CMOS Active Pixel Sensor for a Polarization-difference Camera

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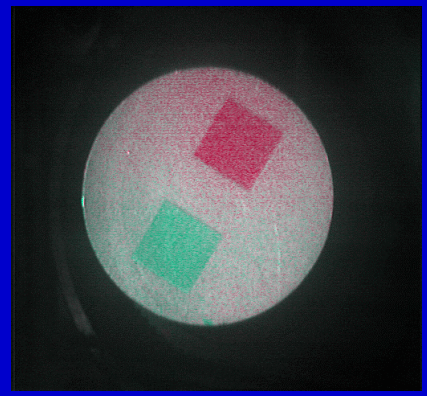
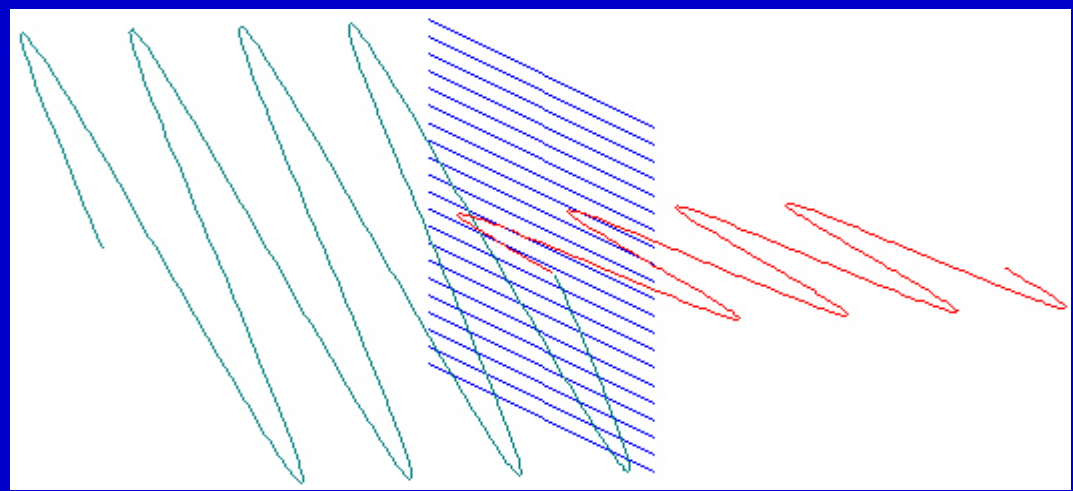


Polarization

- Light is a transverse wave
- The path traced by the tip of the electric field defines the polarization
- A linear polarization filter confines the vibrations of the electric field to one plane

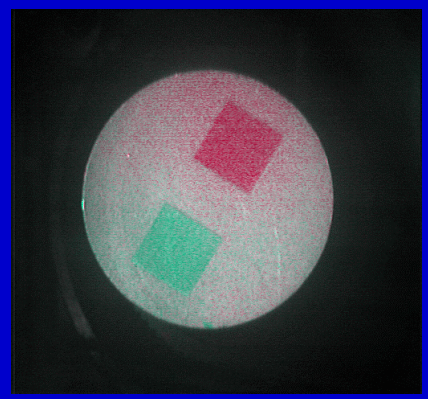


Polarization Imaging

- Humans are polarization-blind
- Some animals (insects, fish) use polarization for vision enhancement and navigation
- The difference of orthogonal components of polarization is used for polarization-difference imaging (PDI)
- The goal of the project is to design a CMOS polarization-difference camera

Applications

- Target detection in scattering media
  - Underwater
  - Fog
- Object and material detection and analysis
- Navigation



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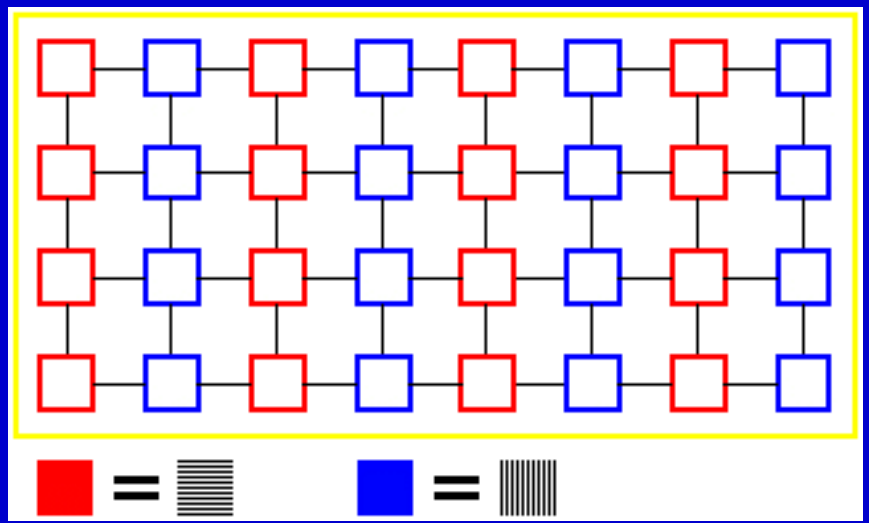
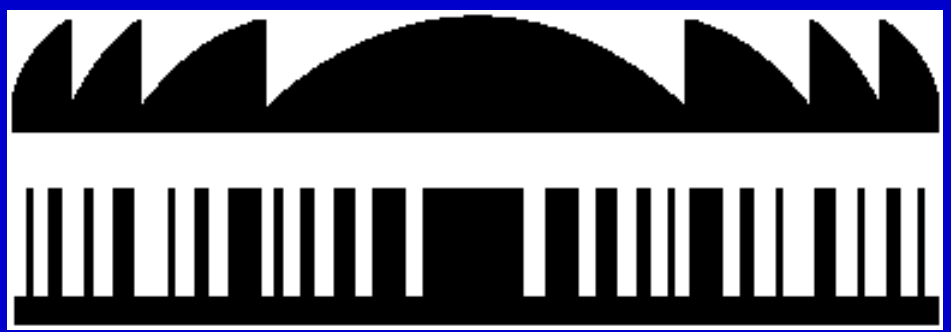
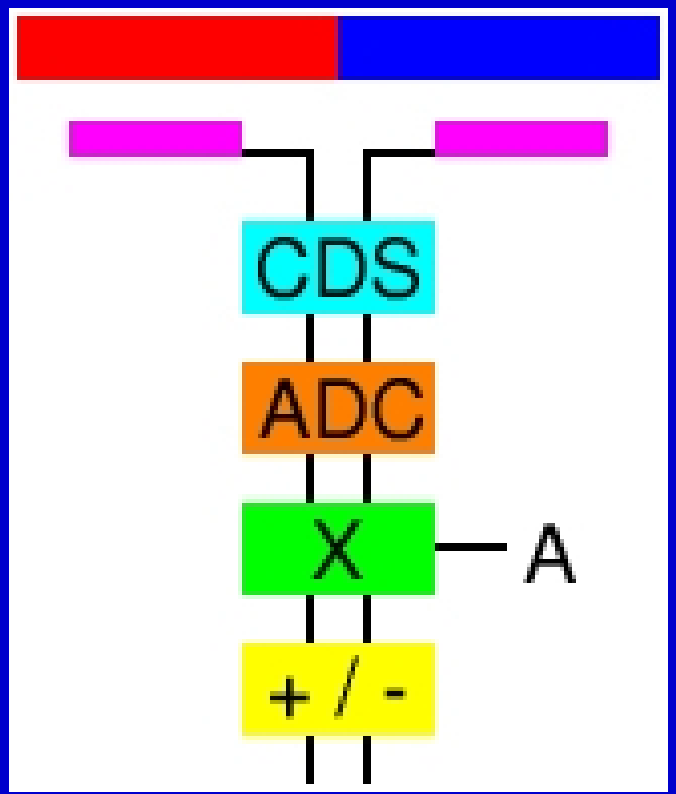
PDI Camera





- Diffractive optical element polarization analyzer overlays pixel array
- Neighboring pixels in a row have orthogonal DOE orientations
- Two input pixels form one output pixel
- Read out row by row

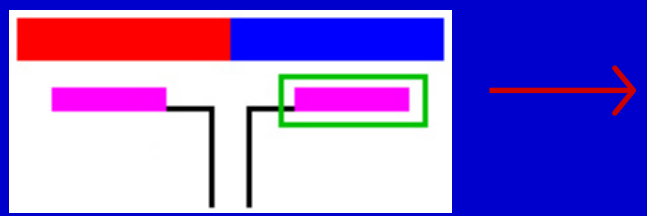
Camera Operation

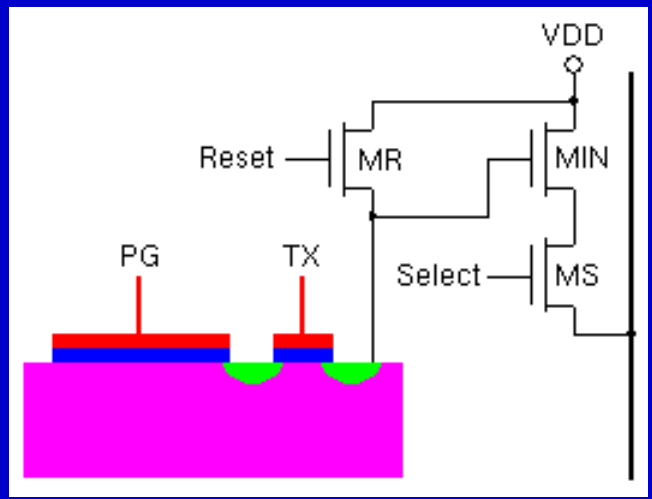


- Polarization analyzer
- Pixels
- Correlated double sampling
- Analog to digital conversion
- Scaling
- Sum and difference

CMOS Active Pixel Sensor

- An active amplifier is included in the pixel
- Lower power than CCD's, easy integration with control and processing electronics
- Circuits must be added to suppress fixed pattern noise

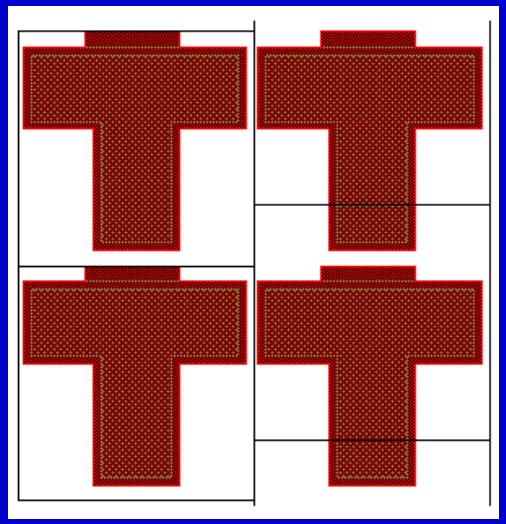


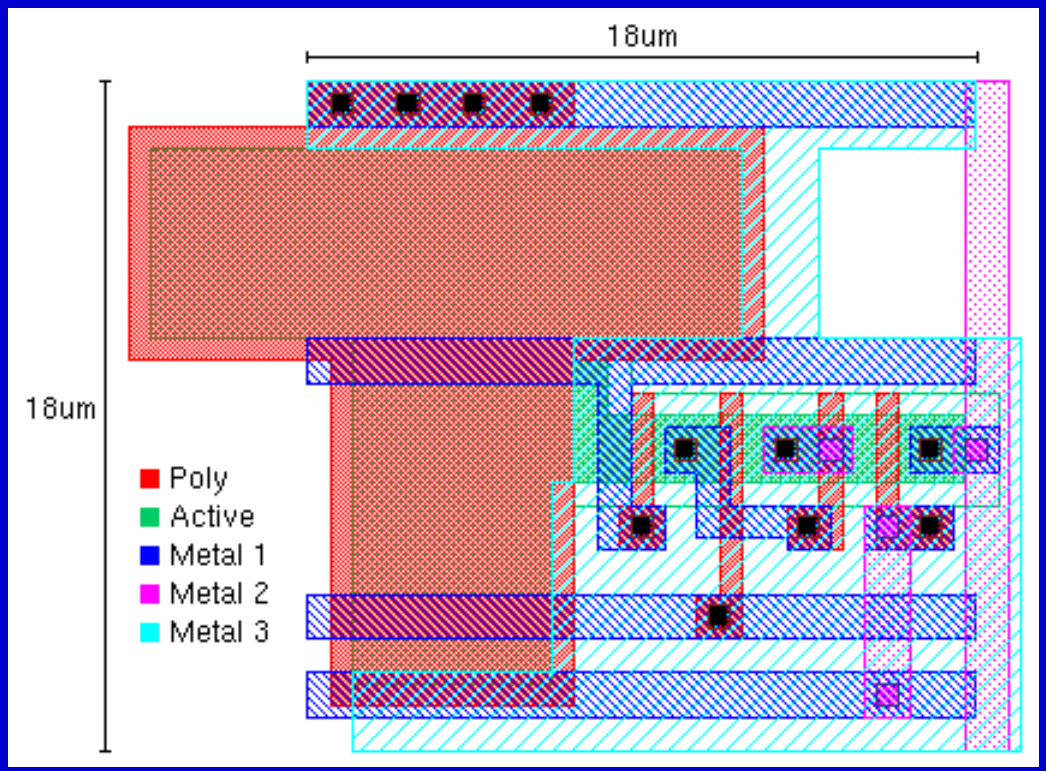


Design Considerations

- Fixed pattern noise (FPN) must be suppressed
- Camera should be capable of high frame rates
- Pixels must be integrated with polarization analyzer
- Scaling should be capable of both performance enhancement and polarization analyzer correction

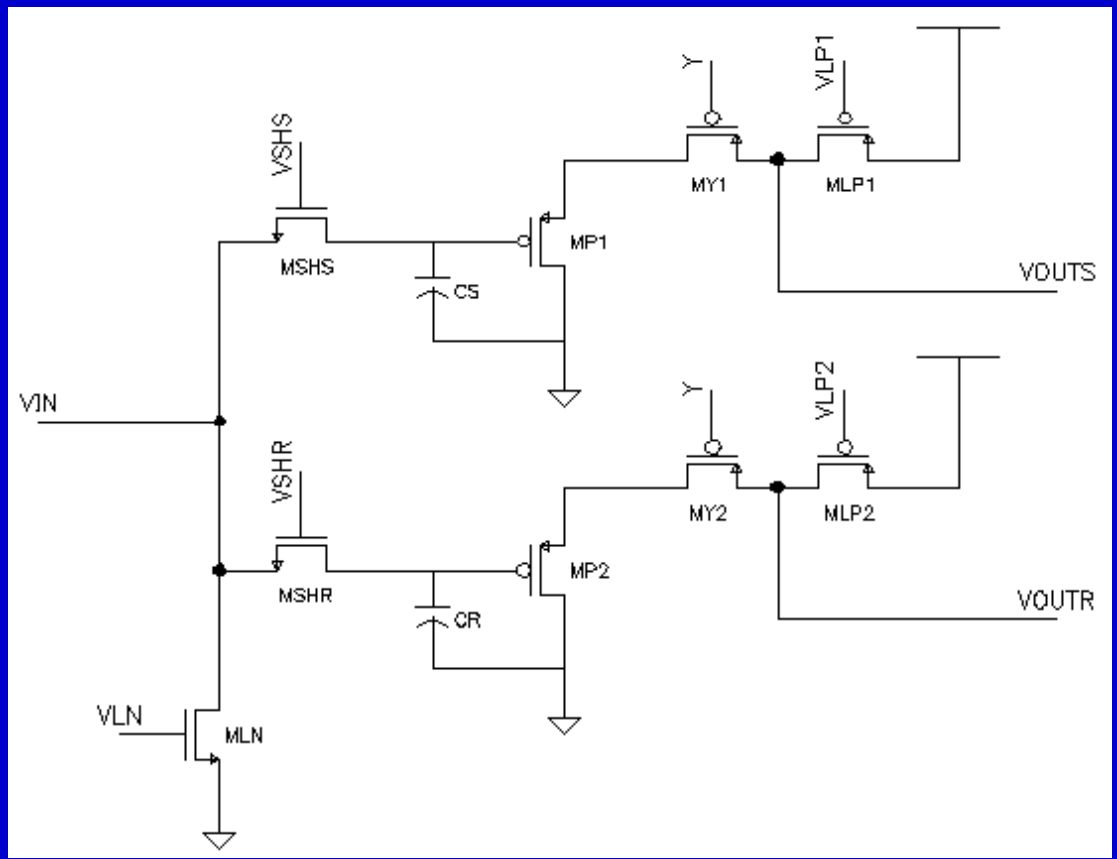
Pixel Layout





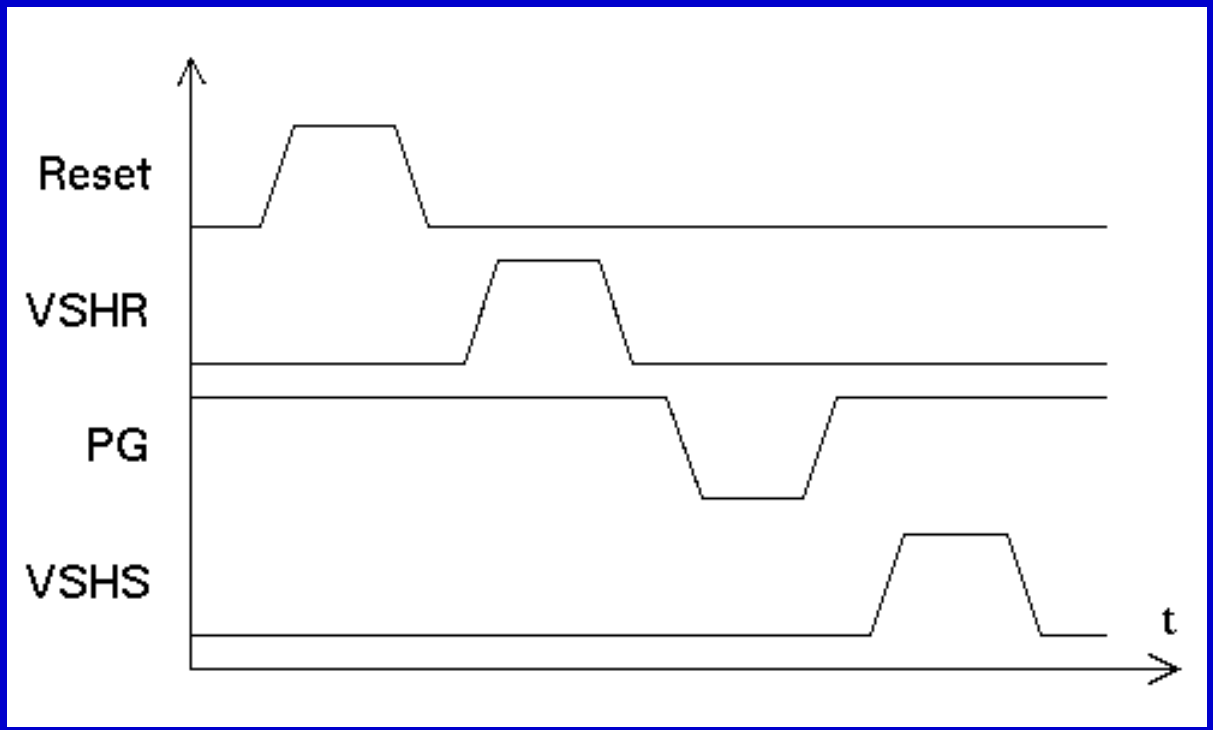
- Detector is T-shaped to integrate well with the DOE
- Pixel overlaps with neighbor
- Light shield (cyan) prevents cross talk between pixels
- Total detector area is ~130 square μm

Readout Circuit



- One readout circuit per column
- Performs correlated double sampling to reduce FPN
- Column reference subtraction is also used to suppress FPN

Operation



- Array is read out by column a row at a time
- Row select switch in pixel and column select switch in readout circuit should be held high during row readout

Intensity Scaling

Unscaled PDI:

$_{PS}I = I_1 + I_2$

$_{PD}I = I_1 - I_2$

Scaled PDI:

$_{PS}I = (s_1c_1 - s_2c_2)\, I_1 + (s_2c_1 - s_1c_2)\, I_2$

$_{PD}I = (d_1c_1 + d_2c_2)\, I_1 - (d_2c_1 + d_1c_2)\, I_2$

Ideal polarization analyzer will give $c_1{:}c_2 = 1{:}0$

Conclusions

- PDI is a method for extracting polarization information from a scene
- PDI is useful for target detection in scattering media
- A CMOS active pixel sensor has been designed for integration with DOE polarization analyzers
- CDS and column reference subtraction are used to suppress FPN
- A scaling methodology was presented

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