The Array Scanner as Microdensitometer Surrogate: A Deal with the Devil or... a Great Deal ?

Don Williams
Eastman Kodak Company, Rochester, NY, USA, 14650-1925

ABSTRACT

Inexpensive and easy-to-use linear and area-array scanners have frequently substituted as densitometers for low-frequency (i.e., large-area) hard copy image metrology. A number of workers and standard's committees[1] have in fact advocated such use. Increasingly, scanners are also being tasked for high spatial frequency, image microstructure metrology, which is usually reserved for high-performance microdensitometers that use microscope optics, photomultiplier tubes (PMT), and log amps. It is hard to resist their adoption for such use given the convenience level. The high speed, large scan areas, auto-focus, discomfiting low cost, and low operator skill requirements of commercial off-the-shelf (COTS) scanners makes one question if their use for such purpose is somehow too good to be true though. To confidently judge their limitations requires a comprehensive signal and noise spatial frequency performance evaluation with respect to available driver options. This paper will outline and demonstrate evaluation techniques that use existing ISO metrology standards for modulation transfer function (MTF), noise, and dynamic range with a comparison to the performance of a Photometric Data Systems (PDS) microdensitometer .

Keywords: MTF, dynamic range, microdensitometer, metrology, standards

1. INTRODUCTION

Despite their half century legacy, microdensitometers continue to serve as de-facto standardized instruments for high spatial frequency photometric image metrology of both transmissive and reflective media. Microdensitometers however continue to excel in their flexibility and imaging performance. Independent aperture and sampling settings, calibration freedom, ease of operator intervention, and PMT/log amp detection make them invaluable as high-end research and development tools. For these reasons, they are unlikely to ever be completely replaced. But, costly or unattainable maintenance, high skill requirements, and slow speeds have forced many metrology centers to abandon them altogether in favor of their speedier and less-expensive brethren, the array scanner. Is this a deal with the devil though ? Will the immediate convenience of rapid and low cost data collection allowed by array scanners haunt adopters with mid-grade imaging performance, cross-device inconsistency, and non-standardized driver settings? Or, is it really a great deal? Are the high dynamic range and resolution claims (summarily and incompletely specified in bits and sampling frequency) of COTS scanners truly achievable in a scientific signal-to-noise ratio sense at such low cost? Using established scientific practices and standardized ISO protocols, a scanner imaging performance accreditation for metrology purposes will be demonstrated.

While the methods described here can be applied to any device intended for quantitative metrology, the candidate COTS scanner chosen for comparison here is an Imacon 848 scanner in transmission mode. The single greatest reason for considering the Imacon 848 as a microdensitometer surrogate had been the claim of true 8000 dpi performance over a 6 frame 35mm film chop. A single frame RGB scan at this resolution will take about five minutes. On the microdensitometer the same resolution scans would take about 8 hours. Clearly, this almost 100X decrease was a factor. Three primary imaging performance metrics were measured on the Imacon 848. They are 1) Opto-Electronic Conversion Function (OECF), 2) noise and signal-to-noise ratio (SNR), and 3) modulation transfer function (MTF). All were measured according to protocols defined in ISO 14524, ISO 21550, and ISO 16067-1 respectively.

The OECF and SNR metrics can be generalized to any scan resolution mode. The MTF results are format dependent however because the effective sampling resolution is dictated by a reduction optics design. Fortunately, the 35mm size format provides the highest potential resolution along with being a popular format for existing microdensitometer requests. So, the 35mm mode was selected for MTF characterization.

2. OPTO-ELECTRONIC CONVERSION FUNCTION – OECF

Unlike microdensitometers which usually encode signals in one of two ways - linear with transmission or density - the finished file encoding for scanners like the Imacon 848 is a function of the various settings available in the software driver. Only the effect of the gamma settings was of interest for this characterization and is described here. The generic driver settings were as follows.

Highlight = *255*, Shadow= *0*, Gamma= *variable*, Sharpening = *disabled*, 16 bit capture

The OECF results for the labeled gamma settings are shown in Figure 1. Though captured in 16 bits, the ordinate is labeled in 8 bit equivalent counts for ease of interpretation. Those wishing for the 16 bit equivalent should multiply the ordinate values by 255. The curves of Fig. 1 apply to all color channels equivalently.

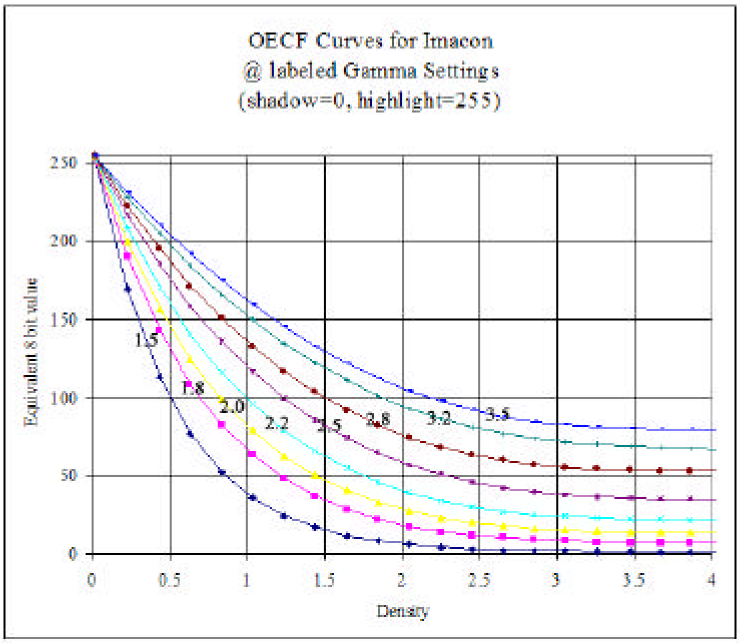


Figure 1 – Imacon OECF curves ; gamma 1.5 thru 3.5 ; color channel equivalence

The behaviors of the OECFs as a function of gamma are typical. Low gammas are characterized with high low-density slopes that quickly diminish at the high densities. This would suggest better signal detection for low density values using low gamma settings. Similarly, greater high-density slopes at high gamma settings might suggest their choice for tasks requiring high density signal detection. Qualitatively, note the increasing plateau behavior of the OECF at high gamma settings. While this would suggest a decrease in effective dynamic range, noise levels also need to be considered for such a measure . So, the OECF is a necessary but insufficient tool for evaluating a device's dynamic. The noise and SNR metrology for the Imacon 848 and PDS microdensitometer are covered in the next section.

3. NOISE AND SIGNAL-TO-NOISE RATIO (SNR)

The measured noise levels for the Imacon 848 and PDS densitometer are shown in Fig. 2. The PDS noise levels remain fairly constant at 0.003 rms density over its range of operation and is clearly superior to the Imacon at densities above 1.5. The Imacon 848 outperforms the PDS up to densities of 1.5 but quickly degrades beyond a 0.02 rms density at a mean density of 2.60.

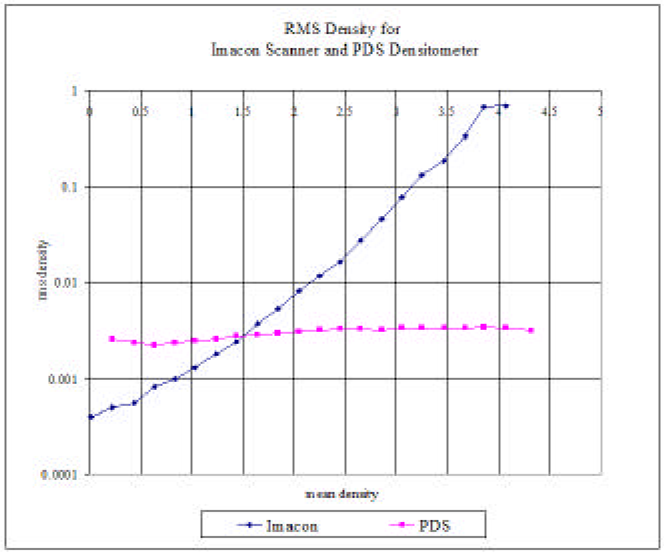


Figure 2 – RMS density for Imacon and PDS microdensitometer

Note that no distinction was made for the Imacon 848 density noise levels as a function of gamma setting. Though the rms noise *in counts* does change as a function of gamma, in terms of equivalent density it does not. This is supported further through the incremental SNR plots of Figure 3. The SNR and thus signal detection abilities of the Imacon 848 remain essentially unchanged for gamma settings between 1.5 and 3.5. This, of course, is the beauty of using incremental SNR as outlined in ISO 21550 and 21550. It is independent of gamma setting.

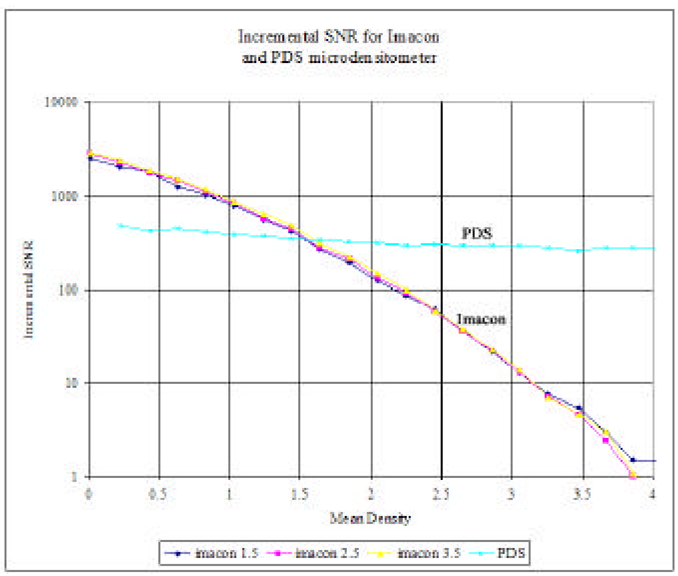
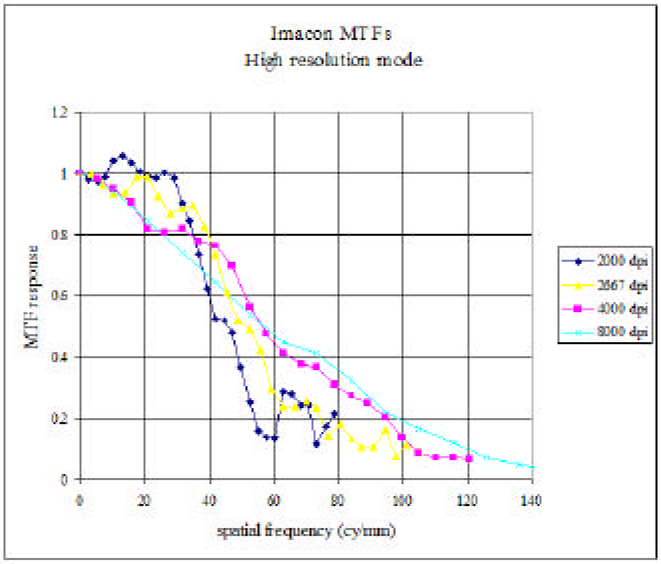


Figure 3 – Incremental* SNR for Imacon and PDS microdensitometer

* Incremental SNR uses the slope of the OECF as its signal metric and is used to measure a systems ability to distinguish incremental rather than absolute signals. For example, how well a density of "X" can be detected from "X + δX".

3. MODULATION TRANSFER FUNCTION - MTF

The single greatest reason for considering the Imacon as a microdensitometer surrogate had been the claim of true 8000 dpi performance over a 6 frame 35mm chop. This claim is reasonably well supported through the MTFs of Figures 4 and 5. The Imacon Colorflex driver allows resolution selection for native and non-native resolutions. Only the native resolutions were tested. Standard resolution MTFs are shown in Fig. 5 while high resolution mode MTFs are illustrated in Fig. 4. For a given sampling frequency, no directional or spectral MTF differences were found. Therefore, the illustrated responses are the same for all colors and scan directions.



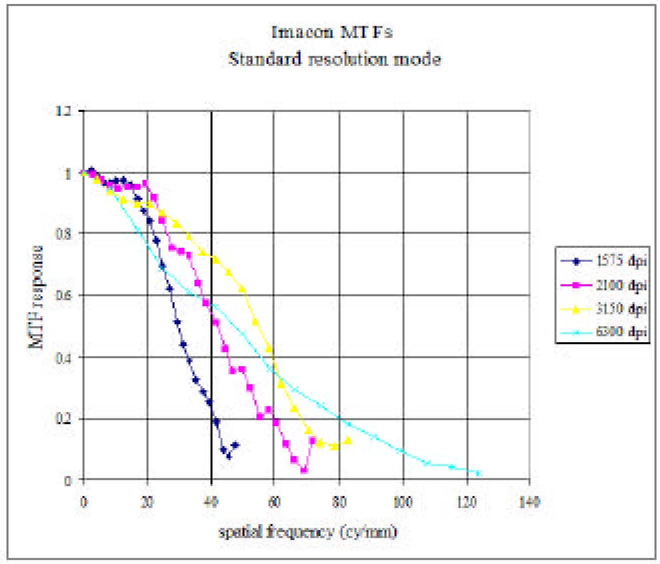


Figure 4 - High Resolution Imacon MTFs

Figure 5 - Standard Resolution Imacon MTFs

A number of the MTFs for each mode are not classically shaped optical MTFs. That is, not characterized by a monotonically decreasing shape. The unorthodox behaviors at 1575, 2100, and 3150 dpi (Fig. 5) and 2000, 2667, and 4000 dpi (Fig. 4) suggest that some form of forced processing is occurring. For these reasons, it was not recommended that these sampling resolutions be used when performing spatial metrology grade scans with the Imacon 848. Either the 6300 dpi (low res. mode) or 8000 dpi (high res. mode) samplings are more suitable. For comparison purposes, the measured MTFs of the microdensitometer using a 10µm, 6.7 µm and 5µm diameter circular aperture are plotted in Figure 6 along with the 6300 dpi and 8000 dpi Imacon 848 MTFs. This illustrates that a 10 µm circular microdensitometer aperture response best matches the Imacon 848 at 8000 dpi. The 6300 dpi match is slightly less congruous but probably still suitable for microdensitometer tasks using a 10-13 µm circular apertures. From theoretical considerations, circular aperture MTF responses are roughly equivalent to square aperture responses 20% smaller in size. (e.g. 10 µm circular aperture response is approximately equal to an 8 µm square aperture response).

The above two sampling frequencies are equivalently efficient in terms of bandwidth per pixel. This can be deduced by taking the ratio of each limiting resolution frequency[2] (10% MTF response) to the half-sampling frequency. The half sampling frequency for 6300 dpi is 124 cy/mm. For 8000 dpi it is 157 cy/mm. These are the maximum useful frequencies that these sampling rates can support as dictated by the Nyquist criterion. The ratio of their measured limiting resolution (maximum measured frequency), 100 cy/mm and 120 cy/mm respectively (see Fig. 6), to their half-sampling frequencies (maximum theoretical frequency) are roughly 80%. The equivalence and relatively high value of this ratio is a good indication that optics or image processing functions are not unduly limiting the spatial frequency potential of this scanner.

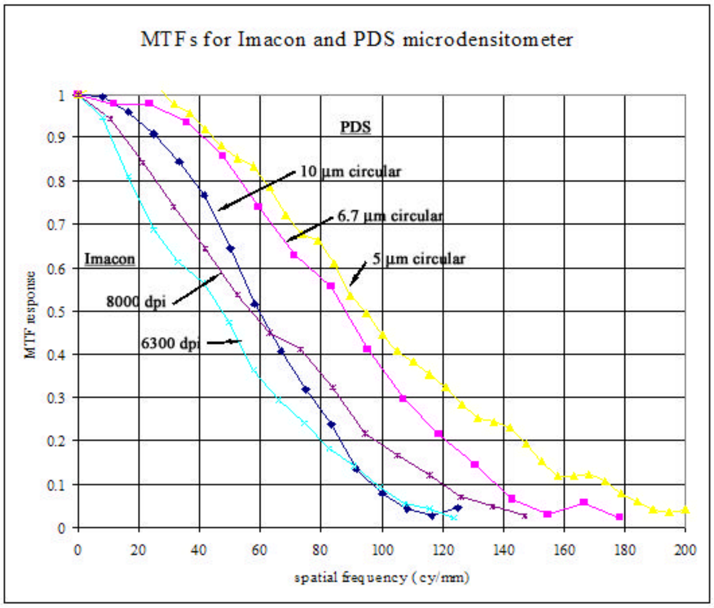


Figure 6 – MTF comparisons between Imacon and PDS microdensitometer

Similar thinking can be applied to any scanner where a continuum of sampling rates is allowed. Only the naïve among us would believe that increasing sampling rates would be followed by true unbounded spatial frequency response improvements. Take the example of the suite of MTFs for a flatbed scanner in Fig.7. Each MTF curve corresponds to a different sampling rate, as labeled, allowed by the scanner driver.

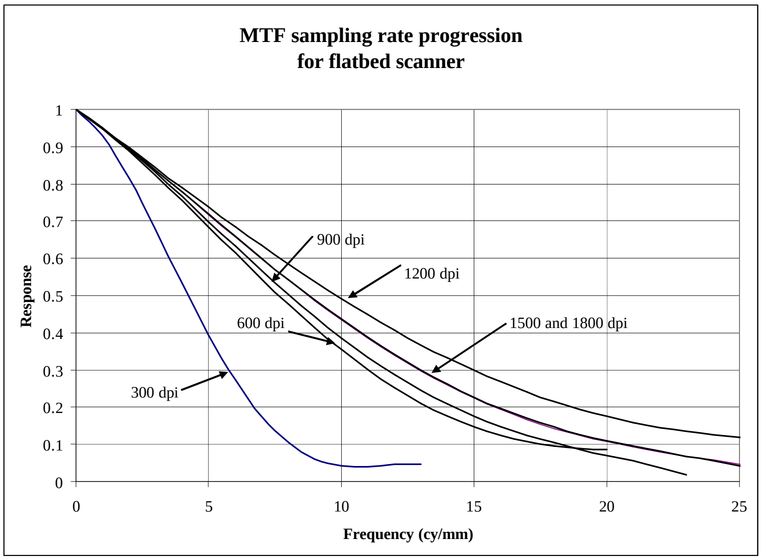


Figure 7 – MTF sampling rate progression for candidate flatbed scanner

Though the sampling rates of Fig. 7 are equally incremented by 300 dpi, the frequency response improvements across sampling rates are not proportional. For instance, there is a very large MTF improvement in the 300-600 dpi transition while there is barely any in the 600-900 dpi transition. Indeed, there is a decrease in MTF performance in the 1200-1500 dpi transition. A simple contour plot technique can be used to more easily evaluate these sampling rate MTF behaviors as illustrated in Fig. 8.

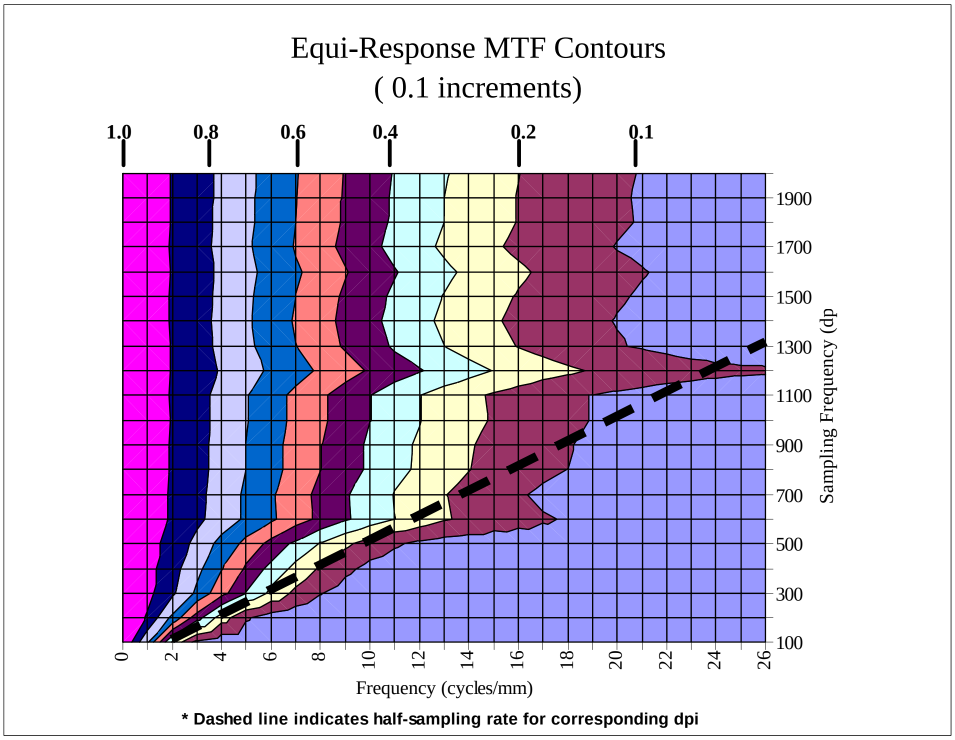


Figure 8 - MTF contour plots for flatbed scanner

Using the 10% MTF contour for demonstration, one can use Fig. 8 to easily track which dpi settings offer the most efficient bandwidth sampling. For instance, the relatively large rightward outcroppings at 600 and 1200 dpi suggest a possible native resolution detent of the scanner. Beyond 1200 dpi it is clear that the MTF performance dramatically decreases, even at the 1300 dpi level. This type graphic allows visualization of overall MTF performance for better sampling rate selection depending on the source object being measured.

4. SUMMARY

For most of today's hardcopy media types, array scanners can easily substitute for micro-densitometers. But OECF, MTF, and noise characterizations are required beforehand to accredit their absolute photometric performance. It is often said, the devil is in the details. Characterizing these details with the protocols outlined in ISO 14524, ISO 21550, and ISO 16067-1 can make the difference between the deal with the devil and the great deal. This paper has provided examples of how these protocols can be used to map and identify the micro signal detection capabilities of array scanners.

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