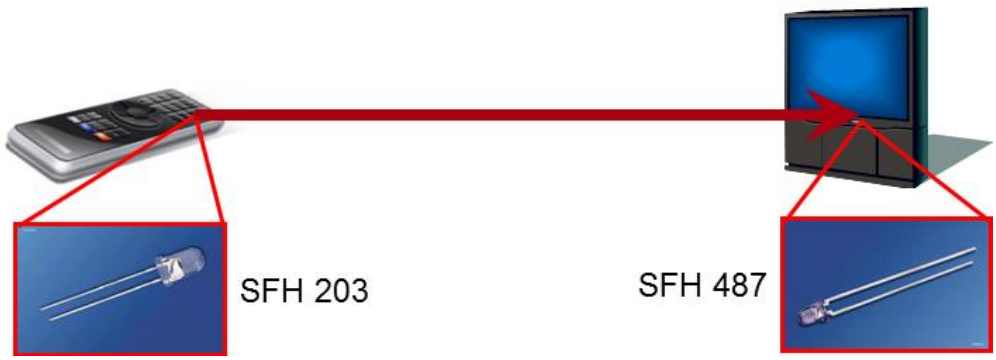
UNIK 4330/9330 Assignment 2



Problem 1: Infrared TV remote control.

Here we consider the case of an infrared remote control for a television set. This problem also gives some practice in reading datasheets for commercial devices.

An IR remote control system contains an LED in the NIR spectral range and a silicon-based photodiode. In such systems, the LED is modulated at a frequency of typically 38 kHz. This "carrier" signal is modulated with a digital bit pattern at some lower frequency, representing the signal to be transferred. Typically, the carrier is switched on or off according to the bit values. Here we ignore the details of the modulation scheme and simply assume that the information transfer requires an electrical signal bandwidth of Δf=1 kHz.

Assume that the LED in the system is an Osram SFH487-2 and that the photodiode is an Osram SFH203, see attached datasheets. Also assume that the LED and photodiode are pointing towards each other at a distance of 4 m, and that the LED is driven with a current that varies sinusoidally between zero and a peak current of 100 mA at a frequency of 38 kHz.

a) What is the peak irradiance from the LED at the detector? Use the lowest value from the datasheet, as we would conservatively do in a design process.

b) Show that the photocurrent in the detector is 0.78 nA at the peak amplitude of the 38 kHz carrier signal.

c) What is the photon noise amplitude in the photocurrent? Use time-averaged signal flux to calculate the noise, not the peak value.

d) What is the shot noise amplitude of the dark current? Use the typical value in the data sheet, not the max value.

e) What is the noise amplitude corresponding to the specified NEP of the photodiode? Note that the NEP is given as a spectral density in the datasheet. To get NEP as a power, multiply by the square root of the signal bandwidth.

f) Considering the combined effect of signal noise and NEP estimated above, show that the electrical signal to noise ratio will be 10 when the distance between LED and photodiode is 45.5 m.

Now consider background light in the room: Assume that the background is a white Lambertian wall filling the field of view of the detector (neglecting the size of the small LED, which is also in the field of view). Assume that the wall is illuminated by the sun at an angle of 20 degrees. Use the same blackbody model as in the first exercise to represent the sun. Use an approximation of your choice to represent the spectral response of the photodiode, which is given as a graph in the datasheet.

g) What is the noise amplitude of the photocurrent due to the background light?

h) What is now the maximum distance for an electrical signal to noise ratio of 10?

i) Suggest at least two ways to improve the range of the remote control system. (Hint: one way may be to employ the other variant of the photodiode. Why?)

Problem 2: Image data (choose one)

The course deals for the most part with highly practical topics, and we end with a practical exercise. Students come to the course with widely varying backgrounds, and cannot be required to master particular skills, such as programming or taking cameras apart. Therefore this last problem has three parts. You are only required to do one of them, although you are of course invited to attempt them all.

Alternative 1. Modulation transfer function, MTF

Measure the modulation transfer function of a digital camera you have access to. It can be your mobile phone, or a camera in your lab, for example. As discussed in the lectures, there are many ways to measure MTF. You need to look at some literature, choose your method and record test images, and you also need software tools to process images. Suggestions and weblinks are given below. The measurement need not be of super high quality, the important thing is to work through the process to get an estimate of contrast as a function of spatial frequency.

Typically you need to make a test pattern of your choice, perhaps using a printer, and then record images of the test pattern. The pattern can be a set of bar charts or sinusoidally varying gray tones, or it can be a "slanted edge" oriented at an angle relative to the pixel grid. You will need to ensure that the images are of usable quality, for example to avoid saturation or incorrect focus. You may need to take into account the nonlinear "gamma" transformation of image data.

Document your results by including at least the following information:

- Camera make, model and type ("mobile phone", "compact", ...)
- Measurement setup and procedures for image recording and analysis
- Camera parameters and settings, to the extent you can find out, looking at camera specifications, metadata and Google (pixel pitch, focal length, aperture, gamma etc.)
- MTF result, plotted together with a diffraction-limited MTF. For colour cameras, give MTF for each of the primary colours.
- Your assessment of the result

Here are links to some internet resources to expand on the treatment in the lecture notes and provide some software tools:

- Image files from commercial cameras contain information about camera settings and characteristics, known as metadata. Many image viewers display this information. A widely used software for reading metadata from image files is ExifTool, found at http://www.sno.phy.queensu.ca/~phil/exiftool/
- A ready made MTF test software utility for the ImageJ software (http://imagej.nih.gov/ij/) is available at http://rsb.info.nih.gov/ij/plugins/se-mtf/index.html (This may be the easiest way, easier than writing your own program, but I have not yet tried this myself. -TS)

- MTF measurement is discussed in a series of blog posts by the recognized image sensor expert Albert Theuwissen:
  1: http://harvestimaging.com/blog/?p=1294
  2: http://harvestimaging.com/blog/?p=1310
  3: http://harvestimaging.com/blog/?p=1321
  4: http://harvestimaging.com/blog/?p=1328
  5: http://harvestimaging.com/blog/?p=1337
  6: http://harvestimaging.com/blog/?p=1353
  7: http://harvestimaging.com/blog/?p=1366
  8: http://harvestimaging.com/blog/?p=1374
- A couple of papers on MTF are enclosed with this assignment.

Alternative 2. Photon transfer

The "photon transfer" technique is very useful for characterizing noise and other characteristics of a camera. Measure the photon transfer characteristic of a camera you have access to. You need to look at some literature, choose your method and record test images, and you also need to write simple software routines to analyze the images. Document your results by including at least the following information:

- Camera make, model and type ("mobile phone", "compact", ...),
- Measurement setup and procedures for image recording and analysis
- Camera parameters and settings, to the extent you can find out, looking at camera specifications, metadata and Google (pixel pitch, focal length, aperture, gamma etc.)
- Photon transfer curve(s) and resulting estimates of read noise, gain and full well capacity
- Your assessment of the result

Here are some tips and links to internet resources:

- To record images of a uniform source at varying light levels without a fancy light source, you can improvise. Use, for example, light falling through a sheet of white paper placed flat on the lens opening, with the focus distance set to infinity. Expose the paper-covered lens to different illumination levels including complete darkness.
- As for the MTF measurement, the ExifTool, software can be useful, found at http://www.sno.phy.queensu.ca/~phil/exiftool/
- The treatment of photon transfer in the notes is a bit short. A more detailed discussion and procedure can be found here: http://www.couriertronics.com/docs/notes/cameras_application_notes/Photon_Transfer_Curve_Charactrization_Method.pdf. Note that the procedure described here is ambitious, with respect to accurate measurement of light sources, for example. Simplifications are possible.
- There are also some articles on Theuwissen's blog, including a discussion of various ways to measure photon transfer characteristics:
  http://harvestimaging.com/blog/?p=1034
  http://harvestimaging.com/blog/?p=1054

Assignment 3. Investigating the construction of a camera

Investigate the construction of a camera, or other optical sensing system, by taking it apart. Unless you are really good at it, this may be an irreversible procedure so that it is suggested to use an old and discarded camera. (Your lecturer will be happy to provide a camera to work on, if need be.) Supplement your investigations with any information you can find about the camera, such as its specifications. Try to describe aspects such as

- image sensor type, pixel count, size, spectral range
- filters and pixel optics placed on the image sensor
- lens construction: focal length, aperture, adjustments, number of lens elements, antireflection coating,...
- electronics around the image sensor
- data flow and storage
- overall size and power requirement

Document the disassembly with pictures. For inspiration, you can search the internet for "camera teardown".