College of Optical Sciences
The University of Arizona

Reverse engineering lens elements

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Introduction

- Need for reverse engineering
- Properties necessary for reverse engineering
- How to make necessary measurements
- How to calculate the paraxial properties
- Use of a spreadsheet for the solution
- Use of a lens design program to find a solution

Need for reverse engineering

- Actually want to copy someone's design
- Concern that lens may be wrong glass
- Lenses got mixed up, need to sort out
- Lens system does not work – right elements?

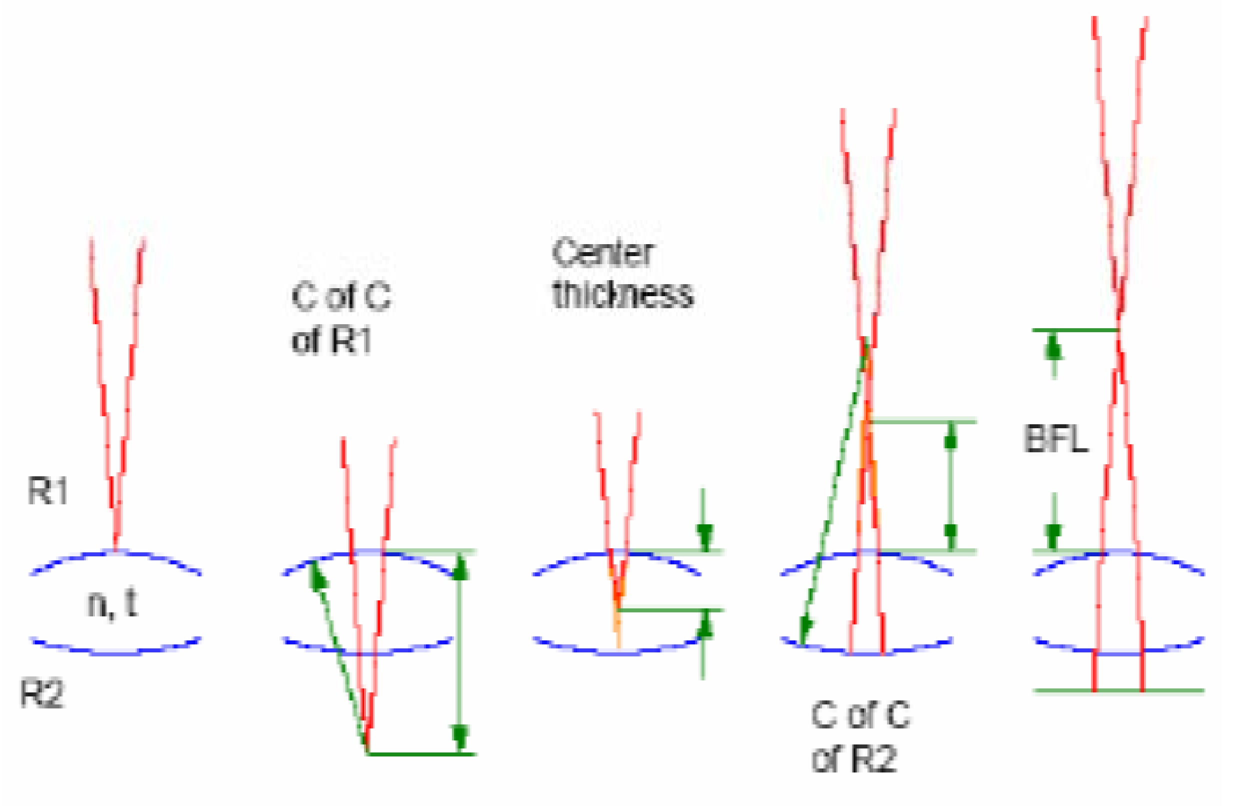
Properties needed to reverse engineer

- Just looking for paraxial properties
  - These are the properties on an optical drawing
- Two radii
- Glass type or index at the measurement wavelength
- Center thickness
  - Could measure physically, but may not want to, or can't

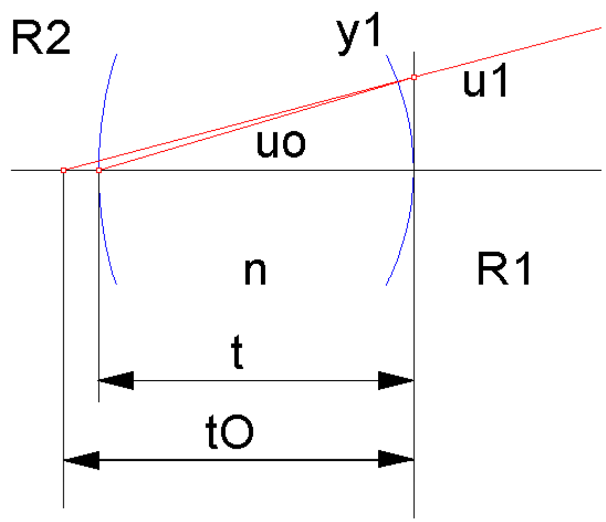
Measurements needed

- Radius of curvature but may not have working distance – reverse lens so backside concave
- Optical center thickness to rear vertex
- Back focal length from one or both sides
- Need at least 4 measurements to solve for 4 unknowns
- Extra measurements increase confidence

Measurements that can be made

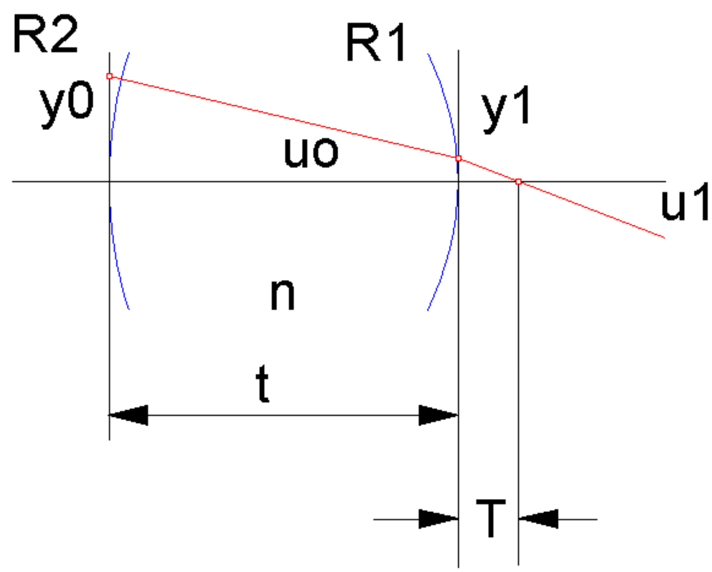


Center thickness



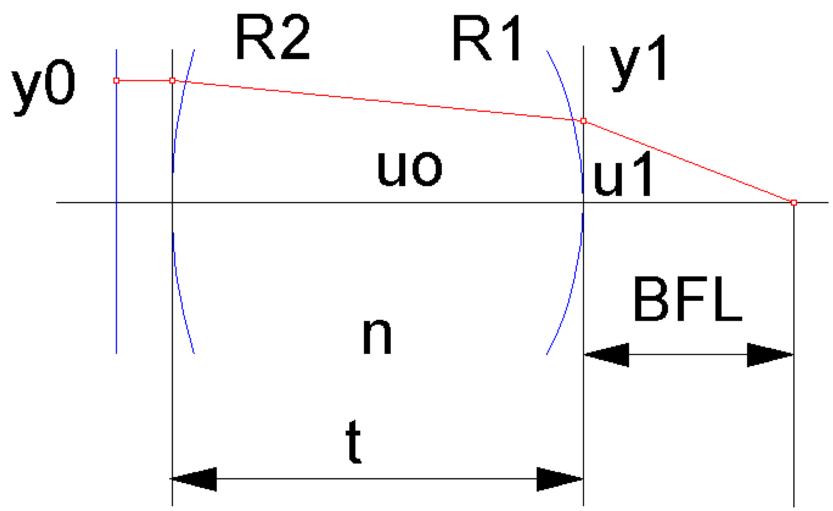
$$t_O = {y_1}/{u_1} = \frac{-tR_1}{nR_1 + t(n-1)}$$

Rear radius



$$T = \frac{y_1}{u_1} = \frac{\left(1 - \frac{t}{R_2}\right)}{\frac{n}{R_2} - \left[\frac{(n-1)\left(1 - \left(\frac{t}{R_2}\right)\right)}{R_1}\right]}$$

Back focal length



$$BFL = \frac{y_1}{u_1} = \frac{\left[1 - \frac{t(n-1)}{nR_2}\right]}{(n-1)\left[\frac{1}{R_2} - \frac{1}{R_1} + \frac{t(n-1)}{nR_1R_2}\right]}$$

No closed form solution for unknowns

- Use spreadsheet
  - Find difference between measured & guessed values
  - Square differences and sum
  - Make sum zero by varying unknowns
- Use a lens design program
  - Model the various measurement configurations
  - Use multi-configuration option
  - Use plane surfaces, guess thickness and a model for index
  - Use optimizer to find solution

Spreadsheet example

		measured	difference	difference^2
n, known or best estimate	1.45099			
t, known or best estimate	2.706816			
r1, known if shorter than working distance	2.237	2.237	0	0
r2, known or best estimate	-3.51362			
c1 = 1/R1, used in the calculation	0.447027			
a, optical center thickness based on	2.990021	2.99	-2.1E-05	4.5377E-10
known or estimated parameters				
b, R2 center of curvature based on	-0.49999	-0.5	-1.1E-05	1.25782E-10
known or estimated parameters				
d, BFL based on	-2.70001	-2.7	9.02E-06	8.13664E-11
known or estimated parameters				
a, b and d are all relative to vertex of R1		sum of squared differe		6.60918E-10

N, t and r_2 were estimated and a, b and c calculated

Solver used to minimize lower right hand cell to give calculated n, t and r_2 shown above.

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Lens design example

	Surf:Type	Comment	Radius		Thickness		Glass		Semi-Diameter	
OBJ	Standard		Infinity		Infinity				0.000000	
1	Paraxial				100.000000				12.700000	U
2	Standard	variable distance	Infinity		99.561047	V			0.000000	
STO*	Standard	R1	60.020000		4.000000		BK7		12.700000	U
4	Standard	R2 config 2 & 3	-353.300000		-4.000000	P	MIRROR		0.000000	
5*	Standard	R2 config 1	-353.300000		10.000000				12.700000	U
6*	Standard	mirror	Infinity		-10.000000	P	MIRROR		12.700000	U
7*	Standard	R2	-353.300000	P	-4.000000	P	BK7	P	12.700000	U
8*	Standard	R1	60.020000	P	-99.561047	P			12.700000	U
9*	Standard	R1 rev	353.300000	P	4.000000	P	BK7	P	12.700000	U
10*	Standard	R2 rev config 2,3	-60.020000	P	-4.000000	P	MIRROR	P	12.700000	U
11*	Standard	R2 rev config 1	-60.020000	P	10.000000				12.700000	U
12*	Standard	mirror	Infinity		-10.000000	P	MIRROR	P	12.700000	U
13*	Standard	R2 rev	-60.020000	P	-4.000000	P	BK7	P	12.700000	U
14*	Standard	R1 rev	353.300000	P	2.650440	P			12.700000	U
15	Standard		Infinity		-100.000000	P			12.700000	U
16	Paraxial	paraxial			0.000000				12.700000	U
17	Paraxial				-100.000000				12.700000	U
IMA	Standard		Infinity		-				0.083519	

Configuration 1 shown for calculation of bfl

Grayed out lines are ignored

Lens design example con't 1

Edit Solves Tools View Help

Active : 1/6		Config 1*		Config 2		Config 3		Config 4		Config 5		Config 6	
1: MOFF	0	BFL		R2		CT		BFL		R2		CT	
2: THIC	2	99.561047	V	77.411271	V	-2.701440	V	97.681577	V	35.085383	V	-2.650440	V
3: IGNR	3	0		0		0		1		1		1	
4: IGNR	4	1		0		0		1		1		1	
5: IGNR	5	0		1		1		1		1		1	
6: IGNR	6	0		1		1		1		1		1	
7: IGNR	7	0		1		1		1		1		1	
8: IGNR	8	0		0		0		1		1		1	
9: IGNR	9	1		1		1		0		0		0	
10: IGNR	10	1		1		1		1		0		0	
11: IGNR	11	1		1		1		0		1		1	
12: IGNR	12	1		1		1		0		1		1	

Configurations 1, 2 and 3 are looking thru short radius first

Configurations 4,5 and 6 are looking thru long radius first

Line 2 shows what the measurements should be knowing the index, thickness and two radii

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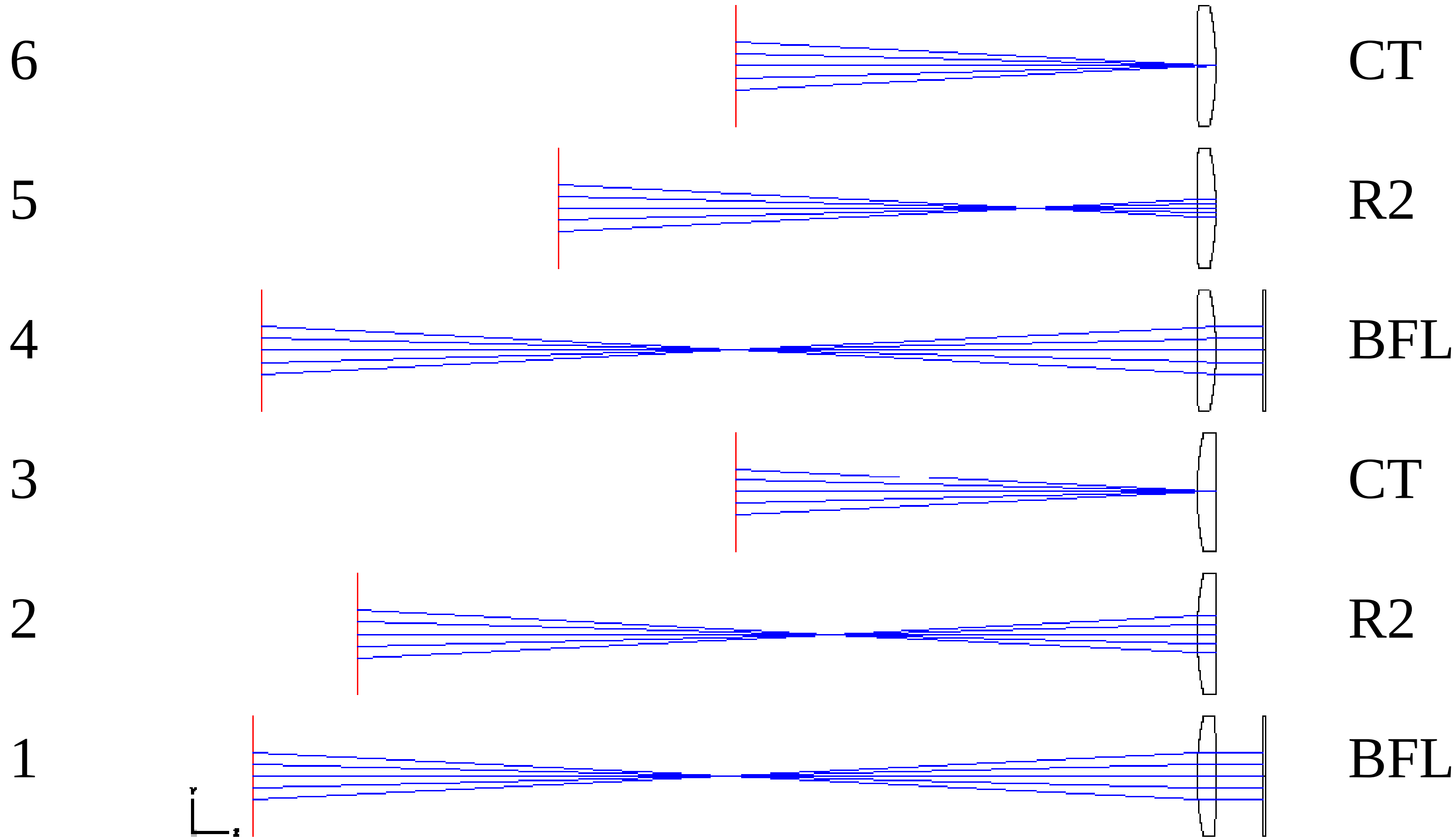
Lens design example con't 2



Lens design example con’t 3

Surf	Type	Comment	Radius		Thickness		Glass		Semi-Diameter	
OBJ	Standard		Infinity		Infinity				0.000000	
1	Paraxial				100.000000				12.700000	U
2	Standard	variable distance	Infinity		99.561047				0.000000	
STO*	Standard	R1	60.020000	V	4.000000	V	1.52,64.2		12.700000	U
4	Standard	R2 config 2 & 3	-353.300000		-4.000000	P	MIRROR		0.000000	
5*	Standard	R2 config 1	-353.300000	V	10.000000				12.700000	U
6*	Standard	mirror	Infinity		-10.000000	P	MIRROR		12.700000	U
7*	Standard	R2	-353.300000	P	-4.000000	P	1.52,64.2	P	12.700000	U
8*	Standard	R1	60.020000	P	-99.561047	P			12.700000	U
9*	Standard	R1 rev	353.300000	P	4.000000	P	1.00,0.0	P	12.700000	U
10*	Standard	R2 rev config 2,3	-60.020000	P	-4.000000	P	MIRROR	P	12.700000	U
11*	Standard	R2 rev config 1	-60.020000	P	10.000000				12.700000	U
12*	Standard	mirror	Infinity		-10.000000	P	MIRROR	P	12.700000	U
13*	Standard	R2 rev	-60.020000	P	-4.000000	P	1.00,0.0	P	12.700000	U
14*	Standard	R1 rev	353.300000	P	2.650440	P			12.700000	U
15	Standard		Infinity		-100.000000	P			12.700000	U
16	Paraxial	paraxial			0.000000				12.700000	U
17	Paraxial				-100.000000				12.700000	U
IMA	Standard		Infinity		-				0.083542	

Radii, thickness and index are set as variables

Optimized with small entrance pupil for paraxial solution

Conclusions

- Use all practical conjugate measurements in model
- Works with interferometer or autostigmatic microscope
- Works for doublets as well as singlets
  - Can usually see cement interface
  - Often better reflection than AR coated surfaces
  - Just a more complicated lens design model
- Need to know surfaces from centers of curvature
- Remember to stop down model before optimization
  - Model must find first order solution
- All in all, pretty easy to do