Rad-icon Imaging Corp

3193 Belick Street, Unit 1 **tel 408-486-0886**
Santa Clara, CA 95054-2404 **fax 408-486-0882**

AN10: QE Measurements of the RadEye1 Image Sensor

Introduction

Visible light and silicon diodes work well together to produce electronic charge. In fact, photosensitive silicon is so receptive to light that incident photons on the order of 200 nW/cm^2 will saturate a RadEye™ sensor. The efficiency with which a photodiode converts incident photons into electrons is known as quantum efficiency (QE). However, QE is dependant on the wavelength of the incident light. Some wavelengths perform better than others! Like the human eye, a photodiode responds to chromatic energies differently. This conclusion is apparent when studying the RadEye1 response to various colors of light.

Whether detecting direct light or indirect x-rays using a scintillator, the RadEye sensor requires absorption of incident light near the silicon surface in exchange for charge. Incident light sources vary considerably. An x-ray source coupled with some type of scintillator will result in a specific color of light. Likewise, when using a direct light source, the incident light color is dependant on the type of source used. In order to optimize a light detection system, knowing the QE response of the sensor is essential. This study evaluates the sensitivity of the RadEye image sensor to various direct light sources. The resulting graphs provide useful information to model the RadEye sensor in a specific application setting.

Experiment Description

In order to measure the RadEye image sensor quantum efficiency, we obtained and categorized several types of LEDs. Prior knowledge of the LED characteristics included centroid and peak wavelength, as well as typical output power and forward voltage. Using the LED light sources, we conducted a study by measuring the incident light simultaneously with a RadEye image sensor located adjacent to a calibrated radiometer sensor head. Both the sensor and radiometer were positioned 25 cm below the light source and enclosed in a light tight box. The light source was attenuated using a white paper diffuser in order to maximize the illumination uniformity. To minimize signal variations due to image sensor nonlinearities, the testing was performed at several fixed RadEye sensor signal levels.

Two data sets were collected for every LED measured: the RadEye sensor signal output and the radiometer output. A Shad-o-Box™ camera was used to operate the RadEye1 sensor. The Shad-o-Box camera output reading is measured in analog-to-digital units (ADU), while the radiometer is calibrated to read in Watts/cm^2. The QE curve for the RadEye image sensor can then be calculated utilizing the radiometer's spectral calibration curve and the Shad-o-Box camera gain correction factor.

Data Collection

Ten types of LEDs, with 5 duplicates of each type, were used to provide the narrow bandwidth monochromatic light input. The emission wavelengths ranged from 466 nm to 741 nm. Table 1 shows results for five typical LEDs. Light output levels were adjusted to achieve a target RadEye sensor output signal of approximately 1500, 1000 and 500 ADU. The actual RadEye signal levels achieved during testing are illustrated in the following table.

Table 1: Test Results

LED Centroid (nm)	503nm	520nm	634nm	700nm	742nm
RadEye Signal (ADU)	1536	1472	1557	1543	1507
Radiometer Power (nW/cm^2)	17.01	15.73	15.36	18.0	17.07
RadEye Signal (ADU)	1008	990	968	1076	994
Radiometer Power (nW/cm^2)	11.55	10.97	9.96	12.94	11.72
RadEye Signal (ADU)	492	481	528	536	498
Radiometer Power (nW/cm^2)	6.06	5.76	5.79	6.94	6.32

Calculations

Quantum efficiency is defined by the ratio of electrons produced to the number of incident photons:

Eq. 1 $$QE = \frac{\#\,\text{Electrons}}{\#\,\text{Photons}}.$$

The QE of the RadEye sensor includes photons absorbed in those areas of a pixel that are not occupied by photosensitive silicon. Although the RadEye pixels have a fill factor of 80%, this ratio is not included in the calculation. To calculate the number of incident photons, the radiometer output readings are normalized to the RadEye pixel dimensions and integration time. A correction factor is also needed to adjust the radiometer readings at wavelengths other than the calibration wavelength of 550nm.

The RadEye image sensor consists of a 1024 by 512 matrix of silicon photodiodes. Each pixel in the array measures 48 µm by 48 µm. Hence, the number of incident photons per reading is

Eq. 2 $$N_P \equiv R \times t_{\text{int}} \times \frac{r_{\lambda_o}}{r_\lambda} \times A_{PD} \div \left[\frac{h \times c}{\lambda}\right],$$

where

N_P = Number of photons

R = Radiometer response $\left(\frac{\text{Watts}}{\text{m}^2}\right)$

t_{int} = Integration time (seconds)

r_{λ_o} = Radiometer response at spectral calibration point (%)

r_λ = Radiometer response at LED wavelength (%)

A_{PD} = Area of RadEye pixel (m^2)

h = Plank's Constant ($6.626\text{x}10^{-34}$ J * s)

c = Speed of light ($3\text{x}10^8$ m/s)

λ = Wavelength of LED light (m).

Note: r_{λ_o} and r_λ were obtained from the radiometer's spectral response curve.

The number of electrons per reading is calculated by simply taking the product of the measured RadEye signal - averaged over a 100 by 100 pixel region - and the camera gain factor (approximately 500 electrons per ADU):

Eq. 3 $$N_e \equiv S \times 500 \frac{e^-}{ADU},$$

where

N_e = Number of electrons

S = Radeye Signal.

Test Results

The test results are summarized in the following graphs. The curves depict the RadEye response to chromatic light.

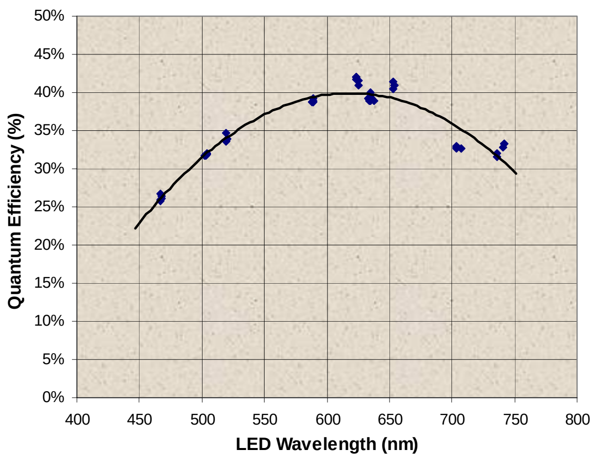

Figure 1 – RadEye Image Sensor Quantum Efficiency at 1000 ADU (data points included).

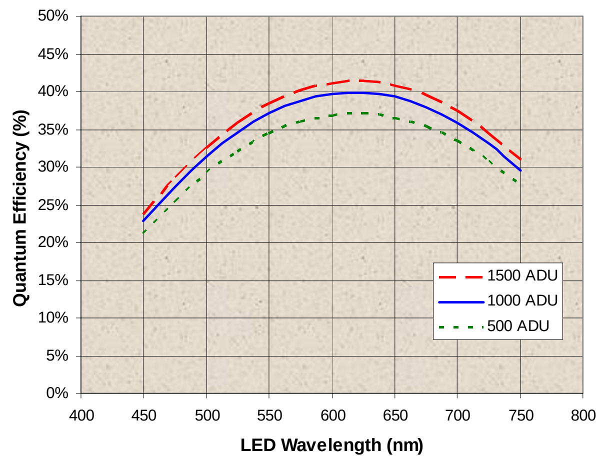

Figure 2 – RadEye Image Sensor Quantum Efficiency at three different signal levels.

Because the RadEye sensor has a nonlinear signal response, the QE curves shift with respect to light power. Figure 1 is a graph showing a data set collected at the 1000 ADU target signal level. The trend line through the points is a best fit 2nd order polynomial. Figure 2 is similar showing three trend lines without the data points, representing data sets at 1500, 1000 and 500 ADU. As expected, the response varies strongly with incident light wavelength. The peak QE occurs between 600 nm and 650 nm.

Conclusion

The quantum efficiency of a silicon photodiode is proportional to the wavelength of the incident light. The experimental results show that the RadEye image sensor QE peaks at about 40% at 625 nm and decreases rapidly above 750 nm and below 450 nm. The results also show that the QE measurement varies with signal level due to the slight non-linearity of the sensor response. The assumption of a constant camera gain factor is not quite correct, and the results should be adjusted for the appropriate sensor response at each signal level. Further study might be indicated in this area.