Effects of Light Scattering by Films on the Performance of CCD Scanners

Introduction

Film scanners that have a long diffuse light source and a CCD detector are susceptible to artifacts that can affect the performance. In particular, when such a scanner undergoes a process to calibrate the intensity of the light source along its length, significant inaccuracies can later occur if measurements are made on a film that scatters light. Since the images in conventional processed radiographic films and radiochromic films are composed of particles dispersed in a matrix having a different refractive index, these films will scatter light. The effects of light scattering are seen in film scanning measurements as an apparent variation of response of the film in a direction parallel to the light source. The magnitude of the effect depends on a number of factors, including the geometric arrangement of some scanner components. Thus the effect of light scattering will generally be proportional to the length of the light source and its distance from the film as well as the distance between the film and the detector.

FilmQA™ software is a fast efficient film dosimetry and image analysis software that contains unique features for correcting for the effects of light scattering by CCD scanners. FilmQA™ is unique in this feature and the use of FilmQA software is essential to providing optimum results with EBT film on the Vidar VXR-16 as well as on flatbed scanners.

Effects of Light Scattering on Image Profiles Parallel to the Light Source

Scanners of the type described above include the Vidar VXR-12 and VXR-16 as well as many flatbed photographic film scanners. Of these, the Vidar scanners have the longest light sources (an 18” fluorescent tube) placed relatively far away from the film. In the Vidar scanners the light source is about 2” from film. Most flatbed scanners have light sources less than 12” in length and only about 2cm from the film. For these reasons the Vidar scanners generally exhibit considerably greater effects due to light scattering than do the flatbed scanners. Figures A1-1 and A1-2 are profiles across the image of an unexposed GAFCHROMIC EBT film on an Epson 1680 and a Vidar VXR-16 scanner respectively. The profiles are parallel to the light sources. In both cases the scanner response is a function of position on the film, but the VXR-16 shows considerably greater variation in response. An explanation of the effect will be given later.

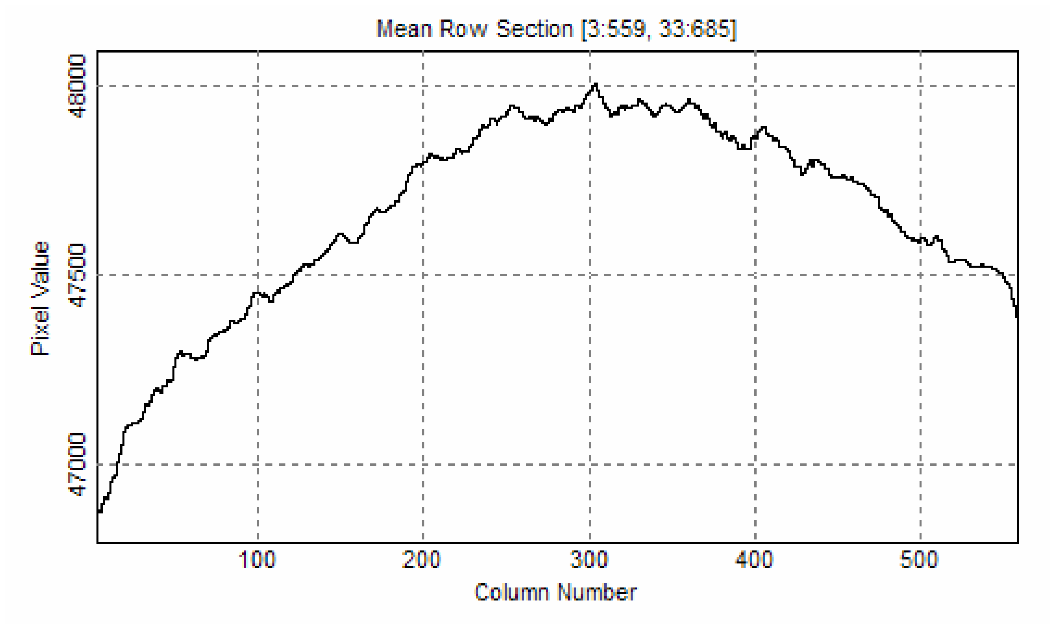

Figure A1-1: Profile across Unexposed EBT film on an Epson 1680 Scanner

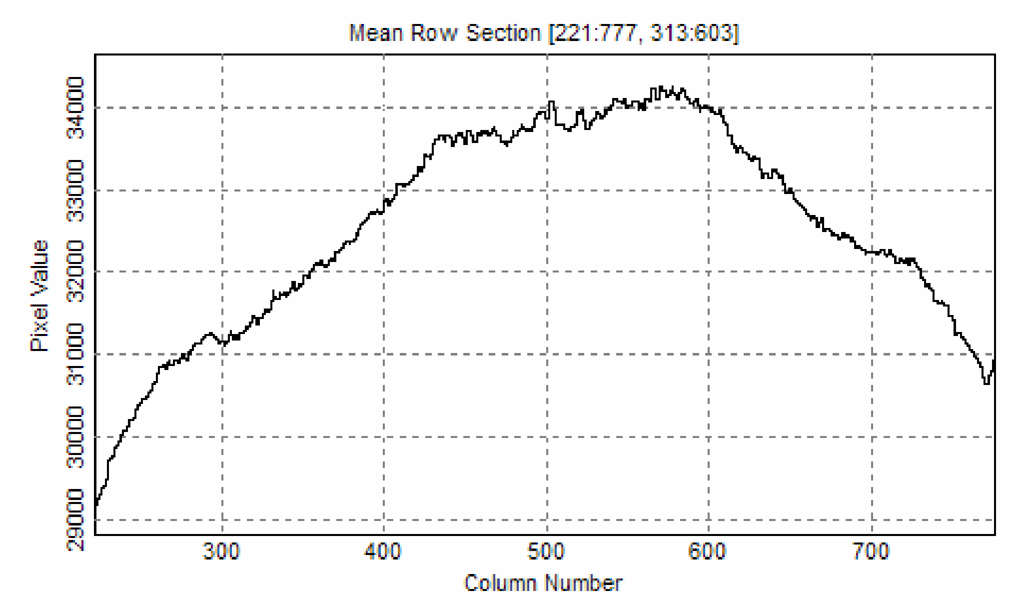

Figure A1-2: Profile across Unexposed EBT film on a Vidar VXR-16 Scanner

Light scattering is caused by particles in the active layer of the film. The magnitude is proportional to the size and concentration of particles and the refractive index difference between the particles and the film matrix in which they are contained. Nevertheless, the effects of light scattering by GAFCHROMIC® radiochromic films in all these scanners can be easily measured and corrected.

In silver halide films light scattering is caused by grains of silver in the image. The number of particle in the silver image is proportional to dose. Since light scattering increases with dose it becomes difficult and complex to compensate for the effects of light scattering in conventional silver film. In GAFCHROMIC® radiochromic films light scattering is caused by particles of the active component. However the number and size of these particles is independent of exposure.

Figure A1-3 is a schematic of a scanner such as the Vidar VXR-16 or Epson 1680. It shows elements important the calibration of intensity along the length of the light source In the VXR-16 this type of calibration occurs at time intervals of a few minutes. In the Epson and most other flatbed scanners this calibration immediately precedes every scan. In neither scanner is there film in the optical path during calibration. Rather the calibration occurs through a transparent, non light scattering medium. Air in the case of the VXR-16 and glass in the Epson 1680. Both scanners have long diffuse light sources, bur essentially only those rays normal to the film plane will arrive at the detector. The response along the detector is therefore proportional to the intensity along the length of the light source and can be used to calibrate and correct intensity differences assuming that the intensity dose not change between calibrations or during a scan. When film is scanned, the calibration will be valid so long as the film does not scatter light.

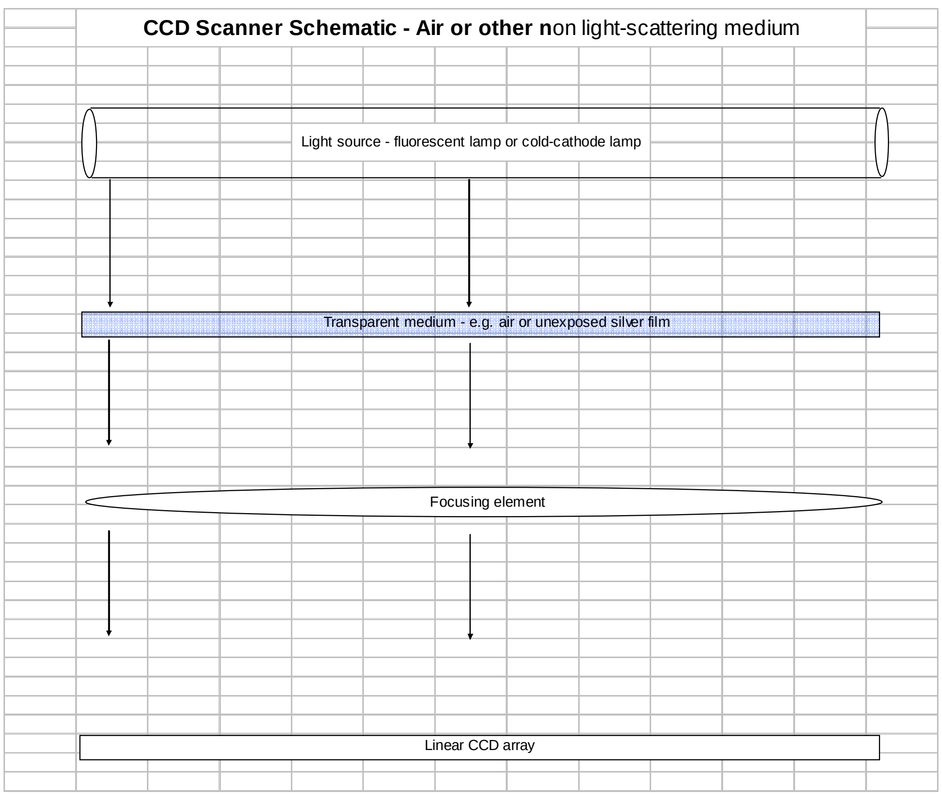

Figure A1-3

Figure A1-4 is a schematic depicting features important to the scanning of a film that scatters light. Because the light source is diffuse, a small proportion of the off-axis illumination at the film plane will be fortuitously scattered by the film and contribute to the signal received at the detector. However, because the light source has a finite

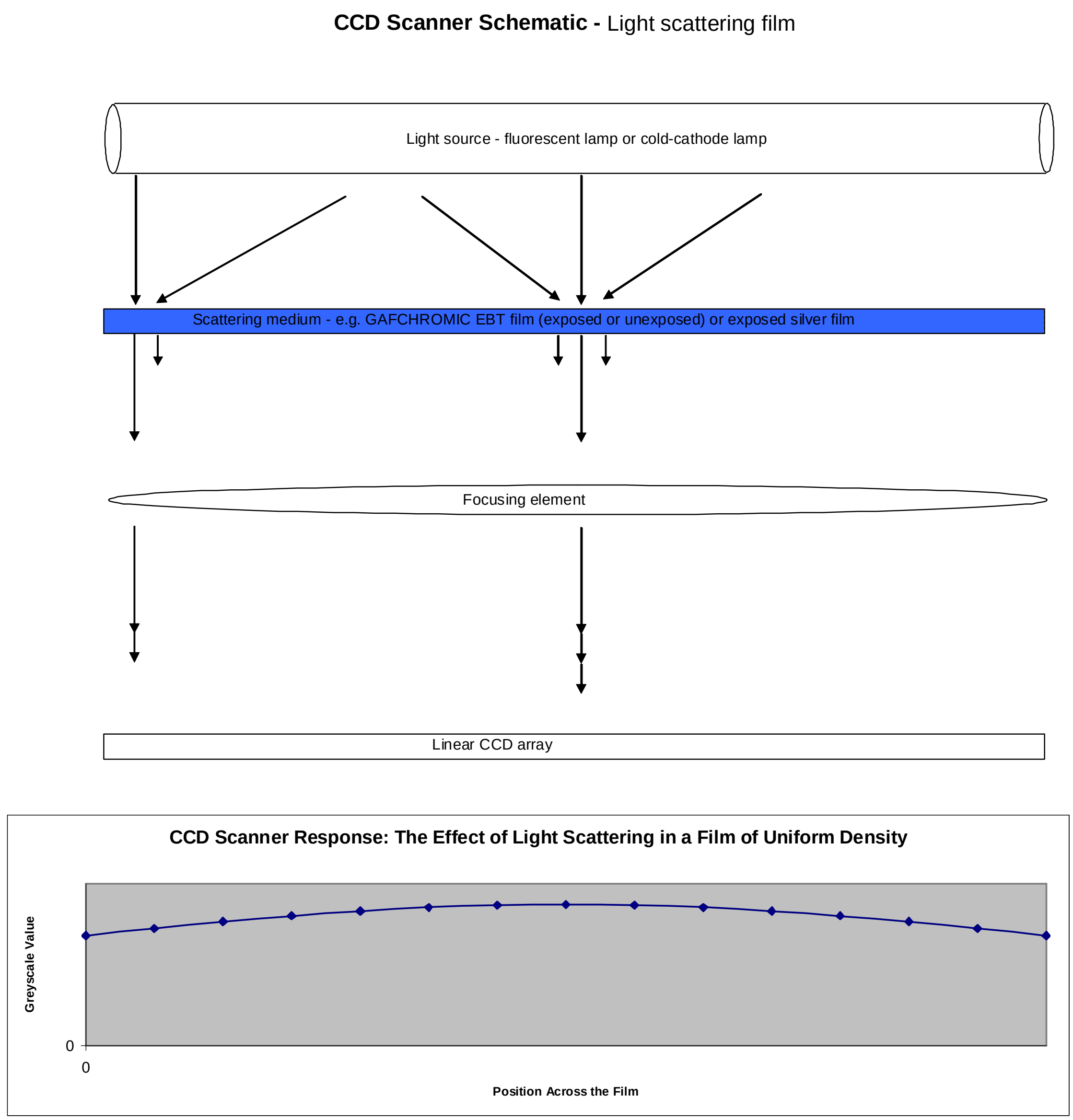

Figure A1-4

length, the off-axis illumination at the center of the film will be greater than at the ends. Consequently the amount of light registering at the detector will be greater in the center and less at the ends. The plot at the foot of Figure A1-4 shows an idealized response profile across a film that has a uniform absorbance, but scatters light.

These effects of light scattering by silver film are shown in Figure A1-5. This figure shows profiles across a 7.5” film uniformly exposed to a net densities of about 0.1. The silver film profile on the left of the figure is from a VXR-16 scan while the right hand profile is from a scan on an Epson 1680. The Vidar scan was made with the left edge of the film registered against the left edge of the scanner. On the Epson 1680 the left edge of the film was registered against the left edge of the scan window. The scanner response values (pixel values) have been normalized by dividing by the mean scanner response value for the area.

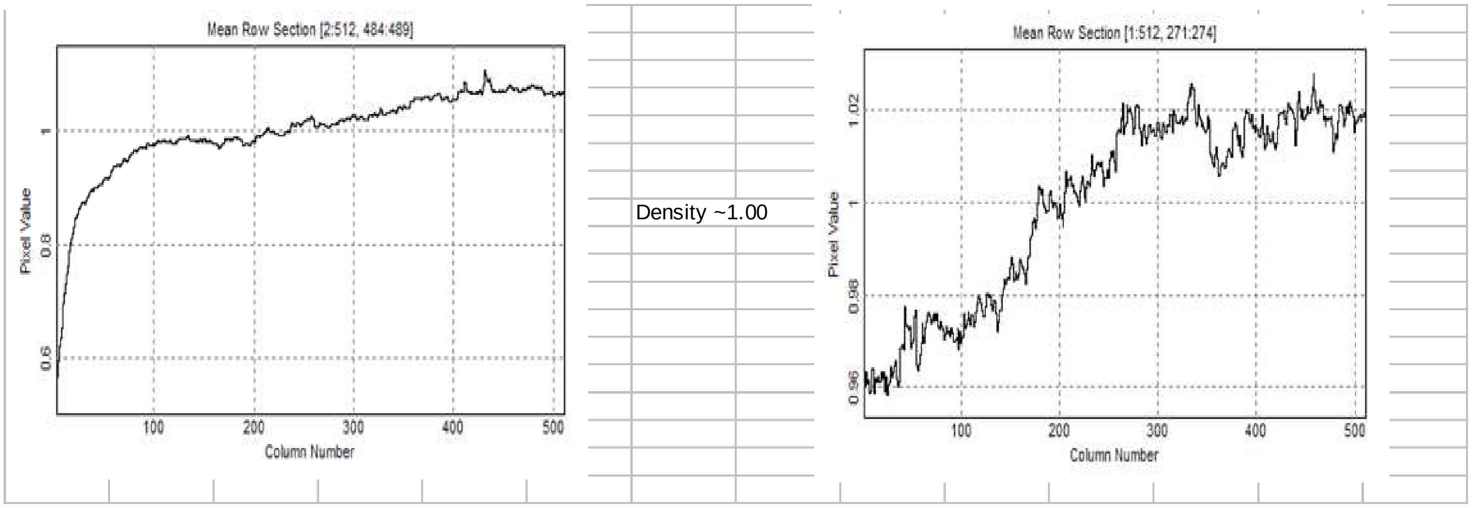

Figure A1-5: Profiles showing normalized scanner response across a silver film having net density about 1.0. The Vidar VXR-16 data is on the left and the Epson 1680 data is on the right.

The source of the steep fall-off at the far left side of the silver film profile is unknown, but it is not believed to result from light scattering. However, the effect of light scattering on the measurement can be seen by the slope from approximately columns number 90 to 500. This shows that the change in scanner response because of the contribution from light scattering by the film approaches 10% across the width. The results on the right of Figure A1-5 are for the Epson scanner and they show about a 5-6% difference between the center and the edge. It is believed that the lower contribution from light scattering exhibited by the Epson scanner is due to two factors – a) the light source in the Epson is shorter than the Vidar (about 11” vs. 18”) and; b) the light source in the Epson scanner is closer to the film (about 1cm vs. 2”).

The effects of light scattering by EBT film for the Vidar VXR-16 and Epson 1680 are shown in Figures A1-1 and -2. Light scattering in EBT film is due to refractive index difference between particles of the active component and the gelatin matrix in which they are embedded. The refractive indices of these materials are essentially unchanged and the size of the active material particles is unchanged by irradiation of the film. Thus it is easy to correct for the effects of light scattering using the following four steps.

1. Scanning an unexposed EBT film
2. Measuring the mean pixel value (i.e. scanner response value) of the unexposed film
3. Creating a “Flat Field Correction Image” by dividing all pixel values in the unexposed film image by the mean pixel value. This is referred to as pixel-by-pixel arithmetic. Figure A1-6 shows a profile across a Flat Field Correction Image on an Epson 1680 scanner. A correction image for the VXR-16 will be qualitatively similar, but the correction factors span a wider range of values. Although the profile in Figure A1-6 has not been smoothed, it would be beneficial

to apply a smoothing filter to the Flat Field Correction Image to remove scanner and film noise before the Correction Image is used.

4. Flattening all images in a set of images using pixel-by-pixel division of the image by the Flattening Correction Image to correct for the effect of light scattering.

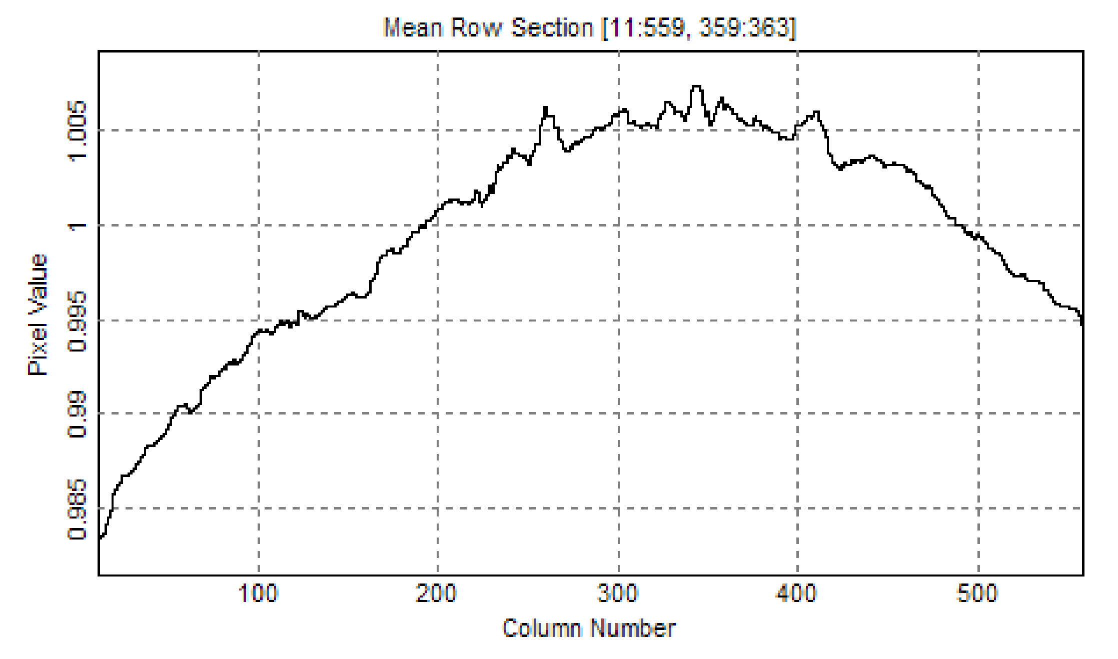

Figure A1-6: Profile across a Flat Field Correction Image

These steps are seamlessly performed by FilmQA™ software. FilmQA™ is unique in this feature and the use of FilmQA software is essential to providing optimum results with EBT film on the Vidar VXR-16 as well as on flatbed scanners

Effects of Light Scattering on Image Profiles Perpendicular to the Light Source

Figure A1-8 shows another scanning artifact that frequently occurs when scanning EBT film on the Vidar VXR-16. Flatbed scanners do not exhibit this defect. Sharp bands may appear across the VXR-15 images about 3cm from the start and/or end of the scan. The profile [A1-8-1] across a typical band [A1-8-2] will show an abrupt change [A1-8-3] in scanner response. In extreme cases the change can approach 2% of the signal. The fact that the band is not physically present on the film can be seen by visual inspection, or inspecting an image of the film turned and scanned at 90°. The artifact may be unimportant if the ends of the film do not have areas of dosimetric interest, but in many cases the effect must be eliminated.

The artifact is caused by a change in the location of the film plane as film is transported through the scanner. The VXR has two sets of rollers to transport film past the “scan slit” where optical absorbance of the film is measured. At the beginning of a scan the film only contacts the rollers on the "entrance" side, but after the film is scanned about 3cm the leading edge of the film contacts

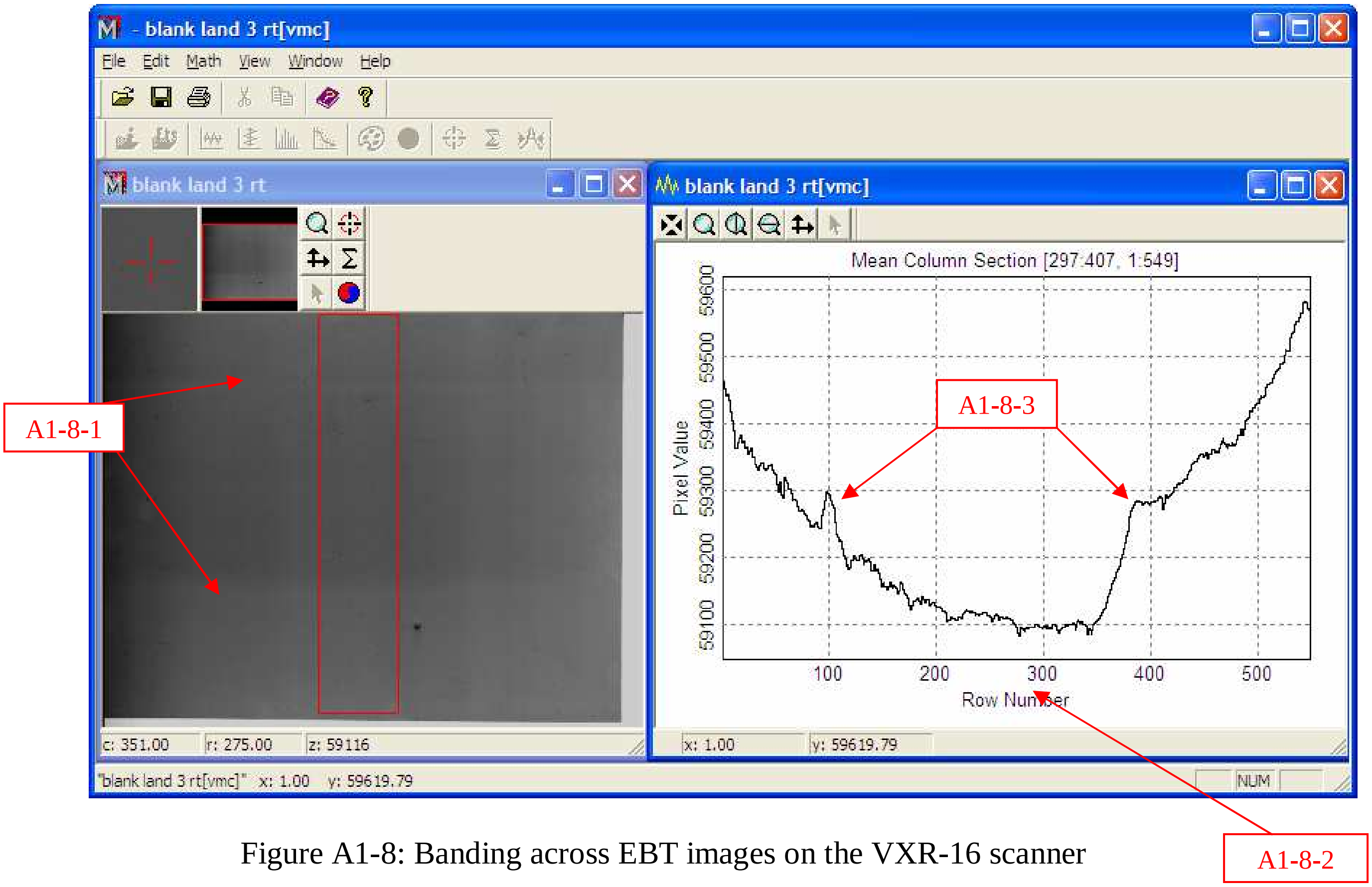

Figure A1-8: Banding across EBT images on the VXR-16 scanner

the second set of rollers. In most scanners the films does not hit the rollers on the exit side tangentially. Instead the leading edge of the film contacts one of the a rollers and is carried around the circumference until is finally caught between the two exit rollers. The movement around the circumference of the roller causes the angle between the film plane and the optical axis of the scanner to change and consequently the amount of scattered light reaching the CCD detector changes abruptly.

For the central part of the scan the plane of the film is fixed because the film is pinned between the entrance and exit rollers. However, about 3cm from the end of a scan the trailing end of the film is released by the entrance rollers and again the film plane can move and cause a band across the image.

ISP has designed a transparent sleeve in which EBT film can be placed for scanning in Vidar scanners. The sleeve is designed so that the leading and trailing end of the EBT film are about 4cm away from the ends of the sleeve. Thus the leading end of the sleeve is pinned by both the entrance and exit rollers before the EBT film reaches the scan slit. In this way the EBT film is held in a stable plane throughout the entire scan and the banding at the ends of the film is obviated. Figure A1-9 shows a profile at the end of a film image obtained by using the sleeve and demonstrates that there are no bands.

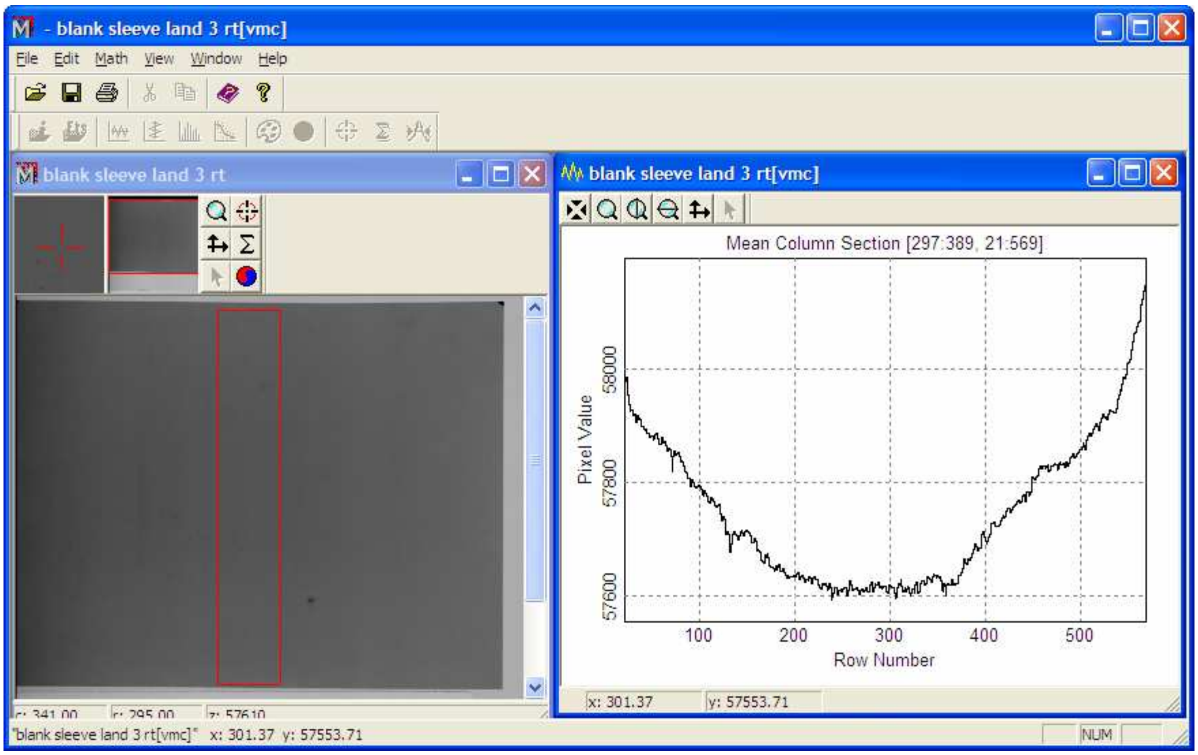

Figure A1-9: Profile of the same EBT film as in Figure A1-8 showing that the banding is eliminated by scanning the film in a sleeve