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| --- | --- | --- | --- |
| *Title:* | **AHG7: Sample-based angular intra prediction for HEVC range extension** | | |
| *Status:* | Input Document to JCT-VC | | |
| *Purpose:* | Proposal | | |
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# Abstract

Efficient lossless coding is required for real-world applications such as such as remote desktop, online gaming, wireless display, video conferencing, automotive vision, long-distance education and content post-production. This contribution reports the test results of the sample-based angular intra prediction (SAP) in the HEVC range extension and HM9.0 environments. The proposed sample-based prediction is exactly same as the HM9.0 block-based angular prediction in terms of prediction angle signaling and sample interpolation, requires no syntax or semantics changes, but differs in decoding process in terms of reference sample selection for interpolation. In the proposed method a sample to be predicted uses its adjacent neighboring samples for better intra prediction accuracy. Compared to the HM9.0 lossless coding method which bypasses transform, quantization, de-blocking filter, SAO and ALF, the proposed method provides an average gain (w/o Class F) of 8.5% in AI-Main, 8.5% in AI-HE10, 6.4% in RA-Main, 6.8% in RA-HE10, 6.2% in LB-Main, 6.9% in LB-HE10, 6.0% in LP-Main and 6.9% in LP-HE10 for AHG7 screen content sequences, and an average gain (w/o Class F) of 7.0% in AI-Main, 6.9% in AI-HE10, 1.8% in RA-Main, 2.1% in RA-HE10, 1.5% in LB-Main, 2.2% in LB-HE10, 1.8% in LP-Main and 2.3% in LP-HE10 for HM9.0 common test condition sequences. For class F sequences only, the average gain is 11.6% in AI-Main, 13.8% in AI-HE10, 6.8% in RA-Main, 9.0% in RA-HE10, 5.5% in LB-Main, 7.7% in LB-HE10, 5.5% in LP-Main and 7.7% in LP-HE10. The SAP is fully parallelized on the encoder side, and can be executed at a speed of one row or one column per cycle on the decoder side.

# Introduction

In HM9.0 the “lossless coding for free” mode is supported in response to increasing needs of lossless video coding for real-world applications such as remote desktop, online gaming, wireless display, video conferencing, automotive vision, long-distance education and content post-production. In HM9.0 the lossless coding is enabled by bypassing transform, quantization and in-loop filters (de-blocking filter, SAO) and can be turned on/off at CU-level by using lossless coding on/off flag at CU level.

The current HM9.0 lossless coding mode can be improved by introducing new coding tools. One of the tools that has been proposed is so-called sample-based angular intra prediction (SAP) [3][4][5][6]. Just like the block-based angular intra prediction defined in JCTVC-K1003, in the proposed SAP all the samples in a PU still share a same prediction angle, but the prediction sample of the current sample in a PU uses two of its adjacent neighbors (not limited to the boundary reference samples from neighboring PU). The prediction angle signaling method and the sample interpolation method remain unchanged. Therefore, the SAP introduces changes only in decoding process, but not in syntax and semantics. For the detailed algorithm description of the SAP, please refer to [3][4][5][6].

This document reports the SAP performance in HEVC ranger extension software and in HM9.0. No technical changes have been introduced when compared to [3][4][5][6]. In both software the SAP is integrated in a way in which it can be turned on/off at CU-level, to align with the current HM9.0 lossless coding signaling method.

# Test Settings and Conditions

The simulations have used both the HEVC range extension software and the HM9.0 software; the simulation platform is LSF equipped with Intel(R) Xeon(R) CPU X5570 64 bits Linux machines of different frequencies. For the simulations with the HEVC range extension software, the following 4:4:4 (YUV and RGB) screen content (SC) sequences are used in addition to Class F 4:2:0 sequence.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sequence** | **Resolution** | **Number of frames** | **Bit-depth** | **Frame-rate** |
| VenueVu | 1920 x 1080 | 300 | 10-bit (YUV) / 8-bit (RGB) | 30 |
| sc-cad-waveform | 1920 x 1080 | 200 | 8-bit | 20 |
| sc-pcb-layout | 1920 x 1080 | 200 | 8-bit | 20 |
| sc-ppt-doc | 1920 x 1080 | 200 | 8-bit | 20 |
| sc-video-conferencing-doc-sharing | 1280 x 720 | 300 | 8-bit | 30 |
| sc-web-browsing | 1280 x 720 | 300 | 8-bit | 30 |

Table 1. List of 4:4:4 screen content sequences

For the simulations with HM9.0, the common test conditions (CTC) and reference configurations specified in [1] are followed, except that only one QP (QP =22) is tested because QP does not play a role in the lossless coding.

# Experimental results

In Table 2 and Table 3, results of two methods are compared, one is the HM9.0 lossless coding method which bypasses transform, quantization, de-blocking filtering and SAO, and the other is the proposed method which simply replaces the block-based angular intra prediction with the proposed sample-based intra prediction in lossless coding mode.

As shown in Table 2, for screen content sequences the proposed method provides an average gain (w/o Class F) of 8.5% in AI-Main, 8.5% in AI-HE10, 6.4% in RA-Main, 6.8% in RA-HE10, 6.2% in LB-Main, 6.9% in LB-HE10, 6.0% in LP-Main and 6.9% in LP-HE10. For class F sequences only, 11.6% in AI-Main, 13.8% in AI-HE10, 6.7% in RA-Main, 9.1% in RA-HE10, 5.7% in LB-Main, 7.8% in LB-HE10, 5.7% in LP-Main and 7.8% in LP-HE10. (Detailed results can be found in *HM-RangeExt-TI-losslessAnchor\_vs\_SAP.xls*)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra Main** | | | **All Intra HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class F | 4.6 | 5.3 | -11.6% | 3.9 | 4.6 | -13.8% |
| SC (YUV) | 10.0 | 10.8 | -7.6% | 9.4 | 10.2 | -7.6% |
| SC(RGB) | 9.4 | 10.3 | -9.3% | 9.3 | 10.2 | -9.5% |
| **Overall (w/o F)** | 9.7 | 10.6 | -8.5% | 9.4 | 10.2 | -8.5% |
| **Overall (w/ F)** | 8.4 | 9.3 | -9.3% | 8.0 | 8.8 | -9.9% |
| Enc Time[%] | 108% | | | 103% | | |
| Dec Time[%] | 102% | | | 97% | | |
|  |  |  |  |  |  |  |
|  | **Random Access Main** | | | **Random Access HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class F | 29.1 | 31.3 | -6.7% | 24.1 | 26.9 | -9.1% |
| SC (YUV) | 133.0 | 142.4 | -6.0% | 125.3 | 135.0 | -6.6% |
| SC(RGB) | 123.4 | 133.4 | -6.8% | 121.9 | 131.5 | -6.9% |
| **Overall (w/o F)** | 128.2 | 137.9 | -6.4% | 123.6 | 133.2 | -6.8% |
| **Overall (w/ F)** | 103.4 | 111.3 | -6.5% | 98.7 | 106.7 | -7.4% |
| Enc Time[%] | 102% | | | 102% | | |
| Dec Time[%] | 101% | | | 100% | | |
|  |  |  |  |  |  |  |
|  | **Low delay B Main** | | | **Low delay B HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class F | 47.0 | 49.5 | -5.7% | 38.9 | 42.4 | -7.8% |
| SC (YUV) | 510.3 | 543.9 | -6.1% | 488.4 | 525.6 | -7.1% |
| SC(RGB) | 460.1 | 494.5 | -6.3% | 457.8 | 492.8 | -6.8% |
| **Overall (w/o F)** | 485.2 | 519.2 | -6.2% | 473.1 | 509.2 | -6.9% |
| **Overall (w/ F)** | 375.7 | 401.8 | -6.1% | 364.5 | 392.5 | -7.1% |
| Enc Time[%] | 102% | | | 96% | | |
| Dec Time[%] | 99% | | | 87% | | |
|  |  |  |  |  |  |  |
|  | **Low delay P Main** | | | **Low delay P HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class F | 46.6 | 49.1 | -5.7% | 38.8 | 42.4 | -7.8% |
| SC (YUV) | 511.9 | 544.4 | -6.0% | 489.8 | 525.6 | -7.1% |
| SC(RGB) | 458.6 | 493.5 | -6.0% | 458.0 | 492.8 | -6.8% |
| **Overall (w/o F)** | 485.2 | 519.0 | -6.0% | 473.9 | 509.2 | -6.9% |
| **Overall (w/ F)** | 375.6 | 401.5 | -5.9% | 365.1 | 392.5 | -7.2% |
| Enc Time[%] | 102% | | | 93% | | |
| Dec Time[%] | 99% | | | 85% | | |

Table 2. Simulation results for SC sequences (SAP vs. HM9.0 lossless coding mode)

As shown in Table 3, for HM9.0 common test condition sequence the proposed method provides an average gain (w/o Class F) of 7.0% in AI-Main, 6.9% in AI-HE10, 1.8% in RA-Main, 2.1% in RA-HE10, 1.5% in LB-Main, 2.2% in LB-HE10, 1.8% in LP-Main and 2.3% in LP-HE10. For class F sequences only, 11.6% in AI-Main, 13.8% in AI-HE10, 6.8% in RA-Main, 9.0% in RA-HE10, 5.5% in LB-Main, 7.7% in LB-HE10, 5.5% in LP-Main and 7.7% in LP-HE10. (Detailed results can be found in *HM-9.0-TI-losslessAnchor\_vs\_SAP*)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra Main** | | | **All Intra HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class A | 2.1 | 2.3 | -7.9% | 1.7 | 1.8 | -7.3% |
| Class B | 2.1 | 2.2 | -4.3% | 1.7 | 1.8 | -4.2% |
| Class C | 2.0 | 2.1 | -6.3% | 1.6 | 1.7 | -5.9% |
| Class D | 1.8 | 2.0 | -8.2% | 1.5 | 1.7 | -8.1% |
| Class E | 2.7 | 3.0 | -9.3% | 2.1 | 2.4 | -10.5% |
| **Overall (w/o F)** | 2.1 | 2.3 | -7.0% | 3.9 | 4.6 | -6.9% |
| **Overall (w/ F)** | 2.5 | 2.8 | -7.7% | 1.7 | 1.8 | -8.0% |
| Class F | 4.6 | 5.3 | -11.6% | 3.9 | 4.6 | -13.8% |
| Enc Time[%] | 104% | | | 102% | | |
| Dec Time[%] | 93% | | | 92% | | |
|  |  |  |  |  |  |  |
|  | **Random Access Main** | | | **Random Access HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class A | 2.4 | 2.5 | -2.7% | 1.9 | 1.9 | -3.0% |
| Class B | 2.4 | 2.4 | -0.9% | 1.8 | 1.8 | -1.4% |
| Class C | 2.5 | 2.6 | -1.6% | 1.9 | 2.0 | -1.9% |
| Class D | 2.6 | 2.7 | -2.0% | 2.0 | 2.0 | -2.3% |
| Class E |  |  |  |  |  |  |
| **Overall (w/o F)** | 2.5 | 2.5 | -1.8% | 1.9 | 1.9 | -2.1% |
| **Overall (w/ F)** | 7.6 | 8.1 | -2.7% | 6.2 | 6.8 | -3.4% |
| Class F | 29.3 | 31.7 | -6.8% | 24.3 | 27.2 | -9.0% |
| Enc Time[%] | 100% | | | 101% | | |
| Dec Time[%] | 97% | | | 97% | | |
|  |  |  |  |  |  |  |
|  | **Low delay B Main** | | | **Low delay B HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class A |  |  |  |  |  |  |
| Class B | 2.4 | 2.4 | -0.7% | 1.8 | 1.8 | -1.2% |
| Class C | 2.5 | 2.6 | -1.3% | 1.9 | 2.0 | -1.7% |
| Class D | 2.6 | 2.7 | -1.5% | 2.0 | 2.0 | -1.9% |
| Class E | 3.2 | 3.3 | -2.8% | 2.4 | 2.5 | -5.1% |
| **Overall (w/o F)** | 2.6 | 2.7 | -1.5% | 2.0 | 2.1 | -2.2% |
| **Overall (w/ F)** | 11.6 | 12.1 | -2.3% | 9.4 | 10.2 | -3.3% |
| Class F | 47.4 | 49.7 | -5.5% | 39.1 | 42.6 | -7.7% |
| Enc Time[%] | 100% | | | 101% | | |
| Dec Time[%] | 97% | | | 100% | | |
|  |  |  |  |  |  |  |
|  | **Low delay P Main** | | | **Low delay P HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class A |  |  |  |  |  |  |
| Class B | 2.3 | 2.3 | -1.0% | 1.8 | 1.8 | -1.4% |
| Class C | 2.4 | 2.5 | -1.5% | 1.9 | 2.0 | -1.8% |
| Class D | 2.6 | 2.6 | -1.6% | 2.0 | 2.0 | -1.9% |
| Class E | 3.1 | 3.3 | -3.6% | 2.4 | 2.5 | -5.0% |
| **Overall (w/o F)** | 2.6 | 2.6 | -1.8% | 2.0 | 2.0 | -2.3% |
| **Overall (w/ F)** | 11.5 | 12.0 | -2.5% | 9.4 | 10.2 | -3.4% |
| Class F | 47.1 | 49.4 | -5.5% | 39.3 | 42.7 | -7.7% |
| Enc Time[%] | 103% | | | 101% | | |
| Dec Time[%] | 101% | | | 97% | | |

Table 3. Simulation results for CTC sequence (SAP vs. HM9.0 lossless coding mode)

# Additional experimental results

Additional test was performed for AHG7 common test condition sequences which include four more 4:4:4 SCC sequences (i.e. sc-cg-twist-tunnel, sc-wordEditing, sc-map, sc-programming) as shown in Table 4. As required by the AHG7, the RGB sequences were coded in GBR order in this simulation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sequence** | **Resolution** | **Number of frames** | **Bit-depth** | **Frame-rate** |
| VenueVu | 1920 x 1080 | 300 | 10-bit (YUV) / 8-bit (RGB) | 30 |
| sc-cad-waveform | 1920 x 1080 | 200 | 8-bit | 20 |
| sc-pcb-layout | 1920 x 1080 | 200 | 8-bit | 20 |
| sc-ppt-doc | 1920 x 1080 | 200 | 8-bit | 20 |
| sc-video-conferencing-doc-sharing | 1280 x 720 | 300 | 8-bit | 30 |
| sc-web-browsing | 1280 x 720 | 300 | 8-bit | 30 |
| sc-cg-twist-tunnel | 1280 x 720 | 300 | 8-bit | 60 |
| sc-wordEditing | 1280 x 720 | 600 | 8-bit | 60 |
| sc-map | 1280 x 720 | 600 | 8-bit | 60 |
| sc-programming | 1280 x 720 | 600 | 8-bit | 60 |

Table 4. List of AHG7 4:4:4 screen content sequences

Table 5 summarizes the coding results for AHG7 CTC sequences, similar gains of SAP were observed. As shown in Table 5, for AHG7 screen content sequences the proposed method provides an average gain (w/o Class F) of 9.8% in AI-Main, 10.8% in AI-HE10, 6.9% in RA-Main, 8.4% in RA-HE10, 6.2% in LB-Main, 7.7% in LB-HE10, 6.2% in LP-Main and 7.8% in LP-HE10. For class F sequences only, 11.6% in AI-Main, 13.8% in AI-HE10, 6.7% in RA-Main, 9.1% in RA-HE10, 5.7% in LB-Main, 7.8% in LB-HE10, 5.7% in LP-Main and 7.8% in LP-HE10.The detailed results can be found in *HM-RangeExt-TI-losslessAnchor\_vs\_SAP\_new.xls*.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **All Intra Main** | | | **All Intra HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class F | 4.6 | 5.3 | -11.6% | 3.9 | 4.6 | -13.8% |
| SC (YUV) | 9.2 | 10.1 | -9.2% | 8.5 | 9.4 | -10.1% |
| SC(GBR) | 7.5 | 8.4 | -10.5% | 7.2 | 8.2 | -11.5% |
| **Overall (w/o F)** | 8.3 | 9.2 | -9.8% | 7.8 | 8.8 | -10.8% |
| **Overall (w/ F)** | 7.7 | 8.6 | -10.1% | 7.2 | 8.1 | -11.3% |
| Enc Time[%] | 104% | | | 108% | | |
| Dec Time[%] | 97% | | | 103% | | |
|  |  |  |  |  |  |  |
|  | **Random Access Main** | | | **Random Access HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class F | 29.1 | 31.3 | -6.7% | 24.1 | 26.9 | -9.1% |
| SC (YUV) | 104.5 | 111.9 | -6.4% | 96.1 | 104.0 | -8.2% |
| SC(GBR) | 88.4 | 96.5 | -7.5% | 85.2 | 93.1 | -8.6% |
| **Overall (w/o F)** | 96.5 | 104.2 | -6.9% | 90.7 | 98.6 | -8.4% |
| **Overall (w/ F)** | 85.2 | 92.0 | -6.9% | 79.6 | 86.6 | -8.5% |
| Enc Time[%] | 104% | | | 102% | | |
| Dec Time[%] | 104% | | | 100% | | |
|  |  |  |  |  |  |  |
|  | **Low delay B Main** | | | **Low delay B HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class F | 47.0 | 49.5 | -5.7% | 38.9 | 42.4 | -7.8% |
| SC (YUV) | 335.8 | 357.6 | -6.1% | 317.8 | 342.1 | -7.8% |
| SC(GBR) | 302.4 | 326.9 | -6.4% | 299.5 | 324.3 | -7.6% |
| **Overall (w/o F)** | 319.1 | 342.3 | -6.2% | 308.7 | 333.2 | -7.7% |
| **Overall (w/ F)** | 273.7 | 293.5 | -6.1% | 263.7 | 284.7 | -7.7% |
| Enc Time[%] | 106% | | | **104%** | | |
| Dec Time[%] | 110% | | | 106% | | |
|  |  |  |  |  |  |  |
|  | **Low delay P Main** | | | **Low delay P HE10** | | |
|  | **compression ratio** | | Bit-rate saving | **compression ratio** | | Bit-rate saving |
|  | Reference | Tested | Reference | Tested |
| Class F | 46.6 | 49.1 | -5.7% | 38.8 | 42.4 | -7.8% |
| SC (YUV) | 336.7 | 357.8 | -6.0% | 318.6 | 342.1 | -7.8% |
| SC(GBR) | 302.7 | 327.4 | -6.5% | 299.7 | 324.3 | -7.9% |
| **Overall (w/o F)** | 319.7 | 342.6 | -6.2% | 309.2 | 333.2 | -7.8% |
| **Overall (w/ F)** | 274.2 | 293.7 | -6.1% | 264.1 | 284.7 | -7.8% |
| Enc Time[%] | 106% | | | 103% | | |
| Dec Time[%] | 107% | | | 105% | | |

Table 5. Simulation results for AHG7 CTC sequences (SAP vs. HM9.0 lossless coding mode)

# Throughput analysis

The sample-based angular intra prediction is fully parallel on the encoder side, and can be executed at a speed of one row or one column per cycle on the decoder side. For a 4x4 intra PU, this would mean 4 cycles per 4x4 block on the decoder side, which is far less than a typical cycle budget of 12 per 4x4 block.

# Conclusion and recommendation

Efficient lossless coding is required for real-world applications such as such as remote desktop, online gaming, wireless display, video conferencing, automotive vision, long-distance education and content post-production. The proposed lossless coding method with sample-based angular intra prediction provides significant gain over the HM9.0 lossless coding method which bypasses transform, quantization, de-blocking filter, SAO and ALF. It is recommended to adopt this method into test model and working draft of HEVC range extension.

# References

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# Patent rights declaration(s)

**Texas Instruments, Inc. may have IPR relating to the technology described in this contribution and, conditioned on reciprocity, is prepared to grant licenses under reasonable and non-discriminatory terms as necessary for implementation of the resulting ITU-T Recommendation |ISO/IEC International Standard (per box 2 of the ITU-T/ITU-R/ISO/IEC patent statement and licensing declaration form).**

# WD text changes

Replace 8.4.4.2.6

##### Specification of Intra\_Angular (2..34) prediction mode

With (changes are marked in yellow)

Inputs to this process are:

– intra prediction mode intraPredMode,

– neighbouring samples p[ x ][ y ], with x = −1, y = −1..nT\*2−1 and x = 0..nT\*2 − 1, y = −1,

– a variable nT specifying the transform block size,

– a variable cIdx specifying the colour component of the current block,

* the residual sample array values r[ x ][ y ], with x, y = 0..nT−1.

Output of this process are:

– predicted samples predSamples[ x ][ y ], with x, y = 0..nT−1.

illustrates the total 33 intra angles and specifies the mapping table between intraPredMode and the angle parameter intraPredAngle.



Figure 8‑2 – Intra prediction angle definition (informative)

Table 8‑4 – Specification of intraPredAngle

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **intraPredMode** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
| **intraPredAngle** | - | 32 | 26 | 21 | 17 | 13 | 9 | 5 | 2 | 0 | −2 | −5 | −9 | −13 | −17 | −21 | −26 |
| **intraPredMode** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** |
| **intraPredAngle** | −32 | −26 | −21 | −17 | −13 | −9 | −5 | −2 | 0 | 2 | 5 | 9 | 13 | 17 | 21 | 26 | 32 |

further specifies the mapping table between intraPredMode and the inverse angle parameter invAngle.

Table 8‑5 – Specification of invAngle

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **intraPredMode** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** |
| **invAngle** | −4096 | −1638 | −910 | −630 | −482 | −390 | −315 | −256 |
| **intraPredMode** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| **invAngle** | −315 | −390 | −482 | −630 | −910 | −1638 | −4096 | - |

If cu\_transquant\_bypass\_flag is equal to 0, the values of the prediction samples predSamples[ x ][ y ], with x, y = 0..nT−1 are derived as follows.

– If intraPredMode is equal or greater than 18, the following ordered steps apply.

1. The reference sample array ref[ x ], with x= −nT..2\*nT is specified as follows.

ref[ x ] = p[ −1+x ][ −1 ], with x = 0..nT (8‑45)

* If intraPredAngle is less than 0, the main reference sample array is extended as follows.
* When ( nT\*intraPredAngle ) >>5 is less than −1,

ref[ x ] = p[ −1 ][ −1+( ( x\*invAngle+128 )>>8 ) ], with x=( nT\*intraPredAngle ) >>5..−1 (8‑46)

* Otherwise,

ref[ x ] = p[ −1+x ][ −1 ], with x=nT+1..2\*nT (8‑47)

1. The values of the prediction samples predSamples[ x ][ y ], with x, y = 0..nT−1 are derived as follows.
   1. The index variable iIdx and the multiplication factor iFact are derived by

iIdx = ( ( y + 1 )\*intraPredAngle ) >> 5 (8‑48)

iFact = ( ( y + 1 )\*intraPredAngle ) & 31 (8‑49)

* 1. Depending on the value of iFact, the following applies.
* If iFact is not equal to 0, the value of the prediction samples predSamples[ x ][ y ] is derived by

predSamples[ x ][ y ] = ( ( 32 − iFact )\*ref[ x+iIdx+1 ] + iFact\*ref[ x+iIdx+2] + 16 ) >> 5 (8‑50)

* Otherwise, the value of the prediction samples predSamples[ x ][ y ] is derived by

predSamples[ x ][ y ] = ref[ x+iIdx+1 ] (8‑51)

* 1. When intraPredMode is equal to 26 (vertical), cIdx is equal to 0 and nT is less than 32, the following filtering applies with x = 0, y = 0..nT−1.

predSamples[ x ][ y ] = Clip1Y( p[ x ][ −1 ] + ( ( p[ −1 ][ y ] − p[ −1 ][ −1 ] ) >> 1 ) ) (8‑52)

– Otherwise (intraPredMode is less than 18), the following ordered steps apply.

1. The reference sample array ref[ x ], with x= −nT..2\*nT is specified as follows.

ref[ x ] = p[ −1 ][ −1+x ], with x = 0..nT (8‑53)

* If intraPredAngle is less than 0, the main reference sample array is extended as follows.
* When ( nT\*intraPredAngle ) >>5 is less than −1,

ref[ x ] = p[ −1+( ( x\*invAngle+128 )>>8 ) ][ −1 ], with x=( nT\*intraPredAngle ) >>5..−1 (8‑54)

* Otherwise,

ref[ x ] = p[ −1 ][ −1+x ], with x=nT+1..2\*nT (8‑55)

1. The values of the prediction samples predSamples[ x ][ y ], with x, y = 0..nT−1 are derived as follows.
2. The index variable iIdx and the multiplication factor iFact are derived by

iIdx = ( ( x + 1 )\*intraPredAngle ) >> 5 (8‑56)

iFact = ( ( x + 1 )\*intraPredAngle ) & 31 (8‑57)

1. Depending on the value of iFact, the following applies.

* If iFact is not equal to 0, the value of the prediction samples predSamples[ x ][ y ] is derived by

predSamples[ x ][ y ] = ( ( 32 − iFact )\*ref[ y+iIdx+1 ] + iFact\*ref[ y+iIdx+2] + 16 ) >> 5 (8‑58)

* Otherwise, the value of the prediction samples predSamples[ x ][ y ] is derived by

predSamples[ x ][ y ] = ref[ y+iIdx+1 ] (8‑59)

1. When intraPredMode is equal to 10 (horizontal), cIdx is equal to 0 and nT is less than 32, the following filtering applies with x = 0..nT−1, y = 0.

predSamples[ x ][ y ] = Clip1Y( p[ −1 ][ y ] + ( ( p[ x ][ −1 ] − p[ −1 ][ −1 ] ) >> 1 ) ) (8‑60)

If cu\_transquant\_bypass\_flag is equal to 1, the values of the prediction samples predSamples[ x ][ y ], with x, y = 0..nT−1 are derived as follows.

* If intraPredMode is less than 18,
* if intraPredAngle is less than 0, ref [0] = p[-1 + x][ y-1], ref[1] = p[-1+x][ y];
* if intraPredAngle is larger than or equal to 0, ref[0] = p[-1 + x][ y]; if y is less than nT -1, ref[1] = p[-1+x][ y+1], otherwise, ref[1] = p[-1+x][ nT-1];
* Otherwise if intraPredMode is larger than or equal to 18
* if intraPredAngle less than 0, ref[0] = p[-1 + x][ y-1], ref[1] = p[x][ y-1];
* if intraPredAngle large than or equal to 0, ref[0] = p[x][ y-1]; if x is less than nT -1, ref[1] = p[1+x][ y-1], otherwise, ref[1] = p[nT-1, y-1].

– The multiplication factor iFact are derived by

iFact = ( intraPredAngle ) & 31 (8‑61)

– Depending on the value of iFact, the following applies.

* If iFact is not equal to 0, the value of the prediction samples predSamples[ x][y ] is derived by

predSamples[ x][ y ] = ( ( 32 – iFact )\*ref[ 0 ] + iFact\*ref[ 1] + 16 ) >> 5 (8‑62)

* Otherwise, the value of the prediction samples predSamples[ x][ y ] is derived by

predSamples[ x][ y ] = ref[0] (8‑63)

* The neighbouring sample p[x][ y] is reconstructed by
* p[x][y] = r [x][ y] + predSamples[x][ y] (8‑64)