Instrument Science Group
Royal Greenwich Observatory

Design and Use of a Light Source for Linearity Measurement in CCD Cameras

RGO TECHNICAL NOTE 111.

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1. Introduction

It is obviously highly desirable for a CCD and its associated signal processing chain to produce a digital output linearly proportional to the number of photons detected. Non linearities at the upper end of the dynamic range of the system caused by full-well being reached or amplifier outputs approaching the supply rails can be easily diagnosed using the photon transfer method. Non linearities at the low end of the dynamic range caused by, for example, thresholding effects in the CCD are harder to diagnose and can be easily overlooked. The photon transfer method is not convenient at low signal levels where read noise exceeds photon noise. To measure linearity accurately in this regime requires a fast electronically switchable source whose brightness is constant down to very short exposure times. Linearity checks can then be made by simply taking a series of exposures of varying duration. The ‘pre-flash LEDs’ that are mounted close to the CCD in almost all RGO built cameras are not suitable for this purpose since their temperature and therefore their brightness is not stabilised. Self heating in these LEDs also means that for longer exposures, the brightness decreases. It will thus be difficult or impossible to distinguish between non-linearities caused by the pre-flash LED and those caused by the CCD. The LED based calibration light sources intended primarily for diode-mode QE measurement (See technical note 107) are also not suitable since they take several hundred milliseconds to stabilise. Since these sources are quite bright, an exposure of this length would result in signal levels of tens of thousands of electrons thus ruling out low level linearity checks. This technical note describes the design and use of a new light source that is ideal for these low level measurements. It switches on and off rapidly; for exposures of 1ms or greater its linearity (total light output versus switch-on duration) is greater than 1%. For exposures of 5ms or greater, the linearity exceeds 0.25%.. Its brightness has been adjusted so that for exposures of 1ms, a signal of approximately 15 electrons will be delivered to a 15 micron CCD pixel.

Figure 1) The linearity source.

2. Mechanical Design.

The linearity lamp is very similar to the QE calibration lamps. This allows them to be attached to the cryostat faceplate in a similar manner. It also means that the standard CCD Controller interface box can be used to provide an enable signal for the lamp.

A schematic of the lamp is shown below in figure 2). At its heart is a specially packaged LED that emits green light downward through a diffuser, a neutral density filter and a 1mm diameter aperture. The LED package also contains a photodiode that monitors the light output and supplies a feedback signal to a small servo circuit mounted above it. The lid of the lamp has a bipolar power connector and a BNC socket for the lamp enable signal.

When attached to the front of a CCD camera, the lamp produces a circular image on the CCD with a diameter of approximately 6mm. The illumination within this spot is fairly uniform.

It is also possible to mount the lamp by way of an extender tube (as with the QE calibration sources) which reduces its intensity by a factor of 0.41.

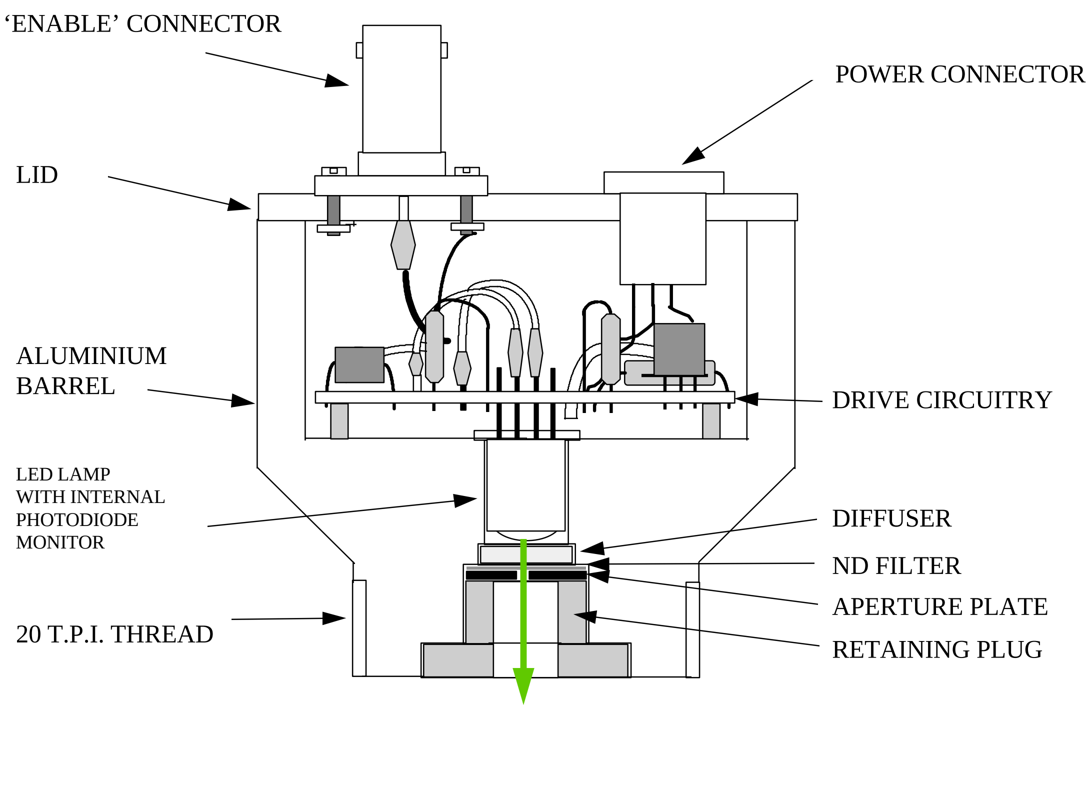


Figure 2) Schematic of the Linearity Lamp

3. Electronic Design.

Central to the design of the lamp is a very special LED device manufactured by IPL. This 5 pin package contains a green LED, a monitor photodiode and a transconductance amplifier,. The output of this ‘on-chip’ amplifier is proportional to the LEDs optical output, its bandwidth is 100kHz. The additional circuitry in the lamp body uses this ‘monitor’ amplifier to close a feedback loop that ensures the LED has a constant brightness thus reducing temperature sensitivity and self-heating effects. The circuitry had to fit on a 35mm diameter board necessitating a compact design. The design required one additional operational amplifier and a stable voltage reference. The LM611 provided both of these in a single 8 pin DIL package. Two other ICs provided supply rail regulation. The circuit diagram is shown in figure 3). The 3M3 resistor shown on the left of this diagram was needed to ensure that the lamp was switched fully off when the enable signal was absent. A small offset on the transconductance amplifier in the IPL 10530GAL device would otherwise prevent this happening. It is possible to run the circuit from a single ended supply but faster switching performance is obtained if a -ve rail is also included.

The only shortcoming of the circuit is that it shows a small temperature coefficient. When moved from a laboratory with a temperature of 22^{o}C to one at 28^{o}C, the output increased by 1%. This error is caused by either the on-chip transconductance amplifier or the monitor photodiode and its effect could not be removed without compromising lamp stability.

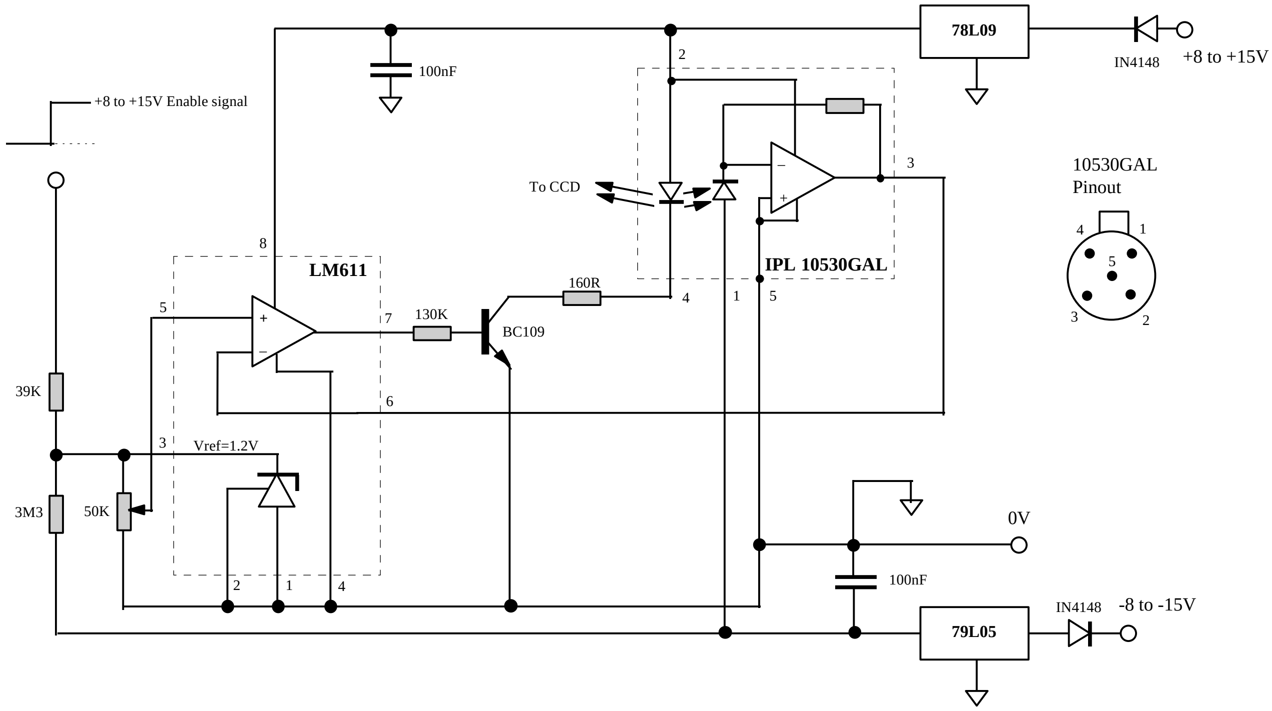


Figure 3) The Lamp Circuitry.

The high bandwidth of the servo circuitry ensured that the LED output stabilised within about 25µs of the enable signal going high. The LED switched off even quicker. Figures 4) and 5) show the relevant waveforms, obtained at pin 3 of the 10530 GAL device.

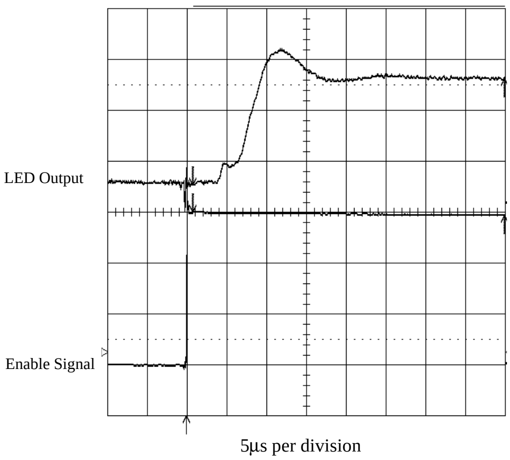


Figure 4) Switch-on delay of lamp

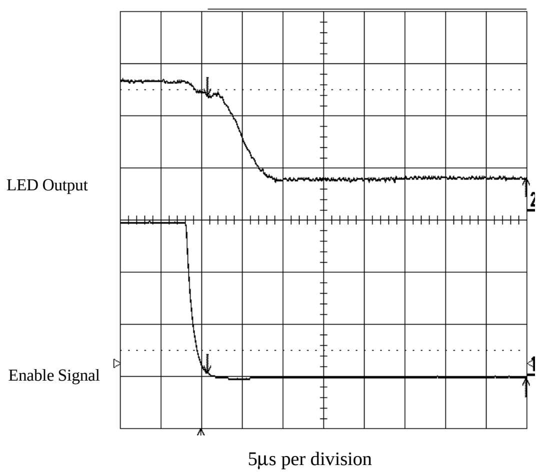


Figure 5) Switch-off delay of lamp

4. Source Performance and Characteristics.

The finite switching time of the lamp obviously meant that at very short exposure times there would be non-linearities. Measuring the non-linearity required comparing pairs of exposures taken with a CCD camera . In the first of each pair the lamp would be pulsed on for a period of 1s and the pixel values at the centre of the resultant spot image measured. A second exposure is then taken consisting of n pulses, each of duration $1/n$ seconds. The brightness of the resultant image can be compared with the first. This technique reduces any non-linearity in the CCD used to observe the lamp to an insignificant second order effect. By taking many exposure pairs with n increasing to 2000 it was possible to measure the linearity of pulses as short as 50µs. Figure 6) shows the results.

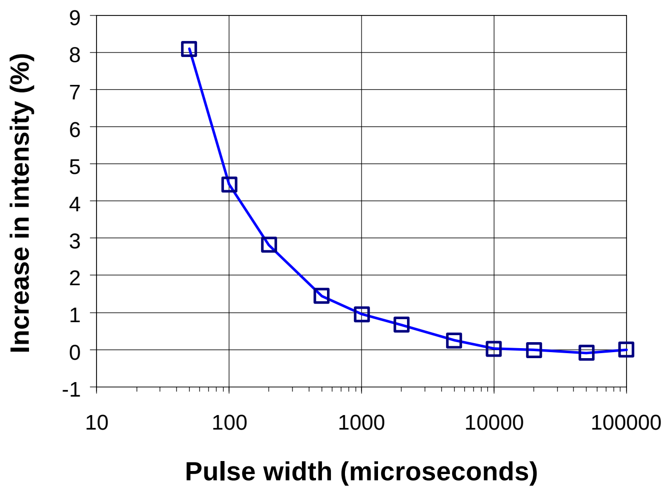


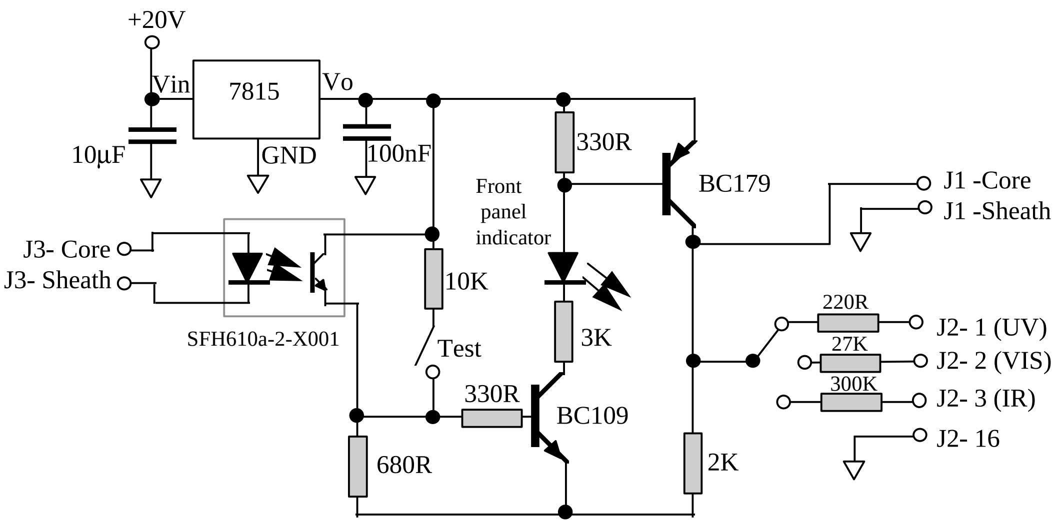
Figure 6) Intensity of lamp as a function of switch-on duration.

As can be seen, the lamp works well for exposure times in excess of 1ms. For really high accuracy, however, the exposure should exceed 5ms. Between 5ms and infinity the lamp will be of constant brightness to better than 0.25%.

It is recommended that the lamp should be attached to the camera cryostat at least one hour prior to the start of measurements. This is for two reasons. Firstly, the cryostat body is generally below ambient temperature and as the lamp cools its brightness may change slightly. One hour will give it time to stabilise. Secondly, in attaching the lamp the CCD under test, the CCD will probably receive daylight illumination which will increase its subsequent dark current. One hour will give this noise component time to stabilise and permit more accurate measurement of the linearity.

APPENDICES

A. CCD Controller Interface Box Circuit Diagram.



- J1 is connected to the ‘Enable’ socket of the linearity lamp.
- J3 receives the ‘preflash’ signal from the CCD Controller using a modified temperature servo cable
- J2 is used to power another piece of equipment : 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.

B. Details of the Specially Packaged LED.

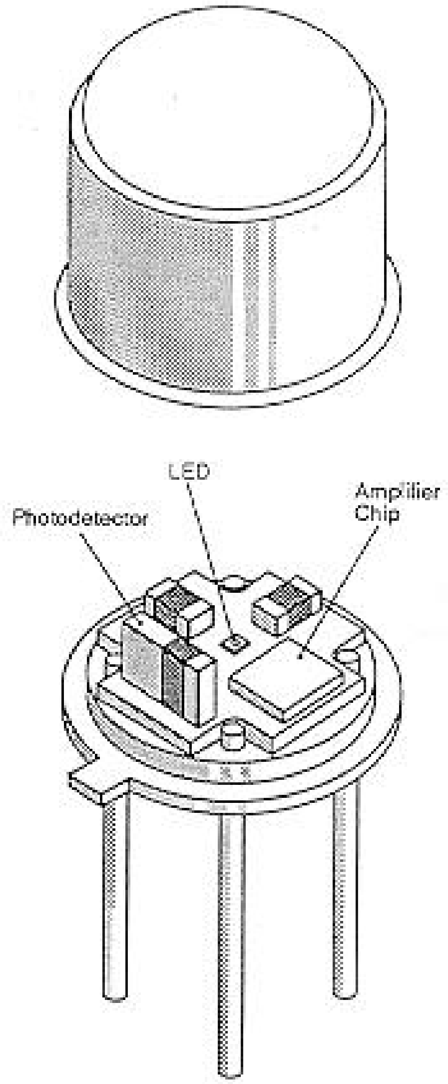
Part Number IPL 10530 GAL.

Manufactured by Integrated Photomatrix Ltd, Grove Trading Estate, Dorchester, Dorset, DT1 1SY, UK. Tel 01305 263673.

Distributed by Farnell and RS.

Output : 565nm peak, 60nm FWHM. Other devices in the range are available with peak wavelengths of 630nm and 880nm.

Diagram from the data sheet :



C. A linearity plot obtained using the lamp.

This plot was obtained with an EEV 42-80 CCD. The line fit through the data points was done using the 'insert trendline' feature of Microsoft EXCEL. To use this function first double click on the chart so that a blue border appears around it. Then click on the graph data series using the right hand mouse button. The y-axis intercept in this example is less than one electron from the origin showing that the CCD is performing well.