Technical Evaluation Report
"Correcting for Changes in the FUV Detector Pixel Scale"

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Prepared By: ______________________________ ________
E. Wilkinson, COS Instrument Scientist, CU/CASA — Date

Reviewed By: ______________________________ ________
J. Morse, COS Project Scientist, CU/CASA

Reviewed By: ______________________________ ________
J. Green, COS Princi — Date

Approved By: ______________________________ ________
J. Andrews, COS Experiment Manager, CU/ — Date

Approved By: ______________________________ ________
J. Vallerga, Detector Scient — Date

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

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THE UNIVERSITY OF COLORADO

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1. INTRODUCTION

This Technical Evaluation Report (TER) discusses the causes and the correction of variations in the pixel scale of the COS FUV detector. It also presents the algorithms necessary to correct for the variations under various operational conditions.

2. OPERATIONAL DESCRIPTION OF THE FUV DETECTOR

The COS/FUV detector utilizes time delay anodes to determine the position of a detected photon incident on the detector in the dispersion and cross dispersion directions. The time delay anode is an analog readout device which is then digitized as opposed to a directly digitized device such as a CCD or MAMA detector. In a CCD or MAMA detector the position of the photon relates directly to a physical location on the detector, e.g. potential wells defined by the substrate structure in a CCD or the anode pattern in a MAMA detector.

A time delay anode detector computes the position of the photon by measuring the difference in the time it takes for photon initiated charge pulses to reach opposite ends of the anode. To be more specific, the photon initiated charge pulse on the anode splits and each half travels towards a different end of the anode at a fixed speed. One pulse is always biased to arrive at the digitizers first and is known as the START pulse. The START pulse initiates the discharging of a precision capacitor, referred to as the integrating capacitor. The second pulse to arrive, known as the STOP pulse, stops the discharging. The remaining voltage on the capacitor is digitized by an analog to digital converter. Thus, the final digitized voltage relates to the original position on the incident photon.

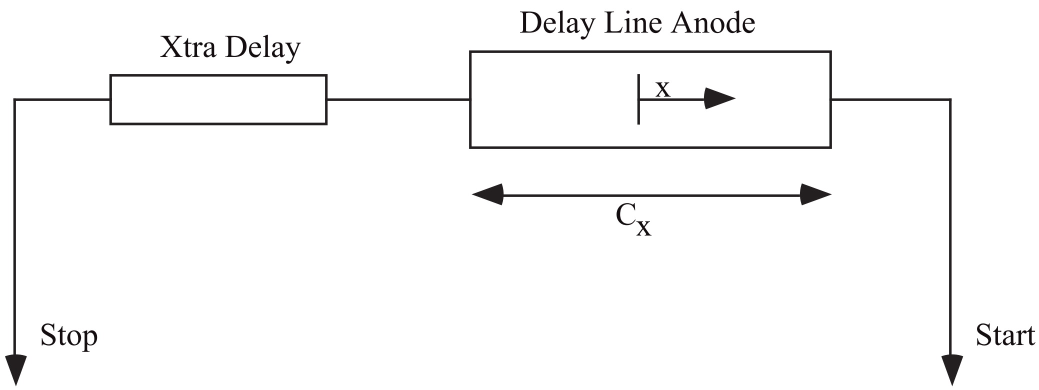

Figure 1: Schematic representation of the time delay concept. The Xtra delay ensures that the Stop signal always arrives after the Start signal. C_x is the physical length of the delay anode; x is the position of the detected photon.

The key point here is that anything that alters how the charge pulses propagate through the detector system prior to the analog to digital converters can and will alter the relationship between pixel value and physical location on the detector. For example, no two integrating capacitors are identical, so subtle differences in the discharge rate will produce different digital values for identical START and STOP arrival times. Thus, different electronics will alter the relationship between physical location and pixel. Another example is that the dielectric constant of the anode substrate varies with temperature. Thus the propagation speed of the charge pulse is temperature dependent, so the pixel value for a given physical location will change with temperature.

The following sections describe the dominant effects and how the variation in pixel scale can be corrected.

3. THERMAL DRIFTS IN THE DETECTOR PIXEL SCALE

There are two temperature dependent components within the detector subsystem that can effect the pixel scale of the detector. The first is the integrating capacitor in the time to digital converter electronics. This is the capacitor, which is discharged between the arrivals of the START and STOP pulses. Small changes in the dielectric constant of the capacitor change the rate of the discharge and thus alter the pixel scale of the detector. The distortion introduced by thermal changes in the capacitors dielectric introduce a stretch that is symmetric about *pixel 0*, so not only does the pixel scale change but the entire image will appear to move to the right or left depending upon the temperature. The second component is the anode substrate itself. The dielectric constant of the anode material determines the propagation speed of the charge pulses along the anode. Variations in the dielectric constant due to temperature change the speed and thus the time it takes to traverse the anode. Therefore, the size of the anode in time will change and the pixel scale along with it. In this case the temperature dependence results in a symmetric stretch in the pixel scale about the *center* of the active area of the detector.

Laboratory studies at UCB using the FUSE detector have shown that the dominant contributor to the change in the pixel scale is the temperature dependence of the dielectric constant of the anode substrate (ref. 7/14/98 memo by John Vallerga and FUSE-UCB-014 by Geoff Gaines at UCB).

One way to visualize the effect of the anode stretch is to consider a rubber ruler (i.e. the pixel scale) behind a fixed aperture (i.e. the active area of the microchannel plates). As the ruler is stretched the distance between the individual rulings (i.e. pixels) increases and thus the apparent length of the fixed aperture will shrink. In reality, the fixed aperture will have fewer, larger pixels across its length because the size of the pixels has changed.

The change in pixel scale induced by thermal variations in the anode substrate can be monitored and corrected by tracking the locations of the electronic stim pulses, which are fixed in physical space. The electronic stims are introduced at both the fast amplifier inputs and which electronically represent two fixed points in physical space on the anode outside the field of view of the detector. Since these pulses traverse the anode delay line, they are ideal for tracking the performance of the anode and electronics as a function of time and temperature.

The detector thermal environment has been engineered to provide a very stable thermal environment. The current design supports a temperature change of <+/- 1 deg. C/orbit. Current estimates of the magnitude of the thermally induced change in pixel scale is +/- 5 pixels/deg. C at the stim locations. The center of the anode experiences no change, as the effect is a stretch rather than an offset of the pixel scale. This information is presented in a memo by Geoff Gaines at UCB (FUSE-UCB-014).

Based on current knowledge the change in pixel scale over a given orbit should be small, however, the change could be substantial between orbits separated in time or between observations where the thermal environment of the COS FUV detectors is quite different. Therefore, it is crucial that plans be put in place now to correct for this effect.

The stretch of the pixel scale is linear, assuming that the temperature of the anode is uniform. It is straightforward to develop an expression that maps the position of any detected photon at an arbitrary pixel scale to it's position in a standardized detector reference frame, i.e. a baseline pixel scale, using information regarding the electronic stim locations.

Definitions:

- X – physical location of a detected photon in microns (NOT pixel value)
- S_1 – the pixel value of the low pixel electronic stim in the dispersion direction at temperature T_1
- S_2 – the pixel value of the high pixel electronics stim in the dispersion direction at temperature T_1
- S'_1 – the pixel value of the low pixel electronic stim in the dispersion direction at temperature T_2
- S'_2 – the pixel value of the high pixel electronic stim in the dispersion direction at temperature T_2
- a – the X offset in microns at T_1 and will be calibrated in the laboratory
- a' – the X offset in microns at T_2
- b – the pixel scale in microns/pixel at T_1 and will be calibrated in the laboratory at T_1

- b' – the pixel scale in microns/pixel at T_2
- P – pixel value of the photon at T_1
- P' – pixel value of the photon at T_2

At T_1 the position X of a photon is described by....

$$X = a + bP$$

and at T2 by;

$$X' = a' + b'P'$$

However, the electronic stims remain fixed in physical space, so that X = X' for an electronic stim. Therefore, we can solve for a and b at all times using the electronic stim locations. The solution goes as follows:

At X = X' we have for each electronic stim location…

$$a + bS_1 = a' + b'S'_1$$
$$a + bS_2 = a' + b'S'_2$$

so,

$$a' = a + bS_1 - b'S'_1$$

$$b' = b\,(S_2 - S_1) / (S'_2 - S'_1)$$

So, given the location of the electronic stims at any given time any photon can be mapped to a fixed position in physical space using the final expression….

$$\mathbf{X' = [a + bS_1 - b(S_2 - S_1) / (S'_2 - S'_1)S'_1] + [b\,(S_2 - S_1) / (S'_2 - S'_1)]P'}$$

Recall that a, b, S_1, and S_2 are calibration constants that will be measured in the laboratory as part of preflight calibration. This is crucial for accurate flat fielding of the detector *as the flat field must be applied to the detector image in physical space not wavelength space*.

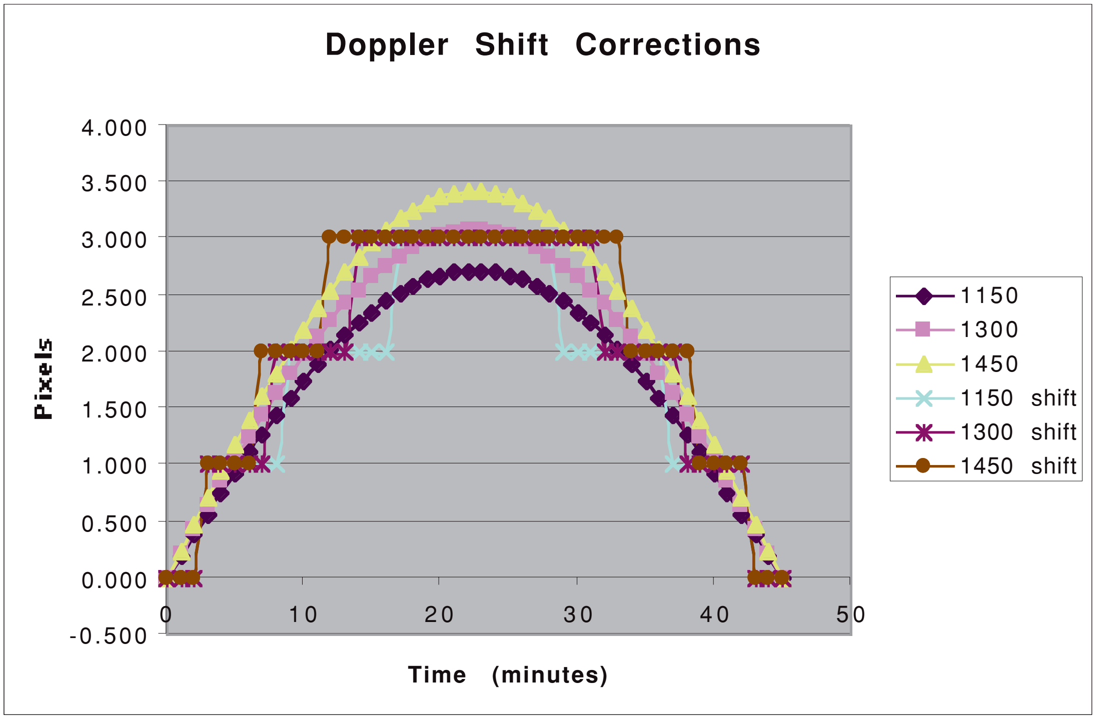

Figure 2: This figure depicts the continuous Doppler shift and the pixelated Doppler shift correction that will be used while in ACCUM mode to compensate for the spacecraft induced Doppler shift. Note how there is often a +/- 1 pixel error in the Doppler shift due to differences in the wavelength dependent Doppler shift.

4. DOPPLER SHIFTS IN THE WAVELENGTH SCALE

During flight the orbital motion of the HST will induce measurable Doppler shifts in the data. These shifts will be of order 0 to 4 pixels in the FUV channel for the M gratings and 0 to TBD in the NUV channel. However, the wavelength shifts are also convolved with the variations in pixel scale. This is further complicated by tbe observing mode employed.

For example, the Doppler correction in TTAG mode is applied during pipeline processing on the ground and can be applied after corrections for pixel scale changes. In ACCUM mode the Doppler correction is applied in flight by shifting the array in memory so that the detector pixels are mapped to the same location in wavelength space. This makes it impossible to correct for changes in pixel scale due to thermal variations in the anode when observing in ACCUM and effectively imposes a maximum exposure time of approximately 15 minutes when observing in ACCUM mode if the maximum resolution is required. This limits the potential errors due to thermally induced variations in the pixel scale to about 1 pixel in the worst case.

The Doppler effect is wavelength dependent, so each wavelength should actually be adjusted a different amount to accurately account for the Doppler shift. However, the planned implementation cannot account for this as each photon event is adjusted uniformly across the detector. Figure 2 shows how the Doppler shift is different for three wavelengths across the detector. The error in Doppler correction is about 1 pixel at the different wavelengths, roughly the same amount as the error introduced by the pixel scale stretch. However, the Doppler shift is biased towards one or the other end of the detector while the pixel scale stretch is symmetric about the center of the anode on each segment. Therefore, at one of the detector image the error in the plate scale (Å/micron) will be smaller than at the opposite end. By minimizing the integration time in ACCUM mode the Doppler shift becomes the dominant source of error.

5. CONCLUSIONS

This TER highlights two concerns relating to the handling of the data and operational constraints of the COS instrument. The first is that in TTAG mode the data must first be corrected for potential changes in the pixel scale of the detector due to changes in the anode temperature. After that is complete corrections for spacecraft induced Doppler shift can be taken into account. In ACCUM mode the integration time for any given exposure must be less than about 15 minutes to ensure that variations in the anode temperature are insignificant compared to the Doppler shift.