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| --- | --- | --- | --- |
| *Title:* | **CE7: Summary Report of Core Experiment on Additional Transforms** | | |
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| *Source:* | Core Experiment 7 | | |

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# Abstract

The purpose of Core Experiment 7 (CE7) is to characterize the performance, in terms of both compression efficiency and complexity, of several transforms other than those currently defined in HM 5.0. Three tools that operate on luma TUs have been evaluated. Tool 1 is mode-dependent secondary transform for 8x8, 16x16, and 32x32 Intra TUs, applied after the HM core transform. Tool 2 is a boundary-dependent primary transform for 4x4, 8x8, and 16x16 Inter TUs. At size 4, Tool 2 extends the HM DST to the Inter case. Tool 3 applies the boundary-dependent transform from Tool 2 for 4x4 Inter TUs and a boundary-dependent secondary transform for 8x8, 16x16, and 32x32 Inter TUs. The secondary transform matrices in Tools 1 and 3 are the same. The performance of Tool 3 is evaluated with and without Tool 1. This document provides a summary of activities and results for this core experiment.

# Summary of proposed tools and activities

Three types of additional transforms for luma TUs have been evaluated:

* Tool 1 is a mode-dependent secondary transform for 8x8, 16x16, and 32x32 Intra TUs, applied after the HM core transform.
* Tool 2 applies a boundary-dependent primary transform for 4x4, 8x8, and 16x16 Inter TUs. Size 4 transforms use the HM DCT or HM DST Type-VII (currently used for Intra TUs) extended to the Inter case. At size 8 and larger, HM DCT and DST-Type IV are used. The DST-Type IV is generated from the DCT-Type IV by flipping basis vectors.
* Tool 3 applies the boundary-dependent primary transform from Tool 2 for 4x4 Inter TUs and a boundary-dependent secondary transform for 8x8, 16x16, and 32x32 Inter TUs. The secondary transform matrices in Tools 1 and 3 are the same. The performance of this tool is also evaluated with Tool 1.

Brief descriptions for each tool and associated activities are shown in Table 1. Bold text indicates the primary contact for the corresponding entry. For more details, please refer to the document number associated with each tool or activity. For a list of documents and cross-checks related to CE7 but not performed as part of the CE7 activities defined in JCTVC-G1207, please refer to Section 0.

Table 1. Description of tools and activities

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Tool #** | **Participants** | **Document** | **Syntax provided** | **Tool Description and cross-checkers** |
| 1 | **A. Saxena, Y. Shibahara**, F. Fernandes, T. Nishi | **JCTVC-H0125** | Yes | Mode-dependent secondary transform for Intra luma: Depending on the Intra prediction mode, a secondary transform may operate on the low-frequency coefficients of the 8x8 and larger HM core transform, for luma. When used, this transform is applied in addition to the HM core transform. Secondary transform sizes of 4x4 and 8x8 will be tested. |
|  | Cross-checks: | JCTVC-H0124 |  | 1. **A. Ichigaya**, Y. Sugito |
| 2 | **J. An**, X. **Guo**, X. Zhao, S. Lei | **JCTVC-H0309** | Yes | Boundary-dependent transform for Inter: For 4x4, 8x8, and 16x16 Inter TUs, different transforms (DST-VII/DCT-IV or DCT-II, using the existing HM transform cores) are selected for luma depending on whether the TU boundary is a PU boundary. When used, this transform is applied in place of the HM core transform. |
|  | Cross-checks: | JCTVC-H0324  JCTVC-H0080  JCTVC-H0127 |  | 1. **R. Cohen**  2. **Y. Sugito**, A. Ichigaya  3. **Ankur Saxena**, Felix Fernandes |
| 3 | **A. Saxena**, **Y. Shibihara**, F. Fernandes, T. Nishi | **JCTVC-H0126** | Yes | Unified boundary-dependent secondary transform for Inter luma: For 8x8 and larger TUs, the HM core transform is followed by a secondary transform. For 4x4 TUs, a boundary-dependent DCT/DST scheme is used. Unifying this tool with JCTVC-G108 for Intra blocks will also be investigated. Secondary transform sizes of 4x4 and 8x8 will be tested. |
|  | Cross-checks:  Inter sec. (Tests 1 and 2)  Inter & Intra sec. (Tests 3 and 4) | JCTVC-H0589  JCTVC-H0393 |  | 1.**M. Mrak**, D. Flynn  2. **R. Cohen** |

The basic architecture of the mode-dependent secondary Intra transform of Tool 1 is shown in Figure 1. For the boundary-dependent primary Inter transform of Tool 2, the transform usage is summarized in Table 2. For Tool 2, the transform type “T” is a flipped DST-VII for 4x4 TUs and a DCT-IV for 8x8 and 16x16 TUs. For Tool 3, Figure 2 shows the decoder operations for the boundary-dependent secondary transforms at sizes 8 and larger. When the horizontal secondary transform is applied, as in Cases 3 and 4 of the figure, the data is also flipped afterwards if the left TU boundary is that of PU. By symmetry, in Cases 2 and 4, when the vertical transform is applied, the data is flipped afterwards if the top TU boundary is that of PU. An overview of how all these transforms are applied is shown in Table 3. Details on the internal transform architectures can be found in the respective proposal documents.

K-Point Inv. Col. Transforms

K-Point Inv. Row Transforms

K-Point Inv. Row Transforms

K-Point Inv. Col. Transforms

8x8 and larger TUs when IntraPredMode = VER, VER+1, VER+2, …, VER+8

HM 5.0 Inverse Quant

HM 5.0 NxN Inverse DCT

8x8 and larger TUs when IntraPredMode = HOR, HOR+1, HOR+2, …, HOR+8

HM 5.0 Inverse Quant

HM 5.0 NxN Inverse DCT

4x4 TUs; 8x8 and larger TUs when IntraPredMode = DC

HM 5.0 Inverse Quant

HM 5.0 NxN Inverse Transform

8x8 and larger TUs when IntraPredMode = Planar; VER-1, VER-2, …, VER-8; HOR-1, HOR-2, …, HOR-7

HM 5.0 Inverse Quant

HM 5.0 NxN Inverse DCT

**Decoder Operations**

**Conditions**

Figure 1. Decoder operations for mode-dependent secondary transforms (Tool 1).

Table 2. Transform mapping (4-pt, 8-pt, and 16-pt trans.) from JCTVC-H0309 (Tool 2)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| TU Boundary | | Horizontal Trans. | TU Boundary | | Vertical Trans. |
| Left | Right | Top | Bottom |
| Non-PU | PU | **Flip-T** | Non-PU | PU | **Flip-T** |
| PU | Non-PU | **T** | PU | Non-PU | **T** |
| PU | PU | DCT | PU | PU | DCT |
| Non-PU | Non-PU | DCT | Non-PU | Non-PU | DCT |

**Conditions for**

**Hor Trans. and Vert Trans.**

TU Hor boundary

(Left and Right) are

both non-PU boundaries;

or both are PU boundaries

TU Ver boundary (Top and Down): one is non-PU boundary; and

other is PU boundary

TU Ver boundary

(Top and Down) are both non-PU boundaries; or both are PU boundaries

TU Ver boundary

(Top and Down): one is non-PU boundary; and other is PU boundary

TU Hor boundary:

(Left and Right): one is non-PU boundary; and

other is PU boundary

TU Hor boundary: (Left and Right): one is non-PU boundary; and other is PU boundary

TU Ver boundary

(Top and Down) are

both non-PU boundaries; or both are PU boundaries; or TU is same as PU

TU Hor boundary

(Left and Right) are

both non-PU boundaries; or both are PU boundaries; or TU is same as PU.

K-Point Inv. Col. Transforms

K-Point Inv. Row Transforms

K-Point Inv. Row Transforms

K-Point Inv. Col. Transforms

HM 5.0 Inverse Quant

HM 5.0 NxN Inverse DCT

HM 5.0 Inverse Quant

HM 5.0 NxN Inverse DCT

HM 5.0 Inverse Quant

HM 5.0 NxN Inverse Transform

HM 5.0 Inverse Quant

HM 5.0 NxN Inverse DCT

**Decoder Operations**

Figure 2. Decoder operations for boundary-dependent secondary transforms at size 8 and larger (Tool 3).

Table 3. Overview of how transforms are applied for all tools

|  |  |  |  |
| --- | --- | --- | --- |
| **Tool** | **Block Size** | **Intra** | **Inter** |
| **HM** | 4 | Mode Dep. DCT/DST-VII | DCT |
| 8 | DCT | DCT |
| 16 | DCT | DCT |
| 32 | DCT | DCT |
| **Tool 1 JCTVC-H0125** | 4 | No Change to HM | No Change to HM |
| 8 | **DCT/DCT+Mode Dep. Secondary** | No Change to HM |
| 16 | **DCT/DCT+Mode Dep. Secondary** | No Change to HM |
| 32 | **DCT/DCT+Mode Dep. Secondary** | No Change to HM |
| **Tool 2 JCTVC-H0309** | 4 | No Change to HM | **Boundary Dep. Primary DCT/DST-VII** |
| 8 | No Change to HM | **Boundary Dep. Primary DCT/DCT-IV** |
| 16 | No Change to HM | **Boundary Dep. Primary DCT/DCT-IV** |
| 32 | No Change to HM | No Change to HM |
| **Tool 3 JCTVC-H0126** | 4 | No Change to HM | **Boundary Dep. Primary DCT/DST-VII** |
| 8 | No Change to HM | **Boundary Dep. DCT/DCT+Secondary** |
| 16 | No Change to HM | **Boundary Dep. DCT/DCT+Secondary** |
| 32 | No Change to HM | **Boundary Dep. DCT/DCT+Secondary** |
| **Tool 1 + Tool 3** | 4 | No Change to HM | **Boundary Dep. Primary DCT/DST-VII** |
| 8 | **DCT/DCT+Mode Dep. Secondary** | **Boundary Dep. DCT/DCT+Secondary** |
| 16 | **DCT/DCT+Mode Dep. Secondary** | **Boundary Dep. DCT/ DCT+Secondary** |
| 32 | **DCT/DCT+Mode Dep. Secondary** | **Boundary Dep. DCT/DCT+Secondary** |

# Summary of Experimental Results

Tables 4-7 summarize the average, minimum and maximum BD-Rates encoding time ratios, and decoding time ratios for Tools 1, 2, and 3. Averages do not include Class F sequences. The LB-HE and LB-LC results for Tool 1 were not required for this CE, but are provided without cross-checking for completeness. N/A means Not Applicable.

Table 4. Performance summaries for All-Intra configurations (N/A: Not Applicable)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Tool** | **AI-HE** | | | | | | **AI-LC** | | | | | | |
| **Avg Y BD-Rate (%)** | **Min,Max Y BD-Rate (%)** | | **Enc Time (%)** | | **Dec Time (%)** | **Avg Y BD-Rate (%)** | | **Min,Max Y BD-Rate (%)** | | **Enc Time (%)** | | **Dec Time (%)** |
| **1: JCTVC-H0125 Mode-dependent secondary (Intra)** |  |  | |  | |  |  | |  | |  | |  |
| 4x4 | **-0.5** | -0.2,-0.8% | | 101 | | 99 | **-0.6** | | -0.3,-1.1% | | 102 | | 102 |
| 8x8 | **-0.7** | -0.3,-1.2% | | 103 | | 102 | **-0.8** | | -0.4,-1.5% | | 105 | | 102 |
|  |  |  | |  | |  |  | |  | |  | |  |
| **2: JCTVC-H0309 Boundary-dependent primary (Inter)** | N/A | | | | | | N/A | | | | | | |
|  |  |  |  | |  | |  |  | |  | |  | |
| **3: JCTVC-H0126 Boundary-dependent secondary** | N/A | | | | | | N/A | | | | | | |

Table 5. Performance summaries for Random Access 8-bit configurations

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Tool** | **RA-HE** | | | | **RA-LC** | | | |
| **Avg Y BD-Rate (%)** | **Min,Max Y BD-Rate (%)** | **Enc Time (%)** | **Dec Time (%)** | **Avg Y BD-Rate (%)** | **Min,Max Y BD-Rate (%)** | **Enc Time (%)** | **Dec Time (%)** |
| **1: JCTVC-H0125 Mode-dependent secondary (Intra)** |  |  |  |  |  |  |  |  |
| 4x4 | **-0.2** | -0.1,-0.3 | 101 | 101 | **-0.3** | -0.2,-0.6 | 100 | 102 |
| 8x8 | **-0.3** | -0.2,-0.5 | 100 | 100 | **-0.4** | -0.2,-0.7 | 100 | 101 |
|  |  |  |  |  |  |  |  |  |
| **2: JCTVC-H0309 Boundary-dependent primary (Inter)** | **-0.3** | -0.2,-0.5 | 101 | 101 | **-0.3** | -0.3,-0.6 | 101 | 100 |
|  |  |  |  |  |  |  |  |  |
| **3: JCTVC-H0126 Boundary-dependent secondary** |  |  |  |  |  |  |  |  |
| 4x4 Inter | **-0.3** | -0.2,-0.4 | 102 | 100 | **-0.3** | -0.3,-0.5 | 101 | 102 |
| 8x8 Inter | **-0.3** | -0.2,-0.4 | 102 | 100 | **-0.4** | -0.3,-0.6 | 102 | 101 |
| 4x4 Inter + Tool 1 4x4 Intra | **-0.5** | -0.4,-0.7 | 102 | 102 | **-0.7** | -0.5,-1.1 | 101 | 101 |
| 8x8 Inter + Tool 1 8x8 Intra | **-0.6** | -0.4,-0.9 | 102 | 100 | **-0.8** | -0.5,-1.3 | 102 | 102 |

Table 6. Performance summaries for Low Delay configurations

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Tool** | **LB-HE** | | | | **LB-LC** | | | |
| **Avg Y BD-Rate (%)** | **Min,Max Y BD-Rate (%)** | **Enc Time (%)** | **Dec Time (%)** | **Avg Y BD-Rate (%)** | **Min,Max Y BD-Rate (%)** | **Enc Time (%)** | **Dec Time (%)** |
| **1: JCTVC-H0125 Mode-dependent secondary (Intra)** |  |  |  |  |  |  |  |  |
| 4x4 | **-0.1** | +0.1,-0.2 | 100 | 100 | **-0.1** | +0.1,-0.2 | 100 | 100 |
| 8x8 | **-0.1** | +0.2,-0.2 | 100 | 101 | **-0.1** | +0.2,-0.2 | 101 | 102 |
|  |  |  |  |  |  |  |  |  |
| **2: JCTVC-H0309 Boundary-dependent primary (Inter)** | **-0.5** | -0.4,-0.6 | 101 | 101 | **-0.6** | -0.6,-0.7 | 102 | 100 |
|  |  |  |  |  |  |  |  |  |
| **3: JCTVC-H0126 Boundary-dependent secondary** |  |  |  |  |  |  |  |  |
| 4x4 Inter | **-0.3** | -0.2,-0.4 | 101 | 99 | **-0.4** | -0.3,-0.5 | 101 | 100 |
| 8x8 Inter | **-0.4** | -0.2,-0.4 | 101 | 99 | **-0.5** | -0.4,-0.6 | 101 | 100 |
| 4x4 Inter + Tool 1 4x4 Intra | **-0.4** | -0.1,-0.5 | 101 | 101 | **-0.5** | -0.2,-0.7 | 101 | 101 |
| 8x8 Inter + Tool 1 8x8 Intra | **-0.5** | -0.1,-0.6 | 102 | 101 | **-0.6** | -0.2,-0.8 | 102 | 100 |

Table 7. Performance summaries for Random Access 10-bit configuration

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Tool** | **RA-HE10** | | | |
| **Avg Y BD-Rate (%)** | **Min,Max Y BD-Rate (%)** | **Enc Time (%)** | **Dec Time (%)** |
| **1: JCTVC-H0125 Mode-dependent secondary (Intra)** |  |  |  |  |
| 4x4 | **-0.3** | -0.3,-0.3 | 100 | 100 |
| 8x8 | **-0.4** | -0.4,-0.4 | 100 | 101 |
|  |  |  |  |  |
| **2: JCTVC-H0309 Boundary-dependent primary (Inter)** | **-0.2** | -0.2,-0.2 | 101 | 100 |
|  |  |  |  |  |
| **3: JCTVC-H0126 Boundary-dependent secondary** |  |  |  |  |
| 4x4 Inter | **-0.2** | -0.2,-0.2 | 101 | 101 |
| 8x8 Inter | **-0.2** | -0.2,-0.2 | 102 | 101 |
| 4x4 Inter + Tool 1 4x4 Intra | **-0.5** | -0.5,-0.5 | 101 | 100 |
| 8x8 Inter + Tool 1 8x8 Intra | **-0.6** | -0.6,-0.6 | 102 | 100 |

# Summary of complexity

Tables 8 to 11 summarize the worst-case and average operations counts for the proposed tools. For secondary transforms, operation counts are preceded by “+” to indicate the number of additional operations the proposed secondary transform applies after the HM transform.

Tables 8 and 9 respectively show the worst-case and average-case counts for Intra TUs. Note that for Tests 3 and 4 of JCTVC-H0126, the Intra TUs case would correspond to the 4x4 and 8x8 case of JCTVC-H0125 respectively. Also, JCTVC-H0309 does not propose any modifications for Intra coding. Therefore, operations count information for only JCTVC-H0125 is included in Tables 8 and 9.

Table 8. Worst-case inverse transform operations count summary for Intra TUs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **TU size** | **Operations** | **HM5.0 DCT** | **HM5.0 DST** | **JCTVC-H0125** | |
| **4x4 Sec. Tx** | **8x8 Sec. Tx** |
| **4x4** | **Mults**  **Adds**  **Shifts**  **Clips** | 48  96  32  32 | 64  120  32  32 | -  -  -  - | -  -  -  - |
| **8x8** | **Mults**  **Adds**  **Shifts**  **Clips** | 352  576  128  128 | -  -  -  - | +128  +128  +32  +32 | +1024  +1024  +128  +128 |
| **16x16** | **Mults**  **Adds**  **Shifts**  **Clips** | 2752  3712  512  512 | -  -  -  - | +128  +128  +32  +32 | +1024  +1024  +128  +128 |
| **32x32** | **Mults**  **Adds**  **Shifts**  **Clips** | 21888  25856  2048  2048 | -  -  -  - | +128  +128  +32  +32 | +1024  +1024  +128  +128 |

Table 9. Average inverse transform operations count summary for Intra TUs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **TU size** | **Operations** | **HM5.0 DCT** | **HM5.0 DST** | **JCTVC-H0125** | |
| **4x4 Sec. Tx** | **8x8 Sec. Tx** |
| **4x4** | **Mults**  **Adds**  **Shifts**  **Clips** | 48  96  32  32 | 64  120  32  32 | -  -  -  - | -  -  -  - |
| **8x8** | **Mults**  **Adds**  **Shifts**  **Clips** | 352  576  128  128 | -  -  -  - | +91  +91  +23  +23 | +731  +731  +91  +91 |
| **16x16** | **Mults**  **Adds**  **Shifts** | 2752  3712  512 | -  -  - | +91  +91  +23 | +731  +731  +91 |
| **Clips** | 512 | - | +23 | +91 |
| **32x32** | **Mults**  **Adds**  **Shifts**  **Clips** | 21888  25856  2048  2048 | - -  -  - | +91  +91  +23  +23 | +731  +731  +91  +91 |

Tables 10 and 11 respectively show the worst-case and average-case counts for Inter CUs. Note that the Inter cases of Tests 1 and 2 are the same as that of Tests 3 and 4, respectively. Since JCTVC-H0125 does not propose any modifications for Inter coding, no operations count information for JCTVC-H0125 is included in Tables 10 and 11.

Table 10. Worst-case inverse transform operations count summary for Inter TUs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **TU size** | **Operations** | **HM5.0 DCT** | **JCTVC-H0309 Bd-Dep Primary Tx** | **JCTVC-H0126 Bd-Dep Tx** | |
| **4x4 Primary Tx** | |
| **4x4** | **Mults** | 48 | 64 | 64 | |
| **Adds** | 96 | 120 | 120 | |
| **Shifts** | 32 | 32 | 32 | |
| **Clips** | 32 | 32 | 32 | |
|  |  |  |  | **4x4 Sec. Tx** | **8x8 Sec. Tx** |
| **8x8** | **Mults** | 352 | 1024 | +128  +128  +32  +32 | +1024  +1024  +128  +128 |
| **Adds** | 576 | 1024 |
| **Shifts** | 128 | 128 |
| **Clips** | 128 | 128 |
| **16x16** | **Mults** | 2752 | 8192 | +128  +128  +32  +32 | +1024  +1024  +128  +128 |
| **Adds** | 3712 | 8192 |
| **Shifts** | 512 | 512 |
| **Clips** | 512 | 512 |
| **32x32** | **Mults**  **Adds**  **Shifts**  **Clips** | 21888  25856  2048  2048 | -  -  -  - | +128  +128  +32  +32 | +1024  +1024  +128  +128 |

Table 11. Average inverse transform operations count summary for Inter TUs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **TU size** | **Operations** | **HM5.0 DCT** | **JCTVC-H0309 Bd-Dep Primary Tx** | **JCTVC-H0126 Bd-Dep** | |
| **4x4 Primary Tx** | **-** |
| **4x4** | **Mults** | 48 | 56 | 56 | 56  108  32  32 |
| **Adds** | 96 | 108 | 108 |
| **Shifts** | 32 | 32 | 32 |
| **Clips** | 32 | 32 | 32 |
|  |  |  |  | **4x4 Sec. Tx** | **8x8 Sec. Tx** |
| **8x8** | **Mults** | 352 | 688 | +64 | +512 |
| **Adds** | 576 | 800 | +64 | +512 |
| **Shifts** | 128 | 128 | +16 | +64 |
| **Clips** | 128 | 128 | +16 | +64 |
| **16x16** | **Mults** | 2752 | 5472 | +64 | +512 |
| **Adds** | 3712 | 5952 | +64 | +512 |
| **Shifts**  **Clips** | 512  512 | 512 | +16 | +64 |
| 512 | +16 | +64 |
| **32x32** | **Mults**  **Adds**  **Shifts**  **Clips** | 21888  25856  2048  2048 | -  -  -  - | +85 | +683 |
| +85 | +683 |
| +21 | +85 |
| +21 | +85 |

# “Non-CE7” (CE7-related) documents

The table below lists documents that are related to additional transforms but were not part of the formal CE.

|  |  |  |  |
| --- | --- | --- | --- |
| **Directly-related CE7 tools** | **Document No.** | **Title** | **Authors** |
| Tool 1 and 3 Secondary  Transforms | JCTVC-H0559 | Non-CE 7 : Recent results for secondary transforms for intra/inter prediction residual | A. Saxena (Samsung), Y. Shibahara (Panasonic), E. Alshina (Samsung), F. Fernandes (Samsung), T Nishi (Panasonic) |
|  |  |  |  |
| **Other tools** |  |  |  |
| ROT | JCTVC-H0456 | Non CE 7: Experimental Results for the ROT | Z. Ma, F. Fernandes, E. Alshina, A. Alshin (Samsung) |

# Summary and Conclusions

Tool 1, JCTVC-H0125, defines 4-point or 8-point secondary transform matrices which are applied after the HM core transform to the low frequency coefficients of 8x8, 16x16 and 32x32 Intra TUs. They are applied either horizontally or vertically, depending upon the Intra prediction mode, using the same mapping table as is used for the existing HM 4x4 DCT/DST. With 4x4 secondary transforms, the overall average BD-Rate changes for All-Intra configurations were -0.5% to -0.6%, with encoder run-time ratios between 101% and 102% and decoder ratios of 99% to 102%. For Random Access and Low Delay configurations, overall average BD-rate changes were -0.1% to -0.3%, with encoder and decoder run-time ratios ranging from 99% to 102%. With 8x8 secondary transforms, the overall average BD-Rate changes for All-Intra configurations were -0.7% to -0.8%, with encoder run-time ratios between 103% and 105% and decoder ratios of 102%. For Random Access and Low Delay configurations, overall average BD-rate changes were -0.1% to -0.4%, with encoder and decoder run-time ratios ranging from 100% to 102%. When this tool was used in conjunction with the Inter transforms of Tool 3, gains appeared to be additive.

Tool 2, JCTVC-H0309, defines one 4-point, two 8-point, and two 16-point primary Inter transforms that can reuse the existing HM transform logic, if implemented in a certain way. The 4-point Flipped DST-VII can be implemented by flipping the inputs or transform coefficients of the existing 4-point DST. For 8- and 16-point transforms, if the HM N-point DCT is implemented as an N/2-point DCT butterflied with an N/2-point DCT-IV, then the 8-point DCT-IV is available as part of the 16-point HM transform and the 16-point DCT-IV is available from the 32-point HM transform. Flipped versions of these transforms are used as well. The 4-, 8-, and 16-point horizontal and vertical transforms used in a square or non-square Inter TU depends upon the TU’s adjacency to the left, right, top, or bottom boundary of its PU. The overall average BD-Rate changes for Random Access configurations were -0.2 to -0.3%, with encoder run-time ratios of 101% and decoder ratios of 100% to 101%. For Low Delay configurations, BD-Rate overall averages were -0.5% to -0.6%, with encoder run-time ratios of 101% to 102% and decoder ratios of 100% to 101%.

Tool 3, JCTVC-H0126, defines 4-point or 8-point secondary transform matrices, identical to those used in Tool 1, which are applied in addition to the HM core transform as secondary transforms on Inter TUs. For square and non-square TUs with size 4, this tool operates identically to Tool 2, applying a boundary-dependent primary transform. For square and non-square TUs with size 8, 16, and 32, the 4-point or 8-point secondary transform is applied after the HM core transform, depending upon the TU’s adjacency to the PU boundary. The same boundary mapping table from Tool 2 is used. For the 4-point secondary transform, the overall average BD-Rate changes for Random Access configurations were -0.3%, with encoder run-time ratios of 101% to 102% and decoder ratios of 100% to 102%. For Low Delay configurations, BD-Rate overall averages were -0.3% to -0.4%, with encoder run-time ratios of 102% and decoder ratios of 99% to 100%. For the 8-point secondary transform, the overall average BD-Rate changes for Random Access configurations were -0.3% to -0.4%, with encoder run-time ratios of 102% and decoder ratios of 100% to 101%. For Low Delay configurations, BD-Rate overall averages were -0.4% to -0.5%, with encoder run-time ratios of 101% and decoder ratios of 99% to 100%.

For all tools, summaries of operation counts were provided. For secondary transforms applied after the HM transform (or before the HM inverse transform in the decoder), operation counts preceded with “+” indicate the additional operations incurred with the proposed tool. For the primary transforms, the operation counts are compared to the existing HM transform which they replace.

In addition to the tests conducted as a formal part CE7, additional tests can be found in directly-related documents corresponding to the proposed tools. A table of related documents is provided.

The final discussion on whether to adopt these tools can be held during the JCT-VC meeting. The decisions can be summarized as follows:

Tool 1, the secondary Intra transform, can be considered for adoption alone or in conjunction with the Inter transforms of Tools 2 or 3. Gains appear to be additive. A decision on whether to adopt the 4x4 or 8x8 secondary Intra transform will be needed.

Tool 2 is a boundary-dependent primary transform for 4-, 8-, and 16-point Inter transforms. Tool 3 is a boundary-dependent primary transform for 4-point Inter transforms and a 4-point or 8-point secondary transform for 8-, 16-, and 32-point Inter transforms. A decision on whether to adopt Tool 2 or Tool 3 will be needed. For Tool 3, a decision on 4-point or 8-point secondary transform will also be needed. Because Tool 3 uses the same secondary transform matrices as Tool 1, a combined adoption would likely use the same size.

# Participant list

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