CHAPTER 2: Instrument Description

In This Chapter...

2.1 Science Objectives

The scientific objective of the WFPC2 is to provide photometrically and geometrically accurate images of astronomical objects over a relatively wide field-of-view (FOV), with high angular resolution across a broad range of wavelengths.

WFPC2 meets or exceeds the photometric performance of WF/PC-1 in most areas. The goal is 1% rms photometric accuracy, which means that the relative response in all 800x800 pixels per CCD must be known to better than 1% through each filter, and that standard calibrations be done at this level. Currently, the absolute calibration in the primary broadband photometric filters is accurate at around the 2% level, and is expected to continue to improve. Success in this area is dependent on the stability of all elements in the optical train, particularly the CCDs and filters.

The narrow point spread function is essential to all science programs being conducted with the WFPC2, because it allows one to both go deeper than ground based imagery, and to resolve smaller scale structure with higher reliability and dynamic range. Further, many of the scientific goals which originally justified the HST require that these high quality images be obtained across a wide field-of-view. The Cepheid distance scale program, for example, cannot be accomplished without a relatively wide field-of-view.

A unique capability of the WFPC2 is that it provides a sustained, high resolution, wide field imaging capability in the vacuum ultraviolet. Considerable effort has been expended to assure that this capability is maintained. Broad passband far-UV filters, including a Sodium Wood's filter, are included. The Wood's filter has superb red blocking characteristics. Photometry at wavelengths short of 3000Å is improved through the control of internal molecular contamination sources and the ability to put the CCDs through warm-up decontamination cycles without loss of prior calibrations.

While the WFPC2 CCDs have lower V-band quantum efficiency than the WF/PC-1 chips, for many applications this is more than made up for by the lower read noise, and by the intrinsically uniform flat field. For example, these characteristics are expected to increase the accuracy of stellar photometry, which was compromised by uncertainty in the flat field in WF/PC-1.

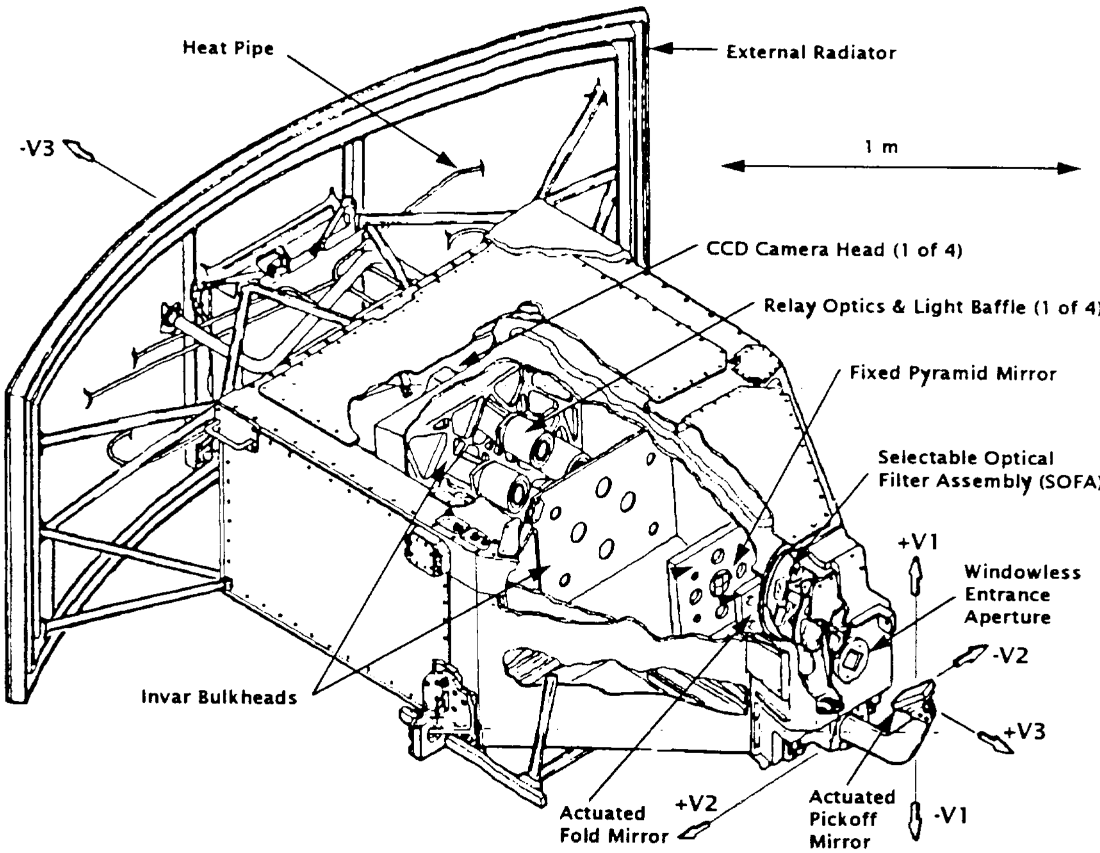
2.2 WFPC2 Configuration, Field-of-View, and Resolution

The field-of-view and angular resolution of the wide field and planetary camera is split up as follows (see Section 4.2 for more details on CCDs):

Table 2.1: Summary of Camera Format.

Camera	Pixel and CCD Format	Field-of-View	Pixel Scale	F/ratio
Wide Field	800 × 800 × 3 CCDs	2.5′ × 2.5′ (L-shaped)	~100 milli-arcseconds	12.9
Planetary	800 × 800 × 1 CCD	35″ × 35″	~46 milli-arcseconds	28.3

Figure 2.1: Wide Field Planetary Camera Concept Illustration. The calibration channel, and pick-off mirror mechanisms are not shown.



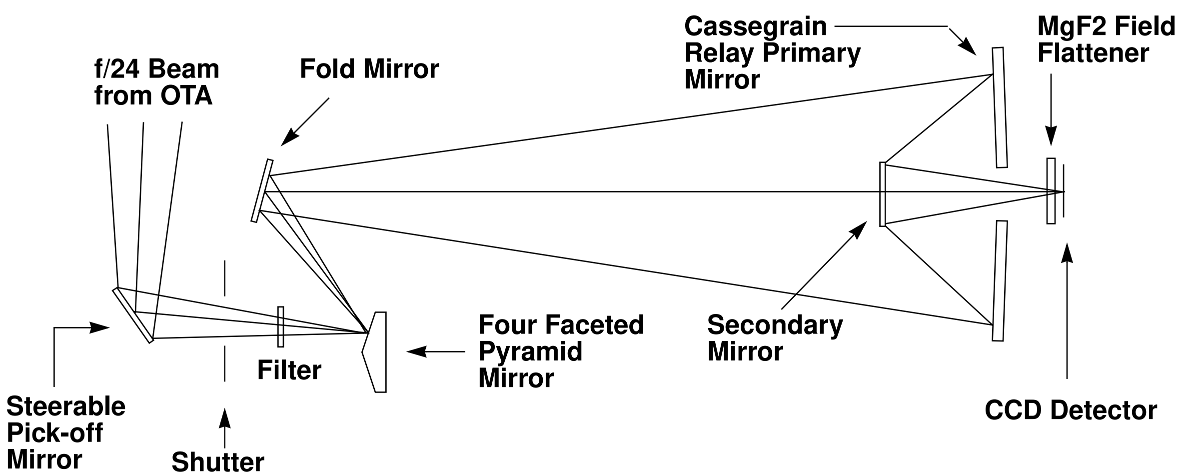
2.3 Overall Instrument Description

The Wide-Field and Planetary Camera, illustrated in Figure 2.1, occupies the only radial bay allocated to a scientific instrument. Its field-of-view is centered on the optical axis of the telescope and it therefore receives the highest quality images. The three Wide-Field Cameras (WFC) at F/12.9 provide an "L" shaped field-of-view of 2.5x2.5 arcminutes with each 15 μm detector pixel subtending 0.10″ on the sky. In the Planetary Camera (PC) at F/28.3, the field-of-view is 35″ x 35″, and each pixel subtends 0.046″. The three WFCs undersample the point spread function of the Optical Telescope Assembly (OTA) by a factor of 4 at 5800Å in order to provide an adequate field-of-view for studying galaxies, clusters of galaxies, etc. The PC resolution is over two times higher. Its field-of-view is adequate to provide full-disk images of all the planets except Jupiter (which is 47″ in maximum diameter). The PC has numerous extra-solar applications, including studies of galactic and extra-galactic objects in which both high angular resolution and excellent sensitivity are needed. In addition to functioning as the prime instrument, the WFPC2 can be used for target acquisition in support of other HST instruments, or for parallel observations.

Figure 2.2 shows the optical arrangement (not to scale) of the WFPC2. The central portion of the OTA F/24 beam is intercepted by a steerable pick-off mirror attached to the WFPC2, and is diverted through an open entry port into the instrument. The beam then passes through a shutter and filters. A total of 48 spectral elements and polarizers are contained in an assembly of 12 filter wheels. Then the light falls onto a shallow-angle, four-faceted pyramid located at the aberrated OTA focus, each face of the pyramid being a concave spherical surface. The pyramid divides the OTA image of the sky into four parts. After leaving the pyramid, each quarter of the full field-of-view is relayed by an optical flat to a Cassegrain relay that forms a second field image on a charge-coupled device (CCD) of 800x800 pixels. Each detector is housed in a cell that is sealed by a MgF_2 window. This window is figured to serve as a field flattener.

The aberrated HST wavefront is corrected by introducing an equal but opposite error in each of the four Cassegrain relays. An image of the HST primary mirror is formed on the secondary mirrors in the Cassegrain relays. (The fold mirror in the PC channel has a small curvature to ensure this, and is why the PC magnification changed from F/30 in WF/PC-1 to F/28.3 in WFPC2.) The spherical aberration from the telescope's primary mirror is corrected on these secondary mirrors, which are extremely aspheric. The point spread function is then close to that originally expected for WF/PC-1.

Figure 2.2: WFPC2 Optical Configuration



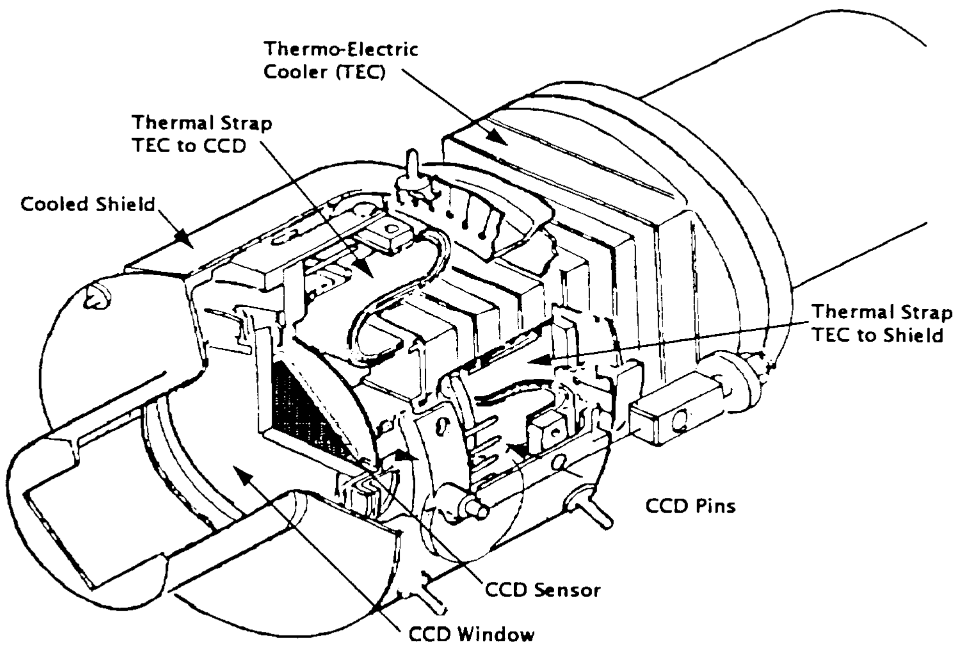
The single most critical and challenging technical aspect of applying a correction is assuring exact alignment of the WFPC2 pupils with the pupil of the HST. If the image of the HST primary does not align exactly with the repeater secondary, the aberrations no longer cancel, leading to a wavefront error and comatic images. An error of only 2% of the pupil diameter produces a wavefront error of 1/6 wave, leading to degraded spatial resolution and a loss of about 1 magnitude in sensitivity to faint point sources. This error corresponds to mechanical tolerances of only a few microns in the tip/tilt motion of the pick-off mirror, the pyramid, and the fold mirrors.

Mechanisms inside WFPC2 allow optical alignment on-orbit; these are necessary to insure correction of the OTA spherical aberration. The beam alignment is set with a combination of the steerable pick-off mirror and actuated fold mirrors in cameras PC1, WF3 and WF4. The 47° pick-off mirror has two-axis tilt capabilities provided by stepper motors and flexure linkages, to compensate for uncertainties in our knowledge of HST's latch positions (i.e., instrument tilt with respect to the HST optical axis). These latch uncertainties would be insignificant in an unaberrated telescope, but must be compensated for in a corrective optical system. In addition, three of the four fold mirrors, internal to the WFPC2 optical bench, have limited two-axis tilt motions provided by electrostrictive ceramic actuators and invar flexure mountings. Fold mirrors for the PC1, WF3, and WF4 cameras are articulated, while the WF2 fold mirror has a fixed invar mounting. A combination of the pick-off mirror and fold mirror actuators has allowed us to correct for pupil image misalignments in all four cameras. Since the initial alignment, stability has been such that mirror adjustments have not been necessary. The mechanisms are not available for GO commanding.

The WFPC2 pyramid cannot be focused or rotated. WFPC2 is focused by moving the OTA secondary mirror, and then COSTAR (or any future science instruments) is adjusted to achieve a common focus for all the HST instruments.

The four CCDs provide a 1600 x 1600 pixel field-format; three of the 800 x 800 CCDs have 0.1″ pixels (WFC), and one has 0.046″ pixels (PC). The CCDs are physically oriented and clocked so that the pixel read-out direction is rotated approximately 90° in succession (see Figure 1.1 on page 2). The (1,1) pixel of each CCD array is thereby located near the apex of the pyramid. As a registration aid in assembling the four frames into a single picture, a light can be turned on at the pyramid to form a series of eleven fixed artificial "stars" (known as Kelsall spots or K-spots) along the boundaries of each of the quadrants. This calibration is normally done in a separate exposure. The K-spot images are aberrated and similar in appearance to the uncorrected HST PSF. The relative alignment of the four channels has been more accurately determined from star fields, and is stable over long periods, but the K-Spot images are useful for verifying the stability.

Figure 2.3: Cooled Sensor Assembly

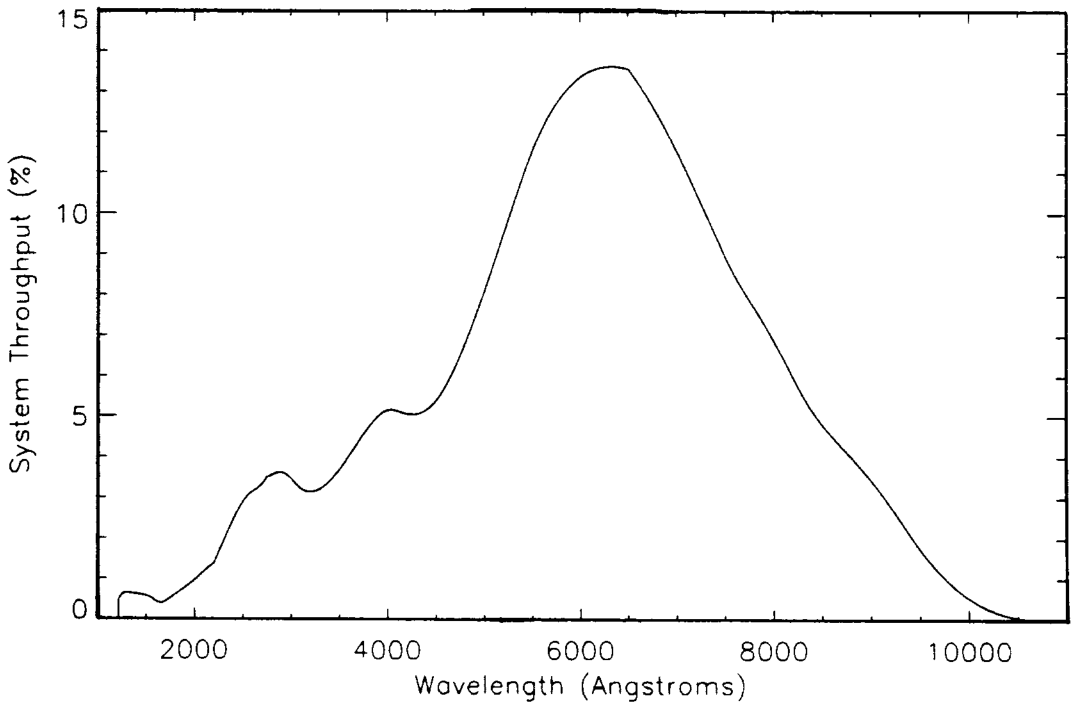


Each CCD is a thick frontside-illuminated silicon sensor, fabricated by Loral Aerospace. A CCD, mounted on its header, is hermetically packaged in a ceramic-tube body that is filled with 1.1 atmosphere of argon to prevent degradation of the UV sensitive phosphor, and sealed with the MgF_2 field flattener. This complete cell is connected with compliant silver straps to the cold junction of a thermo-electric cooler (TEC). The hot junction of the TEC is connected to the radial bay external radiator by an ammonia heat pipe. This sensor-head assembly is shown in Figure 2.3. During operation, each TEC cools its sensor package to suppress dark current in the CCD.

2.4 Quantum Efficiency

The WFPC2 provides useful sensitivity from 1150Å to 11000Å in each detector. The overall spectral response of the system is shown in Figure 2.4 (not including filter transmissions). The curves represent the probability that a photon that enters the 2.4m diameter HST aperture at a field position near the center of one of the detectors will pass all the aperture obscurations, reflect from all the mirrors, and eventually be detected as an electron in the CCD. The throughput of the system combined with each filter is tabulated in Table 6.1 and also shown in the Appendix.

Figure 2.4: WFPC2 + OTA System Throughput. These measurements made on orbit are much more accurate than the pre-launch estimates, and are used consistently throughout this Handbook.



The visible and red sensitivity of the WFPC2 is a property of the silicon from which the CCDs are fabricated. To achieve good ultraviolet response, each CCD is coated with a thin film of Lumogen, a phosphor. Lumogen converts photons with wavelengths less than 4800Å into visible photons with wavelengths between 5100Å and 5800Å, which the CCD detects with good sensitivity. Beyond 4800Å, the Lumogen becomes transparent and acts to some degree as an anti-reflection coating. Thus, the full wavelength response is determined by the MgF_2 field flattener cutoff on the short-wavelength end and the silicon band-gap in the infrared at 1.1 eV (~11000Å).

With the WFPC2 CCD sensors, images may be obtained in any spectral region defined by the chosen filter with high photometric quality, wide dynamic range, and excellent spatial resolution. The bright end of the dynamic range is limited by the 0.11 seconds minimum exposure time, and by the saturation level of the analog-to-digital converter (ADC) at the chosen gain, which is roughly 53000 (gain=14, though called ADT-GAIN=15 in RPS2) or $27000e^-$ (gain=7) per pixel. The maximum signal-to-noise ratio corresponding to a fully exposed pixel will be about 230. The faint end of the dynamic range is limited by photon noise, instrument read noise and, for the wide-band visible and infra-red filters, the sky background.

Table 2.2 gives characteristic values of the expected dynamic range in visual magnitudes for point sources. The minimum brightness is given for an integrated

S/N ratio of 3, and the maximum corresponds to CCD ADC saturation (selected as 53000e^{-}). The quoted values assume an effective bandwidth of 1000Å at about 5600Å (filter F569W). The planets and many other resolved sources are observable in this filter with short exposures even if their integrated brightness exceeds the 8.5 magnitude limit.

Table 2.2: WFPC2 Dynamic Range in a Single Exposure.

Configuration	Exposure (seconds)	Min. V Magnitude	Max. V Magnitude
Wide Field	0.11	8.82	17.83
Wide Field	3000.	19.91	28.14
Planetary	0.11	8.40	17.47
Planetary	3000.	19.49	28.20

2.5 Shutter

The shutter is a two-blade mechanism used to control the duration of the exposure. A listing of the possible exposure times is contained in Table 2.3. These are the only exposure times which can be commanded. Current policy is to round down non-valid exposure times to the next valid value. An exposure time of less than 0.11 seconds will therefore only result in a bias frame being taken.

Some exposures should be split into two (CR-SPLIT) in order to allow cosmic ray events to be removed in post-processing. By default, exposures of more than 10 minutes are CR-SPLIT. If an exposure is CR-SPLIT, the exposure time is divided into two fractions and then rounded down. Normally the fractional split is 50%/50% but, unless constrained by the user with CR-TOLERANCE, the ratio may be up to 70%/30%, as allowed by the default CR-TOLERANCE=0.2. Note that some exposure times in the table do not correspond to commandable values when halved. In preparing a proposal containing an exposure that is to be CR-SPLIT, the simplest procedure to use in order to be sure of a given total exposure time, is to enter double a legal value, and impose CR-TOLERANCE =0.

For the shortest exposure times, it is possible to reconstruct the actual time of flight of the shutter blades. Encoder disks, attached to the shutter blade arms, are timed by means of a photo-transistor. The maximum error is 5 milliseconds. The necessary information is contained in the WFPC2 engineering data stream, however, this information is not in the processed science header.

Diffraction effects from the edges of the shutter blades affect the point spread function for very short exposures. It is advisable to use exposure times greater than 0.2 second when obtaining point spread functions in support of long exposure observations (see the WF/PC-1 IDT OV/SV Report, Chapter 9, for further discussion in the spherically aberrated case).

The control of the initial opening of the WFPC2 shutter during an observation is held by the internal WFPC2 microprocessor in all cases. However, control over when the shutter is closed is held by the microprocessor only for exposures less than 180 seconds in duration. For longer exposures, control passes to the Application Processor (AP-17) in the NSSC-1 spacecraft computer. The consequence of this arrangement is that loss of guide star lock will result in the WFPC2 shutter being closed only for those observations with planned durations of 180 seconds or longer. The AP-17 always controls the shutter closing if the serial clocks are enabled during the exposure (CLOCKS=YES), which then has a minimum planned duration of 1 second, and exposures are rounded to the nearest second. If guide star lock is reacquired prior to the end of the planned observation time, the shutter will reopen to obtain a portion of the planned integration. As discussed in the next section, CLOCKS=YES should generally not be used with exposures shorter than 30 sec., if 1% or better photometric accuracy is needed.

Table 2.3: Quantized Exposure Times (Seconds). Exposure times where the PSF is affected by shutter flight time are underlined. Exposures normally without loss of lock checking are in italics. Times that are CR-Split by default are in boldface. Exposures that take more than one orbit even when CR-split are not normally accessible to GOs and are crossed (and exposures longer than 5400 seconds must be CR-Split). Exposure times that should not be used when CLOCKS=YES are shaded.

0.11	*0.4*	*2.0*	*10.*	*40.*	200.	**900.**	**1900.**	**2900.**	**3900.**	**4900.**	**6200.**	~~**15000.**~~
0.12	*0.5*	*2.3*	*12.*	*50.*	230.	**1000.**	**2000.**	**3000.**	**4000.**	**5000.**	**6400.**	~~**20000.**~~
0.14	*0.6*	*2.6*	*14.*	*60.*	260.	**1100.**	**2100.**	**3100.**	**4100.**	**5100.**	**6600.**	~~**25000.**~~
0.16	*0.7*	*3.0*	*16.*	*70.*	300.	**1200.**	**2200.**	**3200.**	**4200.**	**5200.**	**6800.**	~~**30000.**~~
0.18	*0.8*	*3.5*	*18.*	*80.*	350.	**1300.**	**2300.**	**3300.**	**4300.**	**5300.**	**7000.**	~~**40000.**~~
0.20	*1.0*	*4.0*	*20.*	*100.*	400.	**1400.**	**2400.**	**3400.**	**4400.**	**5400.**	**7500.**	~~**50000.**~~
0.23	*1.2*	*5.0*	*23.*	*120.*	500.	**1500.**	**2500.**	**3500.**	**4500.**	**5500.**	**8000.**	~~**75000.**~~
0.26	*1.4*	*6.0*	*26.*	*140.*	600.	**1600.**	**2600.**	**3600.**	**4600.**	**5600.**	**8500.**	~~**100000.**~~
0.30	*1.6*	*7.0*	*30.*	*160.*	**700.**	**1700.**	**2700.**	**3700.**	**4700.**	**5800.**	**9000.**	
0.35	*1.8*	*8.0*	*35.*	180.	**800.**	**1800.**	**2800.**	**3800.**	**4800.**	**6000.**	**10000.**	

2.6 Serial Clocks

The serial transfer registers of the CCDs can be kept running during an exposure (CLOCKS=YES), or run only during the readout (CLOCKS=NO, the default).

The serial clocks are sometimes used on very bright targets where extensive blooming of the up and down the CCD columns is expected. CLOCKS=YES causes charge which blooms to the ends of the CCD to be read out and disposed of, thus preventing it from flowing back into the image. They will be useful when any single CCD column contains in excess of ~10^8 electrons. Note that the serial clocks do not actually suppress the blooming process, instead they merely remove any charge that blooms to the top or bottom of the CCD.

For most circumstances, we recommend CLOCKS=NO. The reasons for this recommendation are:

1. CLOCKS=YES is not widely used, so anomalies may exist or develop that we are not aware of. Also, this mode is not as well calibrated as CLOCKS=NO (although we expect the calibration to be independent of the state of the clocks).
2. The shutter open time when CLOCKS=YES can have significant errors. In this mode, there are delays of up to 0.25 seconds in opening the shutter (which are not present when CLOCKS=NO). This means that for exposures of less than ~30 seconds, there may be photometric errors greater that 1%, unless special precautions are taken in the data reduction. Furthermore, if a non-integral exposure time is specified in the proposal, it will be rounded to the nearest second. See below for details.

On the other hand:

1. We do advise CLOCKS=YES if you expect star images to be so saturated that a significant amount of charge will bleed off the chip during the exposure. This would mean that you expect much more than 10^8 electrons from at least one star in the exposure (more than 1000 pixels would be saturated). Otherwise the charge can be detected in other parts of the image.
2. One advantage of CLOCKS=YES is that the overhead time is 1 minute less for exposures longer than 180 seconds. This can be significant if you have a large number of exposure times in the 3 to 10 minute range.
3. Unlike the original WF/PC-1, we do not see a significant variation of WFPC2 dark level with CLOCKS=YES.

In summary:

0-0.8 sec	CLOCKS=NO is required.
1 - 30 sec	Use CLOCKS=NO (or attempt photometric corrections during the analysis of the data).
20 - 180 sec	Use CLOCKS=NO unless more than 10^8 detected electrons from a single star are expected.
180+ sec	Use CLOCKS=NO unless more than 10^8 detected electrons are expected, or if you need to save 1 minute of overhead.

While exposure times are corrupted for CLOCKS=YES, and are not accurately reported in the image headers, correct values can be computed. Details are as follows:

1. Non-integer exposure times <3 minutes are rounded to the nearest integer (e.g., 1.2 sec and 1.4 sec will actually be 1.0 sec long, 3.5 sec exposures take 4.0 sec). This roundoff is due to the way the spacecraft computer monitors the take-data flag (AP-17 uses its own integer-based timecode). This rounding is reflected properly in the header keywords (keywords UEXPODUR, EXPSTART, EXPEND, EXPTIME, and EXPFLAG in the `.c0h` file headers, or UEXPODUR and CMD_EXP in the `.shh` headers).
2. All CLOCKS=YES exposures are also shortened by either 0.125 or 0.250 seconds. This decrease in exposure time is ***not*** reflected in the file headers; the amount depends upon which shutter blade was in place at the start of the exposure. The decrease in exposure time is due to the manner in which the application processor (AP-17) in the spacecraft computer operates the shutter blades. When CLOCKS=NO (default), the WFPC2 microprocessor opens the shutter, the AP-17 closes the shutter, and the exposure time is as requested. However, with CLOCKS=YES, the AP-17 opens the shutter, first blade A, then blade B. If blade A is closed at the start of the exposure, the actual exposure begins 0.125 seconds after the AP-17 issues the blade command. If blade B is closed at the exposure start, the exposure starts 0.250 seconds later (after the AP-17 sends the open-A command followed by open-B). The shutter in place at exposure start is given in the SHUTTER keyword in the `.c0h` file.

2.7 Overhead Times

Efficient use of the WFPC2 requires an understanding of the overhead times of the instrument. In this section, the various causes of overhead are presented in a manner that should allow the user to make a fairly accurate prediction of the cost in time of a given sequence of exposures. This information is provided for completeness and background. Guidelines in the Phase I proposal instructions and RPS2 should be followed to develop Phase I and II proposals, respectively. (See also “Choosing Exposure Times” on page 152.)

1. Telescope alignments. A telescope alignment is, in practice, a set of images uninterrupted by a POS_TARG target position change or the end of orbit. The start of an alignment requires 1 minute overhead in order to synchronize timing with a major frame (all commands to the instrument take place on major frames which last 1 minute). The end of alignment uses one minute for tape recorder overhead. If scans are being performed, another minute of overhead is required and, if images are requested in real-time, another 2 minutes must be added to the alignment end. There are additional overheads at the start of each target visibility period associated with guide star acquisition (9 minutes), or reacquisition (6 minutes).
2. Filter changes. A filter change requires at least 1 minute, the use of 2 filters requires 2 minutes of overhead. Furthermore, since the filter history is lost across telescope alignments, at least one minute is spent on selecting the fil-

ter at an alignment start, regardless of the filter in place before the alignment.

3. CCD clearing. Clearing the CCD is done before every exposure and requires 14 seconds. This time is part of the first major frame of the exposure. Therefore, time taken for a given exposure (excluding all other overheads) is the exposure time plus 14 seconds rounded up to the next integral minute. For example, all legal exposure times up to 40 seconds inclusive cost one minute.

4. CCD readout. The readout time for an exposure is one minute. An additional minute is required for exposures 180 sec. or longer, taken with CLOCKS=NO. This extra minute can be saved by using CLOCKS=YES, but this is not generally recommended (see section 2.6, “Serial Clocks”, on page 27). If the exposure is CR-SPLIT, the readout overheads (calculated with the split exposure times) are of course doubled. There is normally no overhead time advantage in reading out a subset of the CCDs. The exception is if the WFPC2 readout occurs in parallel with the operation of a second instrument, when at least 2 minutes is required to read all 4 CCDs.

5. Spatial scans/Dithering. Spatial scans are specially designed sequences of images taken with telescope pointing changes periodically placed between successive images. The pointings in a spatial scan must either be equally spaced points on a single line, or a grid of points formed by the intersection of two sets of equally spaced parallel (but not necessarily mutually perpendicular) lines. Scans avoid the much larger alignment overheads associated with the use of POS-TARG special requirements. Dithering is the use of small spatial displacements to allow better removal of chip defects and/or the reconstruction of sub-pixel resolution. During Phase II the user will be given access to “canned” dithering routines which will allow him/her to avoid many of the tricky details involved in planning spatial scans. The overheads in these canned routines is the same as that of a user-planned spatial scan.

6. The overhead of a spatial scan is similar to that of a sequence of images taken in one alignment; however, at least one minute of overhead is required for each change in pointing. Furthermore, an extra minute of overhead is incurred at the end of the scan and typically about 1 minute of overhead is used at the beginning of the scan positioning the first image.

In summary, it is not possible to schedule exposures in different filters less than 3 minutes apart: commands to the WFPC2 are processed at spacecraft “major frame” intervals of one minute. A filter wheel may be returned to its “clear” position and another filter selected in one minute. An exposure takes a minimum of one minute, and a readout of the CCDs takes one or two minutes depending on the exposure time. Hence a simple exposure requires a minimum of 3 minutes.

Table 2.4: Instrument Overheads. The first and last exposures of an alignment contain extra overheads.

Overhead Type	Time (min.)	Overhead
First exposure	1	Major frame uncertainty, clock synchronization
First exposure	1	To put in initial filter
Per image:	1	Per filter change
Per image:	int(t)+1	t=(shutter-open time in seconds +14 seconds)/60
Per image:	1	If CLOCKS=NO (default) and exposure ≥180 sec
Per image:	1	Readout
Per image:	1	If image done in parallel with another instrument
Last exposure	1	Tape overhead
Last exposure	2	If data requested down in real-time
Last exposure	1	If a scan was done

2.8 CCD Orientation and Readout

The relation between the rows and columns for the four CCDs is shown in Figure 1.1 on page 2. Each CCD's axes are defined by a 90° rotation from the adjacent CCD. If a 4-CCD image is taken and then each subimage is displayed with rows in the "X" direction and columns in the "Y" direction, each successive display would appear rotated by 90° from its predecessor.

Table 2.5: Inner Field Edges. The CCD X,Y (Column, Row) numbers given vary at the 1-2 pixel level because of bending and tilting of the field edge in detector coordinates due to the camera geometric distortions.

Camera	Start Vignetted Field (Zero Illumination)	50% Illumination	Start Unvignetted Field (100% Illumination)
PC1	X>0 and Y>8	X>44 and Y>52	X>88 and Y>96
WF2	X>26 and Y>6	X>46 and Y>26	X>66 and Y>46
WF3	X>10 and Y>27	X>30 and Y>47	X>50 and Y>67
WF4	X>23 and Y>24	X>43 and Y>44	X>63 and Y>64

Figure 1.1 on page 2 also illustrates the projected orientation of the WFPC2 CCDs onto the sky. The beam is split between the four cameras by a

pyramid-shaped mirror in the aberrated HST focal plane. In an effort to insure images from the four CCDs can be reassembled into a single image without gaps, there is a small overlap region on the sky between each CCD and its neighbors (see also Figure 3.11 on page 62). On the CCDs this region appears as a blank "shadow" region along the X~0 and Y~0 edges of each CCD; the exact limits of this region are given in Table 2.5 for each CCD. Because the OTA beam is aberrated at the pyramid mirror, the edges of the shadow region are not sharp, but instead there is a gradual transition from zero to full illumination on each CCD. The width of this vignetted region is essentially that of the aberrated OTA beam (~5″). Table 2.5 gives approximate limits of this vignetted region on each CCD. Note that astronomical sources in the vignetted region are imaged onto two or more CCDs.

The WFPC2 has two readout formats, namely full single pixel resolution (FULL Mode), and 2x2 pixel summation (AREA Mode which is obtained by specifying the optional parameter SUM=2x2 as described in the Proposal Instructions). Each line of science data is started with two words of engineering data, followed by 800 (FULL) or 400 (AREA) 16-bit positive numbers as read from the CCDs (with 12 significant bits). In FULL Mode the CCD pixels are followed by 11 "bias" words ("over-clocked" pixels), yielding a total of 813 words per line for 800 lines. In AREA Mode, there are 14 bias words giving a total of 416 words per line for 400 lines. Either pixel format may be used to read out the WFC or PC. These outputs are reformatted into the science image and extracted engineering data files during processing in the HST ground system prior to delivery to the observer.

The advantage of the AREA Mode (2x2) on-chip pixel summation is that readout noise is maintained at 5 e^- RMS for the summed (i.e., larger) pixels. In addition, more images will fit onto the spacecraft tape recorder. This pixel summation is useful for some photometric observations of extended sources particularly in the UV. Note, however, that cosmic ray removal is more difficult in AREA Mode.

The readout direction along the columns of each CCD is indicated by the small arrows near the center of each camera field in Figure 1.1 on page 2 (see also Figure 3.11 on page 62). Columns and rows are parallel and orthogonal to the arrow, respectively. Each CCD is read out from the corner nearest the center of the diagram, with column (pixel) and row (line) numbers increasing from the diagram center. In a saturated exposure, blooming will occur almost exclusively along the columns because of the MPP operating mode of the CCDs. Diffraction spikes caused by the Optical Telescope Assembly and by the internal Cassegrain optics of the WFPC2 are at 45° to the edges of the CCDs. Unless specified otherwise in the Phase 2 proposal, the default pointing position when all 4 CCDs are used is on WF3, approximately 10″ along each axis from the origin.

Observations which require only the field-of-view of a single CCD are best made with the target placed near the center of a single CCD rather than near the center of the 4 CCD mosaic. This results in a marginally better point spread function, and avoids photometric, astrometric, and cosmetic problems in the vicinity of the target caused by the overlap of the cameras. Even so, for such observations the default operational mode is to read out all four CCDs. This policy has resulted in serendipitous discoveries, and sometimes the recovery of useful observations despite pointing or coordinate errors.

On the other hand, any combination of 1, 2 or 3 CCDs may be read out in numerical order (as specified in the Proposal Instructions). This partial readout capability is not generally available to GOs, although it can be used if data volume constraints mandate it, after discussion with the WFPC2 instrument scientists. It does not result in a decrease in the readout overhead time but does conserve limited space on the HST on-board science tape recorder. The capacity of the present science tape recorder is slightly over 7 full (4-CCD) WFPC2 observations and 18 single CCD WFPC2 observations on a single tape recorder side (of two). Switching sides of the tape recorder without a pause will result in the loss of part of a single CCD readout. Since an interval of about 30 minutes must normally be allowed for the tape recorder to be copied to the ground, readout of only a subset of the WFPC2 CCDs, or use of AREA mode, can be advantageous when many frames need to be obtained in rapid succession. Note, however, that the Solid State Recorder planned for installation during the 1997 Service Mission is capable of hold well over one hundred 4-CCD WFPC2 images. This capability should be phased-in during Cycle 7, and will lead to relaxation of the above data rate restrictions for Cycle 7 proposals.

Multiple exposures may be obtained with or without interleaved spacecraft repointings and filter changes without reading the CCDs (READ=NO). These would then be followed by a readout (READ=YES). Note that WFPC2 must be read out at least once per orbit.

2.9 Calibration Channel

An internal flat field system provides reference flat field images over the spectral range of WFPC2. These are provided by a “calibration channel” optical system mounted outside the main shroud of WFPC2. The system consists of a series of lamps and diffusers, and a flip mirror which directs the beam into the WFPC2 entrance aperture. The lamp set contains Tungsten incandescent lamps with spectrum shaping glass filters and a Deuterium UV lamp. The flat field illumination pattern is fairly uniform for wavelengths beyond about 1600Å. Short of 1600Å the flat field is distorted due to refractive MgF_2 optics. In practice, the flat fields used routinely to calibrate WFPC2 data have been generated by combining flats taken with an external stimulus in thermal vacuum testing with Earth “streak” (unpointed) flats to give the low frequency terms in the OTA illumination pattern. The calibration channel is used primarily to check for internal instrumental stability.