OPIC LENS DESIGN TUTORIAL

Brian Blandford

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INTRODUCTION

This tutorial has been prepared for anyone who has never designed an optical instrument, nor has used an optical design program before. Its aim is to give a simple introduction for the newcomer, not only to the concepts of geometrical and physical optics, but also to the craft of lens design, and the use of any full-scale commercial optical design program.

The tutorial shows step-by-step how to download free optical software, OSLO-EDU, and use it to analyse the optical performance of a concave spherical mirror. It then demonstrates how OPIC, a software procedure in the CCL language of OSLO software, which is also available for free downloading, can be used to carry out a real design task, the design of a three-component objective.

DOWNLOADING OSLO-EDU

- Using an internet browser access the Lambda Research Corporation website at http://www.lambdares.com/downloads/
- Scroll down to the OSLO EDU paragraph shown.
- Click on the online request form.
- Fill in the form as shown. Make sure that the option "Add my e-mail to the OSLO discussion group list" is selected in the list at the end.
- Once you have completed the form select "Submit Query" to submit your information.
- On the following page select the appropriate download for your operating system.
- At this point you may also wish to download the accompanying installation instructions, which cover both the Windows and Linux Operating Systems. You may also download these instructions later on from the above Lambda Research link.

OSLO-EDU

Please note: The free version of OSLO used to be called OSLO LT. We have now changed the name of the free version to OSLO-EDU to avoid confusion with OSLO Light (one of our paid editions). Please see the chart displaying the complete list of the differences between OSLO-EDU and OSLO Light).

<u>OSLO</u> is available in three levels called **OSLO Premium**, **OSLO Standard**, and **OSLO Light**. Each is a full-featured program that can help you design superior systems.

OSLO-EDU is a **free** program with a reduced number of features compared to OSLO Light, and it is also restricts you to working with systems that have up to, or including, 10 surfaces. Please note that although OSLO-EDU does not include all the capabilities of OSLO Light, Standard or Premium, it does give you optical design power that exceeds many commercial programs. OSLO-EDU gives you the basic ability to layout, edit, optimize, analyze, tolerance, and save a wide range of optical systems. OSLO-EDU is perfectly tailored for educational use.

OSLO-EDU is available for download by first filling out our $\underline{online\ request\ form.}~(6.4\ MBytes)$

OSLO-EDU

Items with stars are required.

What is your reason for downloading O Evaluating for purchase of OSLO Light/Standard/Premium:	SLO-EDU? *
Student use:	V
Amateur astronomer use:	
Other (Please specify):	
What Operating System will you be usin	ng OSLO-EDU on? *
Microsoft Windows®:	
Linux:	
Where did you hear about OSI O-FDU?	Other (Please specify)
Where and you near about oblo-libe.	*
	Dr Brian Blandford

Thank you for your request!

To download a copy of OSLO-EDU (v6.3.1), please click on the proper link for your setup.

Operating System	File	Size
Windows 95/98/ME/NT4.0/2000/XP	OSLOEDU631.exe	8 MBytes
Linux with RPM Manager	osloedu-6.3.1-1.i386.rpm	4.8 MBytes
Linux without RPM Manager	osloedu-6.3.1.tgz	4.6 MBytes

To download the installation instructions in PDF format, click here: <u>OSLOEDU-Install.pdf</u> Please contact us for more information.

> TracePro[®] and OSLO[®] are registered tradematic of Lambda Research Corporation APEX[™] and RepTile[™] are tradematic of Lambda Research Corporation. ©2000 Lambda Research Corporation. All Rights Reserved. Sp /download/oclothanics.phtml Last Modified: 8:08 am PST December 15, 2004



INSTALLING OSLO EDU IN A MICROSOFT WINDOWS ENVIRONMENT

 Run the installation file you have downloaded from Lambda Research. Left-click on Next>



• Carefully read the License Agreement and left-click on:.

 I accept the terms of the license agreement Left-click on Next>

 Select an appropriate installation location. The default directory is C:\Program Files\OSLO\EDU63 This, however, is not ideal if you do not have read-write permission to that directory. If you do not have administrator status on your computer, choose another location. Left-click on Next>

[Note to system administrator: The user requires read/write permission for all files and directories in the C:\Program Files\OSLO\EDU63\private\ directory, particularly the \len and \ccl sub-directories]





• Begin the installation. Leftclick on Install>

• Wait for the program to be setup on your computer.

OSLO EDU 6.3.1 - InstallSh	nield Wizard 🛛 🔀
Ready to Install the Progra	am and a second s
The wizard is ready to begin i	nstallation.
Click Install to begin the insta	lation.
If you want to review or chan the wizard.	ge any of your installation settings, click Back. Click Cancel to exit
InstallShield	
	< <u>B</u> ack Install Cancel
OSLO EDU 6.3.1 - InstallSI	nield Wizard
Setup Status	
OSLO EDU 6.3.1 is configurir	ng your new software installation.
Installing	
C:\Program Files\OSLO\EDL	163\bin\bma\prt_oc_spd.bmp
InstallShield	
	Cancel
OSLO EDU 6.3.1 - InstallSt	nield Wizard
	InstallShield Wizard Complete
	The InstallShield Wizard has successfully installed OSLO EDU 6.3.1. Click Finish to exit the wizard.

• The installation has completed successfully. Leftclick on Finish.

• You may remove or modify the program installation from the "Add or Remove Programs" tool found in the Windows Control Panel.

< Back Finish Cancel

RUNNING OSLO-EDU FOR THE FIRST TIME

In these notes, a left click on the mouse is indicated by a red arrow, and a right click by a green arrow. Terms which are defined in the glossary at the end are in **bold**. Anything typed from the keyboard is in **this typeface**. For

those with some OSLO experience, commands relevant to the current topic are shown in **this typeface**. These give examples of command syntax, and are also useful as an index to the on-line documentation, but they are not essential for a first-time reading. Notes which appear whenever the cursor hovers above an icon are shown

thus

- Click on Start ► All Programs ► OSLO► OSLO EDU Edition 6.3.1 (unless you have the desktop icon shown here)
- The program opens with an introductory dialog box. Click anywhere in the box to close it. If a message about re-building the CCL database appears, click on
- The "tip of the day" is a useful tutorial for new users. Click on **Close**...
 Alternatively it can be suppressed permanently by removing the tick from the box in the bottom left corner [stp stas on]
- The "Get_startup_option" window opens. [stp pstc on] Choose the option:
 - Start a new lens

and click on

OK

οĸ	







The window which opens is called the Surface Data Spreadsheet.

III Sur	face Data				
✓ × □□ ?]				
Gen	Setup W	avelengths Va	ariables Draw	Off Group	Notes 🔥
Lens:	No name			Ef1	1.0000e+54
Ent be	eam radius 👥 1.	000000 Field ang	le 5.7296e-05	Primary wavln	0.587560
SRF	RADIUS	THICKNESS	APERTURE RADIUS	GLASS	SPECIAL
OBJ	0.000000	1.0000e+20	1.0000e+14	AIR	
AST	0.000000	0.000000	1.000000 AS	AIR	
IMS	0.000000	0.000000	1.000000 5		
					~

[lens_spreadsheet lse]

DEFINING A SPHERICAL MIRROR

In the surface data spreadsheet:



- 1. Select _Draw On_ for the Autodraw window [dlav set yz]
- 2. Add the lens identifier: Lens: Spherical mirror. [lid spherical mirror] and click on the green tick.

Accept pending entry/Close spreadsheet

On the second line for surface 1 (**AST**):

- **3.** Change the **RADIUS** of curvature (in mm) to: **-16** [rd 1 16]
- 4. Click on the grey button next to AIR under GLASS and select Reflect (hatch) [gla 1 rfh]
- 5. Change the THICKNESS the separation to the next surface from 0.0 to: -8 (mm). [th 1 -8] Once again, click on the green tick to confirm the changes.

Accept pending entry/Close spreadsheet

There is no need to close the Surface Data Spreadsheet, but if you do and then want to open it again, see below under "Saving the Lens".

DRAWING THE SPHERICAL MIRROR	<u>Eile Lens Evaluate Optimize Tolerance</u>
Pull down the menu from the Lens menu header. Select Lens Drawing Conditions	Surface Data Spreadsheet Glass Catalogs Coatings Show Surface Data Show Tolerance Data Show Operating Conditions Ler Show Auxiliary Data Ent Lens Drawing Solutions Cost 0.000000 1.00000
Lens Drawing Conditions < Surface Data	
Initial distance: 0.000000 Final distance: 0.00	0000
Horizontal view angle: 240 Vertical view angle:	30
First surface to draw: 0 Last surface to draw:	0 Autodraw: YZ
X shift: 0.000000 Y shift: 0.000000 DXF/IGE	S view: Unconverted
Apertures: Full Rings: G Spokes: 8 Image s	pace rays: Image srf
Draw aperture stor O Off O On Hatch bar of re	flectors: () off ()
Shaded solid color Red: 175 Given: 185 Blue:	
Number of field point or ray fans: 2 Points fo	offcat EV EV V

In the lens drawing conditions spreadsheet:

- 1. After Apertures: select the option Full apertures. [dlap 3]
- 2. After Rings: type in 6 [dlri 6]
- **3.** After **Spokes:** type in **8** [dlsp 8]
- 4. After Image space rays: select Draw rays to image surface.[dlrs 3]
- 5. Under the column headed Rays type in 11 in the first row for the number of rays to be drawn at the on axis field point (Frac Y Obj = 0.00000). [dlnr 0 11]
- **6.** Close with the green tick:

The Autodraw window should now have the appearance shown in the diagram:

Variables	Draw On Group	Notes
gle 🗖 Aut	odraw	
	Sphericol mirror FOCAL LENGTH = -8 NA = 0,125	UNETS; MM DES: CSLD
₽	<u>199</u>	

👌 [Untitled lens] - OSLO EDU

PLOTTING A SPOT DIAGRAM

Now create a map of the pattern of rays falling on the image. From the **Evaluate** menu header select:

Spot Diagram<mark>≻</mark>Single spot diagram...

Click on three radio buttons:

• Plot spot diagram

Plot ray intersection points as



Show Airy disc in plot



Click on



○ Print spot diagram Plot spot diagram Spot diagram data Reference point Image centroid C ce ray 🖸 Ray data C Ray weights C Path length Plot ray intersection points as -Dots ④ Symbols ion shift of reference point 0.000000 z direction shift of reference point (focus shift) Rays to print: First ray 1 Last ray 1 0.000000 Scale for spot diagram display Show Airy disk in plot C No Set Object Point Cancel ÖK Help

Print or plot spot diagram

X

This diagram should appear. [pls cen sym 0.0 0.0]



LISTING THE LENS SURFACE DATA

• List the lens data in the text window by clicking on **Len** in the text window header: [len]

🔲 ТМ	/ 1 *						
🔠 Len	Spe Rin Ape Wav	Pxc Abr Mrg Chf	Tra Sop Ref Fan Spd Au	f Var One lie			
*LENS Spher	ATA mirror						<u>^</u>
SRF OBJ	RADIUS	THICKNESS 1.0000e+20	APERTURE RADIUS 1.0000e+14	GLASS AIR	SPE	NOTE	
AST	-16.000000	-8.000000	1.000000 AS	REFL_HATCH			
IMS			8.0000e-06 S				~
<							≥:

If you have trouble finding the text window, from the **Window** menu header select **Tile Windows** [tile]



SEEING THE EFFECT OF INCREASED APERTURE

- In the surface data spreadsheet increase the entrance beam radius from 1 mm to 1.72 mm as shown in the diagram below.
 [ebr 1.72]
- Confirm with the green tick.
- Recalculate the spot diagram by right-clicking inside the window and selecting Update window using current data:

				a company of the second se
EEE Surface Data	🔁 UW 2 - Spot Disp	lay *		
	■業生産主	- 🖉 🕱		
Gen Setup Wavelengths	Spherical mi SPOT DIAGR	irror RAM	FBY 0 FBX 0 FOCUS 0	REFHT 0 ₩V1-3 +△□
Lens: Spherical mirror Ent beam radius 1.720000 Field a SRF RADIUS HICKNESS OBJ 0.000000 00000+20 AST -16.0000008.000000 IMS 0.000000 0.000000 Autodraw	GEOMETRICAL RMS R SIZE 0.001015	Update window Re-calculate usi Zoom In Zoom Out Zoom Out (Full) Set Zoom Cente	using current data ing new parameter	0METRICAL MS Y SIZE 0007178

to give the diagram shown.

The spot diagram is now bigger, and the Airy disc is smaller, than before.



CHOOSING A BETTER FOCAL PLANE

Draw the lens system in a graphics window:

- From the <u>Lens</u> menu header select Lens
 Drawing ... ► System
- Accepting all the defaults click on

Lens	Evaluate	Optimize	Tolerance	Source	Tools	Window	Help
Sur Gla Co	rface Data : ass Catalog: atings	Spreadshee S	et) •	<u>III</u> /	۸.		
Shi Shi Shi Shi Shi	ow Surface ow Tolerand ow Optimiza ow Operatir ow Auxiliary	Data ce Data ation Data ng Condition / Data	ns •	5 V	ariabl	es	Draw (
Ler Ler T	ns Drawing. ns Drawing 0.0000 -16.0000 0.0000	 Conditions. 00 00 00	 1. -8.0 0.0 5,	System Element Zoom Lay Element [Zoom Cor	 /out Drawing nditions/	Conditions Weights	ş

[drl; drr fby y 0 11 -1.0 1.0 0 0]

- On the graphics window, left-click-and-drag around the focus to view the pattern of rays at higher magnification this is called "zooming". (Note there is a limit to the extent you can zoom in open up the window to see the full magnification).
- Double click (left) on the graphics window to zoom out to the full screen view (you cannot do these zoom actions in the Autodraw window).

Clearly a better focal plane can be chosen, a short distance to the right of the current one. You might like to experiment to find the one



which gives the smallest spot. Otherwise, try this value:

- Change the thickness at surface 1 from -8.00 mm to -7.976 mm.
- From the <u>Evaluate</u> menu header select <u>Spot Diagram</u> > <u>Single</u>
 <u>spot diagram...</u> and choose the same options as before.

PLOTTING THE POINT SPREAD FUNCTION

Plot the distribution of light at the focus - the point spread function. cal mirror [Spherical_mirror_high_aperture.len] - 0

• From the **Evaluate** menu header select: Spread Function
Spread Function Plot PSF Map/Contour...

In the window which opens:

- Click on the radio button: • Grey scale map
- Type in **0.01** for the Size of patch on image surface.
- Click on the radio button: Normalize to peak of **PSF**
- Click on the radio button: Direct integration

• Type in **128** for Number of lines/points in drawing

and click on **OK**.

[sprd gry chr x 0.0 pek dir 128]

Close inspection shows that the central peak is surrounded by at least one light ring which is just visible. Note the figure at the top of the scale on the right - 0.788. This figure is called the Strehl ratio. A figure of 0.8 or above is very good for most applications.



Evaluate Optimize Tolerance Source Tools Window Help

1 III h

velengths Variables

APERTU

1.0000

1.72

20000 Field angle

THICKNESS

1.0000e+20

-7.976000

Report Graphic...

Plot PSE Man/Contour

5td PSF vs. Field (2D)...

000000 F

Paraxial Setup

Paraxial Ray Analysis... Std Zoom Lens Parameters

Aberration Coefficients...

Zoom Aberrations Other Aberrations

Single Ray Trace...

Other Ray Analysis

Ray Fans

Spot Diagram

Transfer Function

Spread Function

Energy Distribution

Grey scale Map 🥤 Contour

Wavefront

Polarization

Display type C Color Map

128

Chromatic optio Monochroma

SAVING THE LENS

Save the lens in a new folder.

- From the **File** menu header select **Save Lens as ...**
- Click on **Private**
- Click on:



- Type the name for the new folder: **EDU_Tutorial** and click on **Open_**
- Save the lens with the name: **spherical_mirror.len** by clicking on **Save**.
- Close the surface data spreadsheet with the green tick:



Spherical mi

ibraru Din

-

Save as type: Lens files (*)

Accept pending entry/Close spreadsheet

The surface data spreadsheet may be re-opened: Either, from the **Lens** menu header select **Surface Data Spreadsheet...** or click on the blue lens icon in the main screen toolbar. **[Ise]**

```
[shp prid = show_preference Private_directory]
[shp lfil = show_preference Lens_file]
[save len pri "len" "EDU_Tutorial/Spherical_mirror"]
```

EXITING THE PROGRAM

From the **File** menu header select **Exit** [exit]

OPTIMISATION USING OPIC

INTRODUCTION

Note: The first part of this tutorial is essentially copied from the document "Optimization Tutorial using OSLO Light," which is available as a free PDF download from the Lambda Research Corporation web site at the following URL: <u>http://www.lambdares.com/techsupport/tutorials.phtml</u>

It is recommended that the section "Lens Entry" is followed using both documents in parallel. The steps numbered 1 to 16 below correspond to steps 1 - 16 in the tutorial.

The customer requirement may be summarised as follows: A triplet objective is required, of focal length 10 millimetres, and a field of view of 40° (± 20°), which will have an aperture ratio of f/2.8. Vignetting is

permitted, with up to 50% brightness reduction at the extreme field of view. The MTF must be greater than 0.4 at 40 lines/mm everywhere in the field. Distortion must be less than 1%.



LENS ENTRY

1. Open the lens in the public directory:

C:ProgramFiles\OSLO\EDU63\public\len\demo\edu\

with the file name demotrip.len

Save it in the private directory: C:ProgramFiles\OSLO\EDU63\ private\len\EDU_Tutorial with the same file name.

- 2. If it is not open already, open the surface data spreadsheet by clicking on the blue lens icon in the main window toolbar.[lse]
- Scale the lens to focal length 10 mm by right-clicking on any surface number button, and selecting Scale Lens ► Scale to



New Focal Length ► Enter scaled focal length: 10.0. [sle to 10.0]

- 4. Change the entrance beam radius from its current value giving an f-number of f/4 to give an f-number of f/2.8 [ebr 1.785710]
- 5. Verify the f-number using the text window header **Pxc.** [pxc]
- 6. Increase the aperture radii of surfaces 1 to 6 to 1.8 [ap 1 1.8] [ap 2 1.8].. [ap 6 1.8]
- TW 1 * Len Spe Rin Ape Wav <u>Pxc</u> Abr Mrg Chf Tra Sop Ref Pxs Pxt Chr Sei Fif Ref bot d top skw *<u>PARAXIAL CONSTANTS</u> Effective focal leg Numerical aperture: 0.178569 Working F-number: 2.800030 Lagrange invariant: -0.649940

Surface Data

?

X 1.2499864724949*4/2.8

Gen Setup Wavel

Lens: Demo Triplet 50mm f/4 Ent beam radius 4949*4/2.8_

7. Increase the thickness of the first element to 0.7 mm, of the second element to 0.3 mm, and of the third element to 0.7 mm. [th 1 0.7], [th 3 0.3], [th 5 0.7]

Lens: Demo Triplet 50mm f/4 20deg Ef1 9.854505 Ent beam radius 1.785695 Field angle 20.00 🖰 Autodraw RADIUS THICKNESS APERTURE RA SRF Dama Triplet 30mm 1/4 20deg P304L LEXATH = 9.500 NA = 0.161 units: un desi galo 2.0000e+19 OBI 0.000000 7.2793e+18 0.727 1 4.249954 0.700000 1.800000 2 -31.729657 1.199987 1.800000 3 -4.049956 0.300000 1.800000 AST 3.859958 1.199987 1.800000 28.249694 0.700000 1.800000 5 6 -3.456963 8.589907 1.800000 0.000000 0.000000 3.808372 IMS

8. Adjust the radius of surface 6 to restore the focal length to 10 mm using the following method:

6 -3.456963	Direct specification	DO K AIR
IMS 0.000000	Solves (S)	Axial ray angle
	Survature pickup (P)	Axial ray incident angle
■ 1 W 1 *	Minus curvature pickup (P)	Axial ray aplanatic
🗱 Len Spe Rin Ape	Variable (V)	Chief ray angle
Pxs Pxt Chr Sei Fif Re	Special variable (V)	Chief ray incident angle
-		Chief ray aplanatic

Right-click on the grey RADIUS button for surface number 6, and select Solves(S) ► Axial ray angle ... ► Enter solve value: -0.1785695 (this is -0.1 times the entrance beam radius)

9. Remove the curvature solve on surface 6: Click on the grey RADIUS button for surface 6, and select **Direct specification** 28.249694 0.700000 1.8000 The "S" 5 should 6 -3.491631 Direct specification vanish. IMS 0.000000 es (S)

[pu -0.1785695;csd 6 or rd 6 -3.491631]

10. Verify the effective focal length is 10mm.

11. Change the title to **Demo Triplet 10 mm f/2.8 20deg**.

Gen	Setup Wa	avelengths V	ariables Draw	On Group	Notes 🔺
Lens:	Demo Triplet 10m	nm f/2.8 20deg		Efl	10.000000
Ent be	am radius 1.7	785695 Field an	20 0 0000	Primary wavln	0.587560
SRF	RADIUS	THICKNESS	PERTURE RADIUS	GLASS	SPECIAL
OBJ	0.000000	2.0000e+19	7.2793e+18	AIR	
1	4.249954	0.700000	1.800000 K	SK16 C	
2	-31.729657	1.199987	1.800000 P	AIR	
3	-4.049956	0.300000	1.800000	F4 C	
AST	3.859958	1.199987	1.800000 A	AIR	
5	28.249694	0.700000	1.800000	SK16 C	
6	-3.491631	8.589907	1.800000 K	AIR	
IMS	0.000000	0.000000	3.798090 S		~

Save the lens as Triplet10mm_Start.len in the directory C:ProgramFiles\OSLO\EDU63\private\len\EDU_Tutorial.

12. Open the variables data editor: click on the button labelled **Variables** in the lens data editor. **[vse]**

🖽 Variables Data Editor < Surface	e Data		
×			
Default air-space thickness bo	ounds: Minimum O	.100000 Maximum	1.0000e+04 🔥
Default glass thickness bounds	s: Minimum O	.500000 Maximum	100.000000
Vary all curvatures	/ary all thicknesses	Vary all air s	paces
V # Surf Cfg Type Mi	n Maximum Dam	ping Increment	Va
	0.000000 1.0	0.00000 0.000000	0.000
, ,			, 💌
			~

13. Click on Vary all curvatures. Click on Vary all air spaces.

14.Close the variables spreadsheet with the green tick:

Accept pending entry/Close spreadsheet

15. Using the text window header **Var**, check that there are now 9 variables. **[var]**

	Т	W 1 *							
	💴 Lei	n Spe	Rin A	kpe Wa	av Pxc Abr Mrg Chf	Tra Sop Ref	Fan Spd Auf Var	One lie Slv Pkp	Аре
1	Pxs P	xt Chr	Sei Fr	f Ref b	oot chf top skw				
	*VAR	IABLE	s						
1	VB	SN	CF	TYP	MIN	MAX	DAMPING	INCR	VALUE
	V 1	1	-	CV			1.000000	5.6001e-05	0.235297
	V 2	2	-	CV			1.000000	5.6001e-05	-0.031516
	V 3	3	-	CV			1.000000	5.6001e-05	-0.246916
	V 4	4	-	CV			1.000000	5.6001e-05	0.259070
	V 5	5	-	CV			1.000000	5.6001e-05	0.035399
	V 6	6	-	CV			1.000000	5.6001e-05	-0.286399
	V 7	2	-	TH	0.100000	1.0000e+04	1.000000	0.000179	1.199987
	V 8	4	-	TH	0.100000	1.0000e+04	1.000000	0.000179	1.199987
	V 9	6	-	TH	0.100000	1.0000e+04	1.000000	0.000179	8.589907

The lens data spread sheet should have the following appearance:

Gen	Setup Wa	avelengths	Va	ariables 👘	Draw	0n	Group	Notes	^
Lens:	Demo Triplet 10r	nm f/2.8 20de	g				Ef1	10.000000	
Ent be	eam radius 1.7	785695 Field	angl	e 20	.000000	Primar	y wavln	0.587560	
SRF	RADIUS	THICKNESS		APERTURE	RADIUS	G	LASS	SPECIAL	
OBJ	0.000000	2.0000e+19		7.2793e+:	18		AIR		
1	4.249954 V	0.700000		1.8000	00 К		SK16 C		
2	-31.729657 V	1.199987	V	1.8000	00 P		AIR		
3	-4.049956 V	0.300000		1.8000	00 📃 00		F4 C		
AST	3.859958 V	1.199987	V	1.8000	A 00		AIR		
5	28.249694 V	0.700000		1.8000	00 📃 00		SK16 C		
6	-3.491631 V	8.589907	V	1.8000	00 К		AIR		
IMS	0.000000	0.000000		3.7980	90 S				v

16. Save the lens again. [save]



This completes the section duplicated in the document "Optimization Tutorial using OSLO Light." The section which follows may be regarded as being a sequel to the two sections "Optimization using the Aberration Error Function" and "Optimization using the GENII Error Function" in that document.

OPTIMISATION USING THE OPIC ERROR FUNCTION

17. Type the command **opic** in the command line. If the error message **Input error: Unrecognized word 'opic'** appears, the command has not been installed and compiled - see Appendix 1.



Note the message in the text window. The "Vignetting factors" on the second line are the (relative) values of **ymin**, **ymax** and **xmax** for the two off-axis points, at (relative) field heights of 0.7 and 1.0 respectively. These figures are used in the lens drawing conditions spreadsheet (see below).

The procedure above applies to those running OPIC-EDU version within OSLO EDU. An alternative version is available for those with access to OSLO Standard or OSLO Premium. This includes several versions of OPIC, including the one described here. In this case the appropriate command is **opicedu**.

- 18. Optimise ("iterate") 10 times by clicking on the text window header **Ite** once **[ite]** No further improvement is necessary.
- 19. Save as Triplet10mm_opicedu.len in the same directory as the starting lens:C:ProgramFiles\OSLO\Edu63\private\len\EDU_Tutorial\.

DRAWING THE FINAL DESIGN

- 20. Pull down the menu from the **Lens** menu header and select **Lens Drawing Conditions ... [uoc drl]** In the lens drawing conditions spreadsheet:
 - After Number of field points for ray fans: enter 4.
 - Under the column **Frac Y Obj** type **1.0** in the fourth row.
 - Under the column **Rays** type 2 in the second row, 2 in the third row and 1 in the fourth row.

- Under the column Min Pupil, type -0.65 in the second row, -0.5 in the third row. These are the values of ymin for object heights 0.7 and 1 generated by the call of opic described in section 17 above).
- Under the column **Max Pupil**, type in the **ymax** values, 0.9 in the second row, 0.75 in the third row.
- Close with the green tick:



- 21. Draw the lens:
- From the <u>Lens</u> menu header select Lens
 Drawing ... ► System
- Accepting all the defaults click on OK

Note the ray colour sequence is green, blue, red, light blue.



EVALUATING THE FINAL DESIGN

MODULATION TRANSFER FUNCTION

22.Calculate the cut-off spatial frequency at the image using the formula:

Maximum frequency = 2 * numerical aperture/wavelength

Use the central (first) wavelength in this calculation (click on the text window header **Pxc** to find the image space numerical aperture, and on the header **Wav** to find the wavelength in microns). The



answer should be 606 cycles per mm.

OK.

23.From the Evaluate menu header select Transfer function
 ► Through frequency report graphic ... and enter the figure calculated (606.0) in the box labelled Maximum frequency.

Click on

This gives a plot of the MTF out to the diffraction limit (the MTF at the limit is not quite zero as there are three wavelengths, and only the central one was used for the calculation). [rpt_tfr 606.0]

24. Plot the same diagram out to a frequency of only 40 cycles/mm. Note that the MTF is above 0.5 (all curves) at 40 cycles/mm. [rpt_tfr 40.0]



VIGNETTING

- 25. To define the object point at full field, in the command window type: **sop 1.0 0.0 0.0**
- 26. To calculate the amount of vignetting at this field point, in the command window type **spd**

*SET OBJE	CT POINT						
	FBY	FBX	FE	Z			
1.	000000						
E	YRF	FXRF	FY		FX		
YC	XC		YFS	XFS		OPL	REF SPH RAD
3.606943	3	-0.	056343	-0.0133	109	13.420286	11.823588
*SPOT DIA	GRAM - FBY	1.00,	FBX 0.0	0, FBZ	0.00	- POLYCHRO	MATIC
APDIV	17.030000)					
WAV WEIG	HTS:						
WM	11	WW2	WW 3				
1.000	000 1.0	00000	1.00000	0			
NUMBER C	F RAYS TRA	CED:					
WV	71	WV2	WV3				
13	86	136	136				
PER CENT	WEIGHTED	RAY TRAN	ISMISSION	i: 58	.62069	0	
*SPOT SIZ	ES						
GEO RMS	Y GEO RM	IS X GE	EO RMS R	DIFFR 1	LIMIT	CENTY	CENTX
0.00298	0.003	971 0	.004964	0.002	2303	-0.000570)
*WAVEFRON WAVELENG	IT RS TH 1						
PKVAL	OPD RM	IS OPD S	STREHL RA	TIO I	RSY	RSX	RSZ
1.025	5286 0.2	50318	0.18099	2 -0.0	000850		

27. Note the "Per cent weighted ray transmission" value. The brightness reduction is only 41% at the extreme edge of the field.

DISTORTION

- 28.From the **Evaluate** menu header select Other ray analysis ▶ Report graphic ... and accept all the defaults.
- 29. Note that the distortion is less than 0.3% everywhere in the field. [rpt_ric ray 0 0 0]

It may be concluded that the nominal design of this lens meets all the requirements of the customer specification by some margin. For the next stage of the design, the calculation of tolerances, this margin is used in the



calculation, so that the lenses delivered in production all meet the customer requirement.

As a final check, the prescription of this lens is listed below using **Len** and **Pxc** in the text window:

*LENS	5 DATA			
Demo	Triplet 10mm	f/2.8 20deg		
SRF	RADIUS	THICKNESS	APERTURE RADIUS	GLASS SPE
NOTE				
OBJ		2.0000e+19	7.2793e+18	AIR
1	4.052520	V 0.700000	1.800000 K	SK16 C
2	-228.402737	V 1.141096 V	1.800000 P	AIR
3	-6.145935	V 0.300000	1.800000	F4 C
AST	3.857846	V 1.231107 V	1.800000 A	AIR
5	13.439422	V 0.700000	1.800000	SK16 C
6	-4.807852	V 7.824421 V	1.800000 K	AIR
IMS			3.633524 S	
*D3D2	YTAL CONSTAN	דפ		
FAR	tivo fogal l		Tatoral magnification.	-5 01700-10
PTTEC				-5.01/96-19
Numer	rica⊥ apertur	e: 0.177937	Gaussian image height:	3.652670
Worki	ing F-number:	2.809983	Petzval radius:	-23.067815
Lagra	ange invarian	L: -0.649945		

APPENDICES

1. DOWNLOADING AND COMPILING OPIC

- Using an internet browser, open the knowledge base page of the Lambda Research Corp website (Home>Tech Support>Knowledge Base), URL <u>http://www.lambdares.com/techsupport/kb/index.phtml</u>
- Left click on **OPIC (CCL file)**
- In the page which opens, under the header, left click on Click to begin the download
- The file will have name **optim_ic_EDU.ccl**. Left click on **Save**.
- In the Save in: area at the top, navigate to the directory C:ProgramFiles\OSLO\EDU63\private\ccl\ The file type should be OSLO CCL File. Left click on Save. [Take care: Store the file in the Private CCL directory, not in a subdirectory. The file extension must remain .ccl]
- Close the internet browser and open OSLO EDU.
- Either, in the command window, type: **ccl**, or, from the menu header **Tools** select **Compile CCL** ... and click on the green tick three times, accepting the default each time.
- If the message in the text window reads: <u>*CCL COMPILATION</u> <u>MESSAGES:</u> No errors detected then compilation is successful.
- If error messages appear in the text window such as: *CCL COMPILATION MESSAGES:

optim_ic_edu.ccl 8: Name 'colour_weight' has already been declared optim_ic_edu.ccl 133: Duplicate procedure definition optim_ic_edu.ccl 385: Duplicate procedure definition

then the opic command appears in a file already stored in this directory. The old file needs to be either deleted, or have its name changed to (for example) **optim_ic_edu_old.ccx** (The .ccx extension is a signal that the file is not to be compiled).

- If any editing is needed, from the menu header, select <u>Window</u> ►
 Editor ► Open and open optim_ic_EDU.ccl. If you save from this editor, compilation takes place automatically.
- Open any lens, and in the command window, type: **opic**. A message like the following should appear in the text window to indicate that all is working well:

opic: Operands defined for focal system with colour weight 1.00 EDU Vignetting factors ymin ymax xmax ymin ymax xmax for FBY = 0.7, 1.0: -0.60 0.80 0.95, -0.40 0.60 0.80

If OPIC EDU is run within OSLO Standard or OSLO Premium, use the command opicedu instead of opic to avoid conflict with another command of the same name, stored in the file Take care

2. OPIC DOCUMENTATION

The following documentation is contained within the **optim_ic_EDU.ccl** file:

OPIC for OSLO EDU

Contributed by Brian Blandford Email: brian.blandford@physics.org

Generates an error function based on those developed in the 1970s at Imperial College, London by Charles Wynne, Pru Wormell, Mike Kidger and others. This version is intended primarily for users of OSLO LT, OSLO EDU or OSLO Light, but will work with all versions of OSLO.

The command calculates vignetting, and then defines an optimisation error function with 50 operands.

The optimisation error function consists of the weighted sum of the following operands:

Four paraxial ray quantities:

1	ΡΥ	Height	of	the	paraxial	axial	marginal	ray	at	the	image
2	DII	7 7	- E .	1							

- 2 **PU** Angle of this ray in the image space
- 3 **PYC** Height of the paraxial pupil (chief) ray at the image
- 4 **PUC** Angle of this ray in the image space

Two first order chromatic coefficients for wavelengths 2 and 3:

5 **PAC** Primary axial (longitudinal) chromatic focal shift

6 **PLC** Primary lateral chromatic aberration

Two first order chromatic coefficients for wavelengths 1 and 2:

7 **SAC** Secondary axial (longitudinal) chromatic focal shift

8 **SLC** Secondary lateral chromatic aberration

Two geometrical optics parameters:

9 **OALL** The overall lens length (from srf 1 to srf IMS-1)

10 For focal systems, the equivalent focal length EFL; for afocal systems, the paraxial angular magnification AMAG. A user-defined operand:

11 **User**: A spare parameter for user-defined operands programmed by the user within **optim_ic_EDU.ccl**. The routine is supplied with the mean RMS spot radius for the field points FBY = 0.0, 0.7, 1.0 as an example.

The remaining aberrations are those of finite rays:

For focal systems, all monochromatic ray aberrations are linear - (DX, DY etc). For afocal systems they are angular (DXA, DYA etc) expressed as direction tangents - e.g YA=L/M or tan(YANG).

Colour aberrations (COL) are optical path differences between wavelengths 2 and 3, known as the "Conrady D minus d" - or DMD - see Welford WT: Aberrations of Optical Systems (Adam Hilger 1986) p 202. For the axial object point (FBY = 0):

12 **A_DY** the aberration of the marginal ray FY = 1.0).

13 **A_COL** The chromatic optical path difference of this ray

14 **A_Z_DY**For the axial object point, the zonal ray (FY = 0.7)

15 **A_Z_COL** The chromatic optical path difference of this ray

For	the	first	off-axis	image	point	(FBY	= 0.7):	_

16	M_XFS The paraxial sagittal focal shift of the pupil ray.
17	M_YFS The paraxial tangential focal shift of the pupil ray.
18	M_DIST% The percentage distortion at the 0.7 field
19	M_T_DY The aberration of the top marginal ray (FY = +1.0)
20	M_T_COL The chromatic optical path difference of this ray
21	M_TZ_DY The aberration of the top zonal ray (FY = +0.7)
22	M_TZ_COL The chromatic optical path difference of this ray
23	M_BZ_DY The aberration of the bottom zonal ray (FY = -0.7)
24	M_BZ_COL The chromatic optical path difference of this ray
25	M_B_DY The aberration of the bottom marginal ray (FY = -1.0)
26	M_B_COL The chromatic optical path difference of this ray
27	M_S_DX The aberration of the sagittal marginal ray (FX = +1.0)
28	M_S_DY The aberration of this ray in the Y direction
29	M_S_COL The chromatic optical path difference of this ray
30	M_SZ_DX The aberration of the sagittal zonal ray (FX = +0.7)
31	M_SZ_DY The aberration of this ray in the Y direction
32	M_SZ_COL The chromatic optical path difference of this ray

For the second off-axis image point (FBY = 1.0)

33	E_XFS The paraxial sagittal focal shift of the pupil ray.
34	E_YFS The paraxial tangential focal shift of the pupil ray.
35	E_DIST% The percentage distortion at the edge of the field
36	$\ensuremath{E_PLC}\xspace$ The lateral primary chromatic aberration of the pupil ray
37	E_T_DY The aberration of the top marginal ray (FY = +1.0)
38	E_T_COL The chromatic optical path difference of this ray
39	E_TZ_DY The aberration of the top zonal ray (FY = $+0.7$)
40	E_TZ_COL The chromatic optical path difference of this ray
41	E_BZ_DY The aberration of the bottom zonal ray (FY = -0.7)
42	E_BZ_COL The chromatic optical path difference of this ray
43	E_B_DY The aberration of the bottom marginal ray (FY = -1.0)
44	E_B_COL The chromatic optical path difference of this ray
45	E_S_DX The aberration of the sagittal marginal ray (FX = +1.0)
46	E_S_DY The aberration of this ray in the Y direction
47	E_S_COL The chromatic optical path difference of this ray
48	E_SZ_DX The aberration of the sagittal zonal ray (FX = +0.7)
49	E_SZ_DY The aberration of this ray in the Y direction
50	E_SZ_COL The chromatic optical path difference of this ray

<u>To use:</u>

1. Type in command: **opc gen** [operating_conditions general] Check that the evaluation mode (focal/afocal) of the starting design is correct.

2. Type in command: **pxs** [paraxial_setup]

Check that the starting design has the desired values of the key parameters for the four types of optical system: Objective (infinite-finite, focal) the effective focal length and entrance beam radius Reverse objective (finite-infinite, afocal) the effective focal length and object numerical aperture Relay (finite-finite, focal) the paraxial magnification and object numerical aperture Telescope (infinite-infinite, afocal) the paraxial angular magnification and entrance beam radius Type in command **rpt_ric ray 0 0 0**[ray intercept report 3. graphic] Check that at least part of the pupil is traced for each of the three default field points (axis, 0.7 and full field). Then call by typing the command **opic** (or e.g. **opic** 0.5 - the 4. number scales the relative weights of all chromatic ray aberrations; the default value for colour_weight is 1.0) For focal systems: 5. Check that the target on operand 2 is the target numerical aperture (\mathbf{PU}) required, and that the target on operand 9 is the target overall lens length (**OALL**). If equivalent focal length (EFL) is to be controlled, check that the target for operand 10 is the value required and assign a weight. For afocal systems: Check that the target on operand 1 is the paraxial marginal ray height (\mathbf{PY}) for the desired magnification. Also check that the target on operand 9 is the desired overall lens length (OALL). If angular magnification is to be controlled, check that the target for operand 10 is the value (**AMAG**) required, and assign a weight. 6 Define some variable parameters (command **vse**) such as curvatures.

7. Type in command **ite** (or click on Ite in the text window header.

Exceptions:

The mid-field distortion value is incorrect for ray aiming mode = "wide angle". If the aperture is expressed as image space NA or controlled by an angle solve on the last curve, the **PU** control will not be effective - weight the **EFL** instead.