UNIK 4330/9330 Assignment 1

1. Detector materials.

We consider some of the many semiconductor materials used for detectors.

a) What are the bandgaps of GaAs, Si, Ge and InSb?

b) What are the corresponding cut-off wavelengths?

Consider an ideal photon detector with an area of 10x10 µm made from each of these materials, with an integration time of 10 ms. (These numbers are within the possible range for an imaging system.) Assume that the irradiance at the detector is the blackbody irradiance for ambient temperature (20°C).

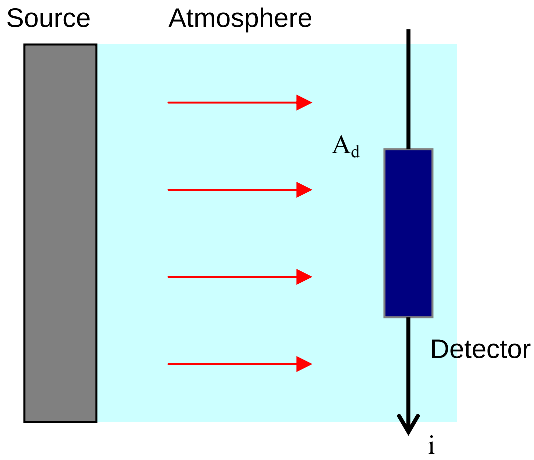
c) Calculate the photoelectron count for each of these materials, assuming an ideal quantum efficiency of 1 for all wavelengths up to the cut-off.

d) Which of these materials are suited for thermal imaging of objects at ambient temperature, and why?

e) The temperature of the detector itself is important for its functioning. Discuss briefly some effects in semiconductor materials that can limit the operating temperature range for a semiconductor-based detector.

f) Discuss: what are the advantages and disadvantages of silicon as a detector material?

2. *Thermal radiation and photon noise*



We consider a detector in a thermal camera. Assume a light input area $A_d=(20\ \mu m)^2$, typical of a detector element in real cameras. The detector is a photon detector with cut-off wavelength λ_c and otherwise ideal properties including unity quantum efficiency ($\eta=1$). The detector receives light through the atmosphere from an ideal blackbody source at a temperature T=20ºC. To simplify the treatment, we do not consider any optics between source and detector. Instead, we assume that the source is an infinite plane facing the detector as shown. Then, if absorption in the atmosphere is neglected, the irradiance on the detector is equal to the excitance of the source.

In the following, you will need to do numeric integration of the Planck spectrum, or as an approximation simply take the average of the spectral photon flux for each micron of wavelength. Indicate which method you have used. Use any calculation tool of your choice.

a) Assume cutoff wavelength $\lambda_c=12.5\ \mu m$. First, assume no atmospheric absorption. Calculate the mean number of received photons per second below the cut-off wavelength.

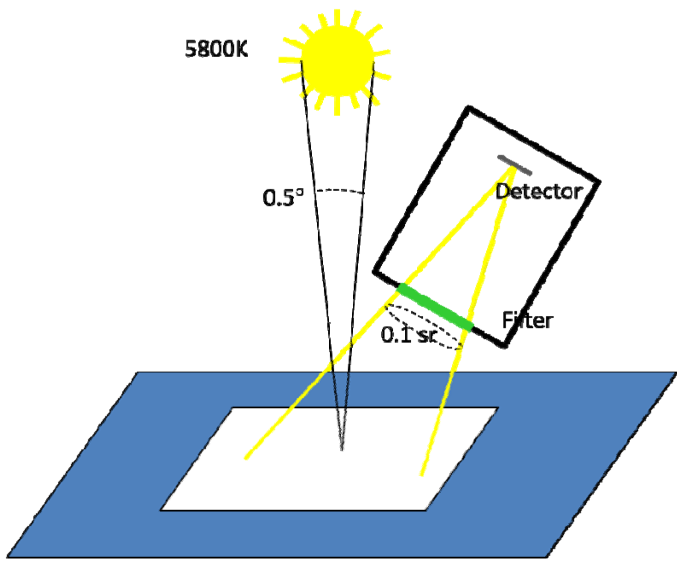
b) Under the same assumptions, calculate the input signal to noise ratio for an integration time $t_i=1$ ms (within the typical range of cameras based on photon detectors).

c) Now assume that the atmosphere is absorbing for all wavelengths below 7.5 µm and has the same temperature as the source. How much does this atmospheric absorption degrade the input signal noise ratio (in percent relative to the case above). Is the change large or small? Why?

d) Assume non-absorbing atmosphere again and calculate the photocurrent i.

e) Also calculate the noise current i_s for $t_i=1$ ms, calculate the output signal-to-noise ratio i/i_s and discuss how it compares to the result in b).

f) Now, assume $\lambda_c=5.5\ \mu m$ (corresponding to a camera sensitive to the medium-wave transmission window of the atmosphere). Neglect the atmospheric absorption and calculate the input signal to noise ratio. Comment on the difference between this result and the results in b) and c).



3. Photon detector for visible light in a cellphone camera

Here we consider a detector representative of a green-sensitive pixel in a cellphone camera. We estimate signal strength when taking pictures in daylight and indoor light.

Assume that the sun can be modelled as a 5800 K blackbody source in zenith with an angular diameter of 0.5 degrees. Consider a horizontal white Lambertian reflector representing an object to be imaged.

a) What is the spectral photon excitance of reflected light from the white reflector at a wavelength of 550 nm, corresponding to green light?

b) Assume that the detector has an optical filter which passes a spectral bandwidth of 60 nm around 550 nm. Plot a spectrum of the quantum efficiency of the filtered detector, overlaid on the blackbody spectrum of the sun.

c) Assume that the filtered detector receives light within a 0.1-steradian solid angle from the white reflector, as indicated in the figure. (As we shall see, this is representative of a detector behind a lens.) What is the photon irradiance at the detector within the filter bandwidth?

d) As we discuss later, it is desirable to collect a signal of at least 1000 photoelectrons per integration time to get a good image quality. In that case, what will the signal to noise ratio be?

e) Assume that the detector area is as small as 1x1 μm, representative of a cellphone camera. How long is the integration time needed to collect a signal of 1000 photoelectrons?

Then consider a more realistic case of indoor lighting, 100 times weaker than the solar illumination, reflected from a grey object with a reflectance of 0.1 and a detector quantum efficiency of 0.5.

f) How long does the integration time now have to be to collect 1000 photoelectrons? Would you say that this tiny detector is element usable for indoor photography, or is the exposure time too long?