

# Optical System Design

## Software Tools Cover Envelope Calculations to the Final Engineering Drawings

▶ Optical design is a convenient phrase that covers the whole range of activities required for the creation of an optical system. Optical design usually begins with simple considerations of the spatial envelope of a new lens – finding the object/image distances and sizes, aperture, focal length etc. The designer must then find a suitable starting design, either derived from basic theory, from his experience or from a design library. This start point will need to be analysed and understood and then optimised to match the requirements of the task in hand [1]. Almost always, optimisation involves repeated simultaneous multi-variable adjustments, and this therefore requires sophisticated software tools as following described in this article.

In the beginning the designer will need to consider the transmission of the optics and also the impact of ghost images and stray light on the system. In particular, when developing UV-systems, the analysis of stray light is an important activity [2] that should not be ignored. Weight may be a consideration, and the actual materials used can have a dramatic impact on cost and handling requirements. The designer will need to consider the effects of manufacturing errors on the performance of the lens, setting tolerances to control the errors. Sometimes, the system will need to be re-designed to reduce the sensitivity to such errors (see Fig. 1).

Finally, engineering drawings, embodying those tolerances, have to be prepared for the machine shop, so the actual hardware can be manufactured. All through this process, the designer will need to make compromises of one sort or another. Unless he has the right tools or experience, these compromises will have to be made almost blind, a risky activity in a field strewn with pitfalls!

### The WinLens 3D software suite

In 1993, Linos Photonics (Spindler & Hoyer) released the first version of its optical design software WinLens. This program was initially

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#### CHRISTOPH GERHARD

Christoph Gerhard is product manager/optics at Linos Photonics and university lecturer in Göttingen. After working as skilled engineered worker in optical manufacturing in Gießen, he studied precision production engineering at the University of Applied Sciences and Arts in Göttingen and then prepared his diploma thesis at the Laboratoire Charles Fabry de l'Institut d'Optique in Orsay. In 2009, he received the Georg-Simon-Ohm-Award 2009 from the German Physical Society for the development of a new ultrashort laser source.



#### GEOFF ADAMS

Dr. Geoff Adams studied physics at the Imperial College of Science & Technology, London, followed by a period at the research department of British Aerospace. He returned to Imperial College to undertake a PhD in optics on "Tolerancing of Optical Systems". Working with Kidger Optics, he developed their tolerancing program and a lens library. Since 1992, he, at the Optical Software Company, has designed and developed the WinLens suite for the Linos Photonics R&D department. Related Linos projects: MachVis lens selector for Machine Vision systems.



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developed for the Linos R&D department, to allow them to easily model systems composed of components from the Linos catalogue and perform a full optical analysis. WinLens was rapidly enhanced to handle custom elements and sophisticated optical systems for the Linos OEM design work. External users benefited from this rigorous environment – for example, with the Toleran-

cer – a program developed to handle the interface between design and the machine shop. WinLens Plus, Tolerancer & Glass Manager, a sophisticated optical materials database, are the major components of the commercial WinLens Suite. Linos Photonics has always provided a free version of WinLens which is widely used by students and laboratory engineers. This tradition has been

followed with the release of PreDesigner – a simple free optical layout program, designed to help find answers to that very first stage of the optical design task.

Most recently, WinLens has been extended to handle non-rotationally symmetric systems. Many optical systems include prisms and/or tilts and decenters (T&Ds) – WinLens 3D (a significant development of WinLens Plus) will now model such systems (Fig. 2) – much time has been invested in making this as easy to use as possible. Tilts and decenters, in all three axes, can be applied to individual surfaces, to whole components, and to groups of components. By default, T&Ds in WinLens do not change the global location of following elements, which is ideal for modelling manufacturing errors. Fold mirrors and the ability to offset tilt centers make setting up scanners easy. Prisms, such as the Dove or the Bauernfeind are non-trivial to setup correctly. However Linos prisms can simply be called up by part number; alternatively a simple wizard will allow the designer to specify the 3 to 5 key parameters defining that prism type and then generate the custom prism on demand.

All plots have been enhanced to eliminate symmetry assumptions. The lens drawing will now display in 3D – either as a simple wireframe or as a properly rendered solid model. Sliders allow for real time image rotation, while many options exist to customise the graphic. A global coordinates table has been added, along with a new 3D wavefront plot. The later displays the wavefront either as a solid model or an interferogram. Again this plot can be customised in numerous ways from colour scheme to view point.

### Optical system design step by step with WinLens

**Preliminary Layout:** PreDesigner is the tool to use when first finding the key parameters for an optical system. With it, both the beginner and the experienced designer can assess the layout or space envelope required for a particular task, and answer many 'what if' questions, all without the need for a real, glasses & curvatures, design. First of all, three key object distance/size parameters are selected from a wide range of options. After entering the values, the required lens layout is shown – as a drawing and in tabular form. The table displays all related parameter values such as object/image distances, focal length, magnification, object/image size and angles. An aperture parameter can be selected and given a value. Then using sliders, quick changes to the key values can be made, with the layout and spreadsheet changing appropriately in real

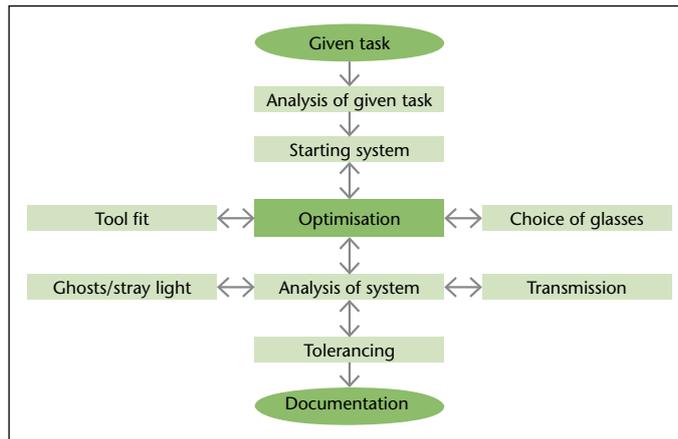


FIGURE 1: Optical system design flow chart.

### THE COMPANY

#### Linios AG

Linios AG is a manufacturer of sophisticated optical systems that operates all over the world. Linios is a development partner and supplier for customers in such growth markets as lasers, optical metrology, medicine, biotechnology and semiconductors. The company is listed in the General Standard index at Frankfurt Stock Exchange and joined the Qioptiq Group, which is an international leader in the design and production of high-precision optical components and modules for military and commercial applications, in June 2007.

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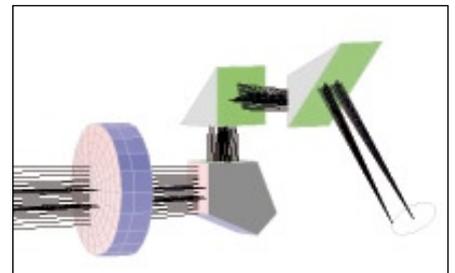


FIGURE 2: Optical system, consisting of a lens and several prisms.

,design' is also highlighted, thus instantly suggesting an appropriate initial lens type.

**Analysis:** The optical design software WinLens 3D can model a variety of optical systems built with user defined and/or standard Linios components. Starting with the simplest of systems, the designer can setup and see the key paraxial points – a helpful tool for teaching. Complex systems of many components are just as easy to setup. In WinLens 3D (and its free companion WinLens 3D Basic), prisms can be defined using a prism wizard. Compound tilts and decenters can be applied to individual surfaces, to components and even groups of components.

time. To help find a suitable real starting design, PreDesigner also shows an f/no vs. field plot. The typical performance regions for different lens families are shown as a series of ellipses. The location of the current

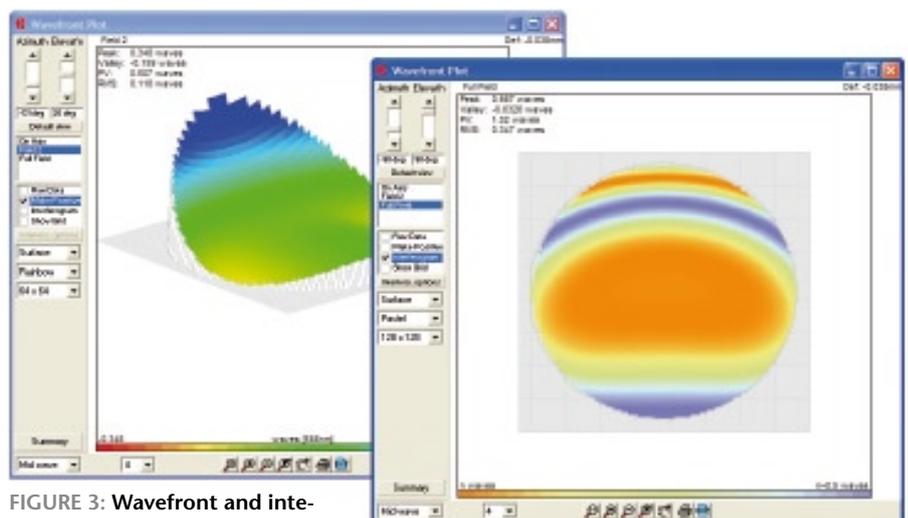


FIGURE 3: Wavefront and interferogram plot in WinLens 3D.

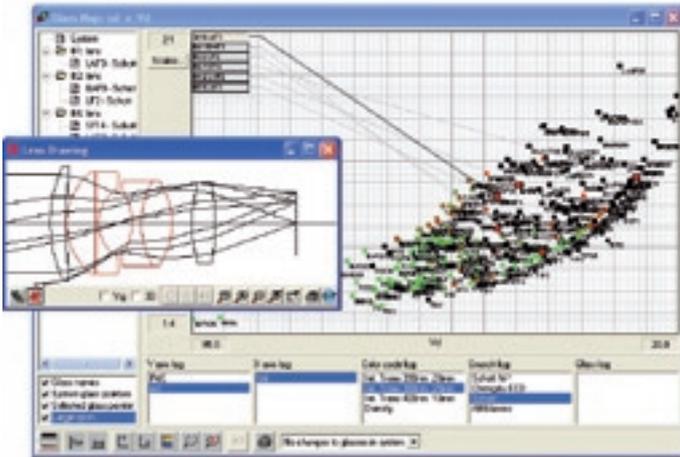


FIGURE 4: Interactive glass map in WinLens.

search option. The merit function is powerful and flexible. Wizards exist to setup the function, but a whole range of defects can be added by drag and drop. In addition, there is a number of aids [4] such as variable selection guide, aspherisation guide, change table display, "video" replay options and a status form to show optimisation activities. Colour coding is extensively used to highlight significant items.

Optimisation is not entirely a blind process – the best results will always be obtained by an experienced designer. However, our goal is to make the task as easy as possible, with maximum feedback, in order to yield good results.

Transmission analysis: WinLens contains tools for key engineering tasks – not classical lens design – but which do impact critically on the overall performance of a lens. Transmission calculations take bulk absorption in the glasses and coatings applied to the surfaces into account. WinLens 3D will show transmission vs. aperture and transmission vs. wavelength. Relative illumination determines the amount of light falling on the image surface. In some application, such as machine vision, it is very important that this be as uniform as possible.

Ghost analysis: Ghost images are caused by reflections from optical surfaces. These follow unplanned paths back to the sensor, causing highlights or flare. WinLens 3D provides a table for quick identification of the key ghosts, and a plot for detailed analysis. The plot can display either a cross section or a footprint type plot, where the footprint is colour coded by transmission of each ray (Fig. 5).

Tolerancing: Manufacturing errors can seriously degrade the optical quality of a good design. Tolerances must be defined to limit the errors in such a way that average performance of a production run is maintained at least extra cost.

WinLens Tolerancer is designed for systems with nominal rotational symmetry. We start with a sensitivity analysis, where each parameter (radius, separation, tilt, decenter, form etc) is varied by a predefined increment. The resulting systems are analysed and the changes in aberrations stored. These sensitivities indicate which parameters are more likely to cause drop in performance of a real lens. Such parameters should then be controlled carefully. Tolerance editors allow tolerances to be assigned to each parameter. Such tolerances can be applied manually or using various tools – inverse sensitivity, standard levels, max-min, scaled etc. Each editor can show immediate statistical predictions of the tolerance impact as a guide to the impact of the editing.

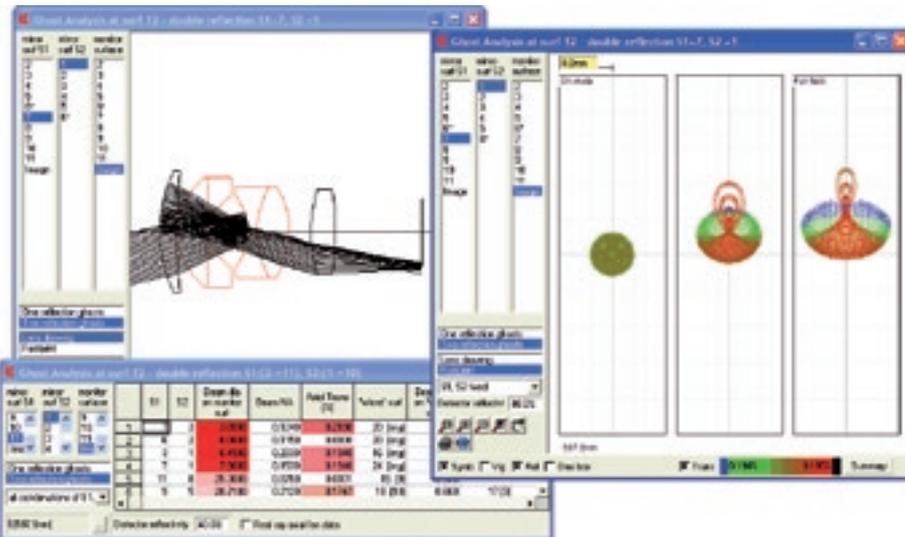


FIGURE 5: Footprint plot of ghost analysis.

values are shown in a table and also a barchart display – the barchart values being user selectable. Both paraxial & Seidel differences are displayed within a sensitivities table.

WinLens also offers a whole range of standard ray based analysis tools, such as single and ray fan tables, isoplanatism and OSC plots, TRA, OPD and longitudinal aberrations, astigmatism, distortion & lateral colour plots, spot diagrams and MTF curves – including MTF vs. Field.

WinLens 3D now includes wavefront and interferogram plots (Fig. 3). These offer real time rotation via sliders and many options including resolution, colour schemes etc.

Optical Glasses: Optical glasses are key to the performance of any lens or optical system. Since there are a large number of optical glasses, browsing the glass catalogues for the right glasses can take a lot of time. Glass Manager, is a sophisticated optical materials database program. It holds data (optical, chemical, mechanical, thermal etc.) for materials from the main glass manufacturers, and new materials and melts can easily be added. Glass Manager

allows the designer to search for glasses with particular properties and to display that data in a wide range of plots, graphs and tables [3]. The designer may define non-standard wave-bands, and the plots will redisplay accordingly. In addition, history logs provide rapid recall of old searches, colour codings etc.

Within WinLens itself, there is a powerful interactive glass map (Fig. 4). This can:

- highlight materials used in the current lens design
- allow the designer to change a glass in the design (by clicking on the map)
- search for and display a subset of glasses
- customise axes and colour code glasses from a range of properties.

Optimisation: Unless an optical system is very simple, improvements have to be made by changing many design parameters simultaneously. This requires a true non-linear optimisation algorithm. The software uses damped least squares as the basic optimisation method, but with several enhancements [4], such as an extended line

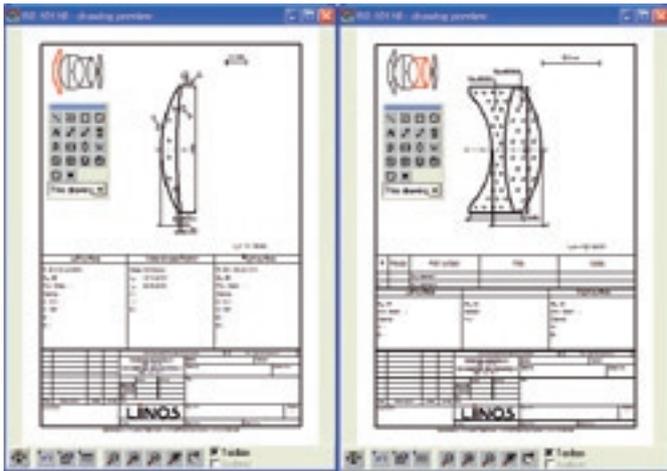


FIGURE 6: ISO 10110 drawings generated in WinLens Tolerancer.

To test out the current set of tolerances, Tolerancer will display Monte Carlo simulations of a production run. Random errors, taken from within the tolerance limits, are applied to each parameter. The system is analysed and the results superimposed on those of previous lenses in the run. Simply visual inspection then shows whether the tolerances are well or poorly chosen.

Once tolerances have been assigned, the system is almost ready for manufacture. First though, engineering drawings have to be prepared. Tolerancer has a built in editor to create ISO 10110 drawings for elements and cemented components. The ISO 10110 drawing editor uses the tolerances defined in the program as the basis for the drawings. As shown in Fig. 6, edges, chamfers, scratch, dig, finish values etc. can be specified and will appear in tables on the drawing. An extra drawing is generated for any aspheric surface. Standard dimensions and symbols are drawn automatically, but their positions can be changed easily. Custom optical drawing elements can be dragged from the toolbox as desired. The drawing can be customised with a logo, choice of font and even location of key elements. These drawings can be then be printed or exported in DXF and BMP format.

### Conclusion

Linus Photonics is actively continuing its development of tools for optical designers, engineers and students with WinLens 3D and WinLens 3D Basic (free). These tools cover almost the entire gamut of optical design tasks from back of the envelope calculations to the final engineering drawings. Some tasks however cannot be handled in the WinLens suite, e.g. the analysis of stray light caused by the micro-structure of optical surfaces, non-sequential ray tracing etc. Other packages, such as TracePro, from Lambda Research, are designed specifically for those

tasks and offer a broad range of capabilities [5], including the analysis of light scattered by the mechanical parts of an optical system, such as lens mounts and housings.

To conclude, one can say that good optical design does imply an experienced designer – otherwise some significant tasks will be overlooked. And even for the experienced designer, software is essential to undertake these calculations, but for the novice, well designed software can also help gain the insight needed to go successfully from ‘back of the envelope’ calculations to final production.

### Further information

[www.winlens.de](http://www.winlens.de) – Free downloads, technical papers, basics of optical design  
[www.opticalsoftware.net](http://www.opticalsoftware.net) – Hints, tips and secrets in short video clips  
[www.linus.com](http://www.linus.com) – web site of manufacturer of WinLens 3D

### References

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