REPORT TITLE Detector Gain Measurement	DOCUMENT NUMBER SDL/09-140
PREPARED BY Harri Latvakoski	**DATE** March 23, 2009

PROPRIETARY DATA NOTICE

1. GAIN CALCULATION

The detector gain can be measured from the observed signal and noise on a pixel. Given a background subtracted signal, S, the noise, N, due to electron counting statistics will be

$$gN = f_{SUR} f_{AC} \sqrt{gS} \ .$$

N and S are measured in counts, g is the gain in electrons per count, and f_{SUR} is the noise increase due to using the sample up the ramp data collection. With 9 samples up the ramp, this is 1.046 and with 8 it is 1.041. f_{AC} is the noise reduction due to pixel crosstalk and is defined by

$$f_{AC} = 1 \Big/ \sqrt{\sum A_{i,j}} \ ,$$

where A is the peak normalized image autocorrelation function. The autocorrelation function measures all pixel crosstalk including inter-pixel capacitance and electrical crosstalk.

Because all pixels also have a dark noise, this must be subtracted off to measure the gain.

$$g = \frac{(f_{SUR} f_{AC})^2 S}{N^2 - N_d^2}$$

2. THE DATA

WISE images were seen to have two effects that confound the measurements of noise on a pixel. The first is the sinusoidal variation in average signal on an image. This is an electronic noise that seems to affect all pixels equally, which was later much reduced by changes in grounding. It is present in the absolute response and flat field data that are most useful for this measurement. The second is changes in image average over time while viewing the MIC extended source, which is due to slight changes source temperature during the data collection. The change in signal level is insignificant, but it does effect the noise measurement.

The solution is to use an algorithm that takes a set of images, finds the average over all good pixels for each image, then finds the difference between this and the average of all good pixels for all images. This difference is then subtracted from each image, which results in the average over all good pixels in each image being the same. This eliminates the two confounding effects mentioned above.

I use the absolute response data to measure detector gain. This data consists of sets of data collected while looking at the MIC extended source. Each set is collected at a different extended source temperature, consists of 10 images, and is contained in one file for each band. A set of 30 images of the cold extended source is collected at the start of this data as a dark image.

To measure signal and noise, I start with the set of dark images, adjust the image means as described above and then calculate the mean and rms image for this set. I then subtract the mean dark image from a set of illuminated images, correct each image for non-linearity, adjust each image mean, and then calculate the mean and rms images for the set. Note that since noise is calculated independently for each pixel, subtracting the background (which is just one value for any one pixel) does not affect the noise.

From this data, gains could be found for each good pixel but with a lot of scatter since the sets only contain 10 images. So I find the mean and median value for all good pixels in the mean image and the rms image. These are listed in the accompanying Excel file. For each band, I used several sets of data at different illumination levels. The file also lists the standard deviation calculated from the rms results. For each illuminated set (background subtracted, linearity corrected and mean adjusted) , I also calculate a difference of two images and find the standard deviation over all good pixels in this image. This and the pixel standard deviation calculated from this are also listed in the Excel file.

The signal mean and median from the images agree to better than 1% in all cases. The noise mean is about 1.2% higher than the median. The standard deviation calculated from a difference image is 2.5% higher then the mean of the noise image for bands 1 and 2 and ~1% higher for bands 3 and 4. The mean and median are different, of course, because the pixels have a distribution of signal (due to varying sensitivity) and noise (due to varying sensitivity and varying read noise levels), and for any non-symmetric distribution, mean and median will be different. Mean being higher than the median reveals there is more of a tail on the high side of the distribution, since mean is more sensitive to outliers. The noise calculated from the difference image is different because the value measured in the difference image for each pixel is

$$v_i = \pm\sqrt{2}\sigma_i \, .$$

The value is a random variable with a standard deviation of σ_i, where the index, i, is to a particular pixel. We calculate the standard deviation the usual way

$$\sqrt{\frac{\sum v_i^2}{N-1}} \, .$$

If we have a normalized distribution of standard deviations $f(\sigma)$ then the expectation value of this is

$$\sqrt{2\int \sigma^2 f(\sigma) d\sigma} = \sqrt{2\overline{\sigma^2}} \, .$$

For a distribution with any range in values, the average of the values squared is greater than the square of the average value. Thus a pixel standard deviation calculated from a difference image will always be higher than that from the mean of a noise image.

The most valid of these is probably the value from the median signal and noise since the median will do best at excluding outliers.

The cross talk noise suppression factor in the excel file is from the ADC optimization measurement.

3. GAIN MEASUREMENT

Excess noise in an image (of the sort that varies from pixel to pixel such as the chevron pattern noise seen during much of the data collection) should not affect the gain measurement as long as the excess noise remains the same in the illuminated and dark images. I first tried calculating the gain by subtracting off the dark noise as measured in the dark image. This resulted in different gains from the data at different illumination levels, which suggests the dark noise changed between the collection of dark and illuminated images (this is easily possible since the excess noise can and did vary and the dark data was collected well before the others). With several illuminated data sets, the gain and read noise can be found from a line fit to N^2 vs. S and using the above gain equation to get the gain from the slope and the read noise from the intercept. This is equivalent to adjusting the read noise value until the gains from all data sets are as similar as possible, which I do in the Excel spreadsheet. For all but band 2, the change needed in the read noise is fairly small.

It is a concern that if read noise can change between the dark and illuminated sets, it could change between illuminated sets also and confuse the measurement. However, the data sets with high illumination levels provide good measurements of the gain simply because the photon noise dominates. As can be seen from the spreadsheet, these values do not change significant with either choice of read noise value. To reduce possible effects of variation in noise over time, the gain value listed in the Excel file is an average of values from the high illumination level data only.

For band 4, each pixel from the DEB is the average of 4 FEB pixels. The measured signal will not be changed by the averaging, but the measured noise is half the noise that would be measured on a single FEB pixel. Because gain is proportional to the reciprocal of noise squared, the binning will raises the gain by a factor of 4. This must be divided out to get the actual detector gain.

4. RESULTS

All results discussed here are from the accompanying Excel file.

4.1 BAND 1

The median values of signal and noise always give the highest estimate for gain. For band 1, this value is 3.74 or only 2.5% lower than the value specified by DRS. They are essentially the same. The gain value from the difference image is 3.46, (10% low).

Joel Cardon measured the gain using dark and gain variation data. There the signal is from the illuminated scatter source images and noise from the difference of two consecutive images. Dark signal and noise are from the composite dark image data product. Since the scatter source is viewed repeatedly, this results in many gain measurements. For the data collected with the flight electronics, the average gain value from the scatter source data is 3.43 and 3.53 after the noise was reduced by changes to the electronics. These match the difference image results described here.

4.2 BAND 2

For band 2, the gain value from the median signal and noise is 4.57 which is 19% higher than the gain specified by DRS. The gain value from the difference images is 4.33 (13% high), which is not far from the gain value of 4.22 and 4.43 (after noise reduction) found from the scatter source data.

4.3 BAND 3

The band 3 gain from the median signal and noise is 6.84 or 45% higher than expected. The result from the difference images is 6.65 (39% high). The scatter source results for the flight electronics at nominal temperature (gain seems to change slightly with array temperature) are 5.17 and 5.35 (after noise reduced). Why these are so different from the results here is unknown.

4.4 BAND 4

The gain from the median signal and noise for band 4 is 4.44 or 94% of the DRS values. From the Excel file, it is clear the uncertainty is higher than for the other bands; ~10% in the gain seems reasonable. This result is essentially consistent with the DRS value. The gain from the difference image is 4.30, which is 91% of the DRS value. The results from the scatter source data at nominal array temperature is 4.02 prior to the noise being reduced. The data after the noise was reduced is not useful since the MIC2 light leak became bright enough to saturate most of this data. There is high scatter in these gain measurements of at least ±0.5, and array temperature seems to have a significant effect on gain. The strong, variable MIC2 light leak may well be affecting those results.