Intelligent Backlight Technology Developments for Uniformity, Privacy & 3D operation

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Abstract

We present new research results for Intelligent Backlight, which 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 performance and describe methodology and results from image uniformity optimisation. Further, we report new modes of light-field control, including multiple implementations of privacy operation and advanced autostereoscopic 3D modes.*

1. Introduction

Mobile display platforms continue to adopt increased resolution, colour gamut and size while cost reductions in the LCD have driven down display prices. Progress with conventional backlight technology in recent years has mainly been driven by efficiency improvements in LED light sources, as the optical systems have not evolved at the same rate.

Intelligent Backlight technology[1-3] (IBT) replaces the scattering light guide plate (LGP), prismatic transmission films and planar rear reflector of conventional backlights with an imaging directional light guide plate (D-LGP) and a microstructured retro-reflecting high brightness film (HBF).

Polarisation recirculation efficiency is increased through geometric rotation of a linear polarisation state at the retro-reflecting HBF. Compared to scattering polarisation recovery schemes used in conventional backlights, very high levels of polarisation conversion efficiency are achieved. Consequently the wide angle illumination mode (with matched angular luminance profile) has a system efficiency that is similar to, or better than for conventional backlights.

Intelligent Backlight structures must deliver thickness, bezel width and footprint that is the same or better than conventional backlights. The directional nature of light propagation within the waveguide provides a challenge to achieve high light uniformity; progress towards that goal is described here.

Previously we described controllable angular light fields that can (i) match conventional backlights (wide angle mode); as well as delivering (ii) power saving (green mode) and (iii) outdoors operation (sunlight mode)[1]. Here we describe additional light field capabilities that enable flexible solutions to privacy operation and autostereoscopic 3D. The capability to switch between modes of operation has accelerated interest in adoption of *Intelligent Backlight*.

2. Uniformity

Display uniformity that matches or exceeds that of scattering light guide plates and prismatic films of conventional backlights is essential for any new backlight technology. Uniformity optimisation includes:

- *Cosmetic & manufacturing.* The materials, design rules and tooling constraints of D-LGP components are similar to conventional light guide plates, reducing fabrication risk.
- *Moiré.* Randomisation and feature size selection, particularly between the D-LGP and HBF can suppress visible Moiré patterns, even for thin backlight stacks.
- *Diffractive design.* Optical mode analysis has been used to minimise the appearance of angular mode loss within the adiabatic imaging waveguide that in the limit resembles a tapered wedge shape.
- *Geometric design.* It is the geometric imaging characteristics of D-LGP that dominate the underlying uniformity performance of Intelligent Backlight. Fig.1 illustrates the directionality of light within the waveguide from a single light source in an off-axis position. Region "Void 1" is a region of essentially no light output, and is formed in the corner closest to the LED because light is not directed from the Fresnel mirror into the void. "Void 2" is generated as a consequence of a planar input facet, which limits the input cone propagating in the waveguide to the critical angle. Between the voids, a trapezoidal illumination region is created.

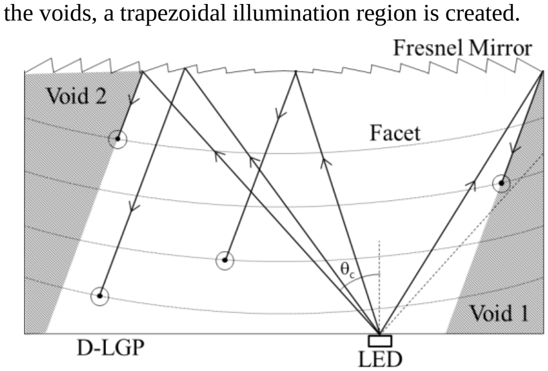

Fig. 1. Void generation in D-LGP

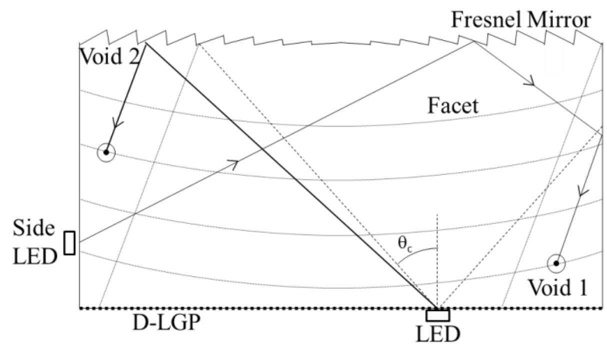

Fig. 2. Void filling using side LED & D-LGP input optical design

As shown in Fig.2, adding LEDs along a portion of the side of the D-LGP, achieves accurate and reproducible control of illumination in "Void 1". Similarly, by design of input facet structural characteristics, illumination within "Void 2" is managed. Between the voids, control of individual LED output is used to manage the illumination uniformity across the width of the Fresnel mirror. These, together with active LED profile control[1], enable a "wide angle" mode of operation that matches or improves the angular and spatial uniformity characteristics of a conventional backlight.

Fig.3 shows the results achieved with a 10" dome mirror D-LGP and TN LCD using a 'single shot' camera measurement at 450mm camera aperture distance from the centre of the display. Though on-axis behaviour is slightly below target levels due to diffraction and collimation errors, the off-axis uniformity can be superior for *Intelligent Backlight*. Subsequent builds will improve on-axis performance through updated optical design so that the same or superior level of uniformity in comparison to conventional backlights is achieved.

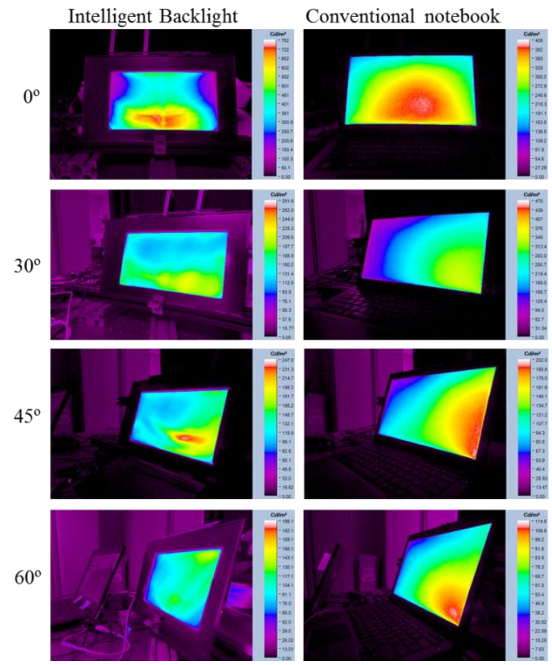

Fig. 3 Single shot uniformity results achieved using 10" D-LGP in comparison to a 14" TN laptop with conventional backlight

3. Privacy operation

As mobile display use becomes increasingly prevalent in public spaces, increased display privacy is likely to be a desirable property.

The controllable directional illumination of *Intelligent Backlight* delivers two approaches to private viewing,
(i) Privacy mode that works with standard 60Hz LCDs and
(ii) *Privacy+* mode that uses 120Hz LCDs. The ability to enable privacy operation at the push of a button is a distinct advantage of *Intelligent Backlight* over solutions that typically require manual handling or factory fitting of additional films[4].

In the same manner as for power saving mode[1], off-axis luminance is substantially reduced while providing a high luminance, full resolution image to the primary observer and low luminance images to the off-axis "snooper" as shown in Fig.4.

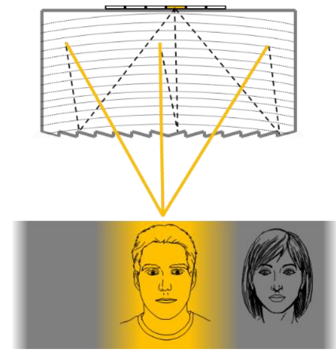

Fig.4 – Illumination in Privacy and Privacy+ modes

3.1 Privacy mode

Intelligent Backlight Privacy mode delivers moderate privacy performance, particularly for users in brightly lit environments.

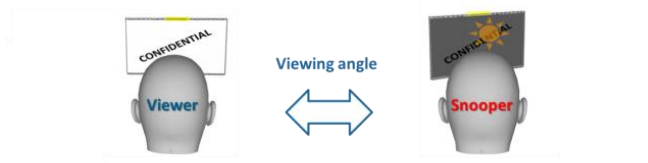

Fig.5 Image appearance in Privacy mode,

3.2 Privacy+ mode

Leveraging the high update rate of 120Hz panels developed for stereoscopic displays, *Intelligent Backlight* Privacy+ mode targets very high levels of viewer privacy by rapid switching of both displayed image and LEDs.

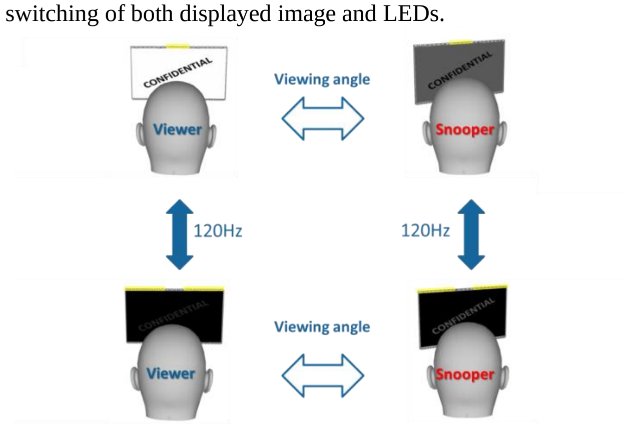

Fig.6 Operation in Privacy+ mode,

Original and intensity-inverted images are sequentially displayed at a 120Hz frame rate. At the same time the illumination is switched in synchronisation between high central and low outer intensity LEDs.

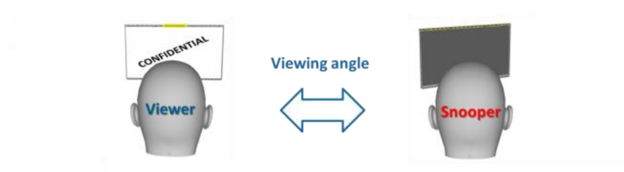

Fig.7 Image appearance in Privacy+ mode,

While the viewer sees a high contrast bright image, the snooper's time averaged image has a minimal residual image contrast of low luminance. Privacy performance is compared in Table 1.

	Micro-louvre film[4]	IBT Privacy mode	IBT Privacy+ mode
Head on luminance	70%	100%	100%
45º luminance spec	<5%	<5%	<5%
Head on contrast	90% panel	As panel	99% panel
45º contrast	90% panel	As panel	<2:1
On-axis cone	Fixed 30º	Controllable	Controllable
Panel response	60Hz	60Hz	120Hz

Table 1. Comparison of Privacy functions

4. 3D operation

Commercialised autostereoscopic 3D displays have largely relied on 2D/3D switchable fixed location parallax barriers and lens arrays aligned to LCDs with conventional backlights. A new generation of observer tracking *e-barrier* products comprising addressable liquid crystal parallax barriers and computer vision based head tracking technology are now emerging[5]. Tracking technology increases viewing freedom, particularly important in mobile displays where both handset and head movements must be accounted for. However e-barriers retain a number of performance constraints, particularly reduced resolution, increased thickness, reduced light transmission and appreciable cross talk between left and right eye images.

Intelligent Backlight can deliver increased 3D performance through multiple implementations that are compared below.

4.1 *Intelligent Backlight* 3D – 120Hz operation

The addition of a fast response LCD to the *Intelligent Backlight* optical stack delivers time sequential autostereoscopic operation. Time sequential illumination is directed to left and right eyes of an observer through LED control. In synchronisation, a 120Hz LCD switches between left and right images as shown in Fig.8.

4.2 Intelligent Backlight 3D – 60Hz operation

Intelligent Backlight can also enhance the performance of conventional spatially multiplexed 3D displays that function with conventional 60Hz panels. By combining the benefits of controllable light fields with e-barrier or alternative spatial multiplexing technologies, uniquely high levels of image performance and functionality are possible. Furthermore, the combination of *Intelligent Backlight*, e-barriers and 60Hz LCDs delivers world beating 3D quality including minimised pseudoscopic zones and reduced cross talk, while maintaining green, sunlight and wide angle modes of operation. This combination structure is shown schematically in Fig.9.

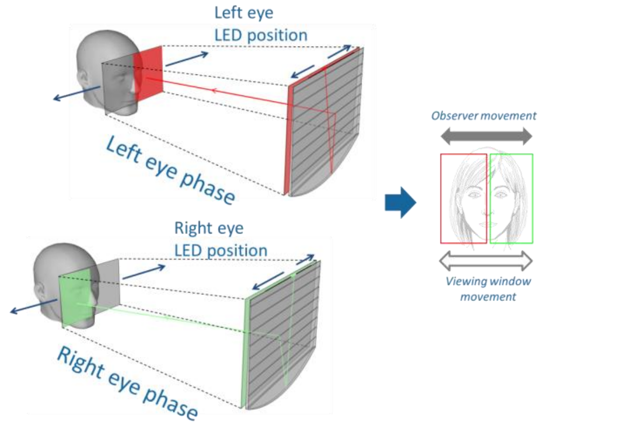

Fig.8 – *Intelligent Backlight* 3D-120Hz autostereo operation

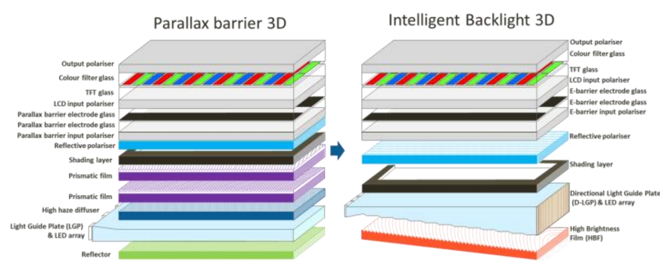

Fig.9 *Intelligent Backlight* 3D–60Hz autostereo structure

4.3 3D cross talk & pseudoscopic zones

Cross talk arises from leaking of right eye image content into the left eye, and vice versa. Cross talk manifests as ghosting in one eye and when seen in stereo is a significant cause of user fatigue and dissatisfaction. As shown in table 2, legacy commercial 3D displays are not yet a match for the user comfort of movie theatres.

Cross talk	Typical implementations	Typical applications
5~10%	Multi-view 3D display, 3D printing	Advertising, Point of Sale, 'Grab attention'
2.5~5%	Commercial 2-view autostereo display	Handheld games, photography, in-car
1~2.5%	Movie theatre	Moving entertainment images
0.5~1%	Visibility threshold	

Table 2 – Cross talk targets for autostereoscopic displays

Most spatially multiplexed 3D displays generate pseudoscopic zones due to the repetition of left and right viewing windows as shown in Fig.10. These cause both increased cross talk and can produce positions at which users see depth inverted (pseudoscopic) 3D images, both of which cause unwanted user discomfort.

By comparison, *Intelligent Backlight* 3D viewing windows minimise pseudoscopic zone visibility, halving the cross talk and eliminates user discomfort from reversed images in pseudoscopic viewing positions.

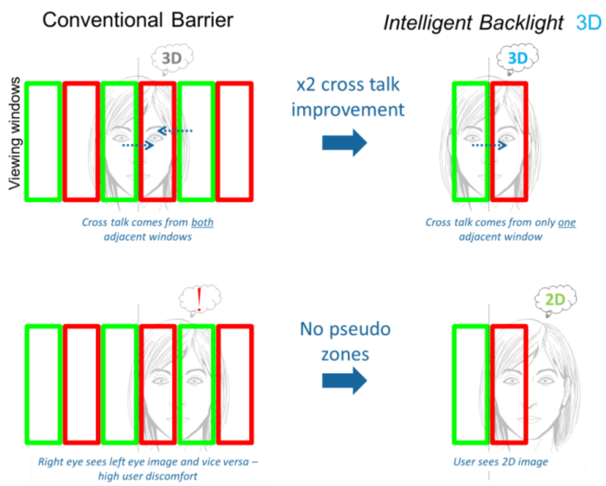

Fig. 10 – Cross talk and pseudoscopic zones

4.4 Viewing freedom and control system

Viewing freedom in a fixed autostereoscopic display is limited by window size, which in turn is limited by eye separation.

However, if the viewing windows from Intelligent Backlight and e-barrier are arranged to move together, then user freedom can be greatly extended. Using computer vision technologies to track user head position, both the LED position and barrier arrangement are adjusted to deliver high quality images over a wide viewing freedom as shown in Fig.11.

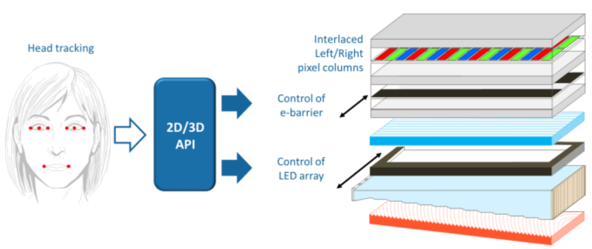

Fig. 11 – *Intelligent Backlight* 3D-60Hz system

4.5 *Intelligent Backlight* 3D Ultra

To further extend autostereoscopic performance space, *Intelligent Backlight* 3D Ultra combines the fast response LCD of 3D-120Hz mode with the e-barrier of 3D-60Hz mode.

Combining both spatial and temporal 3D multiplexing, *Intelligent Backlight* 3D Ultra gives unique opportunities to suppress image cross talk to below the visibility threshold, increase display resolution and extend viewing freedom.

In a first illumination phase, viewing windows are created for left eye by both the *Intelligent Backlight* and by the e-barrier, and similarly for the right eye in a second phase. Such an arrangement may deliver combinations of increased resolution (compared to a conventional e-barrier), reduced cross talk at the visibility threshold, no pseudoscopic zones and simultaneous multiple viewers while delivering wide viewing freedom.

The performance space of different 3D modes is compared in Fig.12.

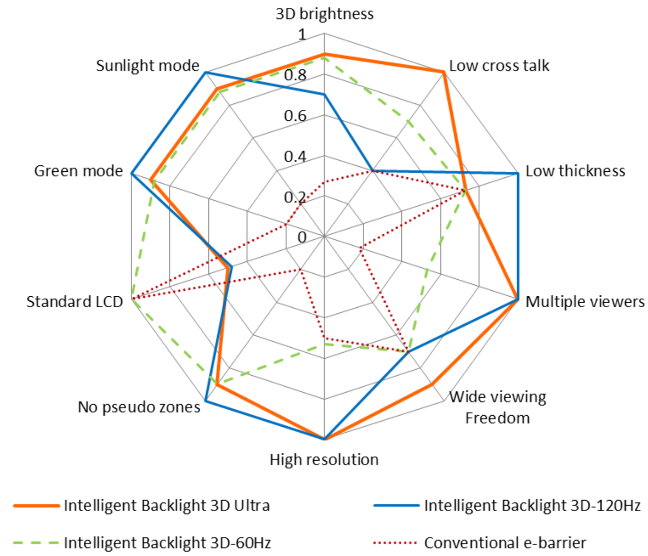

Fig. 12 – Performance space comparison for *Intelligent Backlight* 3D modes compared to conventional e-barrier

5. Conclusion

A novel backlight unit for high volume mobile 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. Significant progress has been made to delivering uniformity targets for mass market consumer products by introducing additional side mounted LEDs and D-LGP input optical design.

In addition to its power saving and outdoors applications, *Intelligent Backlight* technology can deliver a variety of privacy and 3D operation modes from the same optical platform.

6. References

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[4] 3M Advanced Light Control Film privacy filter ALCF-P ABR0 S data sheet

[5] New Nintendo 3DS with face tracking 3D, launched in Japan, November 2014, http://www.nintendo.co.jp/3ds/new/, accessed 21.01.2015