Algorithm & Requirements for Calculating the Local Count Rate for the FUV Detector

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Prepared By:	Dr. Erik Wilkinson Dr. Erik Wilkinson, COS Instrument Scientist	10-26-00 Date
Reviewed By:	Dr. Kenneth R. Brownsberger Dr. Kenneth R. Brownsberger, CU/CASA	10 [illegible]
Reviewed By:	Dr. John Vallerga Dr. John Vallerga, Univ [illegible]	[illegible]0-31-00 Date
Reviewed By:	Dr. Jon A. Morse Dr. Jon Morse, COS Project Scientist	[illegible]-26-00 [illegible]ate
Approved By:	Dr. James C. Green Dr. James C. Green, COS Princ [illegible]	[illegible]0-26-00 Date
Approved By:	John P. Andrews Mr. John P. Andrews, COS Experiment Manager	10-30-00 Date

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Center for Astrophysics & Space Astronomy
University of Colorado
Campus Box 593
Boulder, Colorado 80309

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1. INTRODUCTION

This report presents the derivation of and threshold requirements for the local maximum count rate calculation algorithm for the FUV detector onboard the COS instrument. Included in this presentation is a discussion of the relevant detector effects and how they relate to the maximum local rate. This is included to help motivate the issues and provide clarity for future generations.

For context, the local rate checks are performed during target acquisition using a 2 second exposure time and just prior to a science observation with a 15 second exposure. The later is commanded by the ground software while the former is commanded autonomously by the target acquisition flight software.

Please note that throughout this document the term "resel" refers to a spectral resolution element, which is defined as the wavelength of interest divided by the resolution.

2. MICROCHANNEL PLATE PERFORMANCE & REQUIREMENTS

Under most scenarios the FUV detector is a robust detector system capable of surviving incidents where the detector is exposed to over illumination. The detector has multiple levels of bright object protection which exist at the hardware level and resident in the detector control electronics (DCE) flight software. For a detailed description of these systems please see the Operations Requirement Document (OP-01).

There are two circumstances during which it is possible to depress the gain in a localized region of space: rate induced gain depression and charge extraction. Rate induced gain depression is a temporary condition that is ameliorated after incident flux is removed from the detector. Charge extraction is a permanent effect that requires the spectral region on the detector to be repositioned. Ultimately, charge extraction has the highest potential for impacting the COS mission as it requires significant effort to recalibrate the instrument after the spectral region has been adjusted. From a scientific standpoint and under most operational scenarios, rate dependent gain depression is the primary concern when considering the maximum local rate.

To better appreciate the issues surrounding the maximum local rate it is advantageous to understand both types of gain depression. Microchannel plates in a detector system are responsible for the charge amplification that takes a single photoelectron emitted by the photocathode and amplies the signal so that $\sim 10^7$ e^- are emitted at the backend of the microchannel plate stack. Under normal operating scenarios this is a destructive process as a microchannel plate stack has a finite amount of total charge that can be emitted before the gain begins to decrease. The rate at which this gain degrades is a function of the gain of the plate stack as well as the total extracted charge. For new plates, the gain drops quickly with extracted charge, then levels off to a plateau region. Before launch, the COS plates are subjected to a charge extraction process of high flux at low gain ("scrub") to reach this plateau, such that the rate of gain loss extrapolated over a mission will be less than an amount that will reduce the response of the plates to photons. Typically, this gain loss rate is quoted as a percent decrease in the modal gain per coulomb/cm^2 extracted from the plates (%/C/cm^2). For the COS FUV detector , measurements of flight like plates indicate a rate of ~100%/C/cm^2 can be achieved with a scrub.

A decrease in gain can affect the resolution of the detector and the detection quantum efficiency (DQE). Fortunately, recent tests have shown that the resolution of the FUV detector is fairly insensitive to the MCP gain. The DQE is affected by the gain because as the gain drops some fraction of the detected events with the lowest gain begin to fall below the lower level threshold. For the FUV detector we have specified that the DQE shall not drop by more than 1% for a 1% drop in the modal gain. Using the MCP gain degradation rate specification of 100%/C/cm^2 a total extractable charge of 0.01 C/cm^2 is derived. This value corresponds to a total fluence of 5×10^5 photons/resel before a 1% drop in the DQE is observed (assuming an operating gain of $10^7 e^-$). These numbers are consistent with Technical Evaluation Report "FUV Detector Lifetime Estimates for Observation Planning" (COS-11-0018).

The rate dependent gain depression is a non-destructive effect. In this scenario, the time scale for electrons to propogate through the MCP plates is larger than the time scale for extraction. Basically, the timescale to replenish the microchannel walls with charge is longer than the charge extraction rate.. Therefore, this effect appears at high local rates and vanishes below a specific threshold. Ultimately the local gain depression will be calibrated as a function of rate. However, currently we only have a conservative estimate of the performance based on past MCP stacks of similar resistance of 5 counts/sec/pore with 10% loss in gain.

The question then is which phenomenon, permanent charge extraction or rate dependent gain depression, is the primary concern associated with setting the maximum local rate. Using maximum local rate per pore specification we can calculate the maximum local rate per resel. The typical COS resel is $8X10^{-3}$ mm^2 in area (0.04 X 0.20 mm). The top plate of the FUV MCP stack has 12 μm holes on 15 μm centers, so the area of a pore is about $\pi*(0.0075)^2=1.76X10^{-4}$ mm^2. Dividing the area of a resel by the pore area we get an area of a resel in units of pores, 45 pores/resel. Multiplying the maximum local rate of 5 counts/sec/pore by 45 pores/resel we end up with 225 counts/sec/resel as the rate at which we'll see a 10% decrease in the DQE.

Finally, this value needs to be scaled so that there is no drop in the DQE, otherwise the photometric accuracy of the instrument could be compromised. By using a conservative linear relation ship between gain loss and DQE loss, one can scale the maximum local rate by the ratio of the count rates at which there is no DQE loss and the count rate at which there is 10% DQE loss. In doing so, we derive a value of *120 counts/sec/resel as the maximum local rate at which there is no loss in the DQE*. Above this value there will be a loss in the DQE and thus the ability to accurately calculate the flux is lost.

This limit of 120 c/s/resel is a large value and corresponds to a flux level of 1.1 X 10^{-11} ergs/cm^2/sec/Å (~ 0.7 photons/cm^2/sec/Å) and is about as bright as G191-B2B at ~1300Å. Therefore, there is no need to be concerned that this number will restrict reasonable observations using COS.

However, this value is sufficiently high that gain sag due to permanent charge extraction is a concern. For example, under the current and conservative estimates of the mcp lifetime, only 5×10^5 photons/resel can be acquired before there is a 1% drop in the detection quantum efficiency. A bright line with 100 counts/sec/resel observed for 5000 seconds would extract 5×10^5 photons/resel, thereby necessitating corrective action to restore the accuracy of the calibration. Therefore, target screening is a must to insure that bright emission lines are not observed for extended periods of time. It is also not advisable to lower the local rate thresholds, as this will begin to limit the number of targets that can be observed with COS.

3. EVALUATING THE LOCAL RATE IN FLIGHT

The local count rate is checked in flight as follows. Using the time tag data a histogram of events with 4096 bins in the dispersion direction shall be formed. Functionally this is done by dropping the 2 least significant bits in the dispersion direction for each event. Note that all information regarding the cross dispersion direction is lost.. The measured events in each bin are then compared to the maximum local rate threshold, which is the maximum number of events that is allowable for a given exposure time. If the counts in any bin exceeds the allowable threshold the flight software should follow standard bright object protection protocols, i.e. close the external shutter and turn off all calibration lamps.

Finally, there are about 2300 resels across a single detector segment so binning the spectrum into 4096 bins effectively divides the maximum local rate per resel by 2. Specifically, the maximum local rate for the histogram is scaled by the ratio of the number of resels and the number of bins in the histogram, i.e. (2300resel/4096bins) *

120counts/sec/resel=68 counts/sec/bin. Table 1 presents the maximum local rates for each channel.

As a general warning, these values may change based on the final measurements of the DQE loss versus count rate for the flight plates. Therefore, I recommend that the values of the maximum local count rate thresholds used here be changeable in flight.

Table 1

Mode	Maximum Local Count Rate (MLCR)	Threshold for 2 sec Local Rate Check	Threshold for 15 sec Local Rate Check
G130M	60 counts/sec/bin	164 counts	900 counts
G160M	60 counts/sec/bin	164 counts	900 counts
G140L	60 counts/sec/bin	164 counts	900 counts

Finally, there remains the chance that the local count rate could exceed the threshold from statistical variations in the measured counts. To minimize the chance that this will occur and disrupt HST operations an appropriate amount of margin should be designed into the local count rate thresholds. During target acquisition the flight software utilizes a 2 second exposure time. This sets the maximum threshold at 120 counts. The four sigma variation from this number is 44 counts. Therefore, the threshold for the local count rate should be 164 counts. The equation for deriving this number is shown below.

$$\text{Threshold} = (\text{MLCR})\,\text{texp} + 4\sqrt{(MLCR)\,\text{texp}}$$

where

MLCR is the Maximum Local Count Rate
texp is the exposure time
4 represents the 4σ statistical upper limit which emcompasses 99.994% of all events.

While this allows for the opportunity to successfully acquire a target which exceeds the maximum local rate, the subsequent 15 second observation taken prior to the beginning of the science exposure will detect this condition. There is no risk of permanent damage to the detector by using the 164 count threshold even though there is the potential to exceed the 60 counts/sec/bin maximum local count rate. The threshold for the 15 second local-rate-check observation shall be 900 (=15 seconds * 60 counts/sec/bin).