

Design and Operation of Front Passenger Infotainment Displays without Driver Distraction

Graham J. Woodgate², Michael G. Robinson¹,
Jonathan Harrold², Benjamin C. Ihas¹, Robert A. Ramsey¹

¹RealD ME, 1930 Central Avenue, Boulder, CO, USA

²RealD ME, Magdalen Centre, Oxford Science Park, Oxford, UK

Abstract Switchable front-seat passenger infotainment displays (PID) for vehicles should deliver (i) no driver distraction over a wide headbox with a high quality, bright image for a front-seat passenger (co-driver); and (ii) a sharing mode with high image visibility for both driver and co-driver. Quantification of driver distraction and a method to determine limits of driver distraction is presented. Results from a technology demonstrator using proprietary display optical stacks are reported. Off-axis luminance control is provided by a switchable optical stack with a directional backlight and liquid crystal retarder layers. The display achieves driver luminance <1% of co-driver luminance for all viewing angles between 25° and 65° off-axis in ‘no driver distraction’ (NDD) mode and driver luminance of >30% of co-driver luminance in share mode. High luminance (>1000nits) and reduced power consumption compared to standard LCD and OLED displays is achieved using production-ready materials and processes.

Keywords PID; passenger; co-driver; infotainment; display; privacy; directional; LCD; backlight; liquid crystal; retarder; security; driver; distraction.

1. Introduction

Two major challenges faced by automotive display technology are (i) increased infotainment functionality, particularly for front seat passengers (co-drivers) and (ii) increased power efficiency to support e-vehicles, at the same time as increasing display area. Recent electronically switchable privacy laptop displays control the light directed to a snooper and have employed one or more of the following approaches:

- (i) **Luminance control:** Directional LCD backlight technologies [1,2,3] switching between narrow and wide angle luminance profiles; and field-of-view (FOV) technologies using electronically controllable birefringence layers [4] that modify display polar luminance profiles.
- (ii) **Reflection control:** FOV control technologies are combined with reflective polarisers [5].
- (iii) **Contrast control** Pixel level out-of-plane tilt control in IPS and FFS mode LCD[6].
- (iv) **Image camouflage:** Patterned structures in FOV control technologies [7].

Both luminance control and reflection control technologies achieve contrast degradation off-axis by overwhelming the display output luminance with the reflected luminance of ambient light from the display, and have been demonstrated in shipping laptop products [8] to achieve very low distraction levels while providing high image quality. Contrast control and camouflage control techniques can exhibit residual degradation of the passenger image and so are less widely used.

Passenger Infotainment Displays (PID) demand (i) a no driver distraction (NDD) mode with high co-driver image quality; and (ii) a share mode with high image quality for both driver and co-driver. Here we discuss methods to determine limits for NDD and a class

leading display optical stack to deliver NDD to the automotive cabin.

2. Image distraction for drivers

2.1 Security factor

The human visual system is highly adept at dealing with luminance changes over a remarkably wide dynamic range. For example in a dark environment (e.g. illuminance 1lux) a high contrast display with correspondingly low luminance (e.g. luminance 1nit) will be easily observable. Thus successful privacy displays must deliver performance over a wide range of viewing conditions.

Methods to quantify visual security and thus driver distraction levels have been previously described [4]. In accordance with Fechner’s law [9], a logarithmic relationship between stimulus and perception can be used. At a given driver polar location, the contrast of the image from the display with respect to the luminance of reflected light can be used to determine a security factor, S:

$$S = \log_{10} \left(\frac{Y+R}{Y-K} \right) \quad \text{eqn. (1)}$$

where, as in Figure 1, Y is the white state luminance, K is the black state luminance and R is the luminance of reflected light from the display as seen by the driver.

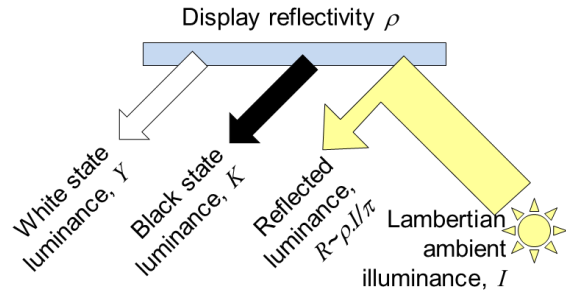


Figure 1. Factors determining the contrast of an image illuminated by an ambient Lambertian light source

In a more general form the security factor, S at a polar angle (θ, ϕ) can be shown to be given by:

$$S(\theta, \phi) = \log_{10} \left(\frac{C(\theta, \phi)}{C(\theta, \phi) - 1} \cdot \left(1 + \frac{I \cdot \rho(\theta, \phi)}{\pi \cdot Y_0 \cdot P(\theta, \phi)} \right) \right) \quad \text{eqn. (2)}$$

where $C(\theta, \phi)$ is the display image contrast, I is the ambient Lambertian light source illuminance at the display front surface, $\rho(\theta, \phi)$ is the display reflectivity, and $P(\theta, \phi)$ is the ratio of the display luminance $Y(\theta, \phi)$ to the peak display luminance, Y_0 , where P is commonly termed the ‘Privacy Level’. For high contrast displays ($C(\forall \theta, \forall \phi) > 100$) this can be simplified to:

$$S(\theta, \phi) = \log_{10} \left(1 + \frac{\alpha \cdot \rho(\theta, \phi)}{\pi \cdot P(\theta, \phi)} \right) \quad \text{eqn. (3)}$$

where $\alpha = I/Y_0$, termed the ‘lux-nit ratio’.

Typically in use structured ambient light sources and specular display front surfaces modify the observed security factor, however the general case of eqn. 3 is a meaningful way of comparing different displays.

2.2 Driver distraction limits

The authors have found that in practice image privacy is a non-linear phenomenon with imagery typically appearing either distracting or non-distracting with a minimal transition region between the two states. Quantifying this seemingly subjective trend is possible and achieved through empirical measurements.

Limits for the security factor, S were determined as follows. As shown in Figure 2, a quasi-Lambertian light box provided front surface illumination along an incident direction for reflection to viewer positions at lateral angles, σ .

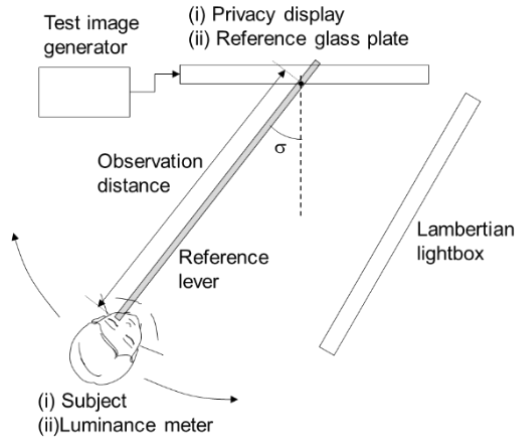


Figure 2. Driver distraction levels are determined by recording the angle, σ at which multiple subjects observe various image content types to become invisible and measuring the security factor S at the angle, σ .

To characterise the display and illumination properties, the spatial and angular variation of front surface illuminance $I(\sigma)$ from the (quasi-Lambertian) lightbox was determined by measuring the variation of reflected luminance of a glass plate with known refractive index and thus known Fresnel reflectivity by using a Konica LS100 luminance meter at a 1000mm observation distance.

The display reflectivity profile $\rho(\sigma)$ was then determined by comparing reflected luminance of the glass plate to the display reflected luminance $R(\sigma)$ with the display backlight switched off.

Using a light baffle in place of the lightbox and a uniform white image on the display, privacy level, $P(\sigma)$ was measured from the ratio of display luminance $Y(\sigma)$ to the maximum luminance Y_0 . The variation of Security Factor $S(\sigma)$ was calculated using eqn. (1).

To characterise the human visual response, a series of high contrast images were provided on the privacy display including (i) small text images with maximum font height 3mm, (ii) large text images with maximum font height 30mm and (iii) moving images. Each observer (with eyesight correction for viewing at 1000mm where appropriate) viewed each of the images from a distance of 1000mm looking down the lever, and adjusted their angle of observation until image invisibility was achieved. The location σ_v of the observer's eye and thus the security factor $S(\sigma_v)$ was recorded. The measurement was repeated using the different images, various display luminances, different lightbox illuminances, different room lighting conditions and for multiple observers at two different laboratory sites.

From the above measurements $S \geq 1.8$ was found to provide complete image invisibility irrespective of content and observer and $S \geq 1.0$ provided no image distraction for most content and observers. A minimum security factor of $S=1.0$ is therefore proposed as a reasonable level to characterise NDD operation.

2.3 Applying security factor to display analysis

Such an analysis can provide a valuable tool in display design and selection. For example from eqn.(3) with a 4% display reflectivity and $\alpha=2$ lux/nit illumination, the condition $S \geq 1$ is equivalent to a high performance privacy level of $P \leq 0.3\%$. As we will show below, the size of the usable driver headbox can then be evaluated.

In another example, a front surface reflectivity of 3% and a comparatively poorly performing 2% privacy level will only deliver NDD operation ($S \geq 1.0$) at $\alpha \geq 18.8$ lux/nit. This implies that at 1000lux ambient illumination, the co-driver brightness will need to be turned down to $Y_0 \leq 53$ nits, rather than the typical $Y_0 > 500$ nits; in other words to one tenth the expected brightness, resulting in an impractical display for the passenger to use.

2.4 Cockpit geometry

Figure 3 illustrates an example cockpit geometry with a driver lateral viewing angle, δ_d of $\sim 45^\circ$. However, angles δ_n in which the driver were to lean towards the passenger (or angles δ_r against the driver side window) must be considered for safe operation. Acceptably high levels of image security must be achieved within a 'NDD headbox'. The passenger must also be provided with a high contrast and comfortable usage headbox in a region around the normal to the display. Such geometries present substantial challenges to the display designer. We will now describe a proprietary display optical stacking and report results of simulation and measurement that fulfil these stringent requirements.

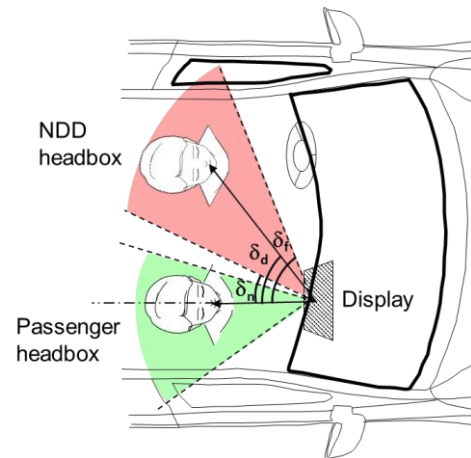


Figure 3. Review of a 'typical' cabin geometry suggests driver locations are within $\delta_n < 30^\circ$, $\delta_d \sim 45^\circ$ and $\delta_r > 60^\circ$.

3. PID display

3.1 PID structure

A proprietary switchable NDD display is illustrated in Figure 4. The backlight is arranged to provide illumination of both passenger and driver regions in share mode, while illuminating only the passenger in NDD mode. However backlight control alone is insufficient to deliver the security factor ($S \geq 1$) to ensure NDD.

RealD ME's proprietary field of view (FOV) control technology illustrated in Figure 5 and described elsewhere [4], uses retarder stacks and a single pixel liquid crystal layer to modify the polar luminance profile from the backlight output of Figure 4b and deliver class leading NDD performance.

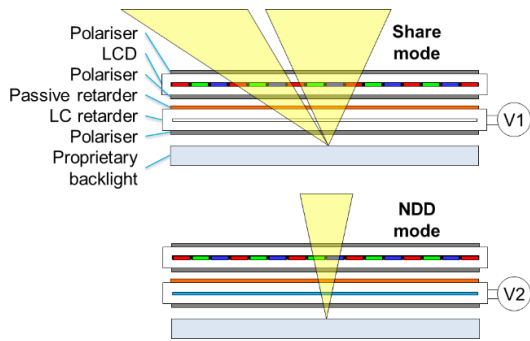


Figure 4a (above) and Figure 4b (below) PID optical stacking uses a proprietary switchable backlight and retarder stack for share mode and NDD mode for passenger infotainment applications.

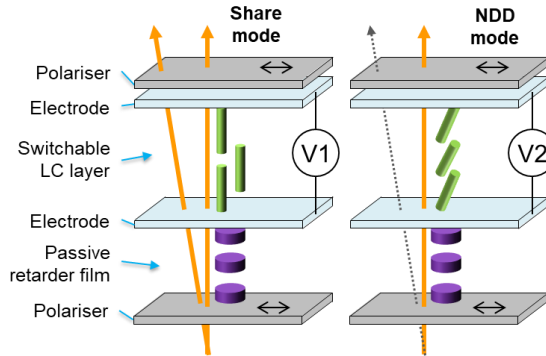


Figure 5. FOV control uses a combination of passive and active retarders to reduce driver luminance in NDD mode, with high driver luminance in share mode. The passenger sees full luminance in both modes.

3.2 NDD mode display simulation

Figures 6a-c show polar distributions from raytracing simulations of the proprietary display elements for luminance, transmission, and reflectivity in NDD mode. Together these provide the security factor $S(\theta, \phi)$ profile shown in Figure 6d, illustrating the sharp transition between driver distraction (red) and NDD (orange/green) polar regions.

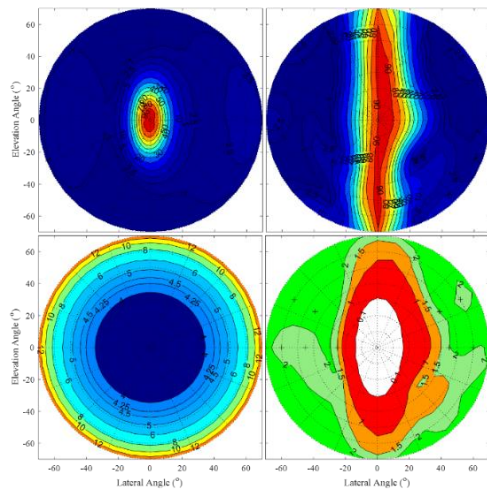


Figure 6a (TL) Backlight luminance; **Figure 6b (TR)** FOV filter transmission; **Figure 6c (BL)** Fresnel reflectivity of a front display polariser; and **Figure 6d (BR)** Calculated Security Factor profile at $\alpha=2$ lux/nit

3.3 Increasing driver headbox size

To increase the NDD headbox width even further (reduce δ_n), switchable off-axis reflectivity can be incorporated as illustrated in Figure 7a and currently available in HP Sure View Reflect™ laptop products [8].

Switchable reflectivity is somewhat counter trend in current cabin designs where the low reflectivity of ‘piano black’ is often considered a desirable target for off-state displays. However the NDD mode reflectivity profile of Figure 7b delivers performance gains that are substantial as shown in Figure 7c and Figure 9a below. It is also the authors’ experience that the on-state reflectors provide an aesthetically pleasing visual appearance in NDD mode with minimal impact on co-driver and share mode image quality.

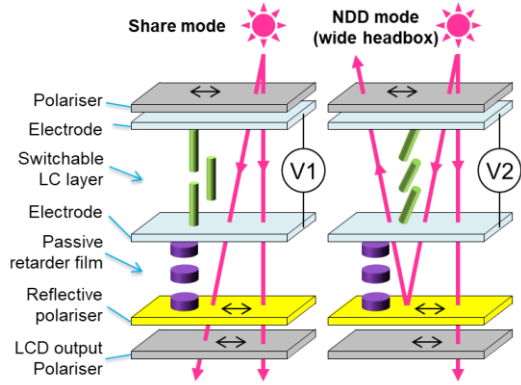


Figure 7a. By inserting a reflective polariser to a front-of-display mounted FOV retarder the passenger sees low display reflectivity in both modes while the driver only sees increased reflectivity in NDD mode.

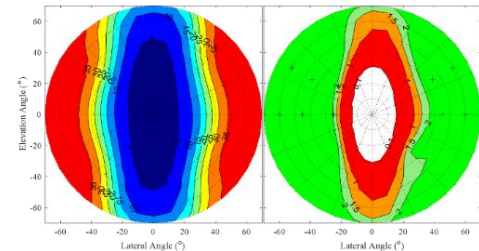


Figure 7b(L) NDD mode simulated reflectivity; and **Figure 7c (R)** calculated Security Factor profile at 2 lux/nit shows increased headbox (larger green zone) for complete image invisibility in the NDD headbox.

4.0 Technology implementation

4.1 PID build and appearance

A technology demonstrator with the specification of Table 1 with the visual performance shown in Figures 8a-8b has been assembled with production-ready component parts.

4.2 NDD mode display measurements

Figure 9a shows the logarithmic variation of luminance, which is the same for both fixed reflectivity (Fig.5) and switchable reflectivity (Fig.7a) display types. A privacy level, $P<0.65\%$ was measured at driver angles δ_n of 25° .

For a more complete description, Figure 9b shows the variation of Security Factor, S at 2 lux/nit for fixed reflectivity and switchable reflectivity type displays. The NDD zone is provided by the region for which $S \geq 1.0$, so the fixed reflectivity display has an NDD headbox at driver angles $>32^\circ$ and the switchable reflectivity display achieves NDD at $>23^\circ$.

Table 1. PID technology demonstrator build

Item	Unit	Specification
Display Size	inch	12.3
Resolution	-	1920×3(R,G,B)×720
Active area	mm	292.032(W) × 109.512(H)
Pixel pitch	mm	0.152 (W) × 0.152 (H)
Passenger luminance	nits	>1000
Driver luminance	nits	>300
Privacy mode	-	Luminance control only (No reflective polariser)



Figure 8a. Display photos @ 1.5lux/nit, share mode



Figure 8b. Display photos @ 1.5lux/nit, NDD mode

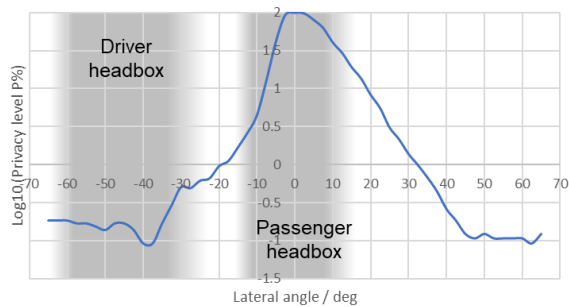


Figure 9a. For fixed reflectivity displays, $\log_{10}(P\%)$ can be used to estimate headbox size.

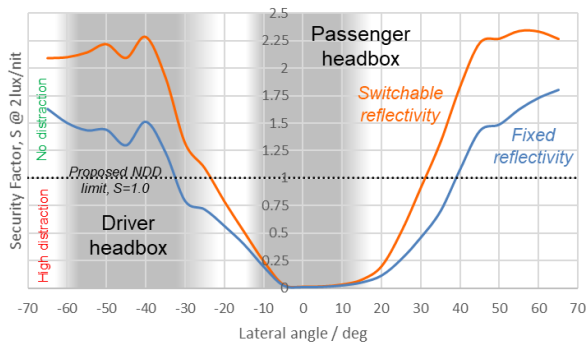
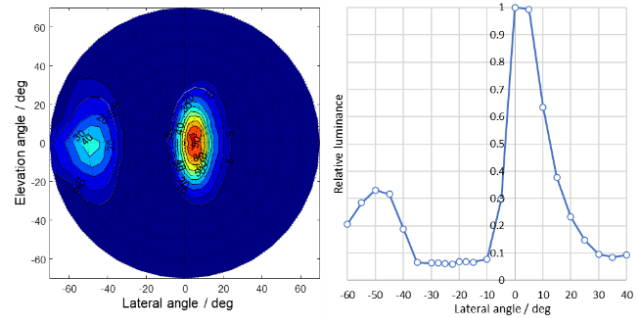


Figure 9b. Security Factor, S incorporates display luminance, reflectivity and illuminance to more completely quantify NDD performance for both fixed reflectivity and switchable reflectivity display types

4.3 Share mode simulation & measurements

Figures 10a-b show that high levels of luminance are achieved around the driver and passenger locations while the image remains visible between the two locations.



Figures 10a(L), Figure 10b(R) Simulated & measured share mode performance

5. Conclusion

Displays capable of no driver distraction (NDD), particularly for passenger infotainment display (PID) applications are described. Such displays can switch between high driver image visibility, for example in a stationary vehicle and passenger infotainment mode where a front passenger can see a high quality image and the driver has quantifiably no image visibility.

A new metric – Security Factor - to quantify the degree of image distraction is proposed. Security Factor takes into account the luminance, reflectance, contrast and ambient illuminance of a display as seen by a driver in a ‘NDD headbox’. Human factors experiments suggest limiting values of image visibility can be directly assigned to a given ambient environment and used to provide control of display distraction across a wide range of usage cases.

An implementation has been demonstrated which meets the challenges of no driver distraction over a wide headbox region while providing a high quality passenger image and switchable share mode operation.

6. References

1. M.Robinson, G.Woodgate, J.Harrold “Intelligent Backlight: A controllable illumination system for high efficiency and sunlight readable mobile displays”, SID Digest **45**, June 2014
2. G.Woodgate, M.Robinson, J.Harrold, B.Ihas, R.Ramsey “Intelligent Backlight Technology Developments for Uniformity, Privacy & 3D operation”, SID Digest **46**, May 2015
3. N.Johnson et al. “Light Control technology: Putting Light Only Where It’s Needed”, SID Vehicle Displays and Interfaces Symposium, September 2017
4. M. Robinson, G.Woodgate, J.Harrold, B.Ihas, R. Ramsey “Switchable Privacy Display Design and Optimisation”, SID Digest **49**, May 2018
5. Patent application no. US2018/0329245
6. S.Tabata et al. “Liquid Crystal Display Element” Japanese Patent Application JPH1130783A. Filing date 14 July 1997
7. B.Broughton et al. “Colour Veil View: a unique feature for Sharp’s smartphones” Sharp Technical Journal **105-10**, July 2013
8. “HP Sure View infosheet” 4AA7-7251ENW, June 2021
9. en.wikipedia.org/wiki/Weber%E2%80%93Fechner_law