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Advances in Testing and Calibration of Modern Optical Sensors

Bill Grube
Sr. Product Marketing Manager
July 16, 2020

Agenda:

Part 1: Optical Sensor Examples – Types, Uses, and Tests

- Ambient light sensors
- Image sensors
- 3D sensing

Part 2: Optical Sensor Testing & Calibration Tools

- Testing and calibration challenges
- Existing test tools
  - Strengths and weaknesses

Part 3: Energetiq Contribution: Laser-Driven Light Sources

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Display Optimization in Handheld Electronics

Image Credit: Consumer Reports

- Adjusting display intensity based on ambient conditions.
  - ➢ Ambient Light Sensor

Image Credit: deccanchronical.com

- Adjusting white point balance on display based on ambient conditions.
  - ➢ Ambient Light Sensor

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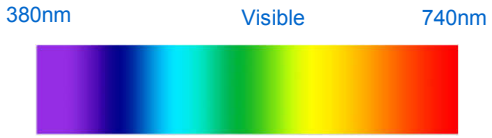
Ambient Light Sensors Emulate Human Vision

Human Eye

Image Credit: learnpick.in



All visible wavelengths.

Ambient Light Sensor

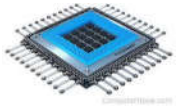
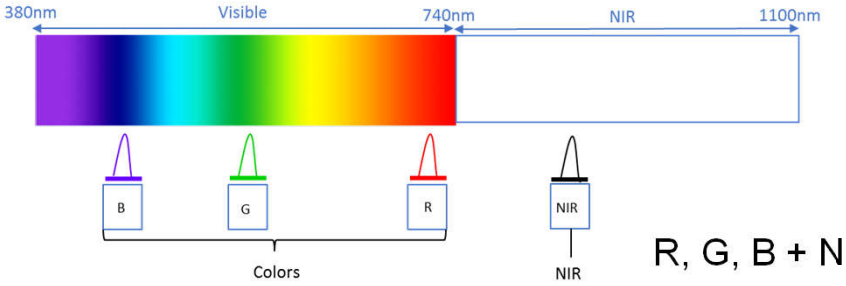
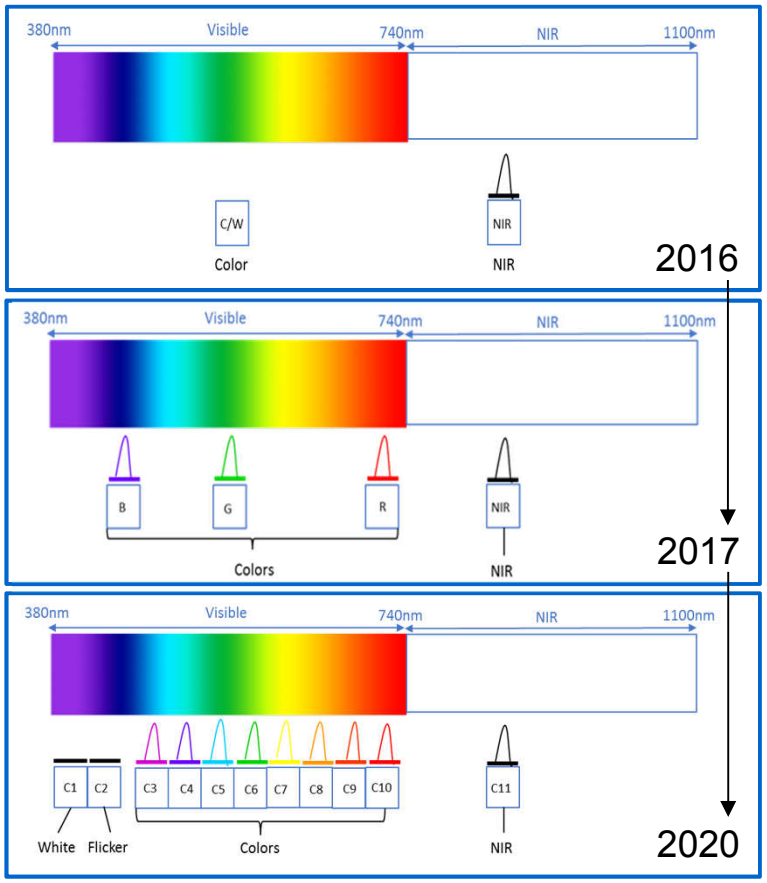


Image Credit: computerhope.com



R, G, B + NIR channels.

Evolution of Ambient Light Sensors in Handheld Electronics



Sensor	Role

Ambient light Sensor (ALS):
• 2 channels
  • White/clear (intensity)
  • NIR (proximity)
• Circa 2016
	• Backlight intensity
	• Proximity to ear

ALS / Color Sensor
• 4 channels
  • Red, Green, Blue (intensity)
  • NIR (proximity)
• Circa 2017
	• Backlight intensity
	• Proximity to ear
	• White point balance

ALS / Color / Spectral Sensor
• 11 channels
  • 1 White (intensity)
  • 8 Color (intensity)
  • Flicker
  • NIR (proximity, intensity)
• Circa 2020
	• Backlight intensity
	• Proximity to ear
	• White point balance
	• Identification of source type

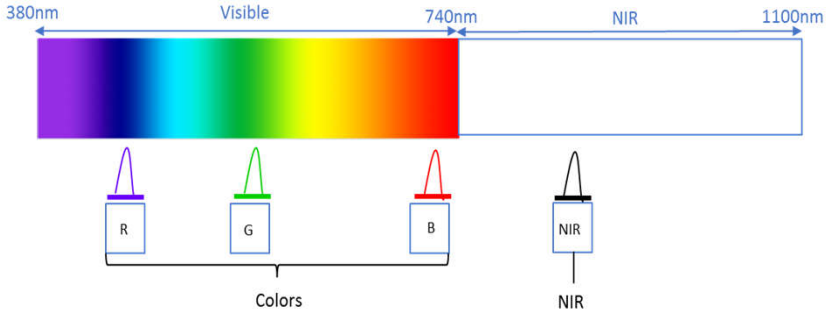
Ambient Light Sensor Test & Calibration Procedures

Goal:

- Eliminate or compensate for unit-to-unit variations in photodiodes and wavelength-specific filters.

Method:

- Scan of “monochromatic” (narrow band width) light with reference measurement.
- < 10nm bandwidth typically required.
- Uniform spectral content and intensity over multiple sensors under test.



Lights Source Types:

- LED-based tunable light sources.
- Monochromator-based tunable light sources.
- Filter-based tunable light sources.

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Image Sensor Applications

Product types:

- Smartphones
- Laptops & tablets
- Mobile gaming devices
- Security cameras
- Automotive and transportation
- Digital cameras & camcorders
- Medical systems
- Machine vision
- Science & space

Security cameras installed:

- 770M worldwide[1]
- 1 camera/4 people in US & China

2019 production: 180M[2]

Image Credit: The Guardian.com

Number of cameras in cars:

- Average >2 cameras/car by 2023[3]

Image Credit: Researchgate

1: IHS Markit, Security Technologies Top Trends for 2019

2: HIS Markit

3: Markets and Markets, Automotive Camera Market by Application, Basis year 2019.

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Image Sensors Fundamentals

Millions of pixels with R,G,B filters

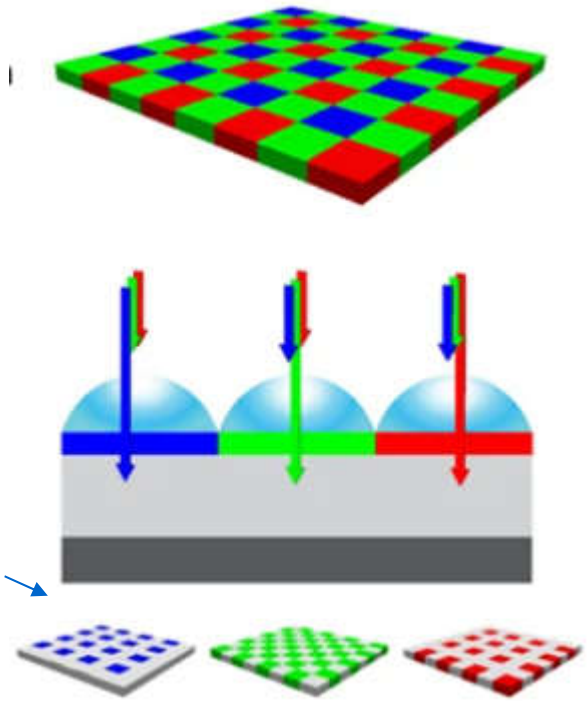

Image Credit: Nature.com

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Image Sensor Characterization Procedures

European Machine Vision Association (EMVA) Standard 1288

Standard for Characterization of Image Sensors and Cameras

- Spectral properties – hot vs. cold pixel identification:
  - Homogeneity is important – flat field source, integrating sphere.
  - LED or broadband source (incandescent bulb, arc lamp) with bandpass filter.
  - Evaluate at color channel wavelengths (RGB).
  - Bandwidth: FWHM ≤ 50nm.
- Spectral sensitivity:
  - Requires light source that can be scanned over wavelength range.
  - A monochromator is typically used.
  - Wavelength range: 350nm – 1100nm
  - Bandwidth: FWHM ~ 10nm.
  - Step size: ≤ 2nm

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3D Sensing in Automotive

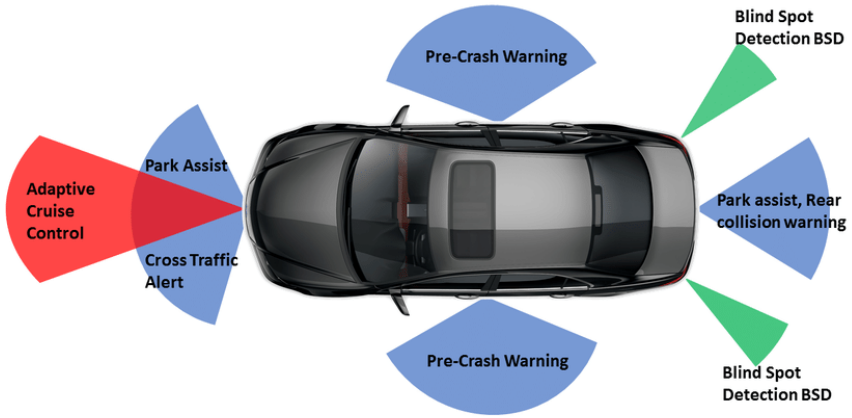

Image Credit: Researchgate

Image Credit: Researchgate

- Advanced Driver Assistance Systems (ADAS)
  - Parking
  - Lane change
  - Blind spot detection
  - Adaptive cruise control …

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Other 3D Sensing Applications

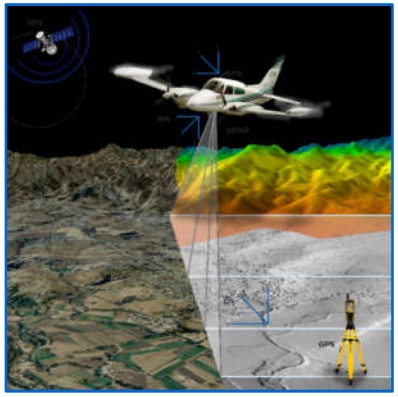
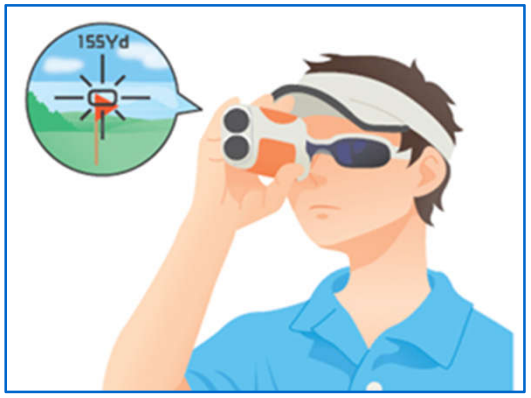


Image Credit: sapub.org

Image Credit: geospatialworld.net

Image Credit: forbes.com



Large number of 635nm, 785nm, 850nm, 905nm, 940nm bandpass filters needed.

3-D Sensing in Handheld Electronics – Facial Recognition

Structured Light

Image Credit: KU Leuven

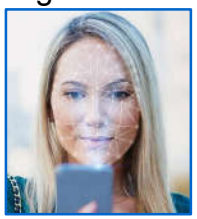


Image Credit: Photonics.com

- Structured Light Sensing
  - ➢ Coherent laser light in NIR band
  - ➢ Sensor includes NIR Bandpass Filter

Time of Flight

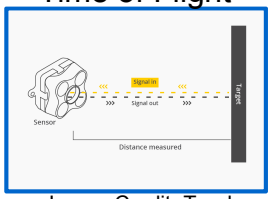


Image Credit: Terabee

- Time of flight (TOF) Light Detection and Ranging (LIDAR)
  - ➢ Coherent laser light in NIR band
  - ➢ Sensor includes NIR bandpass filter

Color Image

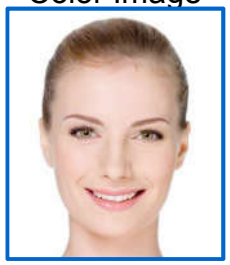


Image Credit: Clipdealer

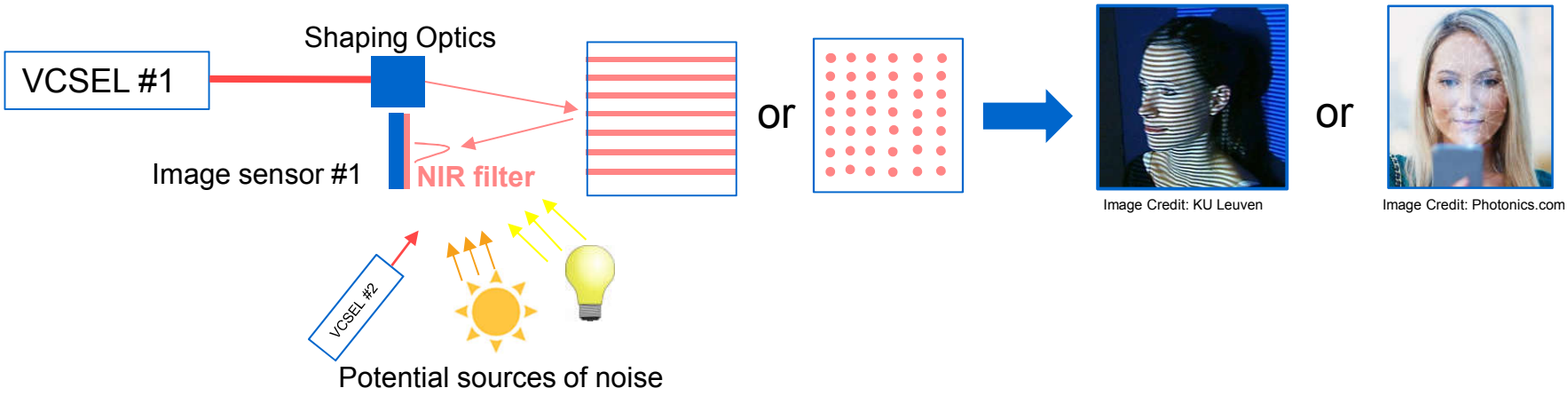
- Color adjusted photograph
  - ➢ Ambient Light Sensor

Optical Sensor Market Trends

1. Growth of 3D sensing
2. Integration of sensor data

3D Sensing Sensor Fundamentals

Structured Light



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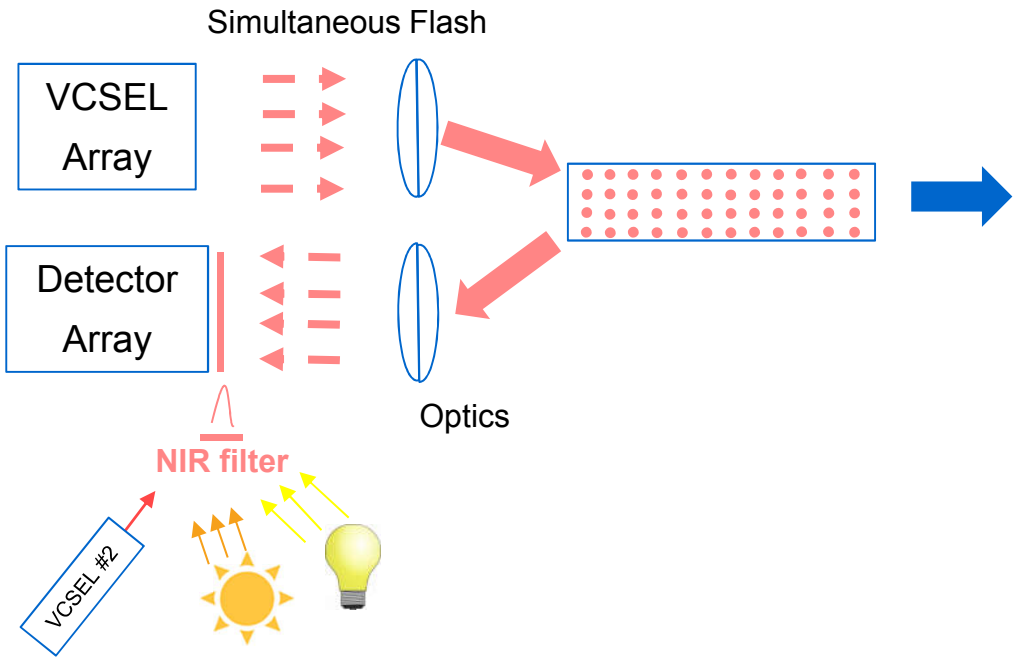
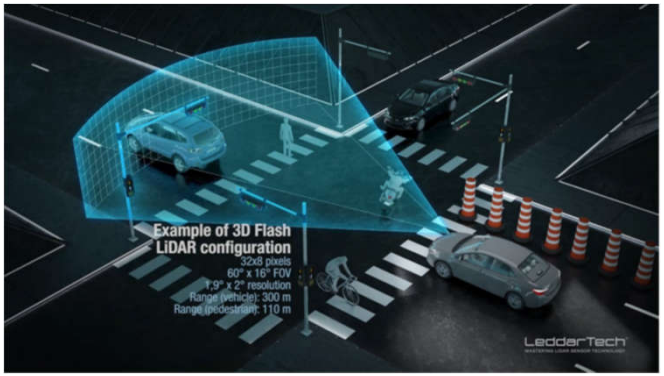
3D Sensing Sensor Fundamentals

Time of Flight LIDAR – Flash





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3D Sensing Filter Test Procedures

Goal:

- Verification of filter performance for blocking unwanted wavelengths from the sun and other sources.
  - Reduce noise, increase signal to noise ratio.

Method:

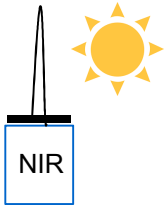
- Scan of “monochromatic” (very-narrow band width) using spectrophotometer.
- < 1.5 nanometer bandwidth.

Lights Source Types:

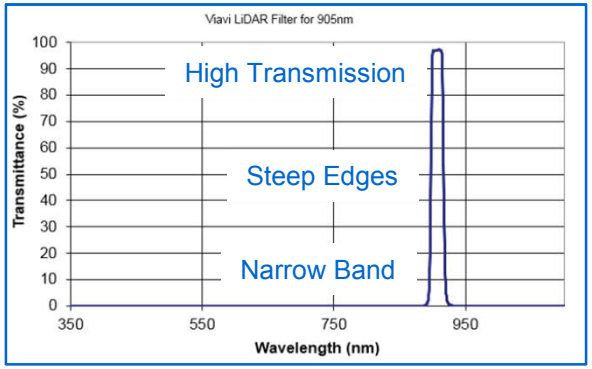
- Spectrophotometer with source:
  - Xenon (Xe) arc lamp
  - Quartz tungsten halogen (QTH) lamp

Ultra narrow-band filter

< 1.5nm FWHM



Various detector types



VCSEL wavelengths:

635 nm

785 nm

850 nm

905 nm

940 nm

1550 nm

…more

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Sensor test challenge #1: High precision

Ambient light sensor calibration

- Increasing number of channels.
- Increased algorithm complexity: Backlight control ⟶ identification of source type.

Image sensor characterization

- Increasing number of pixels (resolution).
- Increasing algorithm complexity: Photos, Videos ⟶ artificial intelligence.

LIDAR filter test

- Increasing number of LIDAR wavelengths used.
- Increased algorithm complexity: Range finding ⟶ identification of hazards.

Repeatable performance is key!

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Sensor test challenge #2: High volume

Smartphone production environment

- 1.5B[A] phones manufactured each year.
  - Two ALS sensors per phone: 3B sensors/year.
  - Two 3D sensors per *high-end* phones: 250M sensors/year.

Automotive production environment

- 53M cars per year manufactured with some level of ADAS by 2022-2024[B].
  - Six 3D sensors in each: 318M filters/year.
  - On average >2 cameras/car by 2023.

Process throughput is valuable – “time is money” in production.

A. Source: Statistica

B. Source: Yole Development.

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LED-Based Tunable Sources (ALS & Image Sensor)

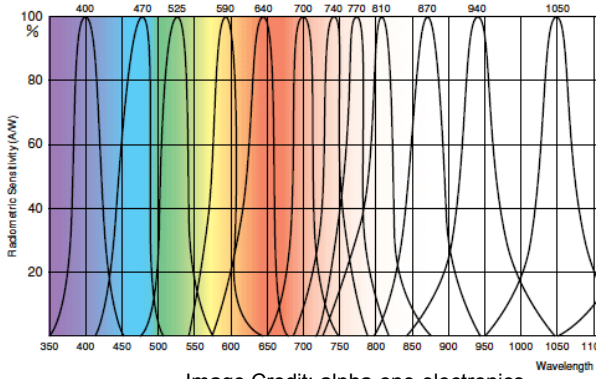


Image Credit: alpha-one electronics

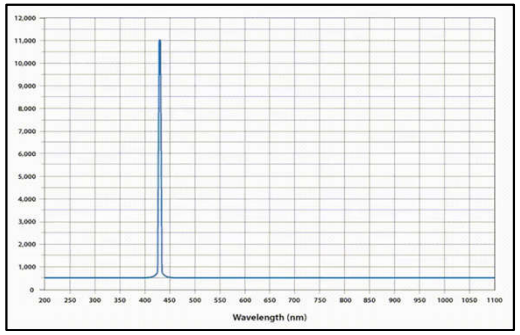
Strengths:

- Amount of light output.
- Can be used with integrating sphere for high uniformity.

Weaknesses:

- Finite number of wavelength steps in scan.
- Serial measurement limited by LED thermal stabilization time needed for wavelength and amplitude accuracy.
- Bandwidth varies with each LED.
- Limited to diffuse illumination.

Monochromator-Based Sources (ALS & Image Sensors)



Traditional sources (Xe arc, QTH) paired with monochromator

Strengths:

- Meet bandwidth requirements.
- Small wavelength steps across scan.
- Flexible monochromator configurations.

Weaknesses:

- Limited light throughput in narrow band.
- Serial measurement potentially limited by throughput.
- Short life of bulbs - frequent maintenance.

Filter-Based Sources (ALS & Image Sensors)

Filter-Based Tunable Light Sources

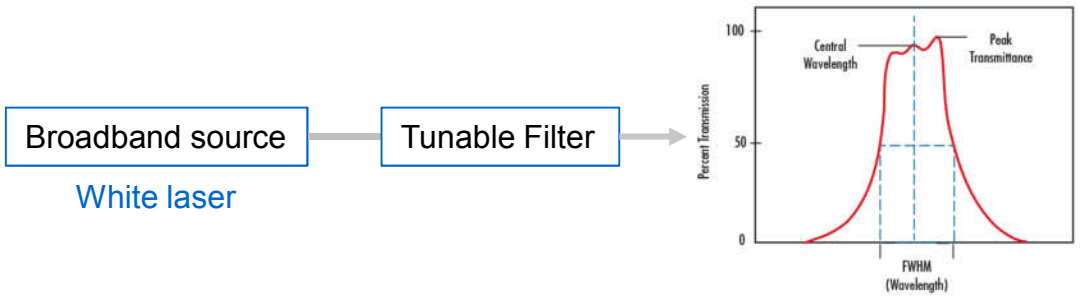


Image Credit: Edmund optics

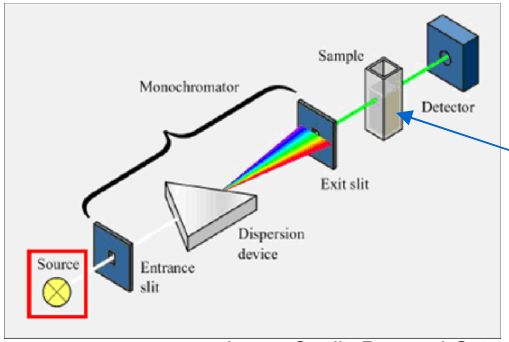
Strengths:

- High optical throughput.
- High out of band extinction/suppression.

Weaknesses:

- Amplitude variation.
- Tunable wavelength range limited.
- Potential issues with laser speckle.
- Not a true continuous source, pulsed source.

Spectrophotometer (LIDAR Filters)



Filter under test goes here.

Image Credit: ResearchGate

Traditional source (Xe, QTH)-Based Spectrophotometer

Strengths:

- Meet bandwidth requirements.
- Small wavelength steps across scan.
- Flexible monochromator. configurations.

Weaknesses:

- Limited light throughput in very-narrow band (<1.5nm).
- Short life of bulbs.

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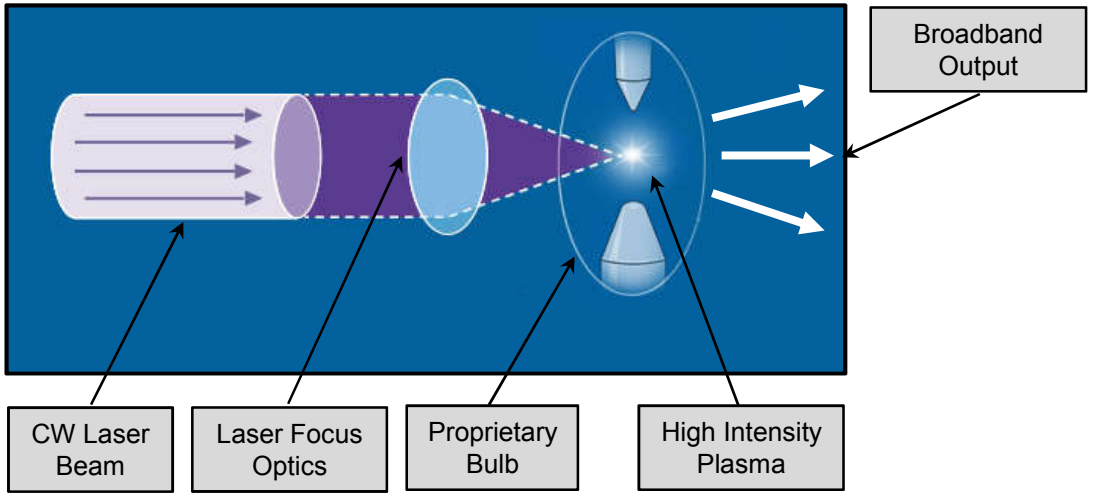
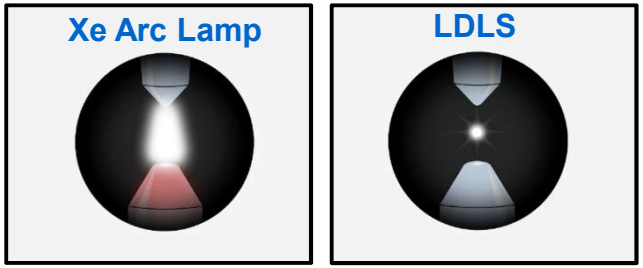
Laser-Driven Light Source™: Principle of Operation





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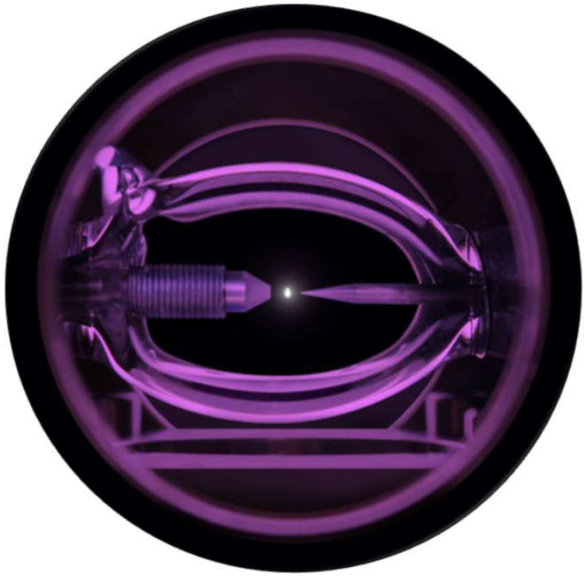
Laser-Driven Light Sources: LDLS™



A combination of valuable features in a single broadband source:

- Broad spectrum: 170nm – 2400nm.
- High brightness/radiance.
- Long life with high stability.
  - >9,000 hours between bulb changes.
  - Operates 24/7/365 with high reliability.
- Provides upgrade path for customers using. traditional Xe, D_2 & Tungsten Sources.

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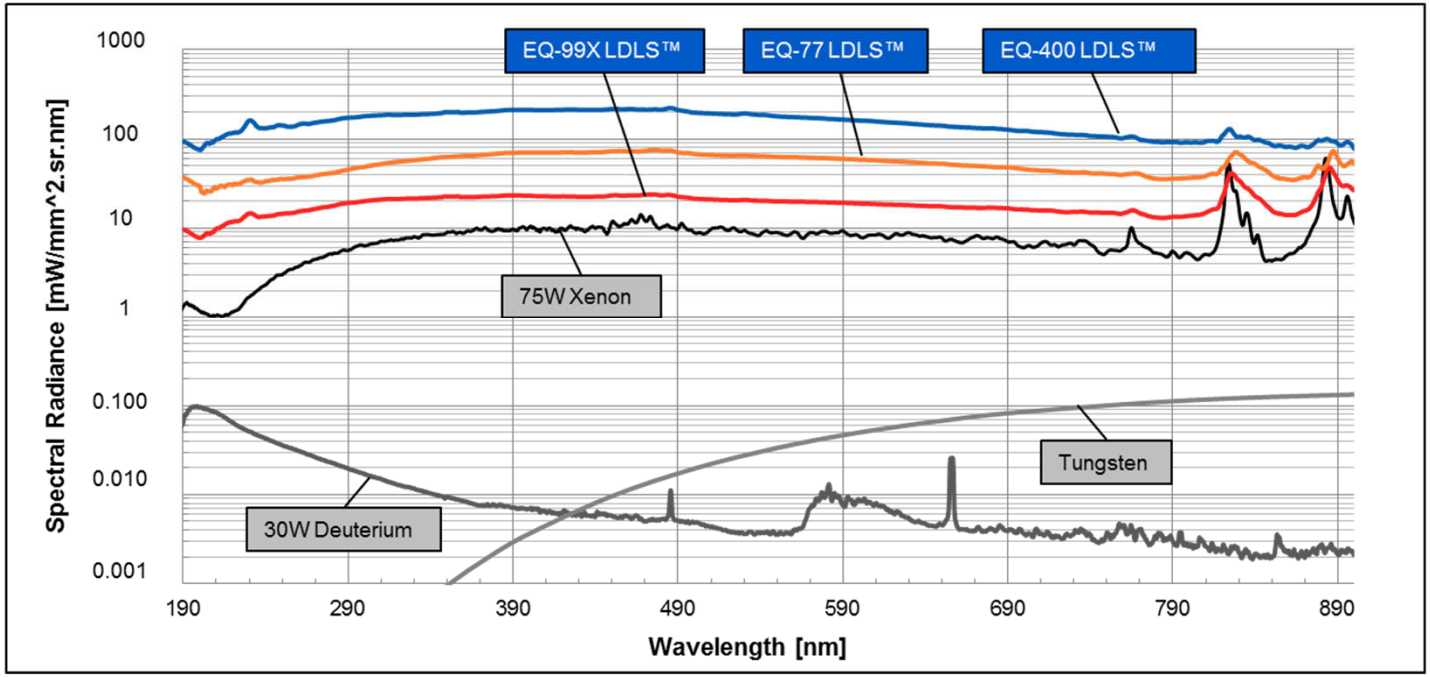
LDLS Spectral Radiance vs. Traditional Lamps



All measured from 100µm diameter emitting area

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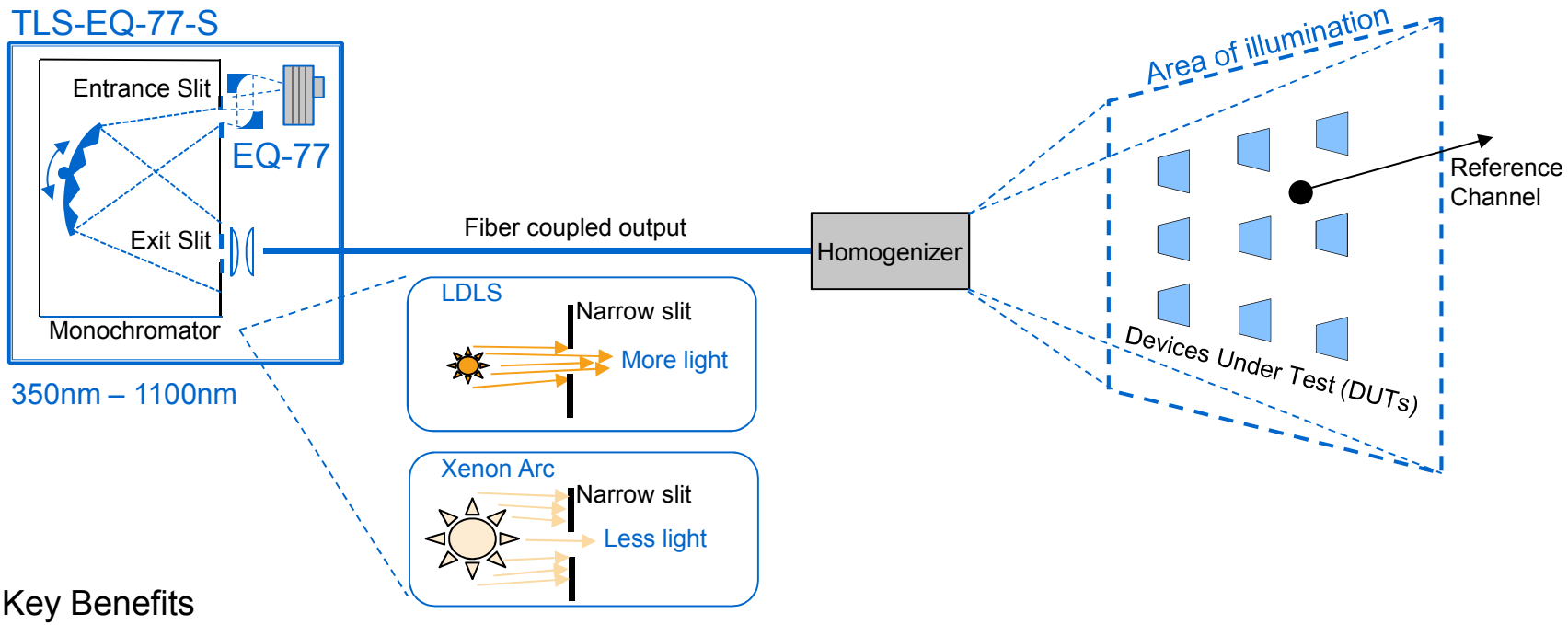
Optical Sensor Characterization and Calibration



Key Benefits

- Broad tunable wavelength range: 350nm – 1100nm.
- Narrow bandwidth: 6.5nm.
- High throughput: 5mW in-band flux at 400nm wavelength.
- Low maintenance: 9,000 hours bulb life. ← Supports “24/7” operation.

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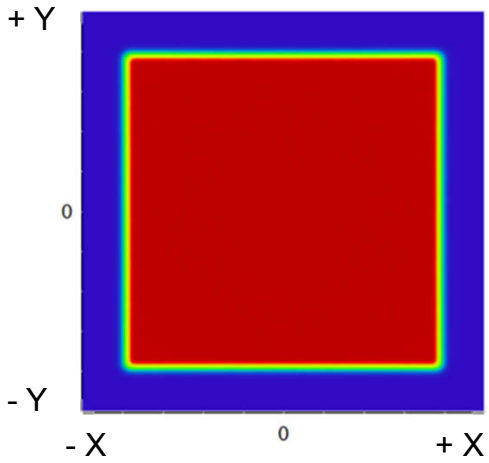
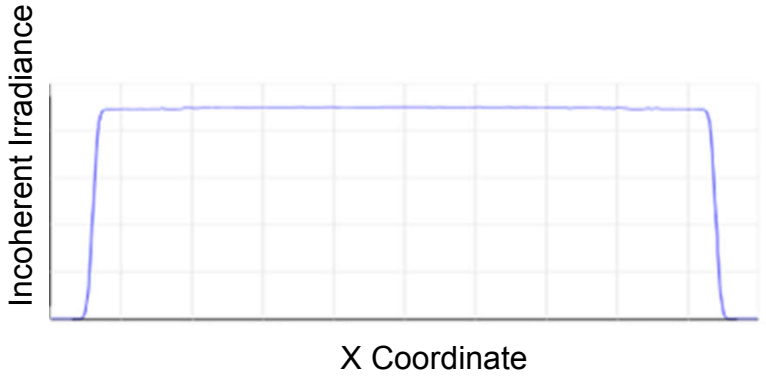
Homogenizer





High uniformity in terms of irradiance and spectral content.

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LIDAR Filter Test

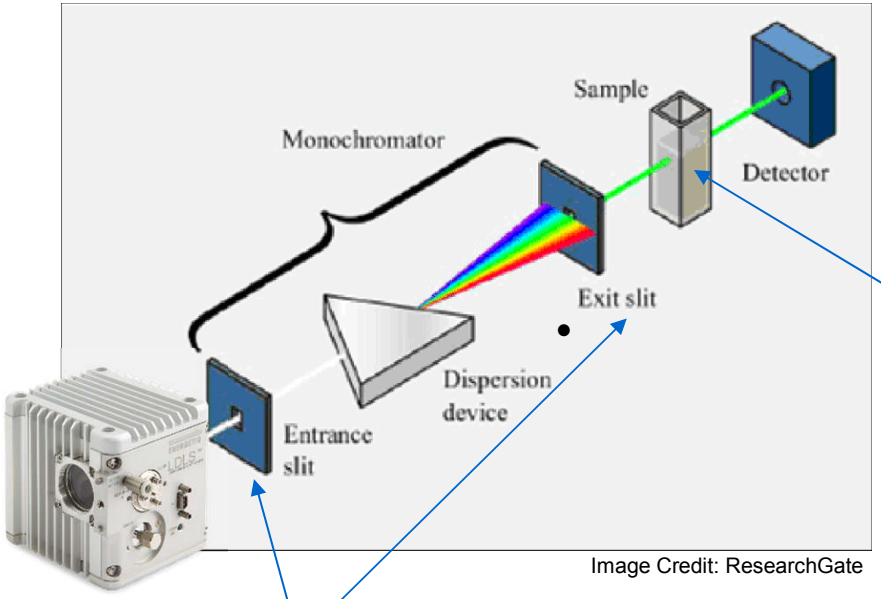

Image Credit: ResearchGate

Filter under test goes here.

Narrow slits,

Narrow bandwidth (~1nm)

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Optical Sensor Test Needs Summary

Sensor Type/Element	Test Requirements	Test Challenges	LDLS benefit
Ambient Light Sensor	Narrow band light (<10nm)	High precision High volume	*** High resolution *** High throughput
LIDAR Filter	Very narrow band light (<1.5nm)	High precision High volume	*** High resolution *** High throughput
Image Sensor	Spectral sensitivity test, Narrow band light (~10nm)	High precision High volume	** High resolution ** High throughput
Image Sensor	Spectral properties test, Narrow band light (<50nm)	High precision High volume	* High resolution * High throughput

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Thank you

Please feel free to contact me with questions:

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Week #	Weekly Topics	# of Talks	Talk #1 Date	Talk #2 Date
1	Introduction to Photodetectors	2	26-May-20	28-May-20
2	Emerging Applications - LiDAR & Flow Cytometry	2	2-Jun-20	4-Jun-20
3	Understanding Spectrometer	2	9-Jun-20	11-Jun-20
1 Weeks Break				
4	Specialty Products – Introduction to Light Sources & X-Ray	2	23-Jun-20	25-Jun-20
5	Introduction to Image Sensors	2	30-Jun-20	02-Jul-20
1 Weeks Break				
6	Specialty Products – Laser Driven Light Sources	2	14-Jul-20	16-Jul-20
7	Image Sensor Circuits and Scientific Camera	2	21-Jul-20	23-Jul-20
8	Mid-Infrared (MIR) Technologies & Applications	2	28-Jul-20	30-Jul-20
1 Weeks Break				
9	Photon Counting Detectors – SiPM and SPAD	1	11-Aug-20	
10	Using SNR Simulation to Select a Photodetector	1	18-Aug-20	

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•https://www.hamamatsu.com/us/en/news/event/2020/20200526220000.html