SPECIAL REVIEW

RuggedPCreview.com

GD-ITRONIX **DYNAVUE** TECHNOLOGY

THE ULTIMATE OUTDOOR-READABLE TOUCH-SCREEN DISPLAY

By Geoff Walker

Don't you just hate it when some marketing guy labels something as "ultimate"? Well, I've found something that really should be labeled as "ultimate". It's General Dynamics (GD) Itronix' brand-new DynaVue outdoor-readable touch-screen display technology. The American Heritage Dictionary defines "ultimate" as "representing or exhibiting the greatest possible development or sophistication", and that's an appropriate description of this new technology. I've been studying and writing about outdoor-readable screens for quite a while, and there simply isn't anything more that can be done to a touch-screen-equipped transmissive LCD to make it work any better outdoors.

Defining the Problem

To support my declaration of superiority, this article explains what GD-Itronix has done and how it works. But before that, to set the stage and describe the scenery, this article defines the problem, explains how to quantify outdoor readability and discusses three alternatives for improving outdoor readability.

The real problem in making any display readable outdoors is reflections. If the light reflected by the surface of the display is close to or greater than the amount of light emitted by the display, it can't be read. In order to read something on a display, there must be a visible difference between the whitest and blackest parts of an image on the display. If the surface of the display is reflecting a lot of light, the difference in the light emitted by the whitest and blackest parts of the screen is masked ("washed out"), and whatever is on the screen can't be seen.

The difference between the whitest white and the blackest black on a display is called the contrast ratio. The "intrinsic" (datasheet) contrast ratio of a typical LCD panel is usually at least several hundred to one, and it can be as high as 1,000:1. In simplified form, intrinsic contrast ratio is calculated as the amount of light emitted by the brightest white pixel divided by the amount of light emitted by the darkest black pixel, with the measurement being made in a dark room. Since an LCD's backlight is always on, what's really being measured is the ability of the black pixel to block the transmission of the backlight. It should be fairly obvious that intrinsic contrast ratio has little or nothing to do with outdoor readability.

Real World Contrast Ratio

In the real world, a user looks at the whole screen outdoors, not just at one pixel in a dark room. Accordingly, an entirely different method of measuring the contrast ratio is used in bright-light environments. There isn't a standard term for this "real world" contrast ratio; it's variously called "high ambient", "extrinsic" or "effective" contrast ratio. For the remainder of this article it will be called the latter. Unfortunately, effective contrast ratio (ECR) numbers are rarely published because they depend on many hard-to-control factors. As a result, it's usually necessary to *estimate* the ECR for any particular display by plugging the display's reflectivity and backlight brightness into a rule-of-thumb formula. The formula is as follows:

ECR = 1 + (Emitted_Light / Reflected_Light)

In this formula, "Emitted_Light" is usually the manufacturer's specification for the brightness of the backlight in nits. ("Nits" is display-industry slang for "candela per meter squared", or cd/sqm, which is a technical measure of light intensity.) "Reflected_Light" is the amount of light reflected by the surface of the display. This is calculated by multiplying the ambient light in nits by the percentage reflectivity of the display. Ambient light is normally measured in lux. Sunlight ranges from approximately 30,000 lux to 100,000 lux; to convert lux to nits, the value must be divided by Pi (3.14159). The low end of the ambient sunlight range is therefore usually specified as 10,000 nits (rounding up from 9,549).

Effective contrast ratio numbers for LCDs are typically in the range of 1:1 to 20:1. While there is no hard and firm standard, the following table provides a generally accepted interpretation of ECR values.

Effective Contrast Ratio (ECR)	LCD Outdoor Readability
1-2	Unreadable in sunlight
3-4	Adequately readable in shade; barely readable in sunlight
5-9	Adequately readable in sunlight; looks OK
10	Very readable in sunlight; looks good
15	Outstanding readability; looks great
20	Totally awesome; excellent readability; can't be improved

For comparison, the equivalent ECR of the New York Times newspaper in sunlight is around 20:1, which is about as good as it gets. A typical notebook LCD in 2007 has a 200-nit backlight, and a surface reflectivity of about 2%. Plugging these numbers into the rule-of-thumb formula shows that the typical notebook is essentially unreadable in sunlight, as follows:

ECR = 1 + (200 / (10,000 x 0.02)) = 1 + (200 / 200) = 2:1

High-Brightness Backlights

Since the backlight brightness appears in the ECR formula, it seems reasonable that increasing the backlight brightness should make the display more readable outdoors. Typical "high-bright" displays used in industrial applications have 1,000-nit backlights. Substituting 1,000 for 200 in the numerator of the formula yields an ECR of 6:1, which is "adequately readable in sunlight."

However, there are several problems with this approach. First, increasing the backlight brightness to 1,000 nits isn't appropriate for portable computers. It drastically increases the power consumption, which reduces battery life and generates a lot of heat which must be removed with a fan or heatsink. Second, the extra brightness tends to overpower the dark pixels' ability to block light, which causes dark colors to appear gray and the image to look washed out. Third, this approach assumes that the reflectivity of the display remains at the 2%, which is usually not the case for any display with a protective cover or touch screen.

Resistive Touch Screens

Figure 1 below shows the construction of a typical analog-resistive touch screen. This type of touch screen is very commonly used in portable computers. (Note: Numbers in parentheses in the following paragraphs refer to the ID numbers on the right side of each Figure.)

The touch screen consists of solid glass substrate (6) coated with indium tin oxide (ITO) (3), a transparent conductor. A flexible polyester (PET) membrane (2) also coated with ITO (3) is suspended above the glass substrate. Transparent spacer dots (5) keep the two conductive surfaces apart, forming an air gap (4). A hardcoat (1) makes the surface of the polyester membrane more resistant to wear. The force of a touch collapses the membrane, causing contact between the conductive surfaces. Electronics measures the resistance along the edges in two dimensions and calculates the point of touch.

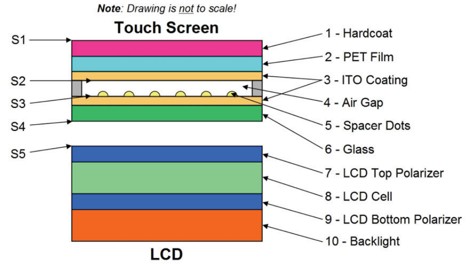


Figure 1: Construction of a typical analog-resistive touch screen

Because of the air gaps, a resistive touch screen has four reflecting surfaces, identified as S1 through S4 in Figure 1 above. In addition, the LCD surface also reflects light (S5 in Figure 1). Surfaces S1 and S4 each reflect 4% of the incident light (normal for PET and glass), while surfaces S2 and S3 each reflect around 5% (higher because of the ITO). Surface S5 reflects about 2%, as previously described. The total reflectivity is therefore 20%. Plugging 20% into the ECR formula with a 1,000 nit backlight yields the following result:

ECR = 1 + (1,000 / (10,000 x 0.20)) = 1 + (1,000 / 2,000) = 1.5

It's clear that an LCD with an untreated resistive touch screen is unreadable in sunlight, even with a 1,000-nit backlight!

Resistive Touch Screen Treatment #1

There are two alternative treatments that can be applied to resistive touch screens to reduce their reflectivity. In the first treatment, touch-screen surfaces S1 through S4 and the LCD surface S5 in Figure 1 are coated with anti-reflective (AR) material.

AR coatings are sometimes called "index-matching films" because one of their functions is to reduce the effect of the difference in index of refraction between air (1.0) and glass (1.5), PET (1.6) or ITO (2.0). Yet another name for AR coatings is "quarter-wavelength films". If the thickness of an AR coating is exactly one-quarter (or an odd multiple of one quarter) of the wavelength of light, destructive optical interference takes place and some of the reflections cancel each other out. High-quality AR coatings consist of multiple layers of different materials, and they're not inexpensive, so this treatment can multiply the cost of the touch screen by as much as 3X or 4X.

The best performance that can be achieved with five AR coatings is a total reflectivity of around 5% (S1 through S5 = 0.5% + 2.5% + 1% + 0.5% + 0.5%). The primary constraint is that reducing reflections from ITO on PET film (surface S2) is particularly difficult because the required flexibility limits the number of AR material layers that can be applied. While the resulting 5% is a substantial improvement over the 20% described above for a totally untreated touch screen & LCD, it's still not good enough, since even with a 500-nit backlight, the ECR is still only 2:1.

Resistive Touch Screen Treatment #2

The second alternative treatment involves the use of a circular polarizer. This requires a bit of background explanation before proceeding further. Figure 2 below illustrates how a circular polarizer eliminates reflections.

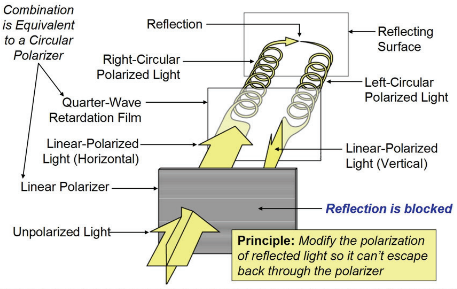


Figure 2: An illustration of how a circular polarizer can be used to eliminate reflections from a surface. *(Artwork courtesy of Gunze USA)*

In Figure 2 above, unpolarized light goes through a linear polarizer and becomes polarized in the direction of the polarizer's axis (shown as horizontal in Figure 2). The light then goes through a quarter-wave retardation film and becomes right-circular polarized. (A retardation film's name comes from the fact that it "retards" or delays the phase of light waves sent through it by a quarter-wavelength, which changes the polarization of the light. The combination of a linear polarizer and a retardation film creates a circular polarizer.) Circularly polarized light changes orientation when it bounces off a surface, so the reflected light on the right side of Figure 2 becomes left-circular polarized. When the light goes back through the retardation film again, it reverts to linear polarization, but this time at right angles to the original direction of polarization. The linear polarizer therefore blocks the reflected light. In Figure 2 the linear polarizer and retardation film are shown separately for clarity; in actual practice they are laminated together.

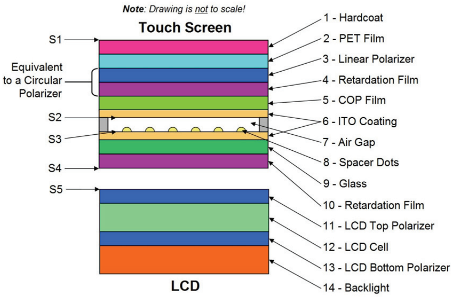


Figure 3: The application of a circular polarizer to a resistive touch screen.

Figure 3 above illustrates how a circular polarizer is applied to a resistive touch screen to reduce reflections. Figure 3 is identical to Figure 1 with the addition of items (3), (4) and (10), and a change in item (5). The circular polarizer (items 3 & 4) is identical to the circular polarizer in Figure 2, except that they are shown as laminated together. Item (5), the touch-screen flexible membrane, can't be made of PET in a circular polarizer system because PET introduces some undesirable retardation of its own. Instead, the membrane must be made of a different, non-retarding material. One of the commonly used materials is cyclo olefin polymer (COP) film.

The second retardation film (item 10 in Figure 3 above) is not involved in reducing reflections. It is required because of the presence of the circular polarizer. The light emitted by the LCD (from the backlight) is linearly polarized as a result of items (11) and (13). This light would normally be blocked by the circular polarizer (3 & 4) the same way that reflected light is blocked. The second retardation film changes the light emitted by the LCD from linearly polarized to circular polarized so that it can go through the circular polarizer (items 3 & 4) and be seen by the user. Without item (10), all light from the LCD would be blocked.

The circular polarizer reduces the reflections from surfaces S2 and S3 to a very low level (about 0.1% each). However, its effect starts at item 3 and ends at the top surface of item 10. That means that surfaces S1, S4 and S5 still require expensive AR coatings. The best performance that can be achieved with this scheme is therefore a reflectivity of 1.7% (S1 through S5 = 0.5% + 0.1% + 0.1% + 0.5% + 0.5%). This is a *lot* better than 20% but still not quite good enough. Assuming a backlight brightness of 200 nits, the ECR formula estimates a contrast ratio of only 2.2 (1 + (200 / 170)), which is still too low for really good readability.

GD-Itronix' Ultimate Solution: DynaVue

GD-Itronix has taken two significant steps beyond the structure illustrated in Figure 3. The first step is to increase the backlight brightness moderately to 500 nits. This causes fewer problems than the 1,000 nit backlight described under "High-Brightness Backlights" above.

The second step is to relocate the top polarizer on the LCD (item 11 in Figure 3), and relocate the second retardation film (item 10 in Figure 3). This new construction is shown in Figure 4 below, where the relocated LCD top polarizer is item (3) and the relocated retardation film is item (10).

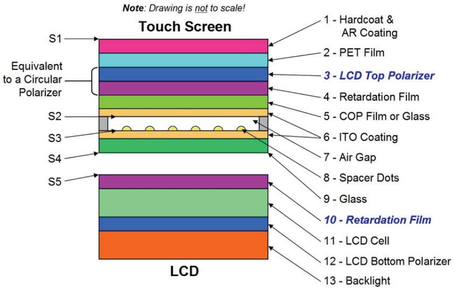
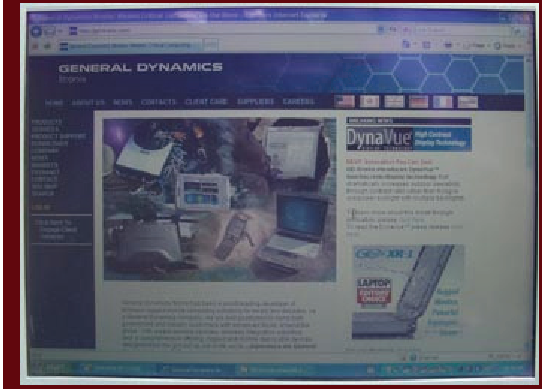


Figure 4: The construction of GD-Itronix' DynaVue outdoor-readable touch-screen display.

The second retardation film (item 10 in Figure 4) is still required because of the circular polarizer (items 3 & 4), as explained under Figure 3. However, the new location of the second retardation film means that reflected light from surfaces S2 through S5 are *all* blocked by the circular polarizer. This means that the only surface that requires AR coating in this construction is S1, which makes it more economical. The performance that results from this construction is a reflectivity of 0.9% (S1 through S5 = 0.5% + 0.1% + 0.1% + 0.1% + 0.1%).

Finally, this is a good number! Plugging the 500-nit backlight brightness and the 0.9% reflectivity into the ECR formula yields the following result:

DynaVue Technology



Unretouched images of GoBook VR-2 DynaVue screen in bright daylight (above) and older VR-1 touchscreen LCD without DynaVue (below).

GD-Itronix GoBook VR-2 in direct sunlight. Picture shows contrast, but the camera was not able to capture the actual brightness, sharpness and colors the human eye saw.

DynaVue ECR = 1 + (500 / (10,000 x 0.009)) = 1 + (500 / 90) = 6.6:1

This is well within the "adequately readable in sunlight" range of 5:1 to 9:1 shown in the ECR table near the beginning of this article.

Just how good is this? The notebook with the absolute best outdoor readability on the market today is the Dell ATG (All Terrain Grade, a semi-rugged model without a touch screen). The Dell has a 500-nit backlight and an AR-coated cover-glass optically bonded directly onto the LCD that produces a total reflectivity of 0.5%. The ECR formula estimates the following result for the Dell:

Dell ATG ECR = 1 (500 / (10,000 x 0.005)) = 11:1

From the raw numbers, it sounds as though the Dell at 11:1 should be substantially better than a DynaVue-equipped Itronix product at 6.6:1. However, someone who has seen the Dell ATG notebook and the new Itronix VR-2 DynaVue-equipped notebook side-by-side outdoors in direct sunlight told the author that they are *very* close in appearance. This is an *amazing achievement* for a touch-screen-equipped notebook. Panasonic's best effort, the fully AR-coated, 1000-nit-backlight Toughbook 30 only achieves an estimated effective contrast ratio of 3.5:1. (This is based on an analysis of all available product literature, not on actual measurements or on data from Panasonic.)

The Secret Sauce

Comparing Figures 3 and 4, the "secret sauce" clearly is the relocation of the LCD's top polarizer and the second retardation film. This eliminates almost all of the reflections from surfaces S4 and S5, which allows the total reflectivity to be reduced to less than 1%. It also decreases the amount of light lost in the touch screen, since there are only two polarizers in the system instead of three. While the secret sauce sounds relatively simple, accomplishing it is definitely not. It requires very close cooperation between the touch screen manufacturer, the LCD manufacturer and the computer manufacturer to pull off this kind of supply-chain magic.

A Few Remaining Details

Readers skilled in the art may notice that there's no anti-glare (AG) coating shown in the DynaVue construction in Figure 4, only AR (item 1). GD-Itronix has determined that an AG coating actually *decreases* DynaVue's performance. GD-Itronix found that (a) the measured reflectivity of an AG-coated DynaVue screen is slightly higher, and (b) users testing actual units unanimously said that the image on an AG-coated screen was less sharp (due to diffusion of the light emitted by the LCD).

Sharp-eyed readers may also notice that item (5) in Figure 4, the touch-screen's flexible membrane, is labeled as "COP Film *or Glass*". There is no difference in reflectivity between the two materials, since there are no exposed surfaces. However, using very thin glass (0.1 mm) instead of COP film provides a reliability advantage. The two primary causes of touch-screen failure are (a) cosmetic damage to the top surface, and (b) cracked ITO coating due to flexing. COP (or PET) film allows the ITO coating to flex at a smaller radius than glass, which makes the touch-screen lifetime shorter. This is why the typical specified lifetime of a 4-wire touch screen used with a stylus is only 100,000 characters.

Readers skilled in the art may also ask why optical bonding isn't considered in DynaVue's construction, i.e., bonding the surfaces of items (9) and (10) in Figure 4 to eliminate the air gap and thus reflecting surfaces S4 and S5. There are two reasons: first, once bonded, the touch screen is very difficult to remove. This means that when a touch screen must be replaced for cosmetic reasons, the LCD must also be replaced – which is uneconomical. Second, the performance gain by optically bonding these two surfaces is only 0.2%, which is a small gain to trade off against (a) the loss of touch-screen replaceability, and (b) the added cost of the bonding. Just for the record, the 0.2% reduction in reflectivity would increase the effective contrast ratio from 6.6:1 to 8.1:1, which is an improvement of 23%.

Finally, a few of the major LCD manufacturers such as Samsung are just beginning to talk about the possibility of "integrated touch screens" in the near future. What they're really talking about is what GD-Itronix has already done. By relocating the top polarizer on the LCD, they are effectively "integrating" the touch screen into the LCD. All that's missing is optically bonding the touch screen to the LCD, which as just noted, has some disadvantages.

The Bottom Line

Outdoor readability is all about contrast, not brightness. The objective is to get the effective contrast ratio high enough so that the screen can be read comfortably. Increasing the effective contrast ratio requires balancing two factors, the amount of light reflected by the screen (reflectivity) and the amount of light emitted by the screen (backlight brightness). Managing only one of the factors won't produce optimum results.

This article has described four levels of touch-screen treatment, ranging from none to GD-Itronix' DynaVue, which the author believes is the best on the market today. The table below summarizes the reflectivity data that has been presented in this article (in the order it was discussed).

Touch-Screen Treatment	Surface S1	Surface S2	Surface S3	Surface S4	Surface S5	Total Reflectivity
Untreated	4%	5%	5%	4%	2%	20%
5 AR coatings	0.5%	2.5%	1.0%	0.5%	0.5%	5%
Circular polarizer	0.5%	0.1%	0.1%	0.5%	0.5%	1.7%
DynaVue	0.5%	0.1%	0.1%	0.1%	0.1%	0.9%

This article has also described a number of real and hypothetical products with and without touch screens, and with varying combinations of reflectivity and backlight brightness. These are summarized in the table below (in the order they were mentioned).

Product Configuration	Touch Screen	Backlight Brightness	Total Reflectivity	Effective Contrast Ratio (ECR)
Standard notebook	No	200 nits	2%	2:1
High-Bright industrial display	No	1,000 nits	2%	6:1
High-Bright industrial display with untreated touch screen	Yes	1,000 nits	20%	1.5:1
Notebook with 5 AR coatings	Yes	500 nits	5%	2:1
Notebook with circular polarizer	Yes	200 nits	1.7%	2.2:1
GD-Itronix DynaVue	Yes	500 nits	0.9%	6.6:1
Dell ATG notebook	No	500 nits	0.5%	11:1
Panasonic Toughbook 30	Yes	1,000 nits	4%	3.5
Optically bonded DynaVue (hypothetical, not available)	Yes	500 nits	0.7%	8.1:1

The DynaVue display technology also meets DOD-STD-3009 military standard for cockpit displays for viewability and ambient light ratio.

Geoff Walker, Pen Computing's and RuggedPCReview.com's Technology Editor, currently heads his own technical marketing consulting firm, Walker Mobile, LLC. Based in Silicon Valley, Geoff has particular expertise in touch screens & digitizers, displays & enhancements, and mobile computers running Windows. Geoff also writes for SID's Information Display magazine and the Veritas et Visus series of display-industry newsletters. Geoff can be reached at geoff@walkermobile.com or 1-408-945-1221.

Contact:
General Dynamics Itronix
www.gd-itronix.com
or 1-800-441-1309