UNIVERSITY OF OSLO

Faculty of Mathematics and Natural Sciences

Exam in: INF5442 and INF9442
Day of exam: 16-December-2014
Exam hours: 4hrs
This examination paper consists of 3 page(s), incl this cover sheet.
Appendices: see last page
Permitted materials: Approved calculator

Make sure that your copy of this examination paper is complete before answering.

1. Draw the circuit diagram of a 3T CMOS pixel and a 4T CMOS pixel. **(5points)**
2. Explain the advantages of 4T pixels compared to 3T in terms of signal/noise ratio and image quality. **(10points)**
3. What physical mechanism creates light (photons) and how is this process similar to photon detection in silicon sensors? **(5points)**
4. Draw a block diagram and briefly describe each step in the signal chain inside a CMOS image sensor from photons entering the sensor surface to jpeg compressed color images out **(25points)**
5. Explain the term 'conversion gain' and how to calculate it based on floating diffusion capacitance (C_{FD}) **(5points)**
6. A 1.75um pixel has maximum voltage swing of 1V at the source follower output. The full-well capacity (FWC) is 10ke-. What is the pixel conversion gain assuming source follower gain of 0.8? **(5points)**
7. The same pixel as in exercise above has a temporal noise floor equal to 2.3e- rms. Calculate the equivalent dynamic range in dB **(5points)**?
8. Explain why dynamic range is an important quality parameter in image sensors. **(5 points)**
9. A green LED at 555nm illuminates a 5x5um pixel with 0.5uW/cm^2. What conversion gain (CG) is required to achieve responsitivity of 20V/sec at the floating diffusion (FD) node? What is the equivalent floating diffusion capacitance (C_{FD})? Assume QE of 40%. **(15points)**
10. What change in lens F-number is required to increase the light intensity on an image sensor by a factor 4x? **(5points)**
11. What are typical max and min wavelength values for silicon photon detectors, and how is this related to the formula $\lambda_{cut\text{-}off} = h \cdot c / E_g$? **(10points)**
12. Explain how the exposure time (integration time) is controlled in a rolling shutter CMOS image sensor, and how this differs from a global shutter sensor. **(15points)**
13. Explain the concept of Modulation Transfer Function (MTF) in camera lenses and sensors and why it is important for image quality. **(10points)**
14. Explain what is fixed pattern noise (FPN), and list three types of FPN sources. **(10points)**
15. List three types of temporal noise sources **(10points)**
16. Explain how to remove FPN in pictures **(10points)**
17. Explain how temporal noise can be removed in pictures **(10points)**
18. A pixel accumulates 1000e- (mean value). What is the signal/noise ratio in this case? What is the signal/noise ratio when including the temporal readnoise floor of 8e- rms? **(10points)**
19. Why is smear only visible in CCDs, not visible in CMOS image sensors? **(5points)**
20. What contributes to defining the black level in the output image of CMOS image sensors, and how is it kept constant in every image even if conditions change such as exposure time, gain, temperature, etc.? **(10points)**
21. Why does Bayer RGB color filter pattern have twice as many green pixels as red and blue? **(3points)**
22. Explain the purpose of demosaicing (color interpolation) in cameras. **(5points)**
23. What artifacts can occur in the image after demosaicing and what are possible mitigation techniques? **(10points)**
24. Explain the pros and cons of linear versus cubic interpolation schemes in CMOS sensors. **(10points)**
25. Explain the basic principles used to automatically white balance the output image in digital cameras. **(15points)**
26. Briefly explain each of the data reduction techniques used in JPEG compression. **(15points)**
27. When a CMOS image sensors outputs pixel data, how does the receiver know which position in the array the pixel value corresponds to? What additional output signals from the sensor are used to help aligning the pixel position? **(10points)**
28. Explain why the image sensor industry is moving away from parallel output and over to serial output. **(15points)**

Below is only for INF9442 students (not for INF5442)

1. Draw the output signal from a 4T pixel and indicate where the signal is sampled to perform correlated double-sampling. **(10points)**
2. List temporal noise sources generated by the pixel. **(10points)**
3. A pixel has temporal readnoise equal to 2e- rms. How many photo-electrons must the pixel capture to reach SNR=5dB? **(10points)**
4. A pixel is read out with correlated double-sampling with readnoise equal to 1.3e- rms and PRNU=0.6% rms. How many photo-electrons must be captured to reach SNR=6dB? **(10points)**
5. Explain how color crosstalk influences image quality (S/N) in color image sensors? **(10points)**

APPENDIX

Planck's constant, h = 6.6E-34 J·s
Speed of light, c = 3E+8 m/s
Electron charge, q = 1.6E-19 C