Digital Darkroom Lighting - Critical Element of Color Management

Introduction

Whether you work in a dedicated, state-of-the-art, professional digital darkroom or just in a corner of your office or bedroom, you need to carefully apply color management to get accurate, predictable and repeatable results.

The type of lighting in the digital darkroom is a critical element of color management and it is often ignored or misunderstood. The lighting can cause a serious color and/or brightness mismatch between what you see on your monitor and what you see in print, the so-called monitor-to-print mismatch. Let's take a look at the major causes.

1. Color temperature difference between the monitor and lighting

Without taking special precautions, the color temperature of the monitor and that of the lighting in your digital darkroom will more than likely be different. This difference in color temperatures will cause problems and the bigger the difference, the bigger the problems. The colors of an image on the monitor will look different from the colors of a print of the same image viewed in the digital darkroom lighting, whether or not you printed the image yourself or had someone else do it for you. Under typical mismatch conditions, as I will explain shortly, the image on the monitor will more than likely look too bluish and the print will look too reddish because the monitor's color temperature is too high as compared to the lighting.

Monitors are routinely set at color temperatures of 6500K or even higher. However, such high color temperature settings do not represent average viewing environments by any stretch of the imagination. Outside conditions are mostly 5000-5500K and inside conditions are mostly less than 5000K. So, 5000K would appear to be a good compromise choice to represent the average viewing environment. So where did this higher setting come from? It's a sad legacy from the CRT era (we will discuss another sad legacy from the CRT screen era, gamma, later on). CRTs cannot deliver sufficiently bright images at around 5000K color temperature to be viewable in bright viewing conditions like on TV screens in living rooms during daytime. This is caused by the limited brightness levels of the CRT's red channel. To get a better image in bright viewing conditions, the green and blue channels with more oomph are turned up, resulting in brighter screens, but at a higher color temperature. People have gotten used to the overly-bluish hue of TV screens and a de-facto, albeit incorrect, standard took hold. When LCD screens became available with the ability to provide sufficient brightness at lower color temperatures, the higher color temperature settings were continued nonetheless.

The color temperature of most digital darkroom lighting ranges between 2500K and 5000K:

Light source	Color temperature
incandescent bulb	2500-2900K
tungsten photoflood bulb	3000-3400K
generic low-voltage tungsten-halogen bulb	3000K
SoLux low-voltage tungsten-halogen bulb	3500K, 4100K, 4700K or 5000K
fluorescent lights	2500-5000K

So, without taking special precautions, the color temperature mismatch between the monitor and the lighting can easily be 1500-4000K or more. Only a few hundred K of mismatch makes a noticeable difference. A mismatch of 1500K is very noticeable, as you can easily see for yourself if your monitor allows you to change its color temperature setting, say between 5000K and 6500K. Compare an image on your monitor with the same image printed on paper. Observe the match between the two: it can be anything between extremely good and extremely bad. Now, change your monitor's color temperature setting by 1500K: the match between the monitor and print will change dramatically.

Adding to this problem is the confusion about "daylight". Many people, well-meaning professionals and amateurs alike, advise us to use "daylight" lighting in the digital darkroom to have a "good" match with the "daylight" settings of the monitor. Problem is, there is no widely-accepted, standardized definition of "daylight", so this advice is too vague and inaccurate to be of any practical use. It does more harm than good, so treat the "daylight" label as absolutely meaningless! Here are some different definitions of "daylight", both in terms of the name and the corresponding color temperature, that I have come across:

Description	**Color temperature**
Horizon daylight	2300K
D50 noon sky daylight, equivalent of daylight	5000K
Average daylight, noon daylight, daylight	5500K
D65 average north sky daylight, daylight, standard daylight	6500K
D75 north sky daylight	7500K

Then there is the confusion about “full spectrum” lights. The term “full spectrum”, while sounding good, has no useful meaning since it is not defined in any scientific way. Treat the "full spectrum" label as totally meaningless!

2. Spectral imperfections of fluorescent lights

Fluorescent lights, including those for so-called critical viewing applications, have enormous spikes and dips in their color spectra, causing certain areas of your prints to appear too bright, too dark or of the wrong color. The wavelengths and magnitudes of these spikes and dips vary between makes and models and include spikes in the violet, purple, green, yellow and orange range of the color spectrum. In addition, there is a significant reduction in output at the red end of the visible color spectrum.

As a result, errors in color evaluation using these lamps are significant. Also, these lights age considerably over time. Their color spectrum and output level change significantly well before they stop working. This requires replacement after a certain amount of hours by means of manually keeping track of the time the lights are used (tedious and error prone) or automatic timers (expensive).

3. Brightness mismatches

Without special precautions, the brightness of the monitor and that of the lighting in your digital darkroom will more than likely be different. The brightness of an image on the monitor will look different from the brightness of a print of the same image viewed in the digital darkroom lighting, whether or not you printed the image yourself or had someone else do it for you.

LCD monitors in particular are often set at brightness levels that are way too high for the digital darkroom. When the monitor is too bright, you have the tendency to edit the image on the screen to be darker, resulting in prints that are too dark.

It doesn't matter if someone else prints your images

You may think that, as long as someone else prints your images, you don't have to worry about monitor-to-print matching, since you won't see the print while you edit your image. You would be wrong. If someone else prints your images, it becomes even more important to set up your digital darkroom - including monitor calibration and lighting - correctly, since you won't have the immediate feedback that something is awry that others have when they print their own images. So, how do you get the needed match between your monitor and the - arguably absent - lighting? For starters, your digital darkroom lighting should never be absent. Working in total darkness is a sure-fire way to develop bad habits and get bad results. Your eyes and brain need a reference point when editing images on your monitor. Without some light of a particular color temperature and brightness falling on your surroundings, your eyes have no reference point and depending on many things, including your mood at the moment and how well your eyes and brain have adjusted to darkness, you will perceive colors and brightness levels mostly subjectively and therefore incorrectly; the colors and brightness of the edited image will vary and so will your prints.
You need to follow the same processes described below of matching your monitor and lighting.

How to find out if you have monitor-to-print mismatch issues

First, you need to follow good digital darkroom practices that I describe further down. Then you need to determine if you have monitor-to-print mismatch issues. If you didn't take special precautions, it's almost guaranteed that you do. For starters, if you use a bright LCD monitor, you need to turn it down; if you use a higher than 5000K monitor setting, you need to reduce the color temperature setting; if you use fluorescent lighting, you need to get rid of it, even if it is a so-called special light for color-critical work!

It's relatively easy to find out if you have a mismatch. There is the "eyeball" approach and then there is the "camera" approach.

The "eyeball" approach

Using your image editing program, put a large, purely white (R, G and B values all 255) "image" on screen. Take a blank piece of printing paper (either what you use yourself or what your outside printing source uses) and look at it under your digital darkroom lighting. Keep the paper under an angle you would normally use to look at a print. Now carefully compare color and brightness of the monitor and paper and look for any mismatches. Do the same with a variety of real images by comparing them on screen and in print. Apart from subtle differences that may be caused by color gamut differences between the monitor and printer, the images should be very similar.

You should realize that your eyes and brain may be playing tricks on you. They have an ability to compensate for differences between the two images that you may not be aware of. During and immediately after the time it takes for you to turn your head from the monitor to the print or vice versa, your eyes and brain work together to mitigate differences that you might otherwise have observed. Differences up to a certain magnitude will thus escape your attention. People with a keen sense of colors and tonality may be able to detect minor differences and thus evaluate the two images accurately. If you are one of those people and you see that both images are close enough, then your prints will faithfully represent what you saw on the monitor. However, if you have less of an acute ability, you may be fooled and the prints will not be what you expected. If you fall in this category, or you like to apply a more scientific method to determine color temperature and brightness matching, apply the "camera" approach.

The "camera" approach

There is a relatively simple method to more objectively test for a color temperature and/or brightness mismatch than eyeballing it. It requires the use of a digital camera that allows you to set it for a particular white balance; it really doesn’t matter which; any setting will do as long as it doesn’t change between shots, because we are interested to see how one shot compares to the next, not if they are color-perfect. It needs to have a long enough shutter speed to correctly expose the relatively dim images on your monitor and prints illuminated by your digital darkroom lighting. It also needs manual shutter speed and aperture settings.

Mount the camera on a tripod. The camera should have a cable release, remote control or self-timer function to eliminate camera shake. Wait until dark so no stray outside light will distort the results. Disable the camera’s flash. In your image editing program, create a purely white image (all R, G and B values at 255) and make a shot of this image on your monitor with all lighting switched off. Then, make a shot of a blank piece of printer paper illuminated by the digital darkroom lighting using the same shutter speed and aperture. Import both images into your image-editing program without making any adjustments and put them side-by-side on your monitor. Now your eyes and brain can no longer play tricks on you. Differences that might otherwise have escaped you attention will clearly show up. Beyond just eyeing the images on the screen, you could measure the brightness and color of each with your image editor with H, S and B and/or R, G and B readings and, if your calibrator allows, you could even measure the color temperature of each image.

Making corrections

Correct any mismatches seen with either approach as described below.

Recommended digital darkroom practices for color-critical work

- **General setup of the digital darkroom**
  - Use a screensaver that darkens your monitor after five or 10 minutes of non-activity to reduce the effects of aging
  - Use appropriate profiles when scanning, particularly for color negatives
  - Use appropriate color spaces for importing and editing images
  - Use appropriate profiles for your printer/ink/paper combinations
  - Let prints dry for 30 minutes to one hour before judging them
  - Switch off all lighting in your digital darkroom other than the lighting used to view printed output
  - Shield light from the outside and other rooms/work areas
  - Use a neutral gray monitor screen background color
  - Use a neutral gray or black monitor hood
  - Paint digital darkroom walls and ceiling in neutral light gray or white
  - Wear clothing that is not colorful to avoid a color cast on your monitor screen
- **Use the best quality monitor you can afford**
  In the past, high-quality CRTs were the standard for color-critical work. Now LCD monitors are available with favorable characteristics for the digital darkroom. Here is a list of specifications that I believe to be crucial for LCD monitors for this type of work:
  - IPS (in-plane switching) panel
  - near-sRGB (which is about 70% of Adobe RGB), or better yet, near-Adobe RGB color gamut
  - Brightness: 200 cd/m^2 or nits or more
  - Backlight adjust: backlighting must be adjustable to reduce brightness to a minimum of between 80 and 120 cd/m^2
  - Gamma range: at least 2.2
  - Viewing angles: at least 170 degrees horizontally and vertically
  - Color temperature: adjustable to at least 5000K
  - RGB controls: R, G and B should be independently adjustable
  These following LCD monitors fit the bill:

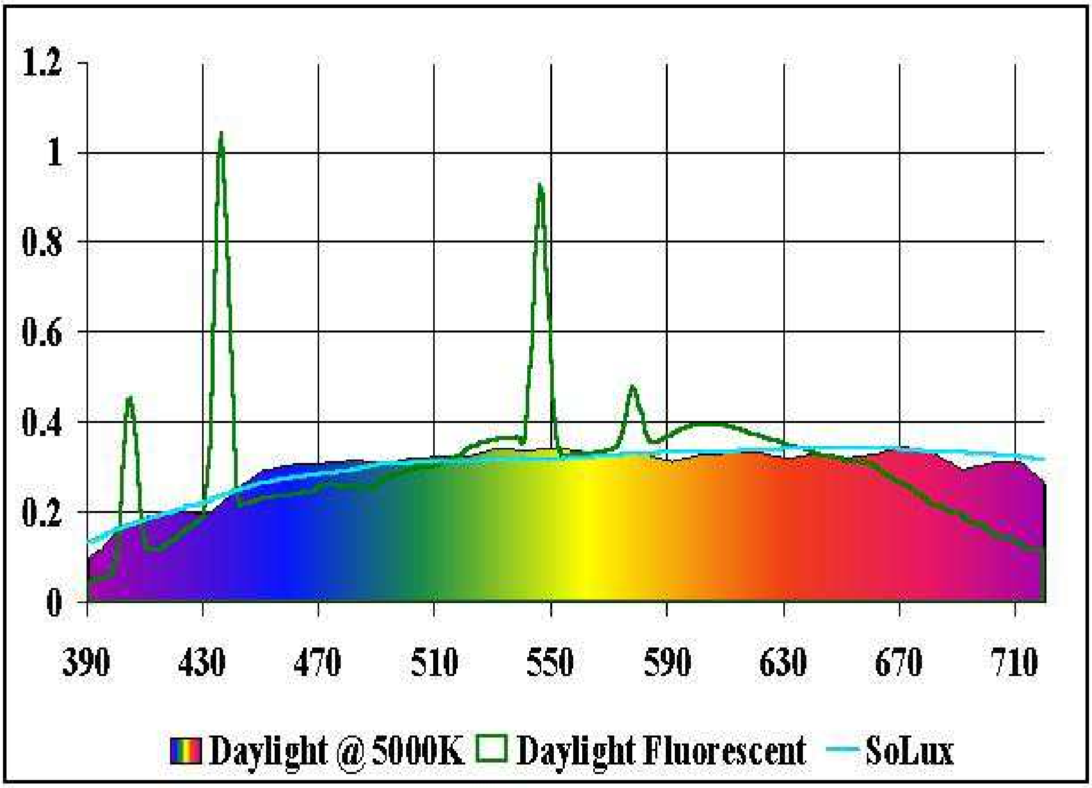
LCD Monitors with an IPS panel and near-sRGB gamut				
Brand	**Product**	**Size**	**Gamut**	**Price range***
ASUS	PA238Q	23"	100% sRGB	$200-$300
ASUS	PA248Q	24"	100% sRGB	$300-$400
ASUS	PB278Q	27"	100% sRGB	$600-$700
Dell	U2913WM	29"	99% sRGB	$600-$700
NEC	PA231W	23"	97% sRGB	$500-$600 $600-$700 with SpectraView calibrator
NEC	P232W	23"	97% sRGB	$500-$600 $700-$800 with SpectraView calibrator
NEC	P241W	24"	97% sRGB	$600-$700 $900-$1,000 with SpectraView calibrator
LCD Monitors with an IPS panel and near-Adobe RGB gamut				
Brand	**Product**	**Size**	**Gamut**	**Price range***
ASUS	PA246Q	24"	98% Adobe RGB	$400-$500
Dell	U2410	24"	96% Adobe RGB	$400-$500
Dell	U2413	24"	99% Adobe RGB	$600-$700
Dell	U3014	30"	99% Adobe RGB	$1,300-$1,400
Eizo	CG246	24"	97% Adobe RGB	$2,300-$2,400 with calibrator
Eizo	CG276	27"	97% Adobe RGB	$2,600-$2,700 with calibrator
Eizo	CX270	28"	97% Adobe RGB	$2,100-$2,200 with calibrator
HP	LP2480zx	24"	100% Adobe RGB	$2,200-$2,300 with calibrator
LaCie	324i	24"	98% Adobe RGB	$1,200-$1,300
NEC	PA241W	24"	98% Adobe RGB	$700-$800 $800-$900 with SpectraView calibrator
NEC	PA271W	27"	97% Adobe RGB	$800-$900 $1,300-$1,400 with SpectraView calibrator
NEC	PA301W	30"	98% Adobe RGB	$1,800-$1,900 $2,300-$2,400 with SpectraView calibrator

*: prices are from B&H's website during April of 2013 and may include limited special offers

I have a strong preference for NEC monitors. Eizo and LaCie monitors are comparable to NEC in quality, but at much higher price points.

- **Color temperature choice**
  As we have seen, it's important that the monitor and lighting match in terms of color temperature and brightness, and that the lighting is of high quality without spikes and dips. Theoretically, the color temperature could fall within a wide range as long as it is the same for both the monitor and lighting. That is because of a phenomenon called color constancy, which says that our vision adapts to changes in color temperature. To the human eye/brain combination, an image viewed in a certain color temperature environment will look about the same in a different color temperature environment. However, as we have seen, 5000K is more representative of average real world conditions. So, if color constancy doesn't work perfectly, than it makes sense to choose 5000K to reflect real world conditions. There is also a major, practical reason why 5000K is a good choice: there are basically no high-quality, affordable light sources without spikes and dips above 5000K. And we want the color temperature of the monitor to be as high as possible to avoid experiencing it as too reddish. So, 5000K appears to be the best overall choice, from both a monitor and lighting perspective.

- **Digital darkroom lighting**
  I strongly recommend using the SoLux 5000K 35W low-voltage halogen bulbs. These bulbs have been specifically designed for critical viewing applications. They have the best match to the D50 color spectrum and their spectrum is very smooth without spikes or dips, as you can see on the following chart:



Spectral purity is represented by the CRI (color rendering index): the higher the index the better and the best being 100%. This particular SoLux bulb has a CRI of 98%. Even the purest fluorescent tubes barely make the 90% mark and many are way below that. The SoLux bulbs also have ultra-low UV and IR output, which significantly reduces fading of sensitive materials. These bulbs do not age noticeably. Total light output decrease by less than 5% over their life and the color spectrum does not change by more than 30K degrees over their total life span. At the time of this writing, you can buy the 5000K bulbs only from SoLux; other vendors seem to carry only the lower color temperature versions.

SoLux also offers a variety of fixtures for these bulbs. There are reasonably priced clip-on lamps, fixtures that screw into standard light bulb sockets, table lamps, floor-standing lamps, adjustable spotlights, track systems, etc.

A ceiling track system allows for the greatest flexibility in where and how many fixtures you use and where you aim each fixture. The 5000K 35W 36-degree beam spread SoLux bulbs will give you a decent size of illuminated area on your desk or table surface to view your printed output if you mount them about 4 feet above your work surface. Two of these bulbs would be a good starting point to see if you get a good match between the brightness of your calibrated monitor and your printed output. In my setup, two such bulbs mounted 1 foot apart at 4 feet above my computer desk surface results in a perfect brightness match when I calibrate my monitor to 105cd/m^2 or nits.

If you use SoLux bulbs in non-SoLux fixtures, make sure to use fixtures with the proper power rating and make sure that those fixtures have no glass window in the front to prevent it from changing the color temperature. Use “closed” fixtures without venting holes; the back of the bulbs emit a significant amount of light with a strong red cast; this light will escape from venting holes and “contaminate” your viewing area. The bulbs will get pretty hot in a closed fixture, but they can take the heat.

- **Monitor calibration**
  Calibrate your LCD monitor every 3 months or more frequently after a warm-up of at least 30 minutes and your CRT every month or more frequently after a warm-up of at least 1 hour. Invest in a calibration program plus sensor that actually measures your monitor’s light output, lets you choose your own values for color temperature, at least 5000K, and gamma value, at least 2.2. When you light your digital darkroom with SoLux 5000K bulbs, calibrate your monitor at 5000K/gamma 2.2.
  Choose a brightness or white point value that will result in a match with the brightness of the blank printer paper, which in my setup is 105cd/m^2 or nits.
- **Gamma: another bad legacy from the CRT era**
  There is a lot of confusion on the issue of gamma. Many people erroneously believe we need a non-linear monitor response to compensate for the non-linear response of our eyes. Nothing could be farther from the truth! We want the system (camera plus monitor) output (image on the monitor) to be directly proportional to the input (scene recorded by the camera).
  In order to understand why we need to apply a gamma correction to our monitors, we need to go back to the time when CRTs were the only choice. CRTs are very non-linear in their response. Corrections needed to be made to achieve a linear response of the overall system of cameras and monitors. Corrections could either be made in the CRTs or in the cameras. As there were way, way less cameras than monitors, the industry choose to make the corrections in the cameras, so no corrections were needed for the CRTs. So, most every image in existence today has been gamma encoded (purposely distorted) to look correct i.e. linear on a CRT. Virtually all images today are still being gamma encoded while this would not really be needed anymore for LCD panels. Even linear images from today's digital cameras are gamma encoded (distorted) by our image editing programs. It is very doubtful that this situation will change anytime soon, as it would require enormous efforts to change the existing system from non-linear to linear ***and*** allow for legacy, gamma-encoded images to be displayed correctly.
- **Use the best photo-quality printer you can afford**
  I have obtained excellent results with Epson printers, inks and papers, giving me prints that will last many decades before noticeable fading occurs when displayed under glass and even longer if in an archival quality album, according to Wilhelm Research.
- **Image editing software color space**
  Don’t change the color workspace of your image editing software; you only want to change the appearance of the colors on the monitor.

What about using a viewing booth?
Viewing booths or stations are also used for viewing prints, art, pre-press artwork, product samples, etc. There are many types and sizes. Most use the undesirable special fluorescent lights mentioned above, only a few use low-voltage tungsten-halogen lights, and some offer LED versions without, as far as I can tell, publishing CRI or color spectrum information.
There are significant drawbacks to viewing booths:

- The above-mentioned color spectrum issues when fluorescent lights are used and, for me, unanswered questions about spectral purity for LED versions
- Most take up a significant amount of real estate
- They are expensive

For CRT users: does calibrating at a lower color temperature cause accelerated CRT wear-out?
The effect on reliability of lowering the color temperature of today's CRTs is negligible. For instance, when lowering the color temperature of a Sony 21" Trinitron CRT from 6500K to 4700K while maintaining the same overall brightness, the red channel brightness increases by only 13%, the green by 3% and the blue decreases by 14%.

Recommended manufacturers/researchers:
- **Epson:** www.epson.com
- **NEC: :** www.necdisplay.com
- **SoLux**: www.solux.net
- **Wilhelm Research**: www.wilhelm-research.com

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