Technical Note 93. ING CCDs- Properties of Operational Cameras.

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January 1994

Abstract

CCD systems on ING telescopes are described briefly. Operational parameters of the sensors are given, together with details of operating modes. Different frame-formats, and details relevant to data reduction are included. Appendices include a chronology of ING CCD history, and manufacturers' data of the CCDs. This document combines and replaces earlier Technical Notes 55 and 79.

Contents

1. Introduction

This report is an updated replacement for the earlier Technical Notes 55 and 79. Both these notes have now been merged, and updated to create this new one; it is intended as a reference document for the current set of CCDs on ING telescopes. It is not intended as a subsititute for detailed technical manuals, neither will it include the most up-to-date performance information (which is held by ING support staff).

The basic properties of our CCD types are presented, including physical properties and performance parameters. Our various different CCD systems are described, together with some information on operational options. Information about the use of different CCDs at various focal stations is included. It must be emphasised that more complete, and more specific information should be obtained from ING support staff.

2. Description of ING CCD systems.

2.1 INT/JKT.

The INT and JKT have operated with CCDs, using the so-called 'phase-1' systems, since they were first commissioned in 1984. The phase-1 system is also known as the 'RGO controller'. The phase-1 systems are connected to the Perkin-Elmer host computers, which now impose limitations to the data-taking especially for large CCD formats (see section 8 also).

The INT also has a privately-built CCD system, known as the Pennypacker camera. This stand-alone system is not integrated into the telescope instrumentation control, although it's image data is coupled to a SUN workstation.

2.2 WHT.

The WHT used an interim phase-1 system at first light in 1987, and this was replaced by the 'phase-2' system in 1989. The phase-2 system is usually known as the 'Dutch controller'. In general, camera-heads cannot be interchanged between the WHT and the other two telescopes.

The WHT has a set of CCD controllers coupled to various CCD-heads. Image data currently passes via the VME DMS (detector memory system) to a SUN workstation. The WHT systems use more sophisticated programmable controllers, and generally more operational modes are available on these systems (eg combined binned & windowed readouts).

CCDs are also used as autoguiders on the WHT. Currently these are the GEC P8603 (coated) devices; however we are in the process of upgrading them to the EEV-02-06 thin devices. Most of this document is concerned with the scientific CCDs.

3. The suite of installed CCD detectors.

3.1 The set of available CCDs.

The set of available CCDs has steadily grown over the years; the evolution has progressed approximately as follows:
1. Small-format (mainly unthinned) sensors. [GEC, RCA, 385*576 typ.]
2. Larger-format (unthinned) sensors. [EEV, 1242*1152].
3. Larger-format, thinned sensors. [TEK, 1024*1024].

Table 1 lists the current set of CCD cameras (including those under construction).

Table 1. ING CCD Cameras.

Name	CCD type	Main Use	Secondary Uses	Notes
RCA2	RCA SID501 thin	INT Prime		TEK3 replaces it.
FOS1	GEC P8603 coated	INT FOS	None	
FOS2	GEC P8603 "	WHT FOS	"	
GEC3	GEC P8603 "	INT IDS	JKT	EEV5/TEK3 preferred.
GEC5	GEC P8603 "	WHT		Hardly used now.
(GEC6)	GEC P8603 "	JKT		Engineering use only.
GEC7	EEV 02-06 thin	INT PF/IDS	JKT	TEK3 replaces it.
EEV3	EEV 05-30 coated	WHT ISIS-blue	other WHT focii	TEK2 preferred.
EEV4	EEV 05-20 "	WHT auxiliary	"	TEK5 may be preferred.
EEV5	EEV 05-30 "	INT IDS	INT PF (& JKT)	TEK3 preferred.
EEV6	EEV 05-30 "	WHT ISIS-red	other WHT focii	TEK1 preferred.
EEV7	EEV 05-30 "	JKT Cass.	(INT)	TEK4 preferred.
TEK1	TK1024 thin	WHT ISIS-red	UES, LDSS, etc.	
TEK2	TK1024 "	WHT PF	WHT ISIS-blue, etc.	
TEK3	TK1024 "	INT PF & IDS	(JKT)	Due in April 1994
TEK4	TK1024 "	JKT	(INT)	Due in June 1994
TEK5	TK1024 "	WHT auxiliary	UES etc	Proposed. Late 1994.
WYFFOS	TK1024 "	WHT	None	Due in 4Q 1994.
INT-PF	Ford-2048 coated	INT PF only	None	Pennypacker camera

Originally we operated the GEC-P8603 devices, together with one RCA SID501 sensor. Within the period 1989/1991 we introduced larger-format EEV-05-xx series devices, and within the period 1992/1994 we have been introducing the TEK1024 arrays. The unthinned Ford-2048 CCD is also available on the INT PF. Appendix 1 gives a detailed chronology of these CCDs.

The various CCDs have different properties, which are described further in the following sections. Most of the small-format sensors were superseded by the larger EEV ones (which also had lower noise). These, in turn, will be superseded largely by the TEK heads, which offer superior quantum efficiency.

3.2 Fields of view with CCDs.

Most of the camera-heads on the JKT & INT may be interchanged if necessary. Similarly, most of the WHT-heads can be moved to different focii on that telescope as required. Table 2 summarises some basic parameters about the use of detectors at different focii. Because of the large number of different detectors, it is not possible to show the pixel scales at each focus (arcsecs/pixel); these can be derived from data in tables 2 and 3 (see following section).

Table 2. Fields-Of-View at various focal stations.

Focus	Tel. scale	Scale at Det.	FOV at Det.		# Comments
	"/mm	"/mm	mm	arcmin	
WHT					
Prime f/2.8	17.6	17.6	60 #	17.6	FOV limited by filters/ instrument mount.
Cassegrain f/11	4.5	4.5	67	5 #	FOV limited by small feed mirror.
Nasmyth f/11	4.5	4.5	33	2.5 #	GHRIL derotator. 5' FOV, 50% vignetted.
ISIS red/blue	4.5 (slit)	15	35*16	λ*4	
UES	4.5 (slit)	23.2	40*20		
Taurus f/2	4.5	25	~25?		
" f/4	4.5	12	~25?		
Cass LDSS f/2	4.5		32		
Cass FOS2 #	4.5 (slit)	35	8*13		CCD is embedded in instrument.
WYFFOS #	4.5 (slit)		26*28		"
INT					
PF f/3.3	24.7	24.7	30	12	
IDS 500 cam.	5.5 (slit)	17	30*16	λ*4.5	
IDS 235 cam.	5.5 (slit)	33	30*8	λ*4.5	
Cass FOS1 #	5.5 (slit)	56	8*13		CCD is embedded in instrument.
JKT					
Cassegrain f/15	13.8	13.8	40	9	

Note: For the spectroscopic instruments the detector field-of-view is a product of spectral range and spatial dimension (slit length).

4. Operational modes with CCD cameras.

All direct imaging camera-heads may be rotated, using a turntable, to align the CCD axis in a preferred sky orientation; in many cases this is not necessary. Camera heads mounted on the spectrographs are rotationally aligned so that the primary dispersion is along a CCD axis (in principle this may be in the CCD X or Y direction, depending on device format).

The JKT CCD photometer incorporates a drift-scan table; this offered advantages particularly for the small GEC detector. The drift-scan has not been commissioned for use with the larger-format sensors since they cover most of the available field in one static exposure.

All camera systems offer full-frame and windowed readouts. On-chip binning in X and/or Y is also supported. The 'phase 1' systems do not currently offer combined windows and binning, nor do they support multiple windows. The WHT systems offer both these facilities. Variable readout speeds, and variable CCD-clear speeds are available; consult user guides or ING staff for details.

The 'Pennypacker' stand-alone camera only offers restricted modes of use; only a full-frame readout is available.

5. Properties of the CCD arrays.

This section describes the basic properties of each type of CCD that we use. For completeness all types of operational sensors are listed. However, as indicated before, many of the earlier sensors are now superseded. In particular, the small-format sensors (except FOS) are unlikely to be widely used in the future; the TEK sensors offer the best overall performance. Note that further upgrades are planned.

The original GEC small CCDs have now been superseded by the larger EEV arrays, which in their turn are being supplanted by the TEK-heads. The Tek CCDs offer the highest quantum efficiency, together with a low readout noise (the EEV chips offer only a slightly lower readout noise). The RCA device is obsolete. The FOS instruments still make use of coated GEC devices. The FORD-2048 chip on the INT offers small pixels, but is unthinned.

Table 3 presents a summary of the main parameters of each CCD type; the performance figures are merely indicative. Appendix 1 gives more specific information about each operational sensor.

The quantum efficiency for each type is shown in figure 1; there are only minor variations between different devices of the same type.

The available image area is determined by the sensor design, however the area that we chose to read-out is under our control; hence the 'readout frame' usually exceeds the 'Image format'. Subsequent sections describe in more detail the different chip regions (underscan/overscan/windows etc.) and relevent frame parameters.

Table 3. ING CCD Parameters.

CCD Type	Applications	Pixel size (μm)	Image format	Readout frame	Image area (mm)	Read-noise (e^-)	e^-/ADU (typical)	Peak QE (%)
GEC P8603 /c	FOS1, FOS2, GEC3, GEC5	22*22	385*578	400*590	8.5*12.7	5-10	1	55
EEV 02-06 /tc	GEC7	22*22	350*512	400*590		8	1	80
RCA SID501 /t	RCA2	30*30	320*512	350*512	9.6*15.4	60	4	75
EEV-05-20 /c	EEV4	22.5*22.5	770*1152	800*1180	17.3*25.9	4	1	50
EEV-05-30 /c	EEV3, EEV5, EEV6, EEV7	22.5*22.5	1242*1152	1280*1180	27.9*25.9	3-5	~1	50
EEV-05-50 /c	(EEV8)?	22.5*22.5	2186*1152	-	49.2*25.9	-	-	50
TK1024 /t	TEK1, TEK2, TEK3, TEK4, TEK5, WYFFOS	24*24	1024*1024	1124*1124	24.6*24.6	4-6	~1.3	70
Ford-2048 /c	INT PF	15*15	2048*2048	2096*2096	30.7*30.7	12	1.5	35

Key: /c : coated for UV response
/t : backside-thinned

Notes: The 'Read-noise' figures are typical, and represent the range of values that our devices have.

The 'e-/ADU' conversion factor is only indicative; it can vary from camera to camera, and is also a function of readout speed.

See figure 1 for more complete data on Quantum Efficiency.

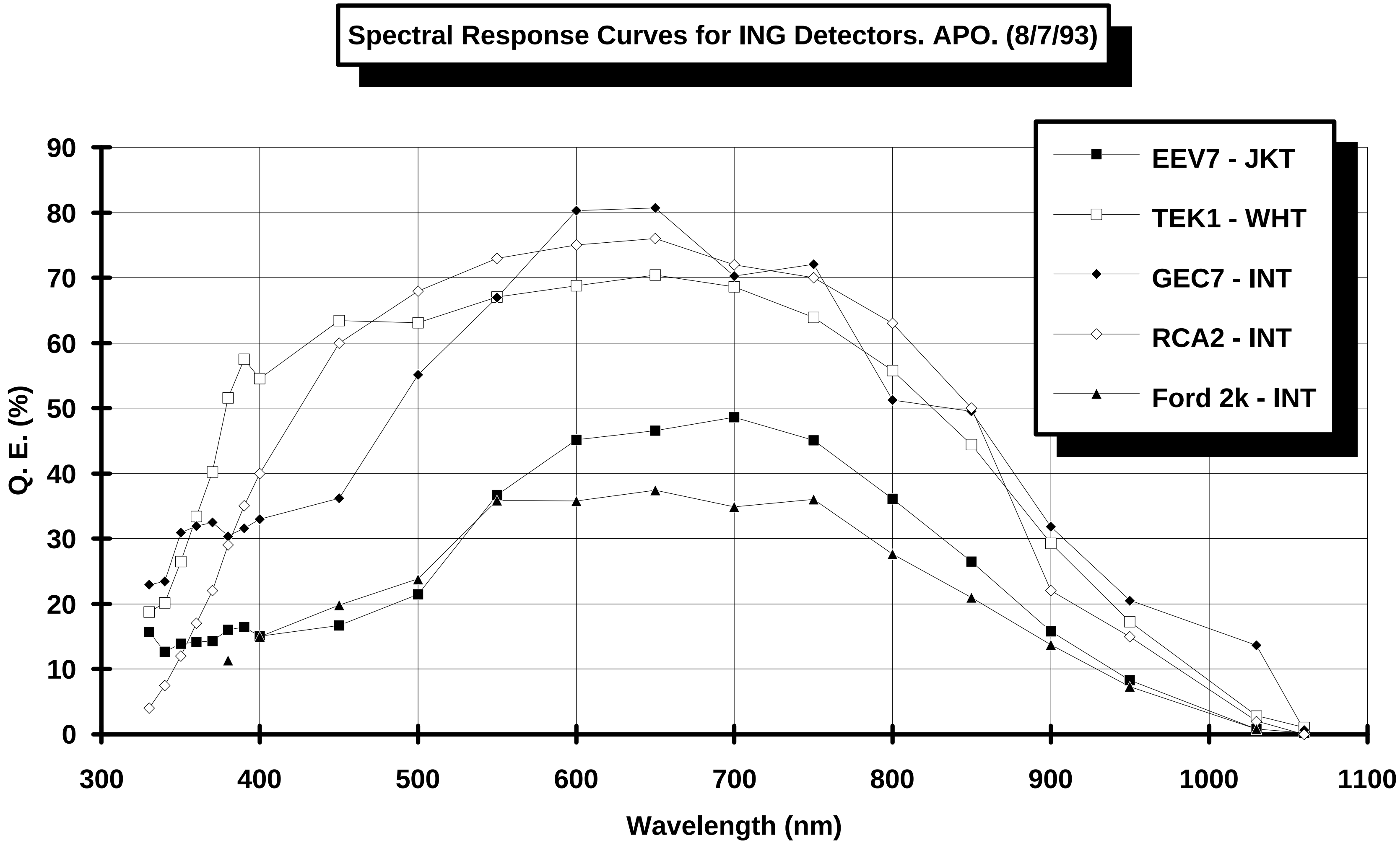


Figure 1. Spectral response of ING CCDs.

6. CCD Construction/architecture

6.1 General structure.

The CCD array is constructed as a two-dimensional array of light-sensitive elements. The signal that is accumulated in each pixel is read-out by a process of internal transfer of charge (hence the name 'Charge-coupled-device'). Each row within the image area can be transferred to the next row until ultimately it reaches the final 'edge-row' (serial register); this is the process of parallel transfer (in the 'vertical' direction).

The edge-row is a serial readout register that allows charge to be transferred (in the 'horizontal' direction) to the output node, where it is measured.

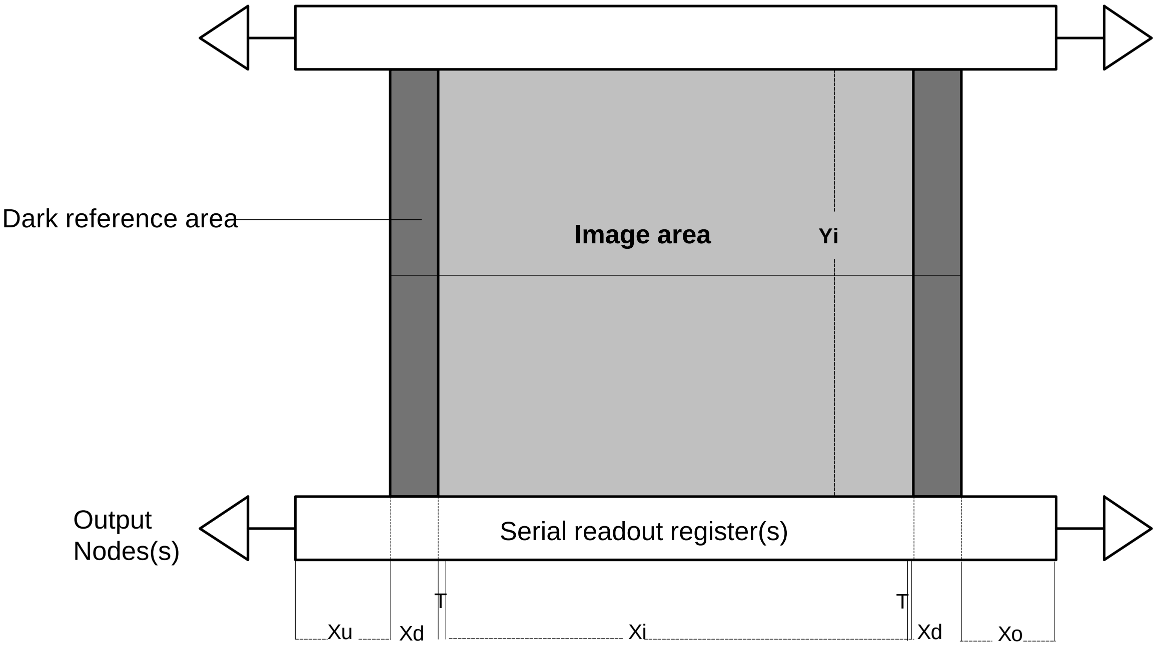
One has to be careful about use of the words horizontal and vertical since the array can be mounted at various physical orientations on the telescope or instrument. Furthermore, the image that is displayed need not match the expected orientation. It is common to use 'horizontal' for the serial readout direction, and 'vertical' for the parallel transfer direction. A 'row' consists of one line of data taken in the serial direction; a 'column' consists of all elements with the same X parameter.

CCDs are always read-out one row at a time; ie all elements in a row are transferred before a subsequent row is measured. (In the case of a windowed readout some elements in a row are skipped, and some are digitised; similarly some complete rows may be skipped). In a full frame, the first digitised element always comes from the first column of the first row, which is nearest the readout corner. The story is slightly more complex with multiple readout corners...

Figure 2 shows how the CCD array is constructed. The main region of interest is the imaging area of size (Xi, Yi). Some devices have a masked-off region on either side of the imaging area; these regions are intended to allow an estimate of the dark current component of the signal. The total image+dark area (of width Xd+Xi+Xd) maps directly onto the serial register.

It is also common to have additional elements between the readout node and the first image-area elements; these 'underscan' elements allow an estimation of the electronic zero or 'bias' level. Some devices also have similar additional elements at the other end of the serial register; these can appear in any 'overscan' of the image. These underscan/overscan elements only exist in the serial register, but appear as additional image columns when the frame is digitised. Additional data elements can be created by 'clocking' the CCD by an amount that exceeds the dimensions of the physical array; this generates a larger data frame, with additional overscan elements, in X or Y.

There may also be 'transition' elements at the edge of the image zone. In general it is wise to ignore data from such edge pixels. It is similarly usual to ignore data from at least the first row of an image frame.



Key: Xu= Underscan in horizontal (serial) dimension
Xd= Dark current reference strip
T= Transition region, at edge of imaging area
Xi= Image area horizontal dimension
Xo= Additional serial register elements, may form overscan
Yi= Image area vertical dimension

Figure 2. Physical construction of CCD array.

6.2 Image area.

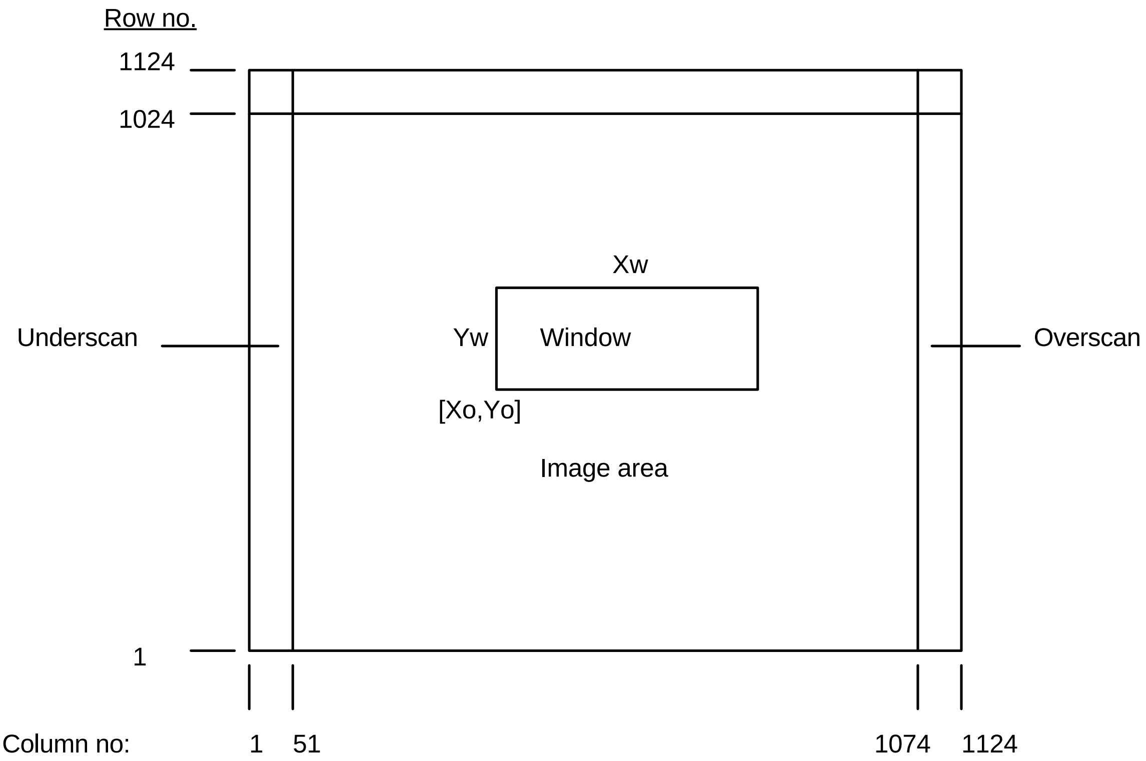
Many CCDs are constructed in two halves; with a split at the mid-point in the 'vertical' direction. If the whole frame is read-out from one corner, it is rare to discern this boundary since both halves are identical. This split-frame allows the device to be operated in 'frame-transfer' mode; this is normally only used for high-speed systems like the autoguiders (since half of the image area is 'lost').

In addition, the EEV 05-xx series devices (previously known as 88xxx) are fabricated by 'stitching' areas together during manufacture; this results in several 'join-lines' which are parallel to the column direction. The larger devices have several such joins at periodic x-positions; they are not readily visible. [For reference, the 05-30 has one 'stitch' at image column 472, and another at column 944, when read-out from corner 'LN4'].

Figure 2 above also indicates that many devices have output nodes on each side. So far on ING systems we have only chosen to read-out the array from one corner- indeed the early GEC chips only had one output. Multiple outputs are to be introduced in the near future, particularly to speed up the readout on larger devices such as the new INT PF mosaic camera.

6.3. CCD Frame-formats and windows.

The nature of the data-frame read from the CCD depends mainly on the physical construction of the device, and partly on any pseudo-pixels that are generated by over-clocking. Figure 3 shows the main components of a typical frame.



Notes

The row and column numbers are given for the TEK1024 CCD, as an example.This chip has 50 elements of serial underscan, and 50 elements of serial overscan. It has an image area of 1024*1024 pixels. We choose to overscan it vertically by 100 rows, so that the default data frame has an 1124*1124 format.

Xo, Yo = Origin of window.
Xw, Yw = Size of window.

Figure 3. The CCD readout frame

The figure shows the origin (1,1) in the lower LHS according to most conventions. However, the image may appear at different orientations on a display screen, possibly including lateral or vertical inversions.

When an array is read-out, all underscan and dark reference elements are seen prior to the image area data. It is usual to overclock and produce some horizontal and vertical overscans; this is normally an 'arbitrary' amount to give a convenient frame size. The overscan region is of limited size in order not to generate an excessive data-frame size.

A windowed readout is obtained by clocking unwanted elements, and not digitising them. A windowed frame may be taken from any arbitrary postion with an X,Y offset relative to the origin (1,1) of the normal frame. Thus, an offset causes skipping of underscan elements as well as (unwanted) image area elements. Recording a small window often means that underscan or overscan elements are not included. Multiple windows are possible (with WHT CCD systems).

6.4 CCD Frame formats.

The above two figures illustrate the nature of the CCD array, and the general form of the data-array that is recorded. Table 4 now lists the x and y components of the data frame for all CCDs that we operate. The following section will then describe the significance of each region.

Table 4. CCD Frame formats.

Device	Serial under-scan	Dark ref.		Image area			Dark ref.	Overscan		ING readout frame	Note
	Xu	Xd	T	Xi	Yi	T	Xd	Xo	Yo		
GEC P8603	10	0	1	385	578	1	0	4	12	400*590	1
EEV 02-06	6	4	1	385	578	1	4	6	12	-	2
EEV 02-06\t	6	~36	1	~320	~500	1	~36	6	'90'	400*590	3
RCA SID501	0	0	0	320	512	0	0	(30)	0	350*512	4
EEV-05-20	17	4	1	770	1152	1	4	17	28	800*1180	
EEV-05-30	17	4	1	1242	1152	1	4	17	28	1280*1180	
EEV-05-50	17	4	1	2186	1152	1	4	17	28	-	2
TEK-512	50	0	0	512	512	0	0	50	0	-	2
TEK-1024	50	0	0	1024	1024	0	0	50	0	1124*1124	
FORD-2048	16	0	0	2048	2048	0	0	16	0	2096*2096	5

Notes:

1. Obsolete; replaced by the EEV-02-06 device.
2. Not used at ING; given for reference only.
3. Thinned 02-06. Part of image area is masked; varies slightly from device to device.
4. Obsolete.
5. Pennypacker camera.

The column (T) is the transition region, at the edge of the image area.

The column (Xo) shows the number of additional serial register balnk elements. In some cases we choose not to read all of these (eg EEV 05-30). A value in parentheses indicates that the overscan is virtual, ie only created by overclocking (eg RCA).

7. Data reduction- use of different CCD regions.

7.1 General Comments

It can be seen that there are several different areas that contribute to the final data frame. However, for all devices in current use (at ING) there is only one readout point. This means that all pixels are read out in the same way.

Any structure (including defects) within the serial register would appear on every row of data. It is almost impossible for one row to exhibit different structure from the next (unless due to structure within a projected image, of course). The only exception is external (electronic) interference which acts on each pixel separately; if its frequency is similar to the row readout time then systematic structure may be visible (diagonal bands). A data-transfer problem may also result in loss of sections of data in the row direction. The electron-digital-unit conversion factor should be constant for every pixel.

It is possible for structure within the image to be seen in the vertical (parallel transfer) direction. Defective elements can cause 'traps' with a characteristic drop in signal and tail in the 'downstream' direction. With recent devices the numbers and strength of such traps is very small. Because a full-frame readout takes many seconds, one can sometimes see a small gradient in the vertical direction due to electronics drifts within the readout time; these are usually negligible. A common occurrence is to see a strong linear gradient due to light leakage during the readout process.

In general it is wise to avoid making measurements near the edge of a region. Therefore, avoid measuring the underscan, image area or overscan in the first few elements of each region. The exact size of a region can sometimes 'change' by one pixel if the method of readout clocking is changed. Thus a particular frame format will be stable but should be considered to have a possible 1-unit error on some values. Always record calibration frames in the same mode as data frames for best precision. Thus, if a widowed data frame is used then one should record a blank, windowed bias frame in order to estimate the bias level.

It is possible to do on-chip binning. In the x-dimension this consists of clocking pixels together before they are sampled at the output node. In the y-dimension multiple rows may be summed into the serial register prior to measurement. In both cases the boundary between different regions can become blurred by the binning process. For example, a four-element dark-reference strip, subjected to a 3 x 3 binning would appear as only a one macro-pixel dark strip with the first pixel within the image area having a dark-reference component.

7.2 Underscan

The serial register underscan provides the best means of estimating the 'bias' level. The bias level is an electronic offset, artificially introduced, to ensure that the analogue-digital converter only receives a positive signal even with readout noise causing fluctuations about a zero illumination level.

Some early devices, including the RCA CCD, do not have any available underscan. Most recent devices have quite an extended serial register (this makes device fabrication easier).

7.3 Dark-reference Regions

Many modern CCD devices have a masked-off region on either side of the image area. This is mainly for use in TV-rate imagers, where dark current is significant and a first-order estimation (to allow subtraction) is very userful.

There are doubts about the efficiency of masking - hence a bright flat-field can allow a small residual 'spurious dark-current' to be visible. In any case, in our cryogenic cameras, dark current should be very low. The estimation of dark current is often irrelevant in the presence of a high sky background.

However, the edge-strips are available, if wanted. Again, avoid the elements at the edge of the region; since the dark-reference regions are small, this means that only a few pixels/rowsl are available for estimating the dark current. As mentioned above, be careful; it is best not to trust the value from a frame with a high level of illumination.

Certain devices (eg EEV-02-06 CCDs) have some dark-reference regions that only cover half of the frame.

7.4 Transition Elements

These are usually the columns on either side of the image area. Because of an uncertain degree of masking they are unreliable for imaging or bias-level estimation.

7.5 Image Area

This is defined as the region of the array that is light sensitive. It is of fixed size for each device type, although we can choose to readout a sub-window if desired. Avoid taking measurements in the rows or columns very near the edge of the area.

As described in section 6.2, the image area may be constructed from several 'identical' regions. The interface between different regions may not be readily apparent and it is often only visible under conditions of uniform illumination. The interface may introduce a small (<1%) change in response, which is expected to be very stable.

7.6 Overscan

In the vertical (y) direction, overscan is obtained by applying more clock pulses than there are image-area rows. This effectively extends the frame with dummy rows.

In the horizontal (x) direction, overscan consists of sampling more pixels than exist within the image area. The first component may consist of additional serial register elements, with further overscan being provided by overclocking.

The bias level may be estimated from the overscan region; however, if charge transfer is less than perfect there can be some contamination. It is, therefore, best to avoid the first 10 elements. If the overscan area is uniform and at the same level as the underscan then this is a sign of good charge transfer (try looking on a frame with a flat field at, say, 100 e^- and 10,000 e^- signal level).

7.7 Bias Level Estimation

The bias level is primarily an electronic offset; it has a mean value which ought to be subtracted from every data frame. A non-illuminated frame ought to be uniform, with a mean level= BIAS. The mean bias level can be estimated from each frame; Table 5 indicates the recommended area to use for this measurement. Very bright flat-fields may cause a small (<0.1%) increase in the bias level; usually this does not matter on these frames.

Table 5. Recommended Coordinates for Bias Level Estimation

DEVICE	X	Y
RCA SID501	340-349	101-500
GEC P8603	5-9	101-500
EEV 05-xx	6-15	101-1000
EEV CCD-02-06	2-6	101-500
TEK-512	11-40	101-500
TEK-1024	11-40	101-1000
Ford-2048	5-15	101-2000

All coordinates start at the first digitised pixel (1,1); a full (non-windowed) frame is assumed here.

The first 100 rows are excluded because the bias level may exhibit a low level change as the electronics 'settle' at the commencement of a readout. Also, the first few elements in each row are best avoided. The overscan areas could also be used for bias level estimation, but could suffer from contamination if charge transfer was poor (which should not be the case of course!).

Any x,y structure to a bias frame can usually only be measured by an exposure in good darkness. This is rarely possible in daytime. It is best to check that the bias frame is uniform and free of systematic structure at the beginning of an observing period. For safety, it is recommended to take one such frame each night.

This level has a low frequency time dependence (temperature changes induce small drifts in the electronics). The bias level can be subject to low frequency drifts, due to thermal changes, and occasionally step changes if the operating conditions are changed.

The best way to determine the bias level is to take the mean value from the middle of the bias strip; avoid the first and last few 'transition' elements.

It is possible that the first few rows, or tens of rows, can have a slightly different bias level - because the readout electronics take a short time to settle after commencing a readout.

Since the readout method does not change, the nature of 'bias structure' (if any) should not change (the one exception is external electronic interface).

8. Upgrades planned in the near future.

1. Provision of Sun workstation on INT. Early in 1994 it is planned to modify these CCD systems so that image-data can be passed directly to a SUN workstation.

2. INT (Pennypacker) camera- thin chip? Discussions are underway, with the aim of procuring a thinned Ford-2048 CCD for the INT PF camera.

3. INT PF mosaic. A project is underway to build a 2*2 mosaic of Ford-2048 CCDs for use on the INT; completion is anticipated in 1995.

4. More TK1024s. As indicated in table 1, we are in the process of constructing TEK3, TEK4 and TEK5 camera heads. These are for INT, JKT and WHT (auxilary) respectively.

5. Procurement of EEV 4k*2k CCDs. In the period 1994/95 we hope to obtain larger CCDS (2048*2048, and 2048*4096), with smaller pixels (~15 microns), thinned spectral response (~75% peak QE), and low readout noise (~3e-). These CCDS will then be installed on the spectrographs and other focal stations.

9. Acknowledgements.

Paddy Oates and Derek Ives contributed data for this document. The CCD systems described here have been built and maintained by many RGO and ING staff.

Appendix 1. Summary of ING CCDs.

ING CCD Summary   Version 10   09/12/93   PRJ

CHIP TYPE	CAMERA NAME	OPERATING DATES	BIAS LEVEL (adu)	READ-NOISE (e^-)	e^-/ADU	Max. Counts (adu)	FORMAT & Pixel size [mm]	Notes
RCA 501EX \t	RCA (PF)	July85- Feb87	~1300	60	3.8	>65K	320*512 [30*30]	1.
RCA 501EX \t	RCA2 [*]	Feb87 onwards	~300	60	3.8	>65K	"	2.
GEC P8603	FOS1 (INT)	May85- May88	~150	7	1	27K	385*578 [22*22]	3.
GEC P8603 \c	FOS1	~May88 onwards	~150	8	1	>65K	"	4.
GEC P8603	GEC1 (IDS)	June84- Dec86	~140	5, 12\pf	0.8	40K	"	5.
GEC P8603	GEC1	Feb87- Dec87	~100	7	~0.8	>30K	"	6.
GEC P8603 \c	GEC3 [*]	Dec87- Apr92	~100	7	~1	>65K	"	7.
GEC P8603	GEC2 (JKT)	Sept85- March86	~100	6	~1	~30K	"	8.
GEC P8607	GEC2	July86- Nov86	~100	8	1.6	35K	385*578 [16*16]	9.
GEC P8603	GEC2	Nov86- Jan88	~150	9	2.2	>65K	385*578 [22*22]	10.
GEC P8603 \c	GEC4 [*]	~Jan88- May89	~200	6.5	1.1	>65K	"	11.
GEC P8603 \c	FOS2 (WHT)	Aug87- May89	~200	10	2	30K	"	12.
GEC P8603 \c	GEC5 (WHT)	July88 onwards	~150	9	1.1	40K	"	13.
GEC P8603 \c	GEC6 [*]	May89- May92	~200	~8	1	~60K	"	14.
GEC P8603 \c	FOS2	May89 onwards	~200	9.5	2.3	>50K	"	15.
EEV P88225	EEV1 (ISIS)	July89- Dec89	2450	5	1.7	60K	770*1152 [22.5*22.5]	16.
EEV 88231	EEV2 [*]	Dec89- June91	2630	4	1.1	60K	"	20.
EEV 0530 \M	EEV3 (ISIS)	Apr91 onwards	3850	3.5	0.8	50K	1242*1152 [22.5*22.5]	21.
EEV 0520 \M	EEV4 [*]	Jun91 onwards	~2700	~4	~1	~50K	770*1152 [22.5*22.5]	22.
EEV 0530 \M	EEV5 (INT)	Oct91 onwards	4100	4.5	0.7	>45K	1242*1152 [22.5*22.5]	23.
EEV 0530 \M	EEV6 (ISIS)	Oct91 onwards	3600	3.5	1.0	>50K	"	24.
Tek. TK1024\t	TEK1 (WHT)	Mar92- Oct92	~450	5/12	2.4	>60K	1024*1024 [24*24]	25.
Tek. TK1024\t	TEK1 (WHT)	Nov92 onwards	2290	5	1.3	>60K	1024*1024 [24*24]	25.
EEV 05-30 \M	EEV7 (JKT)	Apr92 onwards	4300	4	0.76	>60K	1242*1152 [22.5*22.5]	26.
EEV 0206 \tM	GEC7 (INT)	May92 onwards	~7600	8.5	1.4	>60K	335*520 [22*22]	27.

CHIP TYPE	CAMERA NAME	OPERATING DATES	BIAS LEVEL (adu)	READ-NOISE (e^-)	e^-/ADU	Max. Counts (adu)	FORMAT & Pixel size [mm]	Notes
EEV 05-50 \M	EEV8 (UES)	to come..?					2186*1152 [22.5*22.5]	28.
GEC P8603 \c	GEC3.1	May92 onwards	~100?	~7	~1	>65K \100Ke	385*578 [22*22]	29.
Tek TK1024 \t	TEK2 (WHT)	Nov 93 onwards	1125	4.5	1.2	>65K \120Ke	1024*1024 [24*24]	30.
Auto-guiders								
EEV P8603 \c	Cass-A/G	May89 onwards					385*288 [22*22]	17.
EEV P8603 \c	UES-A/G	June91 onwards	1450	12	1.6		"	18.
EEV P8603 \c	Original Spare	? till Dec93					"	19.
EEV P8603 \c	PF-A/G	Nov93 onwards					"	31.
EEV-02-06 \t	Upgraded Spare	Dec93 onwards					"	32.

Comments:

[*] in main table, indicates a change of camera-head name.

'\c', refers to a dye-coating to give enhanced UV-response.

'\M' refers to a 'Metachrome' phosphor coating, for UV response.

'\t' refers to a thinned CCD, for enhanced peak/UV response.

Typical digitised areas exceed the size of the imaging area; e.g. 400*590 for GEC, and 1124*1124 for TEK Cameras.

'Adu' = analogue-digital converter units.

Read-noise is quoted at the Standard readout speed.

The e^-/ADU figures are believed correct, to about 10% . The figure is quoted for the default (standard) readout speed.

The maximum available digitised count is always 65535 (=2^{16}), this is a purely electronic limitation. In some cases measurements close to this limit have not been made; these are often indicated by say, '>55K'. Usually the linearity- limit is constrained by the ADC range combined with the electronic gain of the system, rather than by a real limitation of the CCD (which should exceed 100000 electrons in most cases).

The GEC CCD was originally made by GEC-Hurst Research Centre; however all devices are now made by EEV (Chelmsford, part of GEC group). We have retained the original 'GEC' camera names, for camera-heads containing small CCDs (although they are now supplied by EEV; 'GEC7' is such an example).

NOTES:	CCD s/n	Comments.
1.		??The original RCA chip began to deteriorate, and was exchanged.
2.	5049-1-3.	This is the last but one remaining RCA CCD. N.B. The camera head is now called RCA2 (cf RCA).
3.	2055/15/13.	This chip suffers from poor charge transfer; it was replaced in May 1988.
4.	5/16/49.	This is the replacement high-quality coated-CCD.
5.	2047/12/9.	As originally fitted to IDS Camera. A nominal preflash (pf) was routinely used here. This required repair in Oct/Nov 1984 (Chip electronics was reset). From Oct 1986 chip performance was poor, leading to it's replacement.
6.	2087/10/9.	LPO staff replaced chip. No preflash required. The chip was exchanged for a coated one.
7.	7174/11/27.	This coated chip is now fitted as an upgrade. Destroyed by preamp-OS s/c in April92. See GEC3.1 now.
8.	2046/7/10.	A-grade originally fitted to this camera. The camera was returned to RGO for repair in March 1986; subsequently a new chip was fitted.
9.	2590/8/26.	A 3/4 scale chip; temporary spare in JKT camera. The pre-amp gain was also changed at this time.
10.	2076/10/8.	A normal-sized chip is now fitted; no preflash. Replaced later by a coated chip.
11.	7174/11/12.	This coated chip is fitted as an upgrade. The camera is renamed. For the first month of use the gain was 2.2e/ADU; it is now 1.1 e/ADU. Replaced in May 89 - it exhibited a threshold.
12.	5/13/44.	A standard ESO-coated EEV CCD. Replaced in May 89 - because of poor blue response.
13.	7231/1/18.	A standard ESO-coated EEV CCD.
14.	7231/1/10.	A replacement dye-coated EEV CCD, with negligible preflash needed. GEC4 camera is renamed to GEC6. Destroyed (by GEC3 P-A fault), in May92. Now only has a setup-grade chip for engineering test use.
15.	7201/11/49.	A replacement dye-coated EEV CCD; no preflash used. This chip has the normal coated uv/blue response. ** In July 89 this was switched over to operate with the new WHT Dwingeloo CCD controller. High noise has been seen if FOS-body is not well earthed. Performance figures checked in June '92.
16.	8175/1/7.	A new large-format setup-grade CCD for ISIS. This chip was replaced with a super-grade device in Dec 89. ** This operates with the WHT Dwingeloo CCD controller only
17.	7361/9/22.	Installed & operational on Peltier head (May89).
18.	7361/4/33.	Commissioned at Nasmyth, June 91. Brief performance figures obtained in Jun '92.
19.	7361/9/7.	Spare for A/G use. Replaced by thin 02-06 CCD in Dec 1993.

20. 9115/15/8. Super-grade, un-coated '88200' CCD. Replaces setup-grade chip. The camera-head is renamed to EEV2. System gain is changed to reduce e/ADU factor. The chip was subsequently replaced by a coated one (at LPO).

21. A0416/15/10 This is the default ISIS-blue chip now. It is a Metachrome-coated, super-grade device.

22. 9115/6/7 The previous 88200 chip is replaced (at LPO) by this coated, super-grade device. It is largely superceded on ISIS by EEV6 now.

23. A0416/14/11 This large-format, coated, super-grade chip is now the default sensor on the INT; it mainly replaces the GEC head.

24. A0419/19/9 This is now the default ISIS-red sensor.

25. 1347BR12-02 This is a grade-1, thinned CCD. Used at first for LDSS, but available for use at any WHT focus. When shipped to ING, it exhibited higher noise (13e) than at Cambridge (5e); In Oct '92 it was returned to Cambridge, for examination. The problem was traced to a noisy preamp connection. The head was returned to ING in Nov '92; the preamp-gain was increased (to give minimum noise, for spectroscopic applications).

26. A0416/15/11 This super-grade sensor is similar to the EEV5 one, and is now the default on the JKT; replacing the GEC head.

27. R229 This is a 'GEC' small-format sensor; it has been thinned and Metachrome-coated. It has lower noise, but is less uniform than the RCA2 head. For use on INT/JKT.

28. A0514/16/11 The grade-1, coated EEV chip for UES mainly. Not yet at ING.

29. 7361/9/7 Replacement chip for GEC3. Setup at RGO, installed by LPO, ~15/5/92.

30. 1396CR02-01 The second Tek head; a duplicate of TEK1, with a larger cryostat. 5 readout speeds now introduced. Installed at PF, but also for use on ISIS and UES.

31. 5/13/44 Commissioned at PF (imaging), Nov 1993. Data not available. Note that this is the original FOS2 CCD (see note 12).

32. A2404-7 Thinned CCD installed in Dec 1993. No operational data available yet.

Summary List of available, distinct CCD-heads

In order of installation at ING

CAMERA NAME	FIRST USE AT ING	ALTERNATE USES	NOTES
RCA2	INT PF	INT IDS, JKT	
FOS1	INT	-	
GEC3	INT IDS	INT PF, JKT	
FOS2	WHT	-	
GEC5	WHT	INT/JKT ??	
(GEC6)	JKT	INT	Retired (May 92)
EEV3	WHT ISIS-blue	WHT other focii	
EEV4	WHT ISIS-red	WHT cass. aux. port, etc.	
EEV5	INT IDS	INT PF, JKT	
EEV6	WHT ISIS-red	WHT other focii	
TEK1	WHT LDSS	WHT other focii	
EEV7	JKT	INT	
GEC7	INT PF	INT IDS, JKT	
TEK2	WHT PF	WHT other focii	
(EEV8)	(WHT UES)	"	May not be provided.

Appendix 2. Manufacturer's data on CCD sensors.

The following pages contain extracts of information from manfacturer's data sheets. Device architecture and pin-outs are included. Complete data sheets are not reproduced here.

Page	Manufacturer	Device type	Notes
A2.1	RCA	SID 501EX	
A2.2	GEC	P8603	
A2.3	EEV	CCD-05-20	Used to be called P88200
A2.4	EEV	CCD-05-30	" P88300
A2.5	EEV	CCD-05-50	Not used at ING
A2.6	EEV	CCD-02-06	Not used at ING
A2.7	EEV	CCD-02-06, thin	
A2.8	TEK	TK-512	Not used at ING
A2.9	TEK	TK-1024	

A2.1 RCA SID501EX

A2.2 GEC P8603

A2.3 EEV CCD-05-20

A2.4 EEV CCD-05-30

A2.5 EEV CCD-05-50

A2.6 EEV CCD-02-06

A2.7 EEV CCD-02-06 thin

A2.8 Tektronix TK512

A2.9 Tektronix TK1024