

TechNote: CCD Sensor Resolution, Type, Grey Levels and Speed

Radiant Imaging ProMetric® photometers are powerful, CCD-based light and colour measurement instruments that provide for vastly increased productivity compared with traditional ‘spot’ photometers. Whereas a spot photometer can only measure the brightness and colour of one point on a display or light source at a time, a CCD-based ProMetric photometer can measure millions of points simultaneously. Moreover, because the ProMetric camera views the whole light source at once, localised luminance and colour differences can be easily detected – artefacts that simple spot meters would probably miss.

The ProMetric photometer line-up comprises a family of four cameras; two of the camera types employ a so-called ‘interline’ type CCD whilst the others use what is termed a ‘full frame’ type CCD (see Table 1). This technical note will address the differences between these two types of camera and how they impact on their performance in different applications. For further help and guidance – please contact Pro-Lite.

Table 1: ProMetric Family of CCD Imaging Photometers & Colorimeters

ProMetric Model	PM-1000	PM-1200	PM-1400	PM-1600
CCD Type	Interline	Interline	Full Frame	Full Frame

The word CCD is an acronym which stands for charge coupled device. This is a monolithic, two-dimensional semiconductor (silicon-based) detector array. When each element (pixel) in the array is illuminated by light in the range between approximately 350 and 1100nm, it produces a photocurrent, the magnitude of which is proportional to the level of light received. CCD sensors used in ProMetric cameras can have between 512 x 512 pixels up to 3072 x 2048. The lens fitted to the camera relays the image of the light source under test, as shown in Figure 1. The lower the number of pixels, the lower the optical quality and spatial resolution of the recorded image. For detailed analysis on LCD, OLED and LED displays, as well as automotive instrument panels (IPs), a CCD camera with a high pixel resolution is normally recommended.



Figure 1: Imaging Using a CCD Detector

There are three types of CCD sensor commonly used in imaging photometers and colorimeters: full frame – as used in the PM-1400 and PM-1600 series; interline transfer as used in the PM-1000 and PM-1200 series; and frame transfer (Figure 2). To avoid the problems of image blur when the signal from the CCD pixels is read out, the light reaching the CCD must be blocked off. In an interline transfer CCD, every other column of pixels is

optically inactive – the pixels in those columns are used for charge transfer as shown in Figure 3. This way, there is no need to physically block the light from reaching the active pixels as the charge transfer time is sufficiently fast to avoid image blur during readout.

Interline transfer CCDs are commonly referred to as having electronic shuttering. Frame transfer CCDs work in a similar way – however, instead of every other column of pixels being used for charge transfer, half of the CCD array is reserved for image acquisition and the other half is reserved for charge transfer.

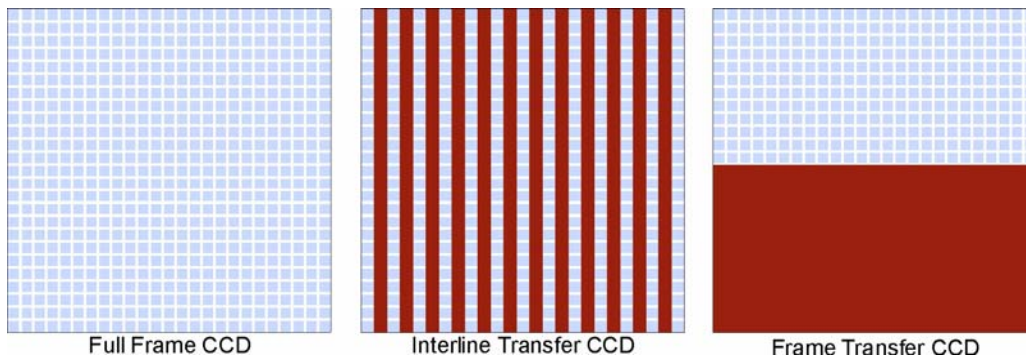


Figure 2: CCD Sensor Types

In a full frame CCD, every CCD pixel is optically active and sees the light source under test. To avoid image smear when reading out the charge in a full frame CCD, a high speed electromechanical shutter is used to shut the light off during read out.

Interline CCDs are less expensive (no shutter, no cooling) and have a faster measurement cycle time, but suffer from two important limitations when used in photometry. The first issue is that the dead pixels in an interline CCD are exactly that – they don't see light. When looking at displays and automotive IPs with small illuminated characters, it is possible for the interline CCD to actually not see or misrepresent what it is seeing. In other words, if the charge transfer pixels are aligned to view a dead pixel or localised luminance inhomogeneity in the display, the interline CCD won't pick this up.

Some may argue that you can create a pseudo full frame CCD type image correction in software; however, no amount of post-measurement software processing (in effect, interpolation) will remedy this. The only solution when using an interline CCD for detailed display testing is to budget on using about 1.5 to 2.5 times the number of full frame CCD pixels in an interline CCD to view the same area on the display under test. To put this another way, you can successfully use an interline type CCD for detailed display and IP testing, but reckon on needing at least 10-15 interline CCD pixels in width for each character on the IP display.

To compare the performance of full frame and interline CCDs in detailed display testing, we have defined a term which we call the *effective pixel resolution*. This is the actual pixels divided by between 1.5 and 2.5. By this analysis, the effective pixel resolution of a 1K by 1K interline CCD reduces to between 392 x 392 and 653 x 653 pixels.

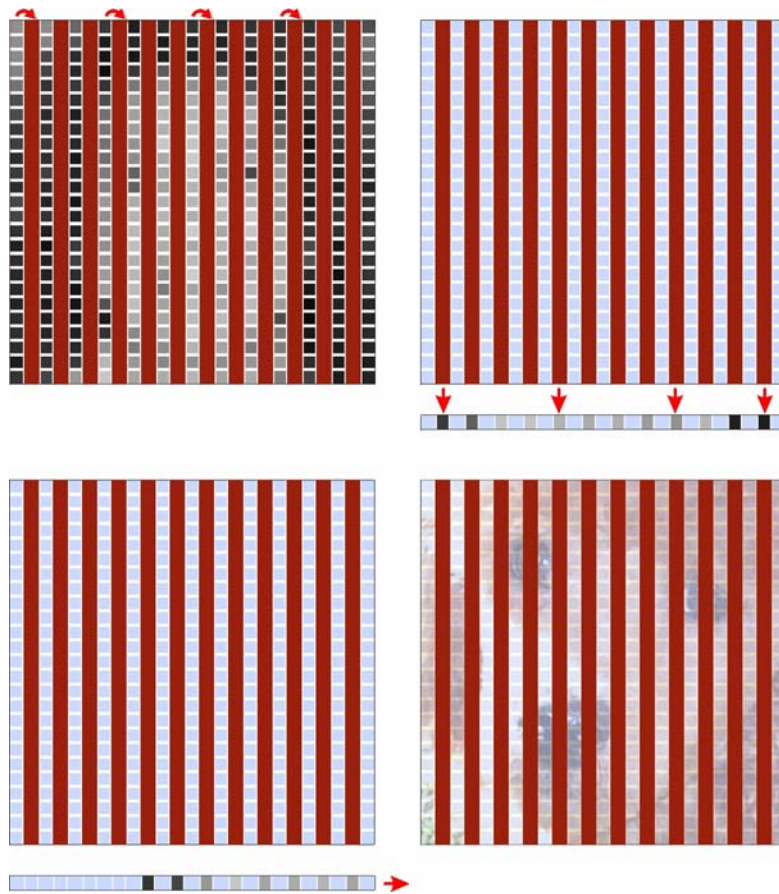


Figure 3: Image Readout from an Interline CCD

The second issue associated with interline CCDs is their speed. One may regard their higher measurement speed as a bonus; in reality, this very speed introduces its own problem. In CCDs, the faster you read out the charge from the camera, the more background 'noise' gets introduced into the image. This is illustrated in Figure 4 – the high speed readout results in a grainy image. This noise limits the photometric measurement range of an interline CCD based camera; consider that while the PM-1000 (10-bit, interline CCD) is specified as having a 0.1 cd/m^2 sensitivity, the PM-1600 (16-bit, full frame CCD) has a much greater sensitivity of 0.005 cd/m^2 .

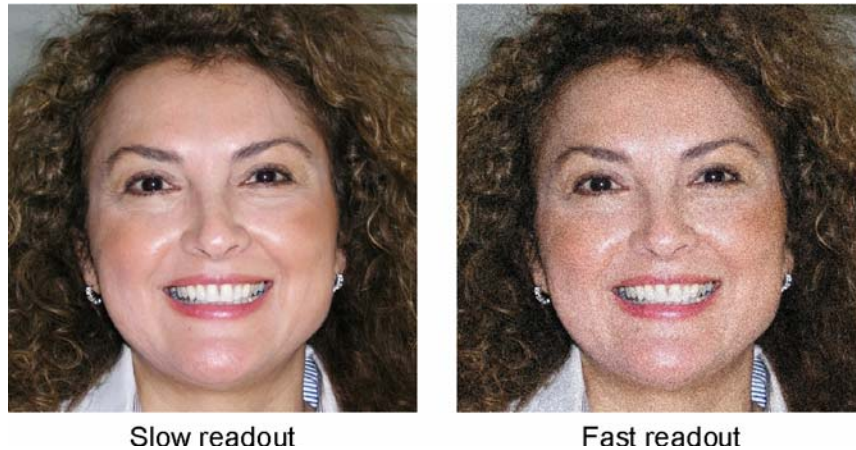


Figure 4: Effect of CCD Readout Speed

Also consider that the greater the number of grey scale bits that the camera can detect, the greater the system's photometric resolution. This is illustrated in Figure 5. To put it at its most basic, the higher the photometric resolution of the camera, the more easily it will pick up differences in luminance and colour - differences which less sensitive cameras will miss.

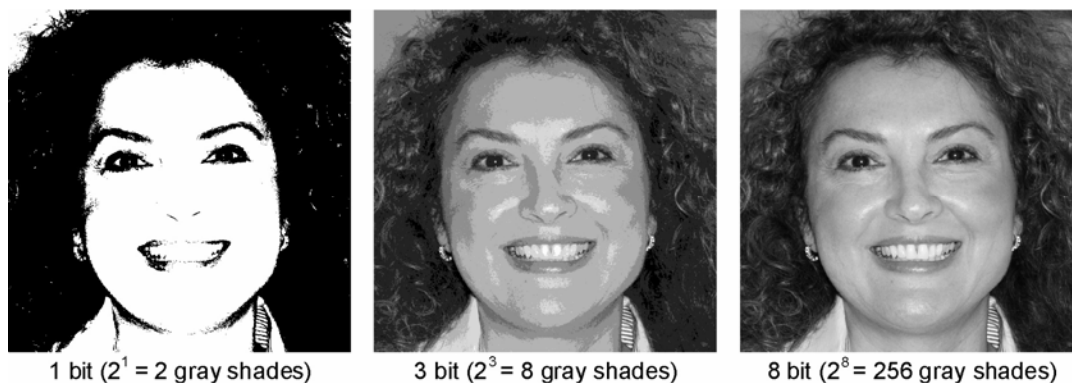
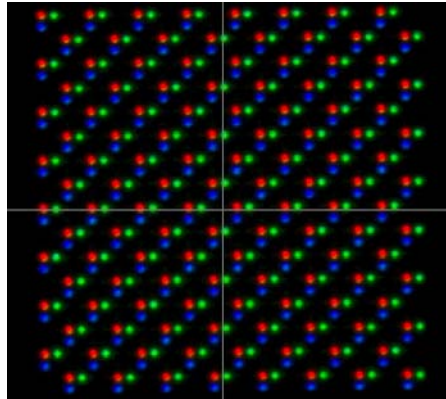


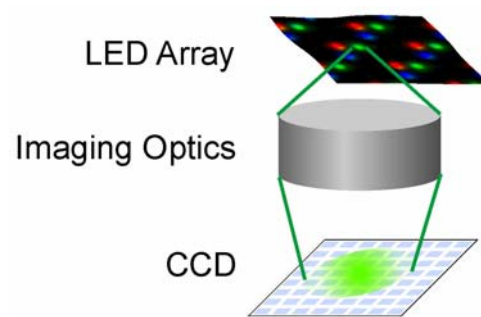
Figure 5: Effect of Grey Scale Resolution (Bit Depth)

Returning to the issue of interline CCDs, let's now consider the effect when testing LED clusters and arrays. Figure 6 shows an image of an RGB LED array as imaged by a ProMetric camera, together with a schematic of the imaging process (Figure 7). Depending upon the size of the CCD array (number of pixels), each individual LED in the array would be imaged with the level of resolution shown in Figure 8. This image appears pixellated as we approach the limit of resolution of this camera (there are about 10 – 11 camera pixels across this image).

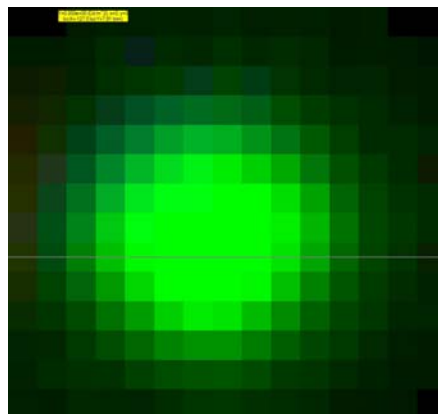
A graphical representation of the LED image as superimposed upon the different CCD types is shown in Figure 9. The CCD types shown are a full frame (left), monochrome interline (centre) and interline with Bayer colour filters (right). The latter is an interline CCD on which the active pixels have either a red, green or blue filter applied in order to impart a colour response. This is the CCD type used in the PM-1000-1 colour camera; the ProMetric PM-1200-1 (interline) as well as the PM-1400 & PM-1600 full frame CCD cameras all use monochrome CCDs with a separate filter wheel containing CIE-matched RGB filters.



**Figure 6: RGB LED Array
Imaged with ProMetric Camera**



**Figure 7: Imaging the LED Array
onto the CCD**



**Figure 8: Zoomed Image
of Green LED**

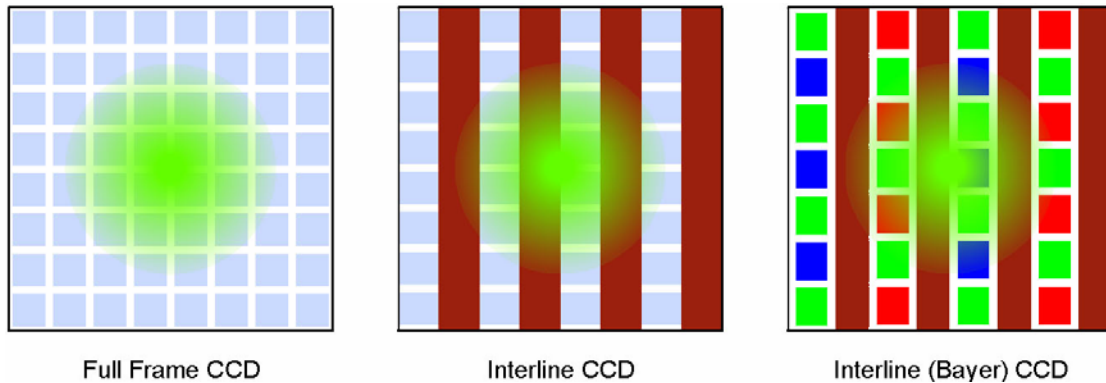


Figure 9: Image of Green LED on a) Full Frame CCD, b) Interline & c) Interline with Bayer Colour Filters

Clearly, the image recorded on the two interline CCDs will be very dependent on the alignment of the LED image onto the CCD sensor. In other words, the measured luminance and colour of the LED will vary depending on where on the interline CCD chip the image is aligned onto.

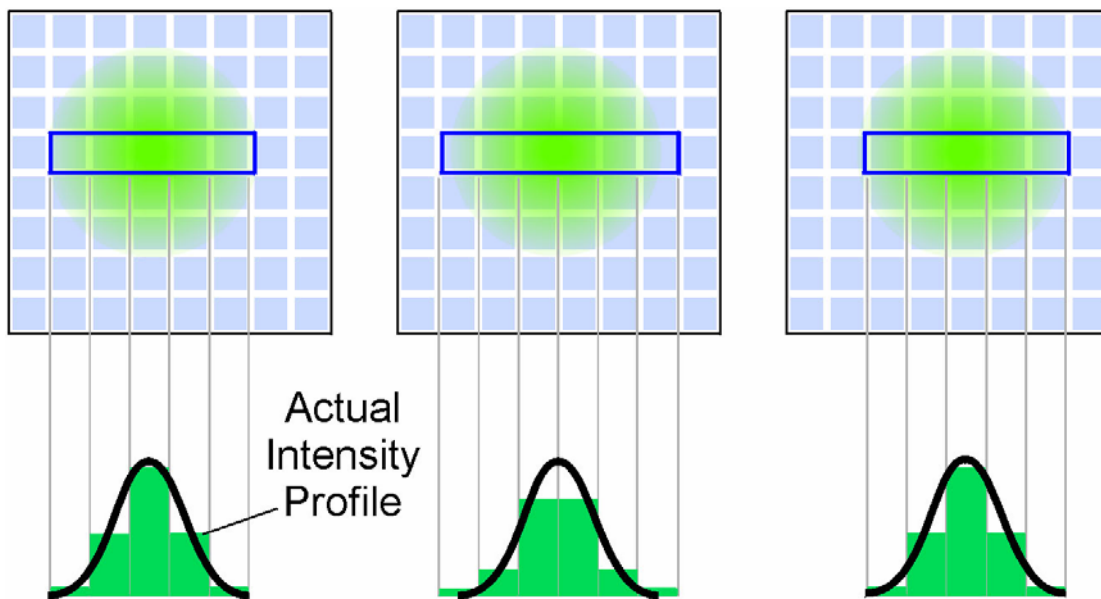


Figure 10: Analysis of LED Image on Full Frame CCD

Figure 10 shows the LED image on the full frame CCD. The measured intensity profile (and hence luminance and colour) is the same regardless of where on the CCD sensor the image is received. In other words, the full frame CCD gives the correct measurement of the LED output. Figure 11 on the other hand shows that the intensity profile of the LED as recorded using the monochrome interline CCD will depend greatly upon the alignment of the image onto the CCD.

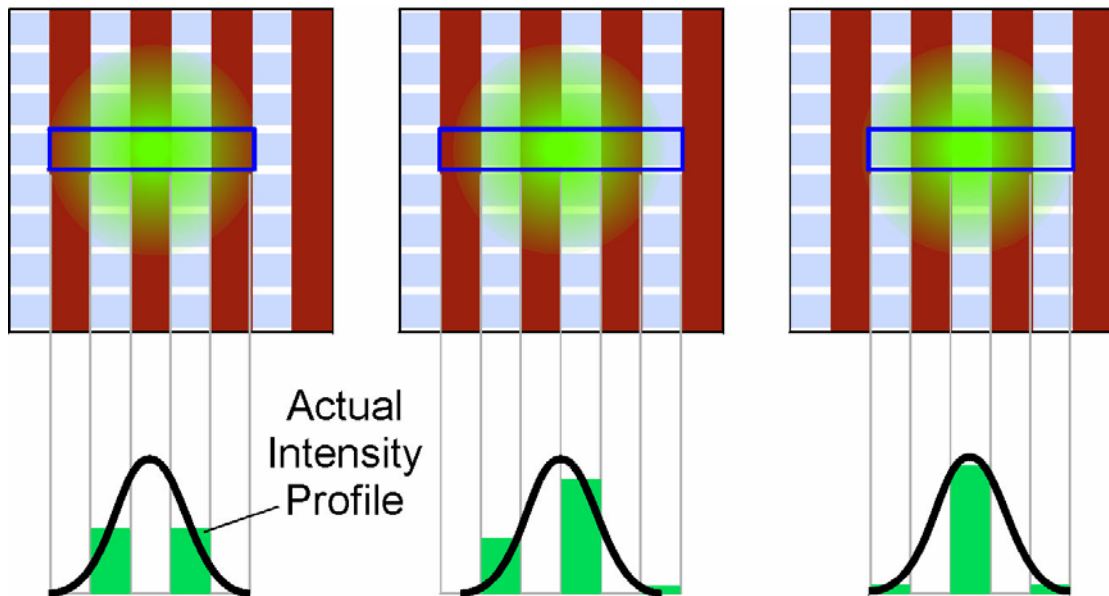


Figure 11: Analysis of LED Image on Interline CCD

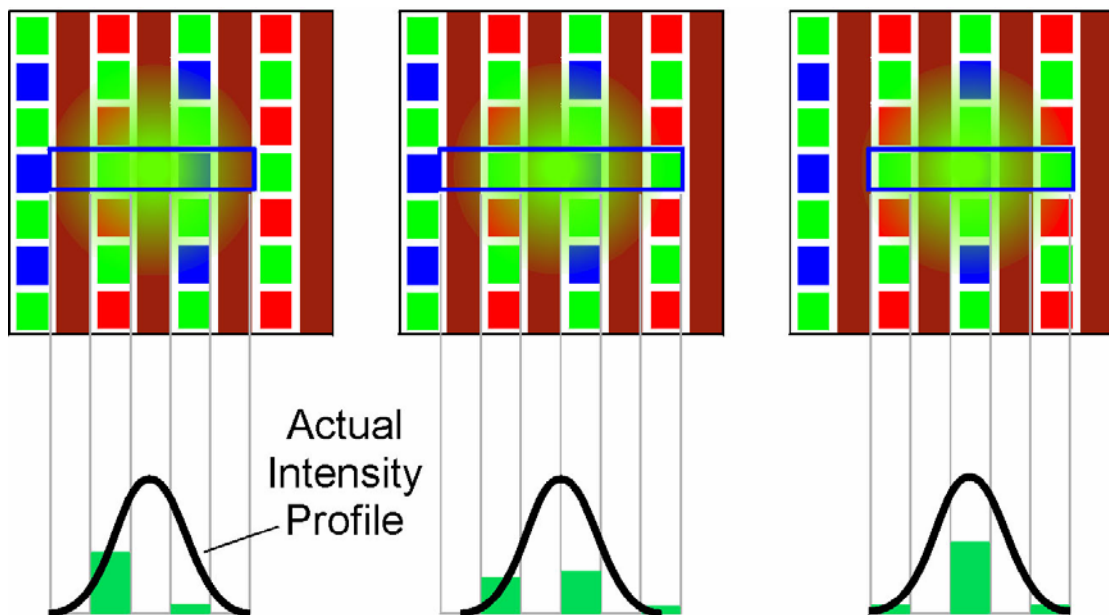


Figure 12: Analysis of LED Image on Interline/Bayer Colour Filter CCD

Figure 12 illustrates the effect of the same LED as imaged onto the colour interline CCD. The results for LED luminance and colour could be highly erroneous. Clearly, over-sampling of the LED over a larger number of pixels on an interline CCD will help reduce errors with this type of camera, but that will lead to a greatly reduced field of view.

In conclusion, the use of interline CCDs (colour or monochrome) for performing photometric and colorimetric analysis of displays at the pixel level, of instrument panels and of LED arrays can be subject to very high levels of uncertainty. Care must be taken if using an interline based CCD photometer to ensure that light source artefacts are not missed or misreported.

To avoid any possibility of obtaining an instrument-specific reading, or one which is dependent on a particular measurement set-up, the use of a full frame CCD photometer is to be recommended. Table 2 provides guidance on selecting a ProMetric camera for particular applications.

Table 2: Recommended Applications for Interline and Full Frame Type ProMetric CCD Cameras

ProMetric Model	PM-1000	PM-1200	PM-1400	PM-1600
CCD Type	Interline Interline/Bayer Filter	Interline Interline/RGB Wheel	Full Frame Full Frame/RBG Wheel	Full Frame Full Frame/RBG Wheel
Key Attributes	Lowest cost	Least expensive CIE colour response	Most sensitive, widest dynamic range, highest spatial resolution, most flexible	
Best For	Area uniformity of CRT & LCD displays; luminaires; non-LED backlights;	Area uniformity of CRT & LCD displays; luminaires; LED backlights; LEDs	Area uniformity & pixel-level testing of CRT, LCD, LED & OLED displays, IPs; automotive headlamps; projectors; architectural; display contrast measurements	