Swift UVOT

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Life time performance of FM-intensifer in analog mode Report-B

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Life time performance of FM-intensifier in analog mode

1. Introduction

The previous report (Swift-UVOT/MSSL.TC/0002) showed capability of high time resolution observation with analog mode by applying lower H.V.s to MCPs, when a target star was brighter than 17.4mag. Swift UVOT may have several bright stars in the field of view during chasing time variation of a gamma ray burster. It is dangerous for the intensifier to observe a bright star for a long time in photon counting mode (high gain in MCPs). The analog mode observation will offer the longer observation time safely, since gain in MCPs is less than 1/5 of the photon counting mode.
This intensified CCD detector demonstrated far longer life time (>100 times) than typical position sensitive detectors in terms of accumulated electrons onto anode (XMM-OM/MSSL.TC/0059). This difference may be due to the lower gain in MCPs with our detector, i.e. 5x10^5 with ours while 5x10^7 with the position sensitive detectors. If the life time is extremely sensitive to the gain, the reduction of the gain by the factor of 5 may extend the life time far more than x5.
In this report, the image intensifier was operated in the analog mode and was exposed to an intense pinhole illumination for 100 hours. Gain depletion of MCPs and sensitivity loss in F-F images were assessed against accumulated photons and electrons.

2. Electric gain

The previous report (Swift-UVOT/MSSL/TC/0002) showed best results in analog mode when applying 90% of nominal MCP voltage for photon counting mode with DEP_#5 intensifier. This damage test was carried out with DEP_#8 intensifier, whose nominal MCPs voltage is 2250V. Therefore, 2020V, 90% of the nominal, was applied to the MCPs for the exposure to the intense pinhole illuminations. The mask pattern consists 11x11 pinholes and their brightness changes along columns by the factor of ~2E+4 (Fig. 1). The light source is made of 64 green LEDs coupled with diffuser and 5300-5700A interference filter. The brightness of the LEDs can be controlled by a constant current source by the factor of ~2E+4 (see detail in XMM-OM/MSSL.TC/0057).

The brightness of the pinhole array was calibrated by 3 exposures with the 3 LED current levels, 1,3 and 10 in order to overcome small dynamic range of the detector. The lower LED current (L=1) was used for determining brightness ration among bright pinhole columns, while the medium LED current (L=3) was for faint pinhole columns (Table 1). The highest LED current (L=10) was only for the faintest pinhole column (col=1). Photon losses due to coincidence were corrected for precise photometries (Table 2). Finally, the absolute brightness of the pinhole columns at the LED current level of 10 is tabulated in Table 3.

Table 1
Raw counts /(hour x spot) 21 June 2000 DEP_#8

	LED = 1	3	10
col=11	264920.0	N/A	N/A
col=10	254720.0	N/A	N/A
col=9	32620.0	N/A	N/A
col=8	24460.0	N/A	N/A
col=7	2381.2	N/A	N/A
col=6	2131.9	23104.0	N/A
col=5	158.2	1680.4	N/A
col=4	84.1	1042.4	N/A
col=3	22.5	186.2	N/A
col=2	(7.0)	169.0	(253160.0)
col=1	14.2	164.6	264110.0

Table 2
True counts /(sec x spot) 21 June 2000 DEP_#8

	LED = 1	3	10
col=11	94.58122		
col=10	90.11536		
col=9	9.74329		
col=8	7.26678		
col=7	.69737		
col=6	.62426	6.85783	
col=5	.04627	.49191	
col=4	.02459	.30502	
col=3	.00658	.05446	
col=2	(.00205)	.04942	(89.43997)
col=1	.00415	.04814	94.22338

Table 3
Pinhole brightness at LED current level = 10

column	1	2	3	4	5	6	7	8	9	10	11
Brtness (c/s)	94.22	96.73	106.59	597.0	962.8	13.4k	15.0k	156k	209k	1938k	2034k
B0 star (mag)	16.5	16.5	16.4	14.5	14.0	11.1	11.0	8.4	8.1	5.7	5.6

The ratio of gains between V_mcp=2250V (nominal) and 2020V were determined by both of the brightness of event splash at phosphor screen and anode current. The pulse height distributions of the event splash with the 2 different voltages to MCPs were shown in Fig. 2. A F-F with the count rate of 15,000 c/s (full area) was used as an input light source. It was difficult to determine the ratio accurately, because the pulse height distribution with V_mcp=2020V was squashed to the lower energy end. The brief ratio determined from the peak positions was > 5.5 times.
The brighter F-F input was used for the measurement of the anode current to provide sufficient current at V_mcp=2020V. The detected count rate for the input F-F measured in photon counting mode was 86,100 c/s (full area). After the correction of the coincidence loss, the true incoming rate is estimated to be 94,000 c/s (full area). The procedure of the coincidence correction followed XMM-OM/MSSL.TC/0050. Where coincidence area of event splashes was assumed to be 12 (CCD_pixels)^2 from other 2 intensifiers, though there was no specific measurement for DEP_#8. A 99.91k Ohm resister was inserted at the anode cable, whose voltage was 8000V, and the small voltage drop across the resister was measured with a precision multimeter, FLUKE 87 IV, in the readout accuracy of 1uV. The resistance value was also calibrated by the FLUKE 87 IV. The small voltage drops were 1012uV and 151uV for V_mcp=2250V and 2020V. Hence, currents were 10.23nA and 1.53nA. The input impedance of Fluke 87IV is 10M Ohm, therefore anode currents were corrected by the factor of 1.01.
The full detector area is (3.37 x256 CCD_pixels)^2, while photocathode area is circle with the diameter of 25mm. Since the anode current was induced from all photocathode area, incoming rate of electrons creating node current were 94,000 c/s * (D=25mm) / (3.37 x256 (CCD_pixels)^2 = 94,000 c/s * 1.2467 = 117,000 c/s. Therefore, the electric gain for low count rate is 5.4x10E+5 with V_mcp=2250V and 8.1x10E+4 with V_mcp=2020V. The ratio of the gain is x6.7 times.

The electric gain for high count rate was measured using the pinhole illumination in the LED current range of L=1-10 for V_mcp=2250V and L=3-10 for V_mcp=2020V. Columns=1-9 of the pinhole array was blocked, so that the brightest 2x11 pinholes with nearly same brightness from columns=10-11 only were used for the illumination. Since voltage display of the FLUKE 87 IV was not stable in the last 2 digits (10uV, 1uV), the display was read 10 times and averaged for the lowest 2 illuminations (i.e. LED current levels=3 and 4 with V_mcp=2020V and L=1 and 2 with V_mcp=2250V). The results for the both of V_mcp=2250V and V_mcp=2020V were tabulated in Table 4 and were plotted in Figs. 3 and 4. The higher electric gains with pinhole input than F-F input at the low count rate are due to global gain variation of MCPs.

1) Electric gain of the intensifier is 5.7E+5 at low count rate with V_mcp = 2250V and 8.1E+4 with V_mcp = 2020V.
2) Gain depletion is 1/9.7 at the count rate of 2E+6 c/s with V_mcp = 2250V, while 1/8 with V_mcp = 2020V, assuming pore paralysis is negligible at the count rate of 100 c/s,

Electric gain of MCPs at pinhole positions should have changed during the heavy photon dose. The anode current was measured after completing the 100 hours photon dose by illuminating exactly same pinhole positions. This gauges the level of the change before and after the photon dose. Again, columns=1-9 of the pinhole array was blocked, so that the brightest 2x11 pinholes from columns=10-11 only were used for the light source. The gains at the brightest pinholes for various input rate were tabulated in Table 5 and were plotted in Figs. 3 and 4 overlaying original gains. In spite of the large gain depletion at the low input rate, the gain in the saturated count rate does not change before and after the 100 hours dose. This is particularly true for the illumination above 1E+5 c/(sec x spot) with V_mcp = 2250V and 1E+6 c/(sec x spot) with V_mcp = 2020V. From these results we can assume anode currents at columns=10 and 11 were constant throughout the dose, hence we can determine total accumulated charge precisely. There is no measurement on the change of gain at other places, i.e. columns=1-9. Since the total accumulated charges themselves are smaller, the anode currents were hopefully same before and after the photon dose.

Because of the large gain depletion at the low count rate region while no gain depletion at the high count rate after the 100 hours photon dose, the gradient of the gain curve against input rate becomes flat. This suggests very hard scrubbing may lighten pore paralysis effect.

Table 4. Electric gain of XMM-OM tube in high count rate

	LED Intensity (c/s pinhole)	Anode current (pA) from 22 pinholes		Electric Gain	
		2020V	2250V	2020V	2250V
F-F	94000	1530	10230	8.1 E+4	5.4 E+5
L=1	92.35	(6.7)	184	(2. E+4)	5.7 E+5
L=2	352	132	585	10. E+4	4.7 E+5
L=3	1014	295	1370	8.3 E+4	3.8 E+5
L=4	3426	800	2880	6.6 E+4	2.4 E+5
L=5	16500	2330	9260	4.0 E+4	1.6 E+5
L=6	51000	5250	20200	2.9 E+4	1.1 E+5
L=7	139000	11100	43300	2.3 E+4	0.88E+5
L=8	410000	29700	114000	2.1 E+4	0.79E+5
L=9	984000	57800	225000	1.7 E+4	0.65E+5
L=10	1986000	102000	412000	1.5 E+4	0.59E+5

Table 5. Electric gain after 100 hours dose

	LED Intensity (c/s pinhole)	Anode current (pA) from 22 pinholes		Electric Gain	
		2020V	2250V	2020V	2250V
L=1	92.35	---	64	---	2.0 E+5
L=2	352	---	219	---	1.8 E+5
L=3	1014	103	664	3. E+4	1.9 E+5
L=4	3426	239	1810	2. E+4	1.5 E+5
L=5	16500	1041	6550	1.8 E+4	1.1 E+5
L=6	51000	2790	16900	1.6 E+4	0.94E+5
L=7	139000	7700	38400	1.6 E+4	0.78E+5

L=8	410000	24000	108000	1.6 E+4	0.75E+5
L=9	984000	50200	225000	1.4 E+4	0.65E+5
L=10	1986000	94100	419000	1.3 E+4	0.60E+5

Ref-2 Files used in this section
/swift/ZPHD010.dat
ZPIN011.dat,ZPIN012.dat,ZPIN013.dat,ZPIN014.dat

3. Gain depletion

Pulse height distributions (hereafter, PHD) for individual pinhole columns, 4-11 (600-2E+6 c/s), in the pinhole array were measured with V_mcp=2250V before starting the photon dose as reference. The photon doses were followed 3 times, 15 hours, 15 hours and 70 hours with V_mcp=2020V. The pulse height distributions were measured after the each photon dose.
Fig. 5 shows the original PHD before the dose and the one after the 100 hours dose by the 2E+6 c/s pinholes. The gain reduced to 1/2.5 of the original. The gain depletion was quantified from peak positions of the PHD. Day by day change of the gain is tabulated in Table 6. The results were plotted against accumulated charge as shown in Fig 6. Fig. 7 is the extract from XMM-OM/MSSL.TC/0059, in which the intensifer was operated in photon counting mode. The plots of anolog mode coincides with that of photon counting mode. This implies that the gain depletion can be described by the single parameter, accumulated charge, for any condition (i.e. different gain, input count rate, exposure time etc.).

Ref-3 Files used in this section
/swift/ZPHD016.dat,ZPHD028.dat,ZPHD047.dat,ZPHD064.dat

4. Photocathode sensitivity loss

The plot of photocathode sensitivity loss against accumulated photons showed split branches in high dose end according to the illumination intensities (Fig. 35 of Report-B). Again, this seemed to be due to the pore paralysis of MCPs. Photocathode sensitivity loss was plotted against anode current in Fig.51, using Table 28 and assuming constant electric gain throughout the photon dose.
The split branches seen in Fig. 35 (v.s. accumulated photons) merged together in Fig. 51. This result implies that ion feed back is proportional to the electron cloud at the 2nd MCP.

4. Sensitivity loss in photon counting image

A F-F image with the blue LED (460nm) was integrated for 15 hours in photon counting mode after each intense illumination to see the impact on science image. The integration started at the elapsed time of 80 hours for the 1st day, 38 hours the 2nd day and 27 hours the last day, since the end of the intense illuminations to avoid fluorescence. Fig. 8 shows 2 raw F-F images, one taken prior to the photon dose for reference and the other after the 100 hours dose. The F-F after the dose clearly shows an array of black spots corresponding to the pinhole positions.

A F-F image in each day of photon dose was divided by the reference F-F to remove detector artefacts and illumination non-uniformity. Then, the 11x11 array of black spots were averaged along the columns to improve S/N. Central positions of the black spots coincided with pinhole positions in the accuracy of 10um. The day by day growth of the black spots is shown in Fig. 9. These images contain all factors, i.e. fluorescence, gain depletion and photocathode sensitivity loss. White spots appeared at 2E+6 c/s pinhole positions in the 1st day, as the fluorescence dominated photocathode sensitivity loss and MCPs gain depletion. The black spots are seen for the illumination intensities of > 19kc/s after the 100 hours dose but not obvious for the illumination intensities of < 2.1kc/s. This is big improvement from the DEP-QM intensifier, in which black spots were clearly seen for the illumination intensities of 0.8kc/s after 21 hours dose (ref. XMM-OM/MSSL/TC/0044). Fig. 32 shows profiles of the averaged black spots from the 5th to the 9th days. Y-width of the slice is 3 twixel (= 58um). Since the integrations were started after the decay of fluorescence for these 5 F-Fs, the peak depths were not affected by fluorescence more than 0.8%. The depth of black spots reached 30% for the brightest illumination after 100 hours dose.

The sensitivity loss at the peak position was quantified from the average of 3x3 twixels square centred on the black spots. The normalization level was determined from 37x37 twixels (=717um) square excluding central D=21 twixels circular area. Then, the effect of fluorescence (3.8% in maximum) was subtracted. The results were tabulated in Table 19 and were plotted against accumulated dose events in Fig. 33. The sensitivity did not decrease up to 1E+8 dose events. It started to decrease steeply from 1E+10 dose events. The sensitivity decreased more slowly for the brighter pinholes. This is again the effect of pore paralysis.

The sensitivity loss for DEP's QM-intensifier was plotted in the same frame as shown in Fig. 34. The QM-intensifier already lost sensitivity by 3% at 3E+7 dose events, while the DEP_#8 intensifier did not up to 3E+9 dose events. The ruggedness of DEP_#8 intensifier is clear at the lower dose events.

The sensitivity loss in F-F image was averaged over central D=210um (=11 twixels) circular area to characterize spatial extent of damage as well as the depth. The results are tabulated in Table 20 and plotted in Fig. 35 after the correction of fluorescence.

A Gaussian profile was fitted to deep black spots to investigate the spatial extent directly. The results are tabulated in Table 21 and shown in Fig. 36. The width of the black spots increased with accumulated dose events. It started from 80um(FWHM) and reached 120um after acquiring 1E+12 dose events.

The sensitivity loss seen in F-F image is the combination of gain depletion and photocathode sensitivity loss. The photocathode sensitivity losses were calculated by removing the effect of gain depletion. The results were tabulated in Table 22 and were shown in Fig. 37. The sensitivity loss of photocathode is not obvious up to 1E+9 dose events. The plot has large scatter at larger dose events, since the calculation becomes less accurate when the gain depletion is large. For instance, 20% of photo-events were lost due to the gain depletion at 2E+6 c/s pinhole position after 100 hours dose.

Table 19. Sensitivity change in blue F-F image at peak position

Total dose (hour)		Pinhole intensity (counts/sec) 120c/s	210	1.1k	2.1k	19k	21k	220k	320k	2070k	2070k
0.3		.996	1.004	.989	1.000	.996	.991	.994	.984	.979	.981
1.0		.994	.980	.990	.983	.986	.992	.999	.988	.980	.983
3.0		.997	1.003	.996	1.000	.983	.986	.981	.967	.968	.971
7.0		.997	1.002	.998	1.012	.971	.981	.963	.961	.911	.928
15.0		.998	.995	.984	1.000	.970	.975	.934	.937	.870	.894
30.0		.999	1.002	.988	1.001	.954	.960	.905	.896	.785	.821
50.0		.994	.992	.984	.990	.942	.950	.883	.878	.747	.779
70.0		1.009	.996	.979	.990	.929	.917	.844	.836	.667	.694
100.0	1D	.996	1.000	.974	.979	.932	.925	.824	.819	.623	.665
100.0	2D	1.003	.980	.976	.981	.942	.938	.881	.848	.652	.698
100.0	5D	1.001	.990	.979	.981	.948	.944	.879	.852	.663	.713

Appendix. Experiment procedure for DEP_#8 intensifier in analog mode

20 June - 6 July 2000

File Name Pinhole PHD Dark F-F Time(start)

Before Damage for reference

2000/06/20

PHD010 300FR 17H 51M 05S

Pin011 L=3 54000S 19H 01M 34S

2000/06/21

Pin012 L=1 3600S 10H 17M 16S

Pin013 L=10 1800S 15H 11M 25S

Pin014 L=10 1800S 16H 21M 36S

DEP015 54000S 18H 13M 44S

2000/06/22

PHD016 70000FRs 11H 27M 18S

Ana017 10000FRs 12H 37M 00S

Ana018 10000FRs 16H 50M 13S

15 hour Day-1 18:24 - 09:24 2000/06/22

2000/06/23

Drk019 7200S 10H 36M 54S

Drk020 7200S 12H 37M 18S
Drk021 7200S 14H 37M 42S
DEP022 Th=15 54000S 17H 48M 35S
2000/06/24
Drk023 7200S 08H 48M 59S
Drk024 7200S 10H 49M 22S
Drk025 7200S 12H 49M 45S
Drk026 7200S 14H 50M 08S
2000/06/26
Ana027 20000FRs 12H 28M 17S
PHD028 70000FRs 14H 34M 34S
Drk029 7200S 15H 37M 46S
DEP030 Th=15 54000S 17H 38M 10S
2000/06/27
Drk031 7200S 08H 38M 34S
Drk032 7200S 10H 38M 58S
\/
15 hour Day-2 13:15 - 04:16 2000/06/27
\/
2000/06/28
Drk033 7200S 12H 41M 57S
Drk034 7200S 19H 37M 23S
Drk035 7200S 21H 37M 47S
Drk036 7200S 23H 38M 11S
2000/06/29
Drk037 7200S 01H 38M 35S
Drk038 7200S 03H 38M 59S
Drk039 7200S 05H 39M 23S
PHD040 50000FRs 10H 41M 54S
Ana041 30000FRs 11H 23M 58S
Drk042 7200S 16H 52M 29S
DEP043 54000S 18H 52M 53S
2000/06/30
Drk044 7200S 09H 53M 17S
Drk045 7200S 11H 53M 40S
Drk046 7200S 13H 54M 03S
PHD047 50000FRs 17H 24M 09S
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70 hour Day-3 18:05 - 16:05 2000/06/30
\/
2000/07/03
Drk048 7200S 17H 20M 36S
Drk049 7200S 19H 21M 01S
Drk050 7200S 21H 21M 25S
Drk051 7200S 23H 21M 49S
2000/07/04
Drk052 7200S 01H 22M 13S
Drk053 7200S 03H 22M 37S
Drk054 7200S 05H 23M 01S
Drk055 7200S 07H 23M 25S
Drk056 7200S 09H 23M 49S
Drk057 7200S 11H 24M 13S

Drk058	7200S	13H 24M 37S	
Drk059	7200S	15H 25M 01S	
DEP060	54000S	19H 26M 24S	
			2000/07/05
Drk061	7200S	10H 26M 48S	
Drk062	7200S	12H 27M 12S	
Ana063	30000FRs	15H 47M 40S	
			2000/07/06
PHD064	50000FRs	09H 39M 36S	

