Lens design
Some of the important topics needed to be addressed in a successful lens design project (R.R. Shannon: The Art and Science of Optical Design)

- Focal length (f)
- Field angle or field size
- F/number
- Numerical aperture (NA)
- Wavelength and spectral range
- Magnification and focusing range
- Zoom ranges
- Type of lenses
- Back focus
- Front focus
- Pupil locations
- Illumination
- Irradiance uniformity
  - Vignetting
  - Transmission
- Ghost images
- Distortion
- Variation with conjugates
- Variation with spectral region
- Interference with optical path
- Image quality
  - Aberrations
  - Resolution
  - Optical Transfer Function (OTF)
  - Modulation transfer function (MTF)
  - Energy concentration (Intensity pattern)
  - Effect of aperture stop
  - at various apertures
- Scattered light
- Polarization
- Veiling glare
- Light baffling
- Off-axis rejection
- Field stop definition
- Diffraction effects
- Tolerances
- Depth of focus
- Interface with variable aperture
- Interface with autofocus system
- Size and configuration
- Zoom Mechanization
- Focus mechanization
- Folding components
- Schedule and delivery time
- Optical interfacing with instruments
- Cost of
  - Design
  - prototype
  - Production
- Materials
  - Availability
  - Cost
  - Continued supply
  - Suitability for processing
  - Compatibility with operation conditions
  - Environmental considerations
  - Hazardous material
- Environment
  - Temperature range
  - Storage conditions
  - Atmospheric pressure
  - Humidity
  - Vibration and shock
- Availability of subcontractors
- Level of technology
- Weight
- Moment about mounting
- Coatings
  - Transmission
  - Reflectivity
  - Absorption
  - Availability
  - Risk
  - Environmental effects
  - Mechanical and optical quality
- Manufacturability
- Produceability
- Manufacturing processes
- Manufacturability
- Produceability
- Manufacturing processes
- Mounting processes
- Mounting interfaces
- Mechanical interfaces with instrument
- Detector
  - Photographic
  - Sampling array
  - Signal to noise
- Surface finish, cosmetics
- Beam parameters
- Radiation damage
- Irradiance damage
- Prior experience
- Track record
- Prior art
- Patentability
- Patent conflict situation
- Competitive situation
- Marketability
- Interface to other producers
- Lifetime of product
- Rate of production
- Liability issues
- Delay to market
- Timing of disclosure
- Integration with other products
- Customer view of product
- Styling
- Investment requirements and risks
- Funding and financial viability
Lens design parameters
Starting a design

- Field (or object) size
- Axial aperture
  - Controls brightness of the image
  - Vignetting: deliberate reduction of irradiance by off axis by proper selection of element diameters. It is a tool to control aberrations
- Image size
- Design concerns
  - Image quality requirements
  - Mechanical layout
  - Material selection
  - Tolerances
  - Definition of starting point
- Passage of rays through the system is studied with geometrical ray tracing. The result is image location.
- Image formation through combination (interference) of rays and bundles is studied with physical optics or diffraction optics. The result is image quality.
Basic design steps

Data supplied by customer

Evaluation of parameters by designer for selection of realistic and economic requirements

Initial selection of parameters by designer

Select first order optical specifications to establish paraxial base set of coordinates in which the image is evaluated

Mechanical and fabrication requirements

Select tolerances (Designer perturbs the system according to these tolerances and makes sure the system still meets the specifications)

1) Requirements on construction parameters
2) The need to use the lens in a defined environment
3) Acceptable irregularities on the lens surface to control absorption and scattered light

Final description of the system and components

Finalizing cost and schedule for delivery

1. Focal length
2. Spectral range,
3. Image quality
4. Number of elements
5. Available space
6. Weight,
7. Cost
8. Delivery schedule
Detailed description of a lens

• Sequentially numbered set of spherical surfaces
  – Curvature
  – Thickness to the next surface or separation
  – Index of refraction of the medium after the surface
  – Surface shape
  – Orientation
  – Dimension
  – Symmetry

• Operating condition

• Use the operating manual of the software in use to enter these data
Merit functions used in design evaluation

Evaluation of a lens is done through sampling state of aberration of the lens by computing light distribution across the lens including diffraction effects. This is achieved by evaluating the:

1. Ray intercept plots
2. Spot diagrams
3. Point Spread Function (PSF)
4. Optical transfer function (OTF)
5. Modulation transfer function (MTF)
Ray Intercept Diagrams
A geometrical optics calculation
Spot Diagrams / Ray Scatter Diagrams

A geometrical optics calculation

• They show symmetry of aberration
Point Spread Function (PSF)
A physical optics calculation

- Light intensity distribution in the diffraction image if the lens were made perfectly.
- It is simply image of a point object.
Optical Transfer Function (OTF)
A physical optics calculation

• A functional representation of the spatial frequency response of the lens.
• OTF is a Fourier transform of the PSF
• Spatial frequency or wavenumber: number of wavelengths in a unit length (not time)
• OTF describes the contrast between images of different sinusoidal elements with specified spatial frequency
• Image analysis with OTF is equivalent to Frequency band analysis in communication
Modulation Transfer Function (MTF)
A physical optics calculation

- MTF which is modulus of the OTF is a more interesting function to the lens users.
Completing a lens design

• Tolerances
OSLO introductory exercise-
Landscape lens

• **Goal**: enter lens data and understand the optical performance of a simple lens. (Make sure the software has its initial settings)

• **Steps**:
  – **Lens entry**: convex-plano lens with displaced aperture stop behind the lens
  – **Lens drawing**: Set up the lens drawing conditions to show desired ray trajectories
  – **Optimization**: Optimize the lens so it has no coma, Focal length of 100, covers a field of +/- 20 degrees at an aperture of f/10
  – **Slider-wheel design**: attach sliders to parameters so you can analyze the trade-offs.
Optimization

• Create the lens
• Set up optimization tasks
  – Define an error function that makes the focal length exactly 100 mm and eliminates the Seidel coma from the image.