Instrument Science Group
Royal Greenwich Observatory

Design and Use of a Novel Flat Field Illumination Light Source

TECHNICAL NOTE 108.

Simon Tulloch. 6th Nov 1996

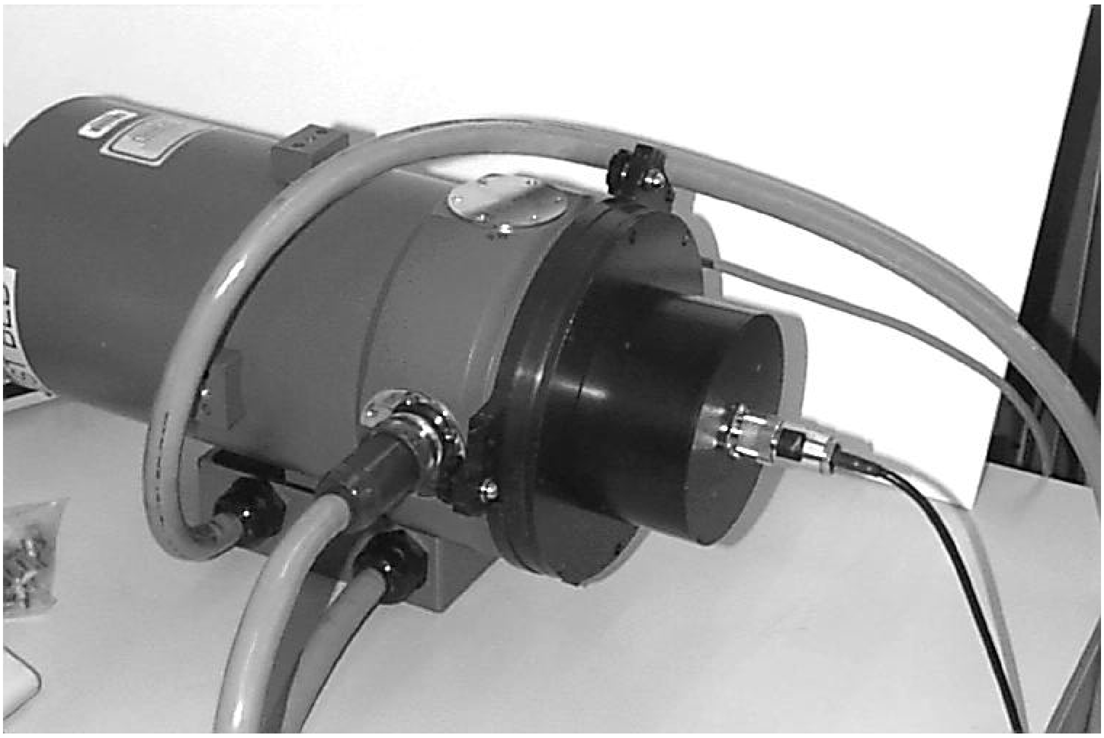
1. Introduction.

Flat field exposures are essential for highlighting cosmetic defects on CCD chips during the optimisation process. They are also useful for diagnosing surface contamination on UV flooded and Passivated Platinum Coated CCDs. This contamination is clearly visible since it causes a strong patterning in the flat field image.

Obtaining flat field images in the laboratory is not easy. A single light source positioned in front of the CCD camera will produce a fairly flat illumination if it is positioned far enough away, however, this will usually require a darkroom. After some experimentation with a spreadsheet model it was found that a remarkably flat illumination profile could be obtained from the overlapping illumination provided by four diffuse light sources. The source geometry meant that a very compact flat field projector could be designed to fit conveniently onto the front of a CCD camera cryostat.

This document explains the geometrical principles, the mechanical design and the use of this flat field projector.

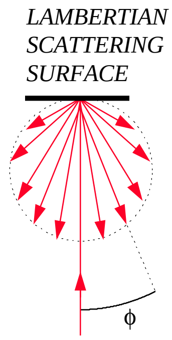
Figure 1) The flat field projector in use



2. Properties of a Diffuse Reflector.

At the heart of the flat field projector is a sand-blasted aluminium plate. This plate is illuminated by a number of LEDs and the light scattered by it combines on the CCD to produce a very uniform illumination pattern. Sand-blasted aluminium scatters light in a ‘Lambertian Distribution’. This is shown graphically below in figure 2.

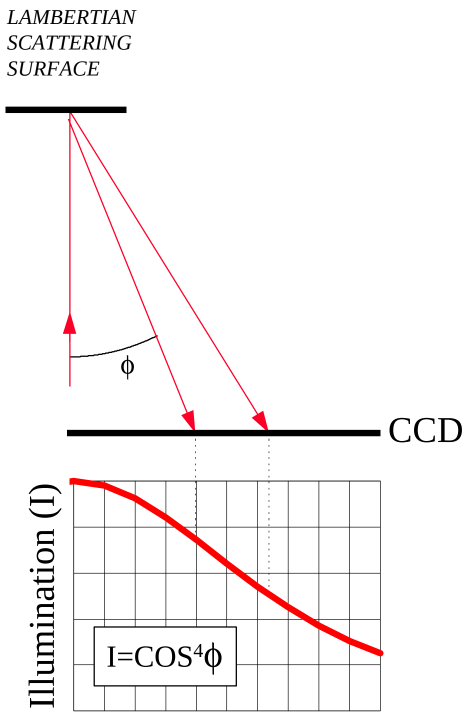
Figure 2) The Lambertian Distribution.



The luminous intensity of the scattered rays is proportional to COS ϕ

If a CCD is placed below this scatterer in a plane parallel to it, as shown in figure 3, it will receive an illumination that varies across its surface as $\mathrm{COS}^4 f$, where f is the angle between the illuminating light source, the diffusing surface and the CCD. This relationship is fairly easy to understand: the first cosine term is due to the Lambertian Distribution, the second to the inverse square law drop off in illumination, the third to the projected area of the scattering surface decreasing with increasing angle and the fourth is due to the same effect in the CCD itself.

Figure 3) Illumination profile on a plane parallel to a Lambertian Scatterer.

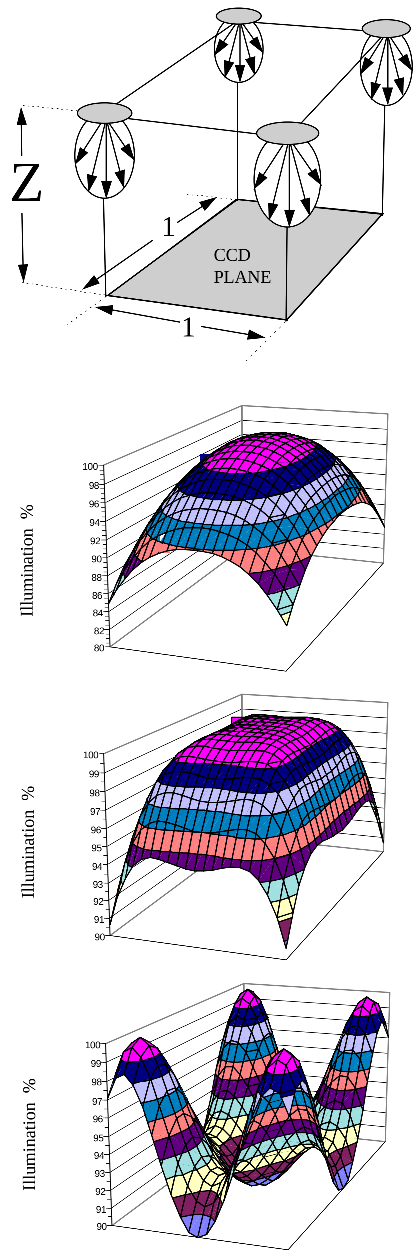


Clearly a single Lambertian scattering source will not by itself provide a flat field illumination.

3. Flat Field Projector Design Theory.

The flat field projector uses four light sources to illuminate the aluminium scatterer. The resultant overlapping illumination profiles can be modelled easily using a spreadsheet. The model shows the light sources arranged in a square pattern, the plane of this square being parallel to that of the detector. Figure 4 shows the resultant illumination profiles for three specific geometeries. In this model the LEDs are in a 'star' arrangement i.e. the sides of the square that join the light sources are parallel to the sides of the CCD. The alternative 'cross' arrangement where there is a 45^{0} offset is not optimum and results in under-illumination of the CCD corners.

Figure 4) The Illumination profile from an array of four Lambertian scatterers radiating downwards onto a plane.



Z=1.2

This geometry provides optimum flatness in the central area.

Z=1

Z=0.8

4. Mechanical Design of the Flat Field Projector.

The design target was to achieve a flat field accuracy of 0.25% when illuminating a 30mm square CCD such as a Loral 2K x 2K or a TEK1024. The spreadsheet model showed that this would require a CCD-diffuser plate separation of 70mm.

The projector, shown schematically in figure 5, consists of a light-tight aluminium barrel with a diameter of 124mm and a height of 69mm. The base of this barrel was threaded so that it could be screwed onto the face of the camera cryostat in front of the window. This first required a cryostat interface plate to be attached to the front of the cryostat. This plate had a central 96mm diameter threaded aperture into which various photometry tools could be mounted. An ‘O’ ring mounted in a groove on the lower face of this plate ensured a light tight seal. The aluminium diffuser plate was 113mm in diameter and mounted close to the top of the barrel. It was illuminated from below (i.e. from the CCD side) by LEDs mounted in a ring. Light from the LEDs was scattered by the plate and passed back through the centre of this ring and onto the CCD. The ring actually contained three colour groups of LEDs so that flat field images could be taken in the ultra-violet, visible and infra-red parts of the spectrum. Each of these groups contained four LEDs arranged equidistantly around the ring. Light from each LED passed up through a 2mm diameter collimation tube and illuminated a 5mm diameter spot near the periphery of the diffuser plate. Recesses on the top side of the ring allowed coloured glass filters to be inserted at the ends of the collimation tubes. Filters were necessary to shift the peak wavelength of the LEDs used for the ultra-violet measurements from 470nm to 390nm. For this, 10mm diameter x 2mm thick discs of UG1 glass were used. The visible and infra-red LEDs were used un-filtered and these recesses remained empty. All the exposed inner surfaces of the projector were sand-blasted and, with the exception of the diffuser plate, black anodized to reduce stray reflections. An electrical connector on the top of the barrel made direct connections to the internal LEDs.

Figure 5) Mechanical Schematic of the Flat Field Projector

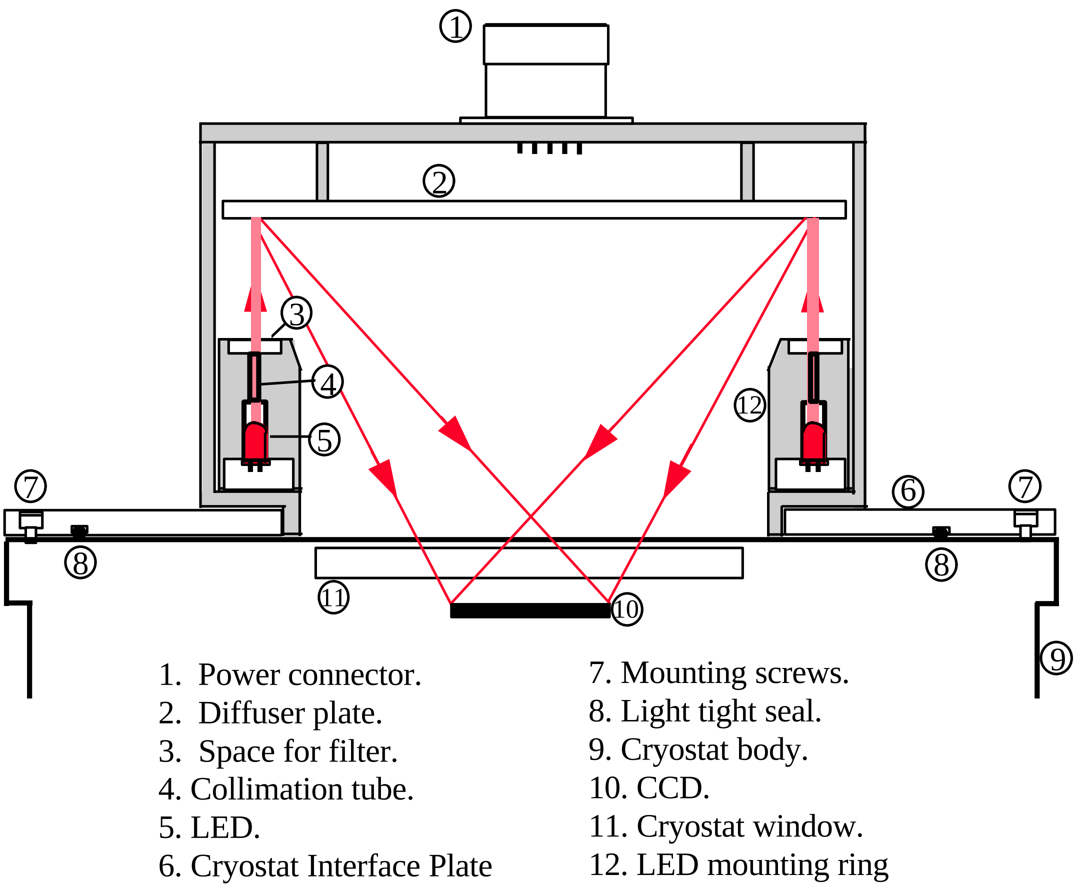
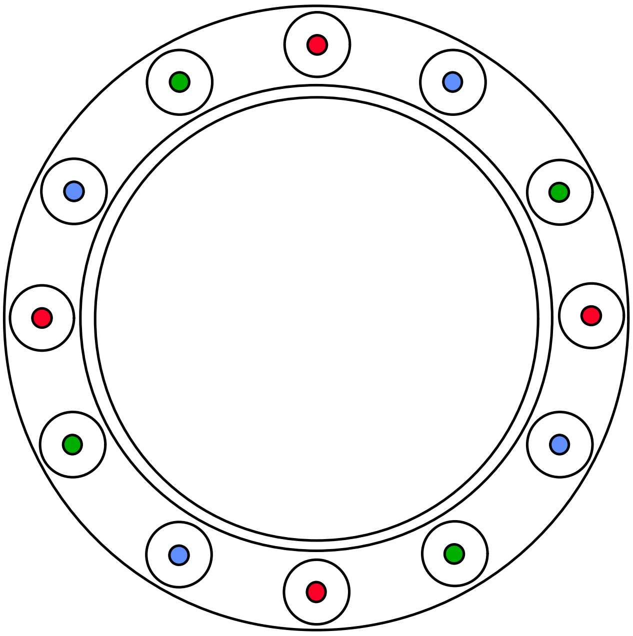


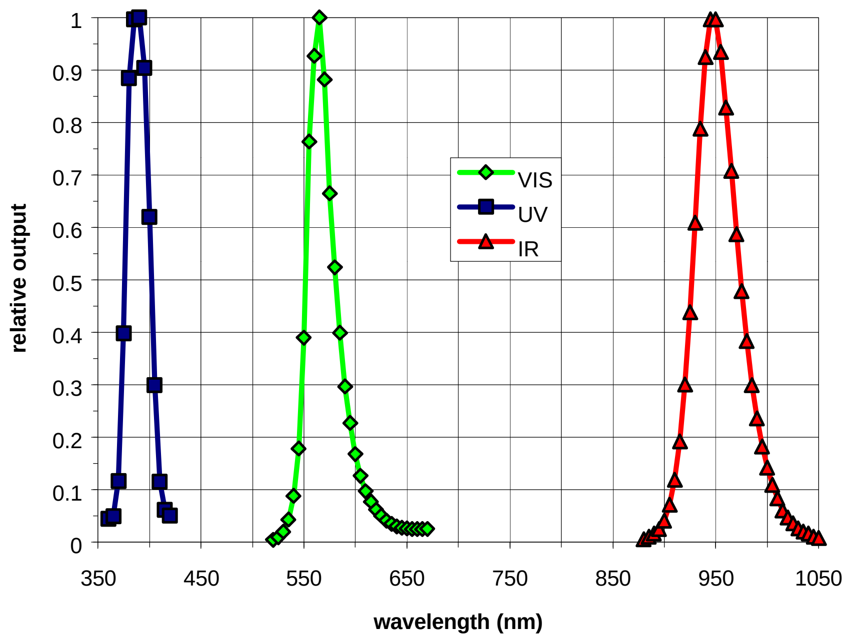
Figure 6) Detail of LED Mounting Ring.



5. Illumination Wavelengths.

Figure 7 shows the colours of the three LED groups used in the flat field projector. The peak wavelengths occur at 390, 565 and 950 nm.

Figure 7) LED Spectra.



6. Performance of the Flat Field Projector

The performance of the projector matched the spreadsheet model. The flat field images obtained were very uniform right to the image corners but exhibited a slight tilt. This tilt can be explained by brightness differences between individual LEDs within a colour group. Figure 8 and 9 show actual data from a TEK1024 CCD flat field image using 565 nm LEDs. The slight turn up at the edge is a genuine effect : the QE of this CCD is higher at the edges, at least in the green part of the spectrum.

Figure 8) IRAF Surface plot of a flat field image obtained at 565 nm.

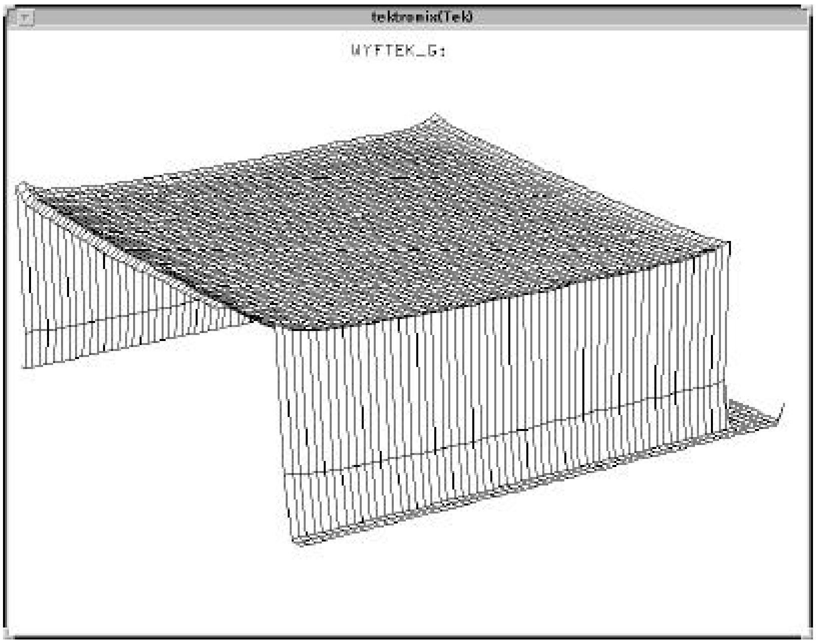
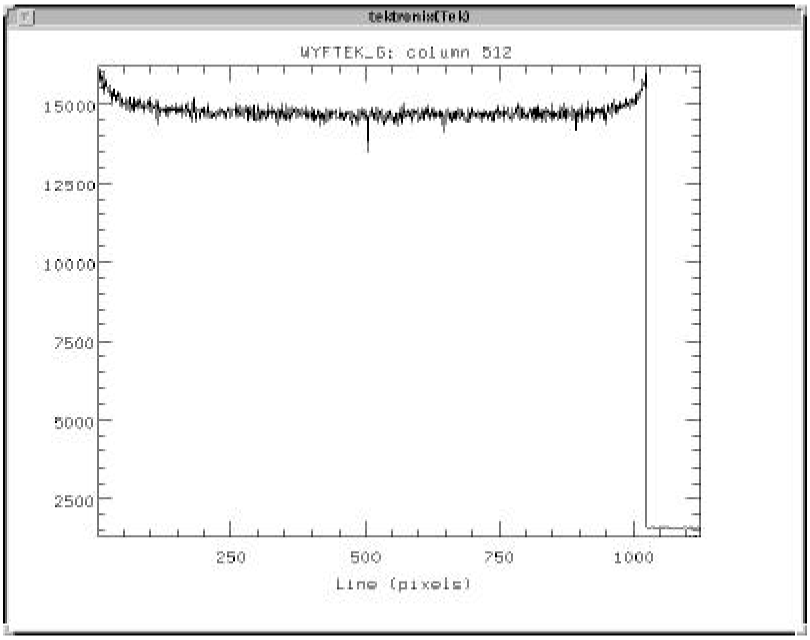


Figure 9) Cross sectional plot of previous image.



The flat field projector was also used to diagnose QE degradation due to surface contamination in a Loral Lick 3 CCD. Figures 10 and 11 show flat field images taken before and after UV flooding. It is easy to see that the QE has been degraded in the first image even without making accurate QE measurements.

Figure 10) A flat field image from a contaminated Loral Lick 3 CCD

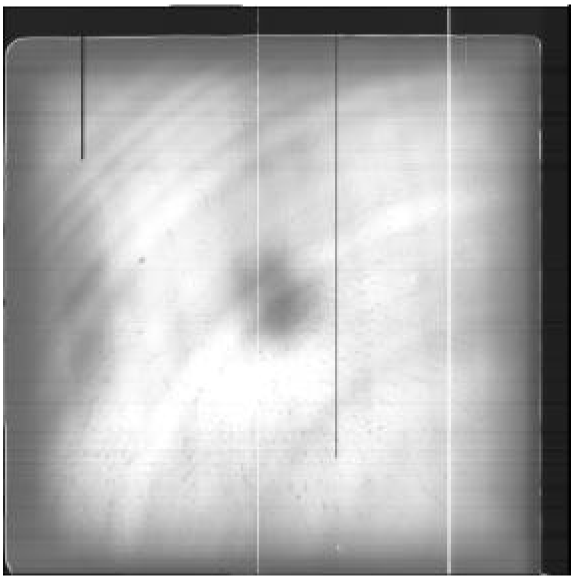
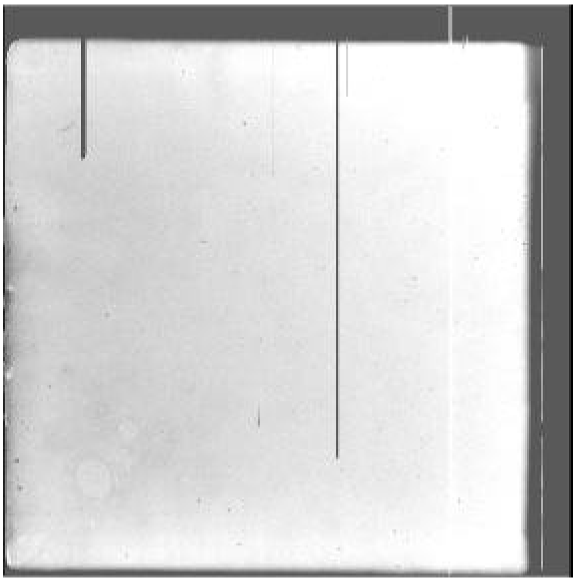
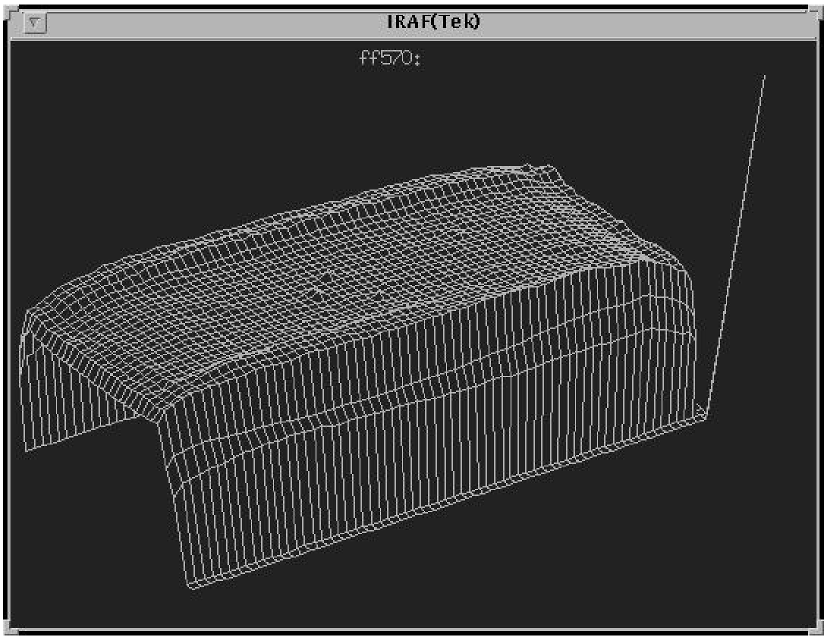


Figure 11) A Flat field image from a recently UV flooded Loral Lick 3 CCD



The flat field projector has also been used with the new large format EEV42 CCDs. The spreadsheet model predicts a 4.5% drop-off in illumination at the corners of this larger (28 x 55mm) device. Nevertheless the flat field images obtained, one of which is shown in figure 12, are still very useful.

***Figure 12) IRAF surface Plot of a flat field image taken with an EEV42 Large Format CCD*.**



7. Future Improvements.

In its current form the flat field projector is limited in its accuracy by the brightness errors of the LEDs. Since the LEDs in each colour group are connected in series there is no way to control the brightness of each one individually. Greater accuracy will be achieved by using parallel connections and tuning the brightness of each LED by a potentiometer. More uniform illumination can also be gained by increasing the diffuser plate - CCD separation. The table below shows this for a number of geometries. In each case it is assumed that a 30mm square CCD is used. All the dimensions will scale linearly i.e. if a CCD measuring 60mm on a side were being used then the diffuser plate - CCD separation would need to be exactly doubled to achieve the same flat field quality. The third column of data is included to show the importance of rotational alignment with the CCD if optimum performance is to be achieved.

Diffuser Plate-CCD seperation (mm)	**Maximum variation in illumination : 'Star' Configuration**	**Maximum variation in illumination : 'Cross' Configuration**
35	5 %	26%
70	0.25%	6.3%
140	0.02%	1.5%
280	0.001%	0.37%

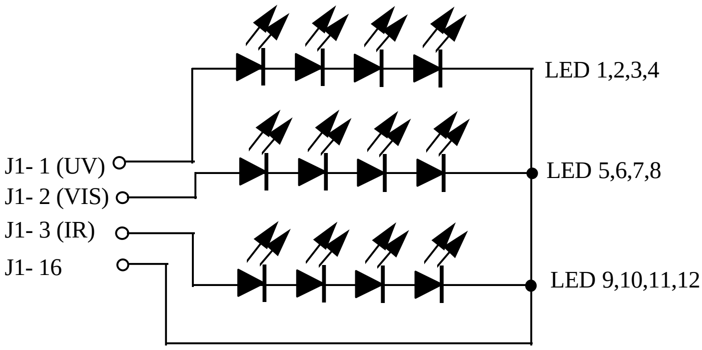
***N.B.** Assumes CCD is 30mm square.*

8. Acknowledgements.

I am grateful to Terry Dobner of the RGO Mechanical Workshop who manufactured all the parts for the flat field projector.

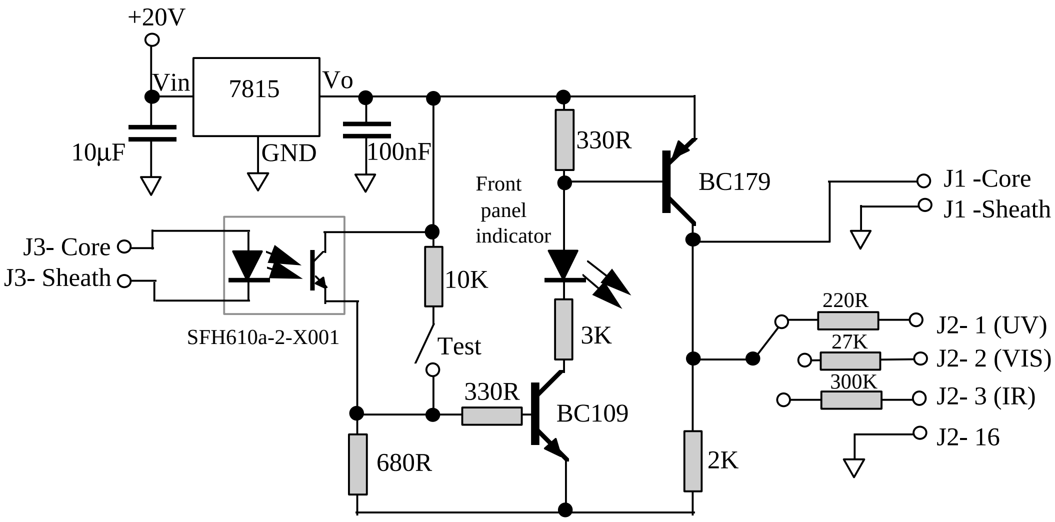
APPENDICES

A. LED connections in the flat field projector.



B. CCD Controller Interface Box.

This box allowed the LEDs in the flat field projector to be controlled from the CCD controller using the pre-flash LED signal. In order to obtain deep images the projector will need to be switched on for about 5 seconds.



- J1 is used to power another piece of equipment : the LED reference lamps.
- J3 receives the 'preflash' signal from the CCD Controller. Details of the connection cable are shown in appendix C.
- J2 is used to connect to the flat field projector.
- A front panel indicator LED shows when the circuit is active. A front panel single pole non-latching switch allows the circuit to be activated manually.

C. Cable Design

The standard cryostat to CCD controller heater cable has an RS404-468 cable mounting plug at the controller end and an RS404-474 cable mounting socket at the cryostat end. The cable used to connect the controller to the interface box shown in appendix B modified this design by connecting a co-axial cable to the controller end of the cable. The sheath was connected to pin D, the core to pin C.

D. Part Numbers

The LEDs used are all available from RS and have the following part numbers:

LEDs 1,2,3,4 (UV) were Nichia NLPB500, RS Stock No. 199-6227
LEDs 5,6,7,8 (VIS) were HLMP8509, RS Stock No.865-672
LEDs 9,10,11,12 (IR) were LD274, RS Stock No. 195-669

The UG1 glass filters were obtained from UQG, Tel : Cambridge 420329