# Optical software investigation

S.Leclercq. 02/11/06.
Update 01/02/07.

Abstract

I looked at some optical design software to choose one to work on the 30m optics but also for general use at IRAM. Among the half-dozen of serious candidates I focused in particular on Zemax and Optalix, because they are popular one hand and it was easy to find a usable versions for free on the other hand.

In the first part I summarize some pros and cons for Zemax and Optalix. Most of these points deal with the interface handiness and optional features, but very few with the performances. The reason is that I was able to perform the same things with both software and couldn't detect any advantage or drawback for any of them so far. They seem to offer comparable tools and performances.

In the second part of the document I summarize some information and the impressions several readings gave me about some other top class optical design and engineering software.

In the conclusion I give the reasons explaining my recommendation to buy one Zemax-EE version and one or more Optalix-LT version.

## I. A first look at Zemax vs. Optalix

I used Optalix-LT 6.50 (2005) that I downloaded from their website as a shareware (30 days trial) but that I converted to permanent use thanks to a license that Optenso crew kindly offered me after some email exchange.
I used Zemax-EE 2003, that Santiago lent me (with hardware serial key). The Zemax demo downloadable from their website allow only to visualize the interface and open example, but not to edit surfaces.

For both programs I designed several systems either following the tutorials or that I created from scratch to reproduce the 30m optics or to test tilted systems with off-axis conical mirrors (mainly elliptic). My overall conclusion is that both programs seems very complete and with similar performances and tools, at least in geometrical optics (with and without paraxial approximation), including Airy spots from differential path calculations; but not including physical optics (wave propagation).

I couldn’t test the following features that may interest us because of the limitations of Optalix-LT (these features are available only in Optalix-Pro):

- Wave front propagation analysis
- Polarization analysis
- Vigneting analysis
- Diffraction analysis (physical optics)
- Optimization
- Tolerance analysis
- Macro Programming

Since optimization is a very important tool for us, I read Optalix optimization tutorial to get a flavor of its possibilities. From this reading and the tests I did in Zemax, Optalix interface seems much more intuitive and comprehensible than Zemax. But

this may just be a biased beginner's impression, and as I discuss later, Optalix optimization tools may be more limited than Zemax.

I listed below the points that seemed to me good and bad while I tested both programs. Most of these points are more a matter of feeling and pretence than performances criteria. Still some of these points may contain some key characteristics that are for you decisive… I underlined the ones that seem to me the most important in this list.

Optalix good points:

- Convivial interface: with the tabs navigation of the surface editor, one can browse at a glance all the surface properties (a bit more hidden in Zemax, which also involved a not so convenient scroll bar for more than 8 parameters per surface).
- Tilts and coordinate breaks may be part of a surface definition (or defined as another surface like in Zemax).
- Angle slider bar for the 3D view.
- Import-export converter between different optical software file types (Zemax, OSLO, ASAP, Code V and others).
- Surface numbering in the graphical display.
- Possibility to do all the work either from graphical user interface, or from command lines.
- Command lines may be used for macros, very similar to Code V language.
- Plot a single ray with aperture and field slider.
- Possibility to move, delete and reverse some surfaces group.
- Zoom configuration (looks a bit better than Zemax multi-configuration tool).
- Documentation more pedagogic than Zemax's one.
- Quick autofocus, best focus according to image curvature with selected fields.
- Thickness in image parameters is the distance between paraxial focus and image plane; when PIM checked, the thickness of previous surface is automatically set to the distance between last surface and paraxial focus.
- When fixed surface aperture is checked (1 in * column) show the trajectory from previous surfaces of the furthest position from the central axis allowed.
- Tools in Pro version that look cool: Weights and volumes calculations, User defined graphics, Analytical setup ($3^{rd}$ order corrected systems created from few input parameters), Slider control (vary some parameters in any window).
- Spot Diagrams vs. fields or wavelength or through focus or grid fields or rms spot size or zoom. Ray intersection plots on a chosen surface. Many aberration tools (Fans/Spots/Grids for Transverse/Longitudinal aberrations in Tangential/Sagittal planes).
- $3^{rd}$ order aberration (Siedel) factors per surface to understand contribution of a surface to the total aberrations.
- Some interesting analysis tools: Ghost Images, Vignetting analysis, (Geom/Diffract)MTF, (G/D)PSF, (G/D) Encircled energy, extended sources Fourier transform (several hats and Gaussian functions), Strehl ratio, Wavefront aberration. Illumination analysis (extended source).
- Physical optics propagation: rays are tables of complex numbers (amplitude and phase) propagated through the system in the Fresnel approximation, diffraction on all elements of the system, not only through the pupil like in

diffraction tools above. Automatic (or not) algorithm switch between Waist-to-Sphere / Sphere-to-Waist / Plane-to-Plane.
- Transmission and polarization tools…
- Optimization tool: Kuhn-Tucker or Levenberg-Marquardt algorithms.
- Complete coating tools, Environment factors (P, T).
- Tolerance tools. Manufacturing support.
- Special apertures such as central obscuration or spider arms can be defined as part of a surface (for example part of the primary mirror).
- Possible to copy text from external application into surface editor cells.

Bad points:
- Click on a window may be interpreted as a big zoom (need to click on unzoom each time).
- Pixels shapes in spot diagrams can't be chosen; rendering not as nice as Zemax.
- For the same number of rays in a spot diagram Optalix seems slower than Zemax to draw the spots (and this occurs each time the window is selected whereas is instantaneous in Zemax with a better rendering…).
- 3D rendering in POV (need to learn how to use POV) not as good and interactive than the Zemax shaded model. Sometimes default POV rendering is ugly and totally inaccurate.
- Rays in Lens Draw display pass through obstruct surfaces
- Rays can exist beyond surfaces limits where they obeys surfaces refraction / reflection laws… unless fixed surface aperture is checked with a 1 in the * column of the surface editor, but this option doesn't work well with aspheric surfaces and if rays aiming is not set to stop surface.
- Hole in primary mirror has to be defined as obstruct surface; if it's defined as a hole and one places an obstruct surface before the primary at the place of the secondary it doesn't work, the central rays pass trough all the surfaces twisting all analysis (spot diagrams, ray fans, etc). If obstruct surface is surface 1, placed behind secondary AND "Check Heights" is checked in the Lens Draw option, rendering is fine in Lens Draw windows, but still wrong in spot diagrams.
- Number of rays can be chosen in Lens Draw display only in command lines and only 4 shapes available (default, x, y, xy, circle, but no grid or concentric circles). For analysis in spot diagrams, only power of 2 rays in squared grid can be chosen, no other shape available.
- No command undo.
- Scale factor for pickups available only in command line (no GUI interface).
- For beginners, not easy to find parameters not available in graphical interface (for example command for ray density, or variable names for zoom configuration), but once one knows the syntax, command line is quick and powerful.
- To disable special aperture one has to do it one at a time and update all graphics each time, otherwise only the first disabled aperture disappear, not the others (bug) !
- In 3D Lens Draw windows movements only in azimuth and elevation from the center of the system, but not from the observer point of view, so all angles of the system viewable with only one point of view; not always the best choice for a good visualization (for example see the telescope at a given observing

elevation angle with the receiver room horizontal and from a profile point of view).

- At high incidence, when only a fraction of rays should not be vignetted by a surface, the rays some rays near the edges of the surface are vignetted although they shouldn't.
- No axis names on the ray fan plots.
- Bug (overflow scratching the program) in astigmatism analysis tool.
- In current version, Physical Optics Propagation limited to axial conditions (not decentered nor tilted system). Limited also to coherent (monochromatic) light.
- Optimized for visible light: glass catalog up to near IR.
- Very slow update of graphical windows when number of rays is big.
- Do not always update the zoom (multi configuration) table correctly when inserting surfaces before one involved in the zoom table (ex: S12 should become S14 when inserting 2 surfaces before, but the parameters applied to S12 in zoom table may shift to S13 instead of becoming S14).
- Updating a display in a system with a lot of tilted surfaces takes a "long" time (ex more than 30 seconds for the 30m telescope with 24 surfaces).

Zemax good points:

- Coloring of surface type in surface editor (convenient for quick identification).
- Highlight of selected surface in graphical display (convenient for quick identification).
- Knowledge database that help to find a solution to a specific problem very quickly in a website that seems complete. Technical support seems more important than in Optalix (emphasized in the sell arguments in Zemax documentation).
- Import of non-sequential elements from CAD software (in particular SolidWorks), allows including some complex elements more easily than Optalix.
- Export to CAD software for better rendering (possible with Optalix, but much better rendering for files from Zemax in Solid Works.
- 3D shaded model, with mouse click and drag correspond to azimuth and elevation (only in latest release, not in the 2003 version).
- Possibility to annotate all graphical windows (text or drawings)
- Better rendering of the spot diagrams than Optalix.
- Apparently more shortcuts than Optalix.
- Great number of options both for the working environment and graphs display.
- Possible to run Zemax with Windows Remote Desktop.
- Tilts and decenter may be define as part of the surface to avoid using coordinate breaks before and after the surface (like Optalix).
- Speed of graphic windows update event with great number of rays.
- Choose a surface as the global coordinates is quite useful for the 3D presentation and rotation of the drawings.

Bad points

- Much longer list of surfaces than in Optalix when the optical axis has to be tilted because of the mandatory use of coordinate breaks (e.g. 3 surfaces needed to create one folded mirror).

- No law of reflection/refraction as in Optalix for the coordinates, so one has to calculate the tilts of coordinate breaks to match the optical axis tilt in order to keep the center of the surfaces aligned with the optical axis !
- Configuration parameters not as easy to find than in Optalix; the interface is not very intuitive at first, but should be handy after a short learning process.
- Pick-ups for surface properties only from precede surface.
- Spiders defined on a curved surface are flat.
- Tilts and decenter data of a surface not supported in optimization.
- Secondary windows (surface editor, displays, etc) are not contained in the main window, so one cannot hide them partially when resizing the main window (for example to see another application behind).
- Can't copy numbers from other application (with clipboard) into lens editor cells.
- Putting a wrong parameter in a cell make the program crash (e.g. a glass that does not exist in the catalog).
- No cell to write a comment to ease the understanding of the purpose of the surfaces used in the simulation (that would help a lot to communicate big simulations that can easily use more than 60 surfaces such as the 30m for one kind of detector only, from primary mirror to detector cryostat).

Both Optalix and Zemax allow to define sequential and non-sequential surfaces, and to create hybrids designs with groups of each category. In the sequential method each rays can hit a surface only once and only in the ordering sequence of the surfaces numbers (for example a ray can't hit surface 2 then 1 then 2 again; it has to hit 1 first then 2, then 3, etc. even if the real physical order should be different), whereas in the non-sequential method rays hit the surfaces in the order they meet them (e.g. 2 then 4 then 3 etc.). The non-sequential method involves much more surfaces definitions, which implies longer design time, longer calculation time for analysis and much more instable optimization algorithms. From the documentation it is not clear whether Optalix can do optimization for non-sequential modes, whereas there's a chapter dealing with non-sequential optimization in Zemax (not found in 2003 version but in the latest release).

Analysis tools look similar in both programs. They both include spot diagrams, ray fans, Modulation Transfer Function and Point Spread Function calculations, illumination and transmission analysis. These functions seem to me the most important and are identical in both software. Still, a lot of other analysis functions and tools seem slightly different between Optalix and Zemax. There are more than 100 of them and since two different names may actually perform the same function or two identical names may "hide" slightly different algorithm, it is very difficult to judge the real power of each software without months of intensive use…

So they may exist some fundamental performances differences but detecting them would require the complete version for each software, giving the opportunity to test optimization, physical optics tools and macro programming. Due to the sophistication of these tools, mastering them enough to be able to judge them would require a learning period of several weeks. Event though I would surely have to learn and use these tools for my work on the 30m optics, I don't know if it worth the time to learn them for both software and then decide which one we keep, or if it is better to decide on the software based on the preliminary work I did and then learn the tools only for the chosen one.

Here is the prices list of both software for a single user license :

| Optalix-LT | Optalix-Pro | Optalix-Edu | Upgrade Optalix-Pro | Optalix manual |
|---|---|---|---|---|
| 40 € (I got it for free) | 1200 € | 500 € (same as Pro, but for universities) | 300 € | 70 € |
| Zemax-SE | Zemax-EE | Upgrade to EE | 1 year support and upgrades | Zemax manual |
| 2000 $ | 4000 $ | 2000 $ | 700 $ | 50 $ |

As you can see, both software exist in a light version and a full one. Optalix-LT does not include diffraction analysis, optimization, multi-layer coating, tolerance analysis, macro programming and some other features. Zemax-SE does not include physical optics and non-sequential features.

## II. Information about other serious candidate software

Here is a short list with short comments of the major other optical software that are serious candidates to perform professional optical design. Karl, Bernard, Laure and Santiago told me the names of several of them before I started this investigation, but note that I found again all these names independently after several "googleings" on the optical design subject. The information I synthesize bellow has been gathered on several websites including the software's companies websites, some independent forums, and magazines website.
Note that all the software I talk about in this report are all very good. I found plenty others, but on an artificial scale from 1 to 10 in terms of performances, I think I kept only the top 3 ranks one can find on the market. Between parentheses after the software name I give such a mark, be aware that this kind of ranking is a bit short-minded and unfair, but at least it gives a quick glance idea of the performances (do not include handiness and usefulness for our purpose!).

Zemax (7/10) and Optalix (7/10) are used as references in the comments bellow.

OSLO (8/10):
Seems similar to Zemax and Optalix in interface handiness and performances ; as Zemax and Optalix, it includes all the usual ray tracing tools, optimization, sequential and non-sequential design, and macro programming. The macro language is more like a real programming language (similar to Java or Visual Basic), offering big customization possibilities of the software but maybe not as easy to use than Optalix simpler macro language. Even though is as some Modulation Transfer Function tools involving convolutions and FFT algorithms, it is not clear if its physical optics tools are as complete as Zemax and Optalix. Still, I read in some forums that it may give better and more accurate results in some systems optimization and performance analysis.

Code V (9/10):
Seems similar to Zemax and Optalix, providing even more powerful and complete possibilities, but maybe with a steeper learning curve. The off-axis presentation in the brochure suggests it is done better than in other software (possibility to define

sections of conics not necessarily centered on the vertex). It is necessary to write the company to get a price quote, but from what I read now and there it seems much more expensive than Zemax. So the question is "do we need a manual-stick-luxury-optical-design-car or is an automatic-full-size-optical-design-car enough for our goals" ?

ASAP (8/10):
It's a pure non-sequential optical engineering software. Non-sequential design, where rays can intercept any surface in any order, is not the best for systems optimization. But it is a very useful tool to analyze real system illumination and parasitic effects. Even though Zemax and Optalix include non-sequential tools (and sequential + non-sequential hybrids), it seems that ASAP analysis tools are more complete and more precise than the others. So Santiago's strategy to use Zemax to design the optics and use ASAP as a complementary tool to simulate and check the performances of the system may make sense.

GRASP9 (10/10):
It seems to be the "bulldozer" of the millimeter-wave reflectors and antennae farms analysis software; more powerful and versatile than ASAP. But it is very difficult to find information about it. Except from the company's website, I found some very specialized articles dealing with millimeter wavelengths astronomy that cited GRASP as the reference software to test the performances of design tools as ASAP or Code V. The lack of popularity of this software despite its apparent tremendous performances suggests it is very difficult to master.

Here are two links of websites dealing with optical software. I found the 2nd one only today, but it is worth reading.

http://www.geocities.com/ivankrat/links.html
http://optics.org/articles/ole/8/7/4/1

## III. Conclusion

It seems that all the powerful software of section II are not very intuitive and worth the investment only if they are used on a frequent basis and for applications asking an extremely high degree of precision in the simulation. Since this kind of figure happens only seldom times at IRAM, it seems more relevant to create a simulation with a medium power software and only if necessary use a special contractor to check the simulation with very high precision. So for most of the cases (including study of the 30m optics upgrade) it seems that software like Zemax and Optalix are powerful enough, in addition of being not only much less expensive than section II software, but also with an interface that is enough user friendly to allow a moderate use by not very experienced user.
So the choice is restrained to Zemax vs. Optalix. They seem competitive and both have a fair list of pros and cons (in the list of bad points above some elements are actually not true, but I let them because their presence attest a not user friendly behavior of the software for these points). The choice is therefore not easy, still my recommendation is the following:

- Buy one Zemax-EE, which includes physical optics.

- Buy one (or more) Optalix-LT, which does not include physical optics.

The reasons are the following:

- Zemax is really widespread in many laboratories and therefore a natural software to use in collaborations. It is powerful enough for almost all the applications and people who know how to use it would not need to be trained on a new equivalent software. In addition it presents some good tools for graphical presentations of the optical elements, it has a rather fast computing core for aberrations and diffractions calculations, and it has a good CAD export tool. But it is not cheap ($4000 or $2700 for an upgrade from SE/XE to EE) and it is not as user friendly as it claims for beginners. Fortunately its learning curve is steep and in the end it can be ranked as pretty much user friendly. So I would recommend its use for people who know how to use it or who do not need to do optical design on a full time basis but need to invest time in a rather complex simulation or who need to communicate about it with nice drawings.

- Optalix has a very well written documentation and is more user friendly than Zemax in many aspects (but not all aspects !). It is as powerful as Zemax, yet with $40 only, its LT version is incredibly cheap. So I would recommend it for people who would do seldom time optical design and need the minimum training time possible to get start with the software or for people who dislike the systematic use of coordinate breaks in Zemax for tilted elements ! If a project started with Optalix need more work, the user can stay with Optalix since it is powerful enough (take care there's no physical optics in LT) or choose to export the project to Zemax (or others) thanks to the very good import/export tool. Note that the learning curve may be not as steep as Zemax for complex things, but this really depend one's feeling with the software. The other advantage to have at least one Optalix-LT version in addition to the Zemax-EE is that if one is already using the Zemax key, there is still the possibility for somebody else to do some optical design while waiting for the Zemax key (if it's necessary), and this for an almost negligible investment.