Evaluation Methodology for Bayer Demosaic Algorithms in Camera Phones

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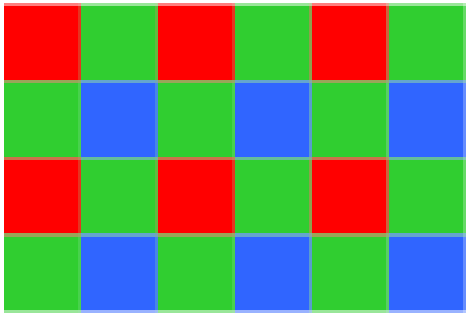
QUALCOMM CDMA Technologies

Outline

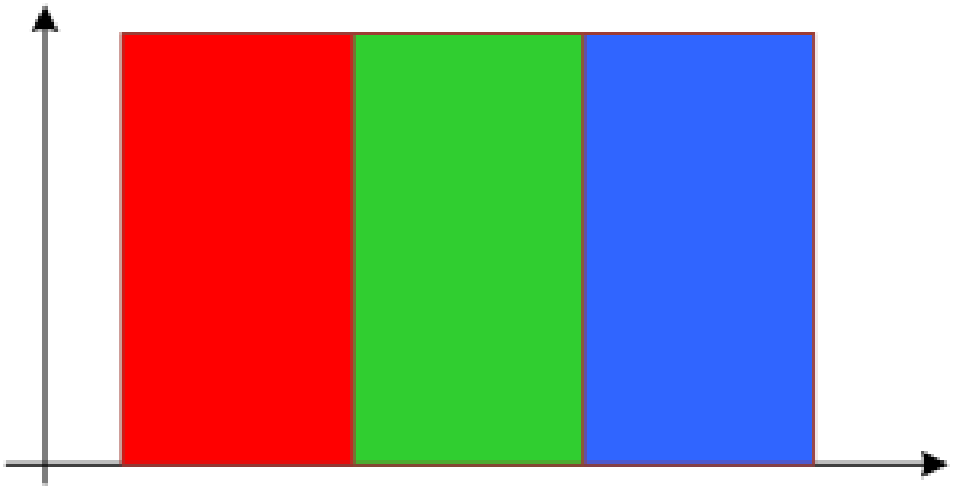
- Introduction – the idea
- Problem Description
- Evaluation methodology – test chart
- Evaluation methodology – data extraction
- Results
- Conclusions and remarks

Bayer Pattern

- The reconstruction of a color image acquired through a Bayer pattern is one of the fundamental problems in color imaging

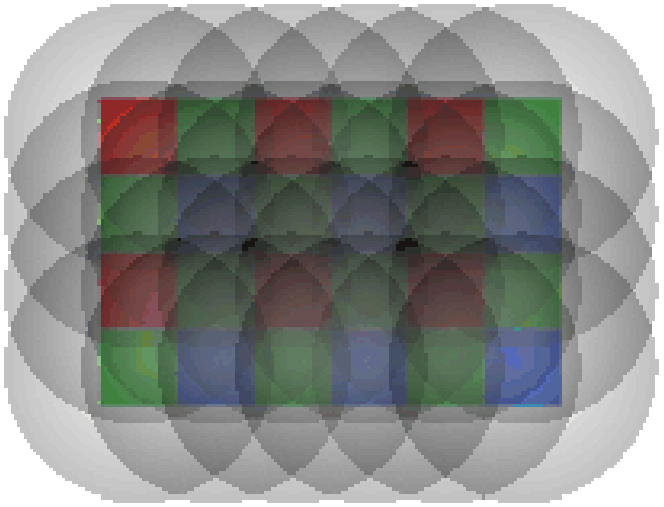


- The process can be imagined as a combined spatial sampling with spectral sampling.

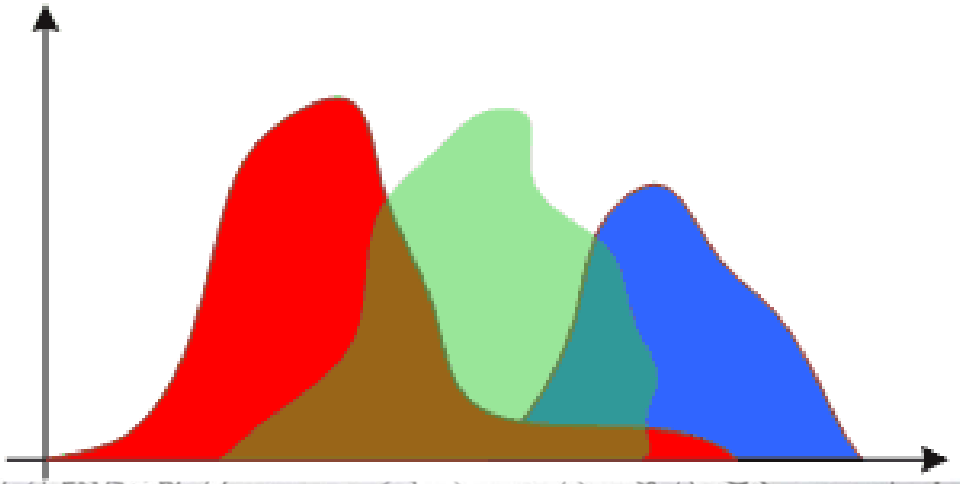


Bayer Pattern

- The spatial sampling is contaminated by adjacent pixels (optical cross-talk, electric cross-talk, PSF of the lens, etc)



- The spectral sampling is overlapped to alleviate the attenuation of color filters



What can go wrong?



What can go wrong?

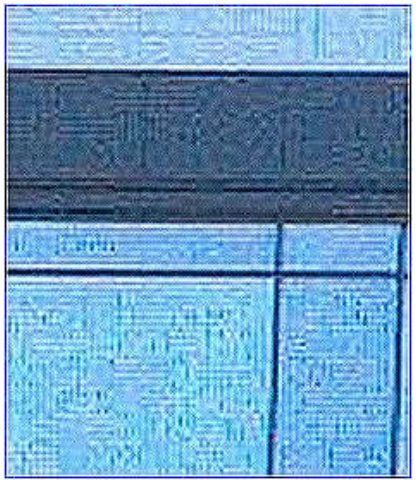




What can go wrong?



What can go wrong?





What can go wrong?





Introduction

- Demosaic evaluation is usually done through visual inspection (or MSE) of well conditioned reference images (color corrected, white balanced and with no noise)

- This approach does not test the robustness of the demosaic algorithm and can provide conclusions that might not correlate well with the real-case situation (those CMOS sensors…).

- A good evaluation methodology should provide an insight into the algorithm performance under different
  - Color cross-talk
  - SNR
  - White balance

Problem description

Evaluation of the demosaic alg using the ‘lighthouse’ picture is not enough to guarantee a good performance in a real case..

Some assumption that are not consistent with a real use case:

1. The input image has low color cross-talk:
    1. The image is white balanced and ‘D65’ corrected
    2. The color component is decorelated and offers enough edge information
2. There is little noise in the image

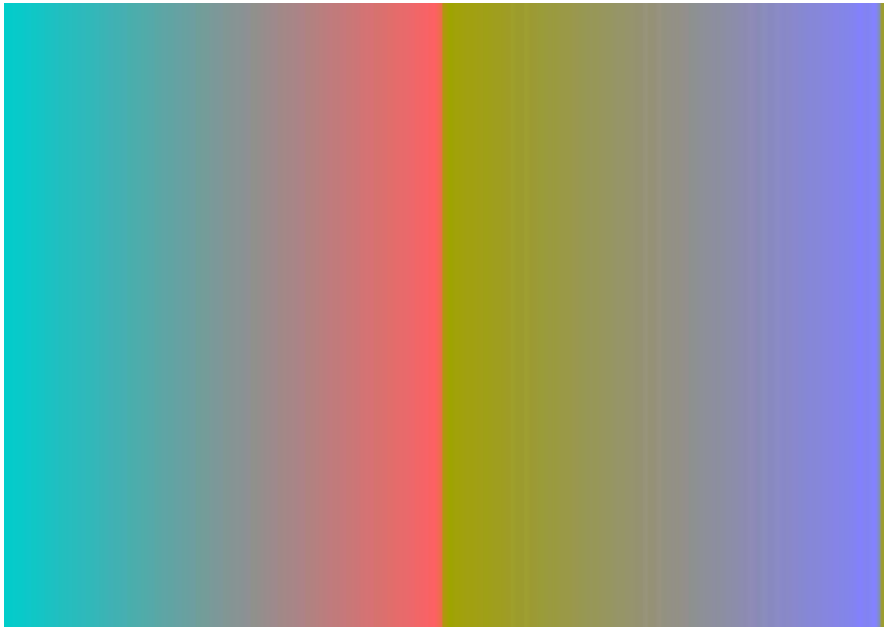
The artifacts introduced by demosaic are further enhanced in the color correction and gamma blocks which usually follow.

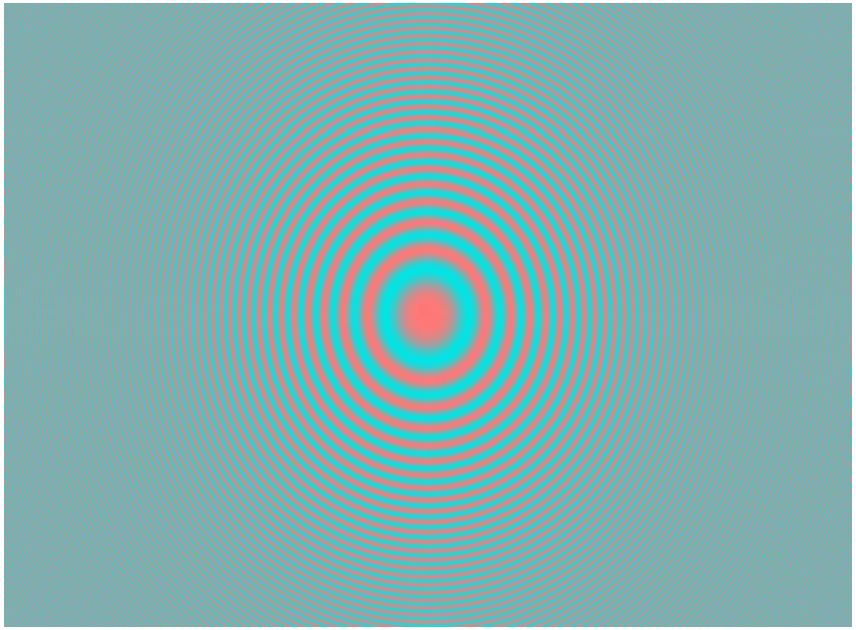
Needed: evaluation methodology that can asses demosaic quality and its robustness in a real case.

Equi-luma (constant luma) patterns

Equi-luma (constant luma) patterns = Patterns that have only variations in chrominance, the luminance plane is flat.

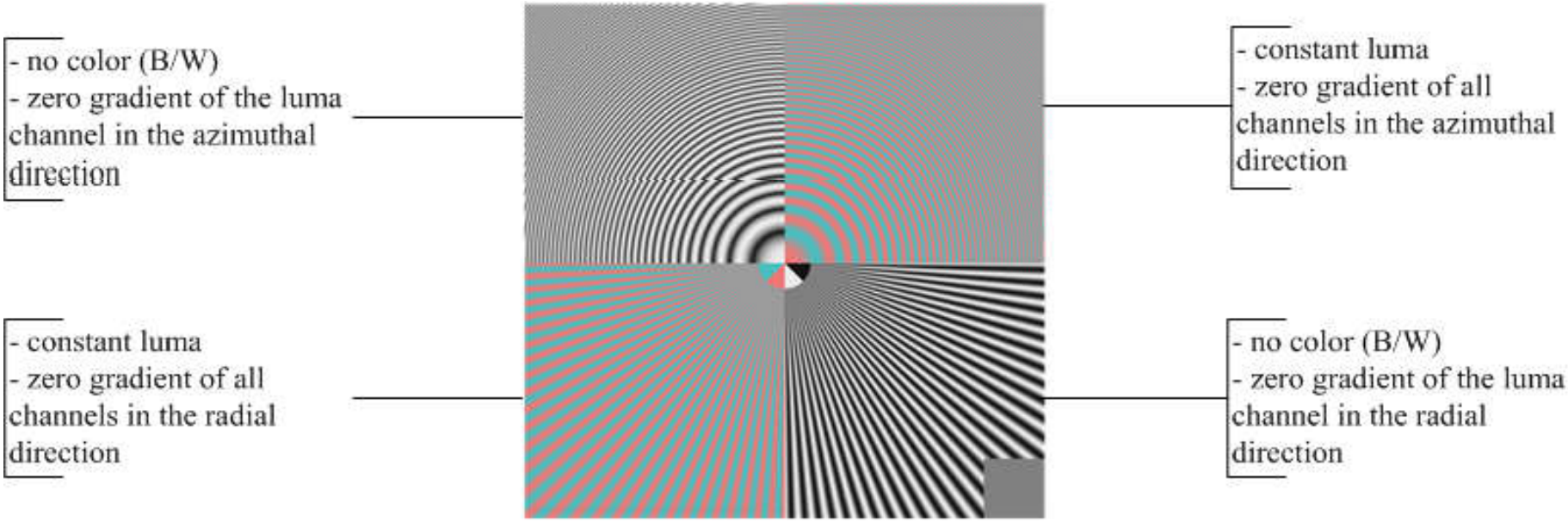
The idea: visible artifacts add information to image, therefore a pattern that has frequency content only in chrominance, after interpolation, the luminance plane will contain only the artifacts introduced.





Evaluation methodology – test chart

- The test chart is comprised of 4 elements similar to the one shown bellow



Evaluation methodology – test chart

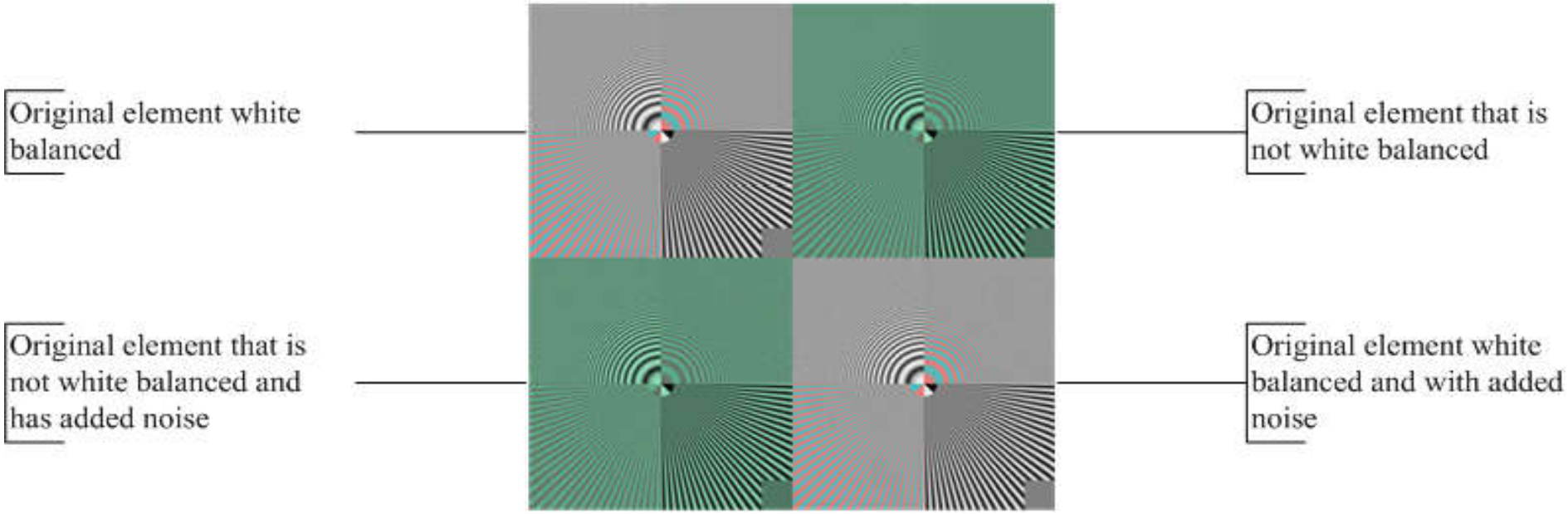
- The final test chart is formed using 4 test elements with the following modifications
  - Top-left: white balanced and without any noise
  - Top-right: without being white balanced and without any noise
  - Bottom-left: without being white balanced and with noise
  - Bottom-right: white balanced and with noise

Note: The white balance (and color correlation) is selected based on typical actual values and the corresponding matrix is

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 4.6497 & -1.3365 & -0.8135 \\ -0.1138 & 1.3318 & -0.2180 \\ -0.1441 & -0.8084 & 2.3811 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Evaluation methodology – test chart

- The final test chart is shown bellow



Evaluation methodology – data extraction

- Both structures, zone plate and Siemens star, have zero derivative in the radial and maximum derivative in angular dimensions
- To characterize a demosaic algorithm performance we propose the following statistics:
  - saturation in the black and white blocks – specifies additional color that is introduced solely by the demosaic algorithm
  - hue variations in the constant luma blocks in the polar dimension (radial or angular) which is flat by design
  - luma variations in the constant luma blocks
  - luma mid frequency response – specifies resolution capabilities of the algorithm

Results

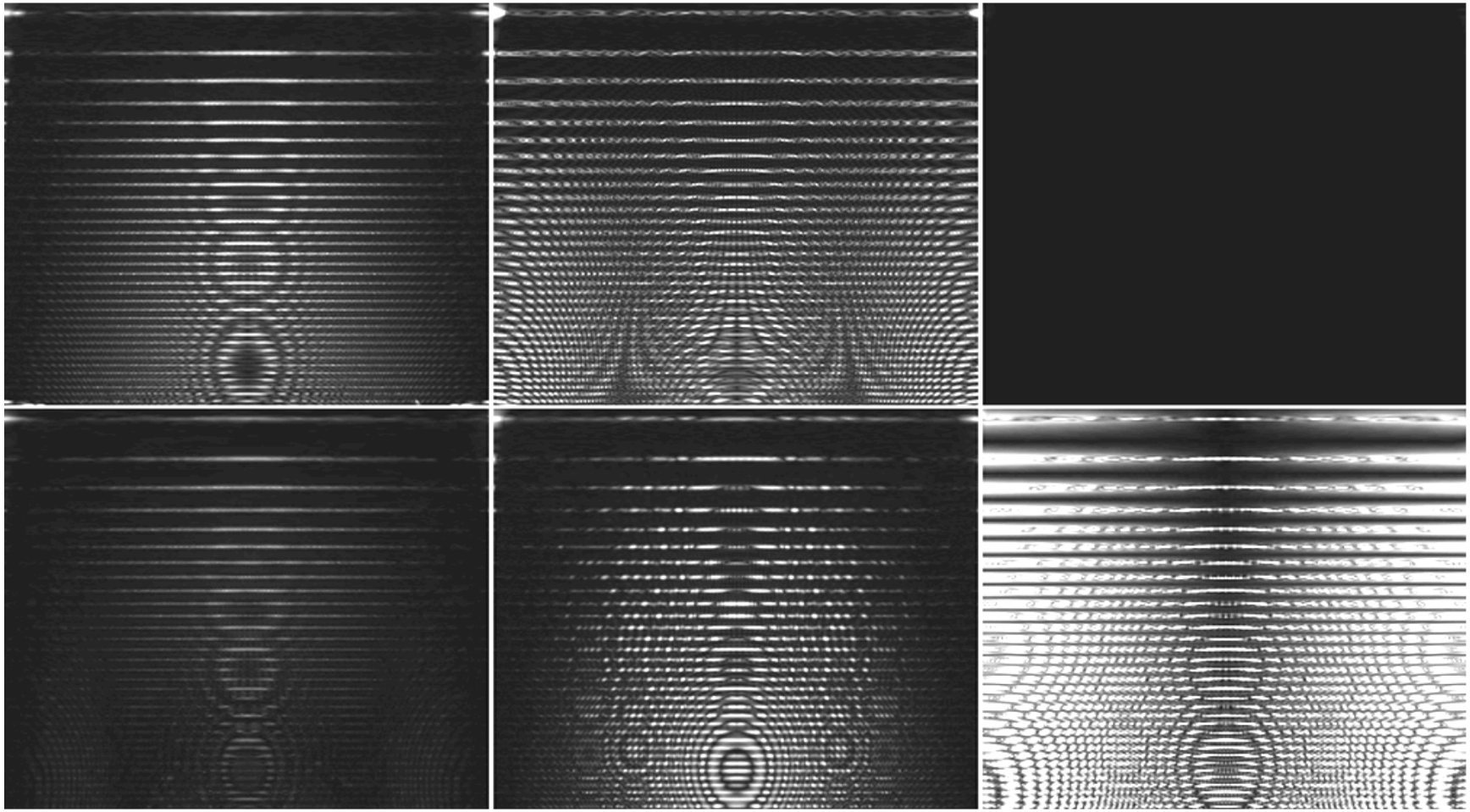
- Several different algorithms are evaluated:
  - camera phone demosaic algorithm one – CAM_SG
  - Matlab included demosaic algorithm – MATLAB
  - original – ORIG
  - AHD demosaic (Hirakawa) – AHD
  - camera phone demosaic algorithm two – CAM_CX
  - bilinear demosaic – BILN

Results

- The following stats are computed from the saturation plane
  - *Saturation MS (zone plate - B&W)* - average over the squared saturation for zone plate (should be 0 by design)
  - *Saturation MS (Siemens star- B&W)* - average over the squared saturation for Siemens star (should be 0 by design)

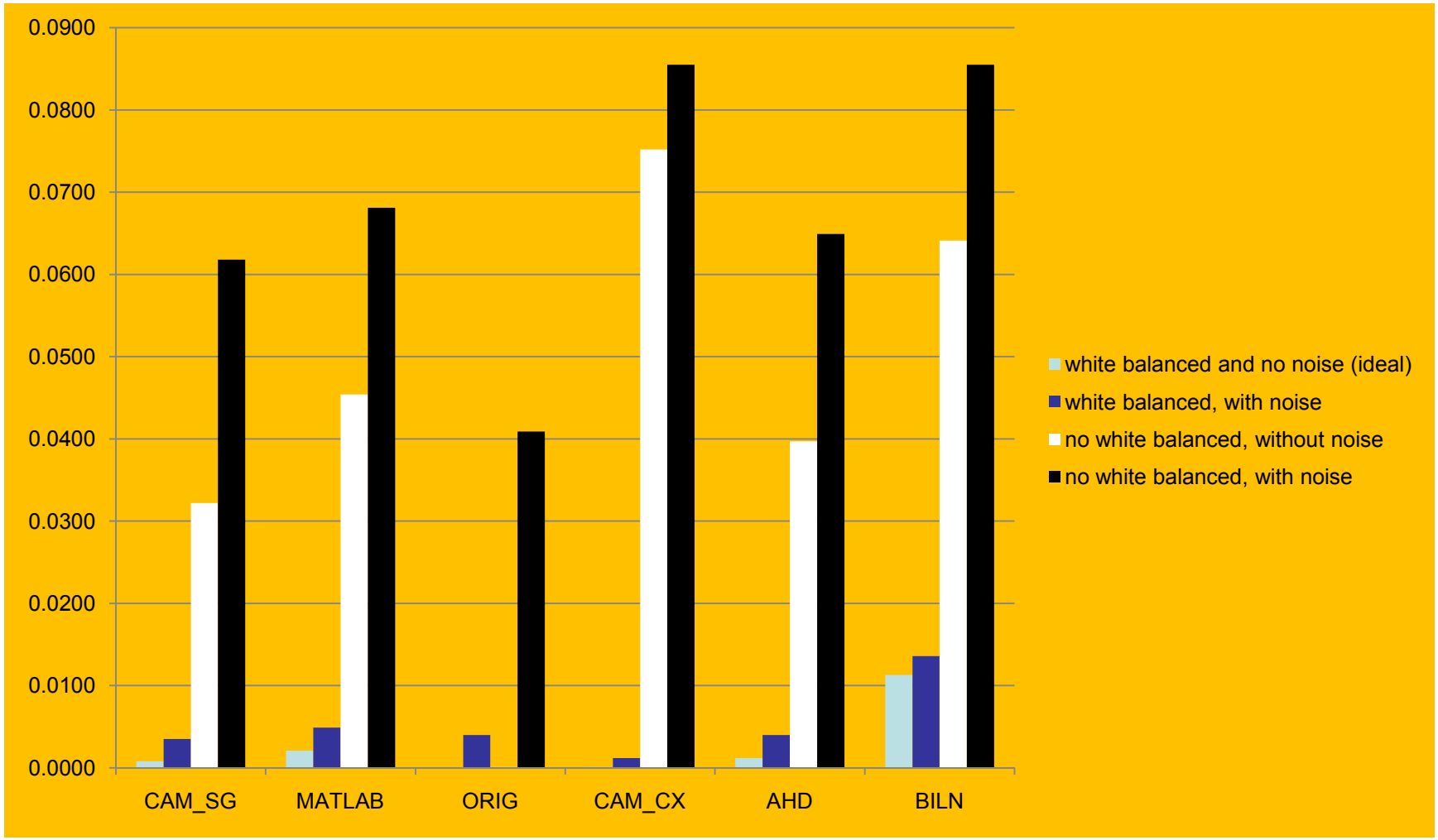
- Measuring saturation in the no-color patches is an indication of introduced color artifacts.
- Any patterns in the saturation plane are perceived as false color

Results - Saturation Zone Plate B&W (polar coordinates)

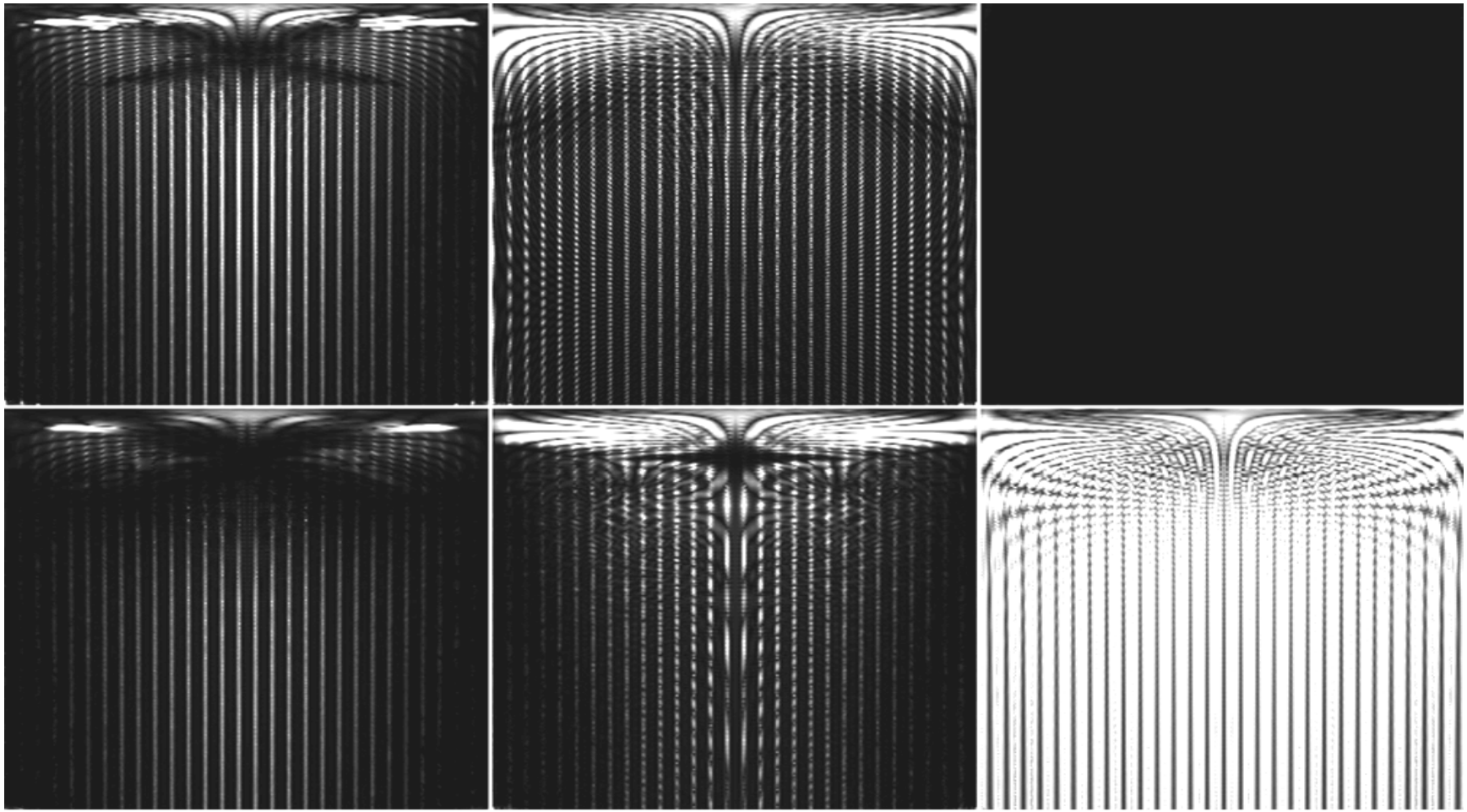


left to right top:	CAM_SG,	MATLAB,	ORIG
bottom:	AHD,	CM_CX,	BILN

Saturation MS (zone plate - B&W)

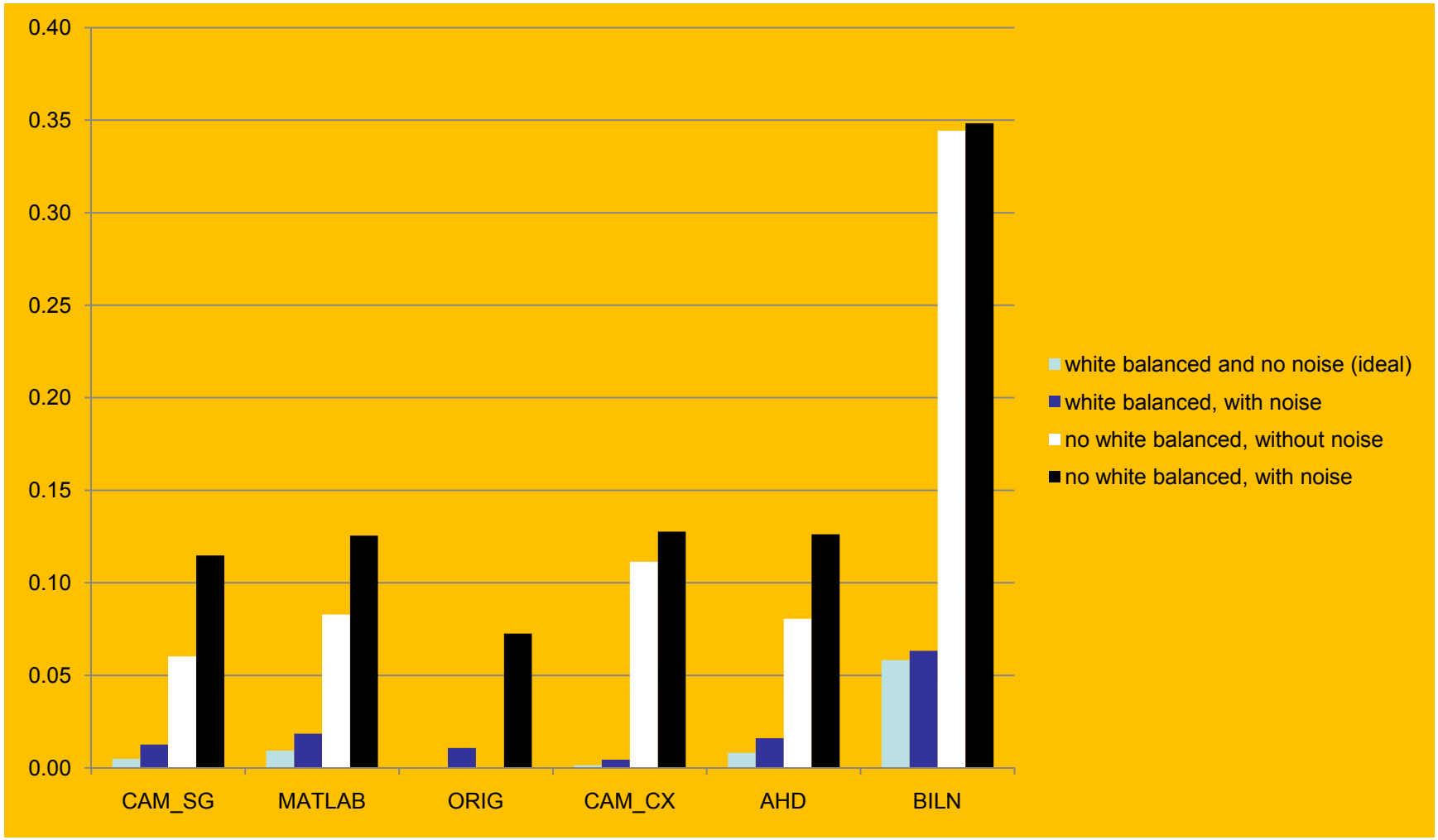


Results - Saturation Siemens star B&W (polar coordinates)



left to right top:	CAM_SG,	MATLAB,	ORIG
bottom:	AHD,	CM_CX,	BILN

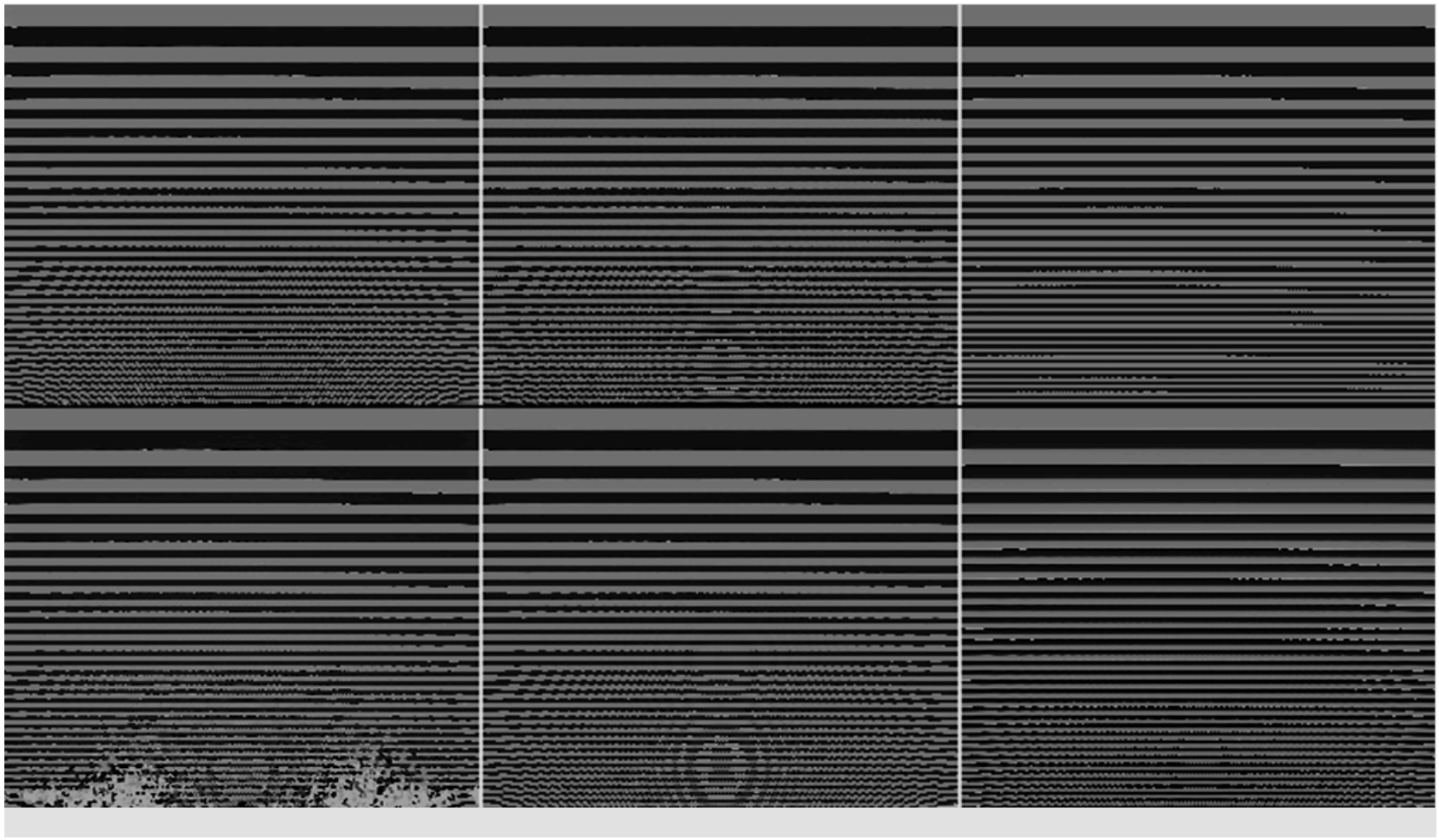
Saturation MS (Siemens star- B&W)



Results

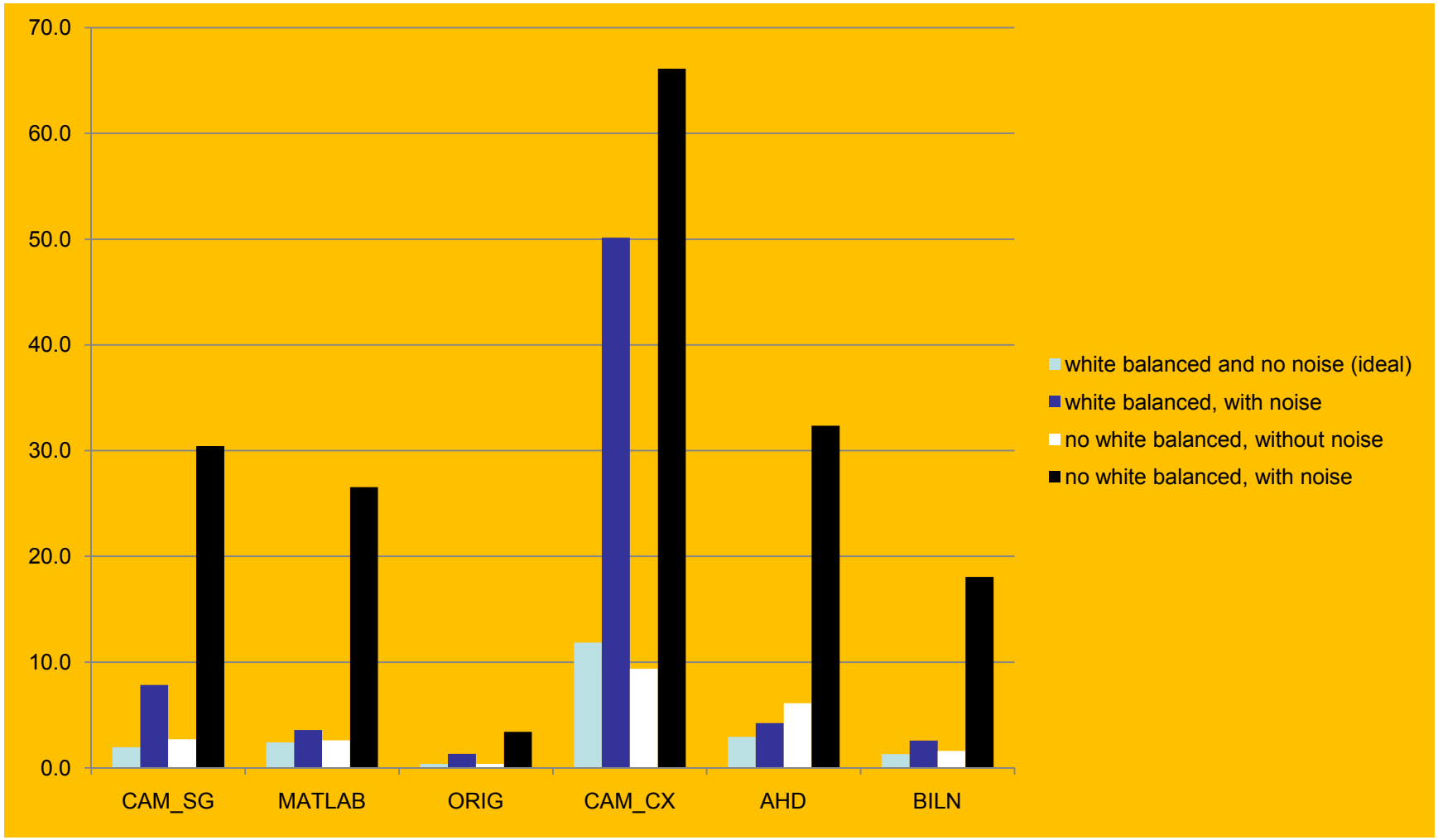
- The following stats are computed from the hue plane
  - Hue Deviation (zone plate – CL)
  - Hue Deviation (Siemens star – CL)
- Computed as follows
  - Low pass filter the hue component along the constant direction
  - Subsample the resulting low pass image
  - High pass filter the hue component along the constant direction
  - Take the square, and average
- Low frequencies are skipped by the computation
- Any pattern deviation from horizontal stripes is an indication of artifacts

Results - Hue for zone plane for constant luma (polar coordinates)

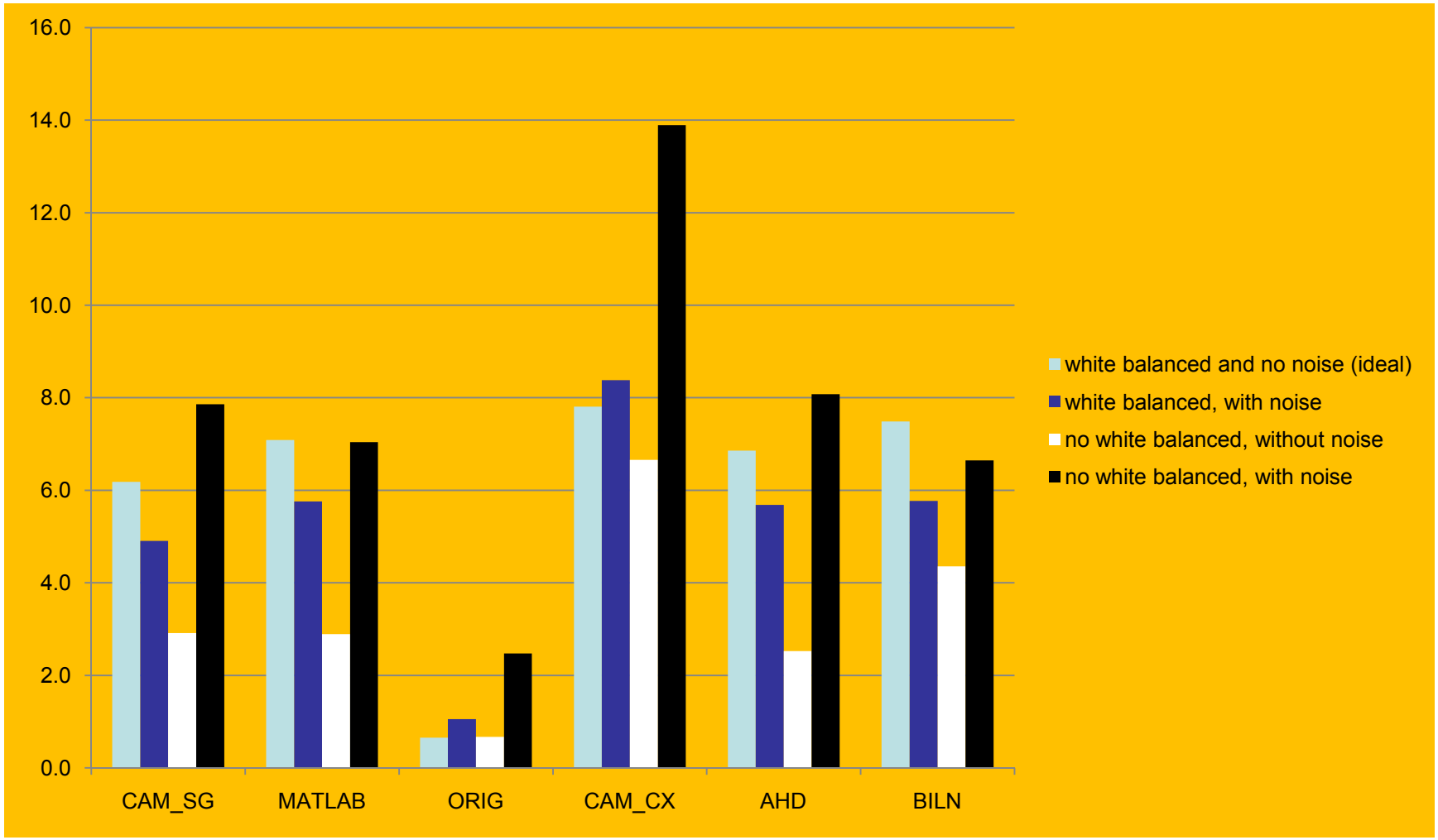


left to right top:	CAM_SG,	MATLAB,	ORIG
bottom:	AHD,	CM_CX,	BILN

Hue Deviation (zone plate – CL)



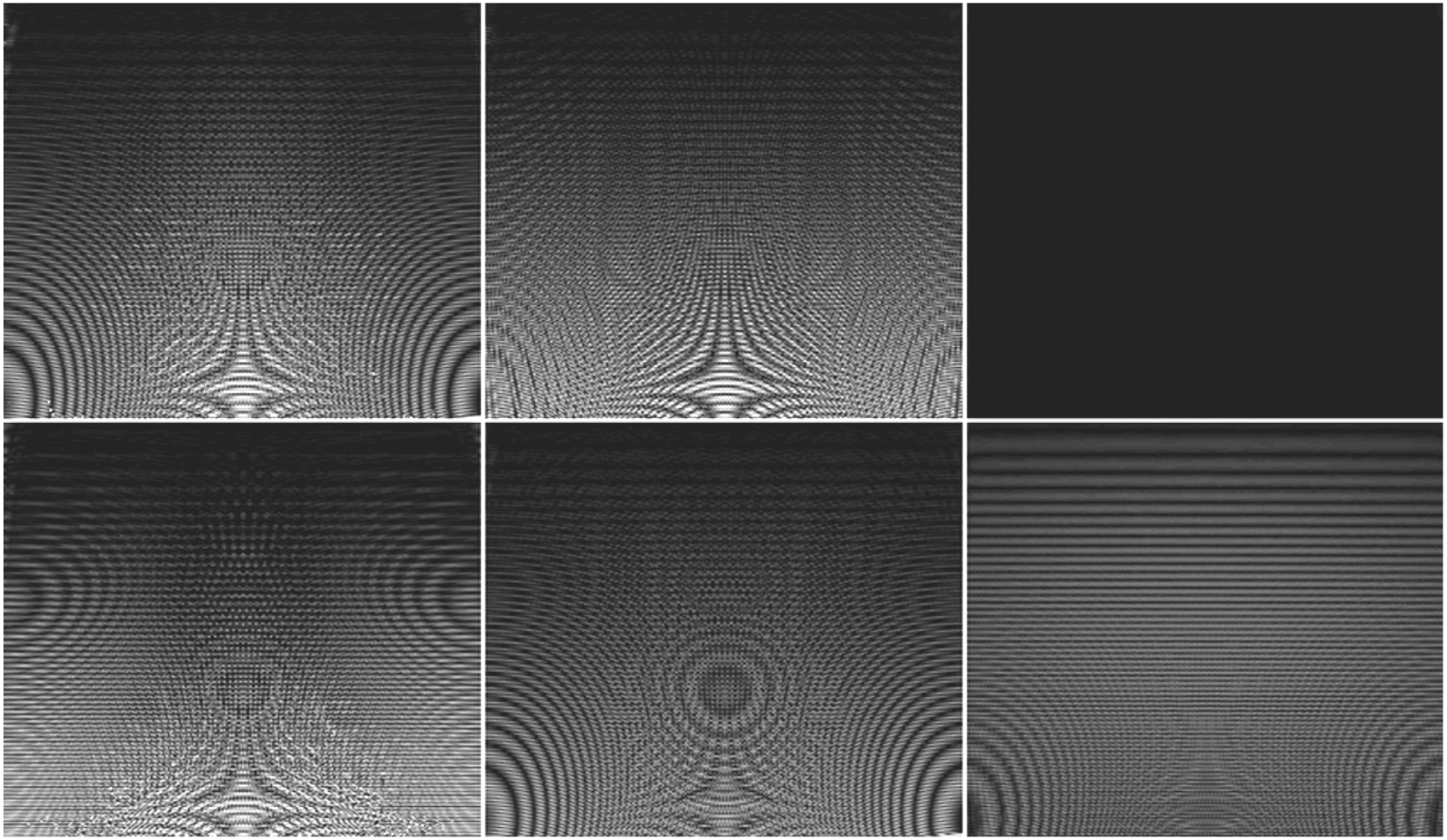
Hue Deviation (siemens star – CL)



Results

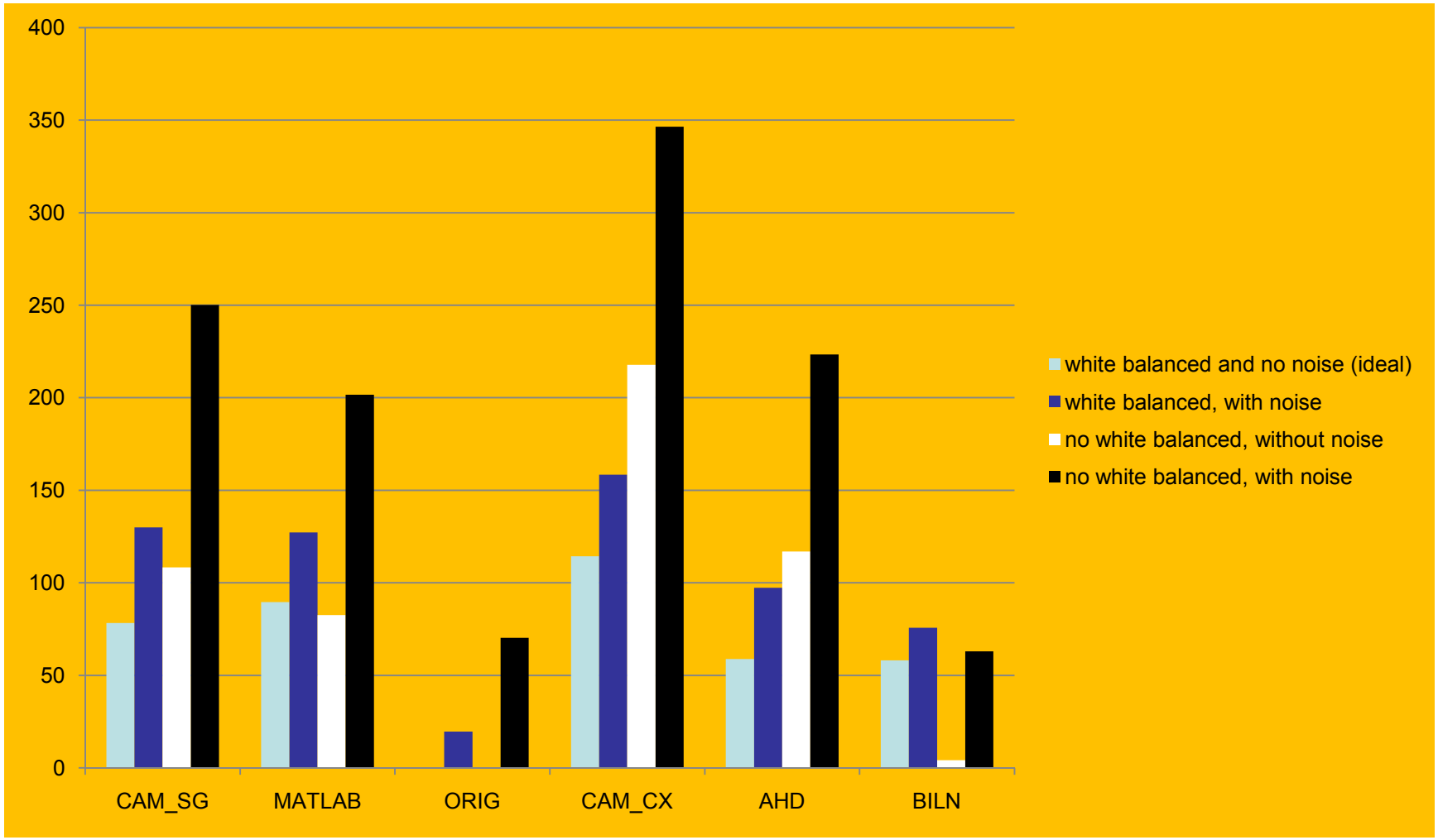
- ***Luma variance (zone plate – CL) -*** all demosaic methods produce luma component around the true mean, the metric is just luma variance
- ***Luma Mid. Frequency (Zone plate –B&W)***
  - Project (average) in alpha dimension
  - The result is a chirp signal (a signal with increasing frequency)
  - Maximum chirp frequency is at the end and is roughly a mid frequency
  - The response at that frequency computed provides an estimation of the resolution capabilities

Results - Absolute luma deviation – zone plate (polar coordinates)

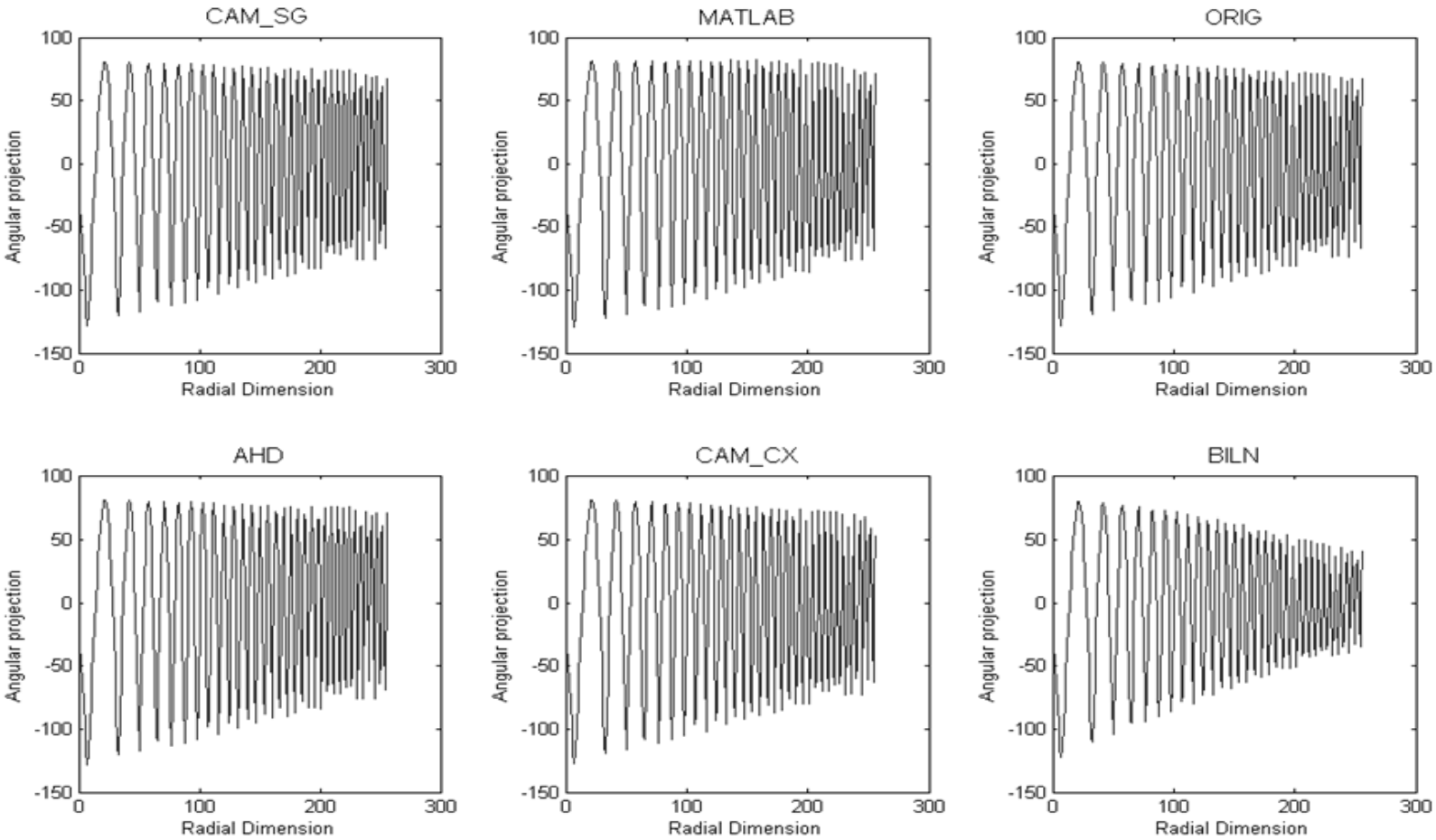


left to right top:	CAM_SG,	MATLAB,	ORIG
bottom:	AHD,	CM_CX,	BILN

Luma variance (zone plate – CL)



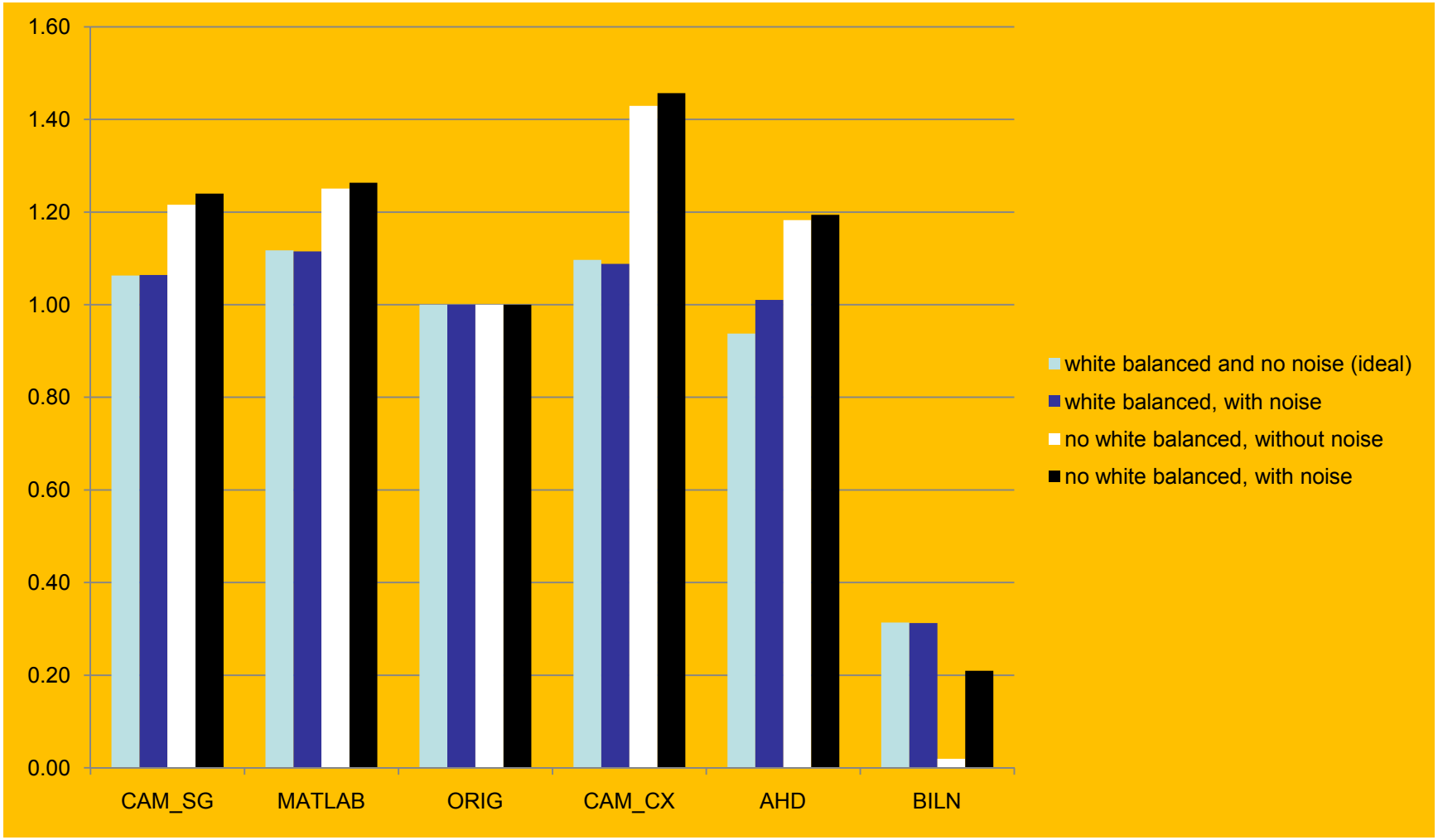
Results - Luma High Frequency – zone plate



left to right top: CAM_SG, MATLAB, ORIG

bottom: AHD, CM_CX, BILN

Luma High Freq. (Zone plate –B&W)



Conclusions

- We propose a test chart comprised of a chirp pattern (zone plate) and a Siemens star both with constant luma and constant saturation variations
- We propose a test procedure that measures deviations around the dimensions that are constant by design
- Our finding indicates that consistent results in presence of noise and on a chart that is not white balanced are a good indication of demosaic robustness – in addition to a good frequency response.

Q&A

END

Results

	Demosaic1	*Demosaic2*	*Original*	*Demosaic3*	*Demosaic4*	*Demosaic5*
Saturation MS (zone plate - B&W)	0.0008	0.0021	0.0000	0.0001	0.0012	0.0113
Saturation MS (Siemens star- B&W)	0.0049	0.0093	0.0000	0.0014	0.0082	0.0583
Hue Deviation (zone plate – CL)	1.9606	2.3968	0.3673	11.8527	2.9190	1.3099
Hue DEviation (Siemens star – CL)	6.1822	7.0857	0.6548	7.8055	6.8575	7.4853
Luma variance (zone plate – CL)	78.3075	89.6316	0.0319	114.3675	58.8574	58.1978
Luma High Freq. (Zone plate –B&W)	1.0633	1.1174	1.0000	1.0971	0.9375	0.3137

Original Test Pattern

	Demosaic1	*Demosaic2*	*Original*	*Demosaic3*	*Demosaic4*	*Demosaic5*
Saturation MS (zone plate - B&W)	0.0322	0.0454	0.0001	0.0752	0.0397	0.0641
Saturation MS (Siemens star- B&W)	0.0603	0.0830	0.0001	0.1114	0.0806	0.3443
Hue Deviation (zone plate – CL)	2.6946	2.5962	0.3716	9.3715	6.1193	1.6061
Hue DEviation (Siemens star – CL)	2.9160	2.8934	0.6677	6.6572	2.5235	4.3550
Luma variance (zone plate – CL)	108.4446	82.6162	0.1189	217.8510	117.0780	4.2168
Luma High Freq.(Zone plate –B&W)	1.2158	1.2506	1.0000	1.4295	1.1828	0.1983

Test Pattern without WB

Results

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Test Pattern without WB

	Demosaic1	*Demosaic2*	*Original*	*Demosaic3*	*Demosaic4*	*Demosaic5*
Saturation MS (zone plate - B&W)	0.0618	0.0681	0.0409	0.0855	0.0649	0.0855
Saturation MS (Siemens star- B&W)	0.1148	0.1255	0.0725	0.1276	0.1262	0.3484
Hue Deviation (zone plate – CL)	30.4175	26.5568	3.3941	66.1227	32.3603	18.0463
Hue DEviation (Siemens star – CL)	7.8570	7.0399	2.4707	13.8935	8.0778	6.6472
Luma variance (zone plate – CL)	250.1378	201.6743	70.2498	346.4383	223.3952	62.9969
Luma High Freq.(Zone plate –B&W)	1.2402	1/2632	1.0000	1.4569	1.1939	0.2093

Test Pattern without WB plus noise