Sorry to miss the program!

PRI is moving to a new manufacturing facility.

Two new products needed some CTO attention, prior to shipping, hence, the CTO is marooned in California.

Measurement Challenges with Modern Display technologies

Tom Lianza
CTO
Photo Research Inc.

Topics to be discussed

- Calibration of modern spectral devices
- Factors that affect accurate color measurement
- Short history of display advances and Advances in measurement technologies
- Advanced measurement systems for the laboratory
- Advanced measurement systems for the factory floor.

Factors that affect spectral color measurement accuracy

- Basic Spectral Calibration
- Spectral Bandwidth
- Linearity
- Dynamic Range
- Polarization Sensitivity
- Temporal variation in source

Calibration Source Characterization

- Illuminant “A” standard
  - Common Reference Source
  - Physics of the source is well known
  - Lamp Current Stabilization=very stable output
- Helium and Helium-Argon lamps for spectral wavelength calibration
  - Very well defined by standards
  - Exceptionally narrow bandwidth with well defined spectral definition.

Calibration Source Characterization

Illuminant A is the basic standard used by all manufacturers :

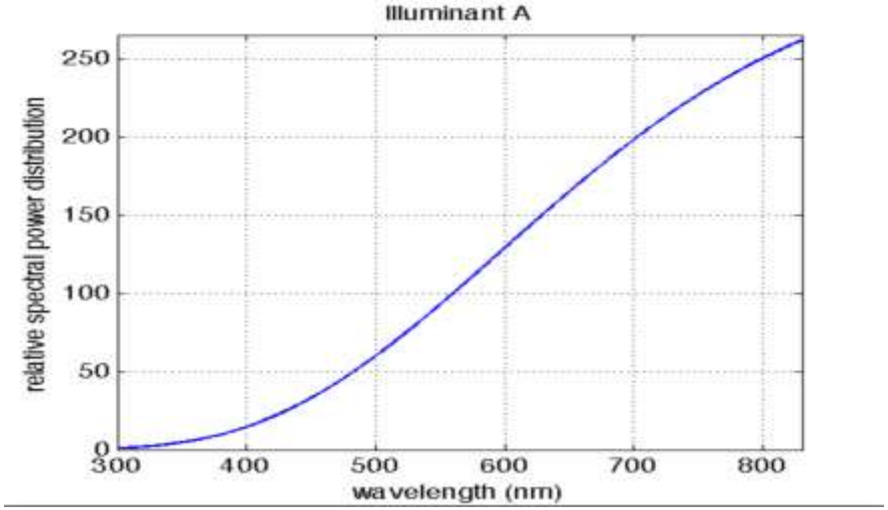
Pros:

- Physics of source well understood
- Source is very stable when properly powered.
- Inter-laboratory comparisons show a high degree of correlation
- Spectra is continuous with no inflection points

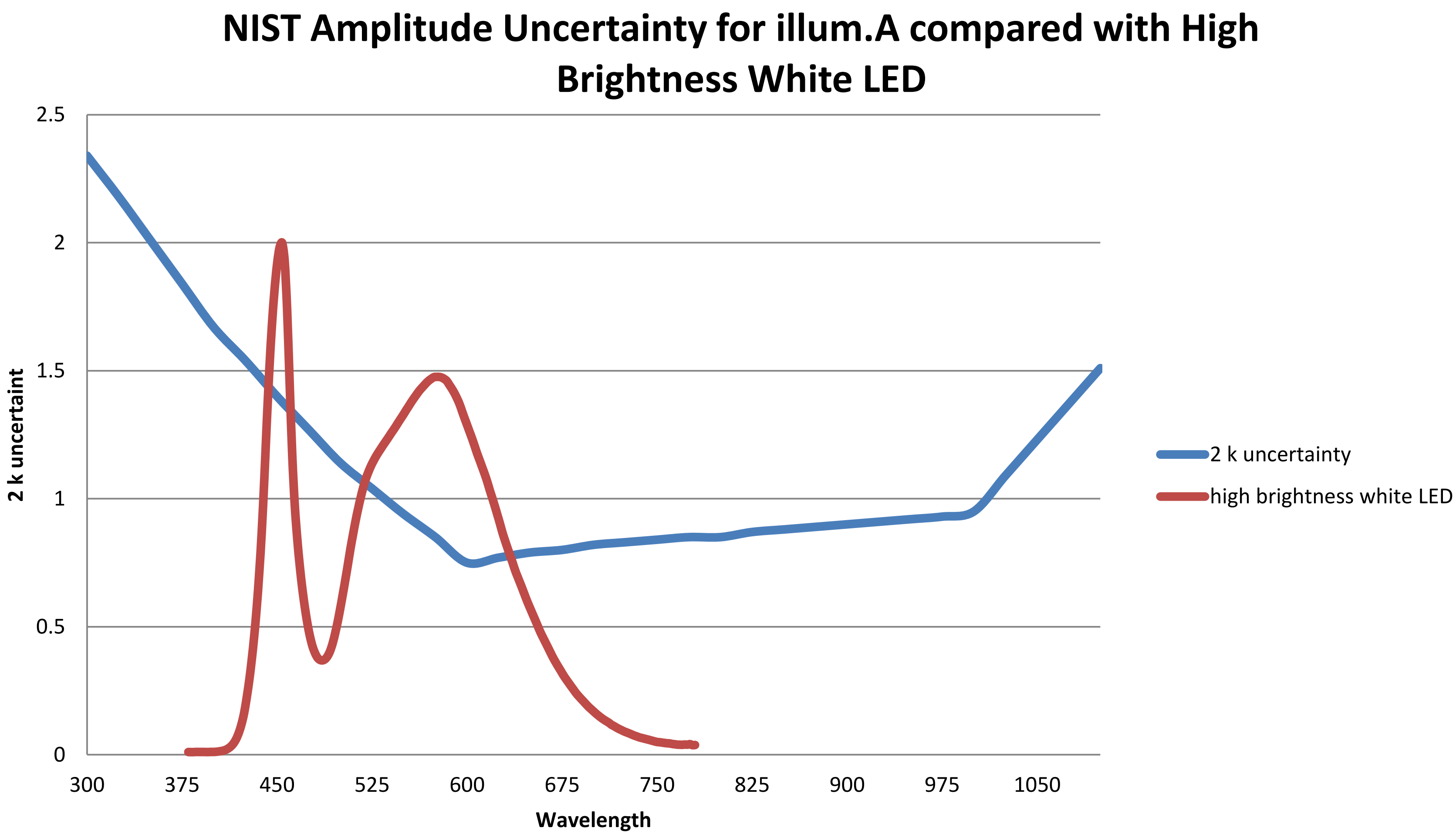
Cons:

- Source has very low blue content
- Source is not representative any modern display
- Very low color temperature relative to contemporary lighting/viewing standards.

- Standard Illuminant A Source.



Illuminant A uncertainty



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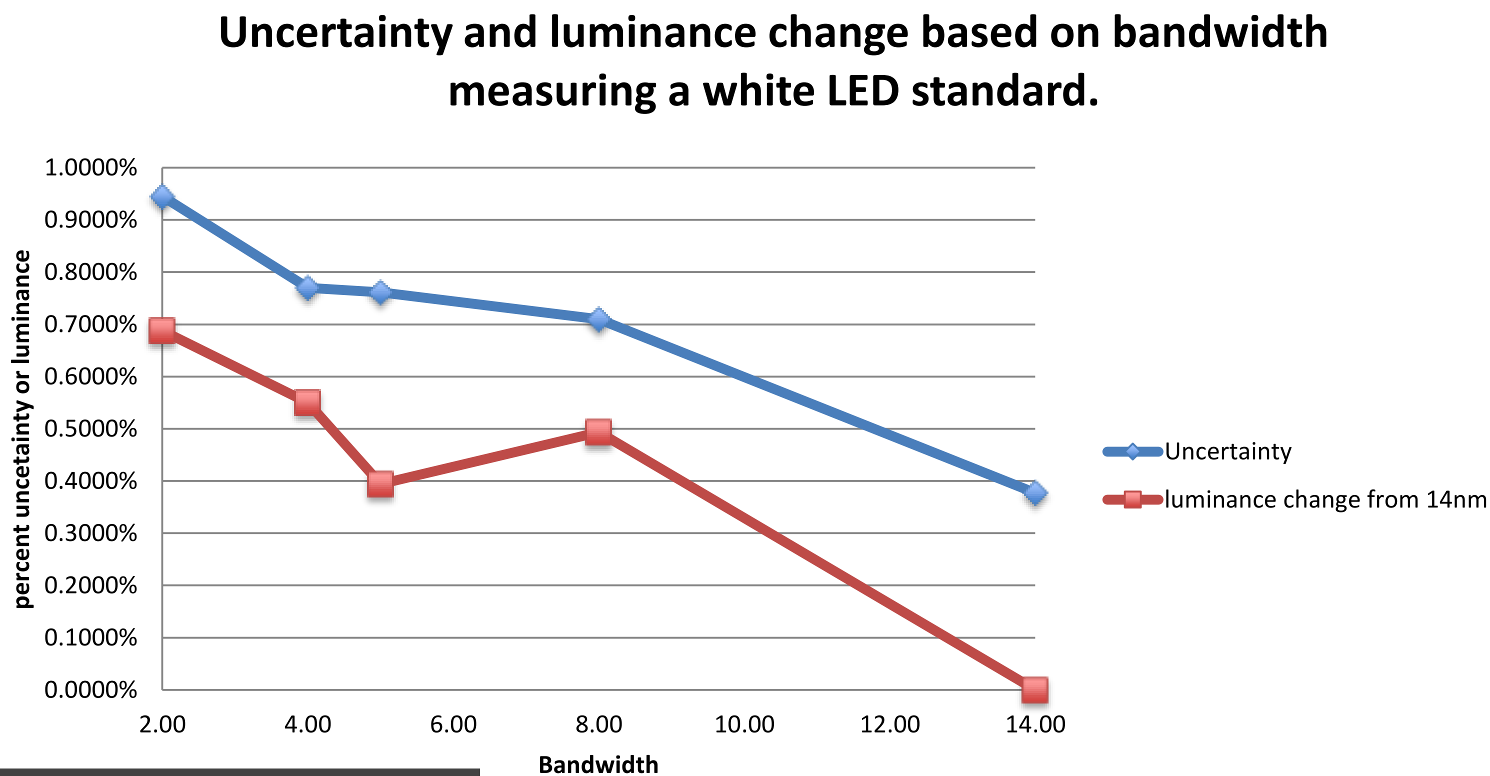
Bandwidth effects and Inter-Instrument Agreement measuring White LED source

- At PRI factory, typical inter-instrument agreement measuring illuminant A is less than 0.2% and uncertainty roughly 0.2%



On going R&D efforts with Standards at PRI

- Current errors and uncertainties are well within the instrument specifications, even on solid state sources.
- Some of the error is due to the ASTM 308 table issues: lack of specification for band shaping.
- Development of a Hybrid source
  - Higher blue green output than tungsten
  - “Soft” spectral slope
- The goal is to improve inter-instrument agreement across all bandwidths.

Why does PRI make so many instruments?

- Display advances lead to instrument changes
  - LCD with CCFL
    - Long history
    - Very structured color signature
    - Linear Polarization
  - LCD RGB backlight
    - Short market life
  - White LED backlight
  - OLED/AMOLED

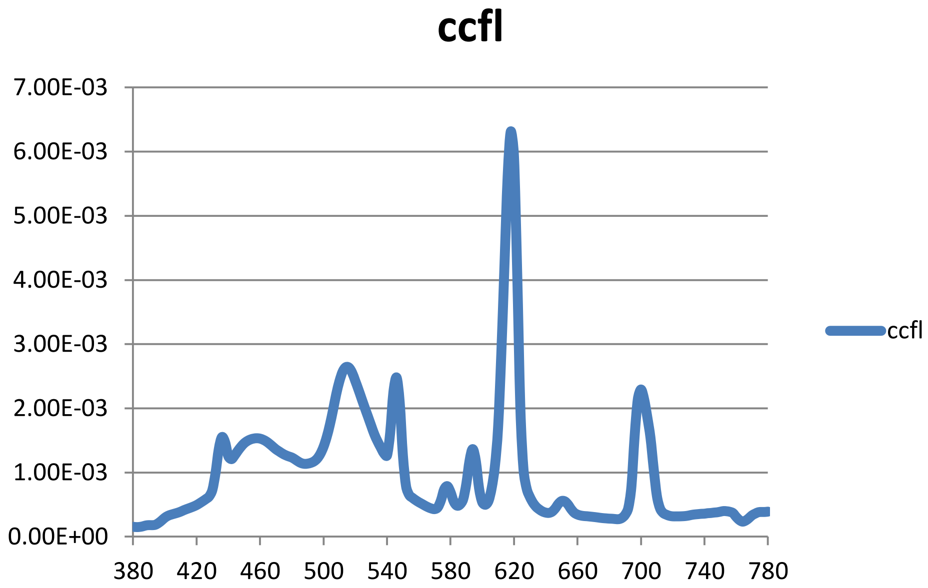
Early LCD with CCFL backlight

- Lamp structure is filtered by dye filters in the physical LCD mask
- Sharp discontinuities in the spectra introduce potential of inter instrument agreement errors due to bandwidth issues.
- Backlight dimming strategies introduce temporal variation
- Display is linearly polarized.

Photo Research PR655

- Available in 5nm bandwidth
- 128 element sampling
- Polarization mitigation in optical system
- Built in frequency sensor to mitigate temporal variation
- Easily measures the complete output dynamic range of the display (300:1)
- Battery powered.

- LED CCFL spectrum



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The Reference in Color and Light Measurement

- RGB led backlight found in very high end displays

RGB backlight LCD

RGB LED backlight filtered by LCD filters

- Spectrum is uncomplicated.
- Relatively bandwidth insensitive due to with of spectrum of each LED
- Backlight dimming typically accomplished wit PWM.
- Complex temporal issues due to screen refresh rates and PWM back light issues.
- RGB backlight is often coupled with high dynamic range LCD panel (600:1)
- High degree of linear polarization.
- Often coupled with 11 bit resolution

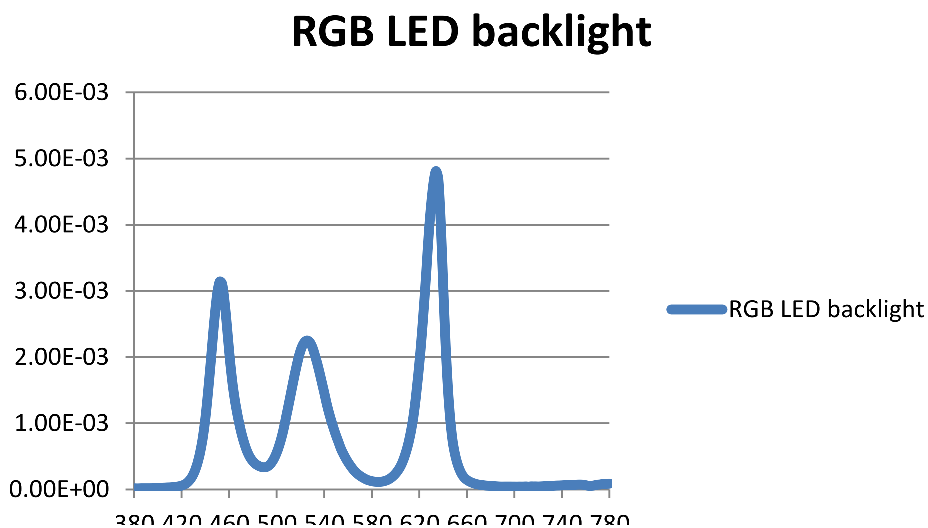

Photo Research PR670

- Higher spectral resolution
- 256 element sampling
- Wide dynamic range of measurement
- Multiple dynamic field of view options
- Auto frequency detection

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White LED backlight

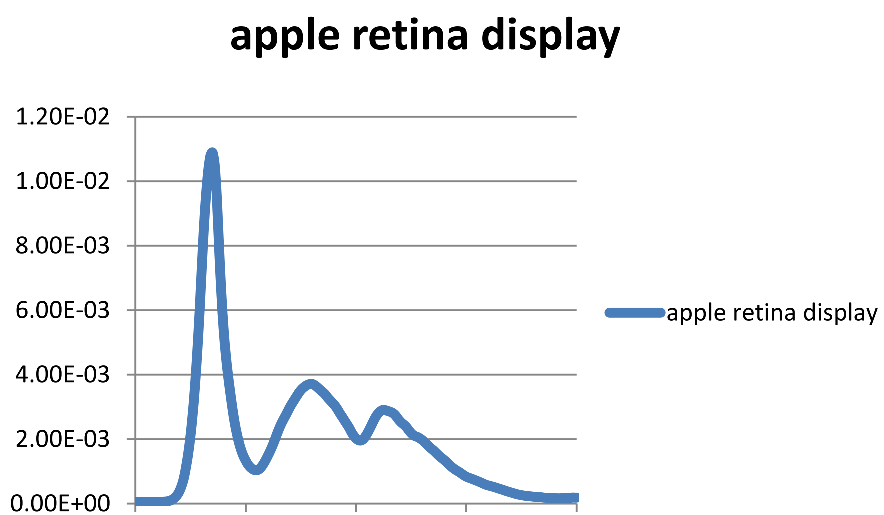
Contemporary Display Technology
Replace CCFL with White LED

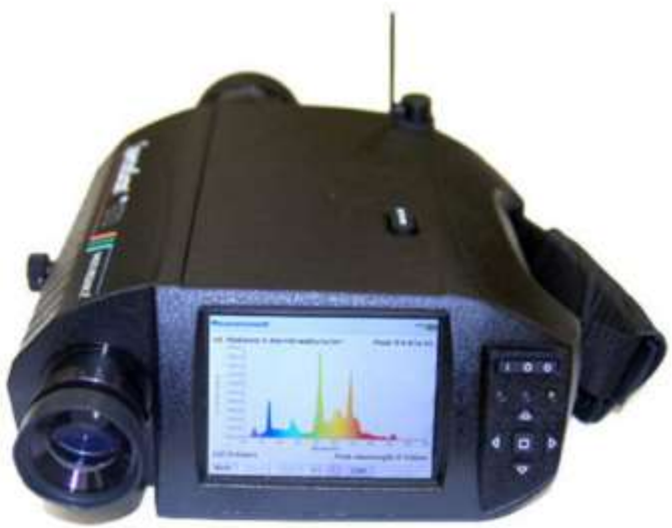
- Very smooth Spectra
- Relatively bandwidth insensitive
- Highly polarized

Photo Research PR670

- Available in 5nm bandwidth
- Multiple FOV options.
- Polarization mitigation in optical system
- Built in frequency sensor to mitigate temporal variation
- Easily measures the complete output dynamic range of the display 600:1)

- Apple retina display





OLED and AMOLED self dimming displays

- Color a bit of a challenge: narrow primaries , wide gamut.
- Relatively low maximum luminance, but very low minimum luminance.
- Huge contrast range and a challenge to measure.
- Displays are typically circularly polarized (minimal challenge to measurement)

PR 680L and PR 740

Optimized for low luminance

PR 680 manages $5X10^9$ dynamic range of measurement

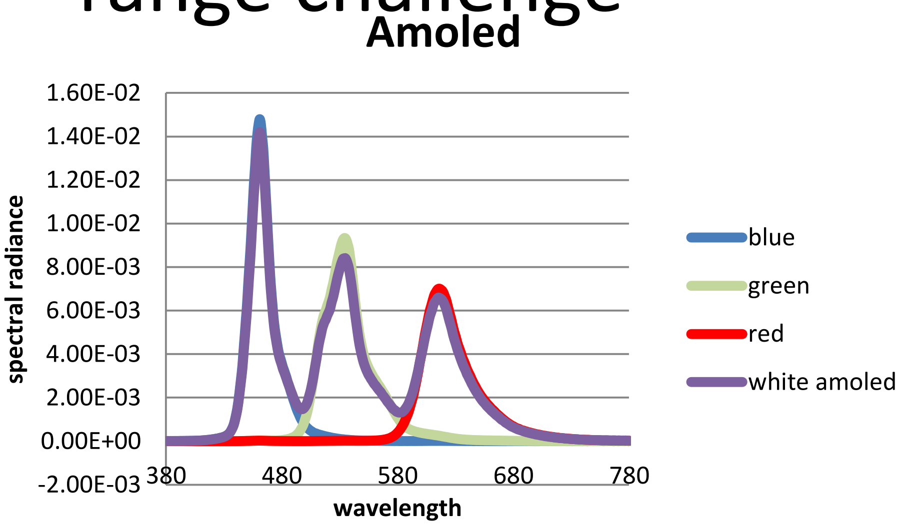
PR-740 lower limit down

to .000015cd/m^2

PR 740 offers 2X resolution of the 680

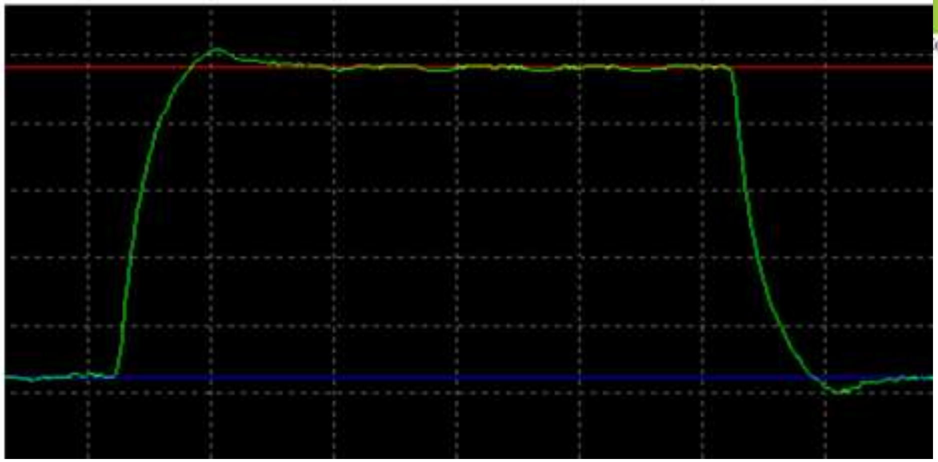
PR 680 offers analog output

• AMOLED high dynamic range challenge



Temporal and "bit-wise" measurements

- Modern Displays have complex time-domain driving architectures.
- Displays can have variable vertical sync rates
  - http://www.vsynctester.com/index.html
  - Electronic sync rate/ lag is simple
  - Display results are not so simple
- The ability to measure single-bit changes at the display surface requires very special instrumentation (PR-810 and PR-810L)



Photometer as optical scope probe

Accurate luminance measurement

Defined aperture field of view

Analog output couples to standard oscilloscope or data acquisition system

These products used by system integrators and R&D labs

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The Reference in Color and Light Measurement

2 dimensional color measurement

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Pros and Cons of 2D measurement

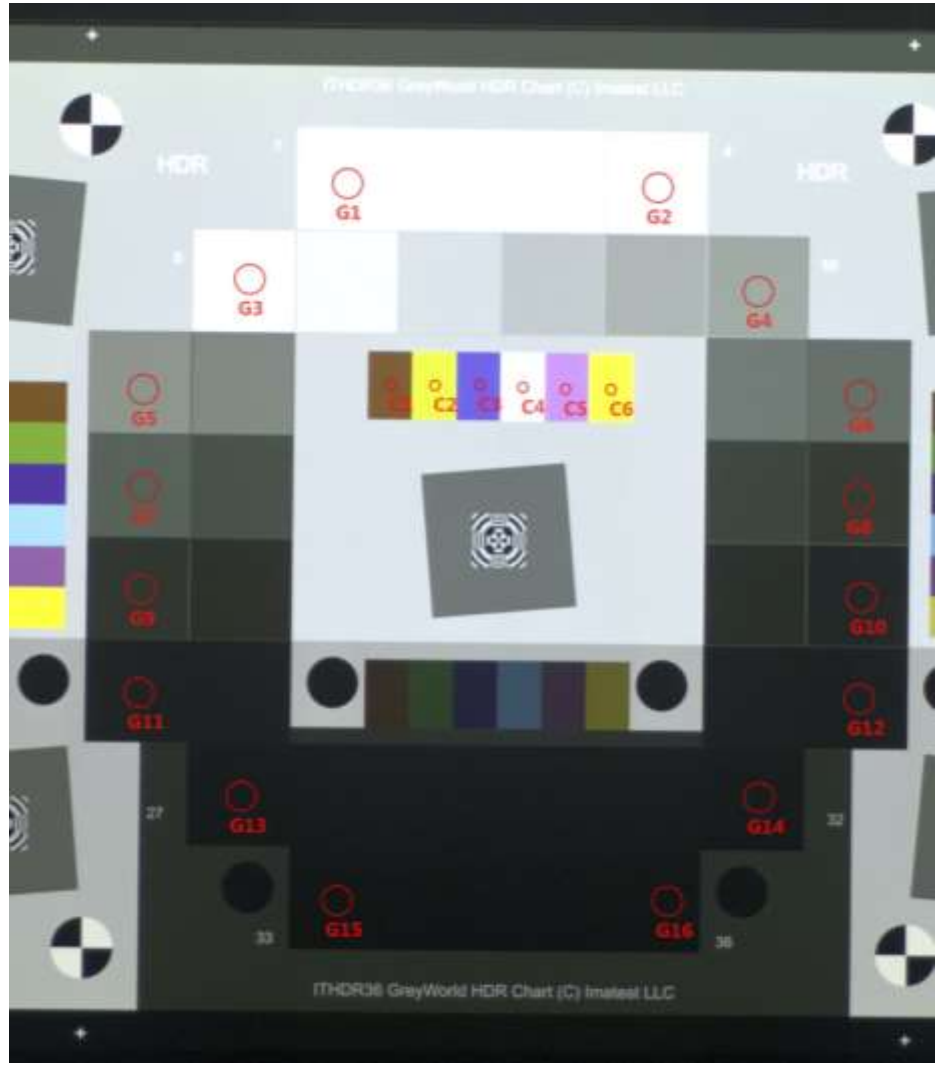
- Pros:
  - Millions of colorimetric measurements simultaneously
  - Very useful for display mura measurements
  - Very useful for indicator (automotive/aeronautics)
- Cons:
  - Data can be affected by veiling glare
  - Useful signal to noise is orders of magnitude lower than single spot instruments
  - Not useful for simultaneous display contrast ratio measurement (can be corrected with secondary measurement using a photometer)

Imatest GreyWorld HDR

Very High Dynamic (Delta D > 6.5)

Very light sections G1-G2 generate a great potential for veiling glare.

Typical imagers quantize to 16 bits with a working dynamic range of 12-14 bits.



Imager Characteristics

- 8 mega pixel
- TE Cooled
- Dynamic range 0.001 to 400 cd/m^2 (higher with ND Filters)
- Color Measurements as Fast as 4 Seconds
  (total cycle time @ 100 cd/m^2)
- High quality CIE filters

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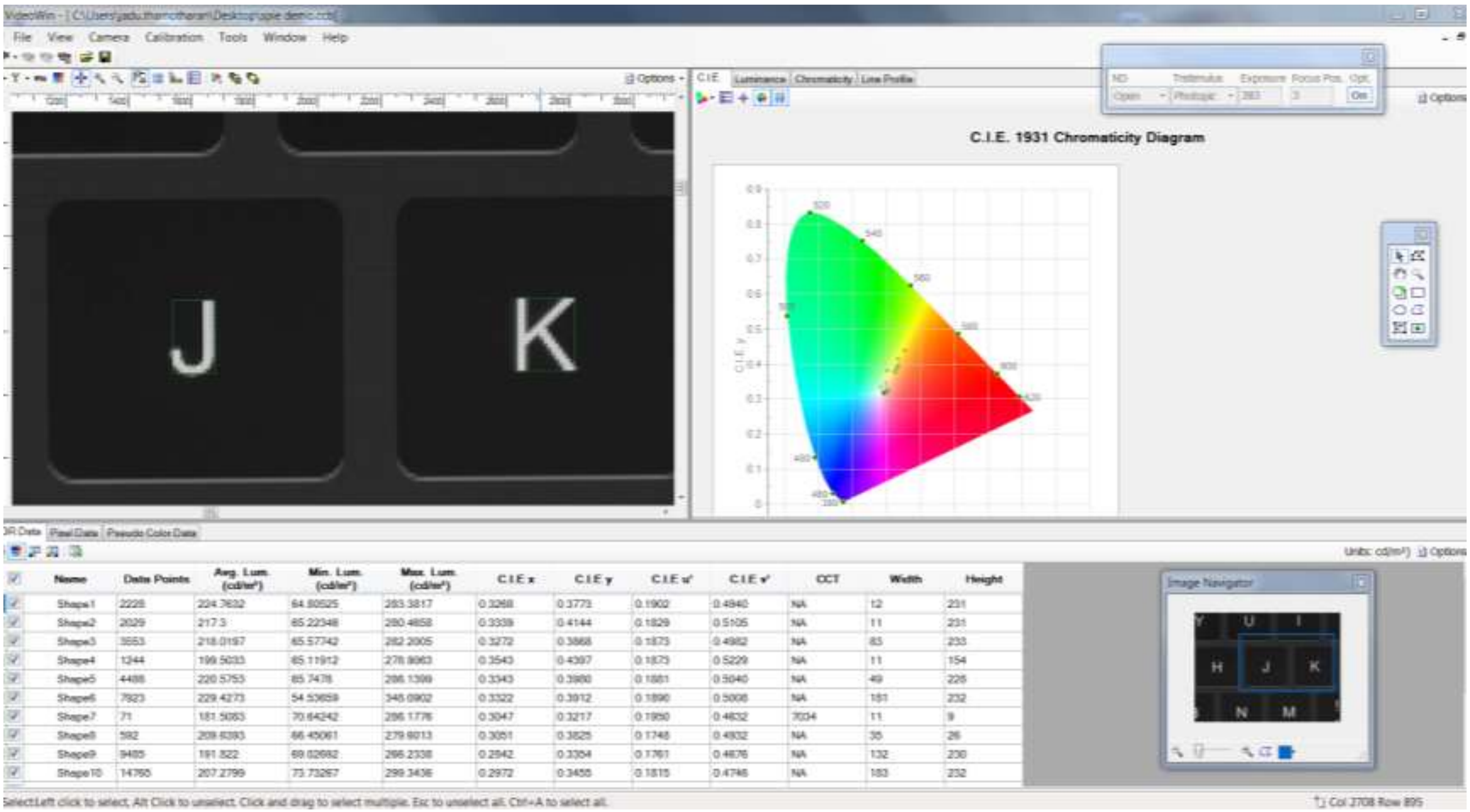
Character and Enunciator Measurements



Mura Evaluation

Medium screen image with two scratches

Mura calculation steps

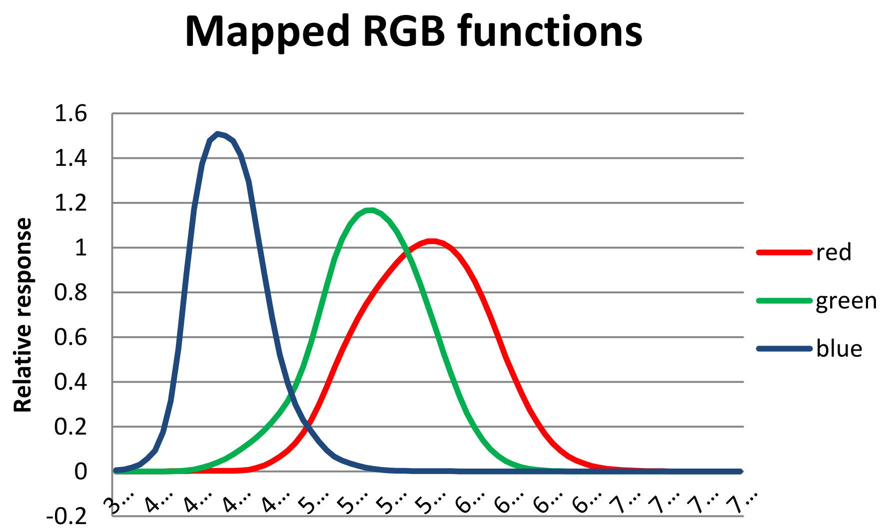
Excellent application for imager

Simultaneous measurement of multiple display issues in seconds.

Mura Evaluation Index	Value of Index	Mura Image
Luminance mura area	0.0013	 Bright Area  Dark Area
Maximum lightness difference	5.5784	
Luminance edge area	0.0019	
Color mura area	0	
Maximum chroma	1.0608	
Color edge area	0.0008	

Colorimetry with three filters

- Filter Set is designed using MacAdam's recommendation for narrowest set of RGB cmfs.
- Described in Yule's "Principles in Color Reproduction" as a "private note from MacAdam"
- RGB cmf's are derived from the CIE cmfs via a simple matrix transformation.



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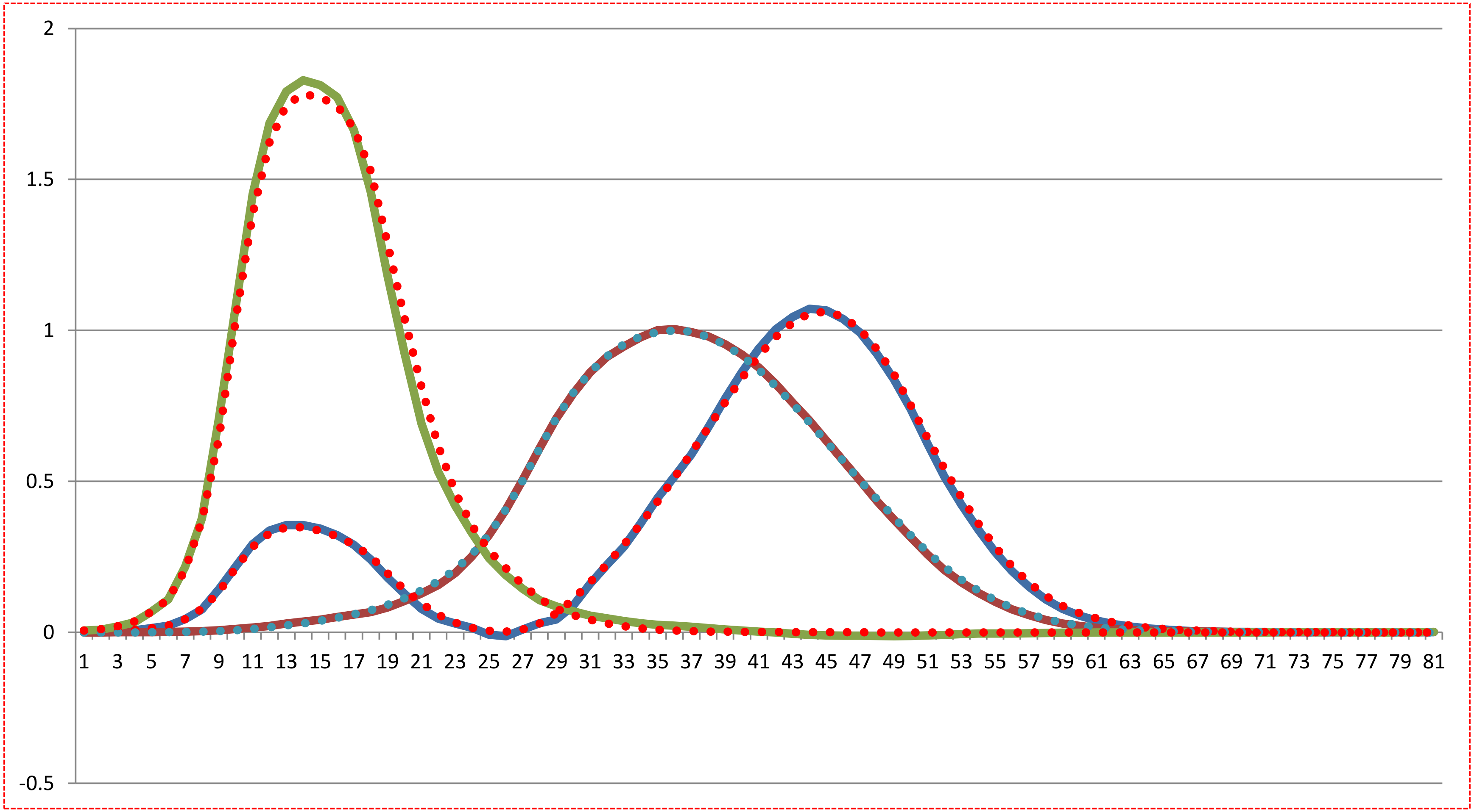
Measured Instrument Response



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Industrial Strength Measurement

- High Speed
- Designed for on line measurement

Industrial Strength Measurement

- Utilizes the same optical technology used in R&D measurement
- Video Camera for remote viewing
- “Learning” software utilized for very rapid measurements of patterns used for display calibration

Thank you!

- Tom.lianza@photoresearch.com