Cooke triplet

Lens Design OPTI 517

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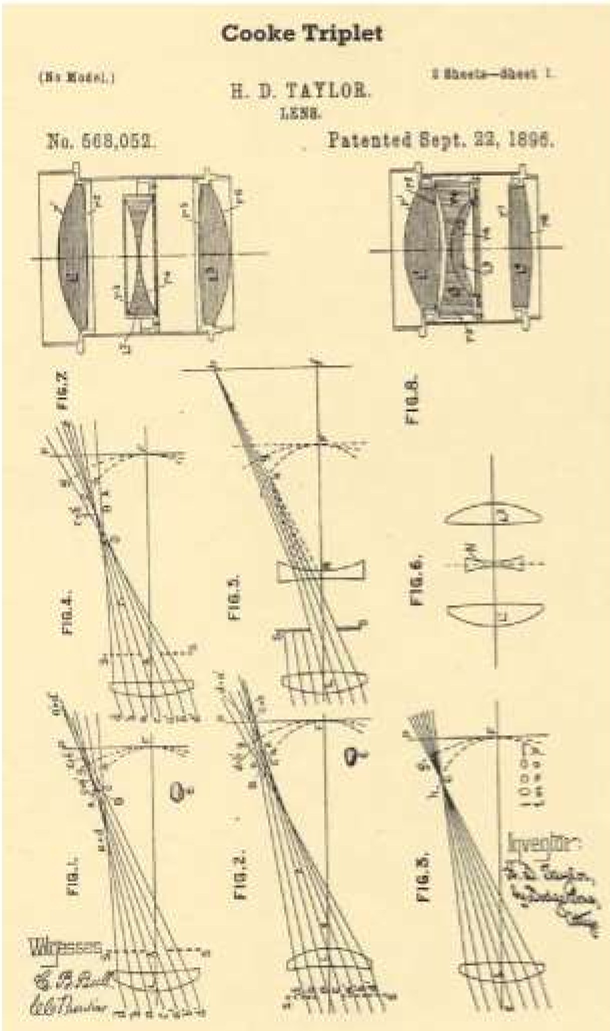
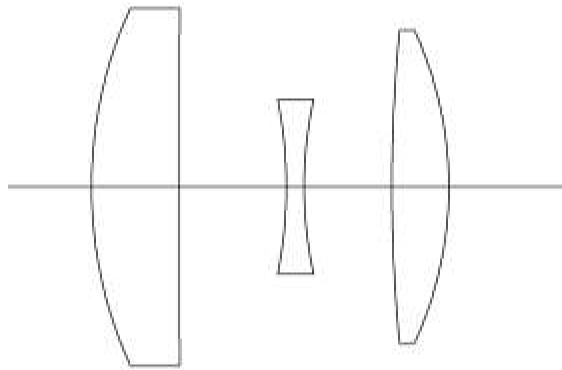
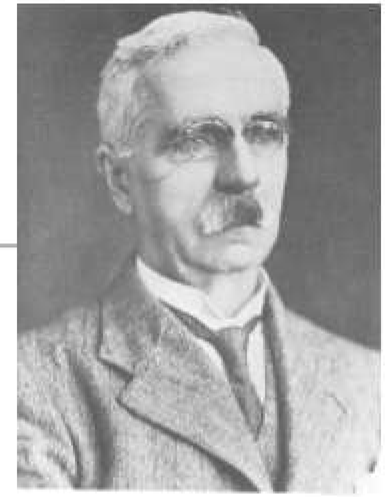
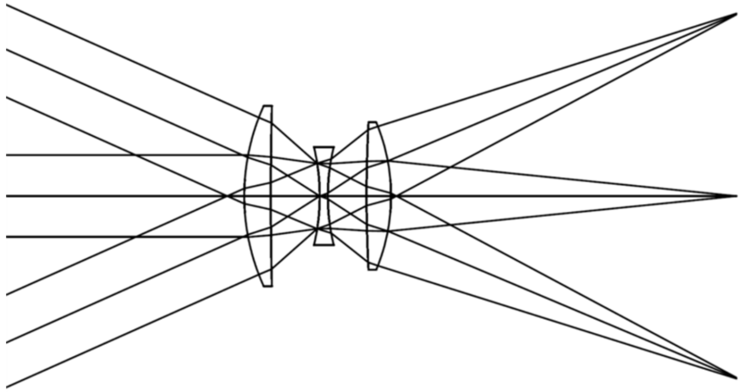
Cooke triplet







- A new design
- Enough variables to correct all third–order aberrations
- Thought of as an afocal front and an imaging rear
- 1896
- Harold Dennis Taylor

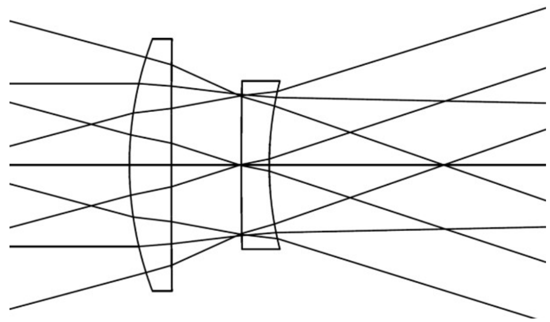


Cooke triple lens. f'=50 mm, FOV=+/-24º, F/5

The Cooke triplet lens was invented by H. D. Taylor who worked for the firm of T. Cooke & Sons of York. U.S. Patents 540,122 (1895) and 568,052 (1896). The essential design goal of the lens design was to obtain a flat image substantially free from astigmatism, distortion, and chromatic aberrations, with the minimum number of lenses possible.

The Cooke triplet is an stressed lens in that there is strong optical power in the components. The aberrations are interlocked.

Taylor's design approach



$$S_{III}^{*} = S_{III} + 2 \cdot \bar{S} S_{II} + \bar{S}^{2} S_{I}$$

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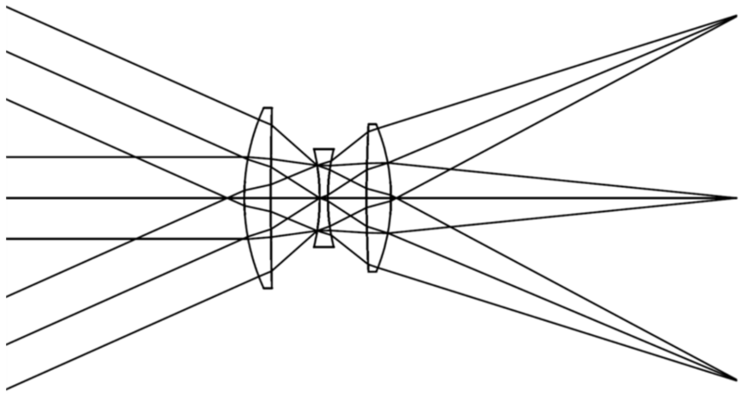
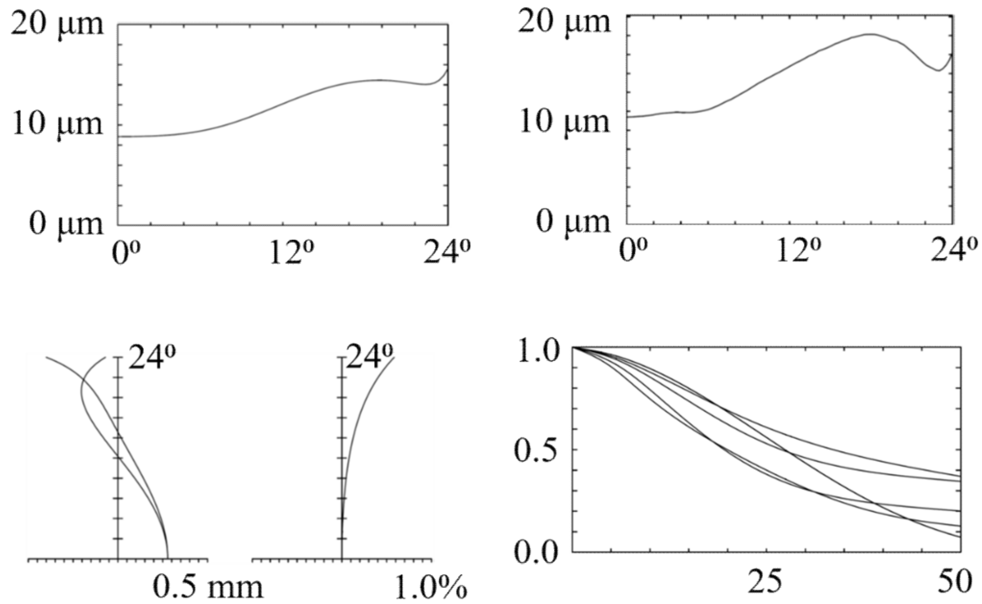
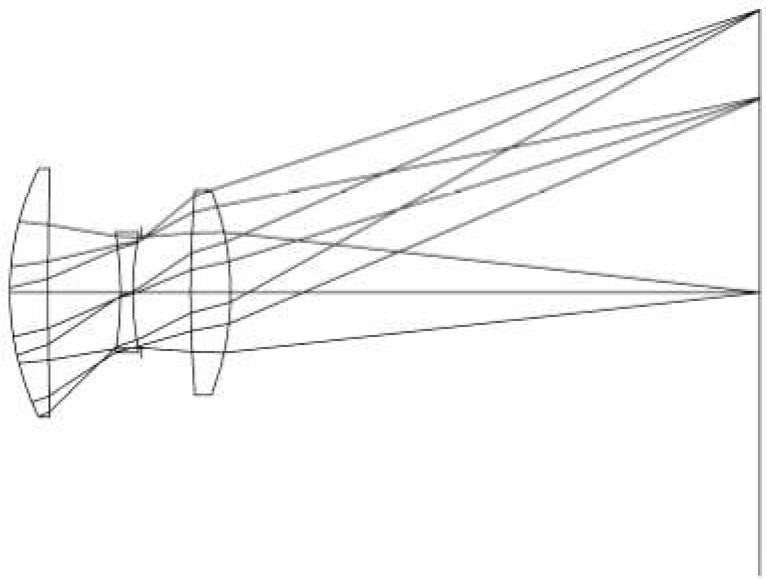


Constructional data of the Cooke triplet lens F=50 mm, FOV=+/-24º, F/5			
Surface	Radius (mm)	Thicknes s (mm)	Glass
1	30.1516	3.25	N-LAK33
2	-677.4312	6.0	Air
3 (Stop)	-23.3371	1.0	TIF6
4	29.3810	4.75	Air
5	5004.4670	3.0	N-LAK33
6	-20.7956	43.1266	Air

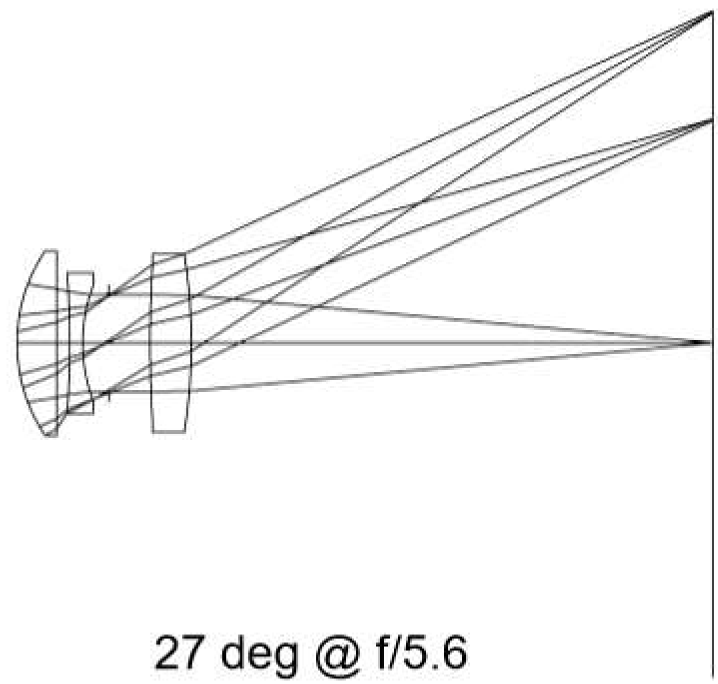


Cooke triplet lens. Top left, RMS Spot size vs. field of field. Top right, radius that encircles 80% of the energy vs. field of view. Bottom left, field curves. Bottom right MTF curves in lines/mm for fields 0°, 17°, and 24°. F=50 mm, FOV=+/-24°, F/5.

Cooke triplet field-speed trade-off's



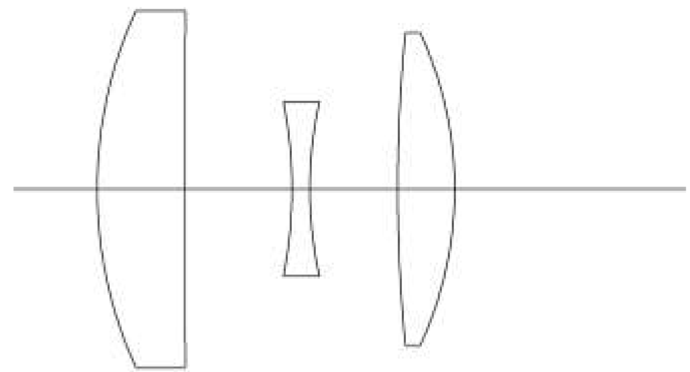
24 deg @ f/4.5



27 deg @ f/5.6

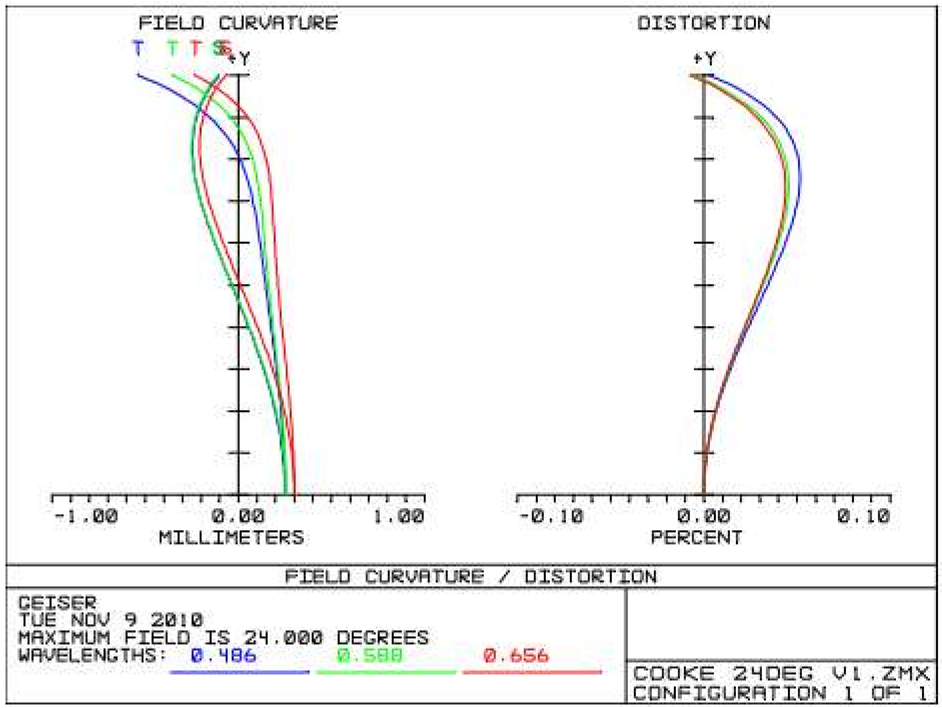
Aberration correction

- Powers, glass, and separations for: power, axial chromatic, field curvature, lateral color, and distortion. Lens bendings, for spherical aberration, coma, and astigmatism. Symmetry.

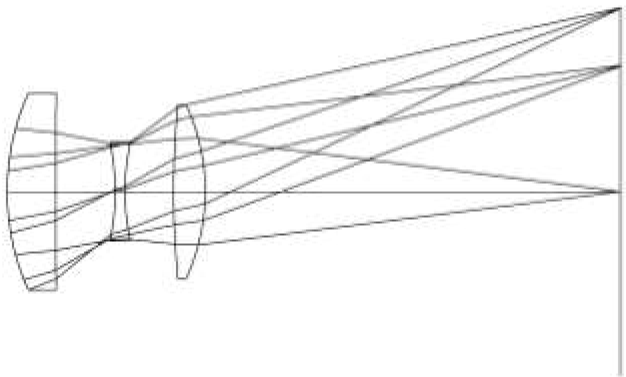


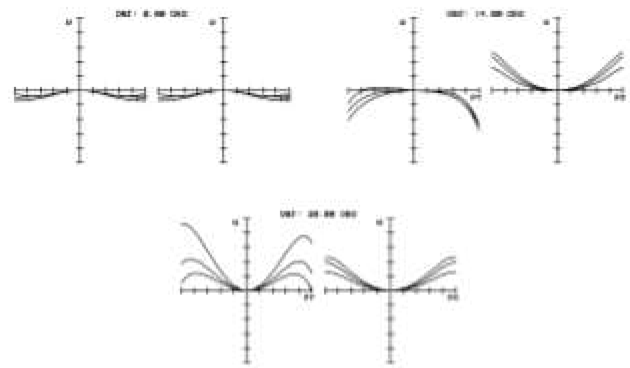
- Power: $$y_a\phi_a + y_b\phi_b + y_c\phi_c = y_a\phi$$
- Axial color: $$y_a^2\phi_a / V_a + y_b^2\phi_b / V_b + y_c^2\phi_c / V_c = 0$$
- Lateral color: $$y_a\,\bar{y}_a\phi_a / V_a + y_b\,\bar{y}_b\phi_b / V_b + y_c\,\bar{y}_c\phi_c / V_c = 0$$
- Field curvature: $$\phi_a / n_a + \phi_b / n_b + \phi_c / n_c = 0$$

- Crossing of the sagittal and tangential field is an indication of the balancing of third-order, fifth-order astigmatism, field curvature, and defocus.



Cooke triplet example from Geiser OE





- 5 waves scal
- visible

F1=34 mm
F2=-17 mm
F3=24 mm

1 STANDARD	23.713	4.831	LAK9
2 STANDARD	7331.288	5.86	
STO STANDARD	-24.456	0.975	SF5
4 STANDARD	21.896	4.822	
5 STANDARD	86.759	3.127	LAK9
6 STANDARD	-20.4942	41.10346	
IMA STANDARD	Infinity		

From Geiser OE f/4 at +/- 20 deg. f=50 mm.

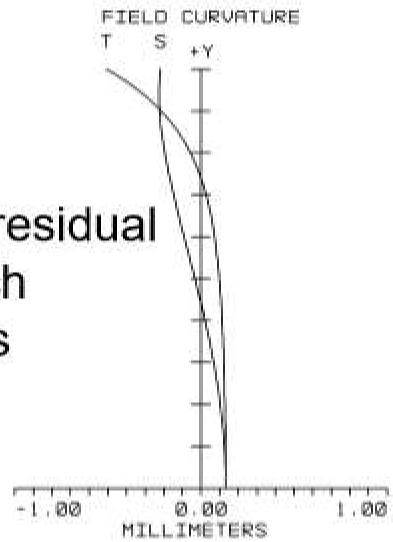
Aberration coefficients

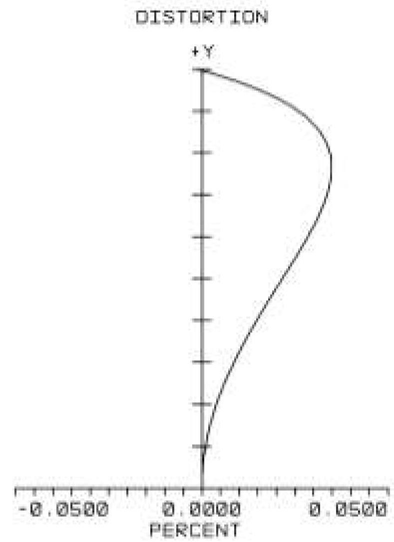
Surf	W040	W131	W222	W220	W311	W020	W111
1	5.883061	16.491222	11.556926	37.942379	61.278483	-0.000000	-0.000000
2	4.697811	-50.633600	136.433840	-0.122724	-366.963936	0.000000	-0.000000
STO	-22.370883	117.170758	-153.424726	-36.207024	295.715864	0.000000	-0.000000
4	-9.649013	-65.348394	-110.643768	-40.440216	-324.276663	-0.000000	-0.000000
5	1.689360	24.150389	86.310980	10.370424	382.592103	-0.000000	-0.000000
6	22.084875	-42.606408	20.549199	43.901573	-52.258664	0.000000	-0.000000
TOT	2.335211	-0.776033	-9.217549	15.444412	-3.912814	0.000000	0.000000

TOTALS

2.3352	-0.7760	-9.2175	10.8356	-3.9128
82.2662	-16.2711	-95.1410	-32.1261	29.4709
-2.1155	3.7462	6.6350	-6.7109	2.3168
-0.7484	-0.5892	-4.6825	-1.2398	

Petzval/Astigmatic residual
de-stresses as much
As possible the lens





Petzval radius
Is -142 mm

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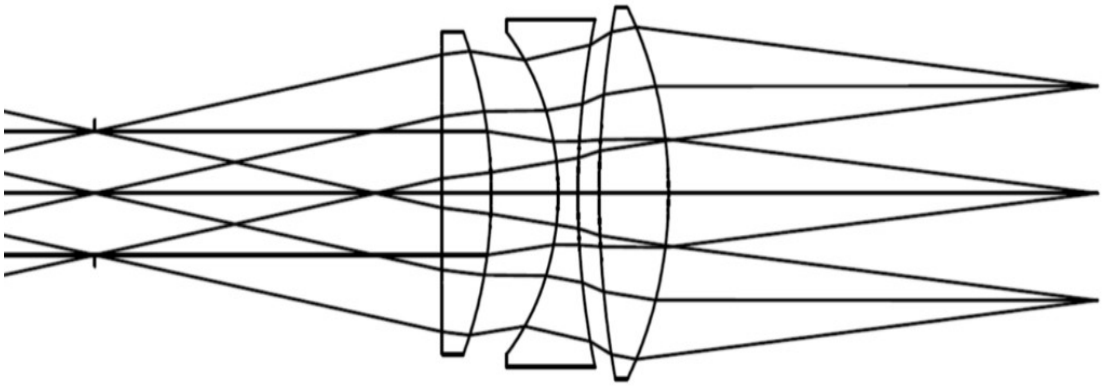
Telecentric

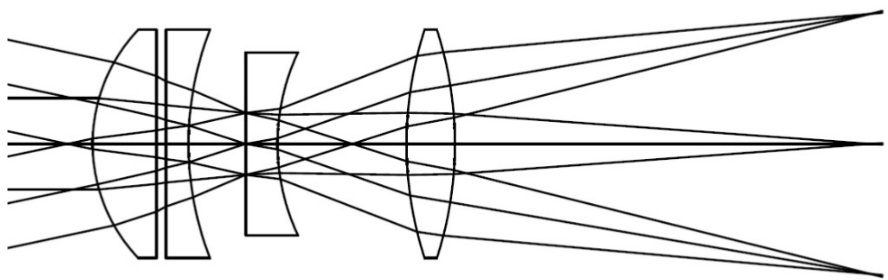


An external stop and telecentric Cooke triplet lens. F=50 mm, FOV=+/-10º, F/5.

Some steps for designing a Cooke triplet

1. Set the entrance pupil diameter to 25 units and the field of view to +/-24º. Start the design monochromatically.
2. Chose a high index glass for the positive elements such as N-LAK33. Chose a glass for the negative element such that there are many glass types with the same index of refraction but different *v*-numbers. For example glass TIF6.
3. Set a positive lens with a focal length of 100 units and a concave-plano lens with a focal length of -100 units. The stop aperture is set at the negative lens. To obtain about half the optical power the airspace between lenses is set to 12 units. Optimize for zero fourth-order astigmatism W_{222} using the radii of curvature as variables but leaving the rear surface of the negative lens as planar.
4. Correct for spherical aberration W_{040} by changing the focal length of the negative concave-plano lens, say to -153 units.
5. Add a rear positive lens with glass N-LAK33 glass with a focal length of 100 units and separated from the negative lens by 12 units. Lens thicknesses are for example 5, 2, and 5 units respectively.
6. Using the rear curvature of the negative lens and the curvatures of the third positive lens, correct for astigmatism W_{222} aberration, and for a focal length of the negative lens half as large, i.e. -76.5 units.
7. Maintaining the focal length of the lenses, and using only the shapes of the positive lenses correct for astigmatism W_{222} and coma W_{131} aberration.
8. While maintaining the correction for coma and astigmatism, correct for spherical aberration W_{040} by changing the focal length of the positive lenses from 100 units to say 120 units. The shape of the negative lens is not changed.
9. While maintaining the correction for spherical aberration coma and astigmatism, correct for distortion aberration W_{311} by changing the second airspace to say 13.5 units. The shape of the negative lens, and the lens focal lengths are not changed.
10. While maintaining zero coma, and by changing only the shapes of the positive lenses, introduce negative, or positive, astigmatism to flatten the tangential field curve.
11. Add the desired wavelengths and change the glass of the negative element to correct for chromatic change of focus, while maintaining the same nominal index of refraction. Change the glass of one of the positive lens elements to correct any chromatic change of magnification residual, while maintaining the same nominal index of refraction.
12. Scale the lens system to the desired focal length, change the relative aperture and field of view as desired. The lens is ready for real ray optimization.

Designing with off-the-shelf lenses



Lens prescription for off-the-shelf lens f'=71.47 mm, F/7, FOV=+/- 12º (mm)				
Surface	Radius	Thickness	Glass	Catalogue #
1	18.11	7.01	N-BK7	EO 45146
2	Plano	1		
3	Plano	2.5	C79-80	EO 48322
4	34.38	6.2611		
Stop	Plano	3.5	N-SF11	EO 45020
6	23.54	14.142		
7	40.42	5.3	N-BK7	EO 45296
8	-40.42	46.86		

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Designing with off-the-shelf lenses procedure

A choice for designing a lens system with off-the-shelf lens elements can be a Cooke triplet lens. The starting point is then a Cooke triplet lens that meets the lens specifications. Then each of the lenses in the Cooke triplet is divided into two plano lenses, either plano-concave and/or plano-convex. If the radii of curvature of a lens element in the Cooke triplet lens system are similar, then the lens might be adjusted to have both radii the same, and have a double equi-convex or double equi-concave lens, so that there is no need to split the lens. The next step is to substitute with an off-the-shelf lens, the lens element that has the strongest optical power. The lens system is re-optimized to restore image quality. The variables used are the curvatures and air spaces of the remaining unfitted lenses. Then the next lens with the strongest optical power is substituted, and the lens system is re-optimized again. This process is repeated until all the plano lenses have been replaced with off-the-shelf lens elements. Airspaces and lens scaling can help to adjust or re-optimize the lens.