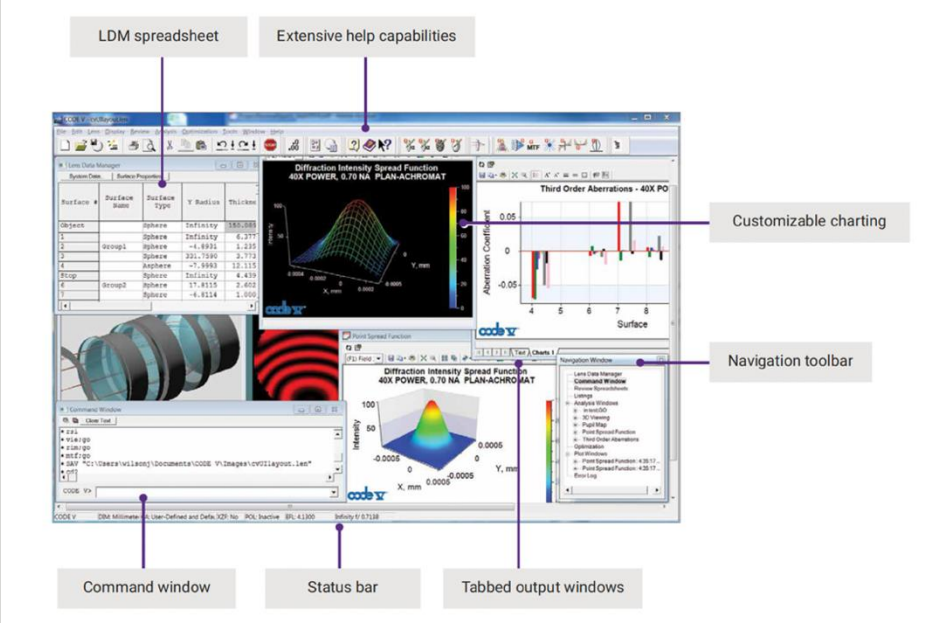

CODE V Optical Design Software

Design, optimize, and fabricate reliable imaging optics

KEYSIGHT

Overview

Using CODE V, our engineers played a key role in the design and implementation of all the primary null lenses used in the highly successful Hubble Space Telescope First Servicing Mission, which dramatically improved the image quality.

Keysight Optical Design Engineering is one of the world's leading developers of optical design and analysis tools, with CODE V imaging design software, LightTools illumination design software, LucidShape products for automotive lighting design, and RSoft products for photonic and optical communication design. The group is also an independent supplier of optical systems design services, with more than 5,500 completed projects in imaging, illumination and optical systems engineering.

Since its worldwide introduction in 1975, CODE V has been instrumental in the development of highly advanced optical systems, sometimes with profound effects on business and culture. It has been used in the development of revolutionary applications such as the compact disk player. CODE V algorithms are a key and dominant technology in the design of the microlithographic lenses that permit the imaging of ultra-fine lines on computer chips — a necessary ingredient in the continuing improvement of computer speeds.

CODE V software has contributed significantly to important technological advances across a wide spectrum of fields such as projection displays, medical instrumentation, advanced military technology, and space exploration.

Because of its established reputation for excellence and quality performance, CODE V is the software of choice when optics are critical to the success of a product or project.

Exceptional Software Support

Technical support

With CODE V, you get much more than the highest-rated optical design and analysis software available. You also get access to more than 50 person-years of optical engineering experience through our technical support staff. When you request assistance, degreed optical engineering professionals are ready to answer your questions.

Training, documentation, and online resources

We offer many options for learning CODE V. Attend online or in-person classes offered worldwide by our international representatives, or schedule an onsite class at your facility to be tailored to your needs. Complete, examples-based documentation and a dedicated customer website with video tutorials, FAQs, example models, macros, tips and training courses are also available to help you be successful with CODE V.

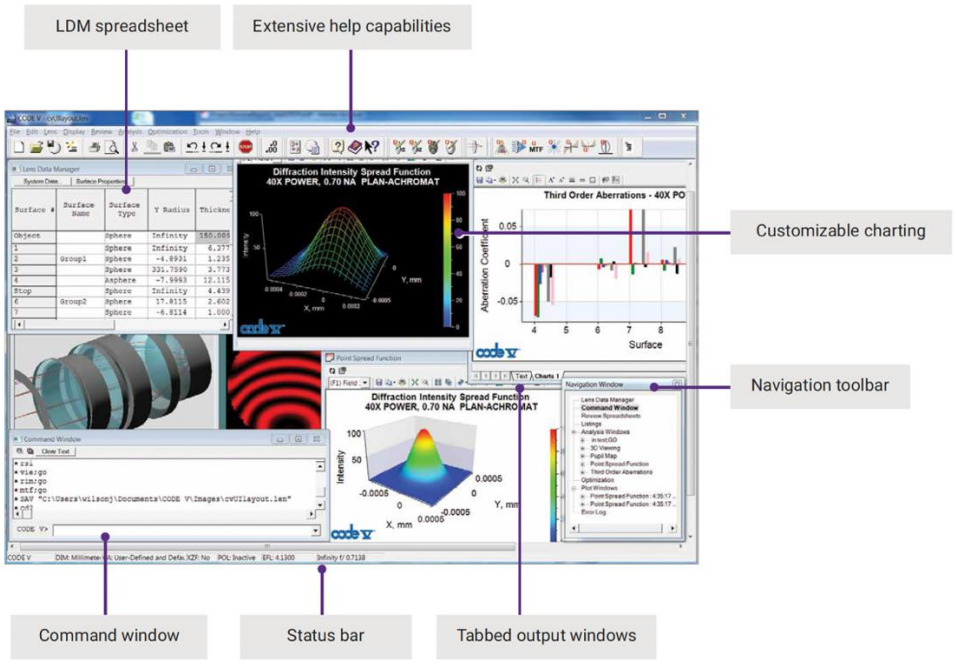

Figure 1. CODE V utilizes a standard Windows user interface with many navigation and usability features.

Program updates

We release extensive program updates approximately once a year to add major new features. We also provide regular program updates with customer-requested enhancements. All software updates, ongoing technical support, and access to extensive content on our dedicated customer website are included in our standard license.

Pre-tested and pre-approved

One of our most important strengths is the synergy between our optical engineering services and software development efforts. Our engineers provide ideas, guidance, testing and feedback for the development of CODE V. For example, expert tools based on unique algorithms developed by our engineers, such as Glass Expert and Asphere Expert, help automate the design process and save you time and effort. Most importantly, before you use the latest version of CODE V for engineering problem solving, you can be confident that the software has been put through rigorous testing by a dedicated team of engineers working at the cutting edge of optical technology.

Applications and Design

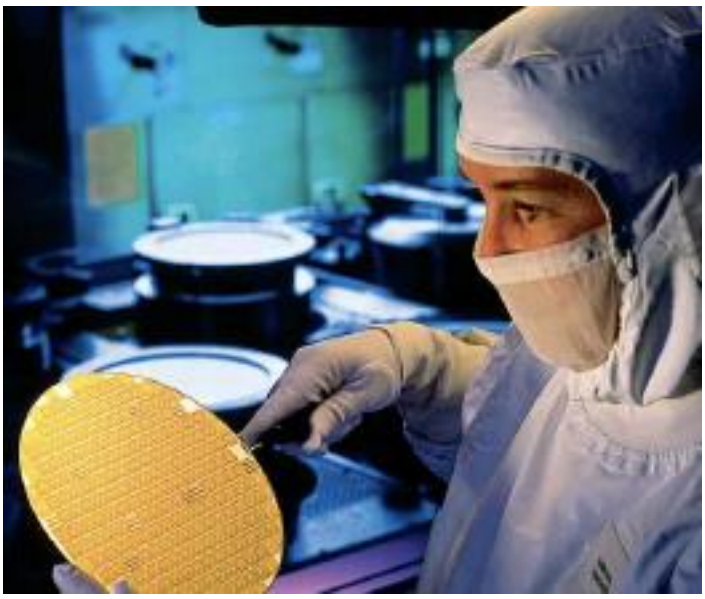

Figure 2. CODE V is the dominant software of choice to meet the stringent optimization, analysis and tolerancing demands of the integrated circuit manufacturing industry

Applications

From the extreme UV to beyond the infrared and from consumer products to government hardware, CODE V will handle your optical imaging applications. CODE V's state-of-the-art algorithms, user-friendly interface and intelligent defaults speed time to market and maximize the quality of your optical solution. Some applications and related CODE V features include:

- **Injection molded plastic lenses** — environmental analysis and material tolerances
- **Grating spectrometers** — wavelength dependent multi-configuration features
- **Digital camera lenses** — tolerance and fabrication analysis features
- **High-NA lithography optics** — polarization ray tracing
- **Reconnaissance lenses** — glass optimization with partial dispersion control
- **Telescopes and other visual systems** — true afocal modeling
- **Space-borne systems** — environmental analysis
- **Laser scanning systems** — diffraction beam propagation analysis
- **Infrared and UV systems** — special material characterization
- **Telecommunication systems** — fiber coupling efficiency computations
- **Segmented aperture systems** — non-sequential ray tracing features

CODE V's Global Synthesis is the most effective and efficient global optimization algorithm available for finding multiple unique configurations for systems with a large number of variables and constraints, including zoom lenses. It uses a directed search — not a random hit-or-miss approach — to seek out new valleys in merit function space. Global Synthesis solves real-world optical design problems faster and easier than other approaches, such as genetic algorithms or simulated annealing.

Figure 3. CODE V optimization delivers the best possible zoom lens designs. Global Synthesis is highly effective for zoom lenses and excellent chromatic correction is possible with powerful glass optimization. CODE V includes specialized features for zoom lens analysis that help you build the best lens, not just design one.

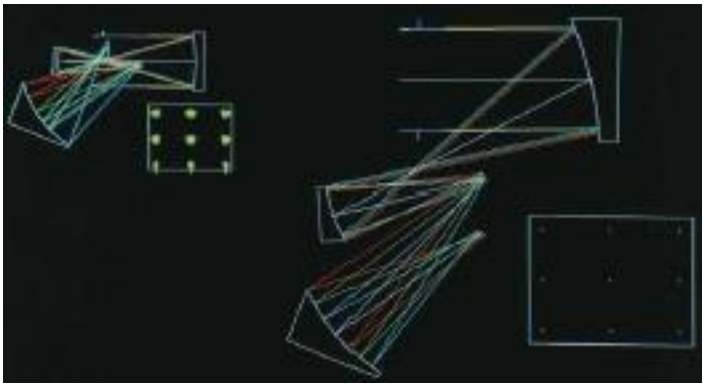

Figure 4. Tilted and decentered reflective systems are easy to set up in CODE V. User-defined optimization constraints allow easy control of optical bundle and component clearances in off-axis reflective systems. CODE V optimized this "Before" system to this "After" system in a single optimization run in seconds on an Intel 2.67 GHz dual-core PC.

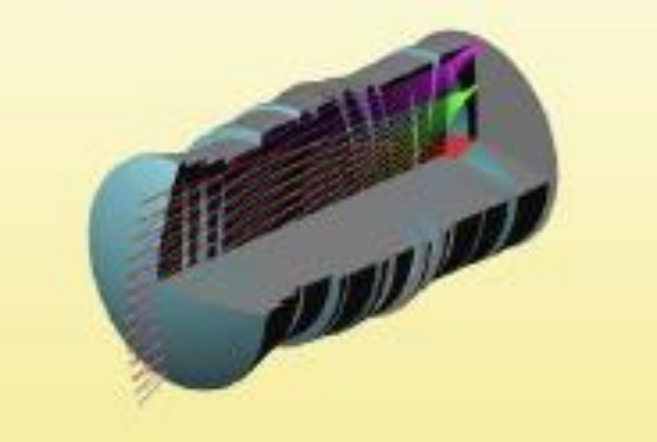

Figure 5. The winning design from the International Optical Design Conference “Camera in a Can” lens design contest was optimized using Global Synthesis.

Design optimization

Optimization capabilities are often the most important consideration when choosing optical design software. CODE V’s award-winning, proprietary optimization algorithms are considered unsurpassed by industry leaders. Features include:

- RMS blur, wavefront variance, MTF, fiber coupling efficiency, and a fully user-defined error function
- The Reduce Tolerance Sensitivity control (SAB), which allows direct optimization of the as-built RMS wavefront error to reduce sensitivity of optical systems to manufacturing tolerances, improve as-built performance, and minimize production costs
- The best, most effective global optimization algorithm available
- Step Optimization (STP), which accelerates optimization convergence and navigates complicated solution spaces more effectively to find optical system solutions with smaller error functions compared to traditional damped-least-squares optimization
- Intelligent optimization defaults and general constraints
- Effective exact constraint handling
- Support of weighted and penalty function constraint handling
- Easy definition of user-defined constraints
- Glass Expert and Asphere Expert that automatically choose the best set of glasses and optimal asphere locations
- Significant feedback to allow you to confirm optimization progress and guide variable, constraint or optimization control changes if needed

Like many optical design programs, CODE V’s local optimization (optimizing to find the local minimum of the error function) is based on damped least squares. However, several proprietary enhancements make CODE V’s optimization algorithm the most effective available. CODE V’s exact constraint handling, using Lagrange multipliers, separates control of constraints from the error function so that the error function

optimization does not stall while attempting to hold heavily weighted constraints. You can develop the best solution — with the correct specifications — that fits the space available.

CODE V's intelligent optimization defaults work well for the vast majority of systems but can be overridden if desired. CODE V's RMS blur, wavefront variance and MTF error functions cover the majority of applications, but you can also define your own merit function. CODE V offers smart defaults, with as little or as much control as you require and consistently yields the best designs. This efficiency results in more freedom to perform useful engineering work instead of time-consuming tweaks of the error function.

Analysis, Tolerancing and Fabrication Support

For photonics systems, some useful CODE V features include gradient index materials, polarization ray tracing and lens arrays.

Analysis

CODE V's analysis algorithms are recognized for their accuracy and speed, and match measurements of real-world hardware. Over tens of thousands of fabricated customer designs, more than 150 person-years of in-house engineering experience, and thousands of daily development test cases assure the quality of CODE V performance predictions — even on the most complex optical systems.

CODE V's extensive suite of analysis capabilities include:

- Many diagnostic evaluation options (for example, transverse ray aberration or OPD curves)
- Many geometrical and diffraction-based image evaluation options (for example, spot diagrams and MTF)
- Non-sequential ray tracing
- Polarization ray tracing, including birefringent material modeling
- General diffraction beam propagation
- Partial coherence 1D and 2D image analysis
- Fiber coupling efficiency
- Illumination analysis
- Thermal infrared narcissus analysis
- 2D image simulation

CODE V's beam propagation analysis accurately predicts intensity, amplitude and phase characteristics of the diffracted optical beam anywhere in the optical system. Beam Synthesis Propagation (BSP), originally developed for NASA to solve the stringent accuracy challenges of the Terrestrial Planet Finder mission, sets an industry standard for accuracy, efficiency, and ease of use. It uses a beamlet-based algorithm with proprietary enhancements designed to deliver extremely accurate and efficient modeling of diffracted wavefronts propagating through an optical system. BSP's groundbreaking Pre-Analysis feature automatically recommends analysis settings based on your lens system and delivers an accurate answer in the shortest time possible.

Partial coherence analysis can predict image structure of one- or two-dimensional objects based on fully coherent to fully incoherent illumination through an optical system. For photonic systems, fiber coupling efficiency of a diffraction image into a single mode fiber can be predicted, including the effects of misalignments and fiber tip cleavage angles.

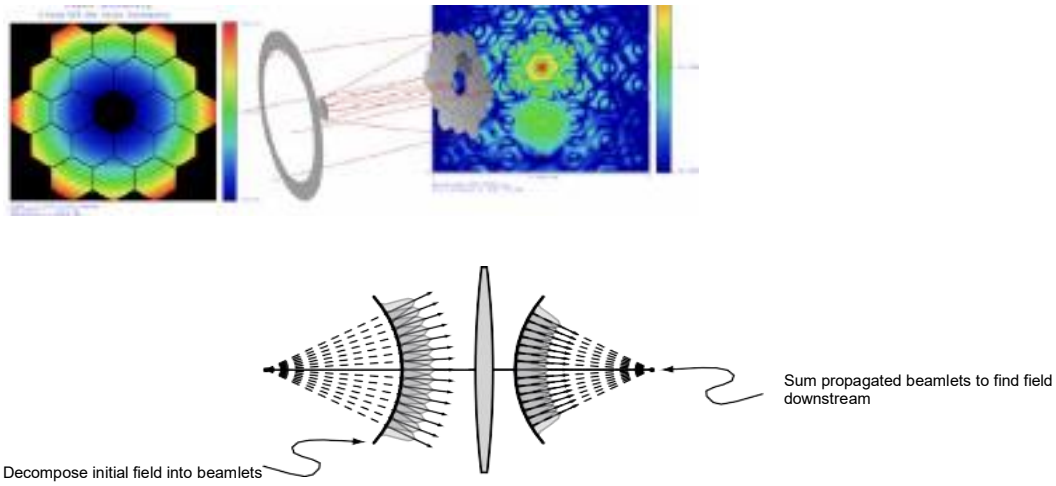

Figure 6. Beam Synthesis Propagation's beamlet-based wave propagation algorithm performs beam propagation analysis more accurately and efficiently than any other commercially available tool.

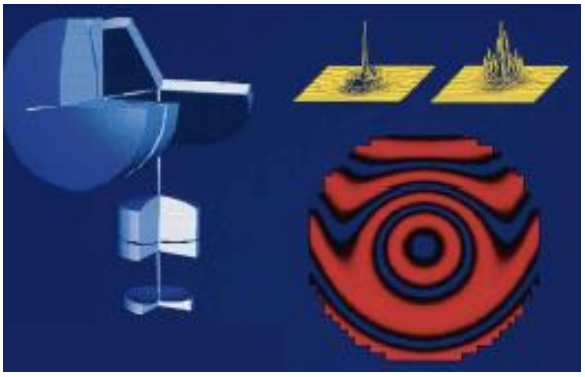

Figure 7. CODE V's transverse ray aberration curves, pupil maps, spot diagrams, MTF curves and point spread function plots use advanced algorithms to ensure the most accurate results.

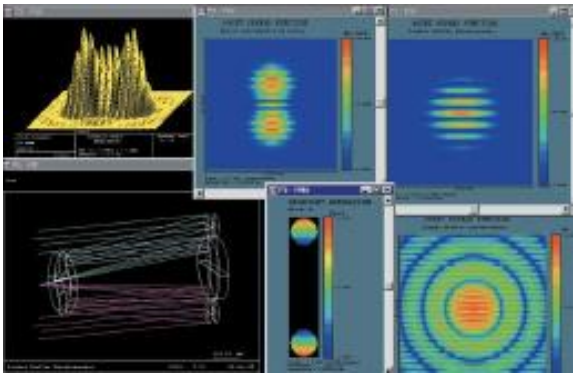

Figure 8. A stellar interferometer showing interference fringes produced from separated apertures using non-sequential surface ray tracing and diffraction analysis features

CODE V is COM-enabled and can be used as a server application for other COM-enabled applications for specialized analysis tasks. CODE V's Macro-PLUS is a powerful, yet easy-to-learn macro programming language with access to a broad range of lens constructional data and analysis output. It can greatly simplify repetitive tasks, and supports efficient generation of custom analysis, such as line and surface charts.

Most CODE V analysis option inputs can be customized, but you aren't burdened with making all the choices. Intelligent input defaults are provided in all options, based on our software knowledge of the computational algorithm and engineering knowledge about the appropriate defaults for real-world problems. You can have confidence in CODE V's results.

Tolerancing and fabrication support

CODE V is used to design optics destined for hardware and has many advanced capabilities to speed time to market and solve production problems before the design reaches manufacturing. You can be confident of delivering the best performing as-built optical design with minimized recurring and non-recurring costs. Features include:

- Accurate and extremely fast tolerancing using CODE V's proprietary wavefront differential algorithm
- Optimization access to the fast wavefront differential algorithm for directly optimizing as-built RMS wavefront error
- Singular Value Decomposition algorithm to determine the most effective compensator set
- Interactive tolerancing spreadsheet to modify tolerance values and instantly see the effect on system performance and compensator motion
- Traditional finite differences and Monte Carlo tolerancing support
- Interferogram interface for applying measured interferograms to the system model
- Automatic system alignment optimization based on as-built interferogram analysis
- CAD export using IGES, SAT and STEP file formats
- Mechanical zoom lens CAM computation
- Lens element weight and cost analysis (material and fabrication costs)

CODE V's sensitivity and inverse sensitivity (automatic error budgeting) tolerancing capabilities are based on measurable performance metrics such as RMS wavefront, MTF, distortion, Zernike wavefront coefficients, and more. Multiple compensators can be declared and if desired, restricted to compensating subsets of tolerances. Boresight compensation can also be included.

CODE V's interferogram interface allows measured surface deformation or system wavefront data to be imported into CODE V and included as part of the lens model. CODE V's alignment optimization is used to automatically guide the alignment of an as-built optical system using measured wavefront data. Whether your hardware is for the consumer, commercial or government markets, if you are planning to build your optical designs, then CODE V's integrated design, analysis and fabrication support features make it the best optical software for the job.

Comprehensive features

User Interface Components

- LDM spreadsheet
- Surface properties window
- System data window
- Custom review spreadsheets
- Wizards
- Navigation toolbar
- Standard menus and toolbars
- Customizable toolbars (including user macros)
- Tabbed output windows
- Undo/Redo functionality
- Extensive help features
- Command line entry window
- Interactive, custom charting

Lens Entry and Editing (LDM)

- Spreadsheet entry or command entry
- Supplied examples and patent lens search
- Off-the-shelf components
- Built-in prisms models
- "Black Box" lens modules
- Pickups and solves
- Zoom/multi-configuration systems
- Decentered/tilted systems
- Array elements
- Non-sequential surface modeling
- True afocal modeling
- Built-in glass catalogs (including IR/UV materials)
- Diffractive properties
- Gradient index materials
- Multilayer coatings
- Pupil apodization
- Interferogram data on surfaces and pupils: grid, Zernike and user defined
- Linear polarizers and retarders
- Birefringent materials
- Special surface types
  - Cylinders and toroids
  - Conics and superconics
  - Radial, XY, and anamorphic aspherics
  - Fresnel lens surfaces
  - And many more
- User programmable features support for surface shape, surface properties and others

Diagnostic and Analysis Options

- Paraxial ray trace
- Real ray trace
- Aberration plots
- Gaussian beam trace
- Third, fifth and higher-order aberrations
- Astigmatism and distortion field curves
- 2D distortion grid
- Pupil map
- Field map (including Zernike polynomial terms)
- Footprint (beamprint) analysis
- 2D image simulation

Optimization

- Ray, wavefront, MTF, fiber coupling efficiency and user defined error function
- Local optimization or Global Synthesis
- Exact constraint control
- Over 60 standard constraint types
- User-defined constraints
- Effective glass optimization, including UV and IR bands
- Zernike coefficient optimization
- Glass Expert
- Asphere Expert

Image Evaluation Options (*including polarization)

- Spot diagrams
- Geometrical radial energy
- Quadrant detector analysis
- Biocular analysis
- RMS wave error
- MTF (vs. frequency, vs. focus)*
- Point spread function*
- Line spread function*
- Encircled energy*
- Detector energy*
- 1D and 2D partial coherence analysis*
- Fiber coupling efficiency
- Polarization dependent loss
- General diffraction beam propagation

Fabrication and Tolerancing Options

- Lens display
  - General lens plots (2D, etc.)
  - Lens element/component drawings
  - Interactive 3D model visualization, including surface selection and editing
  - Gaussian beam plot
- Tolerance analysis
  - MTF/RMS based
  - Distortion based
  - Primary aberrations
  - Fiber coupling efficiency/ polarization dependent loss
  - User defined tolerancing
- CAD Export—IGES, STEP and SAT
- Sag tables
- Cost analysis
- Weight/center of gravity analysis
- Automatic testplate fitting
- Zoom CAM design
- Automatic alignment analysis

Other Features

- Powerful Macro-PLUS programming language
  - Many supplied macros
  - Built-in FFT and other mathematical functions
- Environmental analysis including temperature and pressure
- Illumination analysis
- Multilayer coating design/analysis
- NASTRAN interface macro
- Spectral analysis
- Transmission analysis
- Ghost image analysis
- Narcissus analysis
- User-defined graphics
- COM API interface that links with other COM-enabled software, such as MATLAB® or Microsoft Excel®
- Parallel processing support for key optical algorithms

To learn more

For more information on CODE V and to request a demo, please visit the Optical Design Software page or contact us at keysight.com/find/email-support.