EELE 481 & 582 Optical Design Exam 1 Spring 2017

NAME ______________________________________

This is a take-home exam emphasizing conceptual understanding of optical design principles and practical implementation in Zemax. You may only ask questions of me, but you are free to use your books and class notes.

Timing: This exam will be available via D2L from Wednesday afternoon (March 8, 2017) until 11 pm on Friday night (March 10, 2017). You should expect to complete the exam in several hours. It must be turned in via D2L no later than midnight on Friday, March 10, 2017.

What to turn in:

Option a) Turn in your hand-written exam to Deb in the ECE Department office (610 Cobleigh Hall) by 5 pm on Friday, March 10, and upload a zipped collection of your Zemax files, with each one named so that it is very clear who they belong to and which part of which problem they relate to.

Option b) Upload to D2L a neatly scanned copy (easily readable – not distorted, poorly lit phone pictures) of your hand-written calculations and notes describing your design approach and results. Also upload a zipped collection of your Zemax files, with each one named so that it is very clear who they belong to and which part of which problem they relate to.

1. (10) Geometric optics fundamentals

A lens with center thickness t = 6 mm and refractive index n = 1.5 has the following radius of curvature values for its front and rear surfaces, respectively:

R_1 = 60 mm

R_2 = 120 mm

a) Calculate the effective focal length of this lens.

b) Use paraxial ray trace equations to calculate the back focal length and δ', the distance from the back surface to the second principal plane.

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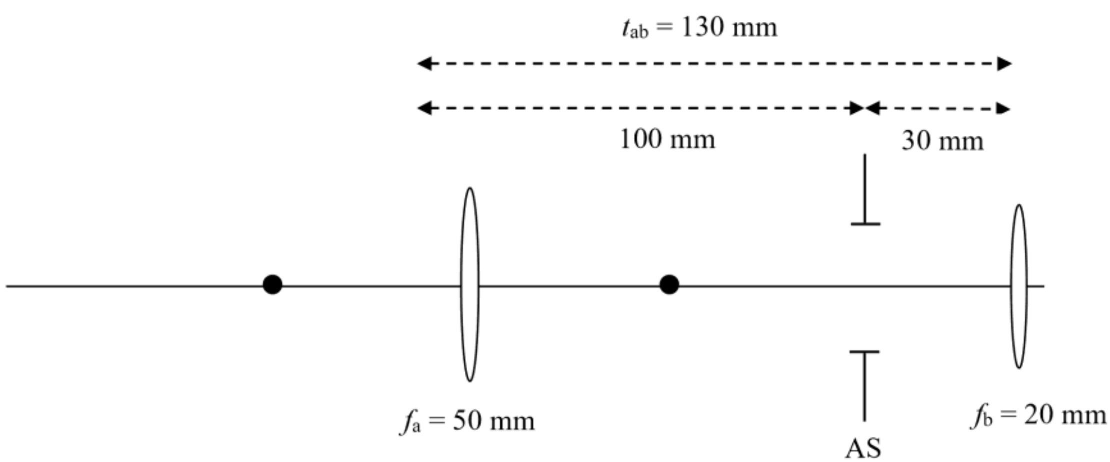
2. (10) Entrance pupil

Sketch three rays to find the location of the entrance pupil for the two-lens system below with aperture stop “AS” as indicated below. Each dot marks a focal point of lens *a*.



3. (10) Aberrations

These questions explore your conceptual understanding of Seidel 4th-order wave-front aberrations. Answer quantitatively (i.e., tell me that it increases 3×, not just that it increases) and justify each answer as simply as possible.

a. How does spherical aberration change if the f/# of a lens is reduced from f/4 to f/2 while holding the effective focal length constant? Why?

while holding the effective focal length constant? Why?

b. How does spherical aberration change if the field is increased from 1° to 3°? Why?

c. How does coma change if the field is increased from 1° to 3°? Why?

d. How does astigmatism change if the field is increased from 1° to 3°? Why?

4. Reverse-Telephoto Design

Design a simple **reverse-telephoto** (wide-angle) lens with the following properties:

- Effective focal length = EFL = f_e = 20 mm
- Back focal length (or distance) = BFL = 30 mm
- Lens separation = $t_{a,b}$ = 15 mm
- Image space $f/\#$ = 8
- Field angles = 0°, 14.14°, 20°
- Wavelength = 0.55 μm (yellow-green)

Design goal: maintain all first-order properties (except when noted) and achieve **rms spot sizes ≤ 10 μm** (use 'dithered' spot diagram setting).

a. (10)
i. Calculate the optical power of two thin lenses to achieve the stated EFL, BFL, and t_{ab}. Show your work and explain any assumptions.

ii. Calculate the radii of curvature for your two thin lenses, assuming equi-convex or equi-concave elements, with the first lens made of BK7 and the second lens made of SF2 glass.

iii. Enter your thin-lens design into Zemax with an aperture stop located just before the front surface of the 2nd lens. Save your file as *Exam1_S17_name_1o1b.zmx* ('name' is your last name).

EFL = _______________
BFL = _______________
f/# = _________________

b. (10) Calculate principal plane locations (ok to use equations).

d' = __________ (distance from last thin lens to p')

d = _________ (distance from first thin lens to p)

Sketch your lens, showing locations of the lenses, focal points, and principal planes.

d = _________ (distance from first thin lens to p)

Sketch your lens, showing locations of the lenses, focal points, and principal planes. Given what you know about a telephoto design, explain why it is called a reverse-telephoto.

c. (10 points) Insert 1-mm thickness for your two lenses. Place a variable on the last lens surface curvature and optimize to restore your EFL and BFL while also maintaining t_{ab}. Verify that the "total track" (length) is longer than the EFL.

Exam1_S17_name_2o1b.zmx → *Exam1_S17_name_2o1a.zmx*

Brief explanation of how you did this in Zemax:

Write down the values for the following first-order properties (from Zemax):
EFL = _______________
BFL = _______________
t_{ab} = _________________ (distance between lens *a* and lens *b*)
Total track = __________

From Zemax, write down the following:

From Zemax, write down the following:

rms spot sizes: ______, ______, ______ μm (use "dithered," "centroid,")

Do these spot sizes meet your design goal? ______________

Which Seidel aberration is dominant? ___________________ (give its name)

List the values for the following Seidel aberration coefficients:

W_{040} = ________ units = _______

W_{131} = ________

W_{222} = ________

W_{311} = ________

Is this solution practical? _____________ Explain:

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate … including the presence of higher-order aberrations if appropriate):

Additional comments:

d. (10 points) Place variables on the four lens surface curvatures, load the default merit function, and optimize to maintain the transverse ray aberration with respect to the centroid (TRAC) while maintaining first-order properties.

Exam1_S17_name_3o1b.zmx → *Exam1_S17_name_3o1a.zmx*

Briefly describe what occurred in this optimization cycle.

EFL = _______________

BFL = _______________

t_{ab} = _________________

rms spot sizes: ______, ______, ______ μm

Do these spot sizes meet your design goal? __________

Which Seidel aberration is dominant? __________ (give its name)
Is this different from before? _________
Why? (explain briefly the main reason):

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = _________
W_{131} = _________
W_{222} = _________
W_{311} = _________

Is this solution practical? _____________ Explain:

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

e. (10 points) Place variables on the distance from the first lens to the stop and the distance from the stop to the second lens. Constrain the stop to remain between lenses and constrain the total distance between lenses to be no more than 30 mm. With variables also on the curvatures, optimize with TRAC while maintaining first-order properties.

Exam1_S17_name_4o1b.zmx → *Exam1_S17_name_4o1a.zmx*

Explain what you did and what happened (did this help? Why or why not?):

EFL = _______________
BFL = _______________
t_{ab} = _________________
Distance from 1st lens to stop ___________________
Distance from stop to 2nd lens ___________________

rms spot sizes: ______, ______, ______ μm

Do these spot sizes meet your design goal? _______

Which Seidel aberration is dominant? __________ (name)

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = ________
W_{131} = ________
W_{222} = ________
W_{311} = ________

Is this solution practical? _____________ Explain:

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

f. (10 points) Now let the BFL vary. Reoptimize with variables on the curvatures, inter-lens separation (constrained to be no more than 30 mm), and BFL, while maintaining EFL = 20 mm.

Exam1_S17_name_5o1b.zmx → *Exam1_S17_name_5o1a.zmx*

Explain what you did and what happened. If you must have BFL > 25 mm (a mechanical requirement based on camera dimensions), will this design work?

EFL = _______________
BFL = _______________
t_{ab} = _________________
Track length ___________

rms spot sizes: ______, ______, ______ μm

Do these spot sizes meet your design goal? _______

Which Seidel aberration is dominant? __________ (name)

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = ________
W_{131} = ________

List the values for the following Seidel aberration coefficients (ok to read from Zemax):

W_{040} = _________
W_{131} = _________
W_{222} = _________
W_{311} = _________

Is this solution practical? ______________
Explain:

What do the ray fans and spot diagrams tell you? (briefly describe shape of ray fans and spots, and tell what the shapes indicate):

Additional comments:

g. (10 points) Explore! See how small you can allow the f/# to become while still meeting the 10 μm rms spot size requirement ... what if we can allow 15 μm spots? Everything but the EFL can change as long as the resulting system is practical.

Show me what you try and explain how you got your best result and how good it is:

How low could you go for the f/#? ___________

Remember: customers generally want “fast” optics, meaning small f/#.

Based on your experience with this design, what is the consistently biggest problem (i.e. the largest aberration) and how will that affect the images?

Additional comments: