

Active Pixels in CMOS Flat Panel Detectors Eliminates Visible Lag

The OEC Elite CFD C-arm Images at 30 fps and Full Resolution Without Visible Lag

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Purpose:

This white paper examines how the architecture of active pixels, such as those used in complementary metal-oxide semiconductor (CMOS) image detectors, reduce visible lag as contrasted with passive pixels, such as those used in amorphous silicon (a-Si) detectors.

- Full frame rate images, uncompromised by lag, give providers a smooth view of motion within the visualized area, so they are able to operate with greater efficiency.

This paper provides specific technical information about the architecture of both active and passive pixels and explains the limitations of passive pixels that result in visible image lag. It also examines why active pixels eliminate visible lag.

Background and Challenge

The OEC Elite CFD obtains X-ray images by first converting high energy X-ray photons into visible photons through a Cesium Iodide (CsI) scintillator, then allowing the visible photons to be captured by a CMOS flat panel detector. Lag is typically defined as the persistence of luminescence after X-ray stimulation has ended. The lag due to a CsI scintillator that converts X-ray photons into visible light is on the order of only 1 ms [1].

Introduction

X-ray imaging technology has taken a leap forward with the introduction of CMOS flat panel detectors. The superior electron mobility of the crystalline structure means that small, active pixels can replace the passive pixels used in a-Si flat panel detectors. One of the many benefits of active pixels is reduced or eliminated visible lag, the after-images of previous frames that distort the displayed anatomy. Eliminating lag provides value for a number of reasons:

- No lag means clearer, more accurate images for healthcare providers, allowing them to work with greater speed and accuracy.

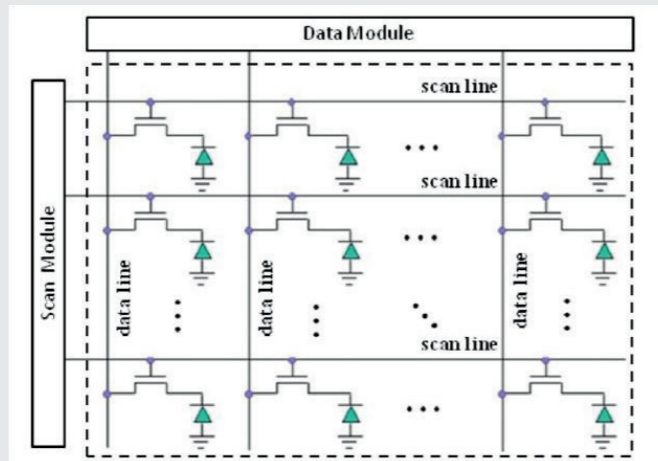


Fig.1: Amorphous silicon (a-Si) passive pixel detector design. Passive pixels lack the mechanisms to read and recharge quickly enough to deliver lag-free images at full frame rates (30 frames per second).

This means that any visible lag effects such as persistent blur or ghosting are governed by the flat panel detector technology that converts visible photons into digital signals.

Since amorphous silicon (a-Si) detectors suffer from poor electron mobility due to the random nature of the material, the photodiodes occupy a much larger space compared to those fabricated by using CMOS [2]. Because of these space limitations, a-Si-based X-ray detectors are designed with passive pixel architecture.

As shown in Figure 1, a passive pixel has only two elements: a thin-film transistor and a photodiode. The pixel array can only be accessed one row at a time, which limits the readout speed.

A passive pixel has only two states: charging and discharging. The arriving X-ray photons are converted into light photons by the scintillator of the X-ray detector. The photodiode then converts the light photons to electrons which discharges the capacitor of the pixel. The system “reads” the pixel by recharging the photodiode and measuring the number of electrons refilled, which correlates to the number of X-ray photons the pixel received. of the respiratory tracts requires high image resolution and contrast is for the navigation guidance.

The process of reading/recharging a pixel can be described by an R-C circuit, shown in Figure 2.

The resistor in Figure 2 includes the resistance of the data line as well as the resistance of the thin-film transistor in its “on” state. The capacitance in Figure 2 is the sum of the capacitance of the photodiode plus the data line distributed capacitance.

The charging voltage is an exponential

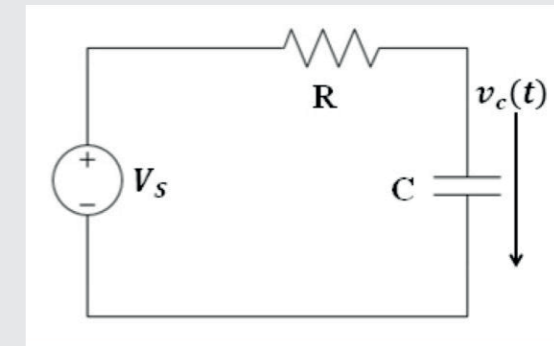


Fig.2: R C circuit analog of an a-Si pixel.

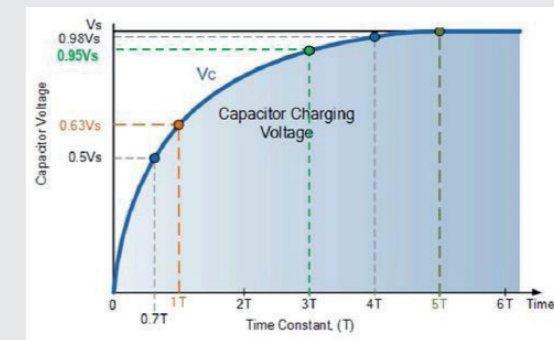


Fig.3: Capacitor charging curve based on time constant T. For a passive pixel to deliver a lag-free reading, it has to have time to charge fully. Most a-Si detectors are unable to overcome this constraint.

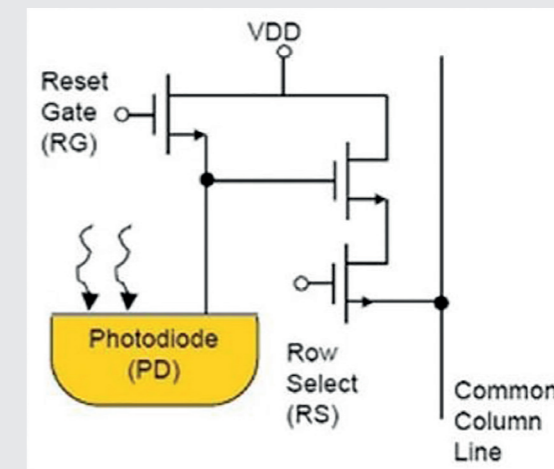


Fig.4: CMOS active pixel. Active pixels, which are smaller and more complex than passive pixels, have amplification, readout, and reset mechanisms built into the pixel itself.

function of the charging time. That is, $(t) = V_s [1 - e^{-t/T}]$ where $T = RC$ is the R-C constant. As Figure 3 shows, $V_c(3T) = 95\% V_s$ and $V_c(4T) = 98\% V_s$; this figure displays the change in charging voltage over time.

The remaining 5% in the $t = 3T$ case and the remaining 2% in the $t = 4T$ case becomes the image lag in the following image frames. That is why a

charge the photodiode to avoid the R-C lag. For example, achieving 30 frames per second (fps) means there is only $1000 \text{ ms} / 30 = 33 \text{ ms}$ to expose the entire pixel array with X-rays and to read all the pixels in the detector. For a 10 ms pulse-width X-ray pulse, the detector readout time must be within $33 \text{ ms} - 10 \text{ ms} = 23 \text{ ms}$.

Assuming that the pixel array has 1536

instance, the highest frame rate currently supported by the Ziehm Vision RFD system is 25 fps [3] and the highest frame rate currently supported by the Philips Veradius Neo system is 23 fps [4].

Solution

The crystalline structure of CMOS-based detectors allows greater electron mobility, which allows for much smaller and more complex pixels. The CMOS-based X-ray detectors use active pixel architecture, shown in Figure 4, rather than passive pixel architecture.

An active pixel consists of a photodiode, a charge amplifier, a row select gate, and a reset gate. The readout process of an active pixel is much faster than that of a passive pixel. Instead of recharging the photodiode, it simply senses the voltage at the output of the charge amplifier.

Since pixel reset and pixel readout are two separate actions in an active pixel, it is possible to reset all pixels at the same time after reading. This is very beneficial in the pulsed X-ray applications where the X-ray exposure and the readout must be completed within the time period limited by the frame rate.

The fast pixel readout and the fast pixel reset of CMOS not only avoids the image lag due to charging the R-C circuit, but also makes it possible to operate at a higher frame rate.

Think of pixels like the buckets shown in the following figures. The process of reading and resetting the detector for each image frame is akin to collecting

and emptying buckets of paint. The X-ray photons are the paint and the detectors are the buckets. The reading process is analogous to collecting the paint in the bucket, and resetting so that reading can start again is analogous to emptying the bucket.

Figure 5 shows the CMOS analogy. In every frame, all the colored paint collected is also emptied with nothing left over inside the bucket—in other words, no lag is carried from a previous frame.

Figure 6 shows the a-Si analogy. Due to poor electron mobility, the detector cannot empty all of the paint at 30 fps, resulting in a mixing of all of the colors. This is represented in the ghosting/lag shown in the center frame.

Conclusion

Since the OEC Elite CFD can reset and readout the entire CMOS detector and process images in less than 33ms, there is no visible image lag at 30 fps. The superior electron mobility in the CMOS detector, which enables the use of active pixels, means that this technology can do what a-Si detector cannot—eliminate visible lag. □

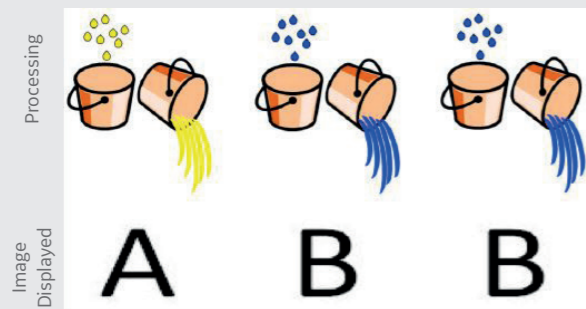


Fig.5: CMOS read/reset analogy. In the first frame, we see clear, unmixed yellow; in the second frame, clear, unmixed blue, and in the third frame, clear, unmixed blue. The letters below the buckets show a corresponding lag-free image.

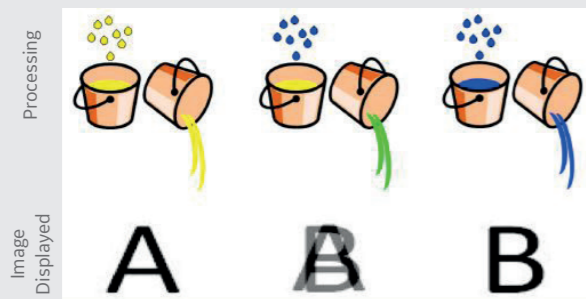


Fig.6: shows the a-Si analogy. In the first frame, we see clear, unmixed yellow, as we did in the CMOS example. However, in the second frame we see green—the lag of leftover yellow in the bucket mixing with the blue of the next frame, which isn't clear.

2%-5% first frame lag is typically observed in a-Si based X-ray detectors.

In addition, frame rate—the number of frames that an X-ray detector can acquire in the time period of a second—influences image quality. a-Si detectors do not have time to fully

rows with data modules on both the top and bottom of the detector, allowing the pixel array to be read in parallel, the readout time per pixel must be less than $23 \text{ ms} / (1536 / 2) = 0.03 \text{ ms}$ or $30 \mu\text{s}$. As a result of this limitation, many of the a-Si based X-ray detectors may not be able to support a frame rate of 30 fps. For