Emulating Correct CRT Color on LCDs with Display Tune™

Joseph Holmes, October 30, 2002

Liquid crystal displays naturally suffer from a few serious limitations which prevent them from displaying colors correctly. CRTs are the basis for the Microsoft® Windows® standard sRGB color space for graphics and image display. Ordinary CRT displays, with correct Brightness and Bias settings, when set to approximately 6500K, come fairly close to the sRGB standard even when uncalibrated (see Figure One)*. Using even the simplest visual calibration methods, CRTs can very closely approximate the sRGB standard (see Figure Two). No supplementary ICC profile-based color management transformations are needed for overall screen color and tonality to be correct on CRT displays used with Windows except under special circumstances.

In stark contrast to CRTs, nearly all LCDs require both accurate adjustment of the OSD hardware settings (especially the Contrast setting) and relatively sophisticated calibration and strong adjustments in the graphics card, in order to be able to display graphics and images with substantial accuracy (see Figures Three and Four). Accuracy is achieved, in large part, by matching the tone curve and gray balance of the sRGB standard. In theory, ICC profile-based color management could be used

*Data for the figures was obtained by rigorously controlled laboratory spectral measurements of a good quality CRT and a typical 18" LCD. These data fairly and accurately represent the potential of Display Tune to calibrate even a difficult LCD. The actual tone curve of sRGB differs from a gamma 2.2 curve in the deepest shadows, however the typical calibrated CRT, with its gamma 2.2 tone curve so closely approximates the sRGB tone curve that the two curves can be referred to interchangeably in the context of this discussion.
to provide accurate color for some or even all graphics and image data displayed on LCDs, even when the display is in a state which differs from sRGB. However, since nearly 100% of graphics and images displayed on Windows systems are displayed without color management, a method of applying full-time, accurate calibration is absolutely critical for LCDs to display graphics and image data accurately. Without proper calibration, nearly all LCD colors are badly distorted and appear incorrectly.

Unlike CRTs, LCDs' natural tone curves do not closely match gamma curves in shape, let alone the gamma 2.2 standard curve, and they generally have very poor gray balance as well. Their tone curves are naturally very dark overall, roughly equivalent to a gamma 3.0 tone curve (see Figure Three). Some of the more modern, higher cost panels show much improvement in this respect. Without calibration to overcome these problems of nearly all LCDs, virtually 100% of displayed colors appear incorrectly.

Simple visual calibration tools, based on the use of one, two or three lined targets that represent only the lighter middle-tone region of the tone scale, are incapable of calibrating these displays adequately. Several carefully placed control points along the entire tone curve must be adjusted by the user to bring these displays into conformity with the tonality and gray neutrality of the sRGB standard.

The only visual or low-cost calibration tool available that can accomplish this complete process is the innovative and patent pending calibration within Display Tune from Portrait Displays, Inc. In contrast, the Natural Color application does not calibrate displays at all, rather it merely creates an ICC display profile that attempts to describe the display sufficiently to enable successful color management simulations. Because such simulations are essentially non-existent in today's Windows environment, this profile would not be a solution to the problem of making graphics and image data appear correctly on LCDs, even if it were correctly implemented, which it is not. Because Natural Color's ability to describe the tonality and gray balance of the display is inadequate, the resulting ICC profile is likely to be insufficiently accurate for any important use.

The unique system used in Display Tune for visual calibration of tonality and gray balance is capable of successfully adjusting LCDs through very accurate adjustments at six critical, carefully chosen points throughout the tone scale. Unlike all other visual calibration methods, Display Tune extends the reach of its visual targets into the highlights and deep into the shadows. This gives Display Tune the unique ability to wrestle curves into shape to an extent that has never been required with CRTs. Display Tune can therefore make even low-quality LCDs

![Figure Three](image1.png)

*Figure Three:* Shows the ideal gamma 2.2 tone curve plus the red, green and blue tone curves of an uncalibrated, medium quality 18” LCD. This plot illustrates a result in which the highlights are only about half as blown out as can be expected when Natural Color is used according to instructions to adjust the OSD controls. The overall tonality and gray balance are also very poor, as shown by the deviation of the LCD’s three curves from the gamma 2.2 curve, and the deviation of those curves from one another.

![Figure Four](image2.png)

*Figure Four:* Shows the ideal gamma 2.2 tone curve together with the red, green and blue tone curves of the same LCD after setup and calibration with Display Tune, illustrating the excellent match to ideal tonality and gray balance achieved here with Display Tune.
emulate calibrated CRTs and thus provide substantially correct color. The only alternatives to achieving this are the few instrument-based calibration systems that work properly with LCDs, at a price of hundreds of dollars U.S., per seat.

Adobe® Photoshop® is a notable exception to the paucity of color managed applications running under Windows. Photoshop can display image colors accurately, even if the computer’s display differs from the sRGB standard, but only if there is a corresponding ICC display profile currently selected as the system’s display profile, which accurately describes the display. Even so, if the calibrated state of the display includes significant gray balance errors, even if they are accurately described by the profile, the color matching within Photoshop is compromised because the user interface colors around displayed images, including visual reference grays, do not appear neutral. Although most factory-supplied ICC profiles for LCDs are of no value today because they do not accurately describe the display, they can be highly effective within color managed applications if the display has first been properly calibrated with Display Tune, and assuming the profile describes the calibrated state. Successful color managed simulations require both accurate calibration to a neutral gamma curve and an accurate profile that matches the calibrated state.

Showing the true colors of graphics and images correctly on Windows computer systems nearly always depends on a display behaving like a standard CRT and thus exhibiting:

1) An accurate gamma 2.2 tone curve adjusted at the user’s preferred viewing angle, with the user’s graphics card, and under the user’s ambient lighting conditions,

2) Excellent gray neutrality throughout the tone scale,

3) A white point fairly close to 6500K, and

4) RGB primary colors close to those of any typical CRT phosphor set, essentially all of which are very close to the sRGB standard, the ITU-R BT.709 HDTV phosphor set.

Further Detail

Because sRGB is the assumed color space for all screen data under Windows, nearly all graphics and images will appear incorrectly unless the display conforms closely to the sRGB standard, particularly the gamma 2.2 tone curve with excellent neutrality.

CRTs, with accurately set Brightness controls, naturally exhibit tone curves which are extremely close to that of a pure gamma curve, with a value between 2.3 and 2.5 as shown in Figure One. When the R, G and B Bias settings are all correct, the gray linearity of the uncorrected CRT tone curve is typically excellent, with nearly zero "color crossover" (shift in hue between lighter and darker tones of gray). Because of this excellent tonal and gray balance behavior, it is simple to calibrate a CRT to a gamma 2.2 tone curve with excellent gray linearity, using either well-designed visual or instrument-based display calibration software (see Figure Two).

Although LCDs have evolved greatly and are continuing to improve, LCDs have natural tone curves which differ considerably from pure gamma curves. They also tend to have naturally poor gray linearity, with often serious and disturbing color crossovers. Because of the nature of LCD red, green and blue tone curves, it is necessary, when attempting to adjust them to a standard gamma 2.2 tone curve, to control their shape with a minimum of six, strategically placed points, unlike adjustment of CRTs which can be reasonably well calibrated in some cases with just a single control point.

The only visual calibration system in the world which is capable of exerting this kind of precise tonal and gray balance control at each of the many critical points of the tone scale of an LCD is the system found in Display Tune. Not merely ported from our experience with CRTs, this elegant and user-friendly method adjusts tonality and gray balance simultaneously, thoroughly, and with a minimum number of steps. This way, any LCD can be calibrated to the gamma 2.2 standard tonality with very good gray linearity in a matter of minutes. The method by which visual calibration has been extended to reach all critical areas of the tone curve, is unique to this system, and was carefully optimized just for LCDs. All other visual calibration methods are limited to controlling upper middle-tones, with no control at all over shadow tonality, little control over highlight tonality, and grossly inadequate control over color crossovers. This level of control can be adequate for CRTs but not for all but the very best LCDs. Without adequate control points on the complex tone curves, it is simply impossible to achieve a close match to the desired 2.2 gamma curve with the vast majority of LCDs. Therefore nearly all LCDs remain incapable of displaying color that can approximately match that of CRTs.

The complete combination of hardware adjustments and tone curve calibration performed by the user with Display Tune is
saved into a settings file. The user may save multiple settings files, any of which can be enabled with a click at any time. For example, the user may have saved settings for more than one preferred viewing angle or different room lighting conditions and can instantly switch between them with a simple selection. Any settings file can also be updated by repeating either all or just a few of the steps in Display Tune, as needed to tweak the setup or calibration.

It is important that the end user be able to quickly and easily calibrate the display themselves. End user calibrations take all the variables into account in a way that factory calibrations cannot, including the effects of the graphics card, the user’s preference of viewing angle (which normally does not match the standard zero-degree measurement angle relied upon by instrumented calibration), and the ambient lighting conditions.

Another important advantage of end-user visual calibration with Display Tune is the ability for the user to actually know that the display is well calibrated, because the visual targets prove that it is or it isn’t. Such assurance is normally missing from the computing experience. Any important color assessment, such as when shopping on the Internet or when printing photographs, can be made with more confidence. Work and game environments can be seen nearly the way the software designers intended them to be seen. If calibration were established at the factory for either a display or a display combined with a computer system, the user would have no simple or positive means to verify the calibrated state. It is one thing for a display to be calibrated well, but another thing entirely for the user to be certain of it. Display Tune also actively maintains the correct calibration, despite any efforts of other applications to impose their own calibrations across the entire system, yet allows individual applications to impose their own calibrations while they have priority over the display, after which time Display Tune automatically reasserts its preferred calibration.

Display Tune presents visual calibration targets so the user can approximately match two large gray regions in lightness, hue and chroma. Human beings are very sensitive to small differences between the colors of good-sized gray regions displayed in immediate proximity to one another at the same lightness. However, we are less sensitive to gray balance errors in most color graphics, including color photographs, therefore the effective accuracy of visual calibration is inherently good. In fact, the ability of a “standard human observer” to perceive such mismatches in good-sized gray targets on screen exceeds the accuracy of most instruments used for display calibration. Therefore the end result of visual calibration tends to be excellent when the calibration tool is built correctly for the job.

The combined-channel (gray) targets of Display Tune allow for higher precision in gray balance adjustments than split-channel (red, green and blue) targets, because humans have the ability to detect very small mismatches in hue or lightness when two grays of about the same lightness are displayed side-by-side. Gray targets also work with very dim shadow control points, which would be impossible to adjust with a split-channel target system. In particular, the darker blues which would need to be matched in split-channel shadow patches are impossible for the human visual system to adequately discern.

In addition to the aforementioned problems of LCDs, the incorrect adjustment of Contrast on LCDs very often causes severe and indeed total damage to the tonal separation of the highlights. This problem is not seen on CRTs. This is just one of the areas where Display Tune excels in comparison with Natural Color and other display setup software. The processes that many of these products use for setting Contrast actually guarantee blown out highlights that assure any subsequent calibration gives very poor results.

The unique user interface of the calibration steps in Display Tune, with large gray areas for matching, and the intuitive rainbow color ring as the guide for hue and chroma adjustment, makes it easy to see the colors well and easy to make the movable gray region blend in well. What appears to be a near match at any given viewing angle will give calibration results for that viewing angle that are more than adequate for the accurate viewing of color images, thanks to successful simulation of the tone curve and gray balance of a standard CRT.

The use of Display Tune’s visual calibration is simple:

1) Choose a favorite viewing angle and use that viewing angle for all adjustments and subsequent critical viewing of graphics and images.

2) Set the Contrast, White Point, Pitch, Phase, etc., using the OSD adjustment portion of Display Tune.

3) For each of the six tone steps, adjust the lightness of the inner square to match that of the surrounding lined pattern, using the slider, the up and down buttons on screen, the up and down arrow keys on the keyboard, or the mouse wheel.
Also adjust the hue and chroma of the inner square to approximately match that of the surrounding lined pattern by dragging the square around within the rainbow circle until it appears to have about the same color as the lined area. When the movable square blends fairly well, you’re done.

Until you make a subsequent change to any of these six tone steps, Display Tune will automatically calculate and apply the corresponding compensation to the video signal. This assures data being sent to the screen are being displayed correctly.

At the end of the process, all of the user’s OSD settings and the information necessary to apply the compensated video signal are saved together in a single settings file. The calibration should not have to be repeated for long periods, but can be performed for a variety of ambient lighting or viewing angle conditions, for example, and recalled at will from a list of saved user-defined settings. The display’s behavior can be quickly and comprehensively modified simply by selecting any saved settings file, which loads all adjustments as previously saved to that file. The user can also double check the state of calibration very quickly and easily by stepping through the adjustment screens without the need to make any new adjustments unless the display’s appearance has changed for some reason. Any change in the Contrast setting also requires the display to be recalibrated.

Display Tune’s process is positive, elegant, simple, and uniquely capable. It is the only application that can make any LCD emulate a calibrated CRT at negligible cost.

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