FA 11.3: A 37x28mm ²600k-Pixel CMOS APS Dental X-Ray Camera-on-a-Chip with Self-Triggered Readout

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A 675(H)x900(V) pixel CMOS active pixel sensor (APS) camera-on-a-chip is implemented in 2μm 1P, 2M technology with a linear capacitor option. The chip measures 37x28mm² with 40μm pixel pitch, and has on-chip timing and control logic, fixed-pattern noise suppression circuits, and features an event-detection circuit for self-triggered readout. The sensor is placed in a patient's mouth for dental x-ray applications.

The sensor floorplan is shown in Figure 1. In product form, the sensor is coated with scintillator and encapsulated in plastic. Pads are all on one side of the chip for simplified packaging. The chip maximum master clock rate is 10MHz, corresponding to a maximum pixel output data rate of 1.25M-Pixels/s.

The core pixel array consists of 675(H)x900(V) photogate (PG)-type active p-channel pixels on a 40μm pitch. The pitch is driven by the application and is much larger than the current state-of-the-art [1]. Operation of the PG-type pixel yields high performance [2, 3]. The main difference between this pixel and most pixels previously reported is the p-channel implementation with well plug. The p-channel pixel reduces collection of direct x-ray generated signal charge in the substrate (i.e. x-rays not absorbed by the scintillator). A schematic of the pixel circuit is shown below in Figure 2.

The analog signal processor is similar to ASPs reported previously but modified for p-channel pixels [4]. It performs temporal and fixed-pattern noise suppression. Rows and columns are sequentially addressed using an ordinary on-chip shift register.

Four event detectors are at the corners of the sensor to detect the onset of x-ray irradiation and put the sensor into integration mode so that the remainder of the signal is captured. The event detector circuit shown in Figure 3 consists of a photodiode, source-follower and a cross-coupled, strobed comparator.

The four event detector circuits are sampled in round-robin fashion at high sampling frequency to ensure the timely detection of x-ray irradiation on the sensor. Four detectors are used to avoid shadowing by opaque material. Any event detector that goes true will trigger integration and readout. Photogenerated charge collected by the photodiode PD flows over the TX barrier to FD and is integrated for approximately 0.8ms. When the event detector is sampled, the output signal is compared to Vref.

The sensor is nominally operated in stand-by mode and all pixels are held in reset (PG off, RST on). The chip awaits an ARM signal. Upon receipt of the ARM signal, the sampling of the event detectors is enabled. When x-ray irradiation is detected by the event detector circuitry, all pixels are placed in normal integration mode (PG on, RST off). After the end of the programmable integration period, the chip commences the readout sequence. The first row is selected for readout and the signals from the first row of pixels are processed by the column parallel analog signal processors. The analog data is then readout by sequentially selecting the columns. The next row is then selected for readout and the process is repeated until all rows have been readout. The chip then enters a global reset state. A second integration period of the same length as the first is initiated automatically. The chip then begins a second readout sequence. The second frame of output data represents a dark reference frame that can be subtracted from the first frame. The chip then returns to standby mode. All this timing is performed on-chip, but can be altered by jumpering selected pads.

A photograph of the completed sensor is shown in Figure 4. The output-referred conversion gain of the sensor is approximately 2.5μV/e+ [5]. Measured output-referred dark current in the sensor at room temperature was measured to be 57mV/s or approximately 250pA/cm². Measured saturation is 1.2V or 480,000 e+. Output referred temporal noise is less than 300μV, or 120 e+ rms, yielding a dynamic range over 72dB (4000:1). QE is lower than typical n-channel devices due to the n-well vertical collection cutoff.

The chip is tested with scintillator and x-ray irradiation. X-ray performance of the sensor is good. An example image taken with the sensor is shown below in Figure 5. A resolution phantom image is shown in Figure 6. The sensor is now in production.

References:

[1] Panicacci, R., et al., "¼-Inch CMOS Active Pixel Sensor With Smart On-Chip Functions And Full Digital Interface," Proc. 1997 (9th) Hot Chips Symposium, Aug., 25-26, 1997.

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[3] Fossum, E., "CMOS Image Sensors: Electronic Camera on a Chip," Tech. Dig. of IEEE International Electron Devices Meeting, pp. 17-25, Dec., 1995.

[4] Nixon, R., et al., "256x256 CMOS Active Pixel Sensor Camera on a Chip," ISSCC Digest of Technical Papers, pp. 178-179, Feb., 1996.

[5] Beecken, B., E. Fossum, "Determination of the conversion gain and the accuracy of its measurement for detector elements and arrays," J. Opt. Soc. America, vol. 35, no. 19, p. 3471-, 1996.

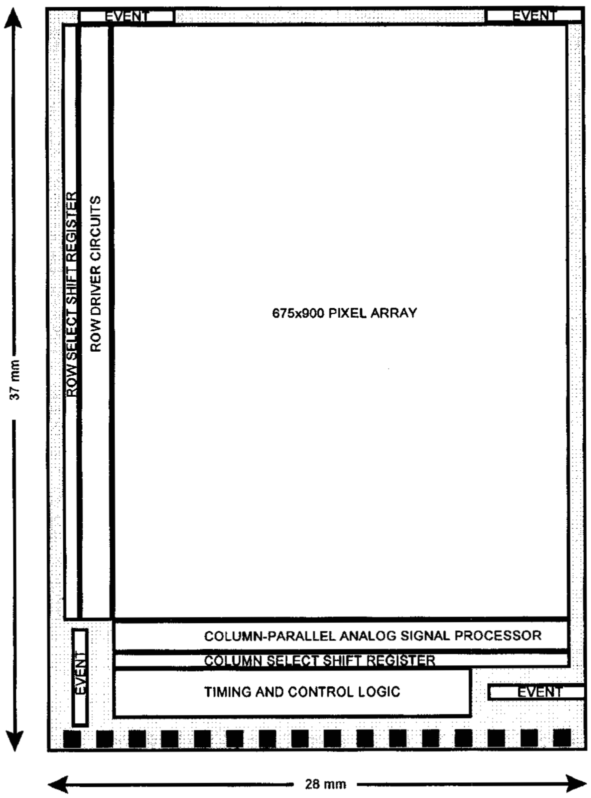

Figure 1: Floorplan of dental CMOS APS.

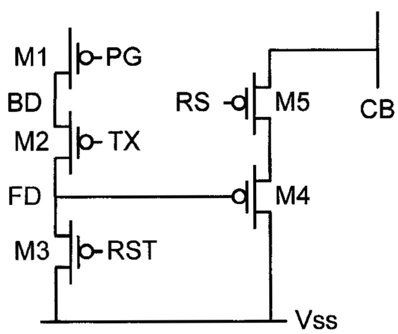

Figure 2: Pixel schematic circuit.

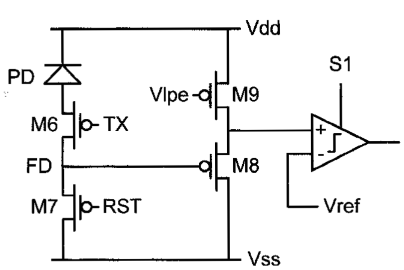

Figure 3: Schematic illustration of event detector circuitry (one of four).

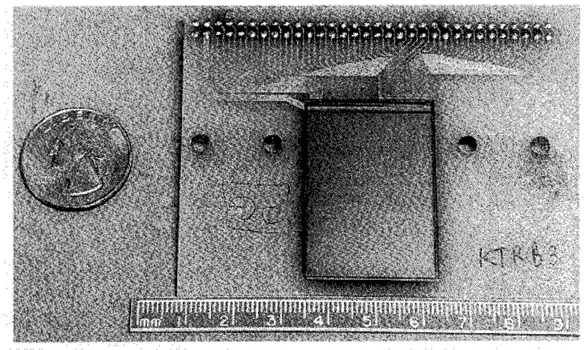

Figure 4: Chip mounted on test board.

Figure 5: Dental radiograph.

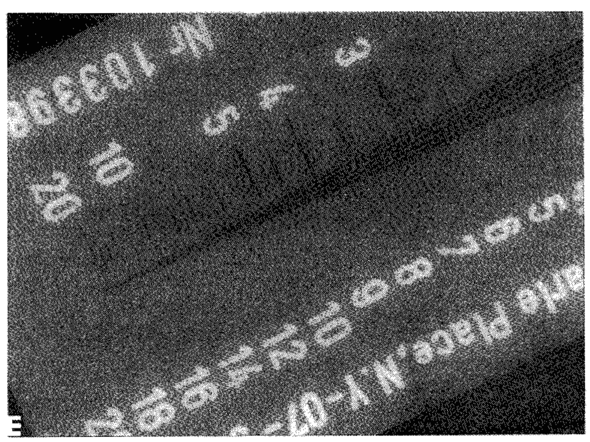

Figure 6: Standard x-ray resolution chart (phantom) radiograph showing ~20-lp/mm resolution.