Design and Evaluation of LCD Backlight Unit by LED Array Modules

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In this paper, we have designated a 42-inch RGB LED BLU, 80 % above illuminance. A desirable brightness performance was attained, by doing anti-parallel configuration, a fitting of LED's strip distance and a height of the top of LED to the back of the LCD. We get the 85.81 % of the brightness uniformity which has 12.8 mm away from LED's top and LCD's back and 51.41 mm of the same spacing between LED's strip in simulation and 82.24 % in experiment.

Keywords : LED arrays, Backlight unit, White light, Illuminance uniformity, LED's strip distance

1. INTRODUCTION

Presently, backlight unit using light emitting diodes (LED) for liquid crystal display (LCD) has various advantages, in terms of good color uniformity, high dimming ratio, reliability, low temperature operation and Hg-free light source, over conventional light sources such as CCFL. The use of LEDs in backlight can be classified into two categories in case of the location of the light sources in module, i.e. edge-lit lighting and indirect lighting[1-3].

An edge-lit lighting BLU has the light source located on one edge side of the module and a light guide plate is installed for light to travel from the source to the display. The light guide is unnecessary in a direct lighting BLU in which the light sources are distributed behind the display screen for the direct view. The advantage of the direct lighting BLU is the relatively uniform luminance for the entire module. The existence of the light guide would be effective to increase the module's weight. So, the edge-lit lighting is suitable in small-size LCD applications such as mobiles. On the other hand, without light guide, the direct lighting BLU is more used in large-size LCD. How to achieve high brightness and homogenous luminance has always been an important issue in the optical designs of the both types of BLU.

In this paper, we have intended to get brightness uniformity by controlling the module thickness, the distance between LED's strip and the height of the LED's top and LCD's back.

2. DESIGN PROCESS

The main purpose of our work is to get the 80 % above of the brightness uniformity for 42-inch LCD. In case of this design, we were used LEDs as lighting engines. Generally, there are three methods to get white light such as 1) combination of three RGB color LEDs, 2) blue GaN-LED is embedded in a phosphor partially pumps the converter to emit yellow light, and 3) UV LED with RGB phosphor. By using R,G&B-LEDs, the color gamut is increased compared to cold cathode fluorescent lamp (CCFL). As the R,G&B LEDs have narrow and well-behaved spectral distributions, and can be tuned (in wavelength) to optimize color performance and efficiency. Due to the smaller spectral width, the light in the overlap regions of the color filters is minimized[4,5]. So, we tried to get white light by combination of RGB LEDs in our work, LED BLU Design. In visible spectrum, the emission power of green is the lowest. So, we were used 2 green, 1 red and 1 blue to get white brightness[6,7]. For 42-inch LCD, the aspect ratio is 15:9 and a depth of 30 mm. We were calculated the amount of LEDs used, the distance between LED's strips and the height of the LED's top and LCD's back to get our brightness target.

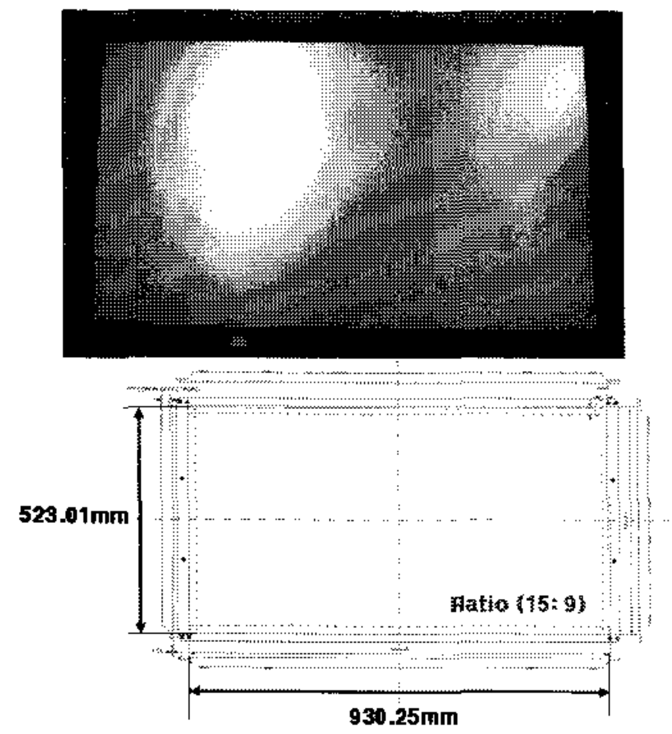


Fig. 1. Schematic diagram of BLU in 42-inch LCD system.

In generally, a beginner may find difficulties in learning software if it uses pre-defined programming languages to create models or even run the whole system. This kind of user interface provides a convenient environment for design optimization. In the design of LED BLU, for instance, the luminance and its uniformity are functions of the light source locations inside the module and the dimensions of other optical components. To achieve the optimal geometry, the parameters need to be varied throughout the design cycle[8]. Before making LED BLU design, we have needed to make LED modeling. And then we will make LED arrays module using the modeling LEDs. Lastly, the whole system have made by these LED array modules. Figure 2 illustrates the simulation procedure.

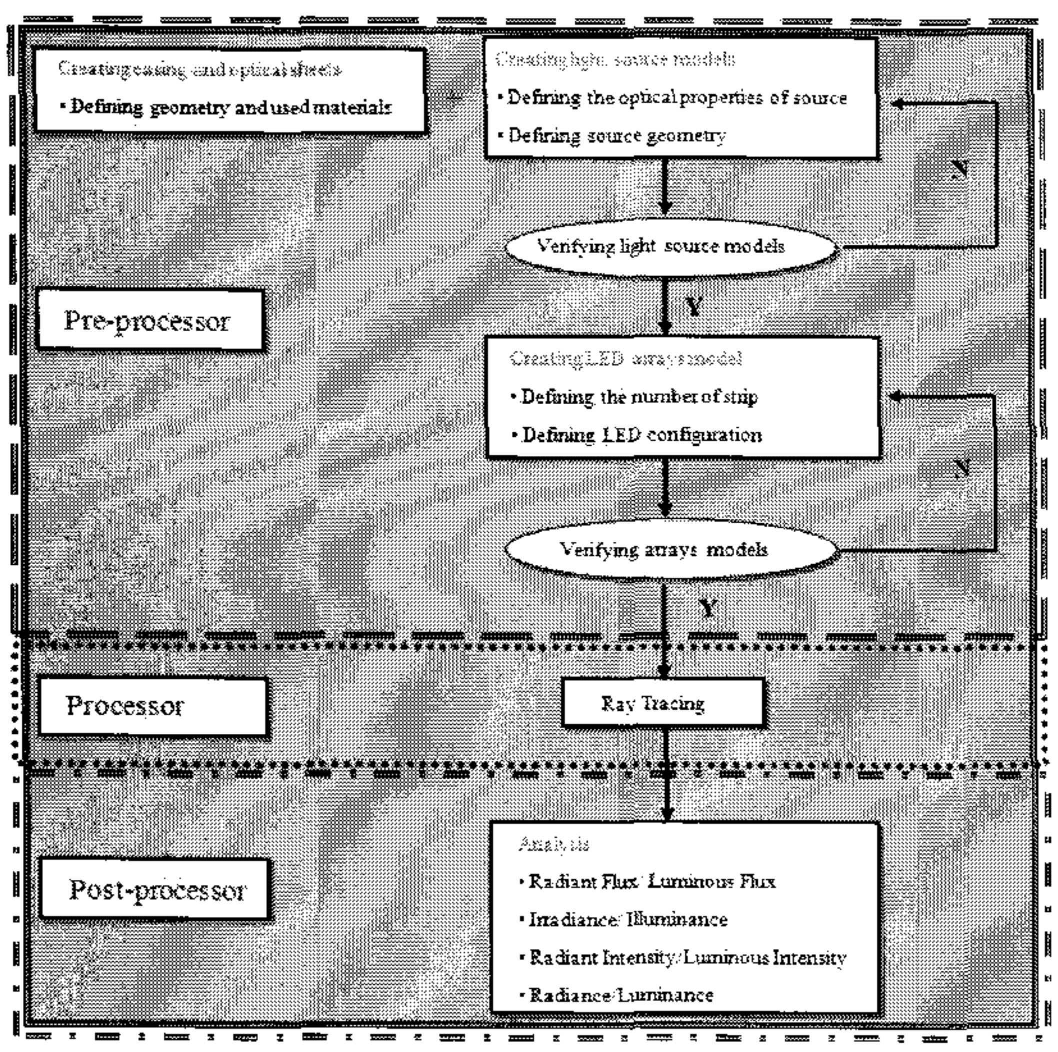


Fig. 2. Typical procedure of LED BLU in LightTools simulation.

3. RESULTS AND DISCUSSION

3.1 Arrangement of RGB LED

We have made the required RGB LEDs modeling to simulate in the illumination software. We need to experiment to get the required optical factors for modeling LED. So, we made some experiment by using reference RGB LEDs. To get viewing angle, experiment was conducted by using Goniophoto-meter (OPI-310). Experiment was carried out by using MINOLTA CS-1000 portable spectral radiometer to get spectrum wavelength of the reference LEDs. Figure 3 illustrates the relative spectrum for reference RGB LEDs. Table 1 gives the optical properties of reference RGB LEDs. These data have been used as an input for the modeling LEDs[9,10].

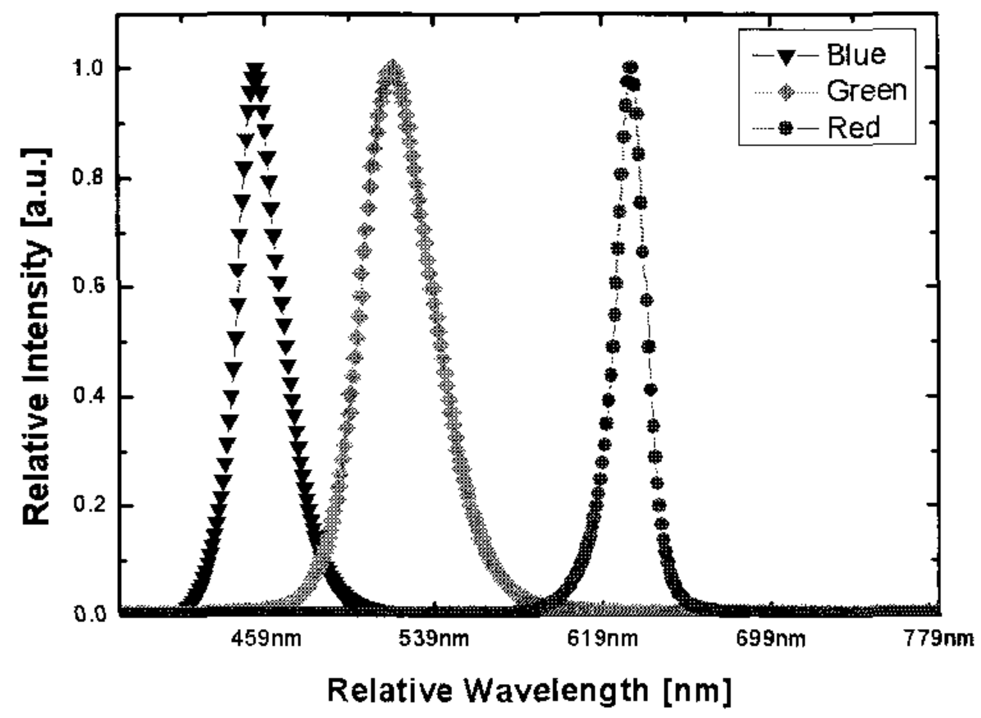


Fig. 3. Relative spectrum for reference RGB LEDs.

In the visible spectrum, the emission power of green is the lowest. With the color sequence of green, red, blue and green repeated along the length of the array, it was important in maximum color uniformity[11]. So, we were used 2 green, 1 red and 1 blue to get white brightness. Moreover, the arrays should be positioned with an anti-parallel configuration to maximum color uniformity as illustrated in Fig. 4.

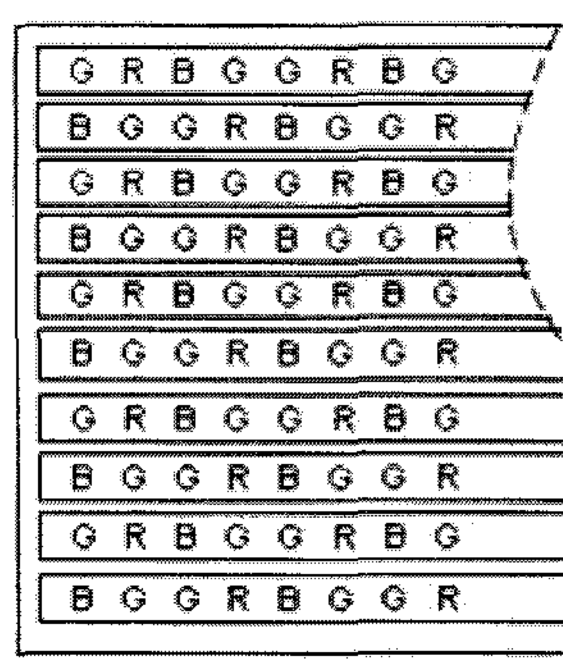


Fig. 4. Anti-parallel configuration.

Table 1. Optical properties of reference RGB LEDs.

	Symbol	Green	Red	Blue	Unit
Luminous Flux	Φ_V	24.5 - 48	24.5 - 30	6 - 11	lm
Dominant Wavelength	λ_D	520 – 527 - 535	618 – 625 - 632	455 – 460 - 475	nm
View Angle	$2\theta_{1/2}$	130	128	130	deg.

Table 2. Evaluation of BLU design by changing number of LED strips.

No.	LEDs' arrangement	Number of strips	Average Illumination	Uniformity	CIE Coordination			
					x(Max-Min)		y(Max-Min)	
1	GRBG,GRBG,GRBG,GRBG BGGR,BGGR,BGGR,BGGR	12	18490.08 (lux)	73.92 %	0.35	0.33	0.32	0.30
2	GRBG,GRBG,GRBG,GRBG BGGR, BGGR,BGGR,BGGR	10	11120.68 (lux)	85.81 %	0.35	0.33	0.32	0.30
3	GRBG,GRBG,GRBG,GRBG BGGR,BGGR,BGGR,BGGR	8	9827.32 (lux)	54.78 %	0.29	0.20	0.30	0.18

3.2 Design of LED BLU

There are fewer optical components in direct lighting BLU where the reflection sheet and diffusion sheet are major ones. In this paper, the most important design parameters are the module thickness, the distance between light sources and LCD's back, the spacing between LED's strips and arrangement of light sources. We have put 12 strips, 10 strips and 8 strips in 930.25×523.01×30.00 mm casing respectively. We have found the best uniformity at 10 strips condition. The average illuminance of 10 strips is lower than that of 12 strips but the CIE coordination and uniformity of 10 strips are more than the other conditions.

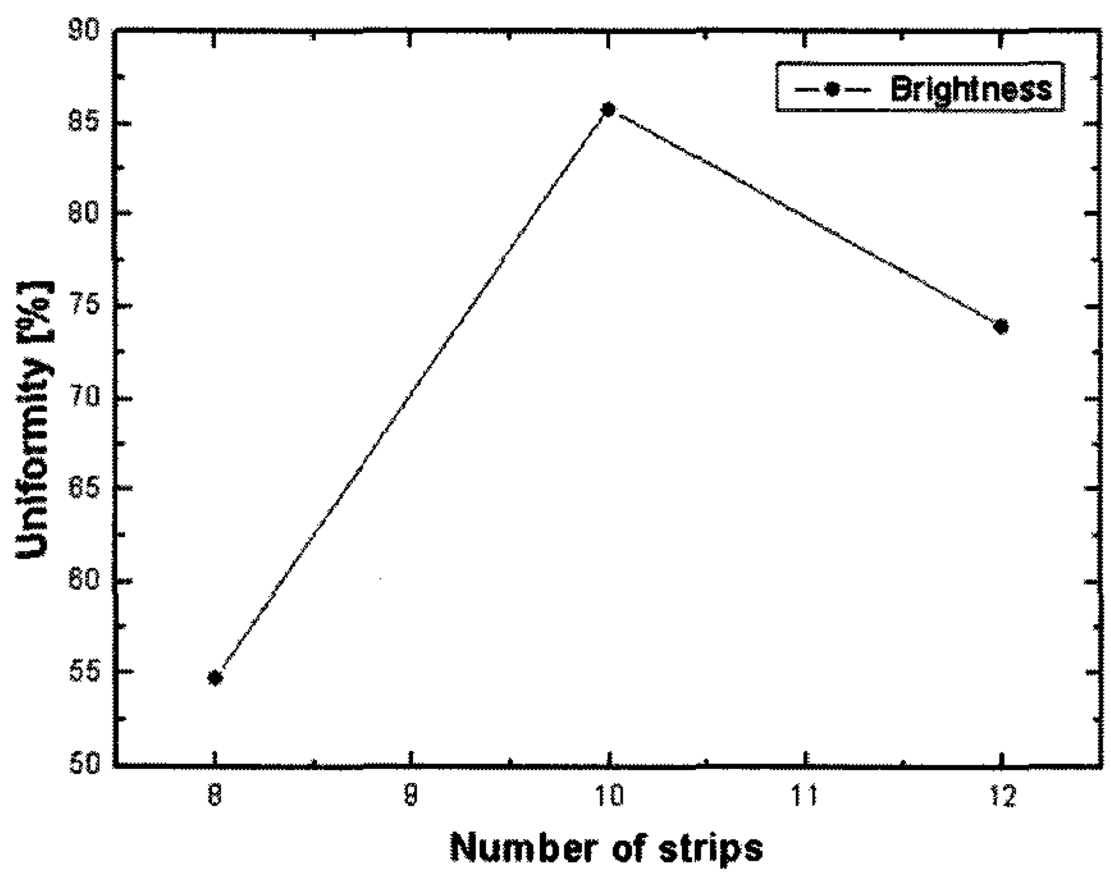
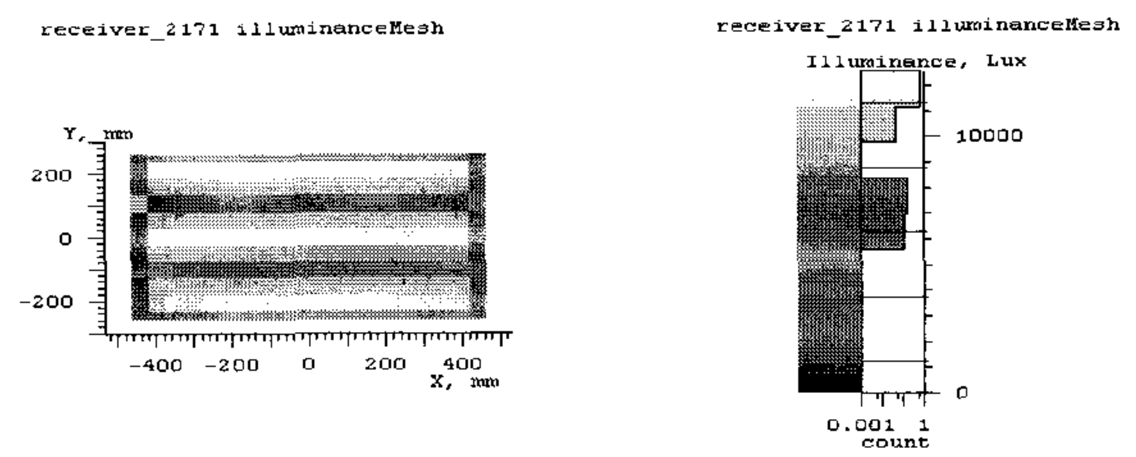
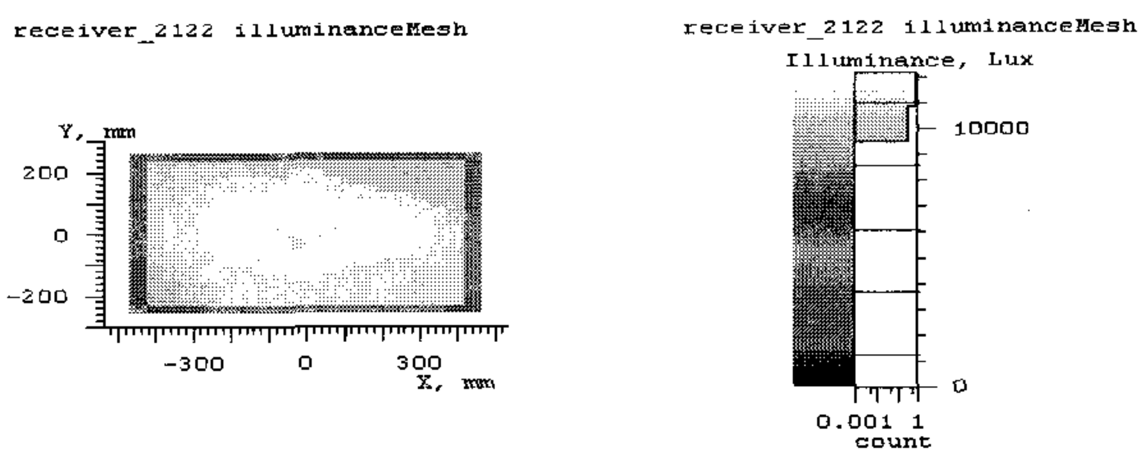


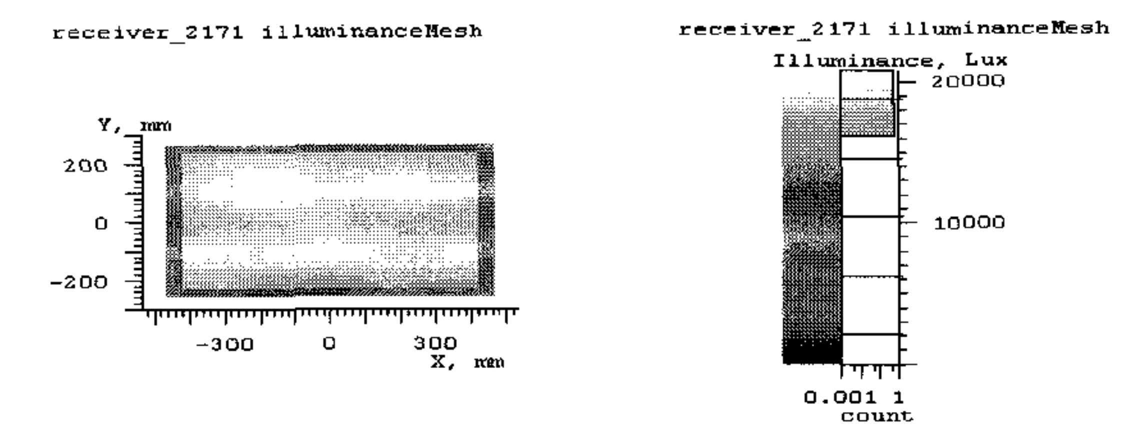
Fig. 5. Uniformity of LED BLU by changing the Number of strips.



(a) 8 strips



(b) 10 strips



(c) 12 strips

Fig. 6. Uniform illuminance distributions of LED BLU by changing the number of strips.

Figure 6 illustrates the illuminance distribution of these three conditions. We concluded that this system consists of an aluminum housing containing 10 linear arrays of 30 LEDs on a Metal Core Printed Circuit Board (MCPCB) to get our uniformity target see Table 2 and Fig. 5 and 6. We got 85.81 % brightness uniformity using 10 strips in 15:9 aspect ratios.

For thickness of BLU, we changed the distance between LED's top and LCD's back during 0.0 mm to 19.2 mm moving 3.2 mm of the collecting receiver going to case by case. The distance of 12.8 mm between LED's top and LCD's back is suitable for our BLU design. Figure 7 shows the brightness uniformity by changing the distance between LED's top and LCD's back.

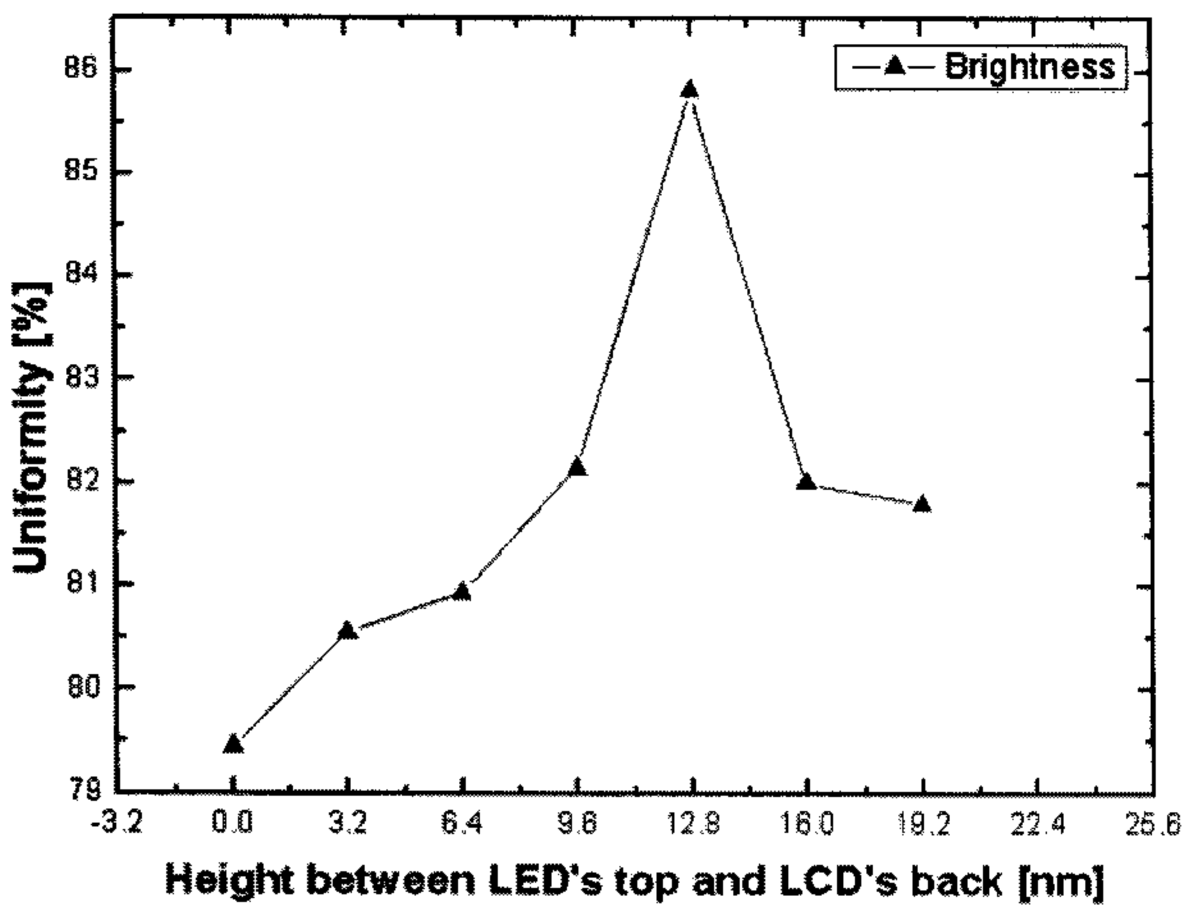


Fig. 7. Brightness uniformity by changing height between LED's top and LCD's back.

The brightness and the luminance uniformity of BLU are functions of the geometrical factors of the entire module and all of its optical components[12]. Those factors may include the enclosure dimensions, the number of light sources, the distance between two light sources, the distance between a source and back side of enclosure, the adjustment of LEDs' strips distance. Figure 8 illustrates the simulation result of the brightness uniformity and CIE coordination for whole system. The illuminance is clearly uniform at the center region of raster chart pattern and becomes decreasing to outer region of raster. On the right side of each raster chart is a histogram of the illuminance levels in the corresponding raster chart. It is the key to interpreting the colors as illuminance values.

The left part of the histogram shows all the 32 distinct colors used. The right side is a histogram showing the colors present in the data. We got illuminance of over 10000 lux and brightness uniformity is 85.81 %. Our intention is 80 % above brightness uniformity. Moreover, we put white color as a standard in LCD screen. So, we need to exam the CIE coordinates. The standard white coordinates in CIE are 0.33, 0.33. We got this data by changing the distance between light sources and LCD's back, the spacing between LED's strips and arrangement of light sources.

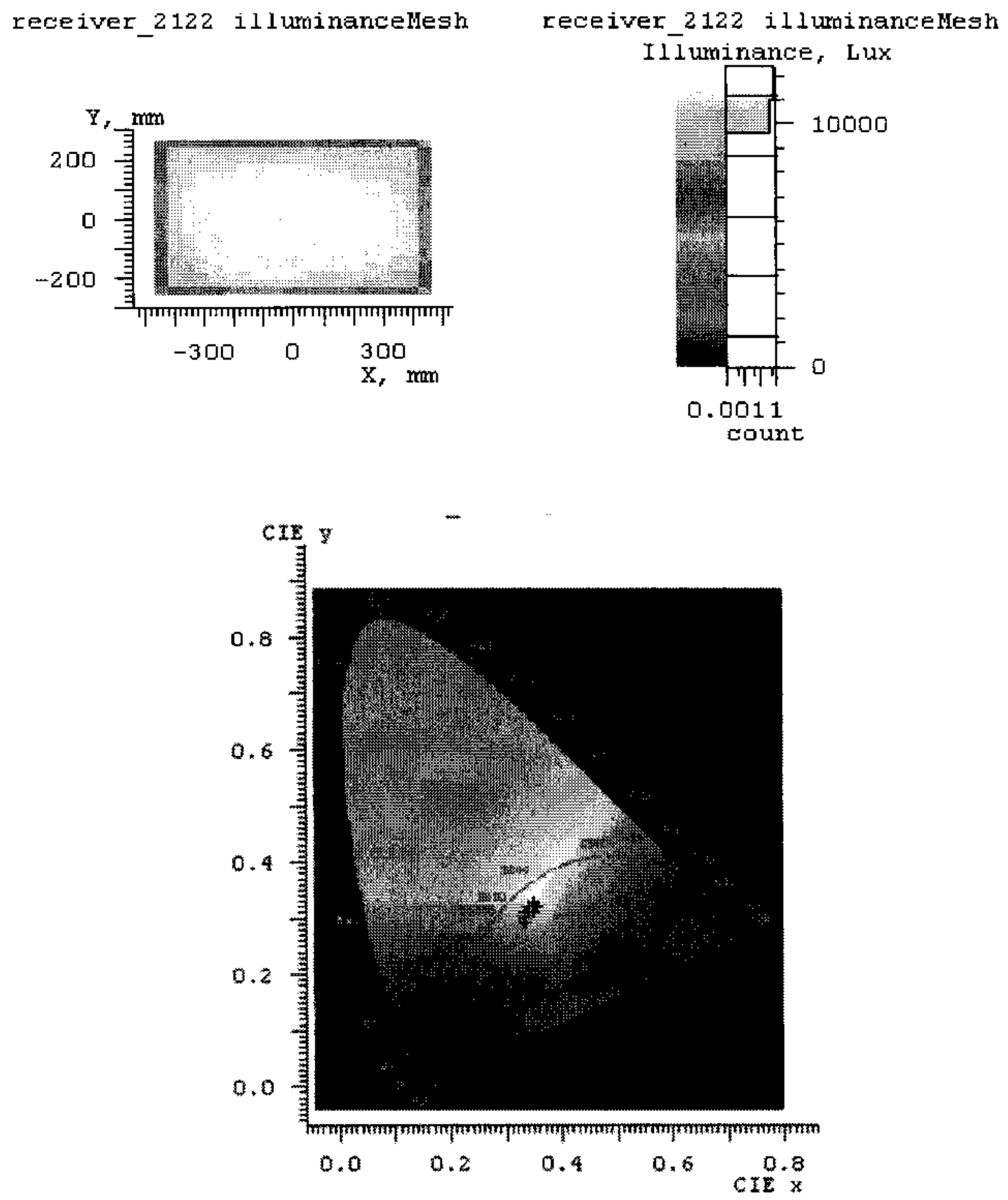


Fig. 8. Uniformity and CIE Coordination of a designated LED BLU.

The surface receiver was put on the LED BLU has 930.25×523.01 mm^2. The receiver was divided into a mesh of 15 squares, each 62.28 horizontal and 34.87 vertical. The illuminance value at each mesh node was measured by an illuminance meter. The equation to calculate the average illuminance of a certain BLU surface is

$$E_{av} = \frac{1}{9}\sum_{i=1}^{9} E_i \qquad (1)$$

where E_{av} (lx) is the average illuminance value, and E_i (lx) is the illuminance value at one corner of the square. The average illuminance distribution of the 42 inch LED BLU was calculated and illustrated in Fig. 9.

Table 3. Evaluation of BLU design by changing the distance between LED's top and LCD's back.

No.	LEDs' arrangement	Height [mm]	Average Illumination	Uniformity	CIE Coordination			
					x(Max-Min)		y(Max-Min)	
1	GRBG,GRBG,GRBG,GRBG BGGR,BGGR,BGGR,BGGR	0.0	11532.27	79.45 %	0.36	0.32	0.32	0.30
2	GRBG,GRBG,GRBG,GRBG BGGR, BGGR,BGGR,BGGR	3.2	11461.75	80.56 %	0.36	0.32	0.32	0.29
3	GRBG,GRBG,GRBG,GRBG BGGR,BGGR,BGGR,BGGR	6.4	11350.62	80.94 %	0.36	0.33	0.32	0.29
4	GRBG,GRBG,GRBG,GRBG BGGR,BGGR,BGGR,BGGR	9.6	11318.25	82.15 %	0.36	0.31	0.32	0.28
5	GRBG,GRBG,GRBG,GRBG BGGR,BGGR,BGGR,BGGR	12.8	11104.86	85.81 %	0.35	0.33	0.32	0.29
6	GRBG,GRBG,GRBG,GRBG BGGR,BGGR,BGGR,BGGR	16.0	11563.21	82.00 %	0.36	0.32	0.32	0.30
7	GRBG,GRBG,GRBG,GRBG BGGR,BGGR,BGGR,BGGR	19.2	11441.47	81.88 %	0.35	0.31	0.32	0.30

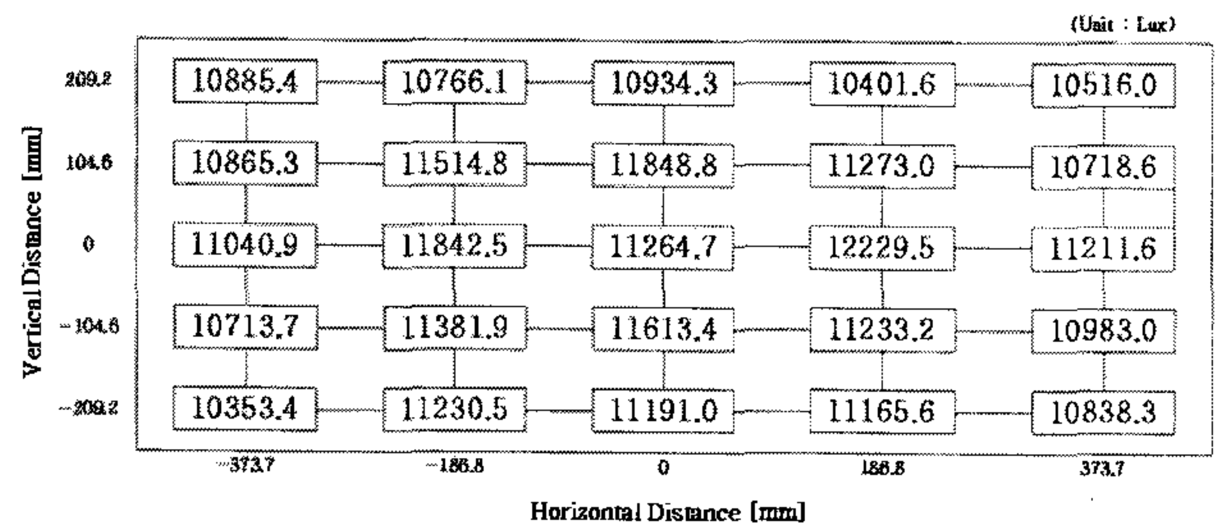


Fig. 9. Average illuminance value of a designated LED BLU.

3.3 Manufacture & evaluation of LED BLU

After learning as much as possible about the design from simulation, several LEDs were built in housing with directly distribution. We made LED arrays and configurations according to simulation result. An array was made up of 300 RGB LEDs with a color sequence optimized to manage brightness uniformity on the screen. This sequence was repeated until the array contained the 300 RGB LEDs. The 10 strips were approximately placed 51.41 mm apart and 12.8 mm away from the back of LCD. The 75 red LEDs had a total flux of 1950 lm, while the 150 green LEDs had 3825 lm, and then the 75 blue LEDs had 225 lm, were used in this system. Figure 10 illustrates the final design of our work.

Diffuser film and protector sheet are key elements, which controlled the brightness and luminance uniformity. These sheets and film were placed on the back of the LCD. The brightness and luminance uniformity were measured with MINOLTA CS-1000 portable spectral radiometer. The result data can see in Fig. 11. We got same CIE color coordinate at 0.34, 0.306 in case of the simulation and experiment data. The average uniformity was 82.24 % uniformity based on 9-point test at a position in 500 mm from LCD and CS-1000.

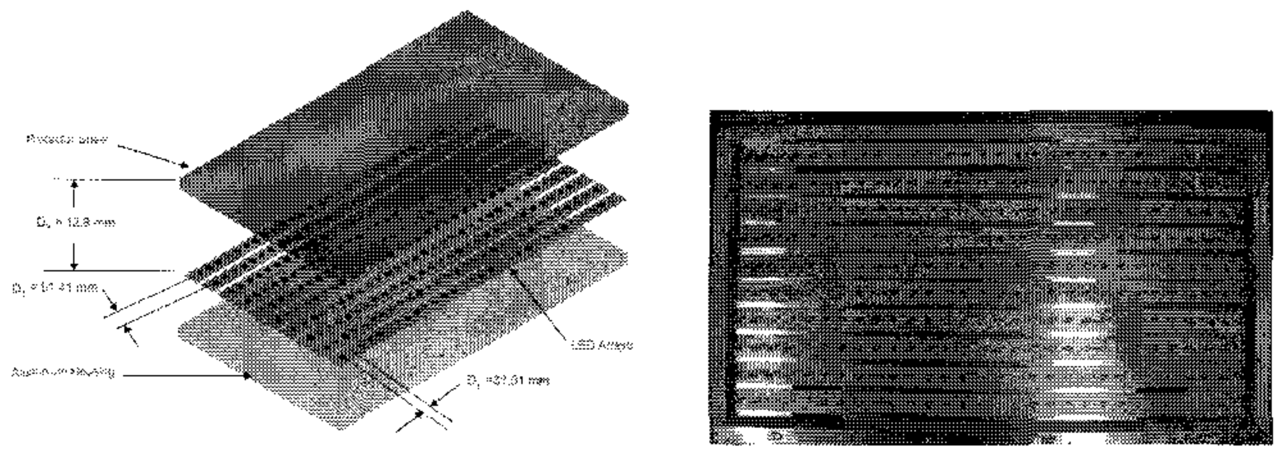
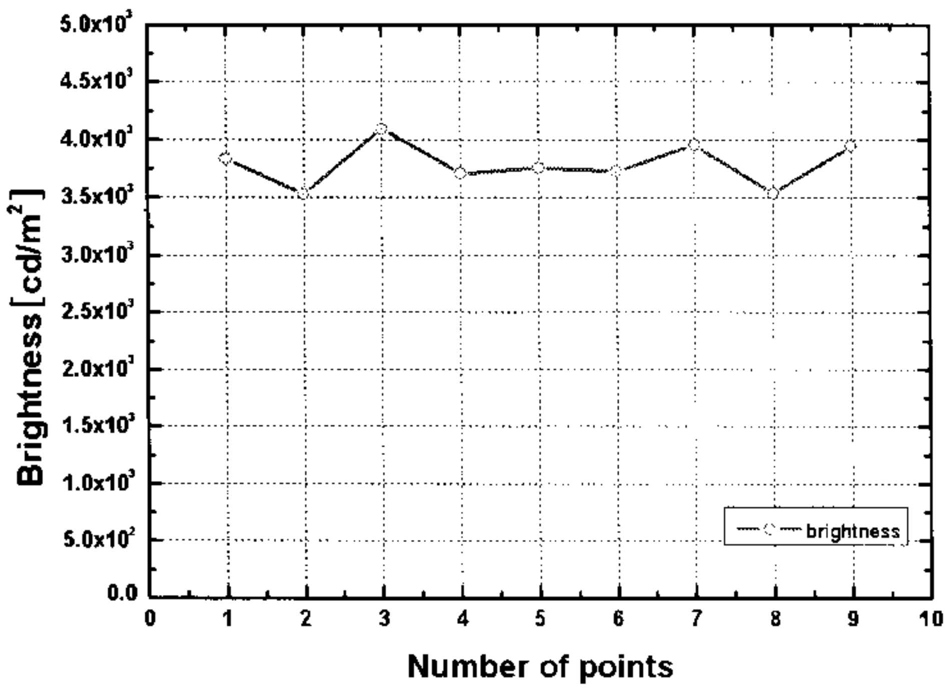


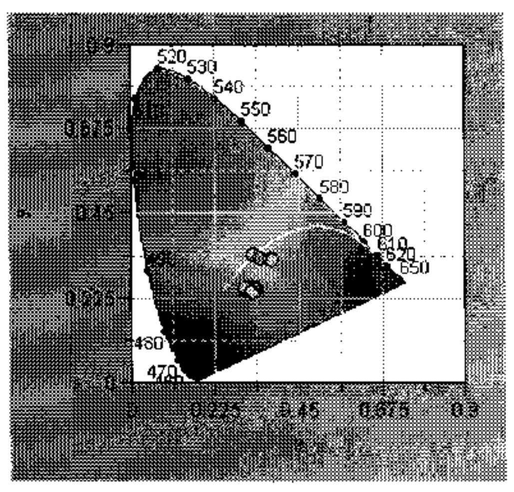
Fig. 10. Final design for LED BLU.

4. CONCLUSION

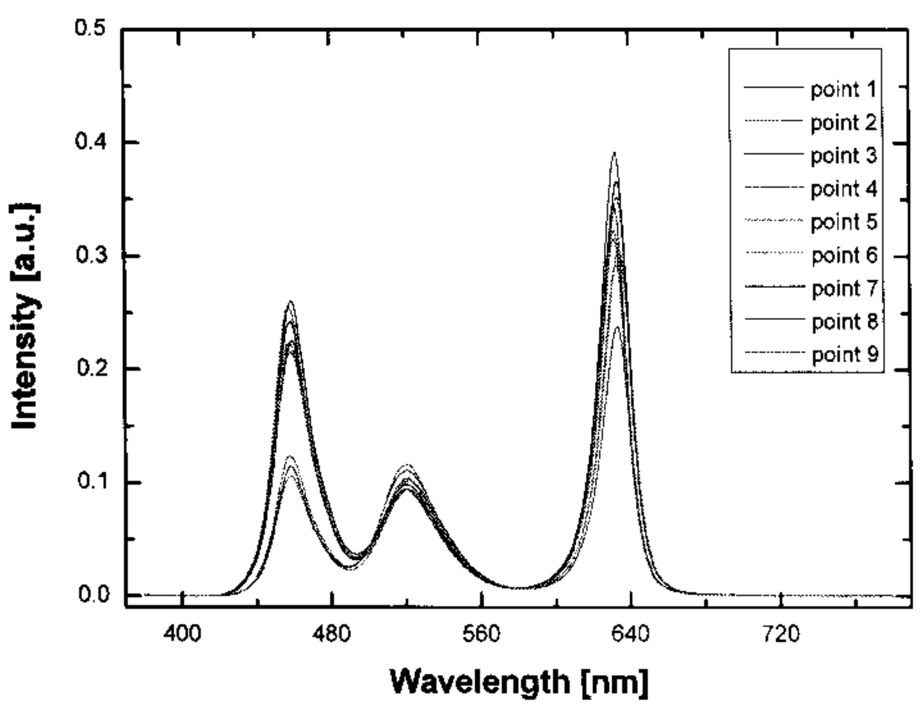
In this paper, we were confirmed to get brightness quality by using these factors; thinner module design and higher brightness efficiency. We were made this design which 930.25 × 523.01 mm active area within 30 mm thickness to get our target color mixing. For higher brightness efficiency, we set up a height of 12.8 mm between the top of the LED and the back of the LCD. Moreover, we were made design with equal spacing of LEDs' strip and arranged LEDs with anti-parallel configuration. This design in simulation, using RGB LEDs as a light source, provided a good color uniform and an optical efficiency of 85.81 %. Otherwise in experiment, we got good color mixing but a decreased optical efficiency of 82.24 % due to operation condition. Therefore, we would consider that the other optical properties of LED BLU such as diffuser sheet, prism sheets, etc., to get higher brightness efficiency.



(a) Brightness of BLU



(b) CIE coordination



(c) Spectrum of BLU

Fig. 11. CIE coordinate & spectrum of LED BLU.

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