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DESIGN OF AN EDGE-LIT BACKLIGHT MODULE FOR AN AUTOSTEREOSCOPIC DISPLAY

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ABSTRACT

Study focuses on optimization of an edge-lit backlight module for a three-dimensional liquid crystal mobile phone display. The module is designed with microstructures on the top and bottom surfaces of the light-guide plate to offer time-multiplexed projection of light into a viewer's eyes. We simulated the module by optical software (TracePro) and liquid crystal software (LCDMaster 2D). The results effectively eliminate the need for prism sheets and satisfy three main performance metrics, namely a direction light-emission angle, uniformity of illumination, and crosstalk elimination.

Keywords: geometrical optics, optics in computer engineering, design and manufacture of optics, physical optics

1. INTRODUCTION

With the gradual popularization of 3D images in daily life, people enjoy the 3D image brought about the sensory stimulation. Autostereoscopic displays work by emitting two lights at different angles for a viewer's left and right eyes, thereby producing a stereoscopic view [1, 2]. This method is called multiplexed-2D, that is to use 2D screen to produce 3D images, and this way can be divided into two main types: spatial-multiplexed and time-multiplexed types. The current technique of spatial-multiplexed type for an autostereoscopic display requires the periodic striped shelter, a prism sheet or lenticular lenses to produce the right eye and left eye of the two groups of signals at the same time, not only the brightness and resolution will be declined, but also the energy is a great loss [3–6]. The technique of time-multiplexed type intermittently generates a left image and a right image projecting the left and right eyes, respectively. The frequency of this signal is greater than the frequency of visual persistence that allows the audience to produce stereoscopic vision [7–15]. An edge-lit backlight module can reduce costs if it can be designed to produce light for left and right eyes only, by using a light-guide plate (LGP). In this study, an edge-lit backlight for a time-multiplexed stereoscopic display is proposed for use in mobile phones.

The viewer's left and right eyes are perpendicular to the light emission. The angles of light emission for viewer's eyes are at about ±10°, as shown in Fig. 1. An LGP can provide directional brightness and uniformity of the output light [16–19].

We design a 5.0-inch time-multiplexed LGP to generate two highly directional lights based on optimized micro-structural plates. When the left- and right-side light sources are active, the LGP can emit light directly into the viewer's right and left eyes, respectively.

Through cooperation between the sequentially switching light sources and the liquid crystal, the left and right eyes can acquire two signals to achieve a stereoscopic effect. Optical software TracePro^{TM} is used to simulate the illuminance, direction, uniformity, and crosstalk of the output lights. It is shown that our proposed LGPs with v-cut and curved microstructures have ideal efficiencies in terms of orientation angle, uniformity, and crosstalk of the output light.

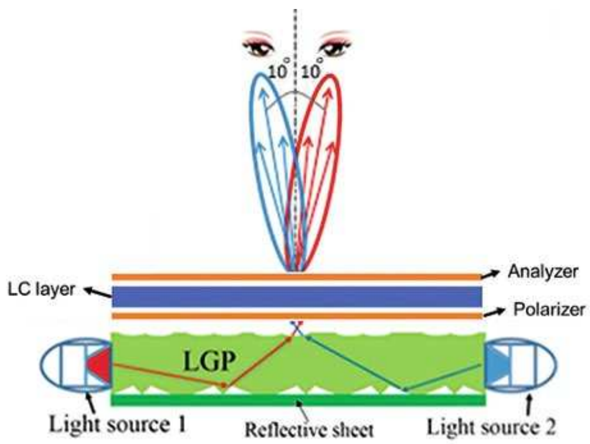


Fig. 1. Edge-lit Backlight Module in Autostereoscopic Display

2. DEVICE STRUCTURE

Fig. 2(a) depicts the structure of the backlight module including the LGP, reflective sheet, observation plane, and left- and right-side light sources. Each light source comprises twelve light emitting diodes (LEDs) placed along the z-axis. The LGP is made of Polymethyl methacrylate (PMMA); its index of refraction is 1.49, its area is 110 mm×65 mm, and its thickness is 3 mm. Structural parameters of the Siemens LWT676 LED are shown in Table 1. The surface of the reflective sheet is diffusely white. The observation plane is 1 mm above the LGP and can detect the distribution of the illuminance of the output light.

Three types of LGP microstructures are compared with one another, as shown in Figs. 2 (b), (c), and (d). Type 1 has v-cut microstructures on its bottom surface. Setting the median of the LGP as the plane of symmetry, the v-cut microstructures are described by a one-dimensional linear equation according to a previous study [20], as shown in Eq. (1).

$$S = aT - b, \quad (1)$$

Table 1. Parameters of the Siemens LWT676 LED Light Source

Source type	Flux
Luminous flux	0.051 m
Wavelength	0.5461 um
Angular distribution	Lambertian
Total rays	240000

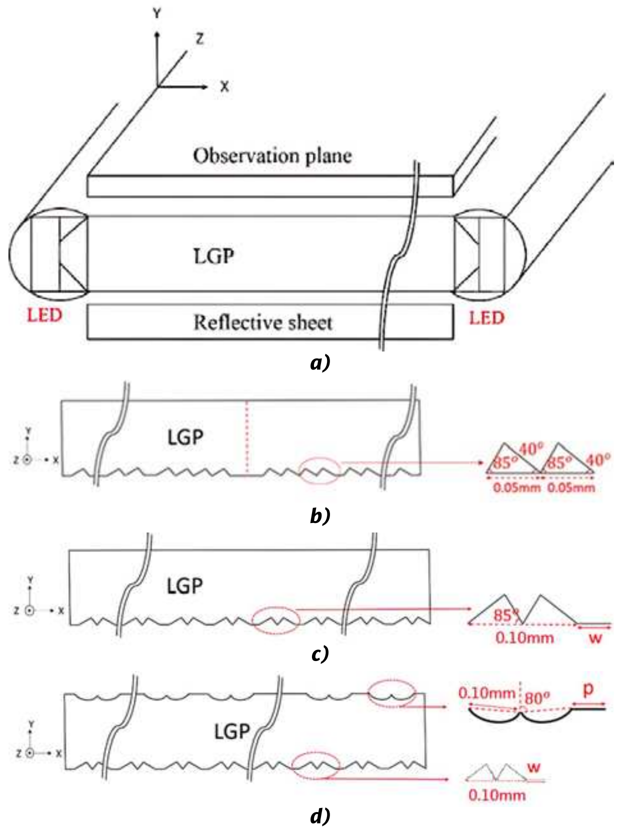


Fig. 2. Structure of the backlight module - (a), Type 1 - (b), Type II - (c), and Type III - (d)

where, S is the interval with v-cut corrugation and T is the interval without v-cut corrugation and are adjustment parameters. The T interval is needed to uniformly distribute the light power across the whole LGP area. Without a T interval, the light rays will be distributed intensely in the area near the light source. Microstructures are placed along the x-axis but in two opposite directions on the bottom surface of the LGP. As shown in Fig. 2(b), the left and right halves of the LGP have microstructures described by one-dimensional linear equations along the +x and –x axes respectively. Each groove of the v-cut microstructure has a 55° vertex angle and base angles of 40° and 85°. There is a 0.05-mm space between each groove climax.

The Type II LGP has a symmetric v-cut microstructure of fixed spacing w, which is uniformly arranged on its bottom surface. The microstructure is created by two oppositely placed Type I microstructures, each with a width of 0.10 mm as shown in Fig. 2(c).

Type III combines the Type II design with another micro-structure uniformly arranged on the top surface of the LGP. This other microstructure is symmetrically curved, with a fixed spacing p. The

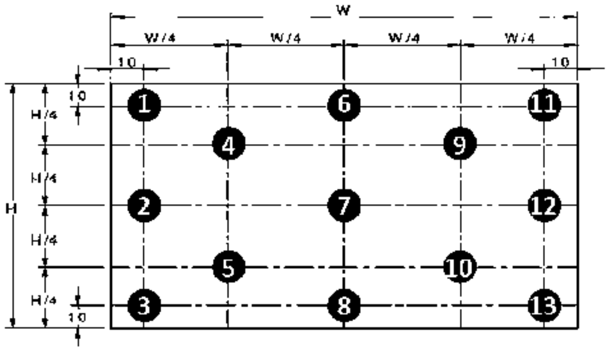


Fig. 3. Illuminance in the 13 points at the observation plane

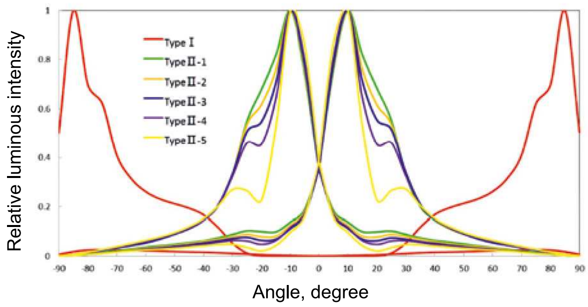


Fig. 4. Rectangular relative luminous intensity distribution plot

curved microstructure consists of two circular arcs, each of width 0.10 mm, and the tilt degree of each curved surface is ±10° as shown in Fig. 2(d).

The crosstalk between the right view and left view for the central observer is determined the following equation [14]:

$$Crosstalk = \frac{1}{2}\left(\frac{I_L(\theta_R)}{I_R(\theta_R)} + \frac{I_R(\theta_L)}{I_L(\theta_L)}\right), \qquad (2)$$

where I_R and I_L are the measured maximum intensity for the right and left views at the viewing angles θ_R and θ_L respectively. In this experiment, we found that leakage and signal ratio is similar at 10˚ and –10˚ in the left eye and the right eye. A definition of crosstalk is present in this study as follow [21]:

$$Crosstalk = leakage / signal \times 100\%, \qquad (3)$$

where leakage is defined as the maximum luminance of light that leaks from the unintended channel into the intended one, whereas the signal is defined as the maximum luminance of the intended

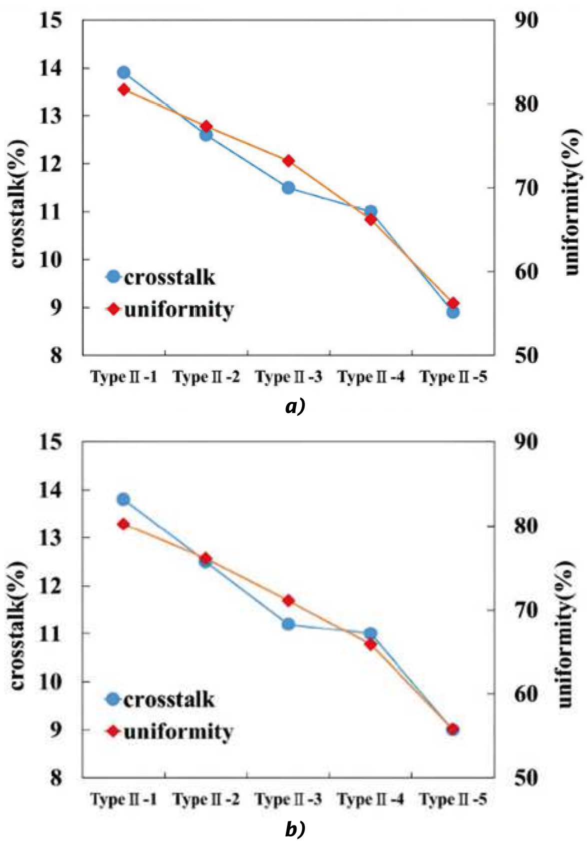


Fig. 5. Comparison of uniformity and crosstalk: (a) – left light source, (b) – right light source

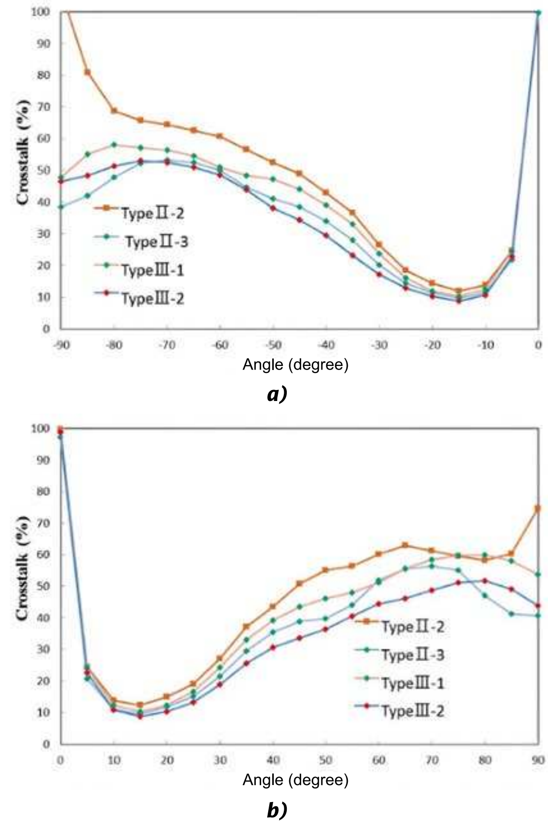


Fig. 6. Crosstalk: (a) – crosstalk when the right side light source emits; (b) – crosstalk when the left side light source emits

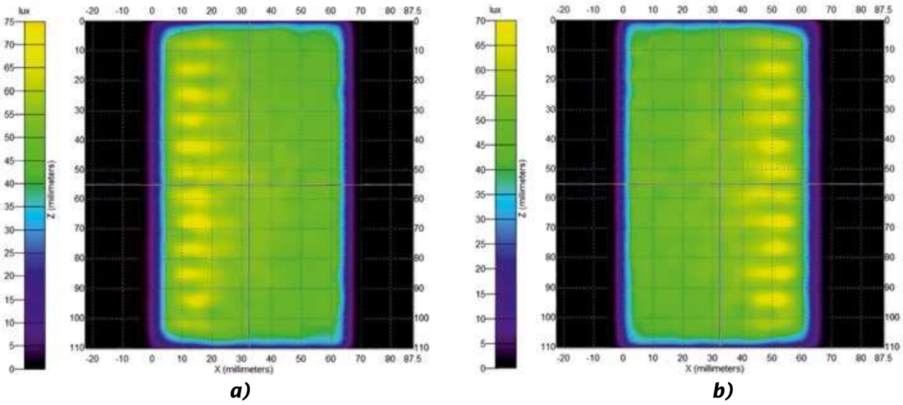


Fig. 7. Illuminance map of Type III-2 LGP: (a) – the uniformity is 76.1 % when the left side light source emits; (b) – the uniformity is 75.9 % when the right side light source emits

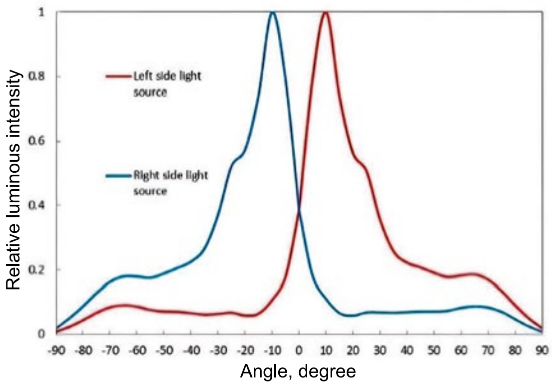


Fig. 8. Restangular luminous intensity distribution plot of Type111-2 LGP when both light sources emit

channel that is detected at an angle of maximum light emission. In this study, we aim to reduce crosstalk. In the right-eye channel, the ratio of the measured luminance of the right-side light source (leakage) to that of the left-side light source (signal) should be lower. Conversely, the ratio should be lower in the left-eye channel too.

In addition to testing the crosstalk of a directional light source, uniformity is considered a metric for evaluating the performance of the backlight module in an autostereoscopic display. Fig. 3 shows the uniformity of the output light. The ratio of minimum illuminance (I_{min}) to maximum illuminance (I_{max}) at 13 points on the observation plane can be expressed as Eq. (4).

$$Uniformity = \left(I_{min} / I_{max}\right) \times 100\%. \quad (4)$$

The optical conversion efficiency of the output light is well-defined as the ratio of the illuminance (I_o) on the observation plane to the emitted illuminance (I_e) of the light sources, and is evaluated as Eq. (5).

$$Opical\ conversion\ efficiency = \left(I_o / I_e\right) \times 100\ . \quad (5)$$

3. RESULTS AND DISCUSSION

Six models of LGP microstructures are compared with one another in terms of uniformity, angle of maximum light emission, and crosstalk, as shown in Table 2. For the Type LGP, the v-cut microstructure on the bottom surface is described by $S=T\text{-}10(T\geq13)$, with a = 1 and b = 10. For the Type II-1, II-2, II-3, II-4, and II-5 LGPs, w (the interval on the bottom surface) is set to 1.5 mm, 1.2 mm, 1.0 mm, 0.8 mm, and 0.8 mm respectively.

In the results all measurements from viewer's left and right eyes are going on in perpendicular direction to the light emission. The maximum light emission of the Type I LGP is concentrated on the source side, and the maximum light-emission angles are 85° and –85°; those of the Type II-4 and Type II-5 LGPs are 9° and –9°, whereas those of all other LGPs are 10° and –10°. These results show that the maximum light-emission angles of the Type II designs are more suitable than those of the Type I design for use in a backlight module, as shown in Figs. 4 and 5.

Comparing the uniformity and crosstalk in Fig. 5, we observe that lower values of w produce lower crosstalk and uniformity, whereas higher values produce higher crosstalk and uniformity. Because the major parameters for evaluating the performance of backlighting modules for time-multiplexed autostereoscopic displays have higher uniformity, lower crosstalk, and maximum light emission, we select the Type II-2 and II-3 designs for use, as their uniformity is higher than 70 %, crosstalk is less than 13 %, and light-emission angles are at 10° and –10°.

To reduce crosstalk in the left- and right-eye channels, we add curved microstructures to the tops of the Type II-2 and Type II-3 LGPs, forming

Table 2. The LGP with V–Cut Microstructures on the Bottom Surface

Type	Uniformity	Light emitting angle [a]	Crosstalk (%) [b]
Type 1, S=T-10(T≥13)	10.3 %	–85° and 85°	
Type 11–1, w =1.5 mm	81.7 %	–10° and 10°	13.8 and 13.9
Type 11–2, w =1.2 mm	77.3 %	–10° and 10°	12.5 and 12.6
Type 11–3, w =1.0 mm	73.2 %	–10° and 10°	11.2 and 11.5
Type 11–4, w =0.8 mm	66.2 %	–9° and 9°	11.1 and 11.0
Type 11–5, w =0.5 mm	56.2 %	–9° and 9°	9.0 and 8.9

a left and right angle of the maximum emitting light
b crosstalk at left and right eye channel (%)

Table 3. Results of Uniformity, Optical Conversion Efficiency and Crosstalk of Emitting Lights

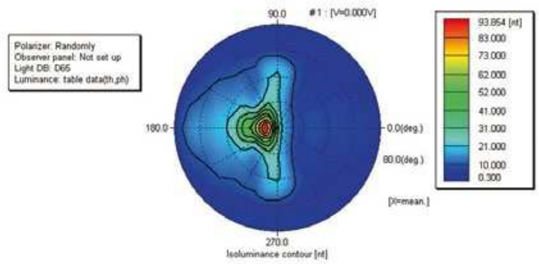
Type	Fixed spacing of *w* and *p*	Uniformity	Efficiency, % [c]		Crosstalk, % [b]	
11–2	*w* = 1.2 mm	77.3 %	49.7 49.9		12.5	12.0
11–3	*w* = 1.0 mm	73.2 %	53.0 53.1		12.6	12.3
11–1	*w* = 1.2 mm, *p*=1.1 mm	77.3 %	56.0 56.0		11.2	10.7
11–2	*w* = 1.0 mm, *p* = 1.1 mm	73.2 %	57.9 57.9		11.5	10.9

c optical conversion efficiency of left and right light
b crosstalk at left and right eye channel

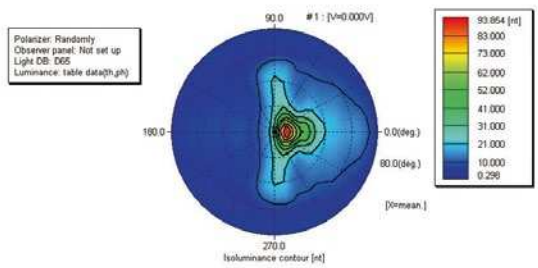
Type III-1 and Type III-2 designs respectively, similar to Fig. 2(d). The curved micro-structures are symmetrically arranged with a regular interval of *p* = 1.1 mm. When the left and right sources are active, the results of uniformity and optical conversion efficiency are detected in the observation plane and those of crosstalk are detected at the maximum light-emission angles of –10° and 10°, as summarized in Table 3.

For the sight range of the human eye from ±7.5° to ±20°, we observe that the Type III-2 design has the best quality in terms of time-multiplexed projection into eyes for an autostereoscopic display, and that the optical conversion efficiencies of the Type III-1 and Type III-2 designs are higher than those of the Type III-2 and Type II-3 ones. Figs. 6(a) and (b) show the crosstalk detected on the observation plane when the right and left sources emit light into the left- and right-eye channels respectively. The illuminance maps of the Type III-2 design are shown in Figs. 7(a) and (b). Fig. 8 provides a rectangular candela-distribution plot of the Type III-2 LGP.

By liquid crystal software (LCD master 2D), the simulated results of the Type III-2 design are shown in Fig. 9. As an example in Fig. 1, we simulate the illumination property of a twist nematic (TN) cell. We set the polarizer thickness is 10 μm and angle is 45˚, the analyzer thickness is 10μm and angle is 135˚ in Fig. 1, the alignment directions of the upper and lower substrates are parallel to the polarizer and analyzer respectively. There are added the liquid crystal that parameters are has elastic constants k11= 16.7pN, k22=1pN, k33=18.1pN, Δn = 0.083 and $\Delta\varepsilon$ = –4.2. The liquid crystal cell gap is 10μm. The simulated results are shown in Fig. 10.

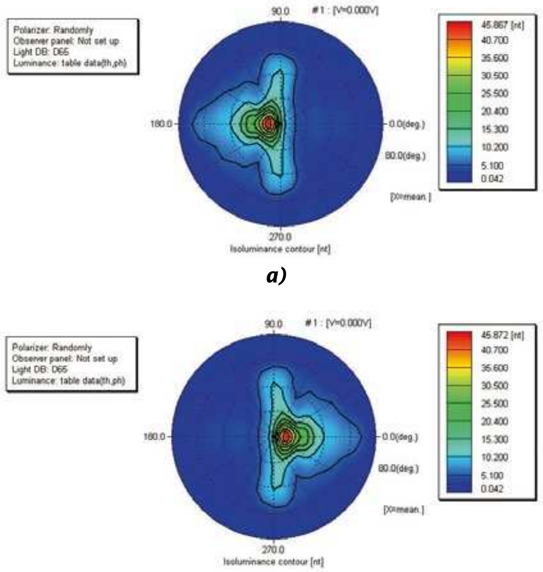


a)



b)

Fig. 9. Illumination: (a) – right side light source; (b) – left side light source



a)

b)

Fig. 10. Illumination through liquid crystal: (a) – right side light source; (b) – left side light source

Checking the Fig. 10 against the Fig. 9, we find almost the same each other about a direction light-emission angle, uniformity of illumination, and crosstalk elimination.

5. CONCLUSION

It was observed that the Type III-2 LGP design offers the largest luminance at ±10° for human eyes. This design exhibits an average uniformity of above 75 %, an average crosstalk ratio of below 10.8 %, and an optical con-version efficiency of above 57.9 %. Our successful results effectively eliminate the need for a prism sheet and satisfy three main performance parameters, including a direct angle of light emission, uniformity of illumination, and elimination of crosstalk.

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