Hawkeye Calibration Report – Exposure Time Non-linearity

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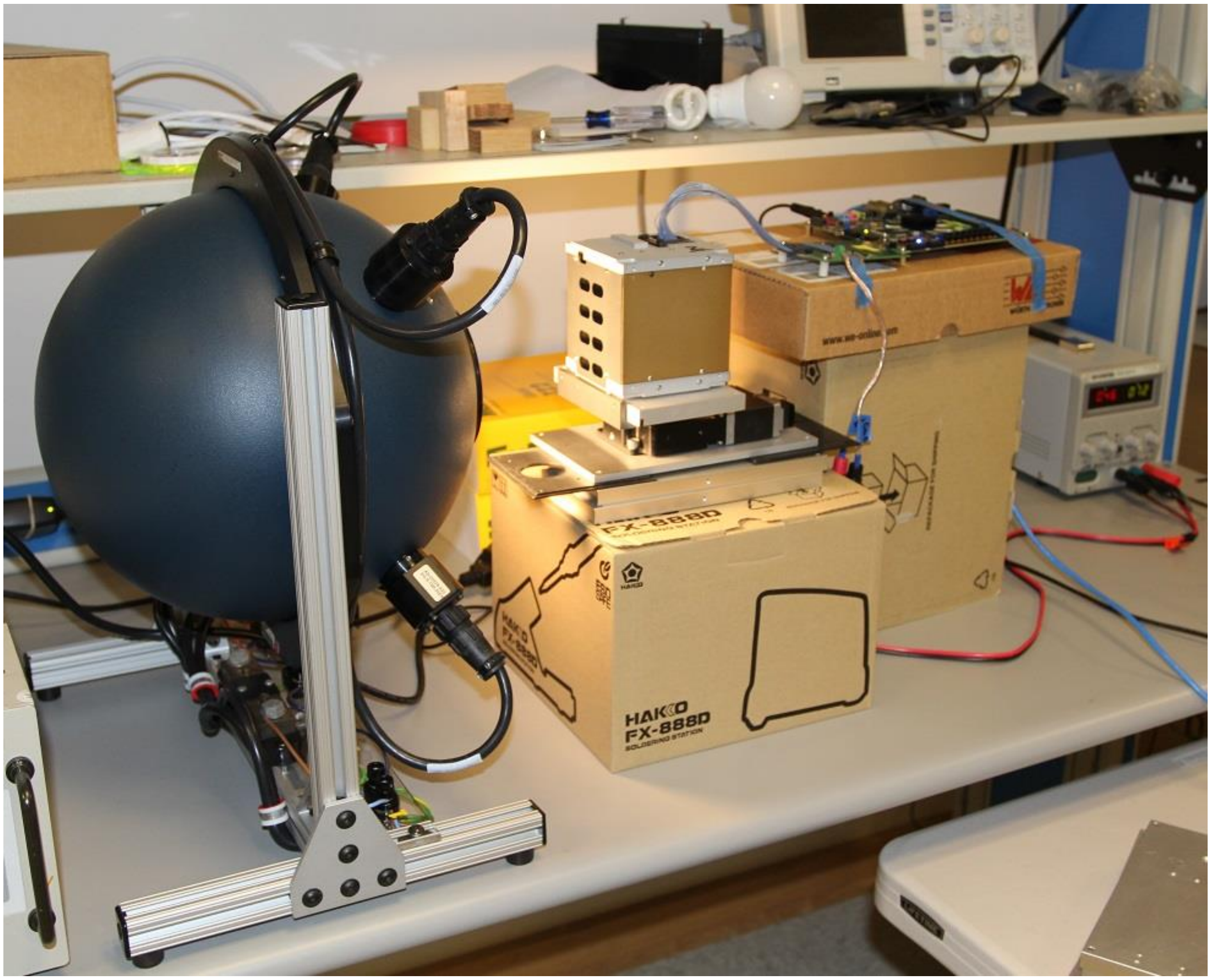
Overview: we discovered in Hawkeye testing that the radiometric data showed a curious effect – the response did not seem to be linear with the commanded exposure time. This was discovered by examining data collected with the NASA 12 inch sphere, which was so bright in the near infrared that it forced us to use exposure times much shorter than expected to be used in orbit. A brief explanation of how the CCD is used to capture data is necessary here.

Exposure Timing: in Hawkeye the linear CCDs are read out multiple times during the dwell time for one pixel. We call this the oversampling. Typically we will read out each pixel 4 times during the time required for the instrument to scan one ground pixel. We call the time required to scan one ground pixel the interval time, or row rate. This is set by the orbit. Within the interval time we can take either 1, 2 or 4 exposures, and average them. The actual exposure time that can be commanded can be as great as the interval time divided by the oversampling, or a short as one tenth of that number. So, three numbers go into the CCD sampling calculation: the interval time, the oversampling, and the exposure time. The nominal value in orbit is an interval time of 18.4 milliseconds (ms), an oversampling of 4, which means that each CCD is readout every 4.6 ms, and the exposure time, which can range from 0.46 ms to slightly less that the readout rate, or around 4.4 ms. The fastest interval time we can use is 5 ms, with an oversampling or 1, or the software can't keep up. So, for the integrating sphere and Band 8, 865 nm, we were forced to use an exposure near 0.5 ms. We ended up using 0.6 ms to be just below saturation.

So, in the nominal case, the CCD is readout every 4.6 ms, but the exposure can be varied by a factor of ten within this limitation. The linear CCD has a clock line that is held low to prevent the exposure from starting for a few ms, and then the line goes high to allow the exposure to start. It turns out that during the "off" time the charge wells are accumulating charge, an effect that is much greater for near infrared wavelengths. This leakage is the mysterious and poorly explained "smear" parameter in the KLI-4104 data sheet. We will refer to the charge that is accumulated during the commanded exposure that is not leakage as the "direct" path.

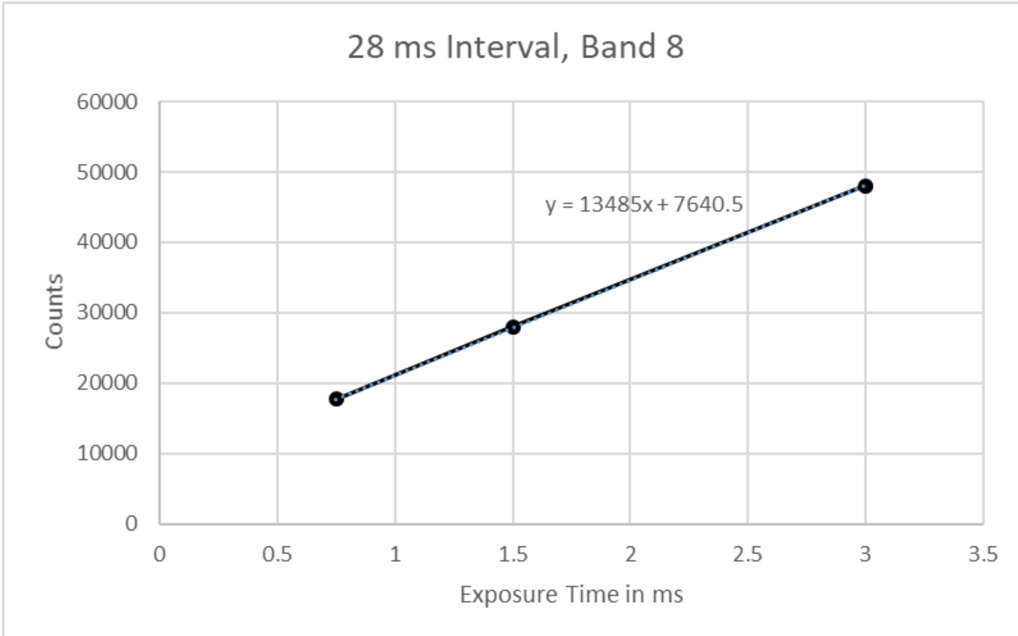
Measurement: Figure One below shows how we measured this effect. We reduced the sphere brightness by taping a 5x5cm neutral density filter over bands 5 through 8 so we could use longer exposures and an oversampling of 4. The ND filter is not shown in this picture, and in practice the sphere aperture was within 2 cm of the instrument aperture, not far back like shown. At the longer wavelengths the ND filter was only about a factor of 5 attenuation, but that is actually not a critical parameter.

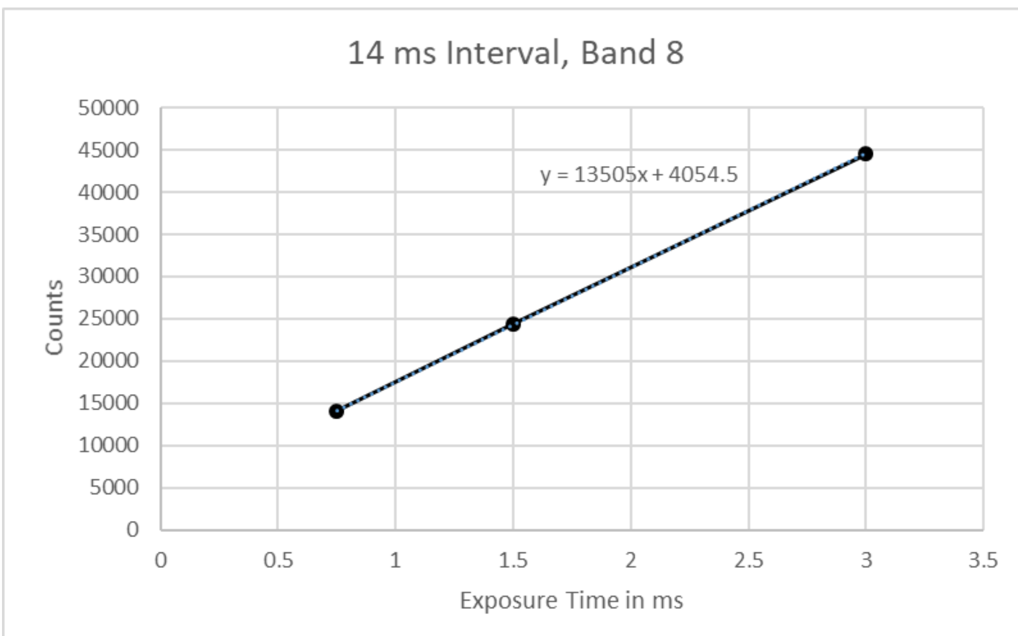
Figure One: Instrument Viewing NASA Sphere through ND Filter



We take sphere data at three different exposure times, and two different interval times. Figure Two shows typical data for band 8. Note that the response as a function of exposure time is linear, but there is an offset. You would expect zero exposure to give zero counts, but that is not the case.

Figure Two: Band 8 data, Unit Two





Magnitude of Effect: The Trendline feature in Excel is very handy for quickly estimating the Y-intercept. From this data, it is a simple matter of solving two equation in two unknowns to determine the relative sensitivity of the leakage to the direct path. We did this for every band, for both units. The effect is graphed in Figure Three, and tabulated in Table One.

Figure Three – Leakage Fraction as a function of Wavelength

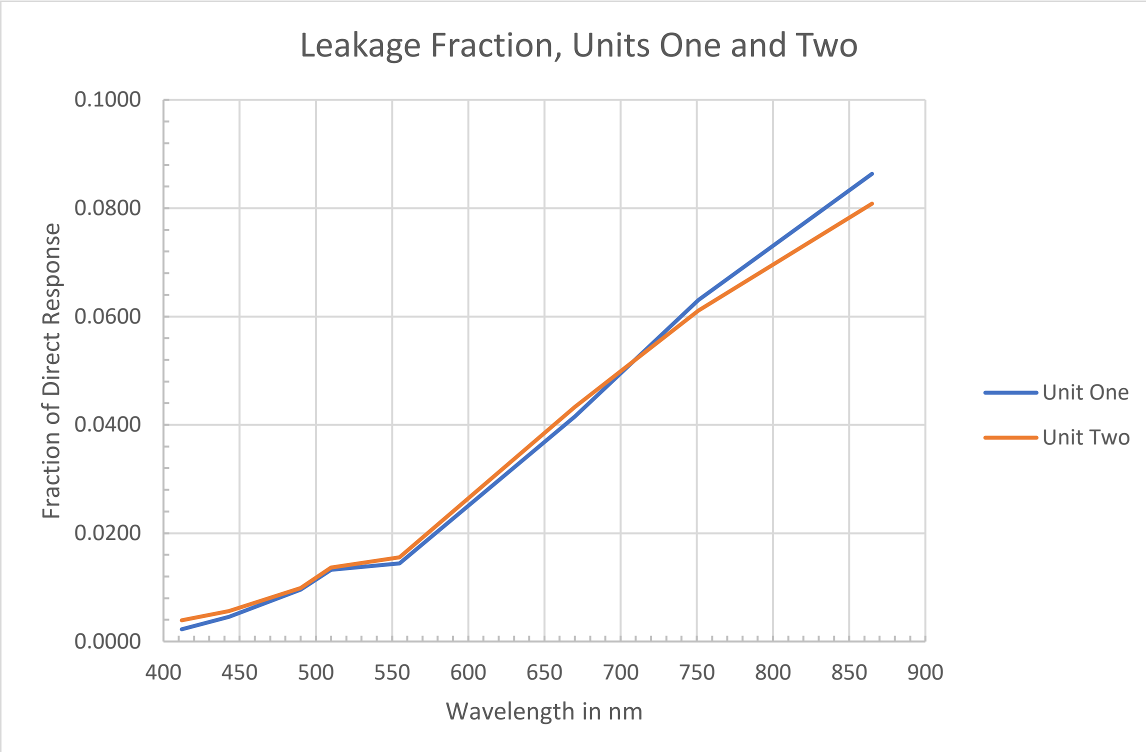


Table One: Tabulated Leakage Fraction

Summary of Both Units	Leakage Fraction, Unit One	Leakage Fraction, Unit Two
Wavelength		
412	0.0023	0.0039
443	0.0045	0.0056
490	0.0096	0.0099
510	0.0132	0.0137
555	0.0144	0.0156
670	0.0415	0.0433
751	0.0630	0.0611
865	0.0863	0.0808

An example of how to use these numbers is helpful. The number tabulated is the leakage fraction, or sensitivity, for an exposure, in terms of counts per ms, relative to the direct path. For example, if we have a band 8 exposure with an interval time of 20 ms, and 4:1 oversampling, then the time between readouts if 5 ms. If we command a 1.5 ms exposure, then the total response is 1.5ms * 1.0 (the direct path) PLUS 5 ms * 0.0803 (the leakage path). The total is therefore 1.9015, so the effective exposure time is therefore 1.9015ms.

How this affects flat fields: unfortunately our best flat fields were captured using no neutral density filter and with short exposures, for bands 5 through 8. We can use the two equations in two unknowns technique to derive a flat field for the leakage path from the sphere linearity test data. It turns out the flat field response pattern is completely different between the direct path and the leakage path, and the leakage path is many times more irregular. This means the best flat field is a function of exposure time, and cannot be calculated without knowledge of the exposure time. We will have more on this in a later calibration report focused on flat fields, but for best results the flat field must be calculated from ND filter data. For unit one, this is the data contained in the directory below.

C:\FlightOneCalibrationBackup\Alan\PostSecondVibeTests-052517\ExposureLinearity

For unit two, the directory is:

C:\FlightTwoCalibrationBackup\Alan3\Unit2\SphereLinearity-062817

I realize the actual folder positions may be slightly different, but this should provide a guide. For unit one, I am not sure we had the unit close enough to the sphere to eliminate vignetting, so perhaps the low frequency data from a regular sphere radiometric test should be merged with the high frequency data from the ND filter test to produce the best flat field. How to do this will be outlined in a later calibration report. The value of the data in this report is to calculate the actual effective exposure time for a measurement, basically deriving the sensitivity of the unit about pixel 900, the center of the field.