Designing with off-the-shelf optics

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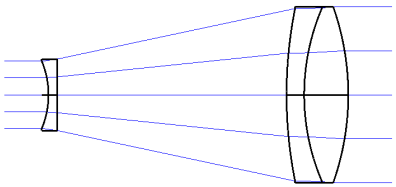
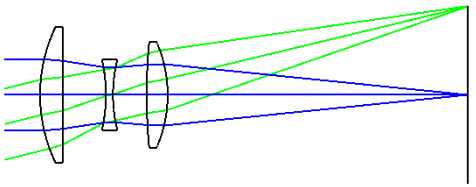
Outline

- **Advantages** and **Disadvantages** of utilizing stock lenses.
- Various types of lenses have different capabilities for the **FOV** and **speed**:
  - Understand the limitations of stock lenses
  - Be aware of types of off-the-shelf optics
- "Best way" to utilize a stock lens for a particular application.

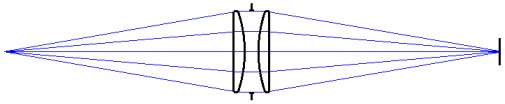
- Beam expander



- Cook Triplet



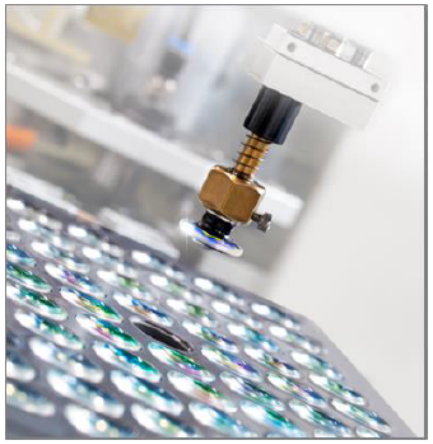
- 1x magnifier



- Optotune

Advantages of stock lenses

- **Cost:**
  - Stock lenses are made in larger quantities.
- **Speed:**
  - Optics production takes a lot of time.
  - Stock lenses are available for immediate delivery.
- **Easily replaceable components:**
  - Damage
  - Extreme use
- **Design for Education and Outreach**



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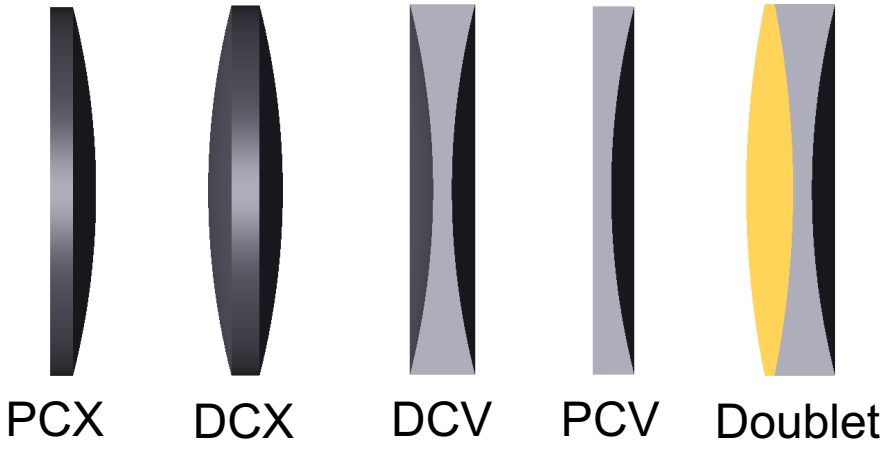
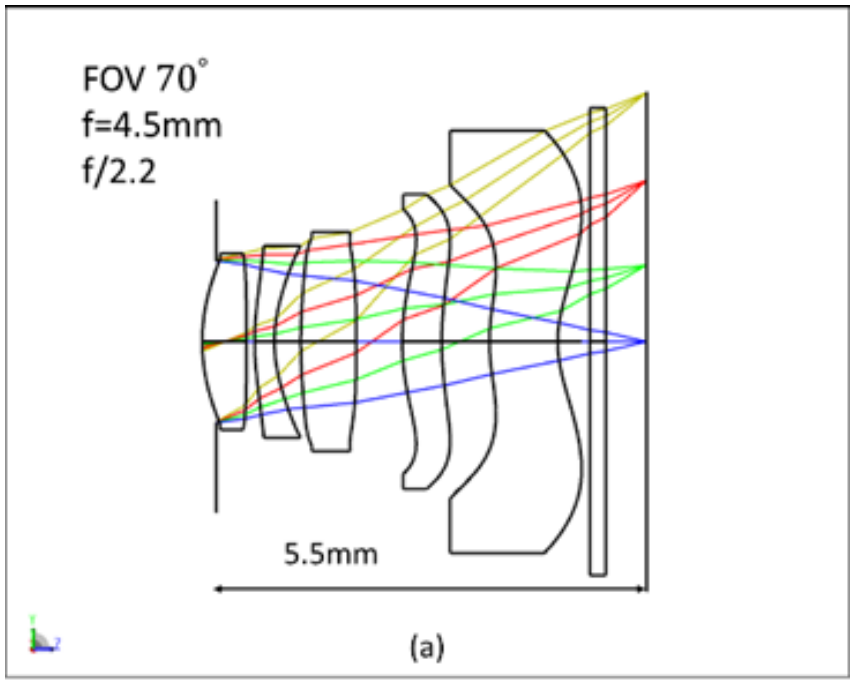
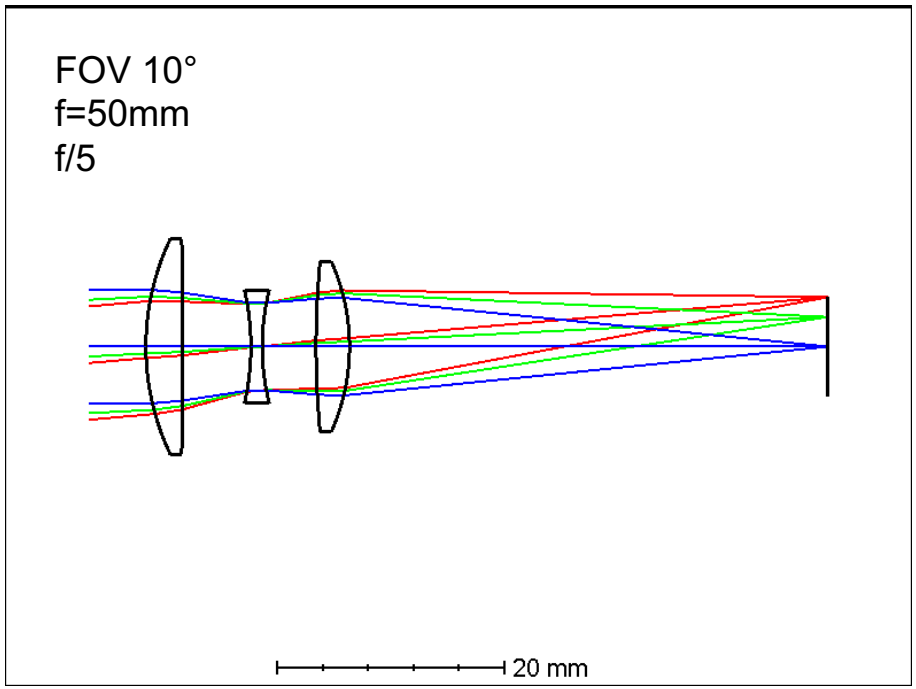
Disadvantages of stock lenses

- The need to select the optics from a **limited** list of available:
  - Shape factors
  - Focal lengths
  - Sizes
  - Glass (flint)
- **Less** control:
  - Tolerances
  - Specifications outside the defined areas
- Many lenses are sold **without** nominal prescription:
  - Cheap optics
  - Clearance products



What can be done?



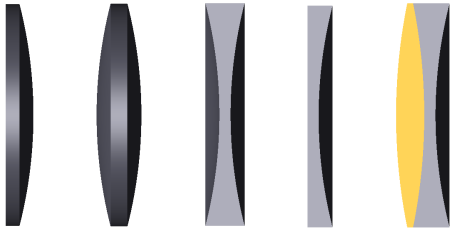


- Our aim is to make our stock lens system as good as the available stock lenses will allow.
- As the rule of thumb, a system that covers the **FOV** of **5-20 degrees** at about **f/6** can be assembled from stock lenses.

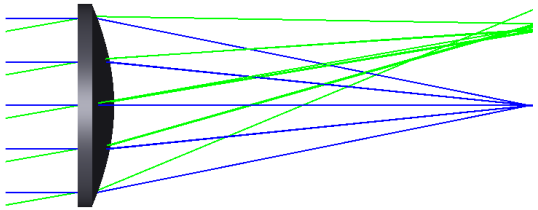
Types of of-the-shelf optics

- **Components:**
  - Singlets
  - Doublets
  - Mirrors
  - Windows
  - Prisms
  - Filters
- **Sub assemblies:**
  - Objectives
  - Eyepieces
  - Relays
  - Photographic Lenses
  - Machine Vision Lenses

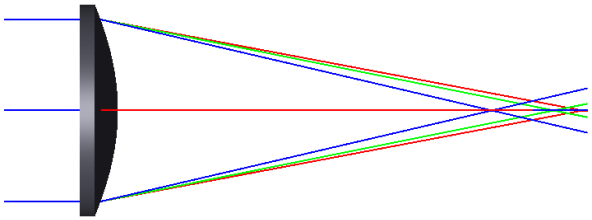
Conjugates and shape factors



Field

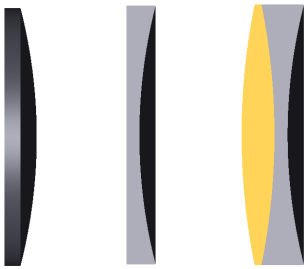


Waveband

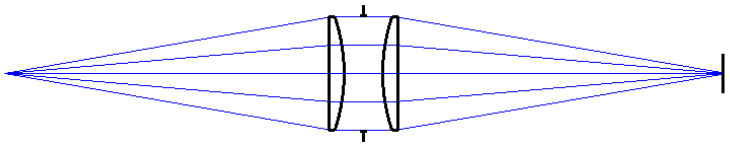


Infinite conjugate design

- Majority of components are designed for **infinite conjugate**:
  - –PCX/Achromat lenses are designed for focusing a collimated beam
  - –PCV lenses are designed to take a collimated beam and diverge it
- Breaking systems into separate infinite conjugate pieces will make fitting stock elements easier.
- Complex subassemblies like infinite conjugate microscope objectives can be substituted as a separate infinite conjugate piece of a larger system.



PCX PCV Doublet



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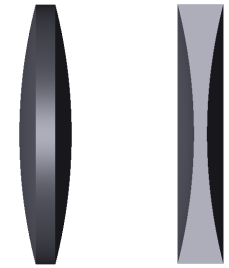
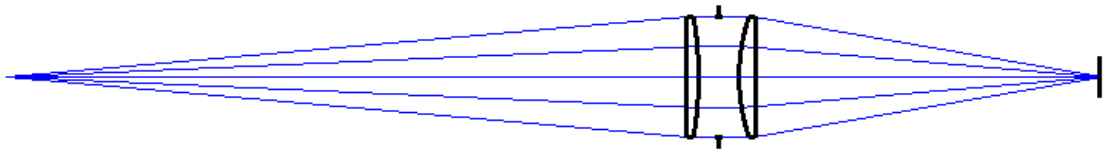
Finite conjugate design

- DCX and DCV are designed to relay a finite point to another finite point.
- These perform best when the object and image are **equal distances** form the lens and form a **1:1** relay.
- **Very few** component choices are available off the shelf that are designed for anything but an infinite conjugate or a 1:1 relay
- To achieve **other finite conjugate** relays it is best to use infinite conjugates together to form the relay system.

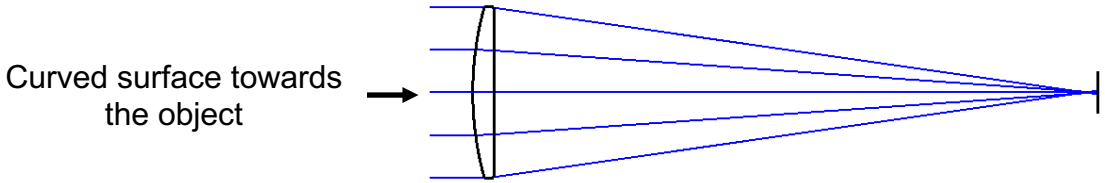


DCX DCV

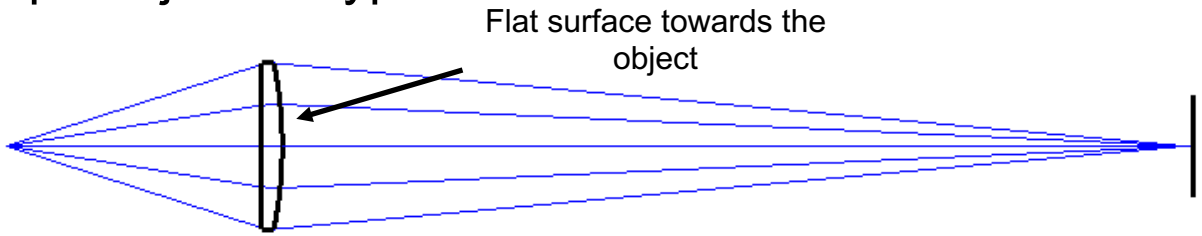


How to use a singlet

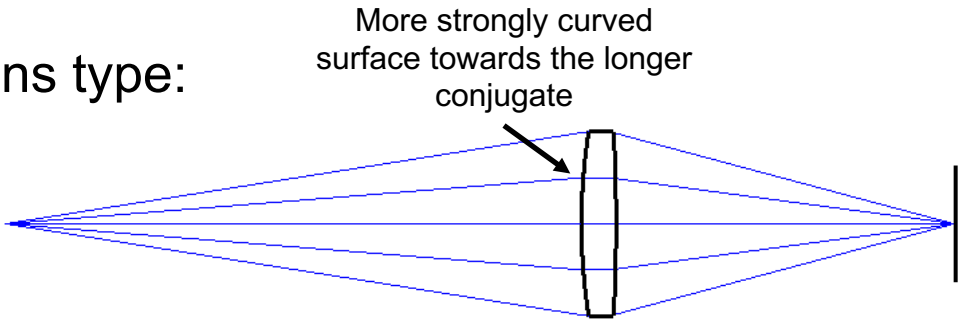
- Telescope objective type:



- Microscope objective type:

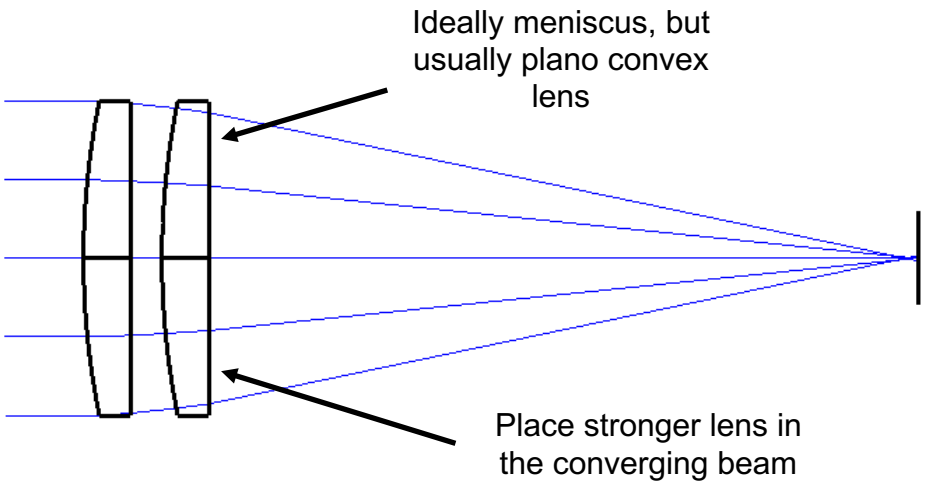


- Relay lens type:



High speed applications

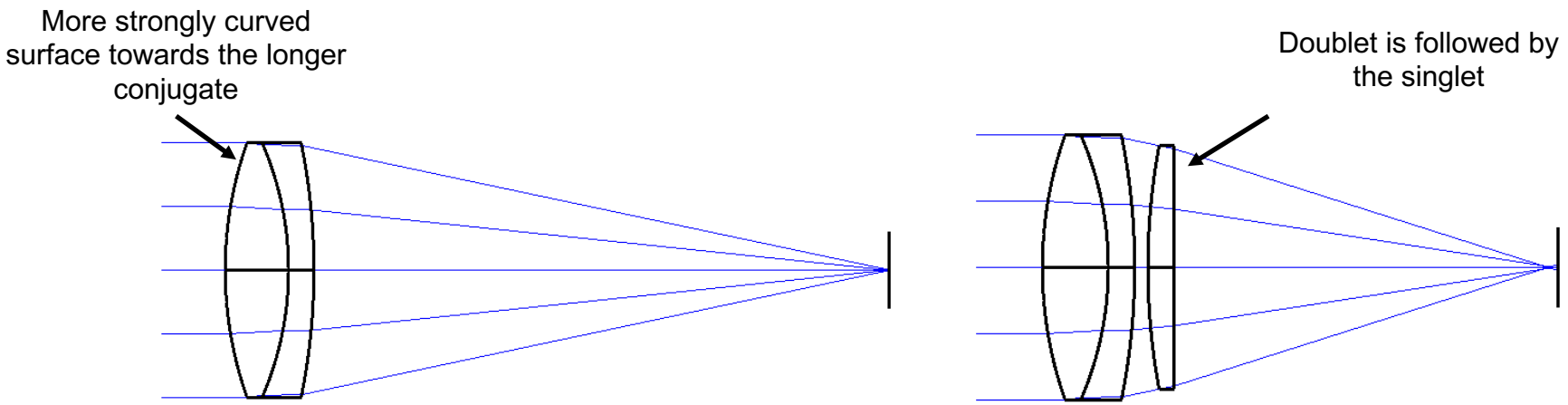
- The limiting aberration in fast systems is **spherical aberration**.
- Using **two** lenses instead of one can reduce spherical aberration by a factor of 3 or so.



- Ideally both elements have the same power, and the sum of their powers equal to the sum of a single element they are replacing.

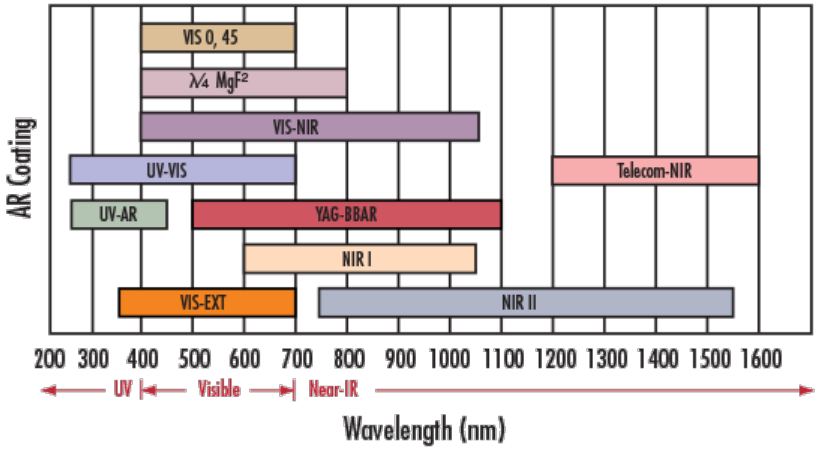
How to use a doublet

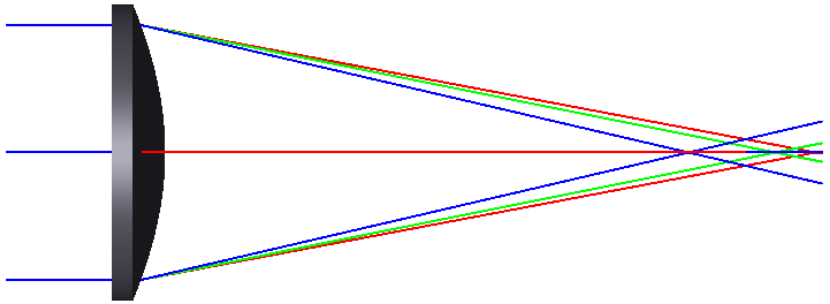
- Achromatic doublets are often designed to balance correction of **color** and **spherical aberration** and will have **better** results when used **monochromatically**.
- When used with object at infinity, doublets are often corrected for **coma** over a **small** FOV.



Wavebands

- When considering the waveband for an off the shelf component or assembly look at both the **color correction** and the **transmission**.
- **Coatings** can have a significant impact on assemblies where many surfaces are used.
- If **broadband** information is **not needed**, the design can be **simplified** with the use of filtering or monochromatic illumination.





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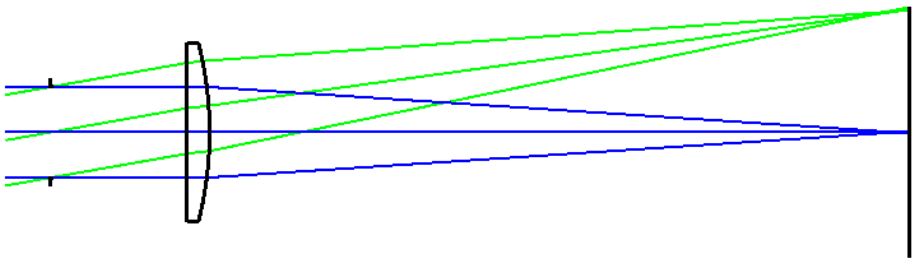
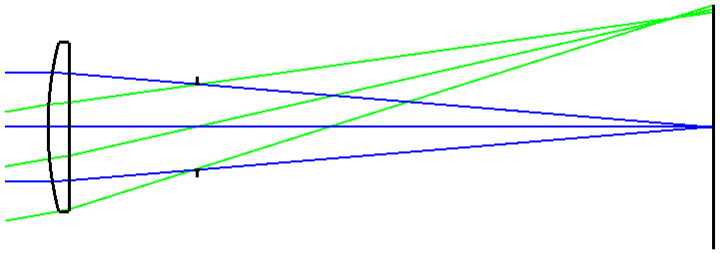
Field correction

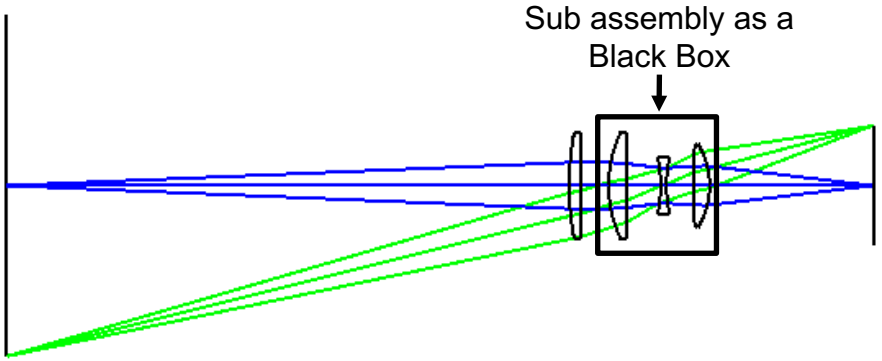
- Stock components **seldom** have any field correction built into them.
- Using **stop** placement and balancing Petzval powers can help reduce your field aberration.
- Keep field angles as **small** as possible -> Lengthening a design will usually **reduce** the field angles.
- If **large field angles** are needed, consider using off the shelf **assemblies** designed for the larger fields.





Sub-assemblies and Hybrid solutions

- **Replace** a component with a **subassembly** like a microscope objective or photographic lens.
- Use a **subassembly** with **components** to make a system solution.
- Use components to adjust parameters:
  - Conjugates -> weak positive lens
  - Focal length -> weak positive or negative lens



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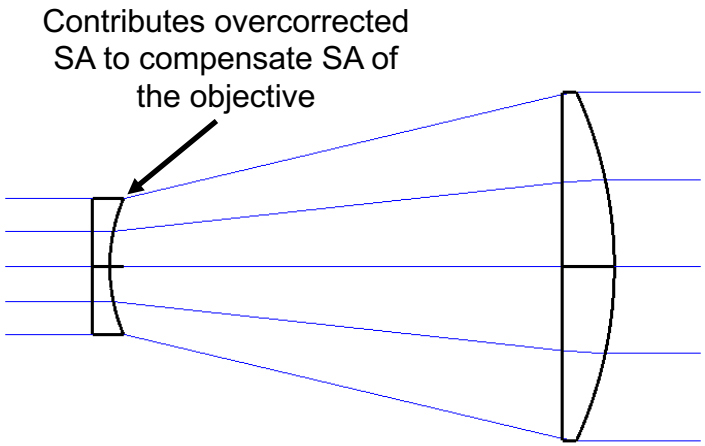
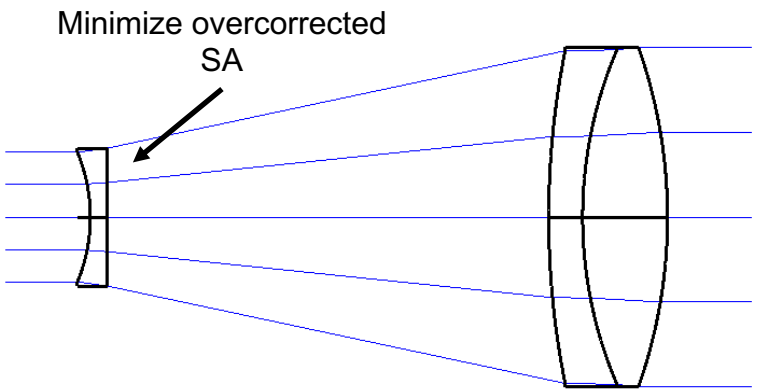
Tips for designing with off-the-shelf optics

- Diameters:
  - There are a **finite number** of sizes available
  - **Larger** sizes than needed are often the best available option
- Lengths:
  - **Extending** the length allows the designs achieve smaller image angles which are easier to design around
  - One way to deal with size constraints in a design is adding **folds** with **mirrors** and **prisms**.
- Breaking designs into infinite conjugate segments typically allows better performance, but increase the length of the design.

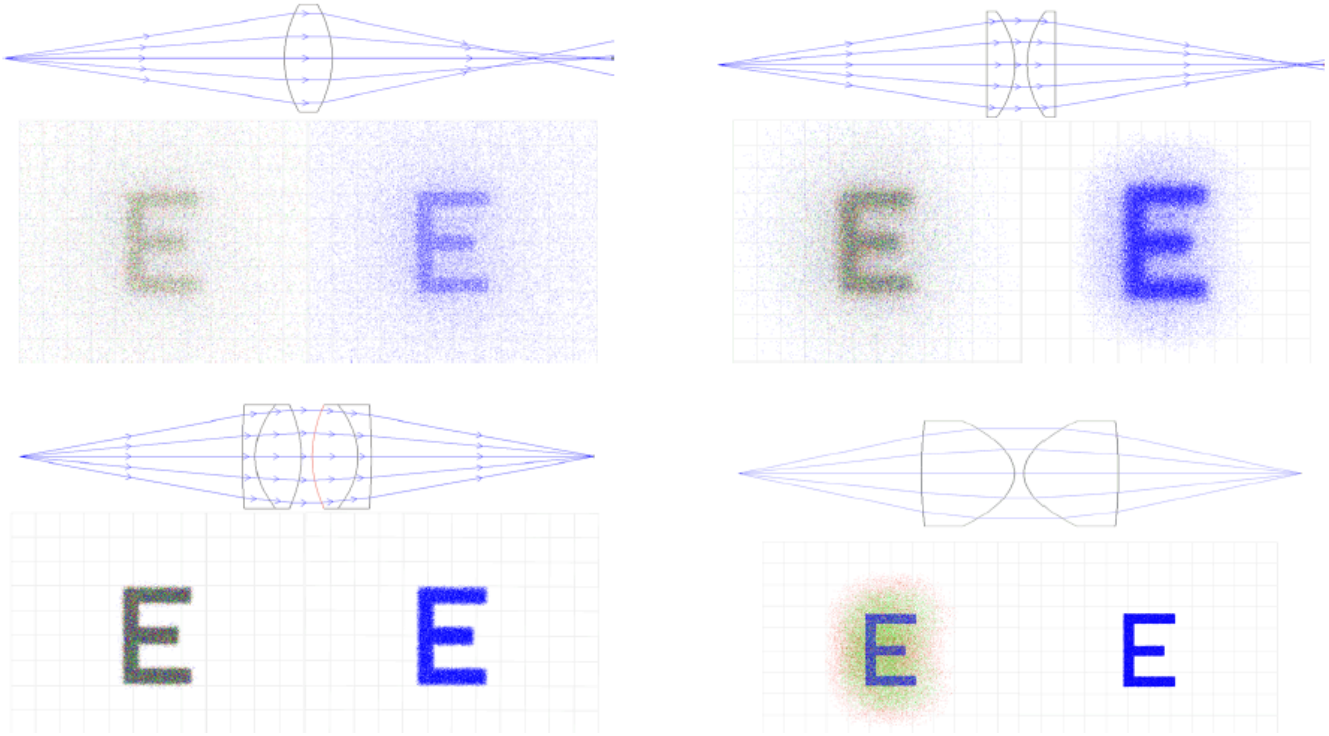
Example: Laser beam expander

- A laser beam expander is a telescope used “back ward” to increase the diameter and to reduce the divergence of the beam:
  - Galilean form -> shorter, no internal focus
  - Keplerian form -> longer, internal focus, more difficult to correct
- Choose configuration to compensate and/or minimize spherical aberration.





Example: 1:1 relay



- 20mm Entrance Pupil and an approximately 100mm total track.
- Black is **polychromatic**, Blue E is **monochromatic**.
- Further improve by using **two sub-assemblies**.

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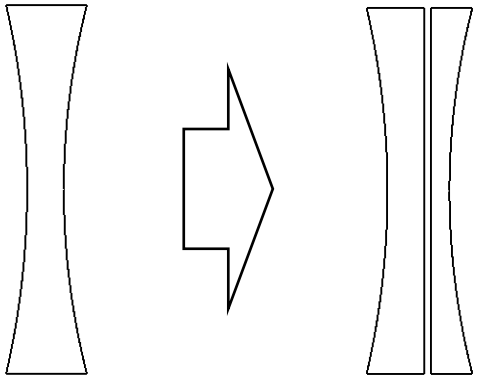
Fitting stock components into existing design

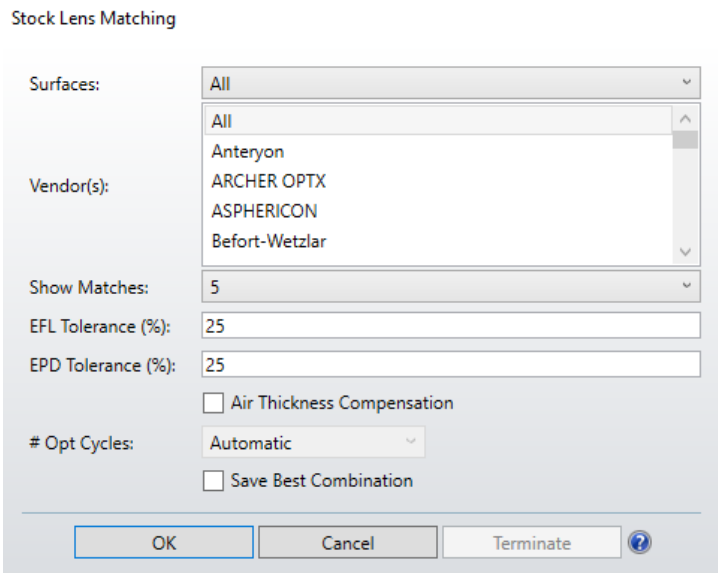
- Starting with an **optimized design** finding ways to replace custom elements with the closest stock options:
  - Start with **negative flint elements**
- Simplify:
  - Be as flexible on **size** as possible
  - Reduce **waveband** as much as possible
  - Look for closest fits, consider shape factors



- If a **non-symmetric** double convex or concave lens is needed, **split** it into two plano-convex or concave lenses with the plano sides touching each other
- Replace **one** at a time and **optimize** air gaps and radii

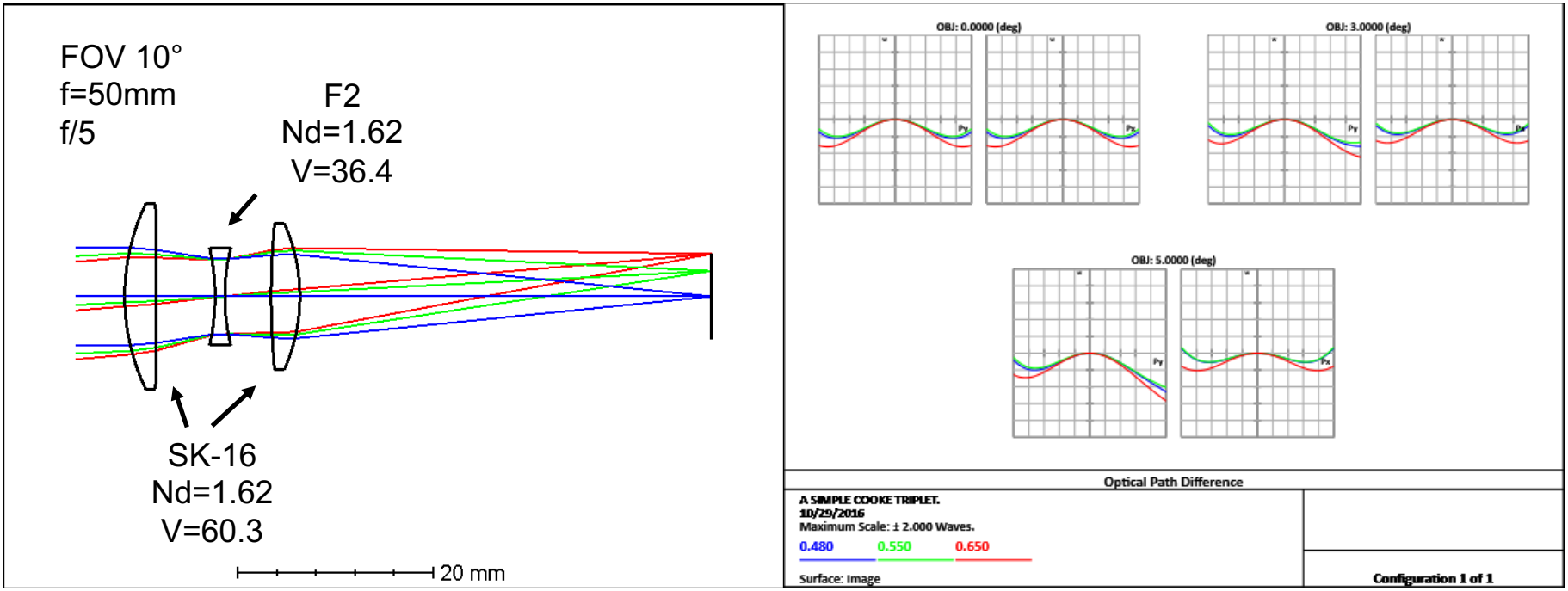
Built-in tools for fitting stock components

Stock element matching tool in Zemax



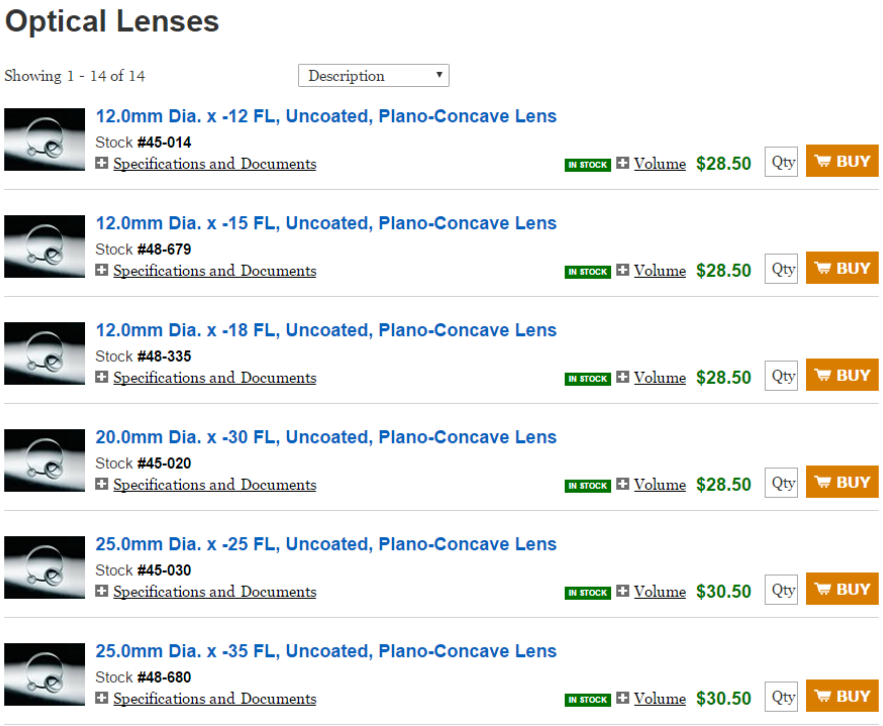
- Open your existing lens.
- Set the Semi-diameters to automatic.
- Open Stock lens matching.
- Under “surfaces” select either “all” to replace all lenses, or “variables” to only change out the lenses you designate by putting a variable on the radii.
- Unless **size** is a big concern, use a large number for the EPD **tolerance%** to check more options.
- Check Air Thickness Compensation to adjust airspaces during optimization.

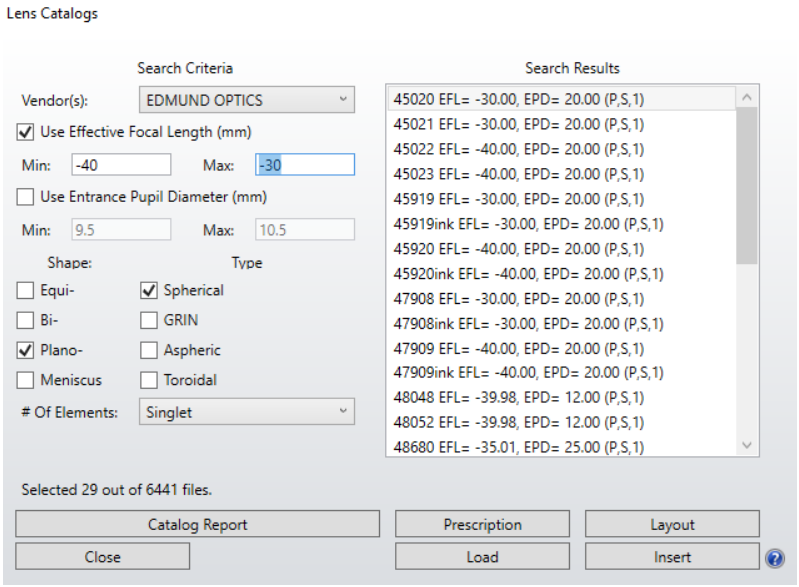
Fitting stock components manually



- Cook triplet from Zemax library.
- Check Edmund Optics and ThorLabs: only N-SF11 and N-BK7 is available.

Fitting stock components manually





- F2 nd=1.62 V=36.4; SK-16 nd=1.62 V=60.3
- N-SF11 nd=1.78 V=25.7; N-BK7 nd=1.52 V=64.2
- Negative element becomes weak: f=-35mm is the weakest element I found.

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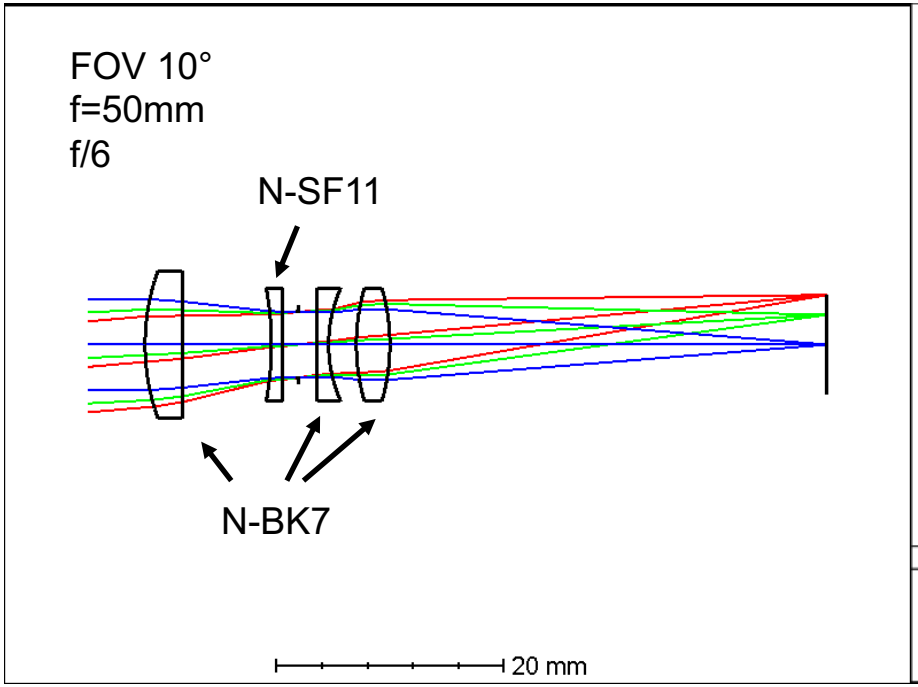
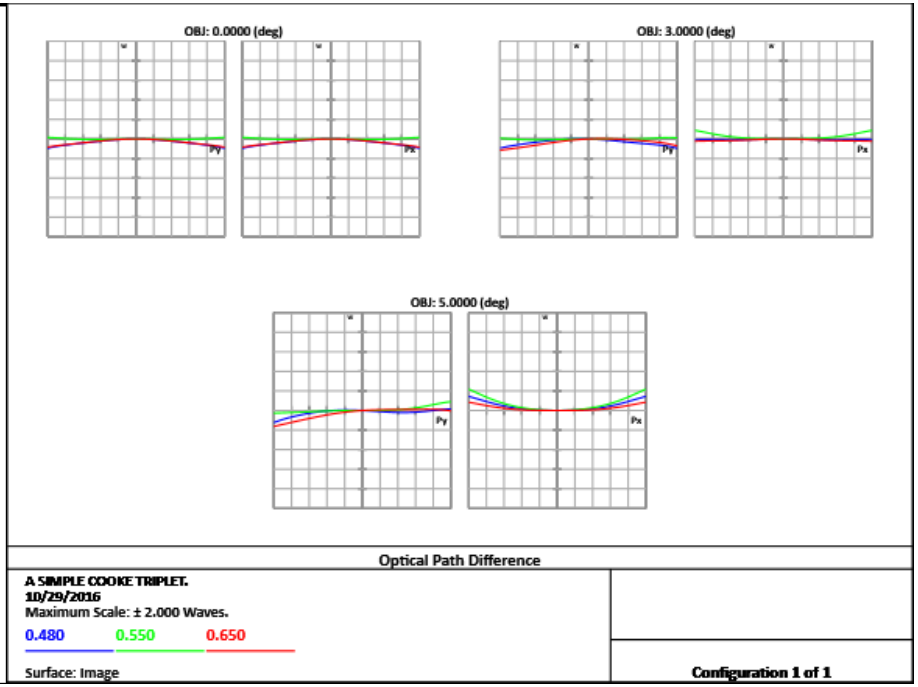
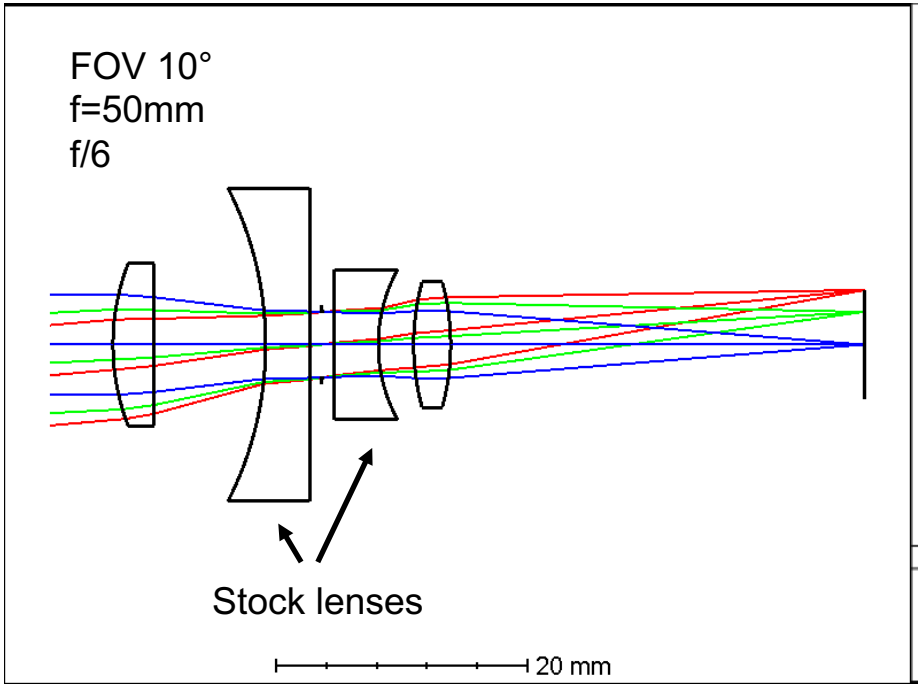
Reoptimize the lens

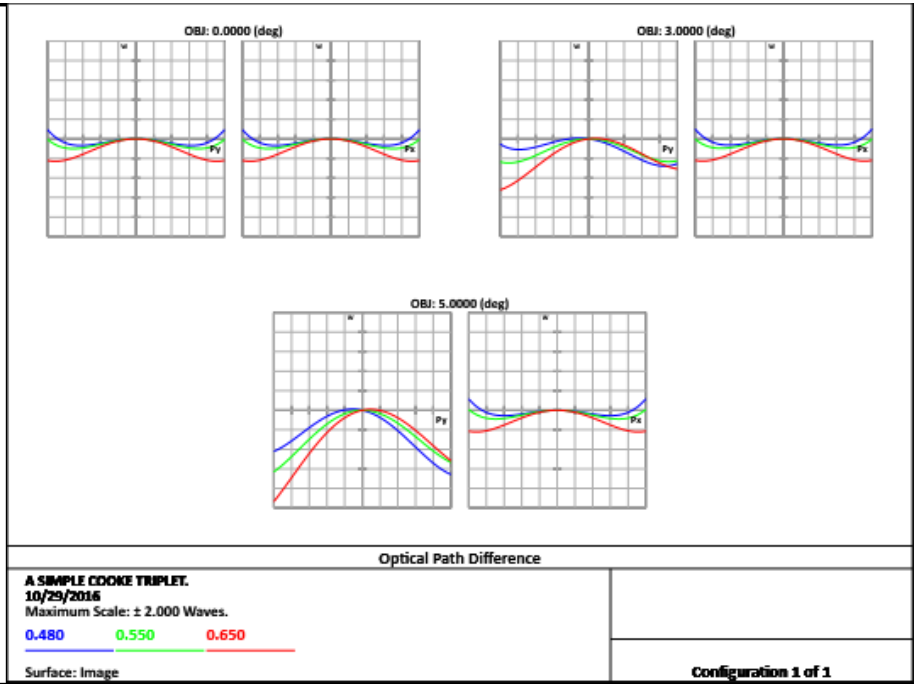




- All lenses are plano- or bi-convex/concave.
- Split the negative element.
- We have some margin in performance.

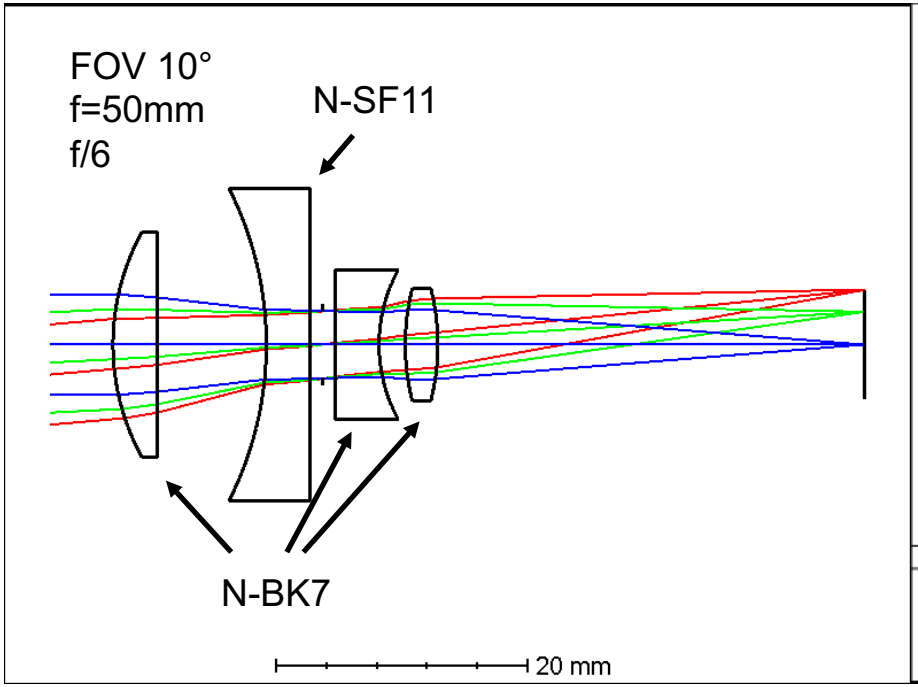
Replace negative elements

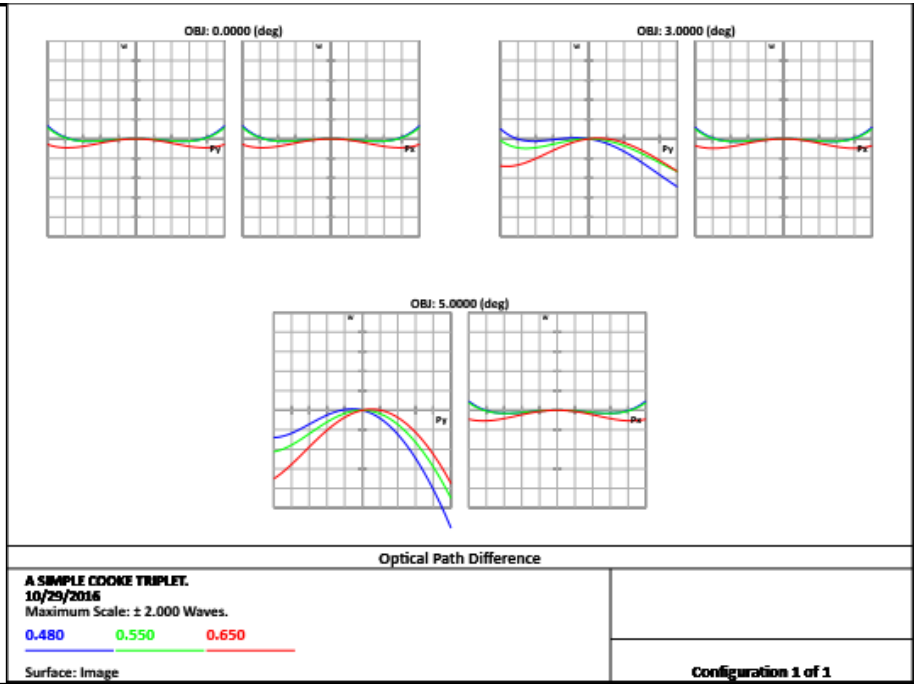




- Flexible with lens sizes.
- Smaller negative lenses have shorter focal length. Sacrifice performance.
- Decent performance after replacing negative elements.

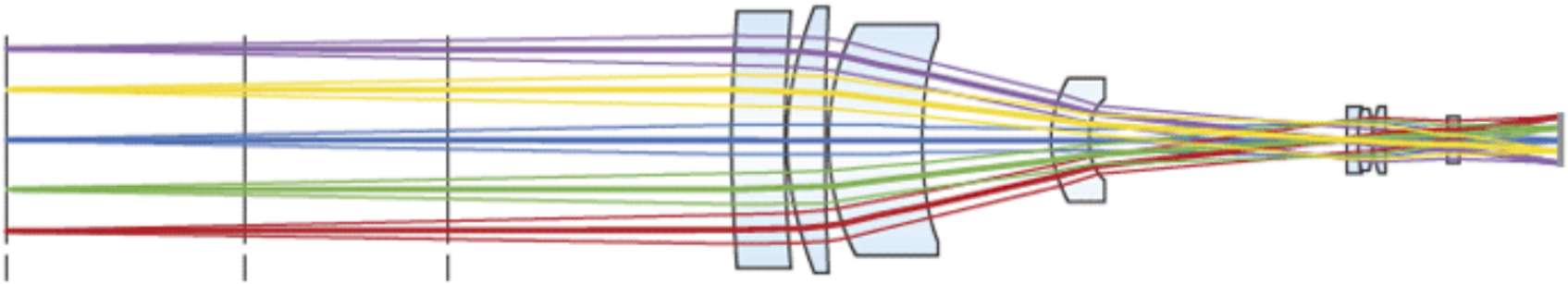
Final design



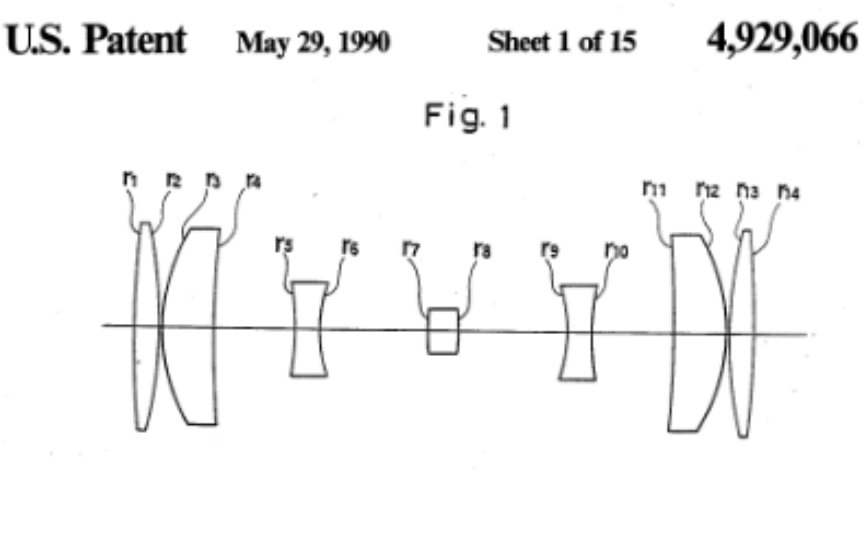


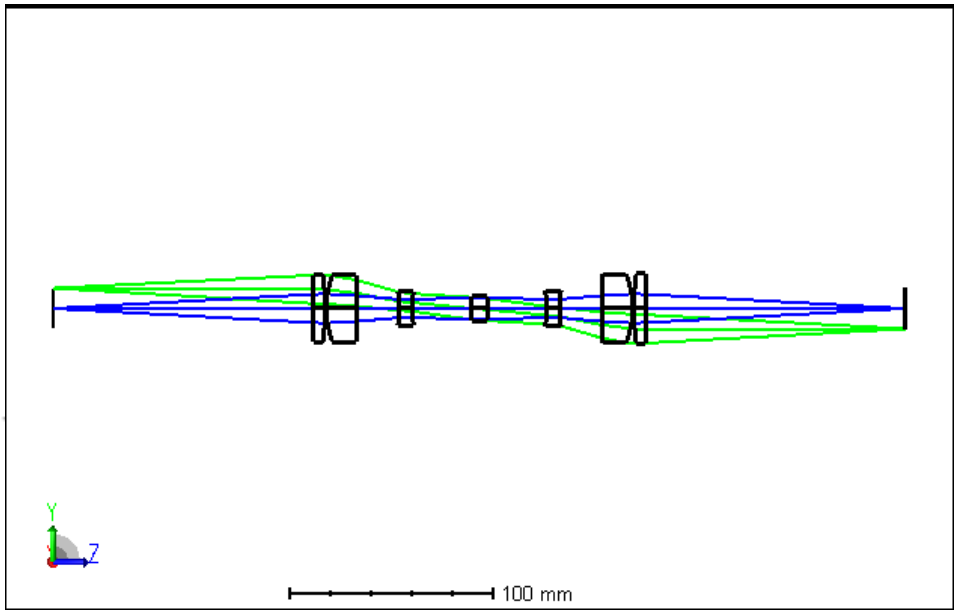
- All lenses from Edmund Optics catalog.
- Limiting aberration - Astigmatism.
- All elements have different diameter!

Optotune Lens Design Completion



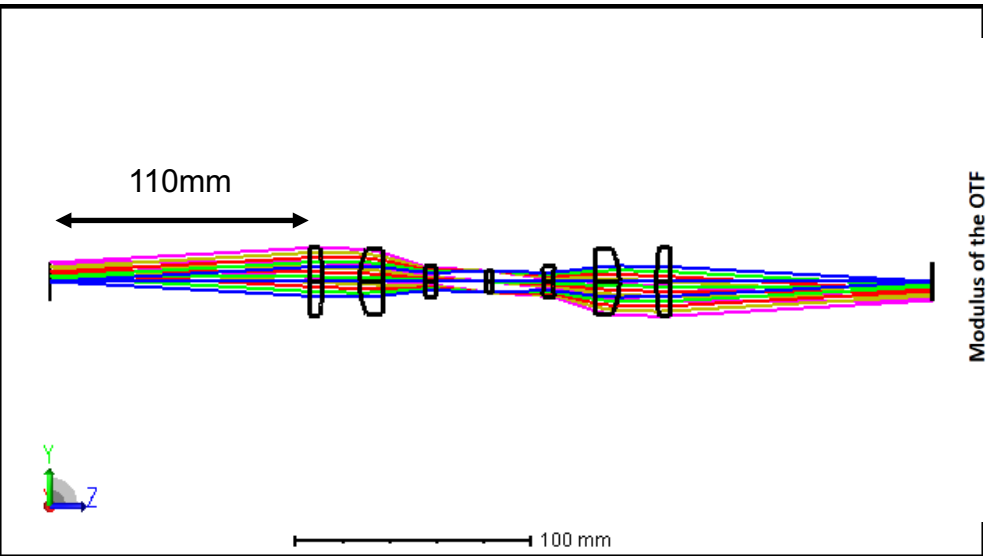
Starting point

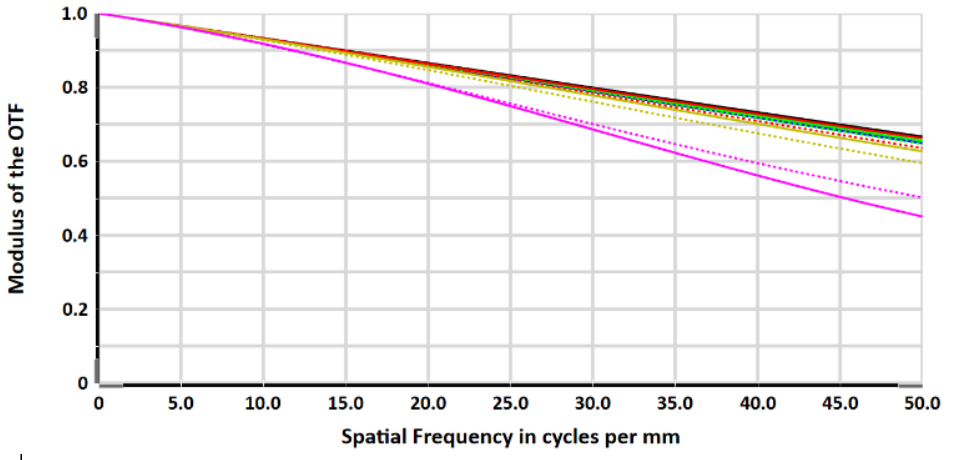




- Google Patent Search: “1:1 relay telecentric”
- R. Kingslake, “Lens design fundamentals”
- Smith, “Modern Lens Design”

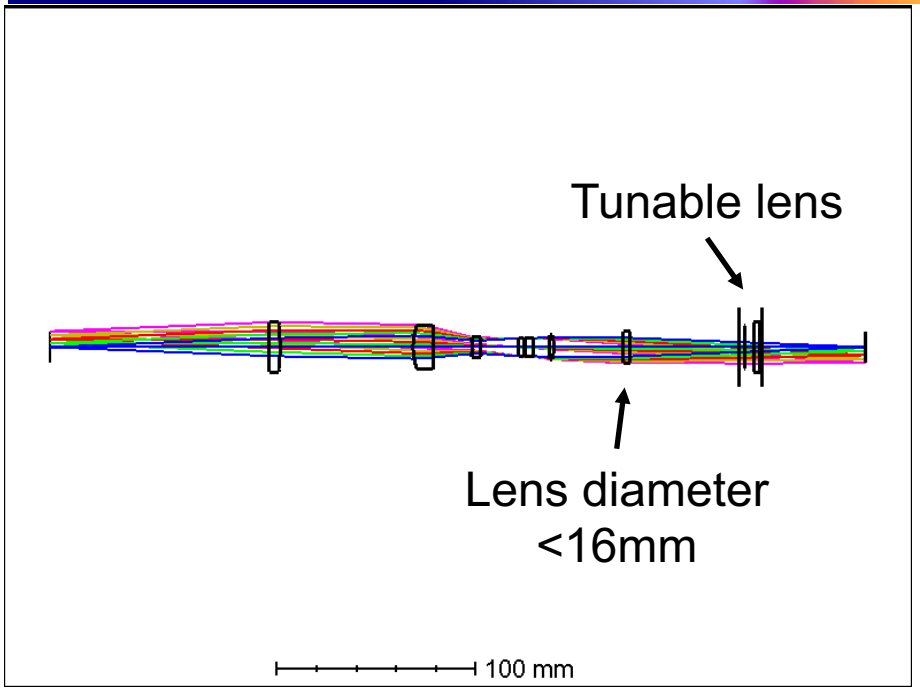
Scale down and reoptimize

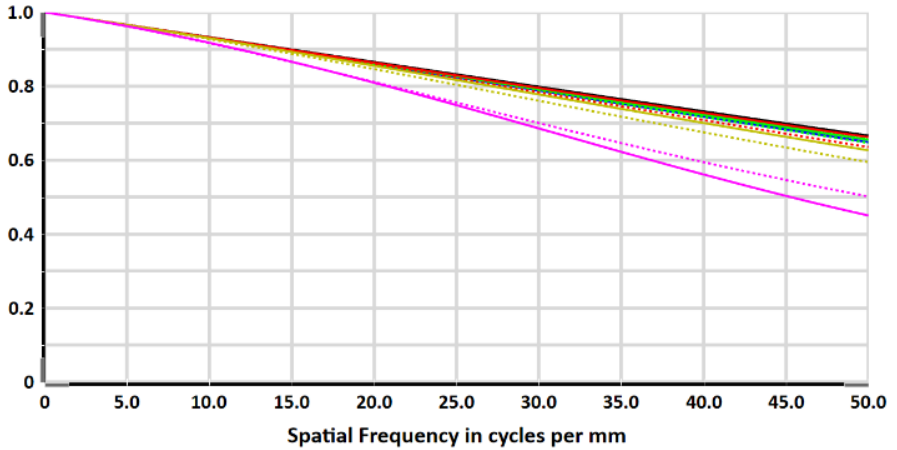




- Keep the lens symmetric – use Pick-Ups.
- All lenses are plano- or bi-convex/concave.
- The design meets spec monochromatically.
- The monochromatic design allows to learn about the **lens configuration**, **feasibility of the requirements**, and **dynamics of the optimization**.

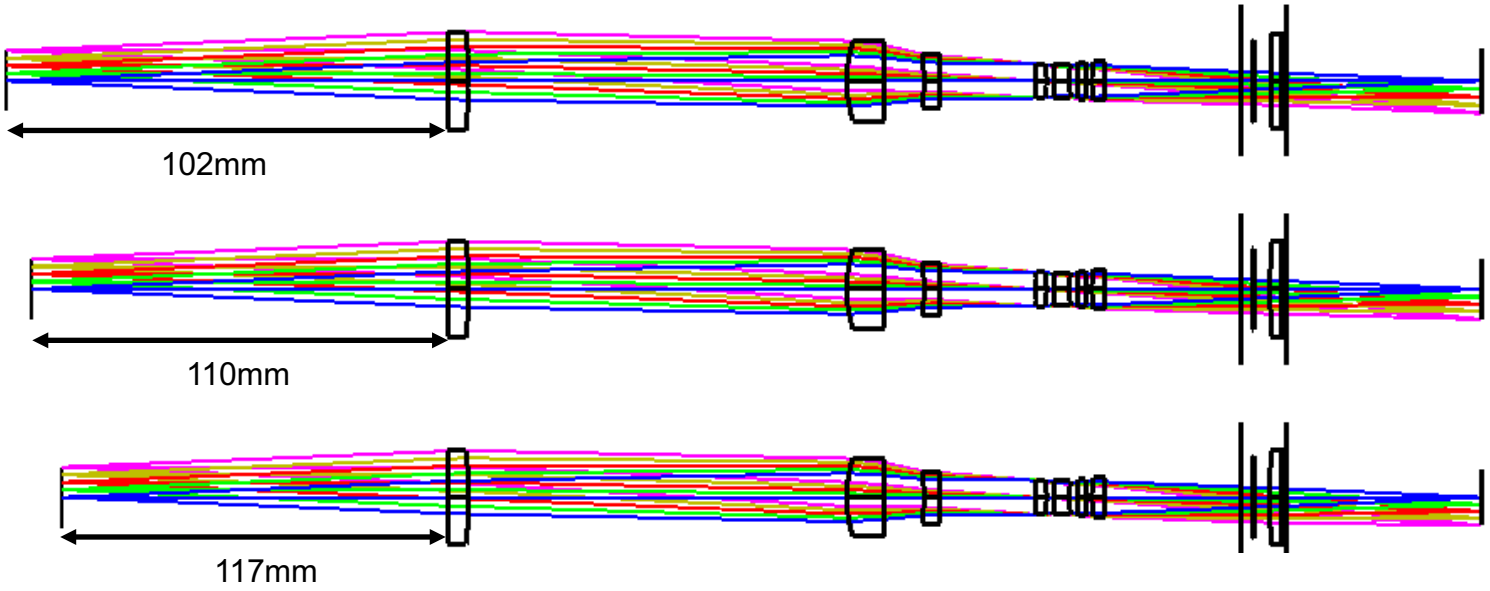
Nominal configuration





- Insert the tunable lens.
- Remove the symmetry constraint.
- The design meets spec monochromatically at **f/12**.
- The lens is not symmetric anymore -> Need to control **Distortion**!

Final monochromatic design



- 3 configurations for **15mm tuning range**.
- TIP: make MIN/MAX WD **variable**.
- TIP: let the magnification vary **slightly** for different configurations.

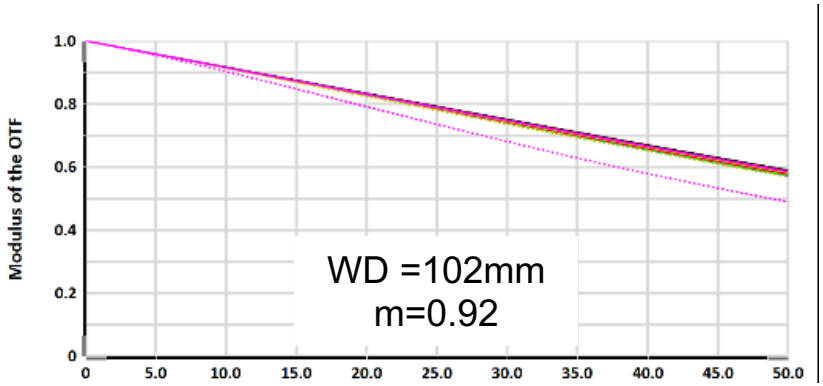
Multi-Configuration Editor

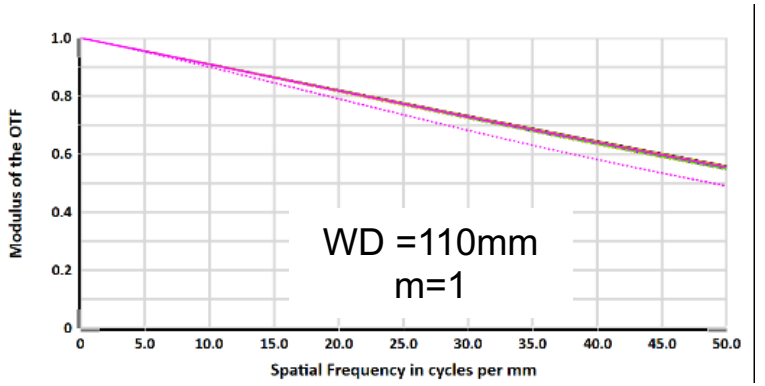
Update: All Windows

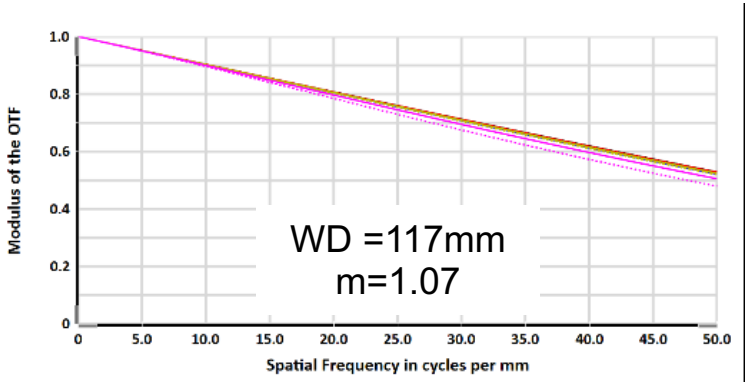
Operand 1 Properties

	Active : 1/3		Config 1*	Config 2		Config 3	
1	MOFF	-	NOMINAL	MIN		MAX	
2	THIC	0	110.000	101.949	V	116.949	V
3	MOFF	-					
4	CRVT	19	0.002	0.010		-0.007	

Final monochromatic design



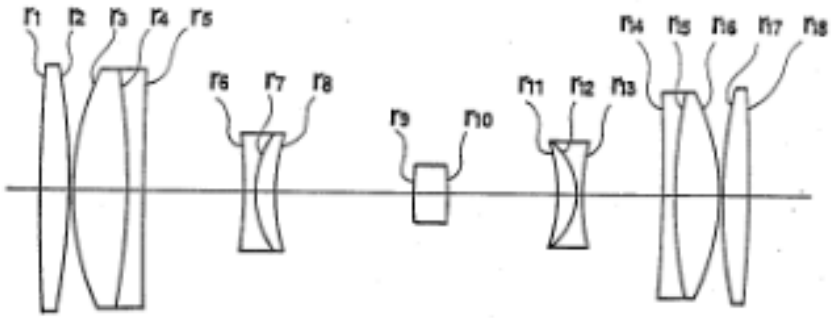




- Diffraction limited monochromatic performance.
- Distortion <0.08%
- Next step is chromatic aberration correction.

Chromatic aberration correction

Fig. 21



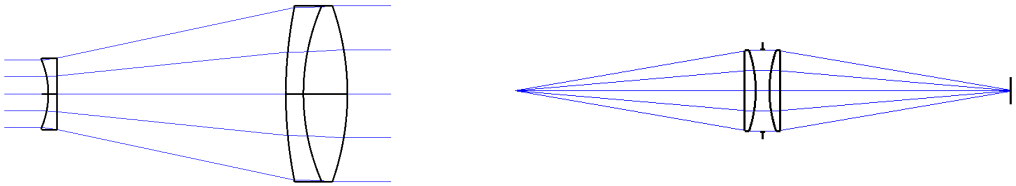
- The patent provides some ideas.
- Replace singlets with doublets or maybe add more elements!

Summary

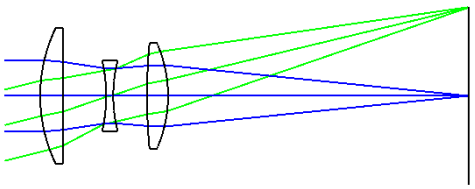
- Limitations of lens design with stock components:

FOV of 5-20 deg. at about f/6

- Types of off-the-shelf optics: PCX, PCV, DCX, DCV, Doublet
- “Best way” to utilize a stock lens for a particular application.



- Fitting stock lenses into existing design: **start with negative elements**



Questions?