Sunex

EXCELLENCE IN DIGITAL IMAGING OPTICS

InCabin 2023

Optics matter in the Future

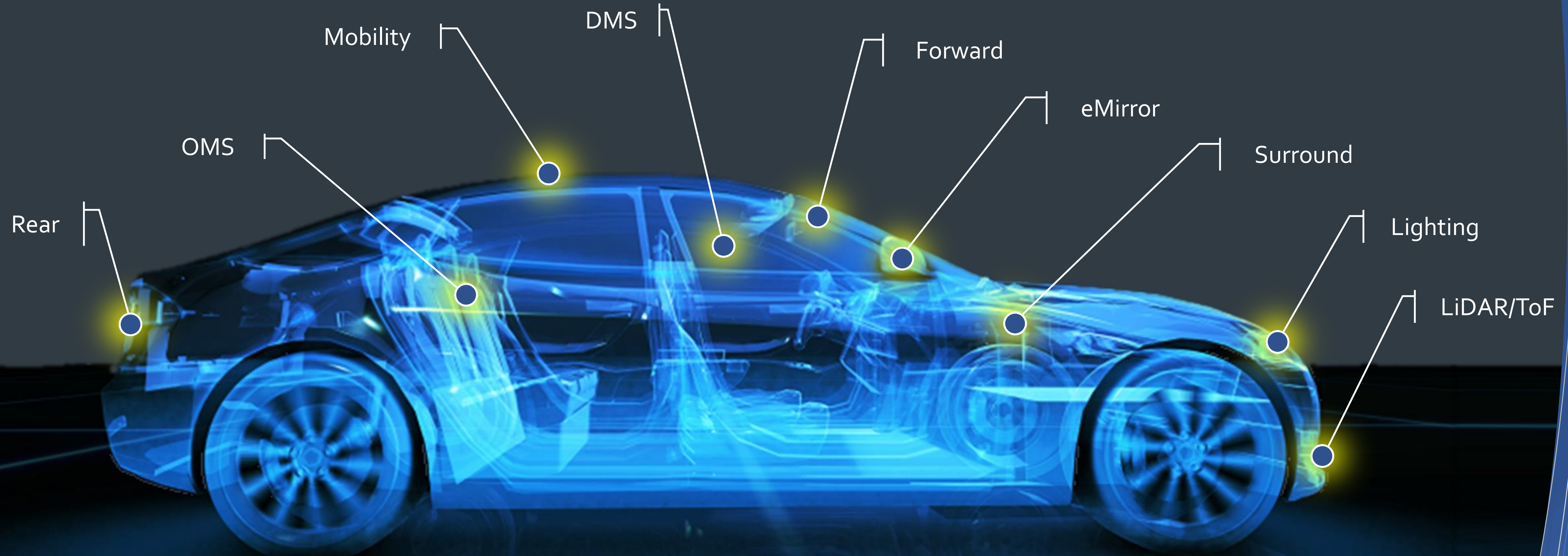
InCabin vision applications seen through the lens of an actual lens manufacturer.

Sunex Inc. – Excellence in Imaging and Projection Optics

- 25+ year track record in design and manufacturing of optics for a global customer base
- >200M lenses delivered to various industries and applications
- 15+ years experience as an automotive Tier2 lens supplier
- Sunex pioneered the miniature SuperFisheye™ lens with hybrid lens design technology and Field of View (FOV) >200° almost two decades ago.
- Over 120M hybrid lenses delivered to automotive customers resulting in millions of cars driving on the road with Sunex Hybrid Lenses.

SUNEX "DRIVES" INNOVATION IN AUTOMOTIVE OPTICS.

Sunex Inc. – Automotive Market Optics



SUNEX "DRIVES" INNOVATION IN AUTOMOTIVE OPTICS.

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Sunex Inc. – Automotive Market Optics

FOR CAMERAS

- 15+ years of premier T2 automotive supplier
- VGA, HD, 4K, to 20 Mpx
- 10° to >200° FOV
- High Dynamic Range
- NoGhost™
- 20+ US patents

FOR LIDAR

- Tx and Rx Lenses
  - Long range and Near Field
  - All Glass and Hybrid
- 20+ year history in Near IR Optics and coatings
  - Narrow IR-band filters
  - Advanced AR coatings
  - Hydrophobic Coatings
  - ITO-based Heating

FOR LIGHTING

- µLED HD Headlamps
- Ground Projectors
- All structures
  - All-glass
  - Hybrid (Glass + aspherical Plastic)
  - All-plastic
- Fast Prototyping Capabilities
- Goniophotometer Test Lab

The 1st BackUp Camera…

…was used in the 1956 Buick Centurion concept car, presented in January 1956 at the General Motors Motorama. The vehicle had a rear-mounted television camera that sent images to a TV screen on the dashboard in place of the rear-view mirror.

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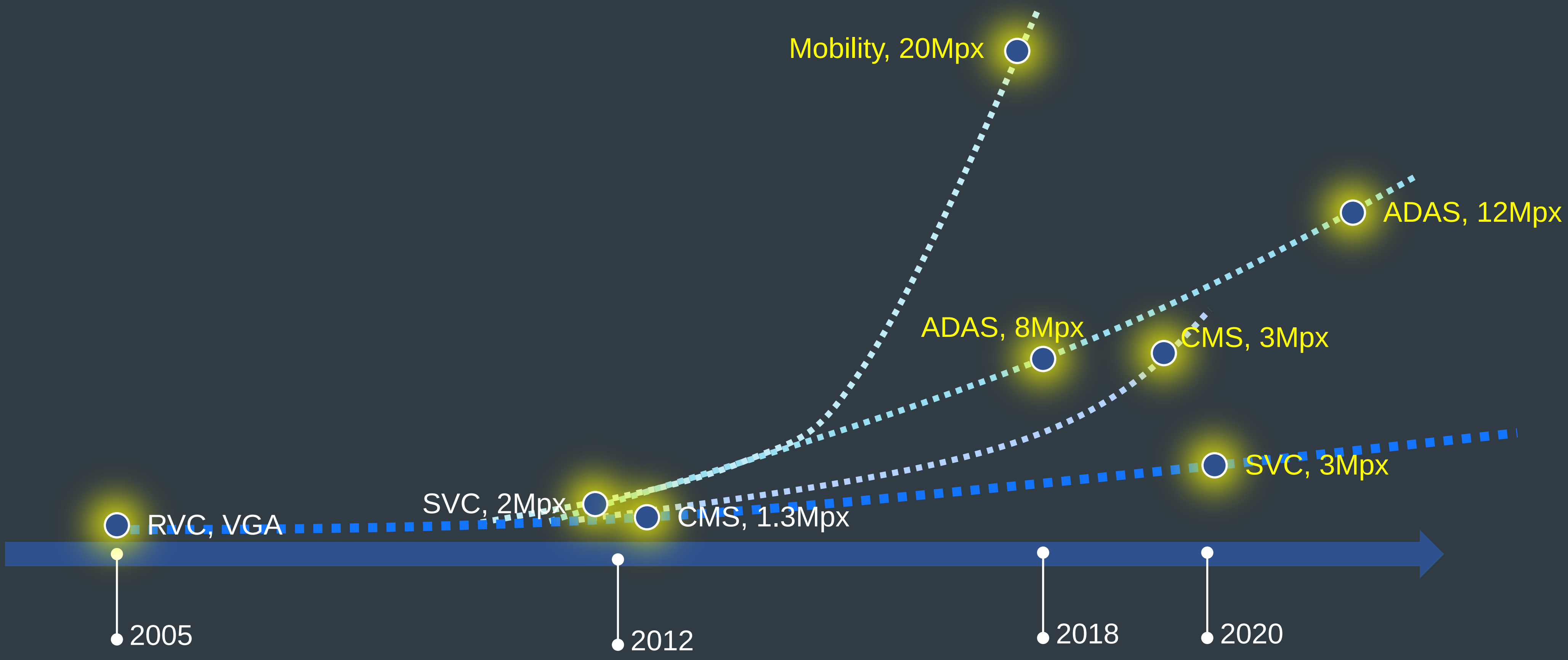
Fast forward to 2023…

…and now cars with 10+ cameras across RV, SVC, ADAS, CMS, and CHMSL are not the future anymore.

Evolution of Automotive Camera/Lens Performance is accelerating



The 1st Driver Monitoring System…

Was introduced in 2006 by Toyota in a Lexus GS 450h. The system uses infrared sensors to monitor driver attentiveness. Specifically, the driver monitoring system includes a CCD camera placed on the steering column which tracks the face, via infrared LED detectors.

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Today's (and future) InCabin application are numerous

- Driver Monitoring
- Occupant Monitoring
- Video Conferencing
- Media Control & Entertainment
- Security, Safety, Access Control (Passenger & Luggage)
- Remote Theft Prevention/Recording
- Remote Customer Service
- … you name it!

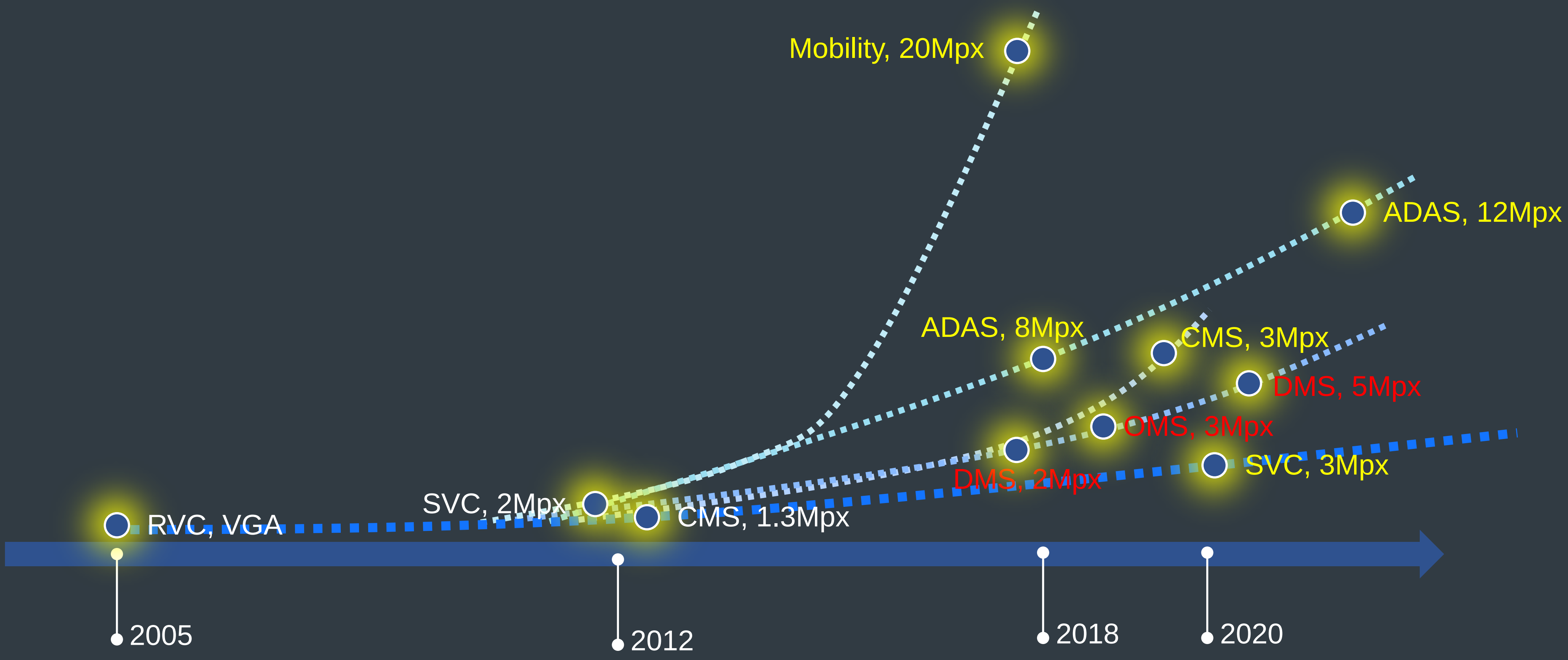

Image source: mbusa.com


Image source: zoox.com


Image source: bmwgroup.com


Image source: shm-afeela.com

Evolution of Automotive Camera/Lens Performance is accelerating, also for InCabin



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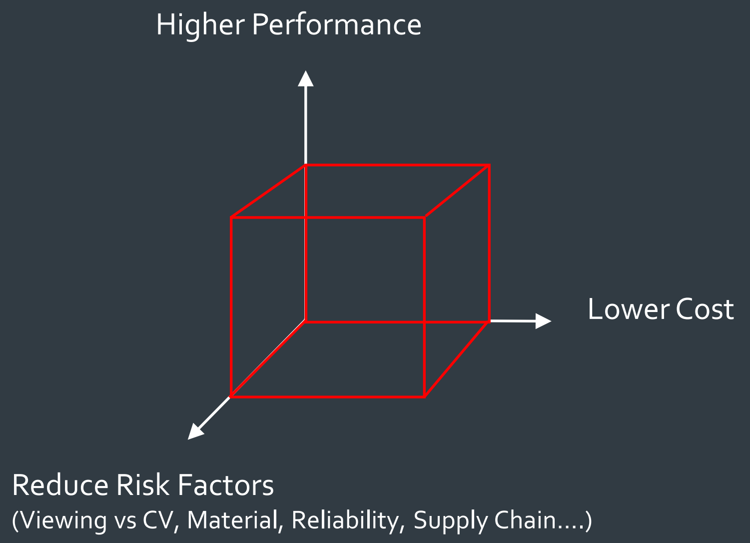
Additional Requirements & Challenges for InCabin Applications

- Size Constraints A
- Visible, IR or RGBIR B
- Consolidating DMS and OMS into DOMS C
- Viewing angle to object
- Hidden or visible (privacy)
- Mounting Location
- Support of vehicle design
- Automotive Reliability (15yrs)
- Cost



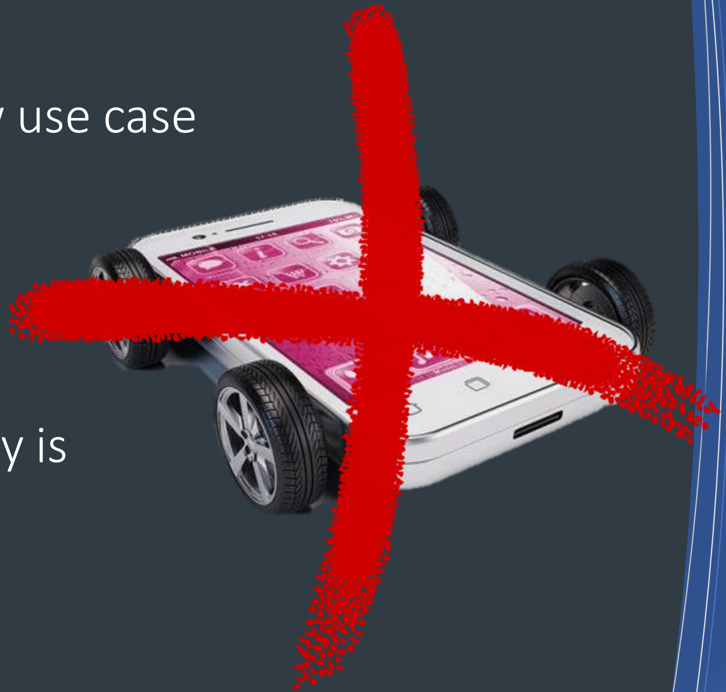
Size Constraints – The Question

A

"Why can't I use a cell phone lens for DMS or OMS?"

Cell phone lenses are designed and engineered for a very specific/narrow use case

- Sensors typically have very High CRA
  - Enables short lens TTL
  - Tradeoffs include low(er) RI, pixel cross talk on the sensor level, and others
- Lenses are designed with all plastic optical stack and the imaging quality is not as good as it could be
  - System relies heavily on post processing for image quality
  - Human eye/brain is very "forgiving"
  - Not well suited for CV
- Lenses don't meet Automotive Reliability and Life-Time Performance Stability (15yrs)

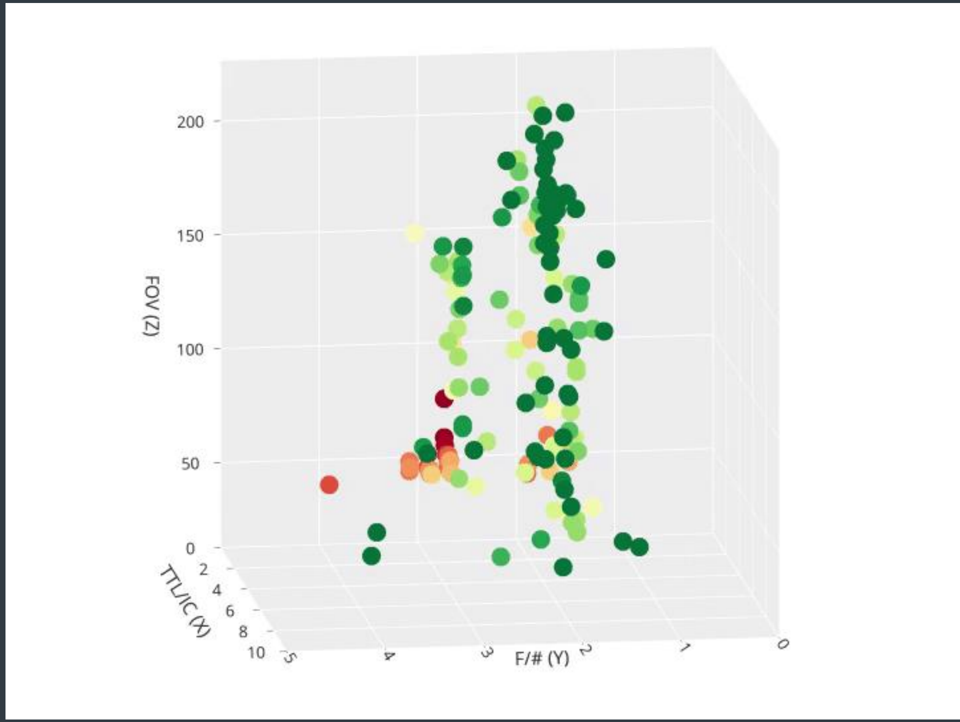


Size Constraints - Lens Design Consideration

A

The lens diameter and total track length (TTL) is driven by

- Sensor:
  - The sensor dimension (H, V, D) is driving the required lens image circle which in turn drives the TTL
  - Rule off Thumb: TTL/IC ratio of 3 is safe, a ratio of ≤2 is a stretch goal
- F/#:
  - Fundamentally the F/# controls light throughput, Depth of Field (DoF), and the ability to achieve contrast at a specific resolution.
  - The F/# is the ratio of the Effective Focal Length (EFL) and the lens Clear Aperture (CA). A smaller F/# increases light throughput, DOF, as well as contrast (up to the detraction limit), but also increases the required lens diameter.
- FOV
  - Large FOVs tend to increase the diameter of the first lens element (L1)
- MTF
  - Higher MTF (specs, smaller pixel pitch) and smaller color aberration requirements often drive the number of optical elements up, which has an impact on TTL.
- Field Curvature
  - Factors heavily in finite imaging design such as DMS, and longer lenses tend to enable smaller field curvature. (shorter TTL may exacerbate)

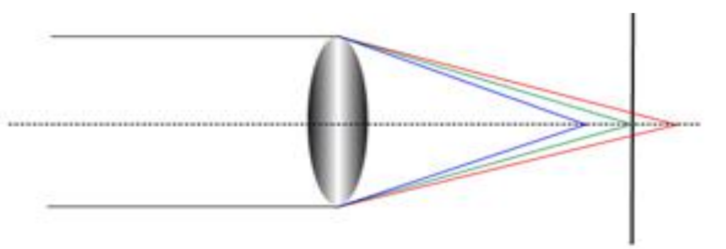


Source: sunex.com/capabilities

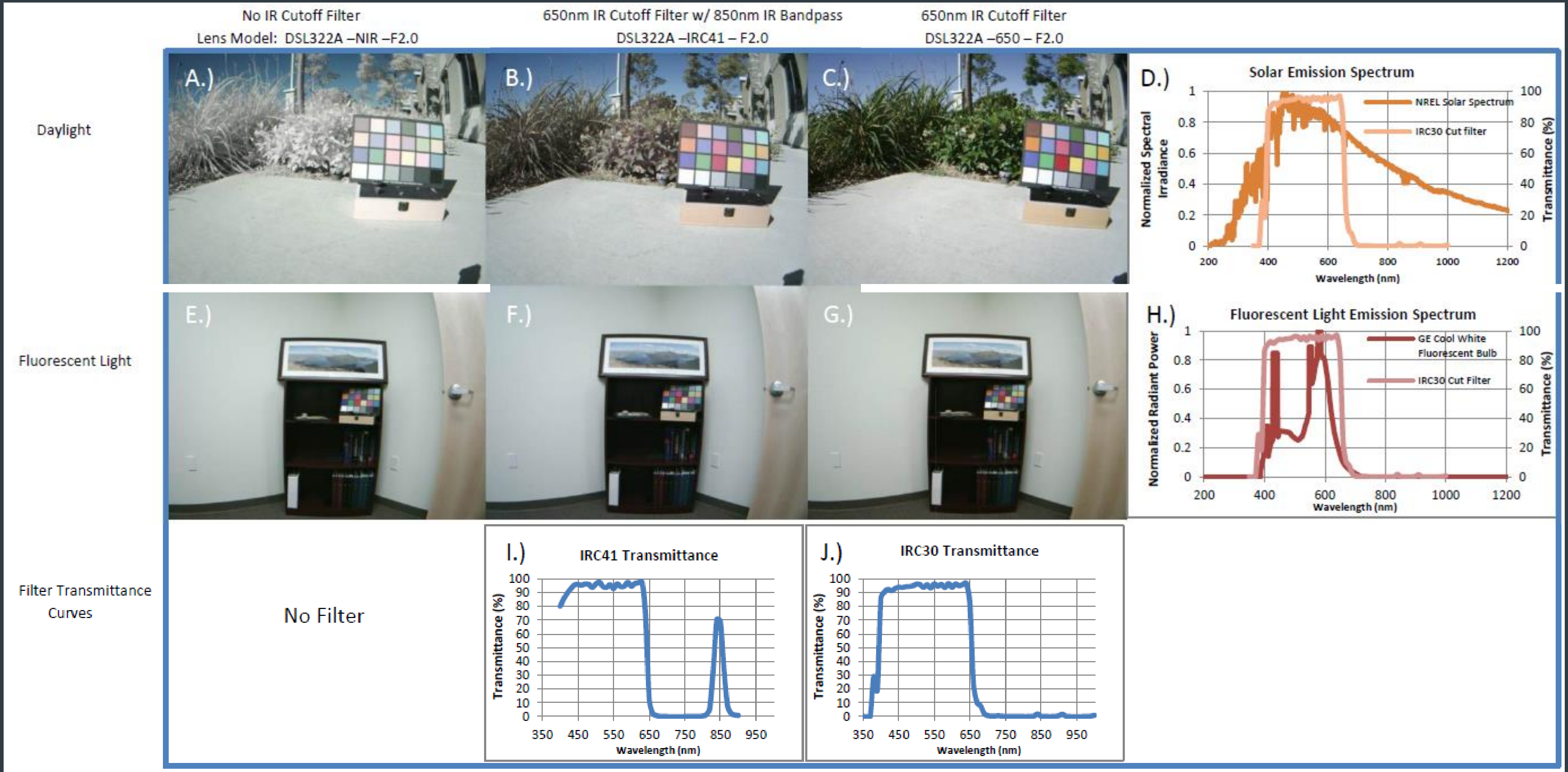
Law of Refraction

Due to the law of refraction, different wavelengths focus at different points along the optical axis (z-axis) which can lead to longitudinal chromatic aberration in an optical system.

Therefore, if a lens is not purposely optimized for NIR AND VIS wavelengths simultaneously, the ideal focus position of a lens for NIR light will occur beyond the VIS image plane and thus look “soft” or out of focus. Even if the lens is using VIS & NIR simultaneously, the image will look soft since much of the light (IR) is out of focus.


longitudinal chromatic aberration

Visible, IR or RGBIR – What difference does it make?

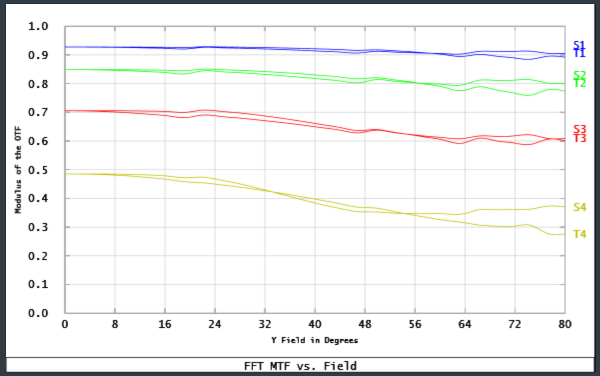


Assumes no possibility to refocus the lens

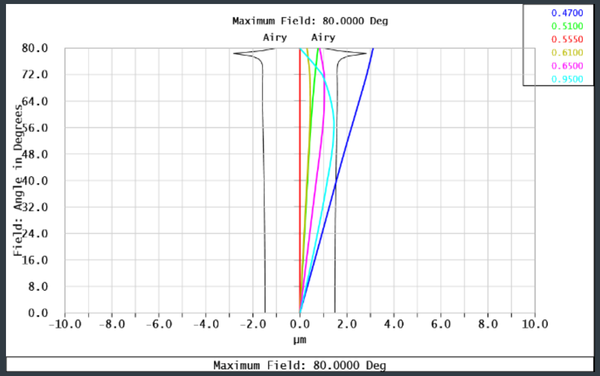
Visible, IR or RGBIR – Lens Design Consideration for RGBIR

A RGB-IR lens delivers a consistent performance across a wide spectrum (VIS to NIR).

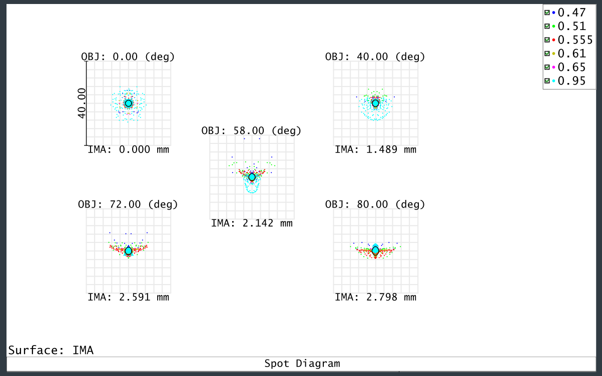
- Optical aberration is minimized at all wavelengths within this spectral band.
- Typically also requires a high performance super BBAR (SBBAR) coating
- Can be combined with a dual band IR-cut filter
- Ideal for application where a mix of visible and NIR LEDs may be used to illuminate the scene, or in scenarios with VIS ambient + IR illumination.



MTF



Lateral Color



Spot diagram

Visible, IR or RGBIR – Lens Design Consideration for RGBIR

B

Notes

- Often requires aspherical optical elements
  - Plastic: cost advantage but requires deep expertise to overcome thermal shift and lifetime degradation
  - Glass: more material choices and regarded as best choice for thermal and lifetime but tradeoffs cost
- Performance vs. Cost balance highly depends on optimized structure (spherical, aspeherical, glass, plastic)
- High volume manufacturability requires deep process and material know-how that only can be gained over time “You actually have to do it!”

Consolidating DMS and OMS into DOMS

C

DMS		OMS
Narrow HFOV (60deg)	⟷	Wider HFOV (~140deg)
IR imaging	⟷	VIS or RGBIR Imaging
Legally Mandated (Euro NCAP, SAFE Act, …)	⟷	“Camera-based” OMS is an addon feature
Legal Requirements (What, When, Test …)	⟷	Defined by OEM and/or Tier1
F-tan Distortion Profile	⟷	F-theta Distortion Profiles
Can be small and compact	⟷	Larger than DMS

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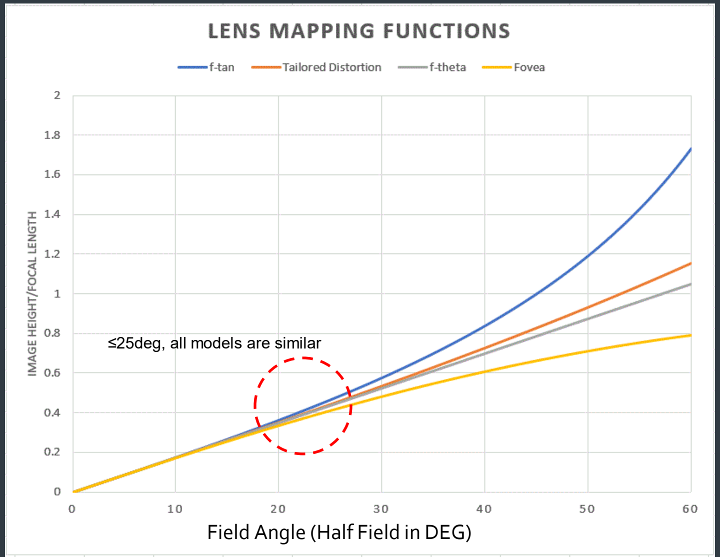
Consolidating DMS and OMS into DOMS – Distortion Profiles

C

The concept of distortion describes how a lens maps a shape on the object plane to the image plane.

There are many different models to predict where you ‘expect’ to see the object in the image.

- For small angles, F-tan and F-theta are not much different.
- Out to ~60deg, there’s less than 10% difference between them.
- It really matters most for wide FOV.



Distortion Model	Behavior	Px/deg	Applications
F-tan (rectilinear)	Straight edge on the object plane is mapped as a straight edge in the image plane	Increases the px/deg ratio towards full field	photographic lenses including smartphone lenses.
F-theta	Forms an image where the image height is proportional to the field angle of the incident light	Perfect f-theta is a linear px/deg ratio	machine vision, computer vision and scanning applications
Tailored Distortion™	Enables wide angle / fisheye lenses with increased peripheral vision	Tailored Distortion increase the px/deg ratio towards full field	Automotive Surround View, ceiling mounted security camera lenses
Fovea Distortion	“Fovea” distortion “exaggerate” the central details while trading off the off-axis details (similar to the human eye)	px/deg ratio I the highest at the center and declines towards full field	Automotive ADAS

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Consolidating DMS and OMS into DOMS – Distortion Profiles

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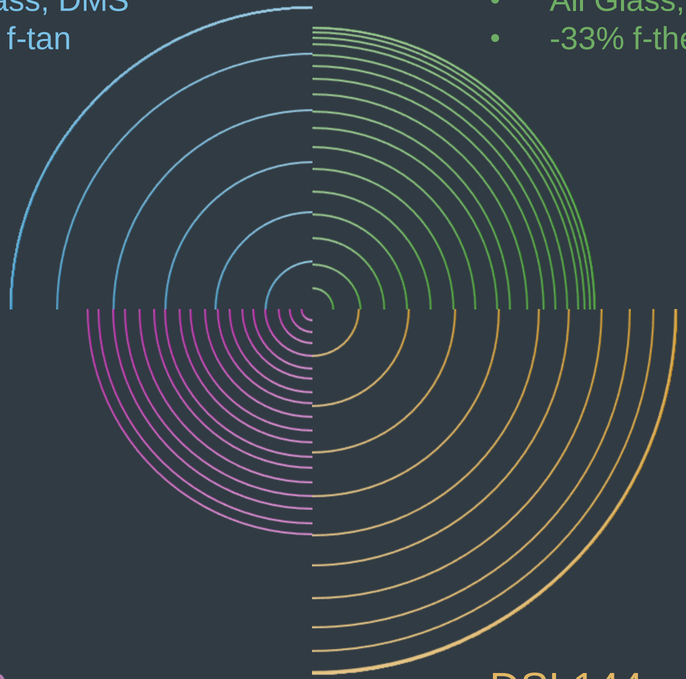
	DSL965	DSL213	DSL189	DSL144
Description	All Glass DMS	All Glass Wide Angle	Hybrid OMS	Hybrid ADAS
Imager Format	1/3"	Up to 1/3"	1/2.7"	1/1.8"
Imager Resolution	2MP	2.0MP	2MP	1.7MP
EFL	5.83mm	3.0mm	1.4mm	6.2mm
F/#	2.8	2.0	2.0	1.6
Image Circle	6.4mm	6.0mm	5.6mm	7.8mm
Field of View	58° @ 6.4mm IC	170˚ at 6.0mm IC	217° @ 5.6mm IC	102° @7.8mm IC
Total Track Length	9.92mm	20.0mm	17mm	24mm
Distortion (full field)	-2.1% f-tan	-33% f-theta	5.2% f-theta Tailored Distortion	-50% f-tan FOEVA

DSL965
- All Glass, DMS
- -2.1% f-tan

DSL213
- All Glass, Wide Angle
- -33% f-theta



DSL189
- Hybrid OMS
- 5.2% F-theta
- Tailored Distortion™ Lens

DSL144
- Hybrid ADAS
- -50% f-tan
- FOVEA Lens

Every ring = 5deg   Larger gap between rings = more px/deg   Outer ring = max IC

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Consolidating DMS and OMS into DOMS – Distortion Profiles

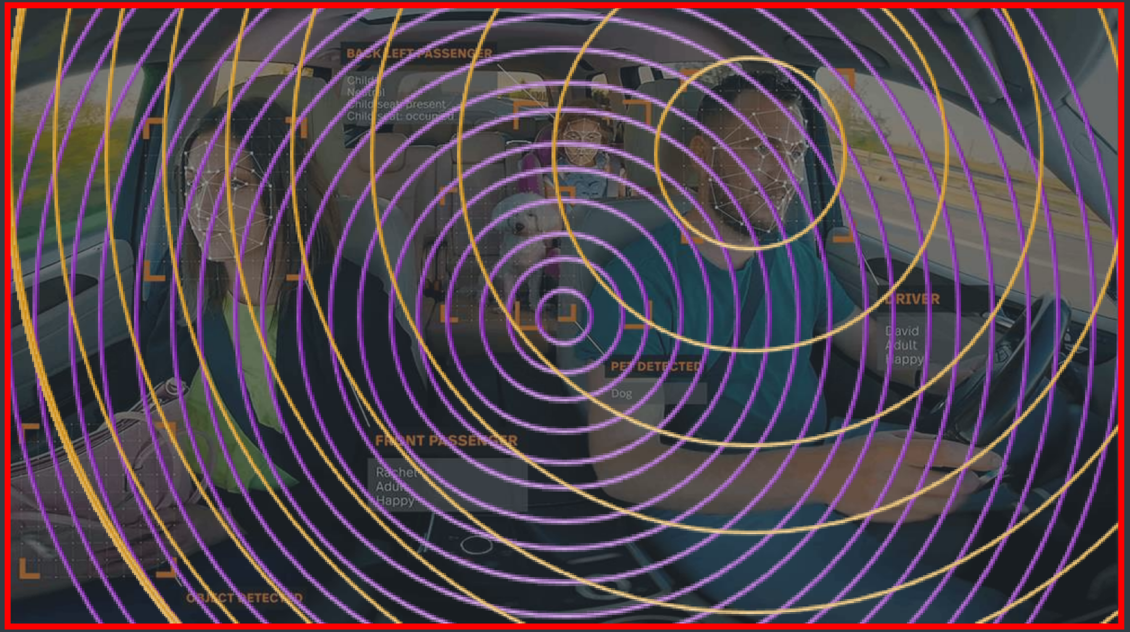
C

DOMS Applications

- Tailored Distortion™ Lens enables wide angle with a linear px/deg ratio, including the off-center position of the driver.
- FOVEA Lenses aligned off-center relative to the sensor can enable a magnified area around the driver while maintaining peripheral view of the remaining occupants with a uniform px/deg ratio.

Both approaches benefit from a radial-symmetric lens system that can be manufactured in high volumes, with good yield, for a reasonable cost.

Example: 1/2.5”, 5Mpx InCabin Sensor (V cropped)



DSL392
- All Glass RGBIR
- 16% F-theta
- Tailored Distortion™ Lens

DSL189
- Hybrid OMS
- 5.2% F-theta
- Tailored Distortion™ Lens

DSL144
- Hybrid ADAS
- -50% f-tan
- FOVEA Lens

Consulting, Design, and Manufacturing Services

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