CCD versus CMOS Image Sensor Technology for Biometric Imaging Applications.

Chalk Talk Presentation Prepared for the Staff of

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Chalk Talk Overveiw

- Review the background and scope of an image sensor technology study I completed for Identix. Share with you what I learned.
- Review the basics of Photo Sensor Theory .
- Briefly Discuss two common Types of CCD image sensors.
- Focus on CMOS Sensor classifications and operational details. This is where biometric imaging is headed.
- Discuss a CMOS image sensor which competes with a CCD device for a “high end imaging application”.
- Discuss the risks and benefits of designing in a CMOS for CCD replacement.
- Technical Terms and Glossary
- Extra Benefits for your viewing pleasure.

Project Background and Scope

Background :

- **Recently completed CMOS image sensor technology study for Identix senior management.**
- **Identix develops and markets Biometric imaging systems (AFIS).**
- **Identix has traditionally with expensive interline CCD image sensors and CCD line arrays.**
- **Identix patents are dated. New competition entering the market.**
- **Customers are complaining about current imaging system costs. Where can Identix reduce cost?**
- **The CCD image sensor is a SONY part. Sony requires a five year minimum purchase agreement with the buyer.**
- **Can the CCD be replaced?**

SCOPE :

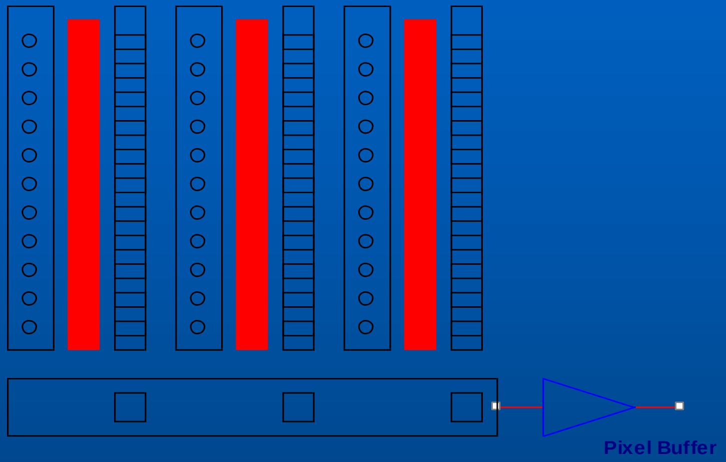
- **Interline CCD Cameras meet FBI Appendix F Specs image quality. (See Appendix).**
- **CMOS image sensors are less expensive . Can a CMOS device meet FBI requirements ?**
- **Need to understand fundamental differences between CMOS image sensors.**
- **Is there an equivalent CMOS technology that can replace a CCD device ?**
- **If so, develop a design spec for a CMOS finger roll camera.**
- **Discuss risk and benefits of a CMOS camera design.**
- **CMOS technology is new to Identix. Take the pain out of the learning curve and improve the odds for a successful design**

PHOTO SENSOR THEORY

- **Photo Sensor Theory.**
- Both technologies, CCD and CMOS, are made from silicon. Silicon has some interesting properties due to its atomic structure. Silicon is classified as a "semiconductor" because of the covalent electron bonds between adjoining silicon atoms. The idea is that Silicon atoms share electrons. These electrons can go mobile without too much coaxing.
- The energy in visible light is sufficient to break the covalent bonds thus freeing up electrons. The under lying principle is the "photovoltaic effect". When silicon is exposed to photons, electrons are released. The number of electrons released is dependent on light intensity. More photons convert more electrons.
- Add impurities to the Silicon and you enhance the "photovoltaic effect", in essence creating a photodiode. Configure silicon photo diodes into an array of light sensing elements (pixels), and you now have a device which can sense a field of view. Voila, the solid state image sensor is born.
- The principle of the "photovoltaic effect" holds true for CCD and CMOS devices. Both devices are built up of many light sensing photodiodes (photo gates are used by frame transfer CCDs). In both CMOS and CCD technologies, the charge (photocurrent) generated by the photodiodes is converted to a voltage. The difference between CCD and CMOS sensors is in conversion (buffering) of photo charge and how it is read out as a pixel voltage.
- Getting into the internal differences of the various image sensor technologies will shed light on how to make appropriate design choices. Let's start with CMOS devices, then move onto CCD devices. From there we will compare the families on a chart. Then we will do a design exercise comparing a CMOS device to a CCD device in a camera front end.

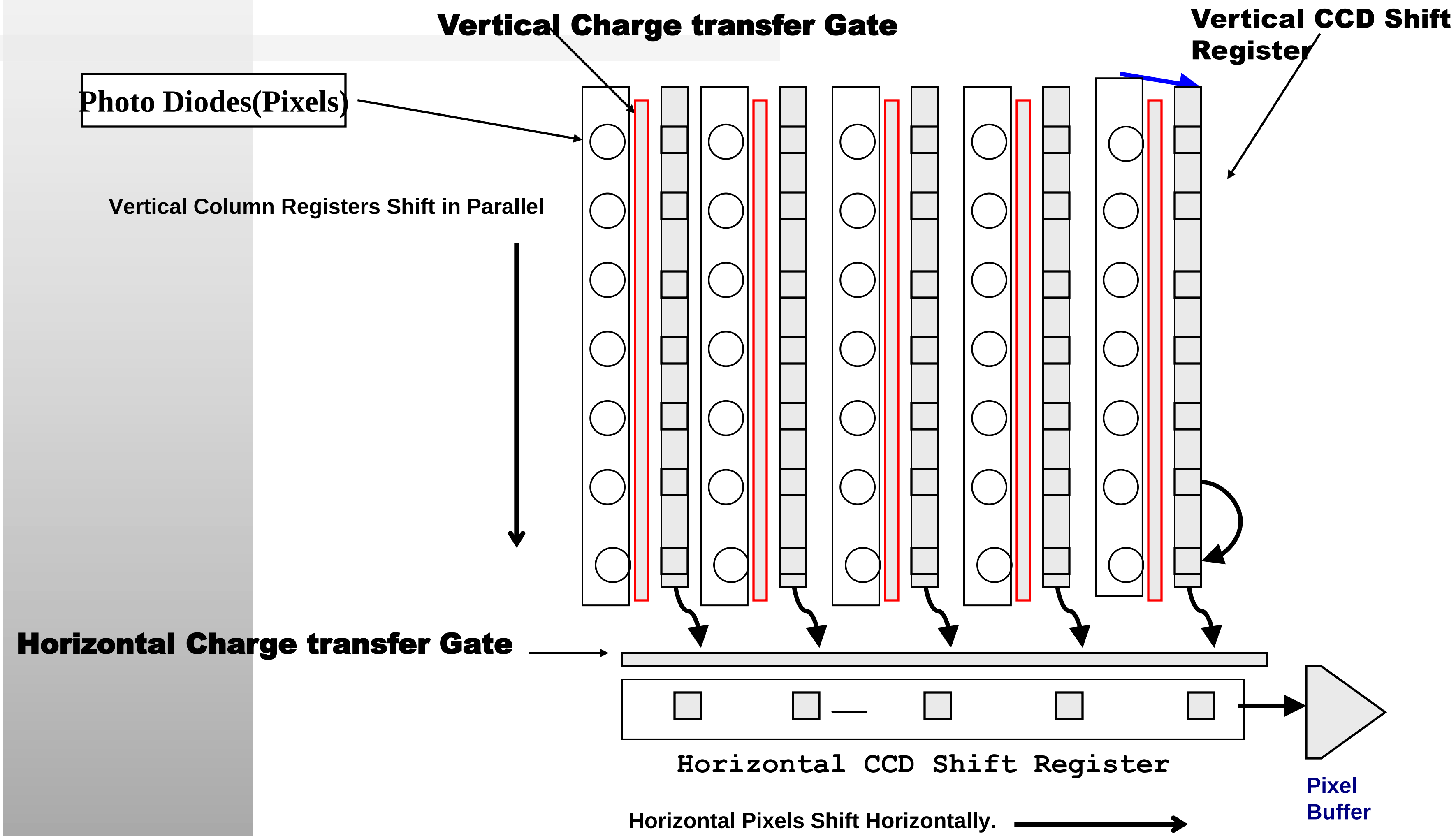
CCD Technology Overview

- **Interline CCD:**
- **Very common in Biometric imaging applications**



- **Full frame transfer devices**
- **Used in Cameras used in astronomy, photo chemistry and extremely low light level applications.**
- **Very high resolution and QE**

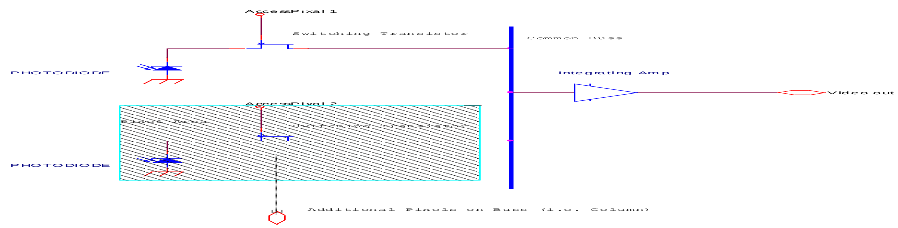
Interline CCD Technology Simplified



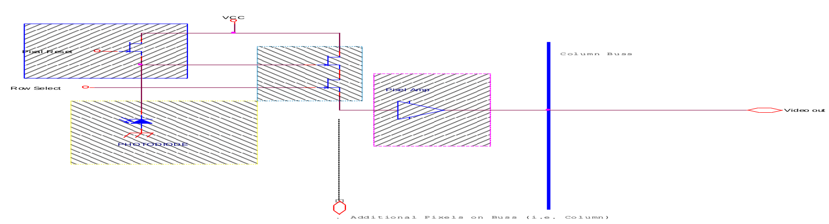
Full frame CCD Technology Simplified

CMOS Image Sensor Technology Overview

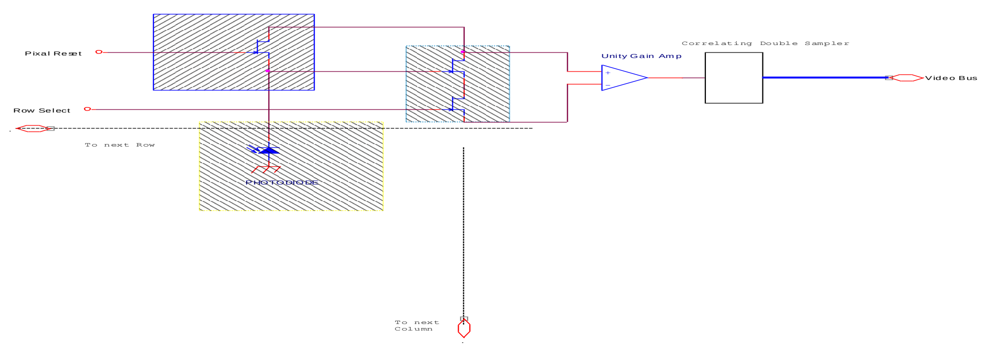
- **Passive Pixel Devices**



- **Active Pixel Devices**

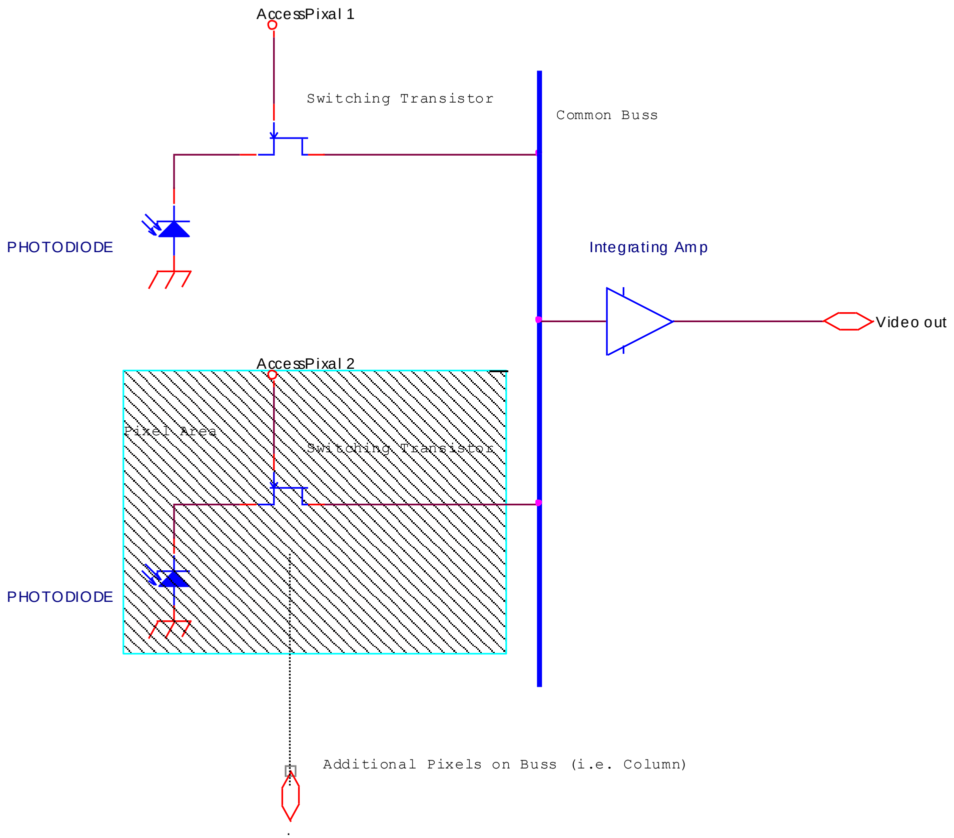


- **Active Column Devices**



Passive Pixel Technology

- **Passive pixel sensors have been around the longest, even a little longer than CCD devices. The architecture is quite simple, as shown in the figure below. The passive pixel device is a photodiode connected to a transistor switch.**



Operation of Passive Pixel Image Sensor (Mother of all CMOS image sensors)

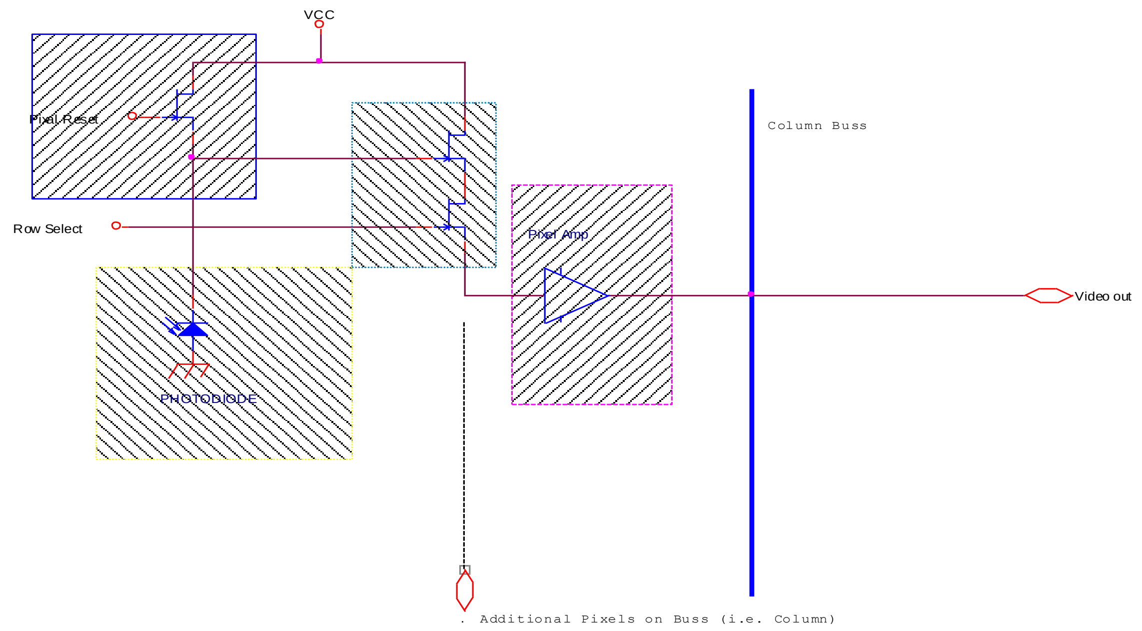
- In operation, these devices have what is known as a "photo charge integration period". During this time, the photodiode is exposed to light. The light is converted to charge (photocurrent). After a timed conversion period, a controller switches the charge onto a bus in a timed sequence. At the end of the bus is an integrating buffer which converts the charge into a voltage. The voltage is then read out as analog value. Commercial versions of these devices provide a formatted output compatible with CIF or NTSC video displays.

- These passive devices have good photon conversion efficiencies (Quantum Efficiency). This is due to the size of the photodiode. Passive pixel devices can be quite sensitive even in the dark. Due to the simplicity of the support circuitry more of the silicon real-estate can be devoted to the photodiode. When a sensor has more area devoted to photodiode sites, it is said to have a high "fill factor". The early versions of these devices had poor signal to noise characteristics. The noise generated by the readout process typically limited the signal to noise ratio of these devices. Switching noise gets worse as the number of switching elements increases.

- The passive pixel sensors were limited in the number pixels. Further complications occurred with process non-uniformities in the pixel switching transistors. This impacted what is known as "fixed pattern noise". Fixed pattern noise can be cancelled with analog processing techniques such as double correlated sampling. We will discuss this later during the design exercise. The OVTxxxx is an example of the commercially available PPs device technology.

Active Pixel Technology

Active-pixel sensors (APS), shown in figure below, were the next step in CMOS image sensor evolution

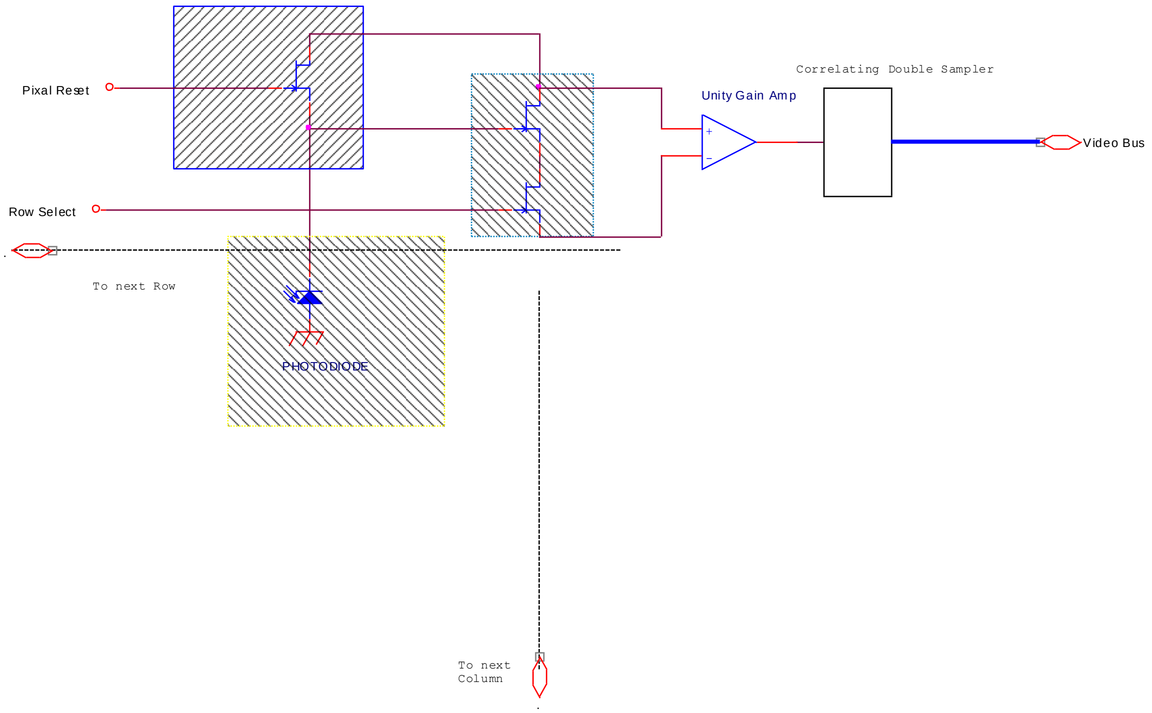


Operation of Active Pixel Technology

- An open loop "source follower amplifier" was added to follow the pixel select transistor. The source follower reduces read out noise.
- The APS tends to suffer in the sensitivity department due to a loss of photodiode area. They have a lower fill factor than passive pixel devices.
- They also suffer from process non-uniformities in the source follower. This degrades fixed pattern noise. Use of analog noise canceling must be applied to improve performance.

ACS Technology

The latest advancement in CMOS image sensors is the Active Column Sensor.



Operation of Active Column Sensor.

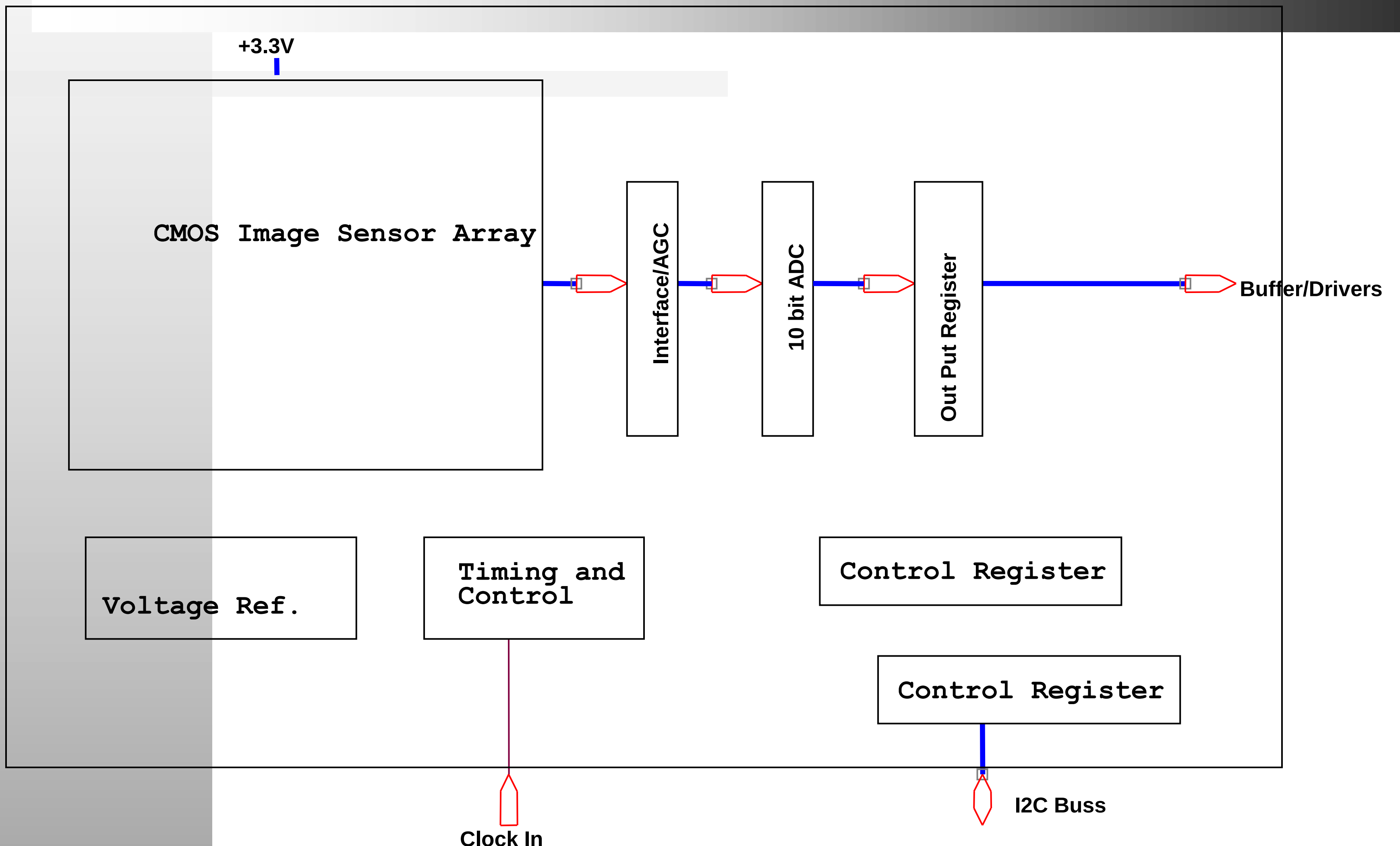
- In this sensor arrangement, the follower buffer is eliminated from each pixel element. This leaves more room for sensor area. At the top of each pixel array column, is a closed loop "unity gain amplifier". A correlated double sampler follows the amplifier and drives the video bus. Further processing occurs away from the active pixel array with improvements in noise. The advantages are better sensor dynamic range and lower fixed pattern noise. The fill factor of the sensor array portion of the ACS devices is higher than the ACS technology. The Zoran ZR32112 is an example of this technology. Zoran digitizes the pixels within the chip.

- The ACS technology combines excellent Fill Factor and chip integration.
- The Zoran ZR32112 compares very well to the Sony ICX825.
- By comparing data sheets, the ZR32112 appears to be a potential replace for the ICX285.

Zoran/Sony Comparison

Table 1	Zoran ZR32112 GEN1 ZR32212 GEN 2.	Sony ICX085L CCD ICX285 CCD
Array Resolution	1304H × 1032V / 1288H×968V	1360H× 1030V
Active Pixels	1288H× 1032V	1300H× 1030V
Array Format	¾'' (12.3mm diagonal) ½"(9.67mm)	2/3" (11 mm diagonal) 4to 3 ratio/Same
Pixel size	7..5μm × 7..5μm 6μm × 6μm	6.7μm × 6.7μm 6.45μm × 6.45μm
Scanning Mode	Progressive	Progressive
Max Pixel Rate	16-24 Mhz	20.25 Mhz/ 28.64 Mhz
Frame Rate	9.3 FPS at 16mhz 14 FPS@24mhz/15FPS	12 FPS/15FFPS
Exposure Time	Programmable down to 1 msec.	?
Saturation	1VDC	400 mV
Temporal Noise	Typ. 400μV	?
Dynamic Range	66dB / 62dB	48dB.
A/D Resolution	10 bits	Analog output. (9 bit conversion)
A/D non Linearity	+/- ½ LSB	?
Supply Voltages	3.3 V	Vdd= 15 Volts, 5, –12.5
Power Dissipation	< 250mW <280mW	<750 mW
Chip package	44 LLCC (.050 pitch)	Ceramic Dip (.080 pitch)
Dark Signal	TBD	8mV
Cost	$69 1-10 quantity	$550

CMOS Image Sensors System On A Chip



Summary of CCD/CMOS Sensor Analysis

Parameter	PPS CMOS	APS CMOS	ACS CMOS		IT CCD
Signal to noise ratio			**60+dB**		**48dB.**
Dynamic Range					
Quantum Efficiency					
Image quality					
Number of Active pixels					
Cost					

Summary of CMOS camera Advantages/Disadvantages

Advantages:

- **Greater on chip component integration.**
- **Reduced Power Consumption in CMOS, no bucket brigade drive capacitance.**
- **Pixel Address ability: Windowing**
- **Manufacturing Cost: CMOS process technology is cheaper Than NMOS.**
- **Competitive market.**

Disadvantages/Risks:

- **Volume driven**
- **Life cycle compatibility**

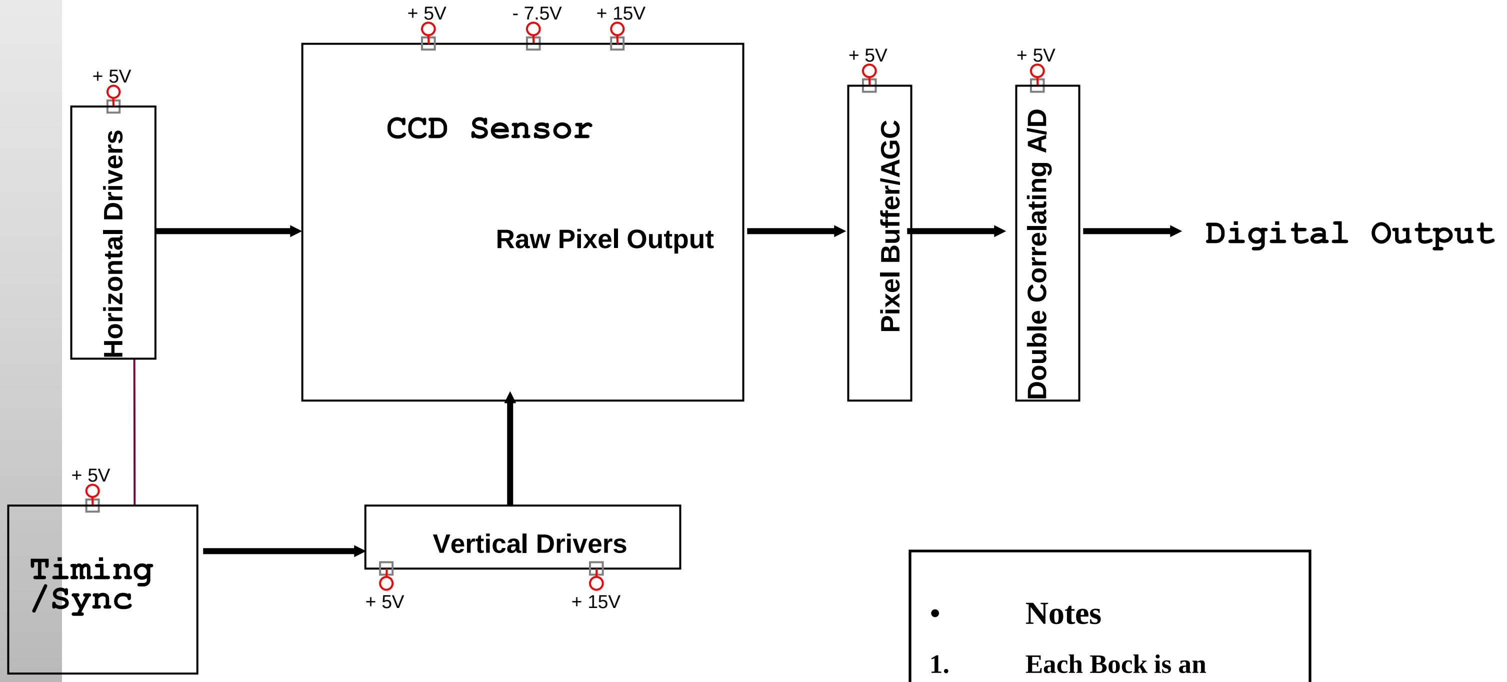
Moving forward

- **Benefits out way risks for prototype development.**
- **Work with vendor and buy product in advance.**
- **Project got green light.**

Camera System Design for Fingerprint imaging

- **Meet FBI appendix F specs.**
- **Compatible with current Optics design.**
- **Must interface with current image processing subassembly.**
- **Must be software compatible with current image processor.**

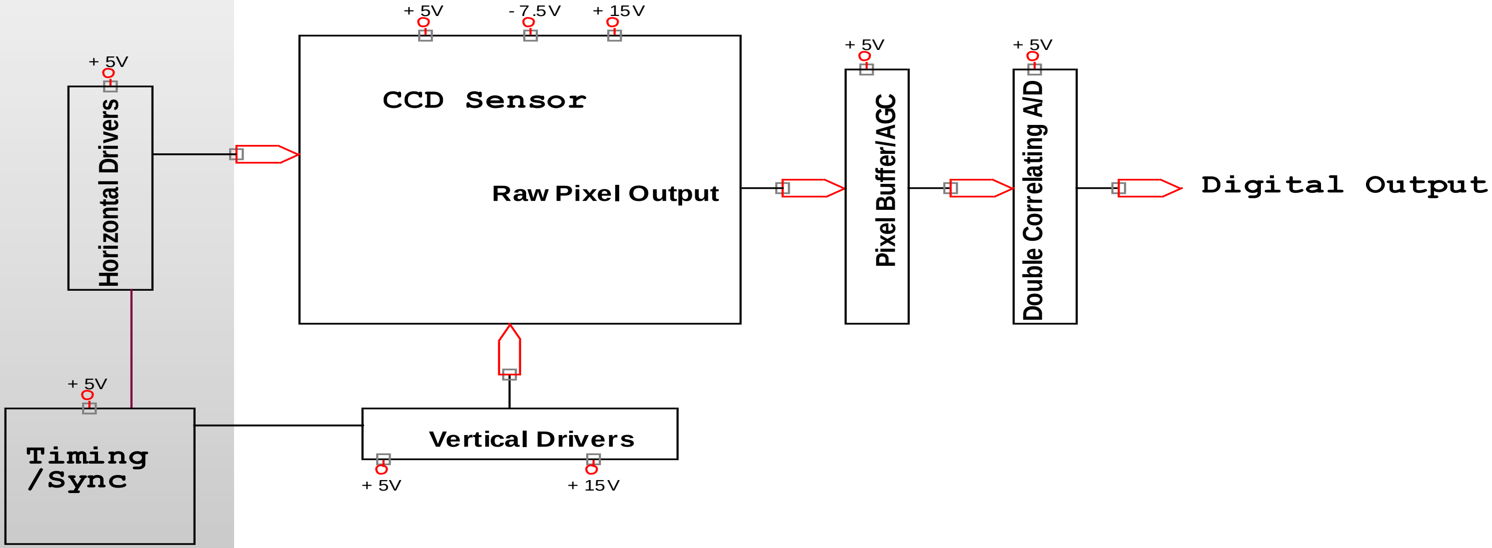
Typical CCD Camera/System



- **Notes**

1. **Each Bock is an Individual Component/s.**
2. **Typically three Power Supply Voltages Required**

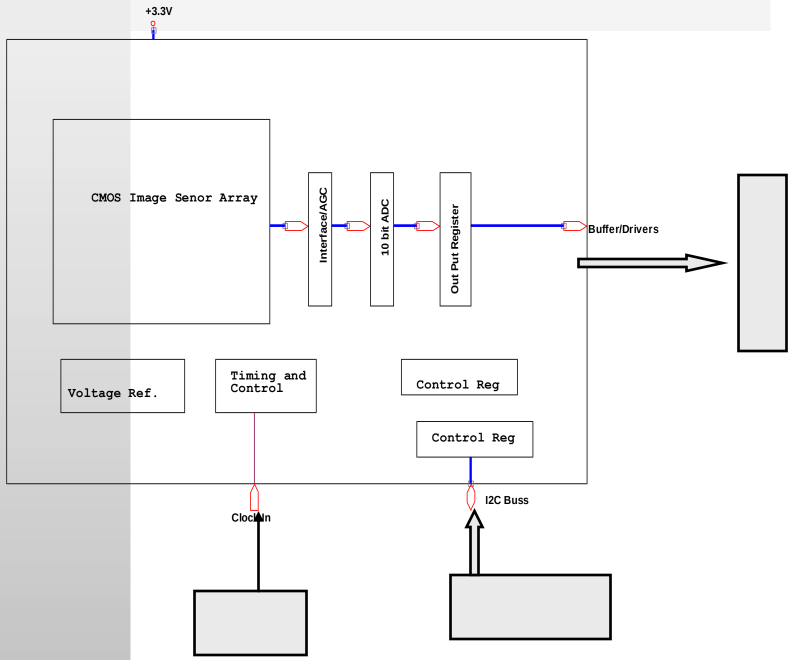
Design Specification for CCD Camera



BOM

1. **Timing Generator: Oscillator and FPGA.**
2. **Vertical Drivers: Sony.**
3. **Horizontal Drivers: Standard CMOS buffer.**
4. **Pixel Amplifier: High Speed OpAmp /Buffer.**
5. **A/D Converter: Double Correlating A/D.**
6. **LVDS Bus interface: 9 bit digitized pixel, Frame Synch and Pixel clock is sent via LVDS driver.**
7. **Housing Keeping : PIC Micro.**
8. **Image Sensor : Sony ICX285**

Cmos Design Spec



BOM:

1. PIC Micro
2. LVDS interface
3. Clock/Osc
4. Zoran Zr32112
5. PCB FAB.

Technical terms/Glossary

- **Fill Factor : amount of pixel capturing light. PPS fill factor > 80% APS >40%**
- **Micro lenses: small lenses manufactured above the pixel. Serve to increase Fill Factor.**
- **Read Noise (Also known as temporal noise): Occurs randomly due to drive electronics.**
- **Fixed Pattern Noise: This noise results because each pixel has different light sensitivity characteristics. In CMOS sensor each pixel may have an amplifier. These amplifiers have slightly different gains and offsets due to manufacturing process variations.**
- **Blooming: Too many photons at a pixel. The pixel current saturates causing current to leak into the adjacent pixel. Blooming is like overexposure in film photography. The condition appears as bright streaks in the image.**
- **Aspect Ratio: Ratio between height and width of sensor. 640*480-pixel resolution would be 480/640 = ¾'.**
- **Optical format: Number of inches determined by taking the diagonal measurement of the sensor in mm and dividing by 16. If a sensor measures 4mm diagonally, then 4/16 = 1/4' format. Lens for cameras come in standard formats of ¼', ½', ¾', etc.**
- **Quantum Efficiency (QE): Imagers convert photon energy into electrical energy. The efficiency at which this conversion takes place is QE. The QE calculation is Electrons/Photons. If no electronics are created then the QE is zero. If one electron is created by one photon then QE is 100%. Image sensor efficiency varies with light wavelength.**
- **Dark current: Thermally created electrons without illumination. Varies with manufacturing process, chip layout, and increasing temperature.**

FBI Appendix F Specs For AFIS

- 500 Dots Per inch
- Must resolve xx line pairs per mm. MTF.
- S/N ratio xx db

The "who's who" of image sensing technology.

- Only a small number of companies engaged in developing CCD devices have the resolution and signal to noise specifications compatible with forensic quality fingerprint imaging. The cost of these devices limits their application.
- Sony , www.sony.com, has been supplying the ICX085 and now the ICX285.
- Texas Instruments. www.ti.com. TI device have been evaluated in the past.
- Kodak. www.kodak.com. Kodak produce very high quality Multi-Mega Pixel image sensors for high quality cameras.
- Most of the players engaged in CMOS image sensing technology are involved with devices with VGA (640*480) pixels.

- www.fillfactory.com/
- www.photobit.com
- http://www.agilent.com/view/Imaging/

- http://www.vvl.co.uk/products/image_sensors/home.htm
- http://www.ovt.com/omnicmoss.htm

- Recent player joining the CMOS image sensor market.
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- http://www.kodak.com/country/US/en/digital/ccd/pr20000828-01.shtml
- http://us.st.com/stonline/products/support/touchip/prod2.htm
-
- **1.3mega pixels and above.**
-
- Two local companies which have promise for Identix are:
- www.zoran.com
- www.y-media.com

- Foveon Dr. Carver Mead Startup.

- Very novel technology.
- High fill factor because of clever design which emulates a human retina.
- Different light wavelengths penetrate at different depths in the silicon. Red penetrates the top layer, green the middle layer, and blue the bottom layer.

Fun and FYI

- **Attaching a Peltier device to a CCD or CMOS imager improves thermally induced noise. By integrating successive frames of video CCD and potentially CMOS imagers can be used to image biotech fluorescence. Very low light levels of a few photons per pixel can be detected.**

- **PPS imager such as "Sugar Cube" (cheap internet) cameras can be used for night vision or very low light level imaging by integrating multiple video frame and subtracting noise.**