A CMOS HDR Imager with an Analog Local Adaptation

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With a basic CMOS imager, it is impossible to encode the High Dynamic Range (HDR) of natural scenes due to several drawbacks: Mainly of them are the limited DR of the pixel and the output limitation due to the quantification of the analog to digital converter (ADC).

Many solutions propose to enhanced the input DR or change integration time following the overall content of the scene in order to encode different dynamics in a single digital image [Spivak09]. These solutions imply in general high digital computational cost or loss in term of contrast or details.

Nevertheless a tone-mapping algorithm is required to give an overall impression of the scene from its local dynamics. Several recent papers propose efficiency local tone-mapping algorithms, but few papers shows a dedicated circuit like in [Vargas11] [Cao11] [Kim12]. Advantages of this kind of implementation are a lower digital computation cost and a reduction of the quantization noise. [Vargas11] proposes to integrate a tone mapping technique in the pixel in order to adapt directly the dynamic range to the final 7-bit format. [Cao11] proposes an analog gamma correction at the ADC level in order to decrease the quantization noise and decrease the power consumption. [Kim12] proposes to use a non-linear (logarithmic) single-slope ADC in order to enhance the dynamic range of the sensor and decrease the power consumption and the silicon area.

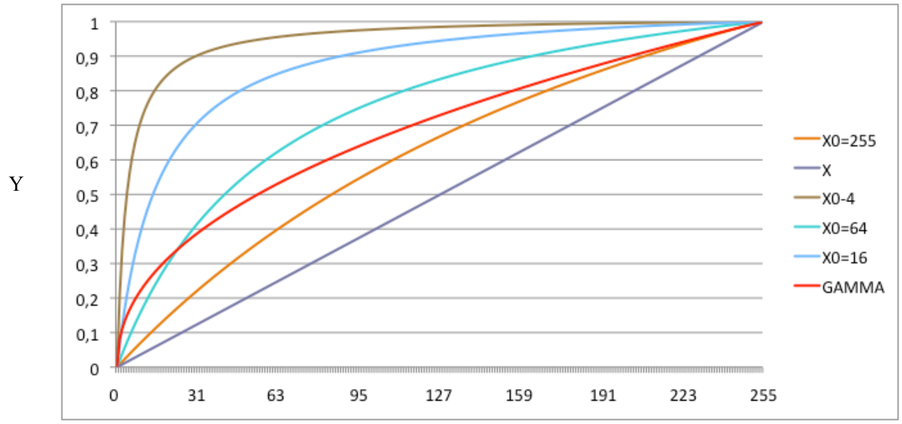
In this project, we would like to implement a direct adaptation of the dynamic range to the final format image like in [Vargas11] but with a low pixel area overhead. We would like to dedicate this adaptation to a FPN compensated linear pixel ([Cao11] uses a Logarithmic one). Due to our entire analog implementation, the ADC could be totally standard (in relation to [Kim12]) with a low resolution. Our circuit allows avoiding the tone mapping procedure including the Gamma correction, maintaining standard functioning for user, and minimizing the pixel silicon overhead.

Here we use the fact that the dynamic range is locally low (for a closed neighborhood of pixels). This is the whole image that has a high dynamic range. This property allows local gain modification (through a non linear function) for a global rendering of the high dynamic range. In this implementation, we choose a modification of the focal plan for allowing the computation of a local average into a “blind pixel”. This is motivated by the fact that in natural systems, the photo-transduction is mobile, adaptive, at the stage of photoreceptors.

I- Bio-inspired light adaptive algorithm

Based on basic global shutter imager architecture, we propose an analog implementation of a Bio-inspired local light adaptive system presented in [Meylan07]. This algorithm, based on non-linear Michaelis Menten law (MM law: $Y=X/(X+X_0)$), is able to compute local tone-mapping procedure without any halo problem. X_0 could take several values. In [Sicard99], X_0 was the mean value of illumination of the entire imager. In this paper, X_0 is the mean value of a local pixel block (with a low resolution, 2x2 pixels for example). Basically, X_0 could be an equation depending of the $pixel_i$ value and its environment. Figure1 shows MM law effect of the X_0 value on the output in relation with basic Gamma correction. We can see that, at low illumination values and low X_0 value, the output is strongly enhanced.

Because the law is smooth and the adaptation parameter does not change too much from point to point in the scene, the overall treatment is also smooth (Figure 2)



Luminance coded on 8bit (0 = Black, 255 = White)

Figure 1: Comparison between Gamma correction (Y=X^(1/2,2)) and Michaelis Menten Law effect with several X0 values. Curves are normalized to one.

Figure 2: Matlab results with a gamma correction and our local gamma correction like

II- Silicon Implementation

We propose an analog implementation of the algorithm in two distinct parts [cica11]: The first (called averaging block) extracts average local information per pixel blocks (typically a 2x2 block). This information is reading in the same time that of the pixel values of the block. The second (called balance block), is placed just before the ADC. This analog part adapts pixel block values in relation with the computing average local value of the block (Figure 3).

Matlab implementation allows us to optimize the number of pixels per block. A 2x2 array proposes the best result because it still avoids halo problems with only few pixels averaging. Moreover, this resolution is very interesting for a design point of view because it allows us an optimized layout in term of silicon area. The designed pixel is shown in Figure 4. This implementation contains 8.5 MOS transistors per pixel. Note that the functionality we propose can be designed with a 6.5T pixel. But, for this first implementation we have preferred the 8.5T pixel for reliable and robustness reasons. The pixel size is 15µmx15µm with a 38µm^2 N$^+$P photodiode in a 0.35µm from AMS, which is at least four times smaller than other tone mapping methods.

After a standard sample & hold procedure (with FPN compensation) in column amplifier, pixel value and its associated mean value are used in the balance block. This analog block implements the bio-inspired Michaelis-Menten law. This first design needs blocks like divider, adder, subtractor, and transconductance circuits. This analog part is not design friendly, but we are confident in improving it in order to simplify the design and to obtain finally at the output the voltage dynamic range of the column amplifier.

Layout and main characteristics of our circuit are shown on figure 5. In term of readout procedure, we read the mean values and their associated pixels in parallel. In this case, the original frame rate is maintained and the readout procedure is close to the basic one.

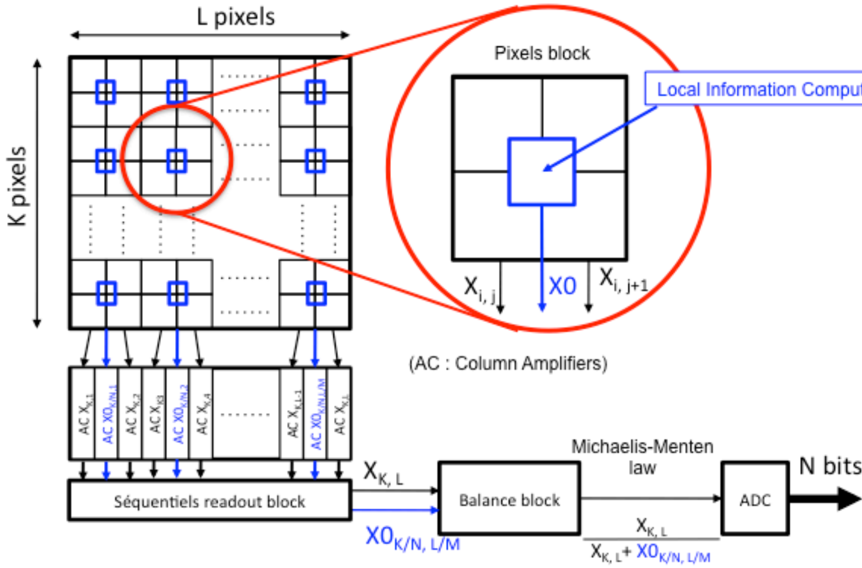


Figure 3: Global architecture of the Circuit. For layout convenience, columns amplifiers dedicated to X0 (in blue) are moved on the top of the array with a dedicated sequential readout block

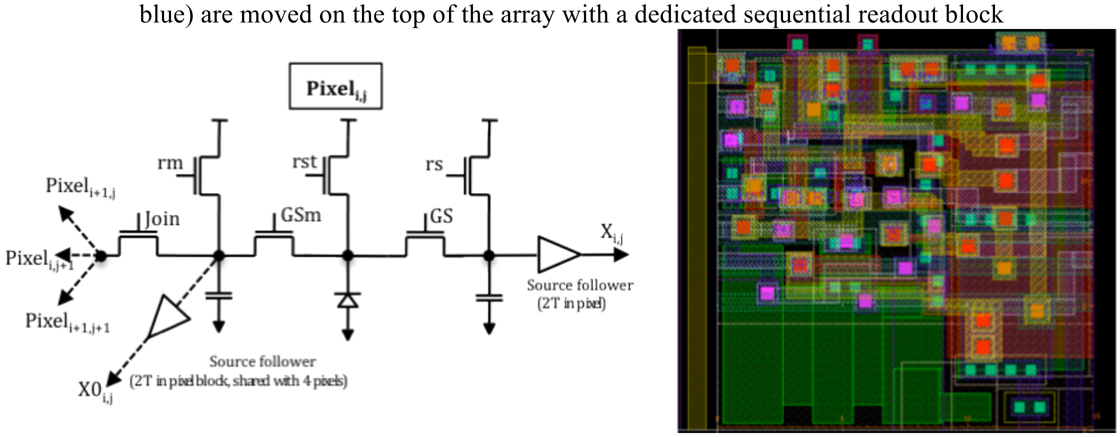
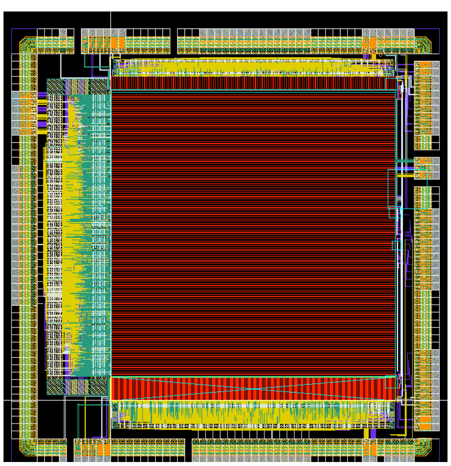


Figure 4: Schematic and layout of our 8.5T pixel



Chip Resume	
Technology	AMS CMOS 0,35µm opto
Resolution	256x256 pixels
TMOS per pixel	8,5
Pixel pitch	15µm
Photodetector	38µm2 N+P photodiode
Fill Factor	17%
Acquisition mode	Global shutter
Power supply	3,3V
Adc resolution	8bits (external), designed for 12bits
FPN correction	Yes
Output Dynamic	0,35V (expected 1V)

Figure 5: Circuit Layout and main characteristics

III- Experimental Results

The Figure 6 shows an image produce with the circuit compared to a mode where the local adaptation is putting off (only the standard global shutter operates). We clearly see that the dark part of the image is enhanced although the bright part is not modified too much. It should be noted that using the Michaëlis-Menten function increase the visibility in the dark area, but any other continuous function could be implemented in the balance block if someone willing operate also on bright areas. This result wouldn't be obtained with a digital implementation of the algorithm (off line for example) because the quantization prevents to apply non-linear function without increasing the noise.

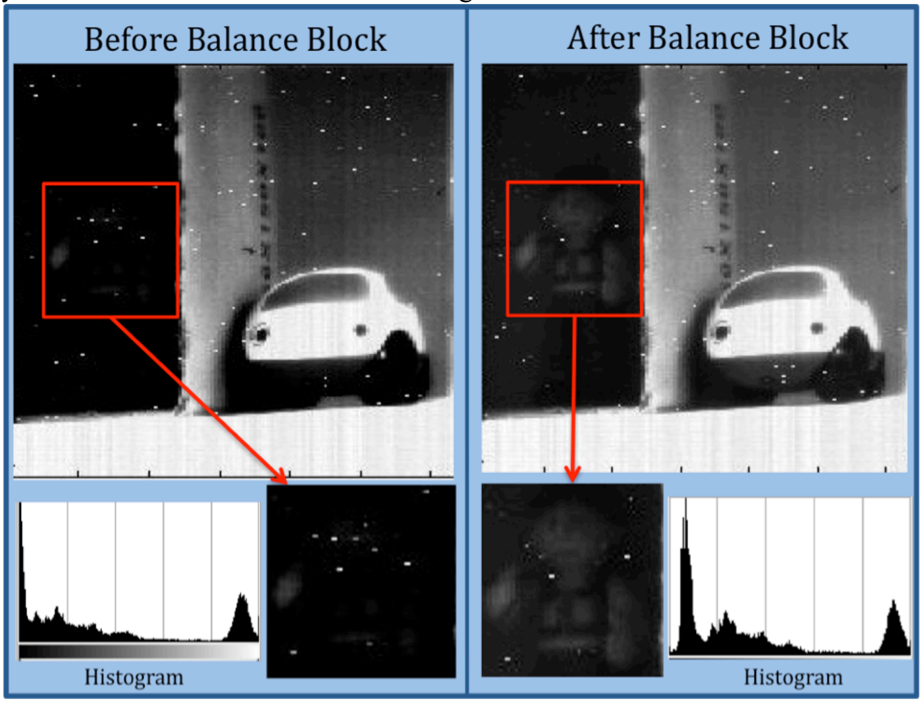


Figure 6: Experimental results with the same circuit (left the local adaptation of off, right it is on), same cameras setup and same scene conditions. Informations in the dark part of the image are enhanced after the balance block and its analog non-linear Michaelis Menten processing. Both results are obtained after an analog integrated FPN compensation

IV- Conclusion

We present in this paper a local adaptive system for linear CMOS imager. This system implements a bio-inspired algorithm without halo problem. This analog implementation takes into account the pixel value and the mean value of its close environment. It allows to enhance image details in dark part of the scene without modify the readout and the frame rate of the imager.

Today the main drawback of our implementation is the pixel fill-factor and future works are focused on reducing it. The first design of the balance block needs to be improving in order to increase its output dynamic range. A test chip is under fabrication in order to test new structures. We are also working on the measure of the increase dynamic range capacity provided by our method. Indeed, because our method used a locally driven non-linear process, basic DR measure doesn't work.

Acknowledgement: The "CICA" project n°090504 was supported by GRAVIT Innovation Grenoble Alps. Authors would like to thanks Julien Lary for his great design job and Alexandre Delorme for his great support.

References:

[Spivak09] A.Spivak, A.Belenky, A.Fish and O.Yadid-Pecht, "Wide-dynamic- range cmos image sensors - comparative performance analysis," Electron Devices, IEEE Transactions on, vol. 56, no. 11, nov. 2009.

[Vargas11] S. Vargas-Sierra, G. Liñán-Cembrano, A. Rodríguez-Vázquez. "A QCIF 145dB Imager For Focal Plane Processor Chips Using a Tone Mapping Technique in Standard 0.35µm CMOS Technology", International Image Sensor Workshop, IISW'11, Hokkaido, Japan, June 8-11, 2011.

[Cao11] Y. Cao, A. Bermak, "An Analog Gamma Correction Method for High Dynamic Range Applications", SOCC 2011, 26-28 September, Taipei, Taiwan, 2011.

[Kim11] D. Kim, M. Song, "An Enhanced Dynamic Range CMOS Image Sensor Using a Digital Logarithmic Single Slope ADC", IEEE Transaction on Circuits and Systems II, Vol. 59, n°10, October 2012.

[Meylan07] Meylan L., Alleysson D., and Süsstrunk S., "A Model of Retinal Local Adaptation for the Tone Mapping of Color Filter Array Images", Journal of Optical Society of America, A, Vol. 24, N°9, September, 1st, 2007, pp. 2807-2816

[Sicard99] G. Sicard, G. Bouvier, A. Lelah, V. Fristot, "An adaptive bio-inspired analog silicon retina ", ESSCIRC'99, Duisburg, Germany, sept-99

[cica11] D. Alleysson, G. Sicard, " Contrôle Contraste Local ", French patent, n° FR1158472, CNRS, 09/22/2011,