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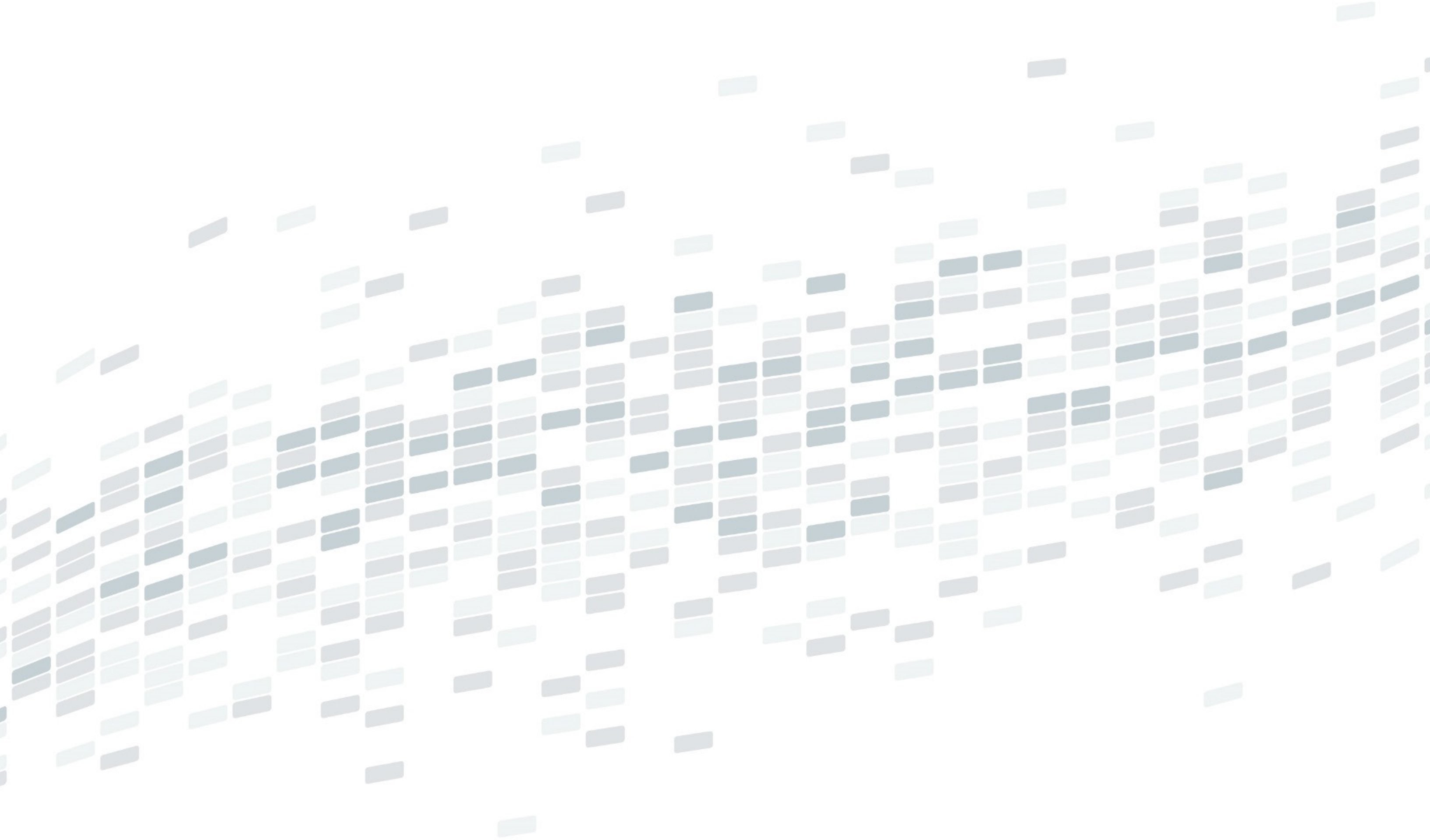
Active Polarizer Dimmable Lens System



Active Polarizer Dimmable Lens System

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Abstract

Display units that utilize a dimmable smart lens may be utilized to reduce the required display luminance compared to a smoked neutral density lens to provide a hidden display appearance. A lens configuration that utilizes an active polarizer in conjunction with a linear polarizer is explored.

Author Keywords

dimmable; lens; active; polarizer; guest-host;

1. Introduction

In the automotive market, electronic displays are becoming more common in instrument cluster and center stack displays. In addition, electronic displays are being utilized for door, outside entry, rear seat entertainment, and passenger entertainment applications. Often for styling reasons, it is desirable to have the display area hidden with a black panel effect in the key off condition. The black panel lens may also be referred to as “dead front” (a.k.a. “secret until lit” or “black panel” or “dark panel” effect). Typically the black panel lens is constructed from a neutral density lens with 20% to 50% transmission of visible light. In addition to neutral density lenses, the use of polarization films [1] may be utilized to enhance the transmission of polarized light from TFT displays while providing a reduced transmission rate of about 40% for non-polarized ambient light. However the low transmission values lead to exceedingly high display luminance requirements in order to be able to see the display under high ambient light conditions. One method to lower the display luminance is to use various anti-reflection (AR) coatings and techniques. However AR coatings are prone to highlighting fingerprints and are generally not desirable.

Another method to reduce the required display luminance, while providing a black panel effect, is to employ the use of a dimmable lens in front of the display. When the vehicle is off, the dimmable lens would be configured to be in a low transmission (dark) state. After the vehicle is started, the lens transmission would be automatically adjusted for proper display visibility with the objective to keep the lens as dark as possible. The use of an active polarizer in conjunction with a linear polarizer offers a possible solution towards providing a dead front appearance while minimizing TFT backlighting power.

2. Background/Objective

The objective of this paper is to detail the active polarizer plus linear polarizer dimmable lens element located in front of a liquid crystal display. There are several types of dimming elements such as suspended particle devices (SPD), electrochromic (EC), dye-doped guest-host liquid crystal (LC) [2], and LC shutter (twisted nematic (TN) or vertically aligned (VA)) systems. Each of these systems has desirable and undesirable aspects. With the exception of LC shutter lens systems, dimmable lenses have been based on absorptive technologies and do not have any polarization effects. A new configuration composed of an active polarizer plus linear polarizer has many desirable attributes:

- Low haze
- High dimming transmission range
- High display polarized light transmission
- Fast response time
- Flexible shape with some degree of 3-D forming possible
- Cell gap dependence is reduced compared to TN and VA
- No memory associated with EC

Active polarizer technology may be utilized in conjunction with a linear polarizer for display systems such as instrument clusters or center stack displays. One such configuration is shown diagrammatically in Figure 2-1, although many other configurations are also possible. The linear polarizer associated with the active polarizer is aligned with the display polarizer transmission angle such that the display polarized light is substantially transmitted. The active polarizer transmission angle is oriented to be substantially orthogonal to the linear polarizer transmission angle and therefore light is mostly absorbed when the active polarizer is in the polarization state. In the “off” state, the active polarizer in conjunction with the linear polarizer has low light transmission and therefore hides the display and bezel structures. When the active polarizer is electrically driven “on”, it changes from a polarized state to a non-polarized state and the display polarized light is transmitted. Therefore even in the “on” state the active polarizer lens configuration affords a “dead front” lens appearance while transmitting a significant amount of the display light.

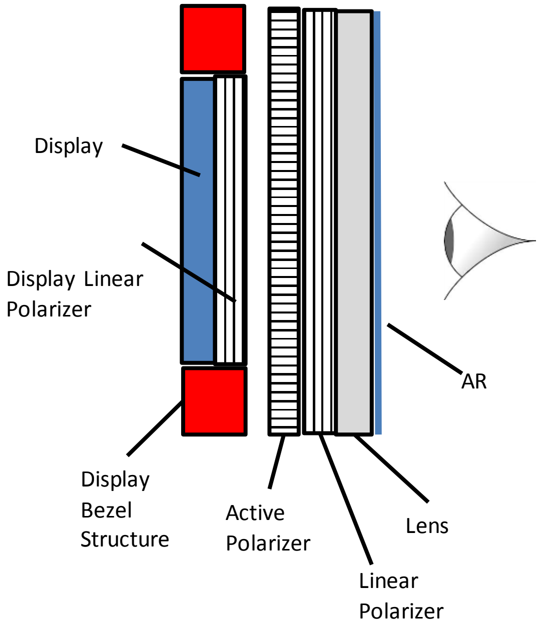


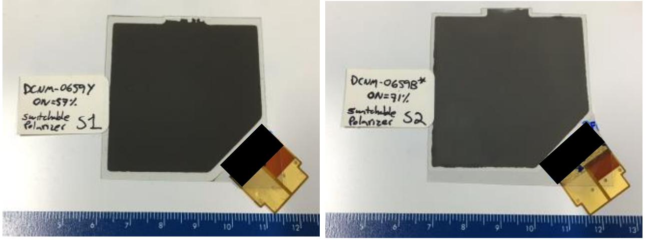
Figure 2-1. Active Polarizer Configuration

An important difference between the active polarizer solution and the typical LC shutter system is that the active polarizer is the light absorbing element instead of the rear polarizer behind the LC shutter. This difference allows the display to be decoupled (not optically bonded) which may allow a more modular service approach with multiple displays behind a single lens.

The active polarizing element is based on a guest-host dichroic dye liquid crystal system where the guest dye acts as the polarizing element. The dye can either be orthogonal or parallel to the host liquid crystal molecules and therefore the "off" state may be the polarizing state or the un-polarized state. For a vehicle off dead front application, it is desirable to have the "off" state be the polarizing state.

3. Active Polarizer Test Data

Two different active polarizer samples with different dye doping levels were evaluated and are shown in Figures 3-0. Note that the samples were configured such that the unpowered "off" state is the polarizing state and therefore the blackish appearance is consistent with a passive polarizing element.



[redacted] [redacted]

Figure 3-0. Lower Transmission S1 and Higher Transmission S2 Switchable Polarizer Samples

Figure 3-1 shows how the transmission varies as a function of drive voltage for unpolarized light. As the active polarizer is electrically driven, it transitions from a polarized to an unpolarized state.

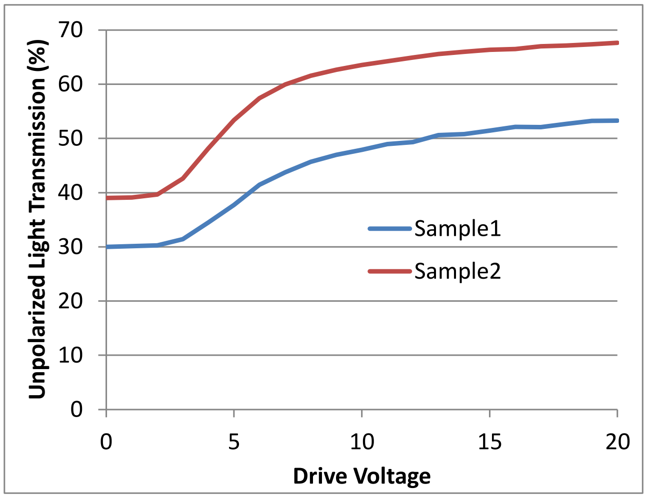


Figure 3-1. Un-polarized Light Transmission

The transmission of polarized light that is aligned to the transmission axis of the active polarizer does not change substantially as a function of drive voltage as shown in Figure 3-2. As can be seen from Figure 3-2, active polarizers are not perfect and exhibit a substantial amount of absorption when polarized light is aligned with the transmission axis of the active polarizer. However since a certain amount of neutral density factor is generally desired in "dead front" lenses, some absorption may actually be desirable so that in the transmissive state the lens still appears dark.

The transmission of polarized light that is orthogonal (cross) to the transmission axis of the active polarizer changes substantially as a function of drive voltage as shown in Figure 3-3. Note that Figure 3-3 is only the transmission of the active polarizer to cross (orthogonally) polarized light and does not include the front linear polarizer as shown in Figure 2-1.

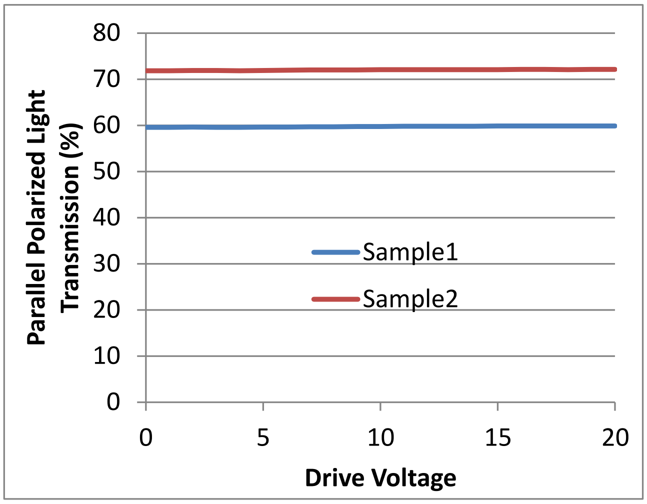


Figure 3-2. Parallel Polarized Light Transmission

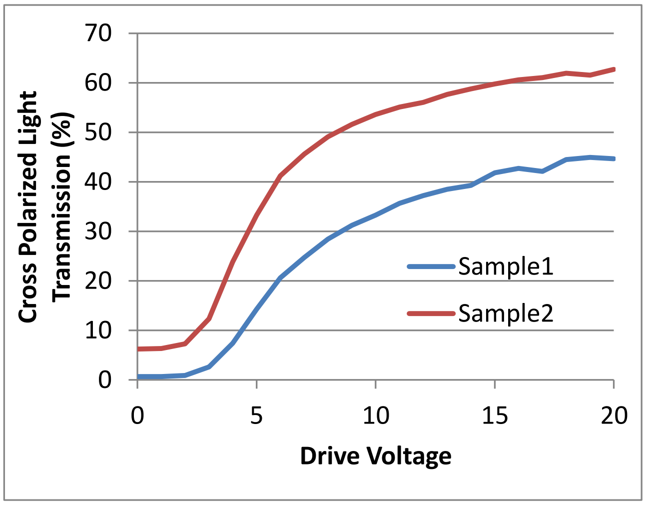


Figure 3-3. Orthogonally (Cross) Polarized Light Transmission

As shown in Figure 3-3, the dye doping level can be adjusted to affect the transmission range. Figure 3-3 also shows that intermediate dimming states may be accomplished and therefore the active polarizer is not restricted to bimodal operational states such as can occur with cholesteric or ferroelectric liquid crystal shutter configurations.

4. Data Analysis

Assuming a front linear polarizer as shown in Figure 2-1 with an 87% parallel polarized light transmission rate, the transmission rate of the polarized light from the display in the "on" (20V drive) condition may be estimated by multiplying the cross polarization transmission rate by the front linear polarizer transmission rate per Equations 1 and 2.

$$T_{P-On} = 44.7\% * 0.87 = 38.9\% \text{ (Sample 1)} \qquad (1)$$

$$T_{P-On} = 62.6\% * 0.87 = 54.5\% \text{ (Sample 2)} \qquad (2)$$

Correspondingly, when the active polarizer is in the "off" (0V drive) condition, the parallel polarized light transmission of the active polarizer and front linear polarizer may be determined per

Equations 3 and 4.

$$T_{P-Off} = 0.67\% * 0.87 = 0.58\% \text{ (Sample 1)} \qquad (3)$$

$$T_{P-Off} = 6.2\% * 0.87 = 5.39\% \text{ (Sample 2)} \qquad (4)$$

Assuming a unpolarized light transmission value of 44% for the front linear polarizer, external ambient light would have a transmission rate through the front polarizer and active polarizer in the "on" (20V drive) condition as determined by Equations 5 and 6.

$$T_{A-On} = 44.7\% * 0.44 = 19.7\% \text{ (Sample 1)} \qquad (5)$$

$$T_{A-On} = 62.6\% * 0.44 = 27.5\% \text{ (Sample 2)} \qquad (6)$$

Finally, when the active polarizer is in the "off" (0V drive) condition, unpolarized external ambient light would have a transmission rate through the front polarizer and active polarizer as determined by Equations 7 and 8.

$$T_{A-Off} = 0.67\% * 0.44 = 0.30\% \text{ (Sample 1)} \qquad (7)$$

$$T_{A-Off} = 6.2\% * 0.44 = 2.73\% \text{ (Sample 2)} \qquad (8)$$

Assuming that the reflected external ambient light **is not substantially depolarized** by the reflection off of the TFT display surface, a neutral density equivalent transmission rate, T_{NDEq} may be determined for ambient reflection light considerations per Equations 9 and 10 for the "on" and "off" states respectively.

$$T_{NDEq-On} = \sqrt{T_{A-On} \times T_{P-On}} \qquad (9)$$

$$T_{NDEq-Off} = \sqrt{T_{A-Off} \times T_{P-Off}} \qquad (10)$$

Substituting actual values into Equations 9 and 10 yields the neutral density lens equivalent transmissions for the two samples per Equations 11 through 14.

$$T_{NDEq-On} = \sqrt{19.7\% \times 38.9\%} = 28\% \text{ (Sample 1)} \quad (11)$$

$$T_{NDEq-On} = \sqrt{27.5\% \times 54.5\%} = 39\% \text{ (Sample 2)} \quad (12)$$

$$T_{NDEq-Off} = \sqrt{0.3\% \times 0.58\%} = 0.42\% \text{ (Sample 1)} \quad (13)$$

$$T_{NDEq-Off} = \sqrt{2.73\% \times 5.39\%} = 3.8\% \text{ (Sample 2)} \quad (14)$$

In the "on" condition, the transmissions per Equations 11 and 12 would represent the transmission of a passive neutral density filter to ambient lighting. Therefore in the "on" condition, the active lens system does provide a reasonable black panel effect.

Correspondingly, an equivalent neutral density filter with transmissions per Equations 13 and 14 will have an outstanding black panel effect in the vehicle "off" condition.

5. Benefit Analysis

A dimmable lens benefit analysis example assumes the following:

- Display reflection of 5% (no AR)
- Front lens surface reflectance of 4% (no AR)
- Dimmable lens rear surface reflectance of 4%
- White shirt luminance of 10000 cd/m^2 (typical of a sunlight illuminated white shirt)
- Comparison with a 20% neutral density filter

Typically, TFT lenses with transmission rates in the 20% arena are considered a "good" dead front and lenses with 8% transmission rates are used for VF type displays. Lower transmission rates are desirable to get a blacker look in a vehicle off condition, however lower transmission rates also increase the amount of TFT backlight power required. At a 0.42% to 3.8% "off" condition transmission rate per Equations 13 and 14, the display lens will have a much blacker look than can be obtained with a 20% neutral density lens. The other advantage is that the lens transmission can be adjusted to maintain display visibility with much less TFT backlight power than is required when a 20% neutral density lens is utilized. Historically the equation that governs display visibility has been shown to be a fractional power function per Equation 15 such as is described by Dr Silverstein per reference [3].

$$ESL = B_O\left(DBL\right)^C \qquad (15)$$

- ESL = Emitted Symbol Luminance in cd/m^2
- B_O = Luminance Offset Constant
- DBL = Display Background Luminance in cd/m^2
- c = Power Constant (This is the slope of the power function in logarithmic coordinates)

Figure 5-1 shows the Silverstein function on a log-log plot. The display background luminance (BGL) that the user would see for the white shirt reflection from the shiny front surface may be calculated per Equation 16.

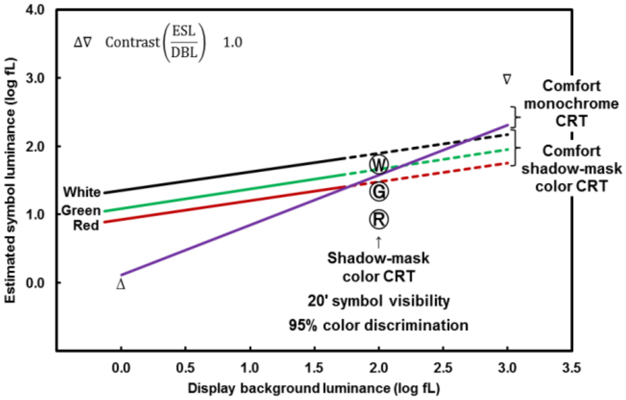


Figure 5-1. Symbol versus Background Luminance [3, page 274 redrawn for clarity]

$$BGL_{Front} = 10K \times 0.04 = 400nits \qquad (16)$$

The reflection that would occur from the display and lens rear surface reflectance in the "on" condition may be determined per Equations 17, 18 and 19 where the equivalent transmission rates per Equations 11 and 12 are utilized.

$$\begin{aligned} BGL_{TFT} &\cong 10K \times \left(0.05 + 0.04\right) \times \left(0.28\right)^2 \\ BGL_{TFT} &\cong 71nits \end{aligned} \qquad \text{(S1)} \quad (17)$$

$$\begin{aligned} BGL_{TFT} &\cong 10K \times \left(0.05 + 0.04\right) \times \left(0.39\right)^2 \\ BGL_{TFT} &\cong 137nits \end{aligned} \qquad \text{(S2)} \quad (18)$$

$$BGL_{TFT} \cong 10K \times \left(0.05+0.04\right) \times \left(0.2\right)^2 \quad \text{(20\%ND)} \quad (19)$$

$$BGL_{TFT} \cong 36 nits$$

The required emitted display luminance after the lens may be calculated per Equations 20, 21 and 22.

$$ESL = 44.3 \times \left(400+71\right)^{0.35} = 382 nits \quad \text{(S1)} \quad (20)$$

$$ESL = 44.3 \times \left(400+137\right)^{0.35} = 400 nits \quad \text{(S2)} \quad (21)$$

$$ESL = 44.3 \times \left(400+36\right)^{0.35} = 372 nits \quad \text{(20\%ND)} \quad (22)$$

If the lens transmission is 20%, the required display luminance as calculated per Equation 23 would be 1860 nits. This is a significantly high backlight level associated with extreme thermal management problems.

$$Display\_Lum = \frac{372}{0.2} = 1860 nits \quad \text{(20\%ND)} \quad (23)$$

On the other hand for the active polarizer configurations, the required display luminance would be reduced per Equations 24 and 25 and is a significant reduction in the required display backlighting. The polarized light transmission rates from Equations 1 and 2 were utilized in Equations 24 and 25 because the TFT display output light is polarized.

$$Display\_Lum = \frac{382}{0.389} = 982 nits \quad \text{(S1)} \quad (24)$$

$$Display\_Lum = \frac{400}{0.545} = 734 nits \quad \text{(S2)} \quad (25)$$

Therefore from a display visibility aspect, being able to increase the lens transmission under high ambient light conditions greatly reduces the display luminance requirements. From a contrast ratio point of view under the high ambient light conditions, Equations 26, 27 and 28 show the contrast ratios do not change substantially even with greatly reduced display luminance for the active polarizer configurations. Note that from a visibility aspect all three would have the same visibility because the eye requires less contrast ratio as the background luminance increases per Equation 15.

$$CR = \frac{\left(372+400+36\right)}{400+36} = 1.85 \quad \text{(20\%ND)} \quad (26)$$

$$CR = \frac{\left(382+400+71\right)}{400+71} = 1.81 \quad \text{(Sample 1)} \quad (27)$$

$$CR = \frac{\left(400+400+137\right)}{400+137} = 1.74 \quad \text{(Sample 2)} \quad (28)$$

If however the same 1860 nit display was used on all three configurations, the associated high ambient contrast ratios would be per Equations 29, 30, and 31 thus showing the substantial benefit afforded by utilizing a dimmable lens from a visibility aspect.

$$CR = \frac{\left(1860 * 0.2 + 436\right)}{436} = 1.85 \quad \text{(20\%ND)} \quad (29)$$

$$CR = \frac{\left(1860 * 0.389 + 471\right)}{471} = 2.54 \quad \text{(Sample 1)} \quad (30)$$

$$CR = \frac{\left(1860 * 0.548 + 537\right)}{537} = 2.90 \quad \text{(Sample 2)} \quad (31)$$

This example shows that from a visibility point of view it is advantageous to increase the lens transmission as much as possible with the active polarizer lens. Automatic dimming control techniques may also be considered to increase the display lens transmission for visibility thus maintaining the best black panel effect for the ambient lighting conditions.

6. Demonstrator

An active polarizer dimmable lens prototype was built for an all-electronic automotive instrument cluster that utilizes a 12.3" TFT display as shown in Figure 6-1.

Figure 6-1. Display "Off", Maximum Lens Dimming (Left) and Display "On" Minimum Lens Dimming Right

In the "off" state, the panel has a very black appearance and it is difficult to see any features (e.g. display bezel) behind the dimmable lens. Using the Sample 1 configuration, the specular component included (SCI) reflection performance was very low, ranging from about 1.1% in the dimmed state to about 1.7% in the transmissive state with a display that was not optically bonded to the lens assembly as shown in Figure 6-1.

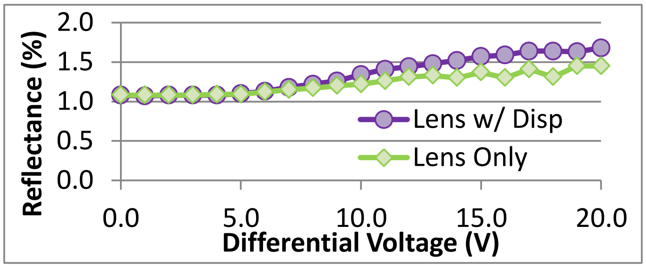


Figure 6-1. Specular Component Included (SCI) Reflectance

7. Conclusion/Summary

The active polarizer may be utilized to provide a dead front look of a display in a vehicle "off" condition while minimizing the backlight power required in the "on" state. Future work on the active polarizer for improved dynamic range and improved spectral performance is required.

8. References

[1] Weindorf et al., Display Unit, Patent US 9,091,883.

[2] Bahman et al., Adaptive Liquid Crystal Windows, DOE Award Number DE-EE0002364

[3] Silverstein, Louis D., Merrifield, Robin M., Hoerner, F. C., The Development and Evaluation of Color Systems for Airborne Applications – Fundamental Visual, Perceptual, and Display Systems Considerations, Reference No. 851774.