

SNR Calculation for UAVHIS

Jim Hagerman, Innovative Technical Solutions

February 4, 1999

Solar irradiance at sea level is a well known measured quantity. It has the appearance of a black body radiation curve (5900K) but with several absorption bands due to the atmosphere. Normally given in Watts per square meter per nanometer wavelength this data is converted to photon counts by

$$eV = \frac{W \cdot \lambda}{h \cdot c}$$

where h is planck's constant of 6.63×10^{-34} J-s, c is the speed of light, and λ is wavelength. The resulting curve is plotted in Fig. 1 in photons per meter squared per second.

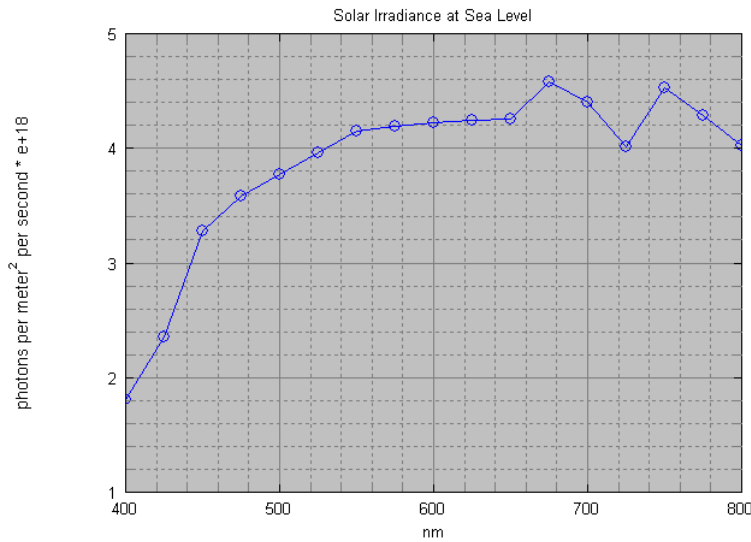


Figure 1. Photons reaching the Earth's surface at noon.

The number of electrons generated in the CCD pixels is a function of many things – reflected irradiance, angle, bandwidth, pixel size, quantum efficiency, transmissivity of optics, etc. This formula is given by

$$electrons = \frac{\Phi \cdot \cos^4(\phi) \cdot \lambda_{bw} \cdot h_{slit} \cdot w_{pixel} \cdot Q_e \cdot \tau_{optics} \cdot \eta_{grating} \cdot \gamma_{fill} \cdot \rho}{4 \cdot F^2 \cdot f_{rate}}$$

where Φ is photon flux (from Fig. 1), ϕ is the angle of view, λ_{bw} is the spectral bandwidth in nm, h_{slit} is slit height, w_{pixel} is pixel width, Q_e is the CCD quantum efficiency, τ_{optics} is the total transmissivity of the optics, $\eta_{grating}$ is the efficiency of the grating, γ_{fill} is the fill factor, ρ is the reflectivity of the object, F is the speed of the optics, and f_{rate} is the frame rate.

Noise sources are shot, thermal, read, and quantization. They are combined to give an expression for SNR of

$$SNR = \frac{electrons}{\sqrt{electrons + [B_{on} + B_{off} + 1] \left(\frac{e_{dark}}{f_{rate}} \right) + [B_{off} + 1] \left[e_{read}^2 + \left(\frac{e_{full}}{2^N \sqrt{12}} \right)^2 \right]}}$$

where B_{on} and B_{off} are the number of on and off-chip binning operations, e_{dark} is the dark current per pixel per second, e_{read} is the CCD read noise, e_{full} is the full well capacity of the readout gate, and N is the number of bits in the A/D convertor.

Models for optics transmissivity, grating efficiency, and CCD quantum efficiency were created by curve fitting. The optics and grating curves are approximated by

$$\eta_{grating} \approx 0.23839 - \frac{1373.86}{\lambda} + \frac{1688048}{\lambda^2} - \frac{4.3214187 \times 10^8}{\lambda^3}$$

$$\tau_{optics} \approx 0.52 + 0.04 \cdot \sin(0.0157 \cdot \lambda + 4.71239)$$

UAVHIS uses a Sony XC7500 camera with ICX074L interline frame transfer CCD. Its quantum efficiency curve is shown in Fig. 2 and approximated by

$$Q_e \approx -99.978 - 0.06531 \cdot \lambda + 2.4754345 \times 10^{-5} \cdot \lambda^2 + 20.41787 \cdot \ln(\lambda)$$

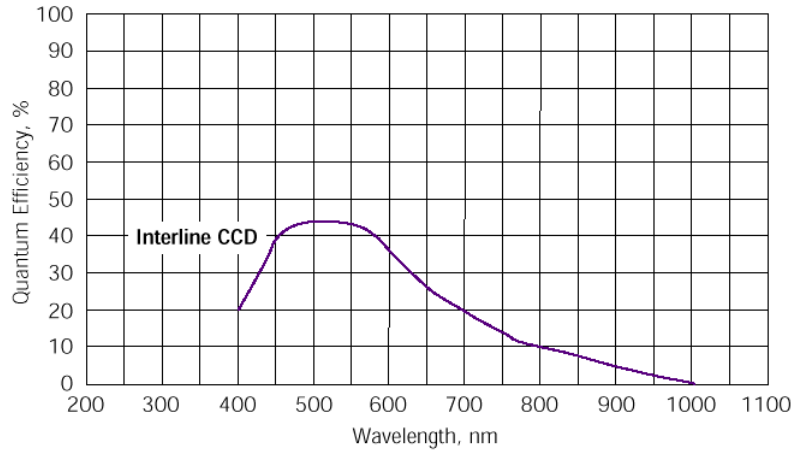


Figure 2. Quantum efficiency of Sony ICX074 CCD.

The low dispersion grating uses only the bottom half of the CCD or 240 lines for spectral information. Binning by 6 gives 40 spectral channels so the optimum slit height is 6 pixels or 60 μm . A 400 nm to 800 nm range gives 10 nm bandwidth per channel. Since the CCD is interline transfer there is a fill factor coefficient of approximately $2/3^{\text{rd}}$ s.

UAVHIS uses a 35 degree FOV (half angle is 17.5°) to match the CCD at 1 mrad per pixel. Dark current is specified as 2 mV (measured at an ambient temperature of 60C) with a full scale output of 500 mV. Assuming a full well size of 100k electrons the read noise can be approximated as 400 electrons at 60 fps. This works out to 2400 electrons per second per pixel. SNR of the camera is specified as 60 dB. Assuming this ignores dark current read noise is 100k electrons divided by 60 dB or 100 electrons. The Sony camera does not perform on-chip binning. Therefore five binning operations are done off-chip by software to combine six pixels into one spectral channel.

For UAVHIS we have

$$\begin{aligned} \phi &= 17.5^\circ \\ \lambda_{bw} &= 10 \\ h_{slit} &= 60 \mu m \\ w_{pixel} &= 10 \mu m \\ \gamma_{fill} &= 0.67 \\ F &= 2.8 \\ f_{rate} &= 60 Hz \\ B_{on} &= 0 \\ B_{off} &= 5 \\ e_{dark} &= 2400 e^- / s \\ e_{read} &= 100 e^- \\ e_{full} &= 100 ke^- \\ N &= 10 \end{aligned}$$

Using the electron formula with a reflectivity of 10% the maximum possible number of electrons captured by the CCD is plotted in Fig. 3.

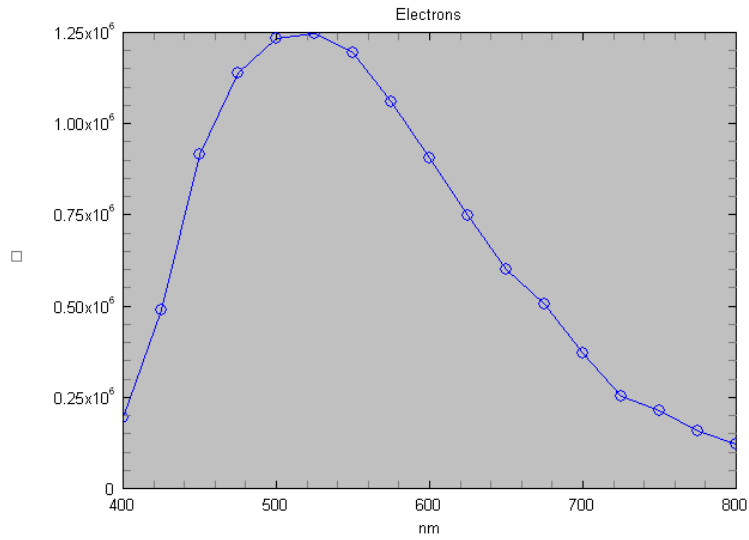


Figure 3. Total electrons generated in CCD per pixel area per frame.

Figures 3 and 4 show the resulting SNRs for various reflectivities.

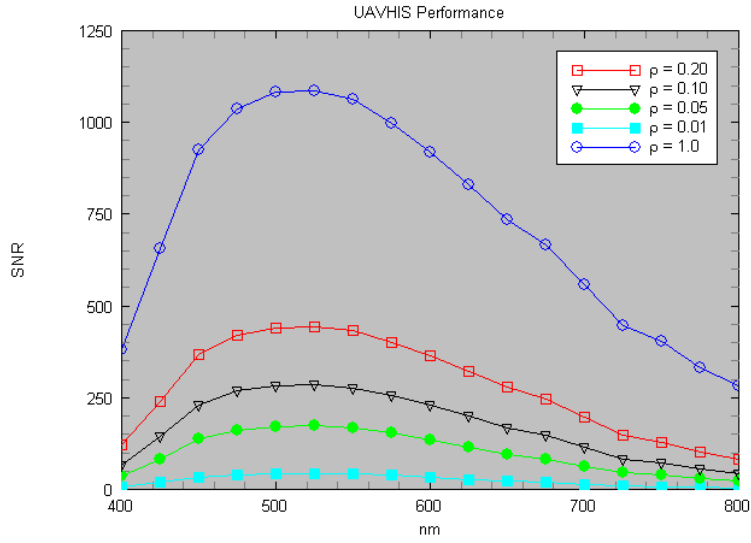


Figure 3. SNR for UAVHIS.

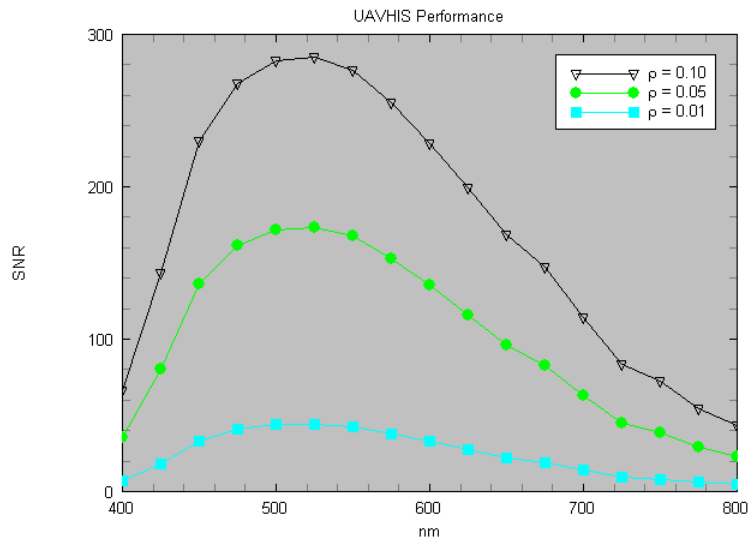


Figure 4. SNR for UAVHI, low reflectance.