



# Lumen Throughput in Front and Rear Projection Systems

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Joe, Inc.



# Why?

Front Projector      1200-2000 lumens

Rear Projection TVs   300- 500 lumens

They use the same basic components - why the vast difference?



# Outline

## Lumen impact on **single panel system** (LCOS, DLP)

1. Color Saturation
  2. White "Segment"
  3. Duty Cycle
  4. Drive Scheme/System Integration Losses
  5. Contrast Requirements
- Summary & Conclusion



# Color Saturation Issues

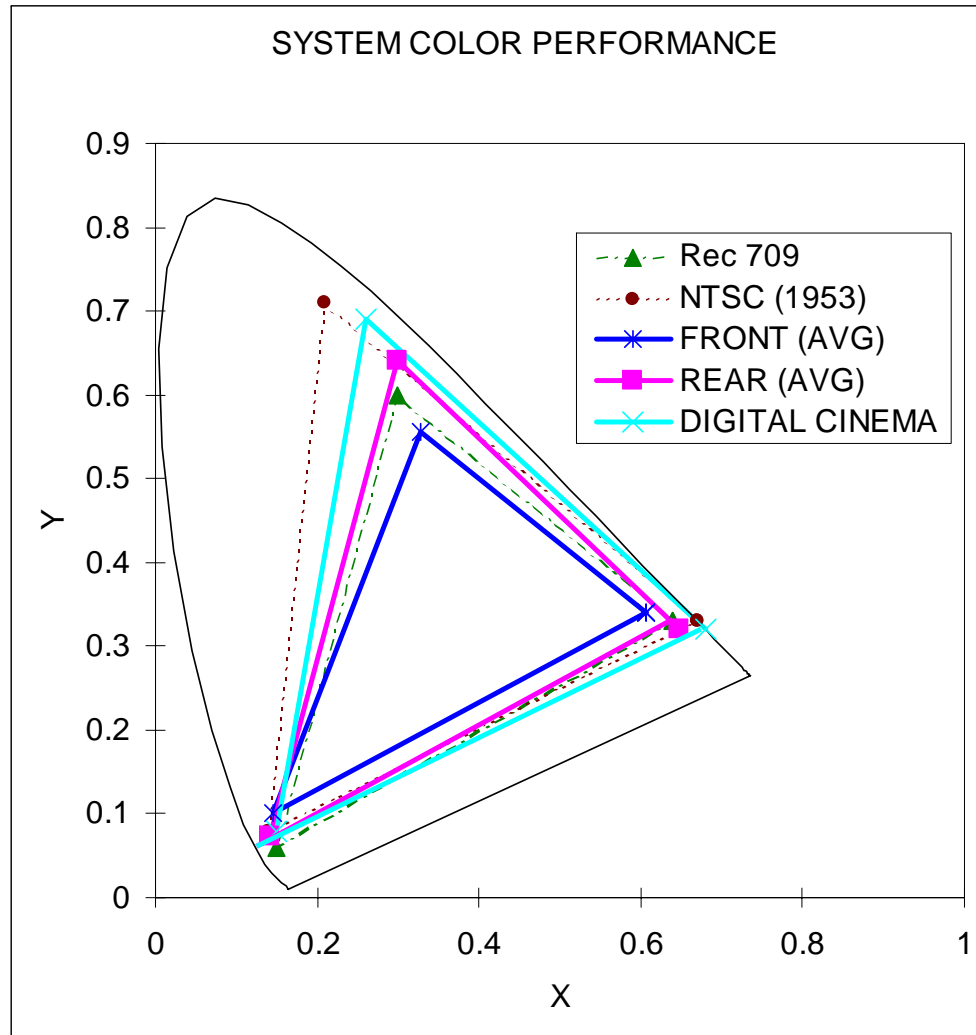


- CIE Color Points
- White Point
- $\bar{Y}$  -> Lumen Throughput

# Color Points of Products

Category	Measured By	System	red x	red y	green x	green y	blue x	blue y
STANDARD		rec 709	0.64	0.33	0.3	0.6	0.15	0.06
STANDARD		NTSC	0.67	0.33	0.21	0.71	0.14	0.08
Digital Cinema	Univ. of Waterloo	DLP cinema	<b>0.68</b>	<b>0.32</b>	<b>0.26</b>	<b>0.69</b>	<b>0.15</b>	<b>0.08</b>
RPTV	Univ of Waterloo	DLP home theater	0.68	0.32	0.31	0.62	0.11	0.08
RPTV	Princeton	LCD triple panel	0.62	0.32	0.29	0.63	0.16	0.04
RPTV	Princeton	DLP	0.65	0.32	0.29	0.62	0.13	0.12
RPTV	Home Theater Magazine	Samsung CRT	0.65	0.3	0.29	0.7	0.15	0.06
RPTV	Home Theater Magazine	Philips LCOS 1p	0.627	0.333	0.297	0.658	0.156	0.036
RPTV	Home Theater Magazine	Sim2 DLP	0.658	0.326	0.322	0.619	0.146	0.101
RPTV	AVERAGE	AVERAGE	<b>0.648</b>	<b>0.32</b>	<b>0.3</b>	<b>0.641</b>	<b>0.142</b>	<b>0.073</b>
FRONT	Univ of North Carolina	NEC	0.65	0.31	0.35	0.57	0.15	0.09
FRONT	Univ of North Carolina	nView	0.54	0.34	0.28	0.58	0.16	0.07
FRONT	Stanford Univ	DLP	0.63	0.369	0.35	0.518	0.128	0.14
FRONT	AVERAGE	AVERAGE	<b>0.607</b>	<b>0.34</b>	<b>0.327</b>	<b>0.556</b>	<b>0.146</b>	<b>0.1</b>

# Color Gamut Plot



# CIE Color points to Flux

$$X_{red} = \frac{\sum_{\lambda=400}^{700} Eng_{\lambda} * red_{\lambda} * \bar{x}_{\lambda}}{\left( \sum_{\lambda=400}^{700} Eng_{\lambda} * red_{\lambda} * \bar{x}_{\lambda} + \sum_{\lambda=400}^{700} Eng_{\lambda} * red_{\lambda} * \bar{y}_{\lambda} + \sum_{\lambda=400}^{700} Eng_{\lambda} * red_{\lambda} * \bar{z}_{\lambda} \right)}$$

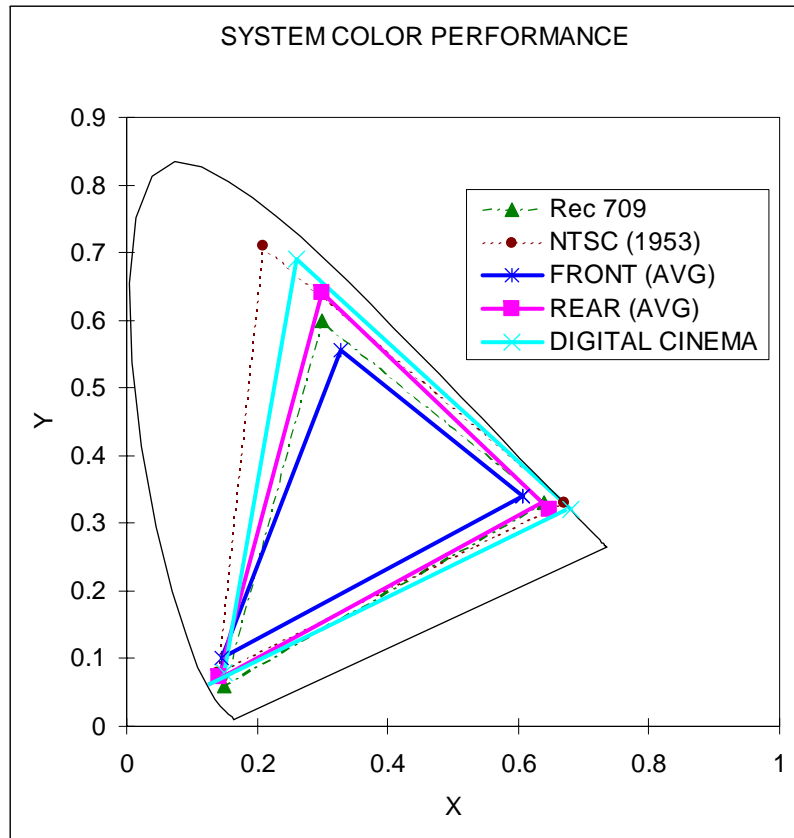
$$y_{red} = \frac{\sum_{\lambda=400}^{700} Eng_{\lambda} * red_{\lambda} * \bar{y}_{\lambda}}{\left( \sum_{\lambda=400}^{700} Eng_{\lambda} * red_{\lambda} * \bar{x}_{\lambda} + \sum_{\lambda=400}^{700} Eng_{\lambda} * red_{\lambda} * \bar{y}_{\lambda} + \sum_{\lambda=400}^{700} Eng_{\lambda} * red_{\lambda} * \bar{z}_{\lambda} \right)}$$

$$X_{red} = \frac{\sum_{\lambda=lowred}^{highred} Eng_{\lambda} * \bar{x}}{\left( \sum_{\lambda=lowred}^{highred} Eng_{\lambda} * \bar{x} + \sum_{\lambda=lowred}^{highred} Eng_{\lambda} * \bar{y} + \sum_{\lambda=lowred}^{highred} Eng_{\lambda} * \bar{z} \right)}$$

$$y_{red} = \frac{\sum_{\lambda=lowred}^{highred} Eng_{\lambda} * \bar{y}}{\left( \sum_{\lambda=lowred}^{highred} Eng_{\lambda} * \bar{x} + \sum_{\lambda=lowred}^{highred} Eng_{\lambda} * \bar{y} + \sum_{\lambda=lowred}^{highred} Eng_{\lambda} * \bar{z} \right)}$$

- Assume red dichroic with T = 100% or 0%
- Then solve for spectral transmission band of engine (use Lamp (UHP) spectrum to start)
- Next multiply by Ybar function to compute relative flux
- quick approximation (I wrote mine in excel)

# Flux as a function of color gamut



**Average Relative Throughput  
From Color Points Alone:**

79% Digital Cinema

100% Rear Projection (Home)

126% Front Projection (Bus.)

143% Worst case Front Proj.

**Joe, Inc.**

Jepsen Optical Engineering

<http://www.joeinc.tv>



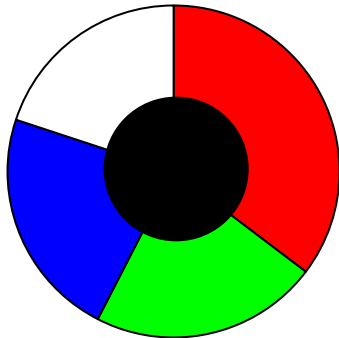
# Brightness increase

of front projection over rear projection



1. Color Desaturation                      IMPACT 126-143%
2. White "Segment"
3. Duty Cycle
4. Contrast (F/#, etc)
5. Contrast Requirements

# White “Segment”



Colorwheel  
With white  
segment

- 32% colorwheel throughput (R,G,B)
- 45-49% throughput (R,G,B,White)
  - White uses the full spectrum ybar
  - 140-153% of r,g,b colorwheel throughput
- White segment only useful in front projection
  - Luminance/Chrominance balance not OK for tv, movies
  - It *is* ok for data, spreadsheets, powerpoint



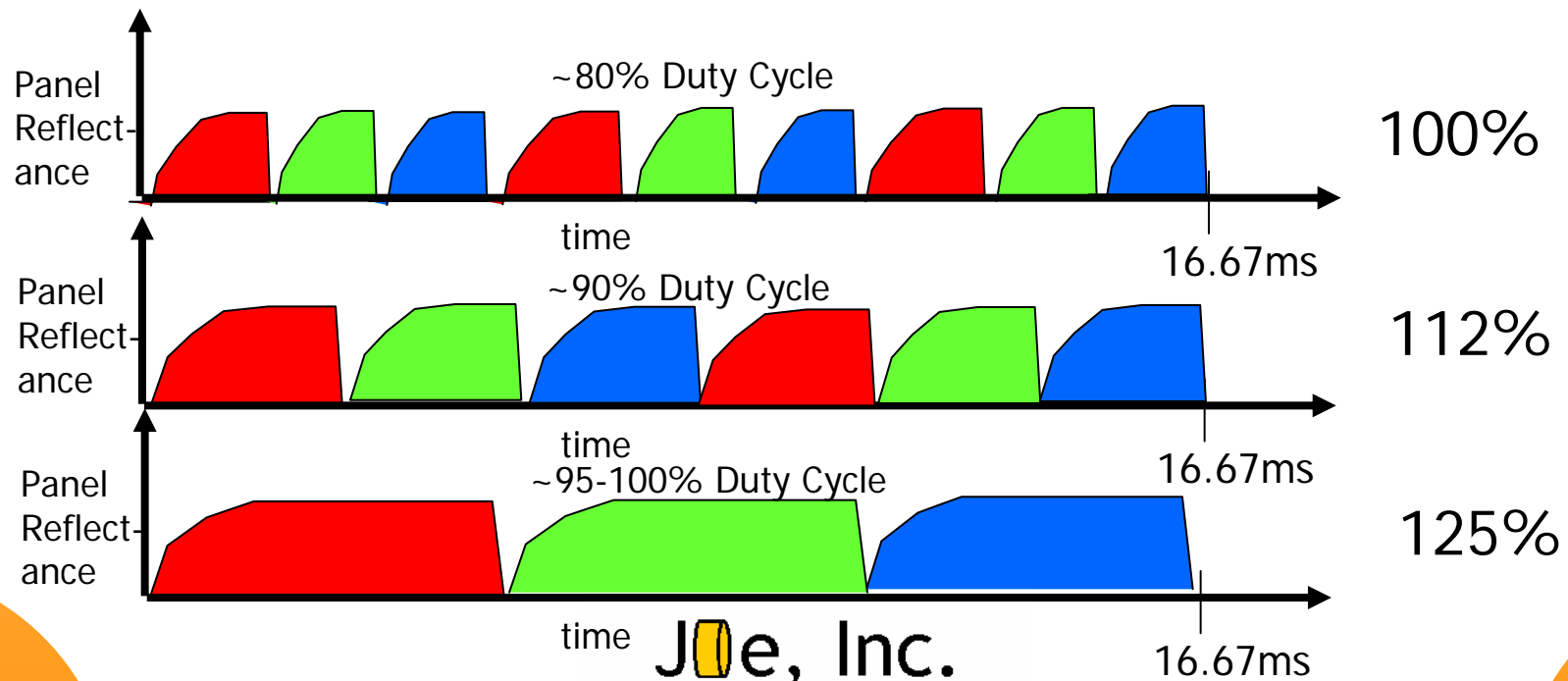
# Brightness increase

of front projection over rear projection

Color Desaturation	IMPACT 126-143%
White "Segment"	IMPACT 140-153%
Duty Cycle	
Drive Scheme/System Losses	
Contrast (F/#, etc)	
<b>SUBTOTAL</b>	<b>TOTAL IMPACT 176-219%</b>

# Duty Cycle

- Frame Rate is faster for Rear Projection
  - (180 RGB color-fields/sec)
- Front Projection Data
  - (60-120 RGB/RGBWhite color-fields/sec)





# Brightness increase

of front projection over rear projection

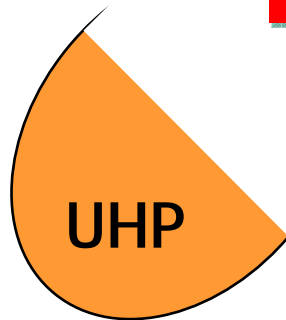
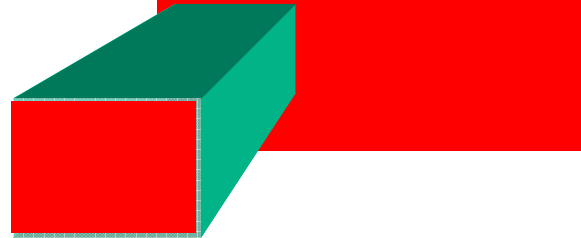
Color Desaturation	IMPACT	126-143%
White "Segment"	IMPACT	140-153%
Duty Cycle	IMPACT	112-125%
Drive Scheme/System Losses Contrast (F/#, etc)		
<b>SUBTOTAL</b>	<b>TOTAL IMPACT</b>	<b>197-273%</b>

# Drive Scheme Artifacts

- Colorwheel transition impacts FLC LCOS, DLP (for non-scrolling colorwheel field sequential systems) ~20%
  - IMPACT 20%
- nematic liquid crystal LCOS drive scheme performance (timing, ito balance, etc)
  - IMPACT 20%

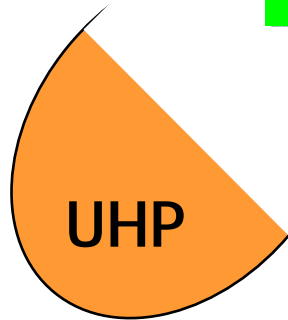
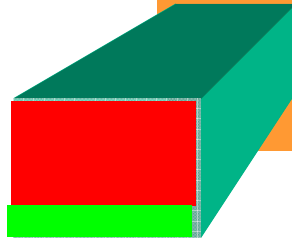
# FSC Mode Colorwheel

Light on panel



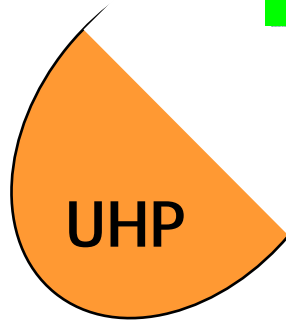
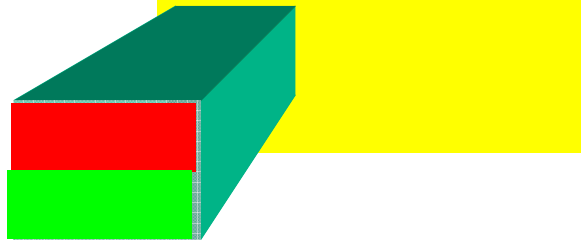
# FSC Mode Colorwheel

Light on panel



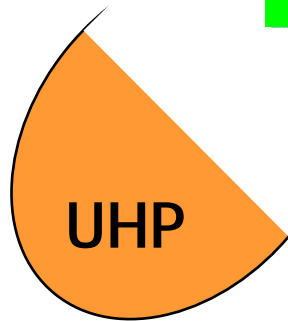
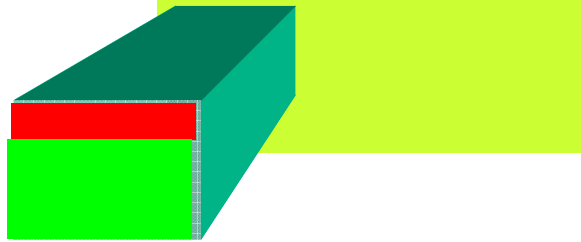
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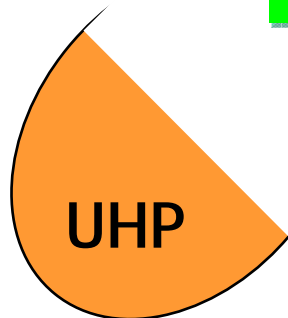
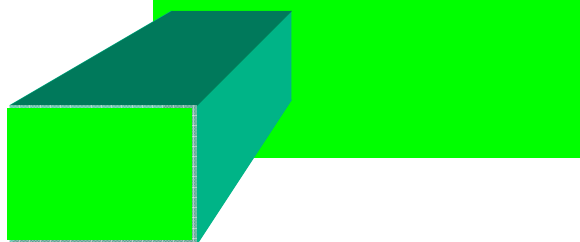
# FSC Mode Colorwheel

Light on panel



# FSC Mode Colorwheel

Light on panel





# Brightness increase

of front projection over rear projection



Color Desaturation	IMPACT	126-143%
White "Segment"	IMPACT	140-153%
Duty Cycle	IMPACT	112-125%
Drive Scheme/System Losses	IMPACT	112-125%
Contrast (F/#, etc)		
<b>SUBTOTAL</b>	<b>TOTAL IMPACT</b>	<b>221-341%</b>



# Contrast Requirement



- Front projectors for business – contrast not an issue
  - HighT Polarizers can be used (0-110%)
  - Cone angle can be increased (120%-150%)
  - Net Impact: 120%-165%



# Brightness increase

of front projection over rear projection

Color Desaturation	IMPACT	126-143%
White "Segment"	IMPACT	140-153%
Duty Cycle	IMPACT	112-125%
Drive Scheme/System Losses	IMPACT	110-120%
Contrast (F/#, etc)	IMPACT	120-165%
<b>SUBTOTAL</b>	<b>TOTAL IMPACT</b>	<b>266-564%</b>

# Conclusion

- Front Projectors 2.5X - 5.5X brighter than RP
  - With "same" components
  - Rooms lights OK with RPTV
- More Photons hit viewers eyes in RPTV

