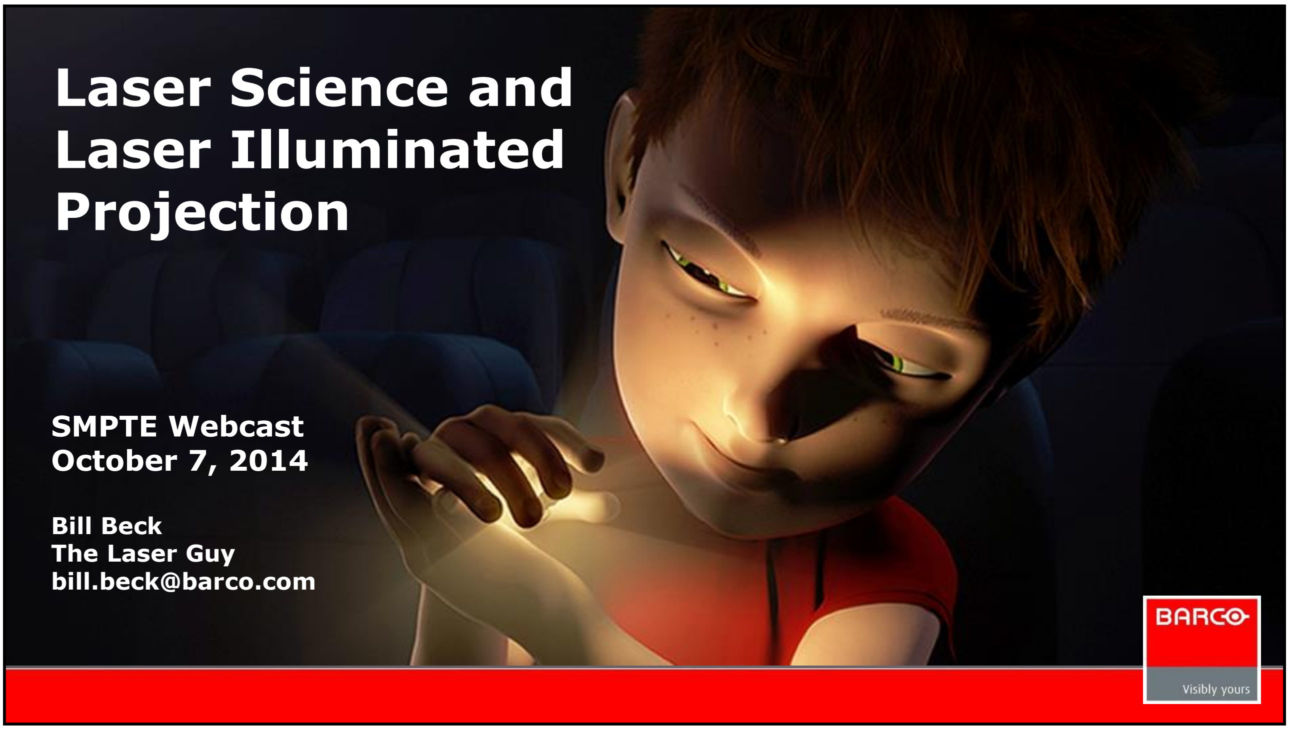

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Your Host

Joel E. Welch

Director of Education

SMPTE

Today's Guest Speaker

Bill Beck

The Laser Guy

Barco

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Goals of the Webcast

- Provide foundational concepts and terms by which to describe, understand and evaluate laser illuminated projectors (LIPs)
- Introduce and explain laser technology basics, laser engine architectures and LIP performance
- Introduce and define key figures of merit (FOM)
- Review current Image Quality and Operational FOMs
- Summarize current state of the art for RGB and BPP LIPs

Laser Webcast Outline

1. Introduction and Status
2. Laser Science
3. Laser Engine Architectures
4. Projector – Image Quality (IQ) Figures of Merit (FoM)
5. Projector – FoMs and 6P
6. Summary
7. Q&A
8. Glossary of Terms, Acronyms and Definitions

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1. Introduction and Status

Introduction and Status

- ***Commercial* Laser Illuminated Projectors are here!**

- High Brightness RGB LIPs deliver >60,000 DCI lumens
  - – Premium Laser Format (PLF) theaters
  - – Larger screen 3D conventional theater
- Blue Pumped Phosphor LIPs do ~6,000 DCI lumens
  - – Small theaters, typically with gain screens

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Who is Selling Laser Illuminated Projectors?

BARCO – Integrated Single Projector

CHRISTIE, IMAX – Dual Projector

NEC, Cinemeccanica Milano, SINOLASER – Fiber Coupled Projector Head

BPP (Laser Phosphor)

- NEC
- SONY
- DELTA
- DIGITAL PROJECTION – Precision Displays for Every Venue
- CASIO
- BenQ
- Optoma
- ASUS
- APPOTRONICS

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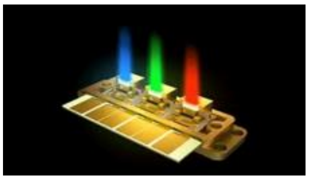
2. Laser Science

What are Lasers?

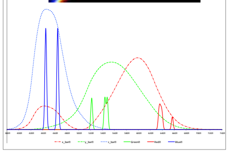
Solid state components that

CONVERT ELECTRICITY INTO LIGHT



With very special Properties…

How do Lasers differ from Xenon lamps?



- **High Spatial Brightness** – power emanates from a very small spot as a collimated beam and diverges (spreads slowly) i.e., low *étendue*

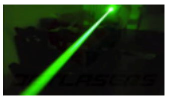
- Lasers produce **narrow wavelengths** or bands of color - 0.1 to 2 nm and are coherent, which causes interference and speckle

- Lasers have **very long lifetimes** - 10,000 to 100,000 hours - with little decline in brightness per hour of use

10-30+%

- Lasers have **high conversion efficiency** - overall Electrical to Optical (E to O); no excess or unwanted wavelengths to block

How is a Laser Light Source different from a Xenon Lamp?



Attribute	units	Laser	Xenon Lamp
E to O Conversion		Stimulated emission High spatial brightness	Gas discharge; short arc creates bright "spot"
Output pattern		Coherent; collimated to moderately divergent	Isotropic = all directions Must be focused to spot
Spectral bandwidth	nm	"Narrow" - 0.01-2	"Wide" - 60 - 80/per RGB Primary
étendue	mm^2-sr	Very small - 0.001-1	High relative to laser 4-20
Lifetime	Hours to end of life	5,000 -100,000 to 80% 30,000 Commercialized	200 - 2000 to 50% power 500 - 1000 (typical)
System Efficiency	lumens / wall plug watt	5 - 8	2-6

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Why use lasers?

- **BRIGHTER IMAGE** – low *étendue* output of lasers enables digital projector brightness levels 2-3 times that of Xenon lamps
- **BETTER IMAGE** – significant, demonstrated increases in uniformity, contrast ratio and color gamut and saturation
- **LONGER LIFETIME** – solid-state lasers hold the promise of NO LAMP CHANGES over 5-10 year life of projector
- **HIGHER EFFICIENCY** – lasers can reduce direct and indirect power consumption by 30-50%

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Laser Device - Figures of Merit (FOMs)

Attribute	Figure of Merit	Unit of Measure	Range or Maximum
Color	Wavelength	Nanometers (nm)	400 to 700
Bandwidth	Full Width/Half Max	FWHM	0.1 to 3
Spectral Power Distribution	Spectral Curve	N/A	up to 30 nm
Output Power	Watts (CW equivalent)	Optical watts (W)	0.5 to 100+
Luminous Efficacy	Lumens per optical watt	lm/W	20 to 683 max
Electrical to Optical Efficiency	$watts_{optical}$ / $watts_{electrical}$	%	3 to 30
Lifetime	Hours until 20% down	hr	10,000 to 40,000
Roll-off rate	Power redux / khour	%	0.67 to 2.5
Beam Quality	Divergence; roundness	Mrad; °; %	~0° to 35°

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Laser types

- Diodes (LD) – single emitter (SE)
  - *Edge emitters*
  - *Surface emitters (SEL; VCSEL;)*
- Diodes – multiple emitter (ME)
  - *Bars or lines of edge emitters (Pumps; Stacks)*
  - *Arrays of surface emitting lasers*
  - *Aggregations of SE or ME into a beam or fiber*
- "Doubled" Diode modules (SHG = Second Harmonic Generation)
  - *Diodes with SHG crystals/devices double frequency CHANGES the* ***COLOR***

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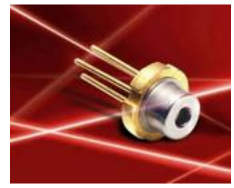
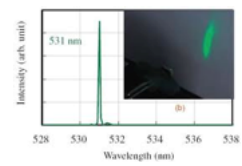
Lasers used for Projection

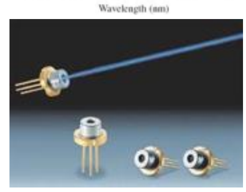
- Diodes (LD) – single emitter (SE)
  - *Edge emitters*
  - *Surface emitters (SEL; VCSEL)*



- RED 635 – 660 nm
  - *mW – 2W Continuous Wave = CW*
  - *10-25% Wall Plug Efficiency = WPE*
  - *Moderate cost/W*



- GREEN 510 - 530 nm (in development)
  - *mW to 1 W CW*
  - *Low % WPE*
  - *High cost/W*



- BLUE 440 - 470 nm
  - *1-3 W CW*
  - *10-30% WPE*
  - *Low cost/W*

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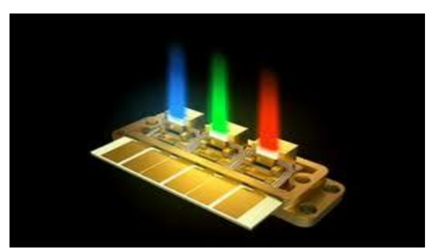
Lasers used for Projection

- "Doubled Diode" modules (SHG)
  - *Infrared diode, array or bar*
  - *Second Harmonic Generation*
  - *1064nm => 532nm*
  - *930nm => 465nm*
  - *mW – 3W (CW)*
  - *5 - 8% WPE*



- Diode pumped SS and FL - IR + SHG modules
  - *Infrared 808nm array or bar pumps laser crystal => 1064nm*
  - *Crystal doubles frequency (SHG) 1064nm => 532nm*
  - *mW – 100W (CW)*
  - *8 – 17% WPE*

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RGB Laser Wavelength Options

Color	Wavelength (nm – FWHM)	Device Type	Watts per Device	Lumens Per watt	Lumens per Device	E to O % Efficiency
RED	657 - 1	Diode	0.5 - 2	50	50 - 100	10 - 20 (est.)
RED	638 - 1	Diode; Bar	0.5 - 16	131	131 - 2096	10 - 30
RED	615 - 8	DPSS + OPO	10	301	3010	5
GREEN	550 - 0.1	VCSEL SHG	2	679	1358	3 - 4
GREEN	546 - 12	DPSS wide spectrum	20 - 50	671	>30,000	8 - 10
GREEN	532 - 0.1	DPSS, VCSEL, FL + SHG	2 - 100	603	>60,000	5 - 17
GREEN	525 - 2	Diode	1	542	542	8 - 12
BLUE	465 - 2	Diode	1.2	50	60	18 - 22
BLUE	445 - 2	Diode	3.5	20	60	20 - 24

DPSS=Diode Pumped Solid State OPO=Optical Parametric Oscillator VCSEL=Vertical Cavity Surface Emitting Laser
SHG=Second Harmonic Generation FL=Fiber Laser

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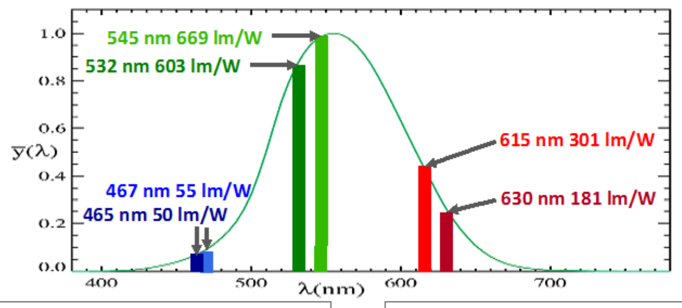
Why RGB Wavelengths Matter…

Lumens per Laser Watt – P3 vs. Rec. 2020



P3			
nm	lm/W	lm/Color	Req'd W
615	301	13,267	44
545	669	43,981	66
465	50	2,739	54
RGB	366	60,000	164

Rec. 2020			
nm	lm/W	lm/Color	Req'd W
630	181	14,752	82
532	603	42,108	70
467	55	3,128	57
RGB	288	60,000	208

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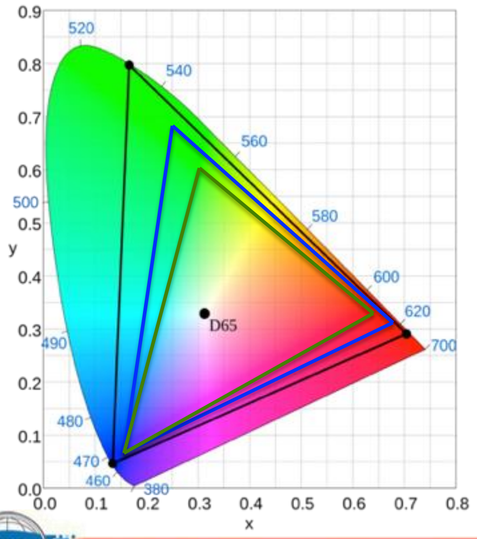
Primary Selection vs. Gamut



Rec 709 (green line)
DCI P3 (blue line)
Rec 2020 (gray line)

- Narrowband primaries "on locus"
- Wider gamut and more saturated
- But higher speckle and OMF
- Longer Reds and shorter Blues are commercially available
- Shorter Green adds Magenta but cuts Yellow saturation
- Wider gamut primaries reduce luminous efficacy (lm/watt)

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Primary Selection vs. Luminous Efficacy

- Luminous Efficacy = White balanced lumens / RGB watt
- Ideal is to use "native" laser primaries:
  - *Rec 709 : 613/550/463 nm = 362 lm/W*
  - *DCI P3 : 615/545/465 nm = **366 lm/W***
  - *Rec 2020 : 630/532/467 nm = 288 lm/W*
- Readily available lasers: 640/532/445 nm
  - *Rec 709 : Raw 249 lm/W Correction reduces lm/W*
  - *DCI P3 : Raw 261 lm/W Correction reduces lm/W*
  - *Rec 2020 : Raw 261 lm/W Very slight reduction in lm/W*

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3. Laser Engine Architectures

Laser Projector Architectures

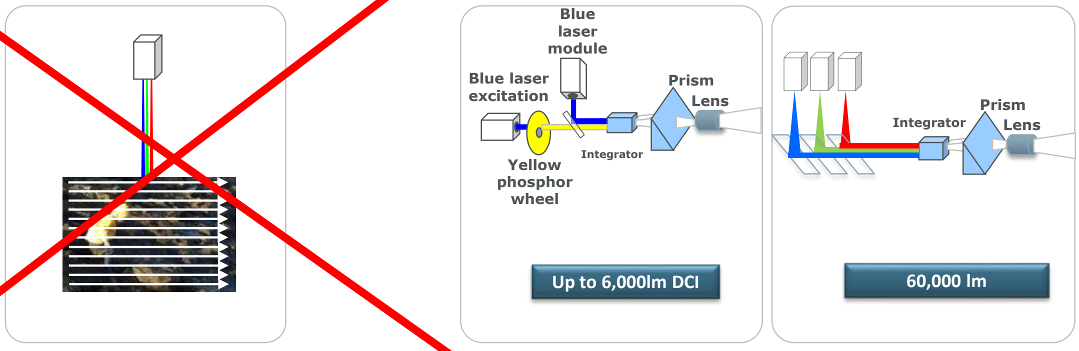
Direct Scanned laser Projection

Laser Illuminated Projection

Laser beam

Blue laser Pumped Phosphor

RGB Laser



Direct laser light projected on the screen
Eye-Safety hazards
Image quality challenges
Not used in front projection applications

Direct laser light + laser pumped phosphor
Diffuse laser light
Limited brightness

Direct RGB laser light for High Brightness

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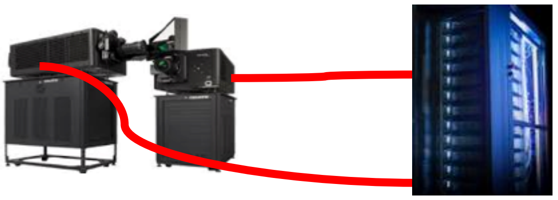
Lasers in the BOX or out of the BOX?

Integrated

- Simple
- Safe
- Efficiency - ~ 10-15% higher

Fiber Coupled

- Complex
- Remote source
- Modular



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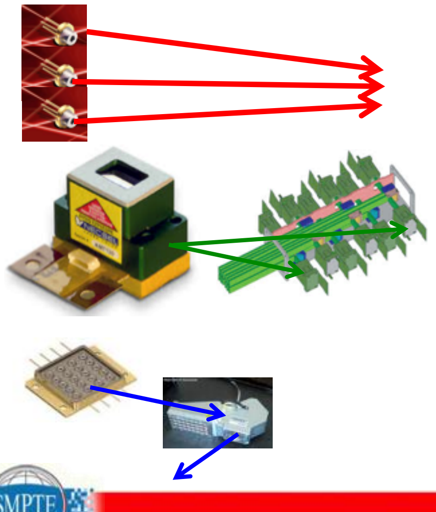
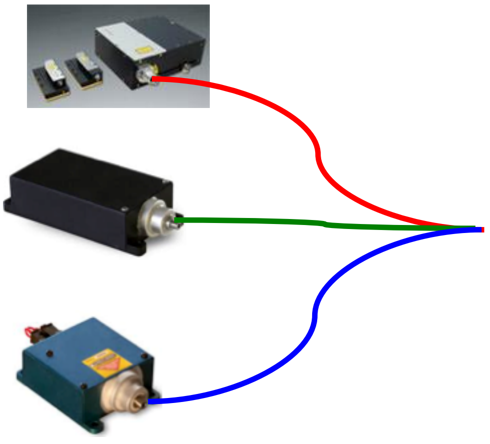
RGB Architectures

Free Space Aggregation



Fiber Coupled



RGB Power Quantification

- Assume Native DCI P3 Primaries 615/545/465
- Generates 366 white balanced lumens per RGB laser watt

60,000 lumens out = ~ 165 RGB laser watts to the screen

- Assume readily available lasers 640/532/445
- Generates only 261 white balanced lumens per RGB laser watt

60,000 lumens out = ~ 230 RGB laser watts out – after color correction

Now assume ~33% projector throughput (after laser input)

~700 RGB watt input required or around 200+ devices

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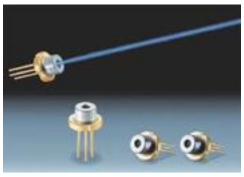
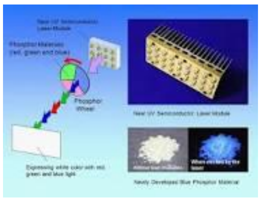
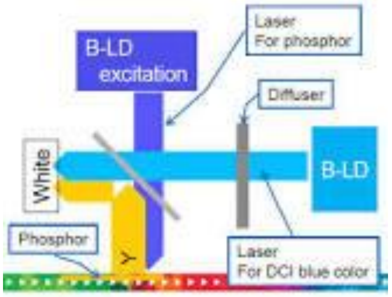
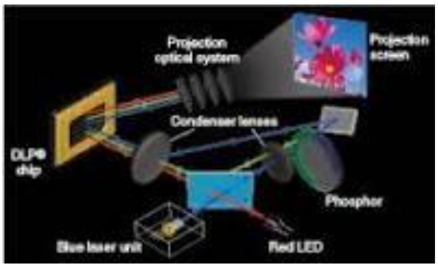
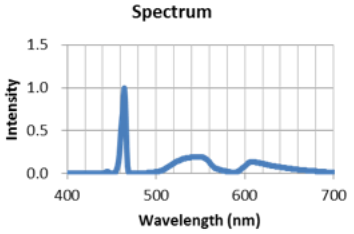
BPP Architectures









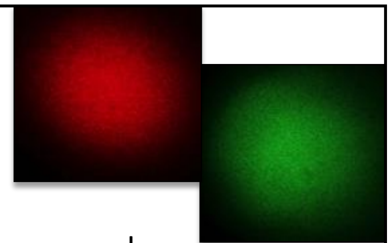


4. Image Quality FOMs

Image Quality - Figures of Merit (FOMs)

Attribute	Figure of Merit	Unit of Measure	Range or Maximum
Brightness	White Balanced Lumens	lm	6,000 – 60,000
Sequential Contrast	Peak White : Full Black	Ratio	2000 - 3000:1
Speckle Contrast Ratio	SCR = S.D./mean	%	~2 - 20
Luminance Uniformity	Min / Max (Center)	%	90 - 95
Color Uniformity	Delta x,y	0.00x	Meets DCI
Spatial Resolution	1000 pixels wide	K	1 - 4
Color Space (Gamut)	Primary points	x,y	P3; Rec. 2020
3D systems			Supports all types
Stereo Contrast Ratio (6P)	Correct eye/incorrect	Ratio	700-1000:1

What is speckle?



You know it when you see it…

- Speckle is an interference pattern image artifact that occurs when highly coherent, narrow band light is used
- Figure of merit is "Speckle Contrast Ratio" (SCR%)

  SCR% = Standard deviation of measured pixel intensity ÷ mean pixel intensity
- Though objectively measureable, level of offensiveness is subjective
- Content, observer, visual acuity, position, screen type all impact speckle

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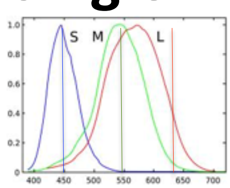
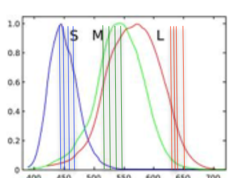
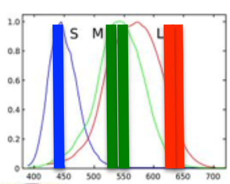
Single line vs. Multi/Wide-band Primaries



Narrow band RGB laser "lines" FWHM ≤ 1 nm
- Simple modeling and supply chain … but
- Massive Speckle
- Potential for "Observer Metameric Failure" (OMF)



Multiple RGB lines per primary - n x FWHM ≤ 1 nm
- Wavelength options depend on physics and availability
- Little impact on speckle if narrowband
- Unknown impact on OMF



Spectrally broadened RGB bands FWHM 10 - 40 nm
- Replicates incoherent white light
- Low speckle and OMF
- Hard to achieve with available lasers

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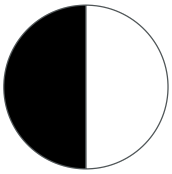
Primary selection vs. Speckle Contrast Ratio (SCR)

- Benchmark is Xenon illumination – Incoherent and Lambertian
  - *RGB pass bands for DCinema installed base ~60 nm wide*
  - *System f# ~2.4 (fast) to maximize angle and usable lamp output*
  - *SCR for Xenon ~ 1% - hard to measure*
- Single wavelength, narrow line (~0.1 nm) RGB primaries SCR ~20%
  - *UNWATCHABLE in Green and Red; speckle noticeable even in Blue*
- Multiple emitters of the same wavelength – some reduction in SCR%
- Multiple wavelengths of different wavelengths further reduces speckle
- 6 primary 3D engines help reduce speckle further

Contrast Ratio / High Dynamic Range (HDR)

- Current DCI spec: 2000:1
- LIPs at 2300 - 3000:1
- All movies are mastered for this spec contrast level!
  - *Post production reference projectors about 2000-2300:1*
  - *If cinema contrast is much higher -> artifact visibility*
- Laser + redesigned projector optics can achieve 10,000:1
- Will require additional HDR DCP (Digital Cinema Package)
- Higher contrast typically results in
  - *Lower optical efficiency*
  - *More speckle*



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5. Projector FOMs

How lasers reduce Operating Costs

- Longer lifetime at full power - > 30,000 hours vs. 500 hours
  - *– Eliminates 60 or more lamp changes vs. 6 kW Lamp Projector*
- Higher projector OPTICAL throughput
- Higher wall plug efficiency - 5 - 6 lm/WPW vs. 2 - 5 for Xenon
  - *– Lower Power Consumption*

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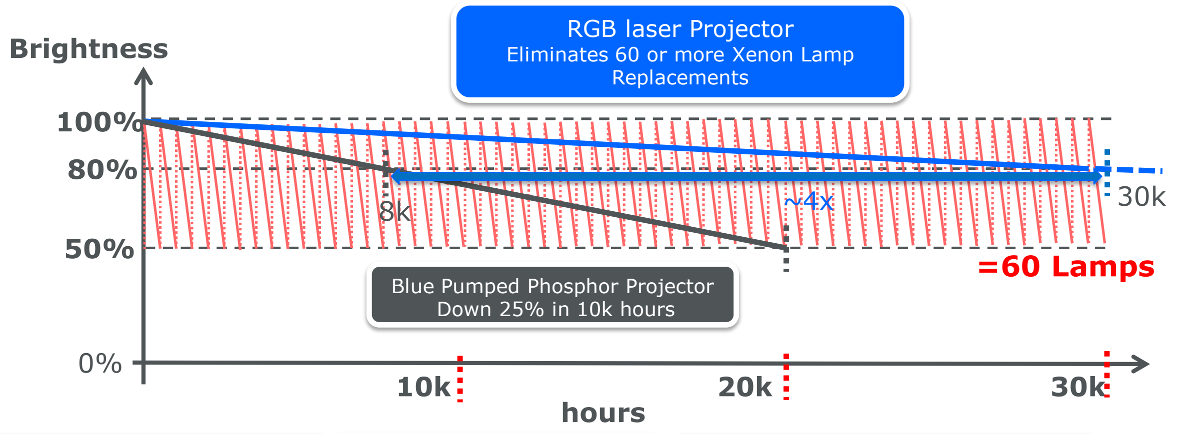
Light Source Lifetime Comparisons



6.5 kW Xenon lamps (500 hrs@50% of initial brightness)

Blue Phosphor Projector (20k hours at 50% of initial brightness)

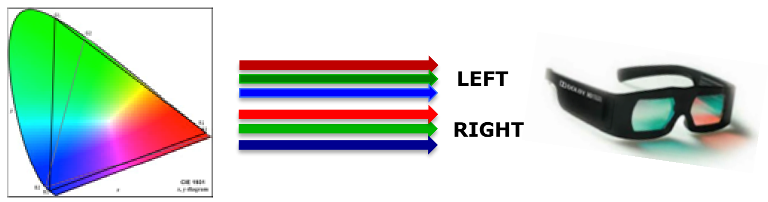
RGB Laser Projector (30k hours@80% initial Brightness)

Xenon vs. Laser Efficiency Comparison

	Initial Brightness	Average Brightness	System Power Consumption	Efficiency (lm/W)	Consumption (W/klm)
Barco Xenon DP4K-32B	33,000 lm	@75% = 24,750 lm	7.5 kW	3.3 lm/W	303 W/klm
Barco Laser DP4K-60L	60,000 lm	@90% = 54,000 lm	10 kW	5.4 lm/W	185 W/klm
			Laser DP4K-60L has:	**64% better efficiency**	**39% lower power consumption**

What is 6 Primary or “6P” 3D?

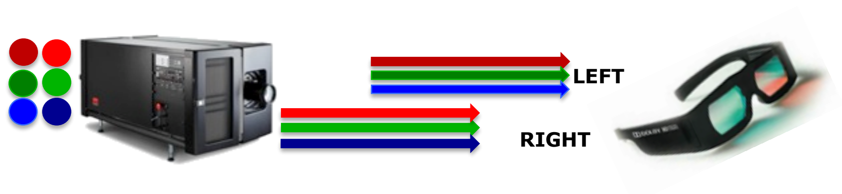
Concept of a 6P laser 3D system:

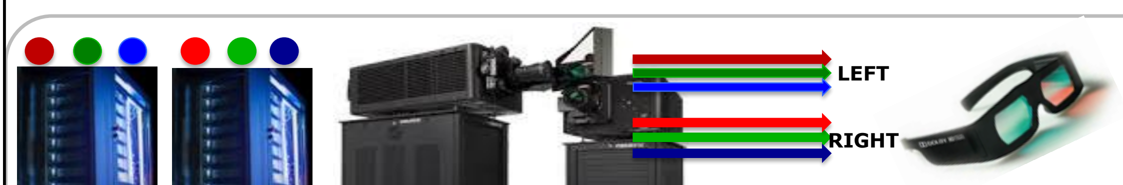


- With lasers, it’s possible to use 6 RGB Primaries for Color3D separation (=**6P**)
- Single and dual projection architectures possible (active and passive)
- In both cases, the image quality and brightness are much better than with Lamp Based Dolby or Infitec Wheels and Polarization systems.

Laser 6 Primary Architectures

Single 6P solution





Dual, 3P + 3P solution

6. Summary and Conclusions

Summary and Conclusions

- Laser Illuminate Projectors are here NOW
- Lasers *DO* provide consistent, higher brightness, contrast, uniformity

- Lasers *DO* provide substantial operating cost saving
- Laser Illuminated Cinema performance already exceeds Xenon illuminated digital projectors

Questions & Answers

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THANK YOU!
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