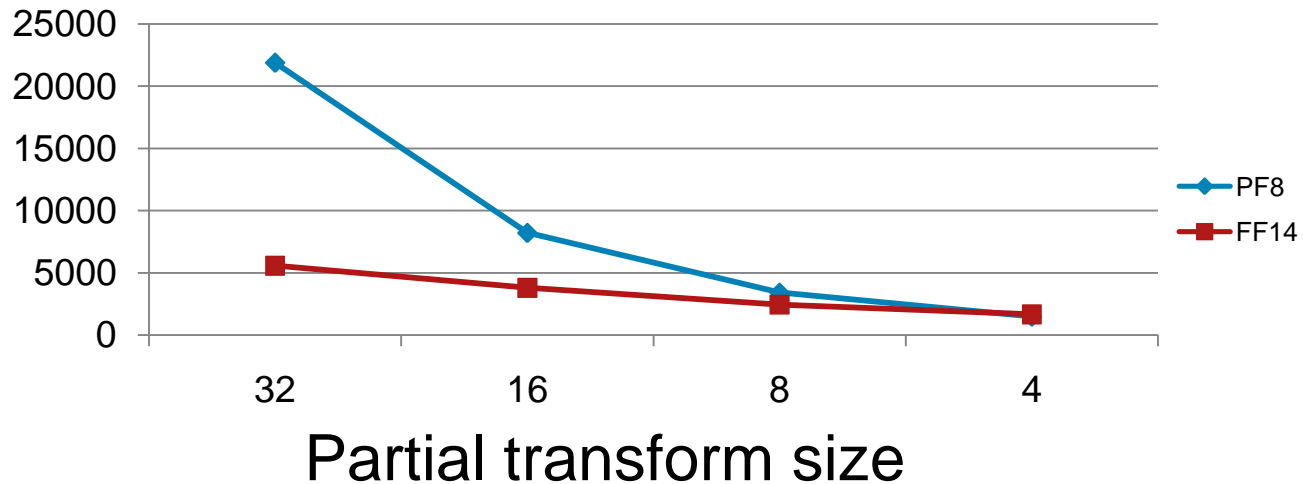


Multiplications for partial 2D transforms

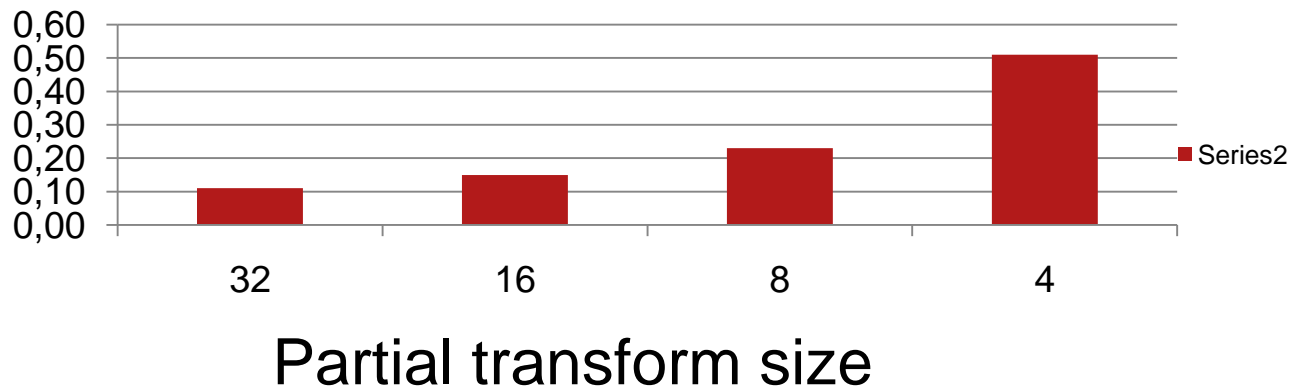
NxN	KxK	PF8	FF14
8x8	8x8	352	176
	4x4	132	108
16x16	16x16	2752	992
	8x8	1032	672
	4x4	420	440
32x32	32x32	21888	5568
	16x16	8208	3792
	8x8	3400	2440
	4x4	1476	1656

Partial transforms of 32x32 size

Mults

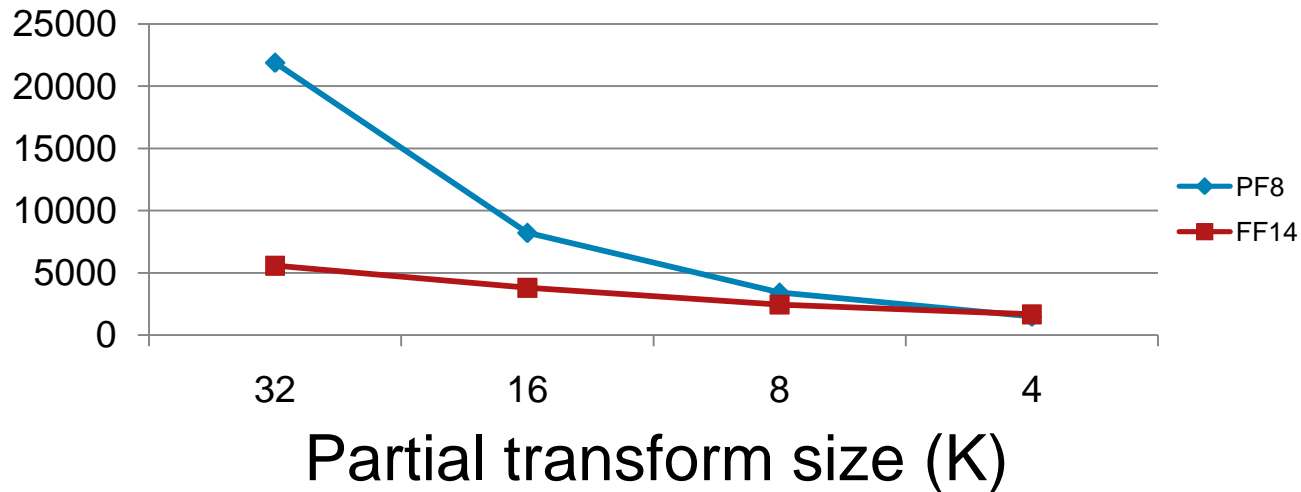


Probability



Partial transforms of 32x32 size

Mults



Full-size transform (N=K=32):

Number of multiplications:	PB8/FF14	= 3.93
SIMD clock cycles:	PB8/FF14	= 0.9 – 1.1

Accumulator bit width

- Full range input:
 - Forward transform: $2^B - 1$
 - Inverse transform: $2^{15} - 1$
- Accumulator >32 bit may be concern in software

N	PF8				FF14			
	FW-1	FW-2	IT-1	IT-2	FW-1	FW-2	IT-1	IT-2
4	17	24	24	24	23	30	30	30
8	18	25	25	25	24	31	31	31
16	19	26	26	26	25	32	32	32
32	20	27	27	27	26	33	33	33

Summary

Feature	G495 (PF8)	G737 (FF14)
Matrix coefficients	8 bit	14 bit
Symmetric "odd-half" sub-matrices	Yes	No
Number of unique coefficients	29	171
Maximum accumulator bit width	27	33

- Reduction in hw costs for PF8:
 - Symmetric "odd-half" sub-matrices: ~40%
 - Number of unique coefficients: ~25%