OSLO Doublet Optimization Tutorial

This tutorial helps optical designers with the most basic process for setting up a lens and optimizing in OSLO. The example intentionally goes through basics as well as some more advanced information to give designers some idea of the wonderful depth and capability of OSLO. The tutorial is broken into three videos:

- the first covering the core checklist and step A (Setting up the starting point) both in bold text,
- the second covering step B (Setting up variables, the error function, and optimizing the design) in bold text, and
- the third covering C (Making the doublet better) and handy tips both in bold text.

OSLO core checklist for setting up a lens from scratch for optimization
1. Enter lens system data (entrance beam radius or equivalent, field angle or equivalent, wavelengths)
2. Enter lens data as needed (if not using a pre-existing starting point)
3. Define variables
4. Define merit function (note built-in options under Optimize>>Generate Error Function)
There are many other features and settings that can be adjusted as required. This checklist is just a fundamental set.

A. Setting up the lens starting point
1. Make new lens using the file name "Example_Doublet_Basic", custom lens, and 4 surfaces.
2. Open the surface spreadsheet editor.
3. Optional: enter lens name (such as "Doublet Set-Up Example").
4. Optional: set name for designer under general operating conditions ("Gen" button on lens editor spreadsheet).
5. Set lens entrance beam radius of 15 (default units are mm).
6. Set field angle of 1-degree (default units of degrees, this is the half field-of-view).
7. Click the wavelength button on the surface data spreadsheet and verify traditional visual wavelengths specified (d, F, C spectral lines). Note the order affects some calculations and should be in that order (central wavelength first).
8. Verify the object distance is set to infinity (> 1e+8), the object is in air, and that the first surface is the aperture stop (it is named AST and says AS under the aperture radius). This means we will have the aperture stop in front of the lens.
9. Enter the following information for the lens surfaces:
> Surface 2 – radius 69, thickness 7, glass BK7;
> Surface 3 – radius –40, thickness 3, glass SF2;
> Surface 4 – radius –130, thickness solve for paraxial image location by clicking on the box to
> > the right of the IMS (Surface 5) and set the axial ray height to zero, keep glass as air.

10. At this juncture, save the lens and click on the lens drawing icon and select plan view (in the graphics window). The lens should look like the following figure (except for the DES field):

Doublet Set-Up Example
FOCAL LENGTH = 109.9   NA = 0.1365
UNITS: MM
DES: Youngworth
6.06
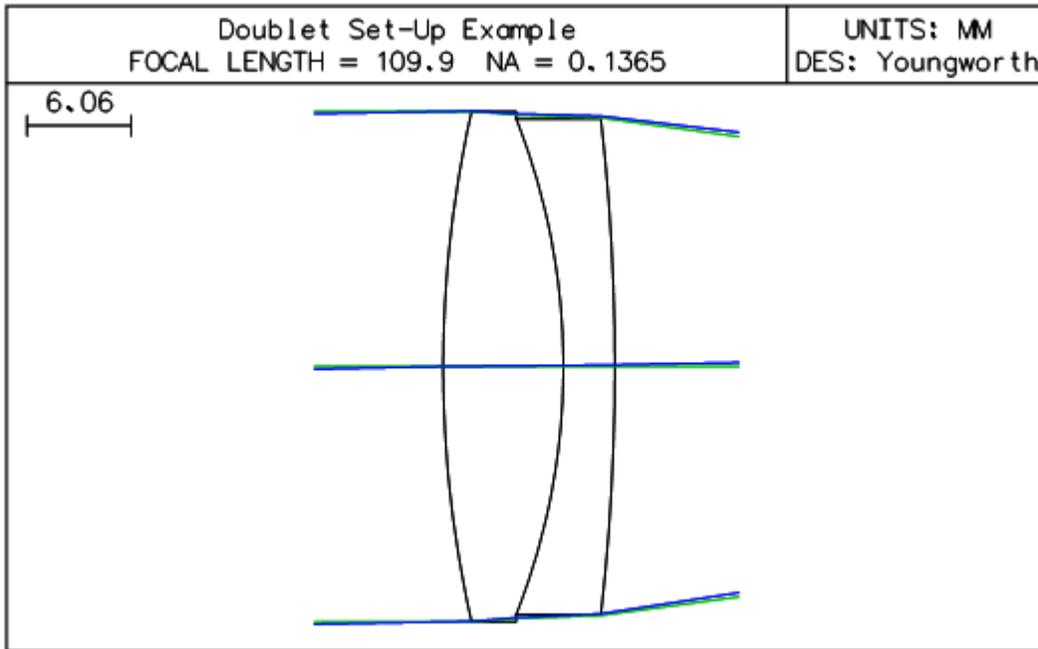
11. Clicking on the "Len", "Rin", and "Wav" button in the text window should yield

```
*LENS DATA
Doublet Example
 SRF      RADIUS       THICKNESS    APERTURE RADIUS      GLASS  SPE   NOTE
 OBJ       --        1.0000e+20    1.7455e+18           AIR

 AST       --            --        15.000000 AS          AIR

  2      69.000000    7.000000     15.000000 S          BK7 C
  3     -40.000000    3.000000     14.562072 S          SF2 C
  4    -130.000000  105.208319 S   14.476056 S          AIR

 IMS       --            --         1.917831 S

*REFRACTIVE INDICES
 SRF   GLASS/CATALOG      RN1          RN2          RN3        VNBR         TCE
  0    AIR            1.000000     1.000000     1.000000      --           --
  1    AIR            1.000000     1.000000     1.000000      --        236.000000
  2    BK7            1.516800     1.522376     1.514322   64.166410   71.000000
       SCHOTT
  3    SF2            1.647689     1.661232     1.642096   33.847676   84.000000
       SCHOTT
  4    AIR            1.000000     1.000000     1.000000      --        236.000000
  5    IMAGE SURFACE

*WAVELENGTHS
CURRENT   WV1/WW1      WV2/WW2      WV3/WW3
   1     0.587560    0.486130     0.656270
         1.000000    1.000000     1.000000
```

12. Clicking on "Pxc" yields gives the following paraxial data

```
*PARAXIAL CONSTANTS
   Effective focal length:  109.872475    Lateral magnification:  -1.0987e-18
   Numerical aperture:        0.136522    Gaussian image height:     1.917831
   Working F-number:          3.662416    Petzval radius:         -150.321801
   Lagrange invariant:       -0.261826
```

B. Setting up variables, the error function, and optimizing the design
13. Use "Save As" under the file menu to save a new copy as "Example_Doublet_PreOpt". We will
now enter variables for optimization. Click on the variables button in the lens data entry spreadsheet.
Enter the following data:
> Variable 1: surf 2, cfg 0, type cv, keep rest default
> Variable 2: surf 2, cfg 0, type th, minimum 6, maximum 8, keep rest default
> Variable 3: surf 3, cfg 0, type cv, keep rest default
> Variable 4: surf 3, cfg 0, type th, minimum 2, maximum 4, keep rest default
> Variable 5: surf 5, cfg 0, type th, minimum 0, maximum 0, keep rest default

Use the green check mark to "accept" changes to this spreadsheet and exit.
(Also can use vary all curvatures, vary all thicknesses, or just use the buttons to the right of radius and
thickness cells in the surface data sheet as wanted.)

14. Note we did not set the last surface thickness or curvature to be variables. Instead the last surface
thickness is going to remain the paraxial focus and the image surface will then set the refocus from that
position. Additionally, the last radius of curvature will now be set to fix the focal length or equivalently
the f-number of the lens. First, click on the blue window box in the upper corner of the text window
and toggle on "aberrations". This step opens new buttons; click on "Pxs" which shows:

```
*PARAXIAL SETUP OF LENS

 APERTURE
   Entrance beam radius: *   15.000000    Image axial ray slope:    -0.136522
   Object num. aperture:    1.5000e-19    F-number:                  3.662416
   Image num. aperture:       0.136522    Working F-number:          3.662416
 FIELD
   Field angle:          *    1.000000    Object height:          -1.7455e+18
   Gaussian image height:     1.917831    Chief ray ims height:      1.917831
 CONJUGATES
   Object distance:         1.0000e+20    Srf 1 to prin. pt. 1:      1.878806
   Gaussian image dist.:     105.208319    Srf 4 to prin. pt. 2:     -4.664156
   Overall lens length:      10.000000    Total track length:      1.0000e+20
   Paraxial magnification: -1.0987e-18    Srf 4 to image srf:      105.208319
 OTHER DATA
   Entrance pupil radius:    15.000000    Srf 1 to entrance pup.:       --
   Exit pupil radius:        15.260961    Srf 4 to exit pupil:      -6.575648
   Lagrange invariant:       -0.261826    Petzval radius:         -150.321801
   Effective focal length:  109.872475
 SPOT DIAGRAMS
   Aperture divisions:       17.030000    Gaussian apod. spec.:       Off
   X 1/e^2 entr. irrad.:      1.000000    Y 1/e^2 entr. irrad.:      1.000000
```

The image axial ray slope is the number needed. If we set the axial ray angle after the last surface to this value, and keep the entrance beam radius fixed, it will effectively hold the EFL and consequently the f-number stationary as the system optimizes. Click on the desired number (next to "Image axial ray slope", in this case -0.136522) in the text window and you will get a cell number that holds the data. Make a note of the cell number. Next, click on the box to the right of the radius number for surface 4, move to solves, and select "axial ray angle". A prompt box then opens; enter the cell number you noted (a letter followed by a number with no space). A solve is on the last physical lens surface radius of curvature serves the purpose of holding the focal length and lens f-number.

15. We're now ready to set up an error function for optimization. In the menu, select Optimize>>Generate Error Function>>OSLO Spot Size/Wavefront. It pulls up a window with a number of options. Only change the color correction method to CHR/DMD and hit "ok". This has generated a spot size error function that includes chromatic aberration effects but no physical constraints or distortion (as this is the default). To view the operands, use the command "ose" or select the menu option Optimize>>Operands.

16. Use the green check marks to exit each spreadsheet capturing the changes. Save the lens to preserve the starting point for optimization. This step can be a good habit if you want to store the starting point for later reference. Then, use "Save As" under the file menu and save the lens with the new name "Example_Doublet_Opt" to the file to preserve the starting point file.

17. We can now optimize the lens using damped-least squares (DLS), which depends on the starting point of the lens design. Select Optimize>>Iterate (or type "ite" in the command line) to run 10 cycles of DLS, noting the marginal improvement (reduction) in the error function value. Running it a second time shows no improvement.

18. Assessing the lens by clicking on the "Graphics ray analysis" button on the graphics window, it is clear that the lens is dominated by monochromatic spherical aberration. The only thing that can really be done with this form and constraints is to use refocus. Having the other variables active tends to bog down the effect of refocus in this case because the best focus is so far from the paraxial location. We will delete the unwanted variables knowing we can add them back in later. First, use the green check mark to accept the data in the surface data spreadsheet (and also this accepts data in the variables spreadsheet). Then, open the surface data spreadsheet again. Click on the variables button and delete all of the variables except the thickness of the last surface (Surface 5). Now accept the changes from this spreadsheet and use the menu Optimize>>Iteration again (no more than 2-3 times should be necessary). At this point, select "Len" in the text window which prints the values of lens data. Make a note of the cell that contains the image surface thickness (i.e. the refocus). Now hit the Red X button and Undo all the changes. Reopen the surface data spreadsheet, select the cell for the image surface thickness, and type in the cell name that contains the optimized value for the refocus. You now will have the variables all maintained in the variables spreadsheet and a defocused lens that is optimized. Alternatively in this step, you can just delete all of the variables, optimize, and add them back into the variables spreadsheet manually.

19. Save this lens as a spherical solution.

C. Making the doublet better

20. Next, use "Save As" under the file menu and save the lens as "Example_Doublet_Asph". There are a few options to make the lens better. For the sake of showing more about OSLO, we will turn one surface into an asphere to reduce the spherical aberration. Since the front surface of the doublet is coincidental with the stop (note the thickness of surface 1 is zero), we will use that surface. First, so that the program recognizes that you want to make the first surface an asphere, open the surface data spreadsheet. Click the last box to the right (under special) for the first surface in the lens (SRF 2) and select Polynomial Asphere (A) >> Standard Asphere. Then, enter a very small value into the 4th order deformation coefficient, such as 1e-20. This has no practical effect on the surface shape but now OSLO recognizes it is an asphere. Next, go to the variables spreadsheet and you will now be able to enter a new line 6 variable, the r^4 aspheric deformation coefficient:

   Variable 6: surf 2, cfg 0, type ad, minimum 0, maximum 0, keep rest default

21. With the new aspheric variable defined, reoptimize with Optimize>>Iterate (or ite). Note that in this case we again are bogged down, but we know we should be able to make progress. It turns out that the same challenges associated with refocus are problematic here. In this case we will use a different technique to alter the damping values of the variables to "freeze" (this is a little advanced). Open the variables spreadsheet using the variables button and increase the damping cell values for Variables 1-5 to 1e+20. Leave the aspheric coefficient damping value at 1. Close the variable spreadsheet and set the defocus value to zero (surface 5 thickness). Next, optimize with Optimize>>Iterate but be sure to change the last value in the pop up menu, "Reset variable damping factors to 1.0" to zero. Repeat (you can use the command history or the command "ite ful 10 std y n") until the optimizer settles on a value. To see the aspheric coefficient value in the text window, select Lens>>Show Surface Data, select special data, and use the pull-down menu to choose "Conic/aspheric data" in the pop-up menu and hit ok. Use the green check mark to exit out of the surface data spreadsheet.

22. Check the lens performance by clicking on the "Graphics ray analysis" button on the graphics window. If the lens is still defocused from the spherical solution, enter zero for the refocus (surface 5) and plot the ray analysis again. You should see a lens with significant improvement. My result is below:
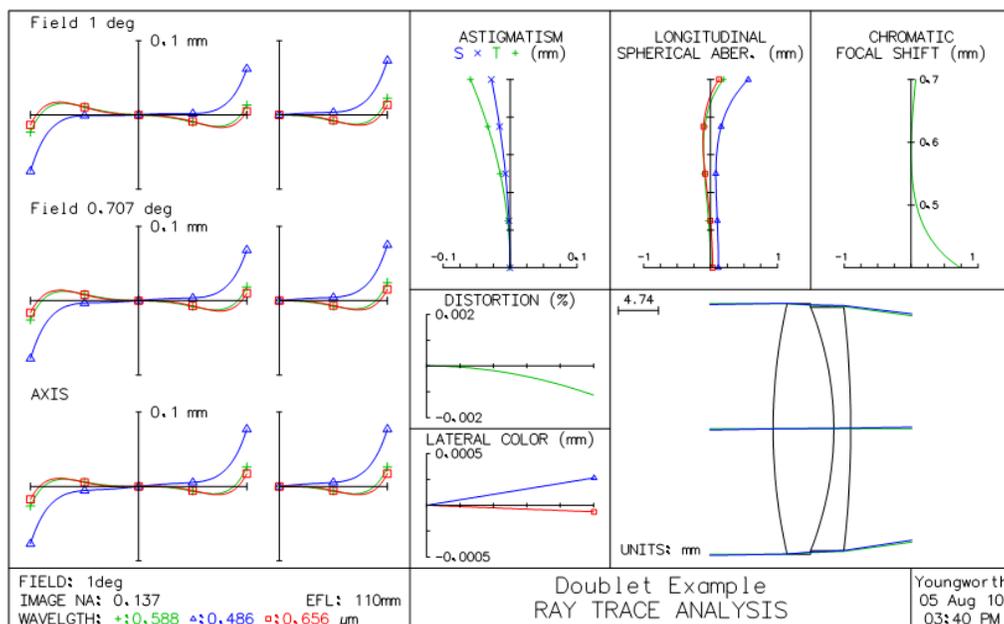
23. Run the DLS optimizer (Optimize>>Iterate or just the command "ite") to reset the variables' damping all to unity. Save the resulting system to conclude the tutorial.

Handy Tips
- Lenses are the document in OSLO. You can open them with a text editor in order to get a listing of commands in a script to generate the file. This is very handy to copy data from one file to another very quickly.
- For a "real" job, the apertures can be set to values larger than the bundle values and "checked" to block light that should not get through (vignetted bundles). Design values would be rounded off for drawings and limits to errors assessed, along with analysis and tolerancing of the lens. There are also means to set vignetting parameters in traced ray bundles for systems where vignetting will be used for performance.
- OSLO has preferences which apply to the entire program and operating conditions that are set for individual lens files. This tutorial only explicitly covered operating conditions.
- The program also includes many extra analysis and features to aid with optical engineering tasks. For a good user intro, see the OSLOUserGuide.pdf from the Lambda website (www.lambdares.com). This guide is very valuable for beginning users. The guide is found on the website under OSLO and Releases.
- Two examples are also on the website under OSLO and Examples. They are "First OSLO Session Example" and "Schmidt Camera Example". The user guide contains a lot of similar information but these are supplemental tutorials to this doublet tutorial and more explicitly show the interaction with the OSLO interface.