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87% & 103% NTSC Color Gamut LCD Display Development With Quantum Dot Optical Filter & KSF Coated LED Light Source Against Conventional White LED Structure

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Abstract: Two different techniques are used in this research platform, were the first attempt is using nano semiconductor-condensed (CdSe) Quantum dot optical filter which works as highly efficient nano-crystals and placed between the blue (444nm) LED light source and liquid crystal module (LCM) to extend the LCD display NTSC color volume more than 103%. Apart from the high costly QD filter, low-cost KSF (Potassium Silicofluoride-K2SiF6) compound material coated on one set blue LED chip and optically placed between reflector film and LCM, act as a main light source which also emits highly efficient narrow-band pure white light to resonate the liquid crystal module (LCM) and extend NTSC color gamut percentage of LCD display panel more than 87%. Mentioned methods are not only improving the color volume but have also improved the overall picture quality (PQ) with low power consumption status of a display panel. These techniques & optical measurements are verified for both edge and direct type display BLU structure within HD & FHD resolution.

Keywords: *Color Gamut; QD filter; LED chip; LCD color.*

Introduction: Color gamut is an NTSC (National Television System Committee) and the International Commission on Illumination (CIE) announced color measuring diagram by which an LCD display device can represent its range of color volume. The efficiency of LCD panel color filters and the BLU spectral combinations are the potential factors of this color calculating system [1]. In Fig.1. the triangular 2D Color gamut diagram consists every visible colors where the x-axis represents the color chromaticity and the y-axis is presenting the luminance and color area occupancy of an LCM device into the diagram represents the improved color vibrancy and higher perceived brightness [2]. Generally, the LCD module and a set of different Opto-electrical components like LED light source, different optical plates or films are called backlight unit (BLU). Liquid crystal displays (LCDs) are non-ejective displays that collect a separate from the BLU source and its red, green, blue color filter sub-pixels are used to display a coloured image on the screen. The LCM module color filters effectively split white light emitted from the source into three different basic color: red, green, and blue. Only light from the narrow wavelength band has permission to penetrate the basic RGB color filters and change the display color vibrancy [3].

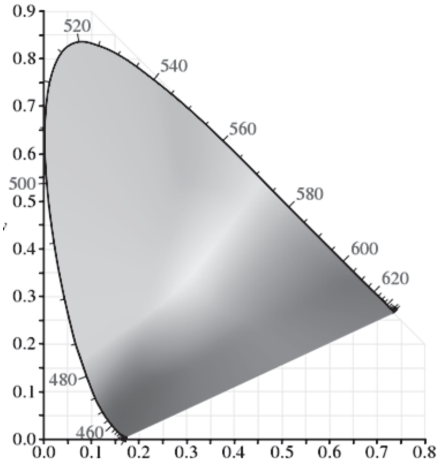

Fig. 1. The CIE 1931 NTSC color measuring diagram.

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Conventional direct or edge type LED display with wide wavelength band can produce roughly 70% of NTSC or less [4]. Two individual methods are used to extend the NTSC of display device in this research platform. At first, advanced Quantum Dot (QD) based optical filter and blue LED sources, which are capable to enhance the NTSC volume has been used. Receiving blue light from backlight source, QD filter produces highly saturated pure narrow-band RGB color spectral, which have an extraordinary response to the liquid crystal module (LCM) color filter [5][6][7][8][9] and this efficient operation extends the display NTSC color volume. In this research approach, not only the color volume but also the overall picture quality (PQ) with improved luminance and calibrated power consumption was also investigated. But the QD filter based structure for large NTSC, production cost is very high and action strategy with display backlight units are very complex to develop [10][11]. However, raw LED chip (Blue:444nm) with several combinations of optoelectrical compound materials on its chip surface can also manipulate the color gamut and brightness of LCD display. Using this procedure, color gamut can be improved from 70% to 85% NTSC or more [12]. To fabricate these kinds of advanced LED chip device, Low-cost Potassium Silicofluoride-K2SiF6 (KSF) compound powder was mixed with the gel form of silicone and finally, KSF compound material coated on conventional blue LED chip for high NTSC [13][14][15]. Both techniques & optical measurements are verified for both edge and direct type display BLU structure within HD & FHD resolution in this research platform.

Materials:

Display optical unit construction: In this research project, Edge and Direct, both types of BLU structure were constructed. For QD configuration: 43" direct-type LED backlight structure with QD optical filter, Blue LED light source (I_f 250mA) and FHD resolution LCM has used. And for KSF configuration: 32" edge-type LED backlight structure with KSF coated LED light source (I_f 200-210mA) and HD resolution LCM has been used. Cross-section views of both panel structures are given below:

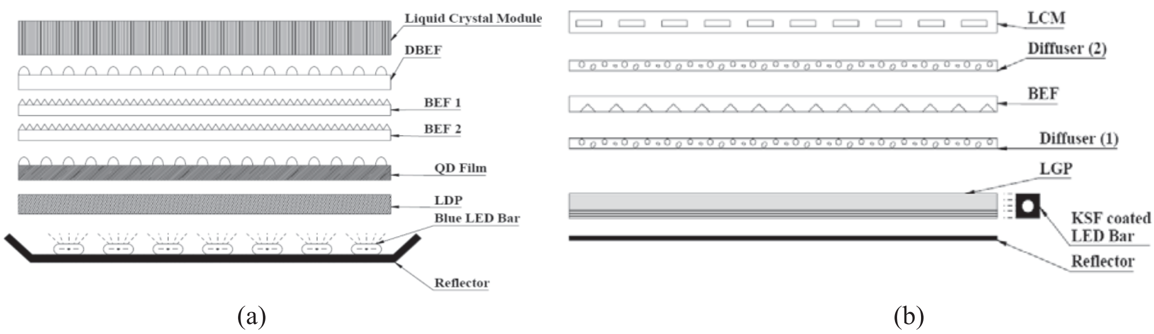


Fig. 2. 43" Direct type display BLU structure (a) and 32" edge type display BLU structure (b) Cross-section view.

For the 1st case of Large NTSC improvement method, high costly optical films and duel brightness enhancement films(DBEF) were used to improve the entire brightness of the display panel. These brightness enhancement films are made with PET (Polyethylene terephthalate) type polymer compound. For the 2nd case of wide NTSC improvement method, the only source LED light of conventional BLU structure interchanged with a low-cost KSF coated LED bar. No extra optical brightness enhancement films have used in this case and that's why this solution is chipper than the 1st case.

Method:

Color Chromaticity measurement: The following instruments are used for chromaticity and different display color parameters measurement: color analyzer CA-310, UA 10, Chroma HDMI pattern generator, DC power supply and SPIC-200 spectral irradiance colorimeter. Specially UA 10 has used here for total display brightness uniformity intensity spectrum measurement & SPIC-200 spectral irradiance colorimeter has been used for LED light color spectrum measurement. Fig.3 shows the chromaticity measuring instruments and their operations.

(a) (b)

Fig. 3. Display color Spectrum measurement using SPIC-200 spectral irradiance colorimeter (a) and Color analyzer CA-310 & UA 10 Display chromaticity measurement (b).

Also, using the measured chromaticity values and NTSC calculator, the display color volume has determined. The % NTSC Area metric in bellow table is calculated based on the gamut triangle area (GTA) of the measured display in comparison to the GTA for the NTSC display gamut standard using the following equations:

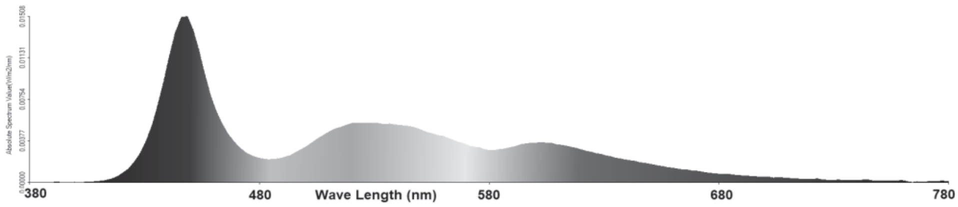
$\%\ NTSC\ Area = GTA_{\ Measured\ Display} \div GTA_{\ NTSC\ Standard}$

$GTA = \{Bx(Gy - Ry) + Gx(Ry - By) + Rx(By - Gy)\} \div 2$

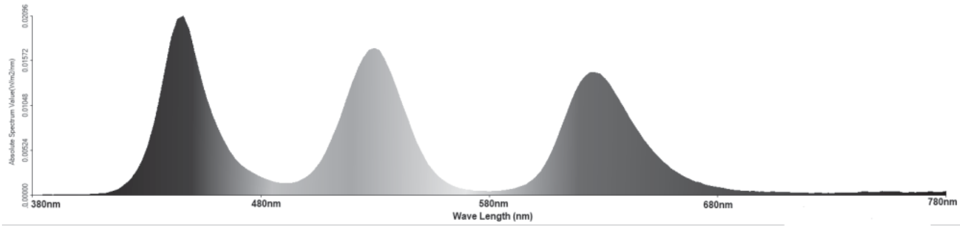
Where Bx and By are the x- and y- coordinates, respectively, of the color point measured when displaying a bit accurate full blue image (RGB triplet = 0, 0, 255). The coefficients R and G then reflect the similar coordinates for full red and green images, respectively.

Red		Green		Blue	
R_x	R_y	G_x	G_y	B_x	B_y

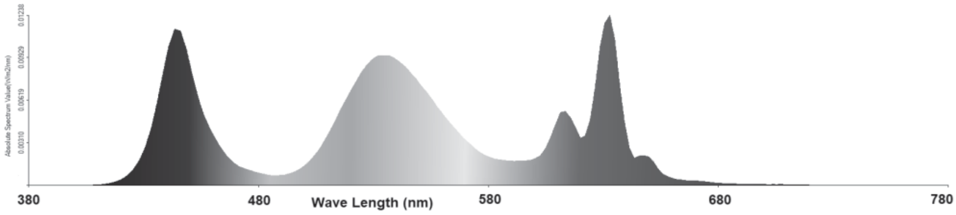
Results and Discussion: The chromaticity variation of any display panel depends on the variation of LED light source, optical sheet or plate and the color properties of liquid crystal module or open cell. The measured color spectrum of the conventional white LED-based display structure, QD filter based display & KSF coated LED-based display has shown in Fig.4.



(a)



(b)



(c)

Fig. 4. The color spectrum of the white LED-based (a) & QD filter-based (b) and KSF coated white LED-based (c) display.

From Fig.4. color spectrum in the green and red region has been distorted in conventional white LED (a). However a narrow band sharp color spectrum in all region has appeared in QD filter based display (b), which is ideal for large NTSC. But in KSF coated LED-based structure (c), color spectrum in red region has been little distorted and not like QD's. The peak red wavelength varied from 629 to 630nm for the Red, from 528 to 530nm for the Green & from 444 to 447 nm for the Blue in QD structure. The peak wavelength of the visible display color is 635nm for the Red, 533nm for the Green & 447nm for the Blue in KSF coated LED display.
In order to study the advanced color performance of LCD display, the picture quality (PQ) and chromaticity variation data of ordinary 43" white LED-based FHD display & blue LED and Quantum dot film based FHD display has shown in the following table:

Table 1. The chromaticity variation of conventional 43" white LED-based FHD display & blue LED and Quantum dot filter based FHD display.

Item	Center Luminance	Color Co-ordinates Neutral		Brightness Uniformity	Color Temp	NTSC Color Gamut
		x	y			
Unit	Cd/m^2			(%)	T (K)	(%)
Standard	100% White					
White LED Display	260	0.280	0.284	66%	11000	69.00%
QD Filter Display	312	0.280	0.293	74%	9500	103.0%

The color temperature of both display panels are nearly the same but the brightness and brightness-uniformity of QD Filter LED display has been increased in Table 1.
The following table represents the RGB x, y values for 43" conventional white LED-based FHD display and QD Filter blue LED-based FHD display to calculate the NTSC.

Table 2. Conventional white & QD Filter blue LED-based 43" direct type FHD display R G B x, y measurement data for 70% and 103% NTSC color Gamut.

Item	Red		Green		Blue	
	x	y	x	y	x	y
White LED	0.649	0.334	0.318	0.597	0.147	0.057
QD Filter Display	0.679	0.308	0.288	0.641	0.149	0.063

The chromaticity variation of ordinary 32" edge type white LED-based HD display & KSF LED-based HD display has shown in the following table:

Table 3. The chromaticity variation of conventional 32" white LED-based HD display & KSF LED-based HD display.

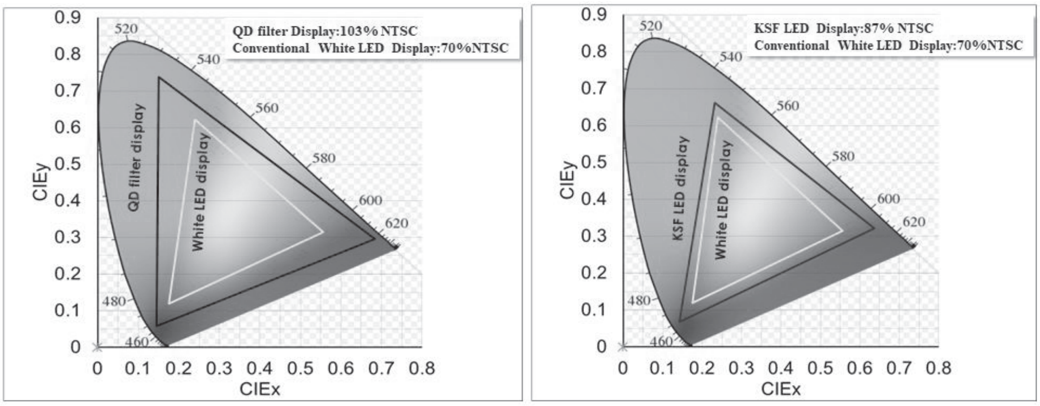
Item	Center Luminance	Color Co-ordinates Neutral		Brightness Uniformity	Color Temp	NTSC Color Gamut
		x	y			
Unit	Cd/m^2			(%)	T (K)	(%)
Standard	100% White					
White LED Display	248	0.280	0.284	71%	8500	70.00%
KSF LED Display	272	0.280	0.293	76%	10000	87.30%

The color temperature of both display panel varied from 8500K to 10000K. But the brightness and brightness uniformity of KSF LED-based HD display has been increased in Table 3.
To calculate the NTSC, the following tables represent the RGB x, y values for 32" edge type conventional white LED-based HD display and KSF LED-based HD display.

Table 4. Conventional white & KSF LED-based 32" edge type HD display R G B x, y measurement data for 70% and 87% NTSC color Gamut.

Item	Red		Green		Blue	
	x	y	x	y	x	y
White LED	0.638	0.333	0.310	0.607	0.150	0.055
KSF LED Display	0.685	0.298	0.196	0.696	0.150	0.058

Plotting this x,y color co-ordinate value of table 2 & 4 in NTSC diagram, the increase of NTSC color Gamut space has shown in Fig.5.



(a) (b)

Fig. 5: The increase of NTSC color Gamut space from conventional white LED based display to QD filter based display (a) & KSF coated LED display (b).

Area achievement comparison data of NTSC color Gamut of QD filter-based, KSF coated LED and conventional white LED display has shown in Fig.6.

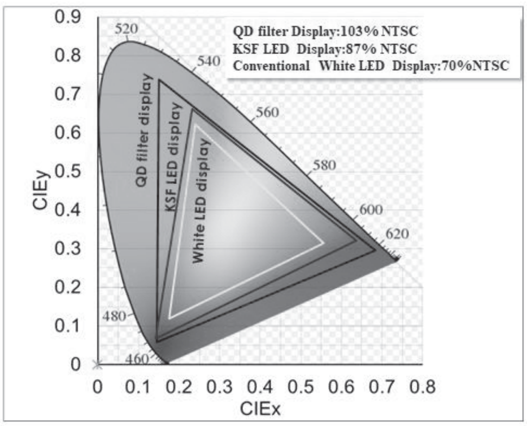
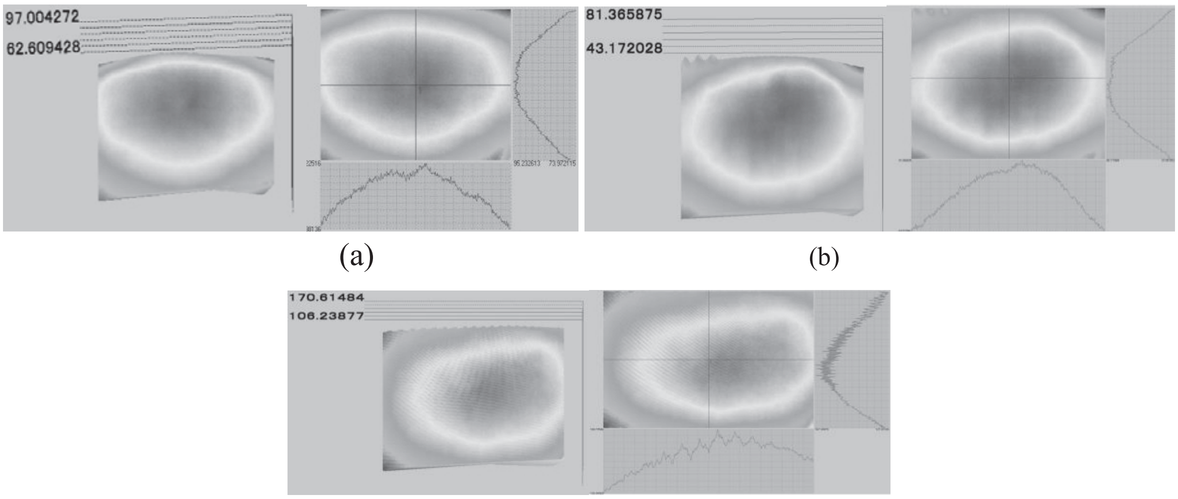


Fig. 6: NTSC color Gamut space achievements of the conventional white LED based display, QD display, KSF coated LED display.

Brightness distribution spectrum of a conventional white LED display, 43” QD filter based FHD display and 32” KSF coted HD display has shown in Fig.8. The UA 10 2D and 3D data of Fig.8. represents that the brightness distribution of QD filter-based and KSF coated LED-based display structures are more accurately distributed and saturated than conventional white LED-based display structure.

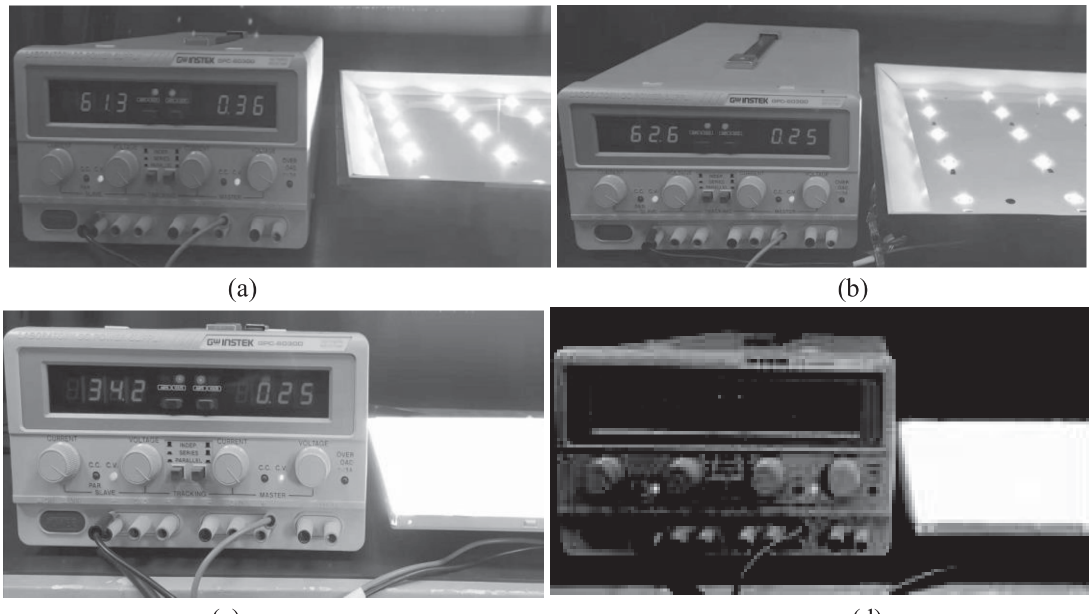


(a) (b)

(c)

Fig. 7: Brightness distribution spectrum of QD filter-based (a), KSF coating and white LED-based (b) display.

The power consumption verification data of all display optical structure (43” Conventional white DLED structure ≈44 watt, 43”QD filter based blue DLED structure ≈32.5 watt, 32” white ELED chip structure ≈17 watt and the 32” KSF coated ELED chip structure ≈14 watt) has shown in Fig.8.



(a) (b)

(c) (d)

Fig. 8: Power consumption data of 43” Conventional white DLED structure (a), 43”QD filter based blue DLED structure (b), 32” white ELED structure (c) and 32” KSF coated ELED chip structure (d).

The overall display picture quality improvement comparison data of white LED display panel, KSF coated LED bar display and QD filter based display has shown in Fig.10.

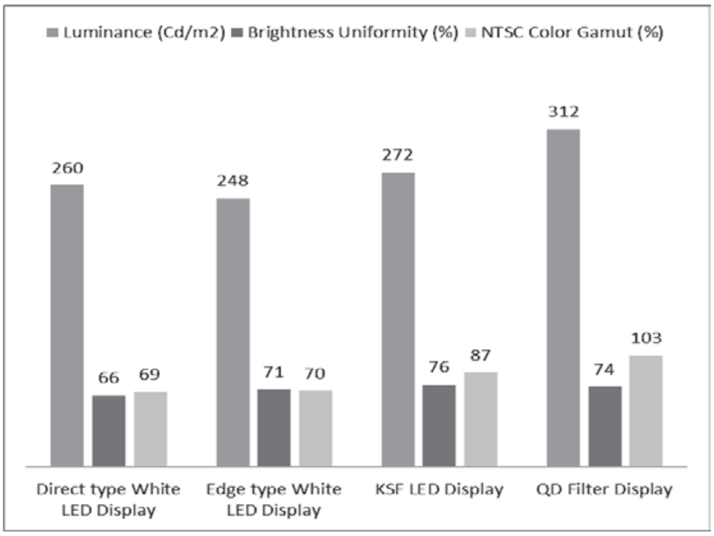


Fig. 9: Picture quality improvement comparison data of white type display panel, KSF coated LED bar display and QD filter based display.

Conclusions: Based on experimental outcomes, the following conclusions can be drawn:

1. Into the QD filter based structure, the NTSC color gamut of 43" FHD DLED type LCD display has improved from 70% to 103% with low power consuming source light.
2. The NTSC color gamut has increased from 70% to 87% in KSF coated LED light sources against the conventional LED.
3. An ideal narrow band sharp color spectrum in all RGB region has appeared in QD filter display. But in KSF structure, color spectrum in red region has been little distorted and not ideal as QD's. Especially the efficiency of Red, Green and Blue region in QD filter based structure becomes more saturated than the conventional and KSF structure.
4. Color uniformity also improved in QD structure from 6 to 9% and KSF LED from 4 to 6% roughly. Also there is some significant developments of overall luminance has appeared in both, QD and KSF type structure with comparatively low power consumption, which has improved the overall display picture quality.
5. Some abnormalities were found and a warm color glow appeared due to abnormal light guide operation of LGP in 32" edge type structure and ununiformed diffusion of LDP for using thin types of optical plate in 43" direct type structure. After improving the thickness and changing the orientations of the optical films the problems were cured. When the thicker optical films were used, more polymer atoms were deposited on the film surface which reduces the defects like voids, crystal defects and dislocation density[16][17] and prevented those abnormalities.
6. The color temperature CCT varied from 9000K to 10000K in both, OQ and KSF. It represents that the display image is neither in warm nor in cool mode and they are maintaining the ideal picture mode of LCD [18] for accurate image processing.

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