Low Light Technical Note 5
An Overview of the Ageing Characteristics of L3Vision^{TM} Sensors

INTRODUCTION

The e2v L3Vision^{TM} EMCCD sensors provide unprecedented imaging performance and enable imaging techniques not possible using other technologies. This is achieved by the high quantum efficiency (>90%), sub-electron noise even at high frame rates, and low spurious charge. However, for a fixed clock bias level, the on chip multiplication gain drops as the device is run. This is known as ageing. Provided that precautions are taken and gain calibration is applied when quantitative output is required, this phenomenon should not cause a problem to the user. This technical note summarises the observations of the ageing phenomena to date.

GENERAL OBSERVATIONS

L3Vision EMCCD ageing is seen as the drop in multiplication gain as the sensor is run. As the multiplication gain is a function of the amplitude of the R∅2HV clock[1], the multiplication gain can be maintained through life with no change in device performance if the amplitude of the R∅2HV clock is increased appropriately. An automatic gain control loop is included within e2v camera systems to maintain the multiplication gain at the required level. The drop in gain can be corrected for by increasing R∅2HV until a point comes when charge ceases to be transferred reliably. This occurs at a voltage shift around 4 to 5 V.

There are several mechanisms involved with the ageing process. Each mechanism appears to produce a shift in the R∅2HV amplitude (the voltage shift) with an exponential dependence on time of the form:

$$\Delta V = A\left(1 - \exp\left(-t/\tau\right)\right),$$

the total shift being the sum of the contributions.

From first manufacture to about 1000 hours of operation with a constant and uniform light level several mechanisms are apparent with time constants ranging from a few minutes to a couple of hundred hours. These mechanisms contribute to "short-term" ageing.

$$\Delta V_{shortterm} = \sum_i A_i - \sum_i A_i \exp\left(-t/\tau_i\right) \quad (1)$$

For an operating time of more than 1000 hours one mechanism appears to dominate. This "long-term" ageing mechanism has a time constant in the order of 8000 hours.

$$\Delta V_{longterm} = A_{long}\left(1 - \exp\left(-t/8000\right)\right) \quad (2)$$

$$\Delta V_{total} = \Delta V_{shortterm} + \Delta V_{longterm}$$

The voltage shift for a CCD65 device, operated at a multiplication gain of 1000x from first manufacture is presented in Figure 1. The device was uniformly illuminated giving an output signal of 300 ke$^-$.

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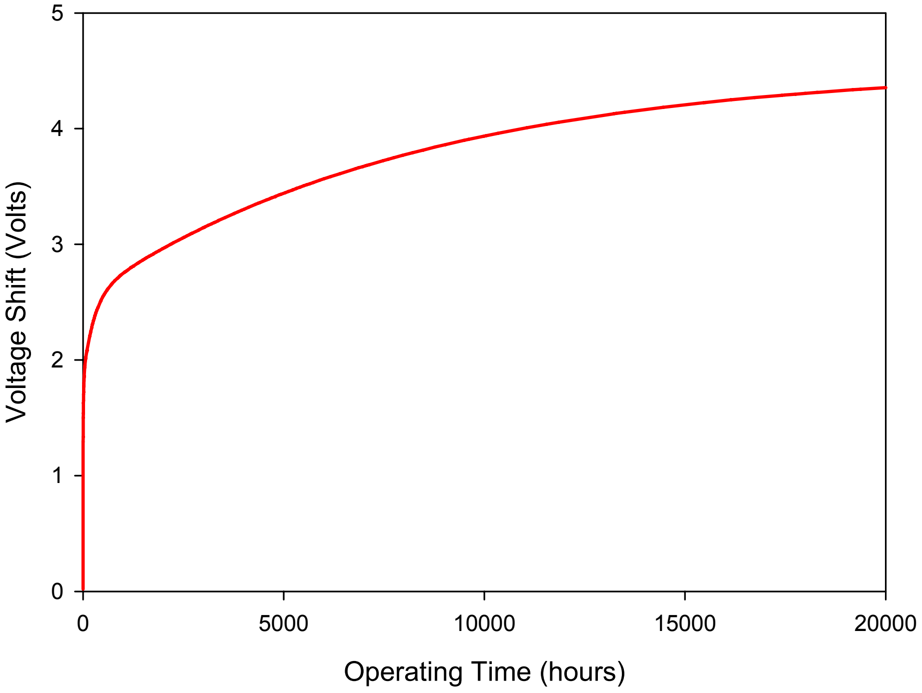
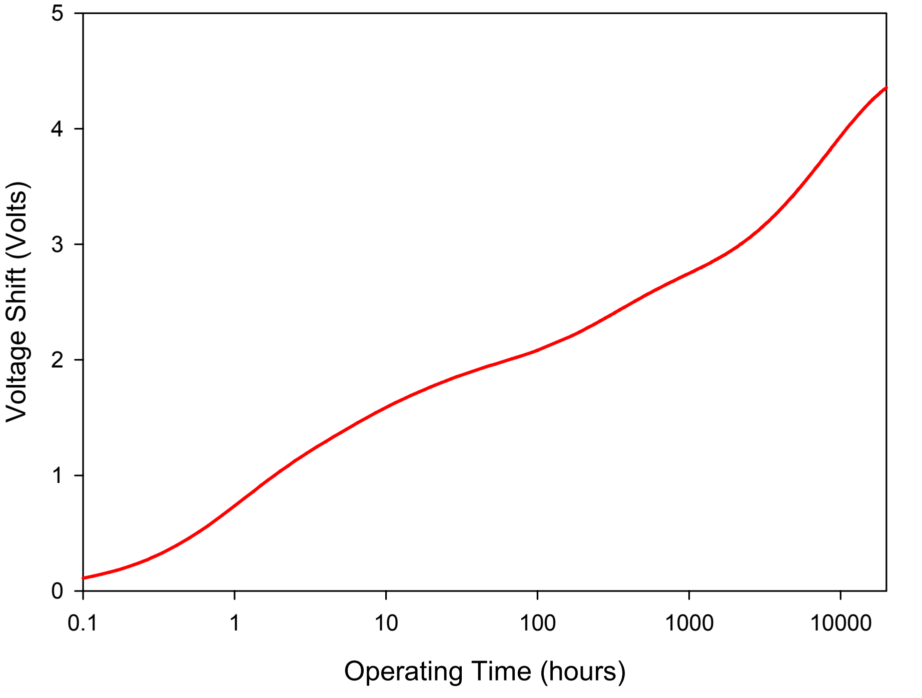
Figure 1: Observed ageing of a CCD65 running at TV frame rates (11 MHz pixel rate), high gain (1000x), high and uniform signal (output signal = 300 ke$^-$).





AGEING AS A FUNCTION OF SIGNAL SIZE

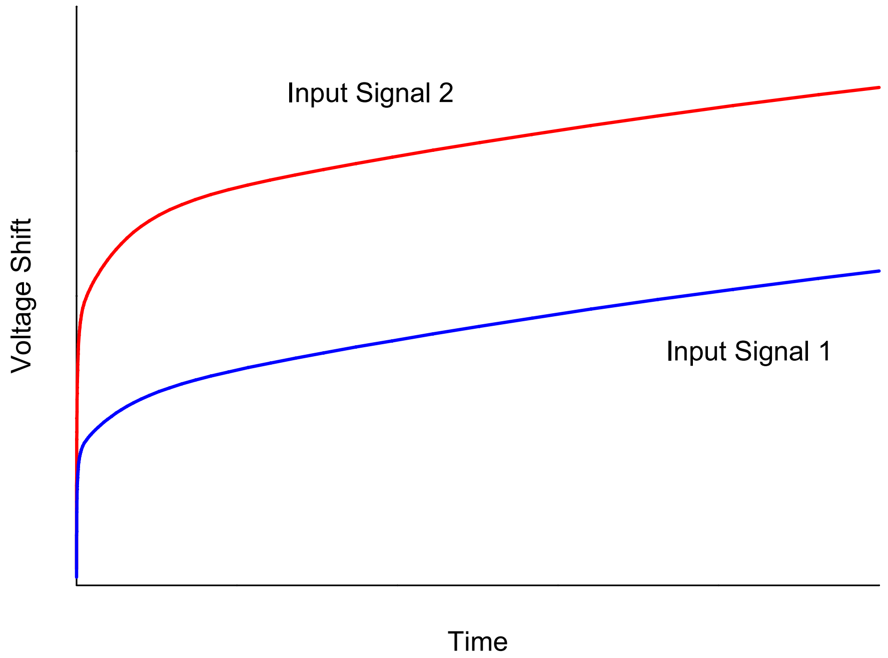
If devices are illuminated uniformly with differing signal sizes a family of curves will be observed. An approximate representation of the characteristic is given in Figure 2.

Under the conditions used to obtain Figure 1, i.e. a gain of 1000x and an output signal of 300 ke^-,

$$\sum_i A_i \approx 2.5\ \mathrm{V} \text{ and } A_{long} \approx 2\ \mathrm{V}.$$

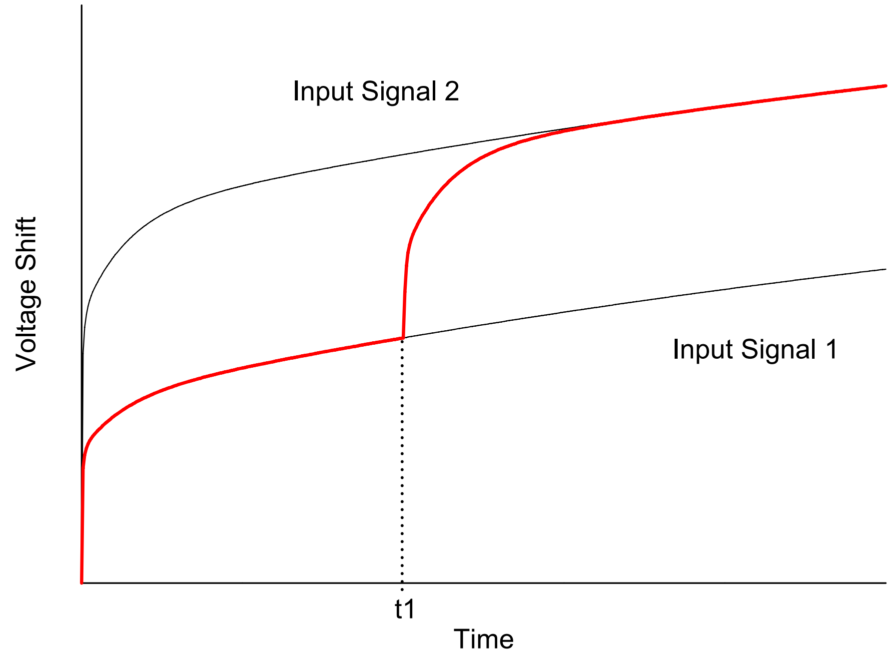
In this case the device was uniformly illuminated giving an output signal of 300 ke^- at a multiplication gain of 1000x. It is not clear how A_{long} varies with signal size, but the dependence appears to be weak. ΣA_i on the other hand does appear to scale approximately linearly with signal size below multiplication register saturation. If the signal in the uniformly illuminated image area is high enough to saturate the multiplication register, at a gain of 1000x, ΣA_i becomes approximately 1.8 x log(s) where s is the signal on the input to the multiplication register. If the image area of the device is saturated but the multiplication gain kept at 1000x, then a ΔV of over 5 V would be observed in just a few hours. This is sufficient to cause the device to fail.

Figure 2: The ageing as a function of time for two different signal levels at the input to the multiplication register. Signal 2 > Signal 1.



If the light level were to increase at a point during life then a characteristic shown in Figure 3 would be observed. Additional short-term ageing commences when the light level increases at time t1. The voltage shift starts to increase rapidly from this point. The rate of change of voltage shift then slows until the shift matched the shift that would have been observed had this new, higher signal been present from the start of operation.

Figure 3:The effect of changing from Signal 1 to Signal 2 at a time t1. The solid thin lines represent the voltage shift that would be observed had the signal remained constant from t = 0.



AGEING AS A FUNCTION OF GAIN

Most of the ageing studies have been undertaken at a multiplication gain of 1000x. This is the maximum value stated in all e2v data sheets. The magnitude of the short-term ageing increases with increasing gain. The short-term ageing for a gain of 1000x is roughly double that observed when using a gain of 100x. The long-term ageing appears to be roughly independent of gain. However, for a gain below ~2x, no ageing is observed. If the gain is increased to a higher level during life, an effect similar to that observed in Figure 3 will be seen.

AGEING AS A FUNCTION OF TEMPERATURE

Only small temperature dependence on the magnitude of the short-term ageing has been observed for a fixed multiplication gain. Tests have been undertaken between 20 °C and –50 °C. No assessment of the long-term ageing has yet been made. It should be noted that decreasing temperature causes gain to increase (for a fixed voltage level). Therefore, care should be taken to ensure that cooling the devices does not cause excessive gain to be applied.

AGEING AS A FUNCTION OF SIGNAL DISTRIBUTION

Data collected to date indicates that the ageing time constants are roughly inversely proportional to the fraction of image area illuminated. Thus, if 90% of the image area is masked off and only a tenth of the image area is illuminated the time constants will be increased by 10x compared with the case when the device is uniformly illuminated. Here it is assumed the device is running continuously in frame transfer mode.

AGEING AS A FUNCTION OF OPERATING FREQUENCY

The effect of readout frequency has yet to be established. All work undertaken so far has been at a readout rate of 11 MHz.

CONCLUSION AND IMPLICATIONS

The observed ageing is a complicated function of several parameters. Details of the processes and dependences are not yet known or need to be confirmed, but it is clear that the most important parameters are the multiplication gain and the amount of charge passing through the multiplication register. The ageing characteristics can be summarised as consisting of short-term and long-term mechanisms. Lowering the multiplication gain and signal level significantly reduces short-term ageing.

As a general procedure, devices are run with high gain and signal levels for a few minutes before testing at e2v. This removes enough of the short-term ageing to enable sufficiently stable operation for the production tests. For quantitative work, the multiplication gain should be calibrated prior to use.

For optimum life, it is recommended that the multiplication gain is not applied unless the low noise capability of the EMCCD technology is required. Care must be taken to ensure that high signals are not present for long periods of time when multiplication gain is applied. The e2v L3Vision cameras employ automatic gain control to ensure a multiplication gain is applied that is appropriate to the input signal level and to reduce it to unity when the input is saturated.

REFERENCES

1 "The Use of Multiplication Gain in L3Vision CCD Sensors" A1A-Low-Light Technical Note2
Available on-line: http://e2vtechnologies.com/datasheets/l3vision_ccds/low_light_technical_note_2.pdf