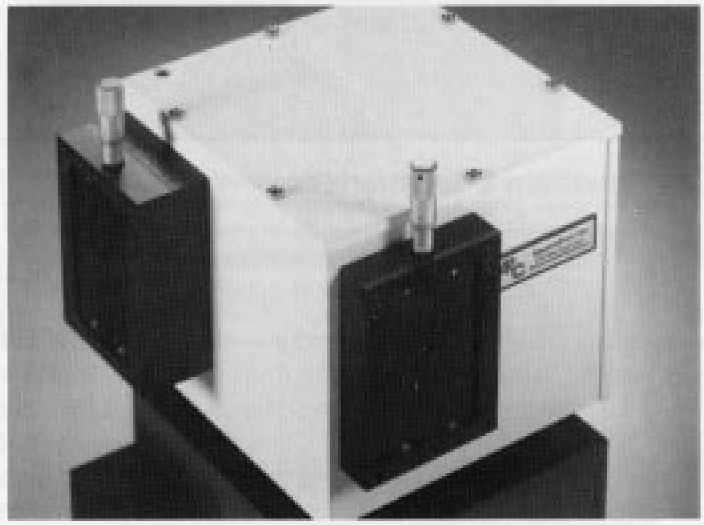
TECHNOTE

Acton Research Corporation
SpectraPro-150 Monochromator / Spectrograph Focal Plane Characteristics

Background: A new, compact 150mm focal length imaging Czerny-Turner monochromator/ spectrograph has been developed. The instrument features an astigmatism-corrected imaging optical system with full scanning capabilities, plus a 25mm wide focal plane for CCDs and diode arrays.

In this *TECHNOTE* we address astigmatism-correction, spectral resolution and multi-channel input capabilities. In addition, we show actual source images collected using the SpectraPro-150 in various imaging modes.



CONVENTIONAL MONOCHROMATOR/SPECTROGRAPH

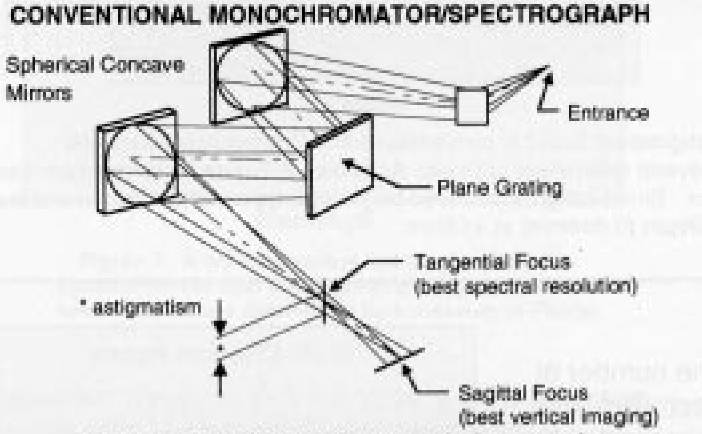


Figure 1: Typical Czerny-Turner optical systems have astigmatism caused by spherical mirrors used off-axis. A point light source images as a vertical line.

NEW SPECTRAPRO-150 OPTICAL SYSTEM

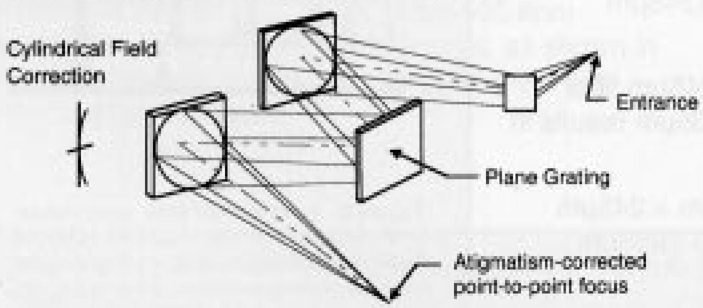


Figure 2: Added cylindrical field correction brings the tagential and sagittal focal planes together. A point light source now images as a point.

General: The SpectraPro-150 was developed to address the need for a compact, multi-grating, imaging monochromator and spectrograph with full scanning and computer control capabilities. It is designed to replace conventional "small" monochromators and spectrographs which have astigmatism resulting from off-axis use of spherical concave mirrors. As shown in Figure 1, the off-axis angles cause a displacement of the tangential and sagittal focus points, which results in astigmatism. In this type of optical system a point light source introduced at the entrance port takes the form of a vertical line image at the exit port, reducing intensity at the CCD and limiting multi-channel input capabilities.

How the SpectraPro-150 Works:
Internal cylindrical field correction introduced by a toroidal mirror brings the tangential and sagittal focal planes together, thereby removing astigmatism. A point source introduced at the entrance port of the SpectraPro-150 images as a point at the detector (Figure 2). The advantages of this design are use of conventional plane diffraction gratings, full scanning and computer control capabilities, broad wavelength range, plus good spectral resolution.

Advantages of Astigmatism-Correction

The SpectraPro-150 delivers brighter, better focused light to a detector than conventional monochromators and spectrographs. At the exit slit, astigmatism has been reduced a factor of 50 or more, from greater than 2.30mm to approximately 0.045mm (Figure 3). A detector, whether a CCD or diode array, sees light with higher intensity, resulting in improved detection capabilities and superior signal to noise levels. This imaging optical system also permits multi-channel light input capabilities when used with CCDs.

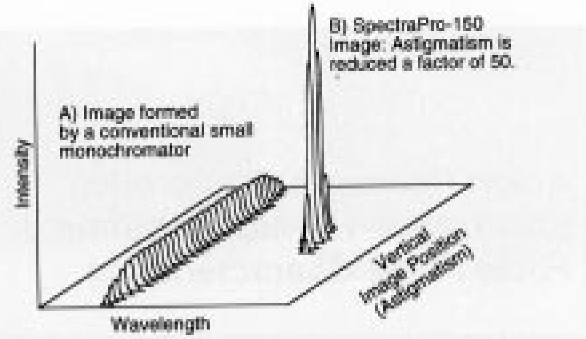


Figure 3:
A) Astigmatism causes an image to spread out in the vertical direction several millimeters or more, resulting in diminished light intensity at the detector.
B) The imaging optical system of the SpectraPro-150 faithfully reimages the light at the entrance slit to the detector resulting in a sharper, brighter image.

Astigmatism Characteristics

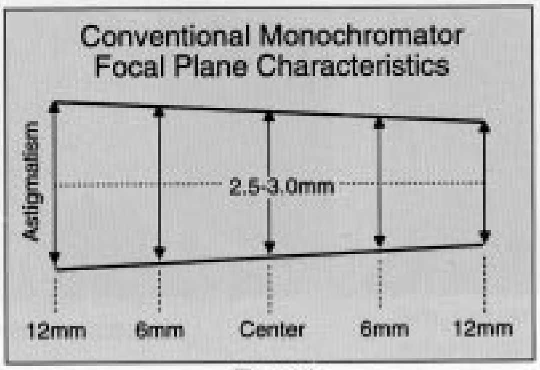


Figure 4

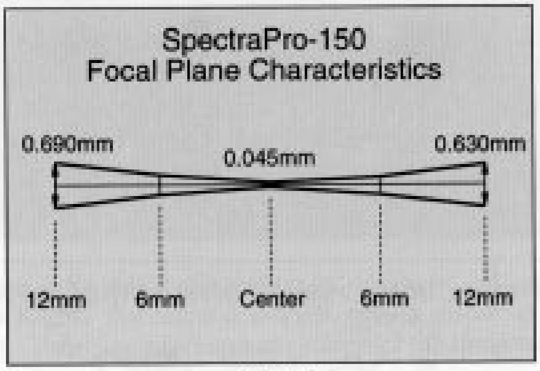


Figure 5

Astigmatism Across the Focal Plane: Figure 4 shows the typical astigmatism found in conventional small monochromators and spectrographs. This causes source intensity to spread out vertically several millimeters or more. As shown in Figure 5, astigmatism has been reduced substantially, providing higher light intensity to a detector. Some astigmatism does begin to reappear at the extreme sides of the focal plane, amounting to ~290µm (0.290mm) at ±6mm, and ~690µm (0.690mm) at ±12mm.

Multi-Channel Imaging

CCD size (width) plays an important role in determining the number of independent channels that can be introduced into the SpectraPro-150, dispersed into individual wavelength components, then reimaged at the CCD without cross interference. As a general guideline, we have outlined some examples below to help you calculate the number of independent inputs accepted by the SpectraPro-150.

These examples assume a single 200µm diameter fiber (245µm diameter with cladding) for each input channel.

7mm high X 12mm wide CCD: 290µm astigmatism + 245µm fiber height = image height of 535µm. 7000µm high CCD ÷ 535µm results in 13 possible input channels.

7mm high X 25mm wide CCD: 690µm max. astigmatism + 245µm fiber height = image height of 935µm. 7000µm high CCD ÷935µm results in 7 possible input channels.

Notes: We recommend taking a conservative approach when calculating the number of possible inputs in order to take into account variations in actual fiber sizes, or the introduction of astigmatism, magnification or other aberrations from any input optics that may be used.

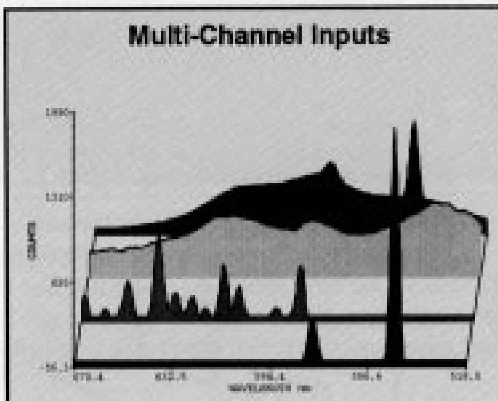


Figure 6: Independent fiber optic inputs to the SpectraPro-150, from four different light sources (top to bottom: fluorescent lamp, incandescent lamp, neon lamp, and mercury lamp)

Resolution Characteristics

The SpectraPro-150 equipped with a 1200g/mm grating was characterized for spectral resolution across a 6mm high by 25mm wide focal plane. A 200µm diameter fiber illuminated by a low pressure mercury lamp was used as the light source, and an image of the fiber at 435.8nm was selected. Resolution was measured with the fiber positioned at the center of the entrance slit and then with the fiber positioned 3mm above center. Since the optical system is symmetrical from top to bottom, this was adequate for test purposes. The grating was then scanned so that the fiber image could be positioned at the extreme edges of the focal plane. This combination of moving the fiber vertically at the entrance slit, and scanning the grating enabled complete coverage of the focal plane area.

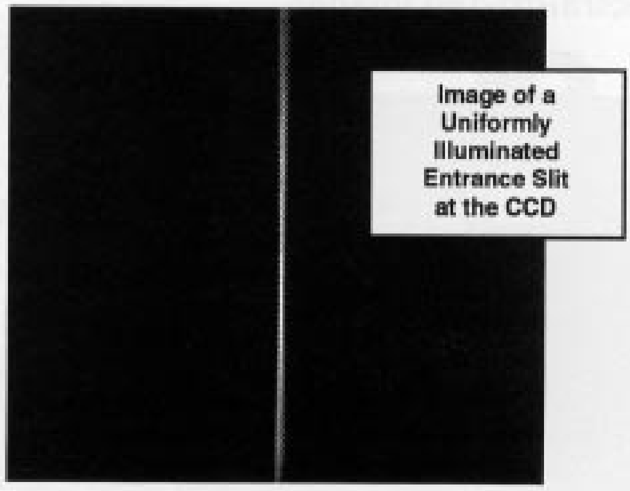


Figure 8 This image of a uniformly illuminated entrance slit shows a central region of sharp, well focused light. There is some degradation which starts to appear at the top and bottom portions of the focal plane, typical for most small spectrographs.

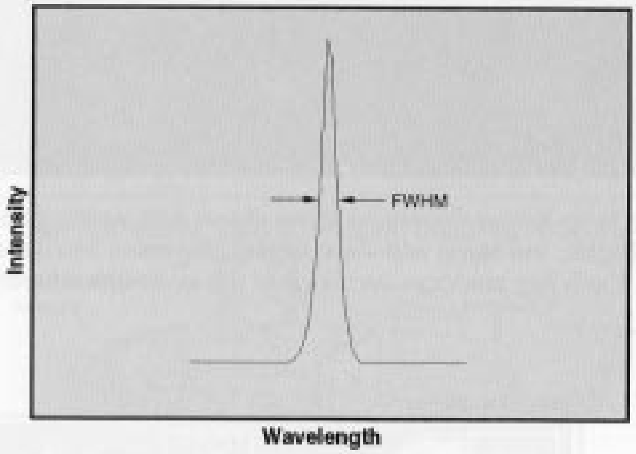


Figure 7: A typical spectral line produced by the SpectraPro-150 with a 1200g/mm grating. Resolution specifications are determined by a measure of FWHM.

Slit Width Settings: Four different slit width settings of 25µm, 50µm, 100µm, and 200µm were used at each focal plane position to provide different bandpasses for the test. The measured FWHM at the focal plane center, plus the FWHM measured at the extreme corners of the focal plane area were then summarized below.

FWHM Summary: Figure 9 shows the measured FWHM using the four different slit width settings. FWHM measurements are shown for the focal plane center, and at the "corners" of the focal plane.

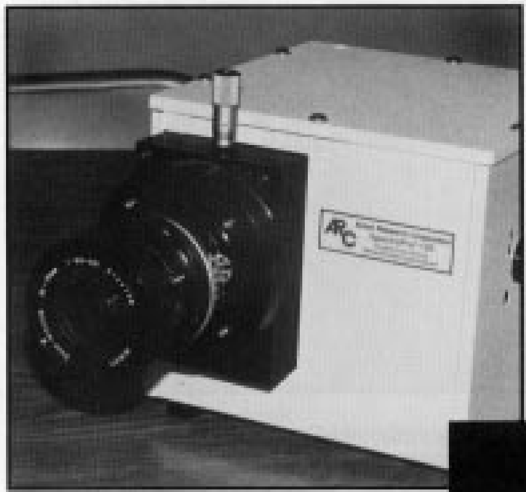
Slit Width	3mm above and 12mm left	Focal Plane Center	3mm above and 12mm right
25µm	0.44nm	0.32nm	0.42nm
50µm	0.53nm	0.38nm	0.50nm
100µm	0.72nm	0.60nm	0.68nm
200µm	1.13nm	1.07nm	1.10nm

Figure 9: Table outlining the typical FWHM characteristics of the SpectraPro-150 under various test conditions.

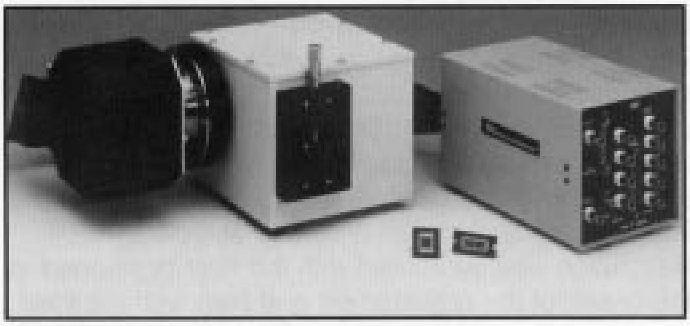
Detection System: For the tests, a CCD detection system with 11.5µm pixels was used, and programmed to "bin" pixel rows to collect a 200µm high fiber image. This CCD setting was used for every fiber position across the focal plane area. Resolution specifications were then determined by a measure of FWHM (Full Width of the 435.8nm spectral line at Half Maximum intensity), as shown in Figure 7. Ray trace analysis is in agreement with actual measured results.

Notes About FWHM Measurements: *Resolution measurements across the focal plane area should be used for area detectors such as CCDs. Spectrographs used with diode arrays do not normally view a 6mm high focal plane, and monochromators view only the center of the focal plane (exit slit), therefore for these instances use only the focal plane center values.*

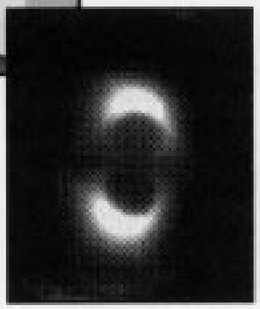
SpectraPro-150 Images

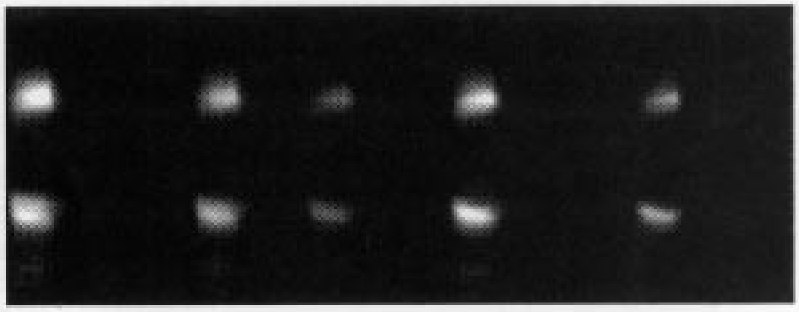


Above: A standard Nikon camera lens adapted to the entrance port of the SpectraPro-150 for source collection and imaging. This permits direct source images (non-dispersing mode) plus analysis of distinct wavelength components (dispersing mode).

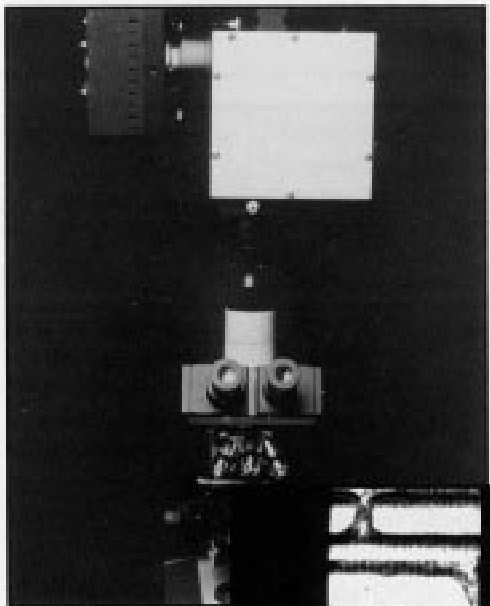


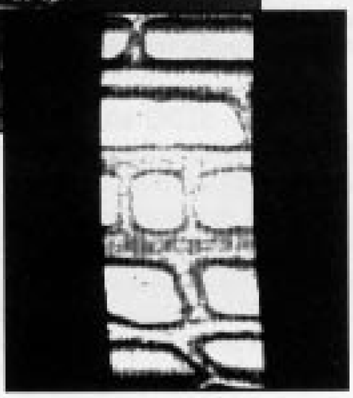
Above: The SpectraPro-150 easily adapts to most commercially available array detection systems, such as this manufactured by EG&G PARC.
(photo courtesy EG&G PARC, Inc.)





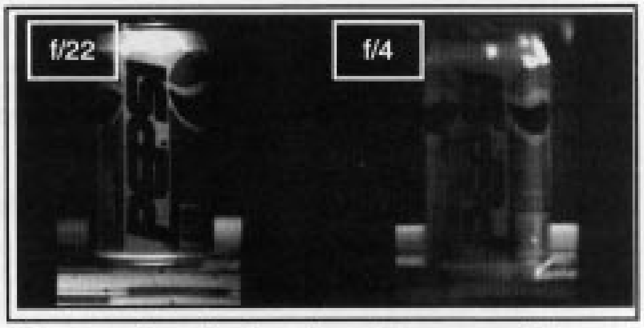
Above Left: End-view of a neon lamp in non-dispersing mode shows light emitting from two circular electrodes. **Above Right:** the same end-view, except dispersed into neon wavelength components (lines). Each line produces an image of the lamp with different intensity.





Left: SpectraPro-150 Spectrograph with Princeton Instruments CCD attached to an Olympus microscope enables direct sample imaging and spectroscopy.

Below: Image of a locust wing through the microscope, SpectraPro-150 and CCD (photos courtesy Princeton Instruments, Inc.).



Above: to show the imaging performance of the SpectraPro-150, images of a soft drink can were collected using a CCD. A Nikon lens (at f/4 and f/22) focussed the image of the can at the entrance port of the SpectraPro-150, which then re-imaged this onto the CCD.

Acton Research Corporation
PO Box 2215 • 525 Main Street
Acton, MA 01720
Tel: (508) 263-3584 • Fax: 508-263-5086

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SpectraSense Software

SpectruMM CCD Detectors

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Grating Rotation Analysis

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