5.1.5 DARK CURRENT

5.1.5.1 NAC FM DARK CURRENT CALIBRATION RESULTS

As reported in Reference 5.1.5.1-1

Reference 5.1.5.1-1 - IOM 388-PAG-CCA97-14 , "NAC FM CALIBRATION RESULTS: DARK CURRENT", C. Avis, October 9, 1997

Reference 5.1.5.1-2 - IOM 388-PAG-CCA97-3 , "WAC FM CALIBRATION RESULTS: DARK CURRENT", C. Avis, March 6, 1997

5.1.5.1.1 INTRODUCTION

The Narrow-angle Flight Model thermal/vacuum testing included the acquisition of a set of images for characterization of the system dark-current. The term 'dark-current' describes the number of DN produced during an exposure which was not the result of incident light or bias level. This includes the contribution of lightflood-generated electrons and ambient thermal electrons.

Over 1100 images were taken in Gain State 3 in full-resolution mode. In order to measure the dark-current as a function of exposure time, the camera was commanded to take image data at each possible exposure time (with the exception of 380, 460, 680, and 1000 seconds). However, the shutter was inhibited. The detector remained cold (about -88° C), but the chamber temperatures varied widely because the data were taken mainly during temperature transitions. Data were taken with Lightflood 'ON' and 'OFF' and with Antiblooming 'ON' and 'OFF'. In addition, all data were taken at a telemetry rate of 6 (365 kbits/sec).

No data were taken in which this camera's image was delayed in readout due to a simultaneous Wide-angle image being read out first. Presumably the effect would be identical to that described in the Wide-angle results (see Section 5.1.5.2).

5.1.5.1.2 METHOD

For this camera system, the pixel value resulting from an exposure with the shutter inhibited may be described by the following equation.

$$DN = \overline{BL} + I + DN(T)$$

where	*DN*	is the measured pixel value
	$\overline{BL}$	is the mean video offset or bias level (in DN) for the image
	I	is the deviation from the mean bias level for an individual pixel (in DN)
	T	is the integration time (would be exposure time if shutter was enabled)
	DN(T)	is the dark-current level (in DN)

In order to analyze DN(T), images may be taken at a given T:

$$DN_B = \overline{BL_B} + I + DN(T)$$

and at T=0:

$$DN_A = \overline{BL_A} + I$$

and differenced:

$$DN_B - DN_A = \overline{BL_B} - \overline{BL_A} + DN(T)$$

This gives

$$DN(T) = (DN_B - DN_A) - (\overline{BL_B} - \overline{BL_A})$$

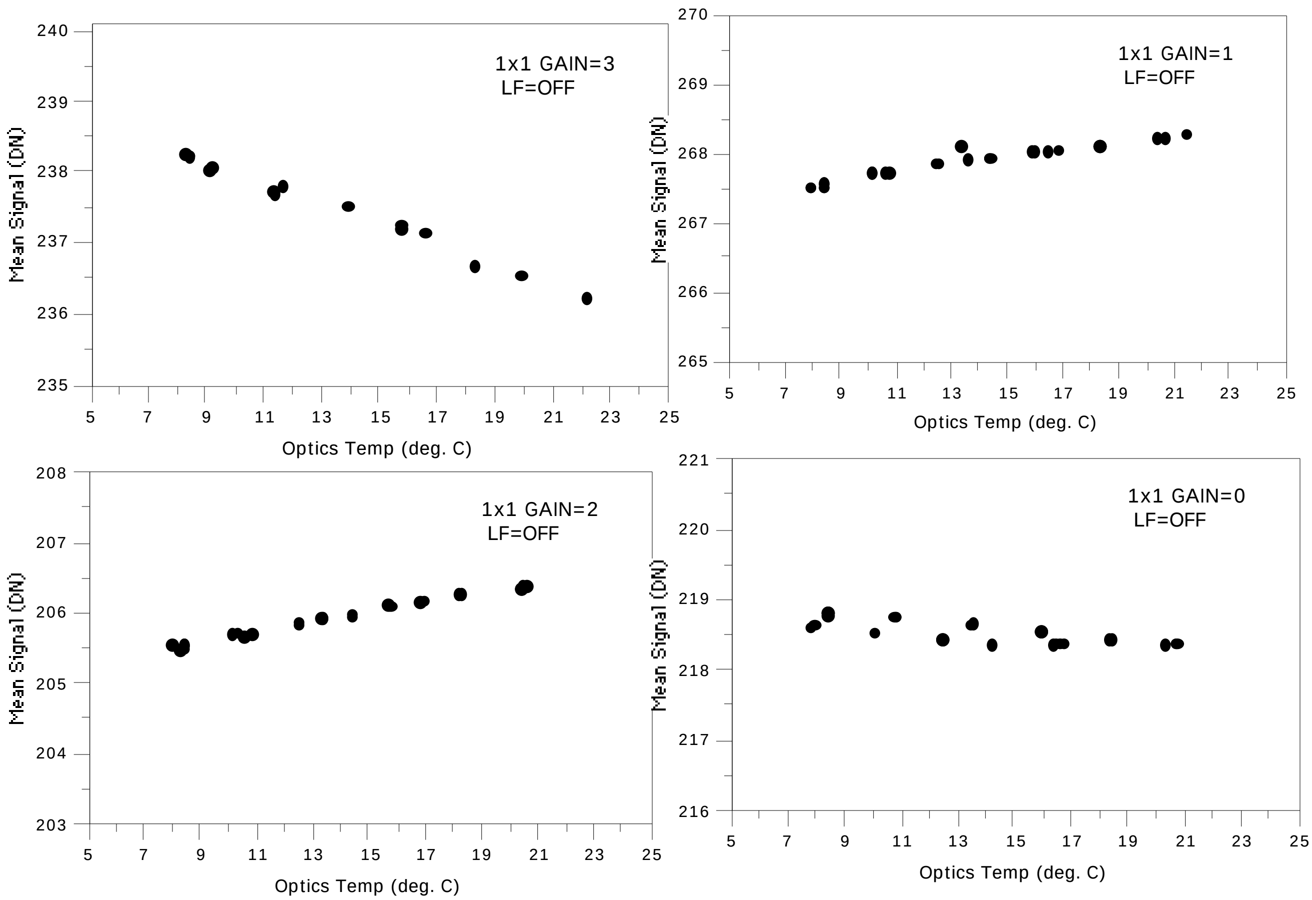
This shows that to measure the DN(T), compensation for the bias inherent in the images must be taken into account.

The available T=0 frames were averaged using an algorithm which checks for pathological DN values and rejects them. These frames were created for each set of images (same Antiblooming and Lightflood state) and then subtracted from each frame of the set. Mean values of the difference frames were tabulated versus T.

The mean bias level of each frame was calculated from the values of the overclocked pixels for each line recorded in the binary prefix of each VICAR image. The difference of these bias levels was used to adjust the values of the tabulated image differences.

5.1.5.1.3 TEMPERATURE SENSITIVITY

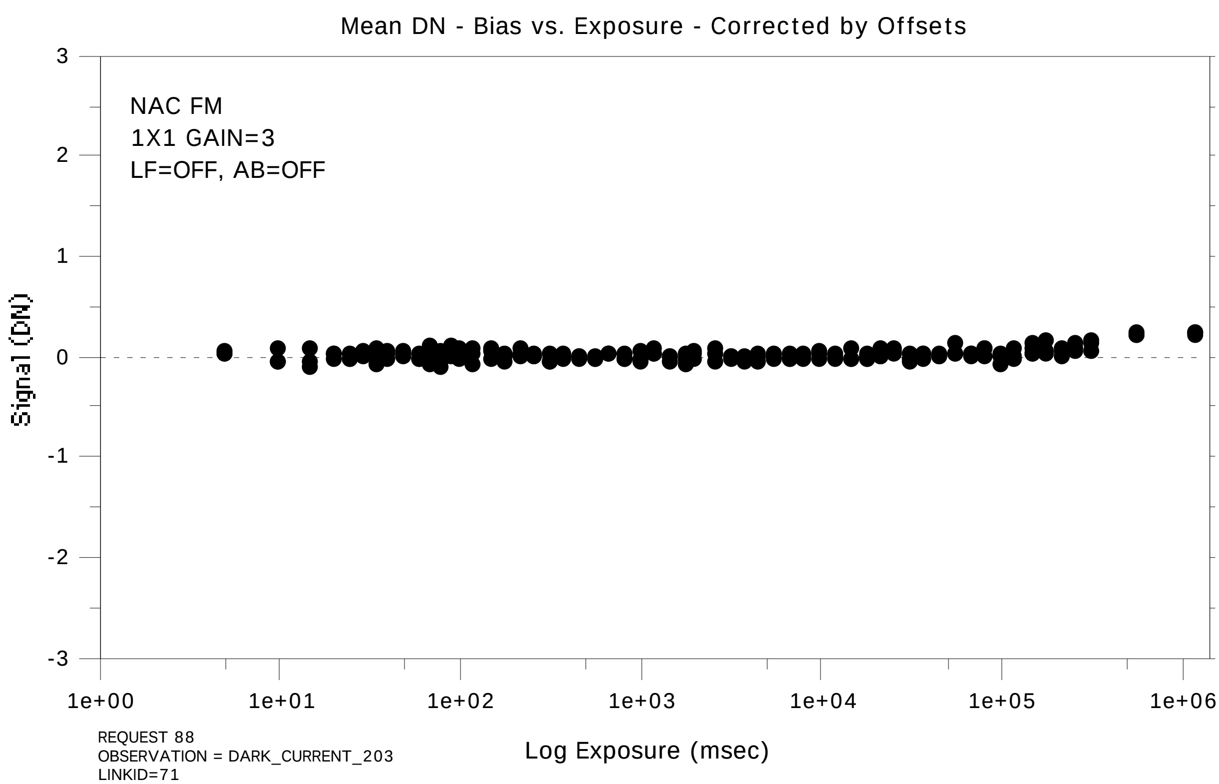
The dark-current tests were taken during times of temperature transition. Plots of Mean DN(T) (without any corrections) vs. Optics Temperature in each Gain State are shown below. All data plotted came from frames with exposure times of 0 or 100 milliseconds. Gain 3 shows a large temperature sensitivity while the others show almost none.

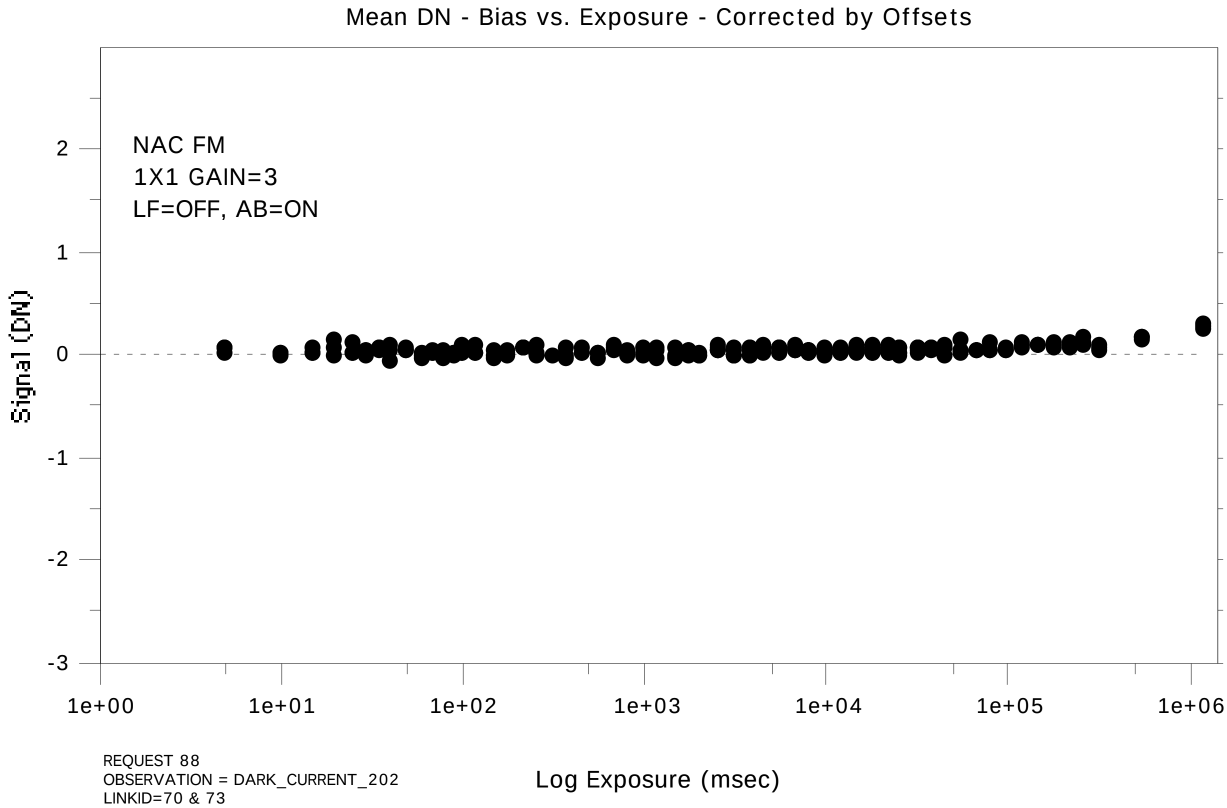


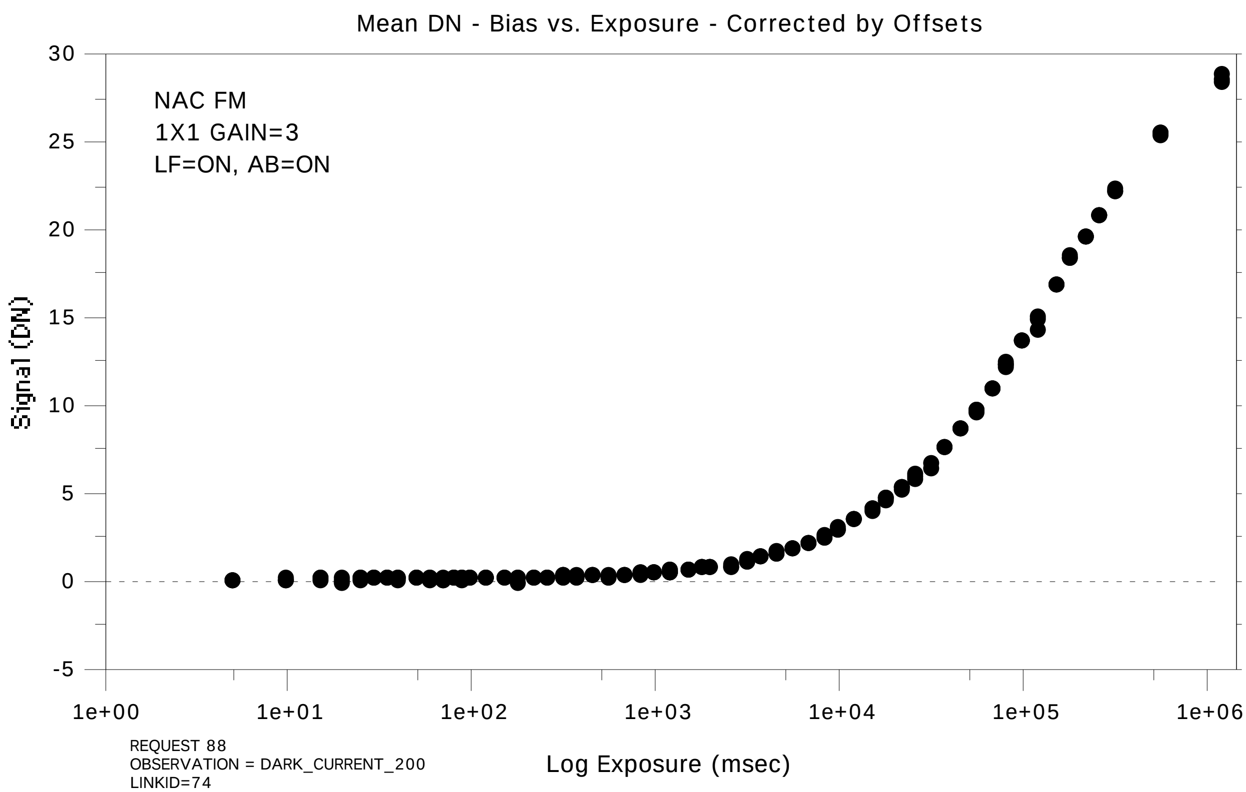
Presumably the effect would be identical to that described in the Wide-angle results (Reference 5.1.5.1-2). That is, that the Sensor Head Chassis temperature directly affects the bias level, while the Optics temperature is a less reliable indicator.

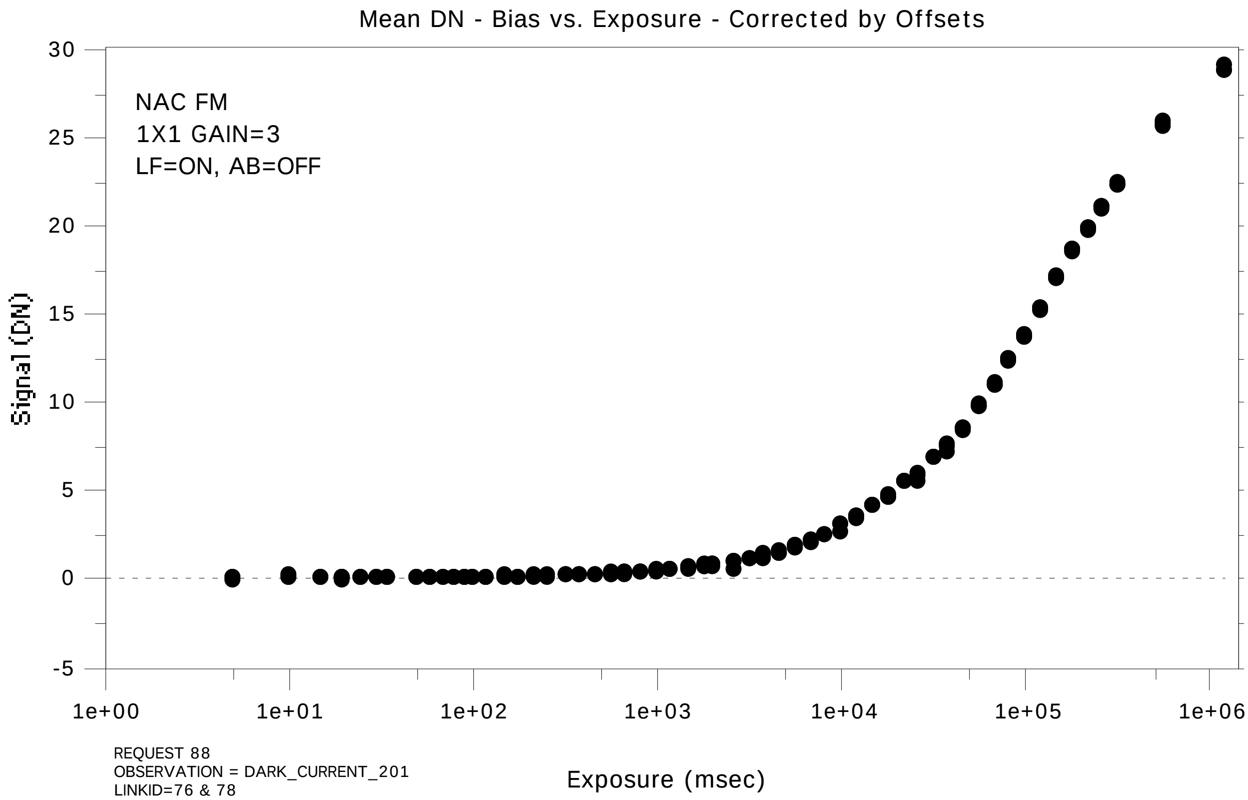
5.1.5.1.4 EXPOSURE TIME SENSITIVITY

The following plots characterize the DN(T) component of the dark-current signal in Gain State 3 in all Lightflood and Antiblooming modes. All the dark-current results below were generated by taking into account the bias levels, as in the equations above.




Mean DN - Bias vs. Exposure - Corrected by Offsets
NAC FM
1X1 GAIN=3
LF=OFF, AB=ON
Signal (DN)
2
1
0
-1
-2
-3
1e+00
1e+01
1e+02
1e+03
1e+04
1e+05
1e+06
Log Exposure (msec)
REQUEST 88
OBSERVATION = DARK_CURRENT_202
LINKID=70 & 73


Mean DN - Bias vs. Exposure - Corrected by Offsets
NAC FM
1X1 GAIN=3
LF=ON, AB=ON
Signal (DN)
30
25
20
15
10
5
0
-5
1e+00
1e+01
1e+02
1e+03
1e+04
1e+05
1e+06
Log Exposure (msec)
REQUEST 88
OBSERVATION = DARK_CURRENT_200
LINKID=74



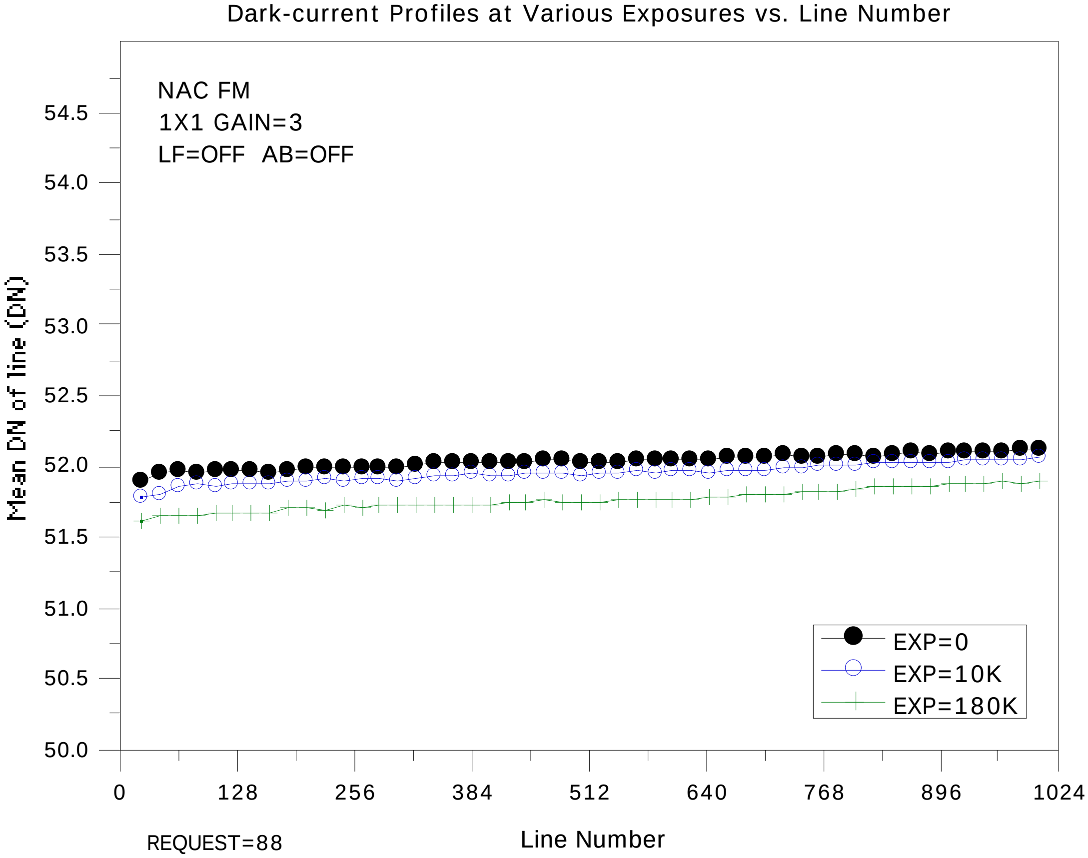
Mean DN - Bias vs. Exposure - Corrected by Offsets
NAC FM
1X1 GAIN=3
LF=ON, AB=OFF
Signal (DN)
30
25
20
15
10
5
0
-5
1e+00
1e+01
1e+02
1e+03
1e+04
1e+05
1e+06
Exposure (msec)
REQUEST 88
OBSERVATION = DARK_CURRENT_201
LINKID=76 & 78

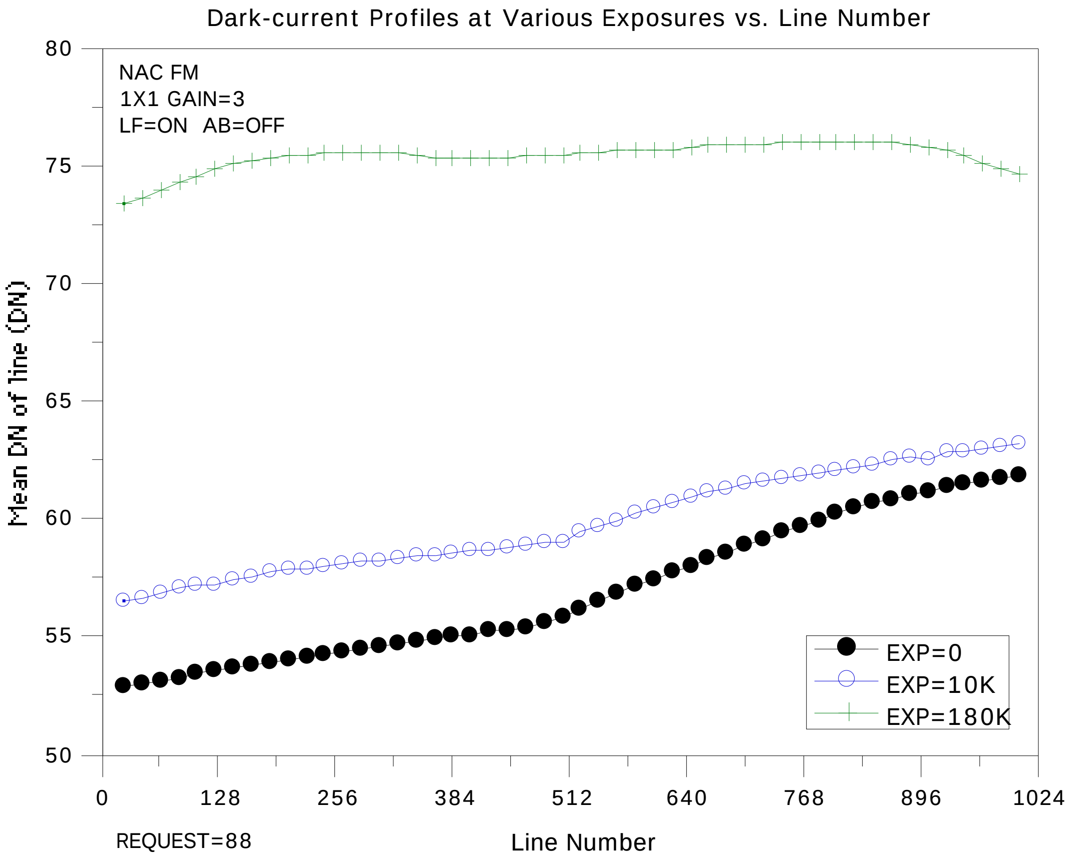
The following tabular results show the mean DN(T) component for Gain=3 derived from all Lightflood=’ON’ cases after compensation for the temperature-dependent bias levels.

Exposure	Mean DN
0	-0.005
5	-0.001
10	0.067
15	0.045
20	0.003
25	0.049
30	0.074
35	0.052
40	0.042
50	0.085
60	0.065
70	0.045
80	0.067
90	0.074
100	0.079
120	0.080
150	0.110
180	0.048
220	0.137
260	0.126
320	0.172
380	0.171
460	0.219
560	0.220
680	0.285
820	0.354
1000	0.435
1200	0.471
1500	0.588
1800	0.679
2000	0.749
2600	0.777
3200	1.087
3800	1.268
4600	1.506
5600	1.802
6800	2.089
8200	2.461
10000	2.921
12000	3.437
15000	4.071
18000	4.647
22000	5.366
26000	5.857
32000	6.747
38000	7.464
46000	8.531
56000	9.685
68000	10.944
82000	12.326
100000	13.637
120000	14.970
150000	16.942
180000	18.484
220000	19.714
260000	20.881
320000	22.268
560000	25.601
1200000	28.744

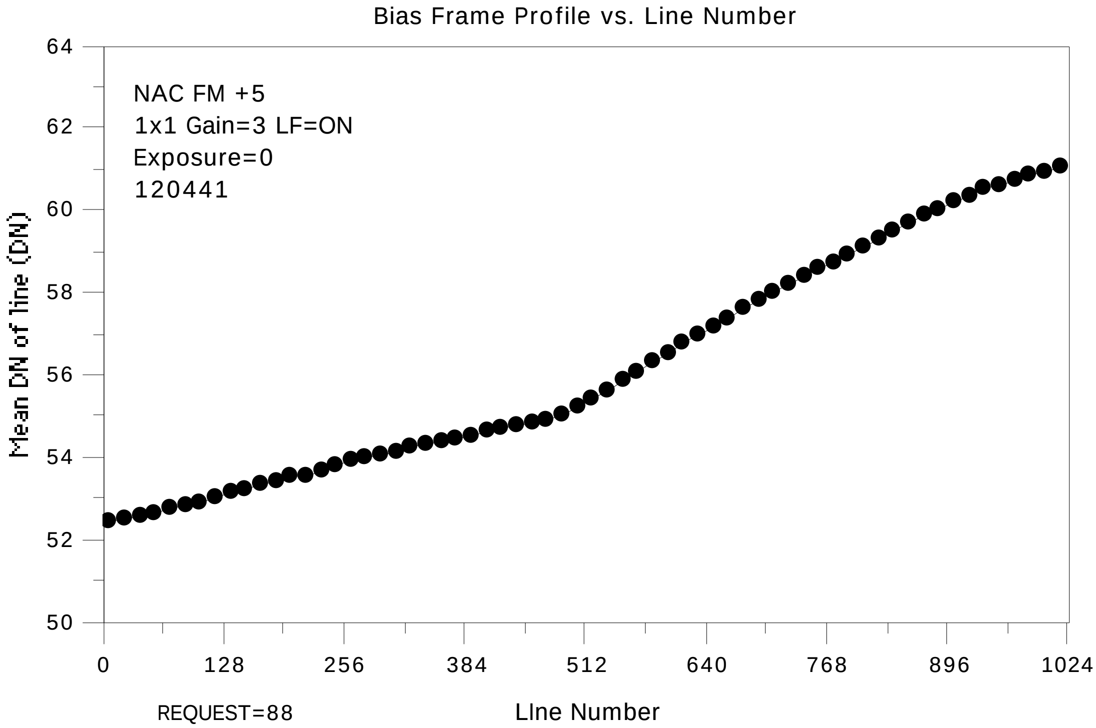
5.1.5.1.5 LINE NUMBER SENSITIVITY

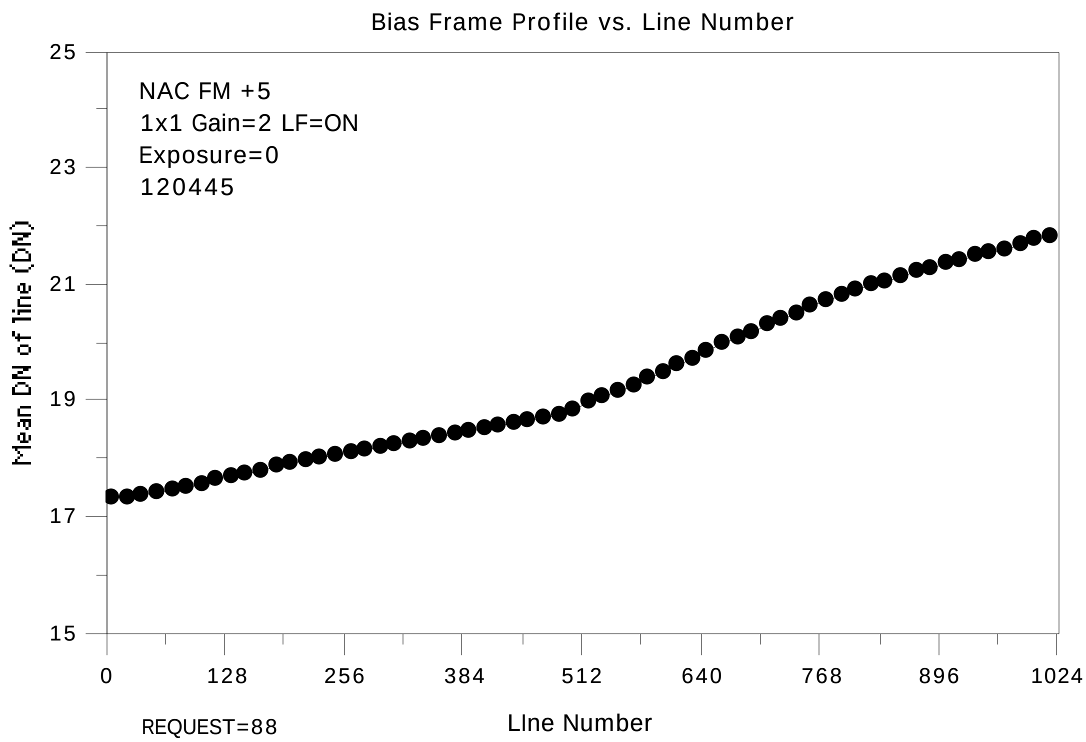
The following plots show the typical dark-current as a function of line number in various camera modes and exposure times. This signal is not corrected by overclocked pixel values.

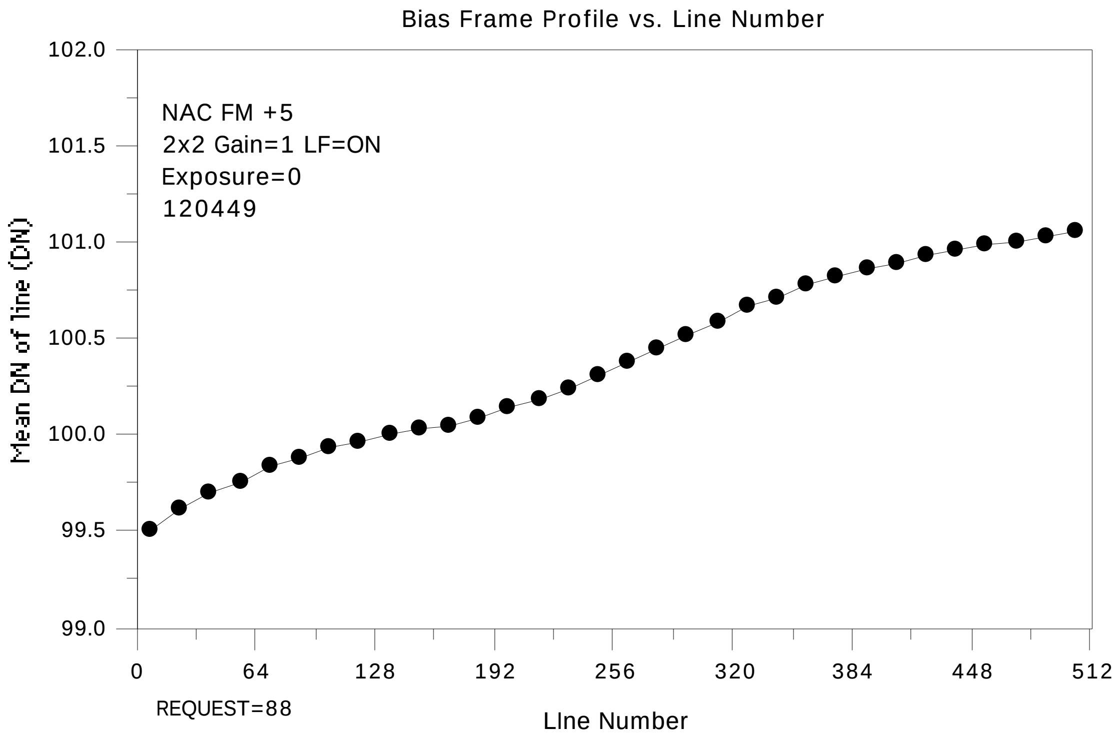



Dark-current Profiles at Various Exposures vs. Line Number
NAC FM
1X1 GAIN=3
LF=ON AB=OFF
EXP=0
EXP=10K
EXP=180K
Mean DN of line (DN)
Line Number
REQUEST=88
80
75
70
65
60
55
50
0
128
256
384
512
640
768
896
1024

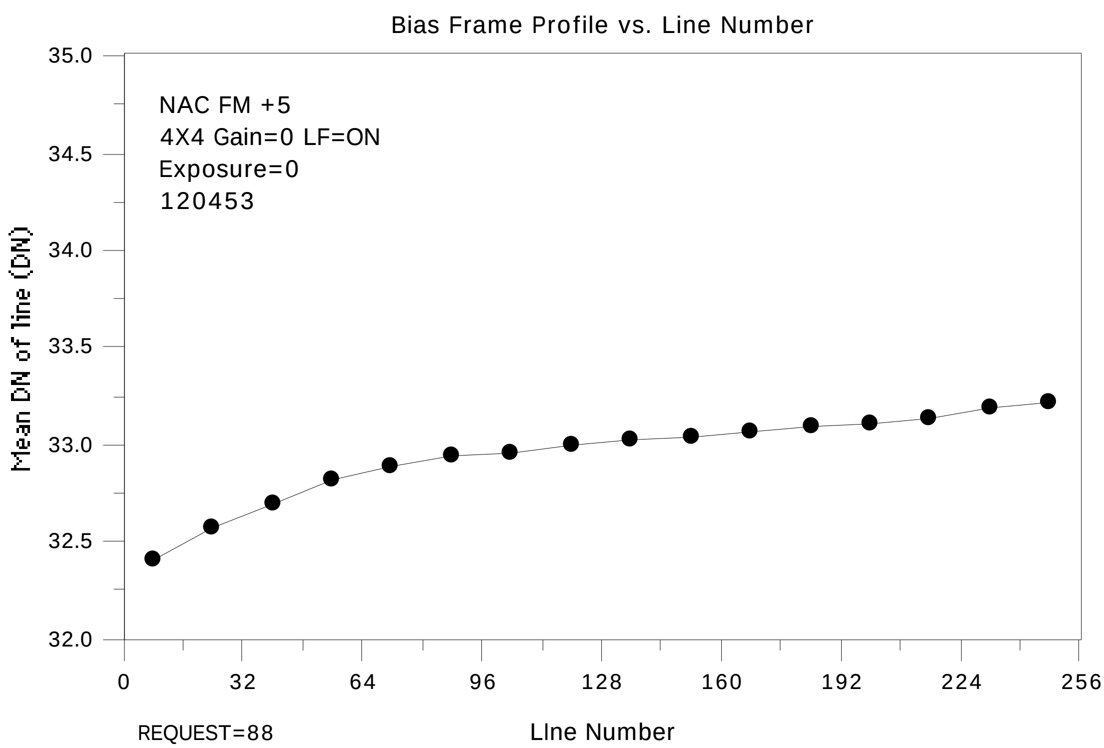
The following plots show the typical signal for exposure=0 frames as a function of line number in various camera modes.







Bias Frame Profile vs. Line Number
NAC FM +5
2x2 Gain=1 LF=ON
Exposure=0
120449
Mean DN of line (DN)
102.0
101.5
101.0
100.5
100.0
99.5
99.0
0
64
128
192
256
320
384
448
512
REQUEST=88
LIne Number

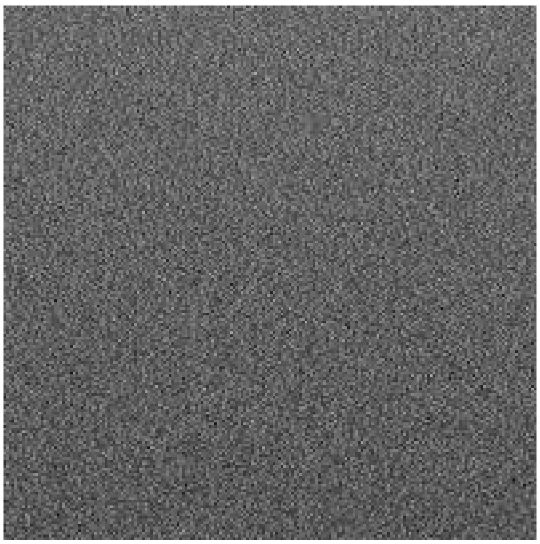


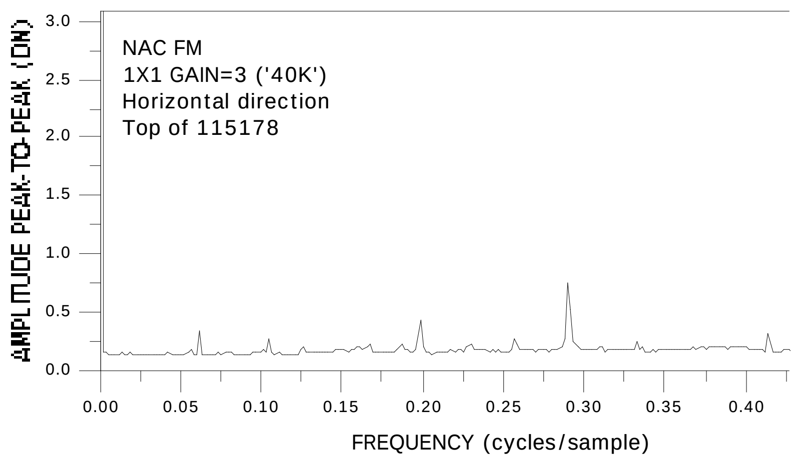
Bias Frame Profile vs. Line Number
NAC FM +5
4X4 Gain=0 LF=ON
Exposure=0
120453
Mean DN of line (DN)
35.0
34.5
34.0
33.5
33.0
32.5
32.0
0
32
64
96
128
160
192
224
256
REQUEST=88
LIne Number

5.1.5.1.6 NOISE PROBLEMS

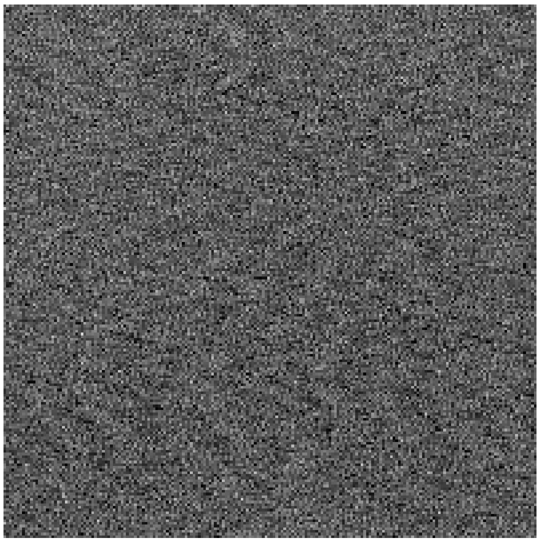
All NAC FM Thermal/vacuum dark-current data are contaminated with coherent noise patterns from unknown sources (presumably several different manifestations of the noise which appear in parts or all of most images. In all cases, the noise signal is out-of-phase the pattern does not appear as vertical lines of extra signal.

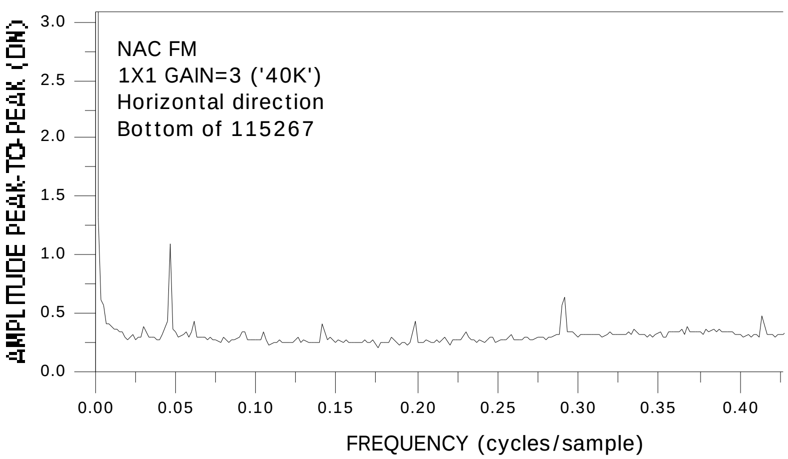
An example of a clean image area (200x200 pixels) is shown here with its associated amplitude spectrum.

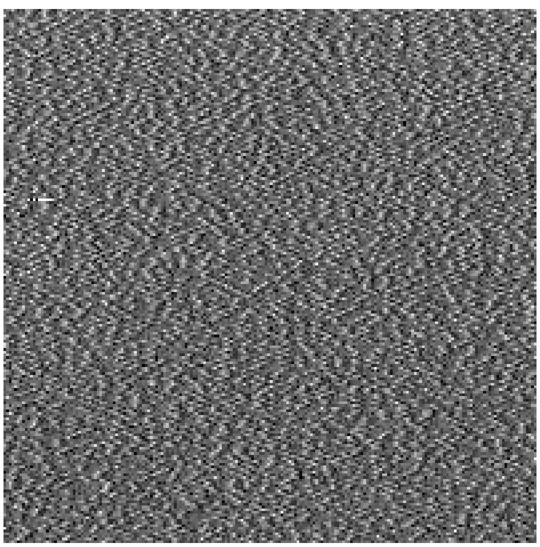


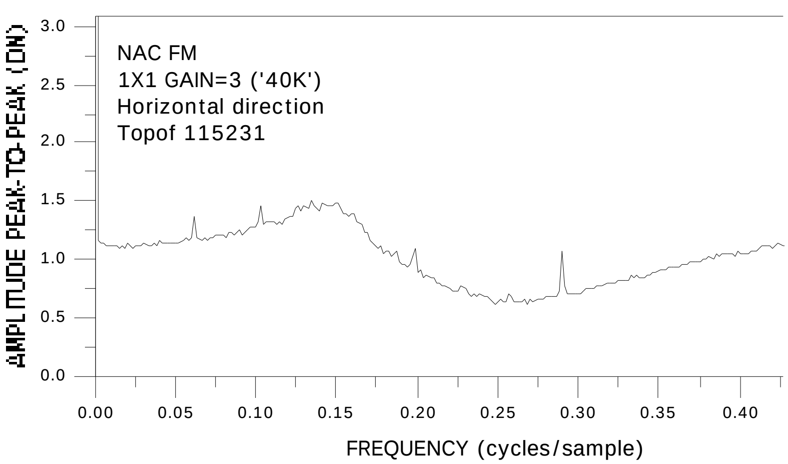


The following examples show two types of contaminated image areas and their associated spectra. The first shows a ‘herringbone’ added frequency. The second has a granular look due to a wide artifact in the spectrum.









For the above example images, the following table shows the statistics of a single 20x20 pixel area for comparison.

image	DN Range	Std. Dev.
115178	7	1.1
115231	14	2.7
115267	12	1.8

5.1.5.1.7 CONCLUSIONS

1. The bias level of Gain 3 is highly sensitive to the temperature of the Sensor Head. This temperature is reported as the Sensor Head Chassis temperature via spacecraft telemetry (not in ISS telemetry data).
2. Antiblooming has no significant effect on the dark-current.
3. For Lightflood='OFF', the Mean DN doesn't rise out of the noise except for the 1000 and 1200 second exposures, and then it is only fractions of a DN. For Gain 3, the profile vs. line number shows no slope change.
4. For Lightflood='ON' Gain 3, the Mean DN doesn't rise past 0.5 DN until an exposure time of 1.5 seconds. There is a slope change in the profile vs. line number around line 490. This is due to the change in transfer rate from detector to memory at the point where the memory fills up. This change gets gradually dominated by Lightflood effects at exposures longer than 1 second. At extreme exposure times, the Lightflood profile is all that is seen. This change from one profile to another causes the top and bottom of the frame to behave differently as a function of exposure time.
5. For Gain 2 (LF=ON, exposure=0), the slope change is also seen in the profile vs. line number.
6. For Gain 1 (LF=ON, exposure=0, 2x2 summation), the profile slope is variable from top to bottom.
7. For Gain 0 (LF=ON, exposure=0, 4x4 summation), the profile slope decreases after about line 64.
8. The telemetry rate also affects the shape of the profile for modes which can't fit all the pixel data immediately into memory (see Ref. 1). All this data was taken at the highest rate.

5.1.5.1.8 MATCHING DARK-CURRENT FRAMES TO EXPOSED FRAMES

The following are some of the considerations to keep in mind when matching dark-current frames to image frames. Simultaneous imaging will leave one frame with a Delayed Readout which must be taken into account.

1. Telemetry Rate, Delayed Readout state and Data Compression may matter only for frames which don't immediately fit into memory.
2. Uncompressed frames which don't fit into memory must be matched by dark-current frames with the same Telemetry Rate and Delayed Readout state.
3. Compressed frames which don't fit into memory when compressed will have an unpredictable dark-current behavior because the rate of memory 'fillup' is scene-dependent.
4. All Lightflood='ON' frames must be matched by dark-current frames with the same exposure time. Although, exposure times of less that 1000 msec are essentially equivalent.
5. The Temperature of the Sensor Head greatly affects Gain State 3, but all effects seem to be tracked by the bias level. This is reported for each frame.

Once a dark-current frame has been matched to an exposed frame, the following considerations apply.

1. Before subtracting a dark-current frame, both the dark-current frame and the exposed frame must have their own bias level subtracted out. This will correct for differences in temperature.

$$S = DN - \overline{BL} - \left(dn - \overline{bl}\right)$$

where S is the signal
DN is the measured DN of the image
$\overline{BL}$ is the mean bias level of the image
dn is the measured DN of the dark-current frame
$\overline{bl}$ is the mean bias level of the dark-current frame

The bias level is recorded in the VICAR label in the OFFSET keyword. This mean value is derived from the over-clocked pixel values recorded in the binary prefix of each line. These values reside in word 12 of the prefix. For 8-bit data, two over-clocked pixel values reside in the two bytes of word 12.

2. All these calculations will be best if done in floating point and when it isn't necessary to truncate back to integer.

5.1.5.1.9 SUMMARY

Inflight collection of unshuttered frames will be absolutely necessary for proper radiometric analysis. The camera modes used for the actual image data need to be used for the unshuttered frames as well. The following list outlines our current knowledge of parameters which seem to affect the dark-current (whether the bias or the exposure-dependent components) for at least some images.

Parameter	Affects Dark Current in this images
Camera	All
Gain	All
Summation Mode	All
Temperature of CCD	All
Telemetry Rate	All that don't fit into memory
Lossless Data Compression	All that don't fit into memory
Lossy Data Compression	All
Exposure Time	All that use Lightflood
Lightflood	All
Temperature of Sensor Head	Gain state 3
Simultaneous Imaging	All that don't fit into memory

The image types which do not fit into memory are:

1. 1x1 12-bit uncompressed
2. 1x1 12-bit Lossless compression
3. 1x1 8-bit uncompressed