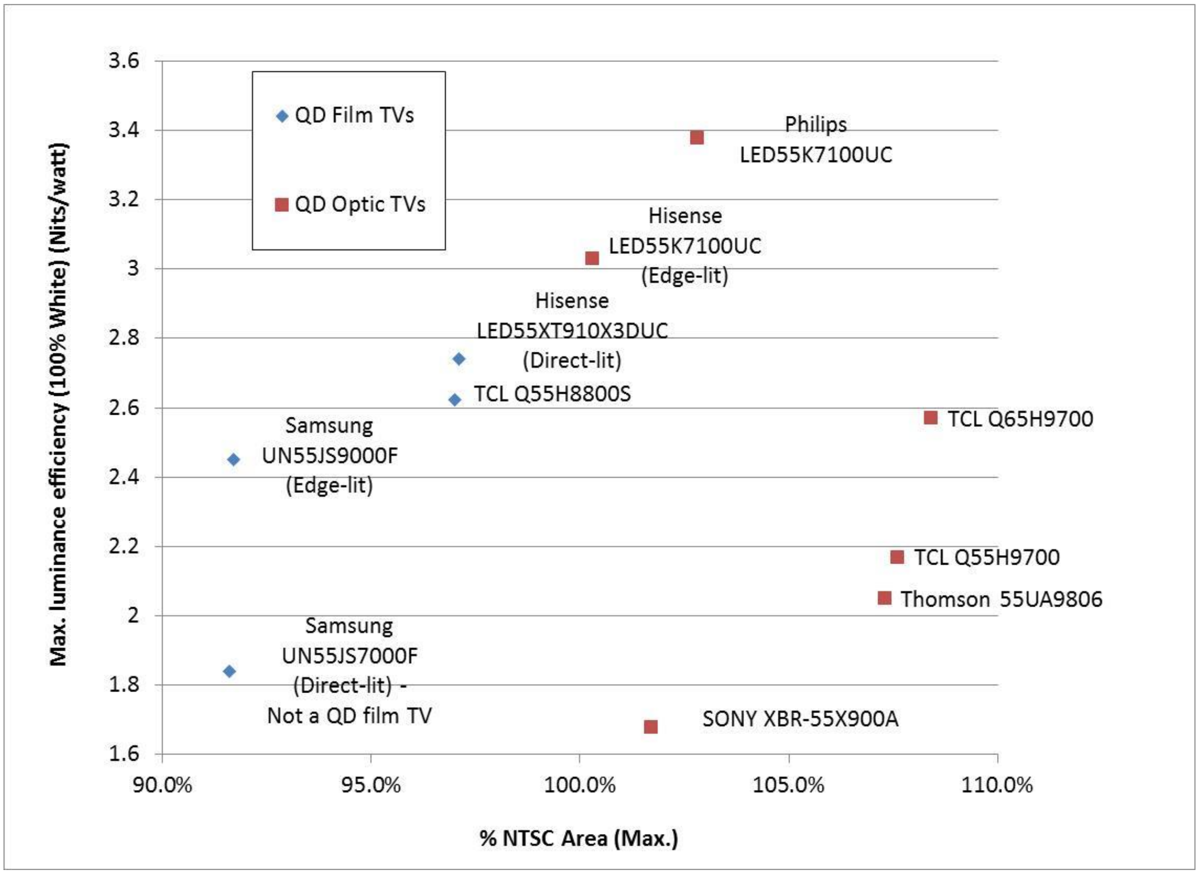
Benchmarking of QD Televisions

QD TV performance (luminance, color, power consumption) was characterized for various TV settings[1]. Setting with maximum luminance, maximum color gamut was chosen as the best indicator of color and luminance efficiency for a particular TV. The luminance efficiency (nits/watt) vs. color gamut is compared for various wide color gamut TVs that are current in the market, and is shown in Figure 1. Key Observations include:

- Hisense QDEF TV has better color gamut and luminance efficiency compared to Samsung sUHD TV. Both these TVs have luminance greater than 500 nits.
- Hisense Color IQ TV (edge lit) has better color gamut and luminance efficiency compared to Hisense QDEF TV (direct lit). Edge lit Hisense TV has 400 nits luminance while the direct lit has 500 nits luminance.
- Philips Color IQ TV (edge lit) has the best luminance efficiency of all wide gamut TVs. All measured TVs have luminance greater than 400 nits. These results line up well with our expectations that for a given size (i.e. 55") 1H orientation TVs lead the luminance efficiency, followed by 2Vand finally by 2H designs.
- TCL and Thomson Color IQ TV (edge lit) has the best color gamut of all wide gamut TVs.
- Samsung Direct lit UN55JS7000F (direct lit) does not use QD film. It uses a LED with RG phosphor and a notch filter film to minimize Green-Red channel leak to improve color quality.

[1] Color and luminance was measured using Konica Minolta CS-200. Color was measured for 100% RGB swatches generated by a SpectraCal VirtualForge v1.1.302 pattern generator with an AJA T-Tap HDMI output device for high quality output from a MacBook Pro. Luminance was measured for a 100% white swatch. SpectraCal CalMAN 5 was used to set the luminance of the WRGB patterns to 100%. The power source was an HP6811B AC Power Source/Power Analyzer that measures power consumption while sourcing power.

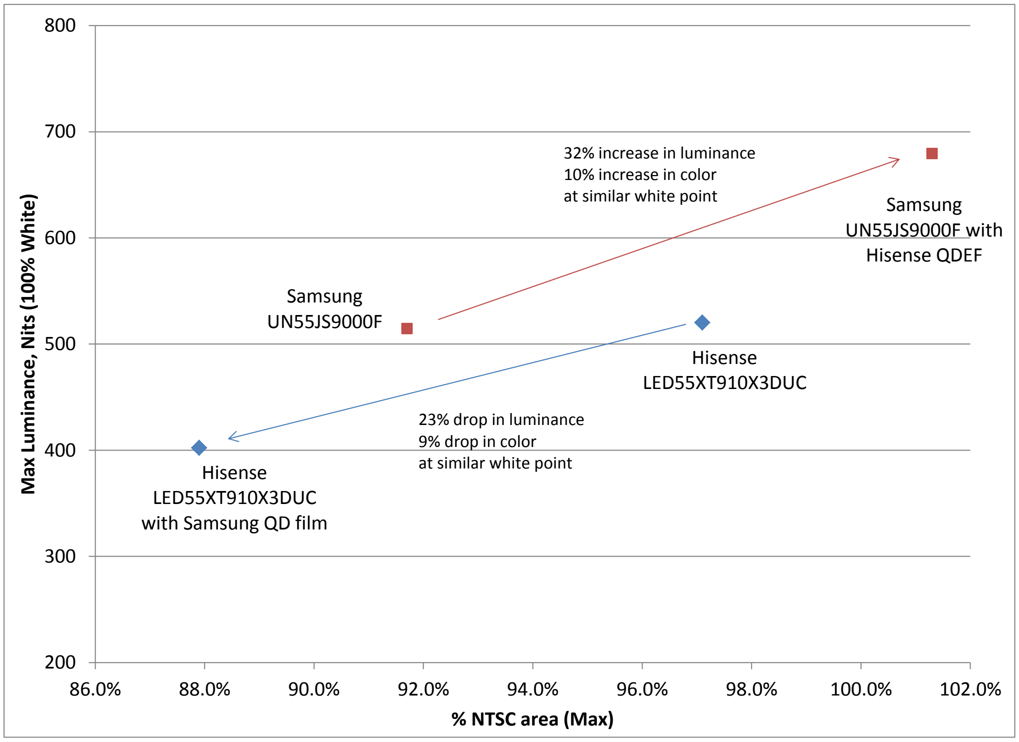


The individual TV settings that show maximum luminance and color gamut is shown in Table 1.

TV	Model #	Edge Lit/ Back Lit	Setting	Luminance (nits)	Power (W)	Luminance Efficiency (nits/watt)	NTSC Area (1931)	White CP
Samsung 55" QD Film	Samsung UN55JS9000F	Edge Lit	Dynamic	515	210.0	2.45	91.7%	(0.274, 0.289)
Hisense 55" QDEF	Hisense LED55XT910X3DUC	Back Lit	Cinema	520	189.9	2.74	97.1%	(0.282, 0.290)
Samsung 55" QD Film	Samsung UN55JS7000FXZA	Back Lit	Dynamic	411	223.6	1.84	91.6%	(0.282,0.299)
TCL 55" QD TV	TCL Q55H9700	Edge Lit	Vivid	462	213.0	2.17	107.6%	(0.272, 0.270)
Philips 55" QD TV	Philips 55PUF6850/T3	Edge Lit	Vivid	408	120.7	3.38	102.8%	(0.282, 0.289)
Thomson 55" QD TV	Thomson 55UA9806	Edge Lit	Dynamic	435	212.1	2.05	107.3%	(0.281, 0.299)
TCL 65" QD TV	TCL Q65H9700	Edge Lit	Vivid	433	168.5	2.57	108.4%	(0.281, 0.279)
Hisense 55" QD TV	Hisense LED55K7100UC	Edge Lit	Cinema	417	137.8	3.03	100.3%	(0.279, 0.287)
TCL 55" QD TV	TCL Q55H8800S	Direct Lit	Vivid	447	170.5	2.62	97.0%	(0.275,0.283)
SONY 55" QD TV	SONY XBR-55X900A	Edge Lit	Vivid	388	231.0	1.68	101.7%	0.271, 0.273

In addition, we compared the performance of Samsung QD film and 3M's QDEF in both Samsung and Hisense TVs, the results are shown in Figure 2. 3M's QDEF film and Samsung QD film was measured in both the systems (Samsung and Hisense). The film stack for Hisense and Samsung was kept identical except for swapping of the QD films. The brightness and color uniformity of TVs were not affected by the swapping of the QD films. This probably suggests that the prismatic structure in the Samsung film performs the role of out-coupling more so than collimation.

Upon swapping the Samsung QD film in a Hisense direct lit TV, we observe a 23% drop in luminance and 9% drop in color gamut. By swapping the 3M's QDEF film in a Samsung sUHD TV, we observe a 32% increase in luminance and 10% increase in color gamut. The big increase noted in Samsung sUHD TV indicates that the InP film in Samsung TV is less efficient than the CdSe based 3M QDEF film.



TV	Model #	Edge Lit/ Back Lit	Setting	Luminance (nits)	Power (W)	Luminance Efficiency (nits/watt)	NTSC Area (1931)	White CP
Hisense 55" QDEF	Hisense LED55XT910X3DUC	Back Lit	Cinema	520	189.9	2.74	97.1%	(0.282, 0.290)
Hisense with Samsung QDEF	Hisense LED55XT910X3DUC with Samsung QD film	Back Lit	Cinema	402	189.7	2.12	87.90%	(0.279, 0.299)
Samsung 55" QDEF	Samsung UN55JS9000F	Edge Lit	Dynamic	515	210.0	2.45	91.7%	(0.274, 0.289)
Samsung with Hisense QDEF	Samsung UN55JS9000F with Hisense QDEF	Edge Lit	Dynamic	680	209.1	3.25	101.30%	(0.277, 0.284)

To confirm this, the External Quantum Efficiency (EQE) of the films were tested in an integrating sphere following the International Electro-technical Commission (IEC) standard I.S.EN 62607-3-1:2014. 2 cm square samples were cut from the film and tested. The table below shows the results, indicating that the Samsung InP film is 23% lower in EQE compared to 3M QDEF (CdSe) film. The magnitude of efficiency drop observed with Samsung InP film matches well with the system level efficiency drop observed in Hisense TV when 3M QDEF film was replaced with Samsung InP film. Additionally, the measured broader FWHM of Samsung InP film is consistent with the measured lower gamut of the Samsung TV relative to Hisense TVs.

#	% EQE	
	Samsung (InP) QD Film	3M (CdSe) QDEF
1	56.9	73.1
2	56.0	73.3

	Samsung (InP) QD Film	3M (CdSe) QDEF
Green Peak Wavelength (nm)	537	532
Green FWHM (nm)	41	33
Red Peak Wavelength (nm)	635	627
Red FWHM (nm)	55	37

NTSC Area Calculation Procedure

The % NTSC Area metric in Table 1 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:

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

$$GTA = \frac{B_x(G_y - R_y) + G_x(R_y - B_y) + R_x(B_y - G_y)}{2}$$

Where B_x and B_y 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.

$GTA_{NTSC\ Standard}$ is calculated using the defined points below to derive an area equal to 0.158

Blue		Green		Red	
B_x	B_y	G_x	G_y	R_x	R_y
0.14	0.08	0.21	0.71	0.67	0.33