Lab #10

Detector Characteristics and Noise

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Photodiode Characteristics

1. Measure the responsivity and quantum efficiency of a silicon photodiode at 633 nm (using the HeNe laser) and at 468 nm (using an LED). We'll use the New Focus detector/amplifier for this measurement, and become familiar with its properties.

Noise Measurements

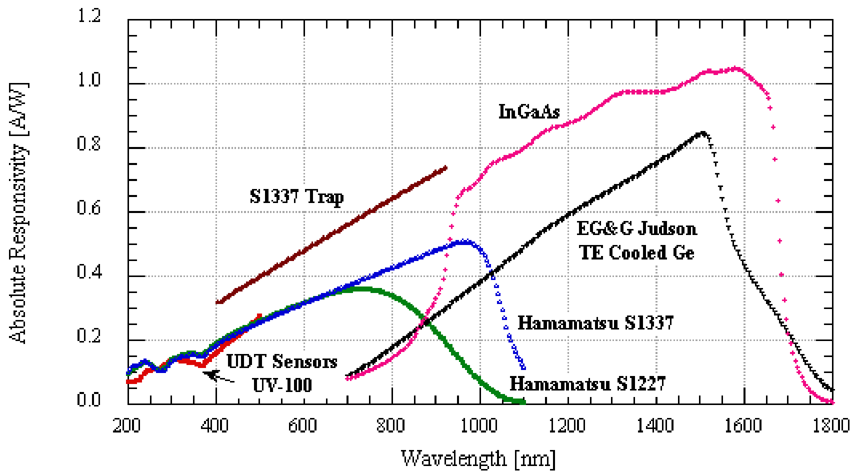
2. Measure the shot noise from a flashlight for several illumination levels using the New Focus detector and the spectrum analyzer.
3. Measure the relative intensity noise of the 637 nm laser diode and the HeNe laser using the New Focus detector and the spectrum analyzer.

2. Introduction

The purpose of these experiments is to familiarize you with the properties of semiconductor photodiode radiation detectors, and the use of those detectors to measure optical signals and noise. You will measure responsivity and quantum efficiency for a silicon detector. Using the New Focus amplified detector and a spectrum analyzer you will measure the intensity noise of a flashlight (shot noise) and of a laser diode (which has additional noise such as partition noise and carrier generation/recombination noise, which exist in excess of the shot noise). This noise is often specified as relative intensity noise, or RIN, meaning the noise power relative to the output DC power of the device.

We are using a silicon photodetector in the photoconductive mode. In this mode of operation, there is a reverse bias across the junction of the diode. The output current is proportional to input power over a large dynamic range (7 to 8 orders of magnitude), limited at the low end by detector and amplifier noise, and at the high end by detector saturation effects. A small area p-i-n photodiode may have a useful bandwidth in excess of 10 GHz, making these detectors extremely versatile and widely used in photonic systems.

The wavelength response of the photodetector is determined by the optical absorption properties of silicon and the geometry of the device. A typical responsivity curve is shown below for a silicon photodiode. Similar curves covering different frequency ranges are obtained for devices made from other semiconductor materials. Important materials for the near infrared, including the communication bands near 1.3 and 1.5 μm, are Germanium and Indium Gallium Arsenide. It is important to note the strong dependence of the responsivity on wavelength. For absolute power measurements you must calibrate your detector at the wavelength of interest.



Typical responsivity curve for a Si photodetector (green), from https://ws680.nist.gov/publication/get_pdf.cfm?pub_id=841265.

3. Measurements

Photodiode measurements

You can measure the responsivity of a silicon photodiode by illuminating the device with a known amount of laser power and then measuring the output voltage developed across a bias resistor. You must first characterize the light sources you will use by measuring the power in the beams.

1) Set up both a HeNe laser and a 468 nm (or other wavelength) LED at your station. Use a 50mm doublet to collimate the LED output. Place an iris behind the lens, and adjust to a diameter of between 5 and 10 mm. With your power meter, measure the optical power P of the HeNe beam and the collimated LED beam. Remember to make the measurements with the correct wavelength setting on the power meter.

2) Use the New Focus 2001 detector/amplifier for these measurements. Measure the responsivity (in A/W) at 633nm, using the HeNe laser, and at 468 nm, using the LED.

   To do this, you will need a lens to focus the beam onto the small detector (use a 50 or 75 mm focal length lens – singlet or doublet is fine; think about the magnification for the LED system – the LED chip is about 400 um across, and its image must fit within the 1mm^2 detector area. What is the expected waist size for the HeNe beam?). Set the gain for the amplifier so that the output signal registers a few volts (not saturated). Record this voltage V, and note the overall gain G (the value from the rotary gain knob times the 1x-3x multiplier set with the rocker switch). From the datasheet, the transresistance of the input stage of the amplifier is R_1=567 ohms.

Calculate the responsivity as V/GR_1P [A/W]. From the responsivity, calculate the quantum efficiency at these wavelengths.

3) The New Focus 2001 detector/amplifier specifies a responsivity, in [V/A], for the silicon detector (you'll find the chart in the datasheet, on the class webpage). Compare your calculated responsivity to the value on the chart, for both wavelengths tested.

Noise Measurements

See the **Hints for the noise measurements** note at the end of the section.

4) Use the New Focus detector and the RF spectrum analyzer to measure the shot noise from a flashlight beam. Connect the output of the detector/amp to the input of the spectrum analyzer, and also to a voltmeter in order to measure the DC level of the detected signal. Note that your conversion factor for the detector is now different, since the input impedance of the spectrum analyzer is 50 ohms (AC coupled, meaning that at DC it is very high impedance), and the model 2001 has a series output impedance of 16 ohms. You also are making a broadband (optical) measurement rather than a measurement at a discrete wavelength, so that the absolute calibration is no longer known. Make the measurement for several different illumination levels, and plot the output noise density vs. DC voltage level, both normalized for the gain settings used to make the measurements, using a log-log axis.

Comment on the spectral properties (RF spectrum) of the noise you observe.

5) Measure the intensity noise of the laser diode using the same method as above. You will be able to make **relative intensity noise** measurements if you use the appropriate gain values to reflect the responsivity of the detector at your laser diode wavelength. If you want to make an absolute noise measurement, you will need to be careful to focus your calibrated beam so that all of the beam falls on the detector active area. Then knowing the responsivity measured previously, and remembering the 16 ohm series output impedance on the New Focus detector, you can convert your noise voltage measurement to optical noise power. How many "times shot noise" is the RIN you measured, for this particular operating point for the laser diode?

Comment on the spectral nature (RF spectrum) of the diode noise.

6) Repeat the measurements to find the intensity noise of the HeNe laser. How does it compare to the diode laser, and to the flashlight?

Hints for the noise measurements: The bandwidth of the New Focus detector is highly dependent on the gain settings. The noise floor also is dependent on the gain settings. In order to make meaningful measurements, you must select a high enough gain in order for the shot noise to be dominant over the detector and amplifier noise, typically 10^2 or higher. If you make measurements over a reasonably wide dynamic range, say two orders of magnitude for the optical signal, you will need to change the gain setting in the middle of your measurements. Therefore, you should make your measurements at sufficiently low frequency such that you remain in the pass-band of the amplifier in all cases.

I recommend the following initial settings, and you can experiment further if you like. Use gain settings on the New Focus detector of either $3x10^2$ or $3x10^3$ (or both in sequence, with appropriately adjusted illumination levels). Watch the voltmeter, and adjust the light intensity until you are not saturating the amp.

Set the spectrum analyzer to sweep from 0 to 100 kHz, with 1 kHz resolution bandwidth and 1 kHz video bandwidth, and video averaging on and set to 10. Turn on the marker, and enable 'marker noise' using the softkeys. The readout will be in dBm(Hz), meaning decibels relative to 1 mW rms, in a 1 Hz bandwidth. To convert from dBm to volts, it is necessary to assume a 50 ohm load, so that dBm = 10 $\log_{10}$ $((v^2/50)/.001)$. Move the marker to somewhere between 20 and 40 kHz, and make your reading of noise power. Leave the marker at the same frequency for all comparative measurements.

Because shot noise varies as the square root of the signal, if you plot DC voltage vs. noise voltage (corrected for the 50/(50+16) gain factor) on a log-log plot, you should see a linear relationship with a slope of ½. If you want to verify absolute noise power, you will need to make some assumptions about the average detector responsivity and amplifier gain over the wavelength range of interest. Reasonable results obtain with the following assumptions:

Amplifier transimpedance: $(1.1x10^7\ V/W)_{peak}/(0.6\ A/W)_{peak} = 18x10^7$ V/A (in highest setting) (we assume response dominated by most favorable wavelengths)
DC gain = $18x10^7$ V/A (in highest setting)
AC gain = $18x10^7$ x 50/(50+16) (in highest setting)

Then you can calculate photocurrent = dc voltage / DC gain. Then calculate shot noise current, multiply by AC gain and convert voltage to dBm(Hz) assuming a 50 ohm load. See whether your measurements line up with the predicted shot noise values.