LCD-Plasma Display Technology Shoot-Out

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Introduction

If you were shopping for a large-screen HDTV just a few years ago you would have seen mostly Rear Projection HDTVs, based primarily on DLP, LCD and LCoS technologies, plus a fair number of pricey direct-view Plasmas, and maybe a few very expensive direct-view LCDs. It's amazing how the TV industry has abruptly toggled into an entirely different lineup. Now you'll see mostly direct-view LCDs together with a small number of Plasmas. If you look in some back corner you may find a few attractively priced Rear Projection DLP HDTVs. CRT and LCoS technologies are dead for HDTV, and Rear Projection is "a dead man walking."

Scientifically, it's hard to understand why this happened because CRT, LCoS and DLP offered the highest picture quality at the lowest price, while direct-view large-screen LCDs have historically offered the lowest picture quality at the highest price. The reason seems to be a series of consumer misconceptions together with some high powered industry marketing. Of course, all of the display technologies have improved dramatically over the last few years, so we decided to revisit this topic and do a new in-depth Shoot-Out comparison and analysis of LCD and Plasma technologies to find out how they are currently performing.

Figure 1 shows 11 HDTVs in the DisplayMate Technologies Demo Lab. Included are two Plasmas, eight LCDs, and one CRT Sony Professional HD Trinitron Studio Monitor, which was used as the reference standard. This was an in-depth scientific study that included precise calibrations, comprehensive spectroradiometer measurements, and a large number of jury panelists that viewed test patterns, test photos, and lots of high quality High Definition video material. The Shoot-Out was a large operation that was jointly produced by DisplayMate Technologies (www.displaymate.com) in collaboration with Insight Media (www.insightmedia.info), however, all of the technical analysis was done by the author.

The HDTVs included models from the top-tier brands of (alphabetically) LG, Panasonic, Samsung, Sharp and Sony - from the mid-line to top-of-the-line models. All of the units were from the 2008 model year. Differences between the 2008 and 2009 models are primarily in their marketing hype. For this article we will concentrate on three flagship top-of-the line LCD models from Samsung (LN-T5281F), Sharp (LC-52D92U) and Sony (KDL-52XBR4), and a flagship top-of-the-line Plasma unit from Panasonic Professional (TH-50PF10UK). By concentrating on the top-of-the-line models from the market leaders we are assured of examining the state-of-the-art for each display technology and each manufacturer.

FIGURE 1

Figure 1. The LCD-Plasma Shoot-Out with the lights turned on.
Photograph by Dieter Michel, Publisher of PROSOUND and Medientechnik & Systemintegration Magazines, Germany.

Features and Specifications

The units compete primarily on features and specifications in addition to price. Regular readers will not be surprised to learn that after extensive testing, measurements and analysis we found that the units delivered their best picture quality with all of their much-hyped advanced features, which are essentially marketing gimmicks, turned off. In particular, all of the settings that dynamically process the image were disabled, such as Dynamic

Backlight, Dynamic Contrast, Dynamic Black, Dynamic White, and Dynamic Color. They all reduce picture quality and accuracy and introduce ugly image artifacts. Note that you generally won't find them with these generic names because they are all promoted as exclusive proprietary features with their own catchy marketing names.

In the next article in this series we will discuss Response Time and Motion Blur. Similarly, in all cases we found that the advanced motion processing enhancement options introduced lots of motion artifacts without notably improving motion blur, so we turned all of those features off as well.

The real battle lines, however, are in the specifications published by the manufacturers themselves, because consumers, corporate and government buyers frequently pick a unit based on the advertised specs, even though very few people understand how they are measured or even what they actually mean. Unfortunately, most of the specs are actually marketing tools rather than a set of scientifically objective tests and measurements. Previous articles in the Display Technology Shoot-Out series have examined many of these specs and issues. Here we continue with an in-depth analysis of Viewing Angles, and in Part 2 on Response Time and Motion Blur.

Set Up and Calibration

The units were all set up, calibrated and compared side-by-side in a Shoot-Out configuration. All of the HDTVs were fed identical digital HDMI signals, simultaneously showing identical high quality all-digital 1080p content. The calibrations were all done with DisplayMate Multimedia Edition test patterns and a Konica Minolta CS-200 Spectroradiometer for accurate photometry and colorimetry measurements. Refer to earlier articles in this Display Technology Shoot-Out series, which are now all available together on www.displaymate.com, for in-depth discussions and explanations.

Sony and Panasonic Units

The Sony and Panasonic units required very little effort to nudge into excellent agreement with the HDTV Rec.709 standard, with accurate primary chromaticities, a D6500 White Point, and an accurate intensity scale with an accurate 2.2 Gamma, which will all be discussed in greater detail below. The calibrations of both units were so close that it was frequently impossible to visually tell them apart. Except… when viewing the Sony LCD slightly off axis, or when there was dark content, or when there was significant motion in the picture. The Panasonic Plasma performed best in all of these areas. The differences were amazing and astonished everyone that came to see and compare them side-by-side. More on that below…

Sharp and Samsung Units

If you had no other source for comparison, then the top-of-the-line Sharp unit might look reasonably good. But next to all of the other flagship HDTVs, including the reference Studio Monitor, it looked significantly worse than all of the other units. The colors, hues, saturations, and intensity scales were way off and there were lots of noticeable ugly artifacts. We started to do a low-level service mode recalibration, but in the end found it to be a pointless exercise and the unit was returned to the original factory settings. So the Sharp unit was punished and sent to the corner where it was mostly ignored.

The Samsung unit was quite good, but definitely a step down in color and gray-scale accuracy from the Sony and Panasonic units. Its most distinctive features were Dynamic LED backlighting together with zoned LED Local Dimming. We turned these features off because they introduced intensity scale errors and ugly halos in scenes with dim content. A challenging test for HDTVs with Dynamic Backlights and Local Dimming is Chapter 14 of *2001: A Space Odyssey*, which includes the trip through hyperspace. For portions of this chapter the Samsung unit decided that the moving star fields and other content were not worth seeing and just showed an entirely black screen. This is because the dimming algorithms are based primarily on the Average Picture Level, which can be very low but still contain important content that needs to be shown and seen.

Photometry and Colorimetry

The only way that an HDTV will deliver good color and gray scale accuracy is if it is accurately calibrated to an industry standard specification, which for digital HDTVs is ITU-R BT.709, and is frequently referred to as Rec.709. If you want to see exactly what the director or content producer saw at the studio, then make sure your HDTV is properly calibrated. This includes an accurate set of primary colors, an accurate white point, and an accurate intensity and brightness scale, which is called the Transfer Function and Gamma. See earlier articles in this series for in-depth explanations.

One common misconception that is frequently exploited by some manufactures is that a wider color gamut indicates a better TV that produces more realistic colors. This is absolutely wrong because a larger color gamut will simply make all of the screen colors appear more saturated than they ought to appear on a calibrated standard HDTV. Wider color gamuts decrease color accuracy and should be avoided except in specialized imaging applications – for example in medical or military applications. If you do get an HDTV with an extended color gamut it will be necessary to reduce the color gamut back to the Rec.709 standard values by using the color saturation control or other color management functions within the unit, so it is a pretty useless feature in HDTVs. It's just a premature technology being used as a marketing gimmick!

Figure 2 shows the 1976 CIE Uniform Chromaticity Diagram with the measured primary colors for the Sony unit. The black triangle is the Rec.709 standard and the red dots are the measured values for the Red, Green and Blue primary colors, which all fall exactly where they should on the triangle vertices. This is quite impressive because the Sony values are virtually indistinguishable from perfect! The other flagship HDTVs were pretty good, but not quite as accurate.

FIGURE 2

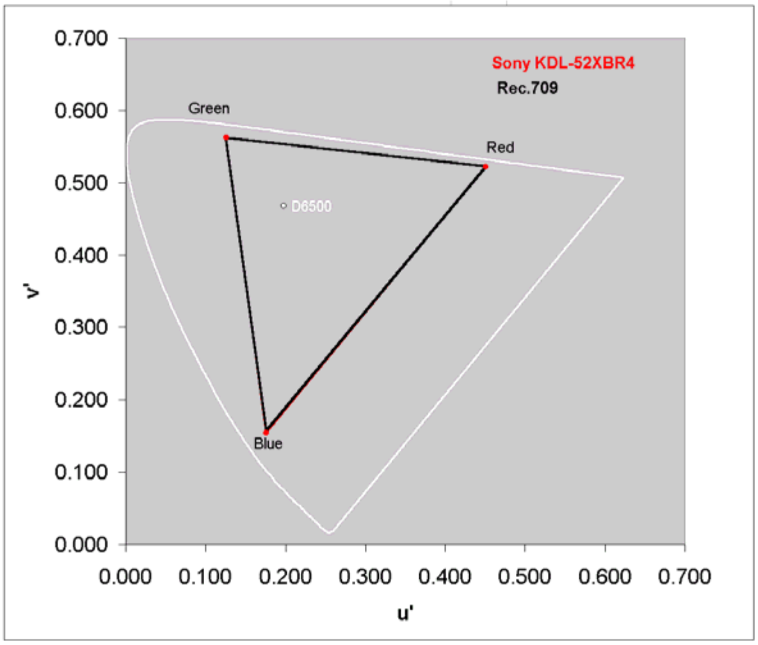

Figure 2. 1976 CIE Uniform Chromaticity Diagram for the Sony unit.

Getting the primary colors exactly right is fairly easy, even though most manufacturers seem to be unable to do so. It's actually a lot harder and much more important to get the intensity scale exactly right. When the intensity scale is wrong the relative mixtures of the Red, Green and Blue primary colors that are used to generate all of the on-screen colors will always turn out wrong. When that happens you may be able to adjust some of the colors in a picture to come out right, but then lots of other colors will turn out wrong, so the picture never looks right.

After performing careful calibrations on all of the units, Figure 3 shows the resulting Transfer Function intensity scales for all four HDTVs together with a perfect mathematical power-law Gamma of 2.2, shown in black. Note that the plotted scales are both logarithmic, which is necessary to properly display the desired power-law relationship. Screen Brightness is on the vertical scale and signal intensity is on the horizontal scale. See the earlier articles for detailed descriptions and explanations. The Sharp unit was way off, particularly at low intensities. This was probably done intentionally to make the unit appear to have a deeper and blacker contrast, but it leads to all sorts of artifacts and color errors. Although it is hard to see on this scale, which covers a range of more than 200:1 in brightness, the Samsung unit initially falls more slowly, and is consistently above the Gamma 2.2 line down to about 20 percent intensity, and then it falls faster, probably for the same reasons as the Sharp. The Panasonic and Sony units track each other and the Gamma 2.2 line fairly well over a brightness range of about 100:1. That is why they are virtually indistinguishable for both color mixtures and brightness scales. Note that the dim part of the intensity scale is still regularly used, even when mixing bright colors that require only a small amount of one or more of the primaries to get the desired on-screen color, so if the intensity scale is wrong anywhere then the colors are wrong everywhere!

FIGURE 3

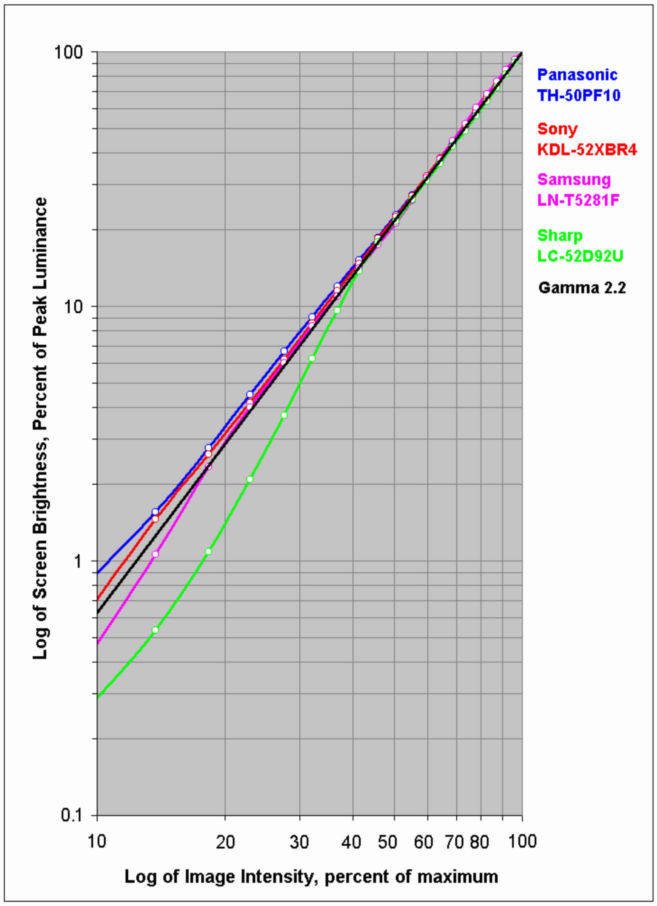

Figure 3. The Transfer Functions for the four HDTVs together with the standard Gamma of 2.2 in black.

Sony is the only major HDTV manufacturer that seems to be able to deliver a fairly accurate calibration across most of its product lines once you take the units out of their factory default Vivid Mode and set them to a Cinema or Custom mode. Surprisingly, most HDTV manufacturers do not know how to accurately calibrate an HDTV on a factory assembly line. There are some manufacturers that can, but choose not to do so because they consider it too expensive and time consuming, or they decide to instead produce an exaggerated punchy picture in a misguided attempt to stand out from the crowd.

Now that many HDTVs are coming with USB ports for Digital Cameras, absolute color and gray scale accuracy will finally become an absolute necessity because family viewers know exactly how all of the people, colors, clothing, and objects in their photos should look, and will be angry at the manufacturer if they do not show up accurately on their HDTV.

Brightness and Contrast Ratio

In the spec wars, Brightness and Contrast Ratio seem to be the most important numbers for both consumers and manufacturers. Unfortunately, both of these specs are significantly misunderstood as well as significantly abused and exaggerated. The values published by most manufacturers are now so outrageous that they are close to absolute nonsense, and it's getting worse. Here's why…

Throughout this series we have measured the Brightness and Contrast values using a consistent and scientifically objective procedure. See earlier articles for an in-depth discussion and explanation. Briefly, here is their significance: you need to have a sufficient amount of brightness for comfortable viewing in your ambient light viewing conditions, but after that more is not better, in fact, for some display technologies it is actually worse. Contrast Ratio is affected primarily by how dark and close to black the screen can get, but that is only important under low ambient lighting conditions. Note that it is only possible to obtain high picture quality and accuracy under low ambient lighting. In that case you need moderate brightness and a high Contrast Ratio. For high ambient lighting, you need high brightness, but don't worry about picture quality or accuracy, or Contrast Ratio, because they are all irrelevant under these viewing conditions.

Table 1 summarizes the principal photometry measurements for the HDTVs. The Highest Calibrated Luminance is the maximum brightness that the unit can produce while calibrated as described above. For the LCDs, this was obtained from the highest Backlight setting available. For side-by-side comparisons the Backlight for each of the LCD units was adjusted to provide a comparable and comfortable Luminance of about 200 cd/m^2. Note that this is actually a bit on the high side for low ambient light viewing without causing eye strain, but is still lower than the settings many consumers are likely to use.

Table 1: Photometry and Colorimetry Measurements Summary

	Highest Calibrated Luminance	Peak Luminance Setting Used	True Contrast Ratio	Correlated Color Temperature
Panasonic Plasma	186 cd/m^2	186 cd/m^2	3,842	6499 K
Samsung LCD	427 cd/m^2	189 cd/m^2	1,877	7035 K
Sharp LCD	307 cd/m^2	192 cd/m^2	1,330	7334 K
Sony LCD	362 cd/m^2	202 cd/m^2	1,344	6495 K

The above are the scientifically objective values, but you may see brightness specs of 1000 cd/m^2 or more, which if true would be dangerous to view indoors without sunglasses. It's pointless to bother explaining how these fictitious values are obtained. But the biggest exaggerations are now with Contrast Ratio, obtained by inventing a new so-called "Dynamic Contrast." In 2008 many TVs were advertised with a "Dynamic Contrast" in the range of 15,000 to 35,000. In 2009 they are now up to as high as 100,000, but there is no real improvement, it's the same trick with a bigger exaggeration. Here is how it is done, it's quite simple: when the video signal is black or very close to black the TV electronics goes into a special standby mode that significantly reduces the light output of the unit (but it generally can't go too low because then it takes longer to emerge from standby when a non-black picture returns). This dark standby value is then used when computing the Contrast Ratio instead of the real dark value when a picture is present. This does not change the Black Luminance or the Contrast Ratio for any picture that is not all black, so it is absolutely meaningless for picture quality. The primary reason for including this feature is that the published Contrast Ratio goes from about 1,500 up to 15,000 to 35,000 or more.

Viewing Angles

Another important and prominently advertised specification is the range of acceptable Viewing Angles for a TV. For virtually all HDTVs the published values are at least 176 degrees (or ±88 degrees) out of a possible 180 degrees (±90 degrees). Viewing Angle is especially important for HDTVs because the audience may be seated at significantly different viewing locations throughout a room. So according to this claim, unless you are seated at a ridiculous 2 degrees from the edge of the screen you will see a perfectly fine picture. For all current LCDs this is absolute nonsense. What we found in both the measurements and viewing tests is that for LCDs the Viewing Angle where there is noticeable picture degradation is a mere ±10 degrees, not ±88 degrees. Let's see how this all comes about. There are three major issues or problems:

The first problem is that the industry standard Viewing Angle specification for LCDs is based on the angle where the Contrast Ratio falls to 10, which is a ridiculously low value because these units have Contrast Ratios of about 1,500 when viewed face on. Let's see how the Contrast Ratio varies with Viewing Angle.

We measured the Peak White and Black Luminance values for the HDTVs at a moderate 45 degree angle and then recomputed the Contrast Ratios for each of the units. The values are listed in Table 2. At 45 degrees the Panasonic Plasma was down by a moderate 9 percent, but the LCD units were down by enormous factors of 2.9 to 7.6. What happens for LCDs is that the Peak White Luminance decreases with viewing angle while the Black Luminance increases with viewing angle. Both of these effects reduce the Contrast Ratio. The Black Luminance values are listed in Table 3. Plasma displays behave very similarly to CRTs and deliver a Peak White Luminance and Black Luminance that is fairly independent of Viewing Angle. The Black Luminance actually decreases a bit with angle for the Plasma unit because of an anti-reflection absorbing layer on the screen.

Table 2: True Contrast Ratio with Viewing Angle

	0 Degrees	45 Degrees
Panasonic Plasma	3,842	3,502
Samsung LCD	1,877	462
Sharp LCD	1,330	174
Sony LCD	1,344	467

Table 3: Black Luminance with Viewing Angle

	0 Degrees	45 Degrees
Panasonic Plasma	0.07 cd/m^2	0.06 cd/m^2
Samsung LCD	0.11 cd/m^2	0.28 cd/m^2
Sharp LCD	0.15 cd/m^2	0.61 cd/m^2
Sony LCD	0.15 cd/m^2	0.28 cd/m^2

The second issue is that the eye is much more sensitive to variations in color than the luminance values used to determine the Contrast Ratio variation. So, while some pictures with very bright and saturated colors may be considered viewable at ±45 degrees, more typical pictures that include a wide range of intensities, hues and saturations will appear significantly degraded at much smaller viewing angles.

Figure 4 shows the variation in color with Viewing Angle for each of the tested units. This effect is due to the fact that for bright LCD sub-pixels the brightness decreases with Viewing Angle and for dim sub-pixels the brightness increases with Viewing Angle, which can in some cases lead to contrast reversal. Since this occurs independently for each of the Red, Green, and Blue sub-pixels that produce the entire gamut of colors seen on-screen, it leads to a rather complex behavior of brightness and color variation with Viewing Angle. Color mixtures show the greatest variations with angle, but displays are engineered so that things balance out for whites and grays, which are particular mixtures of all of the primary colors together.

The eye is much more sensitive to reds and greens than blues, so we've picked a sample color with a mixture of 100% red and 50% green to measure and analyze, which is an orange color that has roughly equal luminance contributions from both red and green. The results are based on spectroradiometer measurements and presented in terms of MPCD Minimum Perceptible Color Difference or JNCD Just Noticeable Color Difference, where 1 MPCD = 1 JNCD = Δ(u'v') = 0.0040 on the 1976 CIE Uniform Chromaticity Scale. Values less than 1 are visually indistinguishable, while values much greater than 1 are blatantly different.

FIGURE 4

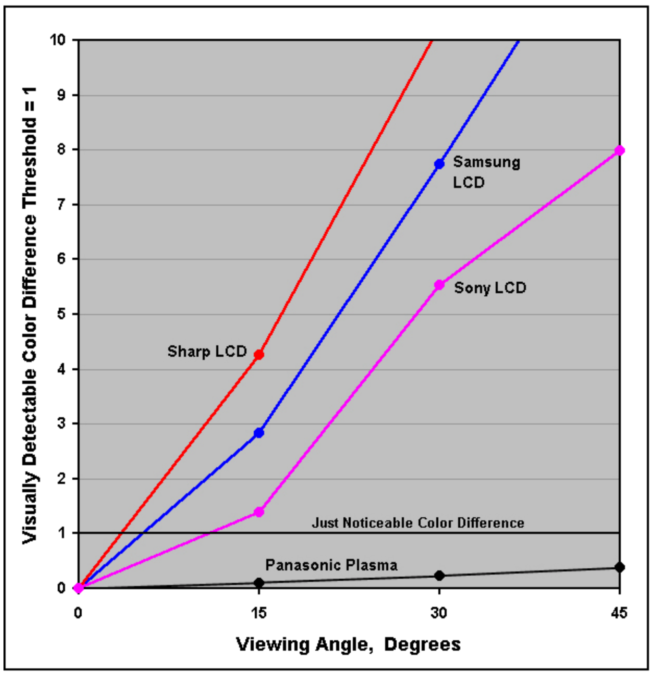

Figure 4. Color mixture color shifts with angle

All of the LCD units have a noticeable color shift at less than ±15 degrees, while the Panasonic Plasma is visually indistinguishable from face on viewing well beyond ±45 degrees. This is true for both the measurements and the viewing tests. The significance of this is enormous, because it means that the "sweet spot" for seeing an accurate picture on an LCD HDTV is only one person wide, even for these top-of-the-line models, so essentially everyone looking at an LCD HDTV will see a picture with noticeably different coloration.

Third: unfortunately, it gets even worse for LCD HDTVs that have an Extended Color Gamut, such as the Sony and Samsung units, which show additional and much stronger Viewing Angle artifacts than LCDs with a standard HDTV color gamut, such as the Sharp unit. Right now there is essentially no commercially available content with an Extended Color Gamut, so this feature is just a marketing gimmick. But a gimmick with a significant penalty for all of the current content with a Standard Color Gamut. This is because the standard HDTV primary colors for these units must be generated as color mixtures of the native extended gamut primary colors, and those color mixtures then vary with viewing angle just like the other colors. As a result a much larger fraction of the HDTV color gamut shows a strong variation with angle. The Sharp unit does not have an extended color gamut and as a result performed much better with primary colors than both the Sony and Samsung units. Figure 5 repeats the measurements and analysis with angle for the pure Red and Green HDTV primary colors in order to examine the effect of Extended Color Gamuts. The Sharp LCD and Panasonic Plasma have only a small shift in primary color chromaticity with angle, while the Sony and Samsung units both show very large variations with angle.

FIGURE 5

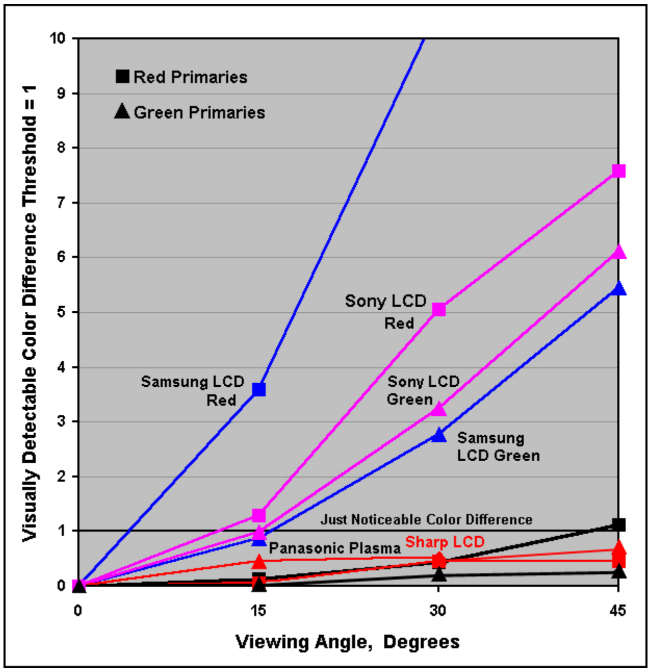

Figure 5. Primary color shifts with angle

The viewing tests were even more dramatic than the above measurements might suggest. The differences were amazing and astonished everyone that came to see and compare the HDTVs side-by-side, including industry experts, manufacturers, engineers, reviewers, journalists, and ISF instructors. Everyone knew there were viewing angle effects, but our side-by-side tests showed how incredibly large they actually are. The best examples were with the two units with the best picture quality: the Sony LCD and the Panasonic Plasma, which were set right next to one another. Their calibrations were both so close that it was frequently impossible to visually tell them apart. But that was true only when standing exactly dead center in front of the Sony unit. Shifting left or right by just one foot at an optimum viewing distance of 7 feet caused the Sony LCD unit to appear noticeably different from the Panasonic unit next to it, which delivered a consistent picture independent of viewing angle. This same effect also applies to vertical viewing positions and angles, so don’t even think about mounting your LCD HDTV over the fireplace! Make sure the center of the TV is close to your normal viewing eye level.

The shocking conclusion is that only one person at a time can see accurate color reproduction on a direct-view LCD HDTV, even on top-of-the-line units from the top manufacturers. Even when viewers are seated close together side-by-side, each person will see a different picture with noticeably different coloration. On the other hand, Plasma displays deliver very close to true 180 degree (±90 degree) viewing, the same as traditional CRT monitors. There is very little change in brightness, contrast, hue, or color saturation over the entire 180 degree viewing area.

A rather interesting method that we used to demonstrate these effects was to have people walk past the lineup of HDTVs shown in Figure 1 while simultaneously viewing and comparing static photographs on the HDTVs, and then seeing how the units drifted in and out of accuracy as they walked by each unit. Static photographs are crucial for evaluating picture quality and accuracy because they stay the same throughout the entire test, whereas live video is constantly changing so a detailed comparison and evaluation, even between two units, can not be done using that method.

Figure 6 is a set of photographs taken at 0 and 45 degrees in front of the Panasonic Plasma and the Sony and Sharp LCD units. These screen photographs demonstrate the change in color with viewing angle for the test units. When viewed in person the differences were much more pronounced than they appear here in these printed thumbnails, which are affected by the Transfer Function of the camera and the printing process.

FIGURE 6

***"Red Door"* – On-axis color is good, but shifts to orange in the off-angle LCD.** Photographer Don Cochran.

Panasonic Plasma **Sony LCD**

***"Girl with Painted Face"* – Note the change in the skin color in the off-angle LCD.** Photographer Steve Kelly.

Panasonic Plasma **Sharp LCD**

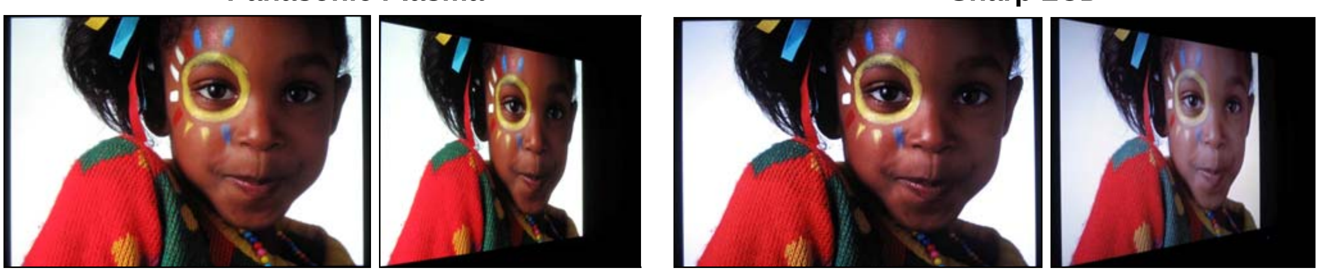

Figure 6. Photographs at 0 and 45 degrees of the Panasonic Plasma and Sony and Sharp LCD units.

What's Coming Next

In Part 2 we will examine LCD Response Time, motion blur, and motion artifacts by using high-speed screen photographs of moving DisplayMate Multimedia Edition Test Patterns and Test Photos. We'll see that the actual Response Times can be almost 10 times their advertised values.

About the Author

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