OPTICAL BONDING TECHNICAL DESCRIPTION

If one were to simply compare the visual appearance of an optically bonded LCD display to that of a traditional “air-gapped”, non-bonded display one will quickly observe that the optically bonded LCD looks noticeable better. This significantly improved visual aspect will be true in any type of ambient light condition, not just in direct ‘sunlight’ environments. So, why does an optically bonded display always produce a much better viewable image, what other major resulting benefits occur, and how does optical bonding work in general? The answers are abundant and many relate to optical physics as well as human vision. This paper intends to explain all of these effects and benefits.

back to top

Human Vision and Liquid Crystal Displays

There exists two primary distinguishing characteristics of human sight, which are directly related to the workings of human binocular eyes. The first revealing quality is full color. Humans can see across the range of the visible spectrum or the portion of the electromagnetic spectrum that can be detected by the human eye. Electromagnetic radiation in this range of wavelengths is called visible light. A typical human eye will respond to wavelengths from about 390 to 750 nm. In terms of frequency, this corresponds to a band in the vicinity of 400–790 THz. A light-adapted eye generally has its maximum sensitivity at around 555 nm (540 THz), in the green region of the optical spectrum. The spectrum does not, however, contain all the colors that the human eyes and brain can distinguish. Unsaturated colors such as pink, or purple variations such as magenta, are absent, for example, because they can only be made by a mix of multiple wavelengths.

The second distinct characteristic of human vision is contrast or the difference in visual properties that makes an object (or its representation in an image) distinguishable from other objects and the background. In visual perception of the real world, contrast is determined by the difference in the color and brightness of the object and other objects within the same field of view. Because the human visual system is more sensitive to contrast than absolute luminance, we can perceive the world similarly regardless of the huge changes in illumination over the day or from place to place. Subsequently, it is for this very reason that ***contrast*** plays the biggest role in viewing images in direct sunlight or high ambient light conditions. Luminance is only a small factor. Try this exercise….as the **contrast level decreases images become less visible** even though the background brightness remains the same. The human eye significantly notices contrast changes, so simply making an LCD display brighter does not necessarily make it visually appear better nor easier to view in direct sunlight. One can increase the luminance of a display to the point of greatly reduced contrast and thus progressively diminishing image visibility.

With regards to Liquid Crystal Displays (LCD), the critical optical unit of measure is defined as “contrast ratio”, or a measure of a display system, defined as the ratio of the luminance of the brightest color (white) to that of the darkest color (black) that the system is capable of producing. For example, a particular LCD panel might have a hypothetical white luminance of 400 cd/m2 or nits (candelas per meter squared, a photometric unit of light measurement) and a black luminance of 2 cd/m2 (or nits). The contrast ratio would then be measured as 200:1. It should be noted here that the average human eye can not see adequate differences in contrast below 5:1 on the low-end or beyond a ratio of 100:1 on the high-end. Current LCD panels typically operate at contrast ratios of 300:1 or higher, which means that the LCD operates beyond the limits of human vision.

back to top

LCD's and Optical Physics

LCD modules currently manufactured by NEC, Samsung, LG, Optrex, AUO and many others are engineered to be highly optimized optical devices specifically designed for human vision. Active matrix liquid crystal displays are standard on most laptop computers as well as commercial and industrial grade display systems. Two properties of liquid crystal are used as tiny switches to turn picture elements (pixels) off and on. First the crystals are transparent but can alter the orientation of polarized light passing through them. Second, the alignment of their molecules (and their polarization properties) is changed by applying an electric field.

In a color display the liquid crystals are held between two glass plates or transparent plastics. These plates are usually manufactured with transparent electrodes, typically made of indium tin oxide, that makes it possible to apply an electric field across small areas of the film of liquid crystal.

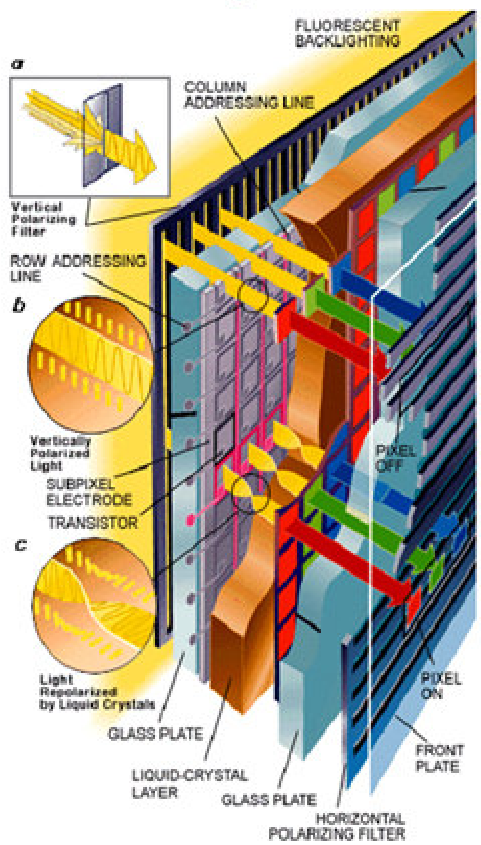
The outsides are coated with polarizing filters. Only light with a perpendicular polarization can pass through these filters. (a). See figure 1.1 below.

Inside the plates are transparent electrodes and color filters, which form very small picture element regions called subpixels. A grouping of a red, a green and a blue subpixels defines the color that the pixel transmits. Fluorescent (or LED) backlighting illuminates a display from the rear. In pixels that are off, light passes through the rear polarizing filter, the crystals (b) and the color filters, only to be blocked (absorbed) by the front polarizing filter. To the eye , these pixels appear dark. When a pixel is turned on, the liquid crystals reorient their position, and they in turn repolarize the light so that it can pass through the front polarizing filter (c).

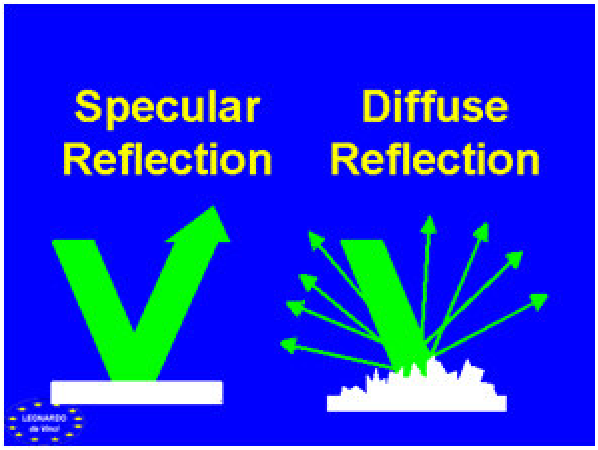
The active matrix provides a superior method of electronically addressing (turning on) an array of pixels. For an image to appear on screen, one row of pixels receives the appropriate voltage. At the same time, software in the computer dictates that voltage be applied to those columns holding active subpixels. Where an activated row and column intersect, a transistor turns on a subpixel electrode, generating an electrical field that controls the orientation of the liquid crystal. This process repeats sequentially for each of the rows which can take 16 to 33 milliseconds.

One of the fundamental problems and inherent limitations with all LCDs in real-world environments is the delicate nature of the polarizer material. The frontal polarizer is easily scratched and physically damaged which will permanently destroy the quality of the display image. Another problem is that this polarizer material is as well very hydrophilic (absorbs water) and can be damaged with prolonged exposure to moisture, such as rain, melting snow, dew, etc. It is because of these fragile characteristics of the front polarizer that system manufacturers, such as VarTech, deem it a necessity to protect the delicate frontal LCD surface with some type of protective window, be it cover glass or polycarbonate or touch screen. And here’s where everything starts to fall apart. Once a cover window or touch screen is placed in front of the LCD, an “air gap” is formed between the front polarizer of the LCD and the overlaying protective cover window. This ‘air gap’, regardless of thickness, causes undesirable optical and performance conditions. From an ‘optical’ standpoint, this ‘gapped’ cover window causes reduction in display contrast, decreases in visible luminance from the LCD, and increases both specular and diffuse reflection levels.

Figure 1.1



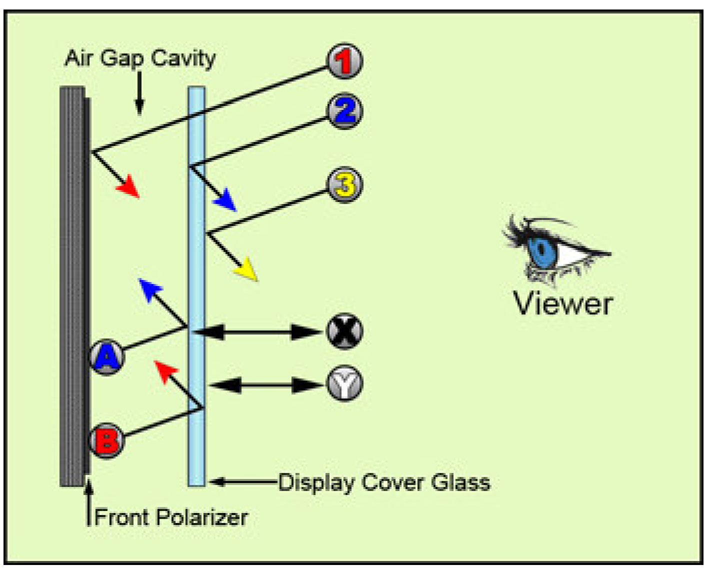
Reflections can be divided into two types: Specular reflection and Diffuse reflection. Specular reflection describes glossy surfaces such as mirrors or LCD cover glass, which reflect light in a simple, predictable way. This allows for production of reflected images that can be associated with an actual (real) or extrapolated (virtual) location in space. Diffuse reflection describes matte surfaces, such as paper or rock.



So, in the end, the protective cover window or touch screen is the direct cause of reduced display viewability….and environmental performance, which will be discussed later on in this article.

The 'air gap' has such an adverse effect on the quality of the LCD image because of the optics of Index of Refraction (Refractive Index) of transparent surfaces. Transparent materials, such as touch screens, Lexan overlays, glass protective windows, heater and/or EMI windows, etc. transmit light at slightly different rates. This variation is measured on the Refractive Index (RI) scale. The polarizer material typically used by the Original Equipment Manufacturer (OEM) has Refractive Index of 1.45; air has a value of 1.00; and the various types of glass substrates such as borosilicate and soda-glass have an average Refractive Index of closer to 1.50. The existence of an Refractive Index mismatch of more than 0.10 units between contacting surfaces is enough to cause significant light reflection to occur at the interface between those substances.

The greater the Refractive Index discord, the greater the interface light reflection levels. Consider this, the three reflective layers of Refractive Index mismatches typical of most LCD "air gap" monitors have several optical effects. First, is external ambient light shining on the display surface at an angle of incidence greater than zero degrees. A subsequent result is specular reflections at each of the three traditional interfaces; (1) Polarizer to Air, (2) Air to Glass and (3) Glass to Air. The second effect is light generated by the LCD's backlight. This generated light causes internal specular reflections at the interfaces of (A) Air to Glass and (B) Glass to Air. The third effect is external ambient light shining onto the display surface at zero degrees of incidence resulting in 'diffuse' reflections (generally referred to as "glare") at the interfaces of (X) Air to Glass and (Y) Glass to Air.



The cumulative effect of the internal specular reflections of A & B alone result in an average loss of 9.0% light transmission (luminance) from the display's backlight(s). Depending on the angle of incidence and intensity of external light, both specular and diffuse reflections can cause image "washout" (see "Reflection Washout" image below). This is the point where reflected light intensity is greater than the emitted light intensity from the display image. As the level of reflected light increases, the contrast ratio of the display image decreases below the level of 5:1, and no longer is visible to the human eye. It is for these reasons that 'air gapped' LCD products are not considered as sunlight viewable. The use of anti-reflective (AR) coatings on the front and back surfaces of the cover glass substrate, and even on the surface of the front polarizer, serves to help minimize these reflection levels by index matching the glass and polarizer surfaces closer to the 1.00 Refractive Index of air. Although the usage of multiple anti-reflective (AR) coatings (commonly referred to as 'passive enhancements') improves the viewability of 'air gapped' display products, the limited efficiency of these AR coatings (see Image 2 below) still permits reflections to occur at all interface surfaces. So, in the end, passively enhanced only displays are marginal at best for achieving LCD image readability in direct sunlight or very high ambient lighting conditions.

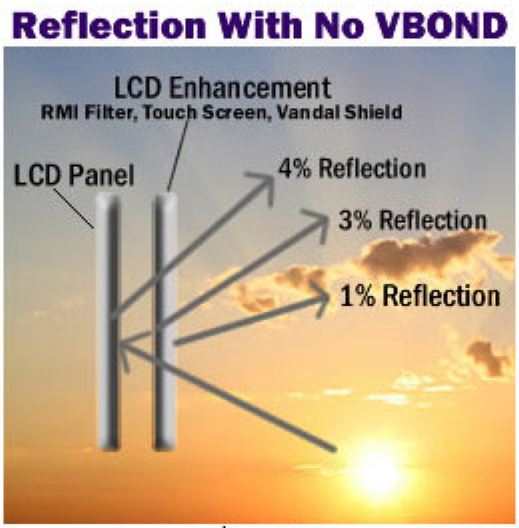


Image 1

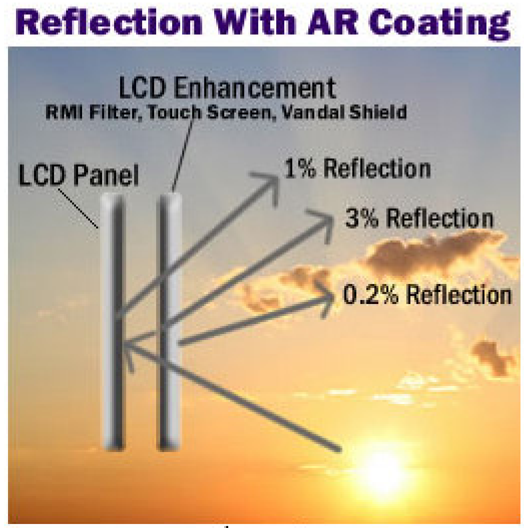


Image 2

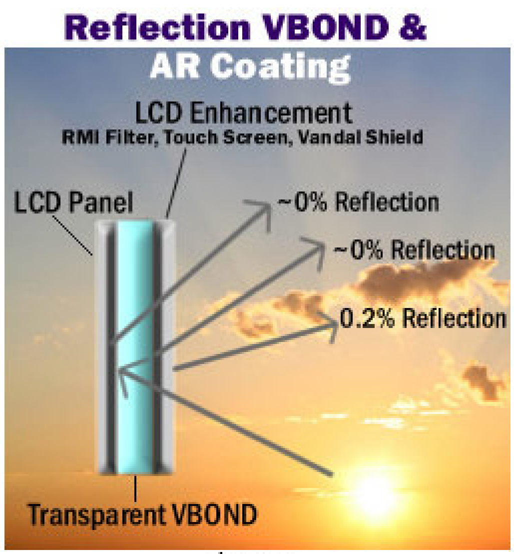


Image 3

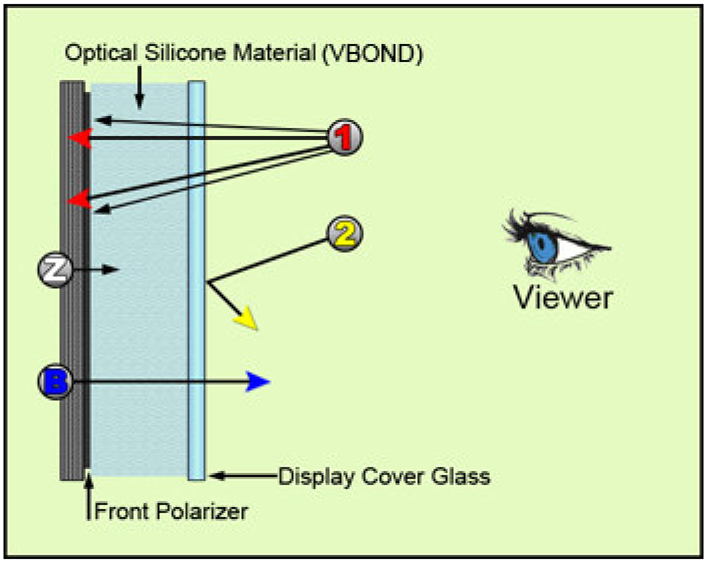
back to top

VarTech's Optical Bonding Solution

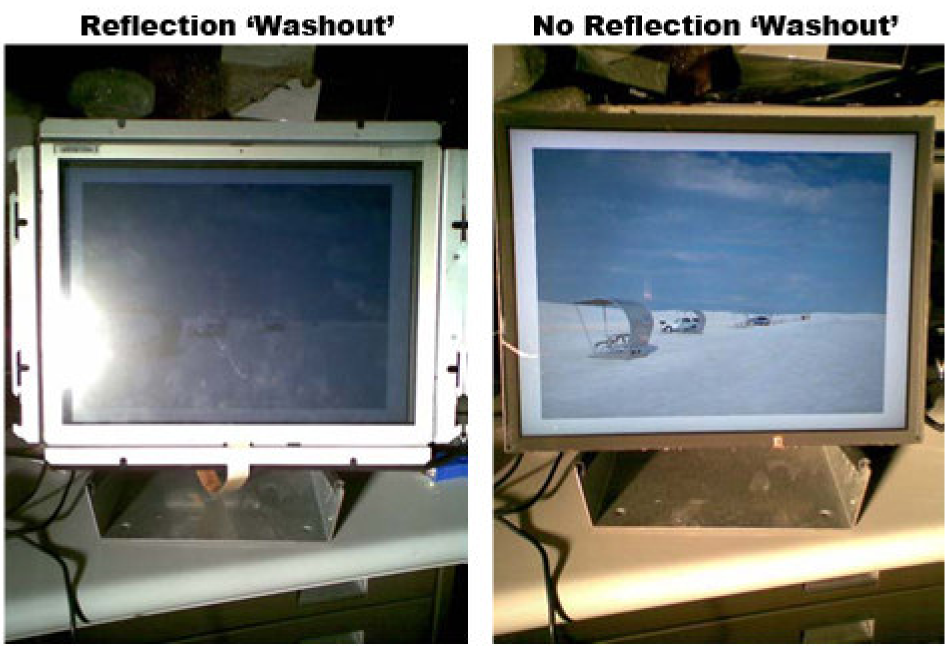
The ultimate solution to the problem of internal and external light reflections and its limitations on human vision is to eliminate all of the Refractive Index (RI) interfaces between the display's polarizer and the LCD product's cover window. This technique is typically referred to as "active enhancement" and is achievable by a unique use and application of special silicon based optical material which has a Refractive Index close to 1.44. This RI value is very close to the polarizer index of 1.45 and within the tolerance range of the nominal glass index of 1.50. VarTech takes this advanced silicon material and utilizes a unique bond design (described below) to join the glass and polarizer surfaces which results in an elimination of the 'air gap'. The ending result is an optical Refractive Index match of materials which allows for uniform light transmission and very low reflection. By utilizing display cover glass with a front surface anti-reflective coating treatment, the following effects are achieved:

> External light strikes the display cover glass at various angles of incidence. About 5% of this light (2) is reflected off of the AR coated surface. More than 93.5% of this external light (1) passes through the now index matched bonded solution. As light passes through the front polarizer, it becomes polarized light. When this polarized light then reflects off of the LCD cell, its polarization axis is rotated to where it is then absorbed and blocked by the front polarizer material.

In addition, due to the operating switching state of the liquid crystal cell sub-pixels, much of this external light will pass directly through the rear polarizer and reflect off of the internal backlight films. At this point this reflected external light (Z) is fundamentally the same as the internal light generated by the display backlight (B).



The end result is that the external light is optically directed, polarized, and utilized to enhance the color brightness of the display image. This enhanced color brightness maintains high contrast ratio levels, independent of the luminance intensity of the external light source. With the contrast ratio maintained and reflection "washout" eliminated the display image is easily seen and thus becomes truly readable in direct sunlight conditions.



back to top

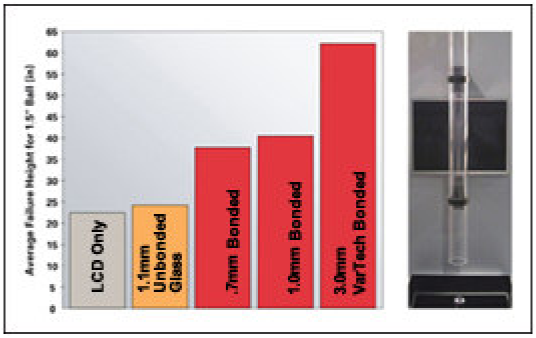
LCD Ruggedization Effects From Bonding

Impact Testing

VarTech's optical bonding technology with 3mm AR-treated cover-glass dramatically improves impact resistance over non-bonded displays in steel ball drop tests performed on LCDs. In fact, the bonding provided up to a 300% increase in impact resistance on even simple notebook PCs.

- Metal ball drop tests used 1.5" diameter steel balls (225g)
- Ball drop height increased 2 inches with each drop until failure occurred

- LCD only (no bond) failed at approximately 22 inches
- LCD with non-bonded 1.1mm protective cover glass failed at approximately 24 inches
- LCD with bonded 0.7mm protective cover glass failed at approximately 37 inches
- LCD with bonded 1.1mm protective cover glass failed at approximately 40 inches
- LCD with bonded 3.0mm protective cover glass (the type VarTech uses) finally failed at approximately 63 inches

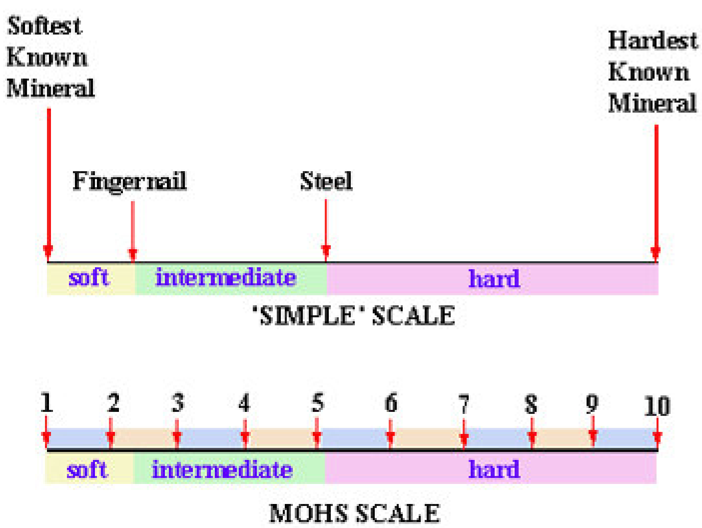


Scratch Resistance

VarTech's bonding process increased scratch resistance by 300% over non-bonded display surfaces in scratch tests.

Pencil grades from 2H to 9H were selected and applied to VarTech bonded and non-bonded LCD surfaces using sufficient pressure to allow the pencil lead to just crush.

Non-bonded LCD surfaces experienced scratches at 3H while the VarTech bonded surface showed no marring or scratches up to 9H.



Vibration Testing

Large displacements of the display glass can occur when LCD monitors are subjected to vibrations. Maximum displacements – where the rear of the LCD glass comes in contact with the backlight unit – can result in film damage and unwanted mura defects. VarTech's optical bonding process improved an LCD modules' resistance to mechanical shock and vibration over non-bonded LCD modules by 300% in testing.

back to top

Other Benefits – The Greenhouse Effect

Aside from the optical and ruggedization qualities discussed above with the elimination of the air-gap, optical bonding prevents heat build-up (see “Going Isotropic” below) from the "greenhouse" effect and prevents fogging from moisture or contamination from dirt or particles.

Going Isotropic

Liquid crystals (LCs) are a state of matter that has properties between those of a conventional liquid and those of a solid crystal. Most modern electronic displays are liquid crystal based (LCD). LC devices usually work at different thermal regimes, within various temperature intervals and in different climatic conditions. LC displays (LCD) have a well-defined isotropic or operating temperature limit, above which the actual liquid crystal molecules will lose their orientation and will assume a random orientation instead of ‘twisting’ through the light valve. If the temperature rise is too high, thermal motion will destroy the delicate cooperative ordering of the LC phase, thus forcing the material into a conventional isotropic liquid phase. In other words, the rod-like molecules will no longer lie in well-ordered planes stacked upon each other and will not be able to pass through the light valve. Isotropic conditions will cause positive image displays to become dark (see image below), while negative image LCD's become transparent. This is the Nematic-to-Isotropic Transition Temperature or NI Transition.

So, optical bonding eliminates the ‘air gap’, an area where heat can get trapped and begin to ‘cook’ the delicate liquid crystals. Isotropic state can still occur with bonded displays, but at a much slower rate.

back to top

The Bond Design

VarTech’s VBOND technology combines an innovative bonding process with an industry-leading proprietary adhesive to optically bond an anti-reflective glass, plastic or touch sensor directly to the front of an LCD display. VarTech’s bonding technology enhances display performance by improving sunlight readability up to 400% and impact and scratch resistance up to 300%. It is ideal for use in consumer, military, marine, and other industrial applications requiring outdoor viewability and the durability to withstand impact, vibration, extreme temperatures, altitudes and dust.

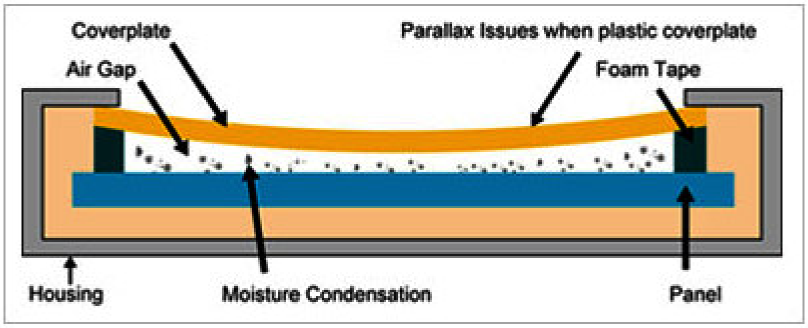
Optical Bonding is the affixing of two optical elements to one another, using a liquid adhesive. In this way, we differentiate bonding from lamination; a lamination process is currently performed by alternate “bonding’ companies as its solution for the ‘air gap’ problem. By lamination, we are referring to the affixing of two optical elements to one another using a pressure sensitive adhesive. Bonding is suitable for use with elements which are rigid and may be substantial in size, while lamination is suitable for affixing a thin membrane, such as an antireflective-coated plastic film, to a more or less rigid substrate, such as an LCD, OLED, Plasma display, touch sensor or anti-vandal shield.

Using the qualifier "optical", implies that the bonded adhesive material is transparent, has a suitable refractive index and is made under adequate control that there are no significant variations in optical properties within a single bond. On a practical side, the adhesive must also provide adequate bond strength, have a reasonable pot life after preparing, not present any health or safety issues, be available at reasonable cost from reliable sources and cure to the finished bond condition using temperatures and time which are friendly to flat panel display manufacture.

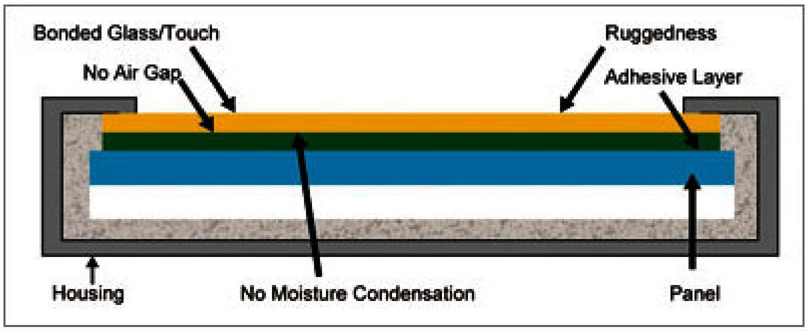
Additionally, when considering the optical bond as a useable material, it is important to analyze the impact of each substance and component to be used jointly as well as the associated properties of each material. Introduction of new materials into the process must be accompanied by a study of such things as environmental stability of the adhesive may be affected by the new materials and cure time(s).

VarTech has devised an innovative bonding formula to address these necessities.

An alternate adhesive agent that some bonding companies use is an epoxy based formula. This makes a much more rigid bond than silicone. However, it is not re-workable in the event of any issues during production or use (including in-warranty or post-warranty period repair situations). The biggest drawback, however, is the ‘yellowing’ effect. This type of material exhibits a severe yellowing over time when exposed to high ambient (solar) lighting conditions. Because of this tendency to yellow, VarTech does not use this type of adhesive.



Traditional Way



Optical Bonding

back to top

Uses and Applications

VarTech's bonding technology provides valuable benefits for displays used in consumer and industrial applications requiring outdoor viewability and the durability to withstand impact, vibration, extreme temperatures, altitudes and dust. Here are some examples of how VarTech bonding technology is currently used:

Marine Electronics

LCDs used in marine electronics are regularly exposed to harsh environmental elements such as high humidity and heat, extreme lighting conditions, rain, salt water, shock and vibration. VarTech bonded displays have been widely deployed in marine electronics and we have led the industry in providing the now standard display enhancement solution that:

- Prevents condensation and fogging
- Improves outdoor readability up to 400%
- Increases the durability to withstand extreme temperatures, shock and vibration

Medical

Medical applications require mobility and reliability features in LCDs and also present demanding challenges such as ambient lighting conditions, shock, vibration, sterile environmental requirements and constant temperature changes. VarTech has been a leading provider of bonding technology to the medical and emergency health care fields and has worked closely with medical display manufacturers to adapt to fast-changing medical technologies where VarTech is used to:

- Improve outdoor readability 400%
- Resist stains, dirt, dust, scratches and moisture
- Increase durability to withstand shock, vibration and temperature changes
- Enable thinner and lighter display designs

Military and Avionics

LCDs installed in military and commercial avionics applications operate in notoriously rugged conditions. Challenges can include rough terrain, extreme temperature changes, high altitudes, harsh ambient lighting, electromagnetic interference (EMI), shock these displays. In military and avionics applications, VarTech bonding technology:

- Enables stable performance in extreme temperatures and altitudes
- Resists stains, dirt, moisture and scratches
- Increases sunlight readability 400%
- Increases impact resistance 300%

Portable LCD Devices, KIOSK or Public Information Displays

The portability and/or versatility features of portable LCD displays and/or KIOSK or outdoor information displays present challenges such as frequent exposure to harsh outdoor lighting and temperatures, ongoing surface stress, shock and vibration. To protect against these challenges, VarTech has been successfully driving implementation of its optical bonding as a standard feature on many of its products. As consumers become more mobile and/or demand more from their outdoor visual devices, VarTech bonding can:

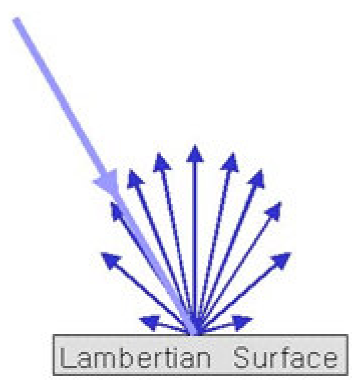
- Improve outdoor readability up to 400%
- Increase impact and scratch resistance by 300%
- Enable thinner and lighter display designs
- Improve overall durability against vibration, extreme temperatures and dust

back to top

Conclusion

By using an optical bond, it is possible to provide a low reflectance outermost surface by coating only one side of one piece of glass. This outer coating, as stated, will be a very low reflectance and the bond will eliminate the optical transitions within the rest of the viewable portion of the display. This is true, even if the refractive index of the adhesive, the cover glass and the display are not exactly matched. Optical bonding of an LCD with an outer polarizer that is antiglare treated will also eliminate the diffuse reflections seen from this surface. As seen in the image below:

The antiglare treatment amounts to a controlled roughening of the surface. This causes a bright glow on the face of the display which cannot be avoided, regardless of the relative angles between the light source, the display and the viewer. It is a Lambertian reflectance (see image below) and will significantly reduce the viewability of the display in high ambient lighting. By bonding an anti-reflective (AR) glass to the face, this Lambertian reflectance is converted to a specular (image forming) reflection. It is now possible to adjust the angles of the display and user to minimize the distraction caused by the reflections.



A side benefit of bonding is an increase in usable light output. Not only have we reduced the reflections of ambient light (an optical noise), but the light from the display which was being reflected out of the path toward the viewer's eye is now directed to the user; this is an increase in the signal, or light output.

Another point to be considered arises when the display is to incorporate a conductive surface, such as an EMI filter or heater. The most commonly used conductor is indium tin oxide (ITO), which has a refractive index of about 1.95. This will yield a Fresnel reflectance (see below images) in air of about 10% per surface. If normally deposited ITO is bonded without regard to index matching, the reflectance will be reduced to less than 2%. By using a graded coating which is index matched to a nominal 1.5 for the bond, the reflectance can be reduced to less than 0.5%.