Circular polarizers in resistive touch screens

by Geoff Walker

Making a transmissive LCD in a portable device readable outdoors in direct sunlight is ordinarily a challenge, but when a resistive touch screen is added to the mix, the problem becomes even more difficult. The problem is that a touch screen adds multiple reflective surfaces, and when more ambient light is reflected back to the user, the outdoor readability goes down. This article describes the role that a circular polarizer plays in solving this problem.

The LCD outdoor viewability problem: Before diving into how a circular polarizer reduces reflections, let's describe the problem that it's 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 to at least 1000 cd/m^2. 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 actually reduces the contrast ratio (all other things unchanged). 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 (more than 30 inches) because large displays already use a lot of backlight tubes.

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.) Increasing the extrinsic contrast ratio improves the outdoor viewability. Some rule-of-thumb values for extrinsic contrast are shown in *Table 1* below.

Extrinsic Contrast Ratio	LCD Outdoor Readability
1-2	Totally unreadable in sunlight
3-4	Adequately readable in shade; barely readable in sunlight
5.5-6	Minimum acceptable readability in sunlight (military spec)
10	Definitely readable in sunlight; looks good
15	Outstanding readability; looks great
20	Totally awesome; excellent readability; can't improve

Table 1: Extrinsic contrast ratio versus LCD outdoor readability

The objective of outdoor-viewability enhancement is to increase the LCD's contrast ratio by reducing the amount of ambient light reflected by the LCD and anything on top of it (such as a touch screen). Light is reflected from any surface in the optical path where there's a change in the index of refraction. The greater the difference, the more light is reflected from the surface. Air has an index of refraction of 1.0, glass has an index of around 1.5 and plastic film has an index of around 1.6. This difference between 1.0 and 1.5 or 1.6 results in an average of 4.5% reflected light per surface (actually it varies from 4% to 5% depending on the difference in refractive index, the wavelength and other factors). *Figure 1* below diagrams the reflected light from an LCD with a standard resistive touch screen; *Table 2* below shows four different enhancement cases.

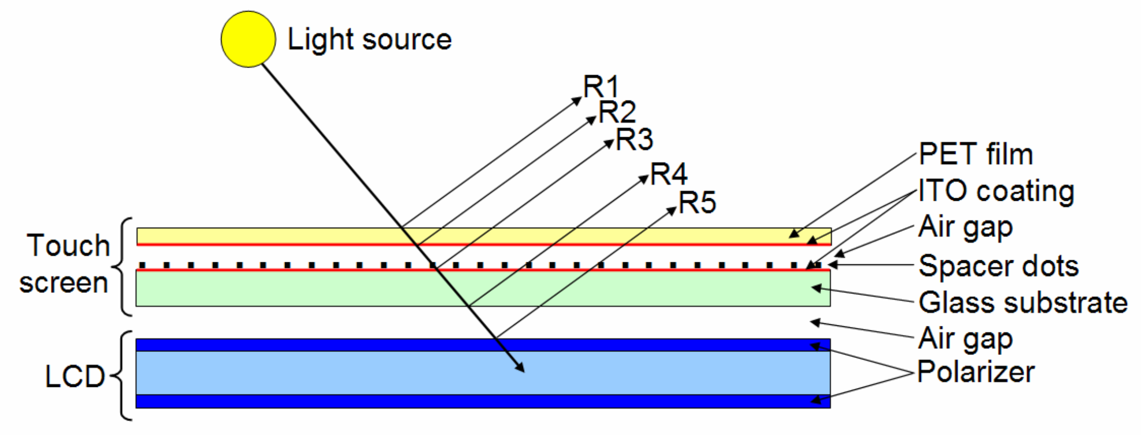


Figure 1: Reflected ambient light from an LCD with a resistive touch screen

Reflected Light	(1) No enhancement	(2) AR on top surface	(3) AR on two surfaces with a circular polarizer	(4) AR on all five surfaces
R1	4.5%	0.25%	0.25%	0.25%
R2	4.5%	4.5%	0.5%	0.25%
R3	4.5%	4.5%	0.5%	0.25%
R4	4.5%	4.5%	0.5%	0.25%
R5	4.5%	4.5%	0.25%	0.25%
Total	**22.5%**	**18.25%**	**2.0%**	**1.25%**

Table 2: Reflected ambient light resulting from four different LCD enhancements

If the ambient brightness is 10,000 cd/m^2 (a somewhat low approximation of direct sunlight), reflected ambient of 22.5% in Case #1 is 2250 cd/m^2. An approximation formula for calculating contrast ratio in this situation (courtesy of White Electronic Designs) is Contrast Ratio = 1 + (Display Brightness/Reflected Light). For a 200-cd/m^2 notebook display, 2250 cd/m^2 of reflected light yields a contrast ratio of 1.1:1 – totally unreadable! Case #2 yields essentially zero improvement. Case #3 yields a contrast ratio of 2:1 – barely readable in the shade. In Case #4, the formula yields a contrast ratio of 2.6:1 – not much better. Increasing the effective backlight brightness to 300 cd/m^2 through the use of passive enhancement films would yield a contrast ratio of 3.4:1 – still not up to the minimum military spec, but at least it's readable in the shade.

Anti-reflective (AR) coating: "AR" in *Table 2* is an abbreviation for an anti-reflective coating. An AR thin-film coating causes the relative phase shift between the light reflected from the upper and lower surfaces of the thin film to be 180 degrees. This causes destructive interference between the two light beams, canceling both beams before they exit the surface of the film. The optical thickness of the film must be an odd number of quarter-wavelengths of the design-center light frequency; this makes the path length difference between the two light beams equal to one-half wavelength, which is what causes their cancellation. For this reason an AR coating is sometimes called a ¼-λ (quarter-wavelength) film. Note that "optical thickness" is a function of both the index of refraction of the film and the physical thickness of the film.

An AR coating is also sometimes called an "index-matching" film. In order for the destructive interference method to work, there can't be any additional reflection from the surface of the substrate on which the AR coating is deposited. For this reason, the AR coating must match the index of refraction of the substrate to that of the air above the coating. The better the match, the less light is reflected.

It sounds relatively straightforward, but in reality, the degree of destructive interference and index-matching varies with both wavelength and temperature. This means that the reflection percentage specified for an AR coating is an average figure, and that the actual value can vary by up to 2x over the wavelength of visible light and over the display operating temperature range. A typical coating material for a simple single-layer AR coating is magnesium Fluoride (MgF_2), which has an index of refraction of 1.38 at a wavelength of 550 nm. This is a broadband material (400-750 nm) that works with substrates having an index of refraction from 1.45 to 2.4. The reflectivity resulting from this coating is around 2%. Actually it varies between 1.3% and 2.2% over the visible wavelength range at 0°C and between 1.9% and 3% at 40°C.

In the real world of touch screens used with transmissive LCDs, a reflectivity of 2% per surface is nowhere near low enough, as evidenced by the analysis of *Table 2* above. Typical AR coatings used on touch screens are made of multiple layers of different materials applied through sputtering or evaporation. A particular combination of materials (e.g. titanium dioxide and silicon dioxide) is optimized for specific glass indices, wavelength regions, polarization requirements, angles of incidence, etc. The figure of 0.25% used in *Table 2* is a representative average for all multi-layer AR coatings with incident light at 30 degrees. The best “military grade” AR coatings can achieve a reflectivity of 0.1% or less. This makes a big difference in the results of Case #4 in *Table 2* – the contrast ratio of 2.6:1 is improved to 5:1 (almost acceptable), and with a 300 cd/m^2 passively-enhanced backlight it becomes 7:1 (above the minimum military spec).

It’s broadly understood that making a touch screen-equipped transmissive LCD fully readable outdoors without increasing the backlight to at least 400 or 500 cd/m^2 is a very difficult task. Just for comparison, consider the case of a Tablet PC equipped with only an EMR digitizer (electromagnetic resonance, located behind the screen). By optically bonding the cover glass (writing surface) to the surface of the LCD, and by applying a single AR coating to the top surface of the cover glass, a total reflectivity of 0.25% can be achieved relatively easily at relatively low cost, which (using the formula above) yields a contrast ratio of 9:1.

Circular polarizers and reflected light: A circular polarizer is an alternative to using an AR coating on all the surfaces of the touch screen. *Figure 2* below illustrates the basic principle of using a polarizer to reduce reflections. Unpolarized light starts in the upper left, goes through a linear polarizer and becomes linearly polarized perpendicular to the direction of travel. The light then goes through a quarter-wave phase retardation film and becomes right-circular polarized. Circularly polarized light changes orientation when it bounces off a surface, so the reflected light becomes left-circular polarized. When the light goes through the quarter-wave film again, it reverts to linear polarization, but this time aligned with the direction of travel. The linear polarizer then blocks the reflected light.

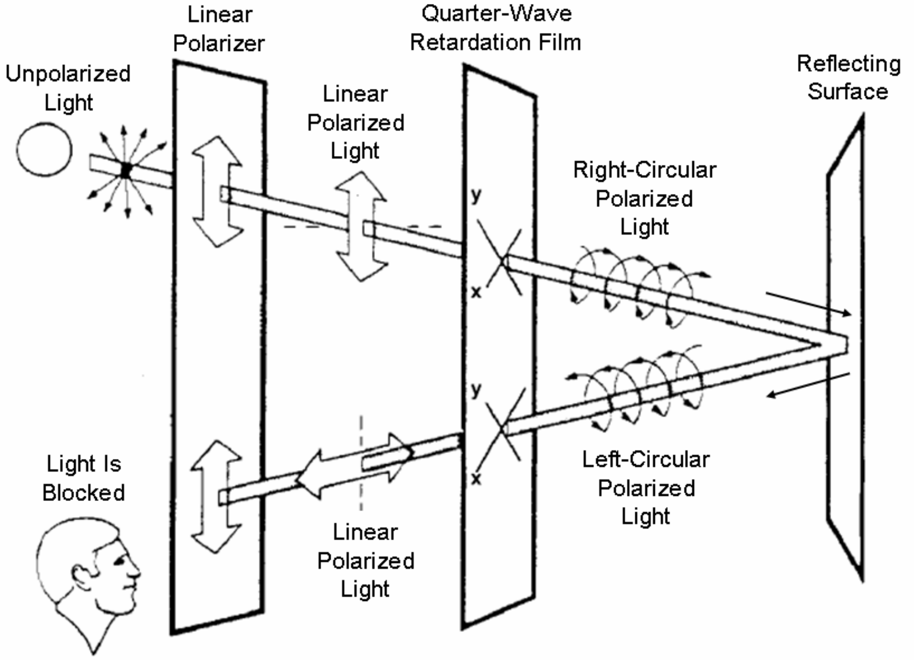


Figure 2: How a polarizer can be used to reduce reflections
(Courtesy of Agilent Technologies, Inc.)

This makes use of the fact that changing the phase of linearly polarized light by 90 degrees (one quarter of a 360-degree wavelength) changes the light to circular polarization. A “circular polarizer” is therefore created by laminating a quarter-wave (¼-λ) retardation film to a linear polarizer. This retardation film (also called a birefringent film) is basically the same as the AR thin-film coating described above, except that it has a different function when used with a polarizer.

The fly in this ointment is that it's not 100% efficient. This is similar to using two crossed polarizers to block all light. When you do that in front of a bright light source you still can see a faint blue color – it doesn't actually block 100% of the light. In addition, the quarter-wave film is by definition optimized for a specific frequency of light; it doesn't work perfectly as you move away from the design-center frequency. The result is that the circular-polarizer scheme lets through about 0.5% of the incident light for each reflecting surface. Since a resistive touch screen has three internal reflecting surfaces (as shown in Figure 3 below), R2, R3 and R4 are 0.5% each for a total of around 1.5% internal reflectivity for the touch screen as a whole.

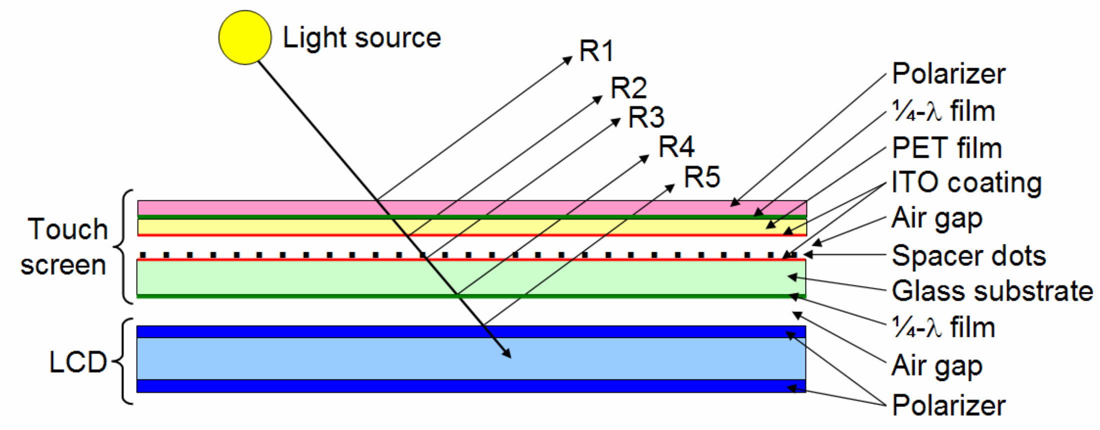


Figure 3: Resistive touch screen shown with a circular polarizer

So why would anyone want to use a circular polarizer for higher reflectivity instead of applying AR coating to all the reflective surfaces and getting lower reflectivity? Cost. A rough rule of thumb is that each high-quality AR coating costs about $15; five times $15 is $75, far more than the total BOM cost of the touch screen. A circular polarizer is lower cost than three AR coatings, however, and it's almost as good.

A circular polarizer-equipped touch screen can be optically bonded to an LCD, but the gain isn't as much as in the Tablet PC case so it's not done very often. In *Figure 3*, bonding eliminates reflections R4 and R5. R4 is already down to 0.5% due to the circular polarizer, and R5 is down to 0.25% due to the AR coating. Bonding thus reduces the reflections by 0.75% and eliminates one AR coating. High-volume bonding in Asia is currently around $50 for a 12-inch LCD; subtracting one AR coating at $15 leaves a net cost increase of around $35 for a reflection reduction of less than 1%, which may be difficult to justify in mainstream applications.

Optimizing circular polarizer touch screens: Another fly in the ointment has been that using an additional polarizer causes a significant reduction in the effective light output of the display. Gunze (http://www.gunzeusa.com with parent http://www.gunze.co.jp), has recently made a number of technical improvements in the design of their circular polarizer touch screens that have increased the transmissivity from 66-67% to 75-76% - almost as high as a standard resistive touch screen at 80%. The improvements include the following:

- Optically matching the absorbing angle of the touch screen polarizer to that of the top polarizer in the LCD. While this ties the touch screen to a particular LCD and/or LCD manufacturer, it's the single most important technical improvement and it's not an unreasonable limitation for most portable device OEMs.
- Using multiple optical layers (e.g. titanium dioxide and silicon dioxide) between the ITO coating and its substrate. By better matching the refractive index of ITO to that of the substrate, the intervening optical layers reduce the reflections from the ITO and thus increase the transmissivity of the touch screen. This is basically a variation of the "index matching" described above under "Anti-reflective (AR) coating".

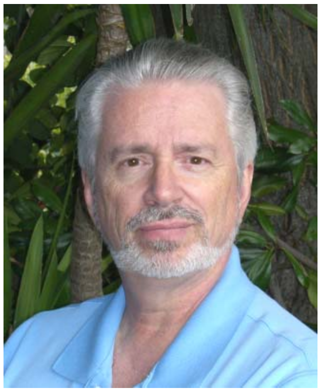
- Changing to a more optically isotropic plastic film. Instead of PET, Gunze has experimented with polycarbonate (PC), polyethylene sulfate (PES) and amorphous polyolefin (APO). One advantage of all of these materials is that they allow the user to wear polarized sunglasses while using the polarized touch screen. Gunze's top-choice material is acrylic siloxane polymer (Gunze calls it "HT"). This new material, made by Nippon Steel Chemical for Gunze in 200-250 micron thickness, has high isotropism, optical elasticity and UV resistance, and it has a hardness of 4H–5H without a hardcoat! (UV-resistance is a significant problem in current touch screens, since after only ~500 hours of UV-A exposure both the hardcoat and the ITO layer tend to peel off the PET film, and the PET film turns yellow.) Finally, anti-glare (AG) treatment can be formed directly on the surface of the HT material. Gunze is currently using HT in the production of automotive GPS touch screens.
- Eliminating the top TAC film layer from the polarizer (this engineering work is still in progress at Gunze). The current polarizer consists of the following stack: (1) protective PET film, (2) top TAC film, (3) PVA (polyvinyl alcohol, the actual polarizer material), (4) bottom TAC film, and (5) adhesive. By eliminating the top TAC film layer and replacing it with PET, the cost of the touch panel can be reduced since PET is cheaper than TAC. However, TAC film cuts UV, while PET film doesn't, so Gunze is developing a special version of PET to avoid problems with UV degradation. In the longer term, the top film is likely to become HT (acrylic siloxane polymer, mentioned above), which eliminates the UV problem and provides a harder top surface than PET.

All of the above discussion has been about film-glass touch screens. Gunze also makes polarizer-equipped film-film touch screens, which are often bonded directly to small LCDs. In this area they have developed an interesting innovation by completely eliminating the isotropic film and depositing the ITO coating directly on the quarter-wavelength retardation film. This reduces cost and makes the complete touch screen only 0.5 mm thick. Combining this change with the "multiple optical layers" technique described above reduces the touch screen's reflectivity by about 1% and increases the display brightness by about 5%. This change is currently in production at Gunze.

The author would like to express his thanks to Dr. Hirotoshi Sato, manager of the New Business Development Center at Gunze Ltd in Japan for his explanation of Gunze's recent touch screen developments.

The author would also like to correct two errors concerning Gunze that appeared on page 22 of the "Highlights from the SID show floor" article in the June 2006 (*Volume 1, Number 6*) issue of this newsletter, as follows:

1. Gunze's annual touch screen revenue is around $80M, not $800M, and it was only about 5% of Gunze Corporation's total $1.5B revenue in 2005.
2. The transmissivity of Gunze's latest circular polarized touch screen is 76%, not 67%, which represents an improvement of 9%, not 13%.



Geoff Walker, Associate Editor for Veritas et Visus, currently heads his own consulting company called Walker Mobile, LLC. Based in Silicon Valley, Geoff has worked on the engineering and marketing of mobile computers since 1982 at GRiD Systems, Fujitsu Personal Systems (now Fujitsu Computer Systems) and Handspring. Prior to 1982, Geoff worked in a number of different marketing, field support, IT and management roles at Hewlett-Packard. In addition to mobile computers, Geoff's areas of particular expertise include displays and digitizers. Geoff holds a BS in Electrical Engineering and a BS in Technical Writing, both from the Polytechnic Institute of Brooklyn, and has completed all the course work for an MBA in Marketing from New York University.