UNIVERSITY OF OSLO

Faculty of Mathematics and Natural Sciences

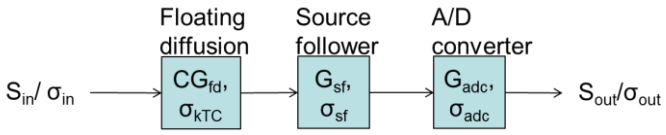
Exam in: INF5442 and INF9442
Day of exam: 16-December-2015
Exam hours: 4hrs
This examination paper consists of 3 page(s), incl this cover sheet.
Appendices: see last page
Permitted materials: Approved calculator

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

1. Draw a block diagram and briefly describe each block in the signal chain inside a CMOS image sensor from photons entering the sensor surface to jpeg compressed color images out **(20points)**
2. Draw a 4T CMOS pixel circuit and briefly explain the role of each circuit device **(10points)**
3. Draw the timing diagram and explain the correlated double sampling (CDS) readout process of a 4T CMOS pixel. **(10points)**
4. Explain the process of photon detection in silicon. **(10points)**
5. Explain what defines the maximum wavelength detectable in silicon photon detectors ($\lambda_{cut\text{-}off}$) **(10points)**
6. Briefly describe how a photodiode works and how it generates an electrical signal proportional to light intensity **(10points)**
7. What are the benefits of a pinned photodiode pixel versus a simple N/P photodiode **(10points)**
8. Briefly explain the pros and cons of 3T pixels versus 4T pixels **(10points)**
9. Explain the term 'conversion gain' (CG). Calculate CG of a 4T pixel with floating diffusion capacitance (C_{FD}) equal to 2fF (femto-Farad). **(10points)**
10. Explain the term 'dynamic range' and why it is an important quality parameter in image sensors. **(10points)**
11. What change in lens F-number is required to increase the light intensity on an image sensor by a factor 4x? **(10points)**
12. Explain the difference between rolling shutter and global shutter image sensors **(10points)**
13. Explain the concept of Modulation Transfer Function (MTF). Name all aspects in a camera system that can influence MTF in the final output image. **(10points)**
14. Explain the term fixed pattern noise (FPN), and list three types of FPN sources. **(10points)**
15. List three types of temporal noise sources **(10points)**
16. Describe a method to remove vertical (column) FPN in pictures **(10points)**
17. Describe a method to filter temporal noise in pictures **(10points)**
18. List pros and cons of CCD sensors versus CMOS image sensors **(10points)**
19. What is the purpose of BLC (Black Level Compensation) in CMOS image sensors and how is it typically implemented? **(10points)**
20. Explain the purpose and basic principle used for automatic exposure control (AEC) in CMOS image sensors **(10points)**
21. Describe the Bayer RGB color filter pattern and its pros and cons compared to other commonly used filters such as CMY and RGBC? **(10points)**
22. Explain the purpose and principle of demosaicing (color interpolation). **(10points)**
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 purpose of white balancing, and the basic principles used in such camera functions. **(20points)**
26. What is the purpose of tone mapping in digital cameras? **(10points)**
27. Briefly explain each step in JPEG compression. **(20points)**
28. A 2um pixel has full-well capacity (FWC) equal to 15000e- which gives a voltage swing of 1.1V at the source follower output. What is the pixel conversion gain assuming source follower gain of 0.85? **(10points)**
29. A pixel has FWC of 20ke- and temporal noise floor in darkness equal to 2.3e- rms. What is the equivalent dynamic range in dB **(5points)**? What is the maximum signal/noise ratio this pixel can deliver? **(5points)**
30. A pixel has average signal level equal to 1000e-. What is the signal/noise ratio assuming only photon shot noise? **(5points)**. What is the signal/noise ratio after adding ADC quantization noise of 20e- rms? **(5points)**
31. Given 2.3e- rms temporal noise floor in darkness, calculate how many signal electrons (from light) are needed to achieve signal/noise ratio of 10dB **(10points)**
32. A green LED at 555nm illuminates a 5um x 5um pixel with 0.5uW/cm^2. Assume QE of 40%. Calculate the resulting photo-current generated by the diode in e-/sec. 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})? **(10points)**

Below is only for INF9442 students (not for INF5442)

1. The readout chain of a 3T pixel can be modelled as follows:



   Briefly explain each of the parameters and write down the formula for output signal/noise ratio (S_{out}/σ_{out}) **(20points)**

2. In a correlated double sampling process, explain why the time between sampling reset and signal level is important for reducing noise. **(10points)**
3. Explain how correlated double sampling removes floating diffusion kTC-noise in 4T pixels. **(10points)**
4. Describe what is meant by color crosstalk, and explain how the color correction matrix (CCM) impacts signal/noise (image quality) in color image sensors. **(20points)**
5. Assuming PRNU (photo response non-uniformity) equal to 1% rms, calculate at which signal level (in electrons) the noise contribution from PRNU is the same as photon shot noise. You can ignore all other noise sources. **(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
The term "e-" means "electrons"
The term "rms" means "root mean square"
Photon energy, $E=hc/\lambda$