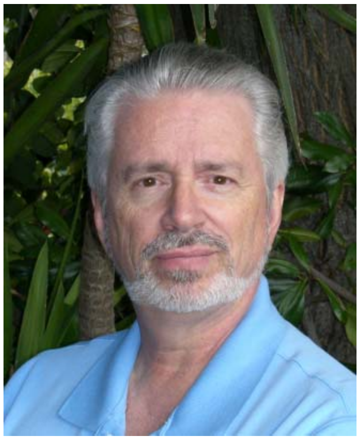
# *Optical bonding for improved LCD outdoor viewability*

*by Geoff Walker*



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In the context of this article, optical bonding, sometimes called "direct bonding", is the use of an optical-grade adhesive to adhere a sheet of glass to the top surface of an LCD. The purpose of the bonding is to improve the optical performance of the display. Optical bonding is currently applied to LCDs from 2.5 inches to 42 inches.

It's not immediately obvious why bonding a sheet of glass to an LCD would improve the optical performance until one realizes that optical bonding is typically done only in applications where the LCD must be covered for protection or to provide a writing surface. In its simplest form, optical bonding eliminates the air gap between the cover glass and the LCD, thus eliminating two reflective surfaces. In the real world, optical bonding is rarely used alone. At the minimum, an anti-reflective coating is usually applied to the top surface of the cover glass, along with possibly an anti-smudge (AS, hydrophobic) coating and often an anti-glare (AG) treatment.

**The LCD outdoor viewability problem:** First, let's describe the problem that optical bonding is trying to solve, that of LCD outdoor viewability. The traditional method of making an LCD viewable outdoors (in bright ambient light) is to increase the intensity of the backlight. This attempts to make the viewable light greater than the reflected ambient light by shifting the display viewing to a higher luminance level. There are a number of problems with this approach. First, increasing the backlight brightness raises both the black luminance and the white luminance, which reduces the contrast ratio. Lower contrast makes the display harder to read. Second, this approach increases the display's power consumption, heat generation and thickness – none of which are compatible with portable devices. Third, this approach is very difficult to accomplish with large displays (>30 inches) because large displays already use a lot of backlight tubes, and passive enhancement films aren't always available in larger sizes.

The real problem with LCD outdoor viewability is contrast, not brightness. Contrast is the ratio of the white level to the black level. Or, said another way, a display's contrast ratio is the difference in light intensity between the brightest white pixel and the darkest black pixel. In this situation we're talking about "extrinsic" contrast, meaning a reading taken from a distance that accounts for ambient light and reflections. (The contrast ratio in a display's specifications sheet is "intrinsic" contrast, measured at the surface of the screen in a dark room.) A good extrinsic contrast ratio is 10:1; an excellent extrinsic contrast ratio is 20:1. As the ambient light increases, the contrast ratio decreases because more light is reflected by the display. When the ambient light gets bright enough, the contrast ratio is reduced to 1.0 and the display can't be read at all. In layman's terms, the reflected ambient light overpowers the backlight.

The goal of optical bonding is therefore to increase the LCD's contrast ratio by reducing the amount of reflected ambient light. The reason that light is reflected from each surface in the optical path is that air and glass have different indices of refraction. The greater the difference, the more light is reflected from the interface. Air has an index of refraction of 1.0, while glass has an index of 1.5. This difference results in an average of 4.5% reflected light per surface (actually it varies from 4% to 5% depending on the wavelength and other factors). *Figure 1* diagrams the reflected light from an LCD with a cover glass; *Table 1* below shows four different enhancement cases.

If the ambient brightness is 10,000 nits (an approximation of direct sunlight), reflected ambient of 13.5% in case #1 is 1350 nits. An approximation formula for calculating contrast ratio in this situation (courtesy of White Electronic Designs) is CR = 1 + (display brightness / reflected light). For a 200-nit Tablet PC display, 1350 nits of reflected light yields a contrast ratio of 1.15:1 – unreadable! For case #4, the formula yields a contrast ratio of 5:1 – not great, but definitely readable. "AR" in *Table 1* is an abbreviation for an anti-reflective coating. AR is a multi-layer coating that matches the index of refraction of glass to that of air. As noted above, the better the match, the less light is reflected.

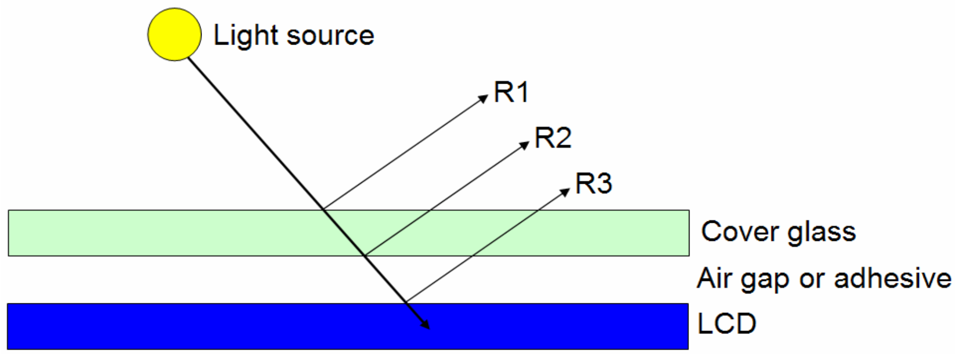


*Figure 1: Reflected ambient light from an LCD with a cover glass*

| Reflected Light | (1) No enhancement | (2) AR on top surface | (3) AR on all 3 surfaces | (4) AR on top surface plus optical bond |
|---|---|---|---|---|
| R1 | 4.5% | 0.3% | 0.3% | 0.3% |
| R2 | 4.5% | 4.5% | 0.3% | 0.1% |
| R3 | 4.5% | 4.5% | 0.3% | 0.1% |
| **Total** | **13.5%** | **9.3%** | **0.9%** | **0.5%** |

*Table 1: Reflected light resulting from four different display enhancements*

**Optical bonding glass and adhesive:** There are two key aspects of an optical bond – the cover glass and the adhesive. While it's possible to optically bond a plastic cover sheet, the great majority of optical bonding today is done with soda-lime silicate glass (a.k.a. "float glass"). In most applications, standard thicknesses of 0.7 mm, 1.1 mm or 3.0 mm are used. Thinner glass is used more often in portable applications, while thicker is used more often in stationary applications (e.g., where vandal-proofing is more important than weight-reduction).

The optical adhesive is a more complex subject. There are three types in general use; in order of decreasing popularity, they are silicon, polyurethane and epoxy. The exact makeup of the adhesive used by each optical bonding supplier is a closely held secret; it's part of their "recipe" for outdoor viewability. In general, the adhesive must meet a variety of requirements, as follows:

- Mechanical: The adhesive must have adequate cohesion, appropriate temperature & humidity specifications, good UV and IR resistance, etc. Generally speaking, most adhesives used by optical bonding suppliers exceed the environmental specifications of most LCDs, so this is not generally a problem area. The line thickness of the bond typically ranges from a minimum of 0.25 mm to a maximum of over 1.0 mm – although different vendors have different thresholds of concern regarding increased susceptibility to shear forces when very thick bonds are used.
- Chemical: The adhesive must be inert with regard to the optical elements (glass and plastic) and to environmental liquids and vapors. In addition, the adhesive's curing process can't degrade the optical elements.
- Optical: The adhesive's refractive index and transparency are the most important properties. For example, the polyurethane adhesive used by one bonding supplier has an index of 1.49 and a transparency of 99.7% - these are very good numbers!

**Optical bonding side-benefits:** While it's clear that the primary purpose of optical bonding is to reduce the reflection of ambient light, it has a number of potentially valuable side-effects. These include the following:

- Increased ruggedness: bonding a sheet of glass on top of an LCD increases the ruggedness of the LCD. Measurements made by one bonding supplier demonstrated this in two areas:
    1) Dropping a 1.5-inch, 222-gram steel ball onto a 13.3-inch notebook LCD resulted in a maximum height (before fracture) of 22 inches for a standard LCD, and 40 inches with 1.1 mm glass bonded to the LCD.
    2) Vibrating the display in the Z-axis over 5-500 Hz at 0.5 g resulted in a reduction of peak resonance amplitude of about 5x and a reduction in the number of resonance peaks from 4 to 2 for the bonded display.
- Improved durability: a bonded display is better able to resist scratches, gouges, fluids, stains and dirt. This can be considered vandal-proofing to some extent.
- No condensation: the elimination of an air gap between the cover glass and the LCD means that moisture can't penetrate and cause fogging.
- Extended temperature range & EMI filtering: the temperature range of the LCD can be extended by incorporating ITO heaters on the cover glass; EMI filters can be added via the same mechanism.
- Reduced parallax error: the elimination of the air gap between the cover glass and the LCD moves a Tablet PC's writing surface closer to the LCD, thus reducing parallax error and making the Tablet PC easier to use.
- Thinner products: while the elimination of the air gap may only save one millimeter or less, in very thin products such as slate form-factor Tablet PCs, every millimeter counts.

**Anti-glare and optical bonding:** Anti-glare (AG) is often included on the top surface of optically bonded cover glass, but it's a bit of a confusing subject and is worth some explanation. Anti-glare is a roughened (textured) surface on the glass formed by chemical or mechanical etching. Anti-glare doesn't reduce the amount of reflected light; its purpose instead is to transform specular reflections into diffuse reflections. When you see a sharp and clear reflection of a light source (e.g. a light bulb) from a sheet of glass, that's a specular reflection. When you see a blurred area (a blob) of light, that's a diffuse reflection. Anti-glare treatment spreads out (diffuses) specular reflected light so that it's less annoying. An anti-glare treated surface without an anti-reflection coating still reflects about 4.5% of the ambient light.
For many years, all notebooks included anti-glare treatments on the top surface of the LCD. Then, about a year and a half ago, a trend towards using "glare" (a.k.a. "glossy") screens in notebooks started in the Japanese retail channel and spread westward. The advantage of a "glare" screen is that the LCD image (indoors) looks crisper and more intense; it's especially noticeable when viewing DVD movies. The image on a "glare" LCD is often said to "pop". The reason is that anti-glare treatment not only diffuses the reflected light; it also diffuses the light emitted by the LCD, thus fuzzing the image to a noticeable degree. Consumer notebooks have mostly transitioned to "glare" screens now; enterprise notebooks are slower to adopt "glare" screens but many analysts feel that it's inevitable.

So does a "glare" screen make sense with optical bonding? Yes, in that the LCD top surface definitely should not have an anti-glare treatment when optical bonding it used. No, in that the top surface of the cover glass should definitely have anti-glare because of the higher ambient levels in which the display is likely to be used. Whether or not the top surface of the cover glass has an anti-reflective coating, whatever reflected light is present should be diffused for maximum viewer comfort in bright ambient light.

**Touch screens and optical bonding:** Essentially any kind of touch screen can be optically bonded to an LCD; however, it's not done very often with the analog resistive touch screens commonly used in portable devices. The reason is that a resistive touch screen has four reflecting surfaces, and optical bonding only eliminates one of them.

In essence, optically bonding the touch screen is pointless without also enhancing the touch screen. Some forms of touch screen enhancements (such as the use of circular polarizers) eliminate the reflection from the bottom surface of the touch screen, which in turn eliminates the primary advantage of optical bonding.

**Tablet PCs and optical bonding:** One of the more visible applications of optical bonding is in the Tablet PC. A growing number of Tablet PC OEMs are offering outdoor viewable screen options; some of these OEMs use optical bonding as part of their "recipe" for the option. I say "recipe" because the OEMs tend to be quite secretive about exactly how they achieve improved outdoor readability, and no two OEMs do exactly the same thing.

Motion Computing http://www.motioncomputing.com was the first Tablet PC OEM to incorporate optical bonding into their recipe; their trademarked name for the option is "View Anywhere". Now Hewlett-Packard http://www.hp.com and several other OEMs are following suit. HP has announced their option (they call it "Enhanced outdoor-viewable display" without a trademarked name) but they aren't actually shipping it yet.

Not all Tablet PC OEMs who offer outdoor-viewable screen options use optical bonding. For example, Fujitsu's recipe for their latest T4210 Tablet PC includes the following ingredients:

1. Low-reflectivity polarizer on the "glare" version of the Hydis 12.1" Tablet LCD
2. AR coating on the back of the cover glass
3. Film that includes both AR and AG bonded to the front of the cover glass

The low-reflectivity polarizer decreases the reflection from the surface of the LCD from around 4% to less than 2%. The incremental cost to the OEM for the low-reflectivity polarizer is less than 50 cents, so this is something that's likely to become much more common in Tablet PCs. For an example of technical information on low-reflectivity polarizers, see the Nitto Denko website: http://www.nitto.com/product/datasheet/optical/001/index.html

The subject of LCD "pooling" is worth a mention at this point. When you press on the surface of some LCDs, you see an optical effect that looks like water pooling. What's happening is that you're temporarily disturbing the mechanical configuration of the liquid crystals. Adding an optically bonded cover glass to an LCD mechanically stiffens it, thus reducing the pooling effect to some degree. (One bonding supplier measured the change in flexibility in a 13.3-inch notebook LCD with a one-pound load and found that the LCD was >30% more rigid with 0.7 mm bonded glass, and >50% more rigid with 1.0 mm bonded glass.) In the Tablet PC world, many OEMs are migrating to Hydis LCDs; these LCDs use a modified cell structure that makes them much more resistant to pooling, so the point is gradually becoming moot.

Other than in Tablet PCs, optical bonding seems to be getting traction mainly in the transportation market. This includes marine navigation electronics (especially strong), avionics, GPS and in-vehicle computing systems. Other less-penetrated markets for optical bonding include medical (portable patient monitors, operating theatre monitors, etc.), test & measurement (portable oscilloscopes and logic analyzers, etc.) and POS (ATMs, outdoor kiosks, etc.).

**Just how viewable outdoors is it?** One of the big difficulties with all outdoor-viewable screen options is that there isn't a standard way of describing the enhanced optical performance of the product. Unfortunately, this means that if you want to be sure you know what you're buying, it's necessary to see an actual demo of the option before making the purchase. Most OEMs don't make any attempt to characterize the option; they just say that it improves the outdoor viewability. Motion Computing and Xplore Technologies are the only Tablet PC OEMs that attempt to quantify the performance, but their data leaves something to be desired, as follows (data taken from OEM websites as of August 14, 2006):

*Image courtesy of ClearView Displays*

**Motion Computing LE1600:**

- 10:1 reduction in unwanted reflectance and glare
- 15% improvement in "light pass-through" efficiency
- 225% increase in sunlight contrast ratio over the standard display
- Better viewability at wide viewing angles

**Xplore Technologies iX104:**

- 86% reduction in reflective loss
- 300% increase in screen effectiveness outdoors
- 16% increase in screen effectiveness indoors
- More efficient light pass-through
- 200% increase in impact and scratch resistance
- No impact on battery life

It seems evident from this data that the outdoor-viewable screen option does make the screen more readable in sunlight – but whether it's actually usable is still unknown. As noted earlier, keeping the contrast ratio as high as possible is the key to outdoor viewability, so the 225% increase in Motion's contrast ratio does represent some degree of improvement. One can only assume that Xplore is referring to contrast ratio when they say "300% increase in screen effectiveness outdoors". And, by the way, optical bonding has no effect whatsoever on the viewing angle of the LCD – Motion is off the mark in that regard.

Admittedly, it's a hard subject to quantify. My personal experience with several of these outdoor-viewable screen options is as follows:

- In the shade (e.g. under the overhang of a building), screen usability is very good. Color shades are easily distinguishable, although there is some moderate color-shifting. This corresponds to a contrast ratio of at least 10:1 or better.
- In moderate direct sunlight, the image on the screen can be seen, but most color shades are indistinguishable. Black-and-white images and text are quite readable, but anything beyond that is very difficult. This corresponds to a contrast ratio of perhaps 3:1 or 4:1. Depending on the time of day, shading the screen with your body can improve the usability somewhat.
- In worst-case maximum sunlight (e.g. on the beach at noon), the screen is essentially unusable. This corresponds to a contrast ratio of close to 1:1.

**Indoor use of an outdoor-viewable screen:** In general, outdoor-viewable screen options should not have any negative effect on indoor usage. The significant reduction in reflected light should actually provide some improvement indoors, although with lower ambient light levels, the improvement is less noticeable. This assumes, however, that the OEM did the enhancement correctly. Some critical reviews of the outdoor-viewable screen option on the Fujitsu T4210 Tablet PC have already appeared in the month since it was launched. The reviews say that the outdoor-viewable screen has a "frosted" appearance and that unless you really need to work outdoors, you're better off with the indoor screen. My own investigation of this issue has revealed that Fujitsu made a mistake in specifying the AG texture; the haze value is much higher than normal. This is the reason for the "frosted" appearance of the screen. Fujitsu is aware of this mistake and is in the process of correcting it. In the meantime, *caveat emptor*!

**Optical bonding suppliers:** *Table 2* below lists a selection of optical bonding suppliers. The list includes three types of companies, as follows:

- Merchant suppliers who are focused on optical bonding: Blue Cube, CI Lumen, ClearView Displays, DuPont Display Enhancements, White Electronic Designs.

- Manufacturers of end-user display products that do optical bonding primarily to enhance their own products but also offer it as a service to others: American Panel Company, General Digital, Global Display Solutions.
- Systems integrators who resell and/or re-brand optical bonding from one of the merchant suppliers: VarTech Systems.

It's worth mentioning that optical bonding is always an "aftermarket" activity from the point of view of an LCD manufacturer. No LCD manufacturer is currently doing optical bonding because the volume isn't high enough. Depending on the logistical capability of the optical bonding supplier, the bonding may take place before the LCD goes to the OEM/ODM, or the LCD may be removed for enhancement from the OEM/ODM's finished product and then reinstalled later. A supplier such as DuPont Display Enhancements who has an optical bonding factory in China is more likely to do the former; a supplier such as ClearView Displays who does all their optical bonding in Oregon is more likely to do the latter – although both can do either, depending on their customer's circumstances.

| Company | URL |
|---|---|
| American Panel Company | http://www.american-panel.com |
| Blue Cube | http://www.bluecubelcd.com |
| CI Lumen (formerly Lumen Technologies) | http://www.lumentec.com |
| ClearView Displays | http://www.clearviewdisplays.com |
| DuPont Display Enhancements | http://www2.dupont.com/displays/en_us/ |
| General Digital | http://www.generaldigital.com |
| Global Display Solutions | http://www.gds.com |
| VarTech Systems | http://www.vartechsystems.com |
| White Electronic Designs | http://www.wedc.com |

*Table 2: A selection of optical bonding suppliers*