Optical Bonding Technical Description

If one compares the visual appearance of an "optically bonded" display product to the very same "air gapped" display product, it is immediately obvious the bonded display simply "looks better". This better appearance is true in any environmental lighting condition, to the extent that bonded liquid crystal displays (LCD's) are viewable in direct sunlight (ref: sunlight viewable & sunlight readable). The questions raised are why is it bonded displays always look better, and how does optical bonding work. The answers to these questions deal with the subjects of human vision and optical physics.

Human Sight & LCD'S

There are two primary characteristics of human vision, which are directly related to the workings of our binocular eyes. The first characteristic is that human sight is in full color. We can see across the range of the "visible spectrum"; (ref: 350 to 800 nanometers wavelength within the electro-magnetic spectrum). The second characteristic is that human sight is based on **contrast**, the difference in brightness or luminosity between dark and light colors. It is for this reason that the most visible thing to the human eye is that with the greatest level of contrast, specifically black color on a white background. This is why as the contrast level decreases the words become less visible, even though the background brightness remains the same.

When human sight is applied to any liquid crystal display product and rated for its "view ability", it is very important to recognize that people "see" the contrast, not the brightness. It is for this reason simply making a display brighter does not necessarily make it look better or easier to view. Taken to the extreme, a display can brightened to the point of diminishing contrast, and the display becomes progressively less visible.

In regard to LCD's and human sight measurement, the optical unit of measure is defined as "contrast ratio" (CR). The CR is simply the ratio of light color luminance divided by the dark color luminance. For example a display may have a white luminance of 400.0 cd/m2 (candelas per meter squared; a photometric unit of light measure), and a black luminance of 2.0 cd/m2. The display in turn has a contrast ratio value of 200:1. It's worth noting that average human sight can not resolve or see differences in contrast below a ratio of 5:1 on the low end, or beyond a ratio of 100:1 on the high end. The newer generations of LCD's however have contrast ratios of 300:1 and higher, which means that liquid crystal displays operate beyond the limits of human vision.

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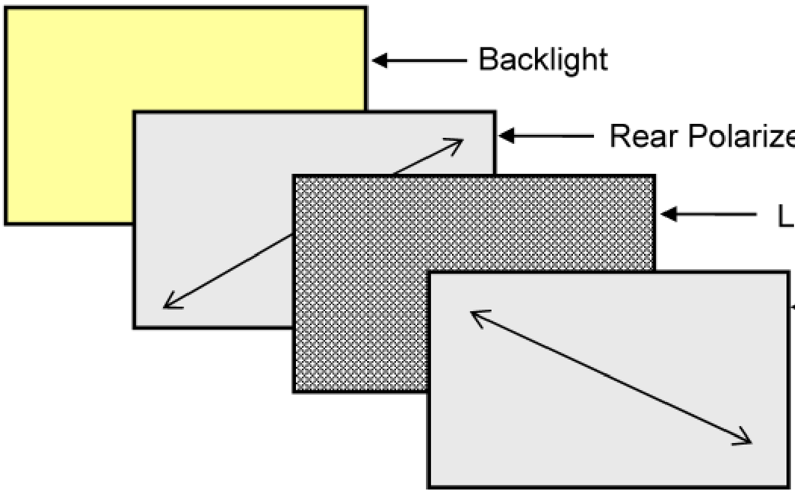
Optical Physics & LCD's

The LCD module products currently produced by the Original Equipment Manufacturers are highly optimized optical devices specifically designed for human vision. The construction of all LCD's utilize an electronically addressed liquid crystal glass cell with cross axis polarizer material on the front & back surfaces. In most products, a backlight assembly is utilized to shine light through the rear polarizer to illuminate the display. The display image is formed by the individual color filtered sub-pixels within the LC cell switching on or off. In one state the LC cell rotates the rear polarized light, allowing it to align with the front polarizer axis and transmit through the front polarizer. In the other state the rear polarized light is not rotated, and the cross polarized light is absorbed and blocked by the front polarizer.



The fundamental problem and limitation with all LCD's in real world applications is the delicate nature of the polarizer material. The front polarizer is easy scratched and physically damaged, which will permanently destroy the display image quality. The other problem is that the polarizer material is very hydrophilic (absorbs water), and can also be damaged with prolonged exposure to moisture. It is exactly because of this delicate polarizer material, that product manufacturers are required to protect the LCD surface with a cover glass or plastic window. Once a glass or plastic window is placed in front of any LCD, an "air gap" is formed between the front polarizer and the cover window. This air gap (regardless of the thickness) causes optical conditions which reduces display contrast, decreases color brightness, and increases both specular and diffuse reflection levels. In the end, the cover window solution used to protect the LCD polarizer is the direct cause of reduced display view ability.

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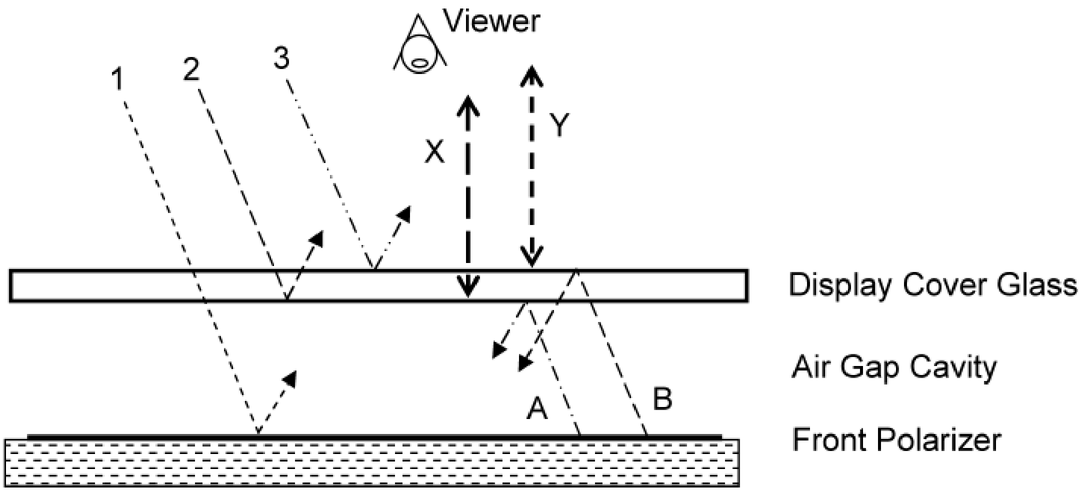
The reason the air gap has such a negative effect on the display viewing quality, has to do with the optical Index of Refraction (Refractive Index) of transparent substances. Transparent materials transmit light at slightly different rates which is measured on the refractive index (Ir) scale. Polarizer material has a refractive index of 1.45, air has a value of 1.00, and the various types of glass substrates such as soda-lime & borosilicate have an average refractive index close to 1.50. A refractive index miss-match of more than 0.10 units between contacting substances, is enough to cause light reflection to occur at the interface between those substances.

The greater the refractive index miss-match, the greater the interface light reflection levels. To better understand this, consider the three reflective layers of Ir miss-matches within the typical air gap display product. The first effect is external light shining on the display at an angle of incidence greater than zero degrees. This results in "specular" reflections at the interfaces of 1) Polarizer to Air, 2) Air to Glass, & 3) Glass to Air. The second effect is light generated by the display backlight, causing internal specular reflections at the interfaces of A) Air to Glass; & B) Glass to Air. The third effect is external light shining on the display at zero degrees of incidence. This results in "diffuse" reflections (commonly referred to as "glare") at the interfaces of X) Air to Glass; & Y) Glass to Air.



The cumulative effect of the internal specular reflections A & B alone, results in an average loss of 9.0% light transmission (luminance) from the display backlight. Depending on the angle of incidence and intensity of external light, both specular & diffuse reflections can cause image "washout". 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 is no longer visible to the human eye. It is for these reasons that air gapped LCD products are not considered to be sunlight viewable. The use of anti-reflective (AR) coatings on the front & back surfaces of the cover glass substrate, and even on the surface of the front polarizer, serve to minimize these reflection levels by index matching the glass and polarizer surfaces closer to the 1.00 Ir value of air. Although the use of multiple AR coatings (referred to as "passive enhancement"), greatly improves the view ability of air gapped display products, the limited efficiency of these AR coatings still permits reflections to occur at all interface surfaces. In the end passively enhanced displays are marginal for achieving direct sunlight viewing.

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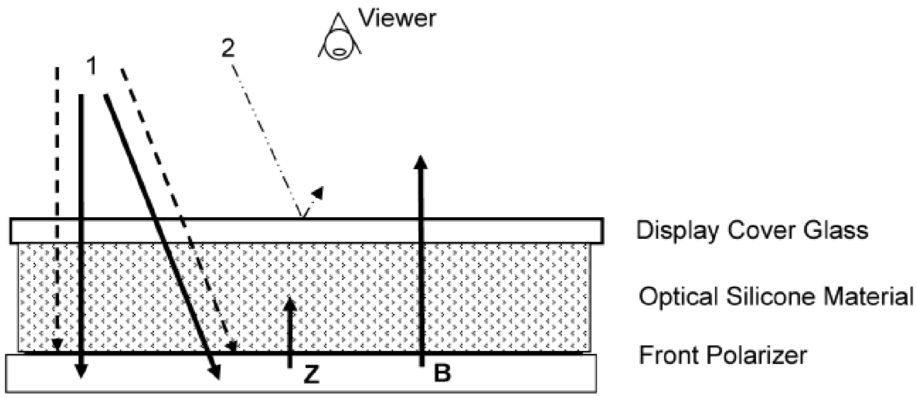
Optical Bonding Solution

The ultimate solution to the problem of internal & external light reflections and its limitations on human vision is to eliminate all the refractive index interfaces between the display polarizer and the display cover glass. This technique is referred to as "active enhancement", and is achieved by Optical Technology with the use of a silicone based optical material which has a refractive index close to 1.44. This Ir value is very close to the polarizer index of 1.45, and within the tolerance range of the nominal glass index of 1.50. This silicone material "optically bonds" to the glass and polarizer surfaces, which displaces and eliminates all the air. The result is an index matched optical stack of materials which allows for uniform light transmission, and very low reflection. By utilizing display cover glass with a front surface AR coating, 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 the AR coated surface. More than 93.5% of this external light (1) passes through the index matched optical stack of glass, silicone and polarizer materials. As this light passes through the front polarizer, it becomes polarized light. When this polarized light then reflects off the liquid crystal glass cell, its polarization axis is rotated where it is then absorbed and blocked by the front polarizer material. In addition, due to the operating switching state of the LC cell sub-pixels, much of this external light will pass directly through the rear polarizer, and reflect off the backlight materials. 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 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 easy seen and thus becomes true sunlight viewable. This in essence is the magic workings of optical bonding, and the foundation of Hatteland's "Optical Technology" display products.

There are several additional benefits gained from display bonding other than the visual and optical. The elimination of the air gap also eliminates the possibility of any particle contamination, condensation or fogging, as well as salt crystals that can form in the air gapped display product. These are critical benefits for the marine and naval display markets. The bonded display also eliminates the possibility of particle contamination from developing between the display and cover glass, typically caused by vibration & shock exposure. Lastly the bonded display cover glass effectively becomes laminated safety glass. If the cover glass were to be broken, the optical silicone material will help protect the LCD and hold the broken cover glass pieces together, limiting the safety hazard, while permitting functional operation of the display product.

End.

17 Aug 2007, J. Sanelle

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