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Non-CE5: Complexity-Reduced Transform Skipping Mode

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- Current TSM design: Four modes
  - TSM_0: Horizontal and vertical transforms
  - TSM_1: Only horizontal transform
  - TSM_2: Only vertical transform
  - TSM_3: No transform

TSM Mode	Dynamic Range Increment	Output Dynamic Range
TSM_0	$\log_2(M)$	$9+\log_2(M)$
TSM_1 & TSM_2	$\log_2(M)/2$	$9+\log_2(M)/2$
TSM_3	0	9

- TSM_1 & TSM_2
  - Two modes are equivalent in terms of dynamic range change
  - The output has half-bit dynamic range, when the transform is 1-D order-8 or order-32

Current TSM Design

- Forward/Inverse Transforms: follow the core transform design and deal with TSM_1 and TSM_2 differently
  - TSM_1: reuse the horizontal transform in core transform
  - TSM_2: reuse the vertical transform in core transform
- Problem
  - Output dynamic ranges for TSM_1 and TSM_2 are different, not making full use of 16-bit precision
  - Different quantization/dequantization operations

Bits for right shift		**TSM_1**	**TSM_2**	**Dynamic Range**	**TSM_1**	**TSM_2**
Forward Trans.	*B*	(1/2/3/4)	(8/9/10/11)	*Forward Trans.*	16	9
Quant.	*Q*	(20/19.5/19/18.5)	(13/12.5/12/11.5)	*Quant.*	10/10.5/11/11.5	
Dequant.	*IQ*	(1/1.5/2/2.5)	(6/6.5/7/7.5)	*Dequant.*	15	10
Inv. Trans.	*IB*	12	7	*Inv. Trans.*	9	

Current TSM Design

- Quantization and dequantization

$$C = (Y \times S + f) >> Q$$

$$Y = (C \times IS + f) >> IQ$$

S: scaling factor; IS: inv. scaling factor; Q and IQ: bits for right shift

Bits for right shift		TSM_1	TSM_2	TSM_3
Quant.	Q	(20/19.5/19/18.5)	(13/12.5/12/11.5)	14
Dequant.	IQ	(1/1.5/2/2.5)	(6/6.5/7/7.5)	6

- Implementation

$$C = (Y \times S + f) >> Q_{TSM\_0} \quad (S = S_{TSM\_0} \times bscale >> bshift)$$

$$Y = (C \times IS + f) >> IQ_{TSM\_0} \quad (IS = IS_{TSM\_0} \times bscale >> bshift)$$

bscale and *bshift* depend on TSM mode and the size of the skipped transform

bscale and *bshift* are obtained by LUT or calculated by logics

Proposed TSM Design

- TSM_1 and TSM_2 share the same bits for right shift, such that intermediate dynamic ranges for TSM_1 and TSM_2 are 16 bits

Bits for right shift		TSM_1 & TSM_2	Dynamic Range	TSM_1 & TSM_2
Forward Trans.	*B*	(1/2/3/4)	*Forward Trans.*	16
Quant.	*Q*	(20/19.5/19/18.5)	*Quant.*	10/10.5/11/11.5
Dequant.	*IQ*	(0/0.5/1/1.5)	*Dequant.*	16
Inv. Trans.	*IB*	13	*Inv. Trans.*	9

Proposed TSM Design

- Quantization and dequantization

$$C = (Y \times S + f) >> Q$$

$$Y = (C \times IS + f) >> IQ$$

Bits for right shift		TSM_1 & TSM_2	TSM_3
Quant.	*Q*	(20/19.5/19/18.5)	14
Dequant.	*IQ*	(0/0.5/1/1.5)	6

- *Q*/*IQ* is an integer: use it directly
- *Q*/*IQ* has half-bit value
  - Replace the original *S*/*IS* with the one three entries away in the LUT
  - For quantization
    - If (*QP*%6 + 3) > 5, *Q* = *Q* + 0.5; otherwise, *Q* = *Q* - 0.5.
  - For dequantization
    - If (*QP*%6 + 3) > 5, *IQ* = *IQ* - 0.5; otherwise, *IQ* = *IQ* + 0.5.

Experimental Results (Random Access)

- Integrated into HM5.0-tsm, the software base for TSM
- Compared with the baseline TSM design

	Random Access HE			**Random Access LC**			**Random Access HE-10**		
	Y	U	V	Y	U	V	Y	U	V
Class A (8bit)	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.1%
Class B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
Class C	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%			
Class D	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%			
Class E									
Overall	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%
	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%
Class F	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%			

Experimental Results (Low Delay)

	Low delay B HE			Low delay B LC		
	Y	U	V	Y	U	V
Class A						
Class B	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
Class C	0.1%	-0.2%	0.1%	0.0%	-0.1%	-0.1%
Class D	0.1%	0.1%	0.2%	0.0%	0.1%	-0.2%
Class E	0.0%	-0.6%	-0.5%	-0.1%	-0.7%	-0.1%
Overall	0.1%	-0.1%	0.0%	0.0%	-0.2%	0.0%
	0.1%	-0.1%	0.0%	0.0%	-0.1%	-0.1%
Class F	0.0%	0.2%	0.2%	0.2%	0.0%	0.3%

	Low delay P HE			Low delay P LC		
	Y	U	V	Y	U	V
Class A						
Class B	0.0%	-0.1%	-0.1%	0.0%	0.1%	-0.1%
Class C	0.1%	0.0%	-0.1%	0.0%	0.1%	-0.1%
Class D	0.2%	0.2%	-0.4%	0.0%	0.5%	-0.5%
Class E	0.0%	-0.3%	0.1%	-0.1%	-0.9%	0.2%
Overall	0.1%	-0.1%	-0.2%	0.0%	0.0%	-0.1%
	0.1%	0.0%	-0.2%	0.0%	0.0%	-0.1%
Class F	0.2%	0.3%	0.5%	0.1%	-0.8%	-0.5%

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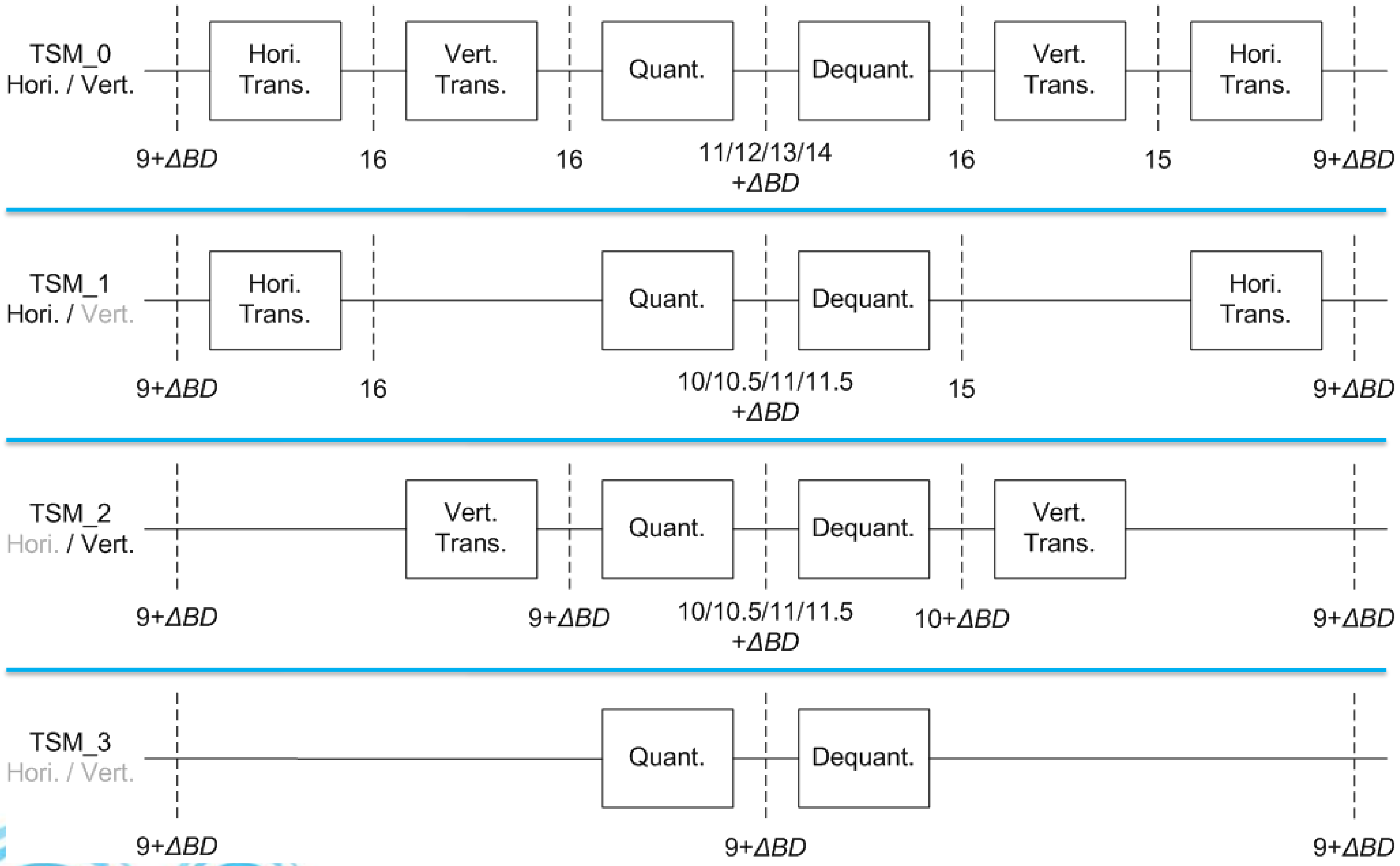
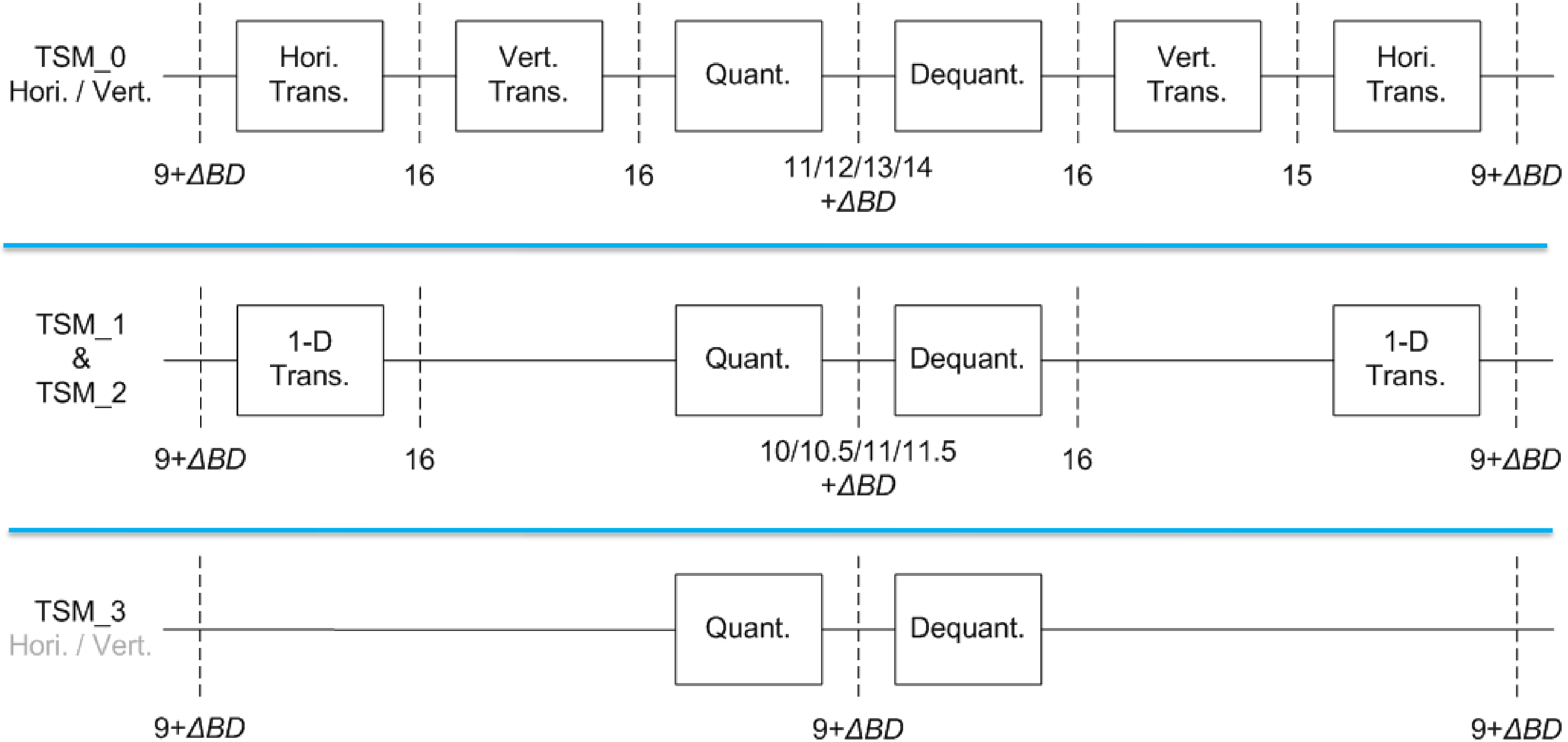
Summary

- Unify operation logics for TSM_1 and TSM_2 with 16-bit implementation.
- Reduce the number of arithmetic operations used in quantization and dequantization.
- Save LUTs used to deal with half-bit right shift.
- R-D performance
  - Class A-E: Luma 0.0% to 0.1%; Chroma -0.2% to 0.0%
  - Class F: Luma 0.0% to 0.2%; Chroma -0.8% to 0.3%

Current TSM Design



Proposed TSM Design



Quantization and Dequantization Defined in HEVC

QP%6	0	1	2	3	4	5
S	26214	23302	20560	18396	16384	14564
IS	40	45	51	57	64	72

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