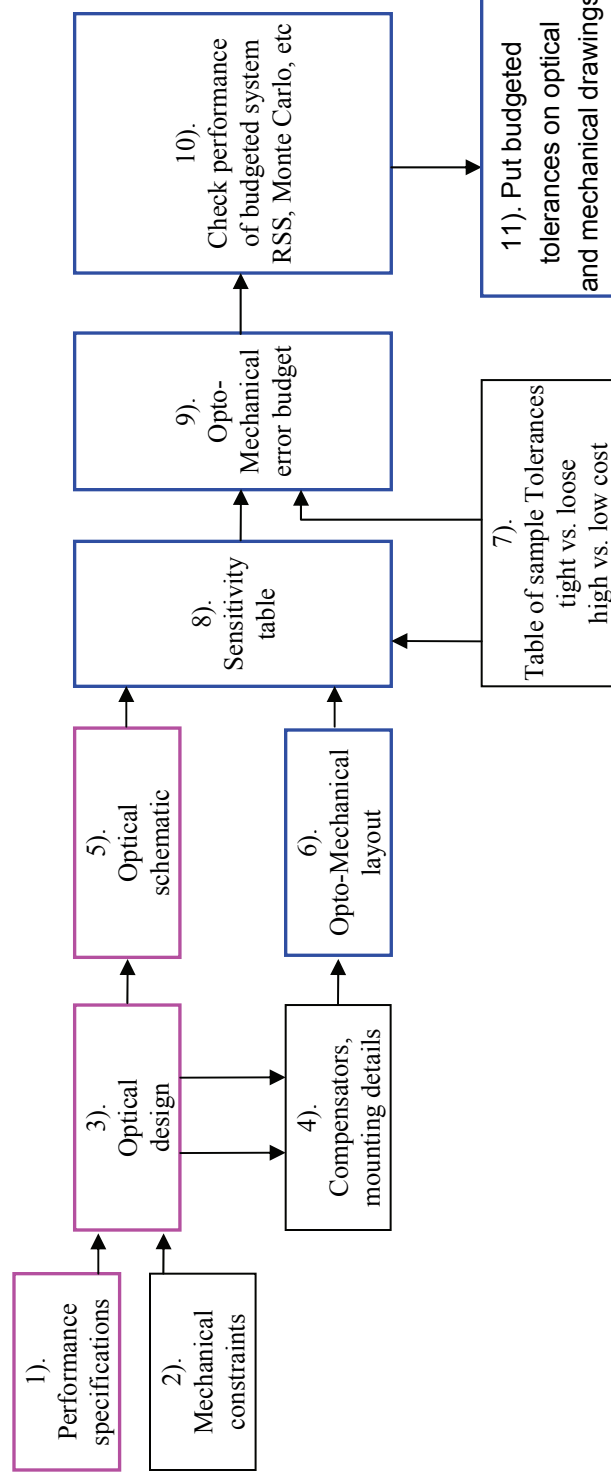



Tolerance analysis using Zemax, the case for the small optics

OPTI521, Sooyong Nam

Purpose and procedure to perform tolerance analysis

- To understand optical system, cell phone camera lens.
- To understand important tolerances in the system.
- To find and implement better fabrication process.





Design specification of the lens –VGA Cellphone camera

- Fixed focus VGA cell phone camera lens specification has presented.
- As a merit function of the sensitivity analysis, 20% MTF drop at 45 lp/mm is used.

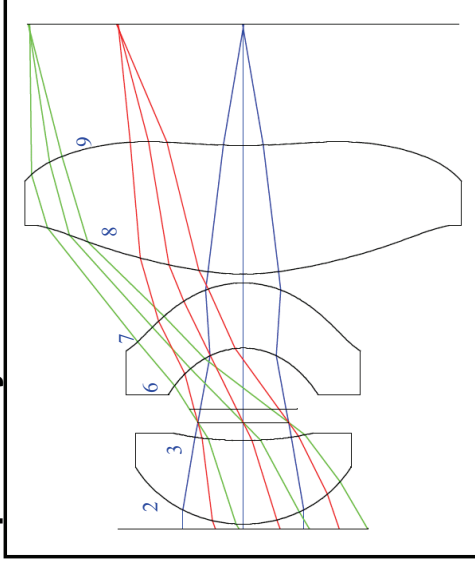
Specification item	Required performance
Field of view	60 degrees
F#	2.8
Number of lens elements	3 plastic lenses
Pixel size	5.6 μm
Distortion	<2%
Image sensor size	3.58mm x 2.69mm
Resolution	125lp/mm @center

Optical schematics and performance

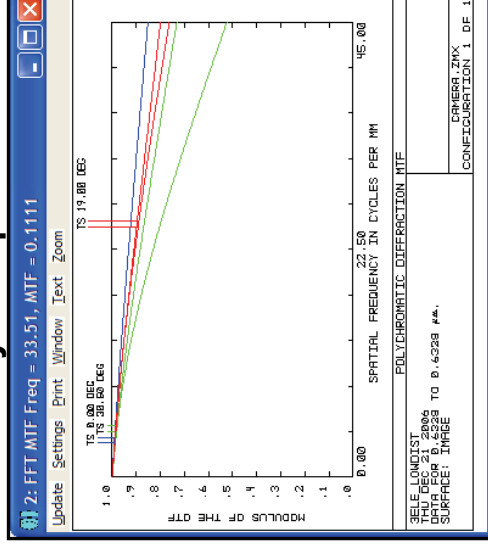
-VGA Cellphone camera

- Three aspheric plastic lenses, both aspheres
- Two aperture stops between surface 3 and surface 6.
- Zeonex E48R and Polycarbonate. 1.45~1.5. It is very clear and stable
- Total length is about 5.3mm
- Diameters are from 2.6mm to 4.6mm.
- Nominal MTF @ 45mm/lp is 0.851
- 0degree field @ .632 μ m ray will be used to analyze tolerance

Optical layout

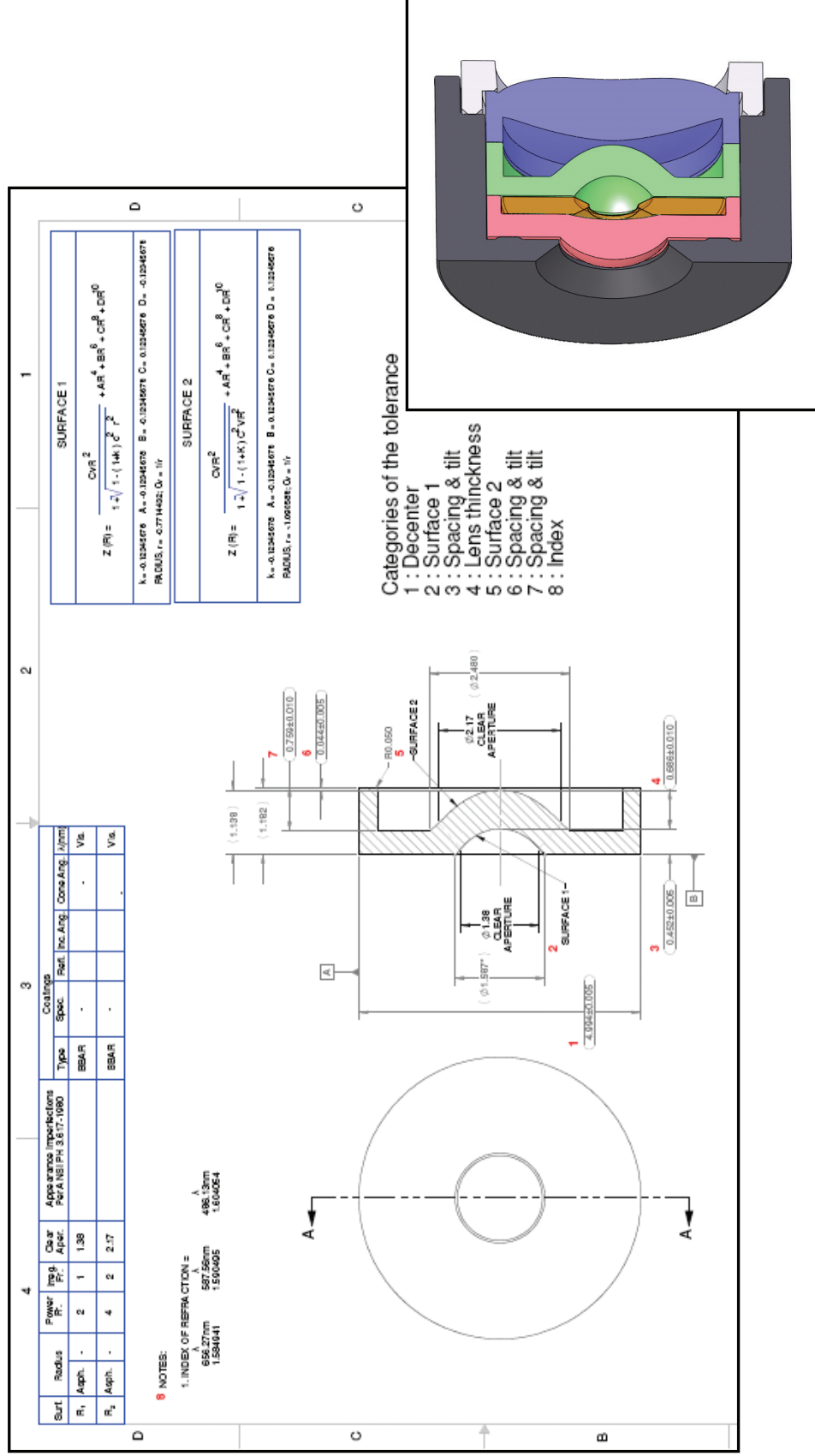


Nominal system performance



Optomechanical layout and tolerance details

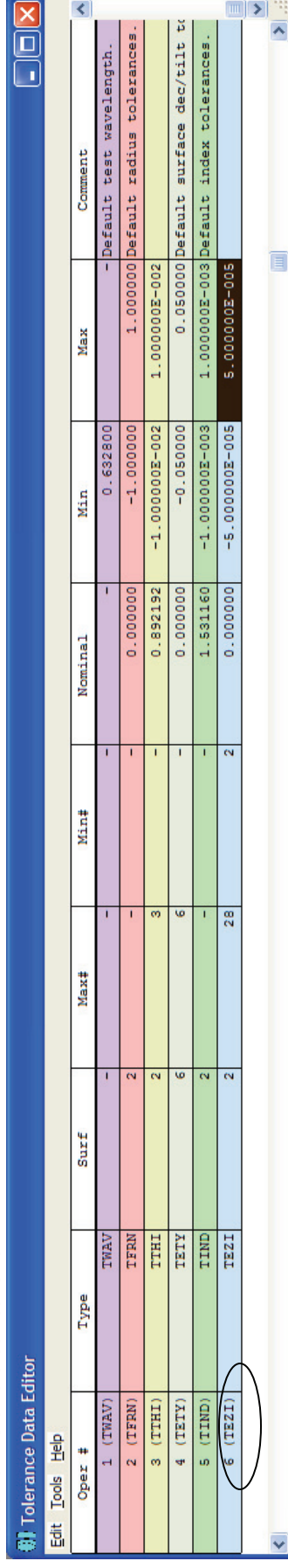
- Individual mount → flange surfaces are stacked together
- Retainer will be glued to the barrel to maintain lens assembly
- Surface power & irregularity, index of refraction, center thickness, element tilt, element decenter, and element spacing tolerance will be analyzed



Tolerancing routine in Zemax

- Input data to execute tolerance analysis from Zemax.
 - Radius of each surface (power) → 1 fringe
 - Thickness → 0.01mm
 - Surface tilt → 0.05 degree
 - Index change → 0.001
 - Element tilt → 0.05 degree
 - Element decenter → 0.010mm
 - RMS surface irregularity → 0.00005mm

Tolerance data table



Oper #	Type	Surf	Max#	Min#	Nominal	Min	Max	Comment
1 (TWAU)	TWAU	-	-	-	-	0.692800	-	- Default test wavelength.
2 (TFRN)	TFRN	2	-	-	0.000000	-1.000000	1.000000	Default radius tolerances.
3 (TTHI)	TTHI	2	3	-	0.892192	-1.000000E-002	1.000000E-002	
4 (TETY)	TETY	6	6	-	0.000000	-0.050000	0.050000	Default surface dec/tilt t
5 (TIND)	TIND	2	-	-	1.531160	-1.000000E-003	1.000000E-003	Default index tolerances.
6 (TEZI)	TEZI	2	28	2	0.000000	-5.000000E-005	5.000000E-005	

Tolerancing routine in Zemax

- Tolerances can be adjusted in “default tolerance window”
- Sensitivity table and statistic result can be calculated from “tolerancing window”

Tolerance control window

Default Tolerances

Surface Tolerances

Radius: 0.200000

Millimeters: 1.000000

Fringes: 0.010000

Thickness: 0.200000

Millimeters: 0.200000

Decenter X: 0.200000

Millimeters: 0.200000

Decenter Y: 0.200000

Tilt (TIR) X: 0.200000

Millimeters: 0.050000

Degrees: 0.200000

Tilt (TIR) Y: 0.200000

Millimeters: 0.200000

Degrees: 0.200000

S +A Ireg: 0.200000

Fringes: 0.200000

Zem Ireg: 0.200000

Fringes: 0.001000

Index: 1.000000

Abbe %: 1.000000

Start At Row: 1

Element Tolerances

Decenter X: 0.200000

Decenter Y: 0.010000

Tilt X: 0.050000

Degrees: 0.010000

Tilt Y: 0.010000

Use Focus Comp

OK Cancel Save Load Reset Help

Tolerance analysis control window

Tolerancing

Mode: Sensitivity

Monte Carlo Runs: 20

Save Monte Carlo Runs: 2

Criteria: Diff. MTF Avg: 45.000000

Sampling: 4

Comp: None

Fields: XY-Symmetric

Script: 0DUZZ.TSC

MTF Frequency: 17/10

Config: Auto

Cycles: Separate Fields/Configs

Force Ray Aiming On

Show Descriptors:

Show Compensators:

Statistics: Normal

Status: Idle

Overlay MC Graphics:


Hide All But Worst:

Show Worst: 10

OK Cancel Terminate Save Load Reset

Sensitivity table and error budget


1. Surface Element	2. Parameters and comment	3. Nominal value	4. Perturbed amount	5. % MTF drop	6. Sensitivity	7. Tolerances	8. Performance degradation
Lens1	Index of refraction	1.5312	0.0010	0.0550	55.03	0.00100	5.50
2-3	Thickness (mm)	0.8822	0.0100	0.0283	2.83	0.01000	2.83
	Tilt (deg)	0.0000	0.0500	0.0001	0.00	0.10000	0.02
	Decenter (mm)	0.0000	0.0100	0.0131	1.31	0.02000	2.62
2	Radius (mm)	1.3941	0.0011	0.0333	30.25	0.00220	6.66
2	Irr (mm)		0.0001	0.0001	2.80	0.00005	0.01
2	Wedge (deg)		0.0500	0.0002	0.00	0.10000	0.04
3	Radius (mm)	2.3987	0.0066	0.0410	6.20	0.01320	8.19
3	Irr (mm)		0.0001	0.0035	69.36	0.00005	0.35
3	Wedge (deg)		0.0500	0.0000	0.00	0.10000	0.00
	L1-L2 Spacing	0.9750	0.0100	0.0006	0.06	0.01000	0.06
	RSS of all Lens1 error			0.0824			12.52
Lens2	Index of refraction	1.2855	0.0010	0.0045	4.52	0.00100	0.45
6-7	Thickness (mm)	0.6690	0.0100	0.0174	1.74	0.01000	1.74
	Tilt (deg)	0.0000	0.0500	0.0001	0.00	0.10000	0.02
	Decenter (mm)	0.0000	0.0100	0.0029	0.29	0.02000	0.58
6	Radius (mm)	0.9225	0.0009	0.0182	21.44	0.00170	3.65
6	Irr (mm)		0.0001	0.0046	91.50	0.00005	0.46
6	Wedge (deg)		0.0500	0.0003	0.01	0.10000	0.06
7	Radius (mm)	1.4327	0.0008	0.0086	10.23	0.00336	3.44
7	Irr (mm)		0.0001	0.0042	83.12	0.00010	0.83
7	Wedge (deg)		0.0500	0.0002	0.00	0.10000	0.05
	L2-L3 Spacing	0.0950	0.0100	0.0348	3.48	0.01500	5.22
	RSS of all Lens2 error			0.0446			7.54
Lens3	Index of refraction	1.5312	0.0010	0.0056	5.56	0.00100	0.56
8-9	Thickness (mm)	1.2940	0.0100	0.0582	5.82	0.01000	5.82
	Tilt (deg)	0.0000	0.0500	0.0000	0.00	0.10000	0.00
	Decenter (mm)	0.0000	0.0100	0.0008	0.08	0.02000	0.16
8	Radius (mm)	4.8695	0.0032	0.0021	0.64	0.01595	1.03
8	Irr (mm)		0.0001	0.0015	29.99	0.00015	0.45
8	Wedge (deg)		0.0500	0.0000	0.00	0.10000	0.00
9	Radius (mm)	8.2474	0.0085	0.0007	0.09	0.04250	0.36
9	Irr (mm)		0.0001	0.0004	4.37	0.00030	0.13
9	Wedge (deg)		0.0500	0.0000	0.00	0.10000	0.00
	L3-image plane Spacing (mm)	1.2170	0.0100	0.0532	5.32	0.01500	7.99
	RSS of all Lens3 error			0.0789			9.97
	Total RSS			0.1226			17.69



Sensitivity table and error budget

-Analysis

- Lens 1 and following space :
 - Dominant tolerance → Index change and power tolerance.
 - Surface wedge is negligible through the entire system.
- Lens 2 and following space :
 - Dominant tolerances → power of each surface and spacing between lens 2 and lens 3.
 - Lens 2 is the least sensitive element.
- Lens 3 and space between image plane :
 - Dominant tolerance → Lens thickness and spacing between lens3 and image plane
 - The rest of the other tolerances are quite forgiving compare to other lenses.



Conclusion

- Dominant errors and negligible errors have been clarified after tolerance analysis.
- Lens thickness, space between lens and power of each surfaces are dominant factors to affect performance.
- From the given optical design, opto-mechanical layout has been presented.
- Actual drawing with tolerance for the lens fabrication has been presented.
- Over all performance degradation is 17.7% MTF drop at 45lp/mm.
→ It achieves required specification.