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Galaxy S4 Display Technology Shoot-Out

Samsung Galaxy S III – Samsung Galaxy S4 – Apple iPhone 5

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Samsung Galaxy S III Samsung Galaxy S4 Apple iPhone 5

Introduction

The Samsung Galaxy S Smartphones are by far the most popular Android Smartphones and are flagship products for Samsung to show off its latest and greatest OLED display technology. The display on the Galaxy S4 is a major enhancement and improvement over the Galaxy S III – it has a full HD 1920x1080 resolution display with 441 Pixels Per Inch. It is also better calibrated, brighter, and bigger. We'll analyze the Galaxy S4 with an in-depth objective series of Lab tests and measurements included below.

Samsung provided DisplayMate Technologies with an early production unit to test and analyze for our Display Technology Shoot-Out article series. It is likely that the retail units will have additional display firmware and software tweaks and improvements over our test unit. If that is the case, we will update the article when our unit is upgraded by Samsung.

OLED Displays

While most mobile displays are still LCD based, OLEDs have been capturing a rapidly increasing share of the mobile display market. The technology is still very new, with the Google Nexus One Smartphone, launched in January 2010, as the first OLED display product that received widespread notoriety. In a span of just a few years this new display technology has improved at a very impressive rate, now challenging the performance of the best LCDs. Virtually all of the OLED displays used in mobile devices are produced by Samsung Display. We have provided an in-depth analysis on the evolution of OLEDs in our [Galaxy S I, S II, and S III Display Technology Shoot-Out](#) article.

The Shoot-Out

To examine the performance of the [Samsung Galaxy S4](#) we ran our in-depth series of [Mobile Display Technology Shoot-Out](#) Lab tests and included the [Galaxy S III](#) in order to determine how OLED displays have improved, and the iPhone 5 to determine how it compares to a leading high-end LCD display. We take display quality very seriously and provide in-depth objective analysis side-by-side comparisons based on detailed laboratory measurements and extensive viewing tests with both test patterns and test images. To see how far Smartphones have progressed in just three years see our [2010 Smartphone Display Shoot-Out](#), and for a real history lesson see our original [2006 Smartphone Display Shoot-Out](#).

Results Highlights

In this Results section we provide Highlights of the comprehensive Lab measurements and extensive side-by-side visual comparisons using test photos, test images and test patterns that are presented in later sections. The [Comparison Table](#) in the following section summarizes the lab measurements in the following categories: [Screen Reflections](#), [Brightness and Contrast](#), [Colors and Intensities](#), [Viewing Angles](#), [Display Power Consumption](#), [Running Time on Battery](#). You can also skip the Highlights and go directly to the [Conclusions](#).

A Full HD 1920x1080 Display

By far the most interesting recent development in Smartphones is a full High Definition 1920x1080 display in a 5.5 inch or smaller screen size – the same pixel resolution as your 50 inch living room HDTV – that's very impressive! First of all, this is a benchmark spec with a tremendous marketing power for driving consumer sales. But there are other important reasons for going to Full HD in a Smartphone – there is a tremendous amount of HD 1920x1080 content available. Displaying that content at its native resolution (without the need to rescale up or down) results in the best possible image quality, plus rescaling requires processing overhead that uses (wastes) precious battery power. The Galaxy S4 is one of the first few Smartphones to offer Full HD.

400+ Pixels Per Inch Displays

Apple started a major revolution in display marketing by introducing their "Retina Display" with 326 Pixels Per Inch (PPI) on the iPhone 4 in 2010. While not equivalent to the resolution of the human retina, people with 20/20 Vision cannot resolve the individual pixels when the display is held at normal viewing distances of 10.5 inches or more. It started a display PPI and Mega Pixel war similar to what happened with Smartphone digital cameras, which is still an ongoing wild goose chase now into the stratosphere... Hopefully the same thing won't happen with mobile displays because there are tradeoffs involved that affect other important display performance issues. The real question is how high do we need to go before reaching a practical visual PPI limit? I'll cover this in an upcoming article. However, a new generation of 400+ PPI displays is already here, driven by the desire to produce a Full HD 1920x1080 display on a Smartphone screen. [The Galaxy S4 has an incredible 441 Pixels Per Inch](#). People with 20/20 Vision cannot resolve the individual pixels on a 441 PPI display for viewing distances of 7.8 inches or more, which is exceedingly close for viewing a 5.0 inch display.

PenTile Displays

The pixels on most current OLED displays have only 2 sub-pixels in each pixel instead of the standard 3 Red, Green, and Blue sub-pixels found in most other displays and display technologies. Half of the PenTile pixels have Green and Red sub-pixels and the other half have Green and Blue sub-pixels, so Red and Blue are always shared by two adjacent pixels. This makes PenTile displays easier to manufacture and at a lower cost. It also improves brightness and reduces aging effects. Because the eye has lower visual acuity for color this works very well for photographic and video images. But for digitally generated fine text and graphics with precise pixel layouts the eye can visually detect the reduced number of Red and Blue sub-pixels unless the number of Red and Blue Sub-Pixels Per Inch is very high. And it is for the Galaxy S4 – there are 312 Red and Blue Sub-Pixels Per Inch, which is only a few percent lower than Apple's Benchmark 326 PPI iPhone Retina Display. Visually the Galaxy S4 PenTile display delivers excellent visual sharpness across the board.

Diamond Pixels

[A high resolution screen shot of the Galaxy S4](#) (provided by Samsung) shows an interesting design and sub-pixel arrangement, which Samsung calls [Diamond Pixels](#). First of all, the Red, Green, and Blue sub-pixels have very different sizes – Blue is by far the largest because it has the lowest efficiency, and Green is by far the smallest because it has the highest efficiency. The alternating Red and Blue sub-pixel PenTile arrangement discussed above leads to a 45 degree diagonal symmetry in the sub-pixel layout. Then, in order to maximize the sub-pixel packing and achieve the highest possible PPI, that leads to diamond rather than square or stripe shaped Red and Blue sub-pixels. But not for the Green sub-pixels, which are oval shaped because they are squeezed between two much larger and different sized Red and Blue sub-pixels. It's display art...

Digital Display Technology

Most consumers are not aware that LCDs are actually non-linear analog displays that perform really well only as the result of highly refined electronics and careful factory calibration. This is the same reason why even living room HDTVs provide coarse and imprecise color and image controls, and why professional calibration is desirable. One interesting technical development is that the latest OLED displays use digital Pulse Width Modulation to specify the brightness of every sub-pixel. This makes it possible for OLED displays like the Galaxy S4 to precisely vary and directly digitally control their Intensity Scales, Gamma values, White Points, color calibration and color management of the display in firmware or software. Plasma and DLP displays also use digital Pulse Width Modulation, but the OLED displays perform better because of higher frequencies and faster response times.

Screen Modes

One important application of the Digital Display Technology mentioned above is that this makes it relatively easy to provide a number of different display calibration options and settings that will appeal to differing consumer tastes and preferences under various viewing conditions and applications. The Galaxy S4 (like its bigger cousin the Galaxy Note II) includes 5 user selectable Screen Modes: Adaptive, Dynamic, Standard, Professional Photo, and Movie, which we discuss below and include measurements for the Standard and Movie Modes.

Color Gamut and Color Accuracy

The Galaxy S4 Movie Mode delivers the closest Color and White Point calibration to the standard sRGB/Rec.709 consumer content that is used for digital camera, HDTV, internet, and computer content, including virtually all photos and videos. Use the Movie Mode for the best color and image accuracy. Its Green primary is still somewhat too saturated – hopefully it will get toned down some as in the Galaxy Note II, which is very accurate. The Professional Photo Mode provides a fairly accurate calibration to the Adobe RGB standard, which is rarely available in consumer displays, and is very useful for high-end digital photography applications. The Standard Mode is the default mode for the Galaxy S4 – it delivers higher color saturation, which appeals to some, and is a better choice for high ambient light viewing conditions, which wash out image colors and contrast. This mode is very similar to the Professional Photo Mode, but has a more bluish White Point. Its Green primary is also too saturated, but noticeably less than in the Galaxy S III. The Dynamic Mode produces the most vibrant image and picture quality. Compare the Color Gamuts in this [Figure](#) and below.

Brightness and Power Efficiency

OLED displays are generally not as bright as the brightest LCD displays. There are two reasons for this: first, while OLED power efficiency has been steadily improving they are not yet as power efficient as the best LCDs. Second: there is a marketing obsession for producing ultra thin and light weight Smartphones, which sacrifices much needed battery power. Since the display often uses 50 percent or more of the total Smartphone power, various display power management schemes are frequently used. The Galaxy S4 uses one innovative approach to overcome this – when Automatic Brightness is turned on, the Peak Brightness becomes significantly brighter in high ambient lighting than is possible with Manual Brightness, up to as high as 475 cd/m², which is 34 percent higher than is possible with Manual Brightness. This is done so that users can't permanently set the brightness to very high values, which would run down the battery quickly.

Performance in High Ambient Lighting

Smartphones are never used in the dark. In fact, they are often used in very bright ambient lighting, which can significantly degrade and wash out their image and picture quality. The Galaxy S4 performs very well in high ambient lighting in spite of its typically lower screen brightness because it has one of the smallest screen Reflectance values of any display we have ever tested, and its more saturated colors can help cut through the reflected light glare. When Automatic Brightness is turned on, the screen brightness increases considerably at high levels of ambient lighting as mentioned above. The Galaxy S4 is then comparable or brighter than most LCD Smartphones, but still 15 percent less than the much smaller iPhone 5, which is the brightest Smartphone we have tested.

Viewing Tests

The Galaxy S4 Movie Mode provides very nice, pleasing, and accurate colors and picture quality. The Movie Mode is recommended for indoor and low ambient light viewing. The Standard Mode has significantly more vibrant and saturated colors. Some people like that. The Standard Mode is recommended for medium levels of ambient light viewing because it offsets some of the reflected glare that washes out the images. The Dynamic Mode provides incredibly powerful colors that are overwhelming in low ambient lighting. The Dynamic Mode is recommended for high ambient light viewing only. For all of the Modes a slight green color tint was sometimes noticeable, but not objectionable. It results from the Green primary being more saturated than the Red and Blue primaries, as shown in this [Figure](#). Readjusting the internal color management could fix this...

Comparing Displays on the Galaxy S III and Galaxy S4

The Galaxy S4 display is a major enhancement and improvement over the Galaxy S III – a good reason to consider trading up. The screen has Full HD 1920x1080 resolution with more than double the number of pixels and with 44 percent higher Pixels Per Inch than the Galaxy S III. It is 25 percent brighter (and up to 68 percent brighter with Automatic Brightness) and the display is 20 percent more power efficient. The Galaxy S4 also has 5 user selectable Screen Modes and delivers much better picture quality and color accuracy.

Comparing the Galaxy S4 with the LCD Display on the iPhone 5

The iPhone 5 is now more than half way through its product cycle, which is important to keep in mind for our comparison. However, high-end LCDs like the iPhone 5 are a very mature and refined display technology, so other than screen size, resolution, and the Pixels Per Inch not much is likely to change in the next generation, no matter what Apple decides to do. The iPhone 5 is significantly brighter than the Galaxy S4, particularly for screens with mostly peak white backgrounds. Its color calibration is a bit better, although the Galaxy S4 has a more accurate White. The Galaxy S4 has a much bigger screen, higher resolution, higher PPI, much darker blacks, and better screen uniformity than the iPhone 5. They each have their own particular strengths and weaknesses, but if you scan our color coordinated [Comparison Table](#) below, both displays are quite good and comparable overall – so it's currently a tie – we'll see how they both evolve and improve in the next generation...

Conclusions: An Impressive OLED Display...

The Galaxy S4 continues the rapid and impressive improvement in OLED displays and technology. The first notable OLED Smartphone, the [Google Nexus One](#), came in decidedly last place in our [2010 Smartphone Display Shoot-Out](#). In a span of just three years OLED display technology is now challenging the performance of the best LCDs. Each have their own particular strengths and weaknesses, but if you scan our color coordinated [Comparison Table](#), both displays and technologies perform quite well and look quite good and comparable overall – we'll see how they both evolve and improve in the next generation, which we consider next...

The biggest challenge for OLEDs is continuing to improve their power efficiency and full screen peak brightness. We measured an impressive 20 percent improvement in power efficiency between the Galaxy S4 and S III, and a 25 percent increase in brightness (and up to 68 percent with Automatic Brightness). If this keeps up then OLEDs may pull ahead of LCDs in brightness and power efficiency in the near future...

Of course, LCDs are not standing still either. There has been a remarkable increase in their resolution and Pixels Per Inch. IGZO and more advanced Metal Oxide backplanes will help to significantly improve their efficiency and performance. Quantum Dots should help them to efficiently enlarge their Color Gamuts to catch up with OLEDs, which is important for delivering accurate color and image contrast in high ambient lighting.

Both OLEDs and LCDs need to carefully expand their color management and color calibration. The biggest improvements for mobile displays will come from dynamically changing the display Color Gamuts and Intensity Scales to automatically compensate and correct for reflected glare and image wash out from ambient light. Which ever one succeeds is likely to win in the next generation of mobile displays...

DisplayMate Display Optimization Technology

All Smartphone and Tablets displays can be significantly improved using DisplayMate's advanced scientific analysis and mathematical display modeling and optimization of the display hardware, factory calibration, and driver parameters. We help manufacturers with expert display procurement and quality control so they don't make mistakes similar to those that are exposed in our Display Technology Shoot-Out series. We can also improve the performance of any specified set of display parameters. This article is a lite version of our intensive scientific analysis – before the benefits of our [DisplayMate Display Optimization Technology](#), which can correct or improve all of these issues. If you are a display or product manufacturer and want to significantly improve display performance for a competitive advantage then [Contact DisplayMate Technologies](#).



Samsung Galaxy S III Samsung Galaxy S4 Apple iPhone 5

Display Shoot-Out Comparison Table

Below we compare the display on the [Samsung Galaxy S4](#) with the [Samsung Galaxy S III](#) and [Apple iPhone 5](#) based on objective measurement data and criteria. For additional background and information see the [Flagship Smartphone Display Technology Shoot-Out](#) between the [iPhone 5](#) and the [Galaxy S III](#), and the [Samsung Galaxy S OLED Display Technology Shoot-Out](#) that compares and analyzes the evolution of the OLED displays on the [Galaxy S I, II, and III](#).

Categories	Samsung Galaxy S III	Samsung Galaxy S4	Apple iPhone 5	Comments
Display Technology	4.8 inch PenTile OLED	5.0 inch PenTile OLED	4.0 inch IPS LCD	Organic Light Emitting Diode Liquid Crystal Display with In Plane Switching
Screen Shape	16:9 = 1.78 Aspect Ratio	16:9 = 1.78 Aspect Ratio	16:9 = 1.78 Aspect Ratio	The Galaxy S4 and Galaxy S III screens have the same shape as widescreen HDTV video content.
Screen Area	9.8 Square Inches	10.6 Square Inches	6.7 Square Inches	A better measure of size than the diagonal length.
Relative Screen Area	92 percent	100 percent	63 percent	Screen Area relative to the Galaxy S4.
Display Resolution	1280 x 720 pixels	1920 x 1080 pixels	1136 x 640 pixels	The more Pixels and Sub-Pixels the better.
Pixels Per Inch	PenTile 306 PPI Very Good	PenTile 441 PPI Excellent	326 PPI Excellent	At 12 inches from the screen 20/20 vision is 286 ppi. See this on the visual acuity for a true Retina Display
Sub-Pixels Per Inch	Red 216 SPPI Green 306 SPPI Blue 216 SPPI	Red 312 SPPI Green 441 SPPI Blue 312 SPPI	Red 326 SPPI Green 326 SPPI Blue 326 SPPI	PenTile displays have only half the number of Red and Blue Sub-Pixels as standard RGB displays.
Total Number of Sub-Pixels	Red 462 KSP Green 922 KSP Blue 462 KSP	Red 1,037 KSP Green 2,074 KSP Blue 1,037 KSP	Red 727 KSP Green 727 KSP Blue 727 KSP	Number of Kilo Sub-Pixels KSP for Red, Green, Blue. PenTile displays have only half the number of Red and Blue Sub-Pixels as standard RGB displays.
20/20 Vision Distance where Pixels or Sub-Pixels are not resolved	11.2 inches White / Green 15.9 inches Red / Blue	7.8 inches White / Green 11.0 inches Red / Blue	10.5 inches for All	For 20/20 Vision the minimum Viewing Distance where the screen appears perfectly sharp to the eye.
Gallery / Photo Viewer Color Depth	Full 24-bit color No Dithering Visible 256 Intensity Levels	Full 24-bit color No Dithering Visible 256 Intensity Levels	Full 24-bit color No Dithering Visible 256 Intensity Levels	Many Android Smartphones and Tablets still have some form of 16-bit color depth in the Gallery Photo Viewer . Samsung Galaxy S4 and S III do not have this issue.
	Galaxy S III	Galaxy S4	iPhone 5	
Overall Assessments This section summarizes the results of all of the extensive Lab measurements and viewing tests performed on all of the displays.				
Viewing Tests in Subdued Ambient Lighting	Good Images Photos and Videos have too much color and accurate contrast	Movie Mode Very Good Images Photos and Videos have very good color and accurate contrast	Very Good Images Photos and Videos have excellent color and accurate contrast	The Viewing Tests examined the accuracy of photographic images by comparing the displays to a calibrated studio monitor and HDTV.
Variation with Viewing Angle	Medium Color Shifts with Viewing Angle Medium Brightness Shift with Viewing Angle	Medium Color Shifts with Viewing Angle Small Brightness Shift with Viewing Angle	Small Color Shifts with Viewing Angle Large Brightness Shift with Viewing Angle	The iPhone 5 LCD has a very large Brightness decrease with Viewing Angle but somewhat smaller color shifts than the Galaxy S4.
Overall Display Assessment Lab Tests and Measurements	Very Good OLED Display	Excellent OLED Display	Excellent LCD Display	The Galaxy S4 and iPhone 5 are both Best of Breed.
Overall Display Calibration Lab Tests and Viewing Tests	Calibration Needs Major Improvement	Movie Mode Very Good Calibration	Excellent Calibration	The iPhone 5 currently has a somewhat more accurate calibration than the Movie Mode.
Overall Display Grade	B+	A	A	The Galaxy S4 and iPhone 5 displays both have their strengths. Overall they are both excellent displays for the current generation.
	Galaxy S III	Galaxy S4	iPhone 5	
Screen Reflections All of these screens are large mirrors good enough to use for personal grooming – but it's actually a very bad feature... We measured the light reflected from all directions and also direct mirror (specular) reflections, which are much more distracting and cause more eye strain. Many Smartphones still have greater than 10 percent reflections that make the screen much harder to read even in moderate ambient light levels, requiring ever higher brightness settings that waste precious battery power. Hopefully manufacturers will reduce the mirror reflections with anti-reflection coatings and matte or haze surface finishes.				
Average Screen Reflection Light From All Directions	Reflects 5.0 percent Excellent	Reflects 4.4 percent Excellent	Reflects 4.6 percent Excellent	Measured using an Integrating Hemisphere. The best value we have measured is 4.4 percent and the current worst is 14.8 percent.
Mirror Reflections Percentage of Light Reflected	7.1 percent Very Good	6.1 percent Very Good	6.1 percent Very Good	These are the most annoying types of reflections. Measured using a narrow collimated pencil beam of light reflected off the screen.
	Galaxy S III	Galaxy S4	iPhone 5	
Brightness and Contrast The Contrast Ratio is the specification that gets the most attention, but it only applies for low ambient light, which is seldom the case for mobile displays. Much more important is the Contrast Rating, which indicates how easy it is to read the screen under high ambient lighting and depends on both the Maximum Brightness and the Screen Reflectance.				
Measured Average Brightness 50% Average Picture Level	Brightness 251 cd/m ² Good	Brightness 313 cd/m ² Very Good	Brightness 556 cd/m ² Excellent	This is the Brightness for typical screen content that has a 50% Average Picture Level.
Measured Brightness 100% Full Screen White	Brightness 224 cd/m ² Poor	Brightness 287 cd/m ² Good	Brightness 556 cd/m ² Excellent	This is the Brightness for a screen that is entirely all white with 100% Average Picture Level.
Measured Peak Brightness 1% Full Screen White	Brightness 283 cd/m ² Good	Brightness 355 cd/m ² Very Good	Brightness 556 cd/m ² Excellent	This is the Peak Brightness for a screen that has only a tiny 1% Average Picture Level.
Measured Peak Brightness with Automatic Brightness	Brightness 283 cd/m ² Good	Brightness 475 cd/m ² Excellent	Brightness 556 cd/m ² Excellent	Some Smartphones including the Galaxy S4 have higher Brightness in Auto Brightness Mode.
Black Level at Maximum Brightness	0 cd/m ² Outstanding	0 cd/m ² Outstanding	Black is 0.41 cd/m ² Very Good for Mobile	Black brightness is important for low ambient light, which is seldom the case for mobile devices.
Contrast Ratio Relevant for Low Ambient Light	Infinite Outstanding	Infinite Outstanding	1,356 Very Good for Mobile	Only relevant for low ambient light, which is seldom the case for mobile devices.
Contrast Rating for High Ambient Light	45 - 57 Good	65 - 81 Auto Brightness to 108 Very Good	121 Excellent	Defined as Maximum Brightness / Average Reflectance.
Screen Readability in Bright Light	Good B Very Good B+ High Color Saturation	Very Good A- Excellent A High Color Saturation	Excellent A	Indicates how easy it is to read the screen under high ambient lighting. Very Important! See High Ambient Light Screen Shots
	Galaxy S III	Galaxy S4	iPhone 5	
 Figure 1. Color Gamuts Click to Enlarge  Figure 2. Intensity Scales Click to Enlarge Colors and Intensities The Color Gamut, Intensity Scale, and White Point determine the quality and accuracy of all displayed images and all the image colors. Bigger is definitely Not Better because the display needs to match all the standards that were used when the content was produced. For LCDs a wider Color Gamut reduces the power efficiency and the Intensity Scale affects both image brightness and color mixture accuracy.				
White Color Temperature Degrees Kelvin	7,860 K Somewhat Too Blue	7,186 K Standard Mode 6,591 K Movie Mode Movie Mode Excellent	7,461 K Somewhat Too Blue	D6500 is the standard color of White for most Content and needed for accurate color reproduction.
Color Gamut Measured in the dark at 0 lux	Gamut Too Large 139 percent	Somewhat Large 132 % Standard Mode	Close to Perfect 104 percent	sRGB / Rec.709 is the color standard for most content and needed for accurate color reproduction.

See Figure 1	See Figure 1	122 % Movie Mode See Figure 1	See Figure 1	Note that Too Large a Color Gamut is visually worse than Too Small.
Dynamic Brightness Reduction in Luminance with APL	21 percent Good	18 percent Good	None Excellent	This is the percent Brightness reduction with APL Average Picture Level. Ideally should be 0 percent.
Intensity Scale and Image Contrast See Figure 2	Very Smooth Contrast is Very Good See Figure 2	Very Smooth Contrast is Very Good See Figure 2	Very Smooth Contrast is Very Good See Figure 2	The Intensity Scale controls image contrast needed for accurate image reproduction. See Figure 2
Gamma for the Intensity Scale Larger means more Image Contrast See Figure 2	Very Good 2.38 But Dim-end Steepens 2.73 Slightly Too High	Very Good 2.42 Straight and Constant Slightly Too High	Very Good 2.36 Straight and Constant Slightly Too High	Gamma is the slope of the Intensity Scale. Gamma of 2.20 is the standard and needed for accurate image reproduction. See Figure 2
	Galaxy S III	Galaxy S4	iPhone 5	
Viewing Angles The variation of Brightness, Contrast, and Color with viewing angle is especially important for Smartphones because of their large screen and multiple viewers. The typical manufacturer 176+ degree specification for LCD Viewing Angle is nonsense because that is where the Contrast Ratio falls to a miniscule 10. For most LCDs there are substantial degradations at less than ± 30 degrees, which is not an atypical viewing angle for Smartphones. Note that the Viewing Angle performance is also very important for a single viewer because the Viewing Angle varies based on how the Smartphone is held, and the angle can be very large if the Smartphone is resting on a table or desk.				
Brightness Decrease at a 30 degree Viewing Angle	28 percent Decrease Medium Decrease	22 percent Decrease Small Decrease	60 percent Decrease Very Large Decrease	Most screens become less bright when tilted. OLED decrease is due to anti-reflection absorption.. LCD brightness variation is generally very large.
Contrast Ratio at a 30 degree Viewing Angle	Infinite Outstanding	Infinite Outstanding	594 Very Good for Mobile	A measure of screen readability when the screen is tilted under low ambient lighting.
Primary Color Shifts at a 30 degree Viewing Angle	Medium Color Shift $\Delta(u'v') = 0.0234$ 5.9 times JNCD	Medium Color Shift $\Delta(u'v') = 0.0359$ 9.0 times JNCD	Small Color Shift $\Delta(u'v') = 0.0077$ 1.9 times JNCD	JNCD is a <u>Just Noticeable Color Difference</u> . IPS LCDs have smaller color shifts with angle.
Color Shifts for Color Mixtures at a 30 degree Viewing Angle Reference Brown (255, 128, 0)	Medium Color Shift $\Delta(u'v') = 0.0168$ 4.2 times JNCD	Small Color Shift $\Delta(u'v') = 0.0076$ 1.9 times JNCD	Small Color Shift $\Delta(u'v') = 0.0098$ 2.4 times JNCD	JNCD is a <u>Just Noticeable Color Difference</u> . Color Shifts for non-IPS LCDs are about 10 JNCD. Reference Brown is a good indicator of color shifts with angle because of unequal drive levels and roughly equal luminance contributions from Red and Green.
	Galaxy S III	Galaxy S4	iPhone 5	
Figure 3. LED Backlight Spectrum Click to Enlarge  Display Power Consumption The display power was measured using a Linear Regression between Luminance and AC Power with a fully charged battery. Since the displays have different screen sizes and maximum brightness, the values were also scaled to the same screen brightness (Luminance) and screen area in order to compare their relative Power Efficiencies.				
Average Display Power Maximum Brightness at 50% Average Picture Level	0.61 watts	0.70 watts	0.74 watts	This measures the average display power for typical image content.
Maximum Display Power Full White Screen at Maximum Brightness	1.30 watts	1.50 watts	0.74 watts	This measures the display power for a screen that is entirely all Peak White.
Display Average Power Efficiency same Luminance same 5.0 inch screen size area	0.83 watts	0.70 watts	0.66 watts	This compares the Average Power Efficiency by looking at the same screen brightness and same screen area.
	Galaxy S III	Galaxy S4	iPhone 5	
Running Time on Battery The running time on battery was determined with the Brightness sliders at Maximum, in Airplane Mode, with no running applications, and with Auto Brightness turned off. Note that Auto Brightness can have a considerable impact on running time but we found abysmal performance for both the iPhone and Android Smartphones in our BrightnessGate analysis of Ambient Light Sensors and Automatic Brightness. They all need a more convenient Manual Brightness Control as described in the BrightnessGate article.				
Running Time at the Average Display Power	Not Yet Available Coming Soon	Not Yet Available Coming Soon	6.6 hours Very Good	Display always On at 50% APL power with Airplane Mode and no running applications.
Running Time at the Maximum Display Power	5.6 hours Very Good	Not Yet Available Coming Soon	6.6 hours Very Good	Display always On at Maximum power with Airplane Mode and no running applications.
Categories	Galaxy S III	Galaxy S4	iPhone 5	Comments

About the Author

[Dr. Raymond Soneira](#) is President of DisplayMate Technologies Corporation of Amherst, New Hampshire, which produces video calibration, evaluation, and diagnostic products for consumers, technicians, and manufacturers. See www.displaymate.com. He is a research scientist with a career that spans physics, computer science, and television system design. Dr. Soneira obtained his Ph.D. in Theoretical Physics from Princeton University, spent 5 years as a Long-Term Member of the world famous Institute for Advanced Study in Princeton, another 5 years as a Principal Investigator in the Computer Systems Research Laboratory at AT&T Bell Laboratories, and has also designed, tested, and installed color television broadcast equipment for the CBS Television Network Engineering and Development Department. He has authored over 35 research articles in scientific journals in physics and computer science, including Scientific American. If you have any comments or questions about the article, you can contact him at dtso.info@displaymate.com.

DisplayMate Display Optimization Technology

All Smartphone and Tablet displays can be significantly improved using DisplayMate's advanced scientific analysis and mathematical display modeling and optimization of the display hardware, factory calibration, and driver parameters. We help manufacturers with expert display procurement and quality control so they don't make mistakes similar to those that are exposed in our Display Technology Shoot-Out series. We can also improve the performance of any specified set of display parameters. This article is a lite version of our intensive scientific analysis – before the benefits of our [DisplayMate Display Optimization Technology](#), which can correct or improve all of these issues. If you are a display or product manufacturer and want to significantly improve display performance for a competitive advantage then [Contact DisplayMate Technologies](#).

About DisplayMate Technologies

[DisplayMate Technologies](#) specializes in proprietary sophisticated scientific display calibration and mathematical display optimization to deliver unsurpassed objective performance, picture quality and accuracy for all types of displays including video and computer monitors, projectors, HDTVs, mobile displays such as smartphones and tablets, and all display technologies including LCD, OLED, 3D, LED, LCoS, Plasma, DLP and CRT. This article is a lite version of our intensive scientific analysis of Smartphone and Smartphone mobile displays – before the benefits of our advanced mathematical [DisplayMate Display Optimization Technology](#), which can correct or improve many of the display deficiencies. We offer DisplayMate display calibration software for consumers and advanced DisplayMate display diagnostic and calibration software for technicians and test labs.

For manufacturers we offer Consulting Services that include advanced Lab testing and evaluations, confidential Shoot-Outs with competing products, calibration and optimization for displays, cameras and their User Interface, plus on-site and factory visits. See our world renowned [Display Technology Shoot-Out](#) public article series for an introduction and preview. DisplayMate's advanced scientific optimizations can make lower cost panels look as good or better than more expensive higher performance displays. For more information on our technology see the Summary description of our [Adaptive Variable Metric Display Optimizer AVDO](#). If you are a display or product manufacturer and want to turn your display into a spectacular one to surpass your competition then [Contact DisplayMate Technologies](#) to learn more.

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