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Robust Design of a Camera Sensor for ADAS and Autonomous Vehicles

Speaker

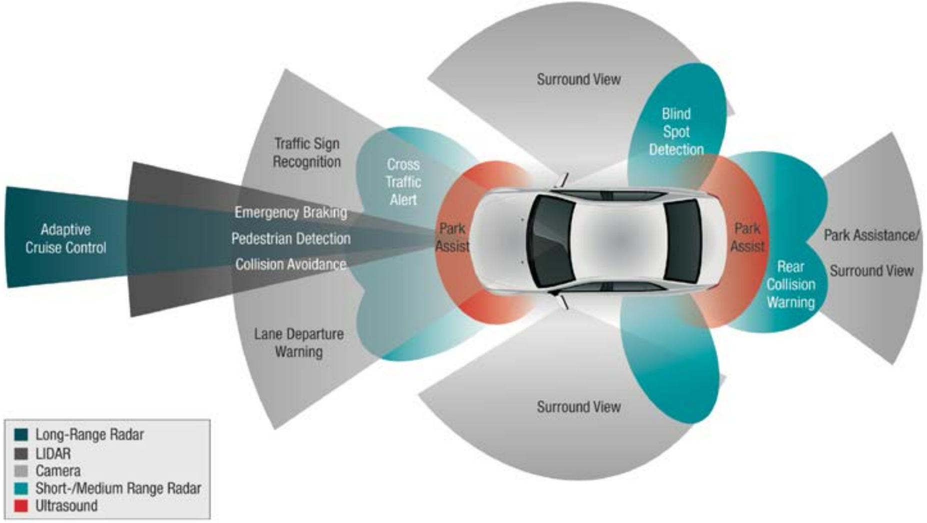
Sanjay Gangadhara

Chief Technology Officer, Zemax

Tasked with identifying new technology that increases the functionality and capability of all Zemax software solutions, Sanjay leads a cross-functional team of product managers, computational physicists, and software development engineers. His background in general physics, electromagnetism, and optical system diagnostics has served him well in his various roles at Zemax, including optical scientist, senior analyst, director of research and development, and now CTO.

Requirements for ADAS and the role of camera sensors

- International standards for autonomous driving range from full driver control (level 0) to fully autonomous (level 5)
- Visible camera systems are an important part of the sensor ecosystem required for level 5 autonomy
- Such systems generally require robust performance over a wide field-of-view



Source: https://www.embedded-vision.com/sites/default/files/technical-articles/Texas_Instruments_spry260/Figure1.png

Designing Wide-Angle Lens Systems for ADAS

- Wide-angle lens systems used for ADAS/AV need to provide high visual acuity over a large field-of-view (FOV) and over the full visible spectrum
- Performance measured using spot size, distortion, MTF

Source: https://www.digitalphotomentor.com/photography/2015/05/wide-angle-lenses-750px-10.jpg

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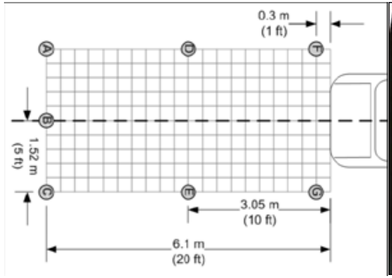
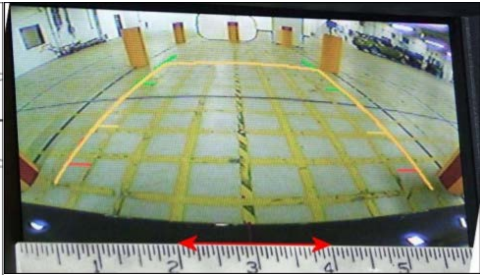
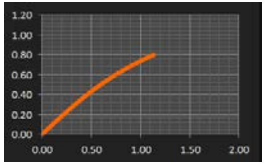
Use Case: Rear Visibility

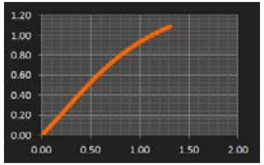
- Virtually validate automotive rearview image against the Federal Motor Vehicle Safety Standard 111 (FMVSS111) of the National Highway Traffic Safety Administration (NHTSA)



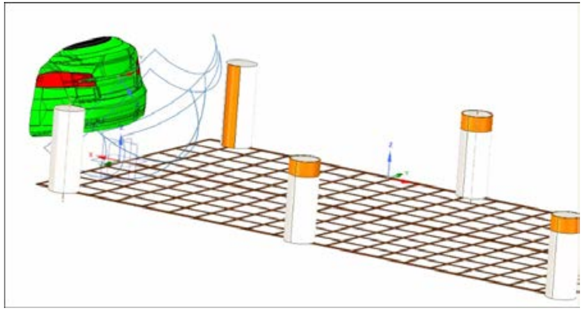




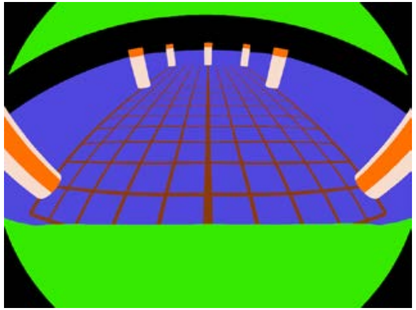
HFOV 130°



HFOV 150°



3D model



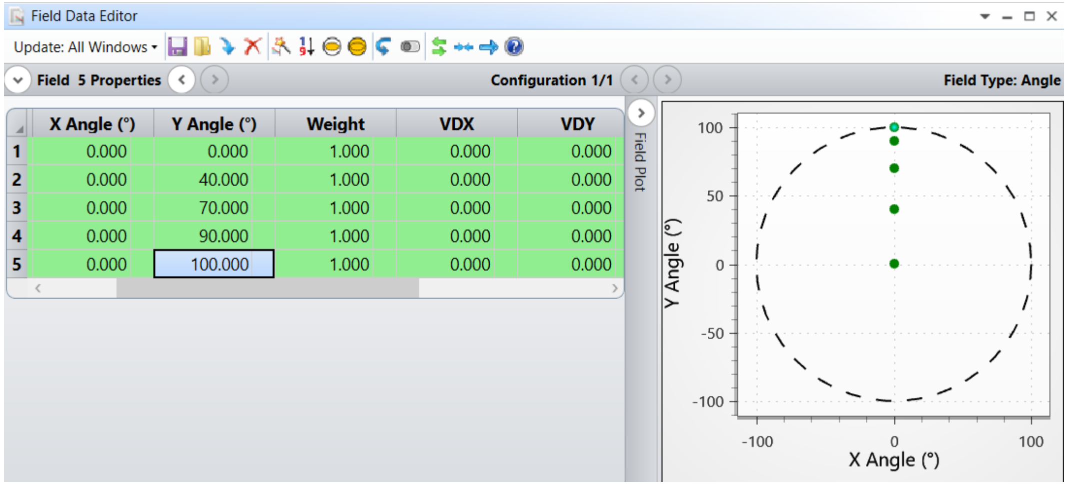
Camera view

Stripe of F visible	false
Stripe of G visible	false
A detected	true
B detected	true
C detected	true
D detected	true
E detected	true
Average visual angle test	true
Average visual angle	21.87
Visual angle A test	true
Visual angle A	23.51
Visual angle B test	true
Visual angle B	21.05
Visual angle C test	true
Visual angle C	21.05
NHTSA FMVSS111 - Rearview image testing	false

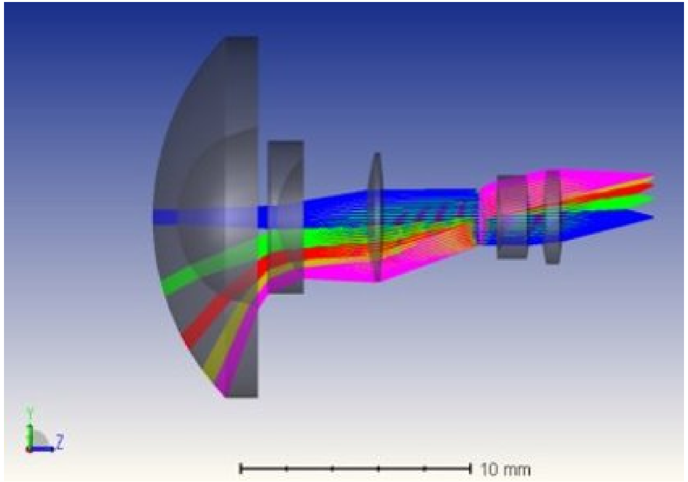
Stripe of F visible	true
Stripe of G visible	true
A detected	true
B detected	true
C detected	true
D detected	true
E detected	true
Average visual angle test	true
Average visual angle	15.05
Visual angle A test	true
Visual angle A	16.23
Visual angle B test	true
Visual angle B	15.05
Visual angle C test	true
Visual angle C	13.87
NHTSA FMVSS111 - Rearview image testing	true

OpticStudio Model

- Wide-angle systems can be designed in the sequential mode of OpticStudio
  - Use Angle for the Field definition
- Designs generally require the first lens to be a large spherical (or aspheric) meniscus lens (i.e. a lens with small, positive radii of curvature on the front and back surfaces)

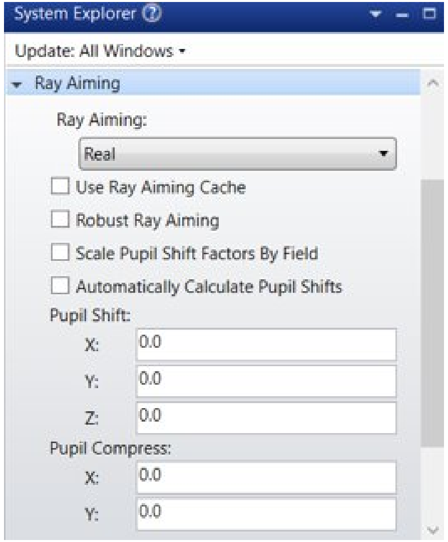


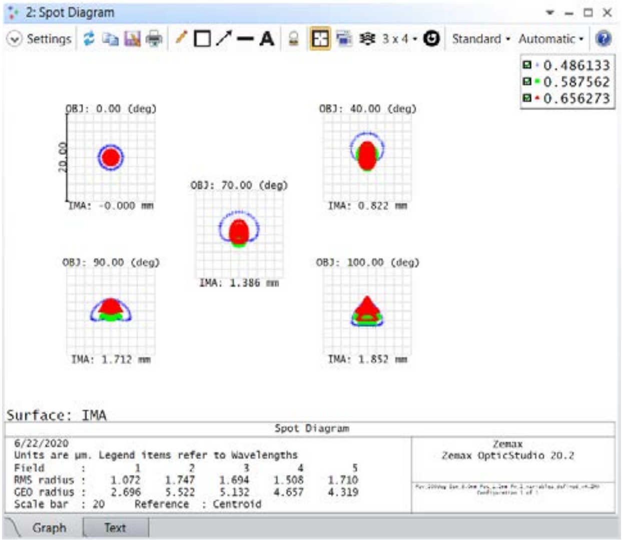
	X Angle (°)	Y Angle (°)	Weight	VDX	VDY
1	0.000	0.000	1.000	0.000	0.000
2	0.000	40.000	1.000	0.000	0.000
3	0.000	70.000	1.000	0.000	0.000
4	0.000	90.000	1.000	0.000	0.000
5	0.000	100.000	1.000	0.000	0.000

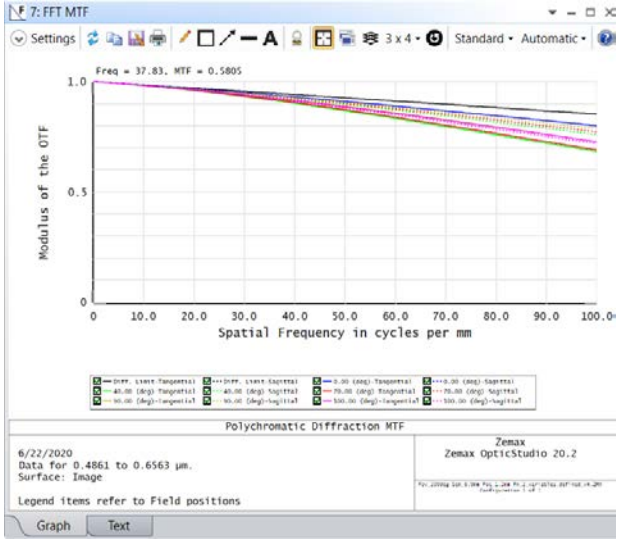


Nominal System Design Performance

- Accurate modeling requires use of Ray Aiming
- Nominal system shows good performance over FOV and wavelength range







OpticStudio Parameterization

- Use Ansys optiSLang to investigate design sensitivity to:
  - Curvature of the front and back lenses
  - Position of the aperture stop and detector
- Values varied within a range of 20%

	Parameter	Start designs	Criteria	Adaption	MOP	Other	Result designs	
	Name	**Parameter type**	**Reference value**	**Constant**	**Value type**	**Resolution**	**Range**	**Range plot**
1	_11_Standard.Radius	Optimization	8.80018	☐	REAL	Continuous	7.04014 10.5602	
2	_12_Standard.Radius	Optimization	-11.4269	☐	REAL	Continuous	-13.7123 -9.14152	
3	_12_Standard.Thickness	Optimization	3.89683	☐	REAL	Continuous	3.11746 4.6762	
4	_1_Standard.Radius	Optimization	11.2011	☐	REAL	Continuous	8.96088 13.4413	
5	_2_Standard.Radius	Optimization	3.94598	☐	REAL	Continuous	3.15678 4.73518	
6	_6_Standard.Thickness	Optimization	4.132	☐	REAL	Continuous	3.3056 4.9584	

Lens Data

Update: Editors Only

Surface 6 Properties

Configuration 1/1

	Surface Type		Comment	Radius	Thickness	Material	Coating	Semi-Diameter	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity	Infinity			Infinity U	0,000	Infinity U	0,000	0,000
1	(aper)	Standard		11,201 V	1,033	TAFD35		7,815 U	0,000	7,815 U	0,000	-
2	(aper)	Standard		3,946 V	4,132			3,927 U	0,000	7,815 U	0,000	0,000
3	(aper)	Standard		-34,626	0,207	TAF5		3,310 U	0,000	3,310 U	0,000	-
4	(aper)	Standard		3,449	3,873			2,623 U	0,000	3,310 U	0,000	0,000
5	(aper)	Standard		9,635	0,826	SF58		2,803 U	0,000	2,803 U	0,000	-
6	(aper)	Standard		-21,624	4,132 V			2,777 U	0,000	2,803 U	0,000	0,000
7	STOP (aper)	Standard		Infinity	0,647			1,180 U	0,000	1,180 U	0,000	0,000
8	(aper)	Standard		9,208	0,683	H-LAK52		1,541 U	0,000	1,828 U	0,000	-
9	(aper)	Standard		-2,422	0,921	SF58		1,541 U	0,000	1,828 U	0,000	-
10	(aper)	Standard		-8,600	0,413			1,828 U	0,000	1,828 U	0,000	0,000
11	(aper)	Standard		8,800 V	0,984	C41-60		2,025 U	0,000	2,049 U	0,000	-
12	(aper)	Standard		-11,427 V	3,897 V			2,049 U	0,000	2,049 U	0,000	0,000
13	IMAGE	Standard		Infinity	-			1,855	0,000	1,855	0,000	0,000

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OpticStudio Figures of Merit

- The following Merit Function operands are used by Ansys optiSLang for analysis:
  - EFFL: Effective Focal Length
  - WFNO: Working F/#
  - RSCE: RMS spot radius with respect to the centroid
  - GMTA: Geometric MTF (average of sagittal and tangential)

Parameter

Name	Value
_11_Standard.Radius	8.80018
_12_Standard.Radius	-11.4269
_12_Standard.Thickness	3.89683
_1_Standard.Radius	11.2011
_2_Standard.Radius	3.94598
_6_Standard.Thickness	4.132

Responses

Name	Value
EFFL	1.19999
GMTA_F1_Freq30	0.94907
GMTA_F1_Freq50	0.908211
GMTA_F5_Freq30	0.937941
GMTA_F5_Freq50	0.879019
RSCE_Hy0	0.000901079
RSCE_Hy0.4	0.00155433
RSCE_Hy0.9	0.00123625
RSCE_Hy1	0.0014626
WFNO	2.00003

Merit Function Editor

Wizards and Operands   Merit Function: 0,00107211320256246

	Type	Samp	Wave	Field	Freq	!Scl	Grid		Target	Weight	Value	% Contrib
1	EFFL		2						1,200	1,000	1,200	6,567E-04
2	WFNO								2,000	1,000	2,000	0,016
3	RSCE	5	0	0,000	0,000				0,000	1,000	9,011E-04	11,773
4	RSCE	5	0	0,000	0,400				0,000	1,000	1,554E-03	35,031
5	RSCE	5	0	0,000	0,900				0,000	1,000	1,236E-03	22,161
6	RSCE	5	0	0,000	1,000				0,000	1,000	1,463E-03	31,018
7	GMTA	2	0	1	30,000	0	0		0,000	0,000	0,949	0,000
8	GMTA	2	0	1	50,000	0	0		0,000	0,000	0,908	0,000
9	GMTA	2	0	5	30,000	0	0		0,000	0,000	0,938	0,000
10	GMTA	3	0	5	50,000	0	0		0,000	0,000	0,879	0,000

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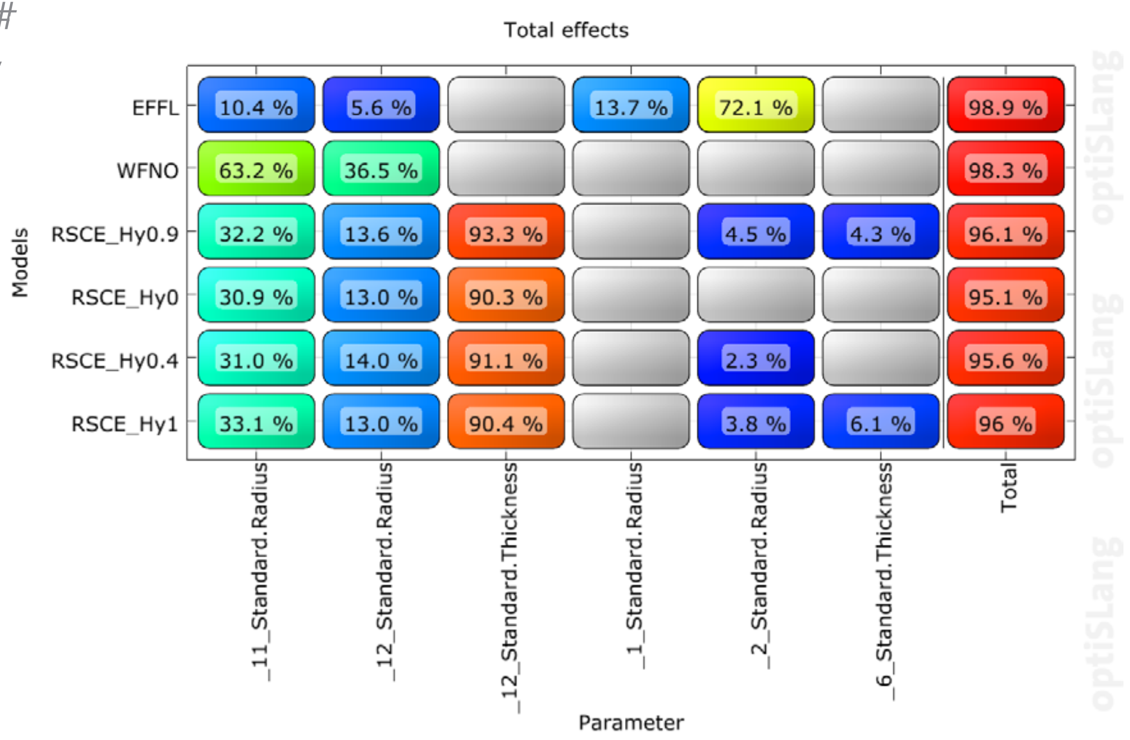
optiSLang Sensitivity Analysis – CoP Matrix

- Effective Focal Length, Working F/# and RMS Spot Radius achieve very high model accuracy
  - CoP > 90%
- Model accuracy is poor for Geometric MTF
  - Rapid degradation of performance with parameter changes



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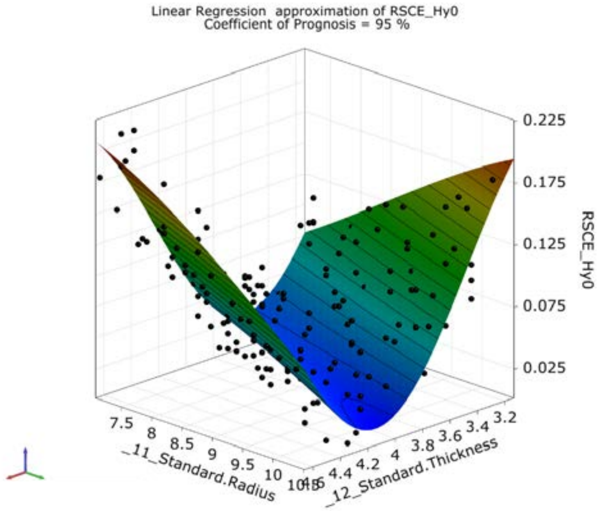
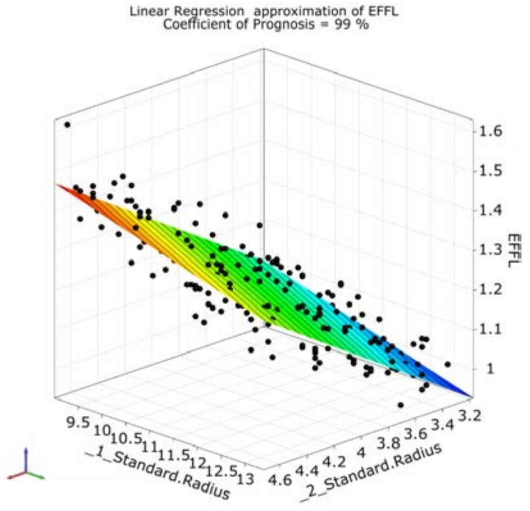
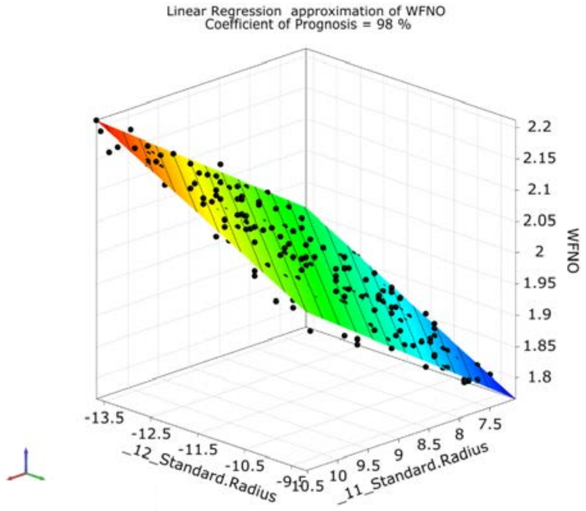
optiSLang Sensitivity Analysis – MOP

- Post-processing shows a 3D-subspace-plot of the approximation function depending on the two most important parameters
- Spot Radius (RSCE) increases quadratically
- Effective Focal Length and Working F/# increase linearly







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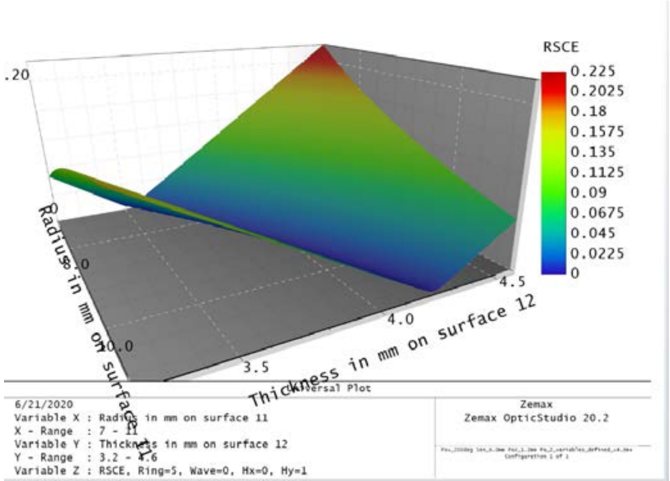
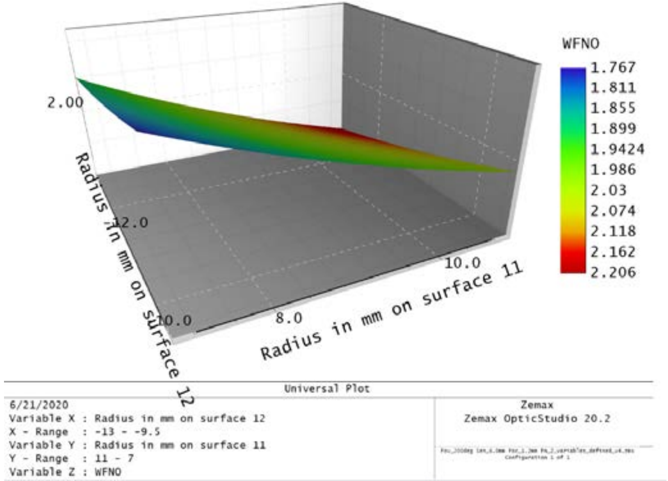
OpticStudio – Universal Plot

- optiSLang results provide insight into which parameters have the highest impact on system performance
- Variational response confirmed in OpticStudio with the Universal Plot





OpticStudio Tolerance Analysis

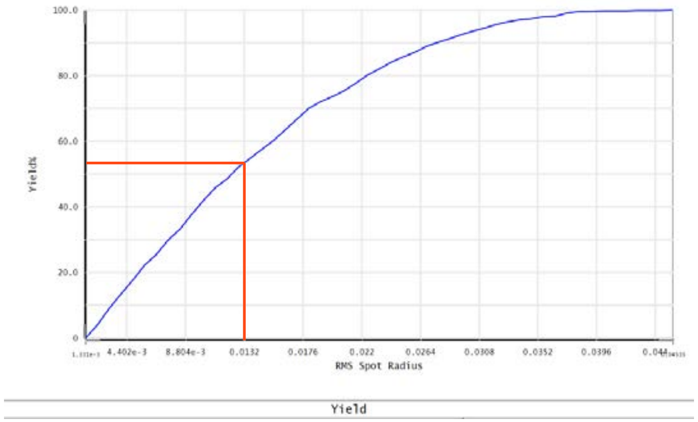
- Using data from optiSLang as a guide, a full tolerance analysis is conducted in OpticStudio
  - Use Normal statistics for parameters under variation
- Results confirm highest sensitivity of RMS spot size and Geometric MTF to front surface curvature of last lens and detector position
- Currently see ~50% yield at nominal design performance
  - May need to modify design or tighten tolerances to improve

Sensitivity Analysis:

			|-----------	---- Minimum	--------------|	|------------	---- Maximum ----	----------|
Type			Value	Criterion	Change	Value	Criterion	Change
TRAD	1	0	-0.20000000	0.00138549	0.00011820	0.20000000	0.00128686	1.9565E-05
TRAD	2	0	-0.20000000	0.00411967	0.00285238	0.20000000	0.00384555	0.00257826
TRAD	11	0	-0.20000000	0.00673456	0.00546727	0.20000000	0.00640024	0.00513294
TRAD	12	0	-0.20000000	0.00334076	0.00207347	0.20000000	0.00350450	0.00223720
TTHI	6	6	-0.20000000	0.00415628	0.00288899	0.20000000	0.00400302	0.00273573
TTHI	12	12	-0.20000000	0.03725487	0.03598757	0.20000000	0.03729178	0.03602449

Worst offenders:

Type			Value	Criterion	Change
TTHI	12	12	0.20000000	0.03729178	0.03602449
TTHI	12	12	-0.20000000	0.03725487	0.03598757
TRAD	11	0	-0.20000000	0.00673456	0.00546727
TRAD	11	0	0.20000000	0.00640024	0.00513294
TTHI	6	6	-0.20000000	0.00415628	0.00288899
TRAD	2	0	-0.20000000	0.00411967	0.00285238
TTHI	6	6	0.20000000	0.00400302	0.00273573
TRAD	2	0	0.20000000	0.00384555	0.00257826
TRAD	12	0	0.20000000	0.00350450	0.00223720
TRAD	12	0	-0.20000000	0.00334076	0.00207347



OpticStudio to SPEOS

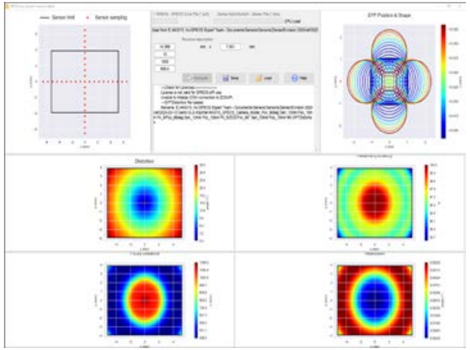
- Once design of the camera is complete, the model can be moved into Ansys SPEOS for a full model simulation

Zemax OpticStudio®

Ansys / SPEOS

Ansys / SPEOS

Zemax Black Box (ZBB)



SPEOS Lens System (SLS)

Lens design

SPEOS Lens System Importer

Camera simulation

Summary

- Wide-angle lenses play an important role in camera sensors used for ADAS/AV
  - Such lenses can be challenging to design
- Rigorous algorithms in OpticStudio provide baseline design
- optiSLang can be used to investigate key parameters that impact system performance
- Results provide engineers insight into decisions that improve system design and reduce time-to-market