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# Status and performance of the Micro Shutter System

## Abstract:

In this report we summarize the results of the testing of NIRspec Micro Shutter System that was carried out during FM2 cycle 1 of NIRSpec Performance Verification and Calibration campaign. The report covers three main areas of MSA performances: the number and variability of failed open and failed closed shutters over the monitoring period and the MSA contrast properties. The impact of the number of failed shutters on NIRSpec Level 1 requirement is presented. The 'glow' anomaly discovered in the early phase of the campaign is also discussed.

## 1 INTRODUCTION

The micro shutter array (MSA) of the NASA-provided Micro Shutter System (MSS) is a configurable array of micro shutters that enables NIRSpec to obtain simultaneous spectra of many targets distributed across the field of view. Observers form apertures by opening selected micro shutters that contain targets or background regions, and by closing all remaining micro shutters. In addition to the MSA, the aperture plane also contains 5 permanently open slit apertures (fixed slits or FS) and the entrance aperture for the integral field unit (IFU) - see section 3.2 of Boeker (2012) for an overall description of the MSA.
The MSA consists of a $2 \times 2$ mosaic of 4 quadrants and each quadrant has 365 micro shutters along the dispersion axis and 171 shutters along the spatial axis, for a total of $62,415 \times 4 = 249,660$ shutters. The MSA shutters are opened and closed by sweeping a permanent magnet across the array. The magnet arm sweeps upward (with respect to NIRSpec Optical Assembly) to open shutters, and downward to close them. A Release cycle closes all of the shutters as the magnet arm moves downward back to its Primary Park position. An Address cycle, in contrast, closes only those shutters that have been commanded to be closed, and leaves open all others. The commanded pattern of closed/open shutters is referred to as 'MSA configuration'. Of course, in an Address cycle, one can also command the array to be fully close or fully open.
In a Release cycle, when the magnet arm reaches its Primary Park position, all row and

column voltages are 0V, and ideally the array will be fully closed. In an Address cycle, when the magnet arm reaches its Primary Park position, the array has been fully addressed and all voltages are nominally set to 'Hold' voltage levels of +16V and -16V, respectively for the columns (171 side) and rows (365 side).

There are therefore two different MSA configurations in which the MSA should be fully open, the so called LATCHED (when the magnet is in Secondary Park) and addressed-OPEN and two different MSA configurations in which the MSA should be fully closed, so called 0-volt CLOSED and addressed-CLOSED. During normal operations, however, some shutters can become stuck open or stuck closed. Additionally, some MSA rows or columns are masked, i.e. kept closed, to prevent shorts and there is a population of damaged shutters that are stuck close following NIRSpec vibration and acoustics tests (De Marchi 2012).

During a science observation, dispersed light (from sources or background emission) through failed open shutters may contaminate a target spectrum acquired through a shutter on the same row, while failed closed shutters will prevent a target to be observed with a given pointing (both in a science exposure or during target acquisition). So shutters failure can impact Level 1 requirements. The tolerable numbers of failed (open and closed) shutters are encapsulated in R21 of the NIRSpec MSS Functional & Performance Requirements Specification document (2009).

For cycle 1 of FM2 of NIRSpec Performance Verification and Calibration (PCV) campaign, a number of exposures at regular interval of approximately 2 days were planned to monitor the number of failed open and failed closed micro shutters. The results of these monitoring tests are described in Sect. 2 and Sect. 3. The impact of the number of failed shutters on NIRSpec MSS requirement R21 is discussed in Sect. 4.

The other important performance parameter for the MSA is its contrast, that is a measure of the light leaks from a source behind the closed MSA – see e.g. Boeker (2012) for a description of the impact of MSA finite contrast on NIRSpec overall performances. Specifically designed set of tests were executed during FM2 cycle 1 to measure the MSA contrast values to both extended sources and point sources, the results of which are summarized in Sect. 5.

Finally, in Sect. 6 we report on the 'glow' anomaly that was discovered during the preparation tests at the beginning of FM2.

## 2 FAILED OPEN SHUTTERS

As mentioned in the Introduction, the default closed configuration for the MSA is the so called 0-volt CLOSED configuration of a Release cycle. So this is the configuration that was initially planned during the monitoring test sequence in order to identify and count failed open shutters. Around the middle of the campaign, however, we noticed that when the MSA was configured to a specific pattern (for example a long-slit pattern for the COMBO test sequence), the number of failed open shutters appeared to be different (and higher) than the number we were counting based on the monitoring exposure with MSA in 0-volt CLOSED configuration. So a further exposure with the MSA in configuration addressed-CLOSED was added to the sequence. Note that for the purpose of assessing the impact of failed open

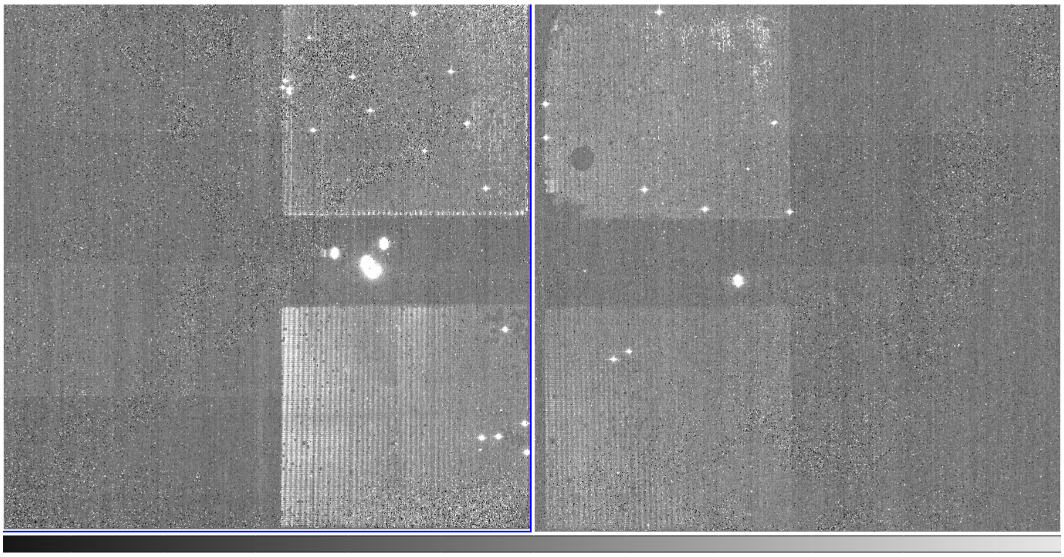

**Figure 1: Count-rate images from an imaging exposure where the closed MSA (configuration addressed-CLOSED) is illuminated by the TEST lamp of the CAA. These type of exposures were routinely acquired during FM2 to monitor the number of failed open shutters in the MSA. The bright sources in the image are the five fixed-slits and the failed open shutters. The outline of the four quadrant are also visible in this deep image, from top right clockwise: Q1, Q2, Q4 and Q3. For a better view of the images please look at the electronic version of this document.**

shutters on science exposures, the relevant MSA configuration is the addressed-CLOSED.
The exposures used to monitor the number of failed open shutters were performed by illuminating the MSA with the 'TEST' lamp of NIRSpec internal Calibration Assembly (CAA) – see Boeker (2012) for a description of the CAA. An example of count-rate images from such exposures is shown in Fig. 1.
From this type of images, failed open shutters were detected for each quadrant individually using a purposely-developed software tool called MSA-*detect* (Giardino 2012). Note that, here, we define as 'failed open' shutters that remain open when commanded closed and that exhibit contrast values smaller than 100. Formally, however, the counting of failed-open shutters should include all shutters with a contrast lower than 2000, see R30 from NIRSpec MSS Functional & Performance Requirements Specification document (2009). A census of shutters in the contrast range 100-2000 can be found in Sect. 5.
The number of failed open in 0-volt CLOSED configuration was monitored using 17 exposures acquired over the period 10 Jan – 4 Feb, while the numbers of failed open in addressed-CLOSED configuration was derived from 11 exposures acquired over the period 24 Jan – 4 Feb. These periods include the two MSA heat-up cycles that were performed on the 3rd and 4th of February. During a heat-up cycle, the entire MSA is brought to a temperature of 260 K by heaters placed on each quadrant, with the aim of releasing shutters that have become stuck open after a number of MSA re-configurations – see Sect. 8.3 of Boeker (2012)

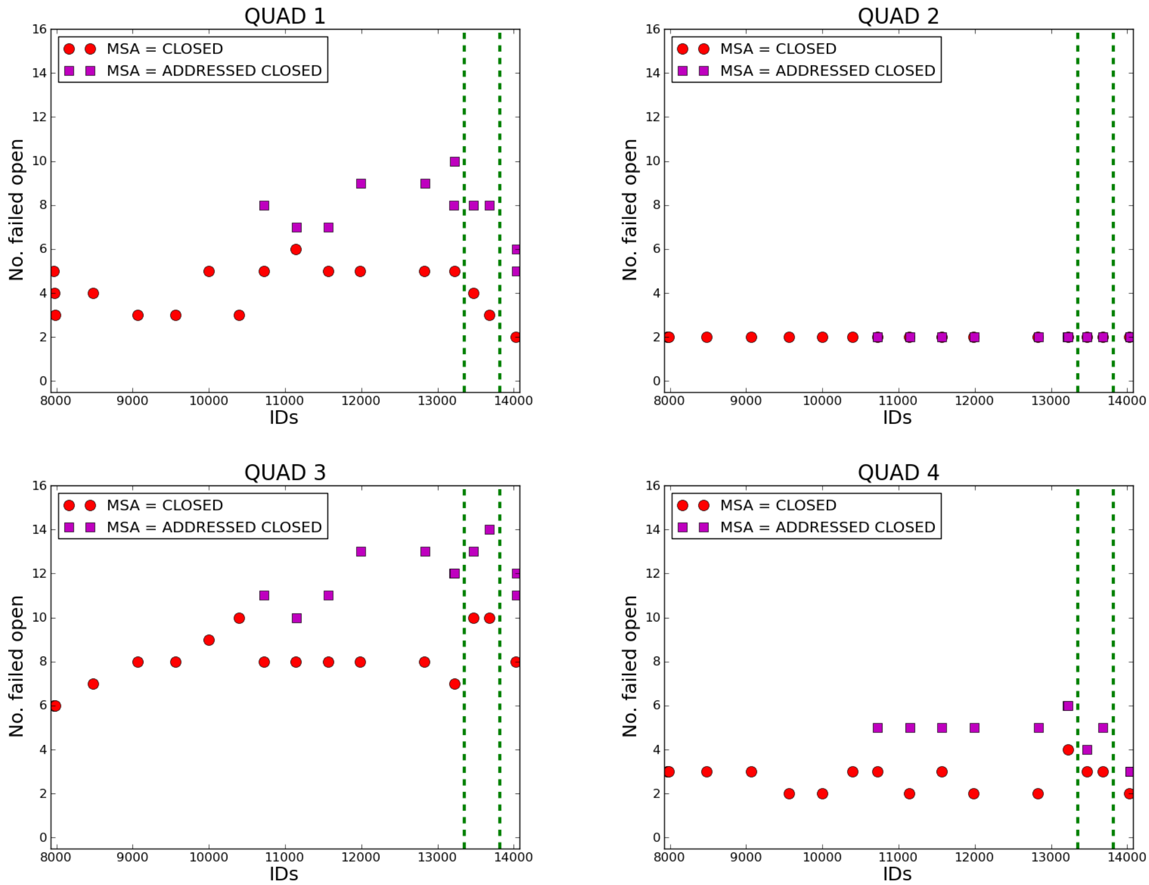


**Figure 2: Number of failed open shutters as a function of exposure IDs (which is a proxy for time), during FM2 cycle 1 of NIRSpec PVC. Monitoring period: 10 Jan – 4 Feb. The two MSA heat-up cycles are indicated by the dashed vertical green lines. The short heat-up cycle was performed before the long – standard – one.**

for more details on MSA heat-up operations. To test the efficiency of this procedure, two different types of MSA heat-up cycles were performed before the end of FM2 cycle 1: the so called 'short' MSA heat-up and 'long' MSA heat-up. The difference between the two is the length of time during which the MSA is kept at $\sim$ 260 K, before letting it cool down to the bench temperature, respectively 1 s for the 'short' cycle and 15 minutes for the 'long' cycle.
In figure 2 the number of failed open shutters is given as a function of the exposure unique ID, for the two different MSA configurations, 0-volt CLOSED and addressed-CLOSED. The exposure ID is just a monotonically increasing number, so it can be used as a proxy for time (and for the number of MSA re-configurations). From the plots, one can see that for quadrants 1, 3, and 4, the number of failed open shutters in addressed-CLOSED is consistently higher than in 0-volt CLOSED configuration. The second (long) heat-up cycle appears to somewhat reduce the number of failed open shutters in these quadrants, but its overall impact is limited.

From monitoring the number of failed open shutters, it is apparent that a significant fraction of them are intermittently failing. Table 1 provides a summary of the total number of shutters that failed to open at least once in each quadrant over the entire monitoring period of 10 Jan – 4 Feb, for the two different MSA configurations 0-volt CLOSED and addressed-CLOSED.

**Table 1: Total number of failed open shutters over the monitoring period 10 Jan – 4 Feb, for the two different MSA configurations. The number of failed open shutters in common between the two configurations is also given.**

| | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|
| 0-volt CLOSED | 9 | 2 | 12 | 4 |
| addressed-CLOSED | 13 | 2 | 15 | 7 |
| No. in common | 8 | 2 | 10 | 4 |

## 3 FAILED CLOSED SHUTTERS

As mentioned in the Introduction, there are two different MSA configurations in which ideally all the micro shutters should be open: LATCHED and addressed-OPEN. The MSA configuration chosen to identify failed closed shutters in our MSA monitoring test sequence was LATCHED and also in this case the 'TEST' lamp of the CAA was used as source. Fig. 3 shows the count rate image from one of these monitoring exposures. Also in this case the software tool called MSA-*detect* (Giardino 2012) was used to automatically identify closed shutters in this type of images.

Fig. 4 shows the number of failed closed shutters in each quadrant for 17 exposures taken over the monitoring period of 10 Jan – 4 Feb. There is variability in the number of failed closed shutters of the order of 0.5 – 2%, but the bulk of failed shutters remained constant over the monitoring period. As expected, the heat-up cycles do not have a significant impact on the number of failed closed shutters.

Although not included in the monitoring sequence, throughout the campaign we also took a number of exposures with the MSA in addressed-OPEN configuration (and using the same 'TEST" lamp of the CAA) and noticed that the numbers of failed closed shutters in this configuration was significantly different from those in LATCHED, for all quadrants.

Table 2 summarizes the mean, standard-deviation (STD) and total number of failed closed shutters in the two MSA configurations LATCHED and addressed-OPEN. Note that for Q2 and Q3 the number of failed closed shutters is higher in addressed-OPEN, while for Q1 and Q4 it is higher in LATCHED. A higher number of failed closed shutters in addressed-OPEN is not unexpected, because in this configuration the static forces holding the shutters open are stronger than in the addressing applied when the magnet is back in primary park. However,

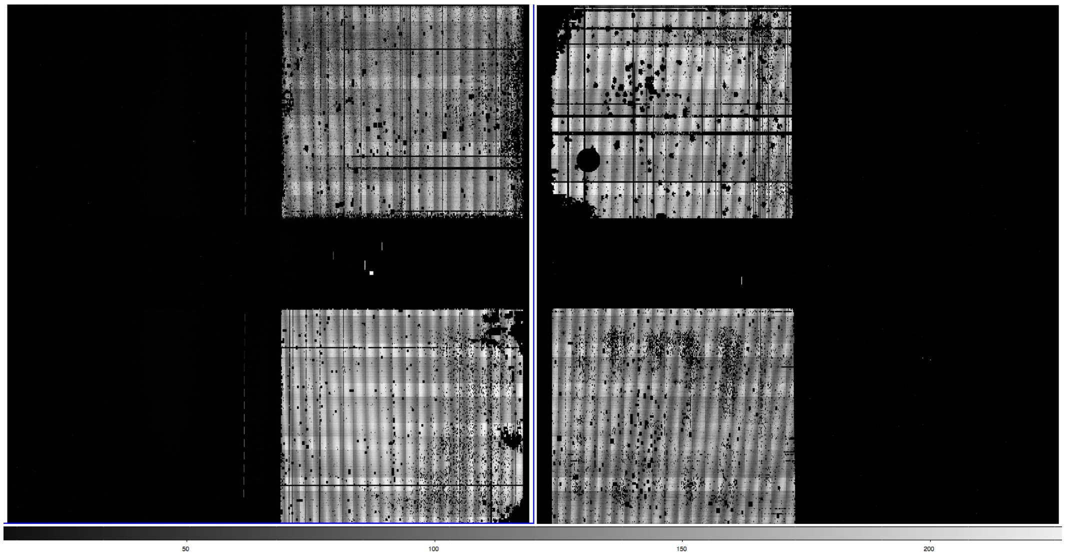


**Figure 3: Count rate image from a monitoring exposure with MSA in LATCHED configuration. The dark pattern in the 4 MSA quadrants are due to failed closed shutters. Note the large number of scattered failed closed shutters that were caused by the last vibration and acoustic tests at NIRSpec level.**

why one should have a higher number of failed closed shutters in LATCHED than in addressed-OPEN is not yet clear and the MSS NASA team is investigating this issue.

**Table 2: Mean, STD and total number of failed closed shutters over the monitoring period 10 Jan – 4 Feb, for the two different MSA configurations LATCHED and addressed-OPEN.**

| | Q1 LATCH. | Q1 OPEN | Q2 LATCH. | Q2 OPEN | Q3 LATCH. | Q3 OPEN | Q4 LATCH. | Q4 OPEN |
|---|---|---|---|---|---|---|---|---|
| Average | 15205 | 12919 | 7450 | 10186 | 9761 | 10977 | 9239 | 7974 |
| STD | 84 | 86 | 23 | 23 | 16 | 69 | 35 | 22 |
| Total | 15445 | 13471 | 7646 | 10518 | 9882 | 19986 | 9362 | 8118 |

One more thing to notice in Table 2 is that for Q3 the total number of shutters that failed during the campaign in addressed-OPEN is nearly twice the average number. This is because of a single episode on 29 Jan, when nearly 10 000 additional shutters failed to open in this quadrant. This anomalous behavior is being tracked in the list of non-compliance items and is currently being investigated.

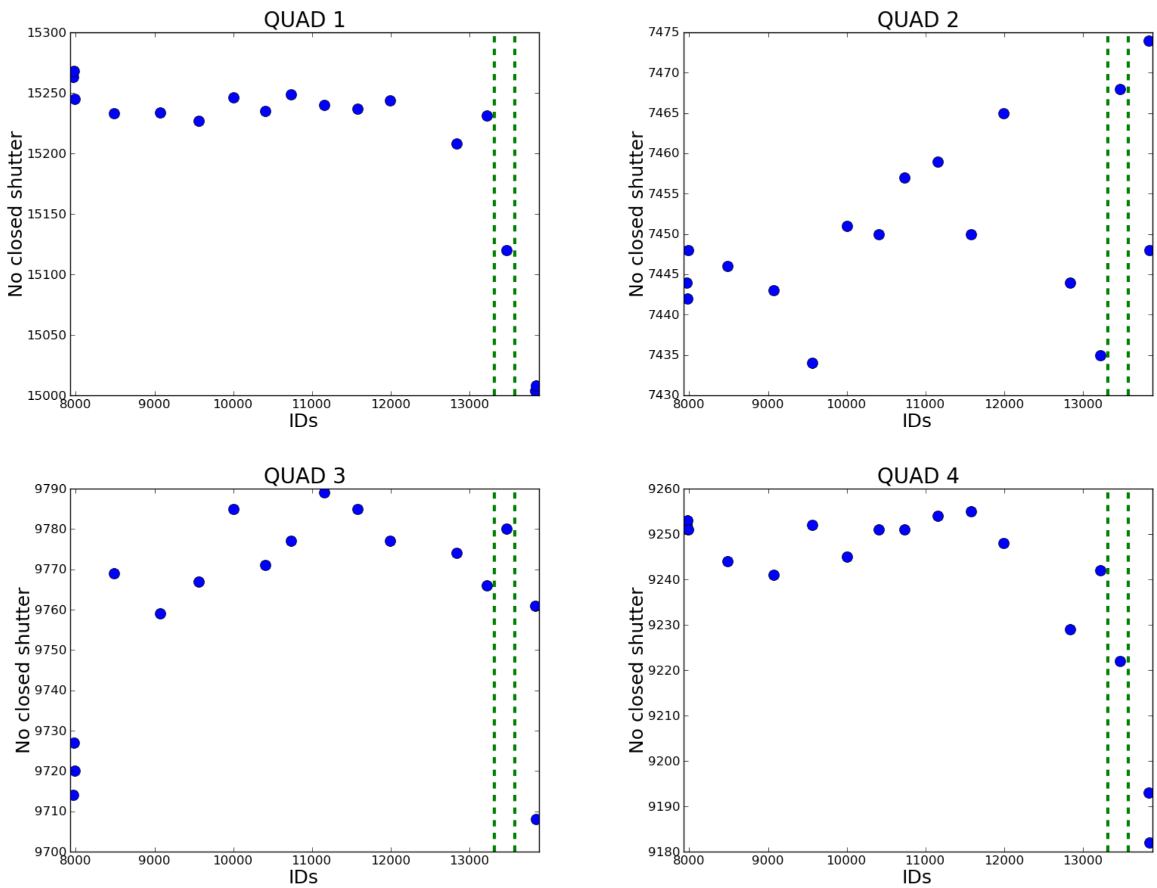


**Figure 4: Number of failed closed shutters in MSA configuration** LATCHED **as a function of the exposure ID, during Cycle 2A of NIRSpec PVC. Monitoring period: 10 Jan – 4 Feb. The two MSA heat-up cycles are indicated.**

**Table 3: Percentage of failed closed shutters within the field of view compared to the percentage of all failed closed shutters.**

| | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|
| Closed shutters in FOV [%] | 20.7 | 10.9 | 13.9 | 13.0 |
| Total closed shutters [%] | 24.4 | 12.0 | 15.7 | 14.8 |

## 4 COMPLIANCE WITH R21 OF MSS REQUIREMENTS

For the purpose of the evaluation of the MSS compliance, the relevant numbers of failed shutters are those within the field-of-view, because failed shutters behind the Field Stop do not impact the MSS performance (as they are not exposed to the sky anyway). In addition, for failed open shutters what counts are the number of rows spanning the entire MSA that contain one or more failed shutters.

The number of failed open shutters over the entire campaign in addressed-CLOSED configuration for each quadrant are given in Table 1. None of these shutter falls behind the Field Stop and they all belong to different rows, so the total number of rows containing failed open shutters is 37, corresponding to 11.6% of the total number of rows within the field of view[1].

In Table 3 the percentage of failed closed shutters within the field of view are given for each quadrant. For completeness the percentages of failed shutters over the entire quadrant areas are also given. The numbers are based on one single exposure (with MSA in LATCHED configuration) from the monitoring sequence taken during FM2 on Jan 29 (exposure ID = 11992).

In Fig. 4 we show how the percentage of rows containing failed open shutters and the percentage of closed shutters compare with the Level 1 requirement of *"observing 2500 high red shift galaxies at $R = 100$ and $R = 1000$ to the sensitivity limit of the instrument within the nominal JWST mission lifetime of 5 years."* This Level 1 requirement is flown down to MSS requirement R21 from the NIRSpec MSS Functional & Performance Requirements Specification document (2009), which reads *"The percentages of failed closed shutters and of rows spanning the entire width of the MSA that contain one or more failed open shutters shall fall below the green curve of Fig. 4 at any time of the mission."* It is clear from the figure that the current MSS does not meet this requirement even though the number of failed open shutters considered here corresponds to only shutters with a contrast smaller than 100. The results would be even worse if we were to include all shutters with a contrast lower than 2000 as formally required (see Sect. 5).

[1]This number is $171 \times 2 - 23$, where 23 are the rows that fall behind the Field Stop

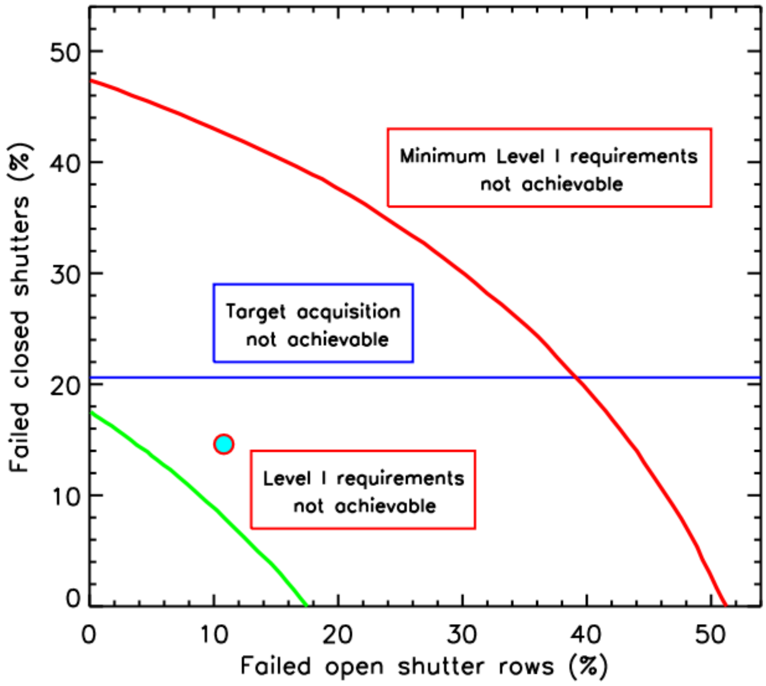


**Figure 5: MSA shutter failures mapped to the formal Level 1 science requirements levied on NIRSpec. The blue dot marks the observed values reported in the text.**

# 5 CONTRAST PERFORMANCE

Two test procedures were performed during FM2 cycle 1 to assess the contrast performance of the MSA. The first procedure, repeated three times during the campaign, is designed to derive the contrast value over the entire MSA using a flat field illumination. In this test sequence, a deep (88-groups) exposure is acquired illuminating the MSA in 0-volt CLOSED configuration with lamp FLAT5 of the CAA. The flux from this lamp was measured from another exposure with detectors in window mode, through the fixed slit A_1600; its value was derived to be $1.84 \cdot 10^4$ counts $s^{-1}$. Given that the typical noise level of a 88-group dark exposure is $\sim$ 0.01 counts $s^{-1}$, using FLAT5 of the CAA, we can probe contrast levels up to $100\,000$ at a signal to noise of at least 18.

The contrast map of the MSA is shown in Fig. 6, from where one can see that, for the most part, the MSA contrast is significantly better than $10\,000$ (indeed better than $20\,000$), but in a large area of Q4 and some smaller areas of Q1, it drops to the significantly lower values of 5000–8000. In Q1 the low contrast areas are associated with the pattern of failed closed shutters that developed after NIRSpec vibration and acoustics tests.

In addition to the low contrast area, Q4 presents also a significant number of individual shutters where the contrast is lower than 2000. The number of shutters with contrast below 2000 for all the quadrants is summarized in Table 4.

The relevant contrast requirement, R30 from the NIRSpec MSS Functional & Performance Requirements Specification document (2009), reads *"The Open-Closed contrast of the shutters*

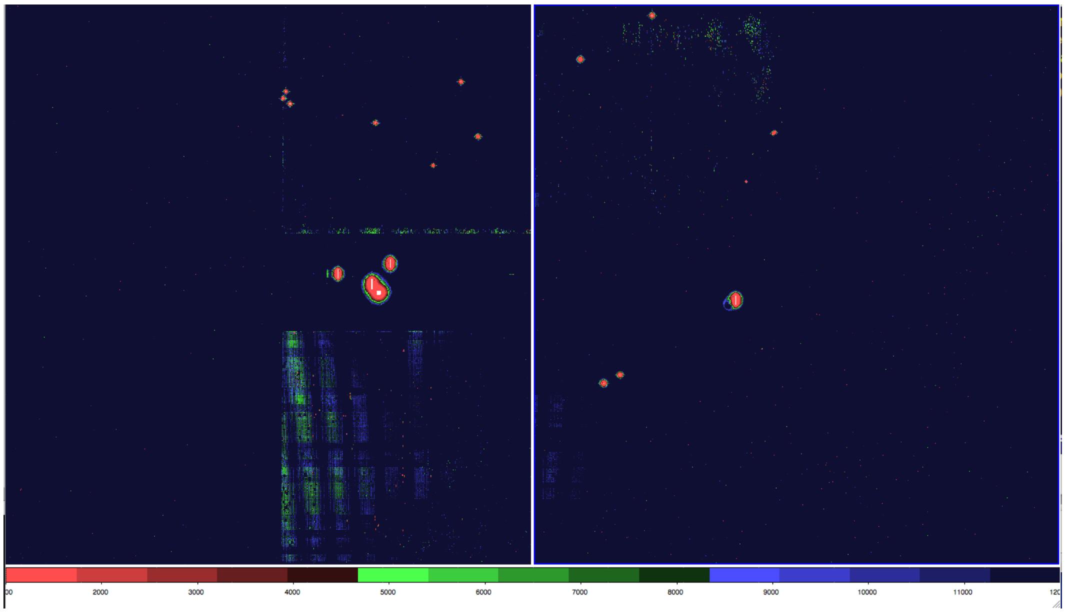


**Figure 6: Contrast map of the MSA. In general the MSA contrast is significantly better than $10\,000$, however, in a large area of Q4 and some areas of Q1, it drops to 5000–8000. For a better view of the images refer to the electronic version of this document.**

*shall be* $\geq$ *2000 with a goal of* $\geq 10^5$ *in the 0.6 to 5* $\mu$*m wavelength range"*. The requirement is met for the great majority of shutters, however, 61 shutters are non-compliant.

**Table 4: Number of micro shutters with contrast ($c$) lower than 2000 for each quadrant.**

| $c$ value | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|
| $\approx$ 500–2000 | 2 | 2 | 2 | 52 |
| $\approx$ 100–300 | 0 | 0 | 0 | 3 |

We notice that the number of low contrast shutters appears to be stable between MSA re-configurations and that the great majority of low contrast shutters are associated with failed closed shutters.
The contrast for point sources was measured using the pinhole mask illuminated by the external Calibration Light Source (CLS) in PSB mode (Birkmann 2011) and by imaging it through the open and closed MSA. Unfortunately, although the PSB mode is the brightest of all CLS modes, only 10 pinholes are actually bright-enough that they can be detected through the closed MSA, by stacking the images of two 88-group exposures. All the other pinholes cannot be detected through the closed MSA, so that they can only be used to give lower limits on the contrast at the location of the pinhole.

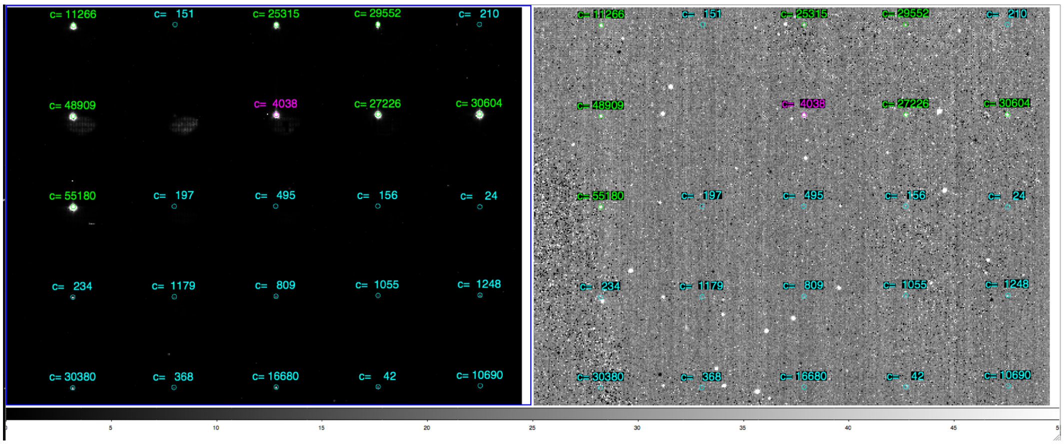


**Figure 7: Images of the pinhole mask illuminated by the PSB mode of the CLS through the open and closed MSA (respectively left and right panel). The numbers on the images give the contrast values at the pinhole location as derived from the ratio of the source photometry through the open and closed MSA. Green points indicates contrast value higher than 10 000, cyan points give lower limits, while the magenta point indicate a contrast value lower than 10 000.**

Fig 7 shows the images of 8 of the 10 bright pinholes for which a contrast value was derived by comparing their photometry through the open and closed MSA. For 9 out of 10 pinholes the contrast value is better than 10 000, but for one we derive a value of $\sim 4000$. Note that the contrast value derived from flat field illumination is better than 20 000, for the same detector area where this pinhole is imaged.
This finding implies that contrast values for a point source depend on the detailed positioning of the point source with respect to an individual micro shutter. Because the detector resolution under-samples individual micro shutters (and does not resolve features within a micro shutter) flat field measurements provide contrast values averaged over an entire micro shutter. Likely, however, the contrast value across a shutter is not constant, and a point source aligned with a lower contrast area of a micro shutter (like a small gap) would have its flux reduced by a smaller factor than the average contrast value for that micro shutter derived from a flat field measurement.

# 6 MSA 'GLOW' ANOMALY

Throughout the entire calibration campaign, we carried out procedures to identify shorted MSA rows and columns and to monitor their evolution, with the objective of masking any affected micro shutters. During the initial tests it was discovered that, besides the MSA electronics itself, also the NIRSpec detectors are very sensitive to the presence of shorted micro shutters. Observations carried out during the monitoring tests revealed a number of 'glowing' shorts across the MSA quadrants, particularly in quadrant Q3, while the other quadrants showed only one glowing short (Q1), which could be effectively masked, or none at all (Q2 and Q4). The issue of glow in shorted shutters, then, appears to be limited to quadrant Q3.

It is now understood that the origin of the shorts in quadrant Q3 is related to the 365-side of the voltage line, which causes shorts in the substrate of the quadrant. As a temporary (yet effective) work around, it was decided to shift solidly the potential difference between the 365-side and the 171-side lines for this quadrant. The normal configuration has the levels at, respectively, -16 V for the 365-side and +16 V for the 171-side. To alleviate the glowing effect, in the case of quadrant Q3 these levels were brought to 0 V and +32 V, respectively. This implies that there is no potential difference anymore between the 365-side and the substrate of the quadrant, thereby preventing any shorts of that type to appear.

This approach is very effective at eliminating the glowing shutters in quadrant Q3, as shown in Figure 8. In order to characterise the robustness of this solution for typical observations of very faint targets, like those planned as part of the NIRSpec guaranteed time programme, we have taken multiple long exposures with no illumination source and with the MSA in addressed-CLOSED configuration[2]. The right panel of Figure 8 corresponds to the combination of thirty such exposures (ID from 12201 through to 12231), each of duration $\sim 900\,$s, for a total exposure time of $\sim 30\,000\,$s. Only a portion of quadrant Q3 is shown, near its lower-left corner as seen from the detector. The exposure shown in the left panel of Figure 8 (ID 8150) corresponds to the same configuration, but the exposure time is only $\sim 450\,$s. Both panels cover the same portion of the detector, with the same grey scale, ranging from $-0.1$ counts s$^{-1}$ to $0.1$ counts s$^{-1}$.

To quantify the effectiveness of the glow mitigation procedure, we have measured the median count rates in two rectangular regions of each image, indicated by the two boxes in each panel. The box on the right corresponds to the bottom-left corner of quadrant Q3, while the box on the left falls outside of the field of view of NIRSpec and, as such, it can be used as a reference because it cannot be reached by any in-field light when in imaging mode (i.e. when the mirror is selected in the grating wheel). The measured count rates, shown in Table 5, reveal that after applying the glow-mitigation strategy there is no difference in the levels measured inside the two boxes, whereas the difference was more than an order of magnitude before.

These measurements allow us to conclude that the glow-mitigation strategy as applied to quadrant Q3 is effective at preventing glowing shorts and can therefore be employed for scientific observations once in orbit. The only MSA configuration where the glowing shorts are still an issue is LATCHED. However, a similar approach of glow-mitigation is currently being studied for when the magnet arm is in Secondary Park position, as this would allow a more efficient target acquisition procedure (Boeker 2012).

[2] In the telemetry, the configuration was aptly named GLOW but it is identical, for all intents and purposes, to the ALLCLOSED configuration, which corresponds to addressed-CLOSED

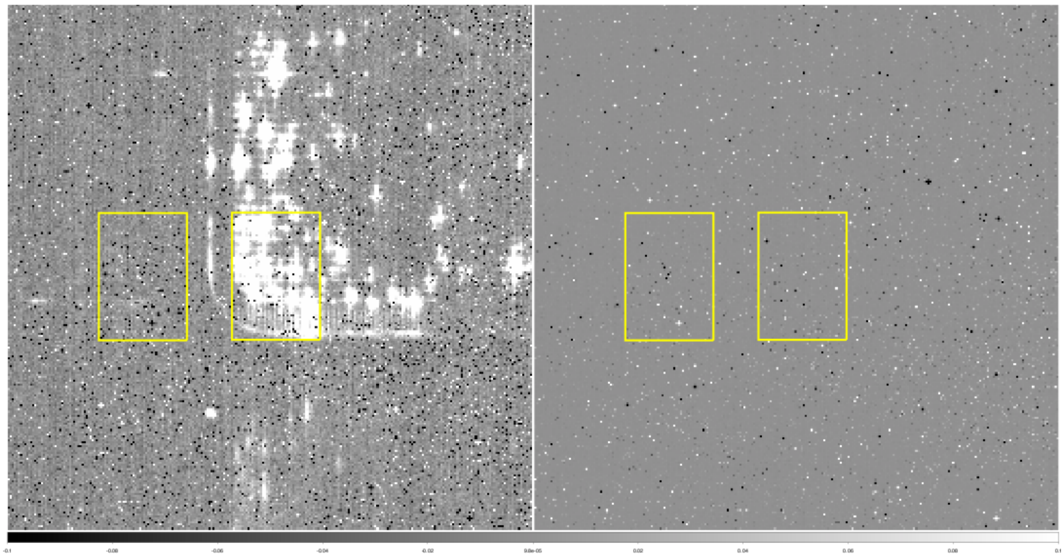

Figure 8: Portion of quadrant Q3 (its lower left corner) as imaged on the NIRSpec detector before (left panel) and after (right panel) applying the glow-mitigation solution. Glowing shorts appear as bright spots on the detector, with a count rate over an order of magnitude higher than that of the surrounding regions. The median count rates measured inside the two boxes drawn in each panel are given in Table 5.

Table 5: Median count rates as measured in the regions indicated in Figure 8.

| ID | Left box | Right box |
|---|---|---|
| 8150 | 0.0048 | 0.0599 |
| 12201 - 12231 | 0.0005 | 0.0005 |

# 7 REFERENCES

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