Detection of Light: Exercise 4

Photo diodes and IR arrays

26 February 2021

Due: Before the start of class Fri 5 Mar 2021
For questions, please e-mail to:
rlandman@strw.leidenuniv.nl —— stockmans@strw.leidenuniv.nl
or visit our office hours on Gather.town.

1 Photodiodes

1. [3 points] **Diffusion in Photodiodes**
In a photodiode, the diffusion length L_n can be understood as the average distance a carrier can move (or diffuse) in the neutral p-type and n-type regions, before it recombines. This is defined as:

$$L_n = (D\tau)^{1/2}$$

where

$$D = \frac{kT\mu}{q}$$

is the diffusion coefficient and τ is the recombination time.

   (a) [1 points] In order to increase detectability of photogenerated carriers, what condition should be imposed on the thickness l of the neutral absorber layer overlying the depletion region, in terms of the impurity concentration N_I? Assume that the variation of the mobility μ with impurity concentration is negligible and that $\tau \propto N_I^{-1}$.

   (b) [1 points] Test your condition by calculating the detector quantum efficiency η for three values of l about the limit determined in part a (eg. the limiting value itself and a factor of 2 either side), where

$$\eta = \frac{2b}{e^{l/L_n} + e^{-l/L_n}}$$

and b is the fraction of incident photons available for absorption to produce carriers. What do you conclude?

(c) [1 points] On the other hand, what is the requirement on the thickness l in terms of N_I in order to guarantee good photon absorption rates? Is it in general possible to meet these two conditions simultaneously in an extrinsic photoconductor?

2 Image noise processing

This part of the exercise set is designed to make you more familiar with the processing of actual data towards a useable science product by removing artifacts from the raw image. Please provide the following in your solution (Should be doable through Brightspace, if that doesn't work via email to stockmans@strw.leidenuniv.nl):

- Relevant numbers and answers to questions
- Output FITS file for each question
- Your reduction/analysis script(s)

Please name the files "prob3a_<myname>_Q<i>.fits" and "prob3_<myname>.py" (or equivalent).

Important: You are free to use any coding language to complete the exercises, however direct support is provided for python (see "DOL_template.py").

2. [2 points] $z = 5$ **galaxy**

Our first data `image1_2020.fits` have been obtained with a 128×128 pixel array. Although the photon shot noise and the read out noise may be low enough to detect our $z = 5$ galaxy, the exposure suffers from a so-called "jailbar pattern". It is due to a slightly different baseline value of the readout amplifiers. There are four channels, organized in rows, where channel 1 reads columns 1, 5, 9, ..., channel 2 reads columns 2, 6, 10, etc. Hence the four-column wide pattern structure. The pre-amp offsets are additive and need to be removed to get a "cleaner" image.

(a) [1 points] What are the offset levels (in counts) for each channel?

(b) [1 points] Subtract the offsets to get a "cleaned" image. Is our $z = 5$ galaxy now visible? If yes, at what approximate pixel location?

3. [2 points] **TV in the control room**

   Our second data `image2_2020.fits` has been obtained with a 512×512 pixel array (any channel offsets have been fixed) and an extra four columns have been read out on one side of the image to measure the readnoise of the array. Unfortunately, someone turned on the TV in the control room during the readout, and the image suffers from a strong horizontal pattern due to the electrical noise. The first 4 columns of the array have not been exposed and so contain only the imprint of this humming.

   Remove the 50 Hz noise pattern to get a "cleaned"image. Check if there is a faint source in the image. If so, at what approximate pixel location?

4. [5 points] **Brown dwarf with LUST**

   Our third data set (`image3a_2020.fits`, `image3b_2020.fits`, `image3c_2020.fits` – all three are cubes of 5 exposures) have been acquired by LUST, the Leiden University Sky Telescope. We targeted a very faint brown dwarf and used three slightly different telescope pointings. At each pointing we took 5 exposures (which are already combined in the image cubes). The three files originate from the three pointings, where the second one (`image3b_2020.fits`) was aiming to get the target close to the center of the array, the first one has a relative offset of the target by 30 pixels to the left on the array, and the third one by 30 pixels to the right.

   (a) [2 points] Co-add (sum up) the five exposures taken at the first position and inspect the image. What are the two dominant structures (effects, artifacts) that dominate the image?

   (b) [1 points] The dominant structures in the raw signal can be attributed to a known thermal straylight problem in the telescope beam, which is fortunately constant in time. Using all available sky data, compute the filtered "sky-only" image with which to clean the images.

(c) [1 points] We also have a "flat field" image, `flat3_2020.fits`, which was taken in twilight conditions looking at a blank patch of sky. Take this flat field image, normalise it by its mean flux, and divide it into all the images in the image cubes to remove the effects of the detector's variation in sensitivity as a function of position.

(d) [1 points] Compute the final image of the total observing sequence (cleaned, sky subtracted, and the pointings combined). Use the second set as the nominal position reference. Did we detect the brown dwarf? If yes, at what approximate pixel location?