

## Computer exercise 1 – a singlet lens

In order to use Synopsys, you must first of all be able to put the specifications of your lens system into the program. This is the point of the first exercise. In addition, you will be able to see some differences between a thin and a thick lens, and test the simplest kind of optimization in the program.

1. Start Synopsys. You will get a dialog saying “The required hardware key was not found”. Click OK. Next, pick “let me run the program with a limit of 12 surfaces”. Now you get a command window with a prompt. It is possible to enter the lens data by commands only, but we will use the simpler, although maybe slower, graphical method.



2. Click the button  on the toolbar. This opens up the SPS lens surface data editor. Each row corresponds to one surface, and each column to a property of the surfaces. Currently 3 surfaces are in use.
3. Click “Add, remove”. Choose “Add” 1 surface, with target surface set to 1. Click OK. Now there will be 4 surfaces in your system. The first one, labeled 0, only defines the starting point of the rays, and the last only their end point. The lens will be made up from surfaces 1 and 2.
4. Click the button named “System data”. At the top row, you can choose a lens ID. Name the lens Your Name 1. In the middle of the screen, there is an option “Select lens units”. Pick mm. Return to the lens Surface Data spreadsheet by clicking the button “Edit surface data”. Now all the lens data will be in mm.
5. In the column marked “Radius”, we type the radius of curvature of the surfaces. For surface one, type 50. For surface 2, type -50. The shape flag to the left of the radius now changes from F (flat) to S (spherical). Since we have no toroidal lenses, we leave the column marked “conic constant” empty. Note that the entry 0 corresponds to infinity, and produces flat surfaces.
6. In the column marked “Thickness”, we give the distances between the surfaces. Type the value 3 for surface 1. This means our lens will be 3 mm thick at the central part.
7. In the column marked “Glass type”, click on the little empty square of surface 1. You will then get a dialog “Index Option, surface 1”. Pick the option “Glass table” and you get a new dialog. Pick Schott, and enter the glass name BK7. Click “OK”, then “Close” in the next dialog. Now the refractive indexes of the next three columns have changed. These are the refractive indexes of BK7 for three specific wavelengths. In order to know which the wavelengths are, you can go to the “System data” spreadsheet again. There you can see that three wavelengths are defined: 656.27 nm, 587.56 nm, and 486.13 nm. These are the default wavelengths for analyzing optical

systems. There is no reason to change them in this exercise. Go back to the “Surface data” spreadsheet.

8. Now you have defined a complete lens. Press “Close” to close the Surface Data spreadsheet and return to the main program.



9. Click the  button on the toolbar to open the PAD window. Here you see an illustration lens you have entered. (You also see some graphs. We will learn to interpret those later.) There are rays entering the lens from the left. But they don't leave the lens on the right, since they will only go to the last surface of the system, and surface 3 is still close to surface 2.
10. Click the Surface Data icon again to return to the Surface data spreadsheet. Using the refractive index in column N2, calculate the focal length of the lens according to the thin-lens formula. Enter this value in the “Thickness or Airspace” column for surface 2. This will now be the distance between the second and the third surface.
11. Close the Surface data spreadsheet, and return to the PAD window. Now the rays continue to the focus of the lens. However, we still need to edit the aperture stop and the angle of illumination.
12. Return to the Surface Data spreadsheet again, then move on to “Object wizard”. The object is already marked as “infinite”, and the object size specified as “Object angle (UP0)”. Leave those as they are. In the area labelled “Formatted input” you can find the variable UP0. Change it from  $1^\circ$  to  $5^\circ$ .
13. There is also information on the aperture stop. In the area labelled “Stop clear aperture” you can see on which surface the stop is located. If it is not at surface 1 already, place it there by entering the surface number and then clicking “Update”. The stop is now at surface 1, that is, at the lens. If we wanted to place the stop away from the lens, we would need a separate surface for this.
14. The information on the paraxial entrance pupil needs to be edited, too. In the area labelled “Paraxial marginal ray height” choose the option “Implied by stop CAO (FILLSTOP)”.
15. In the area labelled “Stop clear aperture” the option “Fixed value” should now be marked. Enter the value 5, then click “OK” to leave the “Object wizard”.
16. Close the Surface Data spreadsheet and take a look at the PAD window. Now you see the differences: the angle of the illumination has increased, and the aperture stop has been widened.
17. If you increase the size of the PAD Window, you see that the rays don't appear to cross where you predicted them to, but rather a bit in front. There could be two

reasons for this:

- a) The lens is thick, and your formula was for a thin lens.
  - b) Your formula was for paraxial rays, and with an aperture radius of 5 mm we might not have paraxial rays.
18. Fortunately, Synopsys can easily be made to find the focus itself. Return to the Surface Data spreadsheet. Find the squares next to the “Thickness” columns (no, they do not belong to conic constants although it looks like that) and click on the empty space of surface 2 (not surface 1!). Then you get the opportunity to choose the option “Edit solves”. Pick the alternative “YMT Marginal Ray Height” and set the target value to 0. Then click “OK” and “Close” to leave the dialogs. This means you have ordered the program to look for the plane where the marginal ray crosses the optical axis, i.e., the focal plane. Back in the Surface Data spreadsheet, you can see the distance between surface 2 and 3 has already changed.
19. Go to the PAD window again. Now the last surface has been moved to the focus. If it still doesn't appear to be exactly where the rays cross the optical axis, this is because the program finds the paraxial focus (i.e. the place where a paraxial marginal ray crosses the axis) but the graphics show the real rays.
20. Find the paraxial focus for thicknesses of 1mm, 3mm and 5 mm. Note the back focal length (the distance from the second surface to the focus) for those thicknesses.
21. Now try changing the second radius of curvature. Let the thickness remain 3 mm, and let the radius of curvature of the second surface be 80 mm, 0 mm and -25 mm. What are the back focal lengths?
22. Save this lens as Yourname1.rle, and print the PAD window. Write the answers to questions 10, 20 and 21 on the paper. You should hand in this page instead of a report.
23. The program can also solve for other parameters. Remove the old solve by clicking on the blue square in the “Thickness” column and picking the alternative “Enter thickness”. Enter a value of 50 mm, click “OK” and then “Close”. Now the solve is removed and the distance is fixed to 50 mm.
24. Instead, click on the empty space in the column “data flags”, for surface 2. This opens the dialog “Surface shape editor”. Click the button saying “Edit pickups”. Choose the surface number to be 1, the M to be -1 and the B to be 0. This means the program will take the curvature of the first surface, multiply it by -1 and give this value to the curvature of the second surface. This way, the lens will always remain equiconvex. Click “OK” and “Close” to exit the dialogs.
25. This time, we wish to solve for the radius of curvature, so that the back focal length is 50 mm. This is not as simple as the solving for the back focal length. Return to the

main program and click the M button on the sidebar.



26. This opens the dialog “Main menu mode”. Click the “MOM” button. This allows you to optimize the lens.
27. Click the button saying “Radii”. This allows us to pick the surface whose radius we want to solve for. Click on the first surface in the image of the system. It is then colored red and the number “1” appears next to the “Radii” button. Now we have chosen the radius of the first surface to be optimized.
28. Click the “Back to MACro editor” button, and the dialog “Lens optimization menu” appears. Now we need to pick a merit function. Merit functions are rather complicated, and we will return to them later on in the course. Right now, we just pick “Select a prepared merit function”. I suggest that from the alternatives that follow, you pick merit function 4. Then click “Back to MACro editor”.
29. Now click the button “Optimize now”. Then the PAD window appears Obviously, the system has been adjusted so that the focus is at the last surface.
30. If you open the Surface Data spreadsheet again, you can see the lens information. The distance between surface 2 and 3 should still be 50 mm. What are the curvatures of the lens surfaces?
31. Save this lens as YourName1b.rle, print the graphics window and write the answer to question 30 on the sheet.

This task was meant as an introduction to Synopsys, and to the possibilities that the program offers. You should have learnt how to write the lens parameters into Synopsys, and also seen that you can optimize the lens in different ways. The optimization will be considered in more detail later on.

You should hand in two sheets of paper for this lab, both marked with your name. The first sheet should contain a drawing of the system in question 21 (you can choose the second radius of curvature yourself) and the answers to questions 10, 20 and 21. The second sheet should contain a drawing of the system in question 30, and the answer to question 30.