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| **Joint Collaborative Team on Video Coding (JCT-VC)**  **of ITU-T SG16 WP3 and ISO/IEC JTC1/SC29/WG11**  7th Meeting: Geneva, CH, 21-30 November, 2011 | Document: JCTVC-G036 |

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| --- | --- | --- | --- |
| *Title:* | **CE6: Summary Report of Core Experiments on Intra Coding Improvements** | | |
| *Status:* | **Input Document of JCTVC** | | |
| *Purpose:* | **Report** | | |
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# Introduction

This document provides a summary report of the Core Experiments (CE6) results on “Intra prediction and improvements”. The experiments are divided into 4 subsets, as indicated below:

1. Subset CE6a: Intra Chroma Prediction
2. Subset CE6b: Intra Mode Coding
3. Subset CE6c: Short Distance Intra Prediction (SDIP)
4. Subset CE6ed: Intra Prediction with secondary boundary

# CE6a: Intra Chroma Prediction

## CE6a Candidate Technologies

### Modified down-sample filters

As shown in Fig. 1, the goal in this CE is to do performance evaluation of a set of modified down-sampling filter candidates as defined in the table below for the pixels of the top and left neighbor lines, and for the internal pixel of the current PU. There are a total of 2x3x3=18 test cases. Each test case is denoted as “TiLjIk” (i=0 or 1, j=0, 1, or 2, and k=0, 1, or 2) where the test case “T0L0I0” is HM4.0 anchor.



**Figure 1 – HM4.0 vs. proposed filters**

|  |  |
| --- | --- |
| Top neighbors | Filter T0:  Filter T1: |
| Left neighbors | Filter L0:  Filter L1:  Filter L2: |
| Internal pixels (Current PU) | Filter I0:  Filter I1:  Filter I2: |

**Table 1 - Candidate down-sample filters for each location**

### Alpha and beta calculation complexity reduction



### Reduction of Storage for Reconstructed Luma Pixels

Store 8-bit and not 10-bit samples for subsampled, reconstructed luma component.

## Cross Check Status

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Contribution**  **6th meeting** | **Tools** | **Proponent** | **Release Status** | **Contribution**  **7th meeting** | **x-checker** | **x-check doc.** |
| JCTVC-F173 | improvement to chroma intra prediction from luma | Mitsubishi | V1 released 9/08  V2 released 9/13 | JCTVC-G455 | ETRI | JCTVC-G169 |
| JCTVC-F502 | Cross-channel techniques to improve intra chroma prediction | Intel | JCTVC-G172 | ETRI  Mitsubishi | JCTVC-G168  JCTVC-G476 |
| JCTVC-F233  JCTVC-F431 | Sub-sampling portion of neighboring pixels | TI & Sony | 9/13 | JCTVC-G129 | Panasonic | JCTVC-G297 |
| JCTVC-F431 | Improvement to chroma intra prediction from luma | Sony | 9/14 | G0510 | Panasonic | G0294 (ok) |

**Table 2 – CE6a: Intra Chroma Prediction**

## Cross Check Results

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **“T0L2I2”** | **All Intra HE** | | | **All Intra LC** | | |
| Y | U | V | Y | U | V |
| Class A | -0.03% | 0.58% | 1.56% | -0.06% | 0.55% | 1.50% |
| Class B | -0.07% | -0.25% | -0.21% | -0.07% | -0.47% | -0.40% |
| Class C | -0.36% | -1.21% | -1.02% | -0.28% | -1.68% | -1.53% |
| Class D | -0.25% | -0.89% | -0.76% | -0.20% | -1.25% | -1.19% |
| Class E | 0.00% | -0.17% | -0.50% | -0.02% | -0.25% | -0.32% |
| Class F | -0.65% | -1.34% | -1.13% | -0.54% | -1.91% | -1.78% |
| **Overall A-E** | -0.15% | -0.39% | -0.17% | -0.13% | -0.63% | -0.39% |
| **Overall A-F** | -0.23% | -0.55% | -0.33% | -0.20% | -0.84% | -0.62% |
| Nebuta | 0.00% | 0.69% | 2.17% | -0.04% | 1.09% | 2.54% |
| SteamLoco | 0.04% | 2.25% | 4.19% | 0.01% | 1.99% | 3.83% |
| Enc Time[%] | 100% | | | 100% | | |
| Dec Time[%] | 100% | | | 101% | | |

**Table 3 – T0L2I2** **vs. HM 4.0**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Number of multiplications per block for calculating alpha and beta** | | | **All Intra HE** | | | **All Intra LC** | | |
| **Subsampling factor** | **4x4** | **8x8** | **16x16** | **Y** | **U** | **V** | **Y** | **U** | **V** |
| HM-4.0 | 16 | 32 | 64 |  |  |  |  |  |  |
| 1:2 for 16x16 | 16 | 32 | 32 | 0.0% | 0.2% | 0.1% | 0.0% | 0.1% | 0.0% |
| 1:2 for 8x8, 16x16 | 16 | 16 | 32 | 0.1% | 0.5% | 0.4% | 0.1% | 0.5% | 0.3% |
| 1:2 for 8x8, 1:4 for 16x16 | 16 | 16 | 16 | 0.1% | 0.8% | 0.5% | 0.1% | 0.7% | 0.3% |

**Table 4 - Different sub-sampling vs. HM 4.0 (JCTVC-G129)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | 0.0% | 0.2% | 0.0% | 0.0% | 0.1% | -0.1% |
| Class B | 0.1% | 0.4% | 0.2% | 0.1% | 0.3% | 0.1% |
| Class C | 0.0% | 0.0% | 0.1% | 0.0% | 0.0% | 0.0% |
| Class D | 0.0% | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% |
| Class E | 0.0% | 0.3% | 0.2% | 0.0% | 0.2% | 0.2% |
| Class F |  |  |  |  |  |  |
| **Overall** | 0.0% | 0.2% | 0.1% | 0.0% | 0.1% | 0.0% |
|  | 0.0% | 0.2% | 0.1% | 0.0% | 0.1% | 0.0% |
| Enc Time[%] | 90% | | | 88% | | |
| Dec Time[%] | 90% | | | 86% | | |

**Table 5 – 2:1 sub-sampling for 16x16**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | 0.0% | 0.1% | 0.1% | 0.0% | 0.3% | 0.1% |
| Class B | 0.0% | 0.1% | 0.0% | 0.0% | 0.3% | 0.2% |
| Class C | 0.0% | 0.0% | 0.1% | 0.0% | 0.2% | 0.3% |
| Class D | 0.0% | 0.0% | 0.1% | 0.0% | 0.1% | 0.2% |
| Class E | 0.0% | 0.1% | 0.1% | 0.0% | 0.1% | 0.2% |
| Class F |  |  |  |  |  |  |
| **Overall** | 0.0% | 0.0% | 0.1% | 0.0% | 0.2% | 0.2% |
|  | 0.0% | 0.0% | 0.1% | 0.0% | 0.2% | 0.2% |
| Enc Time[%] | 100% | | | 100% | | |
| Dec Time[%] | 101% | | | 102% | | |

**Table 6 - 10-bit to 8-bit for HE and 8-bit to 6-bit (except for the 10-bit class A for LC), JCTVC-G510**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.03% | 0.72% | 1.69% | -0.05% | 0.76% | 1.58% |
| Class B | -0.06% | -0.28% | -0.22% | -0.06% | -0.43% | -0.36% |
| Class C | -0.36% | -1.17% | -1.06% | -0.28% | -1.60% | -1.48% |
| Class D | -0.25% | -0.87% | -0.80% | -0.20% | -1.18% | -1.19% |
| Class E | 0.00% | -0.19% | -0.50% | -0.03% | -0.27% | -0.29% |
| Class F | -0.65% | -1.23% | -1.12% | -0.52% | -1.80% | -1.65% |
| **Overall A-E** | -0.14% | -0.36% | -0.16% | -0.13% | -0.55% | -0.35% |
| **Overall A-F** | -0.23% | -0.51% | -0.32% | -0.19% | -0.76% | -0.57% |
| Enc Time[%] | 100% | | | 99% | | |
| Dec Time[%] | 99% | | | 100% | | |

**Table 7 - T0L2I2 + JCTVC-G129 + JCTVC-G510**

## Remarks

Note 1: A bug was reported in the calculation of alpha to 7 bits representation, on 9/15. A bug fix was released on 9/21 testing alpha bits 7 and 8 cases. Both show some gain in chroma component. A strange thing, however, is that the result for alpha bits = 7 is a little better than that for alpha bits = 8 case.

Note 2: Concern about the need for additional memory access/buffer for the use of 3x2 filters!

Note 3: Cross-checkers encoding decoding times seem close to 100% in Table 3!

## Related Non-CE6a Submissions

1. Luma Based Chroma Prediction, JCTVC-G244
2. Use of chroma phase in LM mode, JCTVC-G245

# CE6b: Intra Mode Coding

## CE6b Candidate Technologies

### MPM Derivation



**Figure 3 – 2 MPMS (HM4.0) vs. proposed 4 MPMs**

### Remaining Mode Coding



**Figure 4 – Rank re-ordering**

### Binarization

|  |  |  |
| --- | --- | --- |
| Rank range | Prefix (Unary code) | Remainder (fixed length) |
| 0-1 | 0 | x (1 bit) |
| 2-5 | 10 | xx (2 bits) |
| 6-9 | 110 | xx (2 bits) |
| 10-18 | 111 | xxx (3 bits) |

Table 8 - Codewords for Intra mode coding of 4x4 PUs (includes MPM codewords)

|  |  |  |
| --- | --- | --- |
| Rank range | Prefix (Unary code) | Remainder (fixed length) |
| 0-1 | 0 | x (1 bit) |
| 2-5 | 10 | xx (2 bits) |
| 6-13 | 110 | xxx (3 bits) |
| 14-21 | 1110 | xxx (3 bits) |
| 22-35 | 1111 | xxxx (4 bits) |

Table 9 - Codewords for Intra mode coding of 8x8, 16x16, and 32x32 PUs (includes MPM codewords)

### Combination

Proponents have also combined the above approaches into a unified solution: Intra Mode Coding with 4MPMs and Mode Ranking (JCTVC-G243).

### Differential Coding of Intra Modes (DCIM)

Derivation of additional intra prediction modes based on the available edge information from the top and left neighbor of current PU.

## Cross Check Status

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Contribution**  **6th meeting** | **Tools** | **Proponent** | **Release Status** | **Contribution**  **7th meeting** | **x-checker** | **x-check doc.** |
| JCTVC-F062 | MPMs derivation | MediaTek | V1 Released 9/13  V2 released 9/14 | G203 | SCU  Canon  JVC-Kenwood | G276  G252  G186 |
| JCTVC-F459 | MPMs derivation | Qualcomm |
| JCTVC-F106 | Remaining mode coding | LG | Released 9/9 | G192 | SCU | G276 |
| JCTVC-F269 | Remaining mode coding | Canon | Released 9/13 | G242 | SCU  Sharp  I2R | G276  G311  G080 |
| JCTVC-F566 | DCIM MPM & SDIP Harmonization | Sharp, Sony | Released 9/13 | G868 | Huawei | G789 |
| JCTVC-F269 | Combinations of MPMs derivation and Remaining mode coding | Canon | Released 9/13 | G242 | ETRI  I2R  Sharp | G167  G080  G311 |
| JCTVC-F091 | Combinations of MPMs derivation and Remaining mode coding | Sony | Released 9/13 | G869 | SCU | G276 |
| JCTVC-F062, JCTVC-F459, JCTVC-F091, JCTVC-F106, JCTVC-F269 | Combinations of MPMs derivation and Remaining mode coding | MediaTek, Qualcomm, Sony, LG, Canon | Released 10/14 | G243 | Sharp | G311 |

**Table 10 - CE6b: Intra Mode Coding**

## Cross Check Results

### MPMs derivation

**JCTVC-G203: MediaTek/Qualcomm solution (JCTVC-F062, JCTVC-F459)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.32% | -0.01% | -0.05% | -0.26% | -0.28% | -0.22% |
| Class B | -0.33% | -0.39% | -0.47% | -0.36% | -0.67% | -0.69% |
| Class C | -0.34% | -0.64% | -0.67% | -0.43% | -0.92% | -0.85% |
| Class D | -0.29% | -0.56% | -0.63% | -0.35% | -0.61% | -0.74% |
| Class E | -0.60% | -0.29% | -0.43% | -0.60% | -0.79% | -0.83% |
| **Overall** | -0.36% | -0.38% | -0.45% | -0.39% | -0.65% | -0.66% |
|  | -0.36% | -0.39% | -0.47% | -0.39% | -0.64% | -0.65% |
| Enc Time[%] | 100% | | | 100% | | |
| Dec Time[%] | 100% | | | 101% | | |

**Table 11 - MPMs derivation - MediaTek/Qualcomm solution: Using 18 modes for 4x4 PUs**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.35% | -0.01% | -0.05% | -0.29% | -0.28% | -0.25% |
| Class B | -0.34% | -0.38% | -0.46% | -0.37% | -0.69% | -0.69% |
| Class C | -0.38% | -0.66% | -0.73% | -0.47% | -0.97% | -0.92% |
| Class D | -0.34% | -0.57% | -0.64% | -0.41% | -0.65% | -0.78% |
| Class E | -0.63% | -0.30% | -0.46% | -0.60% | -0.79% | -0.83% |
| **Overall** | -0.39% | -0.39% | -0.47% | -0.42% | -0.67% | -0.69% |
|  | -0.39% | -0.39% | -0.48% | -0.42% | -0.67% | -0.69% |
| Enc Time[%] | 100% | | | 101% | | |
| Dec Time[%] | 101% | | | 101% | | |

**Table 12 - MPMs derivation - MediaTek/Qualcomm solution: Using 19 modes for 4x4 PUs**

### Remaining mode coding

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.31% | -0.07% | 0.00% | -0.16% | -0.07% | -0.07% |
| Class B | -0.25% | -0.04% | -0.07% | -0.18% | -0.14% | -0.12% |
| Class C | -0.27% | -0.09% | -0.13% | -0.23% | -0.20% | -0.18% |
| Class D | -0.14% | -0.04% | -0.05% | -0.10% | -0.07% | -0.08% |
| Class E | -0.11% | 0.00% | 0.00% | -0.03% | 0.01% | 0.11% |
| **Overall** | -0.22% | -0.05% | -0.05% | -0.15% | -0.10% | -0.08% |
|  | -0.22% | -0.05% | -0.06% | -0.15% | -0.10% | -0.09% |
| Enc Time[%] | 101% | | | 101% | | |
| Dec Time[%] | 100% | | | 101% | | |

**Table 13 - JCTVC-G242: Canon solution (JCTVC-F269) – with 2 MPMs**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A |  |  |  | -0.19% | -0.05% | -0.12% |
| Class B |  |  |  | -0.24% | -0.19% | -0.18% |
| Class C |  |  |  | -0.21% | -0.20% | -0.17% |
| Class D |  |  |  | -0.06% | 0.02% | -0.03% |
| Class E |  |  |  | -0.13% | 0.02% | -0.03% |
| **Overall** |  |  |  | -0.17% | -0.09% | -0.11% |
|  |  |  |  | -0.17% | -0.09% | -0.11% |
| Enc Time[%] |  | | | 101% | | |
| Dec Time[%] |  | | | 100% | | |

**Table 14 - JCTVC-G192: LG solution (JCTVC-F106) – with 2 MPMs**

### Combination of MPMs derivation and Remaining mode coding

The following solutions were not described in the CE6 document. As mentioned in CE6b description (JCTVC-F906, section 4.2.3), combinations of proposed MPMs derivation solutions (F062/F459) and proposed remaining mode coding solutions (F091, F106, F269) would be tested. The 3 solutions above consist of different combinations of these two approaches.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.42% | -0.01% | -0.01% | -0.29% | -0.09% | -0.11% |
| Class B | -0.38% | -0.06% | -0.05% | -0.32% | -0.22% | -0.14% |
| Class C | -0.36% | -0.14% | -0.18% | -0.36% | -0.27% | -0.24% |
| Class D | -0.25% | -0.06% | -0.08% | -0.20% | -0.05% | -0.09% |
| Class E | -0.39% | 0.06% | 0.10% | -0.29% | 0.01% | 0.14% |
| **Overall** | -0.36% | -0.05% | -0.05% | -0.29% | -0.14% | -0.10% |
|  | -0.36% | -0.05% | -0.06% | -0.29% | -0.14% | -0.11% |
| Enc Time[%] | 99% | | | 100% | | |
| Dec Time[%] | 101% | | | 100% | | |

**Table 15 - JCTVC-G242: Canon solution (JCTVC-F269) – with 3 MPMs**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.39% | -0.11% | -0.07% | -0.22% | -0.12% | -0.17% |
| Class B | -0.29% | -0.06% | 0.00% | -0.26% | -0.22% | -0.19% |
| Class C | -0.42% | -0.14% | -0.18% | -0.35% | -0.26% | -0.26% |
| Class D | -0.31% | -0.10% | -0.17% | -0.25% | -0.14% | -0.18% |
| Class E | -0.47% | -0.14% | -0.06% | -0.35% | -0.27% | -0.17% |
| **Overall** | -0.37% | -0.10% | -0.10% | -0.28% | -0.20% | -0.20% |
|  | -0.37% | -0.11% | -0.11% | -0.28% | -0.20% | -0.20% |
| Enc Time[%] | #NUM! | | | #NUM! | | |
| Dec Time[%] | #NUM! | | | #NUM! | | |

**Table 16 - Sony solution (JCTVC-F091) – with 3 MPMs**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.47% | 0.00% | -0.10% | -0.35% | -0.30% | -0.30% |
| Class B | -0.44% | -0.46% | -0.52% | -0.44% | -0.74% | -0.76% |
| Class C | -0.48% | -0.74% | -0.77% | -0.51% | -1.00% | -0.92% |
| Class D | -0.40% | -0.54% | -0.58% | -0.36% | -0.64% | -0.76% |
| Class E | -0.65% | -0.28% | -0.52% | -0.57% | -0.79% | -0.81% |
| **Overall** | -0.48% | -0.41% | -0.50% | -0.44% | -0.69% | -0.71% |
|  | -0.48% | -0.42% | -0.50% | -0.44% | -0.69% | -0.69% |
| Enc Time[%] | 100% | | | 100% | | |
| Dec Time[%] | 100% | | | 100% | | |

**Table 17 - JCTVC- G243: Unified solution from Canon/LG/MediaTek/Qualcomm/Sony (F062-F091-F106-F269-F459)**

### DCIM MPM & SDIP Harmonization

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | 0.09% | -0.71% | -0.17% | -0.07% | 0.07% | 0.25% |
| Class B | -0.16% | -0.91% | -0.72% | -0.20% | 0.23% | 0.17% |
| Class C | -0.58% | -0.70% | -1.02% | -0.80% | 0.01% | -0.38% |
| Class D | -0.18% | -0.29% | -0.26% | -0.25% | 0.03% | -0.02% |
| Class E | -0.25% | -1.20% | -1.49% | -0.44% | -0.57% | 0.05% |
| **Overall** | -0.21% | -0.75% | -0.69% | -0.34% | -0.01% | 0.02% |
|  | -0.21% | -0.72% | -0.68% | -0.34% | 0.00% | 0.03% |
| Enc Time[%] | 116% | | | 123% | | |
| Dec Time[%] | 104% | | | 105% | | |

**Table 18 - Sharp & Sony solution (JCTVC-F566)**

## Remarks

## Related Non-CE6b Submissions

JCTVC-G153, JCTVC-G145, JCTVC-G184, JCTVC-G119 and JCTVC-G359.

# CE6c: Short Distance Intra Prediction (SDIP)

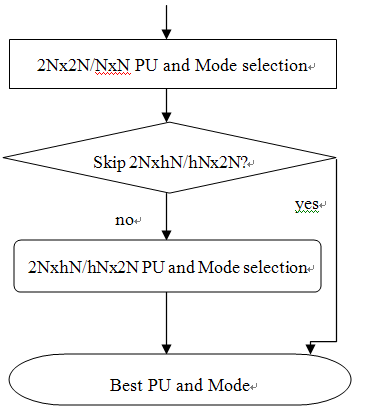
The goal of this experiment is to test the coding efficiency and encoding/decoding run-time of the harmonized SDIP based on the HM4.0 software. This is not limited to improving coding efficiency, it also relates to the harmonization and complexity reduction. Five main subtests are addressed here:

* Tradeoff of coding efficiency and encoding/decoding run-time of SDIP
* Chroma coding scheme for SDIP mode
* SDIP harmonization with HE residual coding
* LM mode harmonization on SDIP
* Intra prediction mode coding with CAVLC on SDIP

## CE6c Candidate Technologies

SDIP introduces two types of PUs which are named as 2NxhN and hNx2N for CUs whose size is smaller than 64x64, where h means half or 0.5. 2NxhN and hNx2N can also be called as SDIP PUs. 2NxhN includes 32x8, 16x4 and 8x2 PU, and similarly, hNx2N includes 8x32, 4x16 and 2x8 PU for 32x32 to 8x8 CU. 2x32 and 32x2 are the second depth of transform unit of 8x32 and 32x8 PU. The candidate non-square PUs are summarized in Table 19.

|  |  |  |  |
| --- | --- | --- | --- |
| **CU size** | **Non-square PUs** | **Non-square TUs** | **Intra Mode number** |
| 64x64 | - | - |  |
| 32x32 | 32x8/8x32 | 32x8/8x32  32x2/2x32 | 35 |
| 16x16 | 16x4/4x16 | 16x4/4x16 | 35 |
| 8x8 | 8x2/2x8 | 8x2/2x8 | 18 |



**Table 19 - Non square PU in SDIP Figure 5 - Non square PU early skip**

### Case 1: Early skip based simplification

In this case, the non square PU type may be skipped according to the coding results of square PU, as illustrated in Figure 5. The threshold T for the skip condition (compared with the bits of 2Nx2N PU type) is calculated by formula (1) when QP is not equal to 0:

T = a \*(64.0 / ((QP < 32)? QP: 64)) (1)

Where variable "a" is set as 5, 10 and 300 for 8x8, 16x16 and 32x32 CU respectively.

### Case 2: Fast non-square PU selection

In addition to the early skip method described in Case 1, a fast non-square PU selection method was used to further reduce the encoder complexity in this case. At the stage of 2Nx2N encoding, the best intra mode for 2Nx2N and its RD cost were saved, if non square PU type should be tested judged by early skip method in Case1, then each PU with hNx2N and 2NxhN type will be encoded with the best mode of 2Nx2N type. The best non square PU type will be selected to compare with the RD cost of 2Nx2N, if the RD cost of the best non square PU (ie.2NxhN) is smaller than that of 2Nx2N, 2NxhN will do a real RDO and choose the intra mode for each PU of 2NxhN type from N Modes, so only one non square PU type need to be tested in RDO for each CU.

### Case 3: NSQT for Intra

In this case, the NSQT\_INTRA introduces non-square quad-tree transform (NSQT) to intra CU. The major changes from SDIP to NSQT\_INTRA in the implementation are, in brief, 1) remove non-square PU and introduce non-square TU instead; 2) move SDIP side info from PU level to TU level; 3) remove modifications introduced to chroma components. For different CU size and trafoDepth, the candidate TU partitioning methods (including both SQT partitions and NSQT partitions) are listed in Table 20.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 64x64 CU  (SIZE\_2Nx2N) | | 32x32 CU  (SIZE\_2Nx2N) | | 16x16 CU  (SIZE\_2Nx2N) | | 8x8 CU  (SIZE\_2Nx2N) | | 8x8 CU  (SIZE\_NxN) | |
| SQT | NSQT | SQT | NSQT | SQT | NSQT | SQT | NSQT | SQT | NSQT |
| trafoDepth=0 | N/A | N/A | 32x32 | N/A | 16x16 | N/A | 8x8 | N/A | N/A | N/A |
| trafoDepth=1 | 32x32 | 32x32 | 16x16 | 32x8  8x32 | 8x8 | 16x4  4x16 | 4x4 | 8x2  2x8 | 4x4 | N/A |
| trafoDepth=2 | 16x16 | 16x16 | 8x8 | 32x2  2x32 | 4x4 | N/A | N/A | N/A | N/A | N/A |

**Table 20 - Candidate TU partitioning methods (including both SQT partitions and NSQT partitions) in case of different CU size and trafoDepth**

## Cross Check Status



**Table 21 - SDIP Cross-check Status**

## Cross Check Results (w/o ClassF)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.51% | -1.55% | -1.94% | -1.25% | -1.91% | -2.54% |
| Class B | -1.25% | -2.36% | -2.58% | -2.33% | -2.43% | -2.97% |
| Class C | -1.53% | -1.43% | -1.73% | -2.30% | -2.44% | -2.89% |
| Class D | -1.51% | -1.18% | -1.13% | -2.12% | -2.05% | -2.14% |
| Class E | -2.18% | -5.34% | -4.88% | -3.76% | -7.06% | -5.61% |
| **Overall** | -1.35% | -2.22% | -2.34% | -2.28% | -2.95% | -3.10% |
|  | -1.35% | -2.21% | -2.32% | -2.28% | -2.93% | -3.07% |
| Enc Time[%] | 128% | | | 134% | | |
| Dec Time[%] | 102% | | | 98% | | |

**Table 22 - Case 1: Fast early-skip results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.28% | -1.11% | -1.35% | -0.76% | -1.29% | -1.84% |
| Class B | -0.90% | -1.97% | -2.11% | -1.61% | -1.63% | -2.14% |
| Class C | -1.04% | -1.02% | -1.26% | -1.58% | -1.80% | -2.18% |
| Class D | -1.13% | -0.93% | -0.92% | -1.59% | -1.62% | -1.74% |
| Class E | -1.62% | -4.27% | -3.87% | -2.72% | -5.69% | -4.44% |
| **Overall** | -0.96% | -1.74% | -1.82% | -1.60% | -2.20% | -2.35% |
|  | -0.96% | -1.74% | -1.80% | -1.60% | -2.20% | -2.33% |
| Enc Time[%] | 114% | | | 120% | | |
| Dec Time[%] | 101% | | | 98% | | |

**Table 23 - Case 2: Fast SDIP PU selection results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.24% | -0.80% | -0.95% | -0.50% | -1.12% | -1.35% |
| Class B | -0.82% | -1.65% | -1.66% | -1.38% | -1.66% | -1.93% |
| Class C | -0.70% | -0.69% | -0.80% | -0.78% | -0.96% | -1.22% |
| Class D | -0.60% | -0.50% | -0.50% | -0.65% | -0.81% | -0.79% |
| Class E | -1.63% | -3.12% | -2.82% | -2.37% | -4.89% | -3.69% |
| **Overall** | -0.76% | -1.28% | -1.29% | -1.09% | -1.72% | -1.71% |
|  | -0.76% | -1.27% | -1.27% | -1.09% | -1.74% | -1.70% |
| Enc Time[%] | 115% | | | 114% | | |
| Dec Time[%] | 103% | | | 98% | | |

**Table 24 - Case 3: Non-square PU removal results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.03% | -0.85% | -0.33% | 0.00% | -1.87% | -1.37% |
| Class B | -0.04% | -1.44% | -1.23% | -0.02% | -2.40% | -2.29% |
| Class C | -0.10% | -1.00% | -1.05% | -0.09% | -1.07% | -1.10% |
| Class D | -0.01% | -1.35% | -1.32% | -0.05% | -1.23% | -1.02% |
| Class E | -0.02% | -1.76% | -1.87% | -0.01% | -2.14% | -2.00% |
| **Overall** | -0.04% | -1.26% | -1.13% | -0.04% | -1.75% | -1.57% |
|  | -0.04% | -1.29% | -1.16% | -0.04% | -1.77% | -1.59% |
| Enc Time[%] | 100% | | | 100% | | |
| Dec Time[%] | 101% | | | 101% | | |

**Table 25 - Case 4: Fast SDIP early-skip with SDM On results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.02% | -0.47% | -0.21% | 0.02% | -0.76% | -0.23% |
| Class B | 0.00% | -0.18% | -0.10% | 0.04% | -0.16% | -0.03% |
| Class C | -0.07% | -0.27% | -0.18% | -0.02% | -0.25% | -0.21% |
| Class D | -0.04% | -0.20% | -0.16% | 0.00% | -0.20% | -0.13% |
| Class E | 0.01% | -0.71% | -0.52% | 0.03% | -0.16% | 0.03% |
| **Overall** | -0.02% | -0.34% | -0.21% | 0.01% | -0.31% | -0.12% |
|  | -0.02% | -0.35% | -0.22% | 0.02% | -0.33% | -0.12% |
| Enc Time[%] | 100% | | | 100% | | |
| Dec Time[%] | 101% | | | 102% | | |

**Table 26 - Case 5: Fast SDIP early-skip with SDM Off results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | 0.00% | -0.68% | -0.43% | 0.01% | -1.43% | -1.05% |
| Class B | 0.00% | -1.34% | -1.15% | 0.00% | -1.98% | -1.94% |
| Class C | -0.03% | -0.90% | -0.92% | -0.05% | -0.82% | -0.86% |
| Class D | 0.03% | -1.16% | -1.06% | -0.02% | -0.95% | -0.80% |
| Class E | 0.01% | -1.54% | -1.61% | 0.00% | -1.75% | -1.63% |
| **Overall** | 0.00% | -1.11% | -1.01% | -0.01% | -1.40% | -1.27% |
|  | 0.00% | -1.13% | -1.03% | -0.01% | -1.41% | -1.28% |
| Enc Time[%] | 101% | | | 101% | | |
| Dec Time[%] | 101% | | | 101% | | |

**Table 27 - Case 6: Fast SDIP PU selection with SDM On results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.01% | -0.32% | -0.18% | 0.02% | -0.52% | -0.10% |
| Class B | 0.02% | -0.11% | -0.03% | 0.04% | -0.08% | 0.01% |
| Class C | -0.02% | -0.16% | -0.11% | 0.00% | -0.10% | -0.07% |
| Class D | 0.01% | -0.13% | -0.04% | 0.03% | -0.08% | 0.04% |
| Class E | 0.04% | -0.44% | -0.41% | 0.03% | 0.00% | 0.11% |
| **Overall** | 0.01% | -0.22% | -0.14% | 0.02% | -0.16% | -0.01% |
|  | 0.01% | -0.22% | -0.14% | 0.02% | -0.17% | -0.01% |
| Enc Time[%] | 100% | | | 101% | | |
| Dec Time[%] | 100% | | | 101% | | |

**Table 28 - Case 7: Fast SDIP PU selection with SDM Off results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.15% | -0.29% | -0.51% |  |  |  |
| Class B | -0.15% | -0.15% | -0.26% |  |  |  |
| Class C | 0.01% | -0.06% | -0.09% |  |  |  |
| Class D | 0.02% | 0.02% | -0.04% |  |  |  |
| Class E | -0.14% | -0.54% | -0.36% |  |  |  |
| **Overall** | -0.08% | -0.19% | -0.25% |  |  |  |
|  | -0.08% | -0.19% | -0.25% |  |  |  |
| Enc Time[%] | 99% | | |  | | |
| Dec Time[%] | 99% | | |  | | |

**Table 29 - Case 8: SDIP Harmonization with HE Residual Coding results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A | -0.02% | -0.48% | -0.22% | 0.00% | -0.99% | -0.36% |
| Class B | -0.01% | -0.25% | -0.24% | -0.01% | -0.41% | -0.28% |
| Class C | -0.07% | -0.37% | -0.29% | -0.07% | -0.44% | -0.36% |
| Class D | -0.06% | -0.26% | -0.21% | -0.04% | -0.35% | -0.27% |
| Class E | 0.01% | -1.02% | -0.73% | 0.01% | -0.75% | -0.60% |
| **Overall** | -0.03% | -0.44% | -0.32% | -0.02% | -0.57% | -0.36% |
|  | -0.03% | -0.44% | -0.32% | -0.02% | -0.58% | -0.36% |
| Enc Time[%] | 99% | | | 98% | | |
| Dec Time[%] | 99% | | | 98% | | |

**Table 30 - Case 9: Best chroma mode order results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A |  |  |  | -0.14% | -0.09% | -0.14% |
| Class B |  |  |  | -0.13% | -0.13% | -0.13% |
| Class C |  |  |  | 0.00% | 0.06% | 0.09% |
| Class D |  |  |  | 0.00% | 0.06% | 0.02% |
| Class E |  |  |  | -0.20% | -0.40% | -0.34% |
| **Overall** |  |  |  | -0.09% | -0.09% | -0.09% |
|  |  |  |  | -0.09% | -0.09% | -0.10% |
| Enc Time[%] |  | | | 99% | | |
| Dec Time[%] |  | | | 99% | | |

**Table 31 - Case 10: Specific VLC tables and counters results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra HE** | | | **All Intra LC** | | |
|  | Y | U | V | Y | U | V |
| Class A |  |  |  | -0.15% | -2.07% | -1.56% |
| Class B |  |  |  | -0.15% | -2.55% | -2.45% |
| Class C |  |  |  | -0.09% | -1.00% | -1.07% |
| Class D |  |  |  | -0.05% | -1.22% | -0.97% |
| Class E |  |  |  | -0.21% | -2.55% | -2.28% |
| **Overall** |  |  |  | -0.12% | -1.88% | -1.67% |
|  |  |  |  | -0.13% | -1.90% | -1.69% |
| Enc Time[%] |  | | | 99% | | |
| Dec Time[%] |  | | | 102% | | |

**Table 32 - Case 11: Combination test for SDIP chroma coding scheme and specific VLC tables and counters results**

## Remarks

SDIP software was released on 9/10/2011.Minor modification for HE inter case released on 9/16/2011. The software includes all three tested cases defined in CE6 subset c.

All the cross-check from Sony finished on 9/21/2011. BD-rate results matched with results from proponents. On 11/16/2011, a bug was reported by proponents of SDIP in Case 3. A request for re-running cross-check for SDIP Case 3 was made.

## Non-CE6c Related Submissions

JCTVC-G135, JCTVC-G354, JCTVC-G598

# CE6d: Intra prediction with secondary boundary

## CE6.d Candidate Technologies

### Direction based Angular Intra Prediction

**Figure 6 - Example of filtering operations in JCTVC-F122 (left: Intra prediction with gradient along the vertical direction, middle: Intra Prediction with gradient along one direction from v+1 to v+3, right: Bi-directional prediction (v+4~v+8 modes) )**

### An improved intra vertical and horizontal prediction (JCTVC-F172)

In this scheme, difference between two reference samples in left or above prediction direction is scaled and added to corresponding prediction samples in intra vertical or horizontal prediction mode. For intra vertical prediction mode, prediction samples are derived by applying the following process:



where x, y represent horizontal and vertical pixel positions within a PU, S(x,y) represents reference sample value and S’(x,y) represents prediction sample value.

For intra horizontal prediction mode, prediction samples are derived by applying the following process:



### Intra planar and angular prediction smoothing (JCTVC-F358)

**Planar prediction smoothing:** In this scheme, a filter is applied to the boundary of planar prediction as described in JCTVC-F358. The process can be described as follows:

rpDst[0] = ( pSrc[-1] + 2\*rpDst[0] + pSrc[-srcStride] + 2 ) >> 2;

for (k=0, l=1; l<blkSize; l++)  
 rpDst[k\*dstStride+l] = ( pSrc[l-srcStride] + 3\*rpDst[k\*dstStride+l] + 2 ) >> 2;

for (k=1, l=0; k<blkSize; k++)  
 rpDst[k\*dstStride+l] = ( pSrc[k\*srcStride-1] + 3\*rpDst[k\*dstStride+l] + 2 ) >> 2;

**Angular prediction smoothing:** In this scheme, a diagonal 2-tap filter is applied to the secondary boundary depending on the intra prediction direction as described in JCTVC-F358. The process can be described as follows:

if ( intraPredAngle > 0 )  
 {  
 for (k=0;k<blkSize;k++)  
 pDst[k\*dstStride] = ( 3\*pDst[k\*dstStride] + refSide[k+2] + 2 ) >> 2;  
 }

### Directional intra prediction smoothing (JCTVC-F456)



**Figure 7 - Example of diagonal filtering applied in JCTVC-F358 and JCTVC-F456**

## Cross Check Status

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **CE6e: Intra prediction with secondary boundary** | | | | | **Cross-check** | |
| **Cat** | **Turin doc** | **Geneva doc** | **Tools** | **Proponent** | **X-check** | **Doc.** |
| 1 | [JCTVC-F172](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2637) | JCTVC-G457 | Intra horizontal and vertical prediction edge smoothing | Mitsubishi | Nokia | JCTVC-G565 |
| 1 | [JCTVC-F122](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2585) | JCTVC-G279(\*) | Gradient based intra prediction for vertical and horizontal set (totally 8 modes) | MediaTek | Nokia Sony | JCTVC-G565 JCTVC-G361 |
| 2 | [JCTVC-F122](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2585) | JCTVC-G279(\*) | Bi-direction intra angular prediction | MediaTek | Nokia Toshiba | JCTVC-G565 JCTVC-G436 |
| 2 | [JCTVC-F358](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2827) | JCTVC-G420 | Intra angular prediction smoothing | ETRI | Nokia | JCTVC-G565 |
| 2 | [JCTVC-F456](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2931) | JCTVC-G565 | Directional intra prediction smoothing | Nokia | Toshiba I2R Inria | JCTVC-G436 JCTVC-G081 JCTVC-G561 |
| 3 | [JCTVC-F358](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2827) | JCTVC-G420 | Intra planar prediction smoothing | ETRI | Nokia | JCTVC-G565 |
| 4 | [JCTVC-F172](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2637),  [JCTVC-F122](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2585),  [JCTVC-F358](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2827) , [JCTVC-F456](http://phenix.it-sudparis.eu/jct/doc_end_user/current_document.php?id=2931) | All above and JCTVC-G280 | Combination of Category 1, 2 and 3 | Mitsubishi, MediaTek, ETRI, Nokia, | HiSilicon Qualcomm | JCTVC-G790 JCTVC-G293 |

**(\*) Uploaded late**

**Table 33 -** **CE6d: Intra prediction with secondary boundary and Cross-check**

## Cross Check Results

The tables in this section summarize objective performance of each of the CE6.d test performed. Tests 1 – 8 measure performance of different candidate technologies separately. Whereas, tests 9 – 13 provide results for the identified most promising combinations of different candidates. Tool IDs in the results tables are described in Table 1.

|  |  |  |  |
| --- | --- | --- | --- |
| **Tool ID** | **Proponent** | **Turin doc.** | **Description** |
| F122(G1) | MediaTek | F122 | Gradient based method for vertical and horizontal modes (intraPredAngle== 0), single line processing |
| F122(GD1) | MediaTek | F122 | Combination of gradient based and directional smoothing for directional modes (intraPredAngle 2, 5, 9), single line processing using fractional pixel accuracy |
| F122(D1) | MediaTek | F122 | Directional smoothing for directional modes (intraPredAngle>= 13), single line processing using fractional pixel accuracy |
| F122(G4) | MediaTek | F122 | Gradient based method for vertical and horizontal modes (intraPredAngle== 0), processing 4 lines |
| F122(D4) | MediaTek | F122 | Directional smoothing for directional modes (intraPredAngle== 32), processing 4 lines using full pixel accuracy |
| F172 | Mitsubishi | F172 | Gradient based smoothing for horizontal and vertical modes (intraPredAngle == 0), single line processing |
| F358 | ETRI | F358 | Diagonal smoothing for modes with intraPredAngle > 0, using full pixel accuracy , single line processing |
| F358(P) | ETRI | F358 | Smoothing for the planar mode, single line processing |
| F456 | Nokia | F456 | Diagonal smoothing for modes with abs(intraPredAngle) > 9, using full pixel accuracy, single line processing |
| Harm(G2) | MTK& Mitsubishi | F122& F172 | Harmonized design for 2-line gradient based approach for vertical and horizontal modes |
| Harm(GD1) | MediaTek | F122 | Identical to F122(GD1), but only applied to directions 2 and 5 |

**Table 34 - Summary of the different methods tested**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Tools enabled for each directionality (intraPredAngles)** | | | | | |  | | |  | | |
|  | **Hor/Ver** | **Low** | **High** | **High** | **-High** | **Planar** | **Intra HE** | | | **Intra LC** | | |
| **Test** | **(0)** | **(2,5,9)** | **(13,...,26)** | **(32)** | **-(13,...,32)** |  | **Y** | **U** | **V** | **Y** | **U** | **V** |
| 1 | F172 |  |  |  |  |  | -0.3 % | -0.2 % | -0.2 % | -0.3 % | -0.3 % | -0.3 % |
| 2 | F122(G1) | F122(GD1) |  |  |  |  | -0.4 % | -0.3 % | -0.3 % | -0.4 % | -0.4 % | -0.4 % |
| 3 | F122(G4) | F122(GD1) |  |  |  |  | -0.4 % | -0.4 % | -0.5 % | -0.4 % | -0.5 % | -0.5 % |
| 4 |  |  | F122(D1) | F122(D1) |  |  | -0.2 % | -0.2 % | -0.2 % | -0.2 % | -0.2 % | -0.2 % |
| 5 |  |  | F122(D1) | F122(D4) |  |  | -0.3 % | -0.3 % | -0.2 % | -0.3 % | -0.3 % | -0.3 % |
| 6 |  | F358 | F358 | F358 |  |  | -0.2 % | -0.2 % | -0.2 % | -0.2 % | -0.3 % | -0.3 % |
| 7 |  |  | F456 | F456 | F456 |  | -0.3 % | -0.2 % | -0.2 % | -0.2 % | -0.3 % | -0.3 % |
| 8 |  |  |  |  |  | F358(P) | -0.1 % | -0.1 % | -0.1 % | -0.1 % | -0.1 % | -0.1 % |
| 9 | F172 | F358 | F358 | F358 |  | F358(P) | -0.5 % | -0.5 % | -0.5 % | -0.5 % | -0.6 % | -0.6 % |
| 10 | F172 |  | F456 | F456 | F456 | F358(P) | -0.6 % | -0.5 % | -0.5 % | -0.5 % | -0.6 % | -0.6 % |
| 11 | F122(G1) | F122(GD1) | F122(D1) | F122(D1) |  | F358(P) | -0.6 % | -0.5 % | -0.6 % | -0.5 % | -0.6 % | -0.7 % |
| 12 | F122(G4) | F122(GD1) | F122(D1) | F122(D4) |  | F358(P) | -0.7 % | -0.7 % | -0.7 % | -0.7 % | -0.8 % | -0.9 % |
| 13 | Harm(G2) | Harm(GD1) | F358/F456 | F122(D4) | F456 | F358(P) | -0.7 % | -0.7 % | -0.7 % | -0.7 % | -0.8 % | -0.8 % |

**Table 35 - Summary of the objective performance of different methods tested**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Tools enabled for each directionality (intraPredAngles)** | | | | | |  | | | |
|  | **Hor/Ver** | **Low** | **High** | **High** | **-High** | **Planar** | **Intra HE** | | **Intra LC** | |
| **Test** | **(0)** | **(2,5,9)** | **(13,...,26)** | **(32)** | **-(13,...,32)** |  | **EncTi** | **DecTi** | **EncTi** | **DecTi** |
| 1 | F172 |  |  |  |  |  | 100 % | 101 % | 99 % | 102 % |
| 2 | F122(G1) | F122(GD1) |  |  |  |  | 100 % | 101 % | 100 % | 100 % |
| 3 | F122(G4) | F122(GD1) |  |  |  |  | 100 % | 100 % | 102 % | 101 % |
| 4 |  |  | F122(D1) | F122(D1) |  |  | 100 % | 100 % | 100 % | 100 % |
| 5 |  |  | F122(D1) | F122(D4) |  |  | 100 % | 100 % | 100 % | 101 % |
| 6 |  | F358 | F358 | F358 |  |  | 100 % | 102 % | 100 % | 101 % |
| 7 |  |  | F456 | F456 | F456 |  | 100 % | 100 % | 100 % | 100 % |
| 8 |  |  |  |  |  | F358(P) | 100 % | 100 % | 100 % | 100 % |
| 9 | F172 | F358 | F358 | F358 |  | F358(P) | 101 % | 101 % | 100 % | 101 % |
| 10 | F172 |  | F456 | F456 | F456 | F358(P) | 101 % | 101 % | 100 % | 101 % |
| 11 | F122(G1) | F122(GD1) | F122(D1) | F122(D1) |  | F358(P) | 101 % | 102 % | 101 % | 102 % |
| 12 | F122(G4) | F122(GD1) | F122(D1) | F122(D4) |  | F358(P) | 101 % | 101 % | 101 % | 102 % |
| 13 | Harm(G2) | Harm(GD1) | F358/F456 | F122(D4) | F456 | F358(P) | 101 % | 102 % | 100 % | 102 % |

**Table 36 - Summary of the run times measured**

## Remarks

When it comes to implementation aspects of the proposals, the following could be considered:

**Gradient based technologies:**

* F122: adding a pixel specific gradient term to sample value and clipping the result
* F172: adding a pixel specific gradient term to sample value and clipping the result

**Directional smoothing:**

* F122: calculation of weighted average of the prediction value and two reference sample values (with angle dependent locations and weights)
* F358 & F456: calculation of a weighted average of two samples with fixed weight

**Methods utilizing both gradient and directional techniques for the same prediction direction:**

* F122: calculation of a weighted average of two reference sample values (with angle dependent locations and weights) and in addition the operations described for gradient based F122.

**Planar smoothing:**

* F358: calculation of a weighted average of two samples with fixed weight

**Variants with multiple line processing:**

* F122: variants with multi-line processing have some additional complexity

## Related Non-CE6d Submissions