Intelligent Backlight: A Novel Display Technology for Automotive Applications

Graham J. Woodgate[1] Michael G. Robinson[2], ,
Jonathan Harrold[1], Benjamin Ihas[2], Robert Ramsey[2]
[1]RealD Research Europe, Magdalen Centre, Oxford Science Park, Oxford, UK
[2]RealD Inc., 5700 Flatiron Parkway, Boulder, CO, USA

Abstract

Intelligent Backlight *is a novel light-field controlling LCD backlight technology using a directional light guide and imaging microstructured reflector illuminated by an addressable LED array. We report progress with development of the technology to target the particular demands of vehicle displays including: very high luminance for direct sunlight; ultra-low stray light for night time operation of large displays; switchable dual user operation; and autostereoscopic 3D viewing of proximity camera images.*

1. Introduction

Recent trends in vehicle displays include increased size, more displays, flexible display location; curved displays and displays for proximity camera viewing. Complex functionality and large centre stack displays in particular have increased in importance for vehicle display designers.

Progress with conventional LCD backlight performance using standard light guide plates and light control films including ESR™, BEF™ and DBEF™ from 3M Corporation[1] has been driven mainly by improvements in LED package efficiency. However such improvements will now slow as LEDs approach theoretical efficiency limits while the optical stacks also appear to approach the practical limits of optimisation.

OLED displays typically have limited luminous emittance with current material systems restricted device lifetime and operation in high illuminance levels for bright cabin environments. The Lambertian output of OLED provides limited or no directionality control.

Intelligent Backlight technology[2-5] (IBT) replaces the scattering light guide plate (LGP), prismatic transmission films and planar rear reflector of conventional LCD backlights with an imaging directional light guide plate (D-LGP) and a microstructured retro-reflecting high brightness film (HBF).

The origins of IBT technology lie in high performance autostereoscopic 3D display, however its directional characteristics also deliver unique benefits for a wide range of 2D modes as will be described below.

2. Optical stack for vehicle displays

Optical stacks for conventional non-imaging backlight and Intelligent Backlight are shown in Figs. 1a-1b respectively. For *Intelligent Backlight* the D-LGP provides the imaging function of the backlight with ray paths shown in Figs. 2a-2b. The optical stack further includes a High Brightness Film having a metallised microstructured surface. A light management film comprises a reflective polariser, a diffuser and a retarder arranged to align the backlight output polarisation with the input polariser of the LCD.

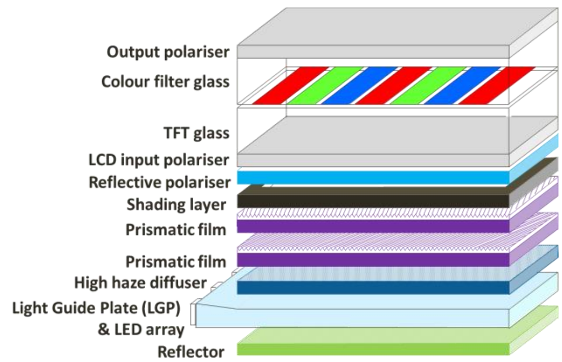

Fig. 1a. Optical stack for conventional LCD

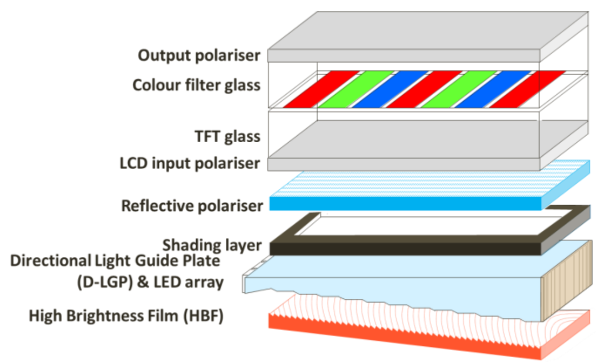

Fig. 1b. Optical stack for Intelligent Backlight

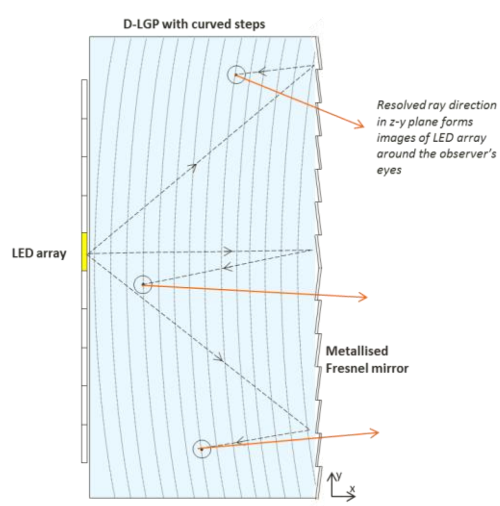

Fig. 2a. Top view of light propagation in D-LGP

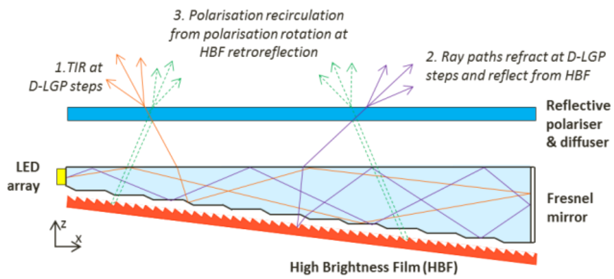

Fig. 2b. Side view of light propagation in the full optical stack of the *Intelligent Backlight*

Light from at least one of the LEDs of the array is coupled into the thin end of the D-LGP and propagates in the x direction while expanding in the y-direction with total internal reflection at the plane surfaces of the guide. The steps of the waveguide are hidden from the propagating beam and importantly, no light is extracted and no loss is present on this first pass from the LED to the mirror. Reflection from the Fresnel mirror at the thicker end of the D-LGP waveguide acts to collimate reflected light, which is guided by the parallel surfaces in the –x direction towards the input end unless it is incident on any of the steps. On incidence with the curved step extraction features the light from each LED is directed out of the waveguide towards a respective viewing window with a limited extent in the yz plane[2-5].

At an extraction feature, a portion of the light is internally reflected back into the waveguide and then out towards the LCD. The remainder of the light is transmitted through the light extraction features and on to the High Brightness Film (HBF), from which it is reflected and redirected back though the D-LGP towards the LCD. The light cones from these two paths may be designed to overlap, so that the total luminance for on-axis viewing positions may be substantially increased.

Spatial uniformity is optimised through the use of side mounted LEDs and input side microstructure design[5].

3. Directional imaging

Intelligent Backlight provides light field shaping so that angular output can be modified to suit the driver's environment.

As shown in Fig. 3, by varying the number of LEDs that are switched on and controlling power distributions, the luminous intensity distribution can be modified.

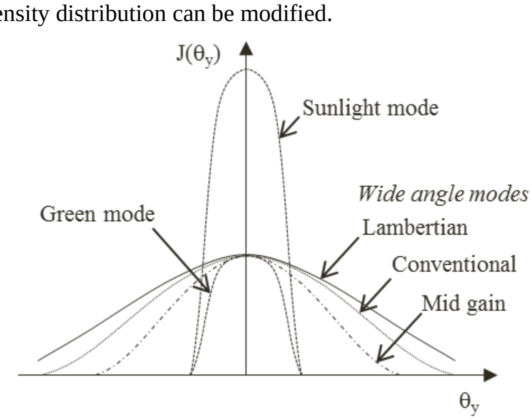

Fig. 3. Varying LED array luminous flux distribution controls luminous intensity distribution

As shown in Fig. 4, the display output can be dynamically switched between various modes for both landscape and portrait panel orientations.

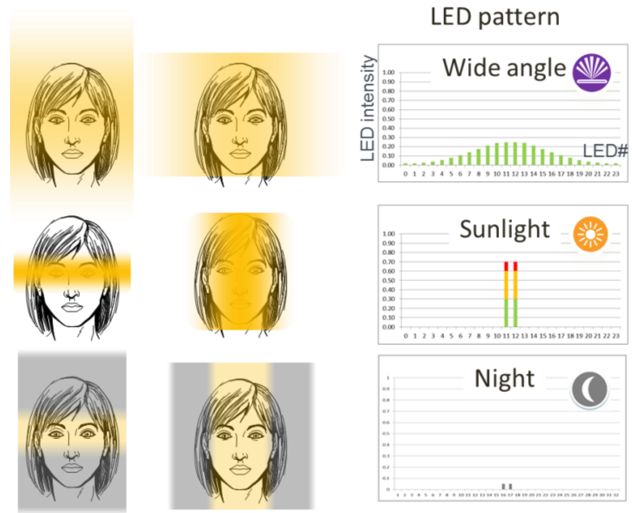

Fig. 4. Directional modes – 60Hz LCD

While the field of view of the display is reduced in some of the modes, the display viewing freedom can be effectively recovered by directing the output viewing cone as shown in Fig. 5. The peak luminance can be arranged to follow a Lambertian, rather than high gain profile; achieving a more natural variation of luminous intensity with viewing angle compared with conventional backlights. Head tracking has been used to automate this function.

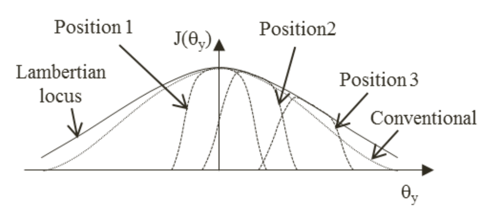

Fig. 5. Varying LED array luminous flux distribution controls luminous intensity distribution

4. Directional modes for 60Hz LCDs

4.1 Wide angle mode

Wide angle mode can be arranged to match the performance of conventional LCDs. In the case of a landscape oriented display:

- In the vertical direction (parallel to the short axis), the illumination profile is provided by optical design of D-LGP facets, HBF facets and diffuser
- In the horizontal direction, illumination profile is provided by LED control. This gives system integrators control of light field profiles that are more closely matched to the locations of drivers and passengers, in comparison to the fixed on-axis illumination of conventional backlights.

Thus the display may be Lambertian, or may have side-lobes that are tuned to typical driving positions, or tuned to actual driving positions when used in cooperation with eye tracking camera technology.

4.2 Sunlight mode - high luminance output

The human visual system can adapt to illuminance levels from 10^{-4} lux to 10^5lux. In a brightly illuminated vehicle interior, the eye adapts to a reference background level so the perceived display brightness (as opposed to measured luminance) varies - typically displays appear dark in bright sunshine.

In *Intelligent Backlight* Sunlight Mode the display can be pumped to very high luminance levels, for example to enable use in environments with 25,000lux or greater because:

- LEDs are imaged directly to the user; the light from each LED is not distributed across a range of angles as is the case for a conventional backlight
- High LED packing density is only required in a small region of the lightbar, the total number of LEDs does not change thus minimising incremental cost
- High flux LEDs developed for TV backlights can be applied to smaller panel sizes

By modifying the output gamma function of test images, the appearance of displays with various luminance levels can be simulated, as shown in Fig.6. As can be seen the experience of the display ‘going dim’ when used outdoors is reproduced. High luminance displays can also overwhelm the reflections from front surface, touch screen and pixel plane components of the display panel, further improving image appearance.

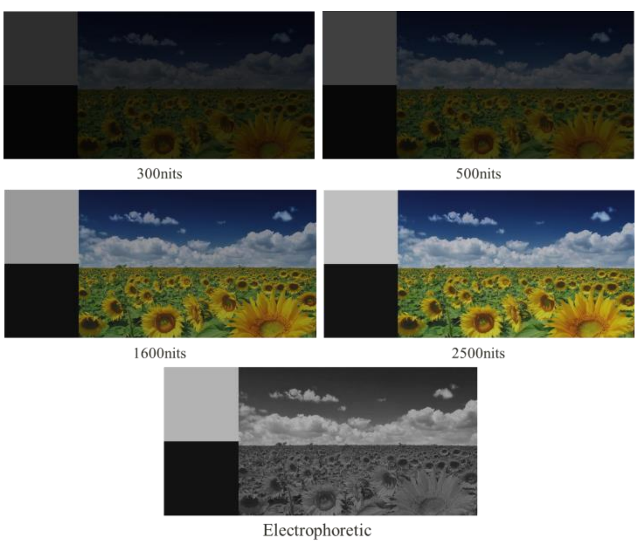

Fig. 6. Simulations of display appearance at 25,000 lux

4.3. Night mode – light spill control

As display diagonal increases, the amount of light spill (the light that is not directed to the driver’s face) increases with the square of the diagonal. Light spill illuminates surfaces within the vehicle and can be distracting for drivers, passengers and other road users. The trend towards 17” and greater display sizes produces at least eight times more light spill than for a legacy 6” display.

Intelligent Backlight can reduce light spill by a factor of up to x4 by directing light only towards the driver. Further the peak display luminance can be directed to the driver rather than normal to the display surface.

As shown in Fig.7, for the same amount of stray light, the display area can at least be doubled in comparison to a conventional backlight.

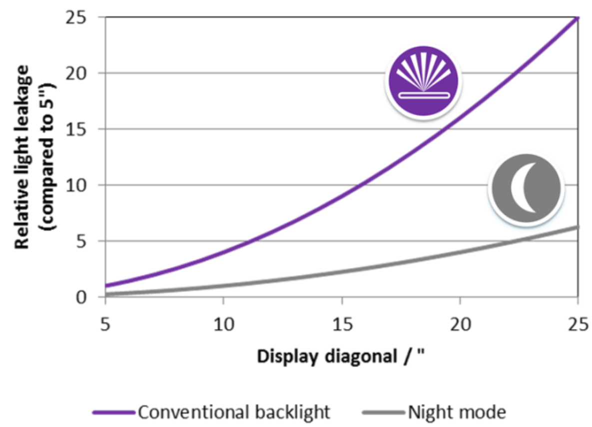

Fig.7 – Variation of light spill levels with panel diagonal

Night mode can cooperate with ambient light sensors, display dimming and software image control to deliver enhanced night time driving performance from large display areas.

Further, light from passenger displays can also be directed away from the area of the driver.

Additionally it is straightforward to program the same display module for left hand drive or right hand drive configurations.

5. Additional directional modes for 120Hz LCDs

Increasing panel update frequency to 120Hz from the conventional 60Hz can deliver further modes as shown in Fig.8.

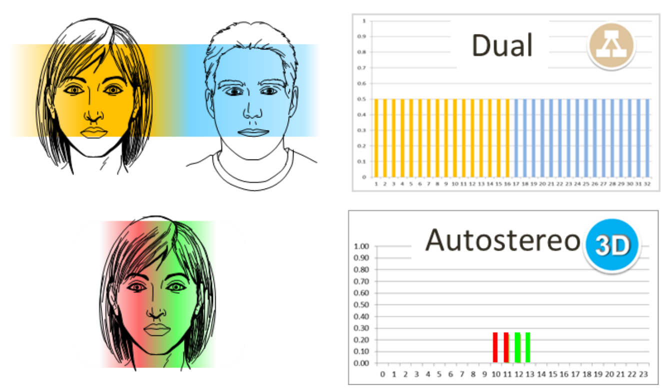

Fig. 8. Directional modes – 120Hz LCD

5.1 Dual mode

Different information can be provided to driver and passenger by alternating driver and passenger light fields in synchronisation with first and second images, each observer seeing a full resolution image as shown in Fig.9.

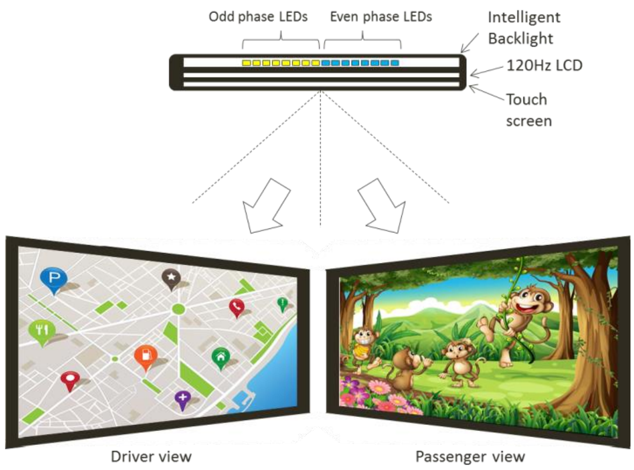

Fig.9 – *Intelligent Backlight* Dual mode operation

5.2. Autostereoscopic 3D operation

Autostereoscopic (glasses free) 3D imaging may provide enhanced judgement of images where proximity detection is required, for example for digital mirrors and parking sensors. The authors anticipate a renewed interest in autostereoscopic application to vehicle displays. Given the other benefits described above, such functionality is likely to be freely available from future *Intelligent Backlight* display products.

In one implementation, left and right eye images may be presented time sequentially to the observer as shown in Fig.10. By synchronising LED illumination with measured eye positions, large freedom of head movement can be provided.

Intelligent Backlight can further deliver increased 3D performance through enhanced implementations that are compared elsewhere[5].

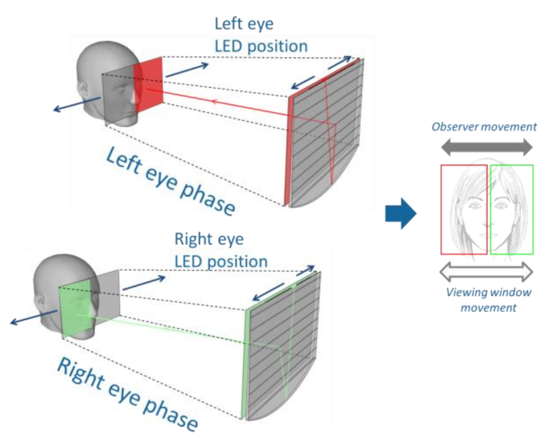

Fig.10 – *Intelligent Backlight* 3D-120Hz autostereo operation

Further, the display can be switched into regular 2D modes (including Sunlight, Night, Wide angle) when 3D mode is not operational, providing optimisation of available real estate to the driver and passengers.

5. Conclusion

A novel backlight unit for vehicle displays uses a proprietary optical stack with a novel directional light guide plate in combination with a microstructured reflective film and an addressable LED array.

In addition to its daytime high illuminance and night-time reduced light spill applications, *Intelligent Backlight* technology can deliver a variety of Dual mode and 3D operation modes from the same optical platform.

6. References

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