Novel YUV 8bpp subsampling pattern

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Asilomar Conference on Signals, Systems, and Computers, November 2010, Asilomar CA

Motivation

Content originating from a camera is suitable to YUV subsampling in a visaully lossless mode due to the following:

- An image acquired through an optical system has a point spread function >1pixel; in the real case, in today's cameras PSF is ~3pixels
- Most of the color sensors in the market use a sparse sampling color pattern – BAYER, so the color plane is sparse already

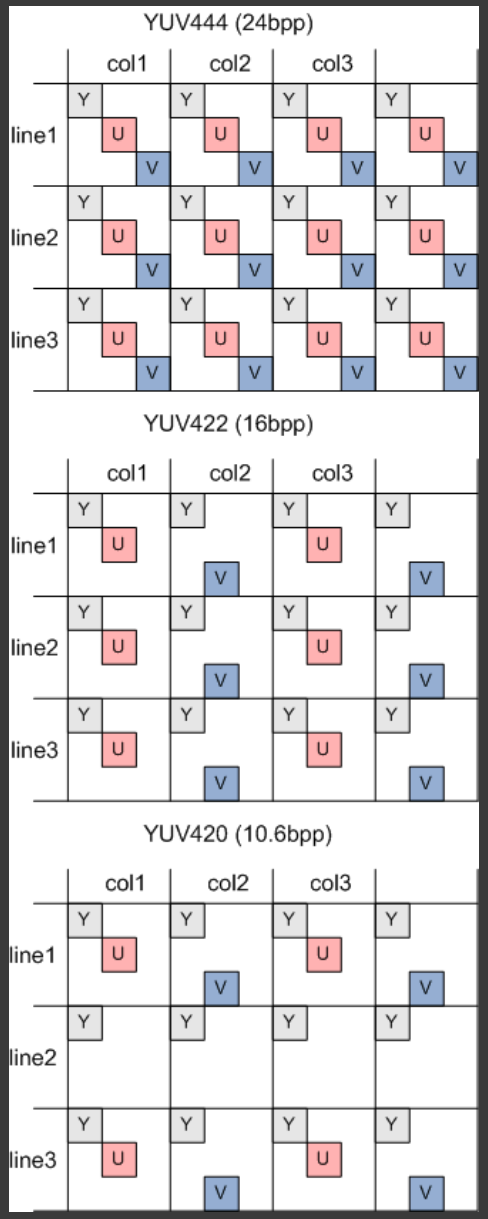
Existing YUV formats vary from YUV444-24bpp, YUV422-16bpp, YUV420-10.6bpp

Ideally, there's need for a YUV format that goes to 8bpp, as it's convenient in terms of memory allocation and transfer bandwidth.

Existing YUV formats

Currently there are 3 sampling YUV patterns in use:

- YUV444: one byte per each color component, providing 24bpp encoding
- YUV422: on each pixel one chroma component is dropped, based on the way chroma is preprocessed it can be cosited or intersitial (the actual phase shfit of chroma sample to luma). This pattern provides 16bpp encoding.
- YUV420: on each pixel, the chroma resolution is further reduced vertically by 2. This pattern provides 10.6bpp encoding



Proposed solution

the proposed solution uses two known visually lossless techniques in image data compression:

1. BAYER subsampling pattern (used in most color image sensors on the market today)

2. DPCM data compression (used in at least 2 standards for bandwidth reduction in cameras - SMIA and MIPI)

those techniques are combined in a YUV pattern to achieve 8bit per pixel data compression.

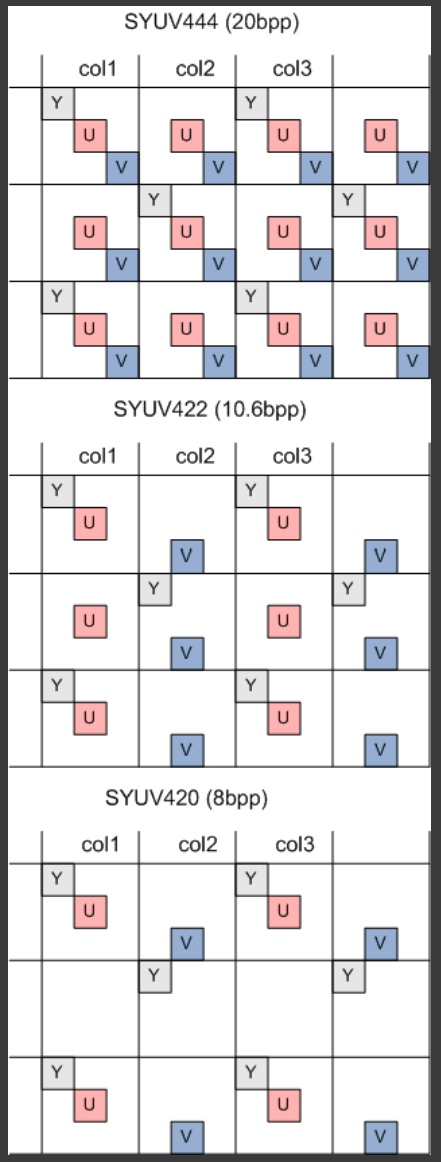
This proposal, uses the BAYER sampling pattern but applied to luminance, also it stores the edge orientation using 1-2 extra bits for each luminance missing sample.

The extra bits are used from each chrominance sample, as the chrominance samples are compressed using 8to7 or 8to6 DPCM compression.

Note: DPCM 8to7 and 8to6 are not currently part of any DPCM compression mode, but this proposal follows the mechanism other DPCM compression modes are implementing (ie. 10to8, 10to7, 10to6, 12to8, etc…)

Proposed solution

- Subample luma component using a checkerboard pattern similar to BAYER pattern used in image sensors (since the source of image is likely to be a BAYER image sensor).
- The biggest problem in reconstruction is the edge direction on the missing pixel. To alleviate that, we propose using 1/2 additional bits to encode that.
- If this type of sampling is used, 3 new sampling YUV patterns are defined (each one with 2 variants):
  - SYUV444 providing 20bpp (compared to 24bpp of YUV444)
  - SYUV422 providing 10.6bpp (compared to 16bpp of YUV422)
  - SYVU420 providing 8bpp (compared to 10.6bpp of YUV420)
- SYUV420 achieves 8bpp and is perceptual lossless (if the edge information is provided – as we propose using 1-2 extra bits).

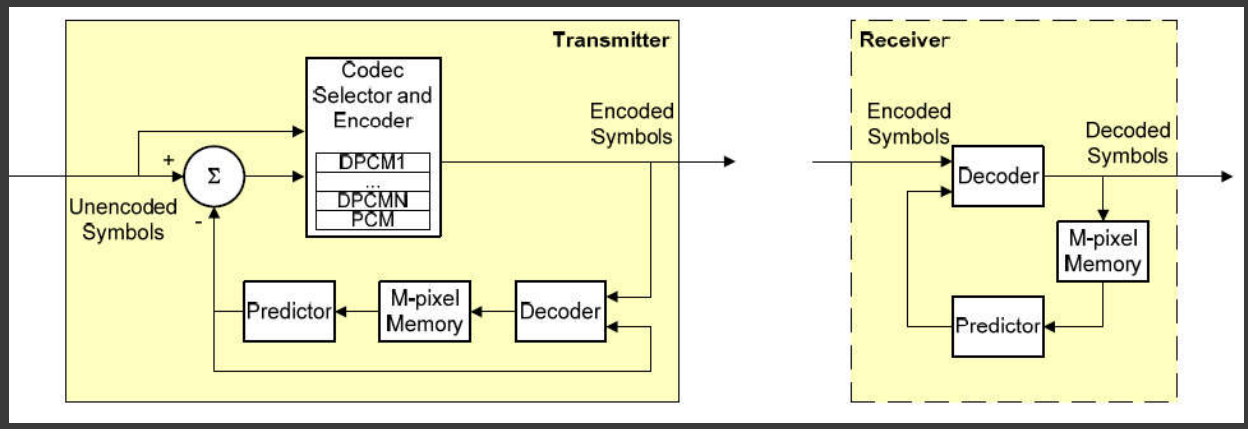


Encoding the edge information

We use bits from chroma samples, and propose two variants:

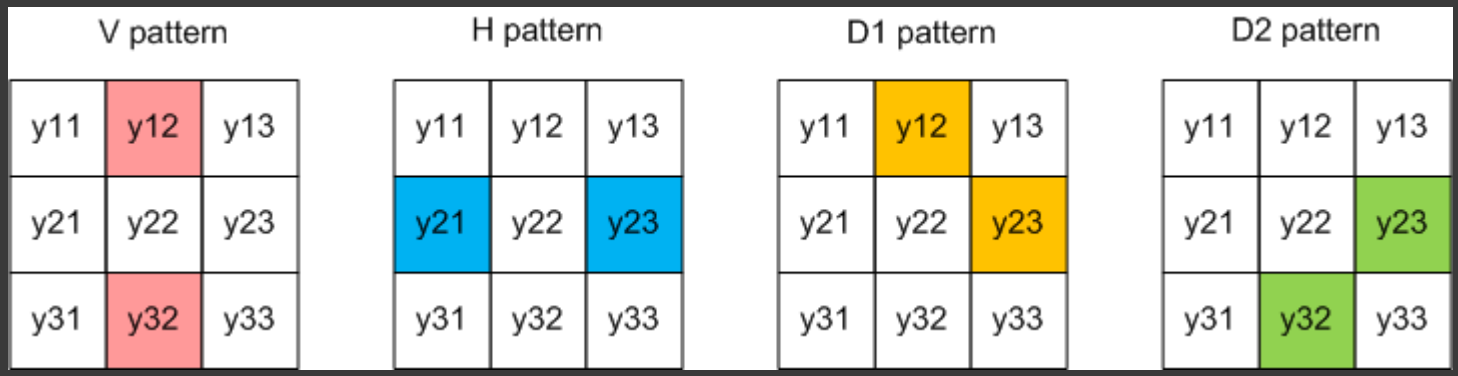
- Using one bit to encode H/V direction of the edge in the missing sample and DPCM8to7 on chroma
- Using two bits to encode H/V and two diagonal edges in the missing sample and DPCM8to6 on chroma

To provide those bits in a perceptually lossless way, we propose a subset of current DPCM existing modes to encode 8bits in 7bits or 8bits in 6bits, thus saving one/two extra bits for edge encoding (DPCM encoding well documented and standardized –SMIA/MIPI - and acknowledged as perceptually lossless for 10bit to 8bit, etc.).



Edge patterns

- For 1 bit edge coding:
  - 0 = edge is vertical
  - 1 = edge is horizontal
- For two bits edge coding:
  - 00 = edge is horizontal
  - 01 = edge is vertical
  - 10 = edge is diagonal NE (D1)
  - 11 = edge is diagonal SE (D2)



Pattern implementation

- A possible implementation of the proposed method is illustrated below. The grey areas represent the bits used to code luminance edge, thus chroma samples are DPCM compressed, to allow for that space.
- This implementation builds on the chroma sampling used in YUV422 (as an example)

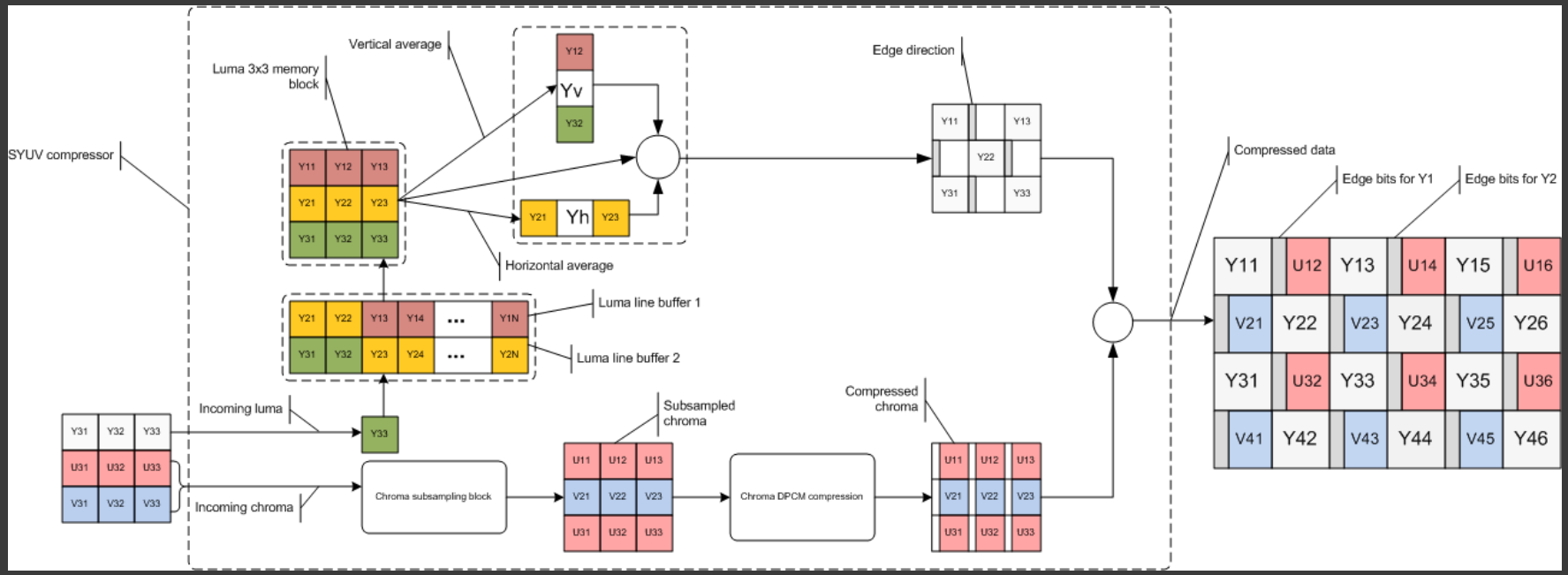
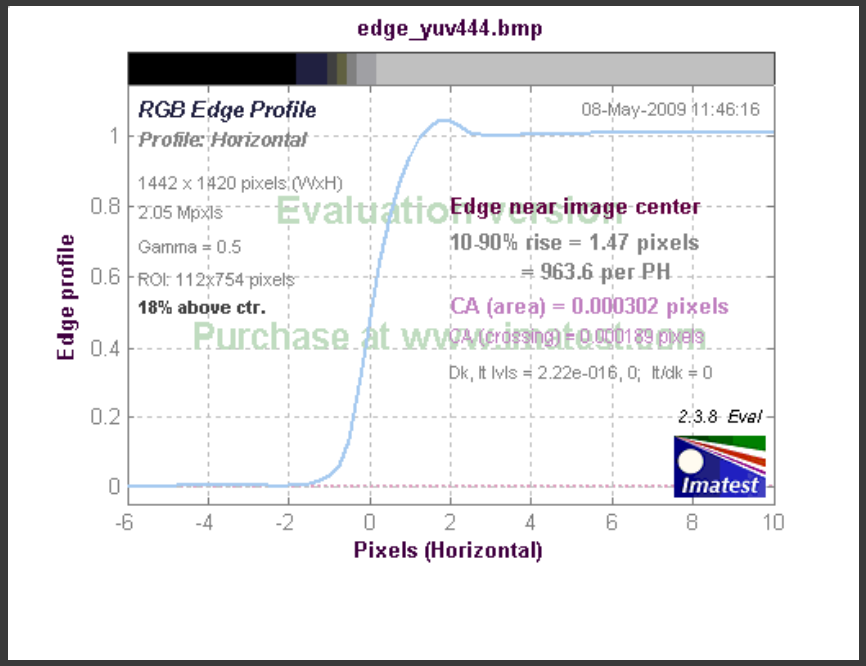
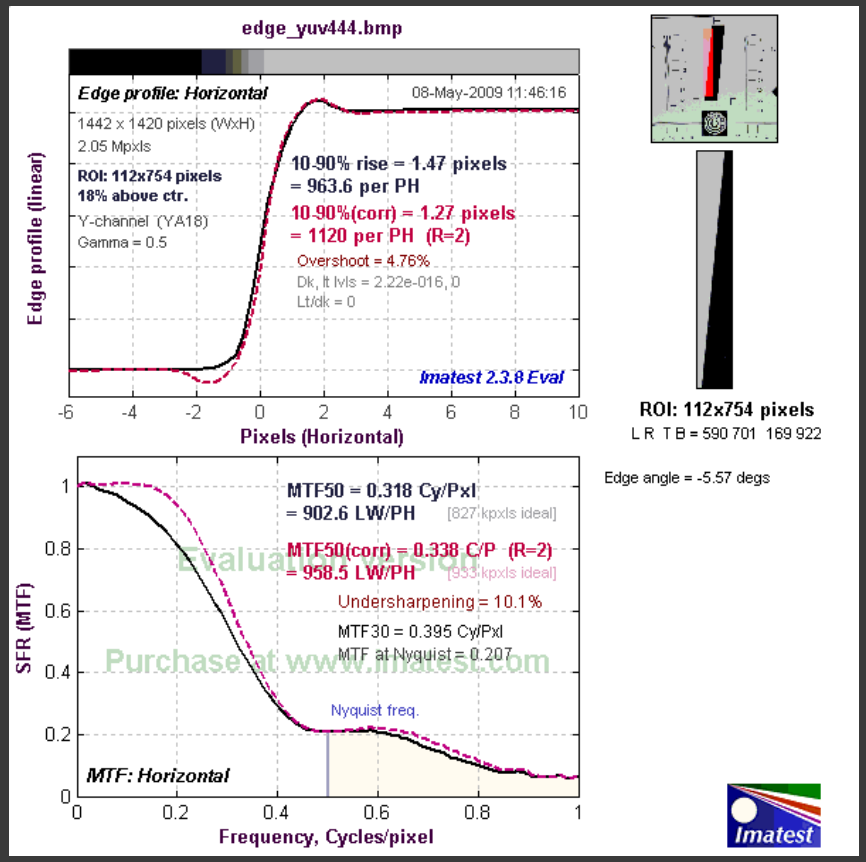


Image quality degradation evaluations

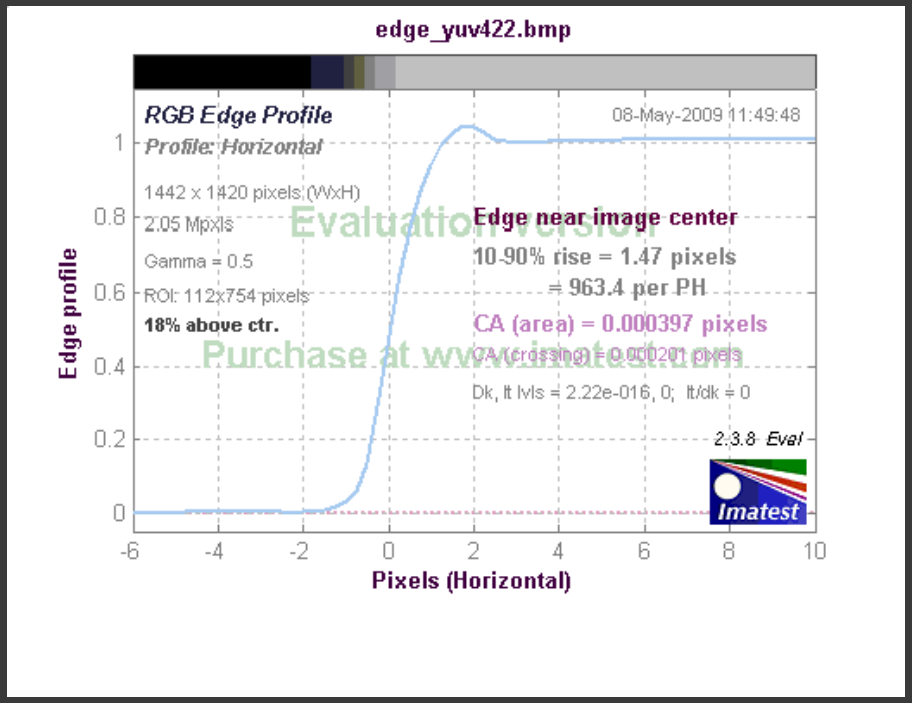
- To evaluate the effect of this type of compression we used the following steps:
  - Evaluate MTF, resolution and chromatic aberrations of high-quality photographic test images (we used an image of a resolution test chart taken with a Nikon D3x)
  - Encode and decode the image using the proposed method
  - Evaluate MTF, resolution and chromatic aberrations of the resultant image
- Evaluations are done using ImaTest over the standard MTF test chart using a high quality image from dpreview (review of Nikon D3x)
- To exemplify, some pictures with high frequency content are provided (to asses chroma degradation and edge restoration)
- The MTF test over a slanted edge calculates the loss of sharpness due to luminance subsampling, whereas the chromatic aberration test estimates the loss due to chroma subsampling.

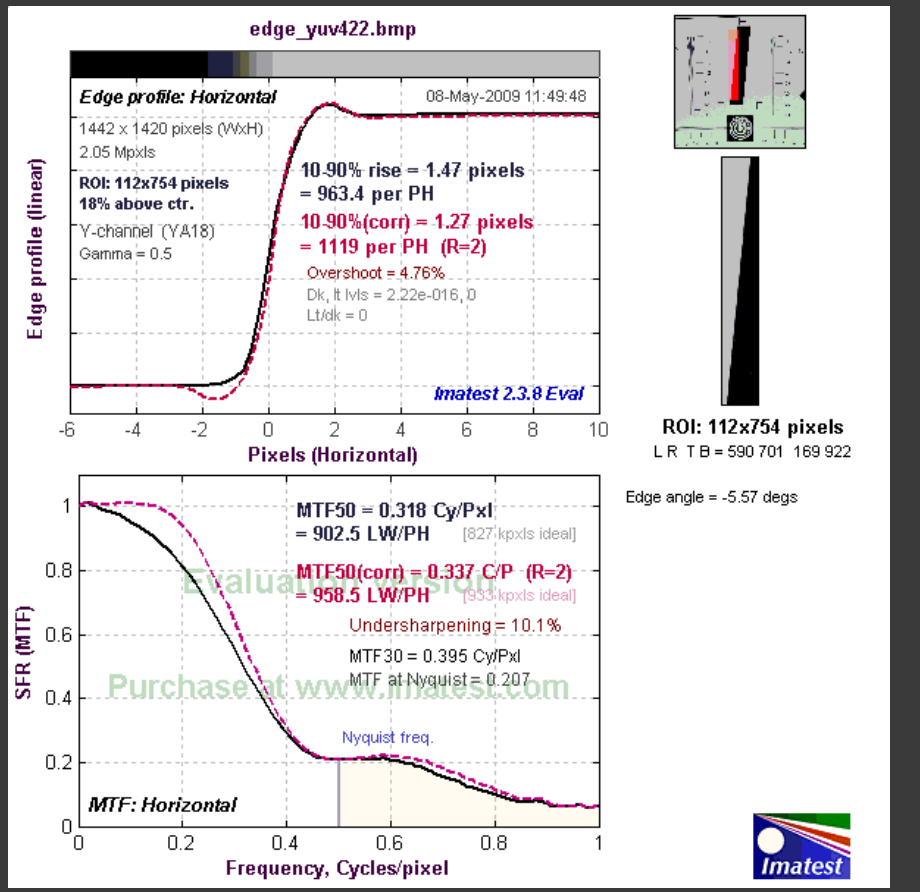
Evaluation results YUV444 Chromatic aberration and MTF



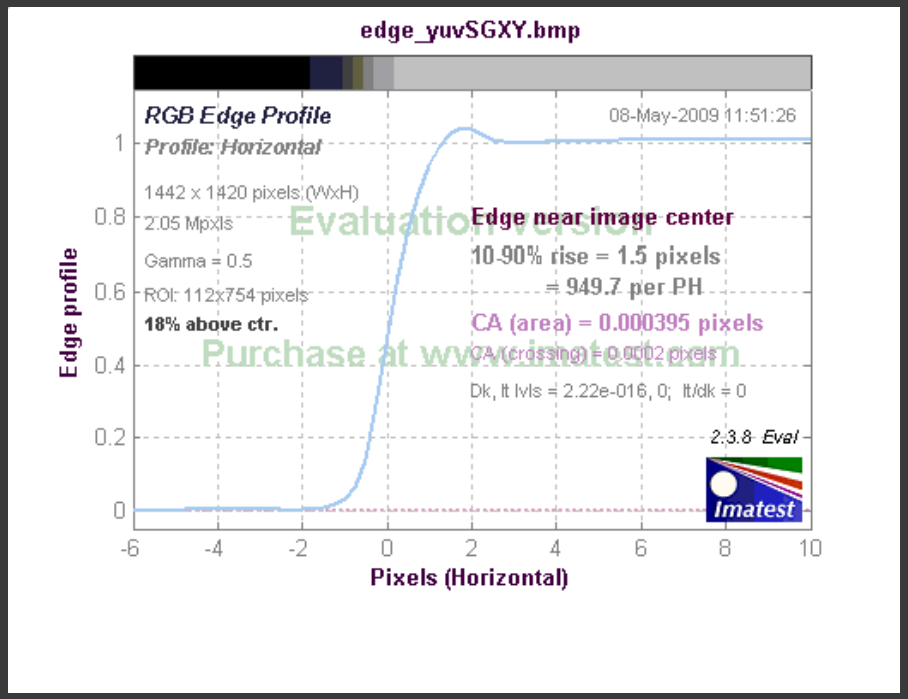


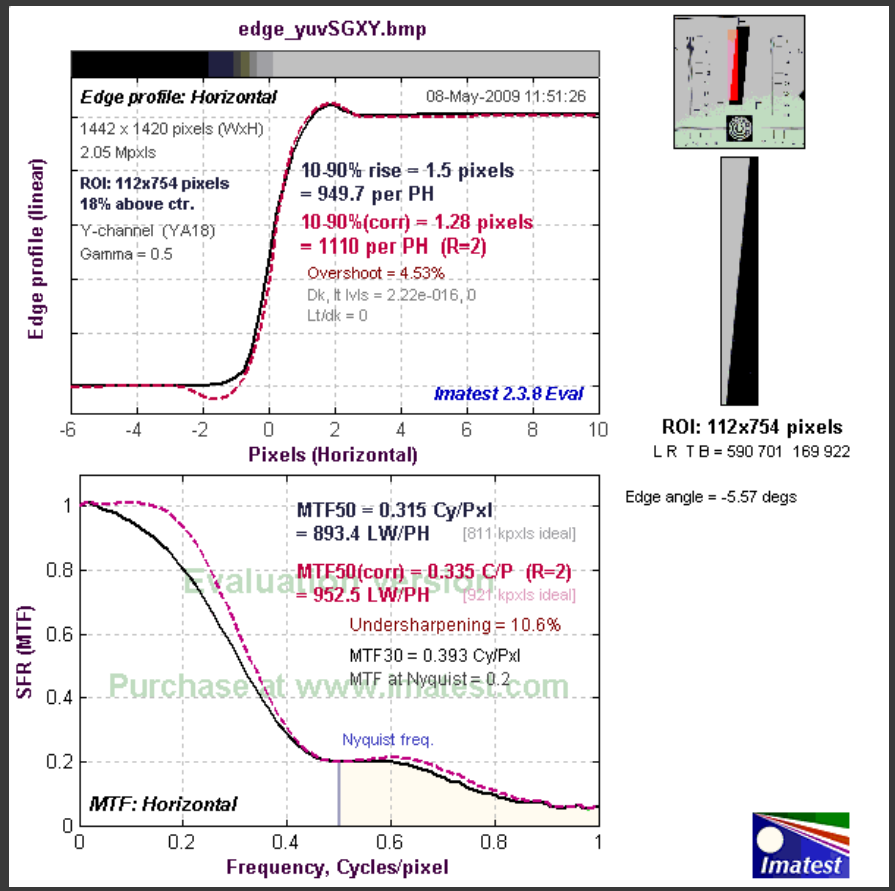
Evaluation results YUV422 Chromatic aberration and MTF



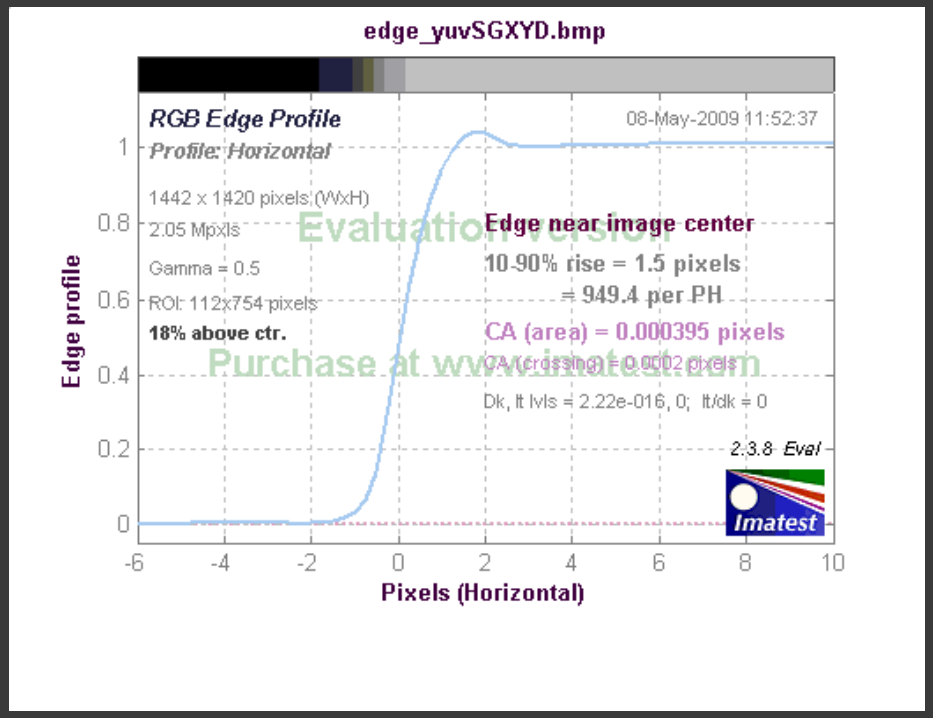


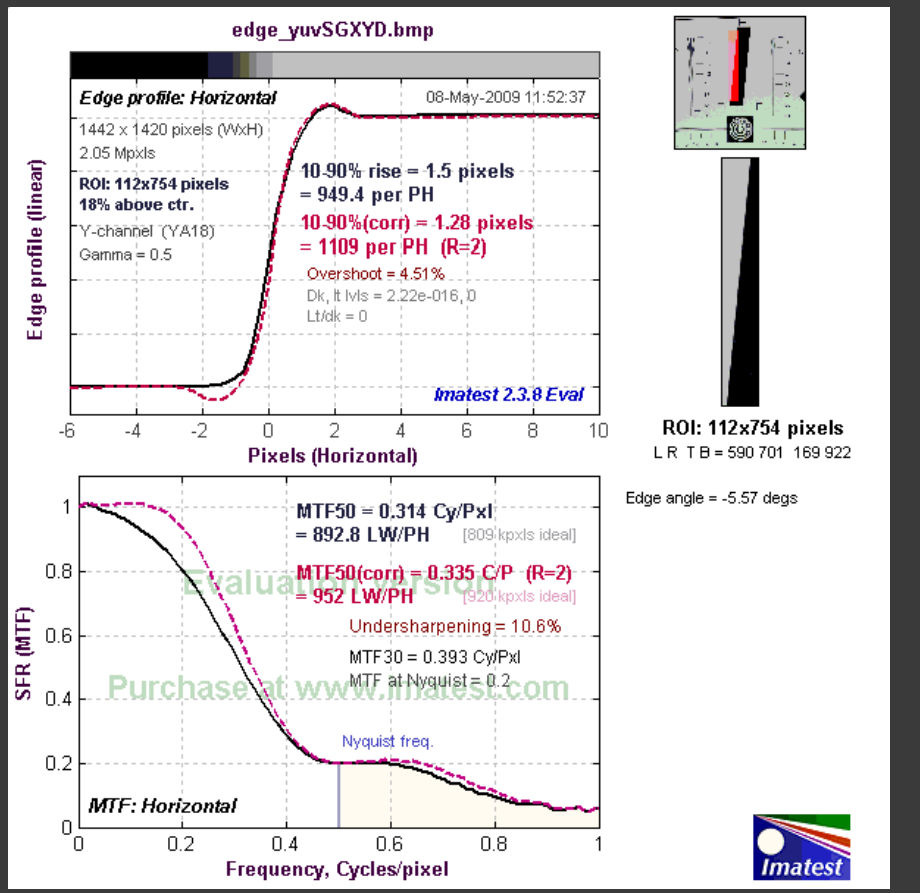
Evaluation results YUVXY Chromatic aberration and MTF (1 bit edge information)



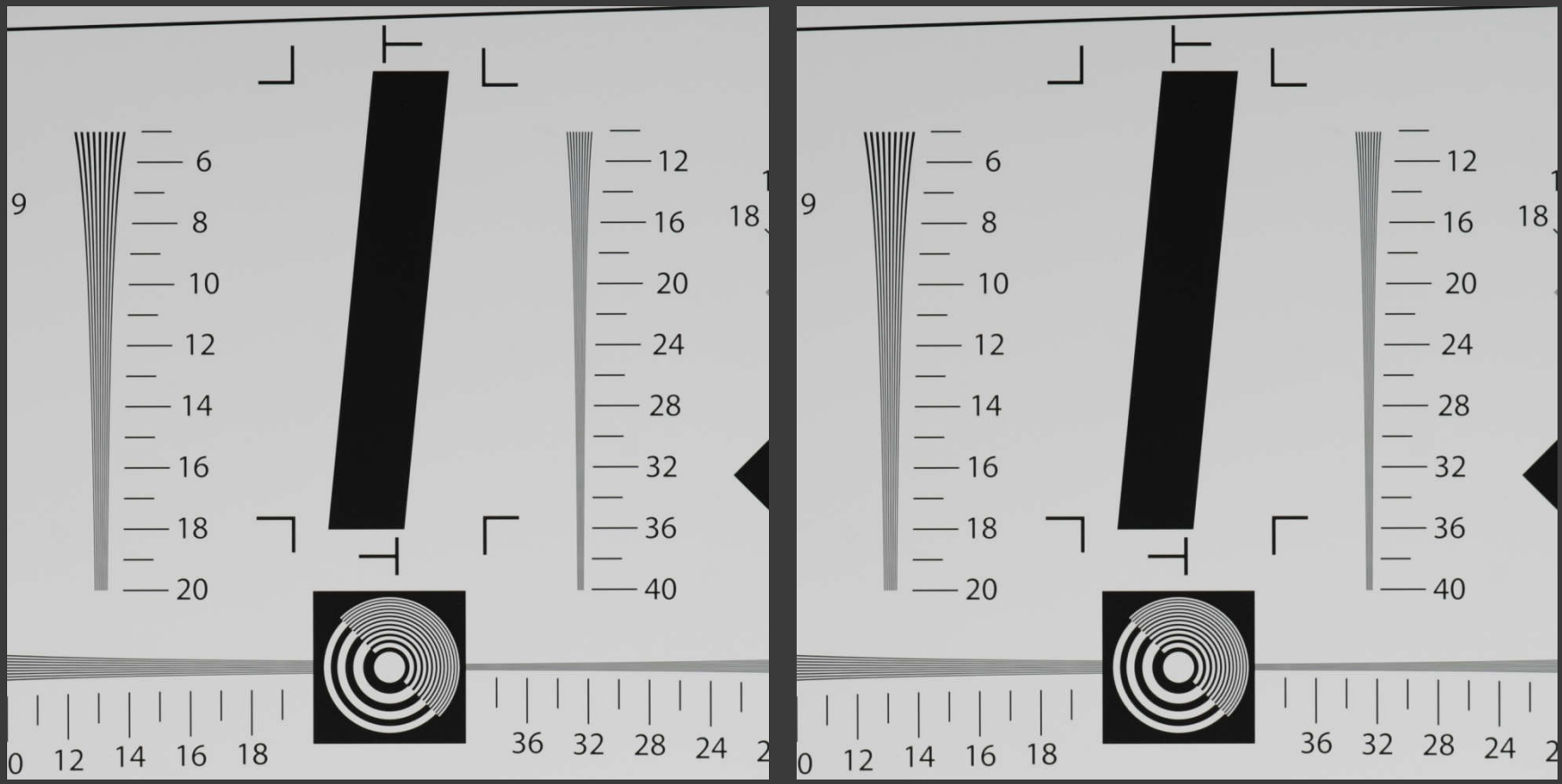


Evaluation results YUVXY Chromatic aberration and MTF (2 bit edge information)

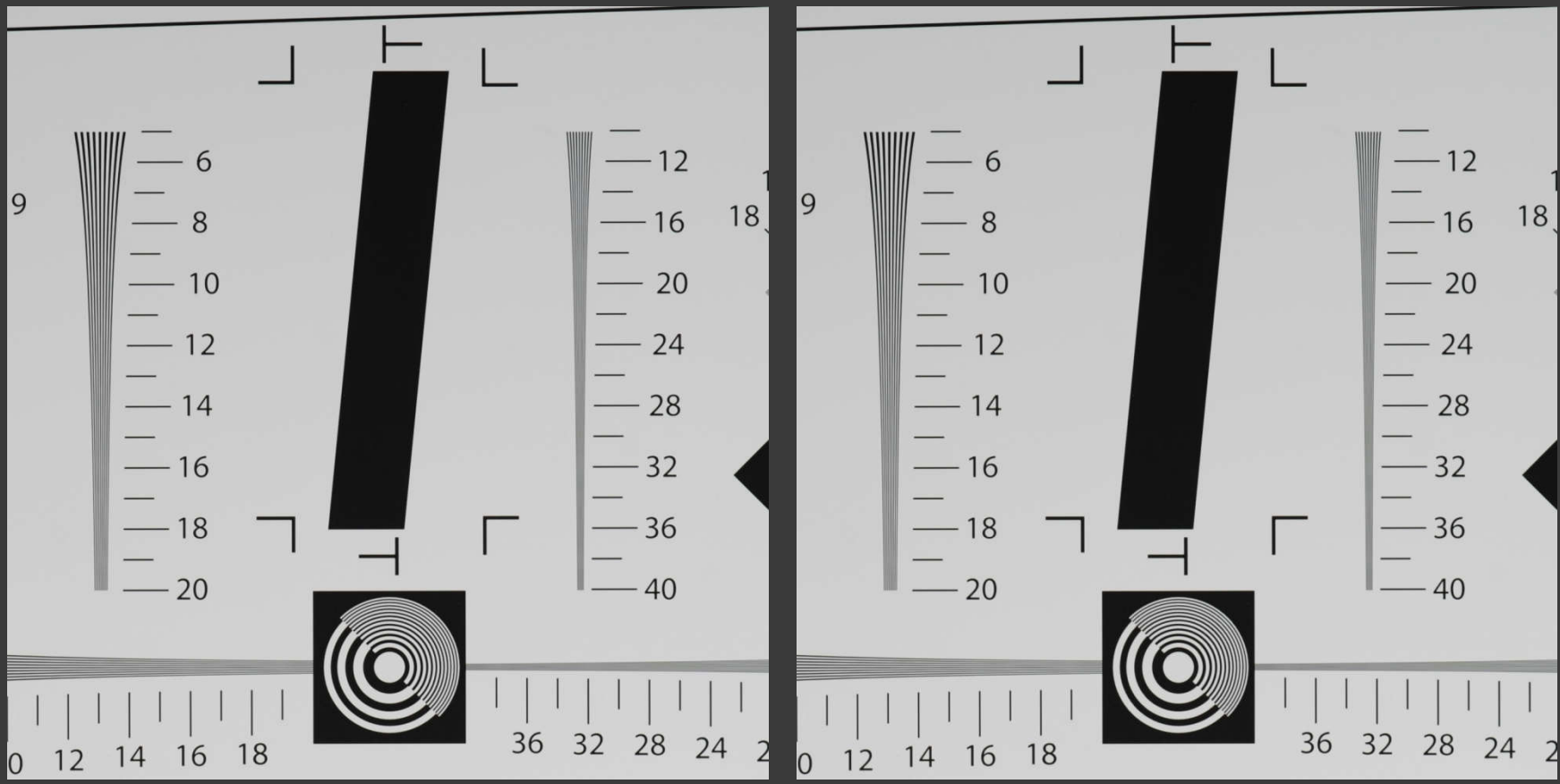


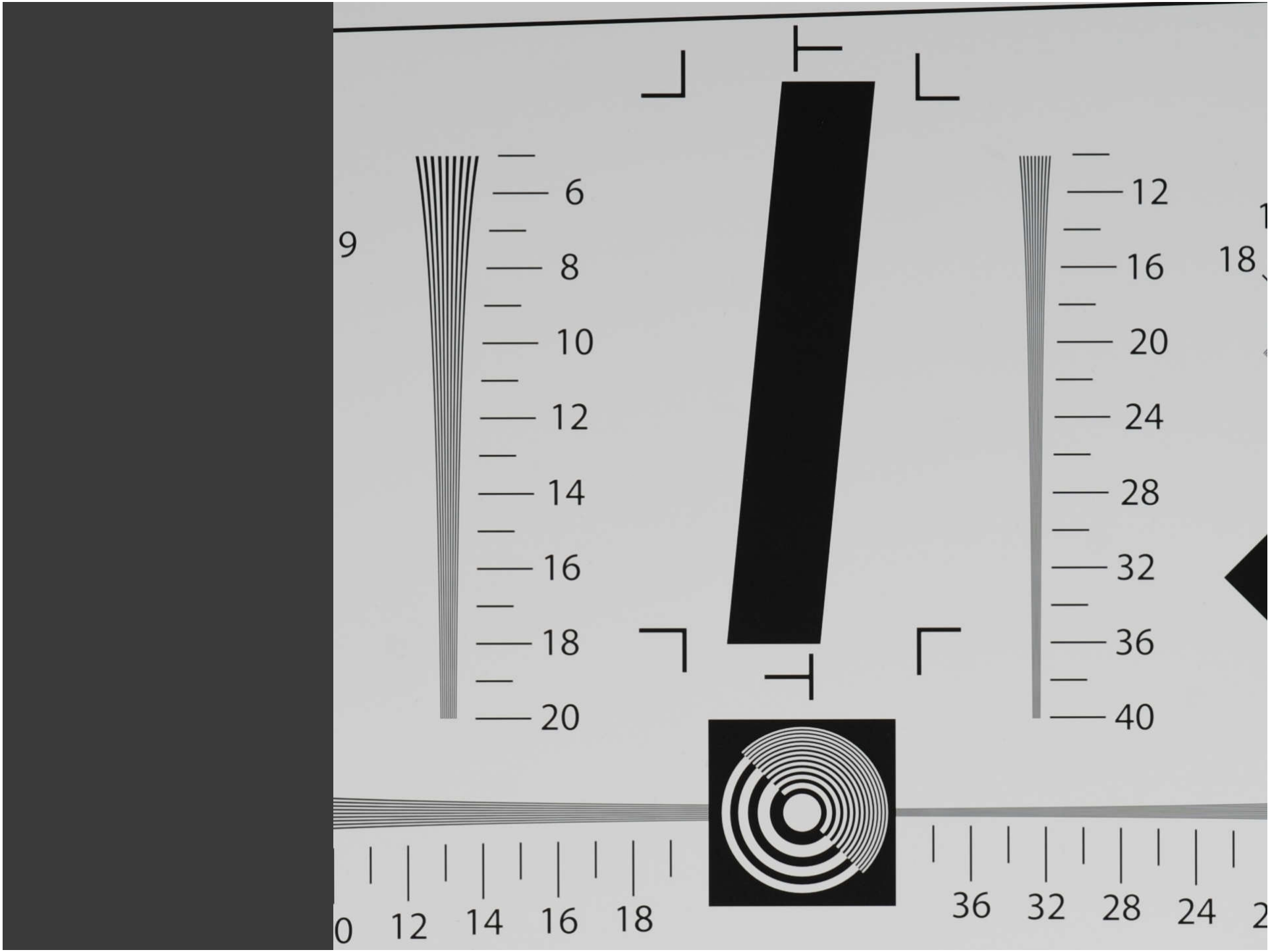


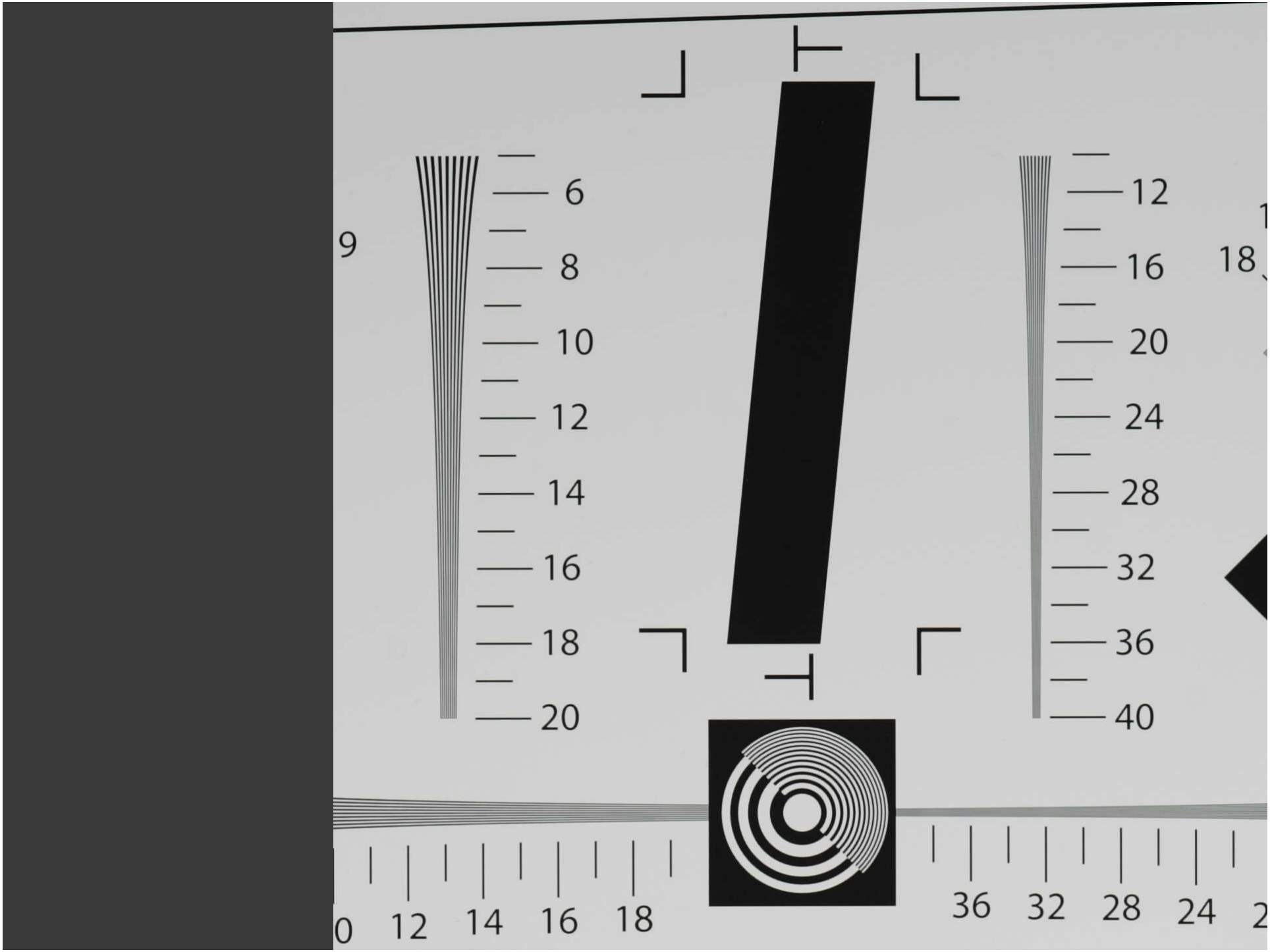
Visual comparisons (YUV444-YUVXY)

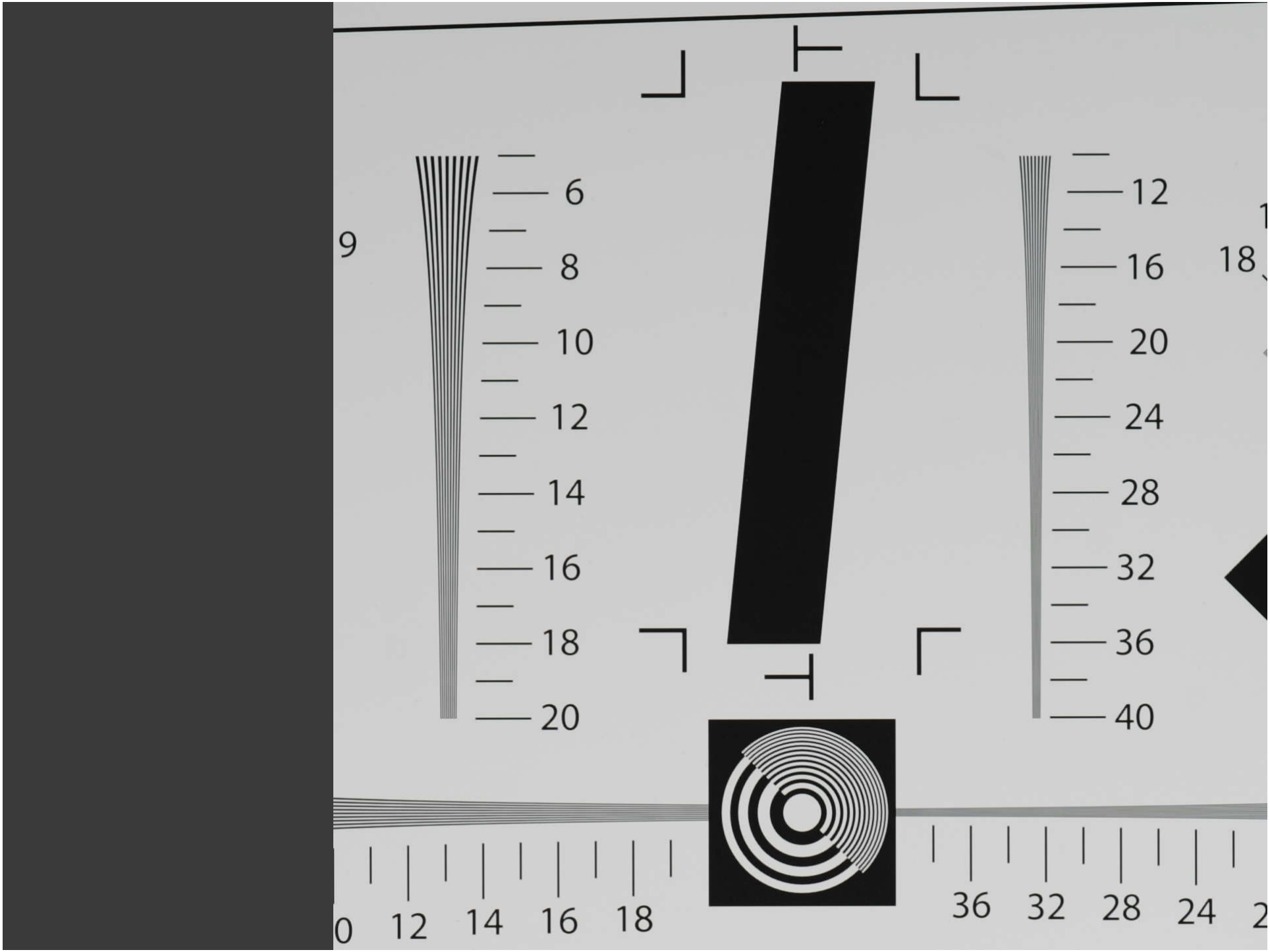


Visual comparisons (YUV444-YUVXYD)




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Visual comparisons (YUV444-YUVXYD)





YUV444 (24bpp)



YUVXY(8bpp)


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YUVXYD(8bpp)


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Visual comparisons (YUV444-YUVXYD)





YUV444 (24bpp)



YUVXY(8bpp)



YUVXYD(8bpp)



Summary

We presented YUV subsampled pattern that achieves 8bit/pixel and still maintains ‘visually lossless quality’

Proposed method: using BAYER subsampling on luminance with embedded edge information in the chrominance samples that are DPCM compressed. Two investigated variants:

- using only H/V edges – requires 8to7 DPCM compression on chroma samples
- Using H/V edges and 2 diagonals – requires 8to6 DPCM compression on chroma samples

Encoding/decoding resources needed in implementation: 2line buffers + 2 pixles memory and small glue logic.

Image quality evaluation: we used MTF degradation (slanted edge method) to quantify the loss in luminance and chromatic aberration evaluation to estimate the loss in chrominance.