MRO FTT/NAS & FLC

First Light Camera Factory Acceptance Test Results

MRO-TRE-CAM-1200-0183

Bodie Seneta <bodie@mrao.cam.ac.uk>

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Cavendish Laboratory
JJ Thomson Avenue
Cambridge CB3 0HE
UK

Change Record

Revision	Date	Author(s)	Changes
0.1	2016-08-10	EBS	Initial version
1.0	2016-08-19	EBS	Incorporated minor changes suggested by John Young

Objective

To report the results of the MROI First Light Camera factory acceptance tests.

Scope

This document reports the results of the First Light Camera factory acceptance tests in Cambridge. These are tests that are specific to the FLC. Tests that are common to the FLC and FTT systems are not included.

Reference Documents

RD1 First Light Camera Test Procedure (MRO-PRO-CAM-1200-0167) – rev 0.2, April 7th 2016

Acronyms and Abbreviations

ASCII American Standard Code for Information Interchange
CSV Comma Separated Values
FAT Factory Acceptance Test
FITS Flexible Image Transport System
FTT Fast Tip-Tilt
FLC First Light Camera
GUI Graphical User Interface
MROI Magdalena Ridge Observatory Interferometer
NAS Narrow-field Acquisition System
RMS Root Mean Square

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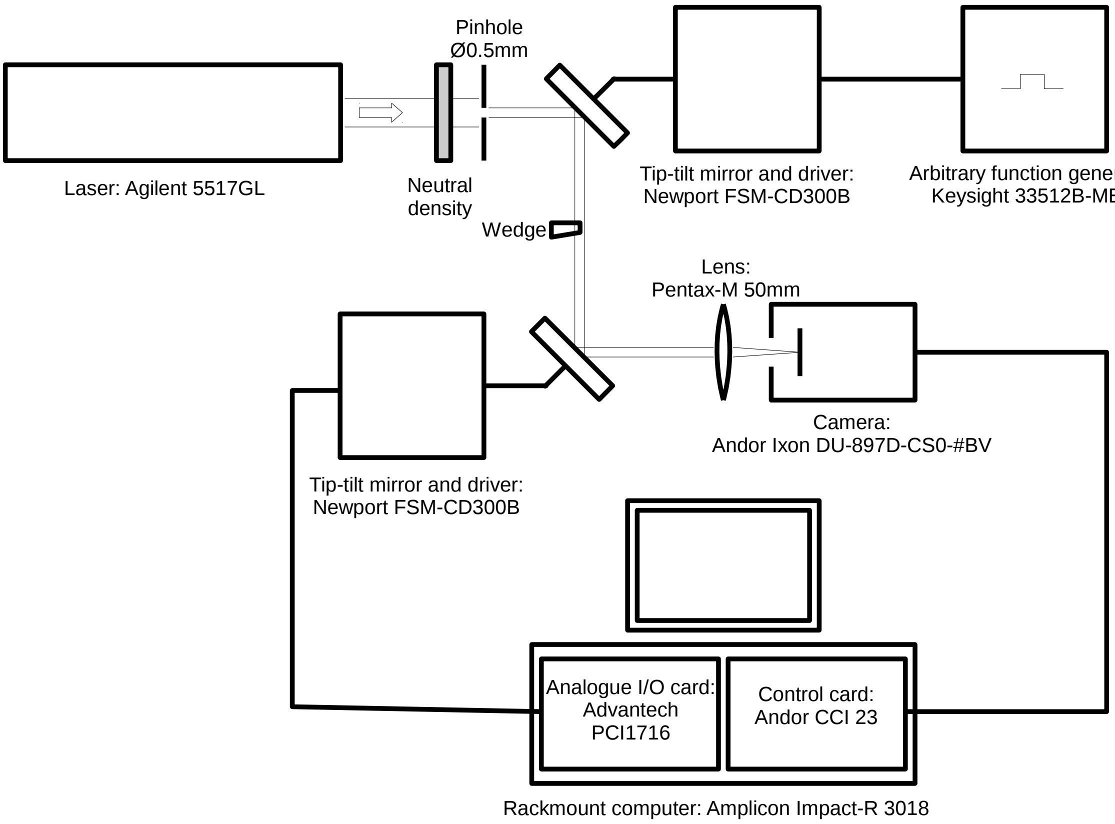

Figure 1: Equipment layout used to perform FLC acceptance tests.

1 Introduction

This document reports the results of the FLC FATs described in [RD1]. These are tests specifically designed to test functionality of the FLC hardware and software as used for commissioning and testing of MROI unit telescopes.

The tests use equipment primarily employed for FTT performance testing (Figure 1). A metrology laser is used as a stable light source. The light passes through a neutral density filter and pinhole, two relay mirrors and a focusing lens that images the beam onto the FTT camera. The two mirrors are electrically steerable, but for the purposes of these tests were held at their centre positions. For test FLC-AT-03, a window with a 30 arcminute wedge was partially inserted in the beam between the mirrors to produce two images on the camera detector.

Tests were carried out in Cambridge between 29 July and 4 August 2016. They followed the methodology described in [RD1] with some minor differences as described in individual tests below. Also, more generally:

- It was sometimes difficult to set exposure times or frame periods within the GUI to the exact quantities described in the individual tests. When this was the case, values as close as possible to those values were used.
- The tests did not specify the electron multiplying gain to be used, so a gain of 1 was chosen to minimise risk of accidental overexposure.

- A choice for remote operation is offered in [RD1]: either the GUI can be run on the acquisition computer, and displayed remotely, or the GUI itself can be run remotely as a system client. Here, the latter approach is used as it requires less network bandwidth.
- The GUI was also run remotely whenever it was necessary to record video of the session (using *kazam*) to minimize the computational burden on the acquisition computer.

Here we copy the description of each test from [RD1] and follow it by a description of any differences in methodology, results and conclusions.

2 FLC-AT-01

Test ID FLC-AT-01

Requirement(s) FLC-UR-2-08: Exposure times from 5–1000 ms and sampling rates between 10 Hz and 1 Hz.

Test description

1. Start system controller
2. Start FLC control GUI (starts a new recording session)
3. Start recording video of the computer display
4. Set acquire decimation to 1 so that every image in the sequence is displayed
5. Focus a single artificial star image onto the CCD and adjust its brightness (or insert neutral density filters) so that the CCD just does not saturate in an exposure time of 1000 ms
6. Connect an oscilloscope to monitor the output of the “Fire” connector on the camera body (the camera is supplied with a suitable cable)
7. For each exposure time/frame period combination to be tested (see Table 1):
   (a) Set exposure time
   (b) Set frame period
   (c) Start acquire run
   (d) Observe update rate of live image display
   (e) Measure exposure time and frame rate from camera “Fire” signal using oscilloscope
   (f) Record next 30 s of data to FITS, adding an informative comment
   (g) Stop run
8. Stop video recording
9. Verify frame periods by examining intervals between frame timestamps in recorded data (this can be done with FV)

	10. Verify exposure times by examining signal levels in recorded data
Test outputs	1. FITS data recording for each exposure/frame period combination 2. Video of the computer display showing the FLC control GUI displaying images
Pass/Fail criteria	1. The frame timestamps in the recorded data must have intervals equal to the specified frame periods 2. The signal levels in the recorded data must increase in proportion to the specified exposure times

2.1 Methodology additions and changes

For this test there was a requirement that screen video be captured, so the camera was controlled remotely. Consequently it was not possible to take oscilloscope measurements concurrently with data acquisition. Instead, the camera was run later under local control with the same period and exposure settings, and the oscilloscope timings noted.

Counts were measured at pixel (256, 256) in the first frame of each FITS file sequence. Frame intervals were measured within *fv* by subtracting the timestamp of each frame from its successor, and calculating a mean and standard deviation for the resulting measurements.

2.2 Results

The results are summarised in Table 1 and graphed in Figure 2. Output data is in the FITS heirarchies as listed in Table 1 and video capture is in FLC-AT-01.mp4.

2.3 Conclusions

The frame timestamps have intervals equal to the specified frame period. Pass/fail criterion 1 is a pass.

The signal levels in the recorded data increase in proportion to the signal levels (Figure 2). There is some evidence of departure from a linear relationship at short exposures, but this may be a consequence

Settings (s)		Scope measurement (s)		FITS heirarchy	Counts	Frame Interval
Period	Exposure	Period	Exposure	fttlog_20160729_	Pixel (256,256)	
0.10	0.005650	0.10	0.0057	105639	169	0.100±0.001
0.10	0.010200	0.10	0.010	105733	215	0.100±0.001
0.10	0.020580	0.10	0.020	105833	343	0.100±0.001
1.00	0.005650	1.0	0.0057	105944	176	1.000±0.0004
1.00	0.011820	1.0	0.0114	110052	252	1.000±0.0009
1.00	0.018630	1.0	0.0186	110154	330	1.0001±0.0003
1.00	0.100390	1.0	0.10	110258	1406	1.0001±0.0006
1.10	0.972250	1.08	0.92	110428	14556	1.100±0.001

Table 1: Exposure times and frame periods for test FLC-AT-01.

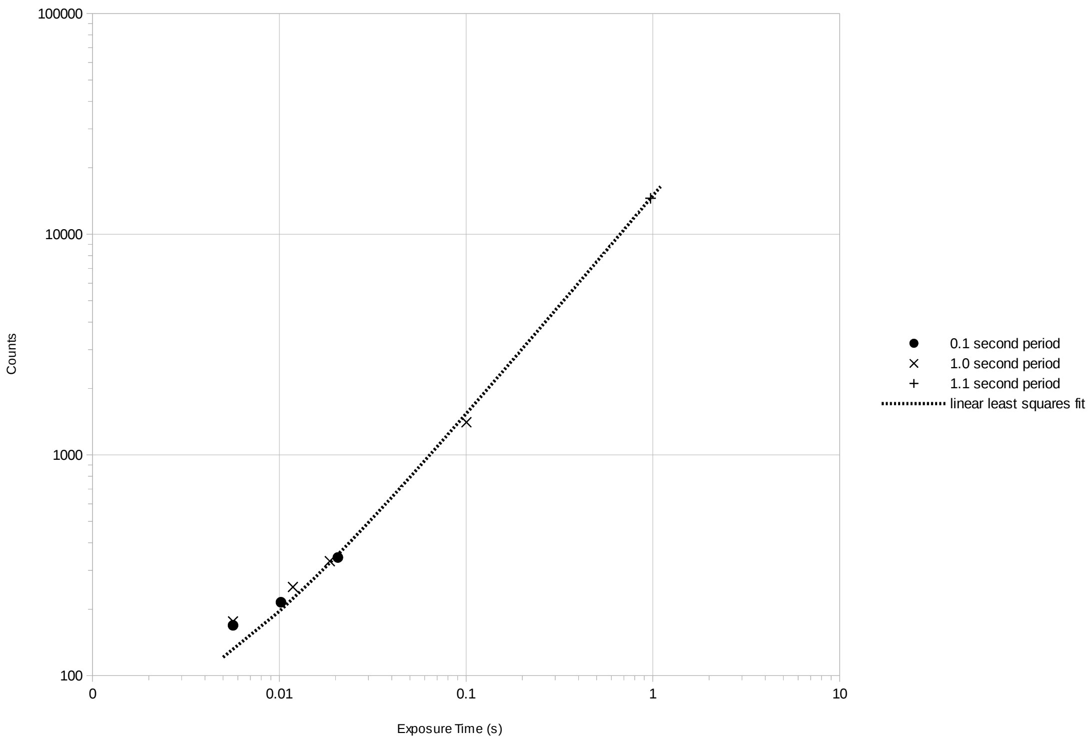

Figure 2: Counts in pixel (256,256) as a function of exposure time for test FLC-AT-01. For comparison, the linear least squares fit is also plotted. This appears as a curve on the log–log plot because of its non-zero y-intercept.

of the signal level being very close to the background level (no background subtraction was done). Pass/fail criterion 2 is a pass.

3 FLC-AT-02

Test ID FLC-AT-02

Requirement(s) FLC-UR-2-09, 2-10, 2-11: Able to be operated from the control room by means of a MRO-owned computer terminal. Able to display full frame images at the exposure sampling rate (i.e. up to 10 Hz). Shall provide an enlarged display of a user-selected region of the full frame images.

Test description

1. Start system controller on rack-mount computer
2. Start FLC control GUI on second computer (starts a new recording session)
3. Start recording video of the computer display
4. Set frame period to 0.1 s

	5. Set acquire decimation to 1 so that every image in the sequence is displayed 6. Focus a single artificial star image onto the CCD 7. Start acquire run 8. Set image display to "Fit in window" to show the full frame 9. Observe image display update rate 10. Click "Zoom In" button several times and pan the image as necessary 11. Observe image display update rate 12. Stop run 13. Stop video recording
Test outputs	1. Video of the computer display showing the FLC control GUI displaying images remotely
Pass/Fail criteria	1. The system controller must accept commands from the control GUI running on the second computer 2. Full frame images must be updated on the remote control GUI at 10 Hz 3. Zoomed images must be updated on the remote control GUI at 10 Hz

3.1 Methodology additions and changes

None.

3.2 Results

Video of the interaction was captured in FLC-AT-02.mp4.

3.3 Conclusions

The system controller accepts commands from the control GUI running on the second computer. Pass/fail criterion 1 is a pass.

Full frame images are updated on the remote control GUI at 10Hz. Pass/fail criterion 2 is a pass.

Zoomed images are updated on the remote control GUI at 10Hz. Pass/fail criterion 3 is a pass.

4 FLC-AT-03

Test ID	FLC-AT-03

Requirement(s)	FLC-UR-2-12, 2-13: Able to compute centroid of selectable star in full frame, with respect to a user-specified fiducial point. The GUI shall display cross-hairs at the fiducial point. Shall provide live numerical display of average and rms of centroids on GUI, updated at intervals equal to the averaging time (user-specified between 100 ms and 5000 ms). Display of recent history of 10 previous average and rms values on GUI.
Test description	1. Start system controller 2. Start control GUI 3. Start recording video of the computer display 4. Set acquire decimation to 1 (this determines the minimum number of frames averaged) 5. Set frame period to 0.1 s 6. Record a dark frame and set the system to use it when calculating centroids 7. Focus two separated artificial images onto the CCD 8. For each number of frames to be averaged (1, 2, 10, 50): (a) Start acquire run (b) Set tip-tilt zero point to an arbitrary location by dragging a box around the intended position on the displayed image; note the new zero point coordinates displayed on the GUI (c) Set acquire scope to a rectangular region containing only one of the two star images, chosen alternately (d) Stop and restart acquire run (e) Record next 30 s of data to FITS, adding an informative comment (f) Stop run (g) Select the displayed average and rms centroid coordinates for the latest run using the mouse; paste these into a text file 9. Stop video recording 10. Use the analysis GUI to verify the consistency of the displayed and recorded centroid coordinates
Test outputs	1. Video of the computer display showing the FLC control GUI displaying cross-hairs and recent average and rms centroid coordinates 2. FITS data recording for each number of frames averaged 3. Text file of displayed average and rms centroids for each number of frames averaged
Pass/Fail criteria	1. The displayed average centroid coordinates must match the position of the selected star image relative to the specified fiducial position, to 0.2 pixel

2. The average centroid coordinates copied from the display must correspond to averages of the raw centroids in the corresponding FITS recording, within rounding error

3. The rms centroid coordinates copied from the display must correspond to rms values of the raw centroids in the corresponding FITS recording, within rounding error

4.1 Methodology additions and changes

This test required an image of two spots on the camera detector, so a wedged window (Thorlabs WW10530, 1/2-inch diameter, N-BK7, 30 arcmin wedge) was partially inserted into the beam, to produce two beams with slightly different angles. The result was two focused spots about 15 pixels apart, which were designated the "left" and "right" spots. As neither beam was now circular, the imaged spots were also slightly irregular.

4.2 Results

The software calculates centroids relative to fiducial positions. However, a centroid can be added to the relative fiducial position to yield a position relative to the fiducial origin (an "absolute position") that can be compared with other absolute positions. This is done in Table 2. For each of the left and right spots, the positions match to within 0.1 pixels.

Table 3 compares the average centroid positions and RMS values from two sources: as calculated from the raw centroids by the analysis program (*plotfttgui*) and as displayed in the GUI. They can be seen to be in agreement to within rounding error.

Finally, Table 4 lists the raw data generated in this test. Also generated was FLC-AT-03.mp4, video of the screen interaction during the entire test, and Frame_20160803_161236.fits, the frame used for dark subtraction.

4.3 Conclusions

The displayed average centroid coordinates match the position of the selected star image relative to the specified fiducial position, to 0.2 pixel. This criterion is a pass.

Spot	Frames averaged	Tip-tilt zero point		Displayed centroid position		Absolute centroid position	
		x	y	x	y	x	y
left	1	246	233	8.7	23.4	254.7	256.4
right	1	246	233	21.9	29.7	267.9	262.7
left	2	229	267	25.7	-10.6	254.7	256.4
right	2	229	267	38.9	-4.3	267.9	262.7
left	10	276	273	-21.3	-16.6	254.7	256.4
right	10	276	273	-8.1	-10.3	267.9	262.7
left	50	263	232	-8.3	24.4	254.7	256.4
right	50	263	232	4.9	30.7	267.9	262.7

Table 2: Absolute spot positions for FLC-AT-03.

Spot	Frames averaged	*plotfttgui* Centroid average±RMS		text output (typical) Centroid average±RMS	
		x	y	x	y
left	1	8.65±0.01	23.40±0.00	8.66±0.00	23.39±0.00
right	1	21.91±0.00	29.66±0.00	21.92±0.00	29.65±0.00
left	2	25.67±0.01	-10.60±0.01	25.67±0.00	-10.61±0.00
right	2	38.91±0.01	-4.33±0.00	38.91±0.00	-4.33±0.00
left	10	-21.34±0.00	-16.59±0.00	-21.34±0.00	-16.59±0.00
right	10	-8.09±0.00	-10.33±0.00	-8.08±0.00	-10.34±0.00
left	50	-8.32±0.01	24.43±0.00	-8.32±0.00	24.42±0.01
right	50	4.90±0.00	30.69±0.00	4.90±0.00	30.68±0.00

Table 3: Centroid average and RMS comparison for FLC-AT-03.

Spot	Frames averaged	FITS heirarchy fttlog_20160803_	Text file
left	1	161403	star-left-average-1-centroids.txt
right	1	161614	star-right-average-1-centroids.txt
left	2	161832	star-left-average-2-centroids.txt
right	2	162024	star-right-average-2-centroids.txt
left	10	162241	star-left-average-10-centroids.txt
right	10	162436	star-right-average-10-centroids.txt
left	50	162637	star-left-average-50-centroids.txt
right	50	162818	star-right-average-50-centroids.txt

Table 4: Files generated during FLC-AT-03.

The average centroid coordinates copied from the display correspond to averages of the raw centroids in the corresponding FITS recording, within rounding error. This criterion is a pass.

The RMS centroid coordinates copied from the display correspond to RMS values of the raw centroids in the corresponding FITS recording, within rounding error. This criterion is a pass.

5 FLC-AT-04

Test ID FLC-AT-04

Requirement(s) FLC-UR-2-14: Able to log time-series of raw (unaveraged) centroids to ASCII CSV-format log file on user command. Logged centroids shall have accompanying UTC timestamps which are accurate to 1 ms. Logging should stop after a user-specified duration or when interrupted by the user. Log-file shall be accessible via a network shared drive.

Test description

1. Start system controller
2. Mount a shared filesystem using NFS
3. cd to the shared filesystem and start the control GUI

	4. Record a dark frame and set the system to use it 5. Set frame period to 0.1 s 6. Focus one artificial image onto the CCD 7. Start acquire run 8. Start recording centroid data to CSV for 30 s 9. Record next 30 s of data to FITS 10. Wait for recordings to complete 11. Record centroid data to CSV for 30 s 12. Interrupt recording while in progress and note the displayed recording progress 13. Use the analysis GUI to verify the accuracy of the centroids recorded to CSV
Test outputs	1. CSV log files (one full length, one interrupted) 2. FITS data recording contemporaneous with full-length CSV recording
Pass/Fail criteria	1. The CSV log files must be saved to the shared drive 2. The CSV log files must be formatted correctly and suitable for import into Microsoft Excel 3. The duration of the CSV log files must be as expected 4. The logged raw centroid coordinates must match those recorded to FITS, to 3 decimal places 5. The logged raw centroid coordinates must match the results of an independent calculation from the recorded images, to 0.2 pixel

How to test the CSV timestamp accuracy? OK to verify the timestamps match the computer clock, with NTP taking care of the rest?

5.1 Methodology additions and changes

The test requires that data be saved to an NFS mounted network drive. An SMB ("samba") mounted network drive was used instead. This was purely a matter of convenience.

Pass/fail criterion 2 requires that files be imported into *Excel*. LibreOffice *Calc* was used instead, again for convenience.

Pass/fail criterion 4 requires a match between raw and recorded centroid coordinates. A spreadsheet was produced to show that this is the case. Note that FITS and CSV recording could not be started simultaneously, so there are some values in each dataset that cannot be compared.

Pass/fail criterion 5 requires an "independent calculation" of the FITS image centroids and a comparison with the CSV data. However, as the FITS acquisition and CSV acquisition are started at different times, they do not fully overlap and there is some CSV data for which concurrent FITS images are not available. However, there *is* a one-to-one correspondence between the FITS images and the recorded FITS centroids, so software was written in Python to compute centroids of the former and compare them with the latter. If those are in agreement, it follows from pass/fail criterion 4 that they also match the CSV centroids.

The independent calculation uses the same method as the FLC software, but has a different implementation and coding language. The Python program is included with the test data and expects to be run with a Python 2 or 3 interpreter from its location there.

5.2 Results

Data was successfully saved across the networked drive.

CSV files were successfully imported into LibreOffice *Calc*.

The FITS heirarchy is in fttlog_20160802_095437. The full and truncated CSV files are in FTT-RUN_20160802_100330.csv and FTT-RUN_20160802_100418.csv respectively.

The dark frame used for subtraction is in Frame_20160802_100029.fits.

The Python program is *FLC-AT-04-centroid-compare.py*.

The centroid comparison spreadsheet is FLC-AT-04-centroid-compare.ods.

5.3 Conclusions

The CSV log files are saved to the shared drive. This criterion is a pass.

The CSV log files are formatted correctly and suitable for import into Microsoft Excel. However, LibreOffice *Calc* is the spreadsheet that was actually used. This criterion is a pass.

The duration of the CSV log files is as expected. This criterion is a pass.

The logged raw centroid coordinates must match those recorded to FITS, to 3 decimal places. This is shown to be the case in FLC-AT-04-centroid-compare.ods. This criterion is a pass.

The logged raw centroid coordinates must match the results of an independent calculation from the recorded images, to 0.2 pixel. This is shown to be the case with *FLC-AT-04-centroid-compare.py*. This criterion is a pass.