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EE Times:

CMOS image sensors combat noise

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It has been nearly 10 years since modern CMOS active-pixel image sensors first demonstrated their potential for high-quality image capture. Today, they are used in such high-volume applications as PC and Web cameras, toys and security cameras. They are also used in high-speed megapixel motion capture systems and in "pill cameras" used in medical diagnostics. And they are expected to find use soon in mobile-phone cameras and many low-end digital still cameras.

The breadth of those applications reflects the technical strengths of the CMOS active-pixel image sensor technology.

CMOS image sensors are mixed-signal circuits containing pixels, analog signal processors, analog-to-digital converters, bias generators, timing generators, digital logic and memory.

The basic, three-transistor CMOS active pixel-the design used in most applications-contains a photodiode; a reset transistor, for resetting the photodiode voltage; and a source follower with select transistor, for buffering the photodiode voltage onto a vertical-column bus. Microlenses help funnel photons to the light-sensitive portion of the pixel, and color-filter arrays arranged in a red green blue mosaic pattern allow for color-information capture.

Additional analog-signal-processing circuitry located in the periphery of the array permits suppression of both temporal and fixed-pattern noise. While fixed-pattern noise was an issue with early CMOS active-pixel image sensors, recent sensors have no discernible fixed-pattern noise induced by circuitry and are instead limited by dark current in the pixels. Dark currents of less than 1,000 electrons/second per pixel at room temperature are routinely achieved.

Standard three-transistor pixels lack the ability to suppress noise generated by the reset of the pixel capacitance to a reset voltage level. In improving CMOS active-pixel sensors, reduction of that noise, called kTC noise, is desired. With typical capacitances of the order of 5 femtofarads, the pixels achieve a conversion gain of approximately 30 microvolts/electron with an intrinsic kTC noise of the order of 30 electrons rms.

Total reset

Improvement in kTC noise occurs if complete reset of the photodiode is achieved. That means all mobile electrons are removed from the photodiode during reset, so there is no uncertainty in the reset level. The pinned photodiode, previously used in charge-coupled devices, was proposed early in the development of CMOS active-pixel image sensors to obtain complete reset.

Recently, several companies reported achieving pinned-photodiode devices based on a four-transistor cell. At the device level, that is a complicated structure that presents several fabrication challenges, causing the introduction of nonstandard CMOS process steps. It is also difficult to construct a pinned photodiode four-transistor pixel that truly yields complete reset under low voltage, for example, 0.7-V operating conditions. Lack of complete reset in a four-transistor pixel may lead to lag (image persistence) and the reintroduction of kTC noise, rendering the promised 4T advantage moot. Further, analog-signal-processor noise can overwhelm pixel noise sources.

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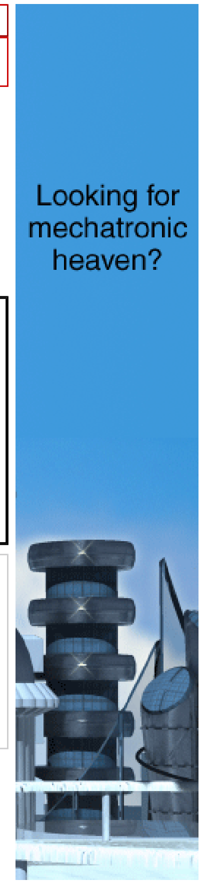

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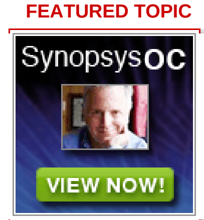

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Besides lower pixel noise, the pinned photodiode offers reduced dark current, due to quenching of surface-interface traps and improved blue response, since it is easier to collect "blue electrons" generated near the silicon-silicon-dioxide interface with the pinned photodiode. Four-transistor pixels are expected to replace 3T pixels soon as the de facto standard.

Pixel size continues to shrink in CMOS image sensors. Early CMOS image sensors had pixel sizes in the range of 7 to 8 microns, but the pressure of reduced chip costs and smaller optical lenses and form factors resulted in pixel sizes' dropping to the 4- to 5-micron range. Multimegapixel image sensors require pixel sizes in the 3- to 4-micron range. To realize those pixel sizes, CMOS image sensors are being produced on 0.25-micron fabrication lines, with a trend toward 0.18-micron sizes.

Use of narrow line widths enables more transistors per pixel when pixel size is not severely constrained. Complex in-pixel circuits have been proposed for in-pixel analog-to-digital conversion or for increasing the dynamic range of captured images.

Use of these line widths enables integration of additional on-chip digital circuits at competitive cost. System-on-chip-scale image sensors that include full-color processing, compression and interface logic are emerging for cell phone applications. But in an image sensor where noise must be managed to the few hundred-microvolt level, implementation of a full system-on-chip requires careful attention to signal contamination sources. Further, total power dissipation must be limited to the 50- to 100-milliwatt range.

The low power dissipation of CMOS image sensors continues to be an advantage in mobile and wireless applications. The reduction of operating voltage results in a concomitant shrink in power dissipation.

But analog circuits (starting with the pixel) face the challenge of lower rail voltages. Boosting circuits and other low-voltage techniques are applied to retain "full well" capacity in the range of 25,000 to 50,000 electrons. That maintains a high signal-to-noise ratio and dynamic range for well-illuminated scenes captured by progressive-scan CMOS sensors with small pixel sizes.

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