

Liquid Color™ and LCD Monitor Calibration

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Color is something that happens in our heads. It's the human response to certain wavelengths of light. Biological mechanisms in the human eye and brain translate light of wavelength 680 nm (for example) into the color "red". You can't actually measure "red", you can only measure the stimulus – the light wavelengths – to which the color red is our response. In addition, our response depends on the ambient lighting, the amount of caffeine or alcohol in our body, our mood and other factors.

It's no surprise, then, that we're surrounded by color inconsistencies in our computing experience. You shoot photos of your kids with your digital camera, and the photos look OK on your monitor but green in the inkjet print. You load the photos of your kids onto your laptop so you can show them to your friends, but the photos look too dark and details are lost in the shadows. You order a nice burgundy sweater that looked terrific on an Internet store's website, but what arrives on the UPS truck a week later is definitely more red than burgundy.

Communicating Color Information

The underlying problem is that communicating color information accurately and easily between different devices is very difficult. In 1993, Apple and seven other vendors founded the International Color Consortium (ICC) to try to solve the problem of delivering consistent color across applications, operating systems and devices. Today the ICC includes 70 manufacturers and software developers. The ICC's approach to the problem uses "profiles". An ICC profile is a data file that describes the color behavior of an input, display, or output device. The data in the file is referenced to a device-independent color model, that is, a mathematical representation of human color response (e.g., CIE XYZ 1931). By always using two profiles, one for the "from" device and one for the "to" device, software should be able to convert color data from one device so that it looks the same on another device.

The problems with the "ICC profile" approach are that it's complex and it doesn't provide a complete solution for all situations. A given device can have many different profiles, depending on the environment in which it's used. For example, a color printer typically has a different profile for each different kind of paper it supports. As a device ages, its profiles may become inaccurate and need to be "tweaked" to properly describe its current color behavior. Ideally, the "from" device profile should be embedded in an image when it's created, but most existing photography file formats don't support color profile embedding. The result is that outside of the professional environment (graphic design, pre-press, CAD, animation, etc.), ICC profiles are rarely used.

The sRGB Standard

Recognizing the need for a simpler method of communicating color information between devices, Hewlett-Packard and Microsoft proposed "a new standard default color space for the Internet" in a seminal paper in 1996. The result, called sRGB, is a standard method of specifying color numerically in terms of varying amounts of the primary colors, red, green and blue. The International Electrotechnical Commission (IEC) approved sRGB as a formal specification (IEC 69166-2-1) in 1999; since then it has become the standard for the Windows world. Most digital cameras, scanners, displays and printers support sRGB; all Windows graphics and images assume sRGB; and web images are produced to target sRGB display devices.

The sRGB specification approximates the color space of a CRT monitor. (A “color space” is simply the universe of colors that a device can produce.) Specifically, sRGB refers to a CRT described as follows:

Characteristics

- P22 phosphors (the light-emitting chemicals commonly used in most CRTs)
- RGB response conforming to a 2.2 gamma tone curve
- Color temperature of 6500°K (average summer daylight)
- Perfect gray neutrality throughout the tone scale (no color tints in gray shades)
- Screen brightness of 80 cd/m² (relatively dim)

Environment

- 64 lux ambient illumination (a dimly lit room)
- 5000K ambient illumination (warm daylight lighting the room)
- 20% reflectance in the area surrounding the image (light gray)

Note that the sRGB specification includes a description of the environment in which the monitor is to be viewed. This is important because color matching is highly dependent on the ambient light level and source.

CRTs Then, LCDs Now

CRTs were almost totally dominant in 1999, but in 2004, LCD monitors account for more than 50% of new monitor sales. This means it's necessary to understand how sRGB applies to an LCD monitor. In order to do so, it's first necessary to introduce the concept of “gamma”.

Every computer monitor of any kind has a non-linear input-to-intensity response curve. As you send the monitor an increasing level of input (for example, tell it to go steadily from black to white), the measurable brightness increases slowly at first and then accelerates. Gamma is a numerical value that describes how quickly the increase in brightness occurs. An optimally calibrated CRT in its native state (for example, the CRT in the sRGB specification) has a consistent gamma of 2.2. (An imaginary monitor with a perfect linearity input-to-intensity response curve would have a gamma of 1.0.) In the process of developing the sRGB standard, Hewlett-Packard provided studies and computations to prove that gamma 2.2 is very close to what humans see as a uniform lightness scale for display viewing conditions. In other words, with a gamma of 2.2, a CRT monitor seems to go uniformly from zero brightness (black) to full brightness (white) – even though it's really not. Gamma 2.2 closely matches the human visual system.

A monitor's gamma curve is actually made up of three separate gamma curves – one each for red, green and blue. Figure 1 below shows a reference gamma 2.2 curve and the individual red, green and blue gamma curves for a typical CRT monitor. Note that the individual curves are very smooth and correspond very closely with the reference curve.

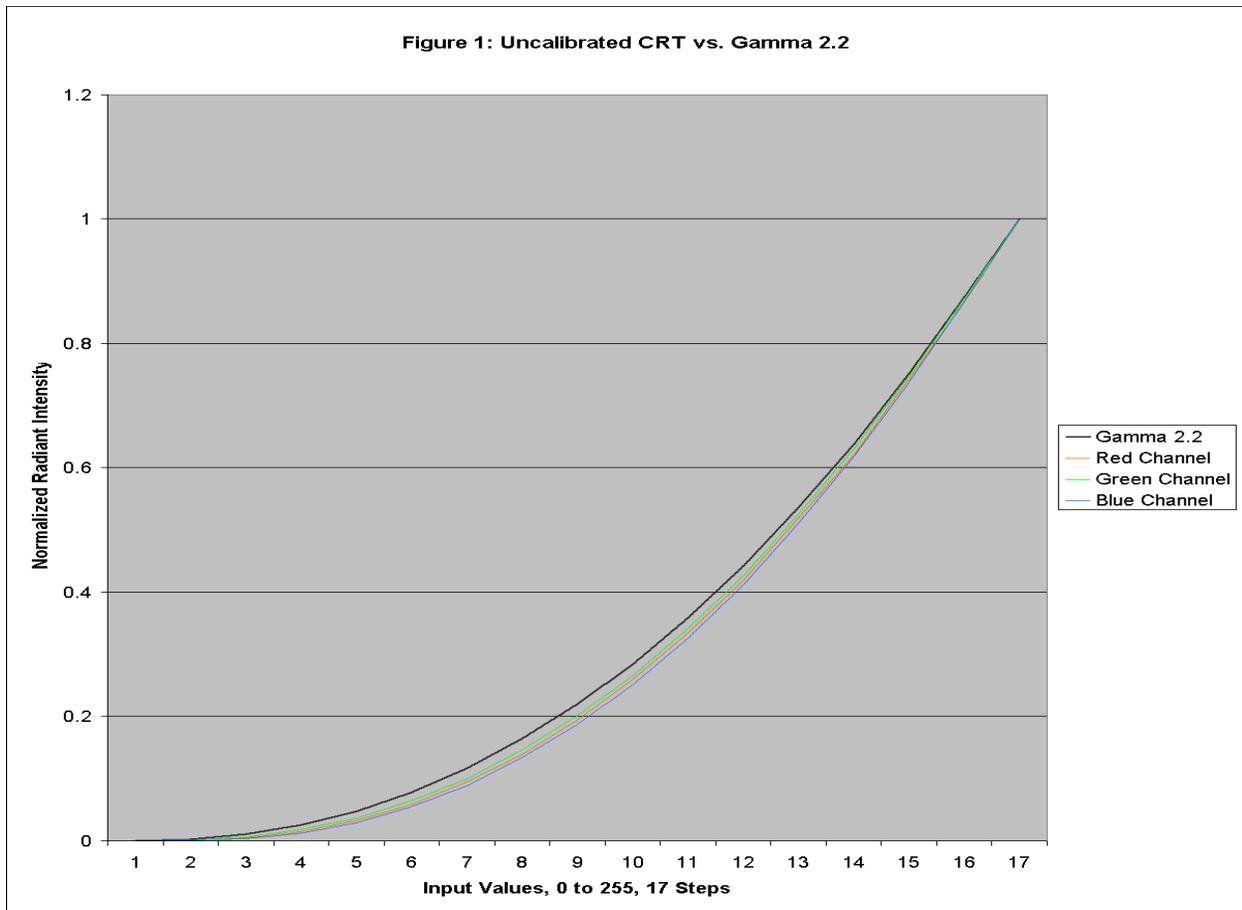


Figure 1: Reference gamma 2.2 curve and the RGB response curves of a typical CRT monitor

Unfortunately, LCD monitors are not so well-behaved. They typically have a gamma closer to 3.0 (meaning that their curve is steeper), and the individual red-green-blue gamma curves are not as smooth. As shown in Figure 2 below, the individual RGB gamma curves are not smooth, further apart, and they cross the 2.2 gamma curve at different points. The result is that an uncalibrated LCD's image is too dark in the shadows and too light in the highlights, with some color tints showing in the gray tones. Not a good match for sRGB, and will display inaccurate color!

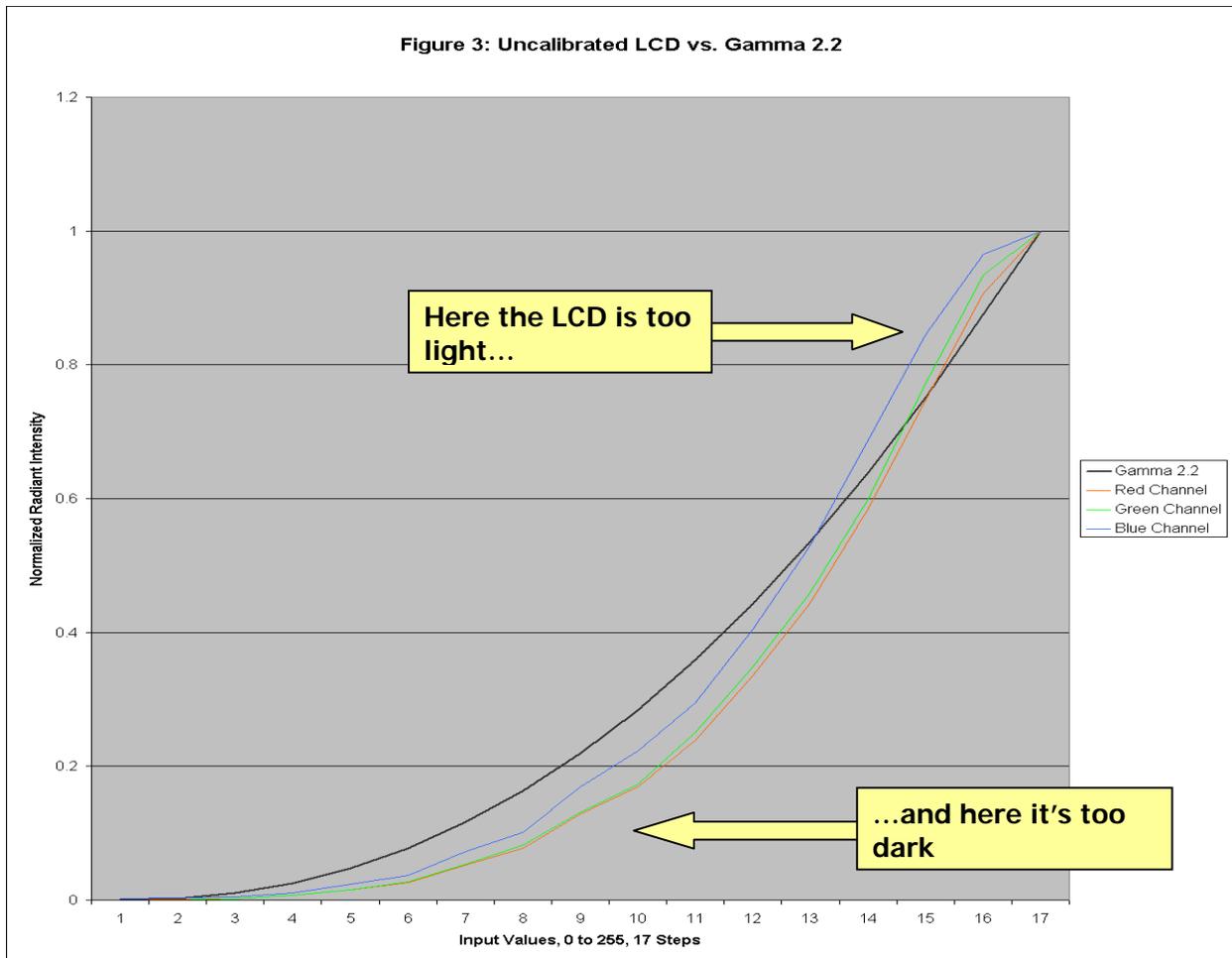


Figure 2: Reference gamma 2.2 curve and the RGB response curve of a typical LCD monitor

Figure 2 is the reason why Liquid Color exists – it’s a tool to help you calibrate your LCD monitor so that its RGB response curve closely matches the gamma 2.2 curve equivalent to gamma 2.2. Once an LCD monitor is calibrated with Liquid Color, it becomes an sRGB-compliant device, ready to participate as a full-fledged member of the Windows world.

Color Temperature

Calibrating any monitor involves four basic steps, as follows:

1. Setting the color temperature
2. Setting the black luminance
3. Setting the white luminance
4. Adjusting the gamma curve

The “color temperature” (sometimes called “white point”) of the monitor refers to how “cool” (blue) or “warm” (yellow-red) the monitor appears. Most monitors have multiple color temperature settings, typically 9300K, 6500K and 5000K. The “K” stands for “degrees Kelvin”.

The human visual system uses the white point color as a reference for all other colors. The “white point adaptation” of the human visual system is instantaneous and automatic. Perception of all colors thus depends on the white point.

Research during the development of the sRGB specification confirmed that a white point of 6500K (also sometimes called “D65”) was the best compromise for viewing images over a wide variety of ambient lighting conditions. To manually set the color temperature of a monitor to 6500K, you can use the on-screen display (OSD). Laptops don’t have color temperature controls; they are usually factory-set to 6,500K.

Brightness and Control Controls

Setting the black and white levels requires using the Brightness and Contrast controls on the monitor. However, there is significant confusion regarding the function of the controls, because they act opposite on CRT and LCD monitors.

Black Level

In Liquid Color, setting the black level is accomplished with the screen shown in Figure 3 below (the image has been lightened slightly for clarity of reproduction).

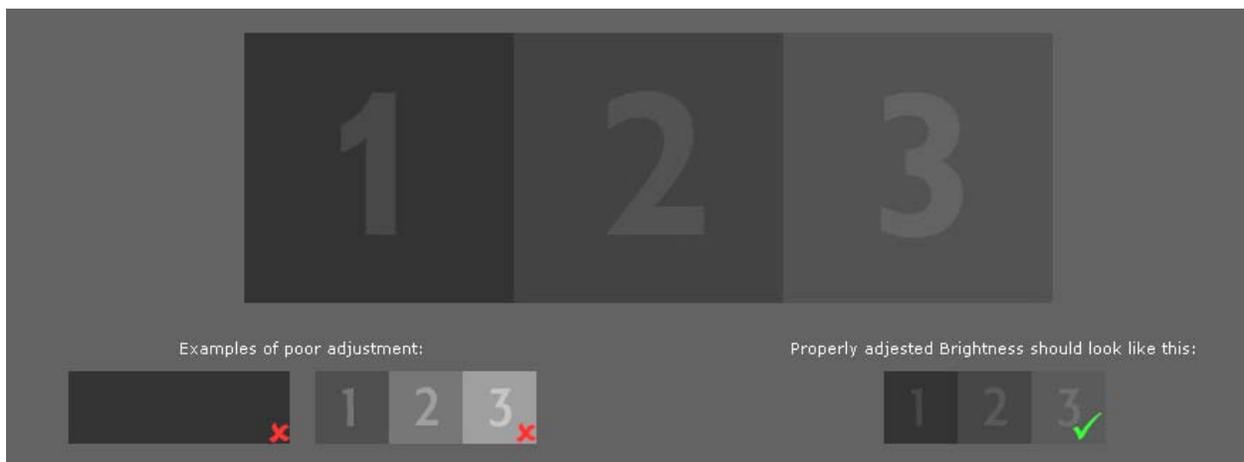


Figure 3: Liquid Color's screen for adjusting black level

The appropriate control on the monitor (see Table 2 above) is lowered until the “1” and “2” boxes disappear. Then the control is raised until “2” reappears and “1” is barely visible – that is, until black and the next higher tone are just barely distinguishable. Two “Examples of poor adjustment” are shown in Figure 3. In the first example, black and the tones near it are indistinguishable. In the second example, black (the “1” box) has turned into a dark gray.

The Viewing Angle Problem

CRTs have naturally wide viewing angles, nearly 180 degrees in all four directions, with no significant color (tone) shift off-axis. LCDs, on the other hand, have inherently narrow viewing angles. Desktop monitor LCDs are specially designed for wider viewing angles. Desktop monitors typically have horizontal viewing cones in the range of 120° to 160°, and vertical viewing

cones in the range of 100° to 160°. The position of the user’s head is therefore not especially critical during the black level adjustment on a CRT monitor, although the user should be positioned for normal use of the monitor.

Laptops are a totally different situation. The LCDs in laptops are designed for moderately wide horizontal viewing cones (typically 90°), but very narrow vertical viewing cones (45° or less). Forty-five degrees sounds like a lot, but it’s actually the range over which the contrast ranges from very high (100+) to very low (5). The result is that moving your head only four inches vertically or adjusting the angle of the laptop screen by only five degrees is enough to totally change the results of setting the black level. Choosing your body position and screen angle are therefore critical when calibrating a laptop LCD. The best procedure is to start with your body in a normal working position, adjust the placement of the laptop for ergonomic keyboard access, then adjust the screen angle until your line of sight is exactly perpendicular with the center of the screen.

White Level

Setting the white level in Liquid Color is accomplished with the screen shown in Figure 4 below (the image has been darkened slightly for clarity in reproduction).

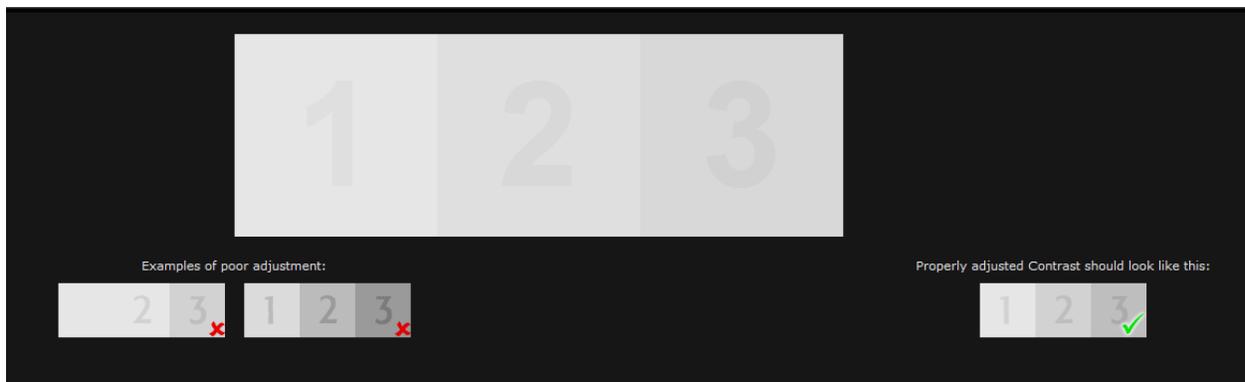


Figure 4: Liquid Color’s screen for adjusting white level.

The appropriate control on the monitor (see Table 2 on the previous page) is raised until the “1” and “2” characters disappear into the background. Then the control is lowered until “2” reappears and “1” is barely visible – that is, until white (the box) and the next lower tone (the “1”) are just barely distinguishable. Two “Examples of poor adjustment” are shown in Figure 4. In the first example, the “1” character isn’t visible at all. In the second example, the “1” is too visible.

The laptop viewing angle issue discussed on the previous page applies in exactly the same way to the white-level adjustment.

Adjusting the Gamma Curve

The final step in calibrating an LCD monitor is to adjust the RGB response (gamma) curve so that it matches the target gamma 2.2 curve. When calibrating a CRT monitor, only one point on the gamma curve is typically required for good calibration, since the shape of the CRT’s RGB response curve is so close to that of the gamma 2.2 curve (as shown previously in Figure 1).

However, since the RGB response curves of an LCD monitor are substantially different in shape from the gamma 2.2 curve, multiple calibration points are required.

Liquid Color uses six, carefully selected calibration points distributed along the curve, as shown in Figure 5 below.

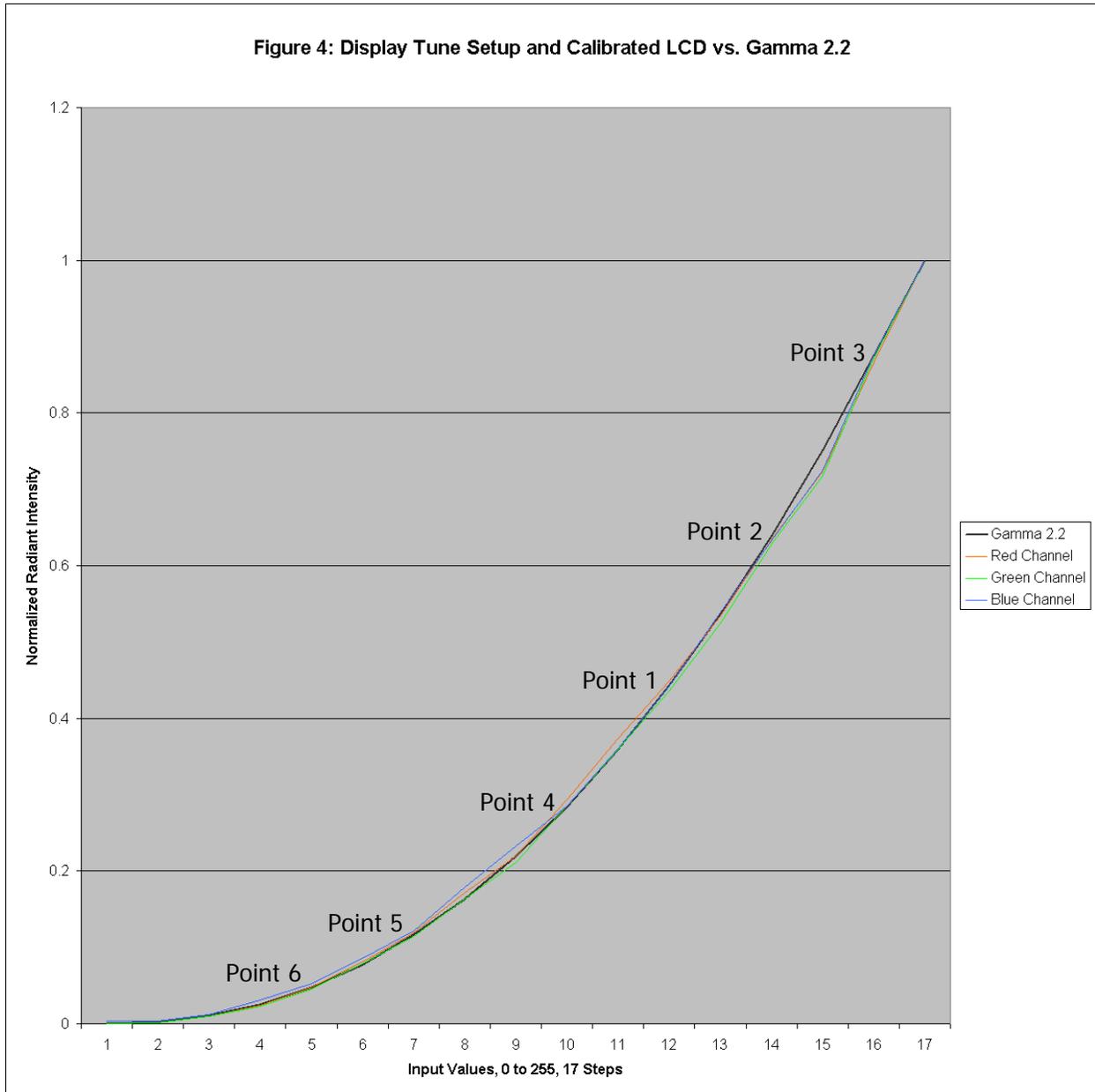


Figure 5: Liquid Color's six calibration points on the gamma 2.2 curve, showing an LCD monitor's RGB response curve after calibration.

Note that the points are not in sequential order. The first calibration point is in the midtone area (first priority), the second and third points are in the highlight area (second priority), and the final three points are in the shadows (third priority).

At each of the six calibration points, the user is presented with the screen shown in Figure 6 below.

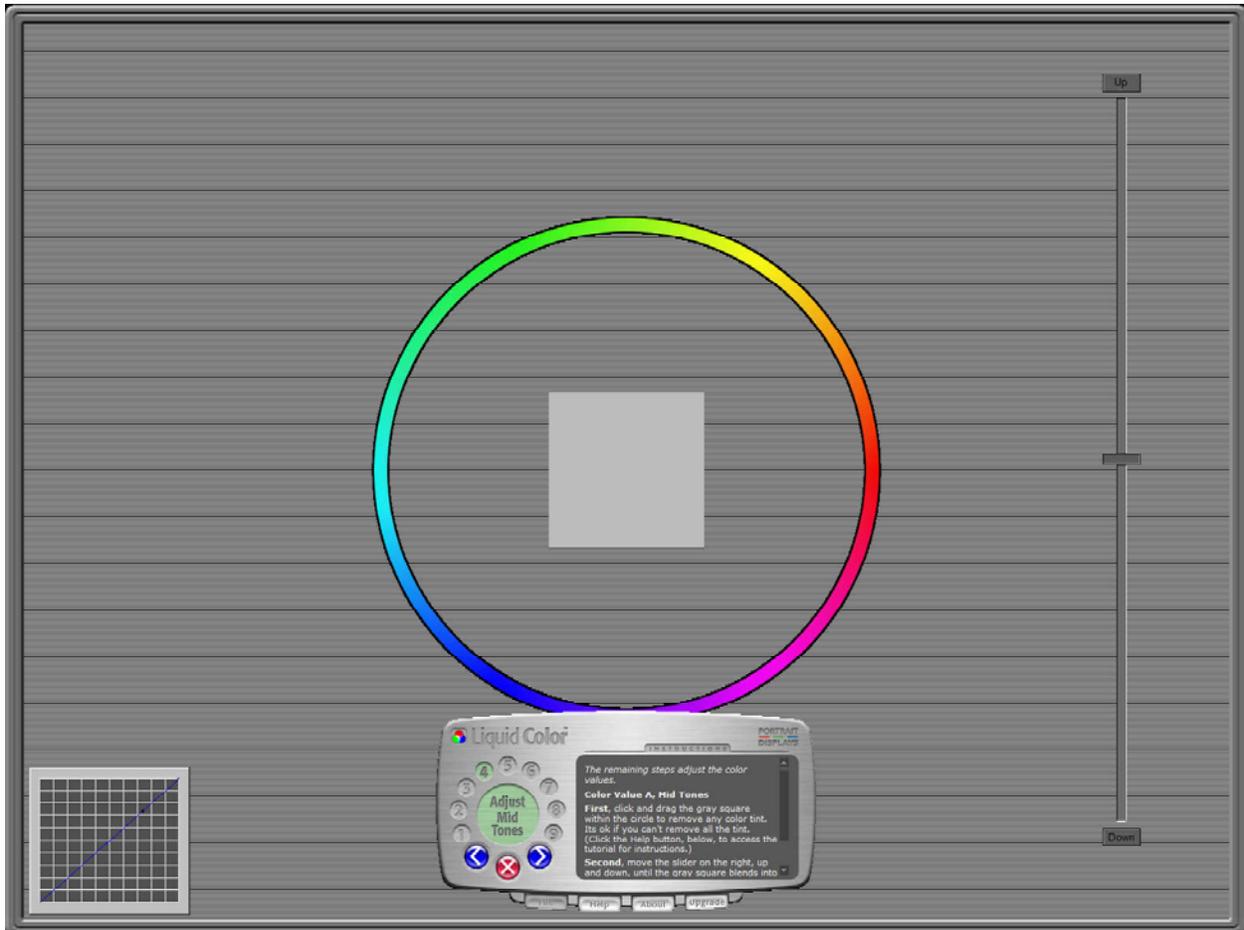


Figure 6: Liquid Color's gamma calibration screen (midtone step shown).

At each calibration point, the user moves the box in the center of the color circle until it is a pure gray, untinted by any color. Moving the box causes the RGB response curves to separate in the vicinity of the calibration point, as shown in Figure 7 on the next page (the curves have been exaggerated by moving the box to the very edge of the color circle). Next the user moves the slider on the right side of the screen until the gray box “blends into the background”. Moving the slider causes the shape of the RGB curves to change in the vicinity of the calibration point, as shown in Figure 8 on the next page (again the shapes have been exaggerated by moving the slider to one extreme).

The technique of adjusting the slider until the gray square “blends into the background” may be unfamiliar at first. The square never really complete disappears into the background, it’s just that the tone of the square and the tone of the background become close. When picking the “best blend” point, it’s often best to look slightly away from the square and let your peripheral vision sense the blending – it seems to work better.

When the user completes the six calibration points, the result is a final set of RGB response curves for the calibrated LCD, as shown in Figure 9 on the next page.

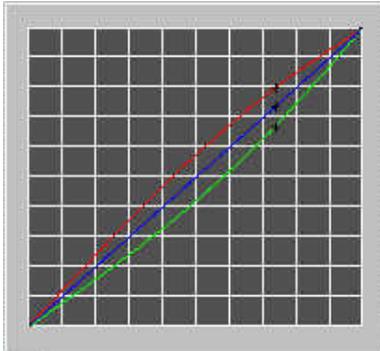


Figure 7: Change in RGB response curves due to moving the gray box (change in the coincidence of the curves)

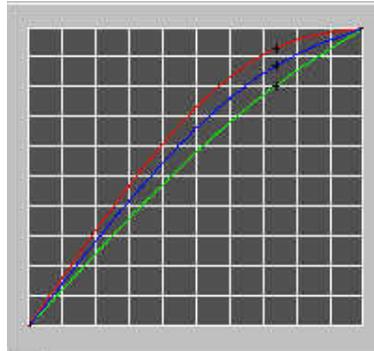


Figure 8: Change in RGB response curves due to moving the slider at the same position of the gray box (change in the shape of the curves).

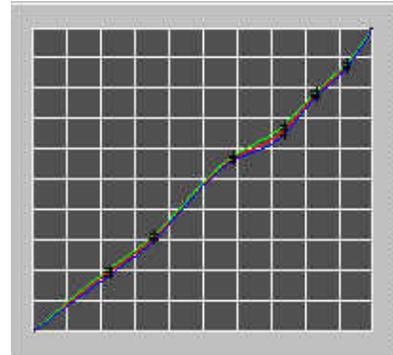


Figure 9: Example of final RGB response curve for a calibrated LCD.

You may have noticed that the curves shown in Figures 7 through 9 above started as straight lines rather than the exponential curves shown previously in Figures 1 and 2. That's because these are "normalized" curves. Any change from the straight line represents a proportional change in the actual curves. It's much easier for the human visual system to see minor deviations from a straight line than it is to see minor deviations in a curved line.

The final result of the Liquid Color LCD monitor calibration process is a monitor that conforms to the sRGB specification, as follows:

- RGB response conforming to a 2.2 gamma tone curve
- Color temperature of 6500°K
- Calibrated gray neutrality throughout the tone scale

A before-and-after comparison of an image on an uncalibrated (left) and calibrated (right) LCD monitor is shown in Figure 10 below.



Figure 10: The same image on an uncalibrated (left) and calibrated (right) LCD monitor.

Note that any monitor should be warmed up 15-30 minutes before starting calibration. Also note that gamma should be readjusted whenever the ambient lighting conditions have changed significantly. Liquid Color supports multiple "Presets" (sets of calibration data) specifically for this

purpose. As the lighting changes from bright daylight through a window to dim incandescent bulbs at night, the user can simply apply appropriate Presets to keep the monitor at optimum calibration.

Calibration Alternatives

Let's back away from the trees for a moment and take a look at the forest. There are three fundamental methods that can be used to calibrate a monitor, as follows:

1. Visual calibration
2. ICC profile-based calibration
3. Mechanical calibration

Liquid Color falls into category #1. It's a sophisticated but purely visual method of calibration. Because it's visual, it's subjective – but that's not necessarily bad. "Visual" doesn't equate to "inaccurate". Liquid Color takes advantage of the most accurate calibration instrument known – the human visual system. The human visual system is a very sensitive gray-scale detector. It's able to detect very small variations in color between adjacent gray areas. This fact is used to great advantage in Liquid Color's (patent-pending) calibration method.

Calibration method #2 (the use of ICC profiles) has already been discussed in the first two pages of this white paper. This method is not significantly better than visual calibration for the non-professional user, in fact, it's probably worse because (a) it's complex, as already noted, and (b) the visual result of any given profile may not be pleasing to the user. The interactive process of Liquid Color is inherently more satisfying to the user than any profile-based calibration method.

Calibration method #3 is the only serious alternative for the non-professional user. It consists of using a colorimeter (an electronic instrument that measures on-screen colors) with appropriate software. The colorimeter is often called a "puck" because it looks vaguely like a hockey puck attached to a monitor screen with suction cups. Typical prices range from \$119 to \$999, depending on the model.

Once a colorimeter has measured a series of colors on the monitor, it compares them with a device-independent standard from CIE. The software then makes adjustments to the video card in the same way that Liquid Color does, resulting in a gamma of 2.2. The software also produces an ICC profile for the monitor that can be used with ICC-aware applications such as all versions of Photoshop (full, Elements and Album). This method of calibration is very consistent (highly repeatable), but sometimes a mechanical calibration process can produce results that don't look quite right. There really is something to be said for letting one's eyes be the final judge.