A Broadcast Quality 2.3MP CMOS Image Sensor with Dynamic Range Extension Mode.

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Abstract – This paper describes a monochrome 2/3-inch CMOS image sensor that offers broadcast level image quality in a commercial CIS technology. The imaging System-on-Chip (iSoC) offers 14-bit output data for highest resolution and greatest detail, 59 dB signal-to-noise ratio (SNR) for high image quality, and up to 90 frames per second (fps) progressive scan. The imager array is built on a 5μm square pixel with standard 4T architecture for a sensor resolution of 2048 by 1164. The measured sensitivity is 80,000 e/(lux.s) and the QE of monochrome samples peaks at 77%.

I. Introduction

The sensor presented in this paper is the third generation of a standard visible CMOS image sensor developed for high quality three sensors cameras [1]. In these types of cameras a glass prism splits the incoming light into three primary color beams and deflects them onto three separate monochrome sensors. Each sensor array contains a total of 2.9M pixels, 2048 by 1164 of which form the active region able to support 2K video formats. Optical black pixels can be used to compensate for dark current, correct for column fixed pattern and reduce row temporal noise. A standard HD frame of 1920x1080 can be read out at 90fps using a 111MHz sensor clock. The output data is transmitted in parallel via 14 sub-LVDS ports running at 222MHz, for a maximum data rate of 3.1Gbit/s per sensor. Due to the possible high intensity of the incoming light a custom organic pigment black mask is added on top of the die to protect sensitive analog circuits and optical black pixels from undesired photo-generated charges. Moreover all photodiodes outside the region of interest are constantly kept in reset to prevent image degradation due to charge blooming.

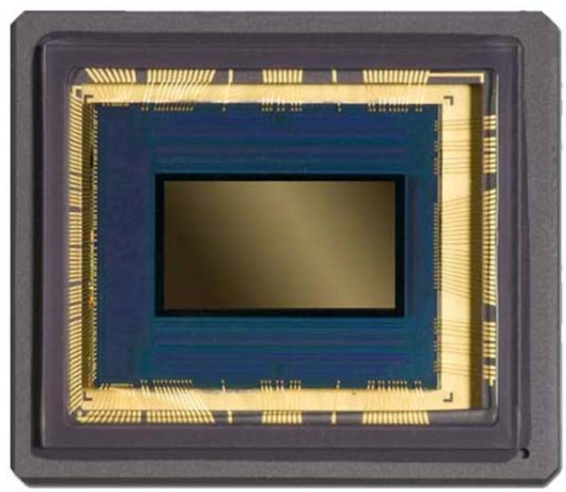

Fig [1]: Image sensor in ceramic PGA package.

Contrarily to most mainstream imaging applications, broadcast and studio cameras are fixed gain cameras. There are three sensors per camera, one per color, and each of the sensors analog gain is set so that the white level of a specific HD test chart with 89.9% reflectivity, illuminated with a 3200K, 2000 lux source, at a specific lens aperture, will deliver 700mV of luminance signal [2] with usually 600% dynamic. The green channel sensor will usually run at low analog gain to achieve good white balance, being the quantum efficiency of the blue and red channels normally about 6dB to 12dB lower. It is therefore imperative for this kind of application to have good noise performance at low gain. Once the camera is calibrated only digital gain, exposure and lens aperture are used to control the saturation.

II. Sensor description

The sensor block diagram is presented in Fig.2. The pixel video information is read out one line at a time using a rolling shutter architecture. The analog readout chain comprises of one column amplifier per column, an array of line drivers, eight PGAs and eight 12bit pipeline ADCs. Correlated double sampling is performed in the column by auto-zeroing the column buffer on the pixel reset level.

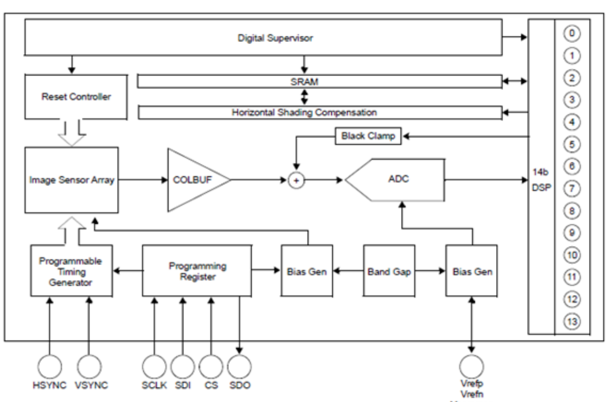

Fig [2]: Image sensor block diagram.

After autozero, the difference between pixel video and reset levels is amplified and stored on one or two available sample and hold capacitors for subsequent serial readout. The column amplifier gain can be adjusted between 0dB and 21dB in 3dB steps.

To achieve highest readout speeds only one capacitor is sampled per line; in this mode of operation the two column capacitors can be toggled at the beginning of each line to implement an analog memory buffer and allow concurrent pixel sampling and horizontal scanning. When running lower frame rates the sensor can still take advantage of the full internal converter readout speed and achieve either lower noise or higher dynamic range. In the first case the difference between pixel video and pixel reset levels, amplified by the column readout circuit is sampled on both sampling capacitors. The time at which the sampling switches open can be independently programmed [Fig.3] so that two samples of the temporal noise are available. After sampling is completed the two samples are averaged by connecting the capacitors in parallel to lower the overall readout temporal noise. The reduction in noise strongly depends on the amount of noise correlation between the two samples as well as on the readout noise spectral distribution and the amplifier bandwidth, but can theoretically go up to $\sqrt{2}$ when the two samples are uncorrelated, the noise spectrum is uniform and the buffer bandwidth is constant.

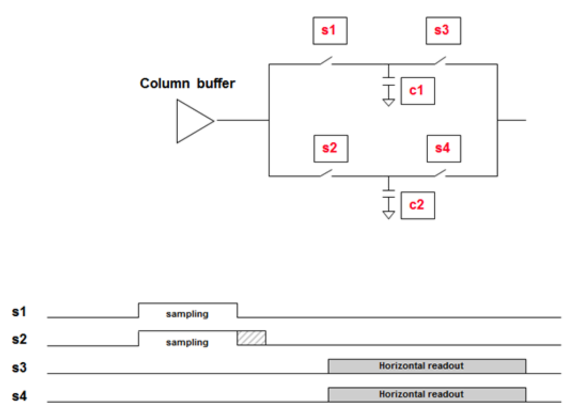

Fig [3]: Dual cap readout mode timing.

A second way to reduce readout noise by running the ADCs at full speed is implemented by converting the same video sample twice and producing a digital average of the two subsequent conversions. This methodology reduces all noise contributions introduced after the sampling capacitor.

Alternatively, the sensor can be programmed so that the vertical read pointer increments only every two horizontal scans; in this mode of operation each line is read out two times in a row. The two readings are from a full frame exposure and from a single line of exposure. The information can be used to recover details in highly saturated areas by stitching the two samples off-chip and extend dynamic range. This method does not suffer from the amount of motion artifacts encountered with other common techniques, the two samples being temporally correlated. Another advantage of this method is that it eliminates the need of a full frame of memory, being the two exposure samples output consecutively. One limitation of this methodology is the inability to change the exposure time for the short integration sample, which in turns limits the exposure ratio of the two samples to very large numbers. The first image of Fig.5 shows an example of a frame captured with this option. The subsequent images are generated by splitting alternating rows of the original image into a long exposed scene and a one line exposed scene. The last image is obtained by mathematically stitching the two images with a square law function.

III. Characterization results

Extensive measurements have been performed both on the single sensor and in a three sensor camera. Standard evaluation included photon transfer curves, dark frames and illuminated scene analysis. All measurements have been performed at 60fps in a temperature controlled environment. At max analog gain the total output noise of 4.5LSB is equivalent to less than 4e of input referred noise, dominated by pixel temporal noise.

Dark current of 300 e/pixel/sec has been calculated as the slope of the mean of dark frames at 250ms and 450ms exposures.

The QE curve has been extracted using a calibrated monochromatic spot light source and peaks at 77% as reported in Fig.4.

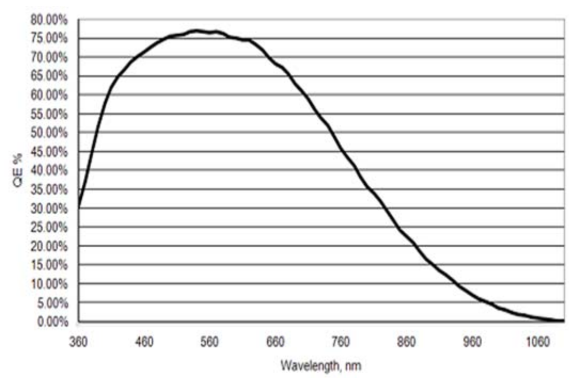

Fig [4]: QE curve.

IV. Conclusions

We presented a broadcast quality 2/3" cmos image sensor targeted to three sensor cameras. Additional features have been implemented to lower analog read noise and to extended dynamic range.

Pixel Array	
Pixel Size	5 μm x 5 μm
Dark Current (60°C)	<300 e/pixel/s
Sensitivity[a]	80,000 e/lux-s
SNR (2000 lux, f11, 600%, 60p)[b]	59 dB
Color Filter	Monochrome
Optical Format	2/3-inch
16:9 Array Format (pixels)	1920 (H) x 1080 (V)
Full Resolution (pixels)	2048 (H) x 1164 (V)

a. With 3200k light and a CM500S IR cut filter.
b. Measured with AltaSens Evaluation Kit.

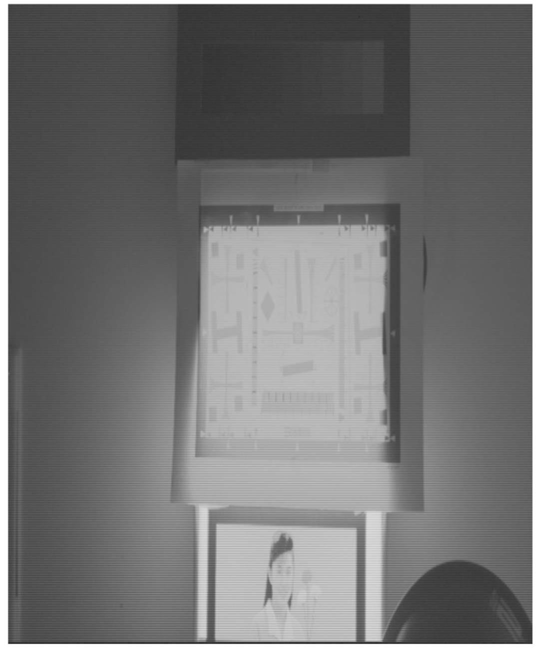

Fig [5]: Extended dynamic range mode.

Acknowledgments

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References

[1] M. Loose et al. “2/3-inch CMOS Imaging Sensor for High Definition television”, IEEE workshop on charge-coupled devices and advanced image sensors, June 7-9, 2001

[2] P. Centen et. al, A 2/3-inch CMOS Image Sensor for HDTV Applications with Multiple High-DR Modes and Flexible Scanning, ISSCC2007, San Francisco, 11-14 February 2007, pp 512-513.