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SMPTE STANDARD

for Television — HD-D5 Compressed Video 1080 System and 720 System — Encoding Process and Data Format



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1 Scope

This standard defines the encoding process of the HD-D5 video compression and its data format for the 1080/59.94i, 50i, 25p, 24p, 23.98p system (hereafter referred to as the 1080 system) and the 720/59.94p system (hereafter referred to as the 720 system).

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below:

SMPTE 274M-2003, Television — 1920 x 1080 Sample Structure, Digital Representation and Digital Timing Reference Sequences for Multiple Picture Rates

SMPTE 296M-2001, Television — 1280 x 720 Progressive Image Sample Structure — Analog and Digital Representation and Analog Interface

3 Acronyms

BUF	Buffer memory
C	Color-difference signal
C3RMB	Compressed data of 3 RMBs
$C(t, u)$	The value of the DCT coefficient at frequency (t, u)
C_B/C_R	Color-difference signal
CC0 ~ CC2	Categories for C DCT block
Ccoef()	C DCT CG
CG	Coefficient Group
CGNR	CG number of one Y/C DCT coefficient block in one RMB
CGNS	CG number of one Y/C DCT coefficient block in one SMB
CN	C3RMB number in one RMBG
CRcoef()	Rearranged C DCT CG
CS	C DCT block number in one SMB
CY0 ~ CY3	Categories for Y DCT block
DCT	Discrete cosine transform
DIF	Digital interface
DIF(n)	DIF block numbered n

DN	DIF block number
EOB	End of block code
EOM	End of 3 RMBs code
exnor	Logical exclusive nor
f()	Offset value table for SMBG distribution
FCB	Category flag of C _B DCT block
FCB'	Category flag of C _B DCT block
FCR	Category flag of C _R DCT block
FCR'	Category flag of C _R DCT
FFL	Field number flag
FMB	Category flag of the MB
FMB'	Category flag of the MB
FYa ~ FYd	Category flags of the four DCT blocks (Ya ~ Yd) of the MB
FYa' ~ FYd'	Category flags of the four DCT blocks (Ya ~ Yd) of the MB
H	The horizontal SMB position number in one video field (1080 system) or one video frame (720 system)
HR	The column position number of RMB
HS	The column position number of SMB in one SMBG
IDCT	Inverse discrete cosine transform
int (A)	Integer part of A
LEN	The byte length of C3RMB
MB	Macro block
mod	Modulus operator
N.A.	Not applicable
Offset()	Offset value for RMB shuffling
P(r, s)	The value of the pixel at the position (r, s) in Y/C DCT block
Qno	Quantization number
Qstep	Quantization step value
r	The horizontal pixel position number in Y/C DCT block
Rg	The RMBG number within the RMBs
RMB	Rearranged macro block
RMBG	Rearranged macro block group
Rn	The number of RMB coding order in each RMBG
s	The vertical pixel position number in Y/C DCT block
SA	The starting address of the remainder data in buffer memory
SABM	One byte data of SA (two bytes)
Sg	The SMBG number in one video field (1080 system) or one video frame (720 system)
SMB	Super macro block
SMBG	Super macro block group
t	The horizontal frequency number in Y/C DCT coefficient block
TableCY0 ~ 3	Set up value tables for Y weighting function
TableCC0 ~ 2	Set up value tables for C weighting function
u	The vertical frequency number in Y/C DCT coefficient block
V	The vertical position number of SMB in one video field (1080 system) or one video frame (720 system)
VLC	Variable length coding
VR	The row position number of RMB
VS	The row position number of SMB in one SMBG
W(t, u)	Weighting value at frequency (t, u)
Y	Luminance signal
Ya ~ Yd	Four Y DCT blocks in one MB
Ycoef()	Y DCT CG
YR	The Y DCT coefficient block number in one RMB
YRcoef()	Rearranged Y DCT CG
YS	The Y DCT block number in one SMB
Z	The row position number of the RMB after RMB shuffling

ZRL Code of 15 successive zero coefficients followed by a coefficient of zero amplitude

4 Video processing

4.1 Overview

Luminance (Y) and color-difference components (C_B and C_R) are derived from the following HD video signals:

- 1080 line / 59.94 Hz field frequency interlace system (1080/59.94i)
- 720 line / 59.94 Hz frame frequency progressive system (720/59.94p)
- 1080 line / 50 Hz field frequency interlace system (1080/50i)
- 1080 line / 25 Hz frame frequency progressive system (1080/25p)
- 1080 line / 24 Hz frame frequency progressive system (1080/24p)
- 1080 line / 23.98 Hz frame frequency progressive system (1080/23.98p)

In the case of a 1080/23.98p, 24p, and 25p system, a single progressive frame is separated into two signals (separated fields) that are mapped into a space corresponding to fields in similar way as an interlace system (see annex B). The two separated fields of the 1080/23.98p, 24p and 25p are then processed as two separate fields at field frequencies of 47.96Hz, 48Hz and 50Hz.

NOTE – Expression field in this standard is used interchangeably for fields from an interlaced signal format or for fields that were created by splitting the progressive frame of a 1080 system into two separated fields.

The time delay of the encoding system is equal to a single frame time for all frame frequencies except 720 system, where it is equal two progressive frame time. (24p – 41.67msec; 23.98p – 41.71msec; 25p / 50i – 40msec; 59.94i / p – 33.37msec). Indicated delay excludes minor processing delays of the actual signal encoder (compressor) circuitry.

After discarding samples in vertical and horizontal blanking periods, active video samples are divided into four super macro block groups (SMBG) per each field in interlaced system or per each separated field in progressive system. Each SMBG consists of 1080 super macro blocks (SMB).

Each SMB consists of two MBs. Each MB consists of four luminance DCT blocks (8 x 4 pixel matrix) and one each of C_B DCT block (8 x 8 pixel matrix) and C_R DCT block (8 x 8 pixel matrix).

As described later, two horizontally adjacent luminance DCT blocks are overlapped by one pixel column at their junction. Two horizontally adjacent chrominance DCT blocks are overlapped by one pixel column at their junction when they are formed into an SMB.

Each DCT block is transformed to represent DC and AC coefficients. Coefficients are weighted through the prearranged categories prior to shuffling, then formed into rearranged MBs (RMB).

DCT coefficients within one rearranged MB group (RMBG) are quantized, and made into a fixed length data set through VLC.

The VLC output code words from one RMBG are formed into 360 DIF blocks.

The compressed video data for one 1080 field or one 720 frame consist of 5760 DIF blocks.

The block diagram of the outline about compression processing is shown in figure 1.

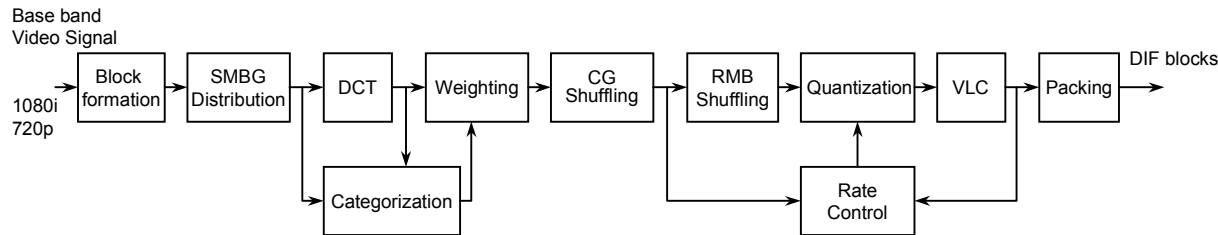


Figure 1 – Block diagram of outline about compression processing

4.2 Video signal

4.2.1 Sampling process

The sampling structure is defined in SMPTE 274M and SMPTE 296M. Sampling structures of the luminance (Y) and the two color-difference signals (C_B/C_R) are described in table 1.

4.2.1.1 Line structure in one field (1080 system) or frame (720 system)

For the 1080 system, 540 lines for Y, C_B , and C_R signals from each field (interlaced or separated) shall be transmitted. In the case of the separated field, the line number is counted as shown in figure 2. For the 720 system, 720 lines for Y, C_R , and C_B signals from each frame shall be transmitted. The transmitting lines on a television frame are defined in table 1.

Table 1 – Construction of video signal sampling

		1080 system		720 system	
The number of active pixels per line	Y	1920		1280	
	C _B /C _R	960		640	
Total number of lines per frame		1125		750	
The number of active lines per frame		1080		720	
The active line numbers		Field 1	21 to 560	Frame	26 to 745
		Field 2	584 to 1123		
Quantization		Each sample is linearly quantized to 10 bits for Y, C _B and C _R			
The relation between video signal level and quantized level	Scale	4 to 1019			
	Y	Quantized level :		877	
		Video signal level of white :		940	
		Video signal level of black :		64	
C _B /C _R	Quantized level :		897		
	Video signal level of gray :		512		

4.2.1.2 Pixel structure in one field (1080) / in one frame (720p)

– 1080 system: All sampled pixels, 1920 luminance pixels per line and 960 color-difference pixels, are retained for processing as shown in figure 2. The sampling process starts simultaneously for both luminance and color-difference signals.

– 720 system: All sampled pixels, 1280 luminance pixels per line and 640 color-difference pixels, are retained for processing as shown in figure 3. Sampling processes start simultaneously for both luminance and color-difference signals.

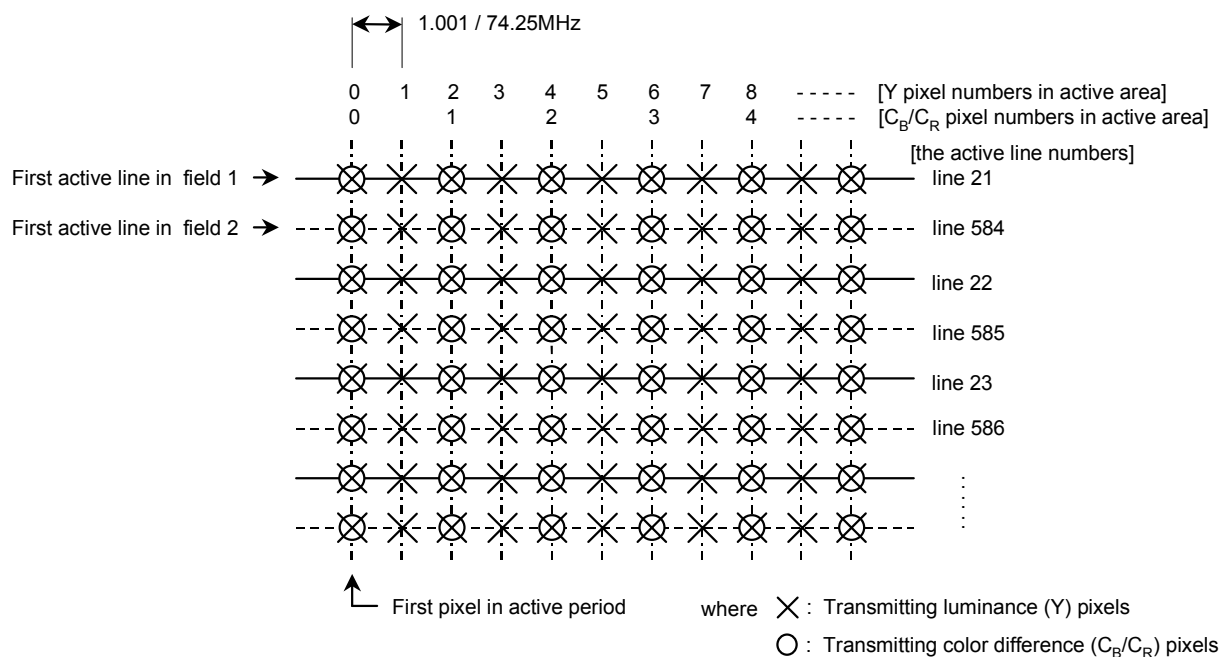


Figure 2 – Transmitting samples of 1080 system

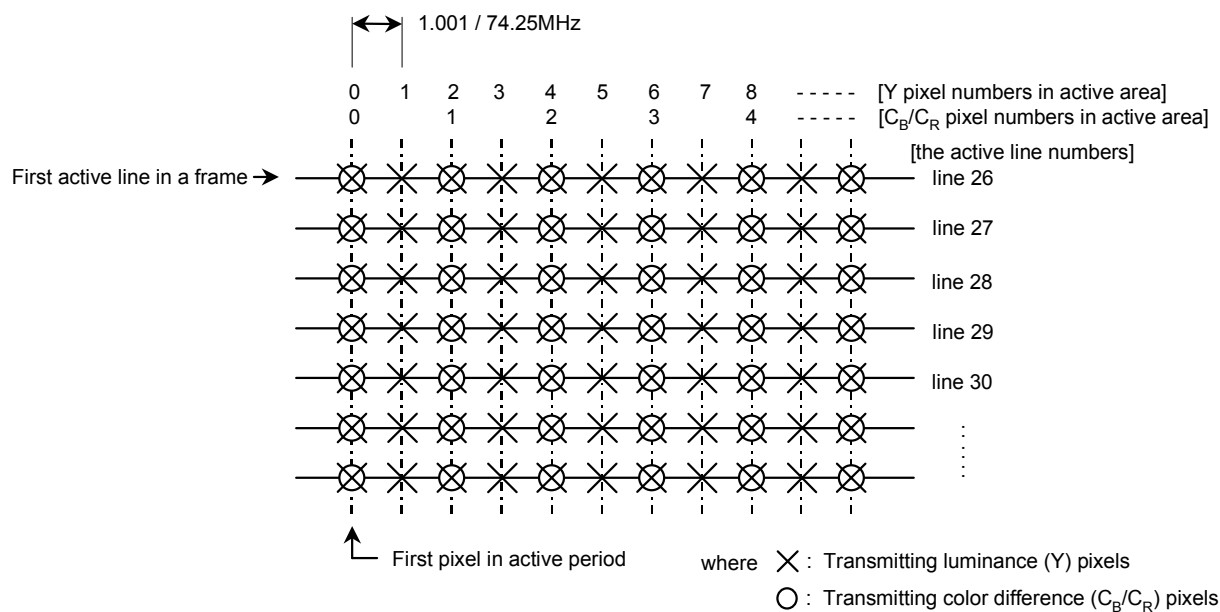


Figure 3 – Transmitting samples of 720 system

4.3 Block formation

4.3.1 DCT block, macro block (MB), and super macro block (SMB)

4.3.1.1 DCT block

The Y pixels in a field (1080 system) and in a frame (720 system) shall be divided into rectangular areas of 15 horizontal pixels and 4 lines. Two Y DCT blocks (one Y DCT block pair) are made from each one of the rectangular areas as shown in figure 4. In each Y DCT block pair, the rightmost pixel in the left DCT block is overlapped with the leftmost pixel in the right DCT block (overlapped blocking).

The C_B/C_R pixels in a field (1080) and in a frame (720) shall be divided into rectangular areas of 15 horizontal pixels and 8 lines. Two C DCT blocks (one C DCT block pair) are made from each one of the rectangular areas as shown in figure 5. In each C DCT block pair, the rightmost pixel in the left block is overlapped with the leftmost pixel in the right block (overlapped blocking).

Overlapped blocking is used for the robustness of error (see annex A).

Let r be the horizontal pixel position number in Y/C DCT block:

$$r = 0, 1, 2, \dots, 7.$$

Let s be the vertical pixel position number in Y/C DCT block:

For Y block, $s = 0, 1, 2, 3$

For C block, $s = 0, 1, 2, \dots, 7$.

Let $P(r,s)$ be the value of the pixel at the position (r, s) .

4.3.1.2 Macro block (MB)

Each macro block (MB) in the 1080 system and the 720 system consists of two Y DCT block pairs, one C_B DCT block and one C_R DCT block. Two Y DCT block pairs are vertically adjacent. The C_B DCT block and C_R DCT block spatially correspond to the two Y DCT block pairs. Four Y DCT blocks (Y_a, Y_b, Y_c, Y_d), one C_B DCT block, and one C_R DCT block are shown in figure 6.

4.3.1.3 Super macro block (SMB)

As shown in figure 7, each super macro block (SMB) in the 1080 system and the 720 system consists of two macro blocks which are horizontally adjacent.

Two C DCT blocks of C_B/C_R in one super macro block are one C DCT block pair of C_B/C_R .

Let Y_S be the Y DCT block number in each SMB as shown in figure 7:

$$Y_S = 0, 1, 2, \dots, 7.$$

Let C_S be the C DCT block number in each SMB as shown in figure 7:

$$C_S = 0, 1.$$

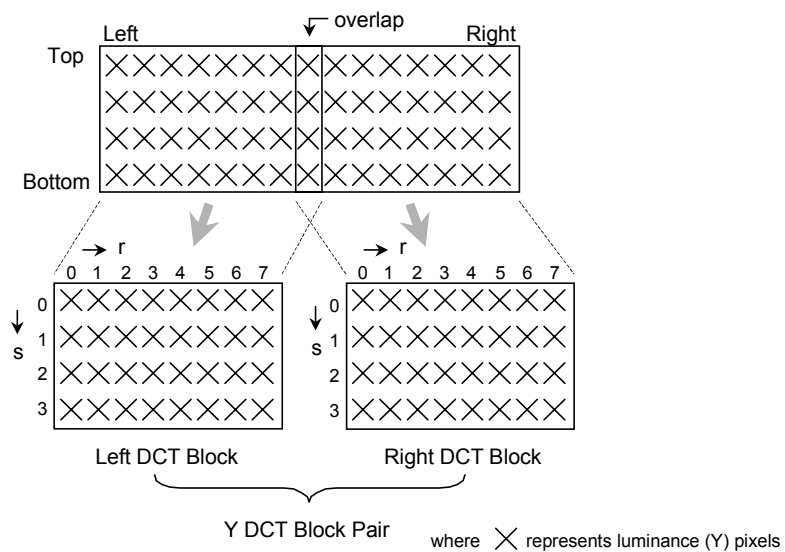


Figure 4 – Overlapped blocking of luminance (Y) pixels

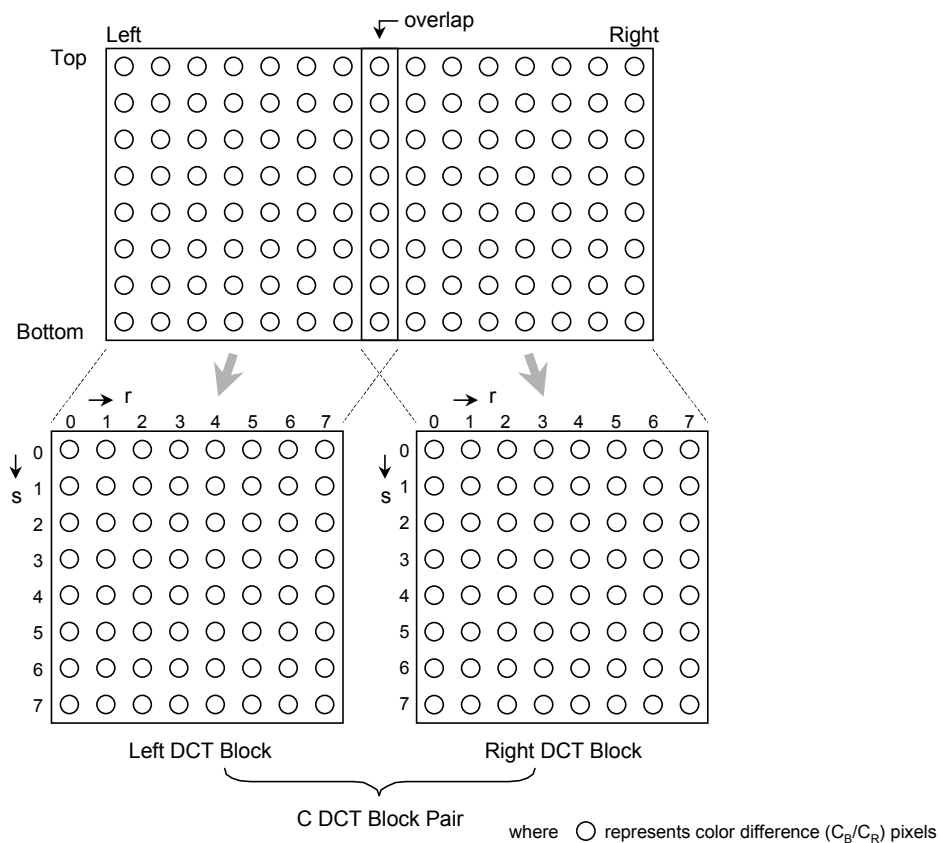


Figure 5 – Overlapped blocking of color-difference C_B/C_R pixels

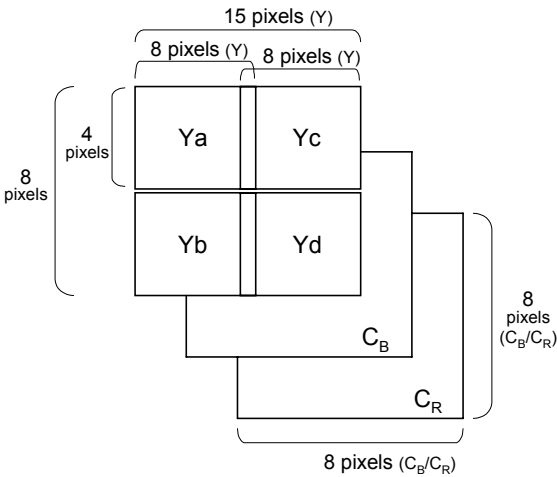


Figure 6 – Macro block structure in 1080 system and in 720 system

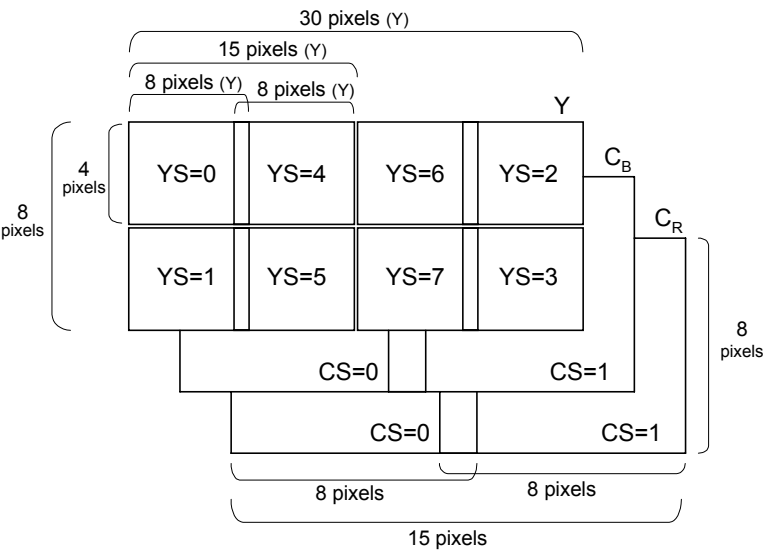


Figure 7 – Super macro block structure in 1080 system and in 720 system

4.3.2 Super macro block arrangement

4.3.2.1 1080 system

The vertical field dimension, 540 pixels long, is not divisible into an integer by the vertical dimension of the SMB, 8 pixels long.

In order to place all SMBs within the 1920 x 540 pixel matrix of the 1080 field, removal and attachment of half-height SMBs are required as shown in figure 8.

1) Y pixels

– Pixels in four rectangular areas of the horizontal pixel position number from $(480 \times N)$ to $(59 + 480 \times N)$ and from $(360 + 480 \times N)$ to $(419 + 480 \times N)$ in the active area and line position number from 536 to 539 in the active area shall be moved horizontally 1020 pixel positions to the right, vertically 4 lines to the bottom ($N = 0, 1$).

– Pixels in two rectangular areas of the horizontal pixel position number from $(240 + 480 \times N)$ to $(359 + 480 \times N)$ in the active area and line position number from 536 to 539 in the active area shall be moved horizontally 840 pixel positions to the right, vertically 4 lines to the bottom ($N = 0, 1$).

Pixels in four rectangular areas of the horizontal pixel position number from $(960 + 480 \times N)$ to $(1019 + 480 \times N)$ and from $(1320 + 480 \times N)$ to $(1379 + 480 \times N)$ in the active area and line position number from 536 to 539 in the active area shall be moved horizontally 900 pixel positions to the left, vertically 4 lines to the bottom ($N = 0, 1$).

– Pixels in two rectangular areas of the horizontal pixel position number from $(1\,200 + 480 \times N)$ to $(1\,319 + 480 \times N)$ in the active area and line position number from 536 to 539 in the active area shall be moved horizontally 1080 pixel positions to the left, vertically 4 lines to the bottom ($N = 0, 1$).

2) C_B/C_R pixels

C_B/C_R pixels occupy the positions held by the even numbered Y horizontal pixel numbers. The half height SMB replacement operation, identical to the Y pixels as described above, is performed for C_B/C_R pixels.

The arrangement of the SMBs in one field is shown in figure 9. The same horizontal arrangement of 64 SMBs is repeated with 67 SMBs in the vertical direction from the top, and there are 32 SMBs in the horizontal direction at the bottom.

The number of SMBs in one field is 4320 as described below:

$$(\text{vertical } 67 \text{ SMBs} \times \text{horizontal } 64 \text{ SMBs}) + 32 \text{ SMBs} = 4320 \text{ SMBs}$$

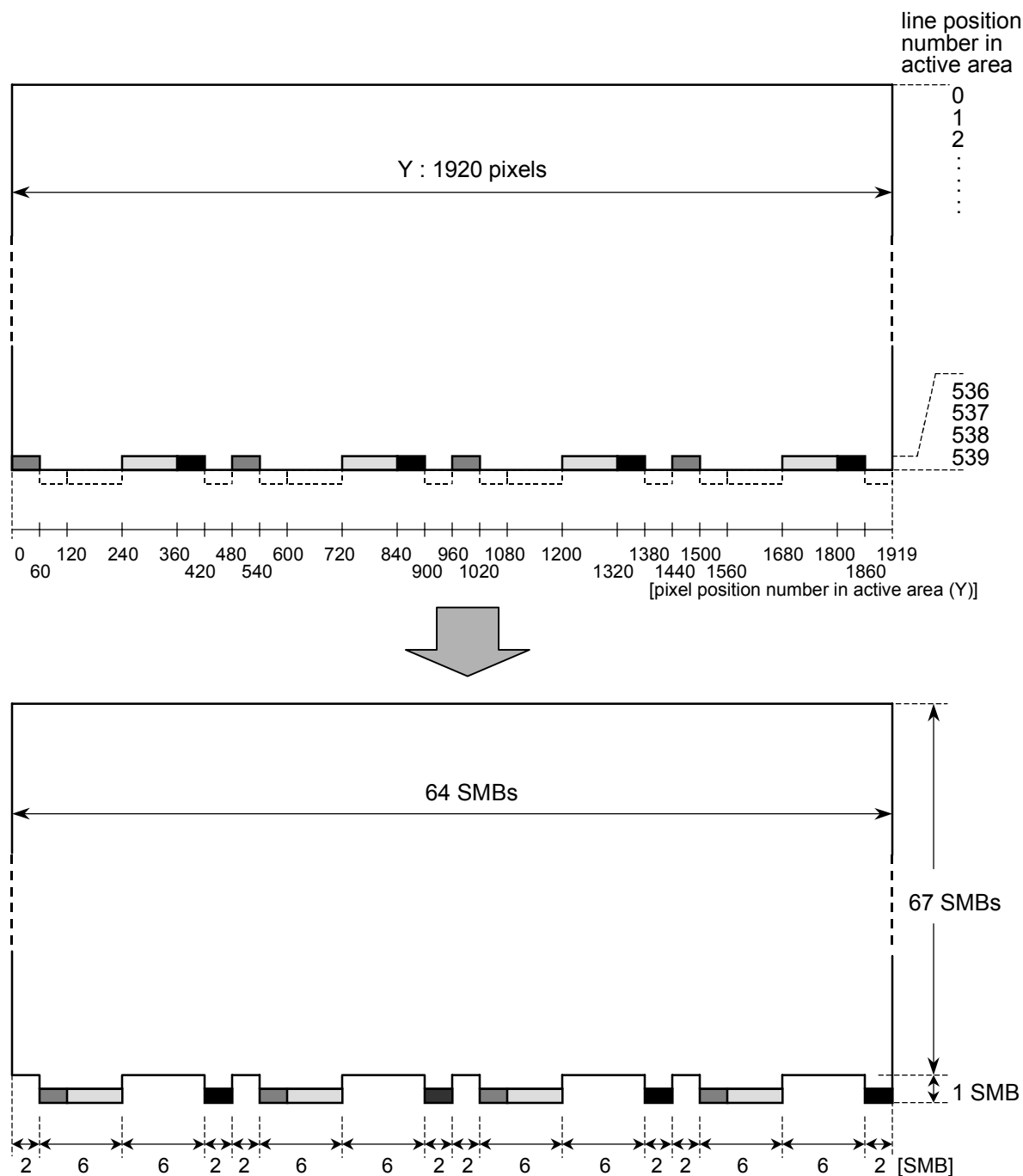


Figure 8 – Pixel arrangement for blocking of 1080 system

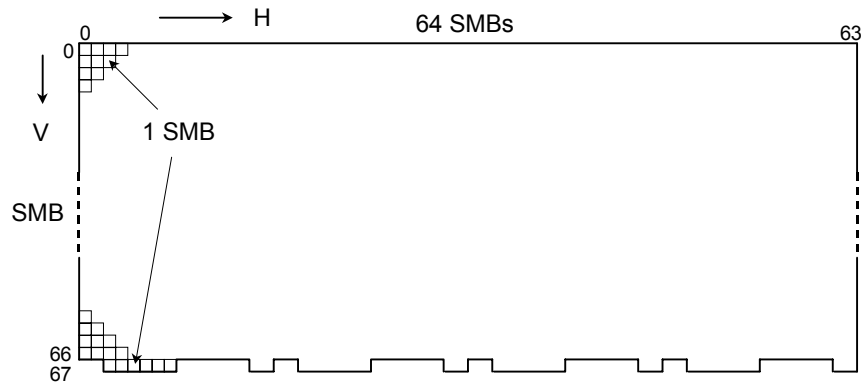


Figure 9 – Arrangement of SMBs in one field for 1080 system

4.3.2.2 720 system

As the first step of block formation, 160 dummy of Y pixels and 80 dummy of C_B/C_R pixels are added as rightmost pixels in each line. The value of dummy shall be 040h for Y and 200h for C.

The arrangement of SMBs in one frame for the 720 system is shown in figure 10. The same horizontal arrangement of 48 SMBs is repeated with 90 SMBs in the vertical direction from top to bottom. The number of SMBs in one frame is 4320 as described below:

$$\text{vertical 90 SMBs} \times \text{horizontal 48 SMBs} = 4320 \text{ SMBs}$$

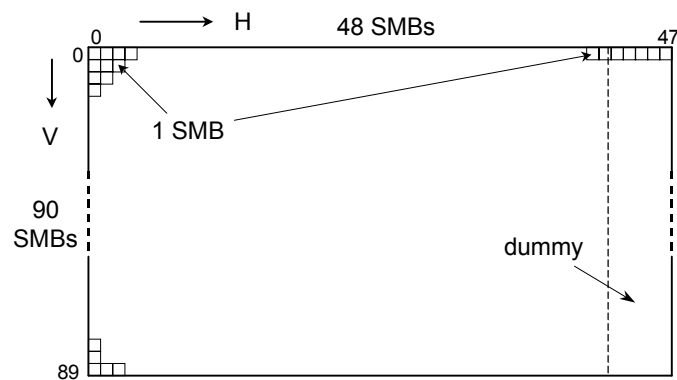


Figure 10 – Arrangement of SMBs in one frame for 720 system

4.4 SMBG distribution

4.4.1 1080 system

4320 SMBs in one field are divided into four SMBGs as shown in figure 11.

Let H be the horizontal position number of SMB within video field

$$H = 0, 1, 2, \dots, 63.$$

Let V be the vertical position number of SMB within video field

$$V = 0, 1, 2, \dots, 67.$$

Let HS be the column position number of SMB within one SMBG

$$HS = 0, 1, 2, \dots, 5.$$

Let VS be the row position number of SMB within one SMBG

$$VS = 0, 1, 2, \dots, 179.$$

Let Sg be the SMBG number in one field

$$Sg = 0, 1, 2, 3.$$

The distribution method is described as follows:

$$V = (\text{int}(VS/8)) \times 3 + \text{int}(((VS \bmod 8) \times 6 + HS) / 16)$$

$$H = ((f(h, v) + ((\text{int}(VS/8)) - Sg) \times 8) \bmod 32) \times 2 + ((\text{int}(VS/8)) \bmod 2) \text{ xnor } (HS \bmod 2)$$

$$\text{where } v = \text{int}(((VS \bmod 8) \times 6 + HS) / 16)$$

$$h = \text{int}(((VS \bmod 8) \times 6 + HS) \bmod 16) / 2$$

xnor : exclusive nor

Value of f(h, v)

$\begin{array}{c} h \\ \backslash \\ v \end{array}$	0	1	2	3	4	5	6	7
0	1	2	0	19	20	21	15	14
1	15	10	9	11	30	29	28	24
2	24	25	5	7	6	20	19	18