Application Note (A8)

A Comparison of CCD and Scanning Systems for Spectroradiometry

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Despite known problems with commercial CCD systems for spectroradiometric measurements, manufacturers continue to market these applications. Features such as speed are emphasized in the sale of such equipment, making them appealing to buyers, but radiometric accuracy is generally not tested. In this study, we investigate a popular commercial CCD spectrographic system for spectroradiometric accuracy and assess its usefulness in such applications. This study was instigated by the manufacturer of the CCD system to provide data on its performance between 200nm and 400nm.

In this study, three lamps were measured by the CCD system and an OL 754 scanning spectroradiometer under identical conditions. These lamps were:

i. A 45W deuterium lamp, calibrated for irradiance relative to NIST standards, and used to provide calibration factors for both systems.
ii. A low-pressure mercury Pen-ray^{TM} lamp, used to provide information on measurement of essentially monochromatic line sources.
iii. A seasoned 200W tungsten lamp with fused silica window, operated from a precision constant-current supply at 6.5A, used to provide information on continuous sources that differ from the calibration source.

To ensure optimum performance, the CCD system was operated by a qualified representative of the manufacturer, and the OL 754 was operated by the author. The CCD system was optimized for 200-400nm operation and had a 400mm UV grade fiber optic at the input. This arrangement was thought to give best results by the manufacturer, but since the fiber formed the entrance aperture to the spectrograph, data were at low spectral resolution. The OL 754 was optimized for 200-800nm operation, with an integrating sphere input and 1nm resolution.

Both systems were calibrated using the deuterium source. This was selected as being the best source for calibration of the CCD system since stray light levels would be minimized due to the small contribution of wavelengths outside the region of interest. However, the CCD system measured this source at two different integration times to verify the linearity of operation. Figure 1 shows the ratio of signals obtained at 204ms and 81ms integrations, which should give a constant value of 2.52 at all wavelengths, but instead clearly indicates a severe spectrally-dependent non-linearity in the system. This is totally unexpected, difficult to account for, and is fundamentally incompatible with good radiometric measurements. Since this was discovered in the analysis following the measurements, the 81ms data was used in the calibration since this was closer to the integration times for the other sources.

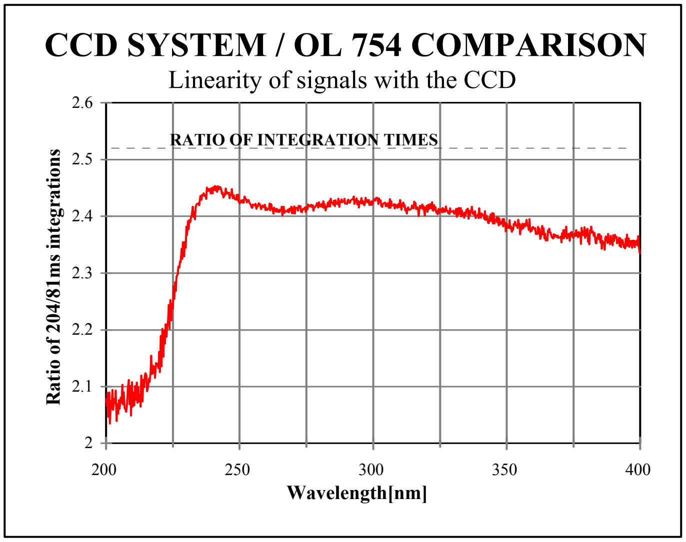
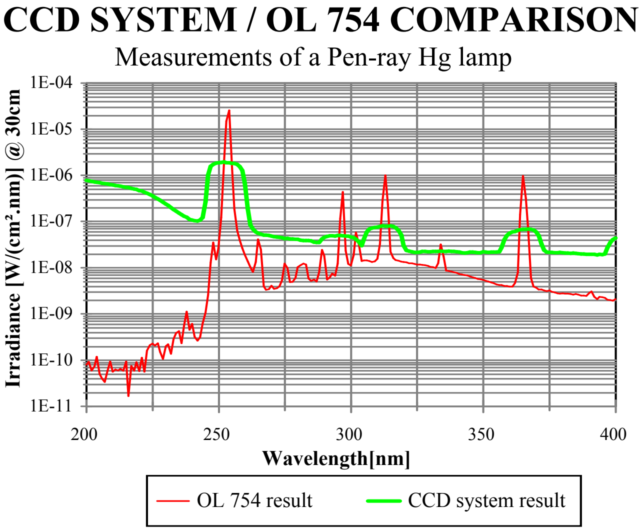


Figure 1

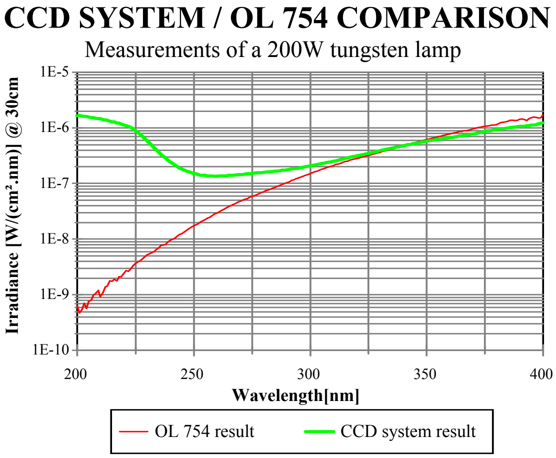
The mercury Pen-ray lamp was then measured for irradiance at a distance of 30cm with both systems. The results, shown in figure 2, clearly indicate a disagreement between the two systems. Since different bandwidths were used in the measurements, one might expect peak intensities of monochromatic lines to disagree but integration over peak areas should match. In fact, the CCD system recorded lower radiation levels than the OL 754, by factors of 1.72 for 240-270nm and 1.55 for 360-370nm intervals. If this was the only measure available, it might be argued that this is insufficient to determine which result is correct. However, the CCD result shows significant emission in the 200-240nm region that can only be interpreted as high stray light levels in the system. Additionally, the dynamic range of the CCD system seems to be limited to two decades whereas the OL 754 data indicates nearly a 5 decade change in the source.

Figure 2



The results from measurements of the tungsten lamp are important, not only in respect of the comparison of the two systems but also since it should be a blackbody and hence independent checks can be made by Plankian calculations. As seen in Figure 3, the CCD system again exhibits high stray light levels. Below 300nm, the agreement between the CCD system and the OL 754 grows increasingly worse and reaches 4 decades at 200nm. The fact that the OL 754 shows high accuracy and negligible stray light even at 200nm is verified by the extremely close agreement at all wavelengths to a 3100K blackbody.

Figure 3



In conclusion, the OL 754 accurately reflects the energy distribution of light between 200-400nm regardless of the source. Unfortunately the same cannot be said for the CCD system under test, showing a lack of dynamic range and severe errors making even approximate measurement impossible. Although one CCD system from one manufacturer was compared, these findings are not new and seem to apply generally to all CCD or other multi-channel systems. Despite the poor performance of these CCD systems, there should be no reason why properly designed CCD systems should not work in spectroradiometry. It is the application of general spectroscopic CCD systems to the field of spectroradiometry, often without sufficient knowledge and using inappropriate calibration techniques, that gives rise to these errors. At this time, no manufacturer of CCD systems can provide equipment to make such measurements adequately. Since CCD systems do offer advantages in other respects, and it is obvious that fundamental changes are required before they can be applied to spectroradiometry, Optronic Laboratories, Inc. has initiated a fully funded program of research into appropriate spectrometer design and calibration techniques.