5. SUBSYSTEM CALIBRATION

5.1 RADIOMETRIC CALIBRATION

5.1.1 SHUTTER OFFSET

5.1.1.1 NAC FM SHUTTER OFFSET CALIBRATION RESULTS

As reported in Reference 5.1.1.1-1

Reference 5.1.1.1-1 - IOM 388-PAG-CCA97-5, " NAC FM Calibration Results: Shutter Offset - Revision 1", C. Avis, March 3, 1997, Revision Note: Corrected the labels of three plots

Reference 5.1.1.1-2 - IOM ISS DFM 387-MS-96-623, "Component Level Calibration for the ISS NAC Flight Shutter", M. Schwochert , December 9, 1996

5.1.1.1.1 INTRODUCTION

The Narrow-angle Flight Model thermal/vacuum testing included the acquisition of a set of images for determination of the Shutter-offset. This is the spatially-dependent correction between the commanded and the actual exposure times.

Three sets of image data were taken at Gain 3 in the 1x1 mode. These were at temperatures of -10° C, +5° C and +25° C. The sequences are designed to maintain a constant DN output by varying the illumination inversely with the exposure time. Three images were taken at each exposure level. At +5° C and +25° C, eleven exposure levels were obtained while increasing the exposure time from 5 to 100 milliseconds and eleven levels were obtained while decreasing the exposure time from 100 to 5 milliseconds. At -10° C, seven levels were obtained from 5 to 35 milliseconds. In addition, images were obtained with a zero exposure time.

5.1.1.1.2 METHOD

The Shutter-offset is spatially-dependent, but for a given small area of the image it is constant and

$$S = VL(T - t_0)$$

where

S	is the measured signal (in DN)
L	is the measured radiance (in arbitrary radiance units)
T	is the commanded exposure time (in milliseconds)
t_0	is the shutter-offset (in milliseconds)
V	is the system's sensitivity (in DN/radiance_unit-milliseconds)

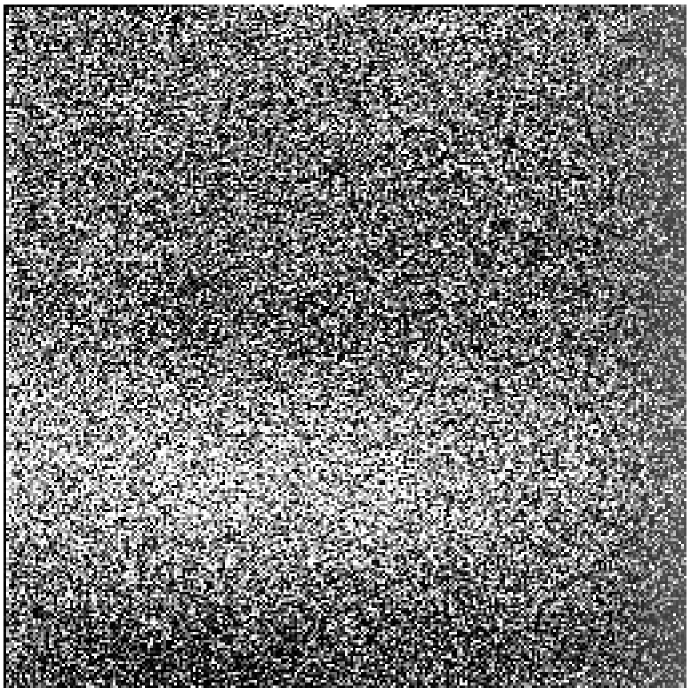
This can be rearranged to

$$S/L = VT - Vt_0$$

This linear equation (with S, L and T known) can then be solved by least-squares because of the many exposure levels available.

Images at the same exposure time are combined to produce signal values at 100 small areas so that the values for V and t_0 can be independently derived there. The 100 derived values are then compared and any areas giving values more than 2 sigma from the mean are flagged as bad. Global values for V and t_0 are then derived by averaging the values at the remaining good areas.

The analysis described here was performed using the top 250 lines of the image because of an unknown signal contaminating the lower part of the frames.



This signal resulted in large disagreement in Shutter-offset values within an image column (all points of which should give the same value). The values derived near the top and bottom of the image agreed pretty well, but near the middle there was a large deviation.

This is the result in spite of using appropriate bias (exposure=0) frames. The imperfect flatness of the flat-field images would not affect the Shutter-offset, only the Sensitivity. A limited investigation has not found the source of the extra signal. Further studies are needed to resolve this issue.

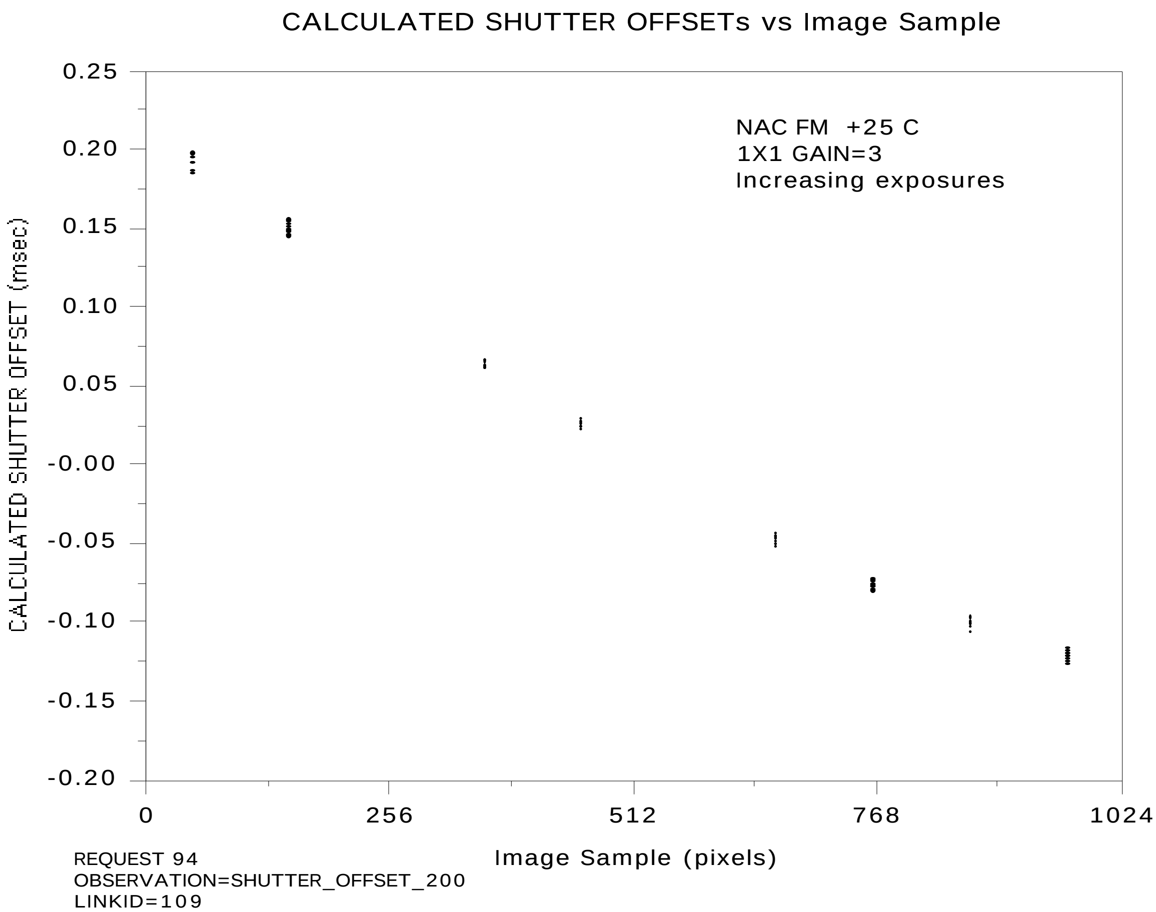
This Shutter-offset analysis shows:

- The observations of increasing and decreasing exposure times agree very well.
- Exposure times of 25 msec had to be ignored because those data did not fit the linear function described in the METHOD section above. This is consistent with the conclusions of Reference 5.1.1.1-2 that this commanded time was 1.65 msec. In addition, the -10° C data at 5 milliseconds had inconsistent radiance values and these data were ignored.
- The Shutter-offset is slightly dependent upon temperature, going from a mean value of -0.00 milliseconds at +25° C to -0.05 at -10° C.
- The Shutter-offset value passes through zero somewhere within the frame, indicating that actual exposure time is longer than the commanded time on the right side of the image and shorter on the left.

Ignoring the region of unexplained signal and the 25 millisecond data gives good results for this Shutter-offset analysis at +25° C and +5° C. The -10° C data, having few exposures to use, is less reliable (see plots below). In this calibration, the radiance was recorded in units of picoamps, giving Sensitivity the units of DN/picoamp-milliseconds.

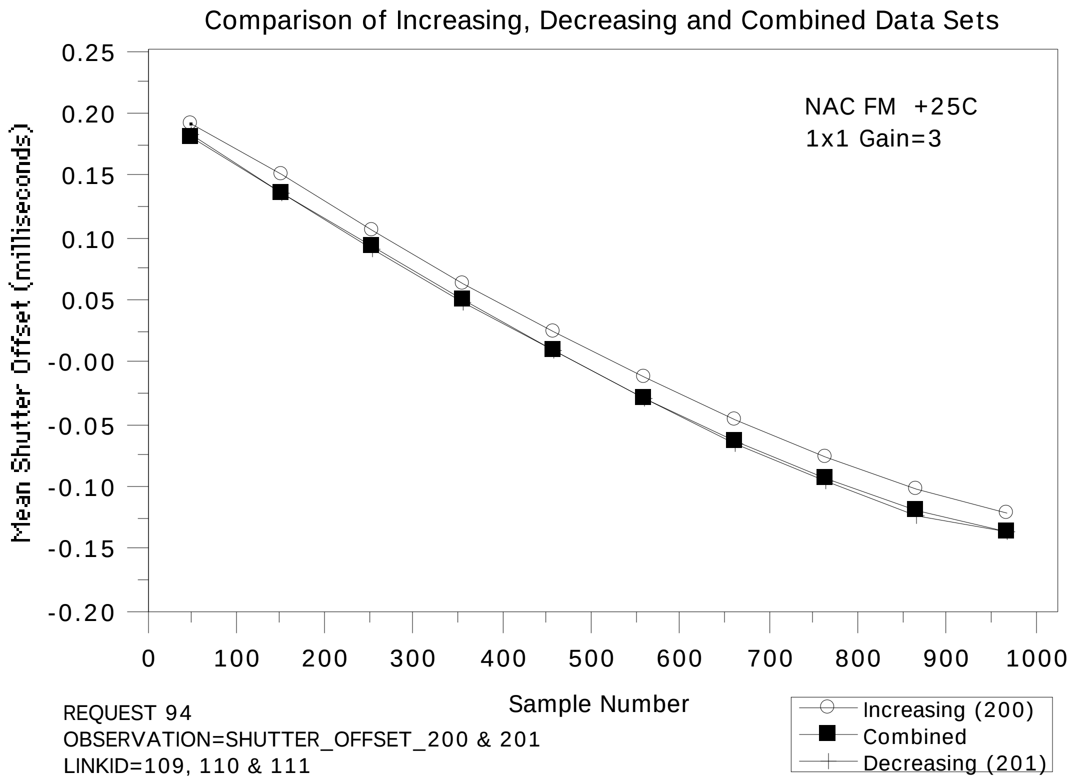
	Mean Global Sensitivity	Mean Global Shutter Offset
+25 C increasing	0.0199 ± 0.0008	+0.0147 ± 0.0007
+25 C decreasing	0.0199 ± 0.0006	-0.0010 ± 0.0006
+25 C combined	0.0199 ± 0.0005	+0.0002 ± 0.0005
+ 5 C increasing	0.0201 ± 0.0016	-0.0484 ± 0.0007
+ 5 C decreasing	0.0201 ± 0.0037	-0.0226 ± 0.0017
+ 5 C combined	0.0201 ± 0.0026	-0.0348 ± 0.0012
-10 C increasing	0.0200 ± 0.0009	-0.0575 ± 0.0009
-10 C decreasing	0.0200 ± 0.0013	-0.0499 ± 0.0013
-10 C combined	0.0200 ± 0.0011	-0.0543 ± 0.0011

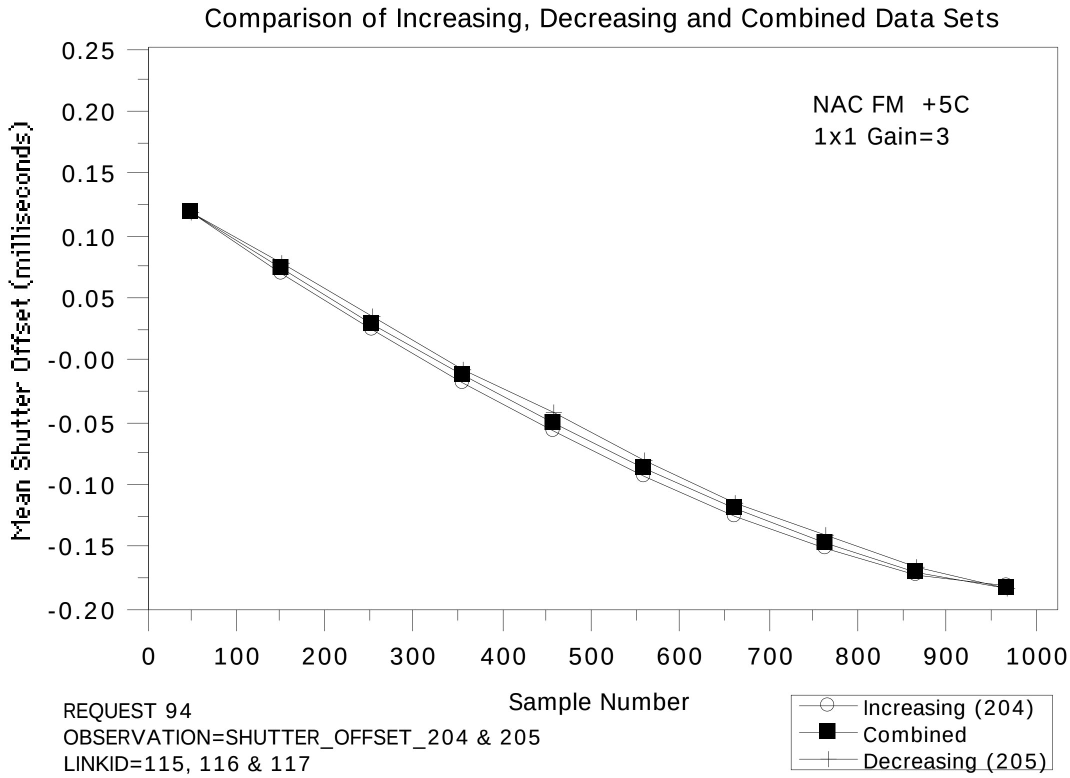
The mean value of t_0 is of little use because we require its functional dependence upon sample number (the shutter travels in the sample direction). The following graph plots the derived t_0 value vs. the sample number of each of the 100 small areas for one case (lines 1-250 only). It shows the degree of agreement between the 10 values derived at each image sample.



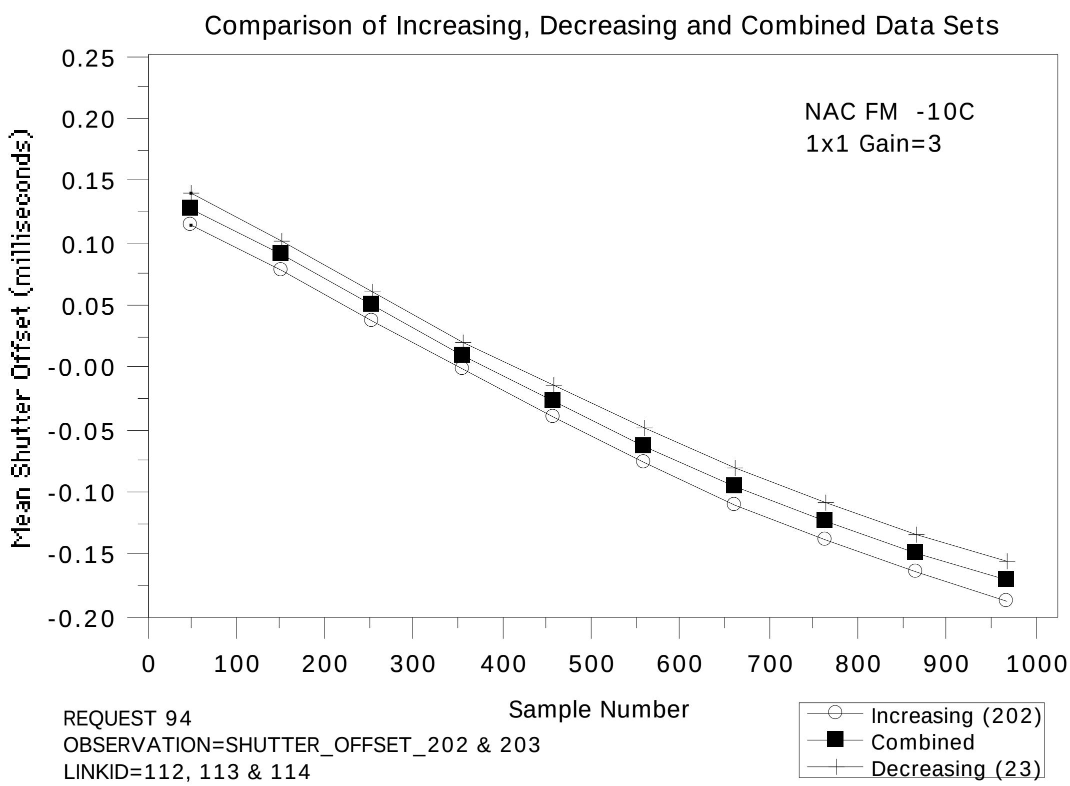
5.1.1.1.3 MEAN SHUTTER-OFFSET vs. IMAGE SAMPLE NUMBER

Using the upper portion of the images, the mean value of the Shutter-offset across the image area is shown below for the three temperatures. The observations with increasing exposure times, decreasing exposure times and the combination of the two are all plotted.





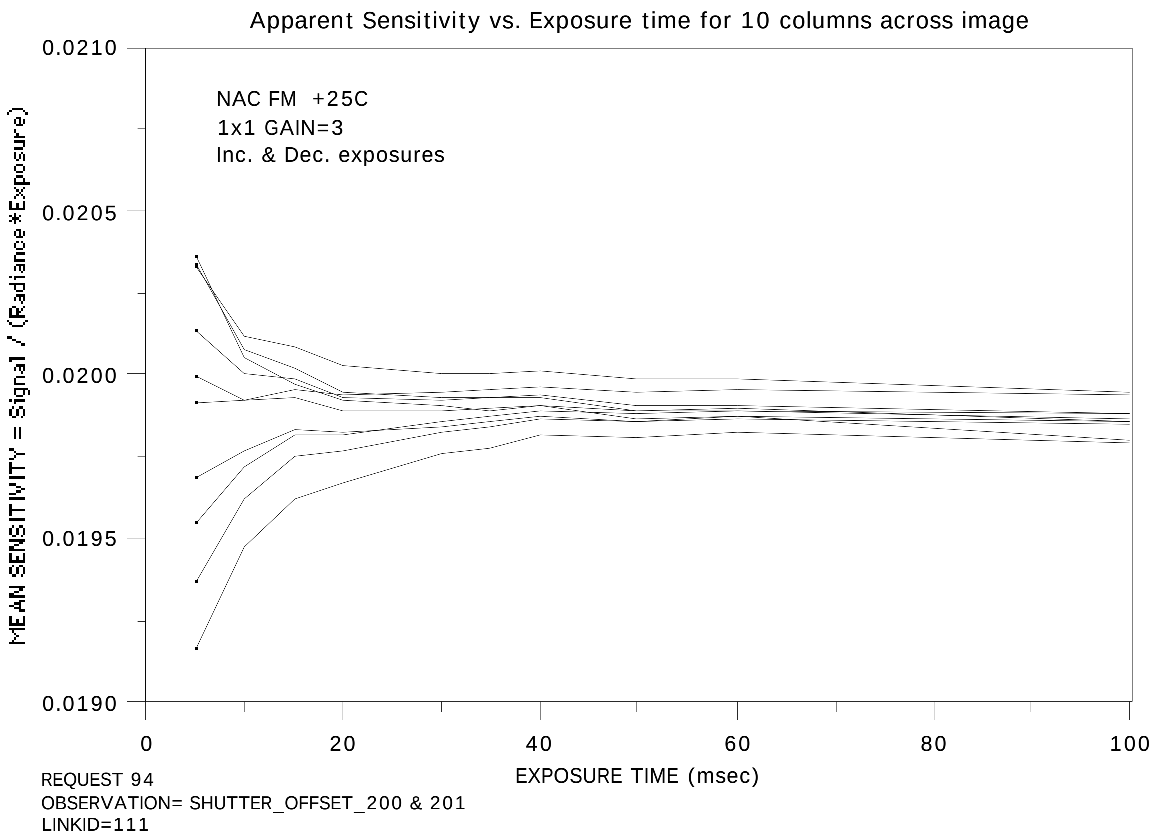
REQUEST 94
OBSERVATION=SHUTTER_OFFSET_204 & 205
LINKID=115, 116 & 117

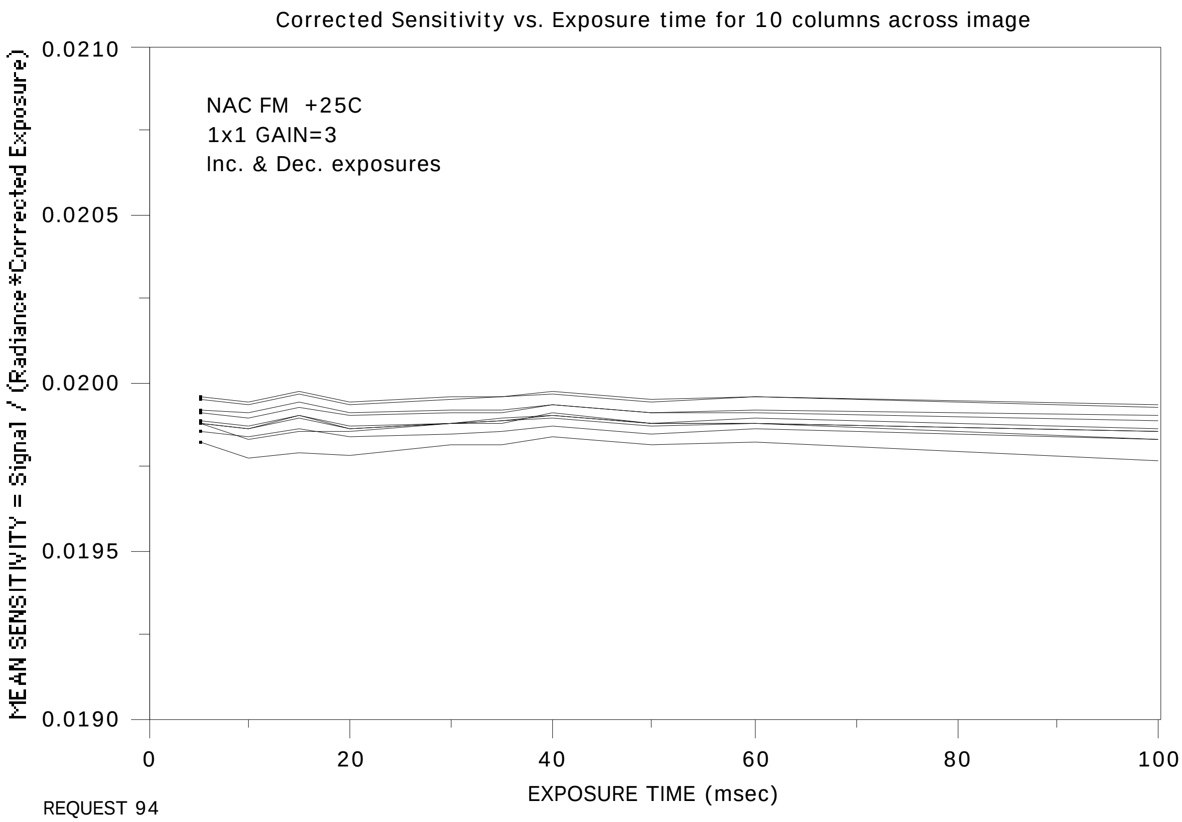


REQUEST 94
OBSERVATION=SHUTTER_OFFSET_202 & 203
LINKID=112, 113 & 114

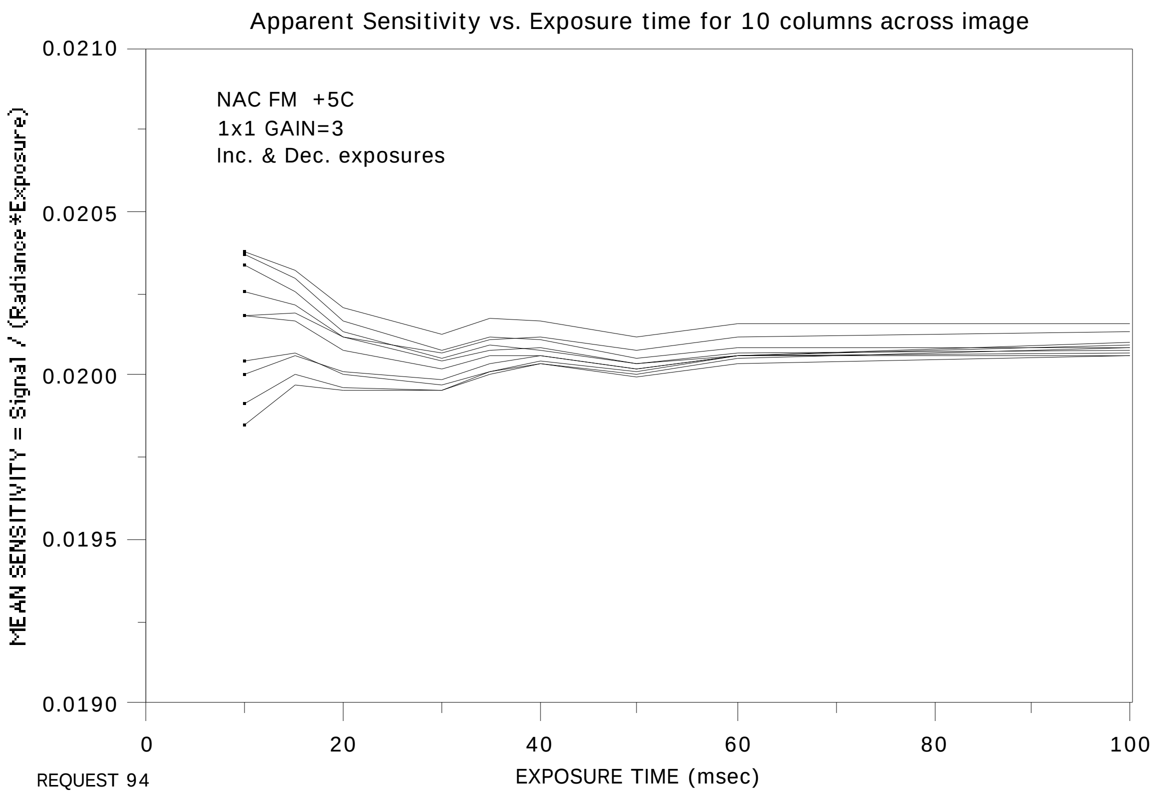
5.1.1.1.4 APPARENT SENSITIVITY - UNCORRECTED AND CORRECTED

To illustrate the effect of the Shutter-offset, the following graphs plot Sensitivity vs. the commanded exposure time (both with and without the Shutter-offset correction). That is, S/LT vs. T and $S/L(T - t_0)$ vs. T. Of course, in the ideal case, Sensitivity should be a constant, and the use of the correction gets the plots closer to that case. The ten columns of data (each with a different Shutter-offset) are plotted in both uncorrected and corrected versions. The lines do not overly even in the corrected versions because of the imperfect flatness of the source (some areas receiving more light, i.e., appearing more sensitive).

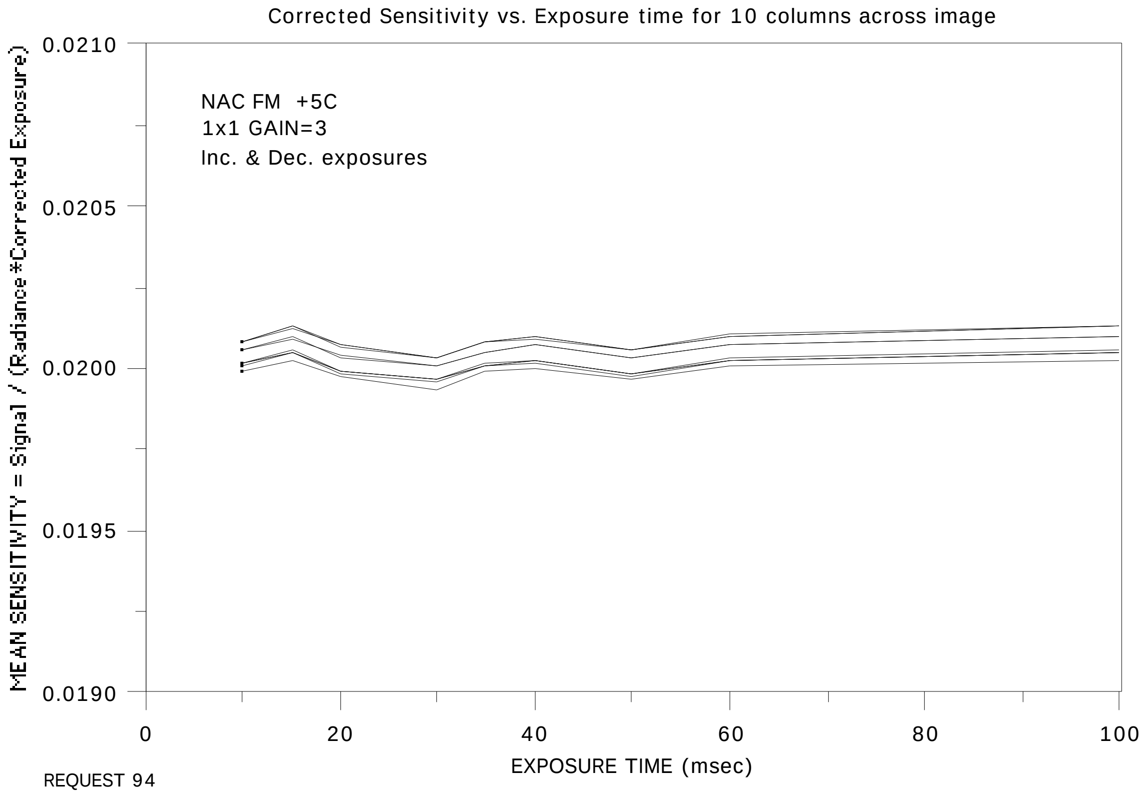




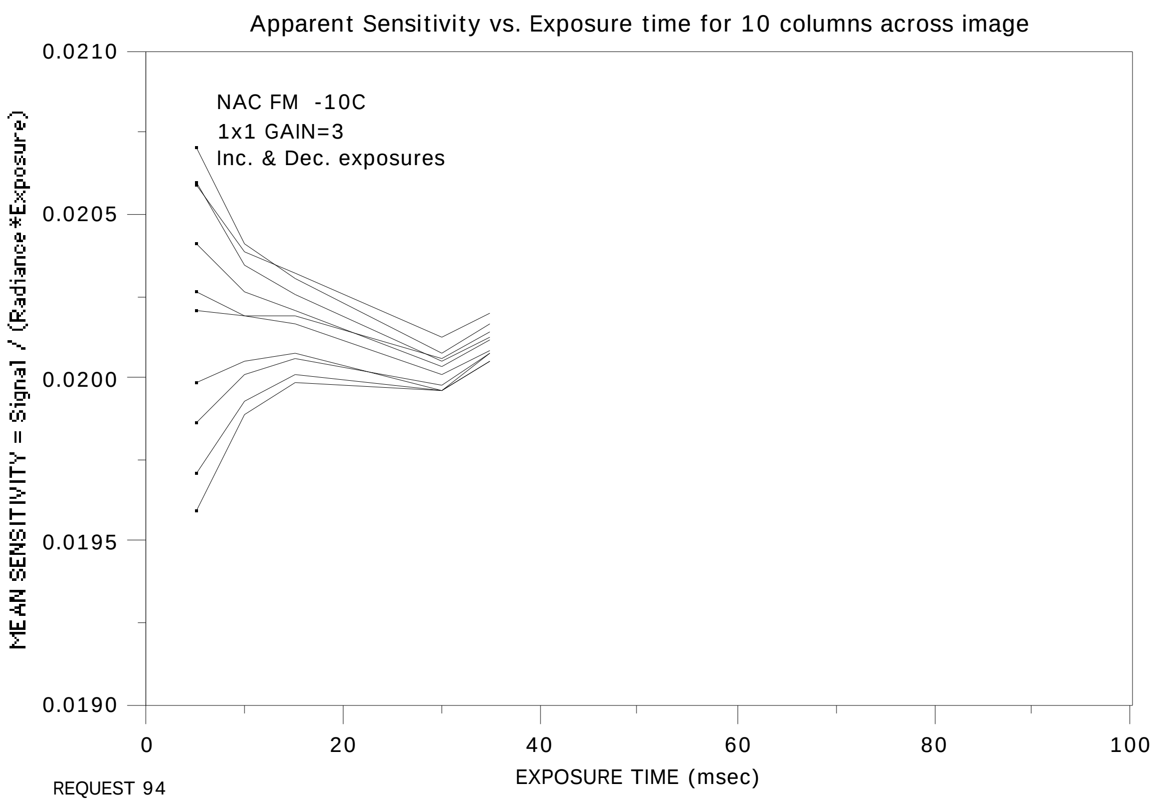
REQUEST 94
OBSERVATION= SHUTTER_OFFSET_200 & 201
LINKID=111



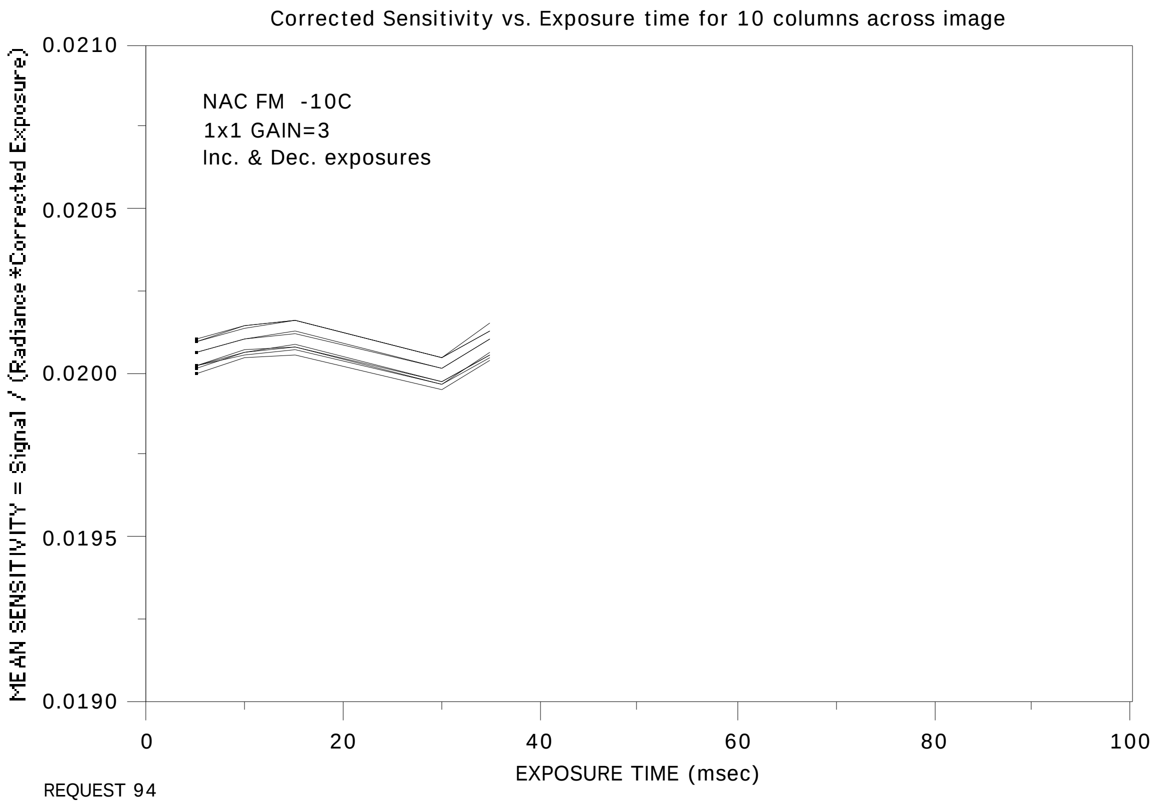
REQUEST 94
OBSERVATION= SHUTTER_OFFSET_204 & 205
LINKID=117



REQUEST 94
OBSERVATION= SHUTTER_OFFSET_204 & 205
LINKID=117



REQUEST 94
OBSERVATION= SHUTTER_OFFSET_202 & 203
LINKID=114



REQUEST 94
OBSERVATION= SHUTTER_OFFSET_202 & 203
LINKID=114

5.1.1.1.5 IMAGES USED IN SHUTTER OFFSET ANALYSIS

image	day	eventtime	observation	mode	gain	expos	radiance
+25°C (LINKID=109,110,111)							
116484	111	9:8:55.0	SHUTTER_OFFSET_200	FULL	40K	0	14600.00
116485	111	9:10:25.0	SHUTTER_OFFSET_200	FULL	40K	0	14600.00
116486	111	9:11:54.0	SHUTTER_OFFSET_200	FULL	40K	0	14600.00
116487	111	9:14:38.0	SHUTTER_OFFSET_200	FULL	40K	5	14600.00
116488	111	9:16:7.0	SHUTTER_OFFSET_200	FULL	40K	5	14600.00
116489	111	9:17:37.0	SHUTTER_OFFSET_200	FULL	40K	5	14600.00
116490	111	9:24:55.0	SHUTTER_OFFSET_200	FULL	40K	10	14600.00
116491	111	9:26:24.0	SHUTTER_OFFSET_200	FULL	40K	10	14600.00
116492	111	9:27:54.0	SHUTTER_OFFSET_200	FULL	40K	10	14600.00
116493	111	9:36:14.0	SHUTTER_OFFSET_200	FULL	40K	15	4880.00
116494	111	9:37:43.0	SHUTTER_OFFSET_200	FULL	40K	15	4880.00
116495	111	9:39:13.0	SHUTTER_OFFSET_200	FULL	40K	15	4880.00
116496	111	9:42:38.0	SHUTTER_OFFSET_200	FULL	40K	20	3660.00
116497	111	9:44:7.0	SHUTTER_OFFSET_200	FULL	40K	20	3660.00
116498	111	9:45:37.0	SHUTTER_OFFSET_200	FULL	40K	20	3660.00
116502	111	9:55:9.0	SHUTTER_OFFSET_200	FULL	40K	30	2440.00
116503	111	9:56:38.0	SHUTTER_OFFSET_200	FULL	40K	30	2440.00
116504	111	9:58:8.0	SHUTTER_OFFSET_200	FULL	40K	30	2440.00
116505	111	10:1:5.0	SHUTTER_OFFSET_200	FULL	40K	35	2090.00
116506	111	10:2:34.0	SHUTTER_OFFSET_200	FULL	40K	35	2090.00
116507	111	10:4:4.0	SHUTTER_OFFSET_200	FULL	40K	35	2090.00
116508	111	10:8:35.0	SHUTTER_OFFSET_200	FULL	40K	35	2090.00
116509	111	10:10:4.0	SHUTTER_OFFSET_200	FULL	40K	35	2090.00
116510	111	10:13:29.0	SHUTTER_OFFSET_200	FULL	40K	40	1830.00
116511	111	10:14:58.0	SHUTTER_OFFSET_200	FULL	40K	40	1830.00
116512	111	10:16:28.0	SHUTTER_OFFSET_200	FULL	40K	40	1830.00
116513	111	10:18:32.0	SHUTTER_OFFSET_200	FULL	40K	40	1830.00
116514	111	10:22:36.0	SHUTTER_OFFSET_200	FULL	40K	50	1460.00
116515	111	10:24:6.0	SHUTTER_OFFSET_200	FULL	40K	50	1460.00
116516	111	10:25:35.0	SHUTTER_OFFSET_200	FULL	40K	50	1460.00
116517	111	10:28:47.0	SHUTTER_OFFSET_200	FULL	40K	60	1220.00
116518	111	10:30:16.0	SHUTTER_OFFSET_200	FULL	40K	60	1220.00
116519	111	10:31:46.0	SHUTTER_OFFSET_200	FULL	40K	60	1220.00
116520	111	10:36:45.0	SHUTTER_OFFSET_200	FULL	40K	100	730.00
116521	111	10:38:14.0	SHUTTER_OFFSET_200	FULL	40K	100	730.00
116522	111	10:39:44.0	SHUTTER_OFFSET_200	FULL	40K	100	730.00
116523	111	10:41:51.0	SHUTTER_OFFSET_200	FULL	40K	100	730.00
116524	111	10:50:20.0	SHUTTER_OFFSET_201	FULL	40K	100	730.00
116525	111	10:51:49.0	SHUTTER_OFFSET_201	FULL	40K	100	730.00
116526	111	10:53:19.0	SHUTTER_OFFSET_201	FULL	40K	100	730.00
116527	111	10:56:37.0	SHUTTER_OFFSET_201	FULL	40K	60	1220.00
116528	111	10:58:6.0	SHUTTER_OFFSET_201	FULL	40K	60	1220.00
116529	111	10:59:36.0	SHUTTER_OFFSET_201	FULL	40K	60	1220.00
116530	111	11:2:51.0	SHUTTER_OFFSET_201	FULL	40K	50	1460.00
116531	111	11:4:20.0	SHUTTER_OFFSET_201	FULL	40K	50	1460.00
116532	111	11:5:50.0	SHUTTER_OFFSET_201	FULL	40K	50	1460.00
116533	111	11:8:1.0	SHUTTER_OFFSET_201	FULL	40K	50	1460.00
116534	111	11:10:32.0	SHUTTER_OFFSET_201	FULL	40K	50	1460.00
116535	111	11:13:55.0	SHUTTER_OFFSET_201	FULL	40K	40	1830.00
116536	111	11:15:25.0	SHUTTER_OFFSET_201	FULL	40K	40	1830.00
116537	111	11:16:54.0	SHUTTER_OFFSET_201	FULL	40K	40	1830.00
116538	111	11:20:17.0	SHUTTER_OFFSET_201	FULL	40K	35	2090.00
116539	111	11:21:47.0	SHUTTER_OFFSET_201	FULL	40K	35	2090.00
116540	111	11:23:16.0	SHUTTER_OFFSET_201	FULL	40K	35	2090.00
116541	111	11:26:22.0	SHUTTER_OFFSET_201	FULL	40K	30	2440.00
116542	111	11:27:52.0	SHUTTER_OFFSET_201	FULL	40K	30	2440.00
116543	111	11:29:21.0	SHUTTER_OFFSET_201	FULL	40K	30	2440.00
116550	111	11:50:57.0	SHUTTER_OFFSET_201	FULL	40K	20	3660.00
116551	111	11:52:27.0	SHUTTER_OFFSET_201	FULL	40K	20	3660.00
116552	111	11:53:56.0	SHUTTER_OFFSET_201	FULL	40K	20	3660.00
116553	111	12:0:54.0	SHUTTER_OFFSET_201	FULL	40K	15	4880.00
116554	111	12:2:24.0	SHUTTER_OFFSET_201	FULL	40K	15	4880.00
116555	111	12:3:53.0	SHUTTER_OFFSET_201	FULL	40K	15	4880.00
116556	111	12:6:27.0	SHUTTER_OFFSET_201	FULL	40K	15	4880.00
116557	111	12:13:6.0	SHUTTER_OFFSET_201	FULL	40K	10	7320.00
116558	111	12:14:36.0	SHUTTER_OFFSET_201	FULL	40K	10	7320.00
116559	111	12:16:5.0	SHUTTER_OFFSET_201	FULL	40K	10	7320.00
116560	111	12:23:1.0	SHUTTER_OFFSET_201	FULL	40K	5	14640.00
116561	111	12:24:31.0	SHUTTER_OFFSET_201	FULL	40K	5	14640.00
116562	111	12:26:0.0	SHUTTER_OFFSET_201	FULL	40K	5	14640.00
116563	111	12:31:15.0	SHUTTER_OFFSET_201	FULL	40K	0	14640.00
116564	111	12:32:45.0	SHUTTER_OFFSET_201	FULL	40K	0	14640.00
116565	111	12:34:14.0	SHUTTER_OFFSET_201	FULL	40K	0	14640.00
-10°C (LINKID=112,113,114)							
119877	138	16:37:58.0	SHUTTER_OFFSET_202	FULL	40K	0	13930.00
119878	138	16:39:27.0	SHUTTER_OFFSET_202	FULL	40K	0	13930.00
119879	138	16:40:57.0	SHUTTER_OFFSET_202	FULL	40K	0	13930.00
119880	138	16:43:36.0	SHUTTER_OFFSET_202	FULL	40K	5	13930.00
119881	138	16:45:5.0	SHUTTER_OFFSET_202	FULL	40K	5	13930.00
119882	138	16:46:35.0	SHUTTER_OFFSET_202	FULL	40K	5	13930.00
119883	138	16:56:24.0	SHUTTER_OFFSET_202	FULL	40K	10	6960.00
119884	138	16:57:53.0	SHUTTER_OFFSET_202	FULL	40K	10	6960.00
119885	138	16:59:23.0	SHUTTER_OFFSET_202	FULL	40K	10	6960.00
119886	138	17:24:47.0	SHUTTER_OFFSET_202	FULL	40K	15	4640.00
119887	138	17:26:16.0	SHUTTER_OFFSET_202	FULL	40K	15	4640.00
119888	138	17:27:46.0	SHUTTER_OFFSET_202	FULL	40K	15	4640.00
119898	138	18:15:33.0	SHUTTER_OFFSET_202	FULL	40K	30	2320.00
119899	138	18:17:2.0	SHUTTER_OFFSET_202	FULL	40K	30	2320.00
119900	138	18:18:32.0	SHUTTER_OFFSET_202	FULL	40K	30	2320.00
119901	138	18:23:38.0	SHUTTER_OFFSET_202	FULL	40K	35	1990.00
119902	138	18:25:7.0	SHUTTER_OFFSET_202	FULL	40K	35	1990.00
119903	138	18:26:37.0	SHUTTER_OFFSET_202	FULL	40K	35	1990.00
119904	138	18:32:49.0	SHUTTER_OFFSET_203	FULL	40K	35	1990.00
119905	138	18:34:18.0	SHUTTER_OFFSET_203	FULL	40K	35	1990.00
119906	138	18:35:48.0	SHUTTER_OFFSET_203	FULL	40K	35	1990.00
119907	138	19:19:19.0	SHUTTER_OFFSET_203	FULL	40K	30	2320.00
119908	138	19:20:49.0	SHUTTER_OFFSET_203	FULL	40K	30	2320.00
119909	138	19:22:18.0	SHUTTER_OFFSET_203	FULL	40K	30	2320.00
119919	138	19:57:17.0	SHUTTER_OFFSET_203	FULL	40K	15	4640.00
119920	138	19:58:47.0	SHUTTER_OFFSET_203	FULL	40K	15	4640.00
119921	138	20:0:16.0	SHUTTER_OFFSET_203	FULL	40K	15	4640.00
119922	138	20:9:49.0	SHUTTER_OFFSET_203	FULL	40K	10	6960.00
119923	138	20:11:19.0	SHUTTER_OFFSET_203	FULL	40K	10	6960.00
119924	138	20:12:48.0	SHUTTER_OFFSET_203	FULL	40K	10	6960.00
119925	138	20:19:46.0	SHUTTER_OFFSET_203	FULL	40K	5	13930.00
119926	138	20:21:16.0	SHUTTER_OFFSET_203	FULL	40K	5	13930.00
119927	138	20:22:45.0	SHUTTER_OFFSET_203	FULL	40K	5	13930.00
119928	138	20:26:54.0	SHUTTER_OFFSET_203	FULL	40K	0	13930.00
119929	138	20:28:24.0	SHUTTER_OFFSET_203	FULL	40K	0	13930.00
119930	138	20:29:53.0	SHUTTER_OFFSET_203	FULL	40K	0	13930.00
+ 5°C (LINKID=115,116,117)							
121172	142	10:32:12.0	SHUTTER_OFFSET_204	FULL	40K	0	14320.00
121173	142	10:33:41.0	SHUTTER_OFFSET_204	FULL	40K	0	14320.00
121174	142	10:35:10.0	SHUTTER_OFFSET_204	FULL	40K	0	14320.00
121181	142	10:57:38.0	SHUTTER_OFFSET_204	FULL	40K	10	7160.00
121182	142	10:59:7.0	SHUTTER_OFFSET_204	FULL	40K	10	7160.00
121183	142	11:0:36.0	SHUTTER_OFFSET_204	FULL	40K	10	7160.00
121184	142	11:4:48.0	SHUTTER_OFFSET_204	FULL	40K	15	4780.00
121185	142	11:6:17.0	SHUTTER_OFFSET_204	FULL	40K	15	4780.00
121186	142	11:7:46.0	SHUTTER_OFFSET_204	FULL	40K	15	4780.00
121187	142	11:11:48.0	SHUTTER_OFFSET_204	FULL	40K	20	3580.00
121188	142	11:13:17.0	SHUTTER_OFFSET_204	FULL	40K	20	3580.00
121189	142	11:14:46.0	SHUTTER_OFFSET_204	FULL	40K	20	3580.00
121193	142	11:33:1.0	SHUTTER_OFFSET_204	FULL	40K	30	2390.00
121194	142	11:34:30.0	SHUTTER_OFFSET_204	FULL	40K	30	2390.00
121195	142	11:35:59.0	SHUTTER_OFFSET_204	FULL	40K	30	2390.00
121196	142	11:39:8.0	SHUTTER_OFFSET_204	FULL	40K	35	2050.00
121197	142	11:40:37.0	SHUTTER_OFFSET_204	FULL	40K	35	2050.00
121198	142	11:42:6.0	SHUTTER_OFFSET_204	FULL	40K	35	2050.00
121199	142	11:45:14.0	SHUTTER_OFFSET_204	FULL	40K	40	1790.00
121200	142	11:46:43.0	SHUTTER_OFFSET_204	FULL	40K	40	1790.00
121201	142	11:48:12.0	SHUTTER_OFFSET_204	FULL	40K	40	1790.00
121202	142	11:50:27.0	SHUTTER_OFFSET_204	FULL	40K	40	1790.00
121203	142	11:53:1.0	SHUTTER_OFFSET_204	FULL	40K	50	1430.00
121204	142	11:56:22.0	SHUTTER_OFFSET_204	FULL	40K	50	1430.00
121205	142	11:57:51.0	SHUTTER_OFFSET_204	FULL	40K	50	1430.00
121206	142	12:2:13.0	SHUTTER_OFFSET_204	FULL	40K	60	1190.00
121207	142	12:3:42.0	SHUTTER_OFFSET_204	FULL	40K	60	1190.00
121208	142	12:5:11.0	SHUTTER_OFFSET_204	FULL	40K	60	1190.00
121209	142	12:7:11.0	SHUTTER_OFFSET_204	FULL	40K	60	1190.00
121210	142	12:10:7.0	SHUTTER_OFFSET_204	FULL	40K	100	720.00
121211	142	12:11:36.0	SHUTTER_OFFSET_204	FULL	40K	100	720.00
121212	142	12:13:5.0	SHUTTER_OFFSET_204	FULL	40K	100	720.00
121213	142	12:15:52.0	SHUTTER_OFFSET_205	FULL	40K	100	720.00
121214	142	12:17:21.0	SHUTTER_OFFSET_205	FULL	40K	100	720.00
121215	142	12:18:50.0	SHUTTER_OFFSET_205	FULL	40K	100	720.00
121216	142	12:23:31.0	SHUTTER_OFFSET_205	FULL	40K	60	1190.00
121217	142	12:25:0.0	SHUTTER_OFFSET_205	FULL	40K	60	1190.00
121218	142	12:26:29.0	SHUTTER_OFFSET_205	FULL	40K	60	1190.00
121219	142	12:28:49.0	SHUTTER_OFFSET_205	FULL	40K	50	1430.00
121220	142	12:30:18.0	SHUTTER_OFFSET_205	FULL	40K	50	1430.00
121221	142	12:31:47.0	SHUTTER_OFFSET_205	FULL	40K	50	1430.00
121222	142	12:34:4.0	SHUTTER_OFFSET_205	FULL	40K	40	1790.00
121223	142	12:35:33.0	SHUTTER_OFFSET_205	FULL	40K	40	1790.00
121224	142	12:37:2.0	SHUTTER_OFFSET_205	FULL	40K	40	1790.00
121225	142	12:40:14.0	SHUTTER_OFFSET_205	FULL	40K	35	2050.00
121226	142	12:41:43.0	SHUTTER_OFFSET_205	FULL	40K	35	2050.00
121227	142	12:43:12.0	SHUTTER_OFFSET_205	FULL	40K	35	2050.00
121228	142	12:47:0.0	SHUTTER_OFFSET_205	FULL	40K	30	2390.00
121229	142	12:48:29.0	SHUTTER_OFFSET_205	FULL	40K	30	2390.00
121230	142	12:49:58.0	SHUTTER_OFFSET_205	FULL	40K	30	2390.00
121231	142	12:51:54.0	SHUTTER_OFFSET_205	FULL	40K	30	2390.00
121236	142	13:2:39.0	SHUTTER_OFFSET_205	FULL	40K	20	3580.00
121237	142	13:4:8.0	SHUTTER_OFFSET_205	FULL	40K	20	3580.00
121238	142	13:5:37.0	SHUTTER_OFFSET_205	FULL	40K	20	3580.00
121239	142	13:8:27.0	SHUTTER_OFFSET_205	FULL	40K	15	4780.00
121240	142	13:9:56.0	SHUTTER_OFFSET_205	FULL	40K	15	4780.00
121241	142	13:11:25.0	SHUTTER_OFFSET_205	FULL	40K	15	4780.00
121242	142	13:14:23.0	SHUTTER_OFFSET_205	FULL	40K	10	7160.00
121243	142	13:15:52.0	SHUTTER_OFFSET_205	FULL	40K	10	7160.00
121244	142	13:17:21.0	SHUTTER_OFFSET_205	FULL	40K	10	7160.00
121248	142	13:27:37.0	SHUTTER_OFFSET_205	FULL	40K	0	14270.00
121249	142	13:29:6.0	SHUTTER_OFFSET_205	FULL	40K	0	14270.00
121250	142	13:30:35.0	SHUTTER_OFFSET_205	FULL	40K	0	14270.00
121251	142	13:32:51.0	SHUTTER_OFFSET_205	FULL	40K	0	14270.00