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Smartphone “Super” LCD-OLED Display Technology Shoot-Out
iPhone 4 – Samsung Galaxy S – Motorola Droid – iPhone 3GS – Google Nexus One

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Introduction and Series Overview

A key element in the success of all smartphones and mobile devices is the quality and performance of their display. There have been lots of articles comparing various smartphone LCD and OLED displays and technologies, but almost all simply deliver imprecise off-the-cuff remarks like “the display is gorgeous” with very little in the way of serious attempts at objective or accurate display performance evaluations and comparisons – and many just restate manufacturer claims and provide inaccurate information, performance evaluations and conclusions. This article objectively compares the display performance of five leading smartphone LCD and OLED displays based on extensive scientific lab measurements together with extensive side-by-side visual tests, incisive evaluations and comparisons, nicely summarized in the [Comparison Table](#) and [Results Highlights](#) below. The term “Super” is marketing puffery being used by some manufacturers, but we have adopted it generically to differentiate the highest performance display technologies. Since smartphones are being used to view photos, videos and a wide range of multimedia content we have evaluated their picture quality on the same terms as HDTVs. In fact, one of the smartphones that we tested has better picture quality than most living room HDTVs – so the bar is already quite high for smartphones. But there is still plenty of room for improvement and we will show and tell you where – we have included images that have been mathematically processed to correct color and imaging errors on each smartphone so you can compare them to the originals. [Part II](#) of this series will be on glare, screen reflectance, ambient lighting and sensors, automatic screen brightness controls and using them to improve picture quality, screen readability, viewing comfort, reduce display power and increase battery run time. Now let’s see how these leading smartphone’s perform...

Results Highlights

The [Comparison Table](#) below covers a wide range of display data on the Google Nexus One, Samsung Galaxy S, Apple iPhone 3GS, Motorola Droid and the Apple iPhone 4, but here are some of the highlights and conclusions culled from the Table:

iPhone 4 – “Super” LCD

Since its introduction the iPhone has been one of the wonders of the modern tech world for many reasons – but its display was never one of them – up until the iPhone 4, where it finally got the display it deserved. The iPhone 4 display, nicknamed the Retina Display, is an outstanding “Super” LCD delivering top performance in many of our test categories – it has the brightest and sharpest display, but on the other hand its color gamut is too small, producing under saturated somewhat washed-out colors, and its image contrast is too high, which produces punchier images and also partially compensates for its smaller color gamut. These were most likely intentional tradeoffs made by Apple to increase screen brightness, power efficiency and battery run time. None-the-less the iPhone 4 earned our [Best Mobile Display Award](#) in the [DisplayMate Best Video Hardware Guide](#). We include a dedicated comparison with the iPhone 3GS below. “Retina Display” is a great marketing name, and it is the sharpest smartphone display available, but quantitatively it is a factor of two lower than the acuity of the human Retina. [Click here for a discussion on the Retina Display](#). Finally, [Part II](#) of this series will discuss some major flaws in the iPhone 4’s Automatic Brightness control, which hopefully will be corrected in the near future through a software update.

Samsung Galaxy S – “Super” OLED

The Galaxy S has Samsung’s next generation premium OLED display marketed as a “Super AMOLED” display. The AM stands for Active Matrix, but all smartphone displays have that. What is particularly impressive is how rapidly Samsung has been improving their OLED technology, and the Galaxy S delivered top performance in many of our test categories. Some of areas where it fell short were the result of manufacturer calibration and OS issues rather than fundamental problems with the OLED technology itself. [Google confirmed](#) that some of the display problems we discovered are caused by Android 2.1. While OLED is still a relatively young display technology that has not yet been perfected to the performance levels of the very best mature LCDs, the Galaxy S is already an impressive display for an upcoming and rapidly evolving technology, so it earned our [Best New Mobile Display Technology Award](#) in the [DisplayMate Best Video Hardware Guide](#). There are comparisons with “Super” LCDs and “non-Super” OLEDs below. [Part II](#) will also discuss problems with the Automatic Brightness control on the Galaxy S, which should also apply to other Android phones.

“Super” LCD versus “Super” OLED

All of the tested LCDs were considerably brighter than the OLED displays – however, that may change in the near future as OLEDs continue to improve... While “Super” OLEDs have roughly 50 times the Contrast Ratio of “Super” LCDs, when a display is set properly to its optimum screen brightness that superior Contrast Ratio is visually insignificant except under dark ambient lighting, which is seldom the case for mobile displays. While OLEDs love to flaunt their vivid colors and large color gamut, that produces gaudy and over saturated pictures – someday they will turn those down and get it right... While the iPhone 4’s sharpness is something of an overkill (it’s that high for App compatibility) the PenTile arrangement of the OLEDs has only two sub-pixels per pixel instead of the usual three, so it sometimes appears more pixilated than its stated resolution implies – it’s excellent for photographic images but is noticeably degraded for colored (red, blue and magenta) text and graphics. While all OLEDs behave considerably better with changes in viewing angle than “Super” LCDs, smartphones are primarily single viewer devices and the user can easily orient the phone for the best viewing angle. LCDs are currently more power efficient for brighter images and OLEDs are more efficient for darker images. But for typical web and app content, which typically use bright backgrounds, the power balance is still decisively in the favor of LCDs by more than 2 to 1 in our tests – again, that should change as OLEDs continue to improve... The big question remaining for OLEDs (and not covered by our tests) is whether the previous uneven aging over time for the red-green-blue OLED sub-pixels has been solved.

“Super” OLED versus “non-Super” OLED

“Super” OLEDs do indeed perform considerably better than “non-Super” OLEDs. What is particularly impressive is how rapidly Samsung has been improving their OLED technology. The “Super” OLED is a much more refined display with many fewer artifacts and a much better factory calibration. [Samsung advertises](#) that the Galaxy S Super OLEDs are 20 percent brighter and use 20 percent less power than “non-Super” OLEDs, and have a screen reflectance of just 4 percent, down from 20 percent for “non-Super” OLEDs. In our lab tests the Galaxy S has a screen reflectance of 4.4 percent, is 25 percent brighter and uses 21 percent less power than the “non-Super” OLED in the Google Nexus One – meeting or exceeding all of Samsung’s specs. Particularly impressive is the very low screen reflectance, which is among the lowest we have ever measured – outdoors it can have a significant impact on screen visibility. The over-saturated gaudy colors are still there – they need to be properly managed and can be used constructively in a calibrated fashion to counteract the effects of glare from ambient light ([Part II](#)).

iPhone 4 versus iPhone 3

The iPhone 4 display is a tremendous step forward over the iPhone 3GS and earlier models. It has double the resolution, a 26 percent brighter screen, 24 percent lower screen reflectance, and 64 percent greater Contrast under bright ambient light, plus it has 8 times the Contrast under dim ambient light. On the other hand, the iPhone 4 has the same reduced color gamut as the iPhone 3GS, producing under saturated somewhat washed-out colors. The iPhone 3GS has very low image contrast, which adds to the display’s washed-out appearance. The iPhone 4 has gone to the other extreme and has too much image contrast, which gives its images a punchier look and also partially compensates for its smaller color gamut. Lastly, the iPhone 4 display consumes only half the power of the iPhone 3GS display.

Motorola Droid – “Super” LCD

The original Droid, launched in October 2009, remains the number one smartphone in terms of overall picture quality and accuracy, close to what you see in a calibrated studio monitor and actually better than most living room HDTVs – just a lot smaller, but still impressive none-the-less. It earned the [Best Mobile Picture Quality Award](#) in the [DisplayMate Best Video Hardware Guide](#) but only for Android 2.0. [Google confirmed](#) that the some of the display problems we discovered afterwards were caused by upgrading to Android 2.1.

Google Nexus One – “Non-Super” OLED

Its “non-Super” OLED display got lots of attention when it was introduced in January 2010, but in terms of objective picture quality and overall display performance it behaves like a rushed and unfinished prototype for early adopters instead of a production quality display. Decidedly in last place for the five smartphone displays tested. [Google confirmed](#) that some of the display problems we discovered are caused by Android 2.1.

And the Winner is...

There is no decisive winner as each of the three “Super” displays significantly outperforms the others in more than one important area and significantly underperforms in other areas. The iPhone 4 by far has the brightest and sharpest display and is the most power efficient of the displays. The Motorola Droid by far has the best picture quality and accuracy. The Samsung Galaxy S by far has the lowest screen reflectance and largest Contrast for both bright and dark ambient lighting, and the best viewing angles. On the flip side, the iPhone 4 has a weak color gamut and viewing angles, the Motorola Droid has weak screen reflectance and viewing angles, and the Samsung Galaxy S has lower brightness, excessive color saturation, higher power consumption and some sharpness issues. Each of these “Super” displays is none-the-less impressive and deserves an award: the iPhone 4 performed better overall so it earned the [DisplayMate Best Mobile Display Award](#), the Motorola Droid earned the [Best Mobile Picture Quality Award](#), and the Samsung Galaxy S earned the [Best New Mobile Display Technology Award](#). Each of these displays has lots of room for improvement and can leapfrog the others in their next iteration with appropriate action...

DisplayMate Display Optimization Technology

All of these “Super” displays can be significantly improved and optimized on many different levels. This article is a lite version of our intensive scientific analysis of smartphone and mobile displays – before the benefits of our advanced mathematical [DisplayMate Display Optimization Technology](#), which can correct or improve many of the deficiencies – including higher calibrated brightness, power efficiency, effective screen contrast, picture quality and color and gray scale accuracy under both bright and dim ambient light, and much more. If you are a display or product manufacturer and want our expertise and technology to turn your display into a spectacular one to surpass your competition then [Contact DisplayMate Technologies](#) to learn more.

Smartphone Display Shoot-Out Comparison Table

Below we compare the displays on the Google Nexus One, Samsung Galaxy S, Apple iPhone 3GS, Motorola Droid and the Apple iPhone 4 based on objective measurement data and criteria. Note that we are testing and evaluating the displays with whatever hardware, firmware, OS and software are provided by the smartphone manufacturers. Note that the Categories in the Table are not intended to have equal weighting in case you plan on scoring the results. For details, measurements, in-depth explanations and analysis see the [Article Links](#) below for the individual dedicated articles for each smartphone.

Categories	Google Nexus One Article Link	Samsung Galaxy S Article Link	Apple iPhone 3GS Article Link	Motorola Droid Article Link	Apple iPhone 4 Article Link	Comments
Display Technology	3.7 inch PenTile OLED Active Matrix	4.0 inch PenTile Super OLED Active Matrix	3.5 inch LCD Active Matrix	3.7 inch IPS LCD Active Matrix	3.5 inch IPS LCD Active Matrix	Technologies are Organic Light Emitting Diodes and In Plane Switching Liquid Crystal Displays . All the smartphone displays have an Active Matrix .
Display Resolution	800 x 480 pixels	800 x 480 pixels	480 x 320 pixels	854 x 480 pixels	960 x 640 pixels	The more Pixels and Sub-Pixels the better
Pixels Per Inch	252 ppi Very Good	233 ppi Very Good	163 ppi Good	265 ppi Very Good	326 ppi Excellent	At 12 inches from the screen 20/20 vision is 286 ppi. Best human vision is about 20/10 vision or 572 ppi. See this link on the acuity for a Retina Display .
Number of Red+Blue Sub-Pixels	0.38 Million Less Sharp	0.38 Million Less Sharp	0.31 Million Less Sharp	0.82 Million Sharp	1.23 Million Very Sharp	PenTile OLEDs have only 2 sub-pixels per pixel instead of the 3 that are used in most displays.
Hardware Color Depth	24-bit color	24-bit color	18-bit color	24-bit color	24-bit color	24-bit color produces 16.8 Million screen colors
Displayed Color Depth	16-bits on-screen Browser and Gallery Android 2.1	16-bits with Dithering to 24-bits Browser and Gallery Android 2.1	18-bits with Dithering to 24-bits	Full 24-bits Browser and Gallery Android 2.0	Full 24-bits	Android 2.1 produces 16-bit on-screen color causing false image contours and color-intensity artifacts. See this link for Google's comments on this topic
Viewing Tests	Gaudy Images Photos and Videos have too much color and too much contrast	Good Images Photos and Videos have too much color and accurate contrast	Subdued Images Photos and Videos have too little color and too little contrast	Excellent Images Photos and Videos have accurate color and accurate contrast	Good Images Photos and Videos have too little color and too much contrast	The Viewing Tests examined the accuracy of photographic images by comparing the displays to a calibrated studio monitor and HDTV.
Photo and Image Comparison Tests	Click Link for Comparison Images	Click Link for Comparison Images	Click Link for Comparison Images	Click Link for Comparison Images	Click Link for Comparison Images	Visually compare images that are mathematically processed to correct a number of imaging flaws with the original images for each smartphone.
Suggestions and Conclusions	Suggestions and Conclusions for Google Nexus One	Suggestions and Conclusions for Samsung Galaxy S	Suggestions and Conclusions for Apple iPhone 3GS	Suggestions and Conclusions for Motorola Droid	Suggestions and Conclusions for Apple iPhone 4	Our Conclusions and Suggestions for improvement for each smartphone.
Overall Display Assessment	Rushed Prototype Needs Updates	Excellent Display DisplayMate Award Best New Technology	Dated Display Needs a Makeover	Excellent Display DisplayMate Award Best Picture Quality	Excellent Display DisplayMate Award Best Mobile Display	Three of these high-end smartphones with “Super” LCD and OLED top performance displays received DisplayMate Best Video Hardware Guide Awards .
Brightness and Contrast						
Measured Maximum Brightness is the Peak Luminance for White	Brightness 292 cd/m ² Full Screen 229 cd/m ² No Google Brightness Specs	Brightness 365 cd/m ² Full Screen 305 cd/m ² No Samsung Brightness Specs	Brightness 426 cd/m ² Excellent No Apple Brightness Specs	Brightness 449 cd/m ² Excellent No Motorola Brightness Specs	Brightness 541 cd/m ² Excellent Apple Advertises 500 cd/m ² typical	Maximum Brightness is very important for mobile because of the typically high ambient light levels. For these OLEDs the Maximum Brightness is lower when the screen is mostly bright or white. Apple exceeds their advertised value – impressive!
Black Level at Maximum Brightness	Black 0.0035 cd/m ² Outstanding	Black < 0.005 cd/m ² Outstanding	Black 3.1 cd/m ² Very High	Black 0.31 cd/m ² Very Good for Mobile	Black 0.48 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	65,415 to 83,430 Outstanding Google Advertises 100,000 typical	Greater than 61,000 Outstanding Samsung Advertises 50,000	138 Poor No Apple Contrast Specs	1,436 Very Good for Mobile No Motorola Contrast Specs	1,117 Very Good for Mobile Apple Advertises 800 typical	Only relevant for low ambient light, which is seldom the case for mobile devices. Don't confuse our measured objective values with the often inflated manufacturer Contrast specs. Samsung and Apple exceed their advertised values!
Screen Reflectance of Ambient Light	Reflects 15.6 percent Relatively High No Google Reflectance Specs	Reflects 4.4 percent Excellent Samsung Advertises Reflects 4 percent	Reflects 9.2 percent Good No Apple Reflectance Specs	Reflects 12.1 percent Good No Motorola Reflectance Specs	Reflects 7.0 percent Very Good No Apple Reflectance Specs	Reflectance is the most important spec for mobile because of the typically high ambient light levels. Samsung matches their advertised value.
Screen Bright Contrast Rating for High Ambient Light	Bright Contrast 15 - 19 Very Low	Bright Contrast 69 - 83 Excellent	Bright Contrast 47 Very Good	Bright Contrast 37 Good	Bright Contrast 77 Excellent	Indicates how easy it is to read the screen under high ambient lighting. Very Important! Defined as Maximum Brightness / Reflectance
Figure 1. Color Gamuts Click to Enlarge  Figure 2. Intensity Scales Click to Enlarge  Figures 1 and 2 show why there are such large differences in image colors, image contrast, and picture quality on the Smartphones.						
Colors and Intensities						
White Color Temperature	8,870 degrees Kelvin White is Too Blue	9,688 degrees Kelvin White is Too Blue	6,977 degrees Kelvin Close to D6500	6,752 degrees Kelvin Close to D6500	7,781 degrees Kelvin White Slightly Too Blue	D6500 White is the standard for most content and necessary for accurate color reproduction.
Color Gamut	Gamut Too Large 141 percent See Figure 1	Gamut Too Large 138 percent See Figure 1	Gamut Too Small 60 percent See Figure 1	Standard Gamut 97 percent See Figure 1	Gamut Too Small 64 percent See Figure 1	sRGB / Rec.709 is the color standard for most content and needed for accurate color reproduction. Too Large is visually worse than Too Small.
Picture Color Saturation	Very High Gaudy Colors	Too High Gaudy Colors	Very Low Subdued Colors	Excellent Beautiful Colors	Too Low Subdued Colors	Picture Color Saturation depends on both the Color Gamut and the Intensity Scale Gamma.
Intensity Scale and Image Contrast	Mostly Too High and Very Irregular	Very Good Close to Standard	Very Low and Concave	Excellent Very Accurate	Good But Too High	The Intensity Scale controls image contrast needed for accurate image reproduction. See Figure 2
Gamma for Intensity Scale	Poor 1.82 to 2.55 Very Irregular	Very Good 2.36 Close to Standard	Poor Less than 1.90 Too Low	Excellent 2.24 Close to Standard	Good 2.68 But Too High	Gamma of 2.2 is the standard and needed for accurate image reproduction. See Figure 2
Viewing Angles						
Brightness Decrease at a 30 degree Viewing Angle	28 percent decrease to 166 cd/m ² From Absorbing Layer	28 percent decrease to 221 cd/m ² From Absorbing Layer	63 percent decrease to 161 cd/m ² Very Large	64 percent decrease to 160 cd/m ² Very Large	57 percent decrease to 235 cd/m ² Very Large	Screens become less bright when tilted. OLED variation is due to screen absorbing layers. LCD brightness variation is generally very large.
Contrast Ratio at a 30 degree Viewing Angle	Extremely High Not Measured	Extremely High Not Measured	44 Extremely Low	280 Low	556 Very Good for Mobile	A measure of screen readability when the screen is tilted under low ambient lighting.
Color Shift at a 30 degree Viewing Angle	$\Delta(u^*v^*) = 0.0262$ 7 times JNCD	$\Delta(u^*v^*) = 0.0229$ 6 times JNCD	$\Delta(u^*v^*) = 0.0418$ 10 times JNCD	$\Delta(u^*v^*) = 0.0020$ 1/5 times JNCD	$\Delta(u^*v^*) = 0.0096$ 2 times JNCD	JNCD is a Just Noticeable Color Difference. IPS LCD has a smaller color shift with angle.
Display Power Consumption						
Display Power for White Screen at Maximum Brightness	0.91 watts	1.13 watts	0.81 watts	0.87 watts	0.42 watts	Lower power consumption is important for energy efficiency and improving run time on battery.
Display Power for White Screen same Peak Luminance 229 cd/m ² same 3.7 inch screen area	0.91 watts	0.72 watts	0.46 watts	0.46 watts	0.19 watts	iPhone 4 is considerably more power efficient for the same size equal brightness full white screens.
Display Power for NASA Sunset on Mars Photo same Peak Luminance 229 cd/m ² same 3.7 inch screen area	0.25 watts	0.20 watts	0.46 watts	0.46 watts	0.19 watts	OLEDs use much less power when there is darker screen content. This is the display power for the NASA Sunset on Mars Photo .
Display Power for Black Screen at Maximum Brightness	0 watts	0 watts	0.81 watts	0.46 watts Dynamic Black	0.42 watts	OLED is zero because it is emissive technology. Droid Dynamic Contrast reduces power for Black.
Categories	Google Nexus One Article Link	Samsung Galaxy S Article Link	Apple iPhone 3GS Article Link	Motorola Droid Article Link	Apple iPhone 4 Article Link	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 dtsso.info@displaymate.com.

About DisplayMate Technologies

[DisplayMate Technologies](#) specializes in advanced mathematical display technology optimizations and precision analytical scientific display diagnostics and calibrations to deliver outstanding image and picture quality and accuracy – while increasing the effective visual Contrast Ratio of the display and producing a higher calibrated brightness than is achievable with traditional calibration methods. This also decreases display power requirements and increases the battery run time in mobile displays. This article is a lite version of our intensive scientific analysis of smartphone and mobile displays – before the benefits of our advanced mathematical [DisplayMate Display Optimization Technology](#), which can correct or improve many of the deficiencies – including higher calibrated brightness, power efficiency, effective screen contrast, picture quality and color and gray scale accuracy under both bright and dim ambient light, and much more. Our 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 our expertise and technology to turn your display into a spectacular one to surpass your competition then [Contact DisplayMate Technologies](#) to learn more.

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