2/3? CMOS Imaging Sensor for High Definition Television

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Abstract

We have developed a CMOS imaging sensor specifically optimized for generating high-definition video with high quality for broadcast television. The device is an imaging system-on-chip (iSoC) that supports the relevant television standards including SMPTE 274 and 2/3? optical format comprising 1936 by 1088 pixels. In addition, the SoC has low-power 12-b A/D conversion, automatic hot pixel identification and replacement, black-level clamping, total power dissipation of only 180 mW, and many other programmable options including analog and digital gain amplification, region-of-interest windowing and sub-sampling.

I. Sensor Architecture

The ProCam-1™ CMOS image sensor is based on a 3 transistor active pixel cell. In addition to hard and soft reset schemes [1, 2], it is operable in a very low noise mode supporting high optical fill factor that provides an active feedback loop during the reset phase [3]. Figure 1 shows the circuit diagram of the pixel and its operation in low noise reset and readout mode, respectively.

During the readout phase, the pixel signals are fed to column-wise sample/hold stages that double sample and amplify with up to 24 dB of gain. Multiplexed on a common bus, the analog signals reach another programmable gain amplifier (0-24 dB) and are then digitized by the 12-bit ADC. Further on-chip digital processing provides additional gain adjustments (0.006 dB resolution) and hot or dead pixel replacement. A digital logic block controls the sensor timing and its different operation modes. It enables the sensor to operate in slave mode (external synchronization) or master mode (self-synchronized).

The sensor's 0.25µm CMOS technology is specifically optimized for CMOS imaging sensors by UMC (Hsin-Chu, Taiwan). The process supports single poly, four metal layers, dark current density <0.7 nA/cm^2 and high MTF at all visible wavelengths. The prototype ProCam-1 sensor in a 68-pin J-lead chip carrier package is seen in Fig. 2. Table 1 summarizes the sensor's key features including the progressive or interlaced readout necessary for supporting high definition television within the SMPTE 274M specification [4].

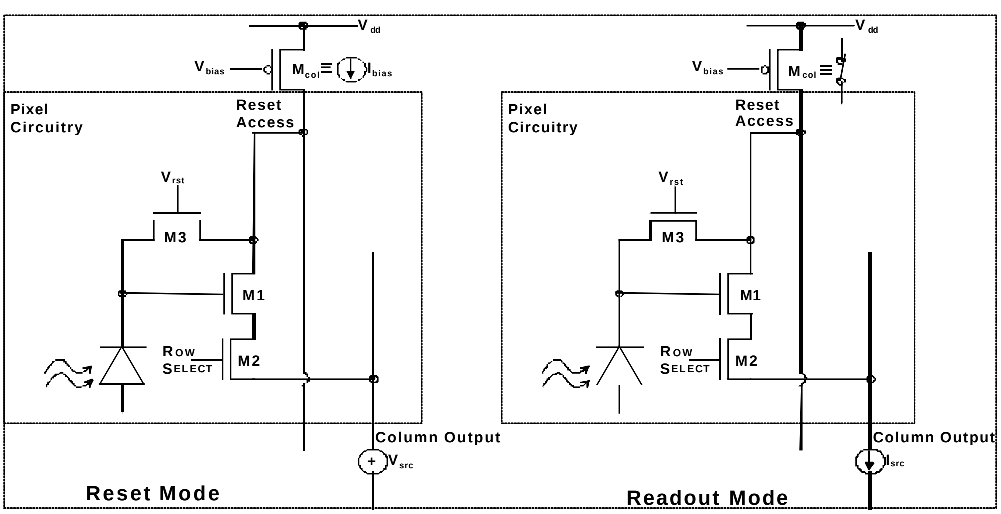

Figure 1: Pixel circuit in low noise reset operation (left figure) and readout operation (right figure).

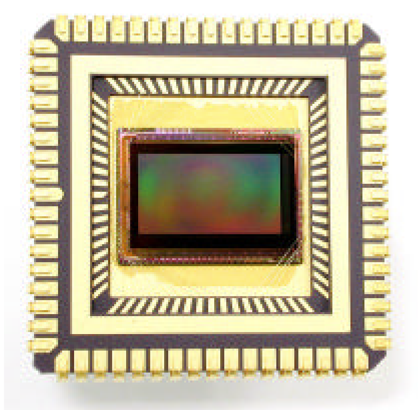

Figure 2: Prototype ProCam-1 sensor for HDTV

Table 1: ProCam-1 Features

Resolution	1936 x 1086 (HDTV)
Optical Format	2/3″
Pixel Size	5 µm square
Digital Output	12 bit
Frame Rate	30 Hz progressive 60 Hz interlaced
Video Modes	Timing freely adjustable to various video and digital still capture standards including SMPTE 274M
Interface, input	Microwire I/O (3-wires)
Interface, output	12 bit parallel
Progr. Gain	-24 to 72 dB at 0.006 dB/step
Electr. Shutter	1/30 Hz to 1/30,000 Hz
Synchronization	internal (master) or external (slave)
Sub-Sampling	1.5, 2, 3 and 4x lower resolut.
Windowing	selectable with 16 Line and 9 column resolution

II. Performance

The ProCam-1™ CMOS imaging sensor operates at progressive frame rates to 30 Hz and interlaced frame rates to 60 Hz with maximum dynamic range of up to 70 dB. The digital video output supplies 12 parallel bits at up to 75 MHz. The temporal read noise is approximately 20 e- to 60 MHz data rate and the maximum charge-handling capacity is between 50 ke- and 60 ke-, depending on the process optimization.

Having a pixel pitch of 5µm, the as-drawn optical fill factor without microlenses is about 50%. Video imaging at 20 Hz frame rate has S/N ratio of at least 40 dB to below 0.1 lux. The sensor's sensitivity is 2.2 V/lux-s with standard microlenses and is expected to be 20 to 30% higher with custom microlenses providing near-100% fill factor.

Figure 3 is a plot of the photoresponse obtained at integration time of 100 ms with 550 nm ±20 nm spectral filter. With corresponding read noise of 24 e- and maximum capacity of 59 ke-, the dynamic range for this sample measurement is 67.7 dB. Of the four process splits, the optimum yielded read noise of 20 e- with 70 dB dynamic range. We are currently working to push this high performance to the maximum frequency of 75 MHz for the production version of the sensor.

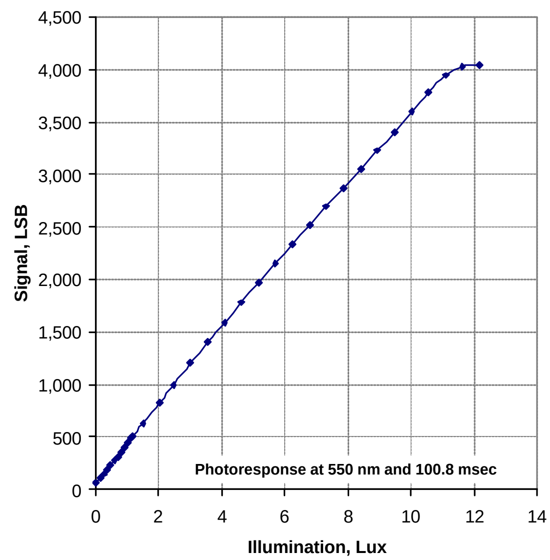

Figure 3: Photoresponse at 100 ms integration time (550 nm)

The sensor's architecture generates low spatial noise. Figure 4 shows the measured fixed pattern noise across the bottom $1/4^{th}$ of the dynamic range at 83 msec integration time on Sensor L1W18C3. The FPN of about 1 least significant bit (LSB) within the 4096 LSB dynamic range implies an upper FPN of 0.025%, which is significantly below the best levels previously reported [5]. In this case the 12-b dynamic range fully maps about 1.5V of the analog signal excursion from each pixel.

Operating from 3.3V and 1.8V power supplies and a single clock in master mode, the sensor produces the HDTV test pattern image shown in Figure 5. The CMOS sensor has Nyquist-limited resolution with negligible electronic shading across the full field of view. The HDTV test pattern implies minimum vertical resolution consistent with the Nyquist limit at 968 line pairs. Similarly, the minimum vertical resolution at Nyquist is 544 line pairs. Obtained with a 550 nm ±20 nm filter, the results imply that the pixel-to-pixel crosstalk is sufficiently low for now developing visible imagers at even higher resolution. Figure 6 is a magnified view of the test pattern's central region. While analog and digital programmable gain amplification stages support gain from –24 dB to 72 dB, the captured images correspond to the standard 0 dB gain. Table 2 summarizes the measured performance of the ProCam-1 sensor prototypes.

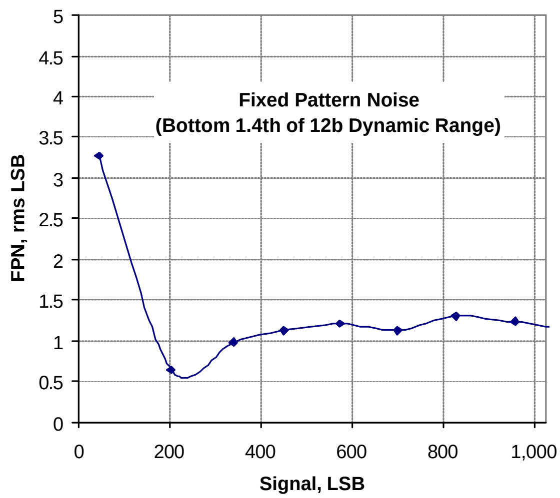

Figure 4: Fixed Pattern Noise for bottom 1/4th of dynamic range.

Conclusion

The ProCam-1 imaging sensor is specifically optimized for generating high-definition video with high quality for broadcast television. We are currently performing full characterization to verify the design changes that may be necessary for supporting production deliveries at the full video rate for the commercial temperature operating range. The sensor currently supports dynamic range >68 dB with read noise <25 e- at total power dissipation below 200 mW with 12b digital interface to 60 MHz. Furthermore, the 0.25μm CMOS technology has dark current below 0.7 nA/cm^2 and enables Nyquist-limited vertical and horizontal resolutions of 968 and 548 line pairs, respectively.

References

[1] Tian et al., IEEE JSSC, Vol.36, No.1, 92-101, January 2001.

[2] Pain et al., in 1999 IEEE Workshop on Charge-Coupled Devices and Advanced Image Sensors, Nagano Prefecture, Japan, June 10-12, 1999.

[3] kTC noise suppression scheme, European Patent Application EP988749A1

[4] SMPTE Standard for Television, 274-1998

[5] Watanabe, in 1999 IEEE Workshop on Charge-Coupled Devices and Advanced Image Sensors, Nagano Prefecture, Japan, June 10-12, 1999.

Table 2: **ProCam-1 measured performance**

Parameter	Measured Value
Quantum Efficiency at 550nm with standard microlens	70 %
Dark Current Density (room temperature)	<700 pA/cm^2
Square Wave MTF at Nyquist	
450 nm	69 %
550 nm	62 %
650 nm	51 %
Vertical Resolution	968 line pairs
Horizontal Resolution	544 line pairs
Temporal Read Noise	< 25 e-
Charge-Handling Capacity	> 50 ke-
Fixed Pattern Noise	1-2 LSB
Dynamic Range	> 68 dB
Internal Analog Signal Swing	1.5 V
Nonlinearity (0 to 300% sat.)	< 0.1 %
Typical Power Dissipation	180 mW
Optical Photoresponse	2.2 V/lx-s

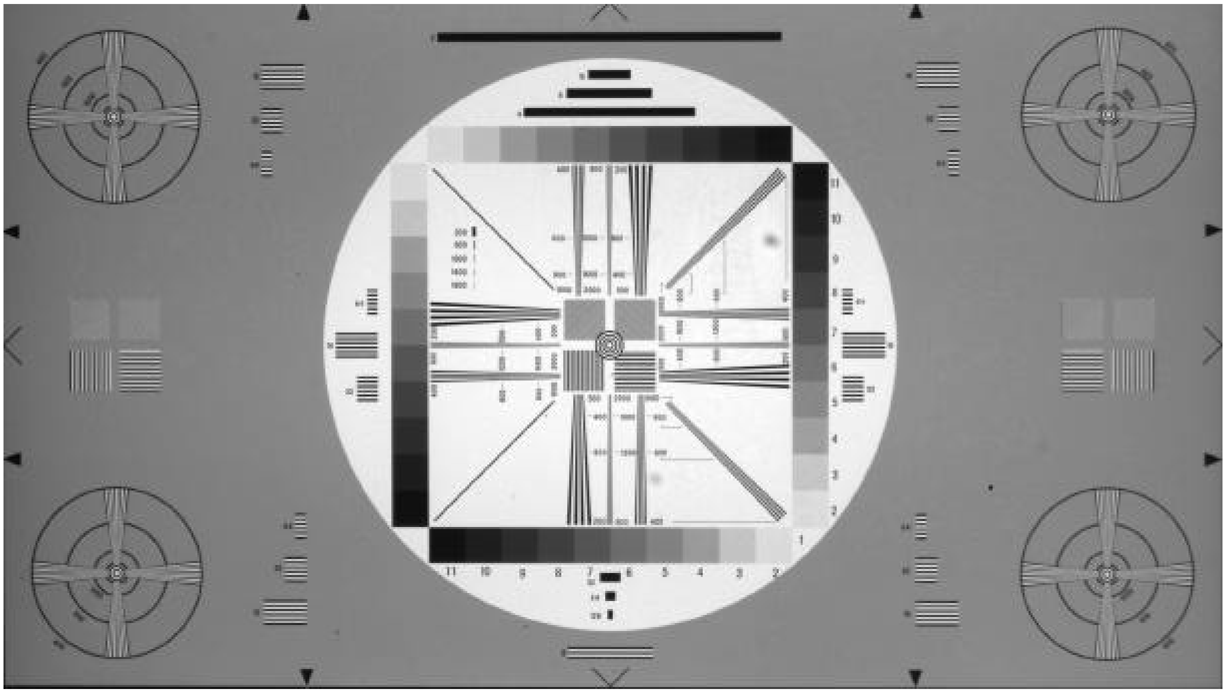

Figure 5: Video snapshot of HDTV test pattern

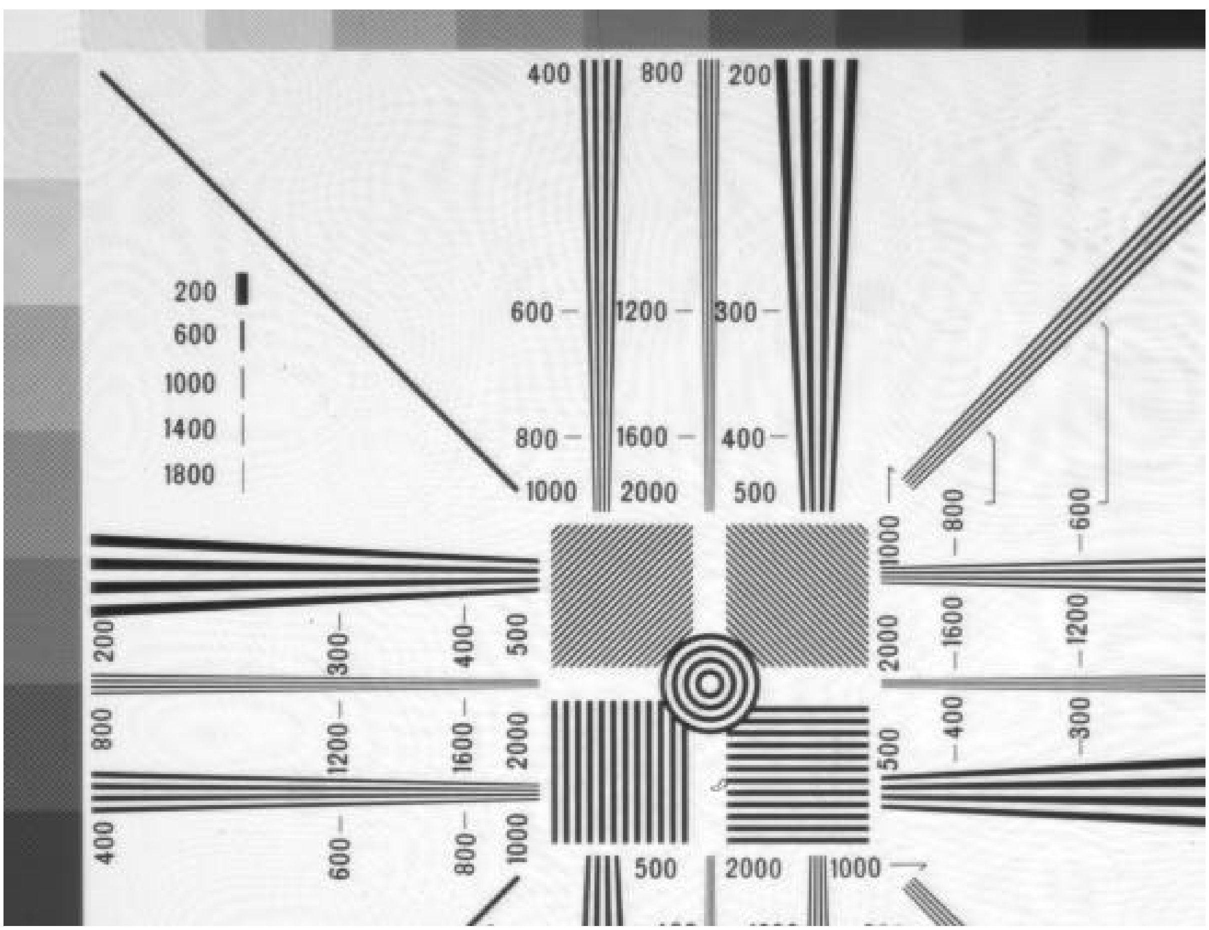

Figure 6: Magnified view of center of HDTV test pattern