

## Operational Definitions and Implementation of WFC3 UVIS Subarrays

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### Abstract

*This technical memo describes the implementation of WFC3 UVIS channel subarrays. The capability described herein allows for both user-defined subarrays and a set of fixed subarray apertures. The precedent and experience for such an implementation are the ACS and STIS instruments.*

### 1. Introduction

This technical memo describes the requirements, operational definition and limitations, and ground and flight software implementation of WFC3 UVIS channel subarrays. Both fixed and user-defined subarrays are available for the UVIS, whereas only fixed subarrays are available for IR channel users. The precedent and experience for such an implementation are the ACS and STIS instruments.

Subarrays in general afford the following advantages:

- Subarrays can potentially reduce readout overheads thus allowing for higher sampling rates and improved S/C efficiency. For a detector without a shutter, as is the case for the WFC3 IR channel, increasing sampling rates produce shorter exposure times, a capability that is crucial for observing bright standard stars with the WFC3 IR channel. In the case of the UVIS channel potential reductions in readout overhead are advantageous.
- Subarrays mitigate data volume and data manageability problems. For example, the WFC3 UVIS channel includes 5 sets of quad filters, hence subarrays the size of the quadrants affords the user the advantage of minimizing data volume.

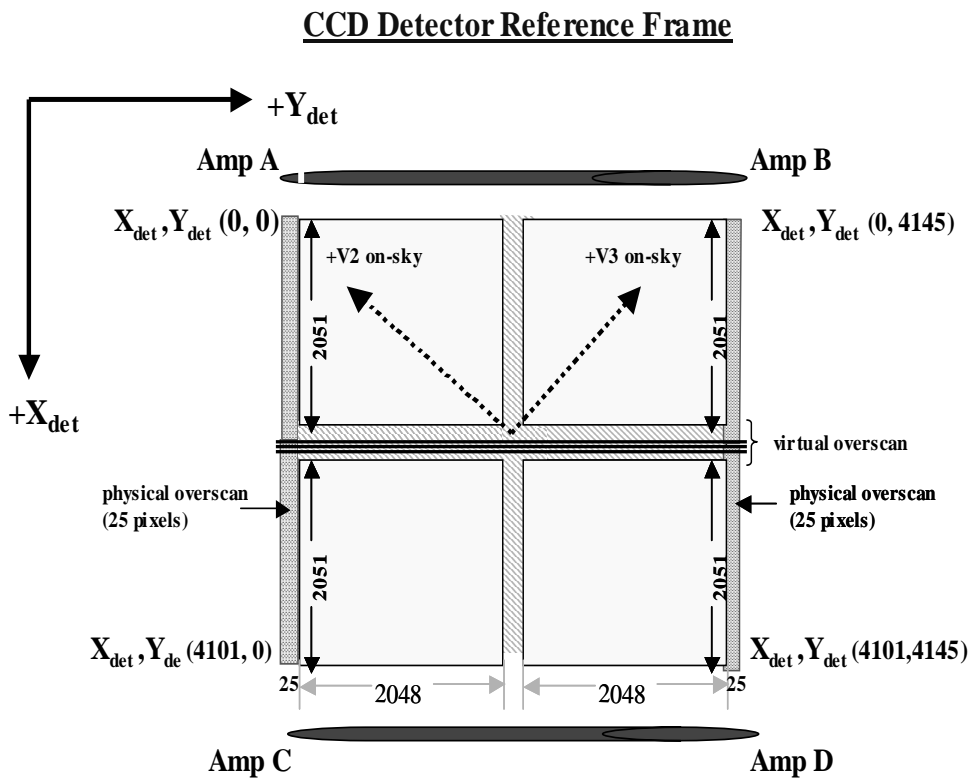
**Fixed subarrays** are sub-images whose size and location on the detector are fixed and described as unique apertures to the ground system. STScI will provide and maintain specific calibration files for these subarrays and users can be confident that observations will be repeatable from a pointing and performance point of view. Fixed subarrays are easily described and offer a straightforward implementation to the GO. The IR channel offers 6 such subarrays and the UVIS channel 12 subarrays.

**Variable subarrays** are sub images whose size and location on the detector are specified, within operational limitations, by the user. The user can also use proposal syntax to center a subarray on a target whose position is shifted from the nominal aperture reference position via the POS TARG special requirement. Variable subarrays provide the following advantages:

- data volume savings and potential savings in readout overhead depending on the size and location of the subarray. The capability is particularly advantageous for calibrations of spatial effects: grism wavelength calibration across the chip, psf, encircled energy, filter throughput uniformity. Some of these calibrations may be performed frequently especially in the early phases of the WFC3 mission.
- Carefully planned variable subarrays can be used to target bright objects in a large field without having to move the telescope thus saving maneuvering overheads.

## 2. UVIS Coordinate Systems

The WFC3 flight software operates the UVIS detector using the DETECTOR reference frame, a coordinate system that is derived from the chip and how it is read out. The ‘DETECTOR’ (and sometimes called the FSW reference) frame encompasses both chips and runs from 0 to 4101 in Xdet and 0 to 4145 in Ydet including the physical overscan. Figure 1 is a schematic of the CCD chips and the corresponding Detector Reference Axes. Note that virtual pixels are ignored by the flight software and so are not numbered in the detector reference frame.



**Virtual Overscan Notes:**

- not included in detector coordinate system
- shown in drawing as slanted areas
- found in whole rows “after” detector data

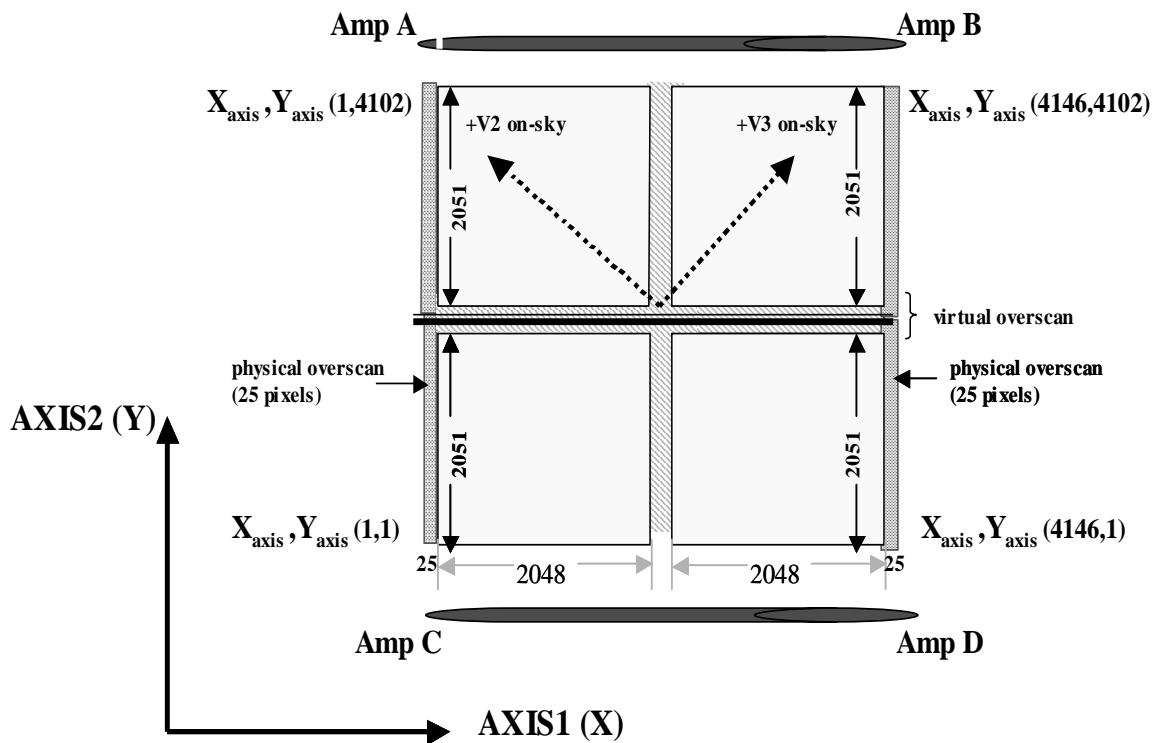
**Physical Overscan Notes:**

- at each end of each row
- shown in drawing as dotted areas
- is included in detector coordinate system

Figure 1: UVIS DETECTOR (or Flight Software) Reference Frame.

The IMAGE (or AXIS) reference frame (AXIS1,AXIS2) was chosen to be consistent with three parameters: 1) the serial register is along AXIS1, 2) the dispersion direction of the UV Grism G280 projects roughly along AXIS1 with the dispersion increasing in the +AXIS1 direction, and 3) the image has the same parity as the sky. The proposal instructions refer to this frame (called “Image-based”) because it corresponds directly to the image processed through OPUS generic conversion. Hence the user specifies variable subarray parameters with respect to the image frame. The ground system software transforms the image coordinates into the FSW detector coordinates used by the onboard software to command the instrument. Figure 2 is a schematic showing the IMAGE reference frame.

### CCD IMAGE Reference Frame



**Virtual Overscan Notes:**   
 - not included in Image Reference Frame  
 - shown in drawing as slanted areas  
 - found in whole rows “after” detector data

**Physical Overscan Notes:**   
 - at each end of each row  
 - shown in drawing as dotted areas  
 - is included in Image reference system

Figure 2: UVIS IMAGE (or AXIS) Reference Frame

### 3. UVIS FSW Subarray Implementation

The FSW requires the subarray dimensions and the coordinates of the bottom left corner in the Detector reference frame . Dimension can be specified in one or both directions and the default for each axis is the full dimension along that axis. We refer the reader to WFC3 OP-01 (W. Baggett and R. Henry, WFC3 Operations Concept) ) for detailed explanation of constraints and readout procedures. Several constraints are imposed by FSW design and minimization of operational complexity:

- Subarrays are read out by the FSW through one amplifier only.
- The subarray must fall entirely within one of the two CCD chips and must reside on the same half of the detector in the Xdet direction as the specified amplifier. The ground system will identify the correct readout amp if one is not specified via Optional Parameter AMP.
- The array must be placed within a border of at least 1 pixel from the edge of the detector. Note that the row on each chip along the gap between chips is useable in a subarray description.
- Both the corner pixel of the subarray in the Ydet direction and its dimension in the Ydet direction must be “even” values of pixels (to keep timing intervals to integer values).

The readout timing patterns for subarrays are cleverly designed to maximize the speed with which the arrays can be read. Rows before the subarray are binned in the serial register using a bin size of 10 and then *fast serial shifted*. This binned section is always an integer multiple of 10 rows. A border of 50 rows prior to the subarray is left un-binned implying that binning only occurs if there are 60 or more rows prior to the subarray start. Border zone rows will not be binned but will be fast serial shifted (to minimize noise effects near the subarray) until reaching the subarray boundary. The destination subarray data are read using slow serial shift timing. The diagram in Figure 3 illustrates the process and timing.

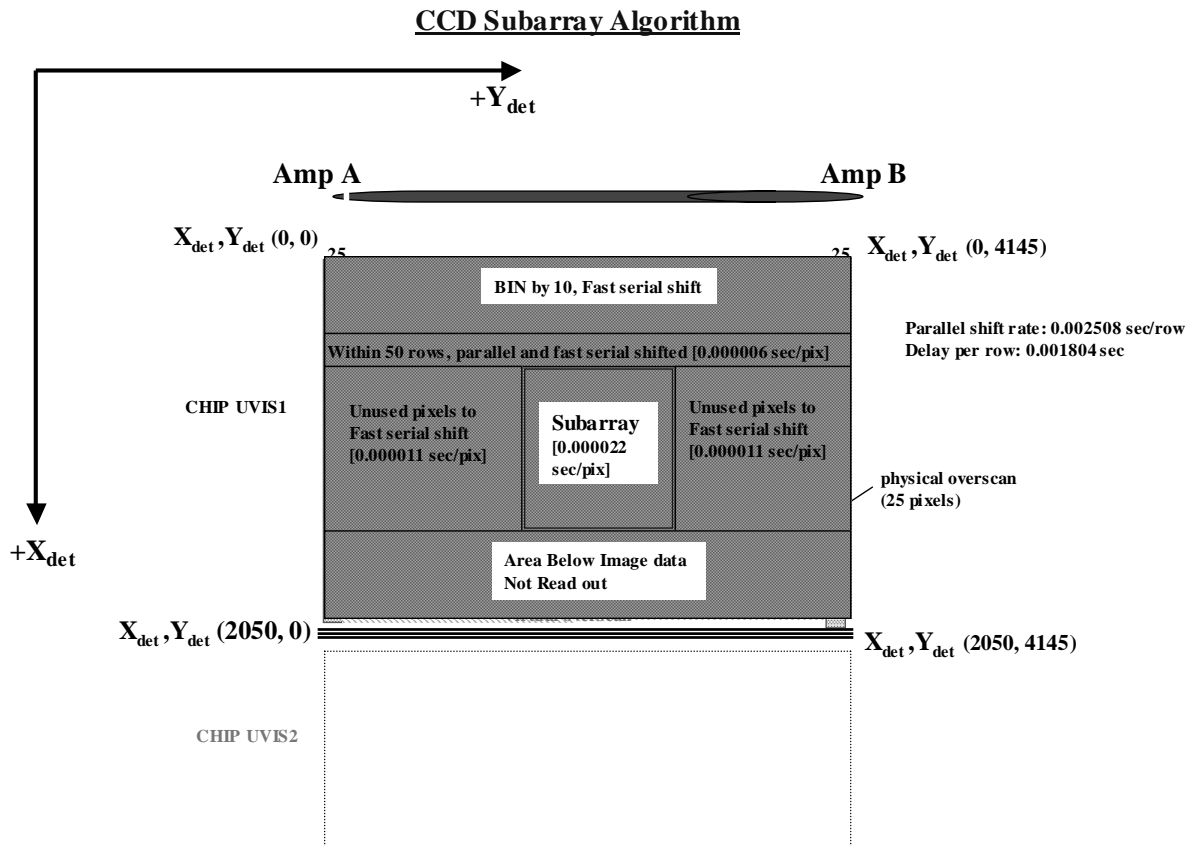


Figure 3: CCD Single Chip Subarray Readout Algorithm. Note that timing values will be verified/updated during ground testing).

## 4. UVIS Proposal Implementation

### 4.1 Variable Subarrays

The user will specify subarray parameters with respect to the Image (or AXIS) reference frame and a transformation algorithm in the ground system will transform the parameters into the Detector coordinates needed by the Flight Software. The transformations between the IMAGE and DETECTOR reference frames is straightforward and consists of a positive parity and a rotation of 90 degrees:

1) AXIS to Detector

$$\begin{aligned} X_{det} &= p ( X_{axis} - Xa0) \cos(g) + (Y_{axis} - Ya0) \sin(g) \\ Y_{det} &= -p ( X_{axis} - Xa0) \sin(g) + (Y_{axis} - Ya0) \cos(g) \quad \text{where} \end{aligned}$$

$p = \text{parity} = +1$ ,  $g = -90 \text{ degrees}$ ,  $Xa0 = 4102$ , and  $Ya0 = +1$

2) Detector to AXIS

$$\begin{aligned} X_{axis} &= p ( X_{det} - Xd0) \cos(g) + (Y_{det} - Yd0) \sin(g) \\ Y_{axis} &= -p ( X_{det} - Xd0) \sin(g) + (Y_{det} - Yd0) \cos(g) \quad \text{where} \end{aligned}$$

$p = \text{parity} = +1$ ,  $g = +90 \text{ degrees}$ ,  $Xd0 = 4102$ , and  $Yd0 = -1$

*(Note that the parity, angles, and zero-point offsets for this transformation reside in the ground system code itself.)*

The GO has the option of specifying the pixel size of the array in either dimension, using optional parameters **SIZEAXIS1** and **SIZEAXIS2**, and also defaulting the size in either dimension. Default sizes are the full range of a *single* chip minus 1) one-pixel edge requirement and 2) the even valued Y size/corner requirement, i.e., 4142, 2050 in Xaxis, Yaxis respectively. The restricted **AMP** optional parameter, set as an engineering option only, must be consistent with the location of the subarray and only a single amplifier can be used to read out a subarray. If the GO fails to describe a subarray subject to constraints and that falls solely within the confines of a chip, the ground system will automatically move that subarray, preserving its size, until it complies with the restrictions. The position of the subarray in pixels is specified using **CENTERAXIS1**, **CENTERAXIS2** optional parameters (i.e., **CENTERAXIS1** is used with **SIZEAXIS1**). Non-default values are valid when the subarray is smaller than the chip size.

### 4.2 Variable UVIS Subarrays and POS TARG Offsets

Further complicating the implementation is the capability to center a subarray on a target that has been shifted (i.e., “**POS TARGed**”) from the main aperture reference position. By entering the keyword value **TARGET** for either or both **CENTERAXIS** optional parameters, the GO can require an automatic shift of the subarray to match the **POS TARG** offset of the target. Now, in order to make this calculation in the ground system, the **POS TARG** offset must be transformed into a DETECTOR coordinate offset in pixels. The following series of coordinate transformations (algorithms are provided in the Appendix) are performed by the ground system software:

**POS TARG X,Y (undistorted, arcsec) → SIAS AXIS X,Y (distorted, pixels) → DET X,Y (FSW)**

### 4.3 Fixed UVIS Subarrays

A set of fixed subarrays has been added to the WFC3 UVIS aperture suite. These are carefully chosen to balance the need for trend studies and calibrated modes for the GO with the minimization of S/C time to calibrate these special modes. Table 1 presents the UVIS apertures, including the fixed subarrays, their definition, sizes, and locations in both IMAGE and DETECTOR reference frames. The apertures are plotted in Figure 4. Each subarray is considered a unique aperture by the ground system with its own targetable reference position (V2V3). A variable subarray cannot be used when a fixed subarray aperture has been selected (no “subarrays within subarrays”). A target may be “POS TARGed” from the center of the subarray as with any other aperture however the subarray will remain fixed. If a target is POS TARGed out of the fixed subarray boundaries, the ground system will issue a warning.

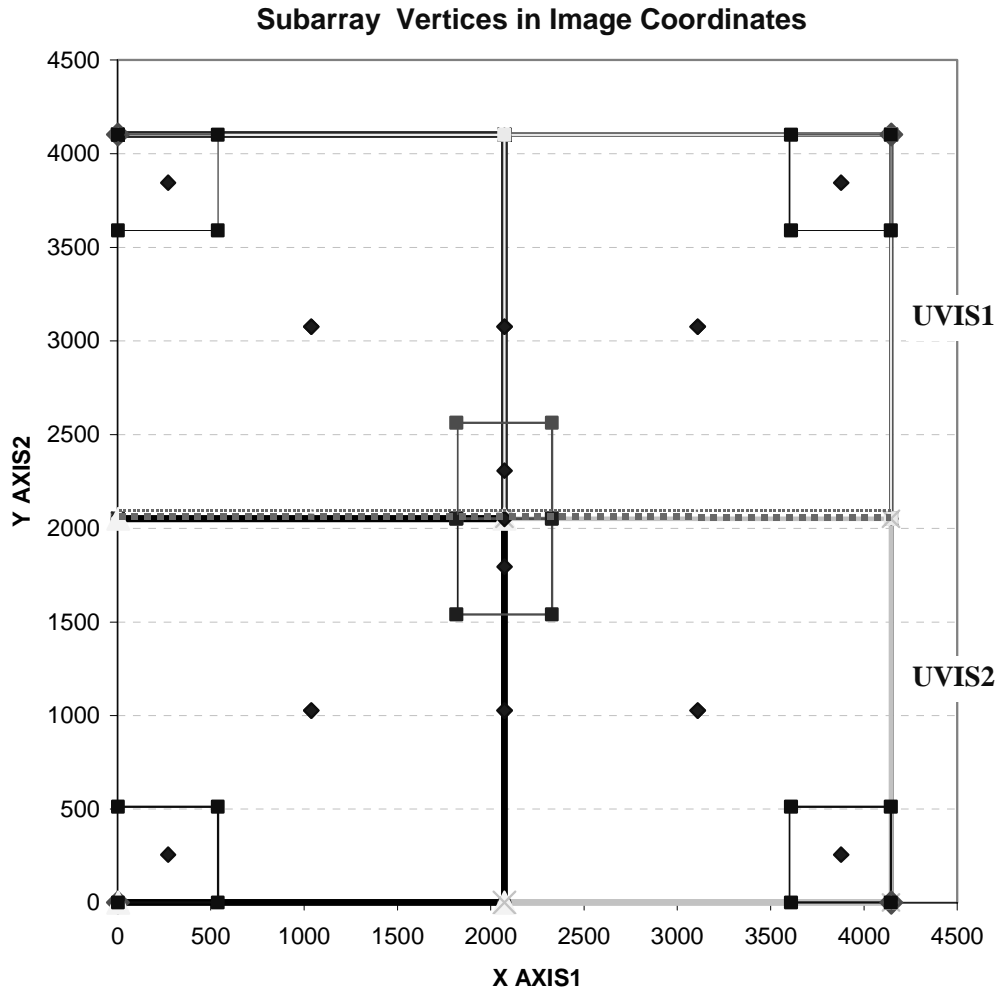
The subarray types include the logical quad subarrays for use with the quad filters, single chip subarrays, and a series of 512-pixel arrays located in the corners and in the center of each chip. The center arrays provide a user with the best optical image quality while the corners can be used for Charge Transfer inefficiency mitigation. Note that physical overscan pixels are included in the coordinate system used to define the apertures.

#### Acknowledgements:

We would like to thank Glenn Foley (GSFC) for his support in preparing and understanding the subarray implementation.

12/2002-oll		IMAGE (or AXIS) Coordinates						Detector (OR Flight Software) Coordinates			
Aperture	Definition	IMG	IMG	IMG	IMG	IMG	IMG	DET	DET	DET	DET
Coord ID		Ap SIZ	Ap SIZ	center	center	corner	corner	center	center	corner	corner
	Full Frame:	Xim	Yim	Xim	Yim	Xim	Yim	Xdet	Ydet	Xdet	Ydet
IUVISMAC	Macro-ap	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
IUVIS	CCD all	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
IUVISFIX	CCD all fix	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
IUVIS1	CCD1	4146.0	2051.0	2074.0	3077.0	1.0	4102.0	1025.0	2073.0	0.0	0.0
IUVIS1FIX	CCD1 fix	4146.0	2051.0	2074.0	3077.0	1.0	4102.0	1025.0	2073.0	0.0	0.0
IUVIS2	CCD2	4146.0	2051.0	2074.0	1026.0	1.0	2051.0	3076.0	2073.0	2051.0	0.0
IUVIS2FIX	CCD2 fix	4146.0	2051.0	2074.0	1026.0	1.0	2051.0	3076.0	2073.0	2051.0	0.0
IUVISB2	Binned 2x2 full read	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
IUVISB3	Binned 3x3 full read	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
IUVISB2FIX	Binned 2x2 full read	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
IUVISB3FIX	Binned 3x3 full read	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
IUVISQA	quad A- full read	2073.0	2051.0	1037.0	3077.0	1.0	4102.0	1025.0	1036.0	0.0	0.0
IUVISQB	quad B- full read	2073.0	2051.0	3110.0	3077.0	2074.0	4102.0	1025.0	3109.0	0.0	2073.0
IUVISQC	quad C- full read	2073.0	2051.0	1037.0	1026.0	1.0	2051.0	3076.0	1036.0	2051.0	0.0
IUVISQD	quad D- full read	2073.0	2051.0	3110.0	1026.0	2074.0	2051.0	3076.0	3109.0	2051.0	2073.0
IUVISQAFIX	quad A- full read	2073.0	2051.0	1037.0	3077.0	1.0	4102.0	1025.0	1036.0	0.0	0.0
IUVISQBFIX	quad B- full read	2073.0	2051.0	3110.0	3077.0	2074.0	4102.0	1025.0	3109.0	0.0	2073.0
IUVISQCFIX	quad C- full read	2073.0	2051.0	1037.0	1026.0	1.0	2051.0	3076.0	1036.0	2051.0	0.0
IUVISQDFIX	quad D- full read	2073.0	2051.0	3110.0	1026.0	2074.0	2051.0	3076.0	3109.0	2051.0	2073.0
IUVISPRSM	UVPRISM - full read	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
IUVIS300RF	300X Ref for prism	4146.0	4102.0	2074.0	2051.0	1.0	4102.0	2051.0	2073.0	0.0	0.0
<b>Fixed Subarrays:</b>											
IUV1_2K4	one chip subarray	4142.0	2050.0	2074.0	3076.0	3.0	4101.0	1026.0	2073.0	1.0	2.0
IUV2_2K4	one chip subarray	4142.0	2050.0	2074.0	1026.0	3.0	2051.0	3076.0	2073.0	2051.0	2.0
IUV1M1_512	512 in mid UV1	512.0	512.0	2073.0	2307.0	1817.0	2563.0	1795.0	2072.0	1539.0	1816.0
IUV1CA_512	512 in corner UV1	536.0	512.0	271.0	3845.0	3.0	4101.0	257.0	270.0	1.0	2.0
IUV1CB_512	512 in corner UV1	536.0	512.0	3877.0	3845.0	3609.0	4101.0	257.0	3876.0	1.0	3608.0
IUV2M1_512	512 in mid UV2	512.0	512.0	2073.0	1795.0	1817.0	2051.0	2307.0	2072.0	2051.0	1816.0
IUV2CC_512	512 in corner UV2	536.0	512.0	271.0	257.0	3.0	513.0	3845.0	270.0	3589.0	2.0
IUV2CD_512	512 in corner UV2	536.0	512.0	3877.0	257.0	3609.0	513.0	3845.0	3876.0	3589.0	3608.0
IUVQA_2K2	quad sub	2072.0	2050.0	1039.0	3076.0	3.0	4101.0	1026.0	1038.0	1.0	2.0
IUVQB_2K2	quad sub	2072.0	2050.0	3109.0	3076.0	2073.0	4101.0	1026.0	3108.0	1.0	2072.0
IUVQC_2K2	quad sub	2072.0	2050.0	1039.0	1026.0	3.0	2051.0	3076.0	1038.0	2051.0	2.0
IUVQD_2K2	quad sub	2072.0	2050.0	3109.0	1026.0	2073.0	2051.0	3076.0	3108.0	2051.0	2072.0

Table 1: WFC3 UVIS Full Frame and Fixed Subarray Apertures

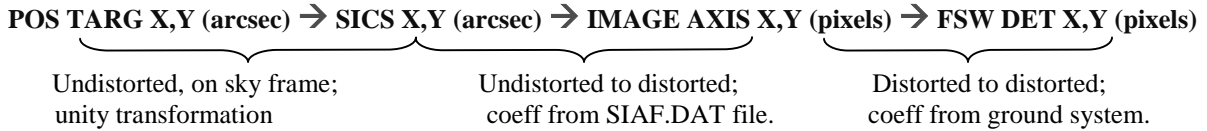


**Figure 4: UVIS Subarray Vertices – blue diamonds indicate aperture centers; pink dotted line delineates the two chips.**

# APPENDIX

## Coordinate Transformation Algorithms

The coordinate transformations performed by the ground system to relate a POS TARG offset slew in arcsec to a motion in detector coordinates are:



For the WFC3 UVIS mode, “SICS X,Y” system, an intermediate aperture-based reference frame originally introduced to add flexibility, is by definition and requirement identical to the POS TARG reference frame. The ground system software uses three sources of input to convert from POS TARG offsets in arcsec to pixel offsets with respect to the FSW Detector Coordinate System:

1. Coefficients that relate WFC3 UVIS POS TARG reference frame to an intermediate Aperture-based reference frame (Science Instrument Coordinate System or “SICS”). These are stored in the ground system software.
2. Coefficients that relate the SICS system to the Image Reference Frame (called SIAS in PDB ICD jargon). These coefficients reside in the SIAF.DAT file.
3. Coefficients that relate the Image reference frame to the Detector reference frame. These are stored in the ground system software.

The POS TARG and SICS systems are orthogonal and are expressed in units of arcsec. It is important to note then that if the POS TARG reference frame is redefined (for some unlikely reason) or the distortion sequence is changed (e.g., polynomial order), the appropriate changes must be reflected in the ground system software as well as the SIAF.DAT aperture file in the SCIOPSD system.

### 1. POS TARG $\leftrightarrow$ SICS

The transformation between POS TARG and the SICS system is linear and we have defined them to be coincident and co-linear for WFC3. The origins of the POS TARG and SICS frames are aperture dependent and are defined as the pointing fiducial for that aperture. The GO can issue a POS TARG offset on the proposal to move the target respect to the aperture “center”.

The general linear transformation algorithm for POS TARG to SICS Transformation:

$$\begin{aligned} X_{sics} &= p \cos(g) (X-XP0) + \sin (g) (Y-YP0), \\ Y_{sics} &= -p \sin (g) (X-XP0) + \cos (g) (Y-YP0) \end{aligned}$$

Where  $p$  = parity between the two systems and  $g$  is the angle between the systems. For WFC3 UVIS, this is the unity transformation:  $p = +1$ ,  $g = 0$ , and the zero point offsets  $XP0 = YP0 = 0$ . The coordinates are expressed in arcsec. The reverse transformation is straightforward. These coefficients are stored in the ground system software and not in the SIAF.DAT aperture file.

## 2. SICS $\leftrightarrow$ IMAGE

The SICS to IMAGE (called the Science Instrument Aperture Frame in the SIAF.DAT file) transformation is for the WFC3 UVIS channel the same as the POS TARG  $\rightarrow$  IMAGE transformation. The distortion and plate scale are used for the conversion. Coefficients may be defined for up to a fifth order polynomial (N=0 to 5). These algorithms are located in the ground system in several places (TRANS, SPSS, PASS, OPUS) and are:

$$X_{sics} = \sum_{J=0}^N \sum_{K=0}^J a^{jk} (X_{axis} - Xa0)^k (Y_{axis} - Ya0)^{j-k} \quad ,$$

$$Y_{sics} = \sum_{J=0}^N \sum_{K=0}^J b^{jk} (X_{axis} - Xa0)^k (Y_{axis} - Ya0)^{j-k} \quad ,$$

Where Xa0 and Ya0 are the origin of the SICSs system in Image coordinates, i.e., the pixel location of the pointing fiducial of the aperture and a and b are the polynomial coefficients.

For illustration sake the algorithms have been expanded to third order.

$$\begin{aligned} X_{sics} = & \underline{a00} + \underline{a10} (X - Xa0) + \underline{a11} (Y - Ya0) + a20 (Y - Ya0)^2 + a21 (X - Xa0)(Y - Ya0) \\ & + a22 (X - Xa0)^2 (Y - Ya0) + a30 (Y - Ya0)^3 + a31 (X - Xa0)(Y - Ya0)^2 + a32 (X - Xa0)^2 (Y - Ya0) \\ & + a33 (X - Xa0)^3 \dots\dots \end{aligned}$$

$$\begin{aligned} Y_{sics} = & \underline{b00} + \underline{b10} (X - Xa0) + \underline{b11} (Y - Ya0) + b20 (Y - Ya0)^2 + b21 (X - Xa0)(Y - Ya0) \\ & + b22 (X - Xa0)^2 (Y - Ya0) + b30 (Y - Ya0)^3 + b31 (X - Xa0)(Y - Ya0)^2 + b32 (X - Xa0)^2 (Y - Ya0) \\ & + b33 (X - Xa0)^3 \dots\dots \end{aligned}$$

The linear components of the algorithm are underlined. The reverse transformation coefficients are also available in the SIAF.DAT file. Note that non linear distortion coefficients must be modified to be consistent with the aperture location on the detector.

## 3. IMAGE $\leftarrow \rightarrow$ DETECTOR

The WFC3 UVIS detector system, described previously in this memo is used by the flight software to operate the detector. Its relationship to the user's Image frame is as follows:

1) AXIS to Detector

$$\begin{aligned} X_{det} &= p ( X_{axis} - Xa0) \cos(g) + (Y_{axis} - Ya0) \sin(g) \\ Y_{det} &= -p ( X_{axis} - Xa0) \sin(g) + (Y_{axis} - Ya0) \cos(g) \quad \text{where} \end{aligned}$$

$$p = \text{parity} = +1, g = -90 \text{ degrees}, Xa0 = 4102, \text{ and } Ya0 = +1$$

2) Detector to AXIS

$$\begin{aligned} X_{axis} &= p ( X_{det} - Xd0) \cos(g) + (Y_{det} - Yd0) \sin(g) \\ Y_{axis} &= -p ( X_{det} - Xd0) \sin(g) + (Y_{det} - Yd0) \cos(g) \quad \text{where} \end{aligned}$$

$$p = \text{parity} = +1, g = +90 \text{ degrees}, Xd0 = 4102, \text{ and } Yd0 = -1.$$