Projector Evaluation and Characterization

by Douglas Goodell – October 2012

The attached report is a preliminary and incomplete examination of digital projectors operations from the perspective of a photographer attempting to present projected images as close as possible to their appearance on a well calibrated graphics monitor from which they were prepared. I have tried to identify quantitative, reproducible, understandable, instructive, and recordable evaluation procedures and parameters to supplement the normal subjective comparisons.

I worked on this for eight months during which the analysis tools and procedures had to be expanded, reworked, and refined. The report as presented here only covers work on one projector. Others will follow but other commitments forced me to set the work aside. I am making this partial report available now only because of questions being asked about projectors – it might provide some insights about system behavior, set-up procedures, and general trends.

Work must still be done in the following areas:

1. More quantitative treatments of color rendering would be desirable. The present work is quantitative only for tonal behavior, but it is now possible to generate more specific color comparisons.

2. More work needs to be done in regard to the treatment of and exposure for camera captures of projection images from systems that differ greatly in luminosity from calibrated graphics monitors.

3. The results for other projectors and driving systems needs to be finished.

I have found this to be a very interesting topic and I have learned a great deal in its pursuit. I hope to get back to is soon. I welcome and comments and recommendations anyone might have.

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Introduction

Two separate events, early in 2012, led me into a rather detailed evaluation of digital projectors. The first was the need to upgrade my aging digital projector to better accommodate the less than optimal lighting conditions encountered in many of my presentation venues; in the process it was hoped to add several additional features. In pursuing this, I found that the image rendering of some current projector models was either not as satisfying or that their adjustments were more sensitive and critical than was characteristic of my older unit. The second event prompting this study was seeing one of my carefully structured images destroyed during a competition presentation through a projector thought (wrongly) to be properly adjusted.

To better understand the nature and subtleties of projector options, functions, and adjustments, I undertook a study of four different units, all Epson PowerLite models. The study began by making visual observations and judgments using a set of fifteen projected images: seven images included clinical type test charts and eight images were from my nature photography work of subjects having a wide range of tonal and color characteristics. The visual observations alone, however, did not provide enough understanding of some underlying behavior and the analysis was expanded (with three of the projectors) to include more detailed, less subjective, numeric analysis based on captures of the projected screen images.

General Conclusions

The study that followed demonstrated that some of the approaches used to adjust projectors for photographic image presentation, however well intentioned, can be quite misleading. The study also uncovered some surprisingly different characteristics between projector models, some of which require significant adjustment of images to assure their best rendering. The highlights are as follows:

1. Use of a grayscale step-wedge to adjust brightness and contrast based on achieving good discrimination of steps at both ends of the scale can be useful, but does not assure optimum image rendering, *and can be very misleading*. (a) In general, a step-wedge should be positioned in the center half of a test image – it should not extend the full width of the screen, as it can then be affected by vignetting. (b) If all steps cannot be well separated, it is generally best to have better step discrimination on the light side – don't blow the highs.

2. Absent more specialized tools, brightness and contrast adjustments are best made using a set of well known images having widely varying but well structured tonal and color characteristics. This might seem obvious but it is often not done in lieu of reliance on <u>seemingly</u> less subjective step-wedge judgements.

3. Incorporation of the projector's profile allows for a somewhat wider range of projector adjustment settings, but even with appropriate settings it is not evident that the resulting image rendering is better with incorporation of the projector profile.

4. For projectors having limited dynamic range, it can be advantageous to compress image tonal range in advance of projection. Tools such as PhotoShop's *Levels* or *Curves* adjustments can be used for this purpose.

5. Why is dynamic range, and hence image quality, not as good with the current high-end Epson units tested as was characteristic of older models? This is very disappointing.

6. Image resolution is adversely affected by internal projector resizing such as occurs with keystone corrections, and these should be avoided if possible.

(There may be additional conclusions or adjustments of these as the study progresses.)

Equipment and Procedures

Table 1 shows the major characteristics of the four different projectors that were examined. I had purchased the PowerLite 715C, an XGA format, in 2003 on a recommendation from George Lepp and Tim Grey, and the unit has preformed extremely well; I have especially appreciated its direct input capability allowing projection without use of an external computer. It has been out of production for many years and newer units have introduced additional features and have luminance levels better suited for use in poorly darkened viewing rooms.

Figure 1. Test set-up with two projectors, laptop computer, and camera..

Table 1. Projector Characteristics

Model No.	Intro Date	Lumens Hi / Low	Contrast Ratio	Native Pixel Size	Lens Type, mm	Keystone Correction	Comp. Req'd	USB Video	Wireless Connect
715C	2001	1200	400:1	1024x768	35,0-42.0	+/-15° V	N	N	N
81P	2004	2000/1500	400:1	1024x768	21.3-25.6	+/-15°V	Y	N	N
1775W	2009	3000/1500	2000:1	1280x800	13.5-16.2	+/-45°V, +/-30°H	N	Y	Y
1925W	2009	4000/2000	2000:1	1280x800	24.0-38.2	+/-45°V, +/-30°H	N	Y	Y

The PowerLite 81P was a selection and recommendation of a local camera club for digital image presentation. It has XGA resolution, good luminance, and has demonstrated good image quality, but does not allow for computer-free operation. It is no longer in production but can still be found in some markets – I purchased a new unit this year for a very low price.

The PowerLite 1775W and 1925W models are WXGA units which have a 16:10 aspect ratio rather than the XGA's 4:3. This provides for wider image presentations and can be especially good for panoramics. Except for being wider, the pixel resolution, 800x1280, is very close to that of XGA. Both models allow for computer-free presentations, but if a computer is used it can be connected wirelessly. The 1775W is an especially small, compact unit. However, being ultra small it has small LCD elements and I felt its 'screen-door' effect was too pronounced. Consequently I returned the unit without doing the more detailed numeric analyses.

Figure 1 shows the set up used in this study. A platform enabled two different projectors to be located in nearly the same positions relative to the viewing screen. The screen was a 70 inch wide white matte type which is very commonly use for presenting projected images. It was positioned approximately 10 feet from the projector, but the distance could be changed as required by the projector lens characteristics. The laptop computer used when necessary was a Sony a VAIO model VGN-SZ330. Calibration and profiling of the computer monitor and projectors was done with a DataColor Spyder 3 Elite system with software version 4.0.2. Photographs of images projected on the screen were taken with either a Canon 5D-MK-II or MK-III using a 24-70mm f/2.8, L class lens.

Input to projectors was from the laptop computer and (where possible) from the direct input, computer-free mode (CF or USB memory). All the projectors had several available color settings which were examined, but all critical analyses were done in the sRGB color mode. Adjustments were made with each projector's brightness and contrast controls covering about 90 percent of the full range of each. A matrix of seven brightness and five contrast settings were used giving a total of 35 settings for each unit and input tested.

To evaluate projectors responses to various adjustments and operating modes, a set of fifteen images was use. These included various composite test charts as well as photographic subjects from the author's work which addressed specific issues of shadow detail, highlight detail, saturation, and different color emphasis. The entire set of test images is shown in Appendix A. Different file sets were prepared to match the native resolutions of the XGA and WXGA projectors.

The principal test chart, shown in Figure 2, contained a grayscale step-wedge ranging in tonalities from 5 to 255 in 10 point intervals, a total of 26 steps. Other parts of this chart included focusing elements comprising both line and dot grids, a neutral gray patch, and numerous color bars and patches.

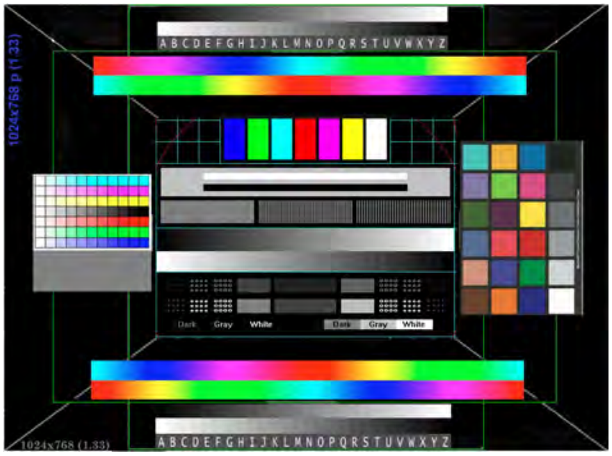


Figure 2. Base test chart with elements for focusing, gray-scale, and color evaluations.

Photographs taken of the projected screen image of this chart were examined in Adobe PhotoShop to determine the specific steps and tonal levels within the step-wedge which could be identified. Additionally, the step-wedge was profiled to study its characteristics over the entire tonal spectrum. Profiling was done using software developed by Wayne Rasband at the National Institutes of Health and is publicly available under the name *ImageJ.*

Since the screen photographs were the used to determine several types of data, their accurate representation of the projected screen images was extremely important. For this reason very careful consideration of exposure and post capture processing was required. This turned out to be a study in itself, and rather that cover all of its details here, they have been presented and discussed in Appendix B.

The following information and data was recorded:

1. A ranking of image quality, Good, Fair, Poor, based on visual examination of all 15 projected images.
2. Average tonal level of the neutral gray test patch.
3. Lowest black step discernible in the step-wedge.
4. Highest white step discernible in the step-wedge.
5. Total number of steps discernible in the step-wedge.
6. Tonal level of the lowest discernible black step.
7. Tonal level of the highest discernible white step.

A typical data set is shown in Table 2 which also includes frame numbers of photographs taken. Data was generated for brightness and contrast settings covering about 90 percent of each projector's full range of adjustment. Essentially, each of the items recorded describes a three-dimensional response surface which can be represented graphically as a series of contours plotted against the brightness and contrast variables.

Representing the data as contours accomplishes several things. Basically, contouring serves as a smoothing operation eliminating irregularities due to the limitations of single point of data collection and sometimes subjective determinations. Absent more computational power and skills, the contouring was done manually, recognizing that physical reality warrants a smooth dependent variable surface (with smooth variations in its first and second derivatives). Manual contouring is obviously not mathematically rigorous, but with the considerations noted, it is efficient, realistic, functional, and very instructive.

Table 2

PROJECTOR SET-UP EVALUATION -- EPSON POWERLITE 81P, 81P-profile (Set N7)

Bright/Contrast Set Points	Frame No.	Set No.	Black Step	White Step	No. of Steps	N.Gray Patch	Black Value	White Value	Visual Judgement
-30 / -30	107		115	255	15	22	7	132	P
-30 / -15	108		95	255	17	49	5	175	P
-30 / 0	109		75	255	19	71	9	224	P
-30 / +15	110		65	255	20	92	13	253	P
-30 / +30	111		55	245	20	112	14	255	P
-15 / -30	112	1338	65	255	20	59	5	260	P
-15 / -15	113	1353	55	255	21	82	9	210	P
-15 / 0	114	1368	25	255	22	102	13	252	F
-15 / +15	115	1383	15	245	22	119	14	254	G
-15 / +30	116	1398	15	225	21	134	18	255	F
-7 / -30	137	1413	45	255	22	78	7	178	F/P
-7 / -15	138	1328	35	255	23	98	11	232	G
-7 / 0	139	1443	25	255	24	115	13	252	G
-7 / +15	140	1458	15	235	23	132	13	253	G
-7 / +30	141	1473	15	205	20	149	16	253	P
0 / -30	117	1263	25	255	24	91	8	192	F
0 / -15	118	1278	15	255	25	111	12	248	G
0 / 0	119	1293	15	245	24	126	16	254	G
0 / +15	120	1308	5	225	23	143	16	255	P/F
0 / +30	121	1323	5	195	20	164	18	254	P
+7 / -30	132	1593	5	255	26	104	12	212	F/P
+7 / -15	133	1608	5	255	26	127	19	253	G
+7 / 0	134	1623	5	235	24	138	22	254	G/F
+7 / +15	135	1638	5	215	22	159	26	255	P
+7 / +30	136	1653	5	185	19	180	27	255	P
+15 / -30	122	1668	5	255	26	118	29	230	F
+15 / -15	123	1683	5	245	25	135	34	254	F/P
+15 / 0	124	1698	5	225	23	156	38	255	P
+15 / +15	125		5	195	20	177	41	255	P
+15 / +30	126		5	175	18	201	42	255	P
+30 / -30	127		5	255	26	144	64	253	P
+30 / -15	128		5	225	23	168	66	255	P
+30 / 0	129		5	195	20	188	69	255	P
+30 / +15	130		5	175	18	216	71	255	P
+30 / +30	131		5	145	15	239	73	254	P

Results and Discussion – Part One

The results will be treated in two parts. This first part considers just one projector/input combination. It will examine in detail each of the individual data elements and their role in understand the system behavior and facilitating conclusions and comparisons. The second part will consider other projectors and evaluations of different input sources and/or input color profiles. These were treated in the same manner as the example in the first part, but with the first example as background the others need not be discussed in such detail.

The first tests were done using the Epson PowerLite 81P projector with input from the laptop computer using a color profile developed from the projector itself. With this projector it became evident in early testing that there was sufficient vignetting to affect test results.

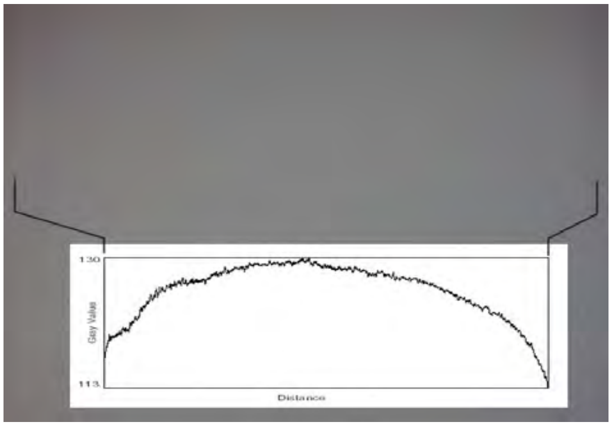


Figure 3. Projection of neutral gray image with profile of actual tone levels across screen center.

This is illustrated by the screen capture in Figure 3 (corrected only for camera lens distortions). Vignetting is obvious in the screen corners; it is not so obvious across the mid-section though it is clearly picked up by tonal measurements and numerical profiling. The magnitude of the effect is such that edge tone levels are shifted down by at least one step increment (10+ tone levels). This is unacceptable for characterization measurements because both the dark and light tones will be rendered too dark relatively to the mid-tones. In terms of projector set-up, adjustment based on a full screen step-wedge will result in central screen areas being too light, and highlights very likely blown out. Therefore, the step-wedge test patterns used in this work (and recommended for all projector evaluations) are positioned only in the center half of the test image (Figure 2). In this position there may still be a small amount of vignetting, but it should be only a few tone levels and within the error limits of the processed data.

The step-wedge data set given in Table 2 shows the measurements and frame numbers for all 35 brightness and contrast settings tested for the PowerLite 81P projector (with its unique color profile). Tone profiles and histograms can be extracted from the individual frames and several types of performance maps can be constructed from the tabulated date.

Figures 4 and 5 show, respectively, tone profile traces and histograms for some of images from this test set. The input form of the step-wedge is given at the top and exhibits uniform step transitions from a tonal value of 5 on the black side (left) to 255 on the white side (right). In contrast, the captured, projected images of this step-wedge varying degrees of non-uniformity, cover different ranges of tonality, have missing steps on one end or the other, and exhibit different slopes for the profile trend line. Each of these characteristics reflects the trends seen in the screen projections and in the data measured therefrom. They provide a form of visual perspective of the behavior and confirmation of the measured data trends. But they were not used quantitatively (though this might have been possible).

Instead, the data measured from the step-wedges was used to generate “performance maps” showing how the projector adjustments affect each parameter. This mapping aids in understanding the system behavior and facilitating comparisons between units. The specific parameters will first be presented individually and then combined to illustrate the overall conclusions.

Figure 5 presents the individual types of step-wedge characterizations in contour form, performance maps, in effect, developed from the data in Table 2. There was no inherent assumption that the discernable steps and their tonal levels be linear, but that often seemed to be the most reasonable contour structure.

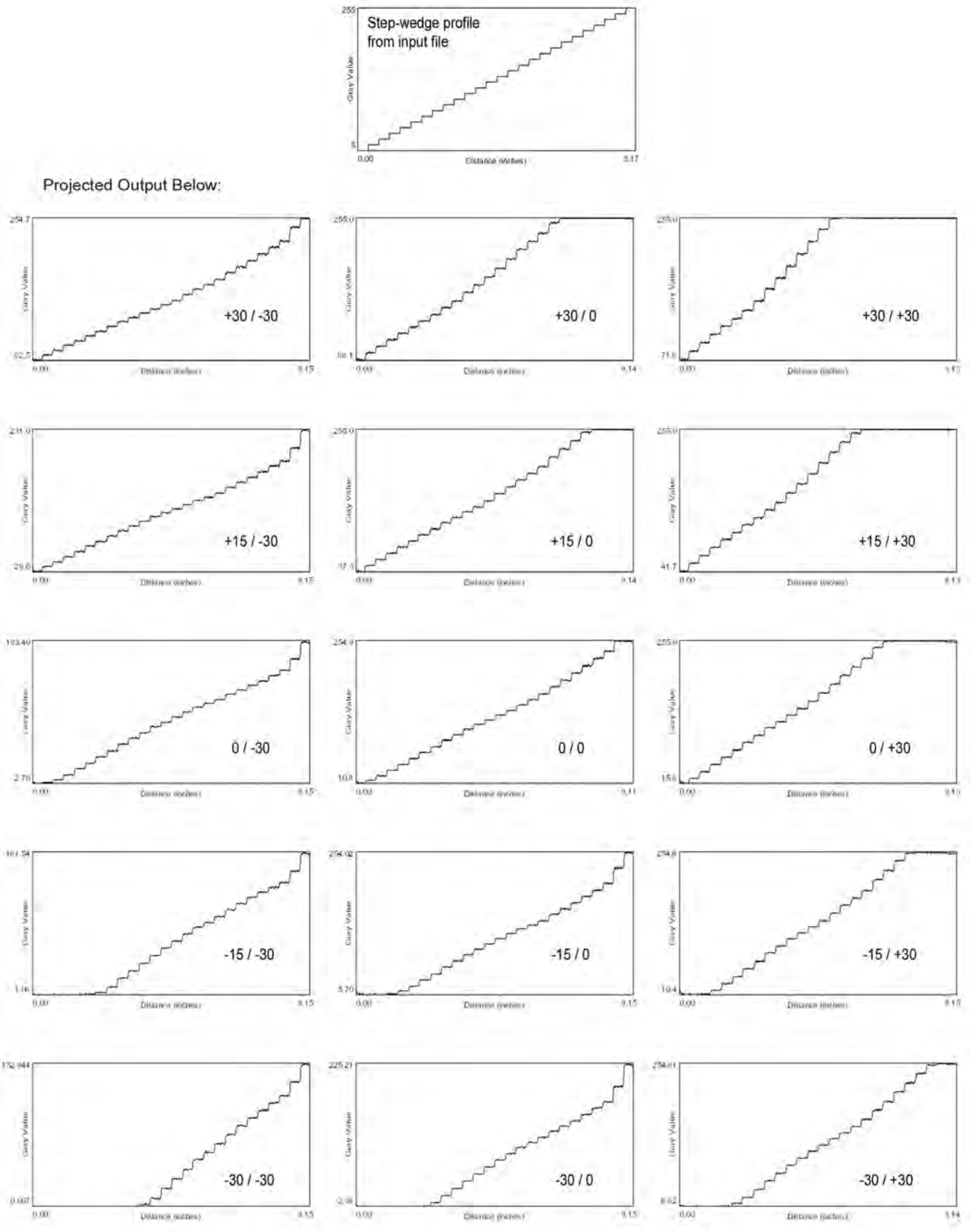


Figure 4. Grayscale step-wedge profiles from scanned photographs of the base test chart at selected brightness/contrast settings.

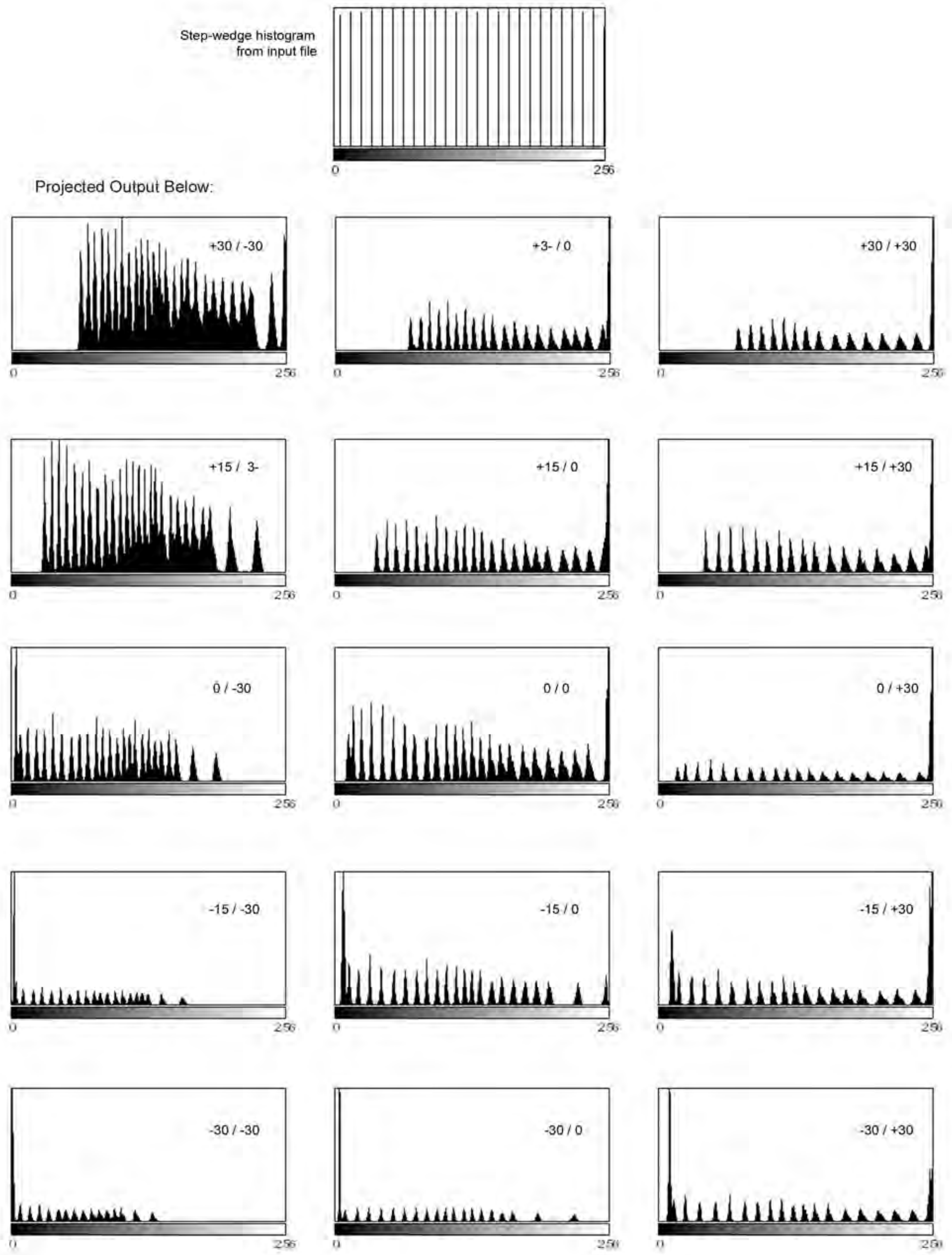
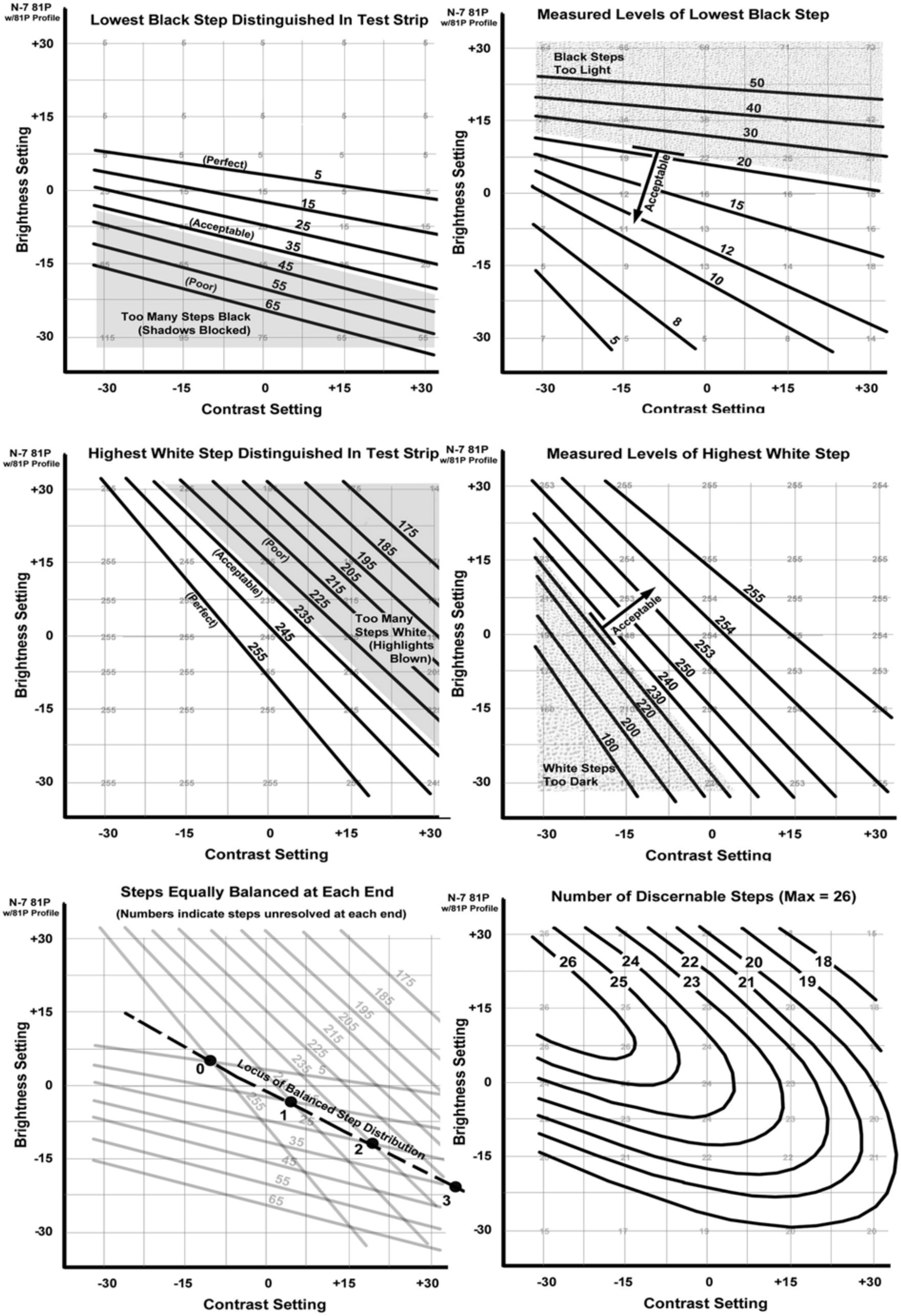


Figure 5. Grayscale step-wedge histograms from photographs of the base test chart at selected projector brightness and contrast settings.



Lowest Black Step Distinguished In Test Strip

Measured Levels of Lowest Black Step

Highest White Step Distinguished In Test Strip

Measured Levels of Highest White Step

Steps Equally Balanced at Each End

(Numbers indicate steps unresolved at each end)

Number of Discernable Steps (Max = 26)

Figure 6. Mappings of individual step data characteristics from the grayscale step-wedge.

The top four graphs (A through D) in Figure 5 show the lowest black and highest white steps discernable and their tonal levels. The gray area in each example indicates the range of brightness and contrast settings considered unacceptable for each feature. Figure 5E combines the discernable black and white steps to show where the loss of end-point definition is equal (i.e., balanced) at each end of the step-wedge. Equal balance of the discernable steps is sometimes used as a basis for projector set-up adjustments.

Figure 5F shows the actual number of steps discernable mapped over the full range of settings; this is a very informative depiction. The *nose* of the contours corresponds to the positions of “balanced” step rendering discussed above and shown in Figure 5E. Below the *nose*, on a given contour, the dark steps tend to lose separation and the white steps, while more discernable become darker in tonality: basically, the histogram is shifted to the dark side. In terms of image perception this tends to be a better situation than the reverse (i.e., being above the *nose*), because in that case the highlights become blown out and that is generally a more objectionable fault than is loss of shadow detail.

Figure 7 maps the effect of the brightness and contrast settings on the measured tonality of the neutral gray patch of the test chart. The correct tonal value for neutral gray is 128 and this an important consideration for proper image rendering. If tonal level of neutral gray is shifted, the whole tonal structure of the image will be different than intended. This can have more impact on the overall image presentation than does maintenance of details at the ends of the tonal scale.

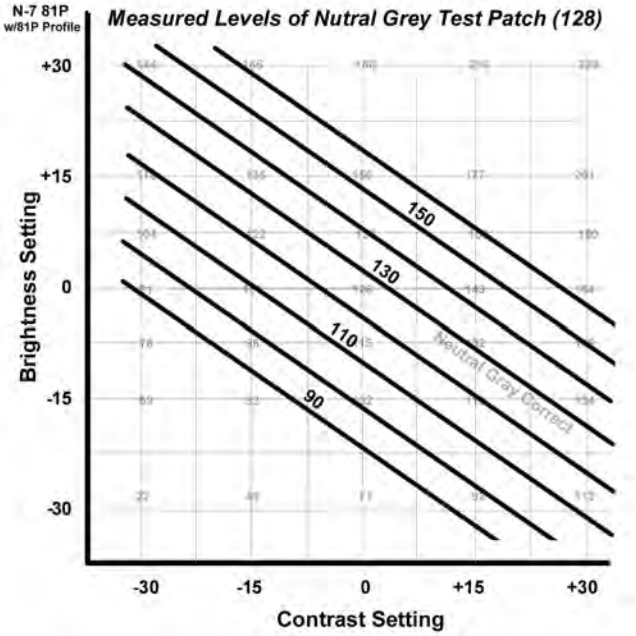


Figure 7. Projected tone level of neutral gray patch.

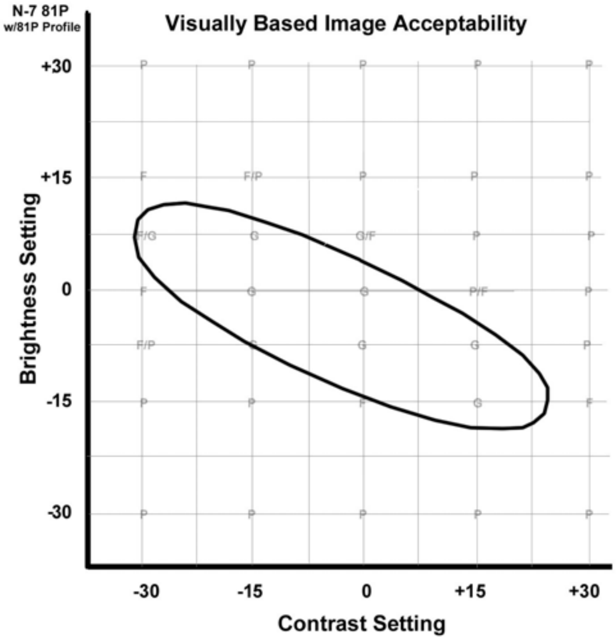


Figure 8. Visual assessment of full 15-image set.

Figure 8 maps the settings judged subjectively to provide the best renderings of the wide range of images. As noted in the introduction, and seen in Appendix A, these images included many different combinations of tonalities and colors. These results indicate that only a small range of brightness and contrast settings provided image rendering reasonably well corresponding to the characteristics of the original input file. This is not unexpected since projectors must be capable of presenting good image quality for a wide variety of lighting and distance requirements. The results mapped here are for just one specific configuration, a dark room and modest magnification. This is a typical configuration, well suited for comparisons of different projectors.

The important features of these various results can be viewed together and summarized in two composite illustrations. Figure 9 combines the step delineation and level date from Figures 5A-D showing that the areas of unacceptable response (gray areas) define a central region of settings (the remaining white area, essentially a polygon) having good response characteristics. Superimposed on this is the region from Figure 6B defining acceptable image rendering as judged by subjective visual inspection. The regions of good image rendering from both sets of results agree quite well.

Figure 10 further highlights the acceptable image rendering ranges shows additional details regarding the step and neutral gray behavior. The steps distinguishable in the step-wedge (contours from Figure 5F) are seen to vary significantly within the acceptable image range: from 26 steps which is perfect to as few as only 22. Also, the numerically correct rendering of neutral gray is near the top of the acceptable range, suggesting an edge for slightly darker mid-tones (possibly due to slightly richer color saturation). For this system a good projector setting combination would appear to be just to the left of the null point.

These results imply that the best and most balanced step rendering does not necessarily assure the most accurate or pleasing image rendering. Losing some step delineation, especially on the dark side is more tolerable than losing delineation on the bright side. Basically, this amounts to – don't blow the highlights. And while that should not be a surprise, it can happen if too much attention is directed to the step-wedge when setting up the projector.

Finally, note that this example represents a system (the 81P projector used with its specific color profile) having very good adjustability over a relatively wide range of brightness/contrast settings. It will be seen in the next section that not all systems are as generous and flexible.

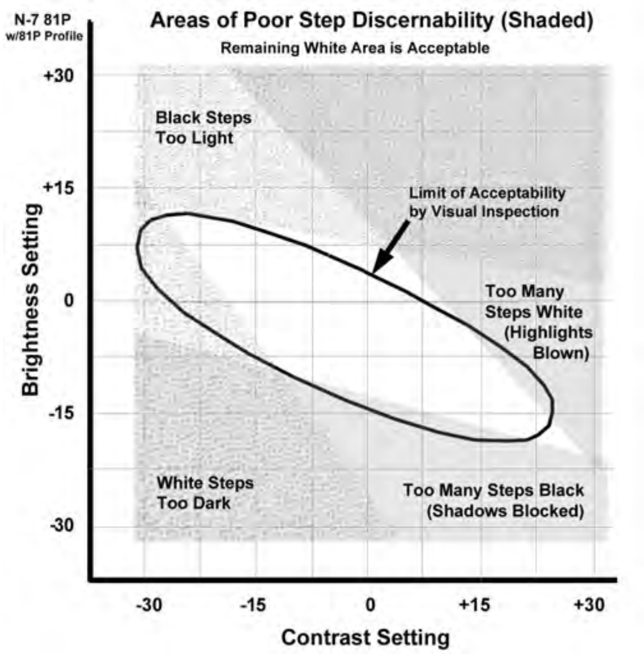


Figure 9. Composite of step-mapped areas and visual assessment of acceptable image rendering.

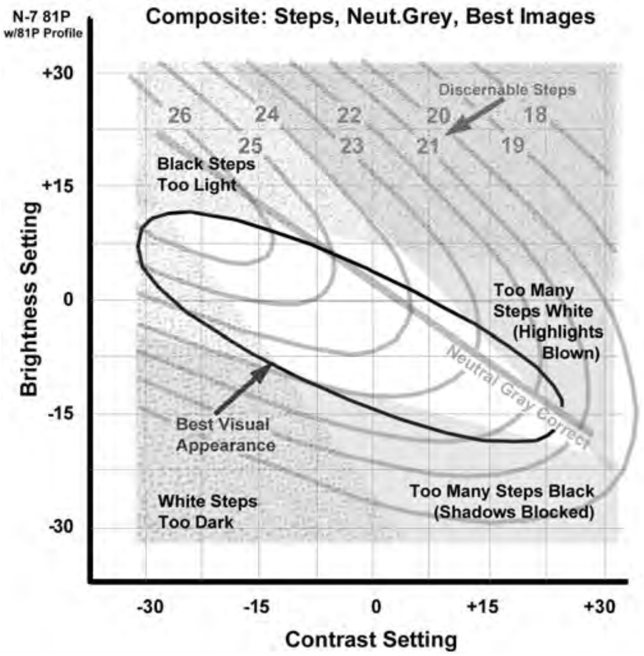


Figure 10. Composite of good image rendering, number of discernable steps, and neutral gray.

Results and Discussion – Part Two

This will compare different projectors and driving systems.

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APPENDIX A – TEST IMAGES

To evaluate projectors responses to various adjustments and operating modes, a set of fifteen images was use. These included various composite test charts as well as photographic subjects from the author's work which addressed specific issues of shadow detail, highlight detail, saturation, and different color emphasis. The entire set of test images is shown in Figure A-1. Different file sets were prepared to match the native resolutions of the XGA and WXGA projectors.

The principal or base image used to establish brightness and contrast settings includes several grayscale step-wedges, a neutral gray patch, focusing elements of both one and two dimensional character, and several types of color patches including a Gretag-MacBeth chart. This is a good all purpose image that can be very effective in establishing projector setting once one is familiar with what its appearance should be.

Image 003 is full neutral gray panels that can be used for exposure determination (first round) and to examine illumination uniformity. Image 004 (not shown) is the same but with an open (white) area in which a neutral gray card can be located to compare with the gray level of the projected gray.

Image 005 is a test chart developed by Andrew Rodney (www.digitaldog.net) for monitor calibration evaluations. It includes gray and color step-wedges, continuous color variations, the Gretag-MacBeth color blocks, and images having flesh tones, and wide ranging tonal variations. Its many elements make it extremely useful.

Image 006 is somewhat like the Rodney chart. It comes from the Monaco EZColor (www.xrite.com) printer profiling system and is especially helpful for its range of different flesh tones and vivid image colors.

Also in the category of composite charts are images 016 and 017 which are from DisplayMate Technologies (www.displaymate.com). They are full range color step-wedges and fine separation gray step-wedges for the light and dark ends of the tonal range.

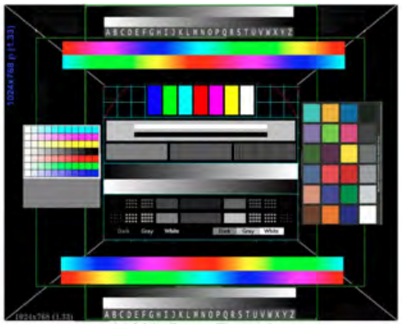
All other images are from the authors work. Images 007 and 008 are for evaluation of dark-side rendering. While both have rich blacks, the Umbrella bird has rather high contrast details and the Toucan has more soft, subtle details. A properly set-up projector will show both types of features well, but if that is not possible, some detail may be sacrificedd so long as the black retains its dark rich character.

At the other end of the tonality range, image 009 of the cicada, is highly dependent on proper rendering of highlights – that's what this image is all about. The tonal range of the cicada is very high but there should be good detail throughout. Projector settings fusing the high-end steps will blow out much of the important detail and destroy the image; settings too dark will have no sparkle. This is a very good indicator of highlight rendering.

Images 010, 011, and 012 are concerned with mid-level tonalities, contrast, and color saturation. Projector settings that are too dark or too high in contrast may increase apparent color richness but sacrifice detail and balance. Settings too light and/or low in contrast will show detail but appear washed-out. Image 014, the sunset is similar, but with more emphasis in the lower tonal range.

Images 014 and 015 emphasize simultaneous criticalities in both the extreme high and low tonal ranges. Compromises, if necessary are better made of the dark than on the light side. The waterfall is especially difficult because there is great detail at the very extremes, which can be a real challenge to maintain without losing the richness of the foliage.

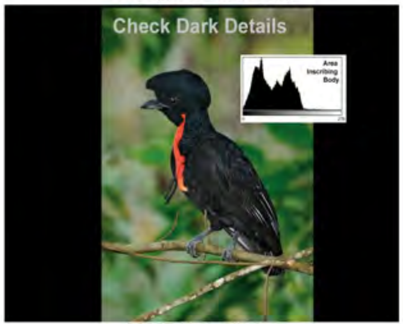
When considered together this set of images provide an excellent basis from which to make projector adjustments. The composite, clinical charts are extremely useful and with familiarity can be used on their own. But their use in combination with “real” images of known character is even better for assuring good reproducibility of images of all types.


00001_Base-Test-1.jpg


00003_Neut-Gray-1.jpg

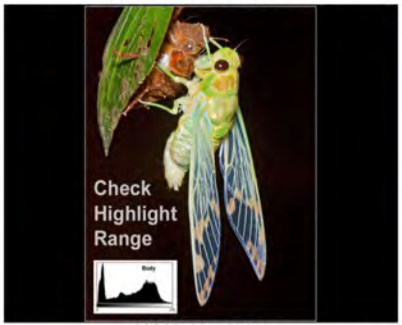
00005-Rodney_Chart.jpg


00006-Tweek_Chart.jpg

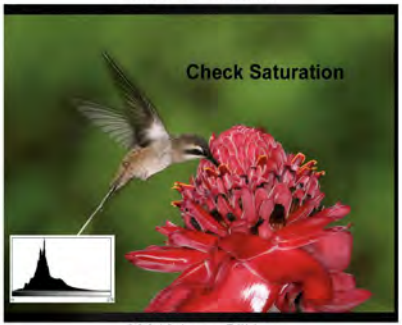


00007-Umbrella.jpg

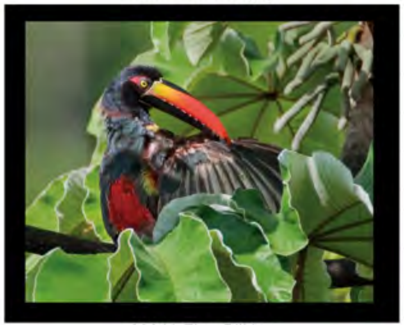
00008-Toucan.jpg



00009-Cicada.jpg



00010-Long-Bill.jpg

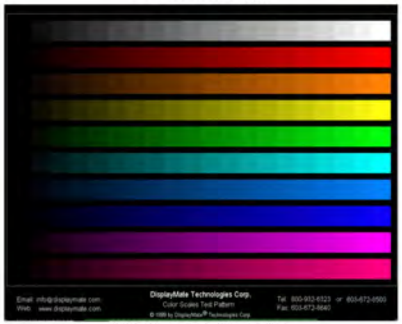

00011-Fire_Bill.jpg


00012-Julia.jpg

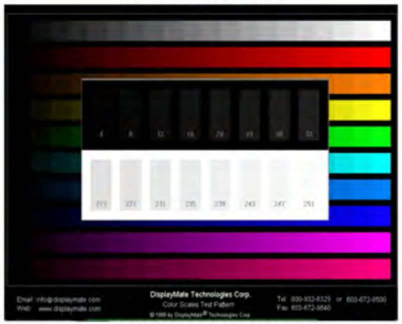

00013-Sunset.jpg


00014-Tortuguaro.jpg


00015-Waterfall.jpg



00016-Color_Steps.jpg



00017-End Bands.jpg

Figure A-1. Examples of the test images used in the projector evaluations.

One approach to obtaining quantitative information for analysis of projected images is to photograph the projected screen. One can then use image analysis software to study the captured images independently of the screen and projection system. Photoshop can be used for some types of image analysis, and it may be supplemented with other tools. For example, the analysis software *J-Image* by Wayne Rasband is especially useful for studying step-wedge profiles and histograms. It is available at no cost from the National Institutes of Health.

For such analyses to be meaningful, the photographed image captures must accurately represent the projected screen images. That seemingly obvious statement, however, is not so easily realized and requires careful preparation and treatment. The issues center around (1) exposure, (2) dynamic range of the camera relative to that of the projector, and (3) the processing of the capture in an appropriate *raw* converter[1]. Typical raw converter adjustments include lens corrections, especially in regard to vignetting, and tone curve corrections, especially with respect to contrast and brightness. Lastly, (4) there is an issue of sharpness (pixel smoothing).

Exposure. It was originally thought that, similarly to normal metering practice, one might determine a camera exposure from an image of a neutral gray tone projected at some reasonable combination of projector settings – either the midpoint or null settings or some combination judge visually to yield good rendering of a step wedge or some other test image. Unfortunately, testing quickly revealed that this approach gave very poor results; the ends of the tonal spectrum were always too dark. The reason, which eventually became clear, is that the metered luminance is a function not only of the tone level, but also of the gamma correction applied by the projector at that tone level.

A somewhat better metering approach, also derived from common practice, would be to select a midpoint exposure between spot metered values at the extreme high and low end of the tonal range, however depending on a cameras metering range this can be rather tricky.

The complicating effect of gamma correction on exposure determination is illustrated in Figure B-1. For simplicity, this figure is based on images from a computer graphics monitor which like a projector, includes a gamma correction. Here the *source* data are measurements from the image used as the source for display (or projection). The *captured* data are analyses of the photographed screen image. In each case, the luminosity (exposure) measurements (with the gamma correction) exhibit a quite different pattern from the measured tone levels. These results show that direct metering from a projected neutral gray image yields an exposure about 1.5 stops too high which is why direct metering is inappropriate, and this is consistent with results found by high/low spot metering. These results also show that the captured (photographed) image, with appropriate processing (to be discussed), can quite accurately represent the source data.

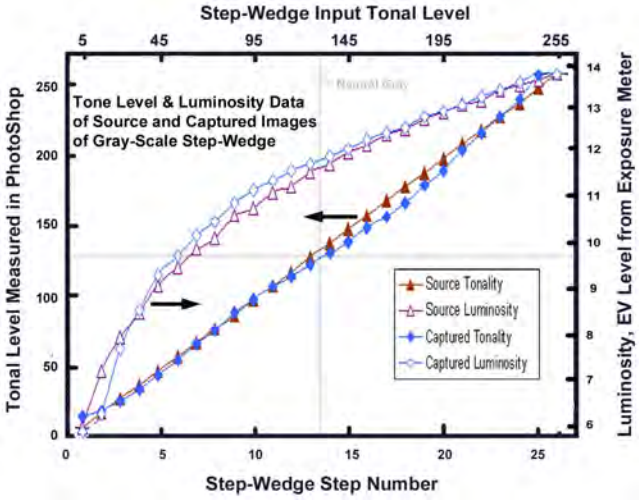


Figure B-1 Tone and luminosity measurements from source and photographed step-wedge strip.

The camera and exposure used to capture the screen image analyzed for Figure B-1 facilitated coverage of

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[1] Even casual inspection of captured images will show that a standard JPEG rendering does not well represent the projected image. The results here will show why.

the entire range of displayed tone levels. Determination of the appropriate exposure was aided by analyses of some preliminary test captures. Several different exposures were made at projector settings giving the darkest images, the lightest images, and some mid-range images. The tonal values were then analyzed in Photoshop and an exposure selected which best included the extremes in the most balanced manner possible[2]. That is, the highest and lowest tones of the projected step-wedge were either within, just match, or were equally outside the high and low ends of the camera's dynamic range (discussed in the next section). Or, from a different perspective, the midpoints of the tonal ranges of the camera and the projector should be alined.

This approach is referred to as the *full range coverage* technique. It requires a bit more work than direct metering, but assures that all tonalities from all images captured from all projector settings will be contained as best as possible within the cameras range.

Dynamic Range. In order to analyze quantitatively the full range of projector adjustments through photographic captures it is necessary that the camera have a range of luminance sensitivity at least as great as that of the projector. If it does not, either or both highlights or shadows may be compromised by the camera sensor and the data will not accurately reflect the projector performance. Some such compromise may be tolerable at extreme settings if there is adequate mid-range sensitivity, but it may handicap the analysis.

On the other hand, if the camera sensor has a greater dynamic range than that of the projector, the entire range of projected tonal values can be well captured by the camera. Moreover, if the camera sensor has a greater range than the projector, the exposure becomes less critical because having captured all the relevant information the exposure can be shifted in the raw converter if necessary to get a good balance between the dark and light sides (see next section).

A corollary, however, is that if the dynamic range of the camera is greater than that of the projector, the captured tonal range must later be mapped to the source range for the values to be most easily understood and meaningful. This is easily accomplished using the Photoshop levels adjustment. With this a fixed expansion can be applied to all captures before any analysis.

An example of dynamic range differences was encountered during this work. The projection captures were started using a Canon 5D-MK-II camera. The sensor in this camera was found to have just enough sensitivity to cover the full range of projected luminosities (7.0 EV or 7 stops) of the Epson 81P projector. With this, the resulting captured tonalities mapped directly to the source levels. Part way through the study, the Canon 5D-MK-III became available and it has a sensitivity just over 8 EV. This difference in range of capture is illustrated in Figure B-2 with histograms of the captured step-wedge made from each camera with Epson 81P projector settings of brightness at 0 and contrast at 0, the mid point settings. It was decided to finalize the study using the MK-III because it would assure minimal impact of the camera in recording the projected images. With it a tonal range of capture from 25 to 235 was mapped to values of 5 to 255.

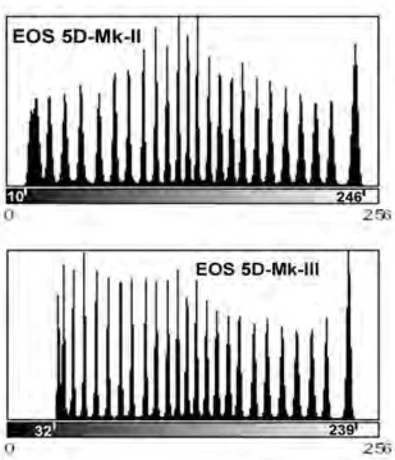

Figure B-2. Histograms of gray-scale step-wedge photographed with different cameras.

Raw Image Processing. It was noted earlier that captured images in default JPEG rendering do not well represent the projected image. The captures must be processed in a raw converter to introduce the adjustments required to match them to the projected image. Various adjustments were developed using the Adobe Camera Raw converter, ACR, version 6.7 ; there is a newer

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[2] Some tweaking of exposure may be possible during raw processing to help achieve this balance (see next section).

version; its used will have to be examined at a later time, but the principles should be the same.

The three considerations in the RAW processing are (1) exposure, (2) lens corrections, (3) and tone curve adjustments. Exposure has already been mentioned. It simply involves any small shifts in the exposure setting necessary to satisfy the *full range recovery* criteria outlined previously so that all of the projector setting combinations yield images for analysis that are uniformly balanced within the entire tonal range. Lens corrections deal with distortions and vignetting caused by the lens. Only the latter is of real concern in a study like this, and the action required is simply to activate the profile for the lens used. Many are built into raw converters. If the converter does not have a profile for a particular lens, it may have to be adjusted manually. Figure B-3 shows the tonal correction for vignetting with a Canon 24-70mm, f/2.8 L lens on the 5D-MK-III body. To avoid including projector vignetting effects this example is derived from a high-quality graphics monitor tested to be uniform across its mid-section. Applying the lens profile reduced the tonal distortion from 22 to 5 points. It must be emphasized that this reflects a vignetting correction due only to the lens and not to the projector. The latter can be much more severe as will be shown in connection with individual projectors.

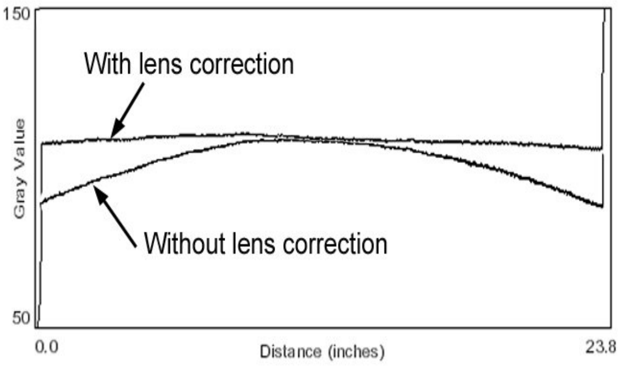


Figure B-3. Profiles of solid gray tone in 5D-MK-III captures from monitor showing the effect of correcting for lens vignetting.

Tone curve adjustments in raw processing are by far the most significant considerations and there are several ways of approaching them. Tone curve adjustments were examined using images captured from a high-quality graphics monitor so as to isolate effects do strictly to the camera capture from those of effects related to a projector. Basically one can either (1) start with the raw processor's default settings and adjust various sliders, e.g., contrast and brightness, or (2) leave all default settings and use the ACR *Tone Curve* tool to develop an adjustment curve specific to this situation. In each case the objective is to have the capture output match the source input. Both methods were found to be successful but the first was judged to be better controlled where as the tone curve development was extremely sensitive to very minor adjustments. It was found that just two parameters in the ACR *Basic* tool set needed critical adjustment. The first was the contrast adjustment which required a setting to its minimum value, -50, from a default of +25. The second was the brightness adjustment which required a setting of 0 rather than its default value of +50.

Figure B-4 shows a comparison between tone level mapping based on the above mentioned ACR adjustments and the default ACR settings. The default settings yield an S-shape curve having a steep slope in the mid range and high values on the bright side. This implies images that have overly bright highlights and high mid-tone contrast; this is why standard JPEG renderings do not match the visual characteristics of the input. The ACR adjustments yield a near linear mapping between input and output tonalities which is the desired outcome.

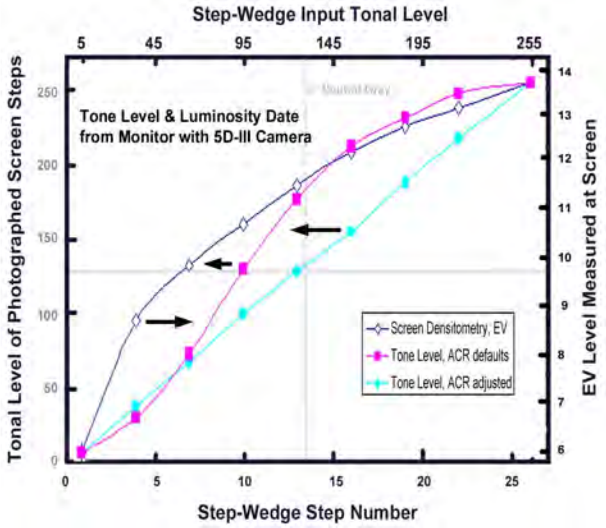
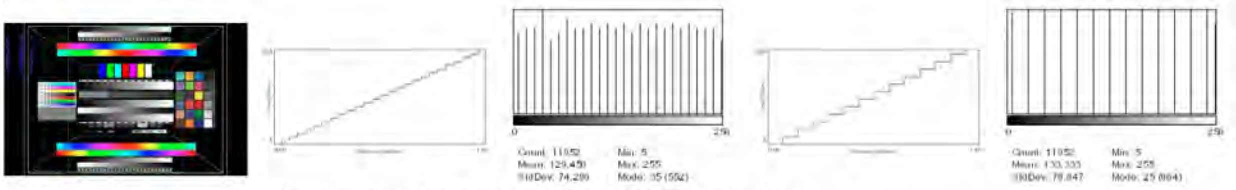
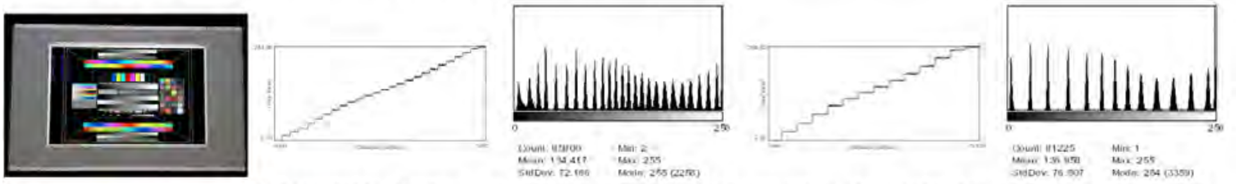


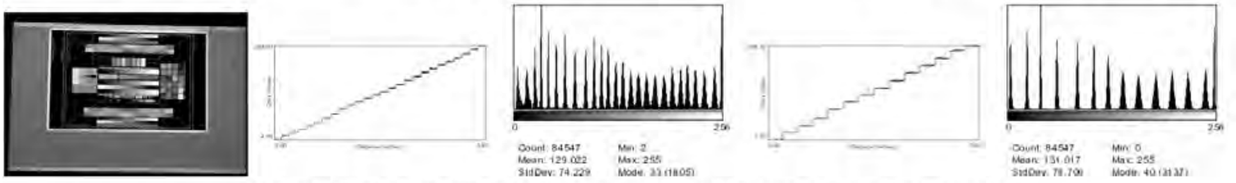
Figure B-4. Effect of raw processing differences on tone levels. Luminosity is also shown.



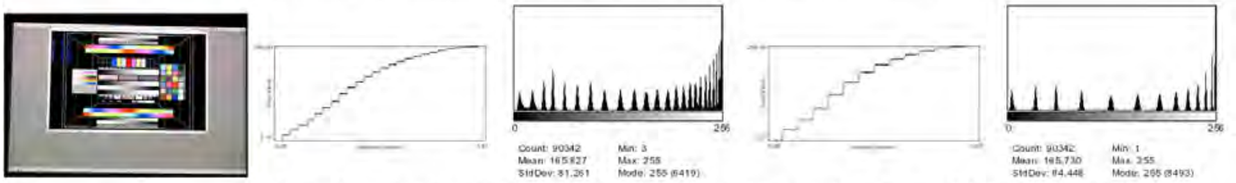
1. Source image (input) from which photograph was taken.



2. Acceptable: Capture processed in ACR with lens correction plus contrast = -50 and brightness = 0



3. Best: Capture processed in ACR as above with additional curves adjustment.



4. Poor: Capture processed with ACR lens correction and basic defaults of C = +25 and B = +50

Figure B-5. Examples with 26 and 9 point step-wedges illustrating effects of different raw processing treatments.

Essentially the adjustments are counteracting the gamma correction imposed by the monitor (or projector) which is reflected in the luminosity data measured directly off the monitor.

The two ACR adjustments cited above provide a simple and direct means of achieving an acceptable (not perfect) result. Many others were evaluated, three of which are shown in Figure B-5 with images and analysis plots made from both 26 and 9 step test wedges. Examination of such step-wedge profiles and histograms can be extremely instructive in understanding the processing behavior and as indicators of how well the processed image matches the source image.

That the processed image reasonably well matches the source image can be seen in Figure B-6 where all the major image elements in the processed capture (right) are seen to be essentially the same as those in the source image (left).

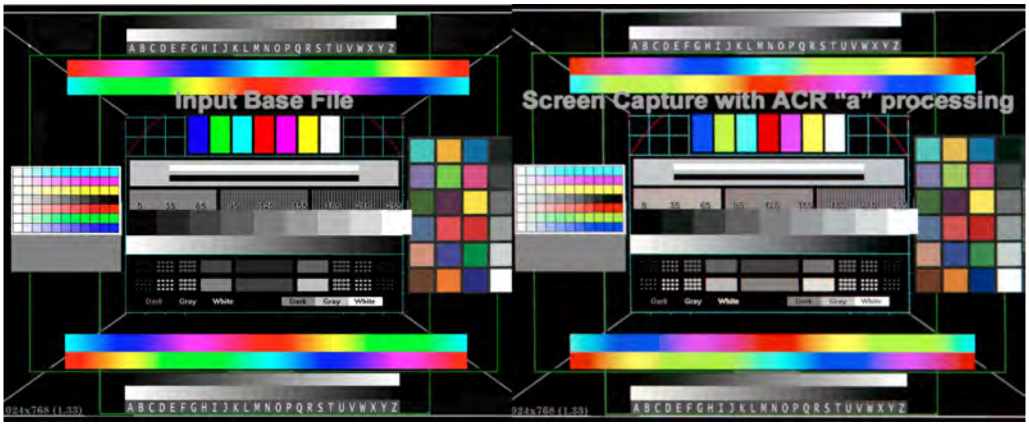


Figure B-6. Source and raw-processed capture of test image showing all major elements to be well matched.

Pixel Frame Smoothing. One final consideration for the use of photographic images for quantitative analysis is the issue of image sharpness. Sharp images captured from a screen projection (or monitor) will contain outlines of the pixel structure of the imaging element. This is sometimes referred to as the screen door effect. For visual evaluation of images this effect is of little consequence. However, with the use of image processing software for analyses, this effect can greatly compromise the results and their ability to be used for instructive, critical analysis. This problem is easily dealt with by softening the image prior to analysis. This can be done by de-focusing the projector, de-focusing the camera, or blurring the captured image in Photoshop. The latter is recommended because it is the most reproducible.

The figure below shows profiles and histograms from a grayscale step-wedge as captured in sharp focus by the camera and the same image softened using a 2.0 pixel Gaussian blur in Photoshop. It is clearly easier to see the details and trends of the image by reducing the effect of the pixel framing. To take advantage of the usefulness of such analytical tools is therefore recommended that a small amount of blurring is incorporated in the workflow prior to analysis.

Sensitivity to Error.

The use of photographic captures of screen projections to analyze projector behavior would not be complete without comment about their sensitivity to processing error and exposure 'accuracy.' As noted earlier, significant adjustment of the captured images is required in raw processing. But the raw processing adjustments for a specific camera and lens combination may be readily established and verified using test image captures from a properly calibrated graphics monitor. Basically, adjustments should yield step-wedge profiles and histograms which are linear and uniform. If this is achieved on a calibrated monitor, they should be applicable to captures from any other device (e.g., a projector) even if results from that device are not linear and uniform.

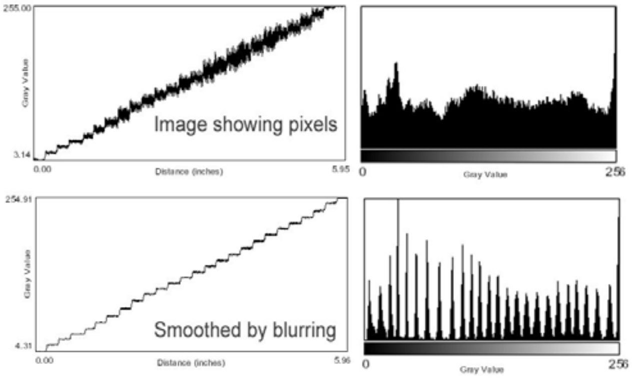


Figure B-7. Profiles and histograms showing the effect of smoothing the pixel frames in sharply captured images.

Unfortunately there is not such a well defined test for the capture exposure of projected screen images. The recommended criteria is that the exposure selected fully encompass the extremes of projector adjustments in the most balanced manner possible. That may seem a bit tricky, but if close, it appears that small variations of exposure do not greatly affect the assessment of acceptable projector adjustment settings. This can be seen in Figure B-8 which shows the effects of one third stop exposure variations on the mapping of acceptable setting limits and the neutral gray test level. These settings maps were outlined in the discussion of projector characterization.

The left figure (of B-8) indicates that the number of discernable steps (dark and light) is essentially the same for each of the exposure variations – this is represented by the limit lines on the right and lower sides of the acceptance polygons. The tone levels of the darkest and lightest discernable steps (left and upper sides) are more significantly affected, but there remains a large area of acceptable step tones regardless of the exposure. Therefore the capture exposure is not so sensitive as to marginalize the treatment. There is a more significant effect of exposure of the tone level captured for the neutral gray test patch representing the image mid-tones (right figure); the range is from 116 to 140 for the input value of 128. However, the settings giving these values are near the outer limits of the acceptance polygons established on the left figure and therefore such settings are not likely to be used. In effect, the step acceptance data helps to minimize any mid-tone error. Taken together the different combinations of data appear to minimize errors due to capture exposure, or highlight them so they may be corrected.

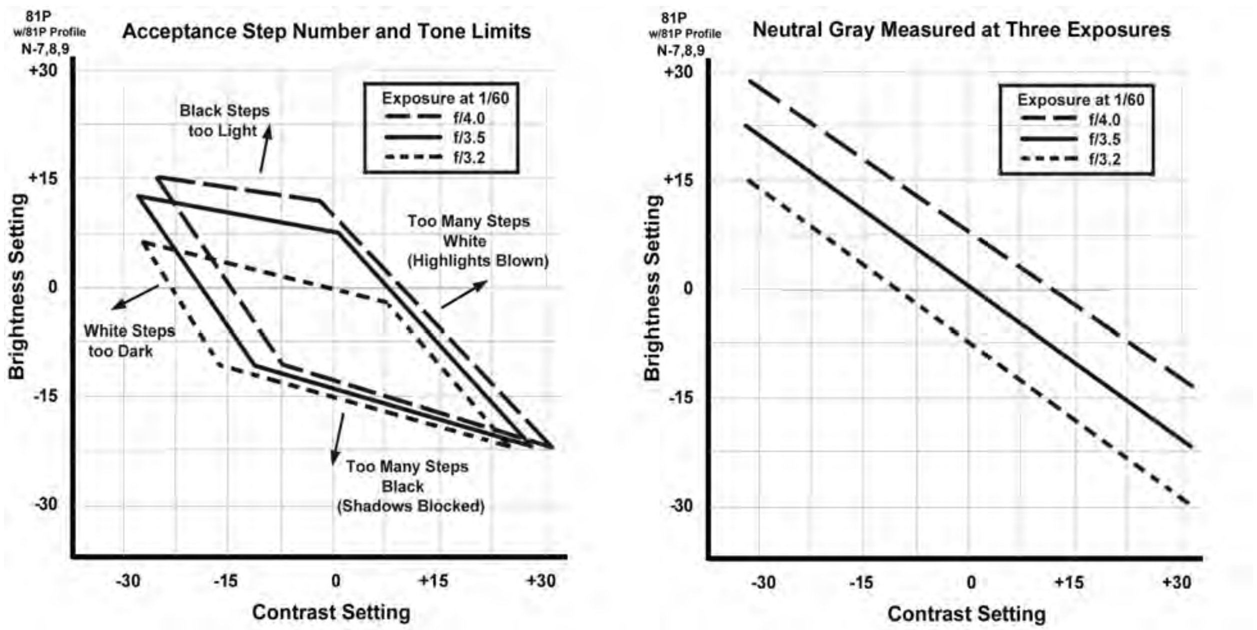


Figure B-8. Maps of projector adjustments for brightness and contrast show the effect of camera exposure on the values measured in captured images of neutral gray and of an image acceptability range as suggested by step-wedge data for number and tone level of discernable steps.

Summary.

Photographing screen images (projector or monitor) can provide a very powerful and instructive tool for comparisons and analyses of different systems. Test images for this may include many different types of elements for checking color and tonal rendering. Among them, the grayscale step wedge is very popular and is especially useful for detailed quantitative analysis. To use it effectively for that purpose requires establishing an exposure that well represents a particular set up and any of its variations that are to be considered. It also requires that the capture device has a dynamic range at least as great as that of the system being evaluated. If either the exposure or dynamic range of the capture on less than optimum, the capture may distort the subject and compromise analyses.

Most critical however is the processing of captured raw images so that the image studied best represents the original subject. One issue is that of vignetting by the camera lens, which in many cases can be easily corrected in many raw converters. Second, in the case of imaging by projectors (and monitors), the hardware gamma correction introduces significant problems within the captured image and these must be dealt with by processing in a raw converter. To make the capture match the source, appropriate raw adjustments can be worked out by trial and error. This process can be greatly aided by consideration of step-wedge profiles and histograms made from images that have been smoothed to eliminate pixel framing artifacts. The examples shown here illustrate that with relatively simple raw converter adjustments a processed image capture can very closely approximate the original source image in all important details. Captures prepared in this manner can then provide the basis for evaluating performance of a projector over a wide range of its adjustments.

APPENDIX C – DATA SPREADSHEETS

I have deleted these to save file space for this presentation.