Optimisation of Ultra Short Focus Lenses

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202406

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Thematic

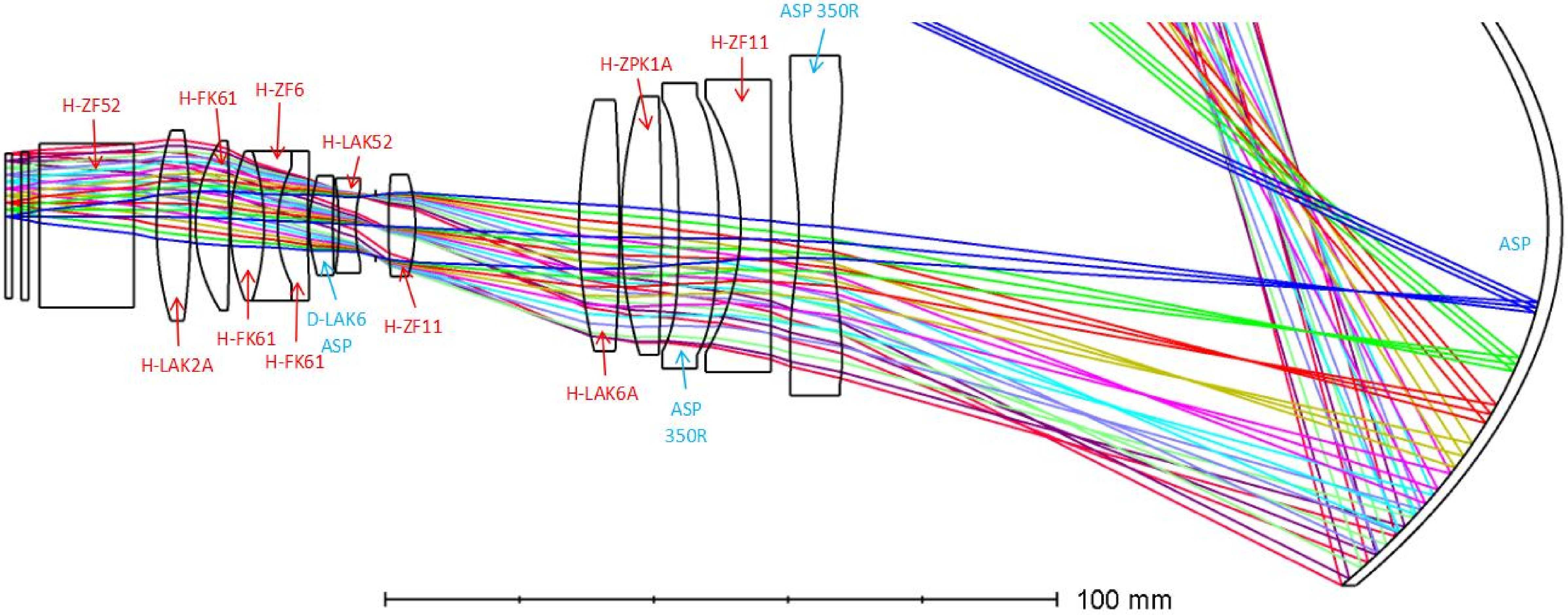
Through the analysis of existing lens architectures, combined with the theory of aberration, targeted optimisation, and ultimately better performance and lower cost optical architecture.

Specification

Chip Type	LCOS
Chip Size	12.18mmX6.85mm
Resolution	1920X1080
pixel size	6.34μm
Throw Ratio	0.25
OFFSET	150%
F#	2.38
Wavelengths and Weights	447nm/520nm/637nm 1/2/1

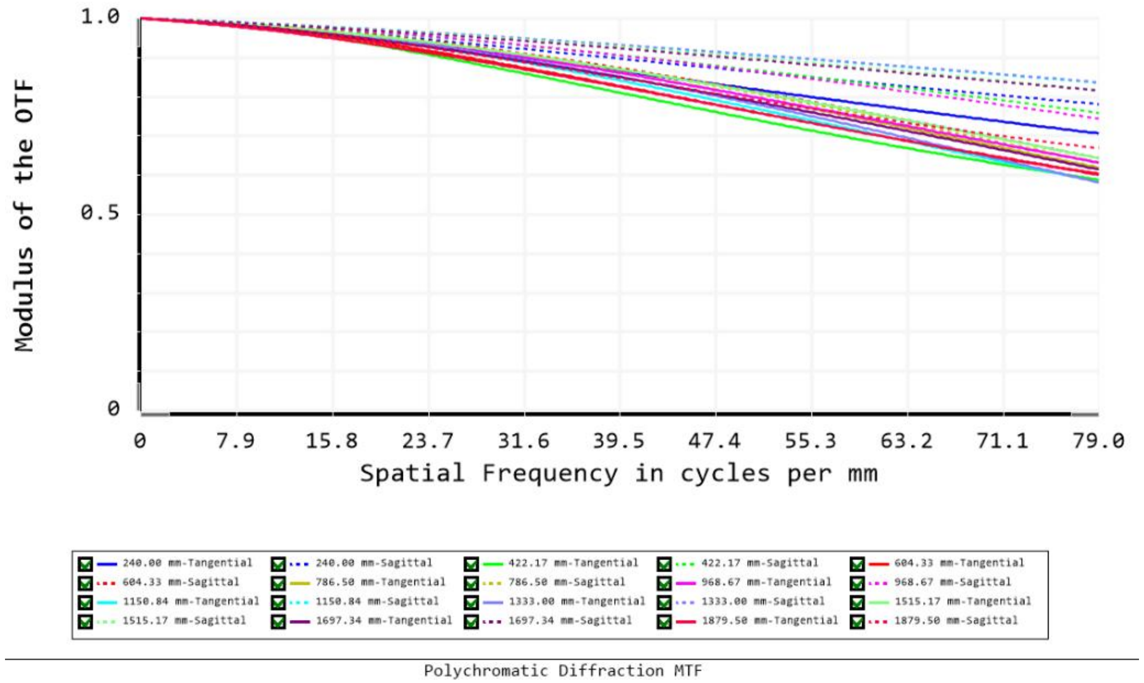
Lens Length (From the Chip)	< 300mm
Working Distance	550mm
Telecentric	< 1°
Relative Illumination	> 70%
TV Distortion	< 0.5%
MTF （Chip-Side）	> 0.5@79lp/mm
Lateral Color	< 0.8 pixel
Spherical Lens	< 8 pcs
Aspheric Lens	< 3 pcs

Initial Structure

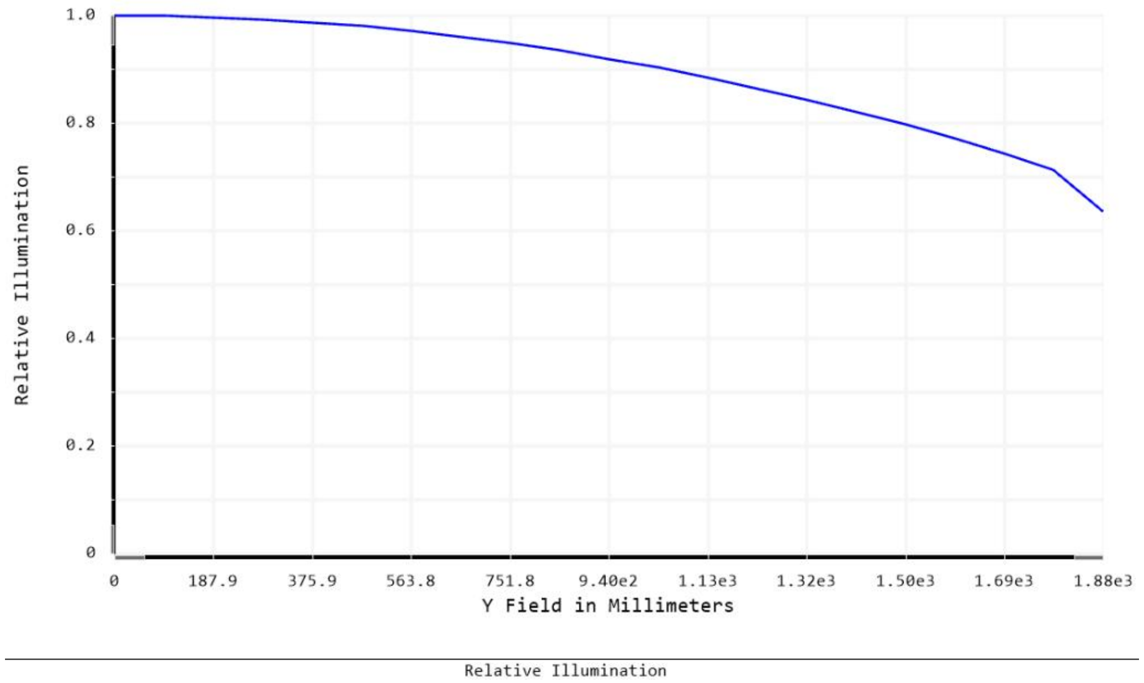


2D layout

Initial Structure

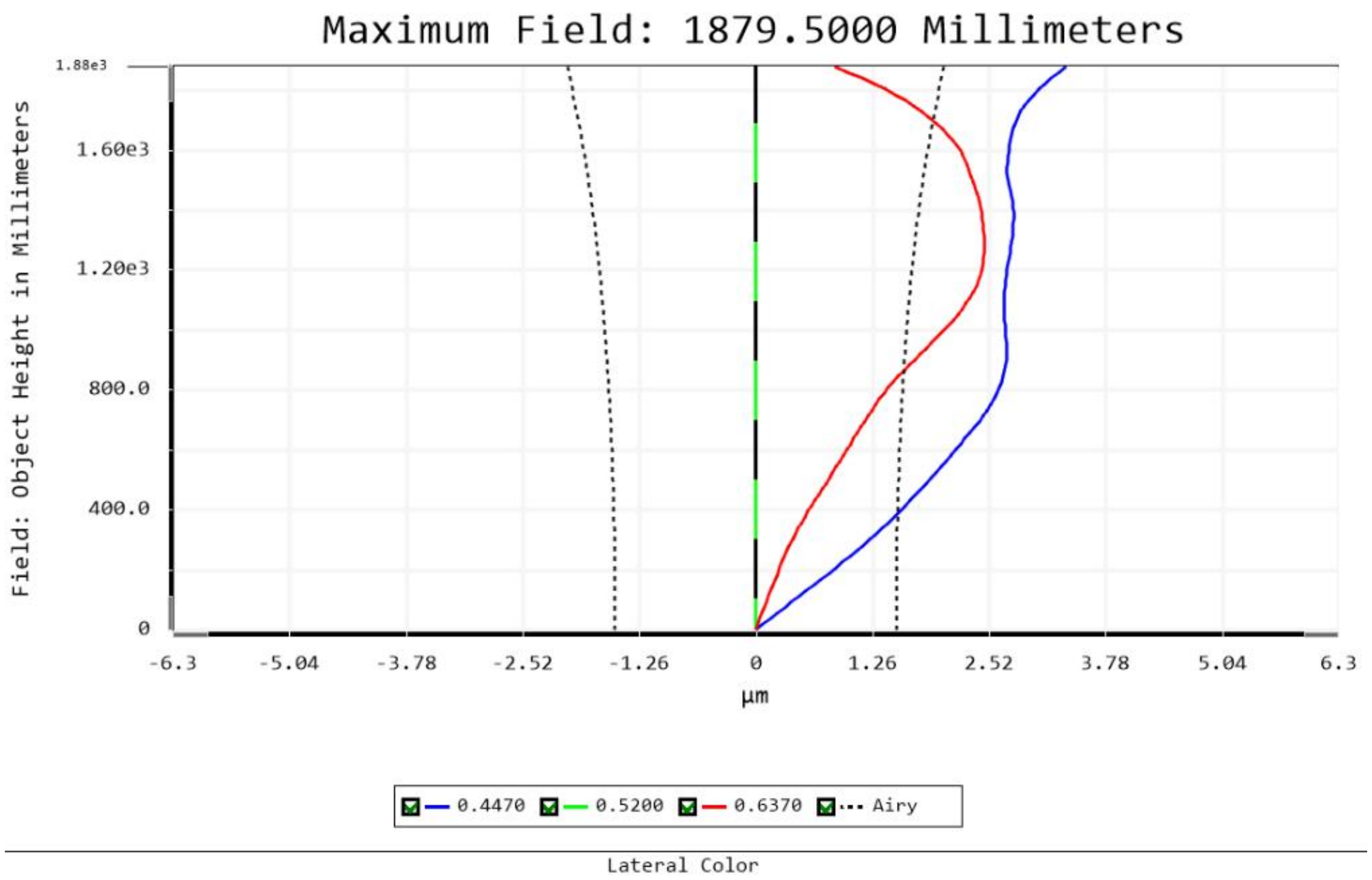


MTF

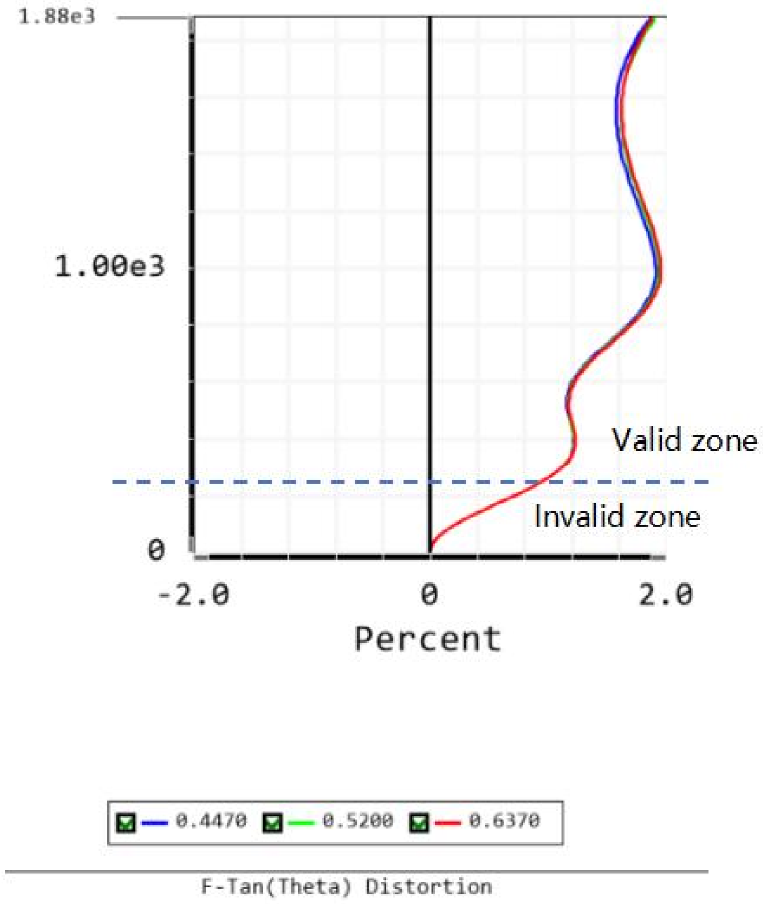


Relative illumination

Initial Structure



Lateral color



Distortion

Optimisation process
1.Setup

chip as the object space.

Optical systems generally set the long conjugate distance to the object space and the short conjugate distance to the image space, so the chip is generally set to the image space.

There are two considerations here:

(i) It is beneficial to confirm line pairs and view MTF based on the chip pixel size without being affected by the working distance as well as changes in magnification, and it is more convenient for the infinite conjugate system in the object space;

(ii) In this setup, the lens can often be used as a small aberration system, and the optimisation process can facilitate the use of RMS optimisation or wavefront optimisation.

But here, we take the chip as the object space.

Optimisation process

1.Setup

chip as the object space.

Reason:

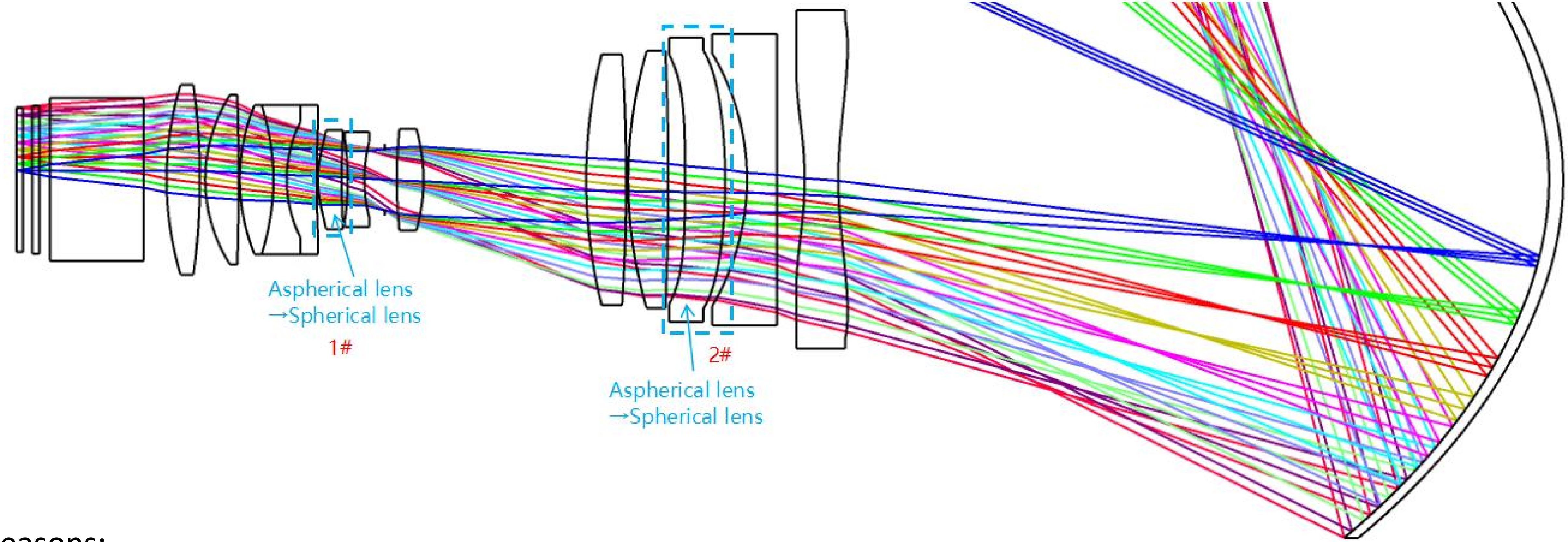
(i) Improve optimisation speed. In the field of view type, the height of the near-axis image plane is adjusted to the height of the object to avoid the reverse tracing of light, which can improve the optimisation speed;

(ii) reduce the probability of light tracing failure. For optical systems with large FOV, ZEMAX is easily misled by stray light passing through the centre of the aperture diaphragm when tracing the chief ray.

At the same time, the original F#=2.38 in image space is converted to NA=0.21 in object space.

Optimisation process

2.Aspherical lens→Spherical lens



Reasons:

(i) Aspherical lens leads to more local minima, increasing the nonlinearity of the system and reducing the optimisation efficiency;

Optimisation process

2.Aspherical lens→Spherical lens

Reasons:

(ii) In the initial stage of optimization of the initial structure, use a spherical lens instead of an aspherical lens as much as possible, and when the performance of the spherical system is optimized to the extreme, convert the spherical lens to an aspherical lens in the middle of the optimization process, which often results in a more cost-effective design;

(iii) 1# aspherical lens has a triplet lens on the left side, the triplet lens has a significant effect on the correction of aberration, the aberration correction effect played by adding another aspherical lens in the vicinity will be seriously weakened. 2# aspherical lens has a positive lens and negative lens on the left and right sides, both of which can be composed of an aberration correction unit. Complemented by an aspherical lens on the right, the aberration correction effect of the 2# aspherical lens will also be severely weakened.

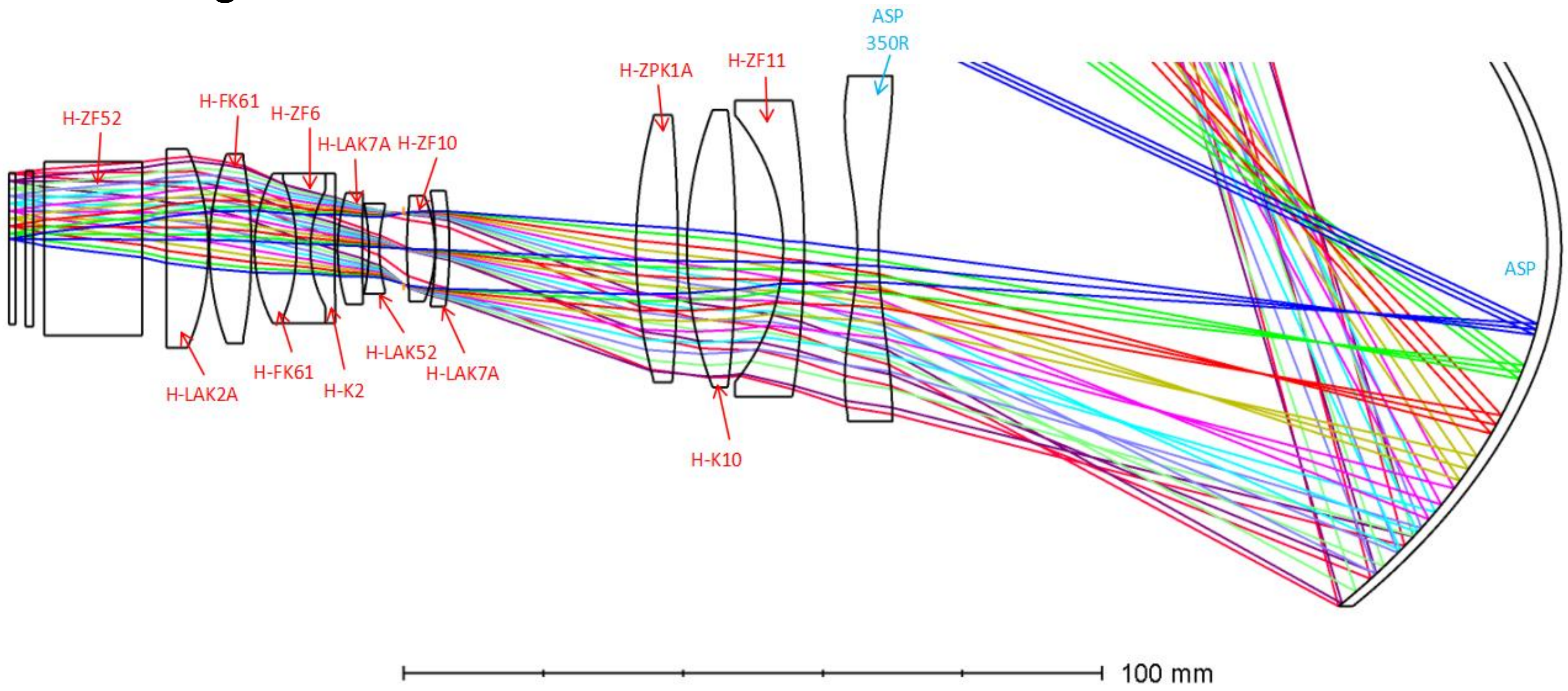
Optimisation process

2.Aspherical lens→Spherical lens

Optimisation methods:

Image height, total system length, telecentricity, distortion, glass thickness, and air spacing are controlled in the merit function, and then, RMS optimization as well as Hammer optimization are used.

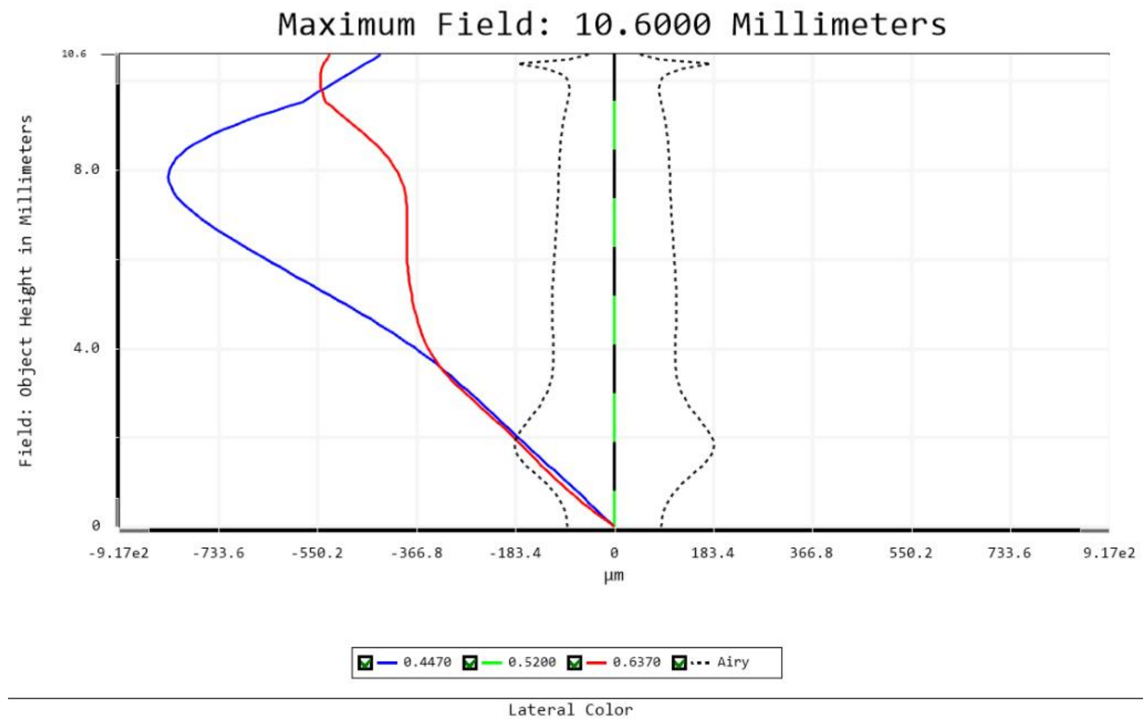
Finally, the following results can be obtained.

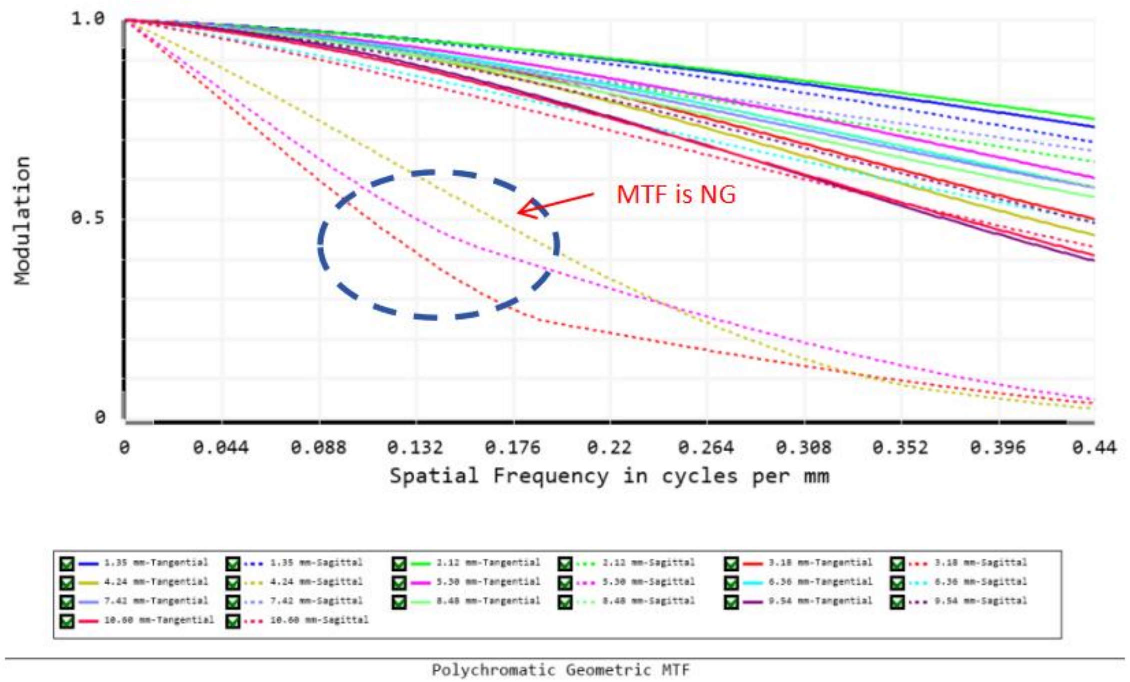


2D layout

Optimisation process

2.Aspherical lens→Spherical lens





Lateral color

Magnification	180.68
Chip Pixel Size/µm	6.344
Image space pixel size/µm	1146.26
0.8 Pixel Size/µm	917.01

MTF

TR	0.25
Projection distance/mm	550
Screen length/mm	2200
Chip length/mm	12.18
Magnification	180.68
Object space lp/mm	79.00
Image Space lp/mm	0.44

Optimisation process

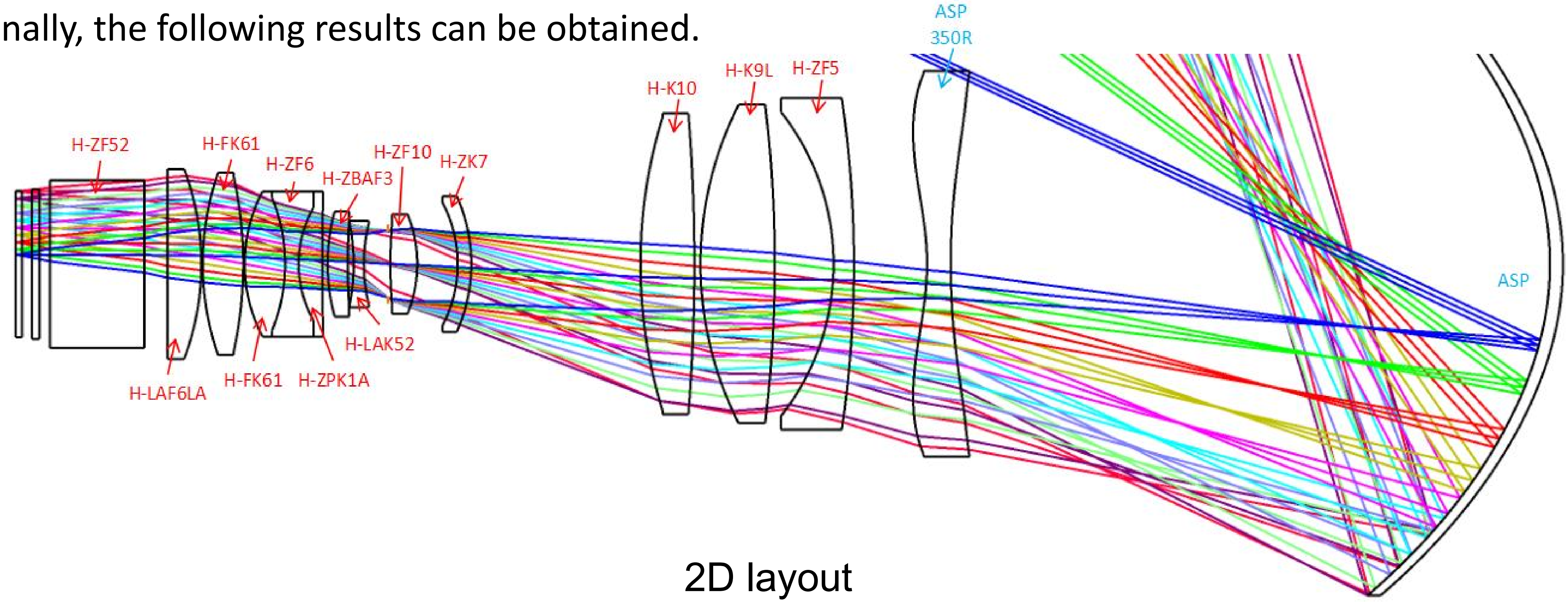
3. Optimised for astigmatism and lateral color aberration

Optimisation methods:

(i) Use GMTS to pull up the sagittal MTF in the merit function;

(ii) According to the definition of the vertical axis chromatic aberration, use REAY to get the height of the vertical axis of different wavelengths in the image plane, and then use DIFF to get the vertical axis chromatic aberration, and finally control the vertical axis chromatic aberration in a certain range can be.

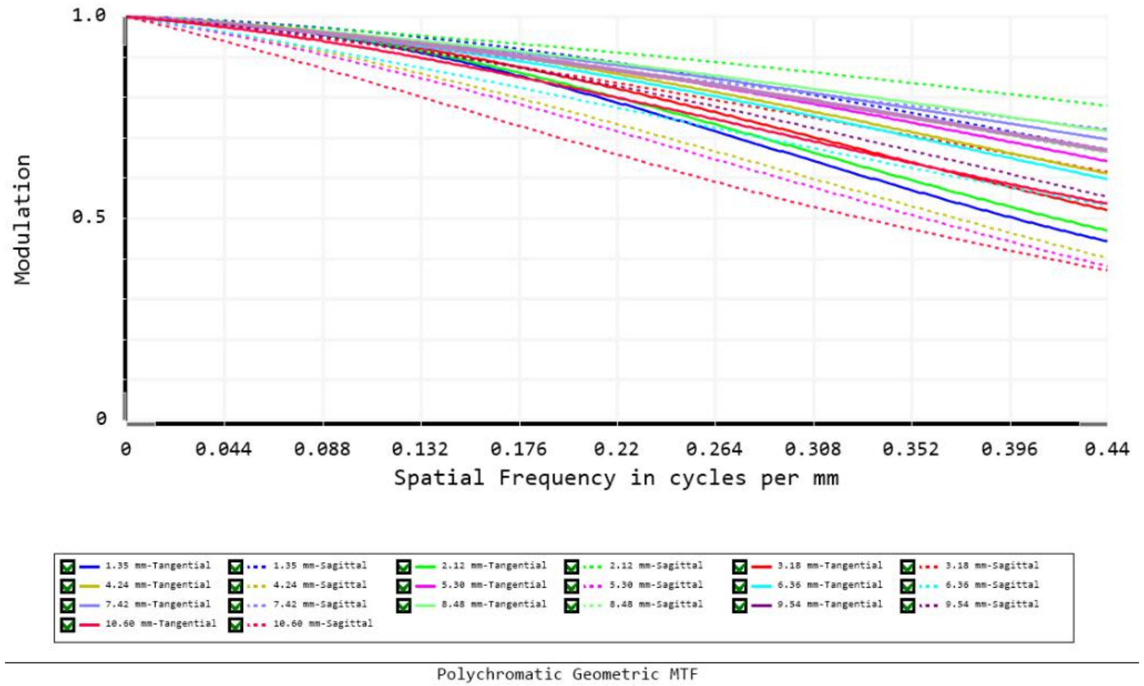
Finally, the following results can be obtained.

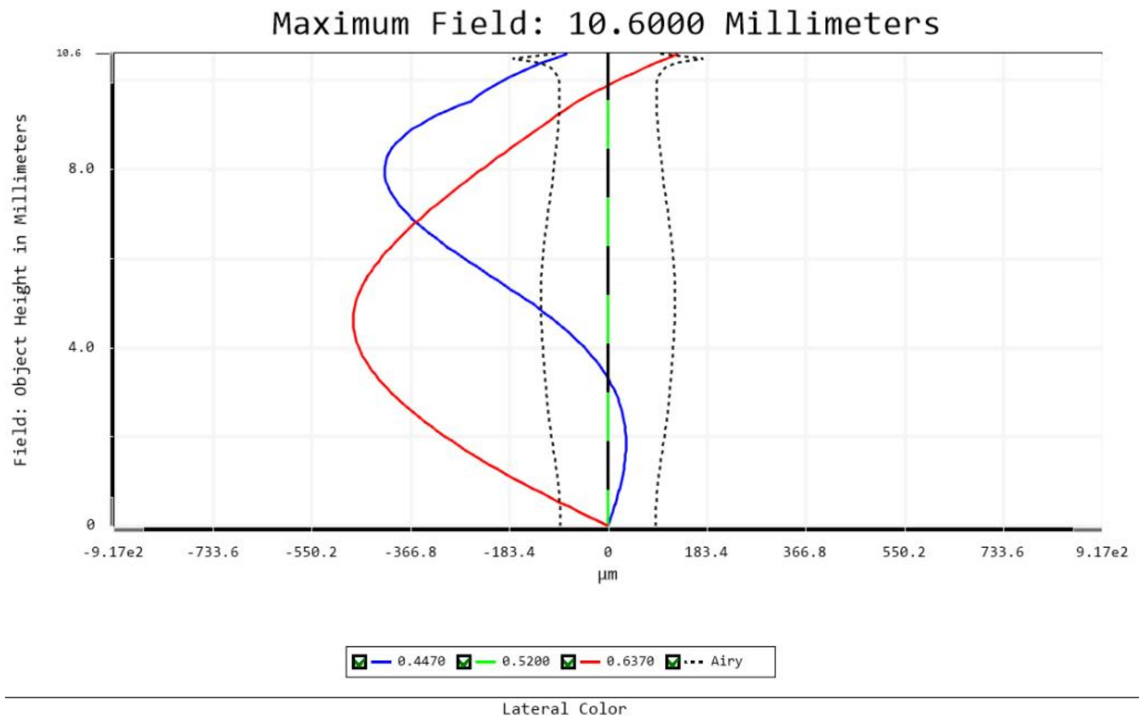


2D layout

Optimisation process

3. Optimised for astigmatism and lateral color aberration





MTF

Lateral color

Looking at the MTF, it is clear that the lens is not up to specification and needs further optimisation.

Optimisation process

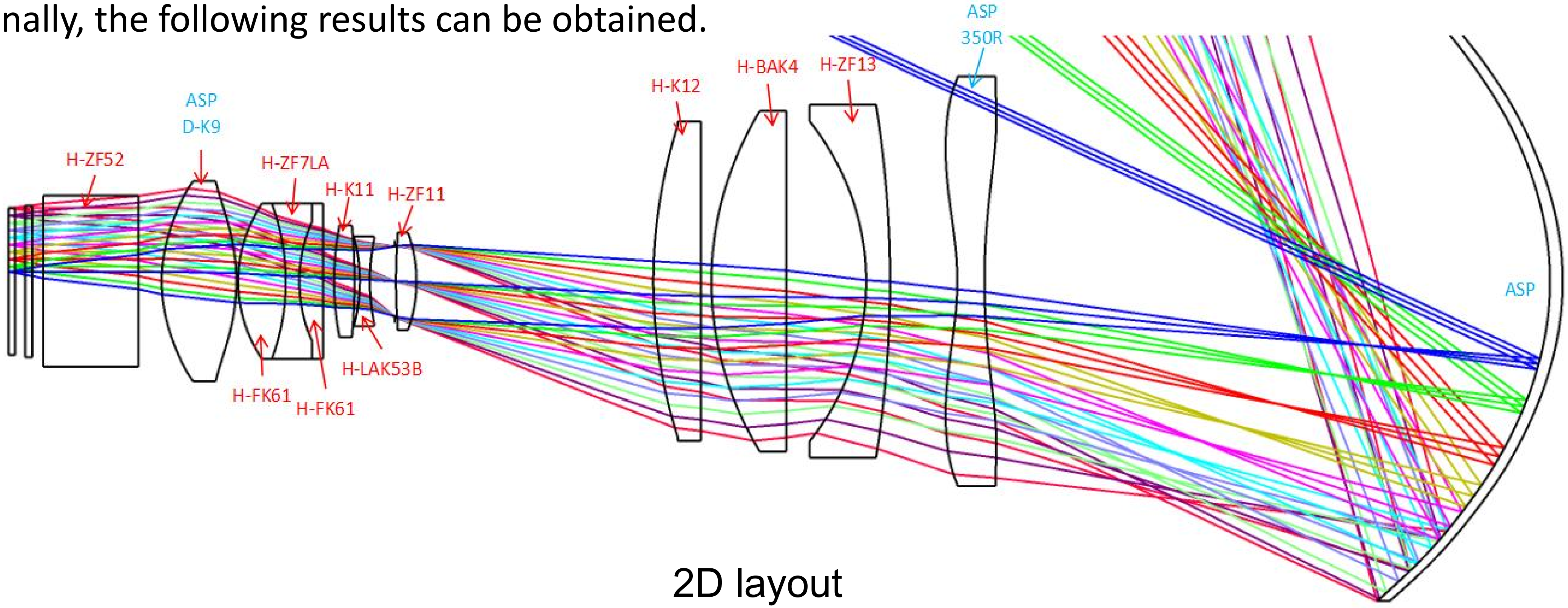
4. Introduction of aspherical lenses and simplification of the system

Optimisation methods:

The two positive lenses near the prism, H-LAF6LA (1.757/47.714) and H-FK61 (1.497/81.595), do not have a high refractive index, and a high refractive index spherical lens or a glass aspherical lens could be considered instead. Considering the image quality, it is obviously more appropriate to use a glass aspherical. The cheaper material is D-K9.

Secondly, the low focal power lens in the centre of the lens could be considered for deletion.

Finally, the following results can be obtained.



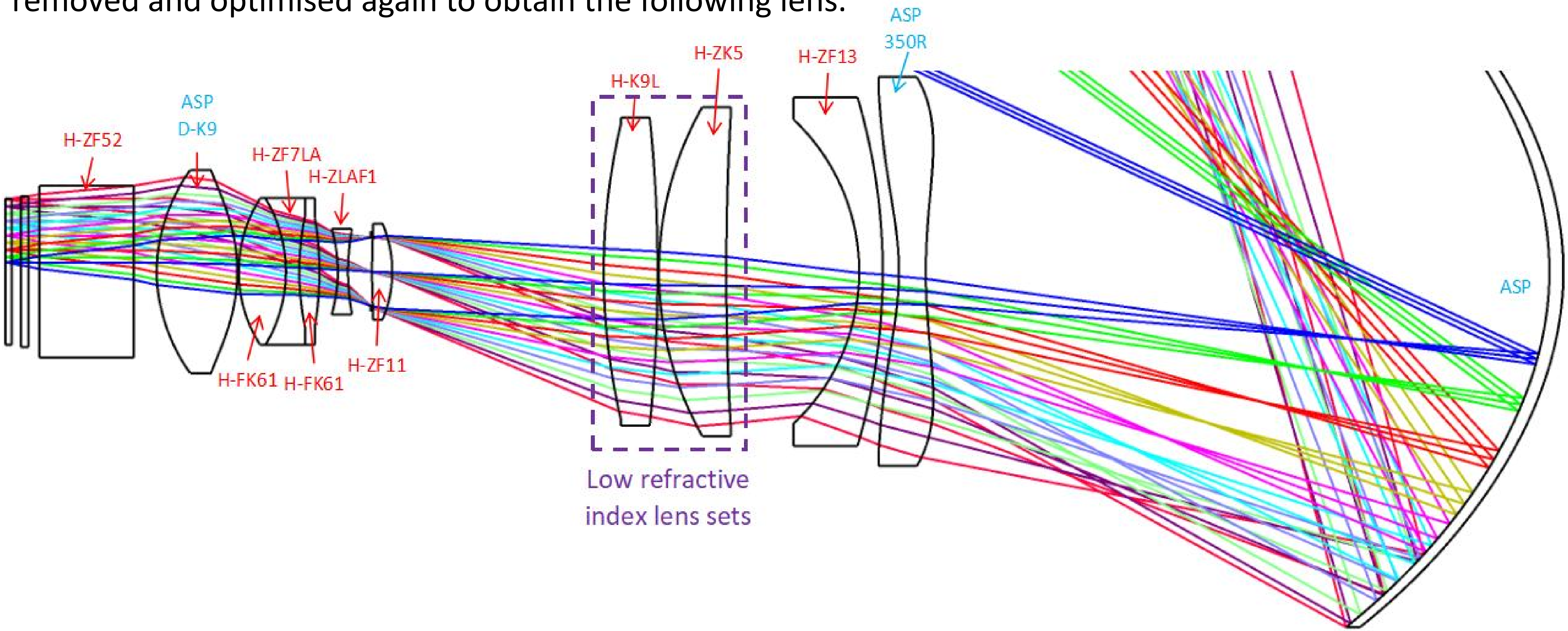
2D layout

Optimisation process

4. Introduction of aspherical lenses and simplification of the system

Optimisation methods:

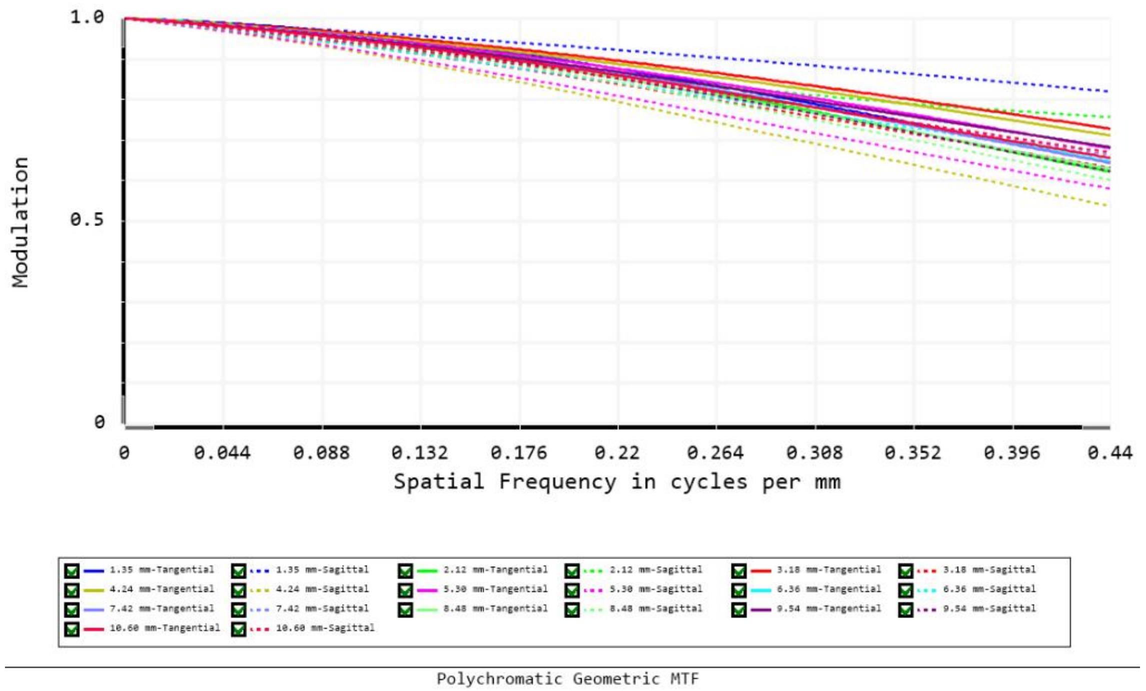
As the Hammer optimization proceeds, another low focal power lens appears in the lens, which is removed and optimised again to obtain the following lens.



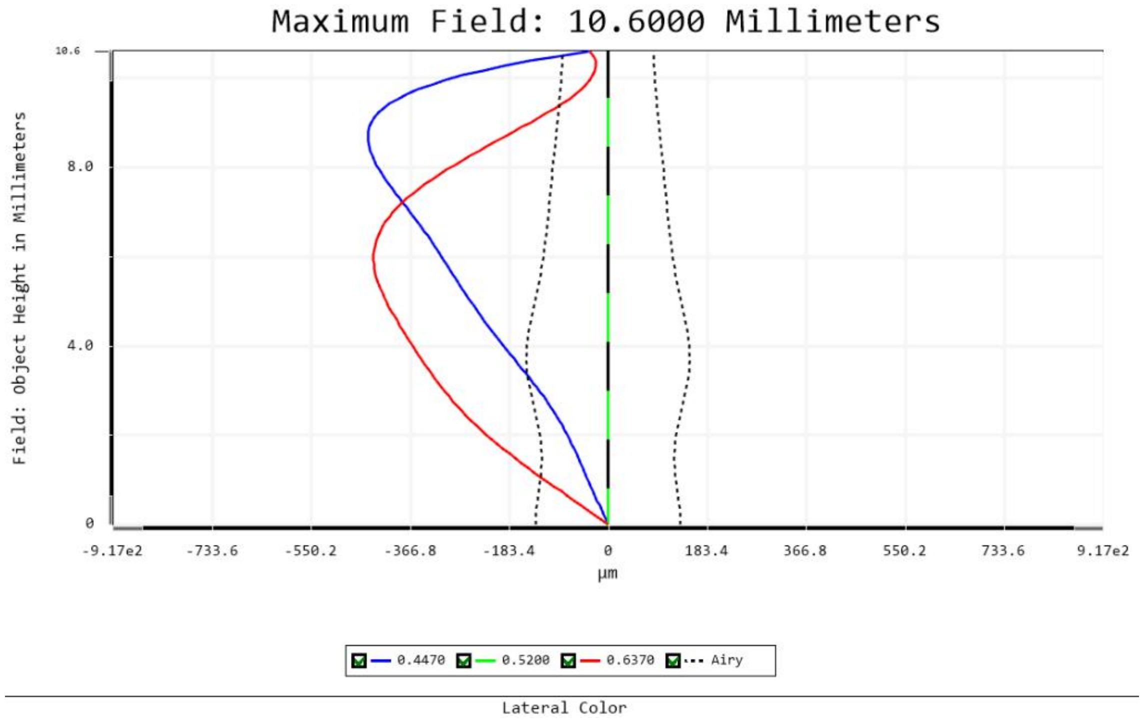
2D layout

Optimisation process

4. Introduction of aspherical lenses and simplification of the system



MTF



Lateral color

Optimisation process

5. Incorporation of low refractive index lens

There are two other areas where optimisation of the lenses in the previous section could be attempted:

(i) The glass aspherical lens D-K9, using a lens material with a higher refractive index, flattens the surface, compresses the lens thickness, and indirectly reduces back focus. However, an increase in refractive index tends to result in a decrease in Abbe number, which is related to chromatic aberration correction, although the strong correction of chromatic aberration by the triplet lens may compensate for the change in chromatic aberration caused by abbe number.

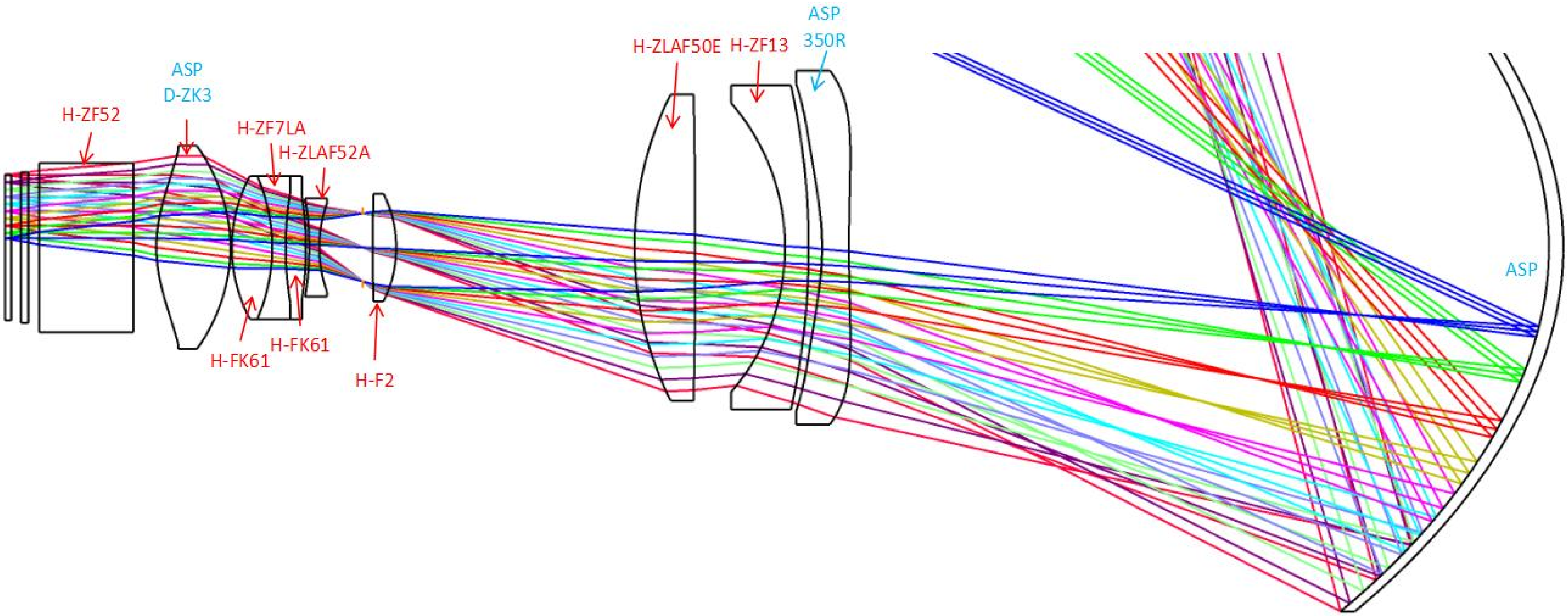
(ii) The refractive index of the positive lenses H-K9L and H-ZK5 in the middle of the lens is not very high, so we can try to use a material with high refractive index instead.

In summary, the material D-K9 of the glass aspherical lens is changed to D-ZK3, the positive lens with material H-K9L is deleted, and the material H-ZK5 is changed to H-ZLAF50E, which is used as the initial structure to start the optimisation.

The optimised lens is shown below.

Optimisation process

5. Incorporation of low refractive index lens



2D layout

Optimisation process

6.Splitting of triplet lens

Optimisation methods:

In the previous section, the triple-concave lens of the lens and the double-concave lens H-ZLAF52A on the right side were very close together, and the two surfaces close together had similar radius and tended to glue together.

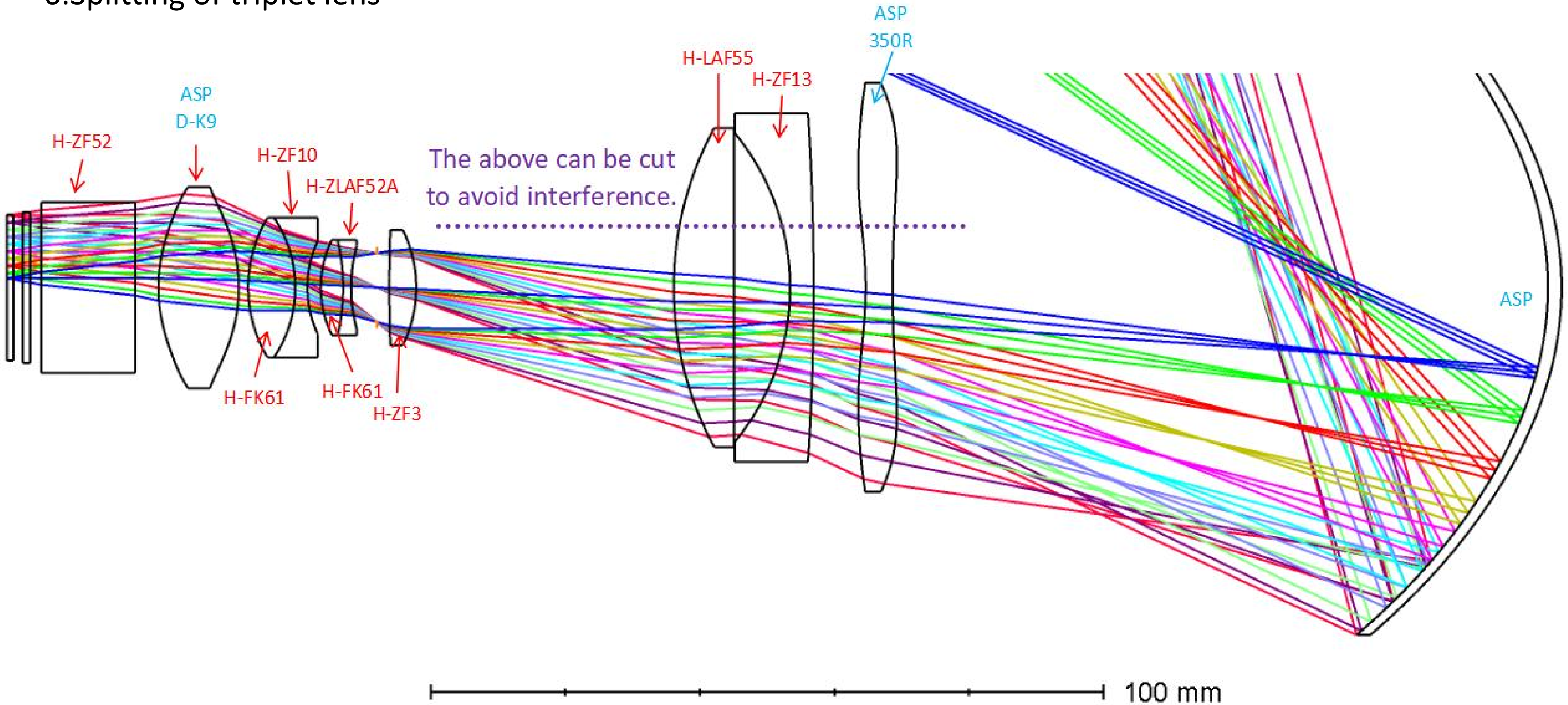
Try recombining the triplet lens and the double-concave lens into two double-concave lenses. The combined materials are H-FK61/H-ZF7LA and H-FK61/H-ZLAF52A, which are optimised for the initial structure.

The optimisation results in the following lens architecture.

As far as quality is concerned, the dismantling of triplet lense is not a profitable operation. However, doublet lens are superior to triplet lens in terms of processing, thermal stability and reliability.

Optimisation process

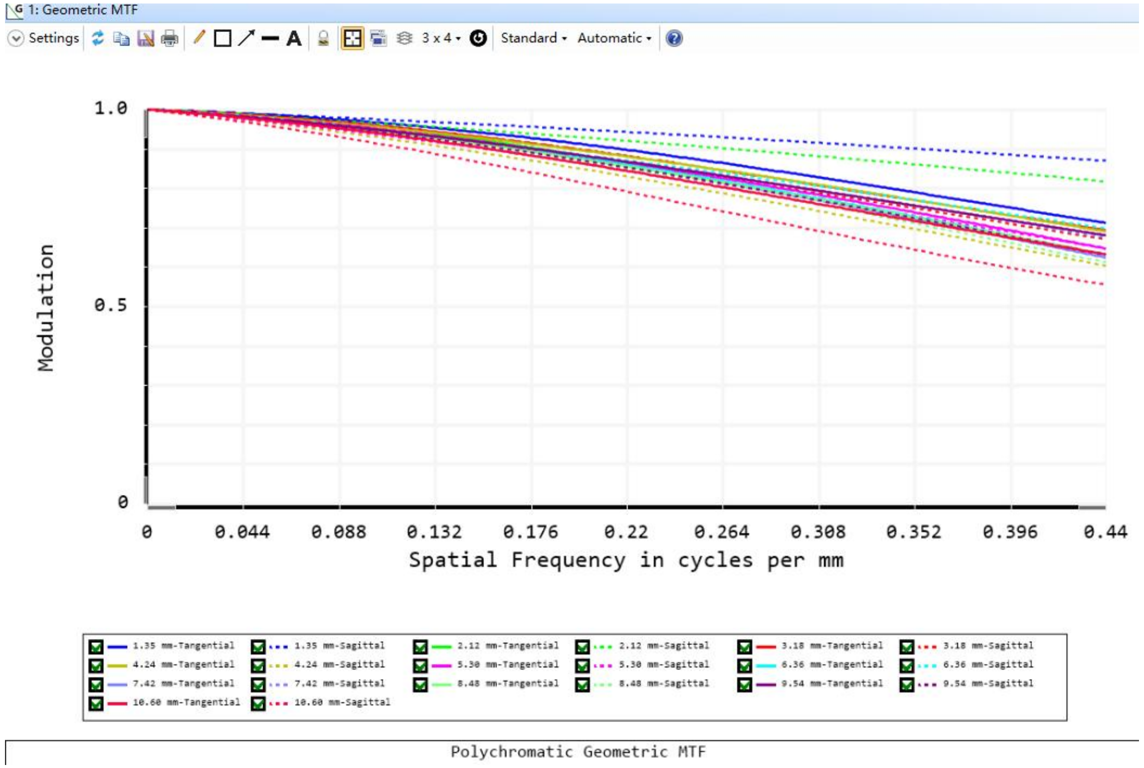
6.Splitting of triplet lens



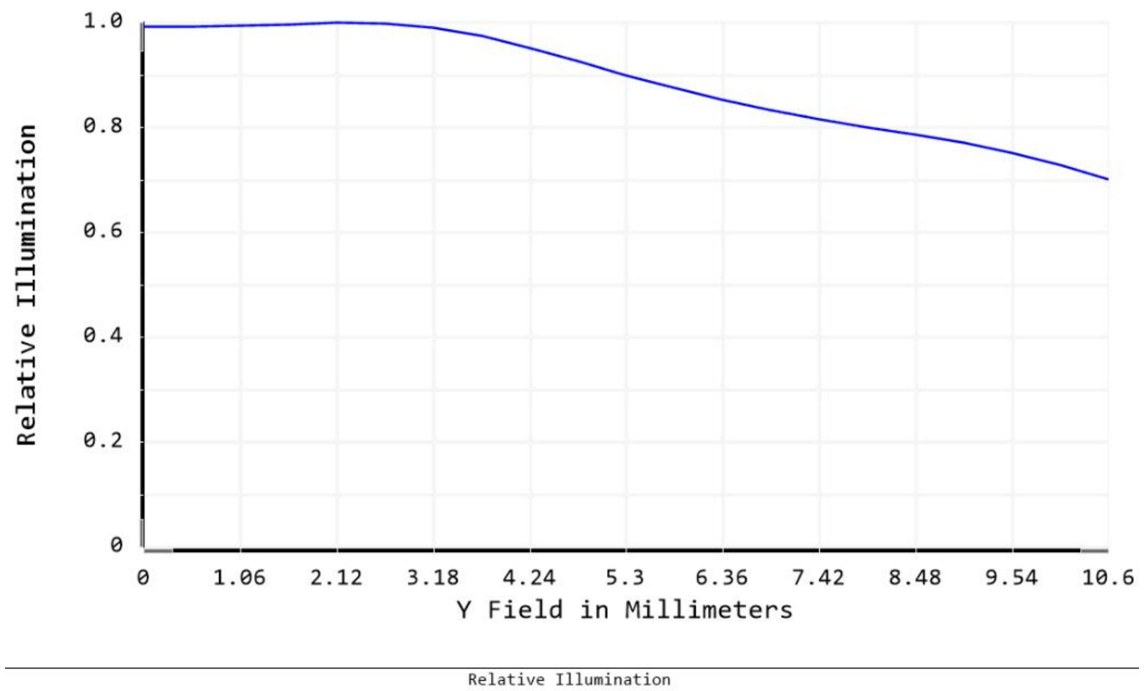
2D layout

Optimisation process

6.Splitting of triplet lens



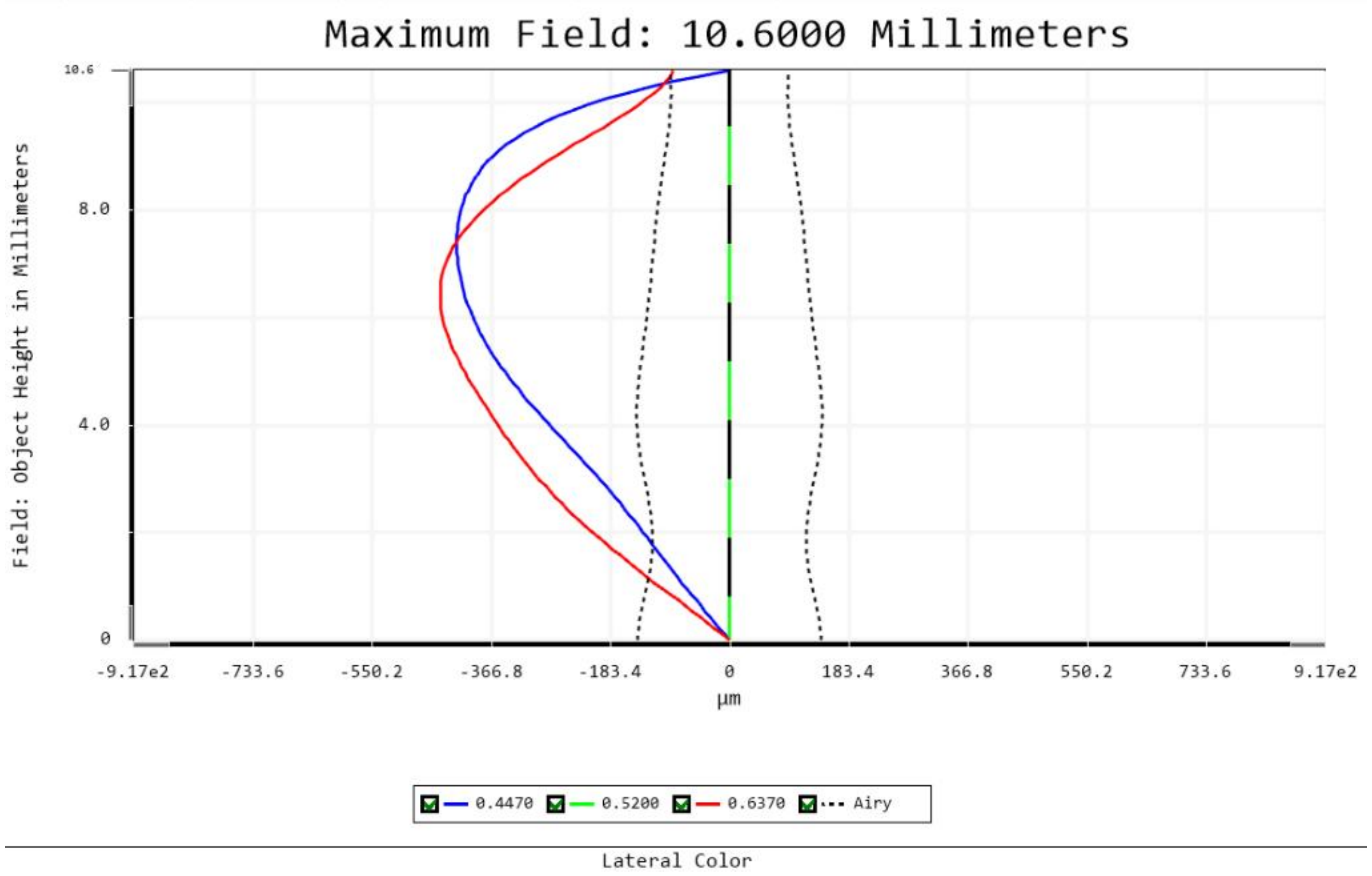
MTF



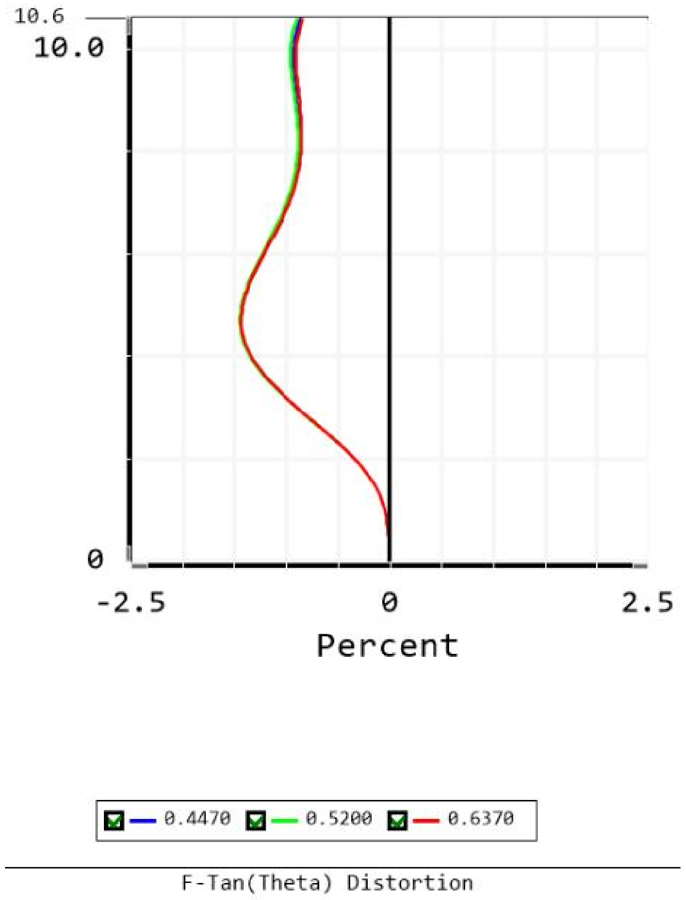
Relative illumination

Optimisation process

6.Splitting of triplet lens



Lateral color



Relative illumination

Suggestion

The optimisation process above simply provides an idea.

If it is to be productised, the following points need to be noted:

1. The wavelength range was increased from the existing 447 nm to 674 nm to 430 nm to 680 nm to avoid purple fringes.

2.As a practical lens, it needs to be optimised for different temperatures using multiple configurations so that the lens is not defocused.

3.As a practical lens, it is necessary to use multiple configurations to achieve focus for different working distances, generally through internal focusing.